Detection of PIT-Tagged Juvenile Salmonids in the Columbia River Estuary using Pair-Trawls, 2005

Richard D. Ledgerwood, April S. Cameron, Benjamin P. Sandford, Luther B. Way, and Gene M. Matthews

Report of research by

Fish Ecology Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112-2097

for

Walla Walla District
North Pacific Division
U.S. Army Corps of Engineers
201 North 3rd
Walla Walla, WA 99362-1875
Contract 56ABNF100030

July 2007

EXECUTIVE SUMMARY

In 2005, we continued a study to detect juvenile anadromous salmonids *Oncorhynchus* spp. implanted with passive integrated transponder (PIT) tags using a large surface pair-trawl fitted with a PIT-tag detection antenna. We sampled in the Columbia River upper estuary between river kilometers (rkm) 61 and 83 for 909 h between 20 April and 5 August and detected 14,101 PIT-tagged juvenile salmonids of various species, runs, and rearing types. Not all stocks and rearing types were equally represented in the annual detection totals. For example, of the total detections, 18% were wild fish and 79% were hatchery-reared; 64% were Chinook salmon, 32% were steelhead, and the remaining 4% were other salmonid species.

During the spring migration period, the principal target fish (yearling migrants) were the roughly 740,000 PIT-tagged spring/summer Chinook salmon and 770,000 PIT-tagged steelhead released into the Columbia River Basin. Some of these fish migrated in the river to the estuary; others were diverted to transportation barges at Lower Granite Dam or at other downstream collector dams. Transported fish were then released into the Columbia River about 9 km downstream from Bonneville Dam. As in 2002, we extended sampling into the summer migration period, targeting the more than 279,000 PIT-tagged subyearling fall Chinook salmon. These fish were released into the Snake and upper Columbia Rivers for NMFS transportation studies. These fish either migrated in the river or were transported from collection facilities at Lower Granite; Little Goose, and Lower Monumental Dams on the Snake River and McNary Dam on the Columbia River.

In this study, we used the antenna that was developed in 2001 and the trawl that was developed in 2003. The antenna weighed about 200 kg in air, with a fish passage tunnel measuring 86 cm in diameter. Two Whit-Patten transceivers were housed inside a separate data-collecting vessel (electronics barge) and recorded PIT-tag detections, electronic status reports, and global-positioning-system (GPS) locations. The barge floated directly above, and was also used to deploy, the antenna. The antenna was attached to a trawl, which we had altered in 2003 to include an extended net floor measuring 9 m. The trawl was towed using a pair of 12.5-m long 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). Hand-written logs, including land marks and events, were also maintained. A camera mounted inside the antenna provided nearly constant video surveillance (during daytime hours) which aided in monitoring fish passage and debris accumulation.

Sampling effort was commensurate with arrival in the estuary of inriver migrating yearling Chinook salmon and steelhead from the Snake River transportation study releases. A single daily crew began sampling on 20 April and the effort was increased from single to double daily crews on 27 April. This double-crew effort continued until 17 June, when we returned to a single-daily crew. During this time period, we averaged 13 h/d of detector on-time and detected 2.8% of all Chinook salmon and 3.5% of all steelhead previously detected at Bonneville Dam. These rates were a rough measure of sampling efficiency with the large trawl.

Of the fish detected, 27% had been transported and released downstream from Bonneville Dam. Another 5% had previously been detected in the bypass system at Bonneville Dam. This proportion was lower than in previous years due to the lack of detection capability associated with a new corner collector at the dam. The remaining 68% had not been transported or detected at Bonneville Dam. These percentages were similar to the migration history proportions of fish detected in previous years, except where noted. A total of 59% of our detections had been released in the Snake River, 34% in the upper Columbia River, and 7% downstream from McNary Dam. Only 25 non-transported PIT-tagged fish detected in the estuary had been released from sites downstream from Bonneville Dam; another 36 had been released from Bonneville Dam and 21 from Bonneville Hatchery (rkm 233).

During the peak of the spring migration period, we sampled nearly continuously. However, high winds and swift currents often hindered sampling between 1300 and 1800 PDT, forcing us to shut down. Sample sizes of yearling Chinook salmon and steelhead were sufficient in most instances to conclude that diel trends among wild and hatchery rearing types were similar; thus, we presented the analyses and summaries from the pooled data. During the two-crew sampling period, we averaged 4 and 10 yearling Chinook salmon detections per hour of daylight and darkness, respectively, for hatchery and wild rear-types combined ($P = 0.005$). We also averaged three steelhead detections per hour of daylight and four per hour of darkness ($P = 0.748$).

Travel speed from Bonneville Dam to Jones Beach was significantly higher for inriver migrant yearling Chinook salmon (median 90 km d^{-1}) than for those released from barges (median 68 km $d^{-1;}$ $P = 0.000$). However, there was no significant difference in travel speed between barged and inriver-migrant steelhead (80 vs. 78 km d^{-1}, respectively; $P = 0.684$).

Since 2001, we have continued development of a PIT-tag detection trawl for use in salt or brackish water. Periodic electronic and net modifications have been required. The goal was to deploy a smaller surface pair-trawl system in lower, more inaccessible areas of the estuary, in hopes of detecting fish previously detected in the upper estuary. A small, rapidly deployable, mobile PIT-tag detection system may also prove useful in smaller rivers, high-volume bypass channels, and other areas of the Columbia River or Pacific Ocean.

In 2005, we deployed a smaller trawl in the lower estuary, primarily between rkm 8 and 16. In this smaller trawl, the trawl body was larger than that used in previous years, and was 4.9 m square at its entrance and 8.5 m in length. A floor of 1.8-cm stretch-measure webbing extended forward 6-m between the wings. A 20-m section of 1.8-cm mesh followed by a 15-m section of 33-cm mesh made up the trawl wings, which were also larger than in previous years. Fish exited the trawl through a single PIT-tag detection antenna coil positioned 1.8 m beneath the surface. We used a new antenna with a circular shape measuring 107 cm in diameter.

The trawl was towed using a pair of 7.5-m long vessels. Under tow, we maintained a distance of about 34 m between the wings of the small trawl. We had an effective sample depth of about 4 to 5 m (measured at the center of the floor). The antenna weighed about 136 kg in air, including ballast. A PIT-tag transceiver (Destron/Fearing model FS-1001A) was mounted on a pontoon barge towed at the rear of the trawl. Cables led from 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.

The small-trawl system was deployed in the lower estuary between 16 May and 8 June during the two-crew sampling period of the large trawl. A total of 38 PIT-tagged fish were recorded during 73 h of sampling along the north and south side of the ship channel during both daylight and darkness hours. No major problems with entanglements of bait fish or salmonids were encountered in the lower estuary. One steelhead detected in brackish water had been previously detected in the large trawl upstream at Jones Beach. Travel time between the two detection sites (mean 35 h) was correlated to the number of flood tides encountered during the journey, similar to years previous. Since 2002, we have detected 10 fish in both trawls, with travel times ranging from 16 to 40 h, corresponding to encounters of 1-3 flood tides during passage from the upper to the lower estuary.

In order to evaluate the ability to guide smolts through an antenna system, we occasionally deployed a passive PIT-tag sampling device along the shoreline at Jones Beach as well. Following the small trawl sample period, we adapted the same Hobe Cat and Pelican box systems for the shoreline sampler, which was equipped with wireless video and data transmission capabilities (Destron-Fearing transceiver). This enabled us to view, record, and potentially quantify fish passage, while capturing detection data, all from the shore. We used a night design that was slightly modified from that used in 2004; the cod end was altered to attach an antenna made up of 3-in diameter PVC pipe. We sampled for about 20 h over a 6-d period with no detections.

CONTENTS

INTRODUCTION

In 2005, we continued a multi-year study to detect juvenile anadromous salmonids *Oncorhynchus* spp. as they migrate through the Columbia River estuary. Migrant fish were collected using a large surface pair trawl and guided through an electronic antenna mounted at the trawl exit in place of a cod-end (Ledgerwood et al. 2004a). Target fish had been implanted with passive integrated transponders (PIT-tags) in natal streams, at hatcheries or at other upstream locations prior to migration (PSMFC 2005). As PIT-tagged fish exited the trawl, their tag code, the date and time of detection, and the GPS position were recorded without handling.

This study began in 1995 and has continued annually (except 1997) in the estuary at Jones Beach, approximately 75 km upstream from the mouth of the Columbia River (Ledgerwood et al. 1997, 2003, 2006). In 2005, we also used a small pair-trawl system to detect PIT-tagged fish in the brackish-water portions of the lower estuary, which allowed sampling in areas that were inaccessible to the larger trawl system used upstream in freshwater.

Over 1.8 million PIT-tagged juvenile salmonids were released into the Columbia River Basin for migration in 2005 (PSMFC 2005). These fish were monitored during downstream migration using detectors installed by the National Marine Fisheries Service (NMFS) and the U.S. Army Corps of Engineers (USACE) at various hydroelectric facilities throughout the basin (Prentice et al. 1990a,b,c). The Columbia Basin PIT tag Information Systems (PTAGIS) database was used to store and disseminate release and detection times and locations, as well as species, origin, and migration history of individual PIT-tagged fish.

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, at river kilometer (rkm) 234. In 2005, over 170,000 PIT-tagged fish were transported. The goal of estuary trawling was to monitor the survival and timing of PIT-tagged fish that migrated in the river through the hydropower system or that were transported by barge past the hydropower system and released downstream from Bonneville Dam. Detection data from pair-trawl sampling was collected with the following objectives:

1) Compare migrational timing and relative survival to the estuary between inriver migrant and transported juvenile yearling Chinook salmon *O. tshawytscha* and steelhead *O. mykiss* during the spring migration period.

2) Estimate survival of inriver migrants from McNary and Lower Granite Dams to Bonneville Dam for major groups of yearling salmonids.

3) Compare migrational timing to the estuary between inriver migrant and transported subyearling fall Chinook salmon during late June through July.

4) Compare migrational timing of individual salmonids between the upper and lower estuary using a small trawl PIT-tag detection system designed for use in the brackish water of the lower estuary.

METHODS

Study Fish

In 2005, we continued to focus research on large groups of PIT-tagged fish migrating through the upper Columbia River estuary near Jones Beach (rkm 75) from late April through early August. According to PTAGIS, these groups included over 90,000 PIT-tagged fish released for a transportation study on the Snake River (Marsh et al. 2005) and nearly 200,000 PIT-tagged fish released for a comparative survival study (Berggren et al. 2006). Fish from other major and minor PIT-tagging studies were detected coincidentally as well.

These releases provided large groups of PIT-tagged migrants with known release locations and times that could be coordinated with trawl system operations. After tagging, transportation study fish were either released to the Snake River downstream from Lower Granite Dam (rkm 695) to continue their migration past the remaining dams or transported and released downstream from Bonneville Dam. In addition, some PIT-tagged inriver migrant fish were diverted to transportation barges at dams further downstream: Little Goose Dam, rkm 635; Lower Monumental Dam, rkm 589; and McNary Dam, rkm 470.

In our analysis of transportation, we used data from all PIT-tagged fish diverted to barges, including hatchery fish or other tagged fish not specifically released for the transportation study at Lower Granite Dam. We created a database of detection records from PTAGIS of fish that were recorded as having been diverted to transportation barges. Diversion at the dams was accomplished by separating fish with a slide gate triggered by PIT-tag code, a technology available at specific dams (Stein et al. 2004). Diversion of fish to transportation barges was confirmed if a fish was last detected on a monitor that led to a transport raceway or barge (monitors were listed on the PTAGIS site map).

Since 1987, over 1.8-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, which in turn enabled us to assign PIT-tagged fish to specific transport barges and subsequent release times.

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

Sample Period

Sampling with the large trawl began in late April and daily sampling continued through June, coincident with the passage of PIT-tagged yearling Chinook salmon and steelhead from the Snake River transportation study. Beginning on 28 April and extending through 17 June, sampling increased from a single daily sampling crew to two daily crews. Generally, one work crew began before daylight and sampled for an 8- to 10-h period, and a second crew began in late afternoon and sampled until dark.

For the first time since 2002, sampling at rkm 75 was extended into early August to target PIT-tagged subyearling fall Chinook salmon, which migrate during that period. Transportation of subyearling salmonids is new and little information on behavior and timing of these fish following release is available. Results from previous years of limited sampling at Jones Beach, generally in the lower river flows of late June and July, have suggested that sampling with a single crew could produce adequate detections of subyearling salmonids to determine timing and behavior differences. Our goal was to detect about 1% of fish previously detected at Bonneville Dam during this extended sample period.

In 2005, sampling was nearly continuous throughout the two-crew period except between 1400 and 1800 PDT, when crews changed shifts. To determine the hourly diel availability of yearling Chinook salmon and steelhead, we pooled weighted detection data during the two-crew sampling period, when sampling was nearly continuous. A smoothed interpolated value was used during the 2-h period between shift changes. To compare diel curves among hatchery and wild fish on the same graphic scale, we weighted the detection data by total fish detected within each category and plotted the percentage of total detections for each hour.

Study Sites

We conducted large trawl operations from Eagle Cliff (≈rkm 83) to the west end of Puget Island (≈rkm 61; 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 has occurred at the study site during flood tides, particularly during years of medium to high river flow. The net 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 at Jones Beach (≈rkm 75).

