Detection of PIT-Tagged Juvenile Salmonids in the Columbia River Estuary using Pair-Trawls, 2006

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EXECUTIVE SUMMARY

In 2006, we continued a multiyear study to detect migrating juvenile anadromous salmonids *Oncorhynchus* spp. using trawl net detection systems in the Columbia River estuary. Fish targeted for detection were those implanted with passive integrated transponder (PIT) tags and released from various locations in the Snake and Columbia River basins. We evaluated three trawls fitted with PIT-tag detection antennas: a large trawl, a matrix trawl, and a shoreline trawl system.

With the large trawl, we sampled in the upper Columbia River estuary from river kilometer (rkm) 61 to 83 for 961 h between 9 March and 1 November, excluding August. We detected 12,361 PIT-tagged juvenile salmonids of various species, runs, and rearing types, not all of which were proportionally represented in annual detection totals. For example, 17% of the detections were wild fish and 82% were hatchery-reared, and 80% were Chinook salmon, 18% were steelhead, and the remaining 2% were other salmonid species.

During the spring migration period, principal target fish were the nearly 953,000 yearling Chinook salmon and 346,000 juvenile steelhead PIT tagged and either released to migrate in the Snake River or transported and released below Bonneville Dam. We also sampled during the summer migration period, targeting nearly 611,900 subyearling Chinook salmon PIT tagged in the Snake and upper Columbia River. Transported fish were collected from Lower Granite, Little Goose, Lower Monumental and McNary Dam and released downstream from Bonneville Dam.

During 2006, we used the same design for the large trawl developed in 2003 that utilized a cod end fitted for a larger antenna. The new antenna weighed about 193 kg in air and had a fish-passage tunnel measuring 1.1 m in diameter. A separate vessel, which floated directly above the antenna, was used for data collection and antenna deployment. Detections and electronic status reports were coupled with GPS location data and recorded automatically. A camera mounted inside the antenna provided daytime video surveillance for continual monitoring of fish passage, impacts to fish, and debris accumulation. During darkness, we monitored debris accumulation by periodically illuminating the antenna with deck lights.

The trawl and antenna were towed by two 12.5-m vessels. Under tow, we maintained a distance of 91.5 m between the wings, which resulted in an effective sample

depth of 5 to 6 m (measured at the center of the floor). Handwritten logs were maintained to record events related to sampling, including land marks.

A single daily crew began sampling on 9 March 2006, as yearling Chinook salmon and steelhead began to arrive in the estuary. Between 29 April and 23 June, we increased sampling effort with a second daily crew. During this two-crew period, we sampled for an average of 12 h d^{-1} and detected 1.9% of the Chinook salmon and 1.4% of the steelhead previously detected at Bonneville Dam. Detection rates declined in mid-June, and a single daily crew was used 3-5 d/week from 23 June until sampling was ended on 20 July. We resumed sampling for subyearling Chinook salmon 3 d/week from 5 September to 1 November 2006.

Of the total fish detected, 22% had been transported and released downstream from Bonneville Dam. Another 10% had been previously detected in the bypass system or the corner collector PIT-tag detection system at Bonneville Dam. Proportions of fish previously detected at Bonneville Dam were higher in 2006 than in 2004-2005 due to implementation of the corner collector system. The remaining 68% of detections had not been transported or previously detected at Bonneville Dam, but had passed the dam undetected (primarily through spill). Proportions of transported and inriver migrant fish were similar to those of migration histories observed in previous years. As a result of decreased PIT-tagging effort in the upper Columbia River, a much larger proportion of trawl detections (85%) were fish originating in the Snake River than in previous years. Only 9% of trawl detections were fish from the upper Columbia River, and the remaining 6% originated from other sources.

During the peak of the spring migration, we sampled intensively, operating two daily crews 7 d/week. We used results from intensive sampling to evaluate diel trends in detections. Sample sizes of wild and hatchery yearling Chinook salmon and steelhead were sufficient in most instances to conclude that diel within species were similar between wild and hatchery fish; thus, we pooled data from both rearing types for analyses. Detections of yearling Chinook averaged 6/h during daylight and 10/h during darkness hours ($P = 0.051$), and those of steelhead averaged 1/h, regardless of time of day ($P = 0.989$).

Travel speed from Bonneville Dam to Jones Beach was significantly higher for inriver migrant yearling Chinook salmon (median 94 km d^{-1}) than for those released from barges (median 70 km d^{-1}; $P = 0.000$). There was also a significant difference for inriver vs. barged steelhead (101 km d^{-1} vs. 95 km d^{-1}, respectively; $P = 0.000$). Furthermore, travel speeds for both inriver migrant and barge-released yearling Chinook salmon were significantly faster in 2006 than in 2005 ($P = 0.000$), as were travel speeds for inriver

migrant and barged steelhead ($P = 0.000$). Overall, the increased travel speed in 2006 was probably due to higher flows: average river flows during 15 April-30 June were 35% higher in 2006 than in 2005.

In 2006, we began development of the "matrix" antenna, a much larger antenna for the pair-trawl system. Rather than a circular antenna, the matrix antenna used two parallel rectangular coils for a total dimension of 2.6 by 3.0 m. Deployment was similar to that of the large trawl system, except that for initial testing, a smaller pair-trawl net was adapted to fit the new antenna. We sampled with the matrix system in the same area as the standard trawl system for 21 h and detected 10 fish.

We attribute the low number of detections using the matrix system to electronic interference and tuning, use of a small pair-trawl net, and low numbers of SST PIT-tags (a newer more powerful tag) available in 2006. We believe that the much larger fish-passage opening of the matrix antenna, when attached to a full-sized trawl, will produce higher hourly detection rates. This larger opening should allow faster tow speeds by releasing more water from the trawl through the antenna, and faster movement of water through the antenna will increase detection efficiency.

An additional research element in 2006 was the occasional deployment of a shoreline-based PIT-tag detection system, which we used at Jones Beach in an area inaccessible to the regular trawl system. We adapted the pontoon raft and wireless data/video system from the large trawl system for this shoreline system. We were able to view fish passage through the antenna and potentially quantify fish passage, while capturing detection and diagnostic data from the beach. The shoreline system used a rectangular antenna configuration with a total dimension of 31 by 51 cm. The single-coil antenna was encased in a 7.6-cm-diameter PVC pipe.

At the end of the season, we also tested the 2-coil matrix antenna with a modified net and the wireless electronics system. We developed routine procedures to deploy and retrieve the shoreline PIT-tag-detection equipment, but detected only a single juvenile steelhead in nearly 100 h of sampling.

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INTRODUCTION

In 2006, we continued a multiyear study to detect migrating juvenile anadromous salmonids *Oncorhynchus* spp. the Columbia River estuary using trawl detection systems. Target fish were those implanted with passive integrated transponder (PIT) tags in natal streams, hatcheries, or other upstream locations prior to or during their migration (PSMFC 2006). During 2006 we continued development and evaluated three trawl detection systems: a large surface pair trawl, a matrix trawl, and a shoreline based trawl system.

In the large and matrix systems, migrant fish were guided through an electronic PIT-tag detection antenna mounted at the cod end of the trawl (Ledgerwood et al. 2004a). As PIT-tagged fish passed out of the trawl through the antenna, their tag code, date, time and global positioning system (GPS) position were recorded without handling. The study began in 1995 and has continued annually (except 1997) in the estuary at Jones Beach, approximately 75 river kilometers (rkm) upstream from the mouth of the Columbia River (Ledgerwood et al. 1997, 2003, 2006).

Over 1.9 million PIT-tagged juvenile salmonids were released into the Snake and Columbia River basins in 2006 (PSMFC 2006). These fish were monitored during downstream migration using detection systems in the juvenile bypass facilities of hydroelectric dams. These detection system were developed by the National Marine Fisheries Service (Prentice et al. 1990a,b,c) and the U.S. Army Corps of Engineers (USACE). The Columbia Basin PIT tag Information Systems (PTAGIS) is a regional database, developed to store and disseminate records of individual PIT-tagged fish, including release and detection times and locations, species, origin, and migration history.

In addition to bypassing fish at dams, fishery managers have the option to transport and release fish downstream from Bonneville Dam, the lowermost dam in the Columbia River Basin (rkm 234). In 2006, over 280,000 PIT-tagged fish were transported and an additional 74,000 were detected as they passed Bonneville Dam. The goal of our trawling effort in the estuary was to monitor timing and survival of PIT-tagged fish that have migrated in the river through the hydropower system to the estuary or have been transported by barge around various dams for release downstream from Bonneville Dam.

Detection data from pair-trawl sampling was collected with the following objectives:

1) Compare migrational timing and estimate survival through the Columbia River hydropower system for inriver migrant and transported juvenile yearling Chinook salmon *O. tshawytscha* and steelhead *O. mykiss* during the spring migration period.
2) Compare migrational timing to the estuary between inriver migrant and transported subyearling fall Chinook salmon during late June through July.
3) Compare migrational timing to the estuary between inriver migrant and transported subyearling fall Chinook salmon migration in the summer/fall of 2006.
4) Develop and test larger PIT-tag detection antennas and related equipment intermittently during the migration season with a goal of improved efficiency.

METHODS

Study Fish

Nearly 2 million fish were PIT-tagged and released in the Columbia River basin during 2006. Over 280,000 of these fish were collected for transport from Snake and Columbia River dams and release below Bonneville Dam. We focused research on large groups of PIT-tagged fish migrating through the Columbia River estuary from April through July. According to PTAGIS, over 339,000 fish were PIT tagged and released for a transportation study on the Snake River (Marsh et al. 2006) and nearly 200,000 were PIT tagged and released for a comparative survival study at several hatcheries in the basin (Berggren et al. 2006).

We coordinated our trawling with these large release groups of PIT-tagged migrants. After tagging and release, Snake River study fish were either bypassed back to the river to continue migration or diverted for transportation at Lower Granite (rkm 695), Little Goose (rkm 635), Lower Monumental (rkm 589) or McNary Dam (rkm 470).

Our transportation analysis included all PIT-tagged fish diverted to barges. We created a separate database for PIT-tagged fish recorded in PTAGIS as having been diverted to transportation barges at any of the 4 transportation facilities. Intentional diversions were accomplished according to a separation-by-code procedure at specific dams (Stein et al. 2004). Diversion to transportation barges either intentionally or unintentionally (i.e., missed being diverted back to the river at slide gates) was confirmed by comparing the last monitor name listed for a PIT-tagged fish to the PTAGIS site map to the route ending at a transport raceway or barge. Fish possibly diverted to transportation but which could not be totally confirmed, were removed from our database, as were fish removed for biological or other samples.

Since 1987, over 2.4 million PIT-tagged fish have been assigned to this database of transported fish. We worked with the USACE (Scott Dunmire, USACE, personal communication) to obtain accurate barge loading dates and times to enable assignment of PIT-tagged fish to specific transport barges based on matching last detection date and time with the next available barge at that facility.

In 2006, 523,000 PIT-tagged subyearling fall Chinook salmon were released in the Snake River to study their behavior and migration patterns. Recent studies evaluating scale samples from adult fall Chinook salmon revealed that a majority of these fish enter the ocean as juveniles during the summer of the year they were released. However, scale patterns also reveal that a small portion of these juveniles rear longer in freshwater to

attain a larger size before entering seawater as yearlings. Smolt-to-adult returns rates (SARs) revealed that of fall Chinook adults returning to spawn, a disproportionately large number had entered the ocean as yearlings (Connor et. al. 2005).

Releases of PIT-tagged fall Chinook salmon from different stocks should help researchers better understand migration timing, overwintering behavior, and impacts from transportation in the Snake and Columbia River systems. By sampling in the fall months, we attempted to document the presence or absence of Snake River yearling fall Chinook salmon in the estuary to further understand this important ESA-listed stock.

In addition to the transportation studies, there were several other studies in the Columbia River basin that released large numbers of spring-migrating, PIT-tagged juvenile salmonids. In this report, we focus our analyses on the more numerous PIT-tagged yearling Chinook salmon and steelhead; however, detections of PIT-tagged coho salmon *O. kisutch*, sockeye salmon *O. nerka*, subyearling Chinook salmon, and coastal cutthroat trout *O. clarki clarki* were also recorded.

Sample Period

Sampling with the large trawl began on 9 March and continued through July, coincident with the passage of PIT-tagged yearling Chinook salmon and steelhead from the Snake River transportation study. We increased sampling to two daily crews between 29 April and 23 June, coincident with increased numbers of PIT-tagged fish entering the estuary. Generally, sampling began before daylight and continued for 8 to 10 h. A second crew began in early evening and sampled until well after dark or until relieved by the day crew. Detection rates declined in mid-June, and a single daily crew was used 3-5 d/week from 23 June through 20 July.

In 2006, sampling was nearly continuous throughout the two-crew period. However, generally between 1400 and 1900 PDT each day, we halted sampling for fueling and maintenance.

Additional sampling with the large trawl was conducted near rkm 75 for PIT-tagged subyearling Chinook salmon between 5 September and 1 November 2006. River flow volume is generally lower during this period, and we estimated we would obtain adequate detections of subyearling Chinook salmon to determine timing and behavior differences with a single sampling crew working 3-6 d/week. Our goal, should there be sufficient daily fish detected to justify the effort, was to detect about 0.75% of fish previously detected at Bonneville Dam. However, daily detections remained low, and we sampled only 2-3 d/week during this period.

Study Sites

We sampled with the large trawl detection system from rkm 83, near Eagle Cliff, to rkm 61, near the west end of Puget Island (Figure 1). This is a freshwater reach characterized by frequent ship traffic, occasional severe weather, and river currents often exceeding 1.5 $m^3 s^{-1}$. Tides in this area are semi-diurnal, with about 7 h of ebb and 4.5 h of flood. During the spring freshet period (April-June), little or no flow reversal occurs in this reach during flood tides, particularly during years of medium to high river flow. The trawl was deployed adjacent to a 200-m-wide navigation channel, which is maintained at a depth of 14 m. The shoreline detection system was deployed along Jones Beach (rkm 75).

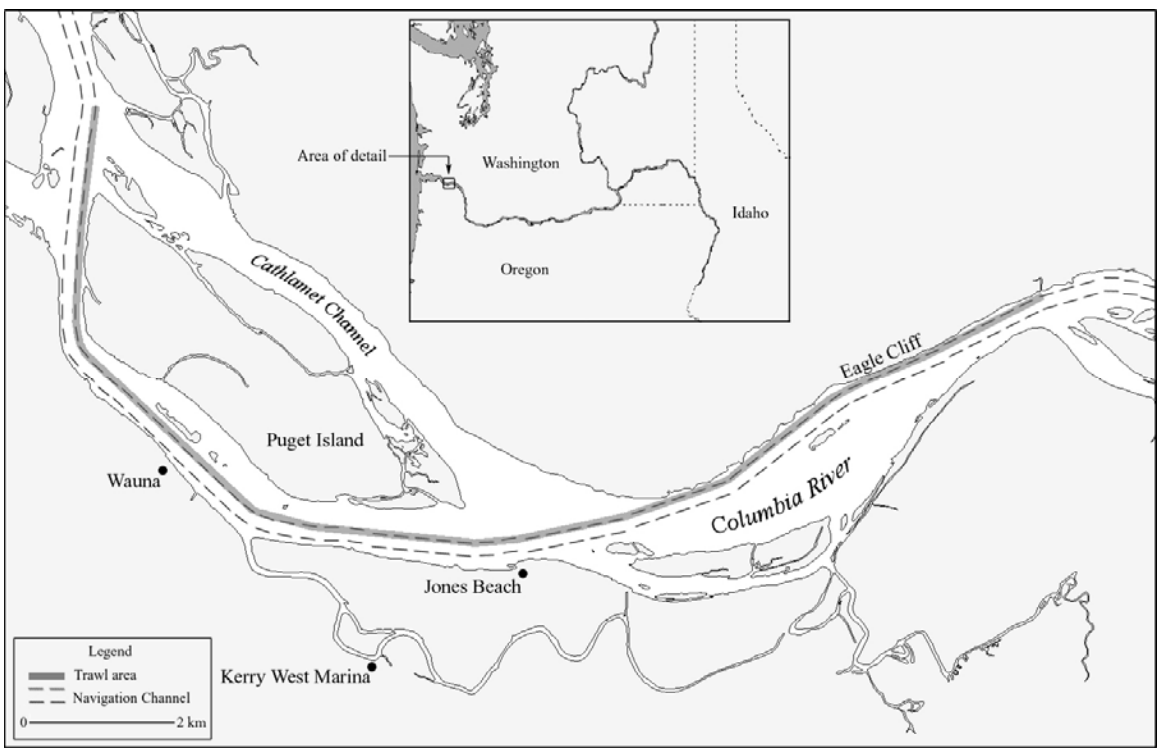

Figure 1. Trawling area adjacent to the ship navigation channel in the upper Columbia River estuary between rkm 61 and 83.

Trawls and System Designs

Large Trawl System

Large trawl components are described below, and their basic configuration remained fairly constant through the study period (Ledgerwood et al. 2004a; Figure 2). To prevent turbulence on the net from the wake of tow vessels, 73-m-long tow lines were used. The upstream end of each wing section of the trawl was shackled to a 3-m-long spreader bar. The downstream end of each wing was attached to the 14-m-long trawl body, followed by a 2.7-m-long cod-end modified for antenna attachment. The mouth of the trawl body opened between the wings and from the surface to a depth of 6 m, with a floor extending 9 m forward from the mouth. The detection antenna measured 1.1 m in diameter and was centered at a depth of 1.8 m. Trawl wings tapered upward from a sample depth of 5-6 m at the floor of the trawl body to 3 m at the tow bridle.

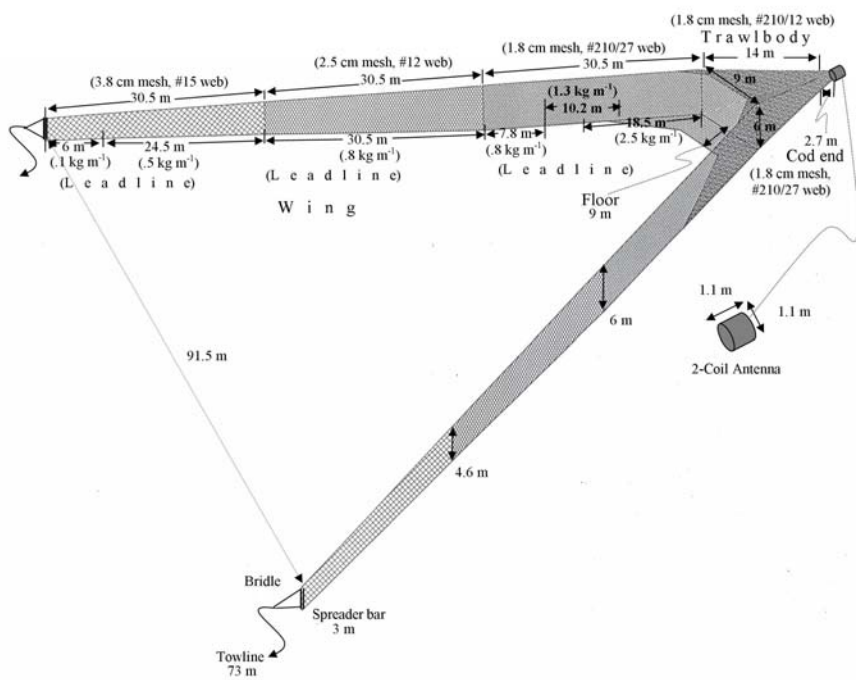

Figure 2. Basic design of the large surface pair trawl used to sample PIT-tagged juvenile salmonids in the Columbia River estuary near rkm 75.

Tag technology has improved over the years, with improvements to read range of the antennas. This greater read range enabled us to enlarge the antenna opening, which also reduced drag and lift on the net, thereby increasing sample depth to 4.6 m. During a typical deployment of the large trawl, the net is towed upstream facing into the current, with a distance of about 91.5 m between trawl wings. Fish that enter between the wings are guided to the trawl body and presumably exit through the antenna. During net retrieval, the antenna is removed and the net is inverted in the current to flush debris and release fish from between the small-mesh wing sections. The deployment/retrieval process of the large trawl requires about 30 min, during which time the vessels and net drift in tidal and river currents often exceeding 1.5 m s^{-1} (3 knots).

Matrix Trawl System

The prototype matrix antenna system incorporated a larger PIT-tag antenna made of 10-cm-diameter PVC pipe attached to a small trawl (Figure 3). This antenna was 2.6 m wide by 3.0 m tall, and consisted of two parallel coils. The inside diameter of each coil was 1.1 m wide by 2.8 m high. The two coils were affixed together at the top and bottom and separated by a 15-cm gap. In air, the antenna weighed about 113 kg and another 113 kg of lead weight was required to sink it for deployment.

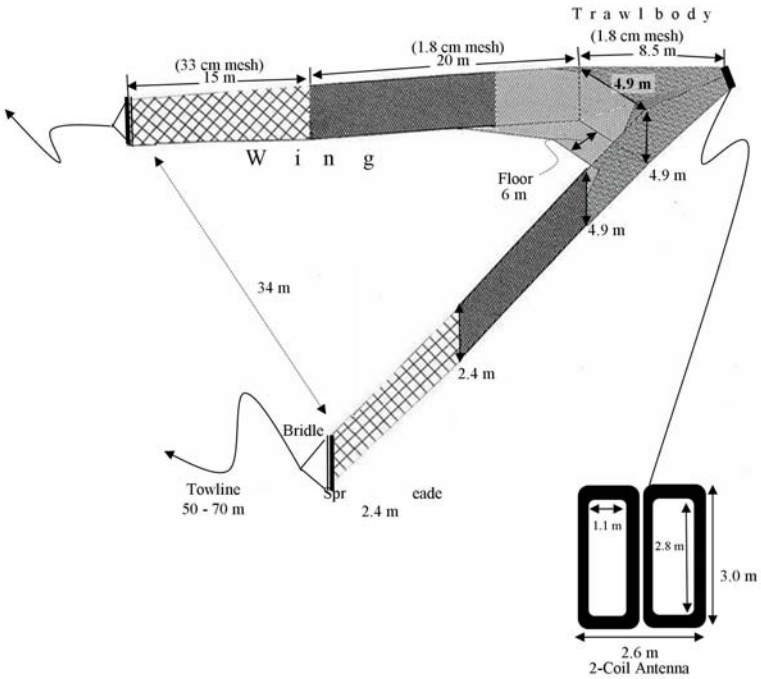

Figure 3. Basic design of the surface pair trawl that was used with the prototype "matrix" antenna system to sample PIT-tagged juvenile salmonids in the Columbia River estuary near rkm 75 in 2006.

