A Study of Salmonid Survival and Behavior through the Columbia River Estuary using Acoustic Tags, 2007

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EXECUTIVE SUMMARY

In 2007, we continued the second phase of a collaborative, multi-year project to estimate juvenile salmonid survival through the lower Columbia River and estuary. The project was funded and coordinated by the U.S. Army Corps of Engineers, and research was conducted by the U.S. National Marine Fisheries Service and Battelle Pacific Northwest National Laboratory. Also in 2007, a pilot project was initiated to examine migration pathways of acoustic-tagged fish migrating through the Columbia River estuary islands.

A total of 1,787 yearling and 2,790 subyearling river-run Chinook salmon were released with both surgically implanted with Juvenile Salmon Acoustic Telemetry System (JSATS) acoustic transmitters and passive integrated transponder (PIT) tags. Fish were released either in groups of approximately 250 through the Bonneville Dam juvenile bypass facility (JBF) outfall or in groups of 60-75 from a boat located mid-river in the tailrace. Yearling Chinook salmon were released during 1 May-2 June (19 releases) and subyearling Chinook during 16 June–21 July (21 releases).

Using the Cormack-Jolly-Seber single-release model, estimates of mean survival ranged from 0.696 (SE = 0.067) to 0.882 (SE = 0.086) for yearling Chinook salmon, and from 0.277 (SE = 0.029) to 0.914 (SE = 0.036) for subyearling Chinook salmon. New stationary arrays installed in 2007 to partition survival by reach showed that the highest loss rate occurred between river kilometer (rkm) 58 and the ocean. Mean travel time from release at rkm 231.3 to the primary array at rkm 8.3 was 3.8 d (SE = 0.07) for yearling Chinook salmon, resulting in a mean migration rate of approximately 65.3 km/d (SE = 0.48). Based on both acoustic detections on the new arrays and PIT-tag detections using a pair trawl, migration rates for both yearling and subyearling smolts tended to decrease as fish approached the estuary. Subyearling Chinook salmon mean travel time from release to rkm 8.3 was 4.8 d (SE = 0.06), with a migration rate of about 49.7 km/d (SE = 0.27). A majority of first detections on the primary array occurred during daylight hours and on outgoing (ebbing) tides for both life history types of Chinook salmon.

Use of alternate migration pathways through the Columbia River estuary islands varied by fish stock and release date. Of the acoustic-tagged Chinook salmon detected at Oak Point, 8.1% of yearlings and 20.4% of subyearlings were detected in the side channels of estuary islands. Survival from the Tenasillahe Island array at rkm 58 to the estuary primary array at rkm 8.3 was similar for yearling Chinook salmon that used island side channels (0.79, SE = 0.019) and those that migrated down the main channel (0.76, SE = 0.047). Survival to the primary array was also similar for subyearling

Chinook salmon that used island channels (0.71, SE = 0.012) and those that migrated down the main channel (0.74, SE = 0.022).

To determine the fate of tagged fish not detected on stationary arrays, over 700 juvenile Chinook salmon were acoustic-tagged as targets to evaluate a mobile tracking system. Target fish were acquired and tracked using an advanced mobile-tracking unit capable of detecting and following free-ranging fish tagged with JSATS acoustic tags. While the majority of targets were tracked in the main river channel, tagged fish were also tracked in the side-channels of estuary islands. In addition, 27 targets were confirmed or suspected to be in a fixed position, and based on depth-sounding data, were apparently resting on the river bottom.

PIT tags from double-tagged fish (acoustic and PIT) found on piscivorous bird colonies in the estuary indicated that at a minimum, 2.1 and 4.9% of the yearling and subyearling Chinook salmon were consumed by birds, respectively.

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INTRODUCTION

Mortality in the estuary and ocean comprises a significant portion of overall mortality experienced by salmon populations throughout the life cycle of individuals. Seasonal and annual fluctuations in mortality in the estuary and marine environments are a significant source of recruitment variability for these populations (Bradford 1995). Understanding the causes of juvenile salmonid mortality during freshwater residence and downstream migration is essential to development of appropriate monitoring techniques. Accurate monitoring of is critical for effective management strategies that support mitigation efforts and conservation policies aimed at salmon population recovery or enhancement.

Recent studies have attempted to evaluate effects of estuarine conditions on salmon. Simenstad et al. (1992) suggest that estuaries offer salmonids three primary advantages: productive foraging, relative refuge from predators, and a physically intermediate environment in which the animal can transition from freshwater to marine physiological control systems. Thorpe (1994) reviewed information from three genera of salmonids (*Oncorhynchus, Salmo,* and *Salvelinus*) and concluded that salmonids are characterized by their developmental flexibility and display a number of patterns in estuarine behavior. He found that stream-type salmon migrants, including some Chinook *Oncorhynchus tshawytscha*, coho *O. kisutch*, sockeye *O. gorbuscha*, and Atlantic salmon *Salmo salar* move through estuaries and out to sea quickly, compared to ocean-type salmon migrants.

Most of our knowledge of how salmonids utilize estuaries is limited to smaller systems that can be more readily sampled. For example, Beamer et al. (1999) assessed the potential benefits of different habitat restoration projects on the productivity of ocean-type Chinook salmon in the Skagit River, Washington. They concluded that restoration of freshwater habitats (peak flow and sediment supply) to "functioning" levels "would provide limited benefits unless estuary capacity or whatever factor that limits survival from freshwater smolt to estuary smolt is also increased." They used productivity and capacity parameters to estimate that estuarine habitat restoration could produce up to 21,916 smolts/ha. Reimers (1973) found that fall Chinook salmon in the Sixes River, Oregon, used diverse estuary rearing periods and strategies.

Little information is available describing historic use of the Columbia River estuary by salmonid smolts. Rich (1920) found that 36% of juvenile yearling and subyearling Chinook salmon collected from 1914 to 1916 demonstrated extensive rearing in the estuary. As many as 70% of the fish sampled during July over the three years of the study had resided in the estuary from 2 to 6 weeks (Jen Burke, Oregon Department of

Fish and Wildlife, personal communication). Subyearling Chinook salmon attained 20 to 66% of their fork length while in the estuary. In contrast, during the early 1980s when hatchery fish dominated the juvenile population, Dawley et al. (1985) noted that movement rates through the estuary were similar to rates from the release site to the estuary, indicating limited use of the estuary by juvenile salmonids originating upstream from Jones Beach, OR (rkm 75).

Schreck and Stahl (1998) found mean migration speed of radio-tagged yearling Chinook salmon was highly correlated with river discharge and averaged approximately 3.7 km/h (2 mph) from Bonneville Dam to near the mouth of the Columbia River. Movement in the lower estuary was influenced by tidal cycles, with individuals moving downstream on the ebb tide and holding or moving upstream during the flood tide. They reported a high proportion of tagged animals were lost to piscivorous bird colonies located on dredge disposal islands. Ledgerwood et al. (1999) also found that travel speed of PIT-tagged fish from Bonneville Dam to Jones Beach was highly correlated with total river flow. They observed significant differences in passage times at Jones Beach between spring/summer Chinook salmon released at Lower Granite Dam to migrate inriver and those transported and released below Bonneville Dam. PIT-tagged fish that migrated inriver and were detected at Bonneville Dam had significantly faster travel speeds to Jones Beach (98 km/day) than those released from a transportation barge below Bonneville Dam (73 km/day). These recent studies provide a cursory assessment of estuarine migration behavior.

Physical processes in the estuary, and thus estuarine habitat, are shaped by two dominant factors: channel bathymetry and flow. River flow is controlled by climate variation and anthropogenic effects such as water storage, irrigation, withdrawals, and flow regulation. The Federal Columbia River Power System (FCRPS) has altered the hydrology of the Columbia River estuary through flow regulation, timing of water withdrawals, and irrigation, which have affected average flow volumes, timing, and sediment discharge (Sherwood et al. 1990; Simenstad et al. 1992; Weitkamp 1994; Bottom et al. 2001). Annual spring freshet flows are approximately 50% of historical levels, and total sediment discharge is roughly one-third of levels measured in the 19th century. The direct effects of these changes to the estuary from FCRPS operations on migrant salmonids have not been evaluated.

The potential for delayed or latent mortality on fish that migrate through the hydropower system is also of concern to fisheries managers and regional decision-makers. Recent quantitative model studies have assessed the importance of survival downstream from Bonneville Dam to the overall life cycle. Sensitivity analyses have identified the life stages where management actions have the greatest potential to influence annual rates of population change, and priorities for research (NMFS 2000). A reduction in mortality in the estuary/ocean and during the first year of life had the greatest effect on population growth rates for all spring/summer Chinook salmon stocks when a 10% reduction in mortality in each life stage was modeled. Use of smolt-to-adult ratios (SARs) calculated by the Plan for Analyzing and Testing Hypotheses (PATH) in the sensitivity analysis produced similar results (NMFS 2000).

These analyses suggest that salmonid recovery efforts will require an understanding of the important linkages between physical and biological conditions in the Columbia River estuary and salmonid survival. Indeed, Kareiva et al. (2000) concluded that modest reductions in estuarine mortality, when combined with reductions in mortality during the first year of life, would reverse current population declines of spring/summer Chinook salmon. Emmett and Schiewe (1997) concluded that survival must be separated between the freshwater, estuarine, and ocean phases to be able to answer management questions related to stock recovery and enhancement.

Thus there is a critical need for information on smolt survival that is specific to the lower Columbia River and estuary, and that encompasses the early marine experience. In response to this need, a research project was initiated in 2001 by the U.S. National Marine Fisheries Service, Pacific Northwest National Laboratory, and the U.S. Army Corps of Engineers to develop tools that can provide rigorous survival assessments for juvenile salmonids migrating through the Columbia River basin, estuary and near-ocean. The statistical model of Cormack (1964), Jolly (1965), and Seber (1965), referred to as the CJS or single-release model, was the most appropriate for this effort, and project goals were geared to assumptions of that architecture.

Three technologies have the potential for marking (tagging) individual fish of small size to assess survival through the lower Columbia River. These include radio tags, passive integrated transponder (PIT) tags, and acoustic tags. Since radio signals are quickly attenuated in deep (> 9 m), fresh water and in all depths of salt or brackish water, they cannot be used over significant portions of the area. PIT tags are appropriate for implant into small salmonids and function in salt water environments. Unfortunately, maximum detection range for PIT tags is only about 2.6 m (Peterson et al. 2006). Thus PIT technology is suitable for sites where fish can be concentrated into a small sampling volume, such as in fish passage facilities at hydroelectric projects. Since the distal portion of the estuary involves fish movement through salt water, acoustic telemetry was the only existing technology with the combination of transmission range and medium independence suitable for tagging small fish that would allow detection of tagged individuals migrating through the entire study area.

Given the ostensible high mortality occurring below Bonneville Dam, the potential for positive response in population growth from improved survival in this area, and the uncertainty over the causal mechanisms of delayed mortality. Thus, detailed studies are needed to evaluate juvenile salmonid survival and behavior through the lower Columbia River and through the Columbia River estuary. This is particularly true for subyearling Chinook salmon, which may utilize portions of the estuary for extended periods as rearing and transition habitat. However, these fish are small, and in general, only 85% of the population passing Bonneville Dam has attained a fork length of 92 mm (3.5 in) or more.

To effectively tag these smaller animals, a small, ergonomic transmitter was developed as part of an overall program to develop acoustic tools (McComas et al. 2005, 2007; McMichael et al. in review). Termed the Juvenile Salmon Acoustic Telemetry System (JSATS), this tool is the current product of an ongoing, iterative process intended to provide regional researchers with acoustic transmitters and detection gear specifically designed to address local information needs.

To produce unbiased estimates of survival, the CJS model requires two successive points of detection, or in this case, transects spanning the river. Each transect (array) was comprised of a succession of passive acoustic receivers with overlapping reception ranges. Early in the development of the acoustic detection system for the Columbia River, design-team consensus was that the most effective receiver gear for the upstream (primary) array would be a series of bottom-mounted receiver nodes. These nodes would be cabled to a station on shore to provide power and data communications.

The ensuing JSATS development effort produced a cabled system capable of meeting these design requirements and sufficiently physically robust to meet demands for extended use in the estuarine environment (McComas et al. 2005). An autonomous receiver was developed for use in the lower estuary as a secondary array. With the completion of development and evaluation in 2004, we initiated the second phase of the multi-year project to estimate juvenile salmonid survival through the lower Columbia River and estuary.

Information gained from studies in 2005 and 2006 indicated higher-than-expected mortality through the study area (McComas et al. 2007, 2008). In response, additional arrays were deployed, partitioning the lower river and upper estuary into segments, to provide a better understanding of where fish losses occurred. In addition, a pilot project was developed using an advanced mobile-tracking device capable of detecting and following fish tagged with JSATS acoustic tags. The intent of the mobile unit was to closely monitor the behavior of acoustic-tagged fish to define migration routes and determine the fate (mortality or prolonged residence past the life of the tag) of individuals not detected on the lower estuary stationary arrays.

This paper is a report of survival and behavioral assessments using micro-acoustic tags and the eleven JSATS autonomous receiver arrays located downstream of Bonneville Dam during 2007, in conjunction with the mobile tracking data, to evaluate run-of-the-river yearling and subyearling Chinook salmon survival and behavior through the lower Columbia River and estuary.

METHODS

Study Area

The study area included the unimpounded mainstem Columbia River and estuary from Bonneville Dam to the Pacific Ocean, a distance of approximately 235 river kilometers (rkm). Sherwood and Greagar (1990) described the annual hydrograph for the Columbia River as ranging from a low of 2,970 m^3s^{-1} during late summer and fall to a high of 17,000 m^3s^{-1} during the spring freshet period. They estimated a mean annual decrease of about 280-570 m^3s^{-1} due to irrigation removal and climate change. Sediment discharge under modern conditions is about 7.6×10^6 mt^3 y^{-1}, about 45% of which is sand (Sherwood et al. 1990). The authors noted that much of this finer material is transported in suspension during high river flow periods. Thus, both high flows and high suspended sediment loads coincide with the peak juvenile salmonid migration, particularly for yearling fish.

The Columbia River estuary conforms to the classic estuary definition as a semi-enclosed coastal body of water which has a free connection with the open sea, and within which sea water is measurably diluted with fresh water derived from land drainage (Pritchard 1967). Though the upper limit of salt water incursion reaches slightly past Harrington Point (rkm 37, Sherwood and Greagar 1990), tidal effects are observable as far inland as Longview, WA, (rkm 105) and are measurable at Bonneville Dam (rkm 235). The estuary hosts four major bays and contains numerous islands of natural and man-made or man-induced origin, as well as extensive inter-tidal and supra-tidal areas. Sherwood et al. (1990) noted that islands constructed of dredge spoils and extensive dikes are the most prominent of these man-made features.

Collis et al. (2001) estimated that nine islands in the estuary supported up to 170,000 piscivorous water birds, including the largest aggregations of Caspian terns *Sterna caspia* and double-crested cormorants *Phalacrocorax auritus* in North America. Two of these islands were particularly important to survival studies for fish migrating through the study area. Rice Island, a dredge spoils site at rkm 35 contained over 16,000 breeding pairs of terns, which were estimated to be dependant on salmonids for 74% of their diet (Collis et al. 2002). Subsequent relocation efforts successfully moved a majority of these birds to East Sand Island, another dredge disposal site at rkm 10, where a colony of about 8,500 breeding pairs was established by 2002. In addition to the terns, Ryan et al (2005) cited presence of a colony of about 8,000 breeding pairs of double-crested cormorants on a 15,000 m^2 area of rock jetty attached to East Sand Island. The colony of cormorants on Rice Island has decreased from 1,082 birds in 1998 (Collis et al. 2002) to no nesting pairs by 2002 (Roby et al. 2005) .

Detection Arrays

Stationary Receiver Deployment and Servicing

All acoustic equipment (receivers and releases) was thoroughly tested prior to use in the field. For more information on receiver acceptance testing, see Appendix A. Prior to deployment, each receiver (Sonic Concepts, Bothell, WA; model N201) was attached to an acoustic release (InterOcean Systems, Inc.[1], San Diego, CA; model 111) by a 3.7-m long bridle made of 12.7-mm-diameter braided nylon rope (Figure 1). The release allowed the receivers to be retrieved for periodic servicing (data retrieval and battery replacement). In places where water depth was less than about 8 m at low tide, this bridle was shortened to 0.9 m. Each bridle end terminated with a splice around a 9.5-mm SeaDog nylon thimble, which was professionally braided. Three yellow buoys (Baolong BL-6, 16.5 × 12.4 cm, 1.45 kg buoyancy each) were threaded on the bridle between the receiver and release. Each acoustic release was shackled to a 68-kg anchor with a 1- to 3-m long shock-corded mooring made of 12.7-mm braided nylon line. The mooring assembly terminated with a 10-cm galvanized steel ring held by the acoustic release.

Figure 1. Autonomous acoustic telemetry receiver (top), acoustic release (middle), and anchor (bottom left) rigged as deployed in the Columbia River estuary.

To deploy the autonomous receivers, all rigging and equipment components were assembled and loaded onto a 10-m vessel. Deployment locations were plotted on an electronic chart, and navigated to using the global positioning system (GPS). Just prior to deployment, the assembly was attached to an anchor, and pertinent information was recorded on a data sheet (receiver serial number, acoustic release code, water depth,

[1] Use of trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

date, and time of deployment). Once the boat was in position, the equipment was fed over the side as the anchor was lowered to the bottom on a slip line. When the anchor reached bottom, the actual GPS point was recorded, and the slip line was retrieved.

To recover the equipment, we navigated to the GPS position of a receiver and triggered the acoustic release, allowing the equipment to float to the surface. Occasionally the gear became fouled, preventing the receiver from detaching from the anchor when the acoustic release was triggered. When this happened, we used a grappling hook towed along the bottom in circles to drag for the receivers. In most cases this was successful in retrieving the equipment.

Autonomous receivers required servicing every 28-30 d. During servicing, batteries were replaced, data was downloaded, and receivers that were missing or malfunctioning were replaced. The deployment schedule for autonomous receivers in 2007 is presented in Table 1 and Appendix B. Batteries used in the receivers early in the 2007 study period failed earlier than expected, resulting in some data loss during mid-May (Appendix C).

Table 1. Names, locations (physical landmark descriptions and river kilometer from the mouth of the Columbia River), and deployment and recovery dates of JSATS stationary acoustic arrays in the Columbia River used to detect acoustic-tagged juvenile Chinook salmon released downstream (ds) from Bonneville Dam (BON) during studies to estimate survival through the Columbia River estuary, 2007.

Array Code	River kilometer	Physical site description	Date deployed	Date retrieved
BON0	225.2	Bonneville egress, 14 km ds of Bonneville Dam	27 Apr	18 July
BON1	210.4	Bonneville primary, Sand Island	27 Apr	30 Aug
BON2	204.0	Bonneville secondary, Reed Island	27 Apr	30 Aug
BON3	199.1	Bonneville tertiary, Lady Island	27 Apr	30 Aug
KLM1	112.6	Kalama primary, Cottonwood Island	27 Apr	2 Aug
KLM2	110.7	Kalama secondary, Cottonwood Island	26 Apr	2 Aug
EIS1	86.2	Estuary islands primary, Oak Pt	26 Apr	28 Sept
EIS2	83.6	Estuary islands secondary, ds from Oak Pt	26 Apr	2 Aug
EIS3	58.4	Estuary islands tertiary, Tenasillahe Island	26 Apr	2 Aug
EIS4	51.9	Estuary islands, Welch Island	26 Apr	2 Aug
EIS5	48.1	Estuary islands, Tronson Island	26 Apr	2 Aug
EIS6	42.9	Estuary islands, Marsh Island	26 Apr	2 Aug
EIS7	42.7	Estuary islands, Karlson Island	26 Apr	2 Aug
EST1	8.3	Estuary primary, W. Sand Island	24 Apr	27 Sept
EST2	2.8	Estuary secondary, between N and S Jetties	24 Apr	27 Sept

Primary Array

To encompass the portion of the study area with most probable predation impact from piscivorous birds on East Sand Island, the primary array for survival estimation was deployed along a transect from West Sand Island to Clatsop Spit (3) at approximately rkm 8.3 (Figure 2). This deployment was comprised of 22 autonomous receivers, which were deployed in two separate arrays to avoid crossing the ship channel. The first array of 19 receivers was deployed southward from the southern end of West Sand Island (46°15.8581' N, 124°0.0539' W) to the north side of the ship channel (46°14.3907' N, 123°59.5947' W). The second array was deployed northward from Clatsop Spit (46°14.1897' N, 123°59.7871' W) to the south border of the ship channel (46°14.2574' N, 123°59.7029' W).

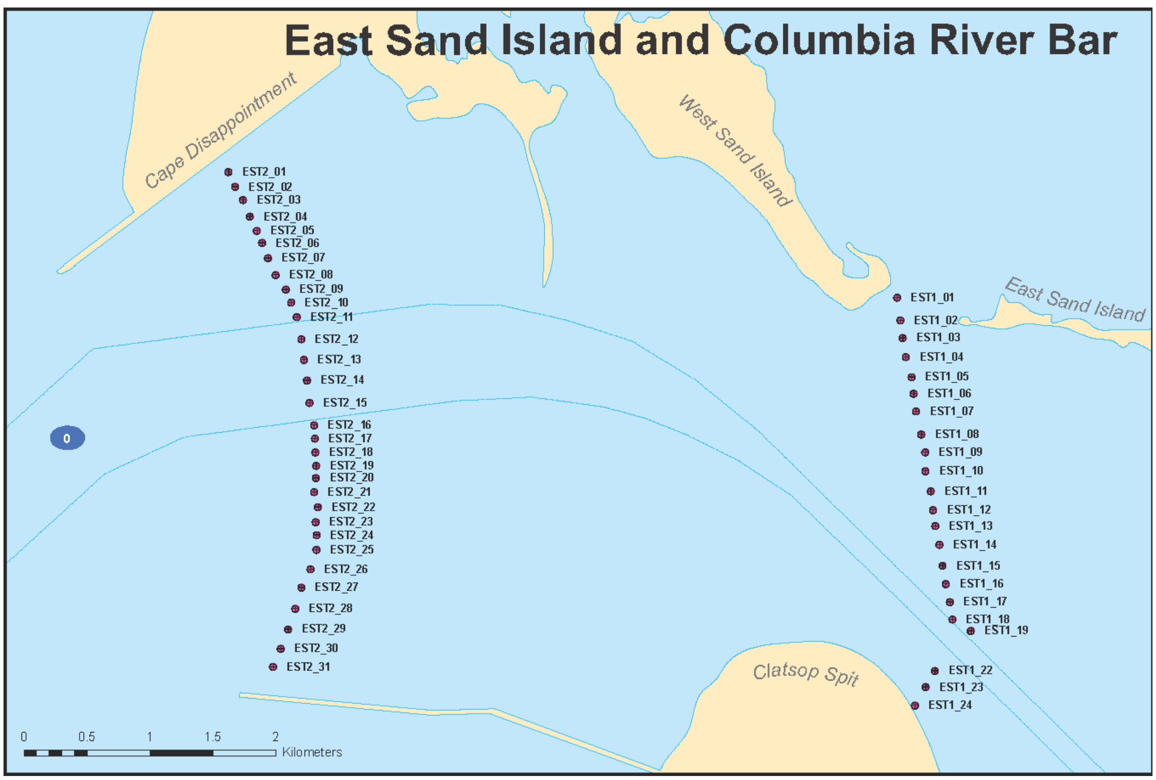


Figure 2. Columbia River estuary showing the locations of acoustic receiver arrays used to detect acoustic-tagged juvenile Chinook salmon during studies to estimate juvenile salmonid survival through the lower Columbia River, 2007.

Secondary Array

For the majority of the season, the secondary array consisted of 27 autonomous receivers similar to those described for the temporary primary array. These were located on a north-south transect at approximately rkm 2.8 with 16 receivers on the Oregon (south) side of the navigation channel, and the remaining 11 on the Washington (north) side of the channel. Three times during the season, 4 additional receivers were deployed temporarily (for 2-d each time) in the navigation channel to increase detection efficiency and collect additional behavioral data (Figure 2).

Other Stationary Arrays

To partition survival from Bonneville Dam to the Columbia River estuary, we deployed an additional five arrays between Kalama and Tenasillahe Island, just downstream of the town of Cathlamet, Washington. The locations of these are described and shown in a comprehensive map in Appendix B. The primary array at Kalama had 6 receivers, one of which was located in Carrolls Channel along the east side of Cottonwood Island. The Kalama secondary array consisted of 4 receivers. Each primary and secondary array near the estuary islands had four receivers. The tertiary array at Tenasillahe Island was made up of nine receivers, two of which were located in Clifton Channel near the northwestern end of Tenasillahe Island. The remainder of the estuary island receivers were located in island side channels downstream of Tenasillahe Island (Figure 3). These were put in place to evaluate the detection efficiency of the main-channel portion of the array at Tenasillahe Island, and to determine the migration pathways through the complex habitat that exists just upstream of where the Columbia widens into the estuary proper. This study also benefited from data collected on receivers deployed between Bonneville Dam and Kalama for other acoustic telemetry projects (Table 1).

Mobile Array

A vessel-mounted mobile detection unit was developed specifically to locate and track free-ranging fish tagged with JSATS acoustic transmitters. The signal reception portion of the unit consisted of four omni-directional pre-amplified hydrophone assemblies (Reson, Inc., TC-4014) inserted into the ends of pylons and suspended from the gunwales of the tracking vessel. The pylons were attached to the gunwales using proprietary mounts, which allowed the pylons to be retracted when not in use, or rotated into pre-defined and mapped positions while tracking.

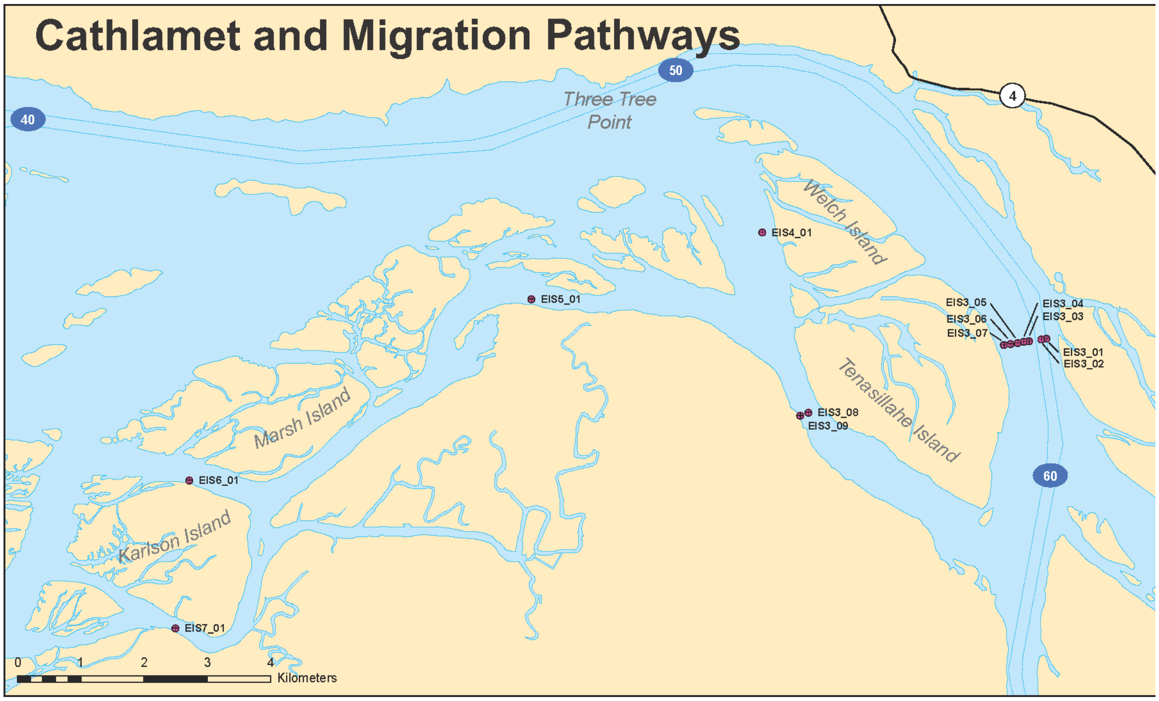


Figure 3. Locations of stationary acoustic receivers (labeled dots) in the Columbia River estuary islands downstream from Cathlamet, Washington, 2007.