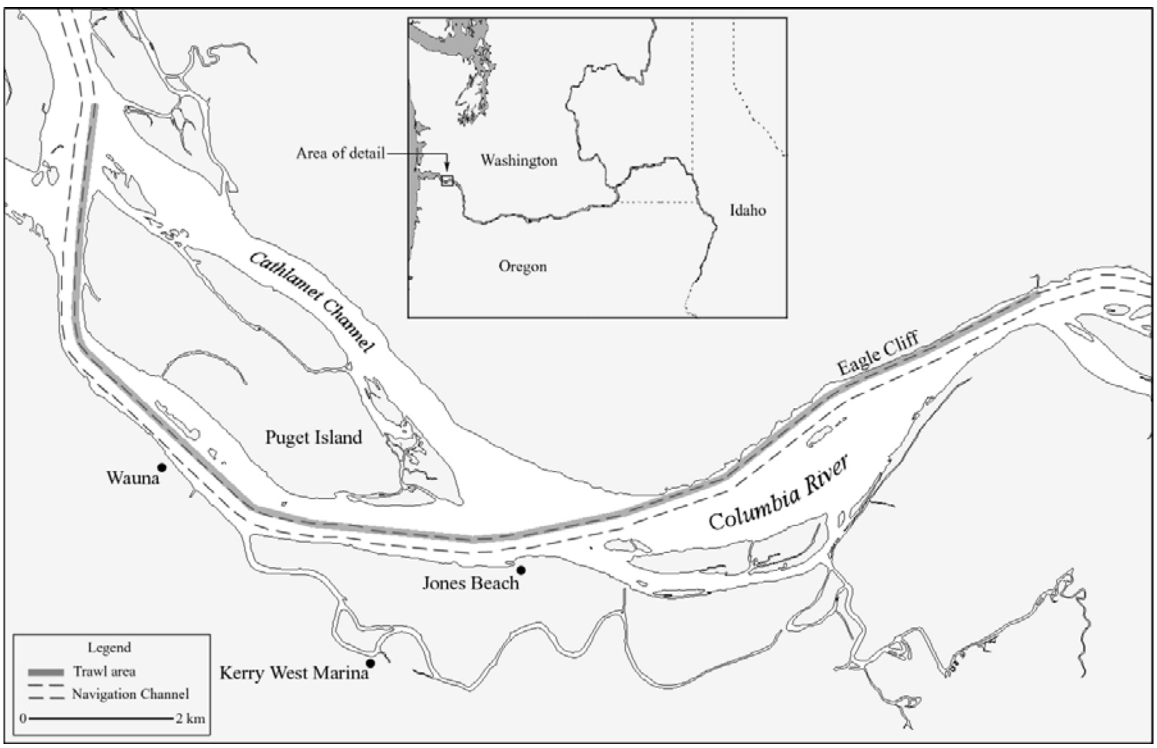


Figure 1. Trawling area adjacent to the ship navigation channel in the upper Columbia River estuary near Jones Beach, rkm 75.

In 1988, during net testing with the large trawl near rkm 10 (Ledgerwood unpublished data), it became apparent that sampling in the lower estuary would only be possible using a smaller trawl. Deployment and retrieval operations for the large trawl required ample maneuvering room not routinely available in the lower estuary. Lower estuary currents are stronger, often exceeding 2 m s^{-1} (4 knots) and are bi-directional, with strong daily ebb and flood tides. There are few, if any, unobstructed areas that would allow for the undirected drift of vessels required for deployment and retrieval of our large trawl system.

Initial testing of a net and associated electronics for a smaller trawl system designed for brackish water began in 2001, with the goal of sampling PIT-tagged fish in areas currently inaccessible to the large trawl (Ledgerwood et al. 2004b). In 2005, we deployed the small trawl system in the brackish water region of the estuary from mid-May through early June. Generally, sampling occurred from the river mouth to around the Astoria-Megler Bridge (rkm 8-16; Figure 2).

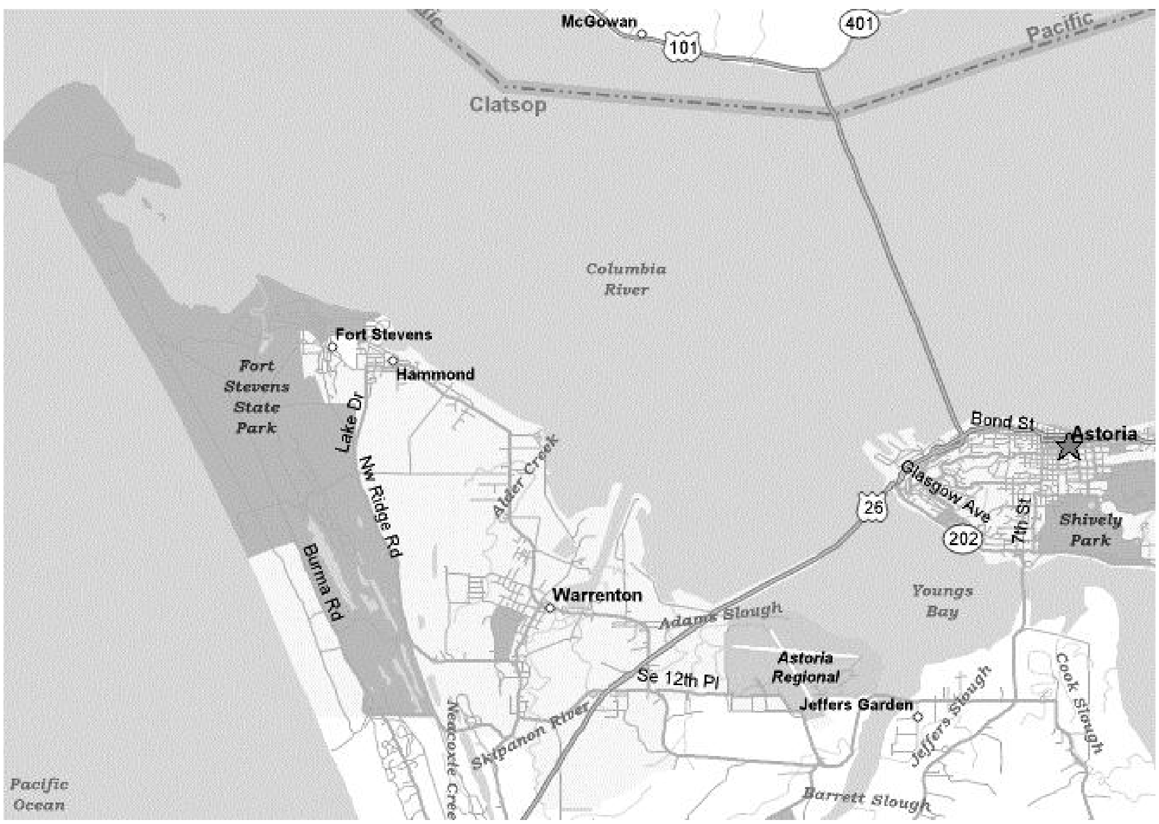


Figure 2. Trawling area for small trawl in the lower estuary, rkm 8-16.

Trawls and System Designs

The large trawl components are described below, and their basic configuration remained fairly constant through the study period (Ledgerwood et al. 2004a; Figure 3). To prevent turbulence on the net from the tow vessels, 73-m-long tow lines were used. The upstream end of each wing of the trawl initiated with a 3-m-long spreader bar, which was shackled to the wing section. The 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 total length of the trawl and components was 110.2 m. The mouth of the trawl body opened between the wings and from the surface to a depth of 6 m; a floor extended 9 m forward from the mouth.

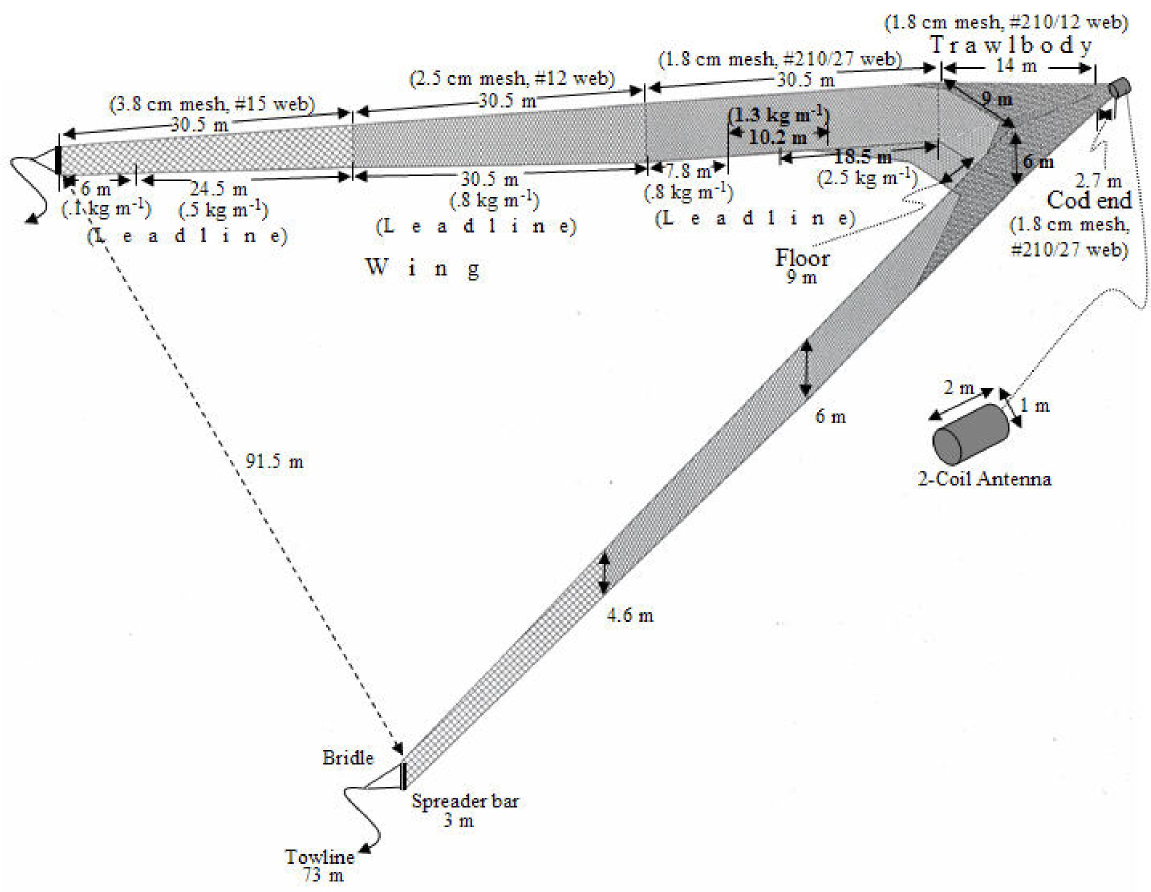


Figure 3. Basic design of the large surface pair trawl that was used to sample PIT-tagged juvenile salmonids in the Columbia River estuary at Jones Beach, rkm 75.

The detection antenna was centered at a depth of 1.8 m, and the 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. Beginning in 2000, basin-wide conversion to the 134.2-kHz PIT-tags and monitors allowed for a larger opening through the antenna. This larger opening further reduced drag and lift on the net, increasing the sample depth of the trawl 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 the wings of the trawl. Fish that enter between the wings are guided to the trawl body and exit through the antenna. During net retrieval, the antenna is removed and then the net is inverted in the current to flush debris and release fish from between the small-mesh wings. The deployment/retrieval process of the large trawl requires about 30 min, during which time the vessels and net are adrift in tidal and river currents often exceeding 1.5 m s^{-1} (3 knots).

The design of the small trawl was based on the large surface pair trawl, with some modifications to allow safe operation in the high-current and confined areas of the lower estuary (Figure 4). We initially deployed and tested the equipment in July 2001 near Chinook, WA (rkm 10) where adequate net handling procedures and electronic components were developed (Ledgerwood et al. 2004b).

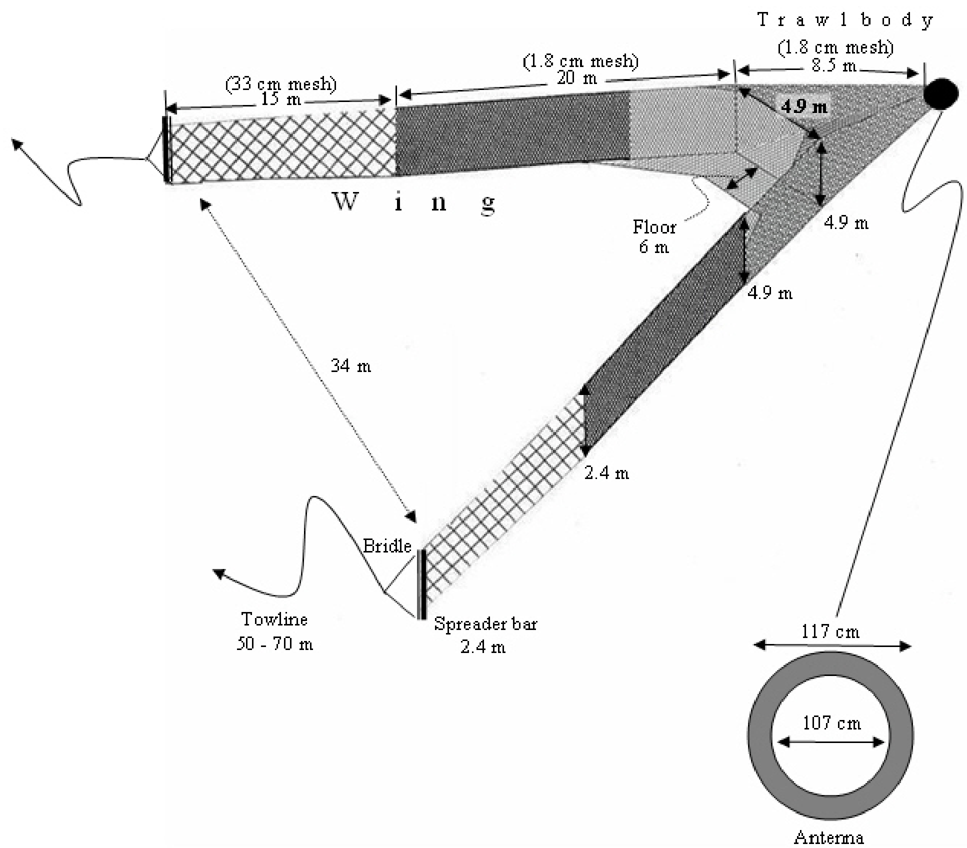


Figure 4. Schematic of the small pair-trawl that was used with a salt-water compatible antenna.