For testing in 2006, a small trawl that had been used in the lower estuary in 2005 was adapted to fit the new antenna. A PIT-tag transceiver, similar to that used on the large trawl, was mounted on a small pontoon barge tethered at the rear of the trawl. Cables led from each coil of the underwater antenna to the barge, where a wireless modem transmitted PIT-tag detections and electronic status reports from the transceiver to a recording computer in the cabin of a tow vessel. GPS locations were automatically recorded every 15 minutes and with each fish detection using Minimon software (Stein et al. 2004). A camera mounted inside the antenna helped to monitor net configuration, fish passage, and antenna alignment in the water column. Under tow, we maintained a distance of 34 m between the wings of the trawl, which resulted in an effective sample depth of 3.7 m (measured at the center of the floor).

Shoreline Trawl System

The shoreline PIT-tag detection system consisted of one wing stretching 27.3 m between one side of a 4.8 m^2 trawl body opening and the shore, and a second 15.2-m wing between the trawl body and a fixed, off-shore anchor (Figure 4). The trawl body was 4.8 m long and positioned at an appropriate depth (about 2.4 m) to float the antenna near-shore by positioning the off-shore anchor. The single-coil antenna (31-cm-tall by 51-cm-wide) was supported on a buoy similar to that of our other trawls.

Generally, we deployed the shoreline system near high tide and sampled during ebb currents. Current velocities varied from 0 to about 0.5 m s^{-1} (1 knot) at maximum ebb. A video camera was mounted within the antenna and used to monitor fish passage. Using a line to shore from the tip of the wing, we developed a method to "flush" the net for cleaning and to encourage fish to exit downstream through the antenna, similar to methods used with the pair trawl system.

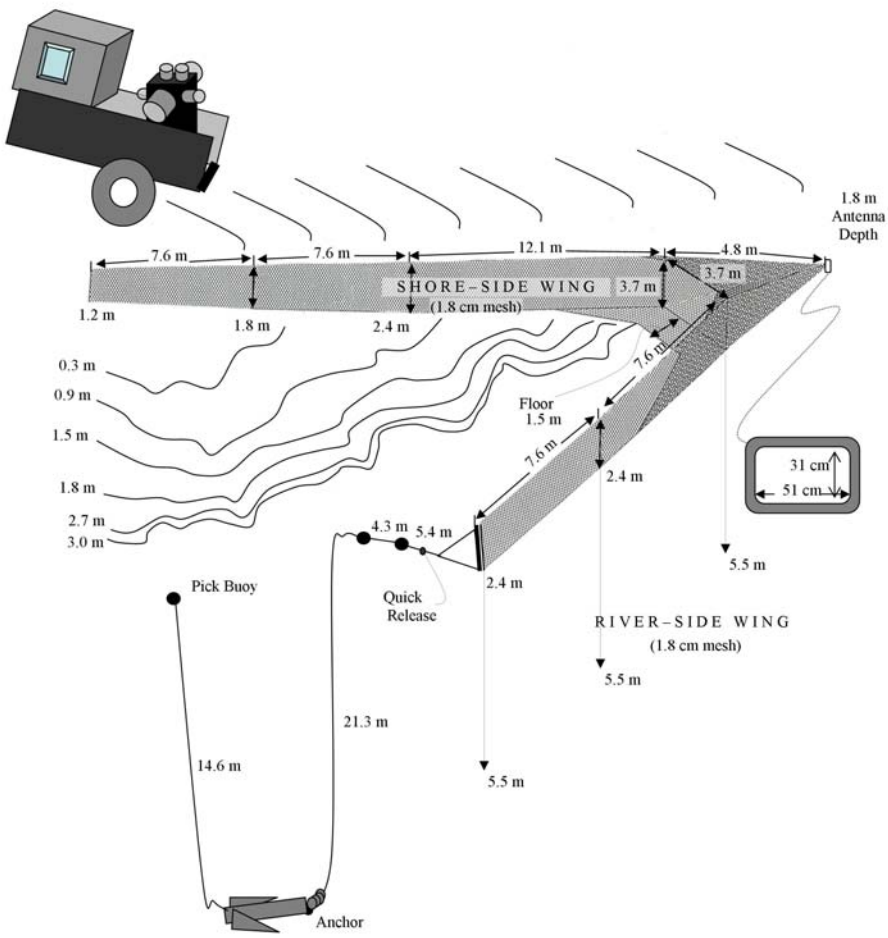

Figure 4. Design for the PIT-tag sampler used along the shoreline parallel to the shipping channel in the Columbia River estuary (rkm 75), 2006.

Electronic Equipment and Operation

For the large trawl system, we used essentially the same electronic components and procedures as in 2001-2005, with the exception of the transceivers. In 2006, we replaced the two Whit Patten† transceivers used previously with a single Digital Angel model FS1001M transceiver. A 10-m-long pontoon barge was towed near the trawl exit, and a gasoline generator powered all electronic equipment. Additional electronic components were mounted in the cabin of the barge, and cables led underwater to a tuner port on each of the two detection coils, which were connected in series. The antenna weighed 193 kg in air and was 1.2 m long with a 1.1-m-diameter fish-passage opening (Figure 5). A video camera mounted inside the antenna tunnel was used to monitor fish passage on a TV/VCR housed in the barge.

Once the system was energized, Minimon interrogation software was used to automatically record date, time, tag code, coil identification number, and GPS location (Stein et al. 2004). For each sampling cruise, written logs were maintained noting the time and duration of net deployment, total detections, number of impinged or injured fish, and start and end of each net-flushing period.

Electronic components for the matrix-trawl and shoreline detection systems were contained in a water-tight box mounted on a 1.9-m long by 1.2-m wide pontoon raft. A DC-powered Destron-Fearing model FS1001M PIT-tag transceiver was used to power the underwater antenna and interrogate tagged fish. The shoreline sample system employed the matrix electronic system, with the exception of the antenna, including the video surveillance system, transceiver, and software. Wireless data and video transmission simplified sampling efforts while improving monitoring capability.

PIT-tag detection data files were uploaded periodically (about weekly) to PTAGIS using standard methods described in the *PIT-tag Specification Document* (Stein et al. 2004). The specification document, PTAGIS operating software, and user manuals are available via the Internet (PSMFC 2006). Pair-trawl detections in the PTAGIS database were identified with site code "TWX" (towed array-experimental) and coil codes A (large trawl), B (shoreline) and C (matrix).

An independent database (Microsoft Access) of detection information was maintained and used for analysis. Records of PIT-tagged fish detected at Bonneville Dam were downloaded from PTAGIS for comparison with our detections (PSMFC 2006). Records of PIT-tagged fish that were transported, including date, time, and site of barge loading and date, time, and site of barge release, were provided by the USACE. Date and location (rkm) of release from a barge were assigned to an independent subset of transported fish based on their last detection at the transport dam.

† Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Detection Efficiency Tests

We used the same procedure for evaluating electronic performance of the large-trawl, matrix-system, and shoreline detection antennae, none of which required the release of test fish (Ledgerwood et al. 2005). All performance evaluations used a 2.5-cm-diameter PVC pipe with a small plastic funnel on each end. The pipe was positioned through the center of each antenna with pipe ends extending past each end of the antenna beyond the range of the electronic field (at least 0.5 m). We evaluated detection efficiency by attempting to detect 50 PIT-tags, attached to a vinyl-coated tape measure at known intervals and orientations, as the tape was passed through the funnel/pipe (Appendix Table 1).

Detection efficiency, the ability to read PIT-tags, was evaluated for each system at the center of the antenna (Figure 5) and was expected to be positively correlated with improved alignment, orientation, and proximity to the electronic field. With each new antenna design, we attempted to maximize the fish-passage opening to reduce possible delay of fish while increasing the potential for detections by filtering more water. These in situ tests of read efficiency in the center of the antenna were biased low and do not reflect actual reading efficiency for PIT-tagged fish, which generally pass in the more optimal areas of the electronic field.

We chose densities and orientations along the test tape such that not all tags would be decoded; the relative consistency of tag detection helped validate electronic tune and identify possible problems with the electronics. During tests, we suspended the antenna underwater and pulled the tape back and forth several times through the PVC pipe. The start time of each pass was recorded in a logbook, and we used standard PIT-tag software to record detections. Efficiency was calculated as the total number of unique tags decoded during each pass divided by the total tags passed through the antenna. The large trawl system was tested about weekly, while the matrix and shoreline were evaluated mainly when in use.

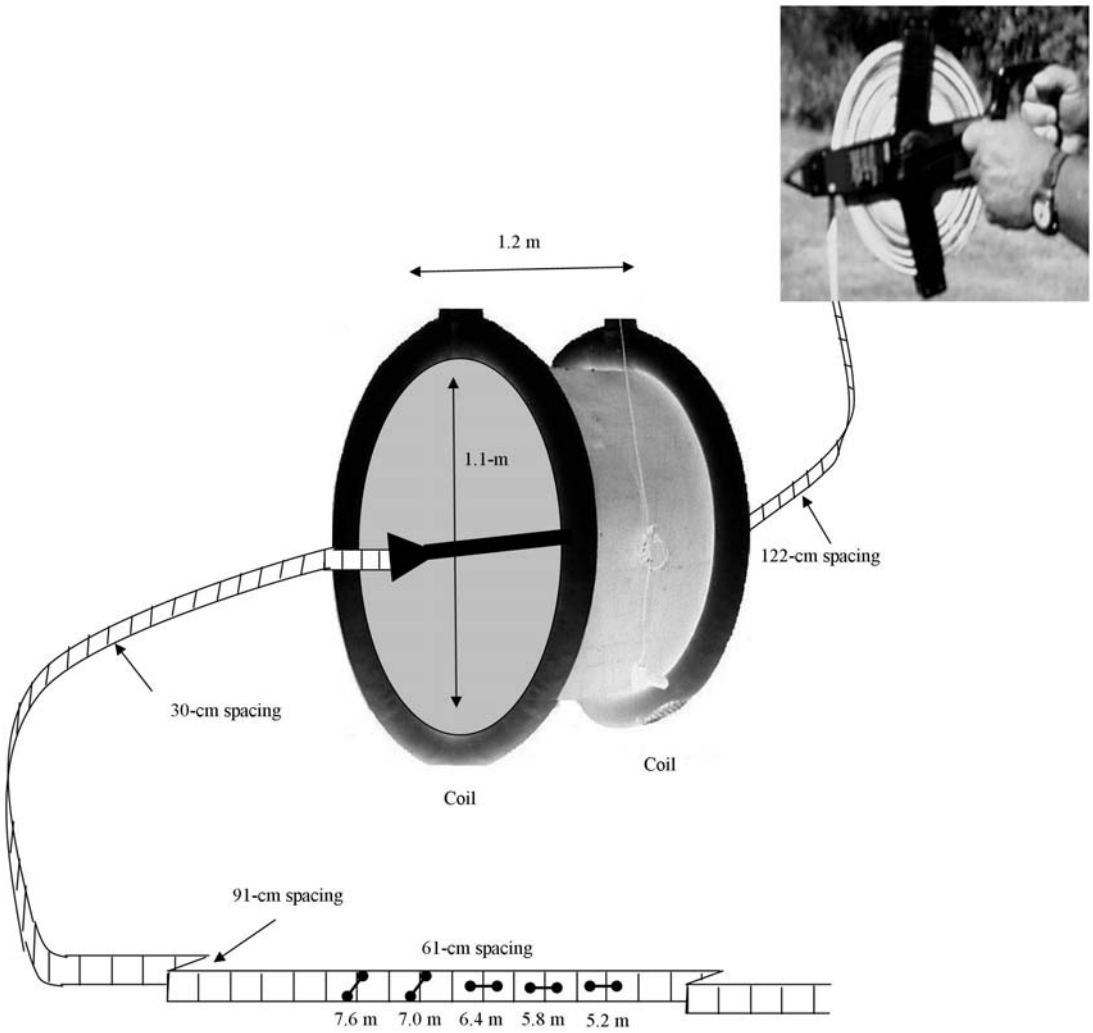

Figure 5. Antenna testing system showing test-tag-laden vinyl tape measure threaded through the center of the 2006 two-coil large trawl antenna. Distinct regions with tags oriented at 0 and 45 degrees were spaced 30, 61, 91 and 122 cm apart.

Impacts on Fish

We used underwater cameras mounted in the antennas during daylight to monitor debris accumulation in the cod end of each net. Other sections of the net were monitored visually, and accumulated debris was removed from all net sections as necessary. When debris accumulated, we reduced tow speed and pulled the antenna to the surface to remove entrained material from the cod end. During conditions of extreme debris loading, we disconnected the electronics and inverted the entire net for cleaning. At night we periodically monitored the antenna with the camera using flood lights.

The large-mesh wings of the matrix trawl system allowed us to retrieve the net directly onto a tow vessel without having to invert the trawl to release fish. One drawback of this design was the occasional accumulation of significant quantities of debris. Since the net was not inverted for retrieval, debris had to be removed by hand either during retrieval, which required longer period of drift, or back at the dock. During debris-removal activities and net-collection and redeployment procedures for either trawl system, we recorded impinged or trapped fish as mortalities in operations log books.

Data Analyses

Diel Detection Rates

To determine the hourly diel availability of yearling Chinook salmon and steelhead, we compiled detection data weighted by hatchery or wild source during the two-crew sampling period. A smoothed, interpolated value was used during the afternoon period between shifts, when sample effort was halted. We found no significant difference in diel availability associated with rearing type. Therefore, we weighted the detection data by total fish within each category.

Numbers of yearling Chinook salmon and steelhead detected per hour of daylight vs. darkness were evaluated using one-way ANOVA-unstacked (Zar 1999). The number of detections and the minutes within each hour of the day that the detector was operating were separated into daylight- and darkness-hour categories. Preliminary analyses, and hourly detection rates were pooled for wild and hatchery rearing types of each species for each category. These mean hourly detections rates were analyzed statistically, and diel detection curves were prepared for yearling Chinook salmon and steelhead weighted by the number of minutes within each hour that the detector was operating. There were insufficient detections of other species for meaningful analyses.

Travel Time from Bonneville Dam

We plotted travel-time distributions and compared detection rates for two subsets of yearling Chinook salmon and steelhead marked and released at Lower Granite Dam and detected in the estuary: inriver migrants detected at both Bonneville Dam and Jones Beach, and transported fish released just downstream from Bonneville Dam and detected at Jones Beach. We prepared similar plots for subyearling Chinook salmon tagged and either released to migrate in the river or transported in late June and July. These plots represented the seasonal presence in the estuary of their respective fish groups. Data from periods of availability in the estuary for the various subsets of fish were compared using analyses of travel-time distributions. Travel time (in days) to the estuary was calculated for each fish by subtracting date and time of release from a barge or detection at Bonneville Dam from date and time of detection at Jones Beach.

One-way ANOVA was also used to evaluate differences in travel speed to Jones Beach between inriver migrants and transported fish. Daily median travel speed (km d^{-1}) for yearling Chinook salmon, steelhead and subyearling Chinook salmon were calculated, based on the travel time divided by the distance traveled from release to detection in the estuary, and plotted through their respective periods of availability. Flow data (daily average discharge rates at Bonneville Dam (m^3 s^{-1})) were plotted during the same time periods for visual comparison

Detection Rates and Migration History

Estuarine detection rates of PIT-tagged yearling salmonids released from barges and detection rates of yearling salmonids previously detected in the juvenile bypass system at Bonneville Dam (inriver migrants) were compared using logistic regression analysis (Hosmer and Lemeshow 2000; Ryan et al. 2003). Inriver migrants detected at Bonneville Dam were grouped and paired to barge-released fish by date of barge release. Groups included only those PIT-tagged fish released at sites from McNary Dam upstream. Barge releases occurring just after midnight were paired with the previous date at Bonneville Dam.

Fish transported early in the migration season were often released below Bonneville Dam before sufficient numbers of inriver-migrant fish for comparison had arrived at the dam. Recovery percentages for both inriver and transported fish groups are shown for the entire season, but daily groups were not used for analysis unless both groups were present and were detected during intensive two-crew sampling periods.

We used the same logistic regression analysis to compare estuarine detection rates between fish transported from different locations. Due to data constraints, we compared fish transported from Lower Granite Dam to those from Little Goose and Lower Monumental Dams combined. Date and date-squared were also considered in the model. Components of the logistic regression model were treatment as a factor and date and date-squared as covariates. The model estimated the log odds of the detection rate of the *i* daily cohorts (i.e., $\ln[p_i/(1-p_i)]$) as a linear function of components, assuming a binomial distribution for the errors.

Daily detection rates were then estimated as:

$$p_i = \frac{e^{\beta_0 + \beta_1 \text{day}_i + \beta X_i}}{1 + e^{\beta_0 + \beta_1 \text{day}_i + \beta X_i}}$$

where β is the coefficient of each respective component (i.e., β_0 for the intercept, β_1 for day *i*, and β for the set "X_i" of day-squared and/or interaction terms). A stepwise procedure was used to determine the appropriate model.

First, the model containing interactions between treatment and date and date-squared was fitted. Second, we determined the amount of over-dispersion in the data relative to the binomial distribution assumption (Ramsey and Schafer 1997). Over-dispersion was estimated as, "σ", the square root of the model deviance statistic divided by the degrees of freedom. If $\sigma>1.0$, we adjusted the standard errors of the model coefficients by multiplying by σ (Ramsey and Schafer 1997). This also exactly inversely adjusted the z statistic used to test the significance of the coefficients. Third, if the interaction term(s) were not statistically significant ($\alpha > 0.05$) the term(s) were removed and a reduced model was fitted. The model was further reduced depending on the significance(s) between treatment and date and/or date-squared. The final model was the most-reduced one from this process, except that date was always included for descriptive purposes.

Various diagnostic plots were examined to assess the appropriateness of the models. Extreme or highly influential data points were identified and included or excluded on an individual basis, depending on the data situation.

The daily barged and inriver groups had similar distributions in the sampling area and presumably pass the sample area at similar times. Thus, we assumed these groups were subject to the same sampling biases (sample effort). If these assumptions are correct, the differences in their relative detection rates reflect differences in survival between the two groups from the area of release (at or near Bonneville Dam) to the

estuary. To examine the assumption that barged and inriver-migrant groups passed the sample area with similar diel timing, we divided the total seasonal detections for each group into interval hours based on the time they were detected.

Diel detection curves were prepared for yearling Chinook salmon and steelhead (insufficient detections of other species precluded this analysis) based on the average number of fish detected each hour weighted by the number of minutes within each hour that the detectors were energized. Average hourly detection rate differences between transported and inriver groups were then constructed by species. Data from study years 2000 to 2006 were plotted to give a visual overview of differences between and among years.

Downstream Passage Survival

Detection data from the estuary are also essential to estimate survival of juvenile salmonids to Bonneville Dam, the last dam encountered by seaward migrants (Muir et al. 2001, Williams et al. 2001, Zabel et al. 2002). The probability of survival through an individual river reach was estimated from PIT-tag detection data using a multiple-recapture model for single release groups (CJS model; Cormack 1964; Jolly 1965; Seber 1965; Skalski et al. 1998). This model requires detection probability estimates for the lowest downstream detection site (i.e., Bonneville Dam), and these estimates are calculated using detections below this site.

RESULTS

Trawl System Detections

Large Trawl System

In 2006, we detected 12,361 PIT-tagged juvenile salmonids of various species, runs, and rearing types using the large trawl system at Jones Beach (Appendix Table 2). However, not all species and rearing types were equally represented among our total detections. For example, 80% of our detections were Chinook salmon, 18% were steelhead, and the remaining 2% were other salmonid species (Table 1). Of the fish we detected, 18% were wild, 81% were hatchery, and less than 1% had no release information available. River basin source and migration history for PIT-tagged fish detected in the estuary are shown in Figure 6. Annual differences in PIT-tagging strategies, hydrosystem operations, and proportions of fish transported each year contributed to variations in the proportions from each source.

Trawl system equipment was operated for 961 h with 12,361 detections in 2006, as compared with 909 h and 14,101 detections in 2005 (Figure 7). According to the PTAGIS database, about 4% more PIT-tagged fish were released into the river basin during 2006 than 2005; however, we detected nearly 2,000 fewer fish in 2006. Many variables are associated with annual detection numbers in the estuary, and these interannual variables complicate comparisons between years among sources, species, and run or rearing types. For example, in the Columbia River, mean flow volumes from mid-April through June were 5,776 $m^3 s^{-1}$ in 2005 and 9,435 $m^3 s^{-1}$ in 2006 (Figure 8). We speculated that, as in previous years, the higher flow volumes in 2006 resulted in fish groups being more dispersed and passing through the sample area more quickly than in 2005. This would have decreased sample efficiency and detection numbers in 2006 compared to 2005.

Table 1. Species composition and rearing-type history for PIT-tagged fish detected in the large trawl system in the upper Columbia River estuary near rkm 75 in 2006.