When deployed, the hydrophone assemblies formed a planar array approximately 5-m wide by 8-m long and were cabled to a central processing module for power and data transmission.

During operation, the central processing module computed acoustic target (JSATS fish tag) bearing and range estimates relative to the tracking vessel and depth from the surface, based on differences in a given acoustic transmission time-of-arrival at each hydrophone. The tracking-unit operator was presented with these target position estimates in real time, displayed by 4-digit code as text and graphic output. Using this information, the operator directed vessel operation to maintain acoustic contact with the target. Decoded receptions were classified as positive if an error-check embedded in the transmission corresponded to the four-digit transmitter-identification code, or negative if the two did not match. For mobile-tracking purposes using the current generation device, a detection event was defined in two ways: a) simultaneous[2] positive reception of a

2 Since relative position estimates rely on differences in time of acoustic signal arrival at the tracking unit hydrophones, we recognize that reception times vary by milliseconds. However, to simplify discussion, multiple receptions from a single tag transmission will be referred to as simultaneous.

verifiable code by multiple hydrophones, or b) two or more positive receptions of a given code on individual hydrophones within 1 minute. Single receptions that did not meet these criteria were considered false positives and discarded during data reduction. Once a code reached the event level, the code was identified as a target eligible for tracking. Only occasionally was reliance on a single event crucial to target identification.

Normally, the series of successive events resulted in a track which reinforced positive initial identification. Following initial identification, events were categorized in three ways, dependent on the number of hydrophones registering a given transmission. Transmissions decoded from one or two hydrophones indicated presence of a target within reception range of the array, but could not provide a solution (bearing or range estimate) to the target. A positively decoded transmission from three hydrophones resulted in a relative bearing estimate from the tracking vessel, and decodes for a single transmission on all four hydrophones additionally provided computed estimates for target range from the vessel and depth from the surface.

All targets identified (positive and negative) were listed on the tracking-unit display. Targets identified by at least three positive simultaneous detections (trackable targets) were listed separately on the display, whether or not they were actively being tracked. Targets selected for tracking (active) were promoted to, or demoted from, the displayed list of trackable targets. Up to four targets could be promoted to active status for simultaneous tracking. However, as a practical matter, only one principle track was sustained for extended periods, since incidental targets rarely maintained proximity to the tracking vessel while tracking the principle target.

All decoded receptions were logged to file by numeric hydrophone identifier, along with date and time stamp, vessel GPS position, signal strength, and decode category (positive or negative for error check). In the case of multiple receptions of the same transmission on more than one hydrophone, timing offsets from the first reception and depth and range estimates were also recorded. Plots of target tracks were completed by post processing tracking event reception data.

Tagging Operations

All Chinook salmon used to estimate survival and assess behavior through the lower estuary using acoustic tags in 2007 were captured and tagged at the Bonneville Dam Juvenile Fish Facility (JFF). Actively migrating Chinook salmon were obtained from the population passing through the JBF by Pacific States Marine Fisheries Commission Smolt Monitoring Program (SMP) personnel on the day prior to tagging.

Sufficient numbers of study fish were usually available so that the tagged-fish group was a subsample of the daily smolt monitoring sample without increasing the collection rate. However, on some dates the SMP sample rate was increased to enable collection of the daily tagging requirement. Study fish were held overnight in a 455-L tank supplied with flow-through river water prior to tagging.

Immediately prior to surgery, fish were placed in an anesthetic bath containing a solution of approximately 60 mg/L tricaine methanesulfonate (MS-222). After equilibrium loss (approximately 2 min), each animal was weighed to the nearest gram, measured to the nearest millimeter (fork length, FL), and placed on the surgery table. A maintenance dose of approximately 40 mg/L solution MS-222 was administered via a tube inserted into the fish's mouth during surgery. With the fish lying ventral side up, a 5-8 mm incision was made 2-5 mm from and parallel to the mid-ventral line, between the pelvic and pectoral girdles. A passive integrated transponder (PIT) tag (Destron-Fearing model TX1411ST 12.5 × 2 mm; 0.06 g in air) was inserted into the peritoneal cavity, followed by an acoustic transmitter. Transmitter vendor varied by migration time: yearling fish were implanted with tags from Sonic Concepts (Model E101), while subyearling fish had transmitters manufactured by Advanced Telemetry Systems. Both models were similar in physical characteristics (17 × 5.5 mm; 0.60 g in air; 0.35 g in water, Figure 4).

a. b.

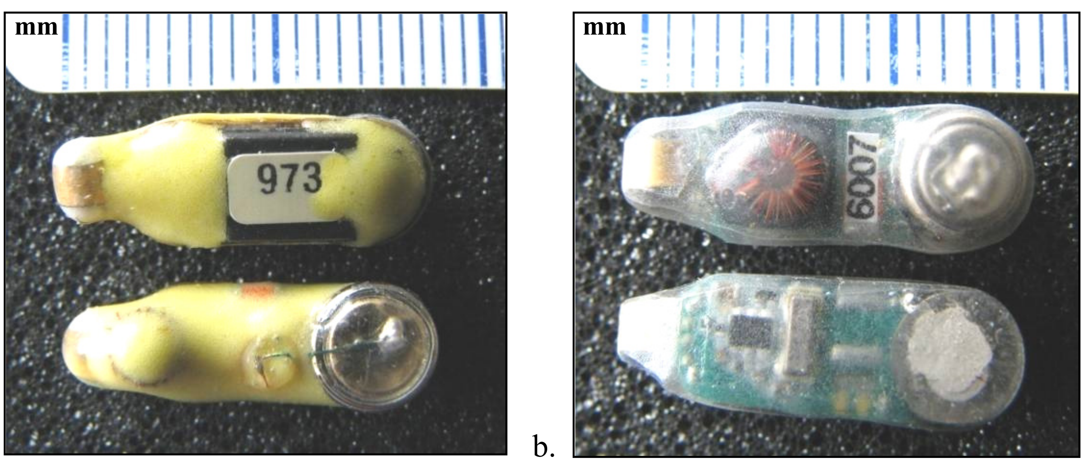


Figure 4. JSATS microacoustic transmitters implanted into yearling (a. Sonic Concepts) and subyearling (b. Advanced Telemetry Systems) Chinook salmon released below Bonneville Dam during studies to evaluate juvenile salmonid survival and behavior through the Columbia River estuary, 2008

PIT and acoustic tags were positioned parallel to the longitudinal axis of the fish, and the incision was closed using two simple, interrupted sutures (Ethicon 5-0 absorbable poliglecaprone monofilament, Model Y303, with attached ½ circle needle, Model RB-1, or equivalent). Following surgery, fish were placed in a dark-colored, 20-L recovery bucket supplied with oxygenated river water. The buckets were perforated with three rows of 1-cm holes approximately midway up their height to allow water to flow through while retaining the fish. When 5 tagged fish had accumulated in one bucket, the container was covered and transferred to a holding tank supplied with flow-through river water at a rate of approximately 7 L/min where they were held for a minimum of 12 h to monitor short-term effects of handling and surgery.

All tagged fish were released below Bonneville Dam the day following tagging. However, the numbers of fish tagged each day and the release protocol were dependant on study objectives associated with the release. For example, to maintain continuity with word from previous years, groups of 250 fish each were released into the Columbia River through the JBF outfall located approximately 2 km west of Bonneville Dam Second Powerhouse. These releases included 3 groups of yearling Chinook salmon (750 fish) and 7 groups of subyearling Chinook salmon (1,750 fish). On the day following tagging, mortalities (if any) were removed from holding containers, and study fish were released directly into the JBF flume approximately 150 m upstream (Table 2).

The first three groups were released between 0700 and 1000 PDT. Beginning with the fourth group of yearling Chinook salmon, the release time was changed to hours of darkness (between 2000 and 0400) due to concerns of avian predation at the outfall of the JBF. All other fish were released from boats at mid river, and these served as control groups to compliment treatment groups released above Bonneville Dam to evaluate survival for fish having passed through the spill bays (Ploskey et al. 2008). Mid-river releases occurred at one of three stations along a transect perpendicular to river flow at rkm 231. At approximately hourly intervals beginning at 1430, from 5 to 10 tagged fish (one to two buckets of fish) were released at one of the three points. The order of release point was random; however, at least one 5-fish group was released at each point for a given hourly interval.

Table 2. Numbers of acoustic-tagged yearling and subyearling Chinook salmon released below Bonneville Dam during studies to assess juvenile salmonid survival and behavior through the lower Columbia River and estuary in 2007. Tagged fish were released at mid-river by boat (tailrace) or through the Bonneville Dam JBF outfall (outfall). All fish had both acoustic and PIT tags implanted during surgery.

Yearling Chinook salmon			Subyearling Chinook salmon		
Release Location	Release Date	Number Released	Release Location	Release Date	Number Released
Tailrace	1 May	65	Outfall	16 June	251
Tailrace	2 May	65	Tailrace	21 June	74
Tailrace	3 May	64	Tailrace	22 June	74
Tailrace	4 May	65	Outfall	23 June	250
Tailrace	8 May	65	Tailrace	26 June	74
Tailrace	9 May	65	Tailrace	27 June	74
Tailrace	10 May	65	Tailrace	28 June	74
Tailrace	11 May	65	Tailrace	29 June	74
Outfall	12 May	250	Outfall	30 June	250
Tailrace	15 May	65	Tailrace	3 July	74
Tailrace	16 May	63	Tailrace	4 July	74
Tailrace	17 May	65	Tailrace	5 July	74
Tailrace	18 May	65	Tailrace	6 July	73
Outfall	19 May	250	Outfall	7 July	250
Tailrace	22 May	65	Tailrace	10 July	75
Tailrace	23 May	65	Tailrace	11 July	70
Tailrace	24 May	65	Tailrace	12 July	80
Tailrace	25 May	65	Tailrace	13 July	75
Outfall	2 June	250	Outfall	14 July	250
			Outfall	17 July	250
			Outfall	21 July	250
Total		1,787			
			Total		2,790

Data Processing and Analysis

Data collected by the autonomous receivers were recorded as a single text file on Compact Flash (CF) cards. Physical data (date, time, pressure, water temperature, tilt, and battery voltage) were written to file every 15 seconds. Valid detection data were recorded on the CF as they were received. Detection data included individual transmitter code, a time stamp, receive signal-strength indicator (RSSI), and a calculated measure of background noise (RxThreshold). Each data file was transferred to a laptop computer following servicing or retrieval events.

Data files from all receivers were coded with the receiver location and stored in a database developed specifically for storing and processing acoustic telemetry data. To filter out "false positives" (detections of otherwise valid tag codes that were not in the set of codes implanted in fish), a post-processing program was implemented. This program was comprised of a sequence of steps that included comparing each detection to a list of tags that were released (only tags that were released were kept), then comparing the detection date to the release date (only tags detected after they were released were kept). A minimum of four detections in 60 s was required, and the time spacing between these detections had to match the ping rate interval (PRI) of the tag, or be a multiple of the PRI for the detections to be retained in the valid detection file.

From the valid detection file, a detection history was created for each fish. Detection histories were analyzed to estimate survival (described below) as well as to determine the relationships between detections and tides, cross-channel distribution, travel time from point of release to point of detection for each release group, and migration pathway through the lower estuary islands.

To evaluate relationships between detections and tides, a count of detections for fish from each release group was made over 5-min intervals. Using the tide-generating software WXTIDE32 (www.wxtide32.com/), we produced tide elevation plots for periods during which tagged fish were migrating past the primary detection array between East and Island and Clatsop Spit. Counts of detections were then plotted against the change in tide along that transect.

Arrival times were defined as the first observation (detection) of each fish observed on an array. A count of fish for each hour (independent of day or night) was then plotted. Day was considered to begin half an hour before sunrise and end half an hour after sunset.

Cross-channel distribution was determined separately for yearling and subyearling fish by plotting all valid tag observations at each receiver location for each release group. From this, the number of valid codes observed at each location was calculated by year class for all release groups combined.

Data from detections of PIT tags on the PIT-tag trawl in the estuary were used to calculate migration rate from release to Jones Beach (rkm 75), and a combination of these data and the acoustic detections were used to calculate migration rate from Jones Beach to the estuary primary array (rkm 8.3). These migration rate calculations were them compared with calculations of migration rate made using only acoustic detections (from the first detection on an array to the first detection on the next downstream array divided by the distance between the arrays).

Migration pathways analyses made use of all JSATS acoustic-tagged fish migrating down the river. This included fish released below Bonneville Dam, as well as fish released for other projects above Bonneville Dam and at Lower Granite Dam. The percentage of fish from each release group detected in island channels was calculated by taking the total number detected anywhere in the channel and dividing by the number estimated to have survived at the array directly upstream. The diel distribution of detections was determined by grouping all detections of fish in the islands by hour (not just the first detection). Travel times were calculated as above.

Rates of avian predation in Chinook salmon tagged with acoustic tags were determined from data gathered by the NOAA Fisheries avian predation project. That project evaluates the impacts of predation by Caspian terns and double-crested cormorants on juvenile salmonids through electronic detection of PIT tags on piscivorous bird nesting colonies in the Columbia River Basin (Ryan et al. 2005). Recovery files downloaded for all bird predation interrogation sites in the Basin were queried for intersection with tagging files specific to this study.

Survival Estimation

Survival estimates were derived from conventional statistical models for mark-recapture data from a single group of marked animals (Cormack 1964; Jolly 1964; Seber 1965). This model is known by various names, including CJS Model and Single-Release (SR) Model. The model is simple when there are only two detection opportunities for each marked animal. For purposes of survival estimation, detection data are summarized as the “detection history” for each marked fish. With only two opportunities, the possible detection histories for tagged fish are:

00 – never detected
10 – detected on primary array but not on secondary
01 – detected on secondary array but not on primary
11 – detected on both arrays

To estimate survival for a release group of tagged fish, counts of fish in each detection history within the group are used, denoted n_{00}, n_{01}, n_{10}, and n_{11}, along with the total number of fish released, denoted R.

The proportion of fish detected on the primary array [$(n_{10} + n_{11})/R$] is an estimate of the joint probability that a fish survived from release to the primary array (S) and that the fish was detected given that it survived (P). Assuming that survival to the primary array and detection on that array are independent events, the joint probability of both events occurring is the simple product of the two probabilities. Thus, the proportion detected on the primary array is an estimate of SP.

To separate the two probabilities in the product requires a method to estimate either of the probabilities individually. The remaining probability can then be estimated by dividing the joint estimate by the estimate of the first. Detection probability on the primary array can be estimated independently by assuming that fish that survived to the secondary array and were detected there ($n_{01} + n_{11}$) represent a random sample of all fish from the group that were alive as they passed the primary array. Detection probability on the primary array is then estimated as the proportion of the sample detected on the primary array [$n_{11}/(n_{01} + n_{11})$].

Survival between the primary and secondary arrays cannot be estimated separately from the detection probability on the secondary array, because without a third detection opportunity there is no way to construct the sample from which to estimate detection separately. Thus, we can estimate only the joint probability of surviving between the two arrays and detection on the secondary array.

RESULTS AND DISCUSSION

Length and weight descriptive metrics for juvenile Chinook salmon implanted with acoustic transmitters and released to the tailraces of Bonneville Dam in 2007 are presented in Tables 3 and 4.

Of 1,787 yearling Chinook salmon released at Bonneville Dam, 1,213 (68%) were detected in the estuary. Tagged yearling fish ranged in length from 116 to 228 mm FL (mean 144.6 mm, SE = 0.32). Mean length of yearling Chinook salmon detected in the estuary (144.6 mm, SE = 0.39) was not significantly different from that of non-detected fish (144.6 mm, SE = 0.58; $t = 0.02$, $P = 0.983$, $\alpha = 0.05$).

A total of 1,632 (58%) of the 2,790 acoustic-tagged subyearling Chinook salmon were detected in the Columbia River estuary following release. Lengths ranged from 92 to 154 mm (mean 105.1 mm, SE = 0.15). Unlike yearling fish, mean length of subyearling Chinook salmon detected in the estuary (106.6 mm, SE = 0.20) was significantly greater than that of non-detected subyearlings (102.9 mm, SE = 0.21; $t = 12.7$, $P < 0.001$, $\alpha = 0.05$).

With a 0.61-g tag, the ratio of tag weight (in air) to body weight ranged from 0.6 to 4.8% (mean 2.2%, SE = 0.014) for yearling Chinook salmon, and from 1.2 to 8.7% (mean 4.9%, SE = 0.025) for subyearling Chinook salmon. For subyearling fish, this was somewhat higher than the recommended 5% ratio.

Survival Estimates

Single-release survival and detection probability estimates are presented by release strategy (outfall and tailrace) in Tables 5 and 6. Estimates were made for each partition array in the lower river and for the lower estuary primary array at East Sand Island (rkm 8.3). Estimated survival from release below Bonneville Dam through the lower Columbia River estuary primary array ranged from 0.696 (SE = 0.067) to 0.882 (SE = 0.0086) for yearling fish and from 0.227 (SE = 0.029) to 0.914 (SE = 0.036) for subyearling fish (Table 5). Overall mean estimated survival for all releases combined was 0.799 (SE = 0.017) for yearling Chinook and 0.620 (SE = 0.010) for subyearling Chinook salmon.

Table 3. Descriptive statistics in length and weight by release date for acoustic-tagged yearling Chinook salmon released by boat (Tailrace) and through the Bonneville Dam JBF outfall (Outfall) to evaluate juvenile salmonid survival through the lower Columbia River and estuary, 2007.

		Yearling Chinook									
		Fork length (mm)					Weight (g)				
Release location	Release date	n	Min	max	mean	SE	n	min	max	mean	SE
Tailrace	1 May	65	122	167	142.7	1.40	64	17.2	47.5	30.3	0.99
Tailrace	2 May	65	120	195	144.3	1.86	65	16.9	81.3	31.2	1.46
Tailrace	3 May	64	118	161	142.2	1.32	64	16.8	45.2	29.1	0.82
Tailrace	4 May	65	120	171	142.5	1.39	64	17.3	48.6	29.2	0.88
Tailrace	8 May	65	125	168	140.1	1.15	65	15.9	46.5	27.0	0.72
Tailrace	9 May	65	120	173	141.7	1.29	65	15.4	53.1	28.3	0.85
Tailrace	10 May	65	119	179	143.0	1.34	65	14.3	58.1	28.6	0.90
Tailrace	11 May	65	122	188	144.7	1.68	65	18.3	66.4	30.3	1.19
Outfall	12 May	250	116	228	145.0	0.89	250	13.9	106.8	29.7	0.63
Tailrace	15 May	65	117	208	144.0	2.38	65	14.0	94.8	28.8	1.84
Tailrace	16 May	62	117	197	146.4	1.83	62	13.3	71.4	29.5	1.37
Tailrace	17 May	65	116	176	144.4	1.22	65	15.5	57.7	28.0	0.78
Tailrace	18 May	65	123	221	143.9	2.15	65	16.4	101.7	28.8	1.76
Outfall	19 May	250	118	211	143.8	0.93	250	14.5	95.5	28.2	0.69
Tailrace	22 May	65	119	201	146.0	1.97	65	15.9	77.9	30.0	1.39
Tailrace	23 May	65	124	199	146.3	1.91	65	16.2	67.6	29.4	1.38
Tailrace	24 May	65	127	194	147.8	1.27	65	18.9	65.8	29.6	0.90
Tailrace	25 May	65	126	204	146.2	2.03	65	18.9	79.8	29.7	1.49
Outfall	2 Jun	250	125	200	146.7	0.79	250	18.5	74.8	30.2	0.56
Total		1786	116	228	144.6	0.32	1785	13.3	106.8	29.3	0.23

Table 4. Descriptive statistics in length and weight by release date for acoustic-tagged subyearling Chinook salmon released by boat (Tailrace) and through the Bonneville Dam JBF outfall (Outfall) to evaluate juvenile salmonid survival through the lower Columbia River and estuary, 2007.

		Subyearling Chinook									
		Fork length (mm)					Weight (g)				
Release location	Release date	n	Min	max	mean	SE	n	min	max	mean	SE
Outfall	16 Jun	251	92	128	102.4	0.50	251	7.0	24.4	11.7	0.18
Tailrace	21 Jun	74	95	130	105.9	0.84	74	8.9	23.9	12.8	0.32
Tailrace	22 Jun	74	95	137	106.3	0.98	74	8.5	27.4	13.0	0.39
Outfall	23 Jun	250	95	135	105.0	0.46	250	8.6	28.4	12.6	0.19
Tailrace	26 Jun	74	95	149	106.7	1.05	74	8.6	50.1	13.6	0.69
Tailrace	27 Jun	74	96	138	108.9	1.01	74	7.7	28.4	13.9	0.38
Tailrace	28 Jun	74	95	129	107.6	0.79	74	9.4	26.0	13.4	0.35
Tailrace	29 Jun	73	95	130	108.4	0.93	73	9.1	24.7	13.7	0.38
Outfall	30 Jun	250	95	136	109.8	0.41	250	8.3	30.0	13.7	0.16
Tailrace	3 Jul	74	96	124	108.0	0.74	74	9.3	18.8	12.8	0.26
Tailrace	4 Jul	74	95	128	106.5	0.86	74	8.4	24.9	12.5	0.36
Tailrace	5 Jul	74	95	132	106.0	0.77	74	8.1	26.1	12.2	0.32
Tailrace	6 Jul	73	95	117	104.9	0.61	73	8.8	15.9	11.9	0.21
Outfall	7 Jul	250	93	139	105.7	0.48	250	8.5	37.2	12.4	0.23
Tailrace	10 Jul	75	95	127	104.3	0.79	75	8.7	22.7	12.2	0.31
Tailrace	11 Jul	70	95	121	103.2	0.78	70	8.7	20.0	11.8	0.32
Tailrace	12 Jul	80	95	124	102.7	0.72	80	8.4	19.6	11.3	0.26
Tailrace	13 Jul	75	95	153	104.7	1.11	75	8.7	39.4	12.5	0.51
Outfall	14 Jul	250	95	128	103.5	0.44	250	8.3	22.2	12.0	0.17
Outfall	17 Jul	250	95	128	101.1	0.34	250	8.4	22.0	11.0	0.13
Outfall	21 Jul	250	95	154	104.5	0.61	250	8.5	38.2	12.7	0.26
Total		2789	92	154	105.1	0.15	2789	7.0	50.1	12.4	0.06

Table 5. Survival estimates (S) and associated standard errors (SE), by reach partition, for acoustic-tagged yearling (CH1) and subyearling (CH0) Chinook salmon released downstream from Bonneville Dam (river kilometer, rkm, 232) to estimate juvenile salmonid survival through the lower Columbia River estuary, 2007. Tailrace releases were pooled by week. Locations associated with array names were: BON1 rkm 202.0, KLM1 rkm 113.0, OAK1 rkm 86.2, EIS3 rkm 58.4, EST1 rkm 8.3.

		Reach											
Release	Release	Release- BON1		BON1 - KLM1		KLM1 - OAK1		OAK1 – EIS3		EIS3 - EST1		Release- EST1	
site	date(s)	S	SE	S	SE	S	SE	S	SE	S	SE	S	SE
		Yearling Chinook											
Outfall	12 May	0.983	0.009	0.989	0.012	0.997	0.017	0.944	0.035	0.965	0.097	0.882	0.086
Outfall	19 May	0.969	0.011	0.990	0.013	0.974	0.018	1.037	0.033	0.852	0.047	0.825	0.038
Outfall	2 Jun	0.982	0.009	0.958	0.015	0.981	0.013	1.000	0.018	0.904	0.037	0.834	0.034
Tailrace	1-4 May	0.959	0.013	0.967	0.012	1.003	0.001	0.986	0.016	0.864	0.038	0.791	0.037
Tailrace	8-11 May	0.953	0.014	0.976	0.012	0.996	0.009	0.989	0.020	0.860	0.056	0.789	0.052
Tailrace	15-18 May	0.974	0.011	0.957	0.018	0.996	0.025	0.946	0.048	0.792	0.081	0.696	0.067
Tailrace	22-25 May	0.958	0.013	0.977	0.011	0.997	0.006	1.003	0.009	0.918	0.026	0.860	0.027
		Subyearling Chinook											
Outfall	16 Jun	0.969	0.011	0.946	0.015	0.999	0.005	0.990	0.017	0.843	0.030	0.764	0.029
Outfall	23 Jun	0.987	0.008	0.958	0.013	0.989	0.008	0.974	0.017	0.868	0.031	0.790	0.030
Outfall	30 Jun	0.988	0.007	0.883	0.021	1.000	******	1.064	0.018	0.985	0.042	0.914	0.036
Outfall	7 Jul	0.960	0.012	0.935	0.016	0.987	0.009	0.945	0.024	0.711	0.037	0.596	0.034
Outfall	14 Jul	0.985	0.008	0.899	0.020	0.942	0.017	0.976	0.023	0.595	0.038	0.484	0.033
Outfall	17 Jul	0.985	0.008	0.857	0.023	0.945	0.019	0.819	0.030	0.424	0.040	0.277	0.029
Outfall	21 Jul	0.972	0.010	0.822	0.025	0.963	0.014	0.843	0.028	0.661	0.038	0.429	0.031
Tailrace	21-22 Jun	0.995	0.007	0.946	0.020	0.985	0.012	0.967	0.025	0.814	0.042	0.729	0.040
Tailrace	26-29 Jun	0.960	0.012	0.957	0.016	0.975	0.020	0.993	0.032	0.892	0.037	0.793	0.029
Tailrace	3-6 Jul	0.963	0.011	0.957	0.013	0.972	0.011	0.984	0.020	0.765	0.039	0.674	0.035
Tailrace	10-13 Jul	0.987	0.007	0.845	0.024	0.935	0.020	0.862	0.033	0.678	0.045	0.456	0.033

Table 6. Detection-probability estimates (P), and associated standard errors (SE) for detection array partitions used to estimate yearling and subyearling Chinook salmon survival through the lower Columbia River and estuary, 2007. Figures in parentheses indicate river kilometer locations associated with the array names.