In the lower estuary, we could not routinely invert the net prior to retrieval. Inverting the net was required for the larger trawl because of the small mesh in the wings and the longer trawl body (14-m) leading to the exit through the antenna attachment. We believe fish could become entrapped in the webbing of the large trawl if the wings were merely collapsed for retrieval without inverting the net. We used a mixture of larger and smaller mesh size for the net of the small trawl, which also reduced drag on the net and thus facilitated use of smaller vessels. To further reduce drag, we used a shorter trawl body with a symmetrical design. The small trawl was 4.9 by 4.9-m at its body entrance and tapered evenly to the antenna attachment, centered 2.4-m beneath the surface.

The small trawl consisted of an 8.5-m-long symmetrical trawl body having 35-m long wings. The trawl body was constructed with 1.8 cm stretch mesh (same mesh size used in the larger trawl). The wings of the small trawl were 20 m of 1.8 cm stretch mesh followed by 15 m of 33-cm stretch-mesh webbing that altogether tapered in depth from 4.9 m, where they attached to the trawl body, to 3 m where they attached to spreader bars and towing bridles. The spreader bars and towing bridles were similar to those on the large trawl system and were used to hold the wings at their full sample depth. We used 70-m-long tow lines to minimize the influence of prop wash from the towing vessels on the net. Under tow, we maintained a distance of about 34 m between the wings so that the effective sample depth was 4 to 5 m at the center of the floor.

Our shoreline PIT-tag detection system consisted of two 15 m-long wings, with one wing leading between one side of a 2.4-m square opening to the trawl body and the shore, and a second wing leading between the trawl body and a fixed, off-shore anchor (Figure 5). The trawl body was 5 m long and positioned at an appropriate depth (about 3.5 m) near-shore by positioning the anchor. The 31 cm-tall by 51 cm-wide antenna was supported on a buoy similar to that of our other trawls.

Generally, we deployed this system near high tide and sampled during ebb currents. Current velocities varied from 0 to about 1.5 knots 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.

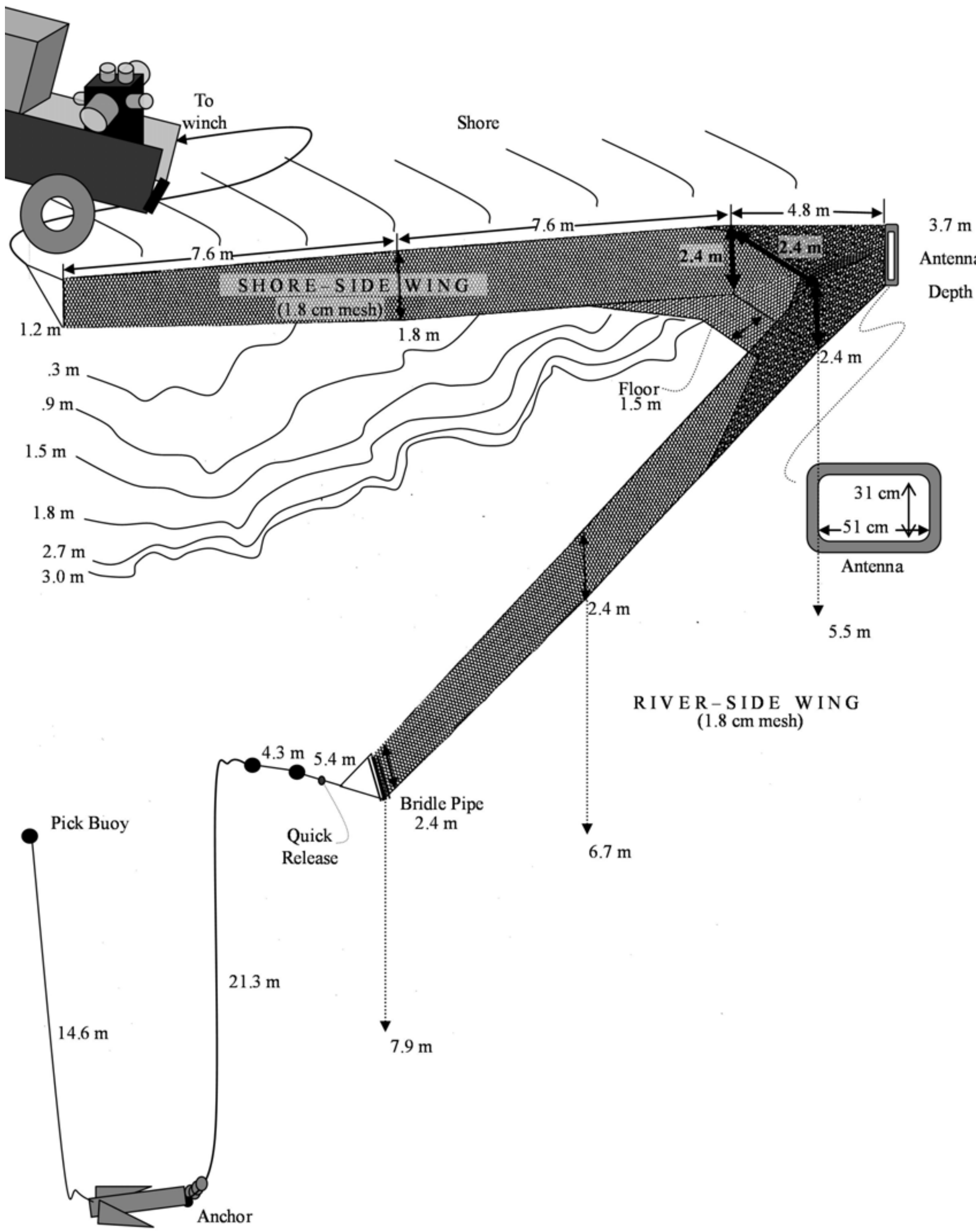


Figure 5. Design for the PIT-tag sampler used along the shoreline parallel to the shipping channel at Jones Beach, rkm 75.

Electronic Equipment and Operation

For the large trawl system, we used essentially the same electronic components and procedures as in 2001-2004. A 10-m-long pontoon barge was towed near the exit to the trawl, and a gasoline generator powered all electronic equipment. Two Whit-Patten[1] transceivers and associated PIT-tag-detection electronics were mounted in the cabin of the barge, and cables led underwater to a tuner port on each of two detection antenna coils. A video camera mounted inside the antenna tunnel was used to monitor fish passage on a VCR/TV housed in the barge. The 200-kg antenna was 2.1 m long and had an 86-cm-diameter fish passage opening (Figure 6).

Once the antenna was energized, a computer software program (Multimon) automatically recorded time, date, tag code, and coil identification number (Downing et al. 2001) and was adapted in 2002 to include GPS locations for each detection record. For each sampling cruise, written logs were maintained noting the time and duration of net deployment, total detections, the number of impinged or injured fish, and the start and end of each net-flushing period.

The shoreline sample system employed the small trawl electronics, 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 periodically (about weekly) uploaded 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 2005). Pair-trawl detections in the PTAGIS database were identified with site code "TWX" (towed array-experimental).

Records of PIT-tagged fish detected at Bonneville Dam were downloaded from PTAGIS for comparison with our detections (PSMFC 2005). In addition, the load sites, dates, times and corresponding release dates, times, and locations (rkm) of transport barges were provided by the USACE. An independent database (Microsoft Access) of detection information was also maintained to facilitate data management and analysis. We modified the PTAGIS release information within our database to reflect the date, time, and river kilometer of releases from transport barges.

[1]Reference to trade name does not imply endorsement by the National Marine Fisheries Service, NOAA.

PIT-tag-detection electronic components for the small trawl and shoreline systems were contained in a 0.8-m long by 0.5-m wide by 0.3-m deep water-tight box mounted on a 1.9-m long by 1.2-m wide pontoon raft (Ledgerwood et al. 2006). A DC-powered Destron-Fearing model FS-1001A PIT-tag transceiver was used to power the underwater antenna and interrogate tagged fish.

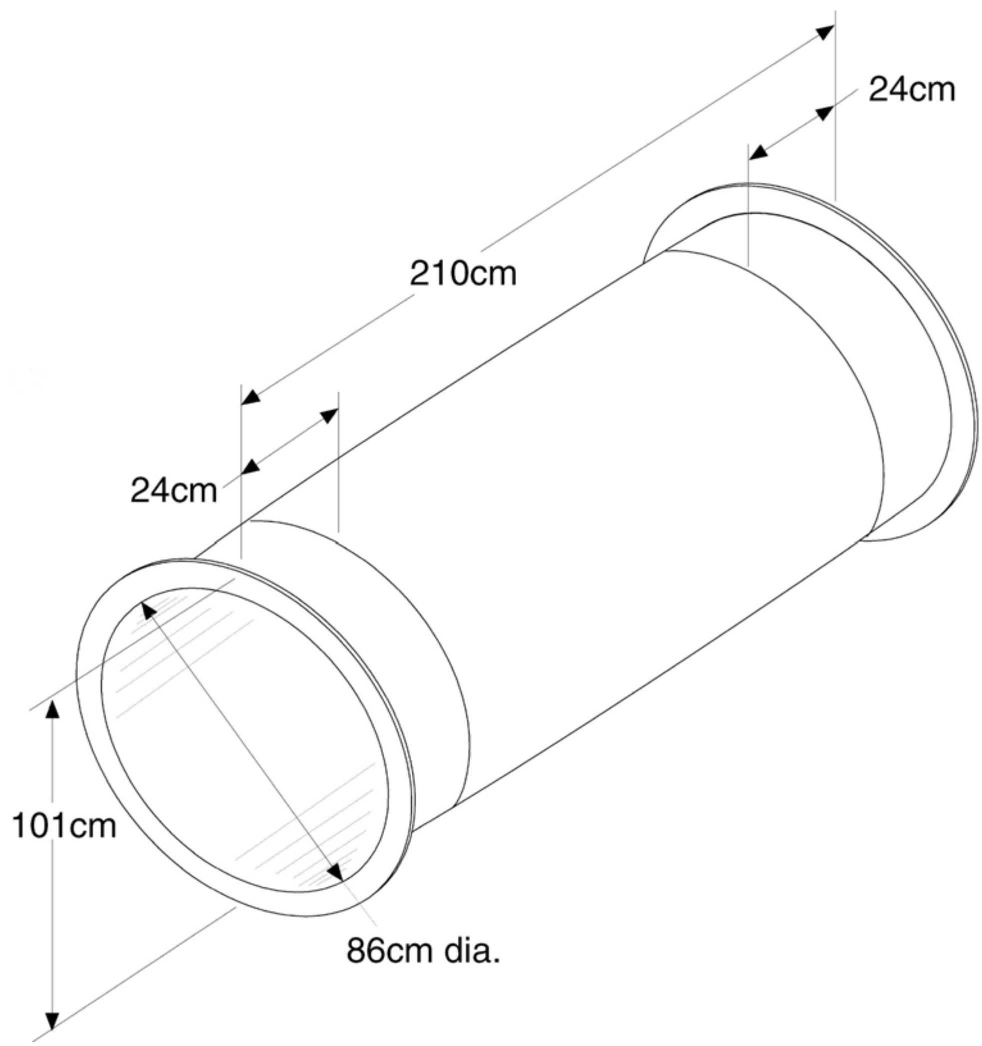


Figure 6. Basic design of the antenna used with the large surface pair-trawl to sample PIT-tagged juvenile salmonid at the entrance to the Columbia River estuary between rkm 61 and 83.

The FS1001A transceiver was specifically designed for installation at hydroelectric facilities on the Columbia and Snake Rivers. The transceiver unit included a serial maintenance port to monitor the status of the system and a high-speed serial port to log individual PIT-tags as they were detected. We used a wireless modem to transmit data and reports to a portable computer mounted in a tow vessel.

Two 12-volt deep-cycle batteries were mounted on each side of the raft for better stability in rough water. Fully-charged batteries provided sufficient power for at least a 10-h daily sample period. A 15-m long cable connected the transceiver to the underwater antenna, which was strapped to the cod end of the trawl and suspended from a buoy 1.8 m beneath the surface. A strain-relief line was wrapped with the cable and bridled to the raft and the antenna to tow the raft and detection electronics with the trawl.

PIT-tag detection and transceiver status monitoring software (Multimon) was utilized for recording purposes. In addition to the date, time, GPS position (of the tow vessel) and tag code of PIT-tagged fish, the software also recorded internal transceiver, diagnostic, and status reports. These reports were set to generate and record every 2 min as part of the standard Multimon data files. During unplanned power outages or computer failures, the internal buffering capability of the FS-1001A transceiver provided backup PIT-tag detection records for the small trawl, but the date and time of detections and the status and diagnostic reports for the transceiver were lost.

During most deployments of the small trawl, we recorded salinity, temperature, and depth at 5-sec intervals with a YSI model 6920 probe. The instrument was mounted on the top of the trawl about 1 m forward of the antenna. We had attempted to mount the unit directly on the antenna but discovered that it created unacceptable electronic interference with PIT-tag recording equipment.