	Rear Type			
Species/run	Hatchery	Wild	Unknown	Total
Spring/summer Chinook salmon	7,021	989	43	8,053
Fall Chinook salmon	1,774	2	22	1,798
Coho salmon	175	0	13	188
Steelhead	1,148	1,017	3	2,168
Sockeye salmon	33	52	0	85
Sea-run cutthroat trout	0	2	0	2
No release info	0	0	67	67
Total	10,151	2,062	148	12,361

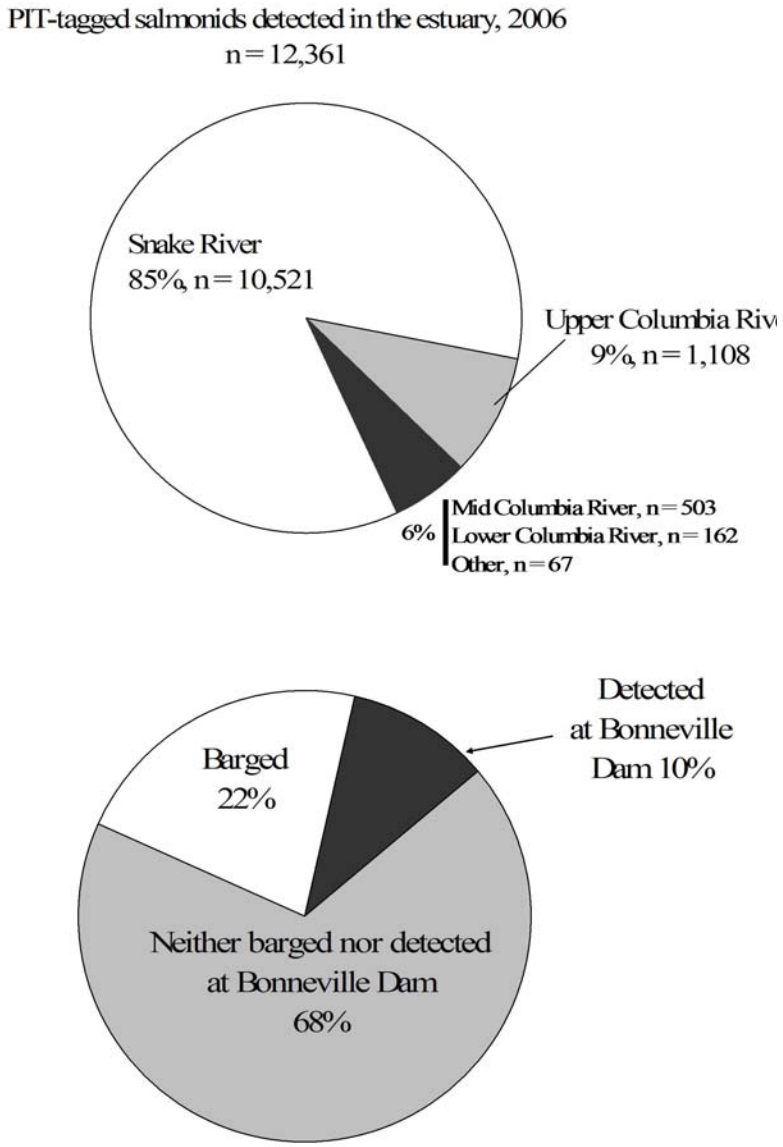

Figure 6. River basin sources and migration histories of PIT-tagged fish detected in the in the upper Columbia River estuary near rkm 75 in 2006.

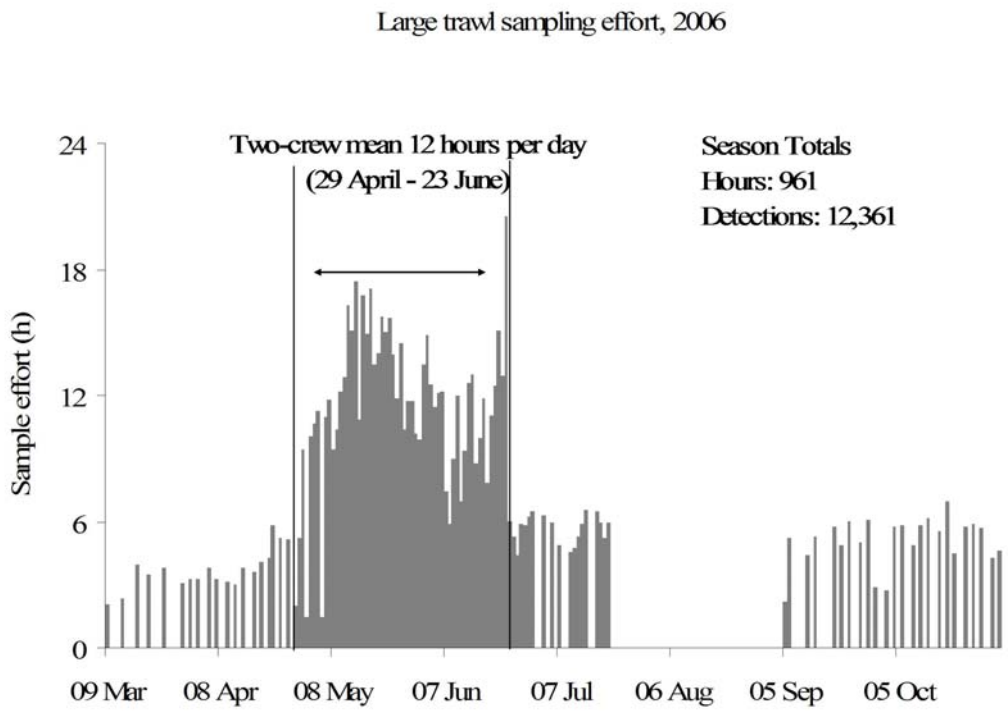

Figure 7. Number of hours sampled with the large trawl PIT-tag detection system in the upper Columbia River estuary near rkm 75 in 2006.

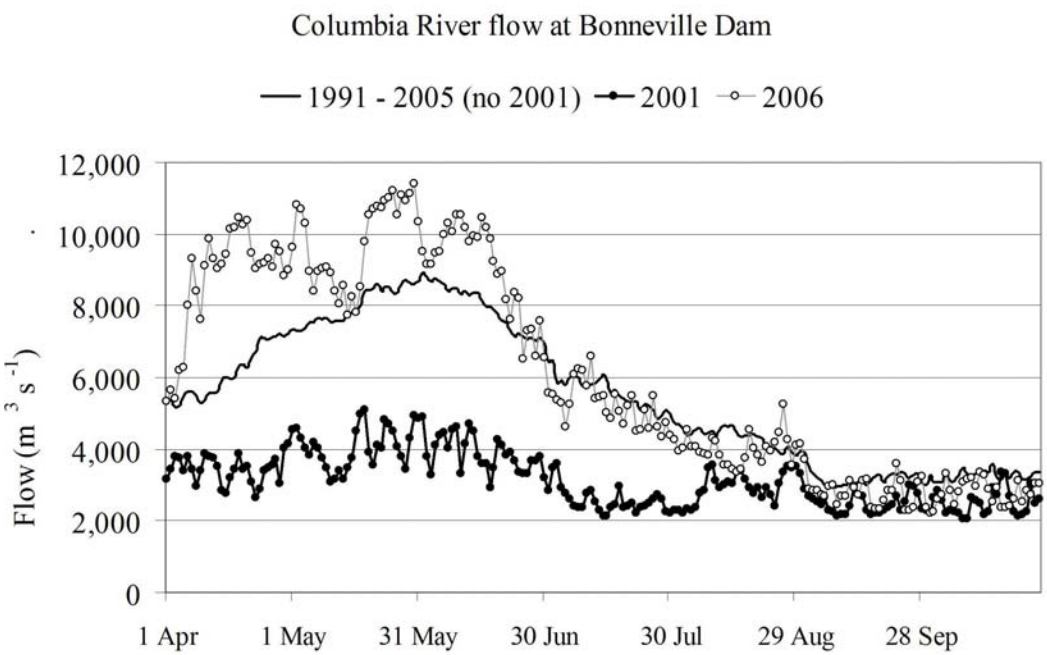

Figure 8. Columbia River flows at Bonneville Dam during the study periods of 2001 (drought year) and 2006 vs. average flow 1991-2005.

Matrix Trawl System Detections

In late June 2006, we sampled using a prototype two-coil parallel "matrix" antenna system at rkm 75. The pair trawl net used with the matrix antenna was approximately one-half the size of the standard net used with the large trawl system. Because of the large antenna size and the logistics involved to deploy the system, sampling efforts focused more on implementing safe handling techniques than actual sampling time. However, PIT-tagged fish were detected with the matrix system. Sample effort totaled 21 h, and we detected 10 PIT-tagged fish (Table 2). All sampling was conducted during daylight hours. On 22 June, a single juvenile fall Chinook salmon was recorded on both the matrix and large trawl systems 78 minutes apart.

Table 2. Results of prototype matrix antenna PIT-tag system sampling by date of deployment, hours of effort, and number of detections near rkm 75 in 2006.

Date	Effort (h)	Chinook salmon (n)	Steelhead (n)	Total detections (n)
20 Jun	1.72	0	0	0
21 Jun	3.22	4	1	5
22 Jun	4.62	1	0	1
26 Jun	2.68	1	0	1
27 Jun	3.50	1	0	1
28 Jun	3.83	0	1	1
30 Jun	1.15	0	1	1
Totals	20.72	7	3	10

Shoreline System Detections

In 2006, we deployed a fixed-position PIT-tag sampling system along the shoreline near river kilometer 75 to evaluate the possible presence of PIT-tagged juvenile salmonids in areas inaccessible to the mobile trawl systems. We sampled for approximately 6-7 h on ebb tides for a total of 98 h on 23 d in early summer and late fall. While deployment and retrieval of equipment in this area was successful, and electronic testing was satisfactory, we detected only a single steelhead, and few fish were observed on the antenna-mounted camera. Flows through the antenna were measured and ranged from near zero at slack tide to between 0.2 m s^{-1} when the net was open and 0.5 m s^{-1} during net-flush procedures during maximum ebb current. Similar measurements of flow through the large trawl under tow in mid-river were between 0.3 and 0.4 m s^{-1}.

Detection Efficiency

Test tags oriented perpendicular to the electronic field were read with greater efficiency than those placed at an angle. Efficiencies were also positively correlated with spacing between tags regardless of orientation. It is important to note that these differences in detection efficiencies were often only observable when the test tape was passed through the center of the antennas rather than when passed near the edge (the optimal area and where most fish pass). These evaluations of reading efficiency helped identify compromised electronic components. Because of low availability of the newer SST-model PIT-tags (about 4% of all detections in 2006), detection efficiency was determined using only ST-model PIT-tags.

For tags spaced 30-cm (~1 ft) apart, the 1.1-m-diameter, two-coil (in series) antenna used with the large trawl system read about 20% of test tags oriented perpendicular to the electronic field, but less than 10% of tags oriented at 45° (Figure 9). When spacing between tags was increased to 61 cm (~2 ft), detection efficiency increased to nearly 80% for perpendicular tags and 70% for tags at 45°. When tags were passed within about 20 cm of the antenna wall, rather than through the center of the antenna, average detection rates were 93%, regardless of spacing and orientation. The two-coil design of the large trawl antenna has improved performance by providing the opportunity to decode each PIT tag twice during passage through the antenna.

Antenna Efficiency

Efficiencies of each antenna and individual coil were evaluated *in situ* periodically through the season (Table 3). The 1.1-m-diameter antenna used with the large trawl system throughout 2006 had lower overall detection rates of test tags (72%) than the 0.9-m-diameter antenna used in 2000-2005 (79%; Figure 9; Ledgerwood et al. 2007). Antenna efficiency of the matrix antenna (46%) was lower than the other antennas and complicated by unexplained electronic interference and the single pass design. Detection rates of the single-pass shoreline antenna (31-cm-tall by 51-cm-wide) were the highest (80%).

Table 3. Antenna efficiencies of four antennas used in 2006 was evaluated periodically by passing 50 test PIT-tags attached to a vinyl tape measure through the center of each antenna.

Antenna dimensions	Total passes (n)	Antenna efficiency (%)
Large trawl (0.9-m diameter)	218	79
2006 Large trawl (1.1-m diameter)	222	72
Matrix (2.6 ×2.8-m area)	109	46
Shoreline (3.1 × 5.1-m area)	18	80

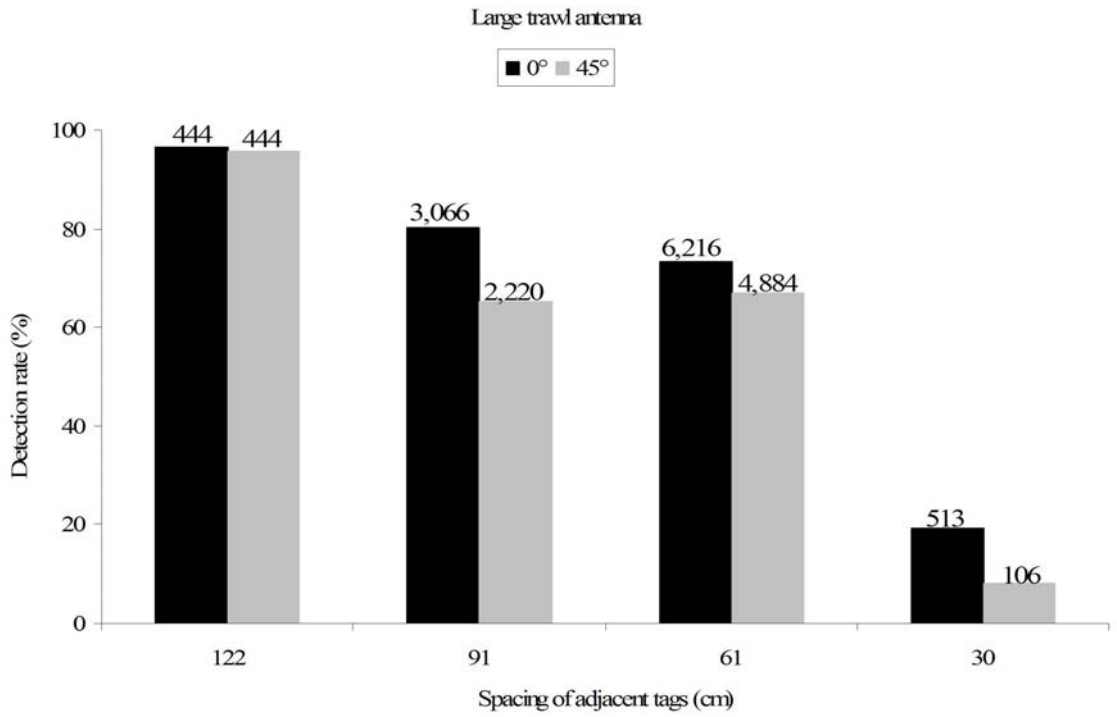

Figure 9. Detection efficiency evaluation using PIT-tags attached to vinyl tape measures, 2006. Various spacing between tags and orientation to the electronic field were used but all tape configurations were identical. Tags were passed through the antenna repeatedly on different dates (total potential tags listed above the bars).

A proportion of fish were missed by the front or rear coil, or escaped the net after initial detection by swimming forward. To evaluate relative efficiency of the front and rear coils, we compared the daily total number of detections in the large trawl system to the daily proportion of this total that was detected only on the front coil (89%) or only on the rear coil (86%; Figure 10). During sampling, when numbers of unique detections recorded on the two coils were radically different, we suspected a problem with electronics. In general, we attempted to keep the best-performing coil at the rear of the antenna, where orientation of fish to the electronic field was thought to be improved.

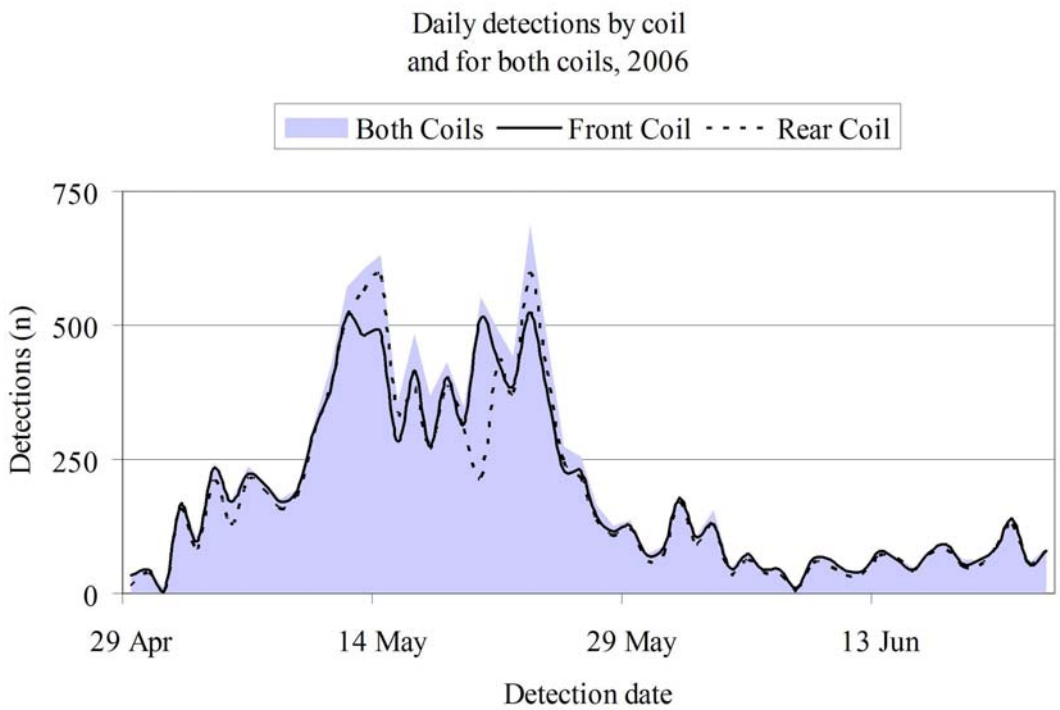

Figure 10. Total daily detections of PIT-tagged fish (no duplicate records) using a two-coil in series antenna and detections by individual front or rear coils during the two-crew large trawl sample period in 2006.

Impacts on Fish

During inspections of all three trawl systems combined, we recovered 90 juvenile salmonids that had been impinged, gilled, or otherwise injured (Appendix Table 4). Due to the net inversion process of the large trawl, it is possible that other fish were unknowingly injured or killed. In years past, divers inspected the trawl body and wing areas of the nets and reported that fish rarely swam close to the webbing except near the antenna. Rather, fish tended to linger near the entrance to the trawl body and directly in front of the antenna.

In response to diver observations, we had eliminated many visible transition areas occurring in seams between the web sizes, and a uniform color (black) was used for all web sections of the trawl body. We continued to flush the net (bring the trawl wings together) every 15 min to expedite fish passage through the antenna to reduce delay and possible fatigue from fish "pacing" near the net transition areas or antenna components. While volitional passage through the antenna occurred while towing with the wings extended, we continued to bring the wings together every 15 minutes, and most fish were detected during these 5-min net-flushing periods.

Some fish were detected repeatedly on one antenna coil or the other. Apparently, fish detected on the front coil occasionally swam forward into the trawl and were detected again as they moved back toward the antenna. Most fish detected on the front coil immediately passed through the antenna and were detected on the rear coil, sometimes repeatedly. In 2006, only 22 fish were detected more than 10 times, with a maximum of 76 duplicate detections. The 1.1-m-diameter antenna used in 2006 produced lower multiple detection rates than the 0.9-m-diameter antenna used in 2005. In 2005, 168 fish were recorded more than 10 times, and 13 of those were detected more than 100 times, with a maximum of 292 duplicate detections.

Overall antenna exit time was also lower in 2006 with the larger antenna (Figure 11): in 2006, 78% of fish exited the antenna less than 11 seconds after the first detection, while in 2005, only 70% exited within this time. Median exit time was 4.0 seconds in 2005 and 2.0 seconds in 2006. The remaining fish required more than 11 seconds to pass through the antenna, and some of them no doubt swam forward into the trawl body after initial detection and returned later to pass through the antenna again.

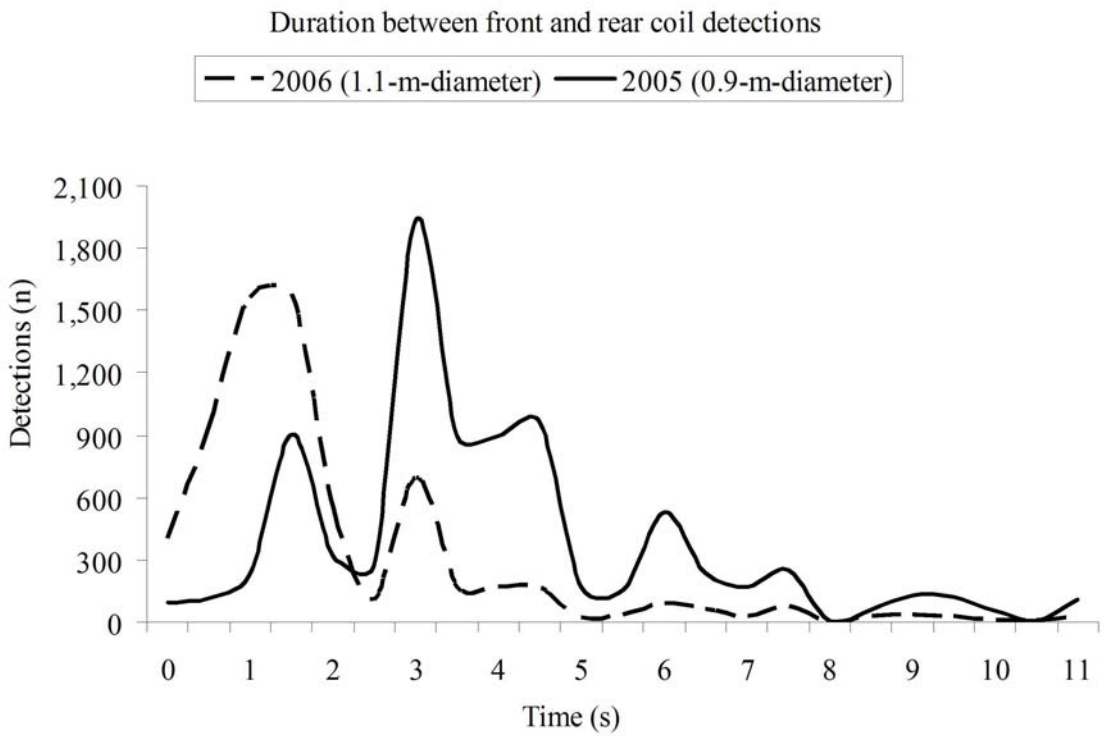

Figure 11. Number of detections and corresponding exit times in 2005 and 2006 for PIT-tagged fish that passed through the antennas in less than 11 seconds. Figure represents 70 and 78% of annual detections in 2005 and 2006, respectively.