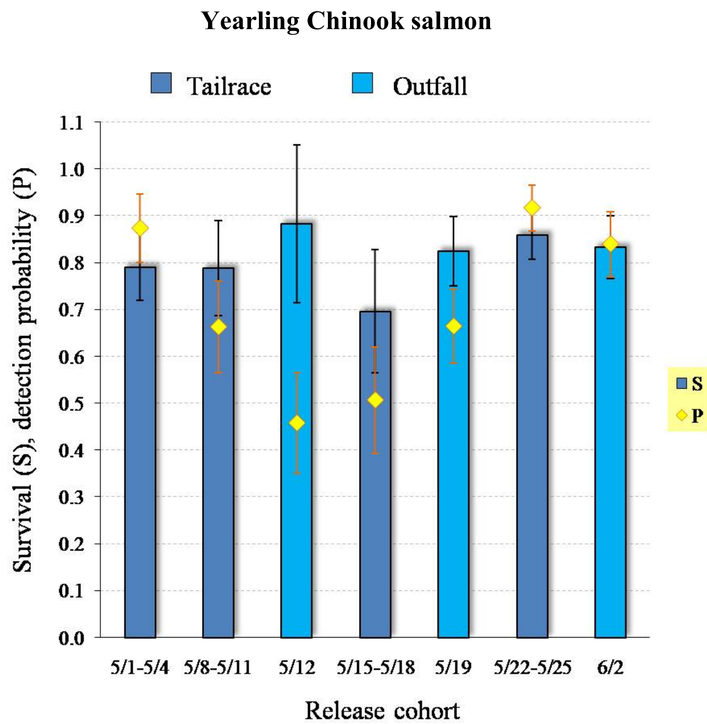
		Array									
		BON1 (202.0)		KLM1 (113.0)		OAK1 (86.2)		EIS3 (57.0)		EST1 (8.3)	
Release site	Release date(s)	P	SE	P	SE	P	SE	P	SE	P	SE
		Yearling Chinook									
Outfall	12 May	0.888	0.020	0.667	0.031	0.772	0.029	0.726	0.037	0.458	0.055
Outfall	19 May	0.945	0.015	0.642	0.032	0.736	0.030	0.557	0.037	0.664	0.040
Outfall	2 Jun	0.953	0.014	0.651	0.032	0.819	0.026	0.750	0.031	0.840	0.036
Tailrace	1-4 May	0.967	0.012	0.679	0.030	0.944	0.015	0.852	0.026	0.873	0.037
Tailrace	8-11 May	0.880	0.021	0.678	0.030	0.842	0.024	0.855	0.027	0.663	0.050
Tailrace	15-18 May	0.923	0.017	0.644	0.032	0.693	0.033	0.648	0.042	0.507	0.058
Tailrace	22-25 May	0.823	0.025	0.719	0.029	0.725	0.029	0.874	0.023	0.917	0.025
		Subyearling Chinook									
Outfall	16 Jun	0.987	0.008	0.904	0.020	0.905	0.020	0.817	0.028	0.855	0.029
Outfall	23 Jun	0.936	0.016	0.897	0.020	0.950	0.015	0.835	0.027	0.836	0.031
Outfall	30 Jun	1.000	******	0.028	0.011	0.064	0.017	0.535	0.035	0.713	0.039
Outfall	7 Jul	1.000	******	0.860	0.023	0.975	0.011	0.860	0.029	0.880	0.033
Outfall	14 Jul	0.996	0.005	0.914	0.020	0.974	0.011	0.890	0.029	0.917	0.030
Outfall	17 Jul	0.991	0.007	0.919	0.020	0.932	0.020	0.985	0.015	0.954	0.032
Outfall	21 Jul	1.000	******	0.912	0.021	0.994	0.006	0.963	0.018	0.989	0.011
Tailrace	21-22 Jun	0.964	0.016	0.854	0.030	0.969	0.015	0.837	0.036	0.880	0.038
Tailrace	26-29 Jun	0.989	0.007	0.695	0.029	0.622	0.031	0.486	0.034	0.805	0.031
Tailrace	3-6 Jul	1.000	******	0.886	0.020	0.988	0.007	0.839	0.027	0.769	0.039
Tailrace	10-13 Jul	0.996	0.004	0.640	0.032	0.979	0.011	0.808	0.035	0.790	0.045

Tailrace releases were pooled by week for comparative analysis between release strategies. There was no significant difference in mean survival between yearling Chinook released to the tailrace (0.78, SE = 0.006) and those released to the outfall (0.85, SE = 0.006; $t = 0.199$, $\alpha = 0.05$, df = 5, $P = 0.199$). Subyearling Chinook salmon survival followed a similar trend ($t = 0.434$, $\alpha = 0.05$, df = 9, $P = 0.673$). For subyearling Chinook salmon, mean survival for tailrace releases (0.66, SE = 0.194) was not significantly different from the mean for outfall releases (0.61, SE = 0.194).

Yearling Chinook salmon survival through the lower estuary was comparable to that from previous years (McComas et al. 2007, 2008). However, battery failures on some receivers in the primary array from 15 to 18 May (Appendix C) resulted in lower detection probabilities than were recorded over the same time period in earlier years. Subyearling Chinook salmon survival also followed the trend seen in 2005 and 2006, remaining higher through the initial weeks of the migration and declining for successive release groups after approximately 1 July. This trend was apparent for both the tailrace (pooled over weekly intervals) and outfall release strategies (Figure 5).

Partition arrays indicated differential mortality for acoustic-tagged fish through the lower Columbia River and estuary. Yearling Chinook salmon displayed an initial decrease in survival to the first detection array (Figure 6), which was not apparent for subyearling fish (Figure 7). Both yearling and subyearling Chinook salmon survival decreased markedly through the estuary below Tenasillahe Island (rkm 53). However, particularly for subyearling Chinook salmon, there appears to have been a temporal component associated with decreased survival: increased mortality began farther upstream in the system as the juvenile migration proceeded for both outfall and tailrace release strategies (Figure 7).

It is possible that subyearling Chinook salmon tended to become less migratory, and an increasing proportion of the tagged population ceased migration later in the season. If this occurred, then these fish may not have been mortalities, but instead failed to migrate past the detection arrays prior to expiration of their acoustic transmitter batteries. They may have adopted an extended-rearing life history strategy, similar to that observed in Snake River reservoirs (Connor et al. 2002, 2005; McMichael et al. 2008; Buchanan et al. in press).



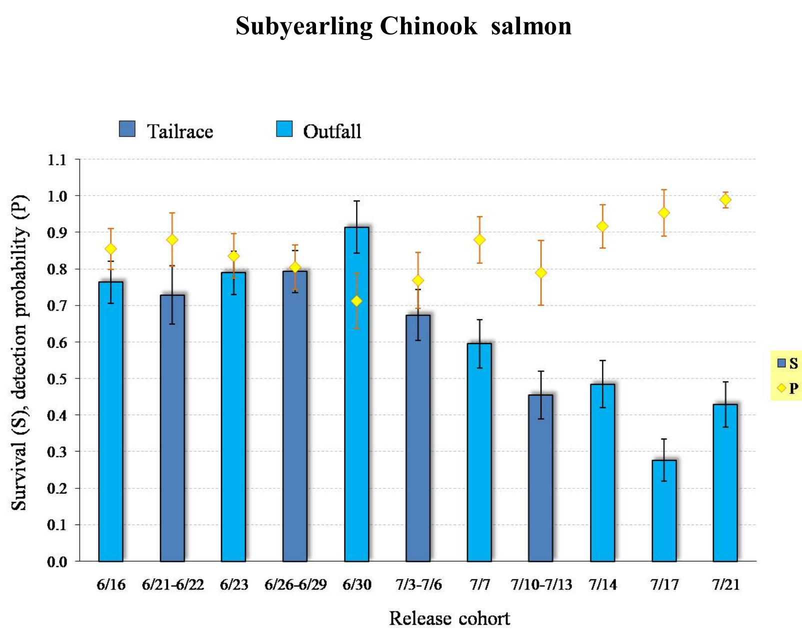
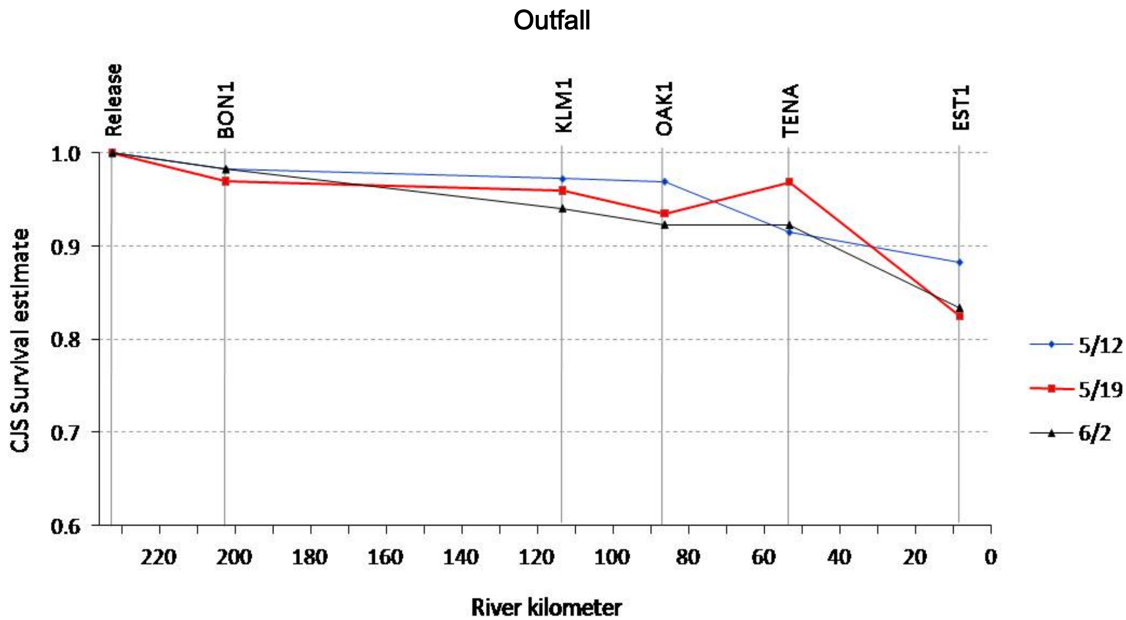


Figure 5. Survival and detection probability estimates (± 95% confidence interval) for yearling (a) and subyearling (b) Chinook salmon cohorts from release mid river from boats (Tailrace, rkm 232) or from the juvenile fish facility bypass outfall (Outfall, rkm 231) through the lower Columbia River estuary (rkm 8.3), 2007. Daily tailrace releases were pooled over the dates indicated to form release cohorts.



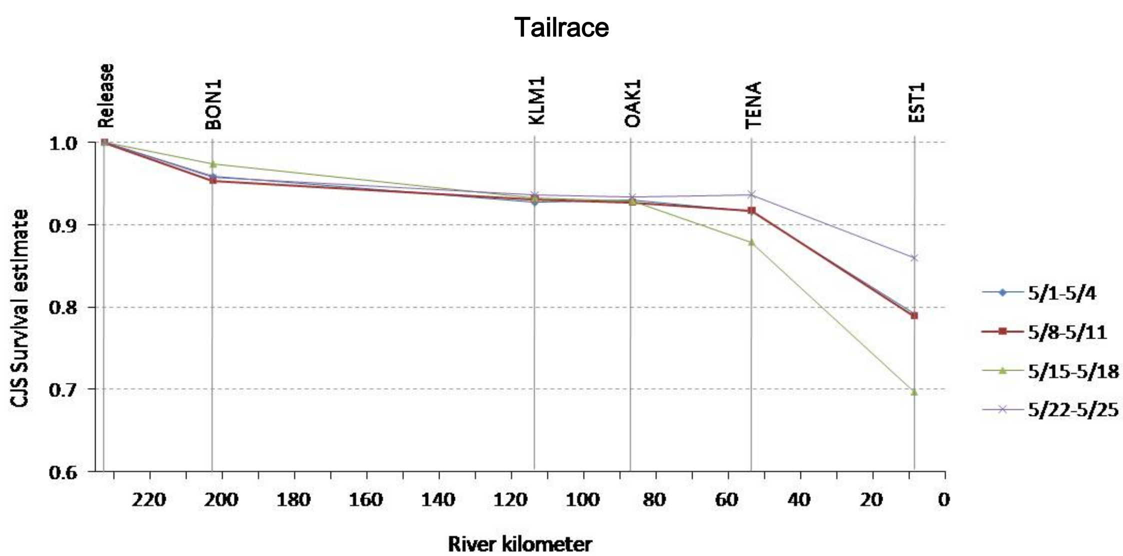


Figure 6. Cumulative survival estimates for yearling Chinook salmon from release at rkm 232 (Release) to stationary arrays in the lower Columbia River and estuary. Tailrace releases were made from boats in mid-river and Outfall releases through the juvenile fish facility outfall. Tailrace releases were pooled over the dates indicated to form cohorts. Locations are BON1 rkm 202.0, KLM1 rkm 113.0, OAK1 rkm 86.2, Tena rkm 57, and EST1 rkm 8.3.

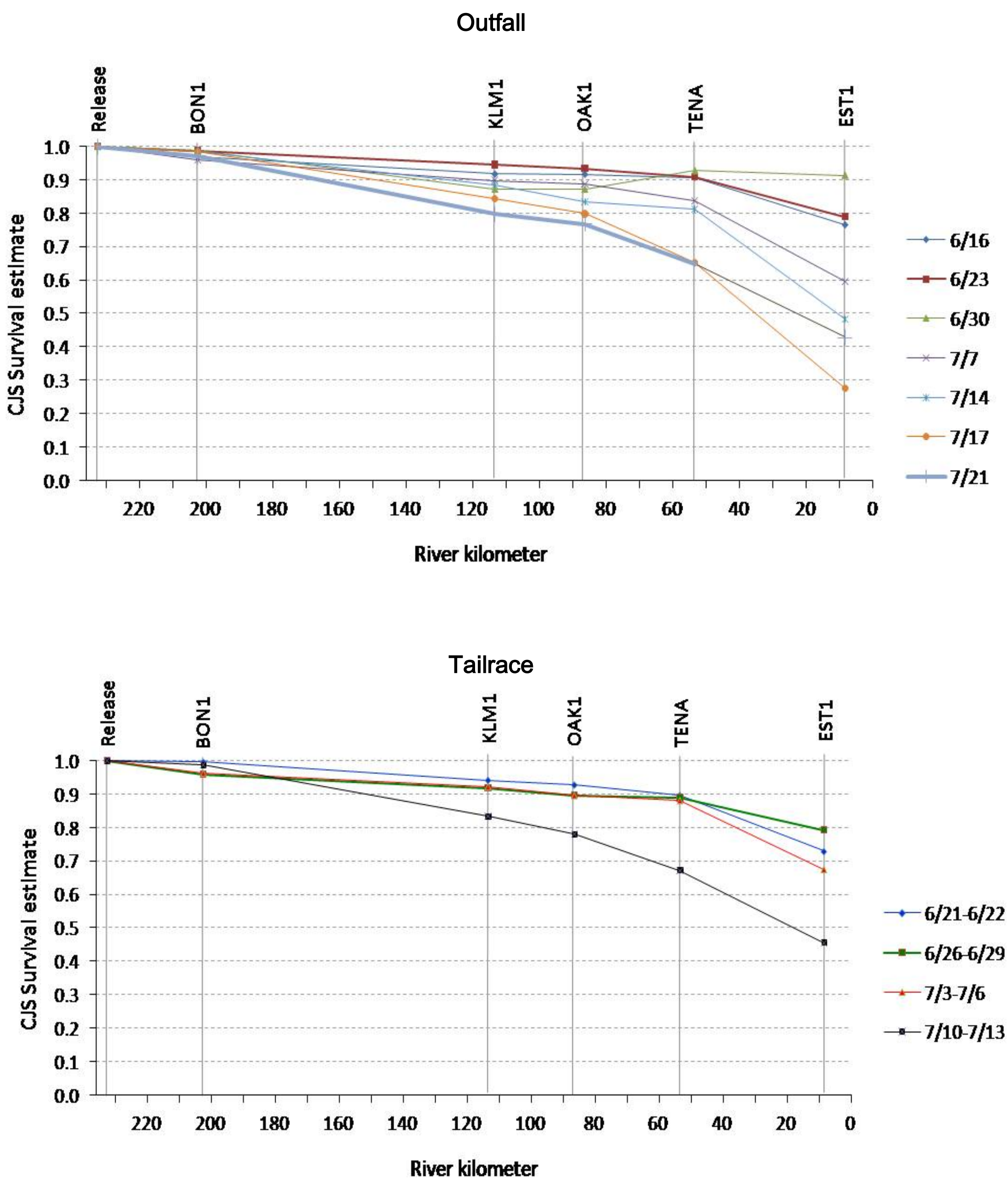


Figure 7. Cumulative survival estimates for subyearling Chinook salmon from release at rkm 232 (Release) to stationary arrays in the lower Columbia River and estuary. Tailrace releases were made from boats in mid-river and Outfall releases through the juvenile fish facility outfall. Tailrace releases were pooled over the dates indicated to form cohorts. Array locations are BON1 rkm 202.0, KLM1 rkm 113.0, OAK1 rkm 86.2, Tena rkm 57, and EST1 rkm 8.3.

Fish Behavior

Travel times to the primary estuary array for acoustic-tagged yearling Chinook salmon released at Bonneville Dam ranged from 2.3 to 14.8 d, with a mean of 3.8 d (SE = 0.07). Mean travel time decreased over the course of the season, as did variability, while discharge at Bonneville Dam also decreased (Figure 8). Yearling Chinook salmon released at Bonneville were first detected on acoustic arrays over a variety of tidal conditions, although 82% of first detections occurred during outgoing tides (Figure 9). The majority of yearling Chinook salmon released at Bonneville Dam (80%) were first detected during daylight hours (Figure 10), and detections on the primary array were oriented towards the middle of the Washington side (Figure 11). The majority of yearling Chinook salmon passing the primary array had well above the minimum number of detections, and the number of detections was similar across the array (Figure 12). Therefore, cross-channel distribution at the primary array did not appear to be an artifact of detection efficiency.

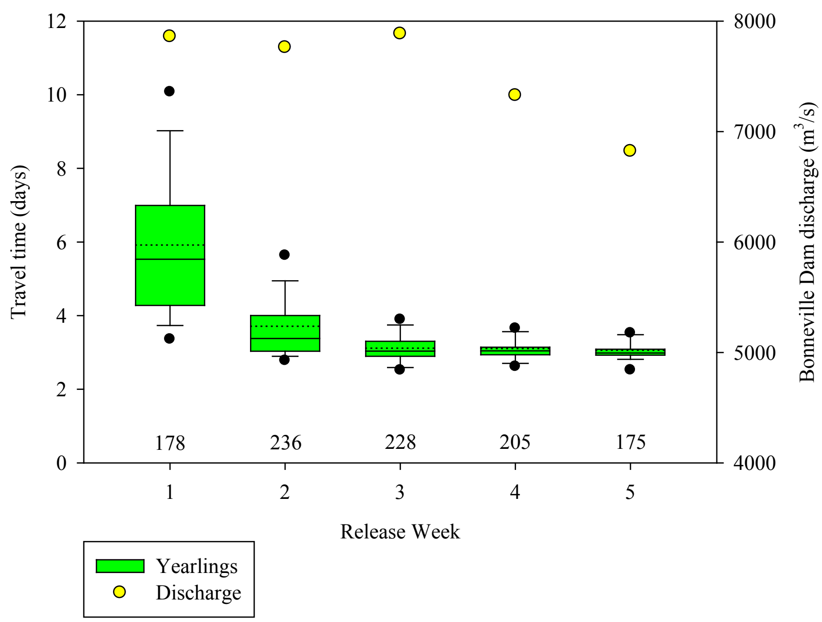


Figure 8. Travel time (d) from Bonneville Dam to the estuary primary array for groups of acoustic-tagged yearling Chinook salmon released to estimate juvenile salmonid survival, 2007. Solid lines within boxes represent medians, dotted lines represent means, upper and lower limits of the box represent the 25th and 75th percentiles, whiskers represent the 10th and 90th percentiles, and dots represent the 5th and 95th percentiles. Numbers above the x-axis are sample sizes.

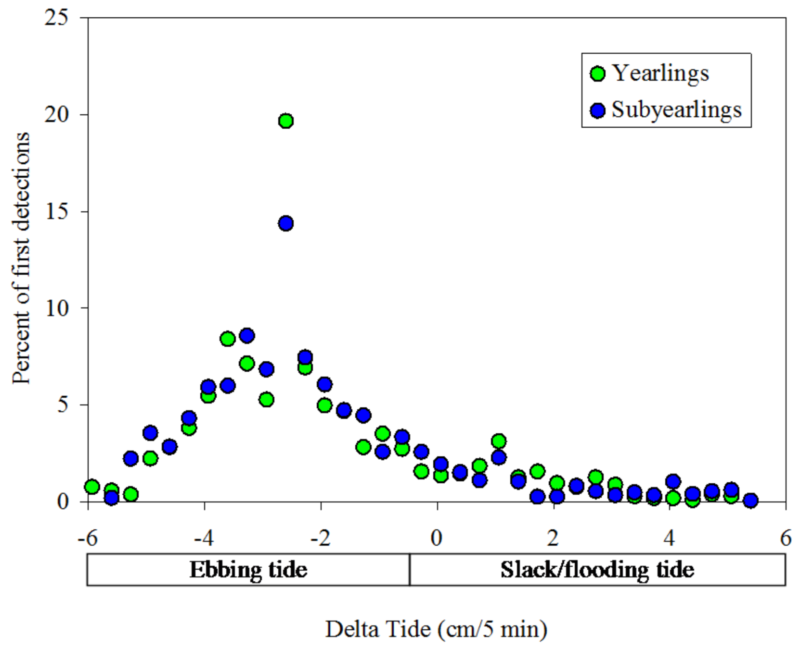


Figure 9. Percentage of first detections of yearling and subyearling Chinook salmon released below Bonneville Dam on the estuary primary array vs. change in tide elevation.

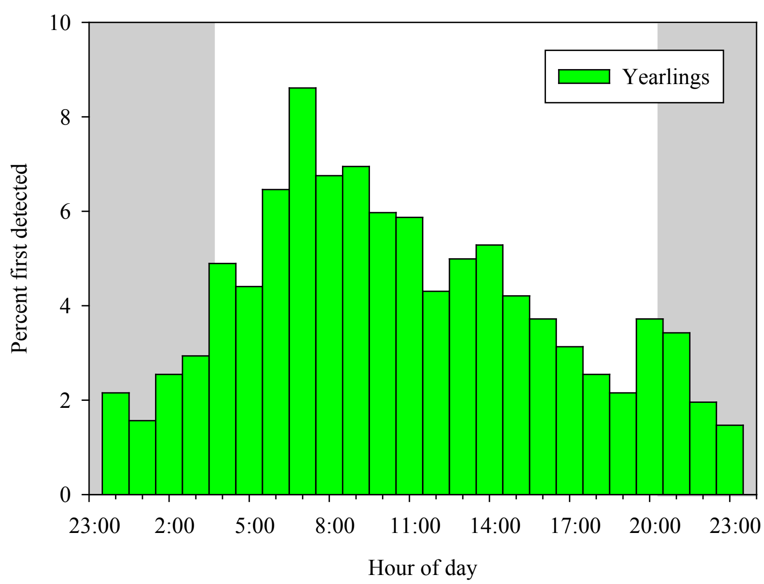


Figure 10. Time of arrival (24-h scale) at the estuary primary array for yearling Chinook salmon released downstream of Bonneville Dam in 2007. Shaded areas represent approximate hours of darkness.

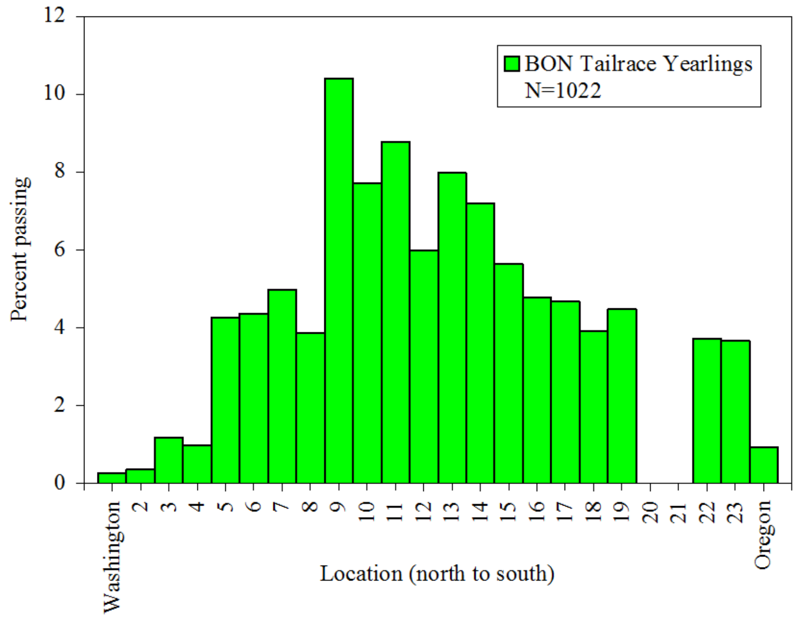


Figure 11. Cross-channel distribution of acoustic-tagged yearling Chinook salmon released below Bonneville Dam and detected on the primary receiving array in the Columbia River estuary, 2007. The navigation channel is located between positions 19 and 22.

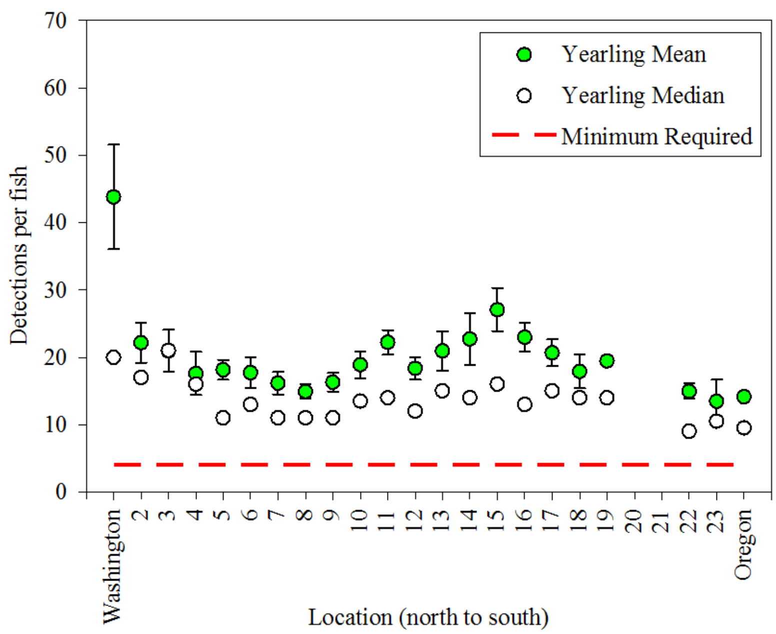


Figure 12. Mean (±1.96 SE) and median number of detections per fish across the primary receiving array in the Columbia River estuary for yearling Chinook salmon released below Bonneville Dam in 2007, shown with the minimum number of detections required.

Subyearling Chinook salmon released at Bonneville Dam traveled to the estuary primary array in an average of 4.8 days (range = 2.8 to 30.4, SE = 0.06; Figure 13). Like the yearlings, the majority of subyearling Chinook salmon were first detected during outgoing tides (84%, Figure 9) and during daylight hours (69%, Figure 14). Subyearling Chinook salmon were detected more frequently near the Washington side of the primary array (Figure 15), and like the yearlings, the majority of subyearling Chinook salmon passing that array had well above the minimum number of detections and the number of detections was similar across the array (Figure 16).