Because of the preliminary nature of the small trawl sample effort in the lower estuary, and the shoreline sample effort in the upper estuary, we did not submit those data files to PTAGIS. Rather, these data files were incorporated into an independent database (Microsoft Access) and correlated with non-MULTIMON data. Sampling activities were also recorded in a hand-written log, with entries made for the date and time of deployment/retrieval of the trawl or net flush, GPS coordinates, salinity, temperature, diver observations, and impacts to fish (numbers of salmonids and non-salmonids entrapped or killed in the trawl). Due to the low detection rates of PIT-tagged fish in the lower estuary during the spring, summer sampling was cancelled.

Detection Efficiency Tests

For both the large and small trawl systems, we used a procedure for evaluating electronic performance of the detection antenna that did not require the release of test fish (Ledgerwood et al. 2004b). A 2.5-cm-diameter polyvinyl chloride (PVC) pipe with a small plastic funnel on each end was positioned through the center of the antennas. The pipe extended out each end of the antenna beyond the range of the electronic field (about 0.5 m). We evaluated detection efficiency by attempting to detect 50 PIT-tags that were attached at known intervals and orientations to a vinyl coated tape measure (Appendix Table 1).

We chose densities and orientations along the 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 and was tested about once per week for each system.

Impacts on Fish

For both the large and small trawl systems, we used nearly continuous video monitoring of fish exiting the antenna. For the large trawl, we used periodic diver observations (about weekly) to assess impacts of trawling on fish. When debris accumulations or other problems were observed near the antenna on the video monitor, tow speed was reduced, and the cod-end and antenna were pulled up to the surface (large trawl) or the net and associated equipment were retrieved (small trawl) for cleaning.

In the small trawl, the large-mesh wings 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 the retrieval process, which required longer drifts, 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.

Statistical Analyses

Numbers of yearling Chinook and steelhead detected per hour during daylight vs. darkness hours were evaluated using one-way ANOVA (Zar 1999). The number of detections and the minutes within each hour that the detector was energized for each of the four diel sampling periods were separated into daylight- and darkness-hour categories, and mean hourly detection rates were pooled for wild and hatchery rearing types of each species for each sampling period.

These mean hourly detections rates were compared by ANOVA. Diel detection curves were prepared for yearling Chinook salmon and steelhead based on the average number of fish detected each hour weighted by the number of minutes within each hour that the detectors were energized. There were insufficient detections of other species for meaningful analysis.

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 fall Chinook salmon tagged and either released to migrate in the river or transported from McNary Dam in late June and July. These plots represent 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.

Multiple linear regression was used to evaluate differences in travel speed to Jones Beach between inriver migrants and transported fish each year. Factors used in the regression models of travel speed included Julian date, flow, "treatment" (inriver migrant vs. transported), and two-way interaction terms for the three main effects. Flow data were daily average discharge rates at Bonneville Dam ($m^3\ s^{-1}$). When interaction between Julian date and flow was not significant, these terms were removed from the model. All regression analyses were performed using data from individual fish.

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). Daily detection data collected in the estuary using a surface pair-trawl is compared for 2005. Treatment groups (barge release or inriver migrant) were defined based on the barge release dates and were treated as "cohorts" rather than individually. The daily inriver migrant groups were paired to barged-released fish by date of barge release and selected to include only those PIT-tagged fish released at sites from McNary Dam upstream. Early season barge releases often occurred before there were sufficient inriver migrating fish being detected at Bonneville Dam for comparison. Recovery percentages for both groups are shown for the entire season but were not used for analysis unless both groups were present.

Components of the logistic regression model were treatment as a factor and date as a covariate. The model estimated the log odds of the detection rate of the daily cohorts (i.e., $\ln[p/(1-p)]$) as a linear function of the components, assuming a binomial distribution for the errors. All analyses in this report are preliminary. A stepwise procedure was used to determine the appropriate model. First, the model containing interaction between treatment and date was fitted. If the interaction term was not statistically significant ($\alpha > 0.05$) the term was removed and a reduced model was fitted. The model was further reduced depending on the significance between treatment and date. Various diagnostic plots were examined to assess the appropriateness of the model. Extreme or highly influential data points were identified and included or excluded on an individual basis, depending on the data situation. Data for yearling Chinook salmon appeared adequate for these analyses; data for steelhead was analyzed, but sample sizes were small.

The daily barged and inriver groups have similar distributions in the sampling area and presumably pass the sample area at similar times. Thus we assume these groups are 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 (near or at Bonneville Dam) to the estuary. To test the assumptions that barged and inriver-migrant groups pass 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.

Hourly proportions were then compared using a contingency table, and the average differences were presented for each hour by subtracting the proportion of inriver migrants from the proportion of transported fish. Thus for each hour interval, no difference between groups indicated that similar proportions of transported and inriver migrant fish passed that hour; a positive difference indicated higher proportions of transported fish, and a negative difference indicated a higher proportion of inriver-migrant fish passed during that hour. These data were not weighed by date.

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

Large Trawl System Detections

In 2005, we detected 14,101 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 stocks and rearing types were equally represented in the total detections. For example, 64% of our detections were Chinook salmon, 32% were steelhead, and the remaining 4% were other salmonid species (Table 1). Eighteen percent of our detections were wild fish and 79% were hatchery-reared. Sources of PIT tags detected in the estuary from the different river basins are shown in Figure 7. Annual differences in PIT-tagging strategies, hydrosystem operations, and proportions of fish transported each year contribute to variations in the proportions from each source. This complicates multi-year comparisons among sources, species, and run or rearing types.

Table 1. Species composition and rearing-type history for PIT-tagged fish detected in the large trawl at Jones Beach, 2005.

Species/run	Hatchery	Wild	Unknown	Total
Spring/summer Chinook salmon	6,593	1,568	121	8,282
Fall Chinook salmon	643	20	37	700
Coho salmon	205	1	14	220
Steelhead	3,627	895	10	4,532
Sockeye salmon	52	28	0	80
Sea-run cutthroat trout	0	6	0	6
Other	0	0	7	281
Grand total	11,120	2,518	189	14,101

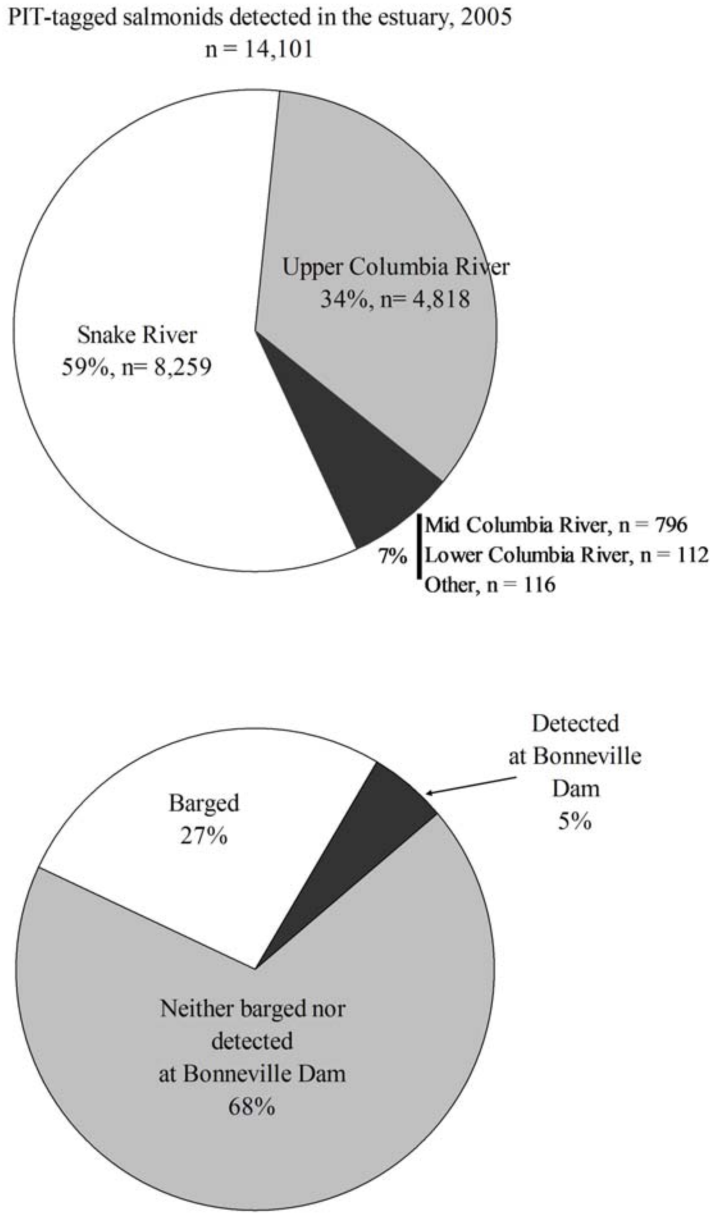


Figure 7. River basin sources and migration histories of PIT-tagged fish detected in the estuary, 2005. Less than 2% of all estuarine detections were of fish released downstream from Bonneville Dam. In 2005, operation of the corner collector/bypass at Bonneville Dam dramatically reduced the number of PIT tag detections there (this route lacks PIT-tag detection capability).

Trawl system equipment was energized for 909 h in 2005, with over 14,000 detections as opposed to 794 h in 2004 with over 16,000 detections (Figure 8). According to the PTAGIS database, there were about 26% fewer PIT-tagged fish released into the river basin during 2005 than in 2004, contributing to the decreased detection numbers in 2005. However, there are additional factors that affect annual detection numbers in the estuary. For example, mean flow volumes in the Columbia River were 6,663 $m^3 s^{-1}$ in 2004 and 5,776 $m^3 s^{-1}$ in 2005 during mid-April through June (Figure 9).

We speculate that as a result of higher flow volumes in 2004, fish groups were more dispersed and passed through the sample area more quickly than in 2005. This would have decreased sample efficiency and detection numbers in 2004 compared to 2005. Large differences in flow volume between years illustrate the complications of attempting direct comparisons of detection numbers between years. For example, spring-time flows in 2002 were much higher than during the same period in 2001, but the total number of estuary detections in 2002 (11,451) was more than twice that in 2001 (5,542). However, this difference was also related to decreased survival of fish during the drought year of 2001 and a 69% increase in the total number of PIT-tagged fish released in 2002 over 2001 (Ledgerwood et al. 2004b).

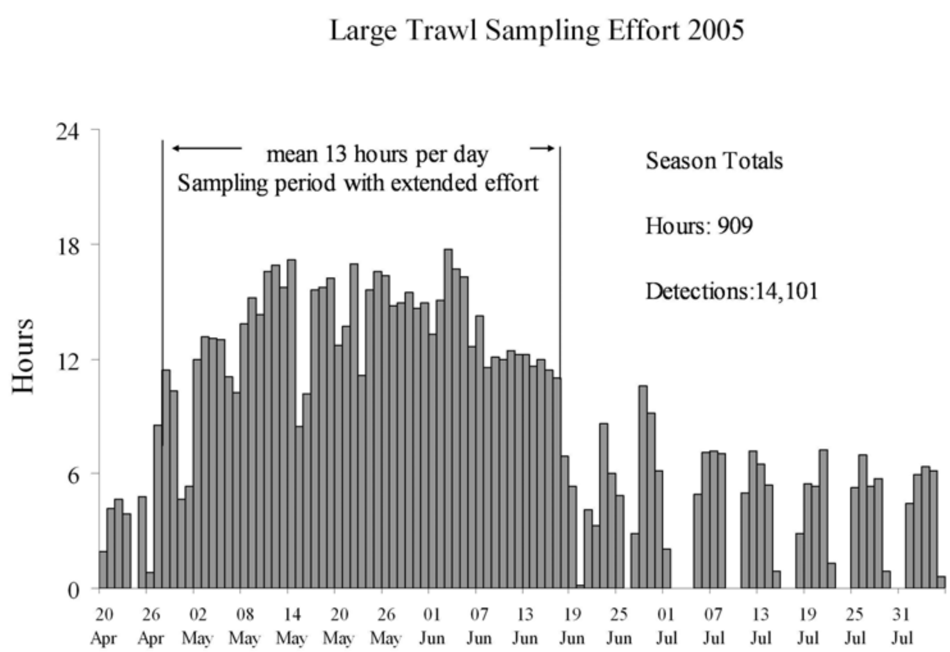


Figure 8. Number of hours sampled in 2005 using the large trawl PIT-tag detection system in the upper Columbia River estuary at Jones Beach, near rkm 75.

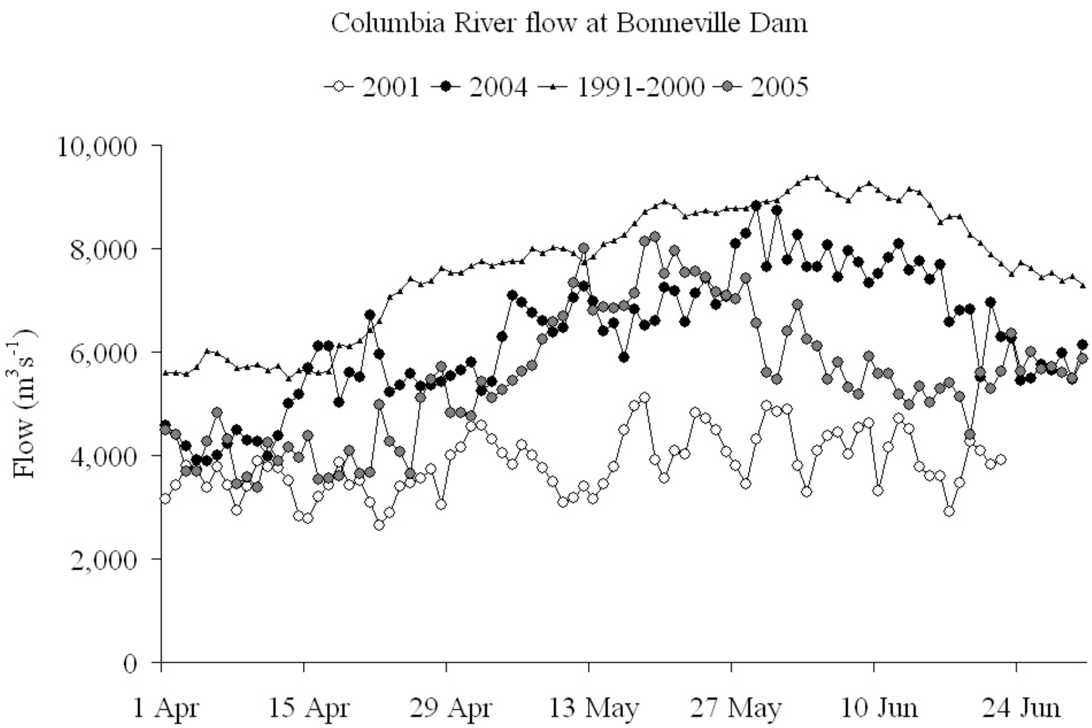


Figure 9. Columbia River flows at Bonneville Dam during the study periods of 2004 and 2005 compared to the average flow from 1991 to 2000. Drought-year flows for 2001 are also shown for comparison.