Diel Detection Patterns (Spring Migration)

Between 29 April and 23 June, we detected 8,219 yearling Chinook salmon and 2,064 steelhead during intensive sampling with two daily crews. We used these totals to evaluate hourly diel detection distributions (Figure 12) and compared 2006 to average distributions from previous years (2003-2005). There were no significant differences between the proportions of hatchery and wild yearling Chinook salmon or steelhead detected per hour in 2006; therefore, we pooled detection rates for these rearing types. Detections of juvenile sockeye and coho salmon were too few to provide meaningful comparisons. During the two-crew sample period, the detector recorded data for an average of 12 h d^{-1}, and we generally stopped to change crews and refuel between 1400 and 1900 PDT (Appendix Table 5).

Hourly detections rates for yearling Chinook salmon were greater during nighttime hours (2100 to 0500 PST) than during daytime hours (16 vs. 8 hatchery fish/h, $P = 0.059$; 2 vs. 1 wild fish/h, $P = 0.266$). Hourly detections rates for steelhead did not differ significantly between darkness and daylight hours (2 hatchery fish/h, $P = 0.274$, and 1 wild fish/h, irrespective of time of day, $P = 0.324$).

Timing and Migration History

Yearling Chinook Salmon and Steelhead (Spring Migration)

Travel time (d) for inriver migrating fish was measured from the tailrace of Lower Granite Dam (rkm 695) to detection at our sample site (rkm 75) for yearling Chinook salmon and steelhead (Table 4). In 2006, median travel time from Lower Granite Dam was shorter than in 2005 for yearling Chinook salmon (15.8 vs. 17.3 d), but longer for steelhead (17.4 vs. 16.9 d). Overall, travel times for yearling Chinook salmon and steelhead from Lower Granite Dam were similar to those observed since 2000, with the exception of the drought year of 2001.

Median travel time from detection at Bonneville Dam to detection in the estuary was slightly shorter in 2006 than in 2005 for both yearling Chinook salmon (1.7 vs. 1.8 d) and steelhead (1.6 vs. 2.0 d; Table 4). For fish released from barges just downstream from Bonneville Dam, median travel time to the estuary was also shorter in 2006 (2.1 d for yearling Chinook; 1.6 d for steelhead) than in 2004 and 2005 (2.2 d for yearling Chinook and 1.9 d for steelhead in both years). Overall, travel times from Bonneville Dam and the barge-release site were similar to those observed in other years since 2000 for both yearling Chinook salmon and steelhead, with the exception of 2001, when travel times were nearly doubled as a result of extremely low flows.

We also compared the daily differences in travel speeds of fish to the estuary based on migration history (transported vs. inriver) and river flow (Figure 13). Median travel speed to the estuary was significantly slower for yearling Chinook salmon released from barges (70 km d^{-1}) than for those detected at Bonneville Dam on the same date (95 km d^{-1}; $P = 0.000$). This difference was similar to observations from previous study years. For steelhead in 2006, median travel speed for fish detected at Bonneville Dam (101 km d^{-1}) was faster than for fish released from barges (95 km d^{-1}; $P = 0.000$); however, these differences were not significant.

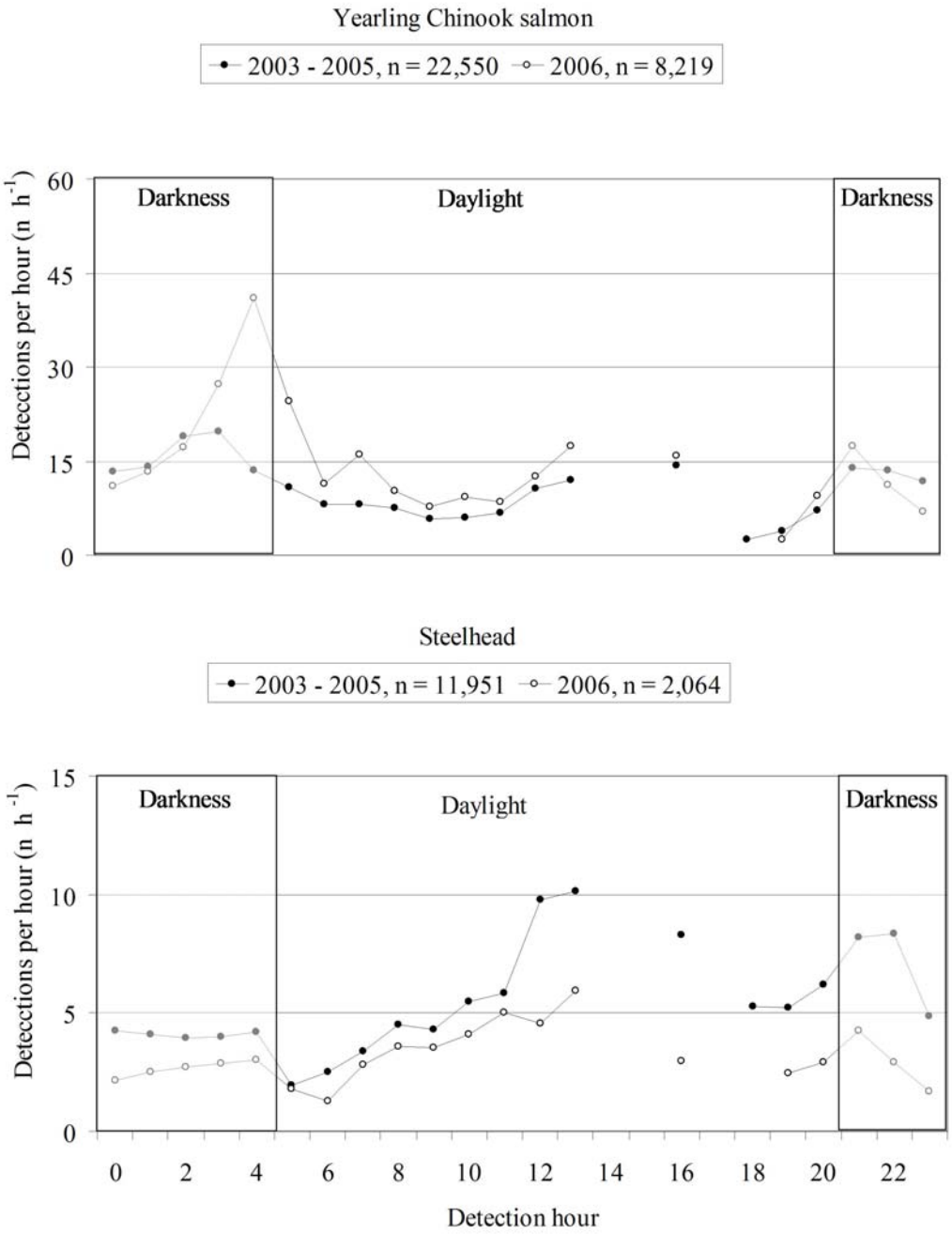

Figure 12. Average hourly detection rates of yearling Chinook salmon and steelhead during the two crew sampling periods of 2003 through 2005 vs. 2006 using the large trawl system in the upper estuary near river kilometer 75.

Table 4. Median travel times in days for yearling Chinook salmon and steelhead released inriver at Lower Granite Dam, detected at Bonneville Dam, or released from a transportation barge to the upper estuary (rkm 75). Mean flow volumes from 15 April to 30 June at Bonneville Dam are shown.

	Release at Lower Granite Dam (rkm 695)				Detection at Bonneville Dam (rkm 234)				Release from transportation barge (rkm 225)				
	Yearling Chinook salmon		Steelhead		Yearling Chinook salmon		Steelhead		Yearling Chinook salmon		Steelhead		
Year	Travel time (d)	Sample (n)	Travel time (d)	Sample (n)	Travel time (d)	Sample (n)	Travel time (d)	Sample (n)	Travel time (d)	Sample (n)	Travel time (d)	Sample (n)	Flow ($m^3 s^{-1}$)
2000	17.4	681	17.1	833	1.7	479	1.7	296	1.9	495	1.6	301	7,508
2001	32.9	680	30.1	44	2.3	792	2.5	59	2.9	1,329	2.3	244	3,853
2002	18.2	538	17.8	93	1.8	1,137	1.7	156	2.0	1,958	1.6	296	7,943
2003	17.0	563	16.5	95	1.8	1,721	1.7	567	2.1	2,382	1.7	435	7,202
2004	16.6	867	16.6	153	1.9	672	2.0	110	2.2	2,997	1.9	333	6,663
2005	17.3	1,183	16.9	278	1.8	81	2.0	471	2.2	2,910	1.9	400	5,776
2006	15.8	450	17.4	51	1.7	894	1.6	115	2.1	1,315	1.6	171	9,435

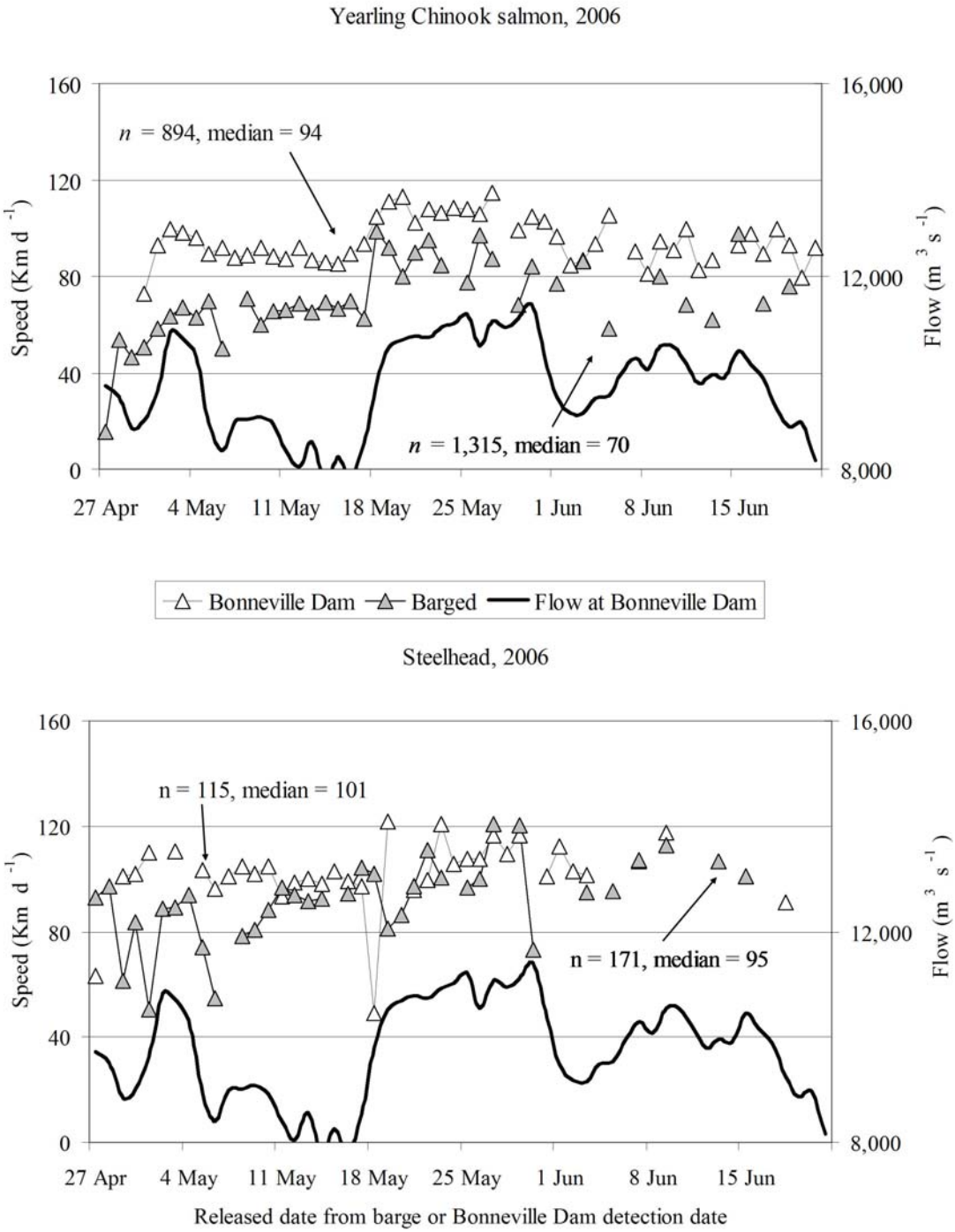

Figure 13. Daily mean travel speed to the estuary of yearling Chinook salmon (top) and steelhead from detection at Bonneville Dam or release from a barge to detection in the estuary (rkm 75) using the large trawl system.

Subyearling Chinook Salmon

We detected 1,522 subyearling Chinook salmon that had been released after 24 April 2006, all of which were less than 120 mm fork length at tagging (Figure 14). The majority of these subyearlings (95%) were released into the Snake River. Of the remainder, 65% originated in the upper Columbia River (above McNary Dam), 27% in the mid Columbia River (from Bonneville Dam to McNary Dam), and 8% in the lower Columbia River (below Bonneville Dam). We detected 166 transported and 1,315 inriver-migrant subyearling Chinook salmon between late May and late July.

Daily average travel speed of PIT-tagged subyearling Chinook salmon released from barges decreased with river flow (Figure 15). The median travel time for barge-released subyearling Chinook salmon to the estuary was 2.5 d in 2005, while travel time for inriver migrants detected at Bonneville Dam could not be estimated due to low detection rates of these fish (n = 6). In 2006, median travel time to the estuary was 2.1 d for transported fish released from a barge (n = 116) and 1.8 d for inriver migrant fish detected at Bonneville Dam (n = 60).

A fraction of the subyearling Chinook salmon released in 2005 suspended their downstream migration and overwintered in the basin before resuming migration the following spring. Between 3 and 15 May 2006, we detected four Snake River Chinook in the upper estuary that had overwintered in fresh water: none of these fish had been transported.

We sampled for PIT-tagged subyearling Chinook salmon in the estuary from 6 September to 1 November using a single crew during daylight hours, 3 d/week. No large groups of fish were detected, so the sample rate was never increased. We detected only one subyearling Chinook salmon during this period; this fish had been released into the Clearwater River on 6 July, was not transported, and was detected in the upper estuary on 9 September. We monitored daily detections at Lower Granite and Bonneville Dam and found few fish detected at these dams during our sample period. Inspection of PTAGIS records for Lower Granite Dam through 8 December, when the facilities were shut down for the winter, indicated a sudden increase in detection rates between 1 and 19 November. However, few if any of these fish were subsequently detected at Bonneville Dam during 2006.

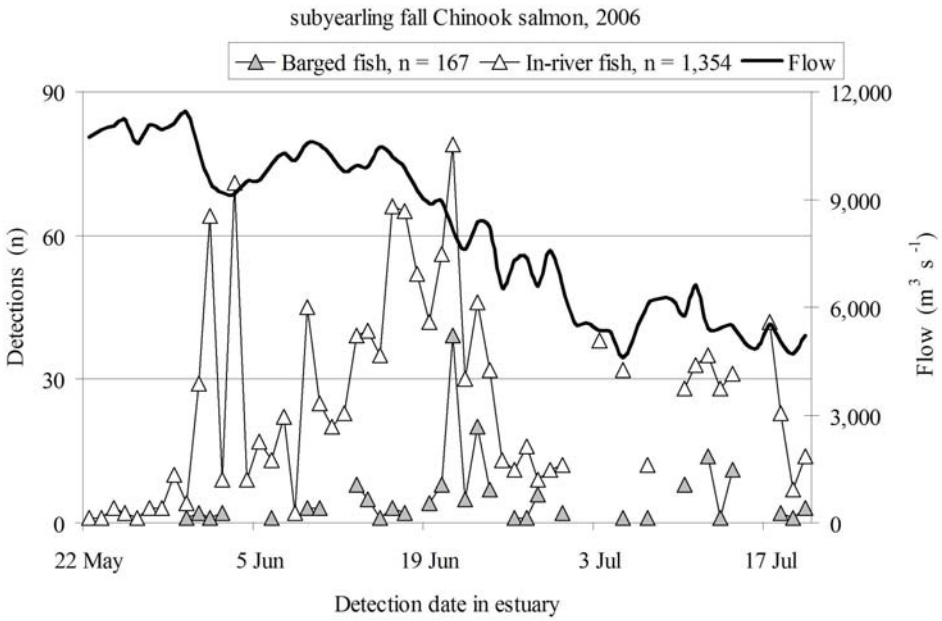

Figure 14. Detection distribution as compared to river flow for subyearling Chinook salmon released from barges vs. those traveling inriver and detected with the large trawl system in the upper estuary (rkm 75).

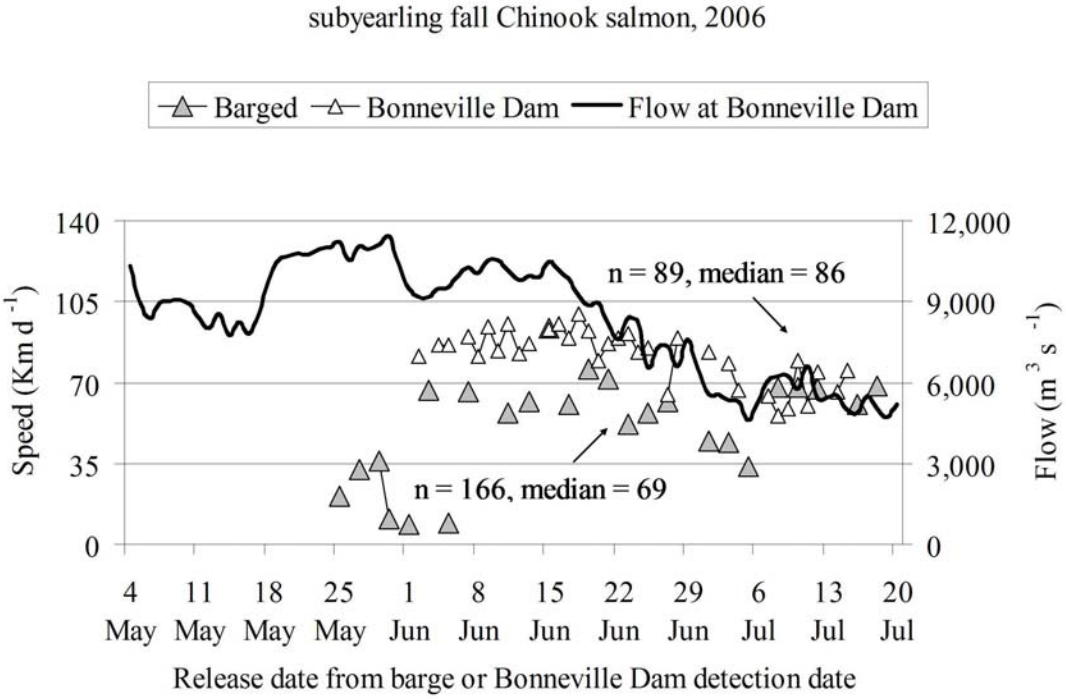

Figure 15. Daily mean travel speed as compared to river flow for subyearling Chinook salmon released from barges vs. those detected passing Bonneville Dam and subsequently detected in the upper estuary at rkm 75.

Transportation Evaluation

Of the 216,279 yearling Chinook salmon and 122,220 steelhead PIT tagged for transportation evaluations in 2006, 37,957 Chinook and 60,513 steelhead were diverted at Snake and Columbia River dams for transport. Including diverted river-run fish, totals of 128,140 yearling Chinook salmon and 77,993 steelhead were transported and released downstream of Bonneville Dam (rkm 222-227). Of those, we detected 1,793 yearling Chinook salmon and 780 steelhead in the upper estuary near river kilometer 75 (Appendix Tables 6-7).

Of the Snake and Columbia River basin fish that remained in river for migration, 47,072 yearling Chinook salmon and 7,182 steelhead were detected in the juvenile bypass system or corner collector at Bonneville Dam. Of those, we detected 938 yearling Chinook salmon and 181 steelhead (Appendix Table 8).

In 2004 and 2005, the corner collector lacked detection capability, so the only fish detected were those that passed via the juvenile bypass system. Fish the passed via the corner collector, turbines, or spillway passed undetected. Of the 73,842 migrants detected at Bonneville Dam in 2006, an estimated 42% passed via the corner collector, and the remaining fish passed through the juvenile bypass facility.

As in previous years, only a small portion of both barged and inriver migrant groups passed through the estuary either before or after the trawl sampling period. In 2006, 92% of the barged juvenile salmonids and 88% of those detected at Bonneville Dam were at or near river kilometer 75 during the two-crew sample period from 23 April to 28 June (Table 5). During this period, we detected 1.3% of the barged PIT-tagged juvenile Chinook salmon available and 2.0% of those previously detected at Bonneville Dam; for steelhead, the detection rates were 0.8 and 1.8%, respectively.

Table 5. PIT-tagged fish released from barges or detected at Bonneville Dam (inriver migrants) and detection numbers in the large trawl during 29 April-23 June 2006. Release totals during this period represented 88% of the annual totals and were selected allowing 2 d for fish to travel to the sample area.

	Transported			Inriver migrant		
	Released	Detected	%	Released	Detected	%
Chinook salmon	129,055	1,818	1.4	49,892	1,011	2.0
Steelhead	67,446	713	1.1	9,456	166	1.8

Detections of Transported vs. Inriver Migrants

We analyzed results from the intensive sampling period to compare daily detection percentages of transported vs. inriver migrant fish previously detected at Bonneville Dam using logistic regression. Barge-releases early in the season often occurred before there were sufficient inriver migrant fish detected at Bonneville Dam for comparison. For analyses of migration history, we further selected the inriver fish from those that originated at or upstream from transportation dams. We also used logistic regression to model the daily detection rates of fish released from the same daily transport barge but loaded at different dams.