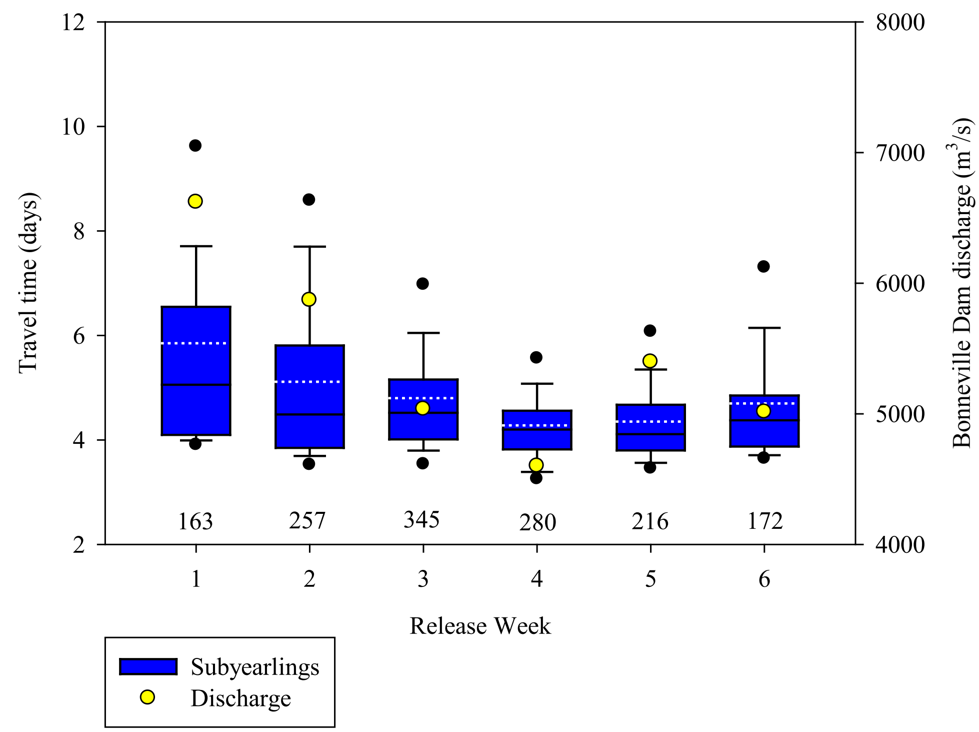


Figure 13. Travel time (days) by release week from downstream of Bonneville Dam to the estuary primary array for groups of acoustic-tagged subyearling Chinook salmon, 2007. Yellow dots show discharge from Bonneville Dam. Solid lines within boxes represent medians, dotted lines represent means, upper and lower limits of the box represent the 25th and 75th percentiles, whiskers represent the 10th and 90th percentiles, and dots represent the 5th and 95th percentiles. Numbers above the x-axis are sample sizes.

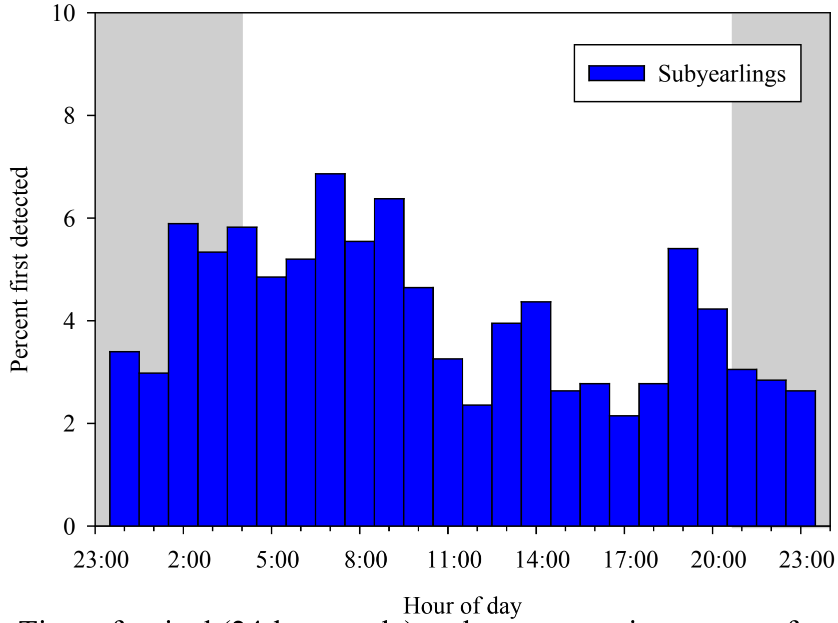


Figure 14. Time of arrival (24-hour scale) at the estuary primary array for subyearling Chinook salmon released downstream of Bonneville Dam in 2007. Shaded areas represent approximate hours of darkness.

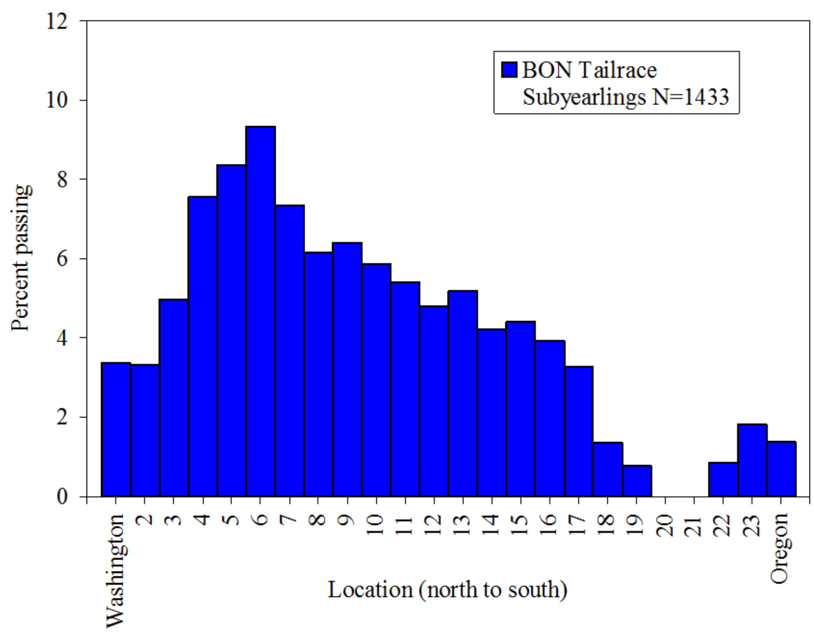


Figure 15. Cross-channel distribution of acoustic-tagged subyearling Chinook salmon released below Bonneville Dam and detected on the primary receiving array in the Columbia River estuary, 2007. The navigation channel is located between positions 19 and 22.

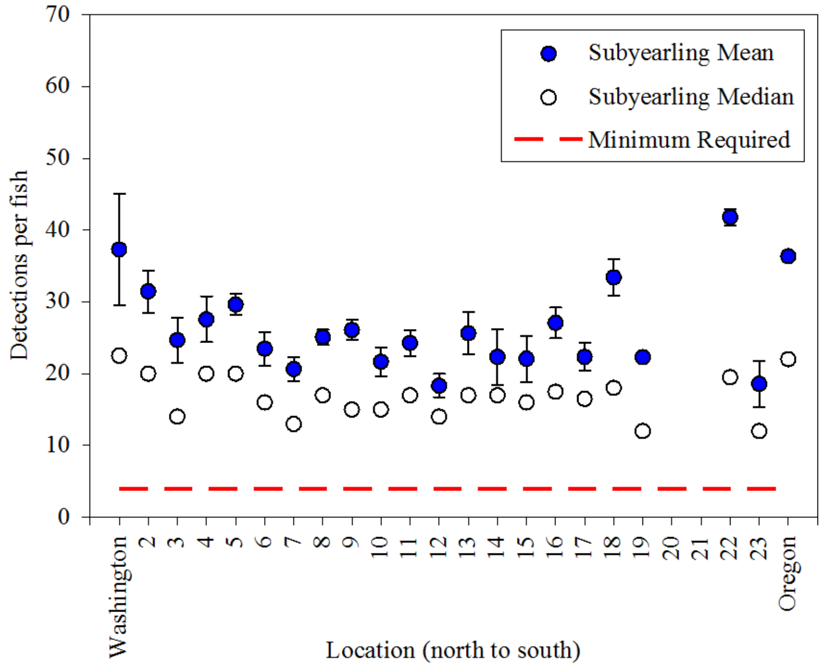


Figure 16. Mean (±1.96 SE) and median number of detections per fish across the primary receiver array in the Columbia River estuary for subyearling Chinook salmon released below Bonneville Dam in 2007, shown with the minimum number of detections required.

PIT tags from 108 acoustic-tagged Chinook salmon were detected on the pair-trawl detection system operated by NMFS at the upper end of the estuary near Jones Beach, Oregon (rkm 75). Of these detections, 78 were yearling fish. Numbers of yearling and subyearling Chinook salmon detected on the pair trawl by release group are presented in Table 6. For all yearling Chinook detected on the pair trawl, travel time from the outfall at Bonneville Dam to Jones Beach ranged from 1.4 to 6.8 d with a median of 1.8 d (mean 2.1 d, SE = 0.091) .

Based on median travel times from the JBF outfall at Bonneville Dam to Jones Beach, and on median travel times of acoustic-tagged fish to the estuary arrays, yearling Chinook salmon required approximately 1.3 d to travel between Jones Beach and the lower estuary. Mean migration rate over the first 156 km from the Bonneville Dam JBF outfall to Jones Beach was approximately 74 km/d for yearling fish detected on the pair trawl from all 19 spring releases combined. The estimated mean migration rate over the remaining distance from Jones Beach to the primary array (66 km) was approximately 51 km/d, indicating that migration rate slowed as the fish approached the ocean. This agrees with migration rates calculated from detections of these fish on acoustic telemetry arrays (Figure 17).

Table 6. Numbers of Chinook salmon released at Bonneville Dam detected on the pair trawl in the upper Columbia River estuary near Jones Beach, Oregon (rkm 75) in 2007. Dashes indicate no detections.

Release location	Release date	Number released	Observed on pair trawl N	Observed on pair trawl (%)
		Yearling Chinook		
Tailrace	1 May	65	1	1.5
Tailrace	2 May	65	1	1.5
Tailrace	3 May	64	2	3.1
Tailrace	4 May	65	2	3.1
Tailrace	8 May	65	2	3.1
Tailrace	9 May	65	--	--
Tailrace	10 May	65	3	4.6
Tailrace	11 May	65	--	--
Outfall	12 May	250	23	9.2
Tailrace	15 May	65	3	4.6
Tailrace	16 May	63	3	4.8
Tailrace	17 May	65	2	3.1
Tailrace	18 May	65	1	1.5
Outfall	19 May	250	16	6.4
Tailrace	22 May	65	1	1.5
Tailrace	23 May	65	4	6.2
Tailrace	24 May	65	2	3.1
Tailrace	25 May	65	2	3.1
Outfall	2 Jun	250	10	4.0
Total		1,786	78	4.4
		Subyearling Chinook		
Outfall	16 Jun	251	4	1.6
Tailrace	21 Jun	74	1	1.4
Tailrace	22 Jun	74	1	1.4
Outfall	23 Jun	250	5	2.0
Tailrace	26 Jun	74	--	--
Tailrace	27 Jun	74	--	--
Tailrace	28 Jun	74	--	--
Tailrace	29 Jun	74	3	4.1
Outfall	30 Jun	250	2	0.8
Tailrace	3 Jul	74	--	--
Tailrace	4 Jul	74	--	--
Tailrace	5 Jul	74	--	--
Tailrace	6 Jul	73	2	2.7
Outfall	7 Jul	250	4	1.6
Tailrace	10 Jul	75	1	1.3
Tailrace	11 Jul	70	--	--
Tailrace	12 Jul	80	--	--
Tailrace	13 Jul	75	--	--
Outfall	14 Jul	250	7	2.8
Outfall	17 Jul	250	--	--
Outfall	21 Jul	250	--	--
Total		2,789	30	1.1

Median travel time from Bonneville Dam JBF outfall to detection on the pair trawl was 2.7 d (ranged 1.9-6.3 d, mean 2.8 d, SE = 0.169) for the 30 acoustic-tagged subyearlings detected. These fish had a mean migration rate of approximately 56 km/d. Estimated median migration rate from Jones Beach to the primary acoustic array for subyearling smolts was about 42 km/d. Data from both the PIT and acoustic telemetry detections showed that subyearling migration rates slowed as fish approached the estuary (Figure 17).

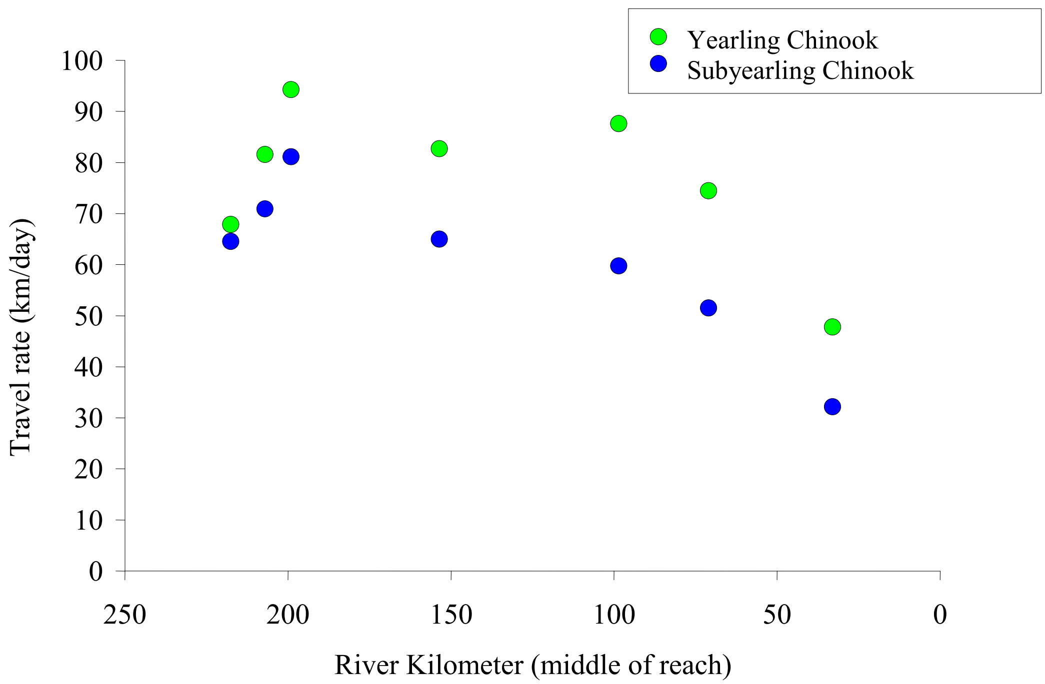


Figure 17. Migration rate in kilometers per day for reaches between acoustic receiver arrays in the lower Columbia River for acoustic-tagged yearling (CH1) and subyearling (CH0) Chinook salmon released below Bonneville Dam in 2007, plotted against the river kilometer at the middle of the measured reach.

Migration Pathways

In 2007, we began a pilot project to examine the migration characteristics of fish traveling in pathways other than the main Columbia River channel downstream from Tenasillahe Island. Using data collected from the six acoustic receivers deployed among the estuary islands (Figure 3), we evaluated when fish were detected, specific migration pathways, travel times, and survival estimates.

Yearling and subyearling Chinook released above and below Lower Granite Dam and below Bonneville Dam were detected on receivers in the estuary island side channels. Regardless of release location, subyearlings were more likely than yearling Chinook to be detected in side channels. Of fish detected on the arrays directly upstream from the estuary islands (EIS1 or EIS2), 8.7% of yearling Chinook and 20.3% of subyearlings were detected at least once in the island side channels (Table 7). Detection rates in side channels varied little among groups released from different locations.

Table 7. Numbers of yearling and subyearling Chinook salmon released at Lower Granite and Bonneville Dam locations that were detected on arrays directly upstream from the estuary islands (EIS1 or EIS2). Also shown are the number and percentage of these fish detected on receivers in side channels of the islands.

Release location	Detection on EIS1 or EIS2 (N)	Detected in island side channel (N)	(%)
	Yearling Chinook		
Lower Granite Dam	1,268	102	8.0
Bonneville forebay	2,279	184	8.1
Bonneville tailrace	1,459	152	10.4
Total	5,006	438	8.7
	Subyearling Chinook		
Lower Granite Dam	502	102	20.3
Bonneville forebay	2,244	451	20.1
Bonneville tailrace	2,208	455	20.6
Total	4,954	1,008	20.3

Seasonal migration timing is presented in Figure 18 as proportions of tagged fish detections for each release date by species and release location. Use of island pathways increased with release date for yearling Chinook, but was variable for subyearlings. This pattern was also consistent among release locations, except that detection rates decreased toward the end of the summer sampling season for subyearlings released from Lower Granite Dam (Figure 19).

Fish from all release locations and groups were detected among the islands during all hours of the day and night, although detections of all groups were more likely to occur in the islands during daylight hours (Figure 19). This was especially evident in the diel distributions of yearling Chinook released from Bonneville Dam tailrace and of subyearlings released from Lower Granite Dam (Figure 19).

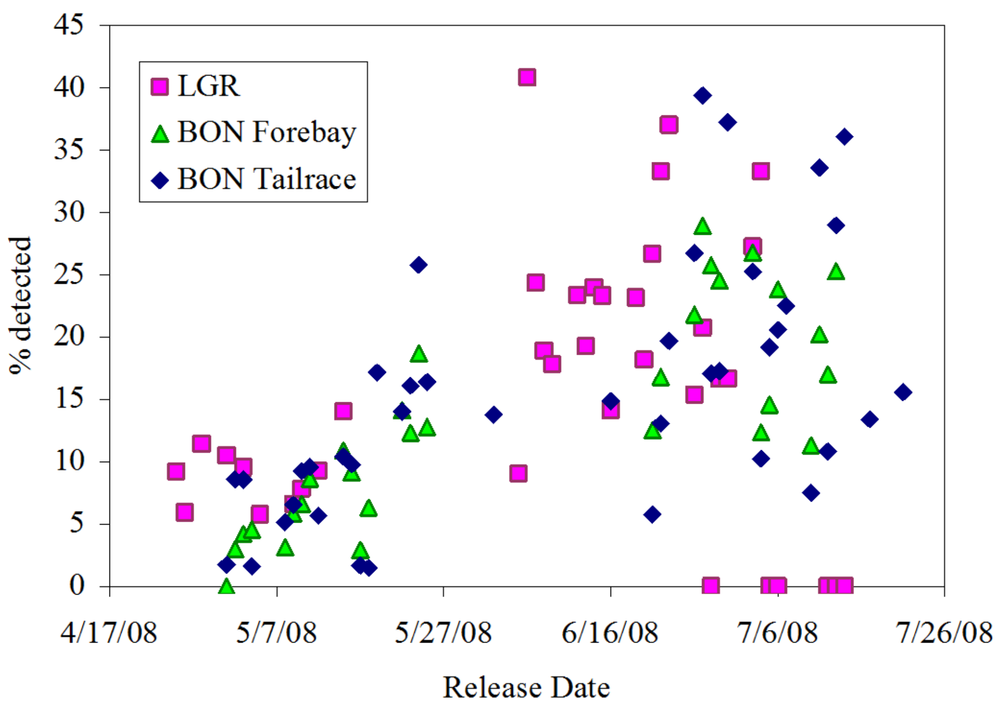


Figure 18. Percentage of juvenile Chinook salmon released at Lower Granite Dam (LGR), and above (BON Forebay) and below (BON Tailrace) Bonneville Dam detected anywhere in the estuary islands by release date, adjusted by estimated survival to EIS2. Yearling Chinook salmon were generally detected prior to 15 June, with subyearlings detected after 15 June.

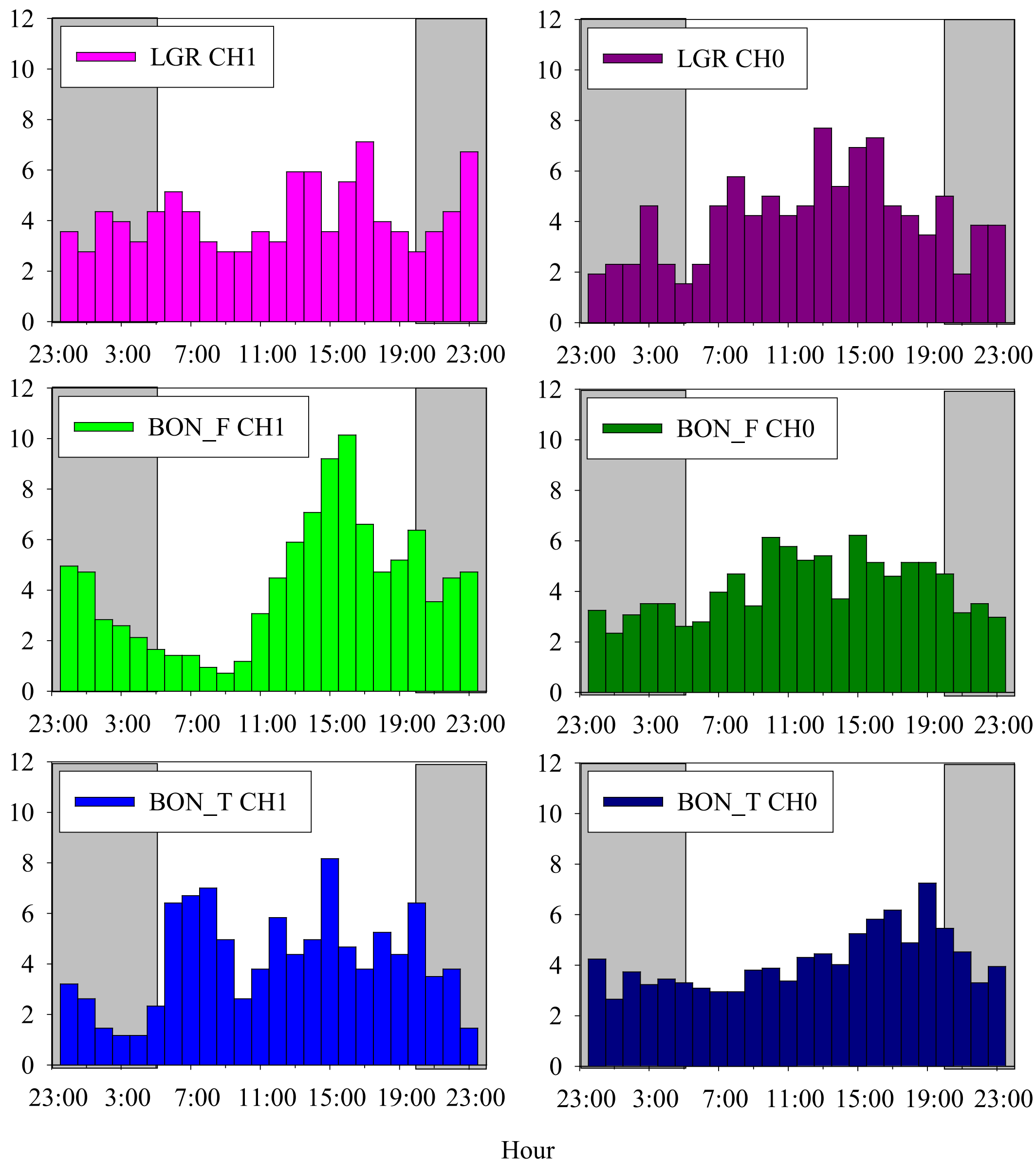


Figure 19. Counts of yearling (CH1) and subyearling (CH0) Chinook salmon released at Lower Granite Dam (LGR) and above (BON_F) and below (BON_T) Bonneville Dam detected by hour on the arrays in the islands in 2007. Shaded bars approximate hours of darkness.

Of fish detected at the arrays adjacent to Tenasillahe Island (EIS3), 10% of yearling Chinook and 26% of subyearling Chinook salmon used the side-channel route through Clifton Channel (Table 8). This corresponds with similar findings (discussed above) for the percentages of fish detected in island side channels that had previously been detected at upstream arrays EIS1 or EIS2 (Table 8).

Of fish detected passing Clifton Channel receivers and last detected at island receivers, the most common migration pathway was through the channel between Marsh and Karlson Islands (EIS6), where 67 and 45% of yearling and subyearling Chinook salmon migrated, respectively (Table 8). The next most common routes were between Karlson Island and the mainland (EIS7; 21% yearlings) and between Tronson Island and the mainland (EIS5; 28% subyearlings; Table 9). Fifty-eight percent of the yearlings and 60% of the subyearlings detected at the Clifton Channel receivers (EIS3_08 and _09) were not detected at other island receivers.

Table 8. Migration pathways of juvenile Chinook salmon in the Columbia River estuary. The data include yearling and subyearling fish detected at EIS3 (main channel) or EIS3sc (Clifton Channel). The island pathways indicate fish detected at EIS3sc that were last detected at island receivers (EIS4, EIS5, EIS6, or EIS7).

	Migration pathways					
	Yearling Chinook		Subyearling Chinook		Total	
	N	%	N	%	N	%
	Main channel/Clifton Channel					
EIS3 Main channel	3,806	90	2,790	74	6,596	82
EIS3sc Clifton Channel	439	10	961	26	1,400	18
Total	4245		3751		7,996	
	Island pathways					
Last detection at EIS4, Welch Isl	4	2	66	17	70	12
Last detection at EIS5, Tronson Isl	19	10	106	28	125	22
Last detection at EIS6, Marsh Isl	123	67	175	45	298	52
Last detection at EIS7, Karlson Isl	39	21	38	10	77	14
Total	185		385		570	

Table 9. Travel times in hours from first detection in either the main channel or side channel of the estuary islands array at Tenasillahe Island to first detection on the primary array in the Columbia River estuary, for yearling and subyearling Chinook salmon released at Lower Granite Dam and Bonneville Dam forebay and tailrace in 2007.

	Travel time (h)					
	Main channel			Side channel		
Release location	N	Mean (SE)	Median	N	Mean (SE)	Median
	Yearling Chinook					
Lower Granite Dam	474	23.8 (0.4)	22.9	59	25.6 (0.6)	25.1
Bonneville forebay	1248	34.5 (0.6)	26.2	128	31.1 (1.4)	25.3
Bonneville tailrace	690	31.4 (0.7)	25.1	97	27.4 (0.8)	25.0
Total	2412	31.5 (0.4)	25.0	284	28.7 (0.7)	25.2
	Subyearling Chinook					
Lower Granite Dam	167	33.7 (1.4)	30.7	63	32.3 (1.2)	30.4
Bonneville forebay	676	46.3 (1.5)	36.5	249	44.6 (2.6)	36.1
Bonneville tailrace	836	45.4 (1.1)	37.1	276	42.3 (1.5)	36.7
Total	1679	44.6 (0.9)	36.1	588	42.2 (1.3)	36.1

Travel times from first detection on the array at Tenasillahe Island to first detection on the primary array in the Columbia River estuary for fish detected in Clifton Channel (EIS3_08 and _09, Figure 3) were not substantially different from those for fish detected in the main channel at Tenasillahe Island (Table 10). Yearling Chinook salmon median travel times were 25.0 and 25.2 h for main-channel and side-channel routes, respectively (Table 10). Median travel times for subyearling fish were identical at 36.1 h for the two pathways past Tenasillahe Island.

Survival to the estuary primary array for yearling Chinook detected on the main channel array at Tenasillahe Island (EIS3, 0.84, SE = 0.011) was similar to survival to the estuary primary array for yearling Chinook detected in the side channel at Tenasillahe Island (0.83, SE = 0.031). Survival to the estuary primary array was slightly lower for subyearlings detected in the main channel (0.72, SE = 0.010) than for those detected in the side channel (0.76, SE = 0.017).

Table 10. Survival estimates (*S*) to the estuary primary array from the main channel and side channel of the estuary islands array at Tenasillahe Island for yearling and subyearling Chinook salmon released at Lower Granite Dam, above Bonneville forebay, and below Bonneville tailrace in 2007.