Small Trawl System Detections

Using the small trawl system, we sampled for 73 h in the brackish-water portion of the lower estuary, but we detected only 38 PIT-tagged fish (Figure 10). The majority of lower estuary sampling was conducted during daylight hours on the south side of the shipping channel between Buoy 10 and the Astoria-Megler Bridge (Figure 11). However, we also made several cruises on the north side of the river up to the bridge during both daylight and darkness hours. Neither sample area in the lower estuary was very productive. There was a strong bias towards detection of steelhead in the small trawl relative to the large trawl, with steelhead comprising 57% of total detections in the small trawl compared to about 34% in the large trawl (Appendix Table 3). A similar bias towards steelhead was seen in the small trawl used in 2004 (86% steelhead in the small trawl vs. 22% in the large trawl). Furthermore, it was apparent that the sample depth of small trawls used in both years was inadequate to collect the deeper traveling and more numerous PIT-tagged Chinook salmon.

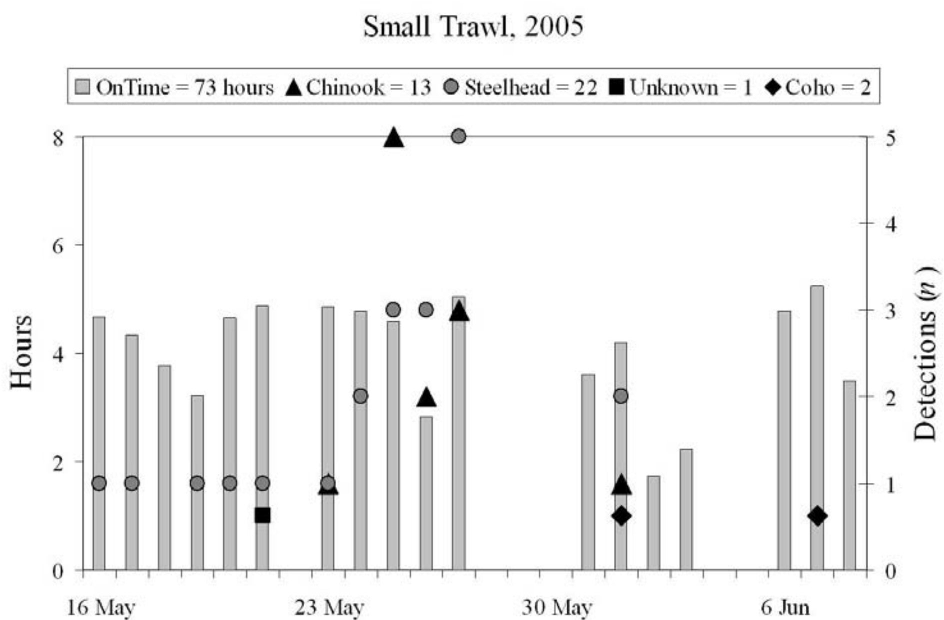


Figure 10. Number of hours sampled and detections obtained in 2005 using the small trawl in the brackish water portion of the lower estuary between rkm 8 and 24.

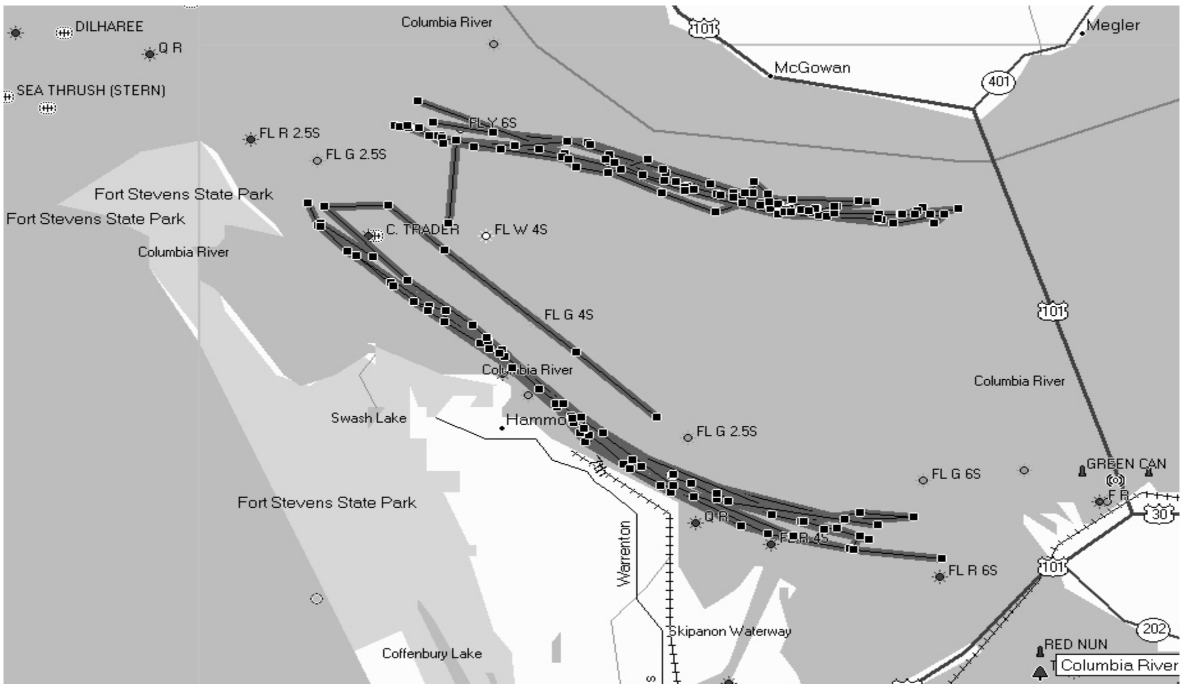


Figure 11. Map showing overlay of the GPS positions recorded during each 15-min net-flushing procedure. The positions were connected as daily 'routes' and illustrate the various sampling cruises of the small trawl in the lower estuary between rkm 8 and 16, 2005.

Shoreline System Detections

In order to evaluate the ability to guide smolts through an antenna system, we occasionally deployed a passive PIT-tag sampling device along the shore at Jones Beach as well. Following the small trawl sample period, we adapted the same Hobe Cat and Pelican box system for the shoreline sampler equipped with wireless video and data transmission capability (Destron-Fearing transceiver). This enabled us to view, record and potentially quantify fish passage, while capturing detection data, all from ashore. We sampled for about 20 h over a 6-d period with no detections.

Detection Efficiency

Tag-reading efficiency of each detection system was evaluated using PIT tags secured to a vinyl tape measure and passing the tape through each antenna within 2 cm of the center. Both the large and small system antennas were designed to maximize the size of the fish-passage opening. Therefore center area of each antenna has marginal detection performance relative to areas closer to the wall. These in-situ evaluations were purposefully designed as a rigorous test of electronic performance; they did not reflect reading efficiency for PIT-tagged fish, which generally pass in the more optimal areas of the electronic field.

In the dual-coil freshwater trawl system, results from these real-time tests showed relative differences in detection efficiency between coils. This helped to validate transceiver and cable problems occasionally suggested by readings on analogue meters. In the single-coil saltwater antenna, test results were used to better understand performance under variable background noise levels, which are reported through the software using digital transceivers. Data presented below are pooled values for the season. In general, one would expect higher reading efficiencies with greater spacing between tags and with improved alignment of tag orientation to the electronic field. However, these results were not always obvious from the pooled results.

For the large trawl, a properly tuned electronic system read test-tags spaced 30-cm apart at rates of about 45% for tags held perpendicular to the electronic field and at rates of about 40% for tags oriented at 45° to the electronic field (Figure 12, top). When spacing between tags was increased to 61 cm, detection efficiency increased to 80% for perpendicular tags and 86% for tags at 45° angles. When tags were passed within about 20 cm of the antenna wall (tests in 2003 and 2004), rather than through the center of the antenna, detection rates increased to 98%, regardless of spacing and orientation.

For the small trawl, a properly tuned electronic system read about 65% of test tags spaced 30-cm apart and held perpendicular to the electronic field. The system read about 42% of the tags spaced 30-cm apart and oriented at 45° to the electronic field (Figure 12, bottom). When spacing between tags was increased to 61 cm, detection efficiencies were similar, at 53% for perpendicular tags and 44% for tags at 45°. As spacing between tags increased to 91 and 122 cm, the detection rate increased for tags at 45° and decreased for tags at 0°.

In the large trawl, detection efficiency was also evaluated by comparing the number of fish originally detected on the front (upstream) antenna coil and subsequently detected on the rear (downstream) coil (Figure 13). Fifteen percent of all individual fish detections were recorded on the rear coil only (missed by the front coil). The miss rate of the front coil, as in previous years, was correlated with higher fish densities during peak passage of fish in mid to late May, and this was more than likely related to electronic collision of tag codes (Downing et al. 2003). At low fish densities (less than about 15 detections/h), the front coil typically missed about 10% of passing fish, but at higher fish densities the miss rate of the front coil approached 20%. Increased 'miss rates' were also noted when the electronic components were not properly tuned, as evidenced during 8-15 June, when a transceiver was failing and miss rates were over 25% on the front coil.

We used the daily proportion of fish detected on the front and rear coils to help flag problems with large trawl components. This proportion also indicated fish behavior inside the antenna; the strongest reading between the two transceivers was from the transceiver associated with the rear antenna coil. From this we inferred that once fish entered the antenna and were swept downstream towards the exit, their tag orientation tended to improve. Presumably, they passed through holding head-first into the current, with the tag perpendicular to the electronic field and thus optimally oriented for detection.

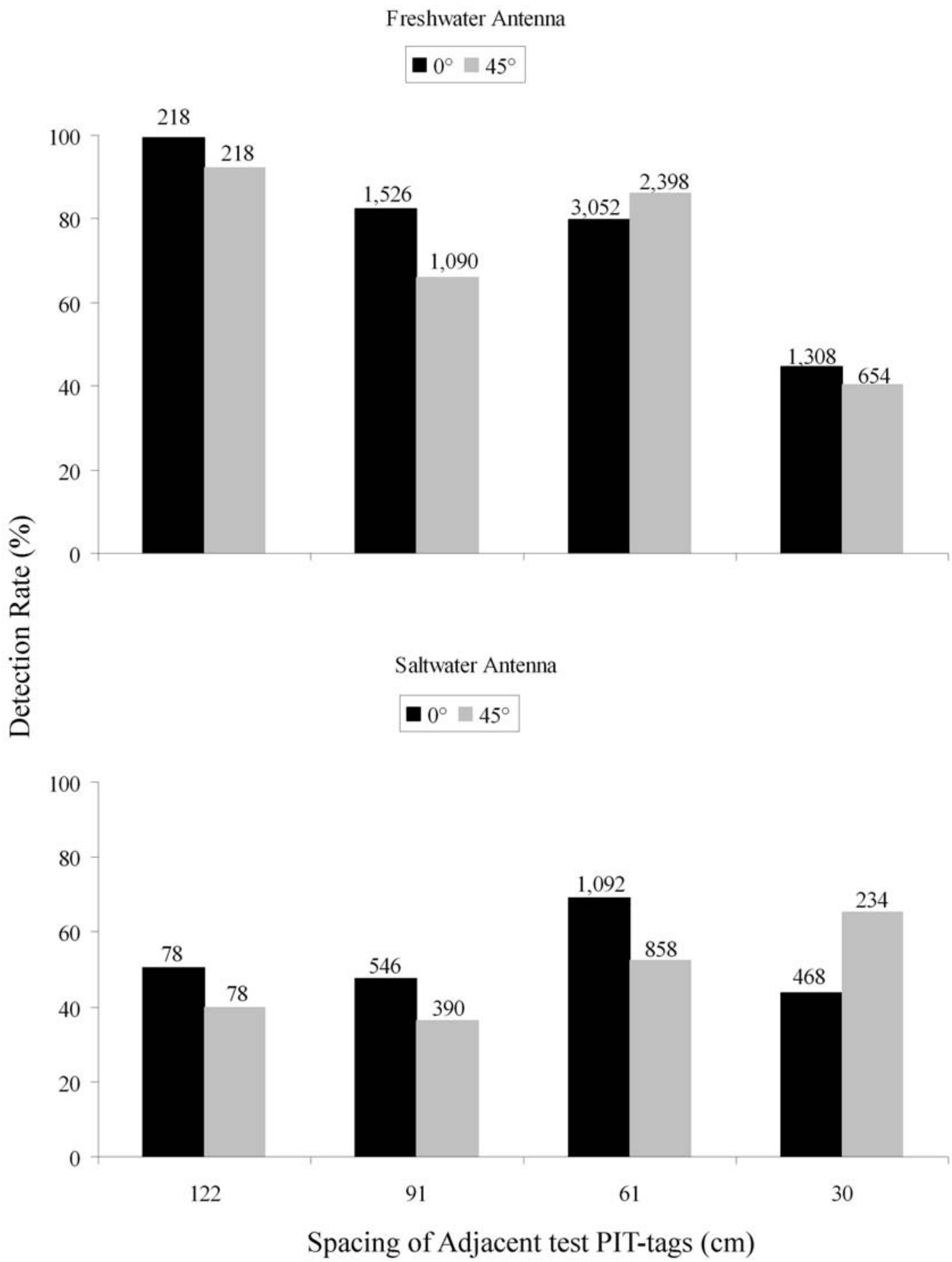


Figure 12. Detection efficiency evaluation using 132.4 kHz PIT-tags attached to vinyl tape measures, 2005. Various spacing between 'super' tags and orientation to the electronic field were used (0° or 45°) but all tape configurations were identical. Tags were passed through the antenna repeatedly on different dates (total potential tags list above the bars).