Regression analysis for yearling Chinook salmon showed no significant interaction between dates of barge release or Bonneville Dam detection and migration history ($P > 0.844$; Figure 16, top panel). The detection rate of barged migrants was significantly lower than that of inriver migrants ($P = 0.012$) and there was a significant change in detection rate through the migration season ($P = 0.046$). For yearling Chinook, estimated sampling efficiency was lower early in the sample period, at 1.0% for transported and 1.2% for inriver migrant fish. Respective efficiencies increased in late May to 1.7 and 2.2%, and then dropped again to 0.6 and 0.8% by the end of the sample period. The adjustment for over-dispersion was 2.2.

Similar analysis for steelhead showed no significant interaction between date and treatment ($P > 0.400$), and detection rates were not dependant on migration history ($P = 0.136$; Figure 16, bottom panel). However, date was a significant factor in the seasonal trend ($P < 0.001$). Detection rates of both barged and inriver steelhead decreased from 2.6% at the beginning of the two-crew period until late May (0.8%) and then increased again to 2.0%. The adjustment for over-dispersion was 2.06. As in 2005, the daily detection data for steelhead was more variable than for yearling Chinook salmon, probably due to smaller sample numbers.

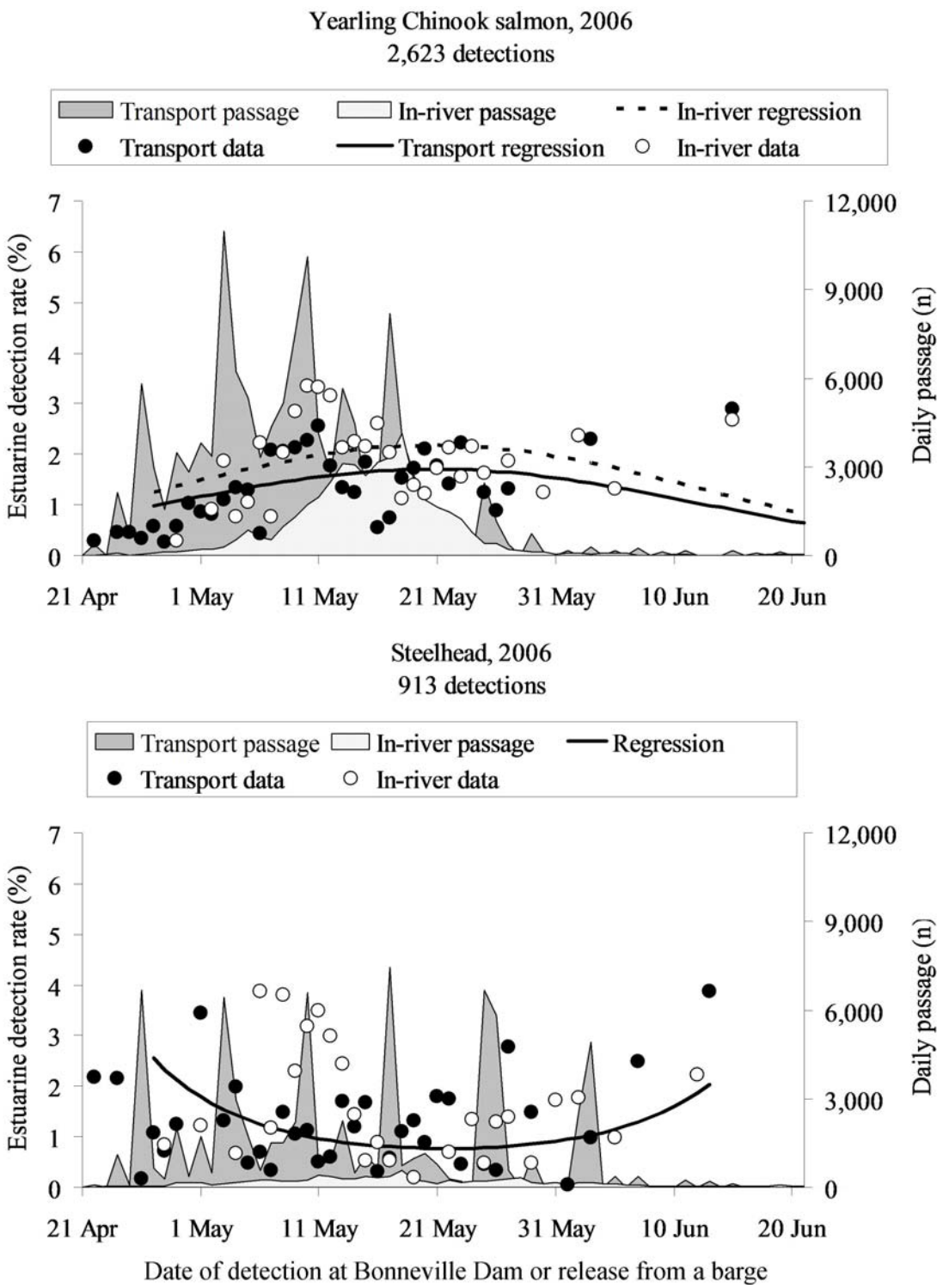

Figure 16. Logistic regression analysis using the quadratic method of the daily detection percentage of transported and inriver migrant yearling Chinook salmon and steelhead detected at Bonneville Dam, 2006.

Mixing Assessment: Transported vs. Inriver Migrants

Comparisons of relative detection rate between transported and inriver migrant fish were based on the assumption that probabilities of detection in the estuary were equal between fish released from barges near Bonneville Dam and those detected in the bypass system at the dam on the same date. To test the validity of this assumption, we calculated hourly differences in detection distributions between the two groups during the two-crew sample period for each year since 2000 (Figure 17).

Average hourly detection distributions for yearling Chinook salmon varied from 0 to 4% (6-year average 2000-2006). There did not appear to be strong trends in the hourly differences for either group of yearling Chinook salmon. This supported the assumption that the two groups were mixed during passage through the estuary. Extreme values in most years represented intervals with low sampling effort (shift change time periods) and perhaps low detection numbers for one group or another during the time of year that those interval hours were sampled. Variability was most extreme for 2001 (range, -9 to 7%), and for 2005, when most inriver fish (-9%) were detected at 1400 PDT and most barged fish (5%) at 2100. In 2006, there was less variability between barged and inriver yearling Chinook salmon than in any other year since 2000.

For steelhead, average hourly differences in detections for the same 6-year period varied from 0 to 3%. While data from individual years indicated the possibility of a trend, when analyzed together, there did not appear to be strong trends in the differences for either group. This finding also supported the assumption that transported fish and those detected at Bonneville Dam were mixed during passage through the estuary. For example, sampling data from 2000 and 2006 suggested that higher percentages of barged fish were present during mid-day and less were present in the evenings, while 2001 and 2005 data suggested the opposite. Ranges of difference were higher in 2000 and 2001 and highest in 2006 than in the other years when sample sizes of steelhead were larger.

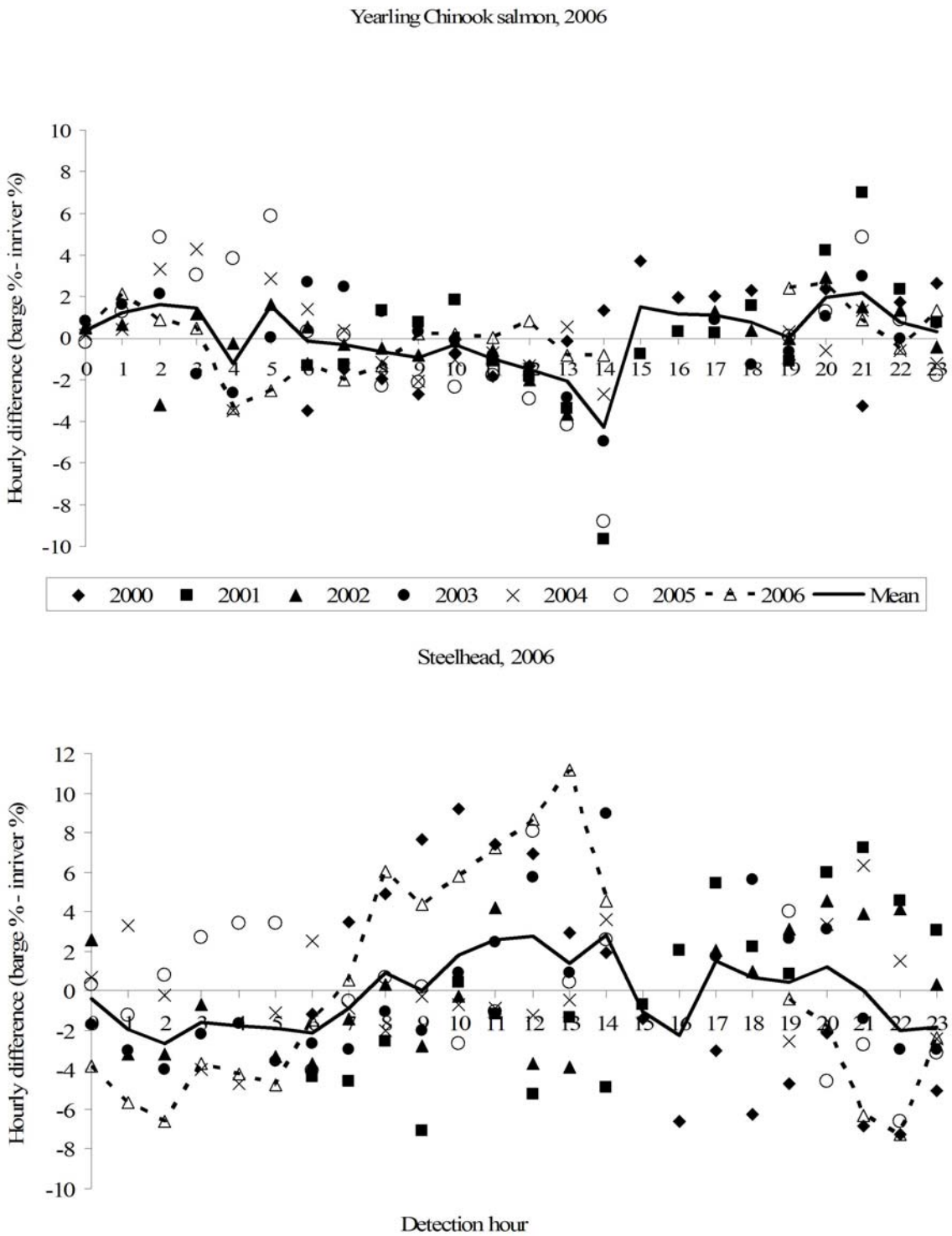

Figure 17. Hourly difference in estuarine detection rates (during intense sampling) of transported fish vs. those previously detected at Bonneville Dam, 2000-2006. Pooled mean differences by year are plotted, and a mean difference greater than 0 indicates that a higher proportion of barged fish were detected during those hours and vice versa.

Transport Dam Assessment

There was no significant interaction in estuarine detection rates between Snake River transport dam (Lower Granite Dam, and pooled data from Little Goose and Lower Monumental Dams) and barge-release date for yearling Chinook salmon ($P > 0.122$; Figure 18, top). Detection rates for fish transported from all dams increased from late-April until late-May and then decreased until the end of the season. There was no significant difference ($P = 0.483$) in the seasonal trends comparing Lower Granite Dam to the down stream dams (regression lines overlapped). The adjustment for over-dispersion was 2.11.

There was a significant interaction in the estuarine detection rate between Snake River transport dam and barge-release date for steelhead ($P = 0.032$; Figure 18, bottom). The detection rate of steelhead from Lower Granite Dam decreased from 2.9% in late April to 0.7% by late-May and then increased again to 1.9% by mid-June. The detection rate of steelhead from Little Goose and Lower Monumental Dams during that same time frame decreased from 1.7 to 0.9% and then increased to 6.9%. The adjustment for over dispersion was 2.12. The earliest Lower Granite Dam transport group had a very large sample size and very small recovery percentage. This atypical result may have occurred from this group passing the sampling site just before full two-crew sampling was implemented. Since this value was highly influential in the modeling results, it was removed from analysis.

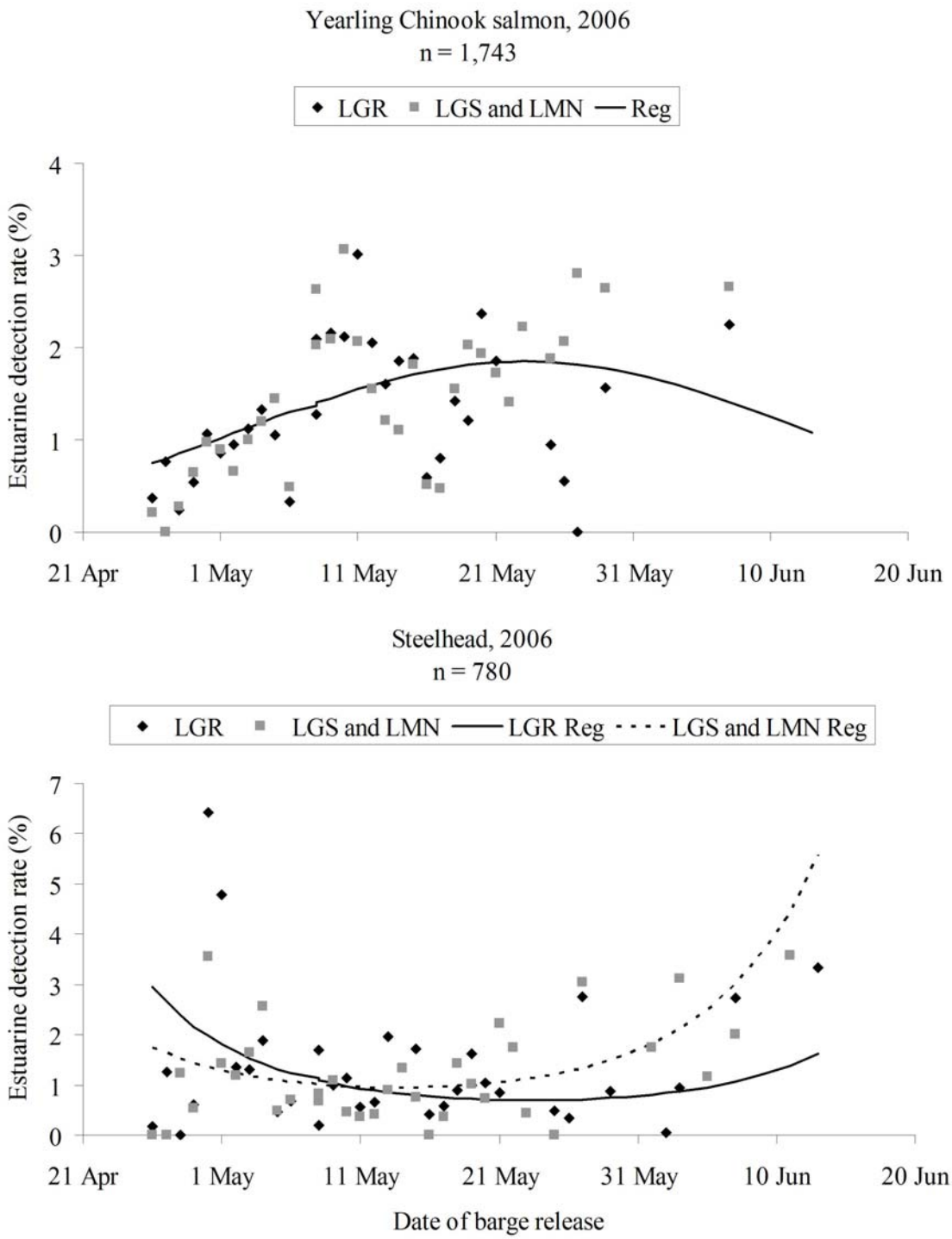

Figure 18. Daily detection rates of yearling Chinook salmon and steelhead released from barges loaded at Lower Granite Dam (LGR) or other downstream dams, Little Goose Dam (LGS) and Lower Monumental Dam (LMN), 2006.

Survival Estimates of Inriver Migrants to the Tailrace of Bonneville Dam

Detection data from the trawl are essential for calculating survival probabilities for juvenile salmonids to the tailrace of Bonneville Dam, the last dam encountered by seaward migrants (Muir et al. 2001; Williams et al. 2001; Zabel et al. 2002). Detections of yearling Chinook salmon and steelhead arriving at McNary Dam were pooled weekly, and survival probabilities of fish released in the Snake and mid-Columbia Rivers were estimated from McNary to John Day, John Day to Bonneville, and McNary to Bonneville Dams (Table 6).

Weighted annual survival estimates were compared for the years 1999-2006 for both Snake and mid-Columbia River basin stocks (Figure 19). In some years, there were insufficient PIT-tags released for one species or the other for a comparison between watersheds. However, there did not appear to be a general trend in survival between the two sources for either species. Annual estimates for yearling Chinook salmon from the Snake River ranged from 50.1% in 2001 to 84.2% in 2006. For mid-Columbia River yearling Chinook, there were too few numbers for an estimate in 2001, and the highest survival estimated was 76.7% in 2003 (survival was estimated at 67.8% in 2006). For Snake River steelhead, survival ranged from 25.0% in 2001 to 64% in 1999 (64.8% in 2006). For mid-Columbia River steelhead, there were too few numbers of fish for estimates in 2001 and 2006, but the estimate was 78.0% in 1998.

Fish transported from Lower Granite Dam on the Snake River avoid a maximum of seven downstream dams. The effectiveness of transportation is evaluated in part by comparing adult return ratios of transported fish vs. inriver migrants. The annual benefit of transportation is related to river conditions experienced by fish that migrate inriver through the hydropower system. In 2005, the seasonal average survival of inriver migrant yearling Chinook salmon from the tailrace of Lower Granite Dam to the tailrace of Bonneville Dam was 52.6%. No estimate was possible for Snake River steelhead in 2005, primarily due to insufficient detections at Bonneville Dam. In 2006, the survival estimate for yearling Chinook salmon was the highest yet at 58.0% and the survival estimate for steelhead was 37.0% (Table 7).

Table 6. Weekly average survival percentages from the tailrace of McNary Dam to the tailrace of Bonneville Dam for yearling Chinook salmon and steelhead, 2006. Total fish used in the survival estimates, weighted average survivals, and standard errors (SE) for each species and water basin are presented. Dashes indicate sample size was too small to estimate survival.

		McNary to John Day Dam		John Day to Bonneville Dam		McNary to Bonneville Dam	
Date	N	%	SE	%	SE	%	SE
			Snake River yearling Chinook salmon				
20 Apr-26 Apr	1,917	85.1	6.8	75.8	39.6	64.5	33.4
27 Apr-03 May	9,932	79.1	2.6	111.5	22.4	88.2	17.5
04 May-10 May	27,949	89.1	2.2	88.5	6.8	78.9	5.8
11 May-17 May	31,498	89.0	3.0	90.4	10.4	80.5	8.8
18 May-24 May	9,904	95.6	8.3	100.8	33.4	96.4	30.8
25 May-31 May	1,532	103.9	20.8	120.8	119.7	125.5	121.8
20 Apr-26 Apr	1,917	85.1	6.8	75.8	39.6	64.5	33.4
Wt. Avg.	82,732	86.8	1.9	89.1	1.1	80.6	2.2
			Snake River steelhead				
20 Apr-26 Apr	694	79.5	4.9	128.3	60.6	102.0	47.8
27 Apr-03 May	1,528						
04 May-10 May	2,532	89.0	5.8	55.4	12.6	49.3	10.7
11 May-17 May	1,906						
Wt. Avg.	6,660	84.0	4.8	69.1	28.5	58.7	20.1
			Mid-Columbia River yearling Chinook salmon				
20 Apr-26 Apr	200	75.4	8.6	79.5	51.6	59.9	38.3
27 Apr-03 May	850						
04 May-10 May	1,583	102.0	10.7	77.5	36.9	79.0	36.8
11 May-17 May	1,551						
18 May-24 May	654	78.0	21.0	51.8	49.7	40.4	37.2
25 May-31 May	101						
Wt. Avg.	4,939	88.9	9.3	74.5	6.5	67.8	9.9
			Mid-Columbia River steelhead				
27 Apr-03 May	39	98.2	36.3	0.0	0.0	0.0	--
04 May-10 May	162						
11 May-17 May	1,021	75.2	6.4	--	--	--	--
18 May-24 May	939						
25 May-31 May	1,287	86.1	9.7	--	--	--	--
01 Jun-07 Jun	226						
Wt. Avg.	3,674	79.8	4.4	NA	NA	NA	NA

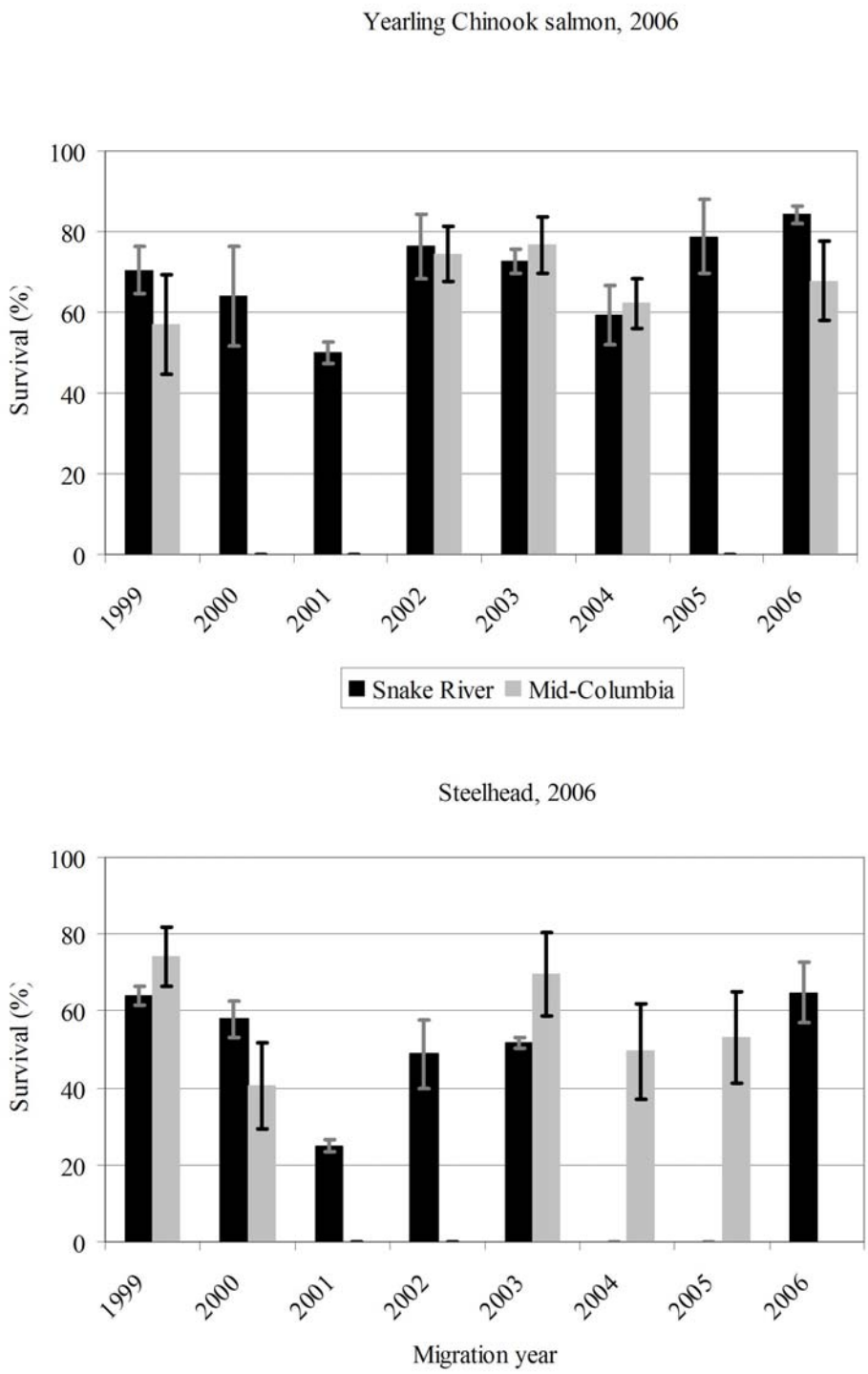

Figure 19. Weighted average annual survival and SE from the tailrace of McNary Dam to the tailrace of Bonneville Dam for Snake and mid-Columbia River yearling Chinook salmon and steelhead, 1999-2006.