Release location	Main channel			Side channel		
		CJS survival estimate to primary array			CJS survival estimate to primary array	
	N	*S*	SE_s	N	*S*	SE_s
	Yearling Chinook					
Lower Granite Dam	834	0.77	0.029	108	0.81	0.094
Bonneville forebay	1,881	0.85	0.015	183	0.88	0.045
Bonneville tailrace	1,092	0.87	0.021	148	0.82	0.048
Pooled	3,807	0.84	0.011	439	0.83	0.031
	Subyearling Chinook					
Lower Granite Dam	265	0.84	0.036	106	0.85	0.071
Bonneville forebay	1,186	0.68	0.016	403	0.75	0.027
Bonneville tailrace	1,344	0.73	0.014	462	0.75	0.025
Pooled	2,795	0.72	0.010	971	0.76	0.017

Mobile Tracking

Use of the mobile tracking array was delayed until the latter portion of the yearling Chinook migration due to lack of qualified vessel operators. We were able to track yearling Chinook tagged as targets during 22-30 May near the tailrace release point downstream from Bonneville Dam (rkm 231) and during 4-6 June in the lower estuary. Mobile tracking of subyearling Chinook salmon was conducted for a total of 22 d, from 19 June through 24 July. Target tags from subyearling fish were also recorded during mobile tracking evaluation and testing on 21 and 22 August. Reception data for verified targets are summarized by release and recovery date in Appendix D.

The mobile tracking unit functioned as intended. Once verified as an event, bearing vectors provided a reliable direction to close with the target. Range and bearing were then used to track the target closely for as long as needed, or until circumstances made continuing impractical (e.g., shallow water, inclement weather, obstructions, etc). We tracked 721 verified acoustic tags from free-ranging target fish, recording over 72,600 individual hydrophone receptions. Of these verified tags, 15 were unique codes from fish released at Lower Granite Dam (5 yearlings and 10 subyearlings), and 652 were unique codes from Chinook salmon released at Bonneville Dam (208 yearlings and 444 subyearlings).

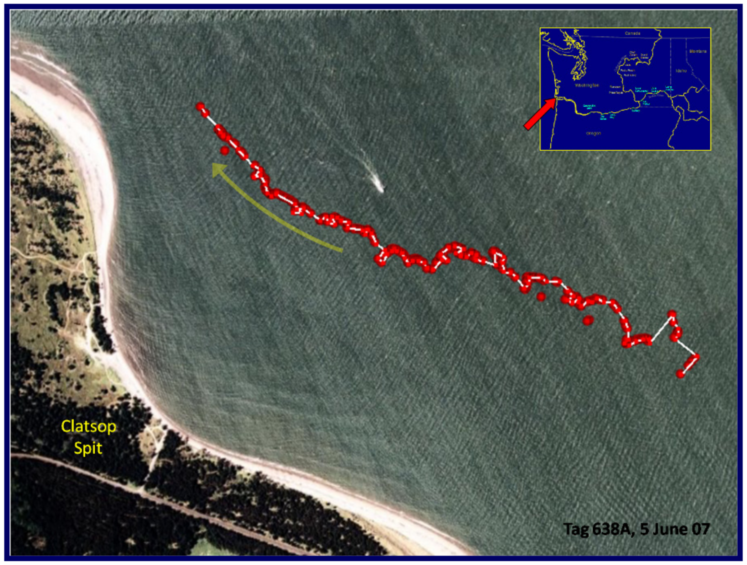
Of the 652 target fish released near Bonneville Dam and detected using the mobile tracker, 204 (31.4%) had been released to the forebay to estimate survival for fish passing through the spill bays, and 448 fish (68.6%) had been released to the tailrace. Of the acoustic-tagged fish released to the tailrace of Bonneville Dam and subsequently detected on the mobile tracking unit, 280 (62.6%) had been released through the JFF outfall and 168 (37.4%) had been released mid-river from boats in the tailrace.

Subyearling Chinook target fish were tracked at locations ranging from Bonneville Dam to the lower estuary. The majority of these target fish (97%) were acquired in the main river channel. However, a small proportion (3%) were also acquired on the shore side of island side-channels. These acquisitions were consistent with observations from the stationary acoustic arrays, which showed migrating juvenile Chinook using the island side-channels. Actively moving target fish were tracked in side channels of Sandy Island (rkm 121) and of the Fisher-Hump (rkm 97) and Lord-Walker (rkm 101) Island complexes. Over the short intervals during which mobile tracking surveys were conducted in 2007, no targets were observed in the side-channels of Tomahawk (rkm 108), Hayden (rkm 105), Crims (rkm 88), or Puget (rkm 64) Islands.

Geodetic positions were computed during post-processing of target points using range and bearing vectors from the tracking vessel. Plots of these positions for individual targets ranged from a single point to tracks of several kilometers in length (Figure 20). Excluding individual points within tracks, we obtained 98 tracks for yearling Chinook and 449 tracks for subyearling Chinook salmon tagged as mobile tracking targets. The majority of these (approximately 95%) displayed movement indicative of directed downstream migration, while a few appeared to move randomly (Figure 20). Several target tags were tracked more than one time, usually on the same day. No target fish were located during successive tracking periods at or near the same location, suggesting that no resident fish were found. However, given the non-systematic nature of these surveys, prolonged residence may well have occurred without being observed.

Although some tracked target fish appeared to remain at fixed geodetic locations (Figure 21), we did not interpret these as an indication of residency. Depth estimates of these tags based on the depth-vector function of the mobile tracking unit agreed closely with depth estimates from the depth sounder on the tracking vessel. These data indicated that fixed targets were at or near the river bottom. To verify the fixed status of a tag, we returned to the tag site at least once, from 24 h to several days following initial contact. Using this process, we were able to confirm the fixed status and location of 22 target tags (Figure 21). None of the tags found to be fixed during mobile tracking were observed on the stationary acoustic arrays downstream, lending confidence to our conclusion of their fixed-position status. Interestingly, several target tags confirmed as stationary were located in island side-channels. One of these tags was found in Carrolls Channel, east of Cottonwood Island, and one was located in Martin Slough, east of Martin Island. Several target tags with fixed status were documented in Fisher Island Slough on the east side of the Fisher-Hump Island complex.

There are at least three mechanisms by which these tags may have come to rest on the river bottom. First, a tagged fish may have died due to tag- or surgery-related causes (tagging effects) and settled to the substrate while the tag was still active. Second, the tags may have been expelled. Several authors have reported rejection or expulsion of surgically implanted active tags in salmonids (Chisholm and Hubert 1985; Lucas 1989; Lacroix et al 2004; Hockersmith et al. 2008). More specifically, Frost et al. (in prep) found evidence for the expulsion of surgically implanted JSATS tags from subyearling Chinook salmon held in raceways during tag-effects evaluations. The time frame between release and travel to the stationary-tag locations was too short to have allowed physiological encapsulation and expulsion to be completed. However, tag expulsion through the incision site is certainly possible within this time frame.



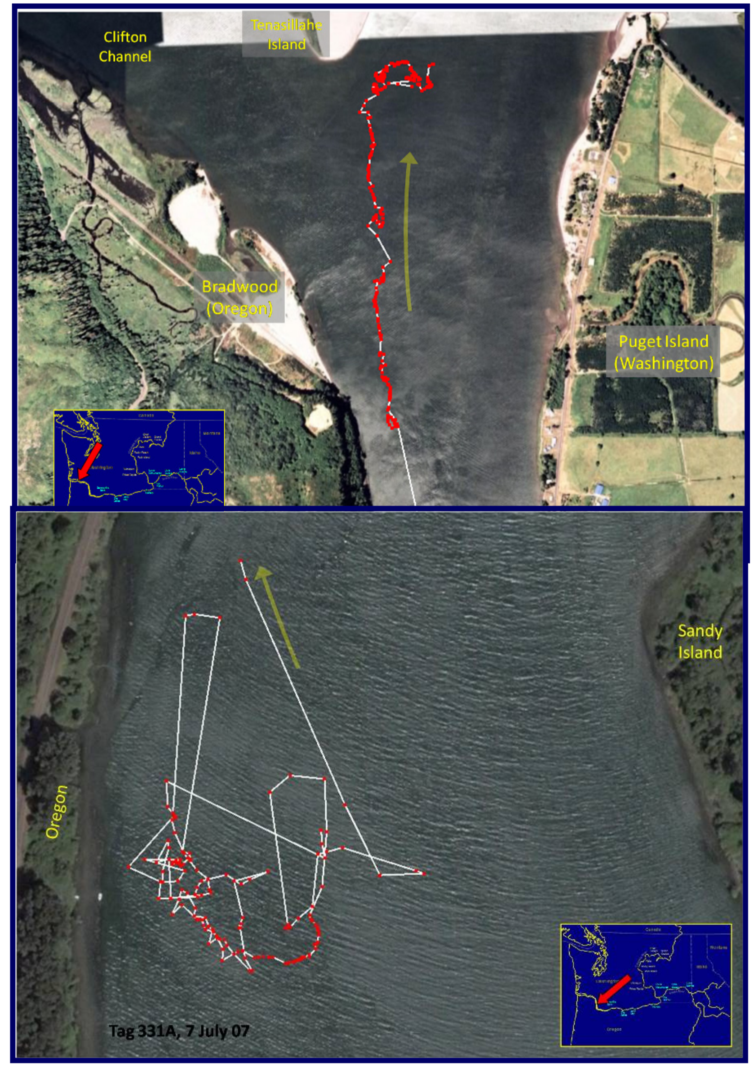


Figure 20. Track details for three JSATS targets obtained during mobile tracking efforts in the lower Columbia River, 2007. Tracking date and target codes are listed in black. Yellow arrows indicate major direction of target movement and river flow. Target 638A was originally tagged as a yearling Chinook salmon at Bonneville Dam, Targets 0109 and 331A were tagged as subyearling Chinook salmon at Bonneville Dam. Subsequent to mobile tracking detections, all three targets were detected on the lower-river secondary detection array (rkm 2.8).

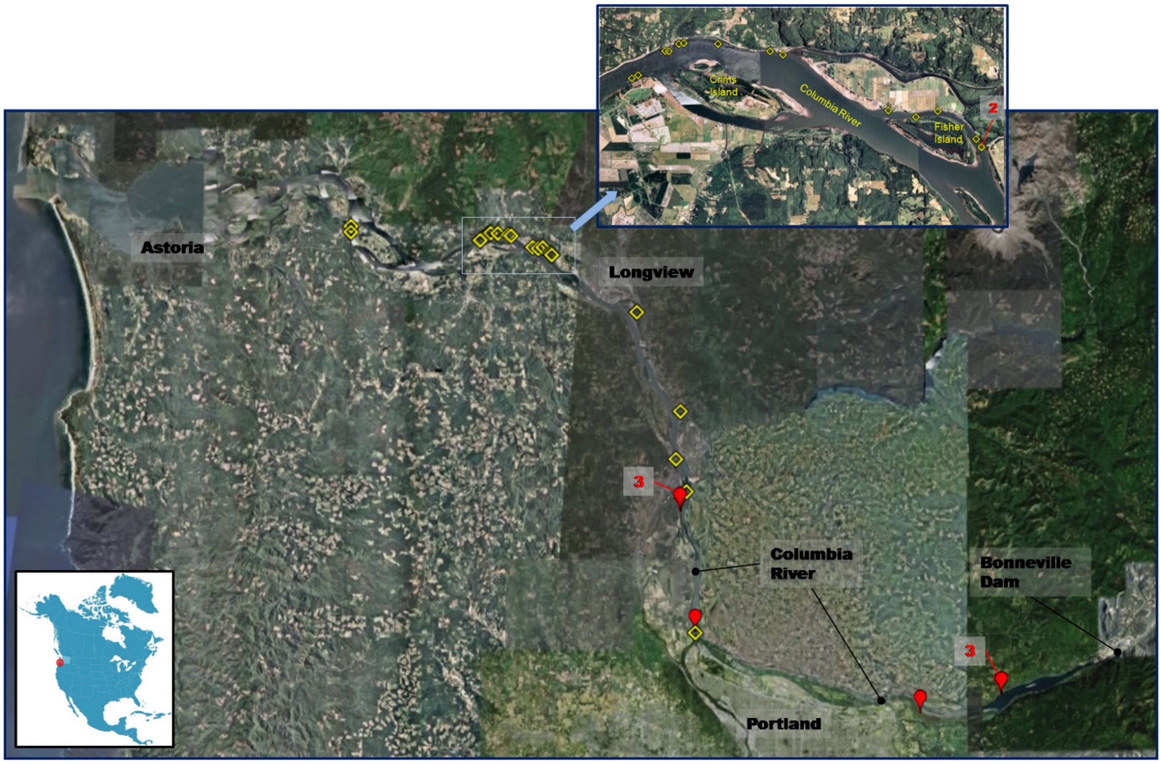


Figure 21. Confirmed (yellow diamonds) and suspected (red balloons) stationary target sites found during mobile tracking efforts in the lower Columbia River, 2007. Numbers associated with markers indicate the number of targets in a small geographic area. All targets were JSATS-coded acoustic tags, located on or near the substrate surface, from juvenile Chinook salmon smolts originally tagged and released at Lower Granite or Bonneville Dams to evaluate survival and tag effects from release through the Columbia River estuary.

A third possibility is that fixed tags observed were those of live target fish that had elected to remain stationary for reasons such as the use of thermal or predator refugia. Finally, these fixed tags may have been evacuated from predators following digestion of the target fish.

Any combination of tag effects, tag expulsion, volitional holding, or predation may have produced these fixed transmitter observations. Thus, without additional information, we cannot definitively ascribe a causal mechanism to the phenomenon. Nevertheless, the relatively clustered distribution of some fixed target tags (inset, Figure 21) suggests locations in need of further attention, particularly with regard to the possibility that some portion of these tags may be related to predation.

A central objective of mobile tracking was to determine the fate of fish that failed to continue migration after entering the Columbia River estuary. An unanticipated contribution to this effort resulted from records of the last known position of some tagged fish. For example, five target fish that appeared to be stationary were located on 21 and 22 July, but were too far upstream to be confirmed on successive dates before the end of the sampling season (Appendix D, Figure 21). However, these five tags were not detected on stationary arrays downstream from the point of last detection on the mobile tracker, and depth-sounder readings indicated that these tags were on the river bottom.

In addition, 43 target fish were acquired with mobile tracking but were never recorded on stationary arrays downstream from the last position recorded using the mobile unit. Three of these tags were not recorded on any stationary array. In the future, mobile tracking could be used in conjunction with stationary arrays to more accurately refine our understanding of where mortality occurs. A combination of stationary arrays deployed in a manner similar to that described by Buchanan et al. (in press) and mobile tracking could provide quantitative estimates of the proportions of fish presumed dead that have actually ceased migration and are alive.

Avian Predation

Of double-tagged fish (acoustic and PIT) released below Bonneville Dam, 174 PIT tags were detected on two East Sand Island bird colonies. Thirty-eight tags were from yearling Chinook and 136 from subyearling Chinook salmon, representing 2.1 and 4.9% of the respective total number released (Figure 22). This proportion of PIT-tag recovery on bird colonies was similar to previous observations for yearling Chinook salmon, but was slightly higher than observed for subyearling Chinook (Ryan et al. 2005). There was no difference in the probability of detection on a bird colony between fish released into the tailrace and those released through the outfall for either yearling ($P = 0.818$, df = 17) or subyearling Chinook salmon ($P = 0.761$, df = 9).

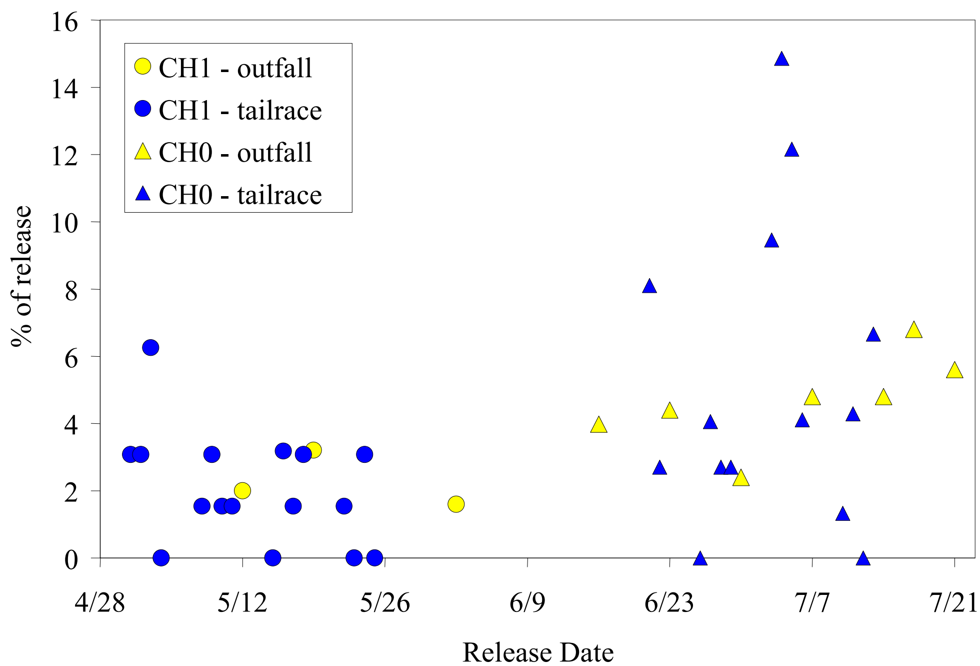


Figure 22. Percentage of each release group of acoustic-tagged yearling (CH1) and subyearling (CH1) Chinook salmon released at Bonneville Dam either into the juvenile bypass outfall or tailrace that had PIT tags recovered from piscivorous bird colonies on East Sand Island during studies to estimate juvenile salmonid survival through the lower Columbia River and estuary, 2007.

Forty acoustic tags (23%) from the 174 double-tagged fish with PIT-tag detections on East Sand Island had been previously detected on stationary acoustic arrays in the estuary. Of these, four were from yearling Chinook salmon released below Bonneville Dam, and 36 were from subyearling Chinook salmon released below Bonneville Dam. Two of the four acoustic tags from yearling fish (50%) and 21 tags from subyearling fish (61%) were detected on both the primary and secondary arrays. The remaining 2 yearling fish and 14 of the subyearling Chinook salmon tags were detected only on the primary array, while 1 subyearling Chinook salmon tag was detected only on the secondary array.

Thirty of the 174 PIT-tags detected on the bird colonies (17%) had been previously detected in estuary island side channels with the mobile tracking unit. Of these, 3 were yearling Chinook and 27 were subyearling Chinook salmon. None of the yearling Chinook salmon and 10 of the subyearling Chinook salmon (33%) that were detected in the islands were also detected on the primary array. Acoustic tags from three of the 174 PIT-tag detections on the bird colonies (1.7%) were never detected on any of the arrays between Bonneville Dam and the estuary. Of the acoustic tags recovered from the bird colonies, 10 (5.7%) tags were previously detected using the mobile array, 2 of which were the last known position for the tag before being found on the bird colonies.

CONCLUSIONS AND RECOMMENDATIONS

1. Based on pooled estimates from both tailrace and outfall releases, mean survival for acoustic-tagged yearling Chinook salmon from the Bonneville Dam tailrace through the lower Columbia River and estuary was 0.799 (SE = 0.0167).

2. Pooled mean survival estimates for acoustic-tagged subyearling Chinook salmon from the Bonneville Dam tailrace through the lower Columbia River and estuary was 0.620 (SE = 0.0102).

3. The greatest rate of decrease in estimated survival occurred in the lower estuary between Tenasillahe Island (rkm 58) and the estuary primary array (rkm 8). Summed across all releases, mean estimated survival through this reach was 0.879 (SE = 0.055) for yearling Chinook and 0.749 (SE = 0.038) for subyearling Chinook salmon.

4. Mean travel time from Bonneville Dam to the estuary primary array was 3.8 d for yearling Chinook and 4.8 d for subyearling Chinook salmon.

5. Use of alternate migration pathways through the Columbia River estuary islands varied by fish stock and release date. Of the acoustic-tagged Chinook salmon detected at Oak Point, 8.1% of yearling and 20.4% of subyearling fish were detected in the estuary island side channels.

6. Survival from the array at Tenasillahe Island to the estuary primary array was similar for yearling Chinook salmon that used island side channels (0.79, SE = 0.019) and those that migrated down the main channel (0.76, SE = 0.047). Survival to the primary array was also similar for subyearling Chinook salmon that used island side channels (0.71, SE= 0.012) and those that migrated down the main channel (0.74, SE = 0.022).

7. The mobile tracking unit evaluated during this study functioned as expected, allowing fine-scale tracking of acoustic-tagged Chinook salmon through the lower river and estuary. Subyearling Chinook salmon traveling between Bonneville Dam and Tenasillahe Island were tracked using previously undocumented island side-channels as migration corridors.

8. Based on mobile tracking, 22 tags of target fish were confirmed to have remained in a fixed position, and 5 additional tags were suspected to have done so. Locations of fixed tags were documented, and these locations indicated specific sites of mortality. The positions of 43 target tags were last recorded from mobile tracking.

9. Avian predation rates of PIT and acoustic-tagged yearling (2.1%) and subyearling (4.9%) Chinook salmon were similar to those of yearling Chinook and slightly higher than those of subyearling Chinook salmon reported by Ryan et al. (2005).

10. This study provides only a third attempt at obtaining rigorous survival estimates for acoustic-tagged juvenile salmonids through the lower Columbia River and estuary. The study was a first attempt at partitioning reaches to define areas of concern. Continued effort over a number of years is essential to developing accurate estimates of survival, as well understanding causes of mortality in the lower river and estuary and the role of inter-annual variation in survival and behavior.

11. The density of stationary-array partitions should be increased downstream from Tenasillahe Island to improve determination of the fate of lost fish, particularly in the lower 58-km of the estuary, where mortality rates increase.

12. Mobile tracking effort should be concentrated downstream from Tenasillahe Island to determine specific mortality sites and migration corridors within the estuary for yearling and subyearling Chinook salmon.

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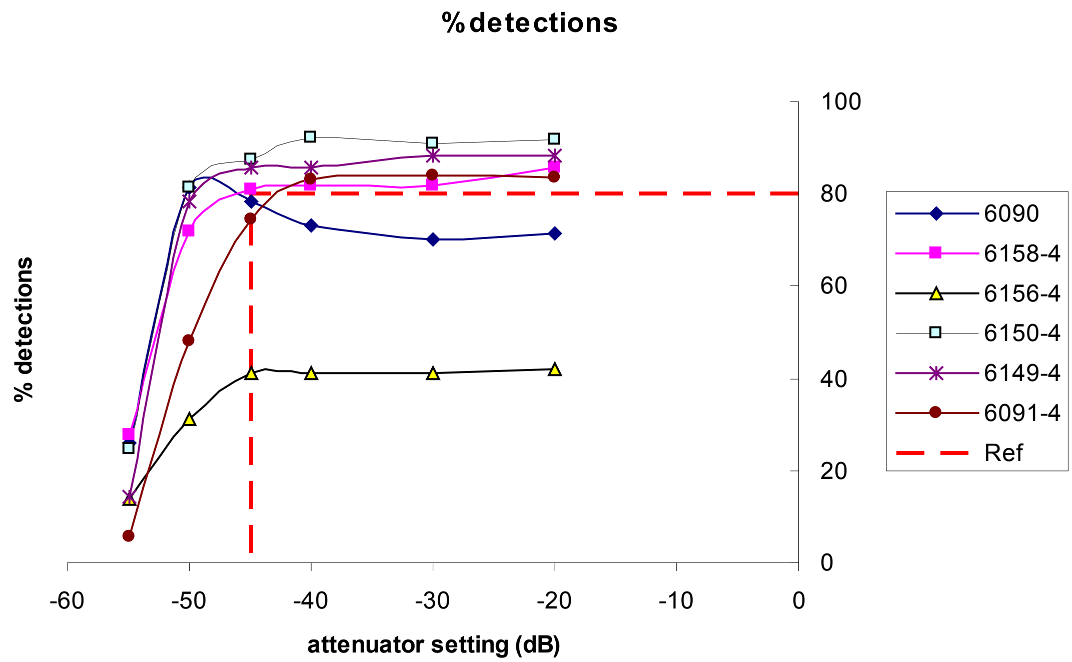
APPENDIX A

Acceptance Testing

Autonomous receivers consisted of electronics, on-board power (30-d battery life), data storage (1 GB Compact Flash (CF) card), and hydrophone housed in a 1.2-m-long by 15-cm-diameter PVC tube. Receivers were deployed to detect and record the presence of passing fish bearing JSATS microacoustic transmitters. Each receiver underwent rigorous acceptance testing by an independent contractor. Acceptance testing was done prior to delivery from the manufacturer and deployment in the field. All testing was performed according to the following protocol.

First, a gross examination was completed to ensure that all parts were present and properly labeled. This included the upper and lower housings, bridle, battery retaining device, board sets, CF card mount switch, stereo plug, hydrophone, and temperature and pressure sensors. Receivers were then activated, and basic function was evaluated, including proper calibration of pressure and temperature sensors and the system clock, and that the receiver was able to properly receive, decode, and store acoustic signals to the CF card.

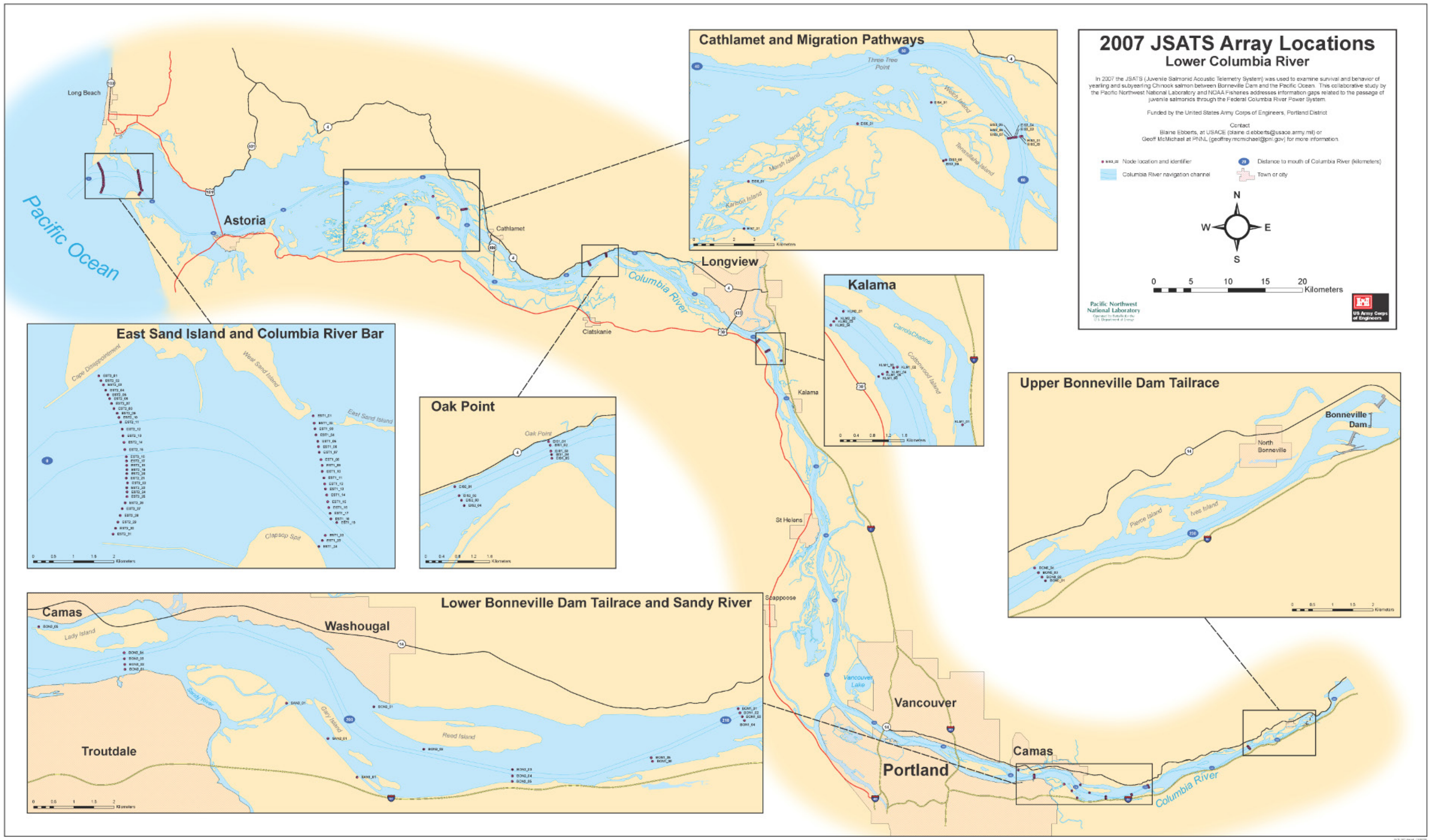
Finally, receiver performance was measured and the housing was tested for leaks. This was done in a small, portable tank lined with anechoic material using a signal generator and attenuator to simulate range. Each receiver was placed in the tank approximately 6 ft from the signal generator element. An attenuation curve was created by calculating the percentage of transmissions that were correctly detected and decoded at each of 6 signal levels (-20, -30, -40, -45, -50, -55 dB). Acceptance criteria required detection efficiency of 80% or higher at each level down to -45 dB (Appendix Figure A). Receivers that failed any of the test protocols were returned to the manufacturer for repair or replacement and retested prior to use in the field.