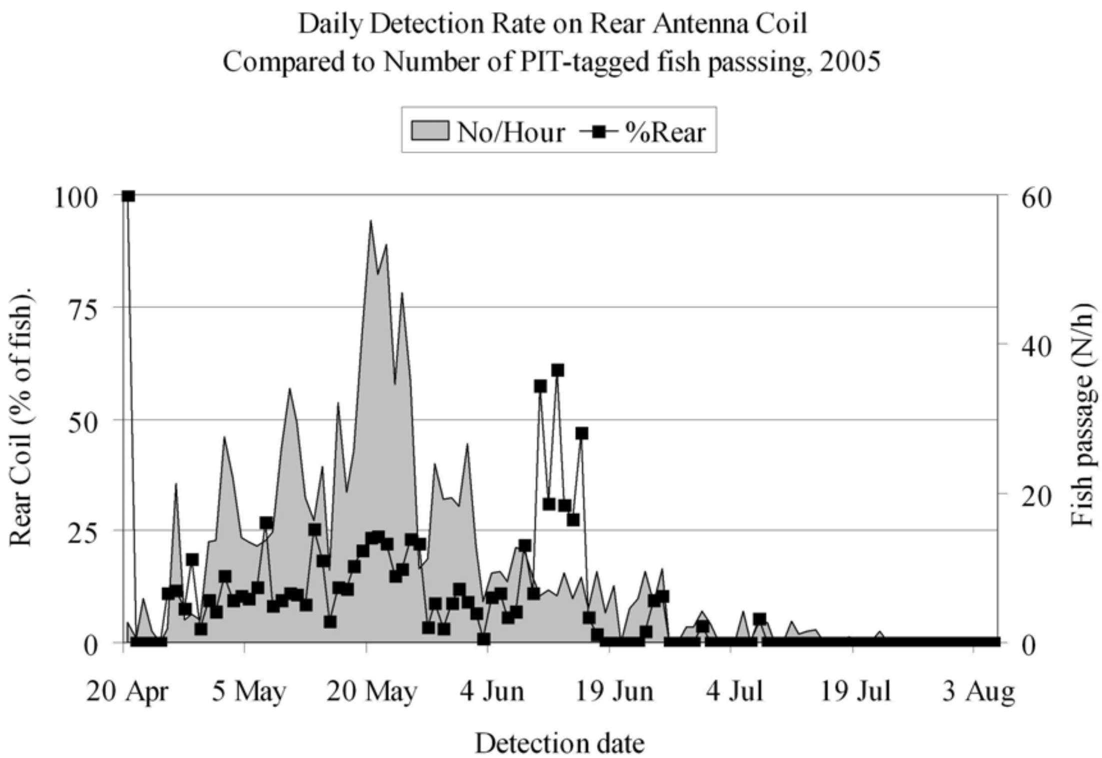


Figure 13. Proportion of PIT-tagged fish detected only on the rear antenna coil of the large trawl compared to daily fish passage, 2005.

The median passage time of fish between detections on front and rear coils was 5 seconds. Of the 11,919 individual fish first detected on the front coil, only 833 were missed by the rear coil (7%). We believe that the combined detection rate of our 2-coil antenna exceeded 95% of all PIT-tagged fish passing through the antenna.

Impacts on Fish

We used nearly continuous (daylight) video and periodic diver observations to visually assess impacts to fish in the large trawl and adjusted sampling operations accordingly. When debris accumulations or other problems were observed, we reduced tow speed and pulled the detection antenna to the surface to clean the cod end of the net. To clean debris in extreme conditions, we disconnected the electronics and inverted the entire net. With the small trawl system, tow durations were relatively short, and the net was cleaned during retrieval.

We recovered 300 impinged, gilled, or otherwise injured juvenile salmonids in the netting during the trawl inspections or upon retrieval of the trawls (Appendix Tables 4). It is possible that other mortalities and injuries to fish occurred, but were not observed due to the net inversion process of the large trawl or by fish being shaken out through the small trawl antenna during retrieval. However, divers that inspected the trawl body and wing areas of the nets reported that it was rare to observe fish swimming close to the webbing except near the antennas. Rather, fish tended to linger near the entrance to the trawl body and directly in front of the antenna.

In previous years, we eliminated visible transitions between web size and color in the trawl body and cod end; these transitions appeared to attract fish and delay their passage out of the net. We continued to flush the net (bring the trawl wings together) every 15 min to discourage fish from holding in the net and expedite their passage through the antenna. Some fish detected on the front antenna coil swam forward into the trawl again and were detected repeatedly on the front coil. Other fish detected on the front antenna coil passed downstream but were detected repeatedly on the rear antenna coil.

For example, one steelhead (3D9.1BF20221A3) was detected twice on the front coil and 250 times on the rear coil over more than 1 h. Altogether, 13 fish, the majority steelhead, were detected over 100 times before exiting the antenna. Such observations were relatively rare, and only 80 fish (0.6%) had greater than 20 multiple detections (Table 2). While volitional passage through the antenna occurred, the majority of fish were detected during the 5-min net-flushing periods.

Table 2. Dates, tag codes, and number of repeat detections for individual salmonids detected more than 20 times during passage through the large trawl detection system, 2005. Species codes are 1 for Chinook salmon and 3 for steelhead. F indicates detection on front coil only, R indicates detection on rear coil only.

Detection date	Species code	Tag ID	Detection records (n)	Duration (h)	Coil
29-Apr-05		3D9.1BF1C336A9	134	1.12	both
30-Apr-05		3D9.1BF1BE9546	94	0.47	both
02-May-05	1	3D9.1BF204D1D8	22	0.27	both
02-May-05	3	3D9.1BF20505D2	56	0.43	both
02-May-05	1	3D9.1BF228997B	62	0.32	both
03-May-05	3	3D9.1BF1A2B87F	27	0.22	both
03-May-05	3	3D9.1BF209C009	39	0.83	both
05-May-05	3	3D9.1BF22ACC42	30	0.21	both
07-May-05	3	3D9.1BF18BA830	77	0.48	both
07-May-05	1	3D9.1BF228D25B	25	0.21	both
07-May-05	1	3D9.1BF20E46B2	25	0.14	F
08-May-05		3D9.1BF18DCFC6	21	0.31	both
08-May-05	3	3D9.1BF1F99035	27	0.13	both
09-May-05	1	3D9.1BF20E9C50	36	0.39	both
10-May-05	1	3D9.1BF18A3228	31	0.41	both
12-May-05	1	3D9.1BF20E1490	28	0.31	both
12-May-05	3	3D9.1BF2084DE1	37	0.66	F
13-May-05	3	3D9.1BF20392B4	26	0.81	both
13-May-05	1	3D9.1BF228943C	22	0.13	both
13-May-05	3	3D9.1BF2089D84	66	2.29	F
14-May-05	3	3D9.1BF1A2F9F9	21	0.13	both
14-May-05	3	3D9.1BF20221A3	252	1.13	both
14-May-05	3	3D9.1BF207EDBE	64	4.15	both
14-May-05	3	3D9.1BF20916F2	183	4.18	both
14-May-05	3	3D9.1BF18E2AB9	93	0.89	both
14-May-05	3	3D9.1BF20A3938	75	0.50	R
14-May-05	1	3D9.1BF22B1371	23	0.47	F
15-May-05	3	3D9.1BF20A98BE	43	0.79	both
16-May-05	1	3D9.1BF2283F19	26	0.79	both
16-May-05	3	3D9.1BF2020BA6	26	0.56	both
16-May-05	3	3D9.1BF22F8815	23	0.37	both
16-May-05	1	3D9.1BF20E7538	51	0.37	both
17-May-05	3	3D9.1BF18CED9F	45	0.41	both
17-May-05	3	3D9.1BF2078B97	41	1.61	both
18-May-05	3	3D9.1BF20030A1	119	0.66	F
19-May-05	3	3D9.1BF2082625	277	2.47	F
20-May-05	3	3D9.1BF18C4146	28	0.17	both
20-May-05	3	3D9.1BF195B026	28	0.16	both

Table 2. Continued.

Detection date	Species code	Tag ID	Detection records (n)	Duration (h)	Coil
21-May-05	3	3D9.1BF20B05DB	21	0.05	both
21-May-05	3	3D9.1BF1F8E7A4	103	2.14	R
22-May-05	3	3D9.1BF2025DE5	92	3.02	both
22-May-05	3	3D9.1BF2083740	99	2.11	both
22-May-05	1	3D9.1BF22B4B79	22	0.78	both
23-May-05	1	3D9.1BF2040B9E	46	0.21	both
23-May-05	1	3D9.1BF239A6B3	27	0.27	both
23-May-05	3	3D9.1BF207E1C7	292	5.65	F
24-May-05	1	3D9.1BF21093C4	113	2.72	both
24-May-05	3	3D9.1BF2276A33	80	1.78	both
24-May-05	1	3D9.1BF201BC11	35	0.52	both
27-May-05	1	3D9.1BF18A7615	82	0.74	both
28-May-05	3	3D9.1BF22DB7A1	106	1.75	both
28-May-05	3	3D9.1BF236A834	63	0.50	both
29-May-05	3	3D9.1BF20B8D4B	51	0.44	both
29-May-05	1	3D9.1BF18D0709	41	0.27	both
29-May-05	3	3D9.1BF18D8CA2	53	0.24	both
29-May-05	3	3D9.1BF18E5EAB	21	0.36	both
29-May-05	3	3D9.1BF20309DE	233	1.33	both
29-May-05	3	3D9.1BF230050E	34	1.18	both
29-May-05	3	3D9.1BF18E71E8	22	1.68	both
29-May-05	3	3D9.1BF227777E	24	0.28	F
29-May-05	1	3D9.1BF23232F0	26	0.09	F
30-May-05	1	3D9.1BF19A246F	23	1.30	both
30-May-05	3	3D9.1BF20C37D2	44	0.32	both
30-May-05	3	3D9.1BF20D0D5A	22	0.85	both
30-May-05	3	3D9.1BF20D2C86	41	1.60	both
31-May-05	3	3D9.1BF23EFED9	171	2.22	both
31-May-05	1	3D9.1BF20E6F6A	22	3.66	F
01-Jun-05	3	3D9.1BF189DCAE	113	0.82	both
01-Jun-05	3	3D9.1BF2047C84	39	0.19	both
02-Jun-05	3	3D9.1BF227A724	31	0.33	both
02-Jun-05	1	3D9.1BF1A26B51	63	0.30	F
04-Jun-05	3	3D9.1BF2023329	44	0.41	both
06-Jun-05	3	3D9.1BF2037182	23	1.37	both
08-Jun-05	3	3D9.1BF2303BE1	42	1.45	both
08-Jun-05	4	3D9.1BF22A7072	190	3.32	F
10-Jun-05	3	3D9.1BF230D992	73	0.39	both
11-Jun-05	3	3D9.1BF2077986	25	0.83	both
13-Jun-05	3	3D9.1BF2090583	22	0.39	both
13-Jun-05	3	3D9.1BF20BC101	51	0.32	F
07-Jul-05	1	3D9.1BF23EEDCC	70	0.50	both

Diel Detection Patterns (Spring Migration)

Between 28 April and 17 June, we detected 8,499 yearling Chinook salmon and 4,469 steelhead using two daily sampling crews. We used these totals to evaluate hourly diel distributions (Figure 14). Detections of juvenile sockeye and coho salmon were too few to provide meaningful comparisons. During this two-crew period, the detector was energized and recorded data for an average of 13 h/d, with scheduled down times generally between 1400 and 1900 PDT (Appendix Table 5).

Hourly detections rates for both hatchery and wild yearling Chinook salmon were significantly greater during darkness than during daylight hours (16 vs. 7 hatchery fish/h, $P = 0.000$, and 3 vs. 2 wild fish/h, $P = 0.000$, respectively). Hourly detections rates for steelhead did not differ significantly between darkness and daylight hours (6 vs. 5 hatchery fish/h, $P = 0.469$, and 1 vs. 2 wild fish/h, $P = 0.559$).

Timing and Migration History

Yearling Chinook Salmon and Steelhead (Spring Migration)

Travel time (in days) for inriver migrating fish was measured from the tailrace of Lower Granite Dam to detection in the large trawl at Jones Beach for both yearling Chinook and steelhead. Median travel times in 2004 and 2005 were similar for both species (17 d), despite the slightly lower flows in the latter year (Table 3).

Median travel time to the estuary for yearling Chinook salmon detected at Bonneville Dam was slightly slower in 2004 than in 2005 (1.9 vs. 1.8 days) whereas travel times for steelhead were the same in both years (2.0 days). Within species, travel times from barge-release sites to the estuary were the same for 2004 and 2005 (yearling Chinook salmon median 2.2 days and steelhead median 1.9 days).