Survival probabilities for yearling Chinook salmon through the entire hydropower system downstream from Lower Granite Dam in 2006 were higher than previous years. Despite the fact that fewer yearling Chinook salmon were tagged and released in 2006, the high survival probability is to be expected, considering the higher than average river flows this year. In addition, increased detection capacity at Bonneville Dam (corner collector) contributed to increase precision of the survival estimates. In 2001 and 2004, two years characterized by extremely low river flows due to regional droughts, survival probabilities were about half that of 2006 and the other years at 27.9% and 39.5%, respectively.

Survival probabilities for steelhead salmon through the entire hydropower system downstream from Lower Granite Dam in 2006 were about mid-range as compared to previous years, with the exception of the 2004 and 2005 when detection rates at Bonneville Dam were too low for valid estimates. Roughly the same number of steelhead were tagged and released in 2006 as in 2005. However, higher river flows and detection capability associated with the corner collector bypass at Bonneville Dam likely resulted in sufficient detections for steelhead in 2006 to enable calculations of survival probabilities.

Table 7. Estimated survival probabilities from the tailrace of Lower Granite Dam to the tailrace of Bonneville Dam for yearling Chinook salmon and steelhead, 1998-2006. SE is standard error; CI is 95% confidence interval for the respective means, and dashes indicate sample sizes were too small to provide sufficient data for survival analysis.

	Estimated survival (%)					
	Yearling Chinook salmon			Steelhead		
Migration year		SE	95% CI		SE	95% CI
1998	53.8	4.6	44.8-62.8	50.0	5.4	39.4-60.6
1999	55.7	4.6	46.7-64.7	44.0	1.8	40.5-47.5
2000	48.6	9.3	30.4-66.8	39.3	3.4	32.6-46.0
2001	27.9	1.6	24.8-31.0	4.2	0.3	3.6-4.8
2002	57.8	6.0	46.0-69.6	26.2	5.0	16.4-36.0
2003	53.2	2.3	48.7-57.7	30.9	1.1	28.7-33.1
2004	39.5	5.0	29.7-49.3	--	--	--
2005	57.7	6.9	44.2-71.2	--	--	--
2006	64.3	1.7	61.0-67.6	45.5	5.6	34.5-56.5

DISCUSSION

Trawl detection systems deployed in 2006 continued to provide data on the migration timing and survival of PIT-tagged juvenile salmonids to the upper Columbia estuary. We used these data to compare trends in survival to the estuary between inriver migrants detected at Bonneville Dam and those transported and released below the dam. Our research efforts continued to adapt new technology to our mobile detection systems with a goal to improve collection efficiency of PIT-tagged fish migrating through the estuary. Operation of these systems provides data to many research programs, which have released a combined total of nearly two million PIT-tagged fish annually for the past several years. These data have increased our understanding of juvenile salmonid migration behavior and survival as they pass from a freshwater to a saltwater environment.

Data collected using the trawl detection system provide context for smolt-to-adult return ratios (SARs), which in recent years have shown substantial variation related to timing of the juvenile migration. Data from trawl detections may help to separate freshwater effects from ocean effects when evaluating possible causes and timing of juvenile mortality. For example, large colonies of predacious birds occur in the lower estuary and have a significant annual impact on migrating smolts (Collis et al. 2001; Ryan et al. 2001, 2003). Temporal comparisons can now be made between estuary detection rates of fish groups released from transport barges and their cohorts detected in the bypass system at Bonneville Dam. Similar comparisons are possible using PIT-tag data collected from abandoned bird colonies. Both sets of data contribute to better understanding of variation in SARs and the benefits of management actions taken to improve SARs.

The larger antenna used in 2006 proved to have lower detection rates for older ST model PIT tags compared to the antenna used in previous years. Our expectations were that newer model SST PIT tags, with presumably longer read ranges, would dominate this year. However, only 4% of the fish we detected in 2006 had SST model tags implanted in them. Extensive testing of both old and new PIT-tags and antennas confirmed important trade-offs between the size of the antennas fish passage opening, orientation of tags in the field, and density of tags.

As antennas increase in size, the power necessary to project the field across a larger opening increases the potential for collision of codes (Downing et al. 2003) which is important primarily during higher fish density situations as during net flushing procedures. However, the increased water volume passing through enlarged antennas

reduces the reluctance of fish to exit the trawl (mean duration from first to last fish detection on our two-coil antennas dropped from 4.0 seconds in 2005 to 2.0 seconds in 2006).

In 2006, our sampling period coincided with the presence in the lower river and estuary of nearly 92% of all migrating PIT-tagged fish, and we detected about 2% of those passing through the upper estuary. Although we detected 1.9% of all Chinook salmon and 1.4% of all steelhead, these values were lower than those obtained in 2005 (2.8 and 3.5% respectively). We attribute reduced detection efficiency to higher flows, resulting in greater dispersion of tagged fish and lower than expected use of SST model PIT-tags.

Testing of the larger "matrix" antenna system provided tentative results for further development. Detection rates of migrant fish with the matrix system were low compared to those of the large pair-trawl system, but these low rates were attributed primarily to the use of a much smaller, shallower pair-trawl net. We also documented intermittent and unexplained electronic interference when using the matrix antenna.

In 2007, additional evaluation of the matrix system will include the use of a full-size net and a 4-coil antenna system (2-front coils and 2-rear coils). These additional antennas will provide dual detection capability for each passing fish. We will focus on refining techniques for deploying this larger antenna and further evaluate tuning and gear configuration for the elimination of electronic interference. The larger fish passage opening should further facilitate rapid exit from the trawl and allow for faster tow speed resulting in increased detections of PIT-tagged fish (filter more water). The larger freshwater antenna design is needed to take advantage of the longer reading distances of the improved SST model PIT-tags planned for release in 2007 and beyond.

We were able to efficiently deploy and operate the shoreline PIT-tag detection system through the full range of ebb tide currents at Jones Beach, although flow reversal along the shoreline precluded its use during flood tides. We detected only a single fish along the shoreline, and we generally observed few fish on the antenna-mounted camera.

Electronic components of the shoreline detection system performed satisfactorily. In 2005, releases of test fish, both tagged and untagged, indicated that subyearling Chinook salmon can hold position in the current for extended periods. From this we can infer that fish were able to exit the trawl body without passing through the antenna (swim forward and pass under the floor of the net). Adaptation of a wireless data and video link from the antenna to shoreline receivers provided much improved monitoring of the system.

In 2007, we intend to adapt the matrix antenna to the shoreline net system. The larger fish passage opening should increase the number of detections by reducing delay and avoidance of the antenna to allow an increased trawl speed to increase the overall volume of water passing through the detection zone.

In 2006, detections of PIT-tagged fish in the bypass facilities at Bonneville Dam increased dramatically from 2004 and 2005. The implementation of PIT-tag detection in the north powerhouse corner collector resulted in 31,013 total detections which was 42% of the 73,842 total detections at Bonneville Dam in 2006. By comparison, a total of only 29,839 fish were detected in 2005 in the absence of this detector. This increase in detections at Bonneville Dam also tightened confidence intervals for our calculated survival probabilities for inriver migrants. The single-release method of survival estimation is dependent on subsequent detections of fish previously detected at Bonneville Dam and, for certain species, runs, and rear types, the small numbers detected at Bonneville Dam have limited the estimates in the years since the corner collector became operational.

Survival probabilities for yearling Chinook salmon through the entire hydropower system downstream from Lower Granite Dam in 2006 were similar to those from 1998-2000 and 2002-2005, when seasonal average river flows were comparable. Survival probabilities in 2001, a year characterized by extremely low river flows due to regional drought, were about 30% lower than in other years. Survival of fish migrating in the river is related to flow levels and other conditions, and these in turn influence the extent to which smolt transportation is used in some years.

Since 2000, our annual sample results have indicated no strong diel trends in differences in detection rates between transported fish released from barges and inriver migrating fish detected at Bonneville Dam. Therefore, we assume that when transported and inriver migrant groups were both present in the estuary on a given day, they were subject to the same sampling procedures and river conditions. This assumption is also applied to fish loaded aboard the same barge at different dams and subsequently released together.

As in previous years, Chinook salmon were more numerous during darkness and steelhead were more numerous during daylight, though not often significantly. However, the afternoon shut down for shift changes no doubt reduced detection rates of steelhead as previous purse seine sampling in this reach indicated peak catches between 14:00 and 16:00 (Ledgerwood et al. 1991).

Comparison of daily detection rates for fish released from barges with selected upriver-released fish detected at Bonneville Dam should properly reflect differences in daily survival to the estuary. In 2006, the detection rate of barged yearling Chinook salmon was significantly lower than for inriver migrants, both groups exhibited steadily increasing detection rates through the season. There was no significant difference in the detection rate between barged and inriver steelhead. Detections of both groups of steelhead decreased from late April to mid-May and increased in mid-June. We suspect that much of the variability in daily detection rates observed for transported fish may have been associated with specifics of barge loading such as species composition, loading densities, and loading sites.

Comparisons of daily detection rates for fish loaded at various dams and released from the same barge showed no seasonal differences among dams for yearling Chinook salmon. However, there was a significant difference between detections of steelhead loaded at Lower Granite Dam as compared to those loaded at Little Goose and Lower Monumental Dams. This apparent difference may be related the low numbers of steelhead loaded at Little Goose and Lower Monumental Dams.

Each year, a fraction of the population of Snake River subyearling fall Chinook salmon (an ESA-listed stock) does not migrate to sea in late summer or fall, but overwinters in the river basin and migrates the following spring. Between 3 and 15 May, trawl sampling detected four of these Chinook juveniles, which had been PIT-tagged and released in 2005 to migrate in the river. Few fall Chinook salmon that migrate as yearlings have been detected in the estuary at rkm 75. However, increased tagging of these fish is planned, and detections of those fish in the estuary will provide further insights into this environmentally induced life history strategy.

Additional pair-trawl sampling was conducted from 9 September to 1 November at rkm 75 targeting the nearly 500,000 PIT-tagged Snake River subyearling fall Chinook salmon released in 2006. We limited sampling during this period, and only a single fish was detected; thus, we never increased sampling beyond 3 d per week. The single fish detected had been released into the Clearwater River on 6 July and was detected in the estuary on 9 September. Because there is no transport data for this fish, and it was seen at several downstream dams, it presumably migrated to the estuary in the river. During this period, detections of subyearling fall Chinook at Lower Granite and Bonneville Dams remained low except at Lower Granite Dam when approximately 2,900 fish were detected between 28 and 19 November. We anticipate some of these late fall migrants will overwinter in the basin and will be detected during estuary trawling or shoreline sampling next spring.

REFERENCES

Berggren, T., H. Franzoni, L. Basham, P. Wilson, H. Schaller, C. Petrosky, E. Weber, and R. Boyce. 2006. Comparative survival study (CCS) of PIT-tagged spring/summer Chinook and PIT-tagged summer steelhead. Report of the Fish Passage Center Comparative Survival Oversight Committee to the Bonneville Power Administration, Portland, Oregon.

Collis, K., D. D. Roby, D. P. Craig, B. A. Ryan, and R. D. Ledgerwood. 2001. Colonial waterbird predation on PIT-tagged juvenile salmonids in the Columbia River Estuary: Vulnerability of different salmonid species, stocks, and rearing types. Transactions of the American Fisheries Society. 130:385-396.

Connor, W. P., J. G. Sneva, K. F. Tiffan, R. K. Steinhorst, D. Ross. 2005. Two Alternative Juvenile Life History Types for Fall Chinook Salmon in the Snake River Basin. Transactions of the American Fisheries Society 134: 291-304.

Downing, S. L., B. P. Sanford, G. A. Axel, and E. F. Prentice. 2003. Evaluation of the TX-1400ST PIT tag using juvenile and adult salmonids. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Hosmer, D. W., and S. Lemeshow. 2000. Applied Logistic Regression, 2nd ed. John Wiley & Sons, Inc., New York.

Ledgerwood, R. D., Thrower, F. P., and E. M. Dawley. 1991. Diel sampling of migratory juvenile salmonids in the Columbia River estuary. Fishery Bulletin, U.S. 89:69-78.

Ledgerwood, R. D., E. M. Dawley, B. W. Peterson, and R. N. Iwamoto. 1997. Estuarine recovery of PIT-tagged juvenile salmonids from the Lower Granite Dam Transportation Study, 1996. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Ledgerwood, R. D., B. A. Ryan, E. P. Nunnallee, and J. W. Ferguson. 2000. Estuarine recovery of PIT-tagged juvenile salmonids from the Lower Granite Dam Transportation Study, 1998. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Ledgerwood, R. D., B. A. Ryan, C. Z. Banks, E. P. Nunnallee, B. P. Sanford, S. G. Smith, and J. W. Ferguson. 2003. Detection of PIT-tagged juvenile salmonids in the Columbia River estuary using a surface-trawl detection system, 1999. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Ledgerwood, R. D. J. W. Ferguson, B. A. Ryan, E. M. Dawley, and E. P. Nunnallee. 2004. A surface trawl to detect migrating juvenile salmonids tagged with passive integrated transponder tags. North American Journal of Fisheries Management 24:440-451.

Ledgerwood, R. D., A. S. Cameron, B. P. Sandford, L. B. Way, and G. M. Matthews. 2006. Detection of PIT-tagged juvenile salmonids in the Columbia River estuary using a pair-trawl, 2003-2004. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington

Ledgerwood, R. D., A. S. Cameron, B. P. Sandford, L. B. Way, and G. M. Matthews. 2007. Detection of PIT-tagged juvenile salmonids in the Columbia River estuary using a pair-trawl, 2005. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington

Muir, W. D., S. G. Smith, J. G. Williams, E. E. Hockersmith, and J. R. Skalski. 2001. Survival estimates for migrant yearling chinook salmon and steelhead tagged with passive integrated transponders in the lower Snake and lower Columbia Rivers, 1993-1998. North American Journal of Fisheries Management 21:269-282.

Prentice, E. F., T. A. Flagg, and C. S. McCutcheon. 1990a. Electronic tags. American Fisheries Society Symposium 7:317-322.

Prentice, E. F., T. A. Flagg, C. S. McCutcheon, and D. F. Brastow. 1990b. PIT-tag monitoring systems for hydroelectric dams and fish hatcheries. American Fisheries Society Symposium 7:323-334.

Prentice, E. F., T. A. Flagg, C. S. McCutcheon, D. F. Brastow, and D. C. Cross. 1990c. Equipment, methods, and an automated data-entry station for PIT tagging. American Fisheries Society Symposium 7:335-340.

PSMFC (Pacific States Marine Fisheries Commission). 2006. The Columbia Basin PIT-Tag-Information System (PTAGIS). Online interactive database, Pacific States Marine Fisheries Commission, Portland, Oregon (available via the internet at www.psmfc.org/pittag).

Ryan, B. A., J. W. Ferguson, R. D. Ledgerwood, and E. P. Nunnallee. 2001. Detection of passive integrated transponder tags from juvenile salmonids on piscivorous bird colonies in the Columbia River Basin. North American Journal of Fisheries Management 21:149-153.

Ryan, B. A., S. G. Smith, J. M. Butzerin, and J. W. Ferguson. 2003. Relative vulnerability to avian predation of PIT-tagged juvenile salmonids in the Columbia River estuary, 1998-2000. Transactions of the American Fisheries Society. 132:275-288.

Skalski, J. R., S. G. Smith, R. N. Iwamoto, J. G. Williams, and A. Hoffmann. 1998. Use of passive integrated transponder tags to estimate survival of migrant juvenile salmonids in the Snake and Columbia Rivers. Canadian Journal of Fisheries and Aquatic Sciences 55:1484-1493.

Stein, C. D. Marvin, J. Tenney, and N. Gruman, editors. 2004. 2004 PIT tag specification document. Report of the Pacific States Marine Fisheries Commission to the PIT tag Technical Steering Committee. Gladstone, Oregon (available via the internet at www.psmfc.org/pittag).

Williams, J. G., S. G. Smith, and W. D. Muir. 2001. Survival estimates for downstream migrant yearling juvenile salmonids through the Snake and Columbia River hydropower system, 1966 to 1980 and 1993 to 1999. North American Journal of Fisheries Management 21:310-317.

Zabel, R. W. and J. G. Williams. 2002. Selective mortality for fish length and migrational timing in chinook salmon: what is the role of human disturbance? Ecological Applications 12:173-183.

Zar, J. H. 1999. Biostatistical analysis, 4th edition. Prentice Hall, Upper Saddle River, New Jersey.

APPENDIX

Data Tables

Appendix Table 1. Design of a tape measure used to test antenna performance in 2006.

Position on tape measure (f)	Orientation (°)	Distance from previous tag (ft)[a]	PIT-tag code[b]
17	0	0	3D9.1BF22F5437
19	0	2	3D9.1BF1A73554
21	0	2	3D9.1BF1A723D6
23	45	2	3D9.1BF1A6BBD5
25	45	2	3D9.1BF1F8B9A4
28	0	3	3D9.1BF1A6BE89
31	0	3	3D9.1BF1F7DDEA
34	0	3	3D9.1BF1A1E4AF
37	45	3	3D9.1BF1CF5597
40	45	3	3D9.1BF1E73089
43	45	3	3D9.1BF1F81373
45	0	2	3D9.1BF1F7D25F
47	0	2	3D9.1BF1F7DC5C
49	0	2	3D9.1BF1F7D8EA
50	0	1	3D9.1BF1A71E13
51	0	1	3D9.1BF1A1CD75
52	0	1	3D9.1BF1F7CDF7
55	0	3	3D9.1BF1F8F242
58	0	3	3D9.1BF1A7A629
59	0	1	3D9.1BF1F85701
62	0	3	3D9.1BF1A72BFD
63	0	1	3D9.1BF1F8CAB0
66	0	3	3D9.1BF1F8BBEB
69	45	3	3D9.1BF1F7CD88
70	45	1	3D9.1BF1A9ADDC
72	0	2	3D9.1BF1F7268D
73	0	1	3D9.1BF1A972D5
75	0	2	3D9.1BF1A6B38B
77	0	2	3D9.1BF1F81389
81	0	4	3D9.1BF1A98D9E
83	0	2	3D9.1BF1A7885E
85	0	2	3D9.1BF1A73F1E
88	45	3	3D9.1BF1A9B578
89	45	1	3D9.1BF1A9919F
91	45	2	3D9.1BF1A78FC4
92	45	1	3D9.1BF1A76D70
94	45	2	3D9.1BF1A9C00C
96	45	2	3D9.1BF1CF51C6
100	45	4	3D9.1BF1A9C20F
102	45	2	3D9.1BF1F7C65E

Appendix Table 1. Continued.

Position on tape measure (f)	Orientation (°)	Distance from previous tag (ft)[a]	PIT-tag code[b]
104	45	2	3D9.1BF1A77453
106	0	2	3D9.1BF1A6C70C
108	0	2	3D9.1BF1A1D513
110	0	2	3D9.1BF1A6C4CF
112	0	2	3D9.1BF1A98396
114	45	2	3D9.1BF1A1D0F8
116	45	2	3D9.1BF22BF651
118	45	2	3D9.1BF1F8DA09
120	45	2	3D9.1BF22A8198
125	0	5	3D9.1BF1A9953C

[a] Distance from previous tag as measured in the direction from 17 to 125 ft
[b] PIT-tags were tested after each antenna evaluation with a hand-held reader and replaced as needed

Appendix Table 2. Daily total PIT-tag sample time and detections for each salmonid species using a large pair-trawl at Jones Beach, 2006.