Appendix Figure A. An example of an autonomous receiver acceptance test data plot. Percent of detections decoded is plotted versus signal strength (dB). Acceptance criteria are defined by the red lines (receivers that produced detection lines that stay above and to the left of the red lines were accepted). In this example, receivers 6156-4, 6090, and 6091-4 were not accepted, while all others were accepted.

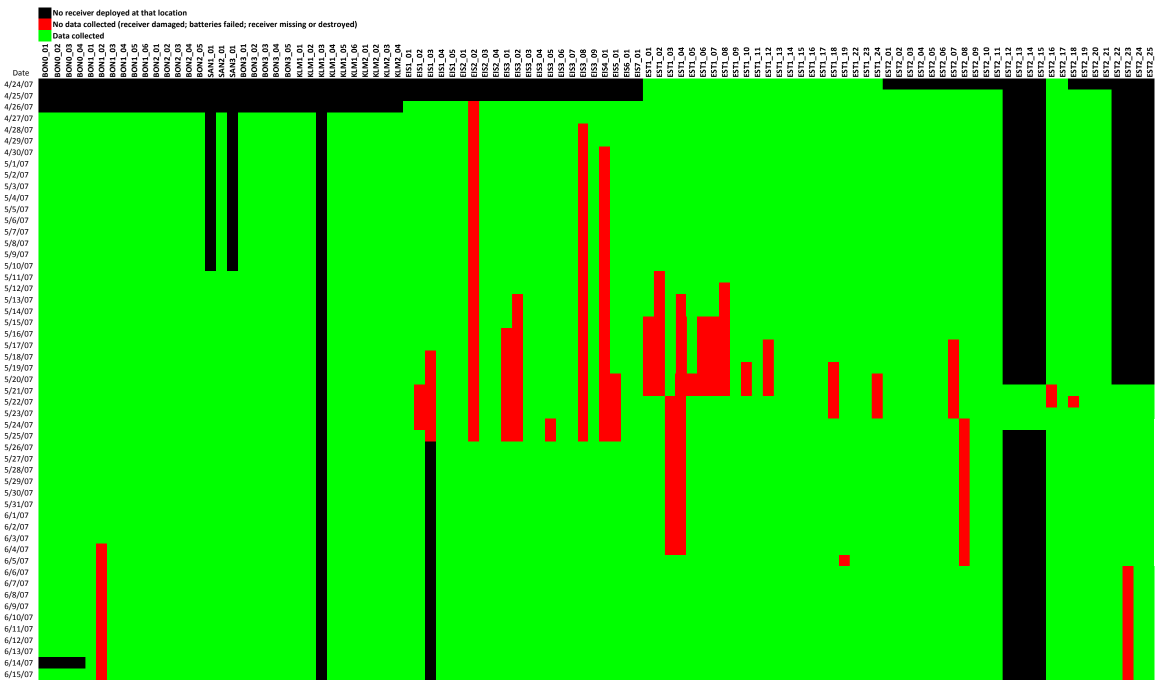
APPENDIX B

Stationary Receiver Locations Downstream of Bonneville Dam

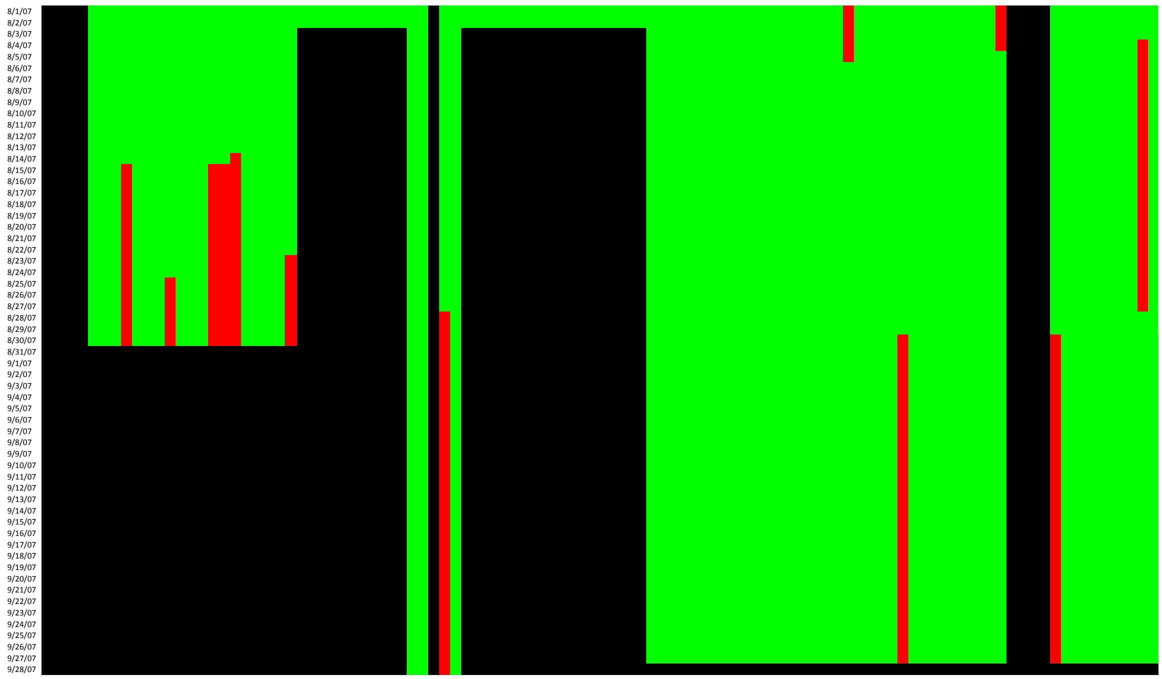


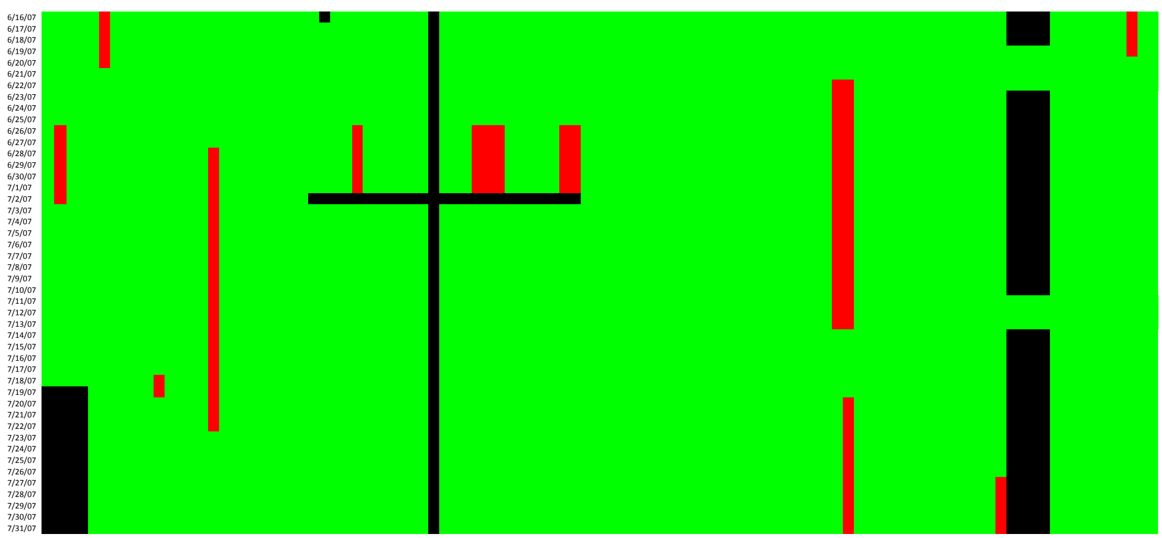
APPENDIX C

Individual Receiver Performance Data



Appendix Figure C. Black indicates the receiver was not deployed, red indicates the receiver was deployed but data were not collected (for any reason; including battery failure, equipment loss or damage), green indicates the receiver was deployed and collected data.





Appendix Figure C. Continued.

APPENDIX D

Mobile Tracking Data

Appendix Table D. Targets acquired using a vessel-mounted mobile tracking unit during studies to evaluate juvenile salmonid survival through the lower Columbia River and estuary, 2007.

Target code	Target CRC	Release site	Release date	Recovery date	Initial acquisition latitude	Initial acquisition longitude	Track length (m)	Track detects
4C00	76	LGr	9 May	22 May	45.632545	-121.964388	0.0	
3F17	8B	LGr	10 May	22 May	45.632505	-121.964385		
3C61	FB	Spill	22 May	22 May	45.631928	-121.965680		
3BB0	9C	Spill	22 May	22 May	45.632233	-121.965540	0.0	
639F	FF	Spill	22 May	22 May	45.631178	-121.965005	0.0	
69F5	03	Spill	22 May	22 May	45.630997	-121.965007		
6550	DE	Spill	22 May	22 May	45.630557	-121.966047		
3B87	A1	Spill	22 May	22 May	45.631023	-121.965327	0.0	
7701	26	Spill	22 May	22 May	45.631802	-121.965368		
3B6D	36	Spill	22 May	22 May	45.631137	-121.965003		
3C5B	3B	Spill	22 May	22 May	45.632540	-121.964403	0.0	
799D	48	Spill	22 May	22 May	45.630878	-121.965017		
39A3	72	Spill	22 May	22 May	45.630692	-121.965383		
3B42	54	Spill	22 May	22 May	45.631298	-121.964528	0.0	
7C44	7C	Spill	22 May	22 May	45.631737	-121.964592		
66A9	63	Spill	22 May	22 May	45.631107	-121.965117		
3C3E	61	Spill	22 May	22 May	45.632415	-121.964402		
7C52	3C	Spill	22 May	22 May	45.632170	-121.965137		
3B55	4A	Spill	22 May	22 May	45.631590	-121.964625		
3C2C	40	Spill	22 May	22 May	45.630552	-121.966002		
3C36	A3	Spill	22 May	22 May	45.630663	-121.965878		
68AB	03	Spill	22 May	22 May	45.632185	-121.965185		
39B1	53	Spill	22 May	22 May	45.631910	-121.965532	0.0	1
3A99	E7	Spill	22 May	22 May	45.631400	-121.965478		*
6601	0E	Spill	22 May	22 May	45.624620	-121.980210	0.0	1
6F95	CC	Spill	22 May	22 May	45.632038	-121.965627		*
66CE	85	Spill	22 May	22 May	45.632152	-121.965025		*
6603	B2	Spill	22 May	22 May	45.632310	-121.965182		*
6A1B	A0	Spill	22 May	22 May	45.632043	-121.965368		*
6D2F	11	Spill	22 May	22 May	45.632167	-121.965065		*
3B6A	B5	Tailrace	22 May	22 May	45.631945	-121.965628		*
6897	1E	Tailrace	22 May	22 May	45.631152	-121.964863		*
77CD	4F	Tailrace	22 May	22 May	45.631298	-121.964528		*
7A5A	54	Tailrace	22 May	22 May	45.631215	-121.964700		*
6B9E	D7	Tailrace	22 May	22 May	45.632222	-121.965668		*
7FCC	67	Tailrace	22 May	22 May	45.632222	-121.965667		*
66E8	7B	Tailrace	22 May	22 May	45.632225	-121.965667		*
6C2E	8B	Tailrace	22 May	22 May	45.632207	-121.965650		*
7A08	33	Tailrace	22 May	22 May	45.631195	-121.964715		*
7AD9	3A	Tailrace	22 May	22 May	45.632227	-121.965657		*

Appendix Table D. Continued.

Target	Target	Release		Recovery	Initial acquisition		Track	Track
code	CRC	site	date	date	latitude	longitude	length (m)	detects
66AD	02	Tailrace	22 May	22 May	45.632220	-121.965668		*
6C16	F7	Tailrace	22 May	22 May	45.632212	-121.965658		*
3B96	62	Tailrace	22 May	22 May	45.631338	-121.964502		*
3B97	3C	Tailrace	22 May	22 May	45.631183	-121.964838	0.0	1
3C55	24	Tailrace	22 May	22 May	45.631158	-121.964853		*
7A1E	73	Tailrace	22 May	22 May	45.632223	-121.965562		*
39A4	F1	Tailrace	22 May	22 May	45.631340	-121.964508	0.0	1
39AE	8F	Tailrace	22 May	22 May	45.632400	-121.964412		*
3C57	98	Tailrace	22 May	22 May	45.632222	-121.965657	0.0	2
786E	1A	Tailrace	22 May	22 May	45.632207	-121.965597	26.4	2
3B95	80	Tailrace	22 May	22 May	45.631202	-121.964822		*
39B1	53	Spill	22 May	22 May	45.631910	-121.965532	0.0	1
3A99	E7	Spill	22 May	22 May	45.631400	-121.965478		*
6601	0E	Spill	22 May	22 May	45.624620	-121.980210	0.0	1
6F95	CC	Spill	22 May	22 May	45.632038	-121.965627		*
66CE	85	Spill	22 May	22 May	45.632152	-121.965025		*
6603	B2	Spill	22 May	22 May	45.632310	-121.965182		*
6A1B	A0	Spill	22 May	22 May	45.632043	-121.965368		*
6D2F	11	Spill	22 May	22 May	45.632167	-121.965065		*
3B6A	B5	Tailrace	22 May	22 May	45.631945	-121.965628		*
6897	1E	Tailrace	22 May	22 May	45.631152	-121.964863		*
77CD	4F	Tailrace	22 May	22 May	45.631298	-121.964528		*
7A5A	54	Tailrace	22 May	22 May	45.631215	-121.964700		*
6B9E	D7	Tailrace	22 May	22 May	45.632222	-121.965668		*
7FCC	67	Tailrace	22 May	22 May	45.632222	-121.965667		*
3B43	0A	Tailrace	22 May	22 May	45.631215	-121.965650		*
66E8	7B	Tailrace	22 May	22 May	45.632225	-121.965667		*
6C2E	8B	Tailrace	22 May	22 May	45.632207	-121.965650		*
7A08	33	Tailrace	22 May	22 May	45.631195	-121.964715		*
7AD9	3A	Tailrace	22 May	22 May	45.632227	-121.965657		*
66AD	02	Tailrace	22 May	22 May	45.632220	-121.965668		*
6C16	F7	Tailrace	22 May	22 May	45.632212	-121.965658		*
3B96	62	Tailrace	22 May	22 May	45.631338	-121.964502		*
3B97	3C	Tailrace	22 May	22 May	45.631183	-121.964838	0.0	1
3C55	24	Tailrace	22 May	22 May	45.631158	-121.964853		*
7A1E	73	Tailrace	22 May	22 May	45.632223	-121.965562		*
39A4	F1	Tailrace	22 May	22 May	45.631340	-121.964508	0.0	1
39AE	8F	Tailrace	22 May	22 May	45.632400	-121.964412		*
3C57	98	Tailrace	22 May	22 May	45.632222	-121.965657	0.0	2
786E	1A	Tailrace	22 May	22 May	45.632207	-121.965597	26.4	2
3B95	80	Tailrace	22 May	22 May	45.631202	-121.964822		*
3BA8	C3	Tailrace	22 May	22 May	45.632240	-121.965525	0.0	1
7871	C6	Tailrace	22 May	22 May	45.632240	-121.965525		*
62B9	C5	Tailrace	22 May	22 May	45.632582	-121.965150	0.0	1
3AB1	06	Tailrace	22 May	22 May	45.632195	-121.965618	25.4	2
3ABA	26	Tailrace	22 May	22 May	45.632390	-121.964442		*
7C4C	BE	Tailrace	22 May	22 May	45.632213	-121.965588	17.9	4
399C	8D	Tailrace	22 May	22 May	45.632227	-121.965553	14.8	2
68BC	1D	Tailrace	22 May	22 May	45.632628	-121.965083	0.0	1

Appendix Table D. Continued.

Target code	Target CRC	Release site	Release date	Recovery date	Initial acquisition latitude	Initial acquisition longitude	Track length (m)	Track detects
7AE0	18	Tailrace	22 May	22 May	45.632415	-121.964405	4.1	2
3B5D	88	Tailrace	22 May	22 May	45.631215	-121.964677	0.0	1
7699	31	Tailrace	22 May	22 May	45.631340	-121.964508	7.0	3
79A1	55	Tailrace	22 May	22 May	45.631333	-121.964492	37.6	2
3B9B	9F	Tailrace	22 May	22 May	45.632117	-121.965692	2.0	2
6692	FD	Tailrace	22 May	22 May	45.632220	-121.965668	28.3	2
3AB8	9A	Tailrace	22 May	22 May	45.632233	-121.965540	4.1	2
629D	87	Tailrace	22 May	22 May	45.632637	-121.965073	0.0	1
6538	79	Tailrace	22 May	22 May	45.631338	-121.964497	0.0	1
3AC5	9F	Tailrace	22 May	22 May	45.632658	-121.965055	18.2	3
3BB1	C2	Tailrace	22 May	22 May	45.632432	-121.964408	0.0	1
6CA8	DA	Tailrace	22 May	22 May	45.632652	-121.965057		*
39A8	52	Tailrace	22 May	22 May	45.632657	-121.965060	287.7	3
7715	DA	Tailrace	22 May	22 May	45.632658	-121.965058	7.0	3
79F9	4C	Tailrace	22 May	22 May	45.632410	-121.964400	72.4	2
6FAE	52	Tailrace	22 May	22 May	45.632658	-121.965058	311.5	11
62A4	A5	Spill	23 May	23 May	45.632312	-121.965085		*
76F0	C8	Spill	23 May	23 May	45.632458	-121.965083		*
5B08	36	Spill	23 May	23 May	45.631415	-121.965578		*
69F4	5D	Spill	23 May	23 May	45.632308	-121.965100		*
62B3	BB	Spill	23 May	23 May	45.632477	-121.965030	0.0	1
6E96	EA	Spill	23 May	23 May	45.631815	-121.965068	0.0	1
6319	AE	Spill	23 May	23 May	45.633735	-121.965282		*
7BC2	43	Spill	23 May	23 May	45.632128	-121.965220	3.5	2
66E9	25	Spill	23 May	23 May	45.632333	-121.965145	20.9	6
6338	D3	Spill	23 May	23 May	45.632427	-121.964963		*
68F3	1A	Spill	23 May	23 May	45.631707	-121.964177		*
651C	3B	Spill	23 May	23 May	45.632383	-121.964932	1.1	3
6F2C	62	Spill	23 May	23 May	45.631780	-121.964275		*
6573	1F	Spill	23 May	23 May	45.631842	-121.965103		*
6A33	41	Spill	23 May	23 May	45.631412	-121.965422	0.0	1
6F8C	CD	Spill	23 May	23 May	45.631595	-121.965155	0.0	1
770E	67	Spill	23 May	23 May	45.631775	-121.965060	0.0	1
62A6	19	Spill	23 May	23 May	45.632083	-121.965812		*
76FC	6B	Spill	23 May	23 May	45.632240	-121.965180		*
68A8	E1	Spill	23 May	23 May	45.632582	-121.964998		*
6C89	A7	Spill	23 May	23 May	45.632265	-121.964975		*
66B0	62	Spill	23 May	23 May	45.630753	-121.966972	506.9	3
6600	50	Spill	23 May	23 May	45.631900	-121.965005		*
6314	53	Spill	23 May	23 May	45.631895	-121.964998		*
6CC0	7D	Spill	23 May	23 May	45.631960	-121.964795	0.0	1
7705	47	Spill	23 May	23 May	45.631888	-121.965028		*
5542	D2	Spill	23 May	23 May	45.631968	-121.964802		*
631A	4C	Spill	23 May	23 May	45.632023	-121.964787		*
66B2	DE	Spill	23 May	23 May	45.631977	-121.964813	6.0	3
57D9	72	Spill	23 May	23 May	45.632080	-121.964793	4.2	2
63A6	DD	Spill	23 May	23 May	45.631792	-121.965010	3.6	2
6C6C	71	Spill	23 May	23 May	45.631415	-121.964662		*
6EBC	B7	Spill	23 May	23 May	45.631428	-121.965502		*

Appendix Table D. Continued.

Target code	Target CRC	Release site	Release date	Recovery date	Initial acquisition latitude	Initial acquisition longitude	Track length (m)	Track detects
69E5	9E	Spill	23 May	23 May	45.631423	-121.965390	0.0	1
6F63	65	Spill	23 May	23 May	45.631540	-121.965252	0.0	1
67B1	F8	Spill	23 May	23 May	45.631912	-121.965650		*
7957	FC	Spill	23 May	23 May	45.631135	-121.964600		*
652F	67	Spill	23 May	23 May	45.633735	-121.965280		*
6C0E	A8	Spill	23 May	23 May	45.631475	-121.965355	26.0	2
5D19	5F	Spill	23 May	23 May	45.631343	-121.964562		*
62B1	07	Spill	23 May	23 May	45.631413	-121.965423		*
795B	5F	Spill	23 May	23 May	45.631410	-121.965433		*
6CA7	9B	Spill	23 May	23 May	45.631423	-121.965392		*
68EE	7A	Spill	23 May	23 May	45.631423	-121.965387	0.0	1
7875	A7	Spill	23 May	23 May	45.631408	-121.965425		*
6317	B1	Spill	23 May	23 May	45.631450	-121.965517		*
67C1	00	Spill	23 May	23 May	45.631415	-121.965388		*
76E0	55	Spill	23 May	23 May	45.631407	-121.965503	12.4	3
6D21	0E	Spill	23 May	23 May	45.631428	-121.965393	39.7	2
6220	48	Spill	23 May	23 May	45.631812	-121.965065		*
65FA	0F	Spill	23 May	23 May	45.631857	-121.965083		*
62BF	18	Spill	23 May	23 May	45.631433	-121.964568		*
6DA0	DC	Spill	23 May	23 May	45.631415	-121.964662		*
6694	20	Spill	23 May	23 May	45.631850	-121.965042		*
6409	5D	Tailrace	23 May	23 May	45.631548	-121.964208		*
669D	BC	Tailrace	23 May	23 May	45.632190	-121.965462		*
6718	CB	Tailrace	23 May	23 May	45.631865	-121.965093		*
67EC	DE	Tailrace	23 May	23 May	45.632105	-121.965727		*
689E	82	Tailrace	23 May	23 May	45.632003	-121.964865		*
7FE2	5B	Tailrace	23 May	23 May	45.632203	-121.965492		*
6149	E4	Tailrace	23 May	23 May	45.631872	-121.965095		*
6569	FC	Tailrace	23 May	23 May	45.632063	-121.965633		*
658A	F7	Tailrace	23 May	23 May	45.632193	-121.965467	0.0	1
6C72	F3	Tailrace	23 May	23 May	45.631995	-121.964858		*
6F1B	5F	Tailrace	23 May	23 May	45.632170	-121.965472		*
6F2A	BF	Tailrace	23 May	23 May	45.631457	-121.964357		*
5D1A	BD	Tailrace	23 May	23 May	45.631463	-121.964362	6.4	2
6109	A2	Tailrace	23 May	23 May	45.631868	-121.965100		*
6228	8A	Tailrace	23 May	23 May	45.632190	-121.965462		*
6408	03	Tailrace	23 May	23 May	45.631997	-121.964860	0.0	1
687B	54	Tailrace	23 May	23 May	45.631613	-121.964227		*
6880	00	Tailrace	23 May	23 May	45.631995	-121.964858		*
6BA8	B4	Tailrace	23 May	23 May	45.632103	-121.965730		*
6C98	64	Tailrace	23 May	23 May	45.632190	-121.965467		*
58A7	8D	Tailrace	23 May	23 May	45.632063	-121.965633		*
6392	02	Tailrace	23 May	23 May	45.631607	-121.964220	0.0	1
6DAE	C3	Spill	23 May	23 May	45.631845	-121.965155	0.0	1
6D06	AE	Spill	23 May	23 May	45.631462	-121.964572		*
66EC	1A	Spill	23 May	23 May	45.631385	-121.964557		*
6CB1	DB	Spill	23 May	23 May	45.631422	-121.964583	0.0	1
6164	3A	Spill	23 May	23 May	45.632073	-121.965685	0.0	1
6A3D	5E	Spill	23 May	23 May	45.631450	-121.964640	28.5	3

Appendix Table D. Continued.

Target code	Target CRC	Release site	Release date	Recovery date	Initial acquisition latitude	Initial acquisition longitude	Track length (m)	Track detects
62CF	E0	Spill	23 May	23 May	45.631130	-121.964595		*
6C8B	1B	Spill	23 May	23 May	45.623502	-121.983978	124.1	2
6221	16	Tailrace	23 May	23 May	45.631593	-121.964172		*
633D	EC	Tailrace	23 May	23 May	45.631885	-121.965085		*
68F6	25	Tailrace	23 May	23 May	45.632065	-121.965720		*
6B81	0B	Tailrace	23 May	23 May	45.632192	-121.965460		*
6CBE	9A	Tailrace	23 May	23 May	45.632063	-121.965650		*
6242	91	Tailrace	23 May	23 May	45.632192	-121.965460		*
639D	43	Tailrace	23 May	23 May	45.631463	-121.964357		*
6553	3C	Tailrace	23 May	23 May	45.631853	-121.965087	0.0	1
669E	5E	Tailrace	23 May	23 May	45.631528	-121.964150	0.0	1
69EC	02	Tailrace	23 May	23 May	45.631883	-121.965082		*
6CEF	1F	Tailrace	23 May	23 May	45.631998	-121.964862		*
615F	A4	Tailrace	23 May	23 May	45.631980	-121.964818	0.0	1
62FA	61	Tailrace	23 May	23 May	45.632000	-121.964860	0.0	1
6BAA	08	Tailrace	23 May	23 May	45.631852	-121.965073		*
6CB0	85	Tailrace	23 May	23 May	45.632103	-121.965720	0.0	1
6F2E	DE	Tailrace	23 May	23 May	45.631465	-121.964380	0.0	1
6556	03	Tailrace	23 May	23 May	45.632043	-121.965640	1.4	2
6889	9C	Tailrace	23 May	23 May	45.632002	-121.964863	0.0	1
68A2	9F	Tailrace	23 May	23 May	45.631548	-121.964208	0.0	1
6C7F	0E	Tailrace	23 May	23 May	45.632190	-121.965468	3.6	3
5D14	A2	Tailrace	23 May	23 May	45.631523	-121.964130	61.8	2
6C08	75	Tailrace	23 May	23 May	45.631858	-121.965090	0.0	1
6F29	5D	Tailrace	23 May	23 May	45.631868	-121.965092	1.4	2
6BA0	76	Tailrace	23 May	23 May	45.631525	-121.964135	41.8	3
6CAC	BB	Tailrace	23 May	23 May	45.632000	-121.964860	6.3	3
5CD6	10	Tailrace	23 May	23 May	45.632077	-121.965650	0.0	1
622B	68	Tailrace	23 May	23 May	45.631523	-121.964138	36.8	3
624B	0D	Tailrace	23 May	23 May	45.631523	-121.964130	1.9	2
770F	39	Tailrace	23 May	23 May	45.631523	-121.964137		*
787A	E6	Tailrace	23 May	23 May	45.631523	-121.964130	80.4	5
6C0D	4A	Tailrace	23 May	23 May	45.631522	-121.964140	35.1	5
672A	C9	Tailrace	23 May	23 May	45.631962	-121.964883	2,323.9	27
6243	CF	Tailrace	23 May	23 May	45.631962	-121.964892	0.0	1
6C22	28	Tailrace	23 May	23 May	45.631888	-121.964912	1,855.6	31
6CDF	A1	Tailrace	23 May	23 May	45.631957	-121.964880	3,379.6	49
6D3A	B3	Tailrace	23 May	23 May	45.631952	-121.964908	1,731.7	58
7959	E3	Tailrace	2 Jun	4 Jun	46.177348	-123.200363	13.5	2
66DF	46	Tailrace	2 Jun	4 Jun	46.188577	-123.145200	25.1	11
63BE	82	Tailrace	2 Jun	5 Jun	46.259310	-123.999907	3.5	2
5A5A	95	Tailrace	2 Jun	5 Jun	46.259068	-123.999398	23.6	8
7955	40	Tailrace	2 Jun	5 Jun	46.259453	-124.005928	0.0	1
59B9	CB	Tailrace	2 Jun	5 Jun	46.259320	-124.005488	293.8	3
6741	8C	Tailrace	2 Jun	5 Jun	46.256455	-123.994618	10.2	3
794B	C2	Tailrace	2 Jun	5 Jun	46.253435	-123.988958	248.1	3
6AFC	CA	Tailrace	2 Jun	5 Jun	46.257522	-123.997988	289.3	12
6596	C9	Tailrace	2 Jun	5 Jun	46.234143	-123.991992	535.9	135
6D46	E8	Tailrace	2 Jun	5 Jun	46.254953	-123.984280	1,960.2	134

Appendix Table D. Continued.