Travel times from detection in the upper estuary to detection in the lower estuary in 2005 fit within the range of similar observations obtained in 2002 and 2004 (Table 4). Though we were unable to confirm the routes of passage through the estuary for these 4 yearling Chinook salmon and 6 steelhead, the variations in travel times to the lower estuary, (range 16 to 41 h), corresponded to encounters with flood tides following arrival in the upper estuary—the more flood tides encountered (range 1 to 3), the longer the travel times.

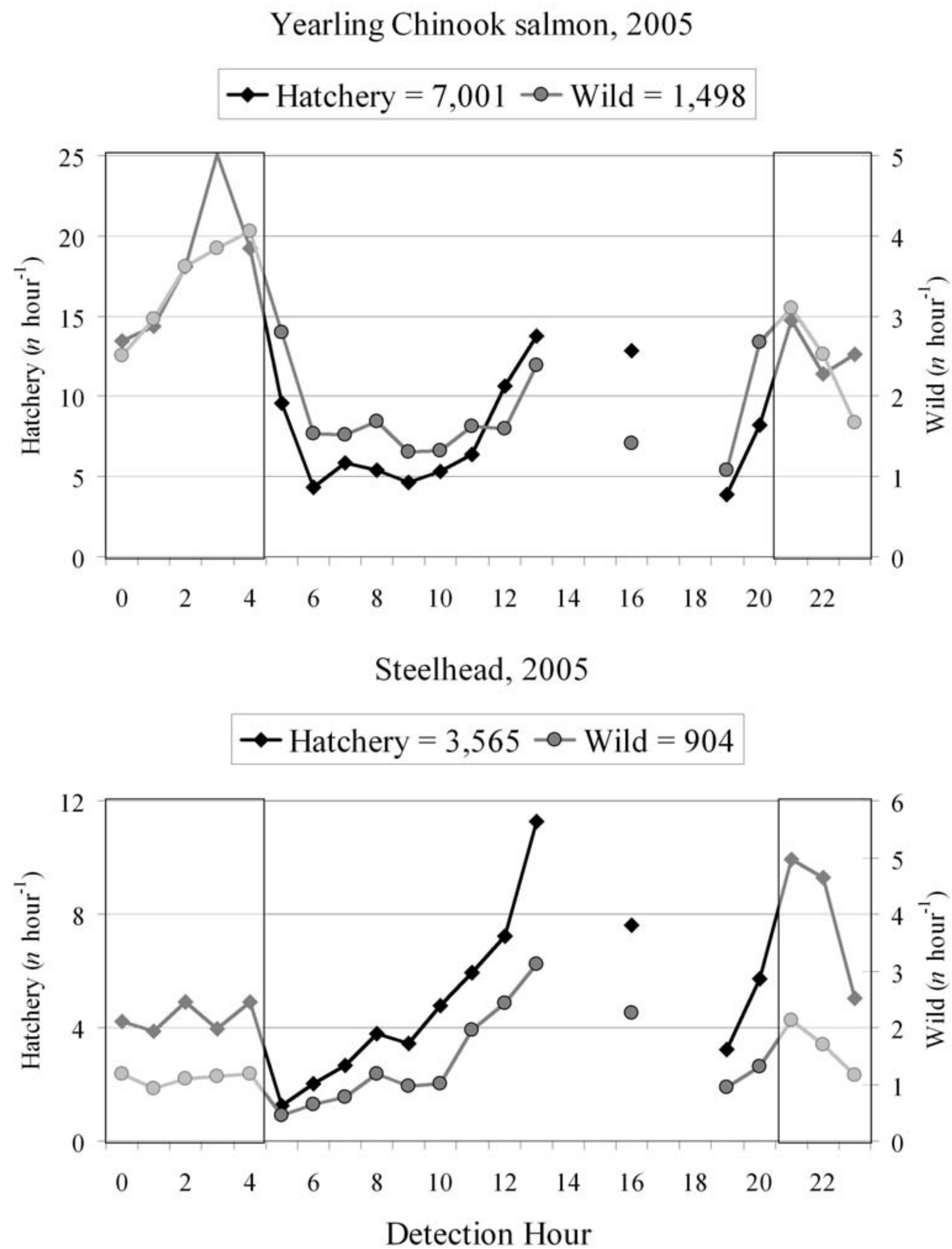


Figure 14. Average hourly detection rates using the large trawl system of yearling Chinook salmon and steelhead during the two crew sampling period in the upper estuary at Jones Beach (rkm 75).

Table 3. Median travel time in days to Jones Beach (rkm 75) for fish migrating in river from Lower Granite Dam, detected at Bonneville Dam, or released from a transportation barge. Yearling Chinook salmon and steelhead released downstream from Lower Granite Dam and those detected in the estuary after 9 June were excluded. Mean flow volume at Bonneville Dam was 6,663 $m^3 s^{-1}$ in 2004 and 5,776 $m^3 s^{-1}$ in 2005.

Yearling Chinook salmon				Steelhead			
2004		2005		2004		2005	
Travel time (d)	Sample (n)	Travel time (d)	Sample (n)	Travel time (d)	Sample (n)	Travel time (d)	Sample (n)
Released from Lower Granite Dam (rkm 695)							
16.6	857	17.3	1,183	16.6	153	16.9	278
Detected at Bonneville Dam (rkm 234)							
1.9	672	1.8	486	2.0	110	2.0	121
Release from transportation barge (rkm 225)							
2.2	1,926	2.2	3,075	1.9	245	1.9	407

Table 4. Lapsed time between detections for PIT-tagged fish detected on both the large and small trawl detection systems in 2002, 2004, and 2005 combined. Dashes indicate data not available.

Tag code/ Species code	Detection date/time: large trawl (upstream)	rkm	Detection date/time: small trawl (downstream)	rkm	Distance between trawls (km)	Lapse time (h)	No. flood tides between detections
3D9.1BF145F0DD/1	21 May/1957	74	23 May/1251	15	56	41	3
3D9.1BF15779BC/1	22 May/0706	71	23 May/1215	15	54	29	2
3D9.1BF11FF94D/1	29 May/1713	69	30 May/0918	23	45	16	1
3D9.1BF1AAD862/3	17 May/0826	75	18 May/0721*	--	--	23	1
3D9.1BF1DAAE17/3	17 May/1221	72	18 May/0721*	-	--	19	1
3D9.1BF1D568D4/3	17 May/1312	74	18 May/0721*	--	--	18	1
3D9.1BF19457EA/3	23 May/1122	72	24 May/1058	15	55	24	2
3D9.1BF1D56C72/3	25 May/2223	74	27 May/0716	19	55	33	3
3D9.1BF1AD077D/1	28 May/0547	68	29 May/0621	12	57	25	2
3D9.1BF22B0B13/3	24 May/2259	68	26 May/0947	18	52	35	3

* Detection time and geographic position data lost, position and time estimated using log book.

We also compared the daily differences in travel speed of fish to the estuary based on migration history (transported vs. inriver) and river flow (Figure 15). Travel speed to the estuary was slower for yearling Chinook salmon released from barges (median 68 km d^{-1}) than for those detected at Bonneville Dam on the same date (median 90 km d^{-1}; $P = 0.000$). Alternatively, there was no significant difference in travel speeds to the estuary for steelhead released from barges or detected at Bonneville Dam on the same date (medians 80 and 78 km d^{-1}, respectively; $P = 0.684$). However, interactions between date of release from a barge or detection at Bonneville Dam, flow, and migration history (transported vs. inriver) were present in some comparisons.

Subyearling Chinook Salmon (Summer Migration)

We detected 566 subyearling Chinook salmon that had been released after 28 April 2005. The majority of these fish (84%) were from Snake River release sites. Of the remaining fish detected, 90% originated in the Upper Columbia River and 6% originated in the mid-Columbia River. We detected 314 transported and 252 inriver migrant subyearling Chinook salmon between late May and early August (Figure 16). Most transported fish were detected prior to July and most inriver migrants in July.

Daily average travel speed of PIT-tagged subyearling fall Chinook salmon released from barges decreased with river flow (Figure 17). We speculate that the distributions of barge-released fish at the sample site would increase through the season, concomitant with decreasing river flows and a propensity for later migrants to slow their migrations and possibly even over-winter in the estuary. The median travel time for barge-released subyearling Chinook salmon to the estuary was 2.5 days. It was not possible to accurately calculate daily median travel time or travel speed for inriver migrant subyearling fish from release site to detection in the estuary due to their low detection rate at Bonneville Dam ($n = 6$).

Subyearling, ocean-type Chinook salmon that were released in 2004 and over-wintered in the basin are termed "residuals." We detected 6 Snake River residuals in the upper estuary between 8 and 22 May, none of which had been transported.

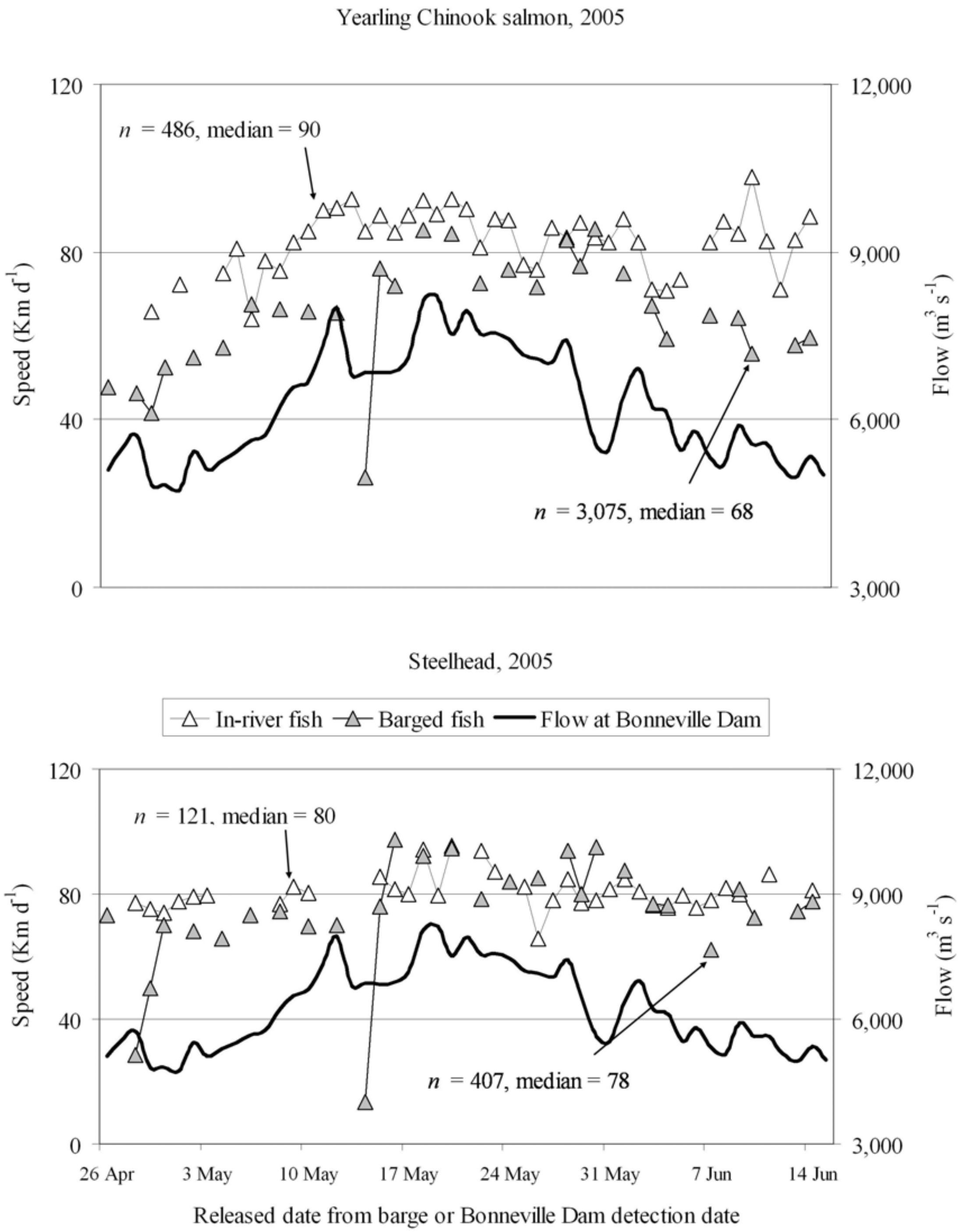


Figure 15. Daily mean travel speed to the estuary of yearling Chinook salmon (upper chart) and steelhead from detection at Bonneville Dam or release from a barge to detection in the estuary (near rkm 75) using the large trawl system.