Date	Total time underway (h)	Pit-tag detections (N)						
		Unknown	Chinook salmon	Coho salmon	Steelhead	Sockeye salmon	Sea-run cutthroat	Total
09 Mar	2.1	0	0	0	0	0	0	0
10 Mar	0.0	--	--	--	--	--	--	--
11 Mar	0.0	--	--	--	--	--	--	--
12 Mar	0.0	--	--	--	--	--	--	--
13 Mar	2.4	0	0	0	0	0	0	0
14 Mar	0.0	--	--	--	--	--	--	--
15 Mar	0.0	--	--	--	--	--	--	--
16 Mar	0.0	--	--	--	--	--	--	--
17 Mar	4.0	0	0	0	0	0	0	0
18 Mar	0.0	--	--	--	--	--	--	--
19 Mar	0.0	--	--	--	--	--	--	--
20 Mar	3.5	0	0	0	0	0	0	0
21 Mar	0.0	--	--	--	--	--	--	--
22 Mar	0.0	--	--	--	--	--	--	--
23 Mar	0.0	--	--	--	--	--	--	--
24 Mar	3.9	0	0	0	0	0	0	0
25 Mar	0.0	--	--	--	--	--	--	--
26 Mar	0.0	--	--	--	--	--	--	--
27 Mar	0.0	--	--	--	--	--	--	--
28 Mar	0.0	--	--	--	--	--	--	--
29 Mar	3.1	0	0	0	0	0	0	0
30 Mar	0.0	--	--	--	--	--	--	--
31 Mar	3.3	0	0	0	0	0	0	0
01 Apr	0.0	--	--	--	--	--	--	--
02 Apr	3.3	0	0	0	0	0	0	0
03 Apr	0.0	--	--	--	--	--	--	--
04 Apr	0.0	--	--	--	--	--	--	--
05 Apr	3.8	0	1	0	0	0	0	1
06 Apr	0.0	--	--	--	--	--	--	--
07 Apr	3.3	0	0	0	0	0	0	0
08 Apr	0.0	--	--	--	--	--	--	--
09 Apr	0.0	--	--	--	--	--	--	--
10 Apr	3.2	0	0	0	0	0	0	0
11 Apr	0.0	--	--	--	--	--	--	--
12 Apr	3.0	0	0	0	0	0	0	0
13 Apr	0.0	--	--	--	--	--	--	--
14 Apr	3.8	0	1	0	0	0	0	1
15 Apr	0.0	--	--	--	--	--	--	--
16 Apr	0.0	--	--	--	--	--	--	--
17 Apr	3.6	0	0	0	0	0	0	0
18 Apr	0.0	--	--	--	--	--	--	--
19 Apr	4.1	0	1	0	0	0	0	1
20 Apr	0.0	--	--	--	--	--	--	--
21 Apr	4.3	0	1	0	1	0	0	2

Appendix Table 2. Continued.

Date	Total time underway (h)	Pit-tag detections (N)						
		Unknown	Chinook salmon	Coho salmon	Steelhead	Sockeye salmon	Sea-run cutthroat	Total
22 Apr	5.8	0	0	1	3	0	0	4
23 Apr	0.0	--	--	--	--	--	--	--
24 Apr	5.3	0	2	0	3	0	0	5
25 Apr	0.0	--	--	--	--	--	--	--
26 Apr	5.2	0	2	0	29	0	0	31
27 Apr	0.0	--	--	--	--	--	--	--
28 Apr	2.0	0	5	0	7	0	0	12
29 Apr	5.3	1	16	0	18	0	0	35
30 Apr	9.5	1	27	0	17	0	0	45
01 May	1.5	0	4	0	4	0	0	8
02 May	10.1	0	50	0	124	0	0	174
03 May	10.6	1	70	0	31	0	0	102
04 May	11.3	1	132	0	110	0	1	244
05 May	1.5	1	114	1	59	0	0	175
06 May	11.0	1	158	1	77	0	0	237
07 May	11.8	1	186	0	24	0	0	211
08 May	9.4	0	148	0	28	0	0	176
09 May	10.4	0	136	2	57	0	0	195
10 May	12.2	0	263	3	54	1	0	321
11 May	12.9	0	320	0	106	1	0	427
12 May	16.3	2	497	2	69	1	0	571
13 May	15.1	2	542	4	57	1	0	606
14 May	17.4	1	551	2	74	3	0	631
15 May	10.9	4	298	2	46	4	0	354
16 May	16.8	3	421	4	56	1	0	485
17 May	15.0	2	336	2	25	3	0	368
18 May	17.1	1	357	1	67	5	0	431
19 May	13.5	1	324	0	22	1	0	348
20 May	14.0	1	470	6	70	5	0	552
21 May	15.8	1	444	1	40	6	0	492
22 May	15.0	1	380	2	57	3	0	443
23 May	15.7	4	598	4	79	2	0	687
24 May	14.0	1	410	9	52	4	0	476
25 May	11.9	1	218	16	36	4	0	275
26 May	14.5	4	199	10	40	2	0	255
27 May	10.4	3	101	4	58	1	0	167
28 May	11.7	0	68	7	47	5	0	127
29 May	11.8	3	80	13	40	2	0	138
30 May	10.2	1	38	3	25	6	0	73
31 May	9.9	1	56	6	23	3	0	89
01 Jun	13.5	5	118	14	42	5	0	184
02 Jun	14.9	2	44	11	48	4	0	109
03 Jun	12.6	1	94	5	52	2	0	154
04 Jun	11.5	0	27	2	15	3	0	47
05 Jun	12.2	2	35	5	36	2	0	80

Appendix Table 2. Continued.

Date	Total time underway (h)	Pit-tag detections (N)						
		Unknown	Chinook salmon	Coho salmon	Steelhead	Sockeye salmon	Sea-run cutthroat	Total
06 Jun	12.2	0	32	2	13	0	0	47
07 Jun	7.5	1	32	0	12	0	0	45
08 Jun	5.9	0	5	0	5	0	0	10
09 Jun	9.0	0	53	4	10	1	0	68
10 Jun	12.0	0	37	5	20	1	0	63
11 Jun	7.0	0	25	3	14	0	0	42
12 Jun	9.4	0	30	4	7	0	0	41
13 Jun	12.6	1	64	6	10	1	0	82
14 Jun	13.0	1	53	4	9	1	0	68
15 Jun	8.8	0	40	1	5	1	0	47
16 Jun	10.0	0	71	3	6	0	0	80
17 Jun	11.9	0	78	1	17	0	0	96
18 Jun	7.8	0	58	1	3	0	0	62
19 Jun	11.1	0	55	0	9	0	0	64
20 Jun	12.5	0	71	2	14	0	0	87
21 Jun	15.1	1	127	1	12	0	1	142
22 Jun	12.9	1	44	4	9	0	0	58
23 Jun	20.5	0	75	1	7	0	0	83
24 Jun	6.1	0	47	1	4	0	0	52
25 Jun	5.3	3	15	0	4	0	0	22
26 Jun	4.5	0	14	0	4	0	0	18
27 Jun	5.9	0	24	1	3	0	0	28
28 Jun	5.8	1	15	0	9	0	0	25
29 Jun	6.2	1	21	0	9	0	0	31
30 Jun	6.5	0	18	0	18	0	0	36
01 Jul	0.0	--	--	--	--	--	--	--
02 Jul	0.0	--	--	--	--	--	--	--
03 Jul	6.3	0	49	0	1	0	0	50
04 Jul	0.0	--	--	--	--	--	--	--
05 Jul	6.0	0	38	0	1	0	0	39
06 Jul	0.0	--	--	--	--	--	--	--
07 Jul	4.9	1	13	1	1	0	0	16
08 Jul	0.0	--	--	--	--	--	--	--
09 Jul	0.0	--	--	--	--	--	--	--
10 Jul	4.6	0	36	0	1	0	0	37
11 Jul	4.8	0	34	0		0	0	34
12 Jul	5.3	0	51	0	1	0	0	52
13 Jul	5.9	0	32	0		0	0	32
14 Jul	6.6	0	43	0	1	0	0	44
15 Jul	0.0	--	--	--	--	--	--	--
16 Jul	0.0	--	--	--	--	--	--	--
17 Jul	6.5	0	45	0	0	0	0	45
18 Jul	6.0	0	27	0	1	0	0	28
19 Jul	5.2	0	13	0	0	0	0	13
20 Jul	6.0	1	21	0	0	0	0	22

Appendix Table 2. Continued.

Date	Total time underway (h)	Pit-tag detections (N)						
		Unknown	Chinook salmon	Coho salmon	Steelhead	Sockeye salmon	Sea-run cutthroat	Total
21 Jul-04 Sep	0.0	--	--	--	--	--	--	--
05 Sep	2.2	0	0	0	0	0	0	0
06 Sep	5.2	0	0	0	0	0	0	0
07 Sep	0.0	--	--	--	--	--	--	--
08 Sep	0.0	--	--	--	--	--	--	--
09 Sep	0.0	--	--	--	--	--	--	--
10 Sep	0.0	--	--	--	--	--	--	--
11 Sep	4.4	0	0	0	0	0	0	0
12 Sep	0.0	--	--	--	--	--	--	--
13 Sep	5.3	0	0	0	0	0	0	0
14 Sep	0.0	--	--	--	--	--	--	--
15 Sep	0.0	--	--	--	--	--	--	--
16 Sep	0.0	--	--	--	--	--	--	--
17 Sep	0.0	--	--	--	--	--	--	--
18 Sep	5.8	0	0	0	0	0	0	0
19 Sep	0.0	--	--	--	--	--	--	--
20 Sep	4.9	0	0	0	0	0	0	0
21 Sep	0.0	--	--	--	--	--	--	--
22 Sep	6.1	0	0	0	0	0	0	0
23 Sep	0.0	--	--	--	--	--	--	--
24 Sep	0.0	--	--	--	--	--	--	--
25 Sep	5.1	0	0	0	0	0	0	0
26 Sep	0.0	--	--	--	--	--	--	--
27 Sep	6.1	0						0
28 Sep	0.0	--	--	--	--	--	--	--
29 Sep	2.9	0	1	0	0	0	0	1
30 Sep	0.0	--	--	--	--	--	--	--
01 Oct	0.0	--	--	--	--	--	--	--
02 Oct	2.8	0	0	0	0	0	0	0
03 Oct	0.0	--	--	--	--	--	--	--
04 Oct	5.8	0	0	0	0	0	0	0
05 Oct	0.0	--	--	--	--	--	--	--
06 Oct	5.8	0	0	0	0	0	0	0
07 Oct	0.0	--	--	--	--	--	--	--
08 Oct	0.0	--	--	--	--	--	--	--
09 Oct	4.9	0	0	0	0	0	0	0
10 Oct	0.0	--	--	--	--	--	--	--
11 Oct	5.8	0	0	0	0	0	0	0
12 Oct	0.0	--	--	--	--	--	--	--
13 Oct	6.2	0	0	0	0	0	0	0
14 Oct	0.0	--	--	--	--	--	--	--
15 Oct	0.0	--	--	--	--	--	--	--
16 Oct	5.6	0	0	0	0	0	0	0
17 Oct	0.0	--	--	--	--	--	--	--
18 Oct	7.0	0	0	0	0	0	0	0

Appendix Table 2. Continued.

Date	Total time underway (h)	Pit-tag detections (N)						
		Unknown	Chinook salmon	Coho salmon	Steelhead	Sockeye salmon	Sea-run cutthroat	Total
19 Oct	0.0	--	--	--	--	--	--	--
20 Oct	4.5	0	1	0	0	0	0	1
21 Oct	0.0	--	--	--	--	--	--	--
22 Oct	0.0	--	--	--	--	--	--	--
23 Oct	5.8	1	0	0	0	0	0	1
24 Oct	0.0	--	--	--	--	--	--	--
25 Oct	5.9	0	0	0	0	0	0	0
26 Oct	0.0	--	--	--	--	--	--	--
27 Oct	5.7	0	0	0	0	0	0	0
28 Oct	0.0	--	--	--	--	--	--	--
29 Oct	0.0	--	--	--	--	--	--	--
30 Oct	4.3	0	0	0	0	0	0	0
31 Oct	0.0	--	--	--	--	--	--	--
01 Nov	4.6	0	0	0	0	0	0	0
Totals	961.0	67	9,851	188	2,168	85	2	12,361

Appendix Table 3. Daily total sample time and detections for each salmonid species using the matrix detection system at Jones Beach, 2006.

		Pit-tag detections (N)				
Date	Total time underway (h)	Unknown	Chinook salmon	Coho salmon	Steelhead	Total
20 Jun	1.7	0	0	0	0	0
21 Jun	3.2	0	4	0	1	5
22 Jun	4.6	0	1	0	0	1
23 Jun	0.0	--	--	--	--	--
24 Jun	0.0	--	--	--	--	--
25 Jun	0.0	--	--	--	--	--
26 Jun	2.7	0	1	0	0	1
27 Jun	3.5	0	1	0	0	1
28 Jun	3.8	0	0	0	1	1
29 Jun	0.0	--	--	--	--	--
30 Jun	1.2	0	0	0	1	1
01 Jul-25 Sep	0.0	0	0	0	0	0
26 Sep	2.1	0	0	0	0	0
27 Sep	3.2	0	0	0	0	0
03 Oct	3.7	0	0	0	0	0
04 Oct	3.2	0	0	0	0	0
05 Oct	4.0	0	0	0	0	0
Totals	37.0	0	7	0	3	10

Appendix Table 4. Combined daily total of impinged fish the large trawl, small trawl and shoreline sampler systems in the upper and lower Columbia River estuary, 2006.

	Chinook salmon				
Date	Yearling	Subyearling	Coho salmon	Steelhead	Sockeye
09 Mar	1	0	0	0	0
10 Mar	--	--	--	--	--
11 Mar	--	--	--	--	--
12 Mar	--	--	--	--	--
13 Mar	0	0	0	0	0
14 Mar	--	--	--	--	--
15 Mar	--	--	--	--	--
16 Mar	0	0	0	0	0
17 Mar	0	0	0	0	0
18 Mar	--	--	--	--	--
19 Mar	--	--	--	--	--
20 Mar	0	0	0	0	0
21 Mar	--	--	--	--	--
22 Mar	--	--	--	--	--
23 Mar	0	0	0	0	0
24 Mar	0	0	0	0	0
25 Mar	--	--	--	--	--
26 Mar	--	--	--	--	--
27 Mar	--	--	--	--	--
28 Mar	0	0	0	0	0
29 Mar	0	0	0	0	0
30 Mar	0	0	0	0	0
31 Mar	0	0	0	0	0
01 Apr	--	--	--	--	--
02 Apr	0	0	0	0	0
03 Apr	--	--	--	--	--
04 Apr	--	--	--	--	--
05 Apr	0	0	0	0	0
06 Apr	--	--	--	--	--
07 Apr	0	0	0	0	0
08 Apr	--	--	--	--	--
09 Apr	--	--	--	--	--
10 Apr	0	0	0	0	0
11 Apr	0	0	0	0	0
12 Apr	0	0	0	0	0
13 Apr	--	--	--	--	--
14 Apr	0	0	0	0	0
15 Apr	--	--	--	--	--
16 Apr	--	--	--	--	--
17 Apr	0	0	0	0	0
18 Apr	0	0	0	0	0
19 Apr	0	0	0	0	0
20 Apr	--	--	--	--	--
21 Apr	0	0	0	0	0

Appendix Table 4. Continued.

Date	Chinook salmon		Coho salmon	Steelhead	Sockeye
	Yearling	Subyearling			
22 Apr	0	0	0	0	0
23 Apr	--	--	--	--	--
24 Apr	0	0	0	0	0
25 Apr	--	--	--	--	--
26 Apr	0	0	0	0	0
27 Apr	--	--	--	--	--
28 Apr	0	0	0	0	0
29 Apr	1	0	0	0	0
30 Apr	1	0	0	0	0
01 May	1	0	0	0	0
02 May	1	0	0	0	0
03 May	0	0	0	0	0
04 May	1	0	0	0	0
05 May	1	0	0	0	0
06 May	0	0	0	0	0
07 May	5	0	1	1	0
08 May	2	0	0	0	0
09 May	1	0	0	0	0
10 May	1	0	0	0	0
11 May	2	0	0	0	0
12 May	1	0	0	0	0
13 May	1	0	0	0	0
14 May	0	0	0	0	0
15 May	0	0	0	0	0
16 May	1	0	0	0	0
17 May	0	0	0	0	0
18 May	0	0	0	0	0
19 May	2	0	0	0	0
20 May	0	0	0	0	0
21 May	0	0	0	0	0
22 May	2	0	0	0	0
23 May	1	0	0	0	0
24 May	0	0	0	0	0
25 May	1	0	0	0	0
26 May	0	0	0	0	0
27 May	1	0	0	0	0
28 May	0	0	0	0	0
29 May	0	0	0	0	0
30 May	0	0	0	0	0
31 May	0	0	0	0	0
01 Jun	0	0	0	0	0
02 Jun	0	0	0	0	0
03 Jun	0	0	0	0	0
04 Jun	0	0	0	0	0
05 Jun	1	0	0	0	0
06 Jun	0	0	0	0	0

Appendix Table 4. Continued.

Date	Chinook salmon Yearling	Chinook salmon Subyearling	Coho salmon	Steelhead	Sockeye
07 Jun	0	0	0	0	0
08 Jun	0	0	0	0	0
09 Jun	0	0	0	0	0
10 Jun	0	0	0	0	0
11 Jun	0	0	0	0	0
12 Jun	2	0	0	0	0
13 Jun	0	0	0	0	0
14 Jun	0	0	0	0	0
15 Jun	0	0	0	0	0
16 Jun	0	0	0	0	0
17 Jun	0	0	0	0	0
18 Jun	0	0	0	0	0
19 Jun	0	0	0	0	0
20 Jun	0	0	0	0	0
21 Jun	0	0	0	0	0
22 Jun	4	0	0	0	0
23 Jun	0	0	0	0	0
24 Jun	0	0	0	0	0
25 Jun	0	0	0	0	0
26 Jun	0	0	0	0	0
27 Jun	0	0	0	0	0
28 Jun	0	0	0	0	0
29 Jun	0	0	0	0	0
30 Jun	5	0	1	1	0
01 Jul	--	--	--	--	--
02 Jul	--	--	--	--	--
03 Jul	24	1	3	2	0
04 Jul	--	--	--	--	--
05 Jul	12	1	1	1	0
06 Jul	--	--	--	--	--
07 Jul	0	0	0	0	0
08 Jul	--	--	--	--	--
09 Jul	--	--	--	--	--
10 Jul	0	0	0	0	0
11 Jul	0	0	0	0	0
12 Jul	0	0	0	0	0
13 Jul	0	0	0	0	0
14 Jul	0	0	0	0	0
15 Jul	--	--	--	--	--
16 Jul	--	--	--	--	--
17 Jul	0	0	0	0	0
18 Jul	0	0	0	0	0
19 Jul	0	0	0	0	0
20 Jul	0	0	0	0	0
21 Jul-04 Sept	--	--	--	--	--
05 Sep	0	0	0	0	0

Appendix Table 4. Continued.

Date	Chinook salmon Yearling	Chinook salmon Subyearling	Coho salmon	Steelhead	Sockeye
06 Sep	0	0	0	0	0
07 Sep	--	--	--	--	--
08 Sep	--	--	--	--	--
09 Sep	--	--	--	--	--
10 Sep	--	--	--	--	--
11 Sep	0	0	0	0	0
12 Sep	--	--	--	--	--
13 Sep	0	0	0	0	0
14 Sep	--	--	--	--	--
15 Sep	--	--	--	--	--
16 Sep	--	--	--	--	--
17 Sep	--	--	--	--	--
18 Sep	0	0	0	0	0
19 Sep	--	--	--	--	--
20 Sep	0	0	0	0	0
21 Sep	--	--	--	--	--
22 Sep	0	0	0	0	0
23 Sep	--	--	--	--	--
24 Sep	--	--	--	--	--
25 Sep	0	0	0	0	0
26 Sep	--	--	--	--	--
27 Sep	0	0	0	0	0
28 Sep	--	--	--	--	--
29 Sep	0	0	0	0	0
30 Sep	--	--	--	--	--
01 Oct	--	--	--	--	--
02 Oct	0	0	0	0	0
03 Oct	--	--	--	--	--
04 Oct	0	0	0	0	0
05 Oct	--	--	--	--	--
06 Oct	0	0	0	0	0
07 Oct	--	--	--	--	--
08 Oct	--	--	--	--	--
09 Oct	0	0	0	0	0
10 Oct	--	--	--	--	--
11 Oct	0	0	0	0	0
12 Oct	--	--	--	--	--
13 Oct	0	0	0	0	0
14 Oct	--	--	--	--	--
15 Oct	--	--	--	--	--
16 Oct	0	0	0	0	0
17 Oct	--	--	--	--	--
18 Oct	0	0	0	0	0
19 Oct	--	--	--	--	--
20 Oct	0	0	0	0	0
21 Oct	--	--	--	--	--

Appendix Table 4. Continued.

Date	Chinook salmon		Coho salmon	Steelhead	Sockeye
	Yearling	Subyearling			
22 Oct	--	--	--	--	--
23 Oct	0	0	0	0	0
24 Oct	--	--	--	--	--
25 Oct	0	0	0	0	0
26 Oct	--	--	--	--	--
27 Oct	0	0	0	0	0
28 Oct	--	--	--	--	--
29 Oct	--	--	--	--	--
30 Oct	0	0	0	0	0
31 Oct	--	--	--	--	--
01 Nov	0	0	0	0	0
Total	71	3	9	7	0

Appendix Table 5. Diel sampling of yearling Chinook salmon and steelhead using a PIT-tag detector surface pair-trawl at Jones Beach (Columbia River kilometer 75), 2006. Two-crew effort, between 29 April and 23 June, was rounded to the nearest tenth and presented as a decimal hour.