Target code	Target CRC	Release site	Release date	Recovery date	Initial acquisition latitude	Initial acquisition longitude	Track length (m)	Track detects
638A	5D	Tailrace	2 Jun	5 Jun	46.232098	-123.983652	1,955.4	153
6C87	B8	Tailrace	2 Jun	5 Jun	46.252013	-123.974762	3,637.1	282
6F83	8C	Tailrace	2 Jun	6 Jun	46.257508	-123.996812	269.3	6
0A38	3B	LGr	6 Jun	19 Jun	46.183290	-123.179723	180.0	14
095C	6A	Outfall	16 Jun	20 Jun	46.164285	-123.214202	174.8	23
298B	7F	Spill	21 Jun	24 Jun	46.171005	-123.224077	0.0	1
2594	EE	Spill	22 Jun	24 Jun	46.169890	-123.226397	37.5	7
2062	B8	Spill	22 Jun	24 Jun	46.163377	-123.242088	0.1	6
2771	A9	Spill	22 Jun	24 Jun	46.163387	-123.242032	2687.6	59
1959	B9	Spill	22 Jun	24 Jun	46.169168	-123.227658	0.0	1
0187	6B	Spill	22 Jun	24 Jun	46.170102	-123.226543	375.3	7
19F6	57	Spill	22 Jun	24 Jun	46.184218	-123.186525	1931.2	18
1A06	76	Spill	22 Jun	24 Jun	46.160767	-123.246287	0.3	53
07E0	27	Spill	22 Jun	24 Jun	46.158478	-123.251223	2323.9	77
2985	60	Spill	22 Jun	24 Jun	46.184012	-123.188625	3471.4	116
274E	56	Spill	26 Jun	24 Jun	46.163405	-123.241970		*
2766	B7	Tailrace	22 Jun	24 Jun	46.173868	-123.214670		*
2424	18	Tailrace	22 Jun	24 Jun	46.170883	-123.223970	1635.1	35
181C	04	LGr	15 Jun	25 Jun	46.186918	-123.140385		*
2229	4F	Spill	21 Jun	25 Jun	46.191003	-123.159588	0.0	1
232A	69	Spill	22 Jun	25 Jun	46.190897	-123.161752		*
239D	D8	Spill	22 Jun	25 Jun	46.187132	-123.126105	319.7	5
2B00	7D	Spill	22 Jun	25 Jun	46.189253	-123.173052		*
2B3F	BD	Spill	22 Jun	25 Jun	46.188697	-123.145785	9,570.8	892
1559	CF	Outfall	16 Jun	25 Jun	46.190567	-123.164563		*
2875	D0	Tailrace	22 Jun	25 Jun	46.188747	-123.174053		*
149F	27	Outfall	23 Jun	25 Jun	46.176255	-123.198882		*
1159	CF	Outfall	23 Jun	25 Jun	46.189225	-123.172067	0.0	1
2276	D5	Outfall	23 Jun	25 Jun	46.189325	-123.171773	69.6	6
07E3	C5	Outfall	23 Jun	25 Jun	46.186460	-123.181073	0.0	1
13D2	F2	Outfall	23 Jun	25 Jun	46.187773	-123.175178	75.0	5
17BD	ED	Outfall	23 Jun	25 Jun	46.186748	-123.127542	138.7	5
0A39	65	Outfall	23 Jun	25 Jun	46.186907	-123.126743	240.2	15
1566	0B	Outfall	23 Jun	25 Jun	46.190295	-123.150285	1,873.3	92
18B8	CA	Outfall	23 Jun	25 Jun	46.188827	-123.173823	1,919.9	183
1823	FB	Outfall	23 Jun	25 Jun	46.187168	-123.125995	4,530.3	177
208E	F2	Outfall	23 Jun	25 Jun	46.189380	-123.171493	4,906.9	326
2347	F1	LGr	20 Jun	26 Jun	46.256922	-123.845265		*
2378	0E	Spill	21 Jun	26 Jun	46.260358	-123.836265	8,169.0	542
1402	CB	Spill	22 Jun	26 Jun	46.256322	-123.846025	1,144.2	29
271E	8D	Spill	22 Jun	26 Jun	46.252382	-123.852448	1,234.4	48
190B	DE	Tailrace	21 Jun	26 Jun	46.254492	-123.849107	3,648.4	22
2B12	63	Tailrace	22 Jun	26 Jun	46.248863	-123.858928	0.0	1
0109	F8	Outfall	23 Jun	26 Jun	46.191323	-123.432190	4,717.0	337
0448	1F	LGr	9 Jun	27 Jun	46.150623	-123.276633		*
0953	2B	Lgr	9 Jun	27 Jun	46.163150	-123.242823	3,952.5	90
06C6	1D	Spill	21 Jun	27 Jun	46.196193	-123.434352	2,695.7	0
0BFB	D7	LGr	12 Jun	28 Jun	45.981120	-122.836380	250.6	8
1828	DB	LGr	19 Jun	28 Jun	45.981615	-122.833885	1,388.9	8

Appendix Table D. Continued.

Target code	Target CRC	Release site	Release date	Recovery date	Initial acquisition latitude	Initial acquisition longitude	Track length (m)	Track detects
5704	D8	Spill	26 Jun	28 Jun	46.020915	-122.861182	181.2	3
27D7	DB	Spill	26 Jun	28 Jun	46.009375	-122.856410	653.4	12
24BA	16	Spill	26 Jun	28 Jun	46.011392	-122.860185	136.5	4
07D5	A6	Spill	26 Jun	28 Jun	45.984098	-122.843267	1,113.7	23
219E	AB	Spill	26 Jun	28 Jun	45.981457	-122.835698	618.0	15
291E	51	Spill	26 Jun	28 Jun	45.993842	-122.846958	626.0	7
2B50	99	Spill	26 Jun	28 Jun	46.018912	-122.858795	511.8	11
2022	FE	Spill	26 Jun	28 Jun	45.994923	-122.851288	1,554.6	17
1452	10	Tailrace	26 Jun	28 Jun	45.994783	-122.850778	79.2	2
0999	9F	Tailrace	26 Jun	28 Jun	46.008208	-122.855410	78.7	4
0BCF	08	Tailrace	26 Jun	28 Jun	45.997572	-122.845337	3,027.2	15
18C8	32	Tailrace	26 Jun	28 Jun	46.009075	-122.855512	540.7	46
0FE8	93	Tailrace	26 Jun	28 Jun	45.996457	-122.845077	2,621.6	111
21C6	B2	Spill	26 Jun	29 Jun	46.073193	-122.888203	3,744.9	75
2A02	3A	Spill	26 Jun	29 Jun	46.066278	-122.883555	1,593.3	19
2967	35	Spill	26 Jun	29 Jun	46.074760	-122.894280	15.2	3
259E	90	Spill	26 Jun	29 Jun	46.065998	-122.883682	363.1	5
2872	53	Spill	27 Jun	29 Jun	46.085913	-122.911000	2,520.2	69
09A3	5F	Spill	27 Jun	29 Jun	46.081773	-122.897683	3,036.8	114
178C	0D	Spill	27 Jun	29 Jun	46.074802	-122.895158		*
2A5B	7D	Spill	27 Jun	29 Jun	46.074868	-122.895017	0.0	1
2977	A8	Spill	27 Jun	29 Jun	46.090060	-122.920983	153.2	13
17A2	31	Spill	27 Jun	29 Jun	46.068005	-122.893780	2,393.1	187
2DDF	FE	Spill	27 Jun	29 Jun	46.080113	-122.905668	3,213.9	172
0D75	EE	Tailrace	26 Jun	29 Jun	46.078027	-122.893403	346.3	3
2108	67	Tailrace	26 Jun	29 Jun	46.072180	-122.887692	4,729.9	17
2117	BB	Tailrace	27 Jun	29 Jun	46.086582	-122.911968		*
22EB	39	Tailrace	27 Jun	29 Jun	46.075063	-122.897035	0.0	1
2330	8A	Spill	21 Jun	1 Jul	46.108205	-122.960863	1,128.2	4
27F7	F8	Spill	21 Jun	1 Jul	46.097537	-122.949290	34.9	4
130B	39	Spill	27 Jun	1 Jul	46.115285	-122.983360	332.4	7
27EA	98	Spill	27 Jun	1 Jul	46.120083	-122.981607		*
27E8	24	Spill	28 Jun	1 Jul	46.102672	-122.948043	5,140.2	289
22FE	9B	Spill	28 Jun	1 Jul	46.096037	-122.946332	1,977.9	18
1848	BE	Spill	29 Jun	1 Jul	46.106667	-122.970273	2,930.6	202
2E4B	DB	Spill	29 Jun	1 Jul	46.118777	-122.988222		*
2B9A	2D	Spill	29 Jun	1 Jul	46.101010	-122.958705	5,621.4	143
31DA	60	Spill	29 Jun	1 Jul	46.093167	-122.937875	8.9	2
2E96	71	Spill	29 Jun	1 Jul	46.136182	-123.044412	319.1	23
1695	C8	Tailrace	26 Jun	1 Jul	46.117432	-122.975487	332.4	5
29F9	3B	Tailrace	29 Jun	1 Jul	46.108042	-122.972267		*
2225	EC	Tailrace	29 Jun	1 Jul	46.103840	-122.965817	0.0	1
0ED9	B7	LGr	6 Jun	2 Jul	46.138532	-123.013815		*
25E8	B5	Spill	22 Jun	2 Jul	46.162415	-123.045115	Stationary	78
2289	E0	Spill	27 Jun	2 Jul	46.157073	-123.056895	2377.0	30
2A9B	B7	Spill	28 Jun	2 Jul	46.165175	-123.047018	68.0	3
0F64	BC	Spill	29 Jun	2 Jul	46.154962	-123.044622	40.8	2
21E4	2D	Spill	29 Jun	2 Jul	46.138403	-123.012755		*
27CE	DA	Outfall	30 Jun	2 Jul	46.171788	-123.062322	1,619.0	45

Appendix Table D. Continued.

Target code	Target CRC	Release site	Release date	Recovery date	Initial acquisition latitude	Initial acquisition longitude	Track length (m)	Track detects
2FD4	4F	Outfall	30 Jun	2 Jul	46.156730	-123.042907	5,383.3	92
2F16	39	Outfall	30 Jun	2 Jul	46.141307	-123.024683	4,145.7	121
2C82	1C	Outfall	30 Jun	3 Jul	46.166722	-123.234455	74.1	5
3CA2	D3	Outfall	30 Jun	3 Jul	46.166562	-123.233377	6,360.1	234
25E8	B5	Spill	22 Jun	4 Jul	46.162775	-123.045050	Stationary	4
0383	9B	LGr	5 Jun	5 Jul	46.055255	-122.884783		*
2723	CE	Spill	29 Jun	5 Jul	46.086143	-122.880903	Stationary	163
3129	F6	Spill	3 Jul	5 Jul	46.053160	-122.884328	994.6	11
31A7	65	Spill	3 Jul	5 Jul	46.049022	-122.880363	9.4	3
3537	4F	Spill	3 Jul	5 Jul	46.057548	-122.886338	2,340.0	45
2CA4	E2	Spill	3 Jul	5 Jul	46.053005	-122.884462	0.0	1
30EB	44	Tailrace	3 Jul	5 Jul	46.048960	-122.881992	0.0	1
2723	CE	Spill	29 Jun	6 Jul	46.086123	-122.880653	Stationary	5
331A	3B	Spill	4 Jul	6 Jul	46.005062	-122.873087	1,868.4	138
32FC	CB	Spill	4 Jul	6 Jul	46.005753	-122.857100	95.9	9
35EE	84	Spill	4 Jul	6 Jul	46.006037	-122.856988	331.0	7
325F	86	Spill	4 Jul	6 Jul	46.006720	-122.857598	0.0	1
2C36	4F	Spill	4 Jul	6 Jul	46.006607	-122.857388	269.4	9
345B	4D	Spill	4 Jul	6 Jul	46.002462	-122.872912	1,696.2	44
3124	0B	Spill	4 Jul	6 Jul	46.004452	-122.856592	157.3	9
3440	F0	Spill	4 Jul	6 Jul	46.003598	-122.856247		*
30C3	A5	Spill	4 Jul	6 Jul	45.993093	-122.861197	843.3	4
30C5	78	Spill	4 Jul	6 Jul	46.006960	-122.857675		*
31E2	1C	Spill	4 Jul	6 Jul	46.006018	-122.856998	297.6	3
3132	4B	Spill	4 Jul	6 Jul	46.005323	-122.856958	157.3	11
2EDA	94	Spill	4 Jul	6 Jul	45.999825	-122.870933	2,214.5	68
3A07	E9	Spill	4 Jul	6 Jul	45.997665	-122.868740	3,812.5	239
3730	5D	Spill	4 Jul	6 Jul	46.005423	-122.856973	497.3	7
2C4C	C9	Tailrace	4 Jul	6 Jul	46.004207	-122.856635	148.1	13
305D	AB	Tailrace	4 Jul	6 Jul	45.990665	-122.850608	1,361.5	20
1A0A	D5	Spill	22 Jun	9 Jul	45.954485	-122.796613	Stationary	47
2723	CE	Spill	29 Jun	9 Jul	46.085707	-122.878928	Stationary	19
37E0	0A	Tailrace	29 Jun	9 Jul	45.887970	-122.804172	Stationary	52
1A0A	D5	Spill	22 Jun	10 Jul	45.954598	-122.797032	Stationary	23
37E0	0A	Tailrace	29 Jun	10 Jul	45.888407	-122.804943	Stationary	6
686E	F6	Outfall	7 Jul	10 Jul	46.033090	-122.881762	2,219.3	45
6B1B	64	Spill	10 Jul	11 Jul	45.659853	-122.766047		*
2B26	BC	Spill	10 Jul	11 Jul	45.660402	-122.765047	75.4	3
6E55	C2	Spill	10 Jul	11 Jul	45.659702	-122.766000		*
622E	57	Spill	10 Jul	11 Jul	45.651268	-122.753322	3,658.0	213
6DEC	39	Spill	10 Jul	11 Jul	45.661245	-122.766795		*
5887	AE	Spill	10 Jul	11 Jul	45.660712	-122.766517	0.0	1
6954	F2	Spill	10 Jul	11 Jul	45.659798	-122.765493	162.9	3
6EFE	4D	Spill	10 Jul	11 Jul	45.663095	-122.766937	582.6	6
6771	32	Spill	10 Jul	11 Jul	45.662010	-122.767682		*
561A	9E	Spill	10 Jul	11 Jul	45.662302	-122.764397	1,932.8	33
6D63	F4	Spill	10 Jul	11 Jul	45.659567	-122.765245	0.0	1
18B4	69	Outfall	23 Jun	11 Jul	45.846478	-122.785443	Stationary	35
3694	57	Tailrace	10 Jul	11 Jul	45.661383	-122.766873		*

Appendix Table D. Continued.

Target code	Target CRC	Release site	Release date	Recovery date	Initial acquisition latitude	Initial acquisition longitude	Track length (m)	Track detects
6D67	95	Tailrace	10 Jul	11 Jul	45.659002	-122.765668	0.0	1
5039	F5	Tailrace	10 Jul	11 Jul	45.662075	-122.764505	47.5	5
6D92	DE	Tailrace	10 Jul	11 Jul	45.660110	-122.765827	365.3	5
7147	17	Tailrace	10 Jul	11 Jul	45.660228	-122.765942	555.2	15
6DCE	A6	Tailrace	10 Jul	11 Jul	45.659562	-122.765253	1,601.3	59
18B4	69	Outfall	23 Jun	11 Jul	47.846435	-122.785343	Stationary	*
0B30	3D	LGr	13 Jun	12 Jul	45.658452	-122.766545	Stationary	35
702C	96	Spill	10 Jul	12 Jul	45.846502	-122.785392	0.0	1
51BB	01	Spill	10 Jul	12 Jul	45.849393	-122.786650	281.6	5
69EF	E0	Spill	10 Jul	12 Jul	45.856548	-122.782535	761.2	9
6B16	99	Spill	11 Jul	12 Jul	45.643788	-122.749930	48.3	2
6AA9	2E	Spill	11 Jul	12 Jul	45.644927	-122.742068	511.8	3
4B9C	AA	Spill	11 Jul	12 Jul	45.646748	-122.748147	2,837.3	85
5666	C5	Spill	11 Jul	12 Jul	45.658043	-122.766358	0.0	1
676A	8F	Spill	11 Jul	12 Jul	45.638122	-122.728198	0.0	0
6EFC	F1	Spill	11 Jul	12 Jul	45.658808	-122.767585	97.1	7
6A9C	AF	Spill	11 Jul	12 Jul	45.639480	-122.725487	5,164.4	35
5FE5	19	Spill	11 Jul	12 Jul	45.653370	-122.761238		*
6ED8	B3	Spill	11 Jul	12 Jul	45.659405	-122.767368		*
4C71	D0	Spill	11 Jul	12 Jul	45.642317	-122.731597	6,162.2	74
3F08	57	Spill	11 Jul	12 Jul	45.657672	-122.765505		*
6A97	8F	Spill	11 Jul	12 Jul	45.639487	-122.725487	6,926.6	553
355F	E8	Tailrace	6 Jul	12 Jul	45.650072	-122.754197	0.0	1
3DB1	68	Tailrace	10 Jul	12 Jul	45.847948	-122.784775		*
66F9	B8	Tailrace	10 Jul	12 Jul	45.848160	-122.784510		*
6630	EE	Tailrace	10 Jul	12 Jul	45.849370	-122.785910	324.2	3
577D	BC	Tailrace	10 Jul	12 Jul	45.850317	-122.786210	19.5	4
6DE3	78	Tailrace	10 Jul	12 Jul	45.847225	-122.785212	952.7	9
5555	CC	Tailrace	11 Jul	12 Jul	45.650358	-122.755870		*
4A10	41	Tailrace	11 Jul	12 Jul	45.645808	-122.746172		*
6B1F	05	Tailrace	11 Jul	12 Jul	45.645680	-122.744677	205.1	2
675A	31	Tailrace	11 Jul	12 Jul	45.659063	-122.767618	71.4	10
568F	B0	Tailrace	11 Jul	12 Jul	45.644792	-122.747982	1,240.8	12
64D8	54	Tailrace	11 Jul	12 Jul	45.652058	-122.757995	249.3	15
545D	CA	Tailrace	11 Jul	12 Jul	45.639762	-122.725345	1,327.7	24
52F4	53	Tailrace	11 Jul	12 Jul	45.642433	-122.732487	1,532.1	27
325F	86	Spill	4 Jul	19 Jul	46.187700	-123.176955		*
335B	23	Spill	5 Jul	19 Jul	46.190857	-123.148747	Stationary	116
39ED	2B	Spill	5 Jul	19 Jul	46.182083	-123.182773	Stationary	283
6F74	7B	Outfall	7 Jul	19 Jul	46.182722	-123.180478	Stationary	3
5C5A	3F	Tailrace	12 Jul	19 Jul	46.186487	-123.180108	23.8	2
6649	8A	Tailrace	12 Jul	19 Jul	46.191457	-123.162475	Stationary	5
46F9	79	Tailrace	13 Jul	19 Jul	46.189440	-123.168543	Stationary	*
5AC8	38	Outfall	17 Jul	19 Jul	46.188963	-123.172348		*
7B4C	D0	Outfall	17 Jul	19 Jul	46.174945	-123.197127	0.0	1
5BD0	A3	Outfall	17 Jul	19 Jul	46.191720	-123.152353	0.0	1
7BE0	DC	Outfall	17 Jul	19 Jul	46.189942	-123.144835	785.4	12
7B5B	CE	Outfall	17 Jul	19 Jul	46.190737	-123.148045	71.7	3
7B49	EF	Outfall	17 Jul	19 Jul	46.182445	-123.181047	815.9	21

Appendix Table D. Continued.

Target code	Target CRC	Release site	Release date	Recovery date	Initial acquisition latitude	Initial acquisition longitude	Track length (m)	Track detects
4BEE	EE	Outfall	17 Jul	19 Jul	46.182135	-123.182085	962.4	58
5EFE	60	Outfall	17 Jul	19 Jul	46.189943	-123.144888	3,201.0	133
0D0C	8A	LGr	9 Jun	20 Jul	46.189303	-123.169742	Stationary	1
3921	42	LGr	3 Jul	20 Jul	46.190403	-123.165943	0.0	1
25E8	B5	Spill	22 Jun	20 Jul	46.163198	-123.045218	Stationary	12
2D6A	F3	Spill	4 Jul	20 Jul	46.190913	-123.164882	Stationary	9
335B	23	Spill	5 Jul	20 Jul	46.191223	-123.148870	Stationary	7
39ED	2B	Spill	5 Jul	20 Jul	46.181627	-123.183270	Stationary	9
5693	8E	Spill	11 Jul	20 Jul	46.188690	-123.129030	Stationary	43
5B37	C9	Spill	12 Jul	20 Jul	46.190098	-123.145578	Stationary	5
4732	57	Spill	13 Jul	20 Jul	46.171430	-123.071512	Stationary	49
3117	57	Tailrace	5 Jul	20 Jul	46.172245	-123.062128	Stationary	55
6F74	7B	Outfall	7 Jul	20 Jul	46.182442	-123.180853	Stationary	5
6649	8A	Tailrace	12 Jul	20 Jul	46.191568	-123.164123	Stationary	12
46F9	79	Tailrace	13 Jul	20 Jul	46.189410	-123.170878	Stationary	84
5DC4	F5	Outfall	17 Jul	20 Jul	46.162987	-123.045098	Stationary	10
5ACD	07	Outfall	17 Jul	20 Jul	46.172322	-123.082073	Stationary	5
55A0	87	LGr	10 May	21 Jul	45.632617	-121.965163		*
4A6D	44	Spill	12 Jul	21 Jul	45.575728	-122.184905	Stationary?	3
323B	82	Tailrace	4 Jul	21 Jul	45.575480	-122.185370	Stationary?	28
3BF7	59	Tailrace	5 Jul	21 Jul	45.575775	-122.184757	Stationary?	32
2523	5F	Outfall	21 Jul	21 Jul	45.632590	-121.965173	3.6	3
34F0	C2	Outfall	21 Jul	21 Jul	45.632543	-121.965163	3.9	4
409A	54	Outfall	21 Jul	21 Jul	45.632590	-121.965167	1,907.1	5
44A8	6D	Outfall	21 Jul	21 Jul	45.632610	-121.965168	1,519.2	32
480F	0C	Outfall	21 Jul	21 Jul	45.632547	-121.965168	6,649.8	8
4ACC	B5	Outfall	21 Jul	21 Jul	45.632547	-121.965162	3.3	3
4D2B	B1	Outfall	21 Jul	21 Jul	45.632550	-121.965168		*
4D4C	57	Outfall	21 Jul	21 Jul	45.632543	-121.965163	548.8	11
4D5F	28	Outfall	21 Jul	21 Jul	45.632542	-121.965165	584.2	14
4E76	C2	Outfall	21 Jul	21 Jul	45.632560	-121.965167	7.6	6
4E7F	5E	Outfall	21 Jul	21 Jul	45.632590	-121.965173	943.1	10
4E84	0A	Outfall	21 Jul	21 Jul	45.632575	-121.965163	1,070.2	9
4F92	8E	Outfall	21 Jul	21 Jul	45.632612	-121.965170	1,794.4	5
4FD0	74	Outfall	21 Jul	21 Jul	45.632530	-121.965167	1,646.4	2
4FD4	15	Outfall	21 Jul	21 Jul	45.632488	-121.965080		*
51D2	F8	Outfall	21 Jul	21 Jul	45.632590	-121.965167	1,921.6	9
537B	5A	Outfall	21 Jul	21 Jul	45.632450	-121.965038	2,208.0	11
5597	BA	Outfall	21 Jul	21 Jul	45.632613	-121.965168	4.6	7
559F	78	Outfall	21 Jul	21 Jul	45.632585	-121.965170	1,839.5	4
5746	22	Outfall	21 Jul	21 Jul	45.632587	-121.965170	3.6	6
577A	3F	Outfall	21 Jul	21 Jul	45.632615	-121.965170	0.0	1
57A5	29	Outfall	21 Jul	21 Jul	45.632580	-121.965168	3.3	5
5812	80	Outfall	21 Jul	21 Jul	45.632542	-121.965165	4.5	5
592C	E5	Outfall	21 Jul	21 Jul	45.632615	-121.965170	772.5	6
5930	DB	Outfall	21 Jul	21 Jul	45.632557	-121.965165		*
5932	67	Outfall	21 Jul	21 Jul	45.632563	-121.965167	2.4	2
5934	BA	Outfall	21 Jul	21 Jul	45.632612	-121.965170	962.4	6
5936	06	Outfall	21 Jul	21 Jul	45.632580	-121.965168	3.6	5

Appendix Table D. Continued.

Target code	Target CRC	Release site	Release date	Recovery date	Initial acquisition latitude	Initial acquisition longitude	Track length (m)	Track detects
593B	FB	Outfall	21 Jul	21 Jul	45.632580	-121.965170	1,158.7	6
5942	9F	Outfall	21 Jul	21 Jul	45.632547	-121.965168		*
595E	A1	Outfall	21 Jul	21 Jul	45.632635	-121.965165	311.3	9
595F	FF	Outfall	21 Jul	21 Jul	45.632615	-121.965167	4.9	5
5966	DD	Outfall	21 Jul	21 Jul	45.632613	-121.965167	46.7	2
596C	A3	Outfall	21 Jul	21 Jul	45.632577	-121.965168	872.3	7
59A8	08	Outfall	21 Jul	21 Jul	45.632400	-121.965008	1,944.1	6
59C3	4D	Outfall	21 Jul	21 Jul	45.632573	-121.965162	0.1	2
59C5	90	Outfall	21 Jul	21 Jul	45.632547	-121.965168	1,815.3	4
59DC	91	Outfall	21 Jul	21 Jul	45.632547	-121.965162	1,697.9	12
59ED	71	Outfall	21 Jul	21 Jul	45.632582	-121.965170	0.7	3
59F6	CC	Outfall	21 Jul	21 Jul	45.632542	-121.965165	1,807.3	16
5A15	92	Outfall	21 Jul	21 Jul	45.632575	-121.965163	3.4	4
5A1C	0E	Outfall	21 Jul	21 Jul	45.632573	-121.965162	418.4	8
5A2C	B0	Outfall	21 Jul	21 Jul	45.632575	-121.965160	886.7	9
5A32	32	Outfall	21 Jul	21 Jul	45.632405	-121.965030	12.7	5
5A6F	14	Outfall	21 Jul	21 Jul	45.632450	-121.965038	4.1	3
5A81	E2	Outfall	21 Jul	21 Jul	45.632583	-121.965170	904.5	9
5A92	9D	Outfall	21 Jul	21 Jul	45.632575	-121.965168	1,590.0	4
5A96	FC	Outfall	21 Jul	21 Jul	45.632517	-121.965143	1,374.4	4
5AA7	1C	Outfall	21 Jul	21 Jul	45.632613	-121.965170	8.2	5
5AA9	03	Outfall	21 Jul	21 Jul	45.632612	-121.965170	4.7	5
5AB6	DF	Outfall	21 Jul	21 Jul	45.632613	-121.965168	753.2	5
5ABF	43	Outfall	21 Jul	21 Jul	45.632610	-121.965168	3.2	4
5AC4	9B	Outfall	21 Jul	21 Jul	45.632540	-121.965165	2,022.9	7
5ACB	DA	Outfall	21 Jul	21 Jul	45.632580	-121.965168		*
5AD3	85	Outfall	21 Jul	21 Jul	45.632612	-121.965168	3.7	5
5ADD	9A	Outfall	21 Jul	21 Jul	45.632542	-121.965165	9.6	4
5AF2	F8	Outfall	21 Jul	21 Jul	45.632540	-121.965168	2,076.1	6
5B34	2B	Outfall	21 Jul	21 Jul	45.632545	-121.965163	182.5	3
5B38	88	Outfall	21 Jul	21 Jul	45.632543	-121.965167	6.9	8
5B39	D6	Outfall	21 Jul	21 Jul	45.632520	-121.965162	3.2	4
5B3C	E9	Outfall	21 Jul	21 Jul	45.632587	-121.965167	3.2	5
5B3D	B7	Outfall	21 Jul	21 Jul	45.632545	-121.965163	1,450.0	9
5B44	D3	Outfall	21 Jul	21 Jul	45.632510	-121.965130	1,974.7	4
5B49	2E	Outfall	21 Jul	21 Jul	45.632425	-121.965008	1,992.4	8
5B4C	11	Outfall	21 Jul	21 Jul	45.632543	-121.965163	5,779.2	5
5B54	4E	Outfall	21 Jul	21 Jul	45.632612	-121.965142	0.2	2
5B57	AC	Outfall	21 Jul	21 Jul	45.632585	-121.965170	1,767.1	15
5B5B	0F	Outfall	21 Jul	21 Jul	45.632623	-121.965132	6,799.5	5
5B61	CF	Outfall	21 Jul	21 Jul	45.632560	-121.965167	5.9	3
5B67	12	Outfall	21 Jul	21 Jul	45.632582	-121.965170	3.1	2
5B6B	B1	Outfall	21 Jul	21 Jul	45.632625	-121.965133	2.4	2
5B6C	32	Outfall	21 Jul	21 Jul	45.632612	-121.965170	1,821.8	4
5B76	D1	Outfall	21 Jul	21 Jul	45.632523	-121.965170	1,536.9	3
5B78	CE	Outfall	21 Jul	21 Jul	45.632562	-121.965170	1,118.5	6
5B79	90	Outfall	21 Jul	21 Jul	45.632620	-121.965133	308.6	5
5B82	C4	Outfall	21 Jul	21 Jul	45.632522	-121.965168	2,927.4	2
5B90	E5	Outfall	21 Jul	21 Jul	45.632573	-121.965162	1,530.5	5

Appendix Table D. Continued.

Target code	Target CRC	Release site	Release date	Recovery date	Initial acquisition latitude	Initial acquisition longitude	Track length (m)	Track detects
5B93	07	Outfall	21 Jul	21 Jul	45.632582	-121.965168	6.5	6
5B94	84	Outfall	21 Jul	21 Jul	45.632590	-121.965173	1,779.9	3
5B98	27	Outfall	21 Jul	21 Jul	45.632613	-121.965167	6.2	5
5B99	79	Outfall	21 Jul	21 Jul	45.632580	-121.965170	3.8	3
5B9B	C5	Outfall	21 Jul	21 Jul	45.632550	-121.965162	7.3	5
5B9E	FA	Outfall	21 Jul	21 Jul	45.632618	-121.965135	4.0	6
5BA1	05	Outfall	21 Jul	21 Jul	45.632527	-121.965170	1.9	2
5BC8	FC	Outfall	21 Jul	21 Jul	45.632617	-121.965165	3.5	3
5BF8	42	Outfall	21 Jul	21 Jul	45.632520	-121.965147	9.0	5
5C0E	85	Outfall	21 Jul	21 Jul	45.632620	-121.965135	782.1	7
5C0F	DB	Outfall	21 Jul	21 Jul	45.632543	-121.965167	3.5	2
5C10	07	Outfall	21 Jul	21 Jul	45.632575	-121.965163	7.3	7
5C1A	79	Outfall	21 Jul	21 Jul	45.632537	-121.965163	1,863.6	7
5C1C	A4	Outfall	21 Jul	21 Jul	45.632592	-121.965173	1,937.7	3
5C1E	18	Outfall	21 Jul	21 Jul	45.632582	-121.965170	0.7	2
5C58	83	Outfall	21 Jul	21 Jul	45.632613	-121.965168	4.3	4
5C72	DE	Outfall	21 Jul	21 Jul	45.632575	-121.965168	1.1	2
5C76	BF	Outfall	21 Jul	21 Jul	45.632592	-121.965173	6.8	8
5CA2	89	Outfall	21 Jul	21 Jul	45.632543	-121.965163	1,985.9	8
5D0C	FD	Outfall	21 Jul	21 Jul	45.632547	-121.965162	5.8	5
5D1C	60	Outfall	21 Jul	21 Jul	45.632517	-121.965143	0.4	2
5D68	F9	Outfall	21 Jul	21 Jul	45.632575	-121.965165	766.0	2
5D6A	45	Outfall	21 Jul	21 Jul	45.632515	-121.965137	867.4	10
5D76	7B	Outfall	21 Jul	21 Jul	45.632632	-121.965173	272.8	2
5D78	64	Outfall	21 Jul	21 Jul	45.632547	-121.965162	1,877.6	14
5D7C	05	Outfall	21 Jul	21 Jul	45.632620	-121.965133	722.6	3
5D84	B3	Outfall	21 Jul	21 Jul	45.632575	-121.965160	1,950.5	5
5D85	ED	Outfall	21 Jul	21 Jul	45.632520	-121.965147	1,902.2	2
5D86	0F	Outfall	21 Jul	21 Jul	45.632510	-121.965130	3.2	3
5D8A	AC	Outfall	21 Jul	21 Jul	45.632545	-121.965163	1,969.8	4
5D97	CC	Outfall	21 Jul	21 Jul	45.632587	-121.965170	1,168.4	9
5D98	8D	Outfall	21 Jul	21 Jul	45.632583	-121.965170	1,062.2	7
5DA3	13	Outfall	21 Jul	21 Jul	45.632617	-121.965163	927.0	4
5DAA	8F	Outfall	21 Jul	21 Jul	45.632623	-121.965132	2,917.7	12
5DAB	D1	Outfall	21 Jul	21 Jul	45.632430	-121.965013	4.9	3
5DB1	32	Outfall	21 Jul	21 Jul	45.632405	-121.965030	10.5	4
5DB5	53	Outfall	21 Jul	21 Jul	45.632548	-121.965162	1,892.6	2
5DB8	AE	Outfall	21 Jul	21 Jul	45.632540	-121.965168	0.9	2
5DB9	F0	Outfall	21 Jul	21 Jul	45.632547	-121.965162		*
5DBB	4C	Outfall	21 Jul	21 Jul	45.632582	-121.965170	2,312.6	5
5DC1	CA	Outfall	21 Jul	21 Jul	45.632348	-121.965065	27.4	6
5DC5	AB	Outfall	21 Jul	21 Jul	45.632613	-121.965168	175.0	4
5DCF	D5	Outfall	21 Jul	21 Jul	45.632613	-121.965168	1,239.2	6
5DDB	29	Outfall	21 Jul	21 Jul	45.632573	-121.965162	2.7	3
5DEE	A8	Outfall	21 Jul	21 Jul	45.632402	-121.965012	807.9	7
5DFF	6B	Outfall	21 Jul	21 Jul	45.632615	-121.965165	1,479.0	5
5E18	54	Outfall	21 Jul	21 Jul	45.632590	-121.965163	1,171.6	8
5E19	0A	Outfall	21 Jul	21 Jul	45.632550	-121.965168	7.3	2
5E1B	B6	Outfall	21 Jul	21 Jul	45.632582	-121.965170	0.4	2

Appendix Table D. Continued.

Target code	Target CRC	Release site	Release date	Recovery date	Initial acquisition latitude	Initial acquisition longitude	Track length (m)	Track detects
5E20	28	Outfall	21 Jul	21 Jul	45.632587	-121.965170		*
5E21	76	Outfall	21 Jul	21 Jul	45.632547	-121.965162	748.3	4
5E22	94	Outfall	21 Jul	21 Jul	45.632543	-121.965163	6,756.0	3
5E24	49	Outfall	21 Jul	21 Jul	45.632547	-121.965162	1,147.5	6
5E2B	08	Outfall	21 Jul	21 Jul	45.632543	-121.965163	457.1	3
5E70	F3	Outfall	21 Jul	21 Jul	45.632518	-121.965155		*
5E99	86	Outfall	21 Jul	21 Jul	45.632510	-121.965127	1,828.2	2
5E9A	64	Outfall	21 Jul	21 Jul	45.632547	-121.965162	1,945.7	5
5E9E	05	Outfall	21 Jul	21 Jul	45.632542	-121.965165	2,003.6	5
5EBE	26	Outfall	21 Jul	21 Jul	45.632543	-121.965167	6,334.4	6
5EC8	03	Outfall	21 Jul	21 Jul	45.632547	-121.965162	1,203.8	10
5ED1	02	Outfall	21 Jul	21 Jul	45.632592	-121.965173	2.8	2
5ED3	BE	Outfall	21 Jul	21 Jul	45.632495	-121.965092	202.5	2
5EEC	41	Outfall	21 Jul	21 Jul	45.632548	-121.965162	1.2	3
5EEF	A3	Outfall	21 Jul	21 Jul	45.632545	-121.965163	1,733.3	7
5EF2	C3	Outfall	21 Jul	21 Jul	45.632613	-121.965168	4.9	5
5EF5	40	Outfall	21 Jul	21 Jul	45.632435	-121.965020	4.8	3
5F00	CF	Outfall	21 Jul	21 Jul	45.632592	-121.965173	0.0	1
5F03	2D	Outfall	21 Jul	21 Jul	45.632575	-121.965160	1,620.6	21
5F13	B0	Outfall	21 Jul	21 Jul	45.632550	-121.965162	27.2	3
5F1A	2C	Outfall	21 Jul	21 Jul	45.632612	-121.965170	1,145.9	7
5F20	EC	Outfall	21 Jul	21 Jul	45.632582	-121.965168	382.4	4
5F2D	11	Outfall	21 Jul	21 Jul	45.632520	-121.965150	1,931.2	4
5F34	10	Outfall	21 Jul	21 Jul	45.632617	-121.965168	1,937.7	7
5F37	F2	Outfall	21 Jul	21 Jul	45.632547	-121.965162	1,667.3	5
5F3C	D2	Outfall	21 Jul	21 Jul	45.632667	-121.965095	308.5	5
5F40	89	Outfall	21 Jul	21 Jul	45.632587	-121.965167	1,129.8	9
5F41	D7	Outfall	21 Jul	21 Jul	45.632615	-121.965133		*
5F43	6B	Outfall	21 Jul	21 Jul	45.632562	-121.965170	1,968.2	9
5F47	0A	Outfall	21 Jul	21 Jul	45.632420	-121.965008	4.5	3
5F59	88	Outfall	21 Jul	21 Jul	45.632582	-121.965170	857.8	8
5F5E	0B	Outfall	21 Jul	21 Jul	45.632613	-121.965167	1.8	5
5F67	29	Outfall	21 Jul	21 Jul	45.632592	-121.965172	5.0	3
5F6A	D4	Outfall	21 Jul	21 Jul	45.632580	-121.965168	47.4	2
5F6D	57	Outfall	21 Jul	21 Jul	45.632623	-121.965132	0.8	2
5F74	56	Outfall	21 Jul	21 Jul	45.632527	-121.965170	3.6	4
5F75	08	Outfall	21 Jul	21 Jul	45.632582	-121.965170		*
5F7C	94	Outfall	21 Jul	21 Jul	45.632557	-121.965165	1,973.1	2
5F88	81	Outfall	21 Jul	21 Jul	45.632613	-121.965170	1,833.0	3
5F98	1C	Outfall	21 Jul	21 Jul	45.632580	-121.965168		*
5F99	42	Outfall	21 Jul	21 Jul	45.632618	-121.965177		*
5FA7	E3	Outfall	21 Jul	21 Jul	45.632613	-121.965168	1,747.7	8
5FA8	A2	Outfall	21 Jul	21 Jul	45.632613	-121.965168	0.0	1
5FC4	64	Outfall	21 Jul	21 Jul	45.632577	-121.965168	0.1	2
5FE3	C4	Outfall	21 Jul	21 Jul	45.632550	-121.965162	1,419.4	6
5FE4	47	Outfall	21 Jul	21 Jul	45.632573	-121.965162	0.6	2
602B	F9	Outfall	21 Jul	21 Jul	45.632545	-121.965168	1.3	3
60B1	96	Outfall	21 Jul	21 Jul	45.632488	-121.965080	0.0	1
61B7	8F	Outfall	21 Jul	21 Jul	45.632612	-121.965170	3.4	5

Appendix Table D. Continued.

Target code	Target CRC	Release site	Release date	Recovery date	Initial acquisition latitude	Initial acquisition longitude	Track length (m)	Track detects
6B3E	78	Outfall	21 Jul	21 Jul	45.632488	-121.965080	0.0	1
6CED	A3	Outfall	21 Jul	21 Jul	45.632488	-121.965080		*
7016	56	Outfall	21 Jul	21 Jul	45.632615	-121.965172	3.4	2
79D7	70	Outfall	21 Jul	21 Jul	45.632617	-121.965163	134.2	2
79EC	EE	Outfall	21 Jul	21 Jul	45.632583	-121.965170	973.7	4
79FA	AE	Outfall	21 Jul	21 Jul	45.632632	-121.965168	0.0	1
7A02	4D	Outfall	21 Jul	21 Jul	45.632618	-121.965133	1,343.8	4
7A16	B1	Outfall	21 Jul	21 Jul	45.632575	-121.965163	952.7	5
7A17	EF	Outfall	21 Jul	21 Jul	45.632587	-121.965170	1,422.7	4
7A1B	4C	Outfall	21 Jul	21 Jul	45.632545	-121.965163	952.7	5
7A2F	93	Outfall	21 Jul	21 Jul	45.632548	-121.965162	972.0	6
7A34	2E	Outfall	21 Jul	21 Jul	45.632623	-121.965132	9,367.8	6
7A3E	50	Outfall	21 Jul	21 Jul	45.632550	-121.965162	2.8	2
7A46	6A	Outfall	21 Jul	21 Jul	45.632420	-121.965008	2,369.0	10
7A52	96	Outfall	21 Jul	21 Jul	45.632543	-121.965163	2.6	4
7A62	28	Outfall	21 Jul	21 Jul	45.632560	-121.965167	806.3	8
7AB9	5F	Outfall	21 Jul	21 Jul	45.632520	-121.965150	18.0	16
7AC1	65	Outfall	21 Jul	21 Jul	45.632548	-121.965162	2,026.2	4
7AC2	87	Outfall	21 Jul	21 Jul	45.632540	-121.965165	2,183.9	4
7AC6	E6	Outfall	21 Jul	21 Jul	45.632612	-121.965170	1,028.4	3
7AD3	44	Outfall	21 Jul	21 Jul	45.632580	-121.965170	1,852.4	5
7AD7	25	Outfall	21 Jul	21 Jul	45.632545	-121.965163	7.1	5
7ADA	D8	Outfall	21 Jul	21 Jul	45.632562	-121.965170	3.6	4
7ADD	5B	Outfall	21 Jul	21 Jul	45.632612	-121.965170	0.7	3
7ADE	B9	Outfall	21 Jul	21 Jul	45.632515	-121.965137	9.8	6
7AE5	27	Outfall	21 Jul	21 Jul	45.632542	-121.965165	1,878.1	12
7AEA	66	Outfall	21 Jul	21 Jul	45.632613	-121.965170	1,891.0	5
7AF1	DB	Outfall	21 Jul	21 Jul	45.632613	-121.965167	1,178.0	4
7B06	E8	Outfall	21 Jul	21 Jul	45.632543	-121.965163	5.1	6
7B09	A9	Outfall	21 Jul	21 Jul	45.632557	-121.965165	814.3	5
7B0F	74	Outfall	21 Jul	21 Jul	45.632562	-121.965170	1.1	3
7B12	14	Outfall	21 Jul	21 Jul	45.632580	-121.965170	1,179.6	7
7B3F	CA	Outfall	21 Jul	21 Jul	45.632610	-121.965168	114.8	3
7B4B	53	Outfall	21 Jul	21 Jul	45.632543	-121.965167	1,041.2	3
7B4F	32	Outfall	21 Jul	21 Jul	45.632540	-121.965165	2.5	2
7B86	64	Outfall	21 Jul	21 Jul	45.632612	-121.965170	2.7	2
7BA8	58	Outfall	21 Jul	21 Jul	45.632617	-121.965168	0.2	2
7BD4	03	Outfall	21 Jul	21 Jul	45.632580	-121.965170	194.9	2
7BEC	7F	Outfall	21 Jul	21 Jul	45.632575	-121.965168	910.9	6
7BF4	20	Outfall	21 Jul	21 Jul	45.632492	-121.965087	396.2	3
7BFC	E2	Outfall	21 Jul	21 Jul	45.632495	-121.965092	8.0	3
7C01	05	Outfall	21 Jul	21 Jul	45.632542	-121.965165	0.6	3
7C07	D8	Outfall	21 Jul	21 Jul	45.632583	-121.965170	1,807.3	4
7C09	C7	Outfall	21 Jul	21 Jul	45.632542	-121.965165	0.0	1
7C11	98	Outfall	21 Jul	21 Jul	45.632545	-121.965163	179.2	4
7C15	F9	Outfall	21 Jul	21 Jul	45.632542	-121.965165		*
7C18	04	Outfall	21 Jul	21 Jul	45.632507	-121.965120		*
7C2C	DB	Outfall	21 Jul	21 Jul	45.632480	-121.965072	10.0	6
7C2F	39	Outfall	21 Jul	21 Jul	45.632548	-121.965162	2,121.1	2

Appendix Table D. Continued.

Target code	Target CRC	Release site	Release date	Recovery date	Initial acquisition latitude	Initial acquisition longitude	Track length (m)	Track detects
7C30	E5	Outfall	21 Jul	21 Jul	45.632613	-121.965168	817.5	6
7C46	C0	Outfall	21 Jul	21 Jul	45.632585	-121.965170	0.4	2
7C4D	E0	Outfall	21 Jul	21 Jul	45.632585	-121.965170	1,511.2	12
7C53	62	Outfall	21 Jul	21 Jul	45.632520	-121.965162		*
7C6E	21	Outfall	21 Jul	21 Jul	45.632547	-121.965162	729.0	10
7C8C	74	Outfall	21 Jul	21 Jul	45.632580	-121.965168		*
7C8F	96	Outfall	21 Jul	21 Jul	45.632547	-121.965162	1,414.6	6
7CA4	95	Outfall	21 Jul	21 Jul	45.632615	-121.965172	936.6	11
7CBA	17	Outfall	21 Jul	21 Jul	45.632625	-121.965133	1,089.5	8
7CC1	CF	Outfall	21 Jul	21 Jul	45.632562	-121.965170	0.0	1
7CC8	53	Outfall	21 Jul	21 Jul	45.632547	-121.965162	1,845.9	2
7CC9	0D	Outfall	21 Jul	21 Jul	45.632515	-121.965137	0.3	2
7CF8	ED	Outfall	21 Jul	21 Jul	45.632613	-121.965168	6.4	5
7D34	40	Outfall	21 Jul	21 Jul	45.632435	-121.965020	1,332.5	11
7DB1	F3	Outfall	21 Jul	21 Jul	45.632630	-121.965163	666.3	11
7E3D	89	Outfall	21 Jul	21 Jul	45.632537	-121.965163	1,963.4	17
7EF1	E0	Outfall	21 Jul	21 Jul	45.632613	-121.965168	1,120.1	10
7F1F	D2	Outfall	21 Jul	21 Jul	45.632547	-121.965162	872.3	9
7F4D	B5	Outfall	21 Jul	21 Jul	45.632573	-121.965162		*
0B30	3D	LGr	13 Jun	22 Jul	45.658512	-122.766992	Stationary	2
6C32	B5	Spill	10 Jul	22 Jul	45.820263	-122.797185	Stationary?	38
638B	03	Spill	12 Jul	22 Jul	45.822160	-122.797268	Stationary?	12
6957	10	Tailrace	13 Jul	22 Jul	45.826597	-122.796827	672.7	4
4974	10	Tailrace	13 Jul	22 Jul	45.551260	-122.339113	Stationary?	45
7A2B	F2	Outfall	17 Jul	22 Jul	45.551758	-122.338613	Stationary?	4
51D5	7B	Outfall	17 Jul	22 Jul	45.659970	-122.767890	Stationary?	4
5D97	CC	Outfall	21 Jul	22 Jul	45.804970	-122.792768		*
5B34	2B	Outfall	21 Jul	22 Jul	45.834305	-122.792385		*
5D7C	05	Outfall	21 Jul	22 Jul	45.805935	-122.794093	265.8	2
4FD0	74	Outfall	21 Jul	22 Jul	45.830938	-122.795175	732.3	7
5F20	EC	Outfall	21 Jul	22 Jul	45.817812	-122.796733	1,303.6	5
7A3E	50	Outfall	21 Jul	22 Jul	45.573585	-122.467248	136.5	10
577A	3F	Outfall	21 Jul	22 Jul	45.804377	-122.791938	2,697.3	16
59F6	CC	Outfall	21 Jul	22 Jul	45.813198	-122.797130	881.9	23
7CA4	95	Outfall	21 Jul	22 Jul	45.813587	-122.797230	2,566.9	39
5DB1	32	Outfall	21 Jul	22 Jul	45.659545	-122.767903	671.1	44
068D	7B	Spill	6 Jul	23 Jul	46.185477	-123.127170	Stationary	4
6E4A	1E	Outfall	14 Jul	23 Jul	46.145445	-123.035433	202.6	3
7C9B	6A	Outfall	21 Jul	23 Jul	46.155043	-123.053200		*
4F92	8E	Outfall	21 Jul	23 Jul	46.143793	-123.030320		*
7CA4	95	Outfall	21 Jul	23 Jul	46.151427	-123.044398	44.6	3
5D98	8D	Outfall	21 Jul	23 Jul	46.143713	-123.029942	494.1	4
595F	FF	Outfall	21 Jul	23 Jul	46.185522	-123.127467	407.2	12
5BA1	05	Outfall	21 Jul	23 Jul	46.183797	-123.131732	471.5	14
5C0E	85	Outfall	21 Jul	23 Jul	46.185463	-123.126952	795.0	22
595E	A1	Outfall	21 Jul	23 Jul	46.185732	-123.128900	753.2	38
7C8F	96	Outfall	21 Jul	23 Jul	46.185152	-123.128422	1,940.9	0
7ADD	5B	Outfall	21 Jul	23 Jul	46.185447	-123.128272	2,307.8	51
0D0C	8A	LGr	9 Jun	24 Jul	46.189117	-123.168690	Stationary	*

Appendix Table D. Continued.

Target code	Target CRC	Release site	Release date	Recovery date	Initial acquisition latitude	Initial acquisition longitude	Track length (m)	Track detects
25E8	B5	Spill	22 Jun	24 Jul	46.163235	-123.045077	Stationary	58
2B0F	03	Spill	26 Jun	24 Jul	46.163513	-123.045223	642.1	4
2D6A	F3	Spill	4 Jul	24 Jul	46.191227	-123.165060	Stationary	2
335B	23	Spill	5 Jul	24 Jul	46.190970	-123.149100	Stationary	13
39ED	2B	Spill	5 Jul	24 Jul	46.181557	-123.183445	Stationary	10
068D	7B	Spill	6 Jul	24 Jul	46.185190	-123.129243	Stationary	13
5693	8E	Spill	11 Jul	24 Jul	46.188765	-123.128050	Stationary	33
5B37	C9	Spill	12 Jul	24 Jul	46.190113	-123.146037	Stationary	30
4732	57	Spill	13 Jul	24 Jul	46.171603	-123.071740	Stationary	43
5B62	2D	Spill	13 Jul	24 Jul	46.163152	-123.045558	133.1	16
3117	57	Tailrace	5 Jul	24 Jul	46.172643	-123.061165	Stationary	*
6F74	7B	Outfall	7 Jul	24 Jul	46.182587	-123.180808	Stationary	*
6649	8A	Tailrace	12 Jul	24 Jul	46.191335	-123.163733	Stationary	6
46F9	79	Tailrace	13 Jul	24 Jul	46.189510	-123.169323	Stationary	46
6858	95	Outfall	14 Jul	24 Jul	46.187755	-123.124908	1,144.2	25
5DC4	F5	Outfall	17 Jul	24 Jul	46.162782	-123.044878	Stationary	14
5ACD	07	Outfall	17 Jul	24 Jul	46.172283	-123.081812	Stationary	15
5B34	2B	Outfall	21 Jul	24 Jul	46.191513	-123.150452	494.1	22
4FD0	74	Outfall	21 Jul	24 Jul	46.163315	-123.045142	553.6	66
305C	F5	Spill	3 Jul	21 Aug	46.192053	-123.432910	Stationary	1
5B5B	0F	Outfall	21 Jul	21 Aug	46.196942	-123.432898	Stationary	21
305C	F5	Spill	3 Jul	22 Aug	46.192632	-123.433070	Stationary	*
5693	8E	Spill	11 Jul	22 Aug	46.189045	-123.128875	Stationary	2
5B37	C9	Spill	12 Jul	22 Aug	46.189167	-123.144600	Stationary	6
5B5B	0F	Outfall	21 Jul	22 Aug	46.197020	-123.433092	Stationary	5

* Release sites were LGr (tailrace of Lower Granite Dam), Spill (immediately upstream from the spill bays at Bonneville Dam), Tailrace (mid river from boat, river kilometer, rkm, 231), Outfall (Bonneville Dam juvenile fish facility outfall, rkm 232).