		Yearling Chinook salmon				Steelhead			
		n		n/h		n		n/h	
Diel hour	Effort (h)	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild
0	45.0	467	10.4	68	1.5	55	1.2	43	1.0
1	42.0	548	13.0	60	1.4	71	1.7	36	0.9
2	31.7	572	18.1	35	1.1	60	1.9	26	0.8
3	12.9	333	25.8	29	2.2	21	1.6	16	1.2
4	7.0	262	37.6	24	3.4	11	1.6	10	1.4
5	9.0	202	22.4	21	2.3	6	0.7	10	1.1
6	37.5	416	11.1	59	1.6	24	0.6	23	0.6
7	50.5	789	15.6	109	2.2	82	1.6	60	1.2
8	49.0	541	11.0	62	1.3	75	1.5	101	2.1
9	49.3	394	8.0	63	1.3	84	1.7	89	1.8
10	46.1	466	10.1	67	1.5	83	1.8	107	2.3
11	36.8	332	9.0	49	1.3	86	2.3	99	2.7
12	21.9	271	12.4	31	1.4	39	1.8	61	2.8
13	14.4	259	17.9	17	1.2	39	2.7	47	3.3
14	8.9	199	22.4	22	2.5	25	2.8	20	2.2
15	2.7	41	15.3	2	0.7	1	0.4	2	0.7
16	2.0	3	0.0	0	0.0	0	0.0	1	0.0
17	1.1	0	0.0	0	0.0	0	0.0	0	0.0
18	1.8	1	0.5	0	0.0	0	0.0	0	0.0
19	7.3	15	2.1	8	1.1	12	1.6	6	0.8
20	39.6	355	9.0	75	1.9	51	1.3	64	1.6
21	47.9	863	18.0	84	1.8	134	2.8	70	1.5
22	47.9	675	14.1	45	0.9	88	1.8	53	1.1
23	45.7	324	7.1	36	0.8	45	1.0	32	0.7
Total	657.9	8,328		966		1,092		976	

Appendix Table 6. Number of PIT-tagged yearling Chinook salmon loaded on transport barges at each of four dams and numbers detected in the estuary. LGR, Lower Granite; LGO, Little Goose; LMN, Lower Monumental; MCN, McNary Dam. Transport dates 22 April-11 August; trawl operation 9 March-20 July and 5 September-1 November; no sampling 21 July-4 September, with intensive sampling 29 April-23 June, 2006. Totals for the entire season are shown, excluding fish released below our sample site.

Release date	Numbers loaded at each dam and total fish loaded (n)*					Percent detected from each dam and total numbers detected (n)					
and time	LGR	LGO	LMN	MCN	n	LGR	LGO	LMN	MCN	n	(%)
22 Apr 17:20	347	0	4	0	351	0.3	--	--	--	1	0.3
24 Apr 18:06	2,150	0	0	0	2,150	0.4	--	0.1	--	10	0.5
26 Apr 00:35	650	0	0	0	650	0.5	--	--	--	3	0.5
26 Apr 18:15	4,893	927	1	0	5,821	0.3	0.0	--	--	20	0.3
27 Apr 18:00	2,212	774	0	0	2,986	0.6		--	--	17	0.6
28 Apr 20:00	834	731	0	0	1,565	0.1	0.1	--	--	4	0.3
29 Apr 22:45	2,395	851	243	0	3,489	0.4	0.2	0.0	--	20	0.6
30 Apr 19:40	1,789	800	221	0	2,810	0.7	0.2	0.1	--	29	1.0
01 May 21:15	2,455	789	545	0	3,789	0.6	0.2	0.1	--	33	0.9
02 May 21:15	1,684	1,302	386	0	3,372	0.5	0.2	0.1	--	27	0.8
03 May 21:50	8,589	1,687	718	0	10,994	0.9	0.1	0.1	--	120	1.1
04 May 20:15	3,398	2,312	530	0	6,240	0.7	0.5	0.1	--	84	1.3
05 May 23:05	1,993	2,240	1,088	0	5,321	0.4	0.9	0.0	--	69	1.3
06 May 22:42	1,239	1,545	537	0	3,321	0.1	0.3	0.0	--	14	0.4
08 May 03:55	1,801	1,781	771	0	4,353	0.5	1.2	0.3	--	90	2.1
08 May 23:15	2,538	1,840	776	0	5,154	1.0	0.8	0.3	--	106	2.1
09 May 19:25	3,345	3,291	958	0	7,594	0.9	0.9	0.3	--	161	2.1
10 May 22:40	8,381	1,245	484	0	10,110	1.8	0.4	0.1	--	230	2.3
11 May 22:45	2,120	1,281	747	0	4,148	1.5	0.8	0.2	--	106	2.6
12 May 21:35	1,270	773	711	0	2,754	0.9	0.7	0.2	--	49	1.8
13 May 18:20	1,739	2,261	1,635	0	5,635	0.5	0.6	0.2	--	75	1.3
14 May 21:57	862	3,177	432	0	4,471	0.4	0.9	0.0	--	56	1.3
15 May 22:20	957	673	597	0	2,227	0.8	0.7	0.4	--	41	1.8
16 May 19:55	851	684	693	0	2,228	0.2	0.2	0.1	--	12	0.5
17 May 20:35	6,323	858	1,026	0	8,207	0.6	0.0	0.1	--	60	0.7
18 May 21:10	775	2,324	905	0	4,004	0.3	0.9	0.3	--	61	1.5
19 May 22:00	996	846	876	0	2,718	0.4	0.5	0.8	--	47	1.7
20 May 19:05	676	582	506	0	1,764	0.9	0.7	0.5	--	37	2.1
21 May 23:50	376	784	431	0	1,591	0.4	0.9	0.4	--	28	1.8
22 May 18:06	0	630	223	0	853	--	1.3	0.1	--	12	1.4

Appendix Table 6. Continued.

Release date and time	Numbers loaded at each dam and total fish loaded (n)*					Percent detected from each dam and total numbers detected (n)					
	LGR	LGO	LMN	MCN	n	LGR	LGO	LMN	MCN	n	(%)
23 May 19:35	0	420	210	0	630	--	1.1	1.1	--	14	2.2
25 May 19:05	1,679	522	274	0	2,475	0.6	0.4	0.2	--	31	1.3
26 May 20:10	900	168	74	0	1,142	0.4	0.4	0.0	--	10	0.9
27 May 19:30	204	121	57	0	382	0.0	0.5	0.8	--	5	1.3
29 May 18:30	512	148	79	0	739	1.1	0.7	0.1	--	14	1.9
30 May 19:30	39	51	35	0	125	2.4	2.4	1.6	--	8	6.4
01 Jun 19:10	54	78	47	0	179	1.1	2.2	1.1	--	8	4.5
02 Jun 21:00	47	0	0	0	47	0.0	--	--	--	0	0.0
03 Jun 17:45	211	75	18	0	304	0.7	0.7	0.0	--	4	1.3
05 Jun 19:20	67	64	22	0	153	1.3	0.7	0.0	--	3	2.0
07 Jun 22:20	165	57	21	0	243	1.2	0.0	0.0	--	3	1.2
09 Jun 20:20	54	46	21	0	121	1.7	0.0	0.8	--	3	2.5
11 Jun 18:25	64	61	25	0	150	1.3	0.0	2.0	--	5	3.3
13 Jun 21:20	27	27	1	0	55	0.0	0.0	0.0	--	0	0.0
15 Jun 20:35	125	36	16	0	177	1.1	0.6	0.6	--	4	2.3
17 Jun 20:55	26	36	19	0	81	0.0	1.2	2.5	--	3	3.7
19 Jun 16:25	57	39	11	0	107	2.8	0.9	0.0	--	4	3.7
21 Jun 22:14	34	20	4	0	58	1.7	0.0	0.0	--	1	1.7
23 Jun 19:30	16	18	3	0	37	0.0	0.0	0.0	--	0	0.0
25 Jun 21:00	7	11	1	0	19	0.0	0.0	0.0	--	0	0.0
27 Jun 19:20	13	16	4	0	33	3.0	0.0	0.0	--	1	3.0
29 Jun 21:45	15	20	2	0	37	0.0	0.0	0.0	--	0	0.0
01 Jul 19:30	4	26	1	0	31	0.0	0.0	0.0	--	0	0.0
03 Jul 21:35	4	25	2	0	31	0.0	0.0	0.0	--	0	0.0
05 Jul 21:40	4	26	8	0	38	0.0	0.0	0.0	--	0	0.0
08 Jul 04:15	3	7	1	16	27	0.0	0.0	0.0	0.0	0	0.0
10 Jul 04:55	3	3	0	12	18	0.0	0.0	--	0.0	0	0.0
12 Jul 04:55	0	0	1	6	7	--	--	0.0	0.0	0	0.0
14 Jul 03:40	4	2	2	2	10	0.0	0.0	0.0	0.0	0	0.0
16 Jul 03:50	0	0	0	5	5	--	--	--	0.0	0	0.0
18 Jul 03:05	0	1	0	2	3	--	0.0	--	0.0	0	0.0
24 Jul 03:40	0	0	0	1	1	--	--	--	0.0	0	0.0
26 Jul 02:30	0	0	0	1	1	--	--	--	0.0	0	0.0
28 Jul 05:00	0	0	0	1	1	--	--	--	0.0	0	0.0
07 Aug 03:27	1	0	0	0	1	0.0	--	--	--	0	0.0
09 Aug 05:08	0	0	0	1	1	--	--	--	0.0	0	0.0
11 Aug 03:20	0	0	0	1	1	--	--	--	0.0	0	0.0
Totals	71,977	39,112	17,003	48	128,140	1.3	1.6	1.3	0.0	1,743	1.4

* Beginning in mid-June most PIT-tagged Chinook salmon detected in the estuary were subyearling migrants tagged in the Upper Columbia River or the Snake River.

Appendix Table 7. Number of PIT-tagged steelhead loaded on transport barges at each of four dams and numbers detected in the estuary. LGR, Lower Granite; LGO, Little Goose; LMN, Lower Monumental; MCN, McNary Dam. Transport dates were 22 April-14 July; trawl operation 9 March-1 November; no sampling 21 July-4 September, with intensive sampling 29 April-23 June, 2006. Totals for the entire season are shown, excluding fish released below our sample site.

Release date and	Numbers loaded at each dam and total fish loaded (n)					Numbers detected from each dam and total numbers detected (n)					
time	LGR	LGO	LMN	MCN	n	LGR	LGO	LMN	MCN	n	(%)
22 Apr 17:20	91	0	1	0	92	2.2	--	0.0	--	2	2.2
24 Apr 18:06	1,117	0	0	0	1,117	2.1	--	--	--	24	2.1
26 Apr 00:35	76	0	0	0	76	0.0	--	--	--	0	0.0
26 Apr 18:15	6,562	118	0	0	6,680	0.2	0.0	--	--	11	0.2
27 Apr 18:00	562	94	0	0	656	1.1	0.0	--	--	7	1.1
28 Apr 20:00	117	162	0	0	279	0.0	0.7	--	--	2	0.7
29 Apr 22:45	1,829	96	94	0	2,019	0.5	0.0	0.0	--	12	0.6
30 Apr 19:40	156	72	154	0	382	2.6	1.0	1.0	--	18	4.7
01 May 21:15	1,361	121	231	0	1,713	3.8	0.1	0.2	--	70	4.1
02 May 21:15	149	130	210	0	489	0.4	0.4	0.4	--	6	1.2
03 May 21:50	5,995	219	209	0	6,423	1.2	0.1	0.0	--	85	1.3
04 May 20:15	2,502	230	199	0	2,931	1.6	0.2	0.1	--	58	2.0
05 May 23:05	1,075	348	286	0	1,709	0.3	0.2	0.0	--	8	0.5
06 May 22:42	147	223	208	0	578	0.2	0.3	0.2	--	4	0.7
08 May 03:55	1,067	218	233	0	1,518	0.1	0.1	0.1	--	5	0.3
08 May 23:15	1,129	195	173	0	1,497	1.3	0.1	0.1	--	22	1.5
09 May 19:25	1,009	962	235	0	2,206	0.5	0.5	0.1	--	23	1.0
10 May 22:40	6,367	119	102	0	6,588	1.1	0.0	0.0	--	74	1.1
11 May 22:45	538	138	133	0	809	0.4	0.0	0.1	--	4	0.5
12 May 21:35	616	51	186	0	853	0.5	0.0	0.1	--	5	0.6
13 May 18:20	1,691	180	383	0	2,254	1.5	0.0	0.2	--	38	1.7
14 May 21:57	54	381	71	0	506	0.0	1.0	0.2	--	6	1.2
15 May 22:20	940	55	80	0	1,075	1.6	0.0	0.1	--	18	1.7
16 May 19:55	479	41	121	0	641	0.3	0.0	0.0	--	2	0.3
17 May 20:35	7,170	88	195	0	7,453	0.6	0.0	0.0	--	43	0.6
18 May 21:10	445	91	191	0	727	0.6	0.6	0.0	--	8	1.1
19 May 22:00	494	134	354	0	982	0.8	0.0	0.5	--	13	1.3
20 May 19:05	581	165	391	0	1,137	0.5	0.0	0.4	--	10	0.9
21 May 23:50	237	170	370	0	777	0.3	1.0	0.5	--	14	1.8
22 May 18:06	0	106	181	0	287	--	0.3	1.4	--	5	1.7
23 May 19:35	0	37	187	0	224	--	0.0	0.4	--	1	0.4
25 May 19:05	6,469	60	162	0	6,691	0.5	0.0	0.0	--	31	0.5
26 May 20:10	5,767	16	51	0	5,834	0.3	0.0	0.0	--	19	0.3

Appendix Table 7. Continued.

Release date and time	Numbers loaded at each dam and total fish loaded (n)					Numbers detected from each dam and total numbers detected (n)					
	LGR	LGO	LMN	MCN	n	LGR	LGO	LMN	MCN	n	(%)
27 May 19:30	510	25	43	0	578	2.4	0.0	0.3	--	16	2.8
29 May 18:30	883	46	82	0	1,011	0.8	0.4	0.2	--	14	1.4
30 May 19:30	14	14	39	0	67	0.0	0.0	3.0	--	2	3.0
01 Jun 19:10	20	16	46	0	82	0.0	0.0	0.0	--	0	0.0
02 Jun 21:00	2,570	0	0	0	2,570	0.0	--	--	--	1	0.0
03 Jun 17:45	4,865	39	25	0	4,929	0.9	0.0	0.0	--	48	1.0
05 Jun 19:20	295	34	52	0	381	3.1	0.0	0.3	--	13	3.4
07 Jun 22:20	285	16	84	0	385	1.0	0.3	0.3	--	6	1.6
09 Jun 20:20	9	22	30	0	61	0.0	0.0	3.3	--	2	3.3
11 Jun 18:25	175	14	37	0	226	3.1	0.0	0.0	--	7	3.1
13 Jun 21:20	202	7	8	0	217	1.4	0.5	0.0	--	4	1.8
15 Jun 20:35	105	8	14	0	127	4.7	0.0	1.6	--	8	6.3
17 Jun 20:55	3	4	7	0	14	0.0	7.1	0.0	--	1	7.1
19 Jun 16:25	81	3	7	0	91	3.3	0.0	0.0	--	3	3.3
21 Jun 22:14	36	3	0	0	39	12.8	0.0	--	--	5	12.8
23 Jun 19:30	0	0	1	0	1	--	--	100.0	--	1	100.0
25 Jun 21:00	0	1	2	0	3	--	0.0	0.0	--	0	0.0
27 Jun 19:20	0	3	0	0	3	--	33.3	--	--	1	33.3
08 Jul 04:15	0	1	0	3	4	--	0.0	--	0.0	0	0.0
14 Jul 03:40	0	1	0	0	1	--	0.0	--	--	0	0.0
Totals	66,845	5,277	5,868	3	77,993	1.0	1.4	1.0	0.0	780	1.0

Appendix Table 8. Detection rates in the Columbia River estuary of PIT-tagged juvenile Chinook salmon and steelhead previously detected at Bonneville Dam, 2006. The juvenile bypass system and corner collector at Bonneville Dam operated 5 March–20 December; trawl operation 29 April–20 July and 5 September-1 November, with intensive sampling 29 April–23 June, 2006. Totals for the entire season are shown.

Detection date at Bonneville Dam	Bonneville Dam detections		Jones Beach detections			
	Chinook salmon (n)	Steelhead (n)	Chinook salmon (n)	Steelhead (n)	Chinook salmon (%)	Steelhead (%)
5 Mar-11 Apr	55	11	0	0	0.0	0.0
12 Apr	185	1	1	0	0.5	0.0
13 Apr	174	1	0	0	0.0	0.0
14 Apr	153	1	1	0	0.6	0.0
15 Apr	92	2	1	0	1.1	0.0
16 Apr	82	0	1	0	1.2	0.0
17 Apr	89	0	0	0	0.0	0.0
18 Apr	87	5	1	0	1.1	0.0
19 Apr	53	5	0	0	0.0	0.0
20 Apr	55	5	0	0	0.0	0.0
21 Apr	52	20	1	0	1.8	0.0
22 Apr	69	18	0	0	0.0	0.0
23 Apr	61	30	0	0	0.0	0.0
24 Apr	65	53	1	0	1.1	0.0
25 Apr	57	38	1	0	1.4	0.0
26 Apr	60	31	1	0	1.2	0.0
27 Apr	81	35	0	1	0.0	2.9
28 Apr	115	55	0	0	0.0	0.0
29 Apr	127	147	0	1	0.0	0.7
30 Apr	184	167	1	5	0.8	3.0
01 May	210	152	1	1	0.4	0.7
02 May	221	91	2	0	0.8	0.0
03 May	270	112	6	2	2.0	1.8
04 May	522	150	5	0	0.9	0.0
05 May	848	186	9	1	1.2	0.5
06 May	632	232	14	9	2.2	3.9
07 May	525	256	6	3	1.1	1.2
08 May	982	210	20	8	2.1	3.8
09 May	1,299	218	37	5	2.8	2.3
10 May	1,739	252	59	8	3.3	3.2
11 May	1,959	401	65	17	3.3	4.2
12 May	2,509	368	80	11	3.2	3.0
13 May	3,096	288	66	7	2.1	2.4
14 May	3,063	281	69	5	2.2	1.8
15 May	2,697	381	60	2	2.2	0.5
16 May	3,136	337	88	3	2.8	0.9
17 May	3,337	385	73	3	2.2	0.8
18 May	4,130	575	50	7	1.2	1.2

Appendix Table 8. Continued.

Detection date at Bonneville Dam	Bonneville Dam detections		Jones Beach detections			
	Chinook salmon (n)	Steelhead (n)	Chinook salmon (n)	Steelhead (n)	Chinook salmon (%)	Steelhead (%)
19 May	2,515	243	40	4	1.6	1.6
20 May	1,895	223	24	1	1.3	0.4
21 May	1,633	141	28	2	1.7	1.4
22 May	1,464	246	31	4	2.1	1.6
23 May	1,224	184	20	2	1.6	1.1
24 May	792	223	19	4	2.4	1.8
25 May	430	211	7	1	1.6	0.5
26 May	430	231	16	4	3.7	1.7
27 May	205	288	3	4	1.4	1.4
28 May	166	346	0	1	0.0	0.3
29 May	142	152	1	1	0.6	0.7
30 May	141	130	0	1	0.5	0.8
31 May	40	174	3	4	3.0	2.3
01 Jun	81	80	3	1	2.5	1.3
02 Jun	79	145	1	2	2.3	1.4
03 Jun	51	172	1	5	0.9	2.9
04 Jun	70	119	1	1	1.6	0.8
05 Jun	80	128	3	4	1.7	3.1
06 Jun	80	90	0	0	0.0	0.0
07 Jun	50	71	0	2	1.7	2.8
08 Jun	25	53	0	0	1.2	0.0
09 Jun	11	49	0	3	0.8	6.1
10 Jun	26	52	2	0	2.7	0.0
11 Jun	30	36	1	0	1.3	0.0
12 Jun	22	43	0	0	1.2	0.0
13 Jun	13	47	0	0	1.6	0.0
14 Jun	16	23	0	1	0.0	4.3
15 Jun	18	34	0	0	2.1	0.0
16 Jun	18	29	1	1	1.6	3.4
17 Jun	214	38	0	0	0.4	0.0
18 Jun	25	44	0	3	0.3	6.8
19 Jun	38	74	1	7	2.1	9.5
20 Jun	33	36	0	1	2.0	2.8
21 Jun	23	40	1	2	0.8	5.0
22 Jun	247	33	6	3	1.5	9.1
23 Jun	21	44	0	1	0.3	2.3
24 Jun	28	23	0	2	0.4	8.7
25 Jun	17	31	0	0	0.9	0.0
26 Jun	10	50	0	2	0.0	4.0
27 Jun	228	53	3	2	1.0	3.8
28 Jun	11	63	0	4	0.6	6.3
29 Jun	8	46	0	0	0.0	0.0
30 Jun	5	19	0	0	0.0	0.0
01 Jul	12	30	0	0	1.6	0.0
02 Jul	224	21	0	0	0.2	0.0

Appendix Table 8. Continued.

Detection date at Bonneville Dam	Bonneville Dam detections		Jones Beach detections			
	Chinook salmon (n)	Steelhead (n)	Chinook salmon (n)	Steelhead (n)	Chinook salmon (%)	Steelhead (%)
03 Jul	21	23	0	0	0.5	0.0
04 Jul	13	20	0	0	1.2	0.0
05 Jul	18	36	0	0	0.0	0.0
06 Jul	26	22	0	0	0.0	0.0
07 Jul	217	6	0	0	0.1	0.0
08 Jul	21	4	0	0	0.2	0.0
09 Jul	11	12	0	0	0.5	0.0
10 Jul	10	6	0	1	0.4	16.7
11 Jul	17	11	0	0	0.4	0.0
12 Jul	224	5	0	0	0.2	0.0
13 Jul	11	4	0	0	0.0	0.0
14 Jul	10	5	0	0	1.4	0.0
15 Jul	8	3	0	0	3.2	0.0
16 Jul	5	7	0	1	0.0	14.3
17 Jul	215	1	2	0	0.8	0.0
18 Jul-18 Dec	283	23	0	0	0.0	0.0
Totals	47,072	10,296	938	181	2.0	1.8