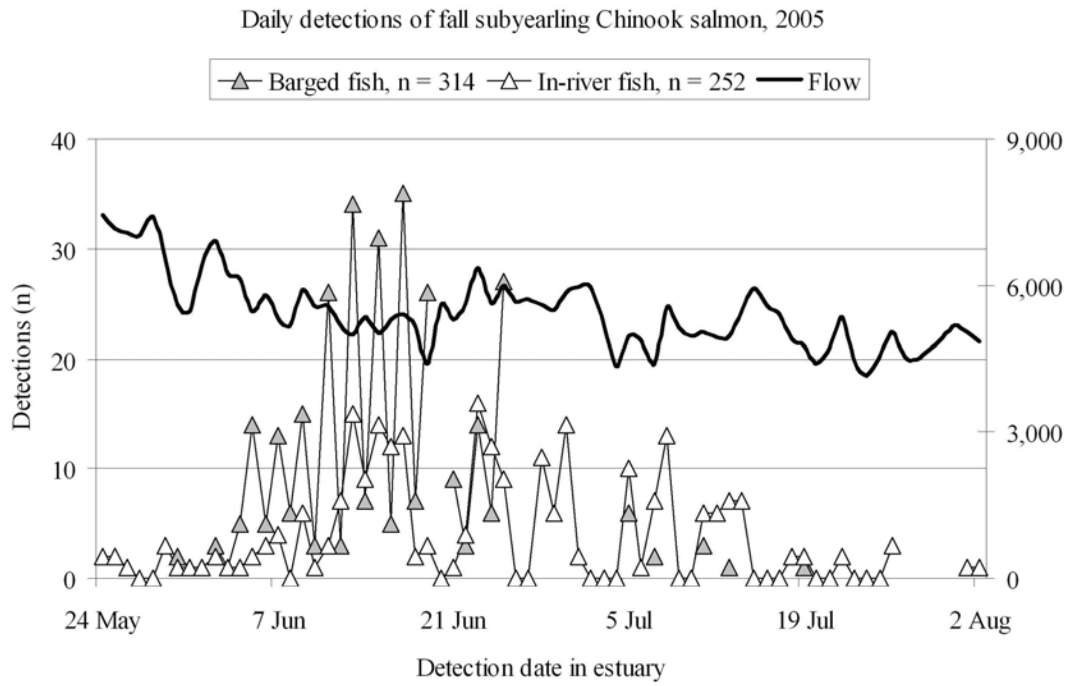


Figure 16. Detection distribution for subyearling Chinook salmon released from barges and detected with the large trawl system in the upper estuary at Jones Beach (rkm 75) as compared to river flow.

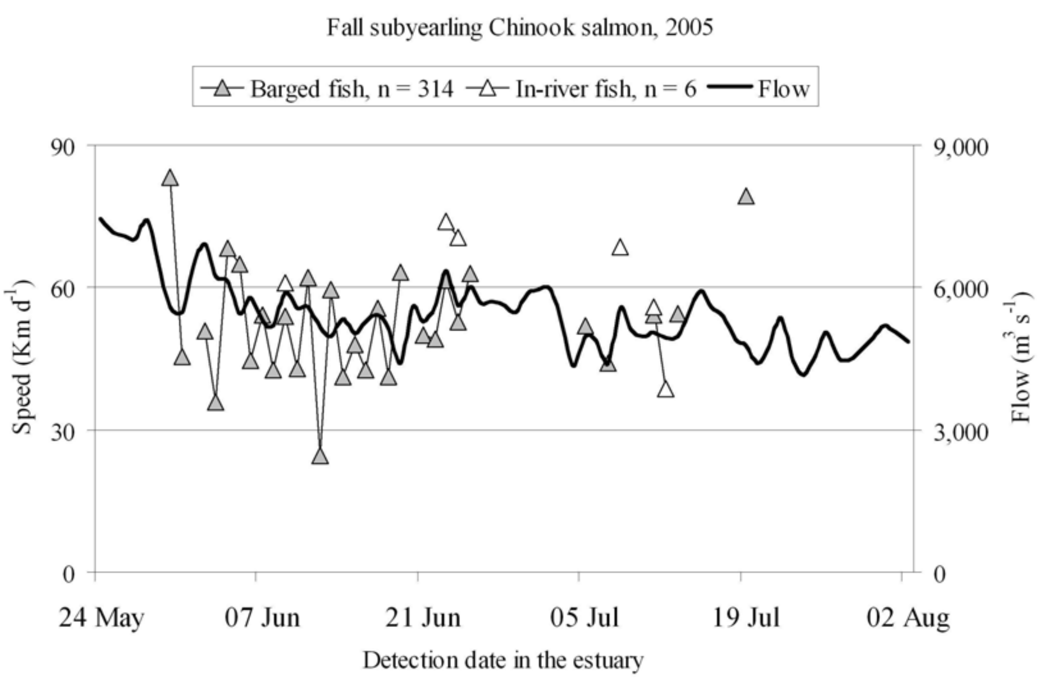


Figure 17. Daily mean travel speed for subyearling Chinook salmon released from barges and detected with the large trawl system in the upper estuary at Jones Beach (rkm 75) as compared to river flow.

Transportation Evaluation

Of the 55,962 Chinook salmon and 34,156 steelhead PIT tagged for the NMFS transportation study in 2005, 12,726 and 10,488, respectively, were diverted at Snake and Columbia River dams for transport. Including diverted river-run fish, totals of 122,954 Chinook and 44,026 steelhead were transported. Of these totals, we detected 3,338 Chinook and 659 steelhead in the estuary (Appendix Tables 6-7).

Of fish that completed migration in the river (including fish originating in the Columbia River), 21,640 yearling Chinook and 7,182 steelhead were detected in the juvenile bypass system at Bonneville Dam. We detected 560 yearling Chinook salmon and 146 steelhead that had previously been detected at Bonneville Dam in 2005 (Appendix Table 8).

Detection numbers of fish passing Bonneville Dam were down from previous years due to a lack of detection capability associated with the new corner collector bypass. In 2003, for example, over 91,000 Chinook salmon and 44,000 steelhead were detected passing Bonneville Dam. The corner collector collects fish directly from the forebay at the Second Powerhouse, and an exit flume returns them to the river downstream from PIT-tag detection antennas at the juvenile bypass facility. The estimated proportions of migrants that passed Bonneville Dam via the corner collector during spring and summer 2004 were 39% for yearling Chinook, 74% for steelhead, and 39% for subyearling Chinook salmon.* Remaining proportions exited the forebay via either turbines or the juvenile bypass system.

A small portion of both barged and inriver migrant groups passed through the estuary either before or after the trawl sampling period. In 2005, 89% of barged and 88% of the juvenile salmonids detected at Bonneville Dam were in the lower river and estuary during the period of our daily two-crew sample (28 April to 17 June; Table 5). During that sample period, we detected 2.9% of the barged or previously detected PIT-tagged juvenile Chinook salmon and 1.6% of the steelhead.

* Passage estimates based on radio-tagged fish (Blaine Ebberts, U.S. Army Corps of Engineers, Portland, District, personal communication).

Table 5. PIT-tag fish released from barges or detected at Bonneville Dam (inriver migrants) and detection numbers in the large trawl during the intensive daily two-crew sample period of 28 April to 17 June 2005. The release totals during this period represent 89% of the annual totals and were selected allowing two days for fish to travel to the sample area.

	Barged			Inriver		
	Released	Detected	%	Released	Detected	%
Chinook salmon	110,540	3,172	2.9	18,263	538	2.9
Steelhead	38,911	609	1.6	6,896	144	2.1

Using logistic regression analysis, we compared the daily detection percentages of transported fish to the daily detection percentages of inriver migrant fish previously detected at Bonneville Dam during the period of our two-crew sampling effort. 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 upstream from or at the 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.

Detections of Transported vs. Inriver Migrants

Logistic regression analysis showed no significant interaction between dates of barge release or Bonneville Dam detection and migration history ($P = 0.197$), and no significant difference in detection rates of barge or inriver migrant yearling Chinook salmon ($P = 0.955$, Figure 18, top). There was a significant increase in detection rate through the migration season ($P < 0.001$). Estimated sampling efficiency was lower early in the season (about 2.7%) and increased to about 3.7% by mid-June.

Similar analysis for steelhead showed no significant interaction between date and treatment ($P = 0.133$), and date was not a significant factor in the seasonal trend ($P = 0.025$). However, the daily detection data for steelhead was more variable than for yearling Chinook salmon, probably due to smaller sample numbers. There was an apparent decrease in detection rate through the migration season, from about 1.8% to 1.2%, though not significant ($P = 0.265$, Figure 18, bottom). It is likely that two time periods in early and late May, marked by low detection rates of barged steelhead, may have biased the detection rate low by the end of the season.

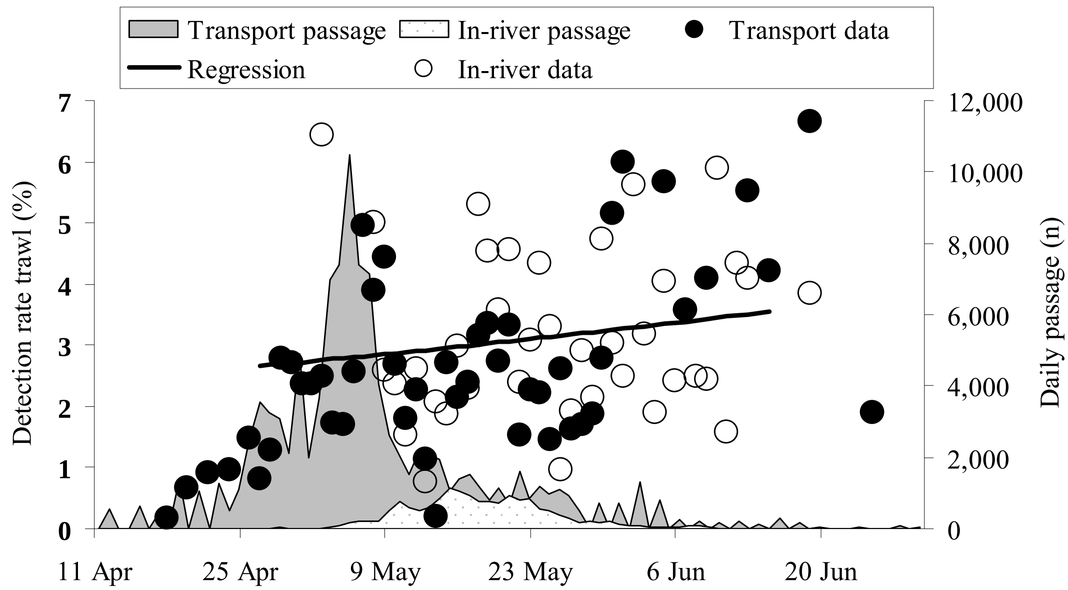
Mixing Assessment: Transported vs. Inriver Migrants

Relative detection rate comparisons between barged and inriver migrants were based on the assumption that fish released from barges near Bonneville Dam have a probability of being detected in the estuary that is equal to that of fish detected in the bypass system at Bonneville Dam on the same date. To test the validity of this assumption, we calculated the hourly differences in diel detection distributions between the two groups for each sample year since 2000 (Figure 19).

The average hourly differences in diel distributions for yearling Chinook salmon varied from 0 to 6% (6-year average 2000-2005). There did not appear to be strong diel trends in the difference for either group of yearling Chinook salmon, which supports a conclusion that the two groupings of fish were well mixed during their passage through the estuary. The 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 time slots were sampled. In 2001, diel variation was highest for the 6-year period (range -9-7%), with the highest numbers of inriver fish (-9%) detected at 1400 PDT and the highest of barged fish (7%) at 2100.

The average hourly differences in diel distributions for steelhead during the same 6-year period varied from 0 to 3%. While individual years indicated the possibility of some patterning, when analyzed together, there did not appear to be strong diel trends in the differences for either group, which also supports the assumption that the two groupings of steelhead were well mixed during their passage through the estuary. For example, sampling data from 2000 suggested that higher percentages of barged fish were present during mid-day and less were present in the evening, while 2001 data suggested the opposite. Ranges of difference were higher in 2000 and 2001 than in the other years with larger sample sizes of steelhead.

Yearling chinook salmon, 2005
3,531 detections



Steelhead, 2005
779 detections

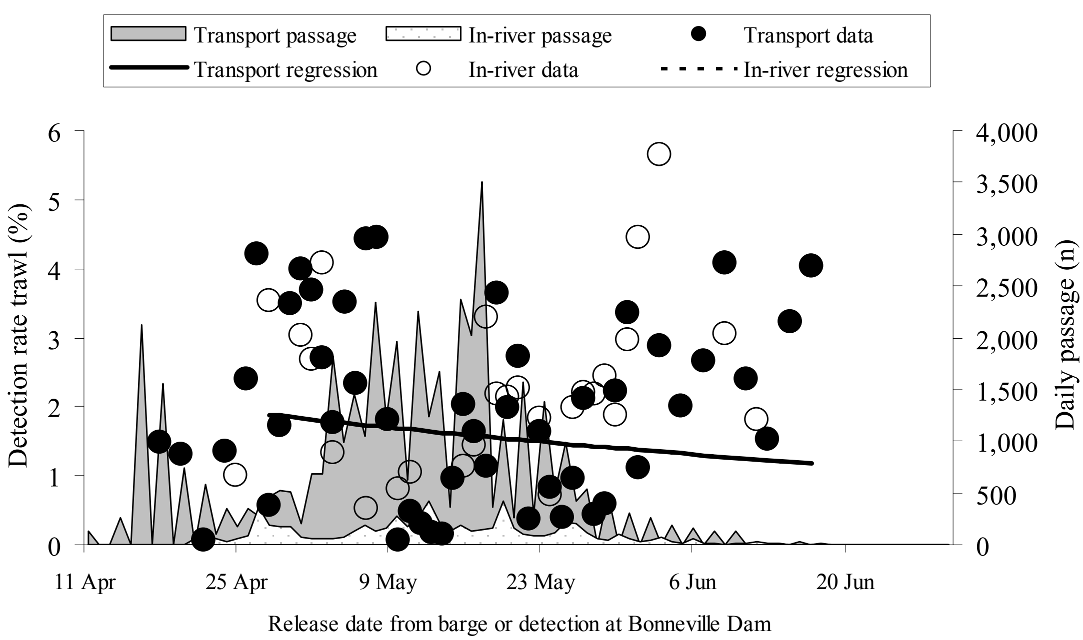


Figure 18. Logistic regression analysis of the daily detection percentage of transported and inriver migrant Chinook salmon (upper chart) and steelhead detected at Bonneville Dam, 2005.

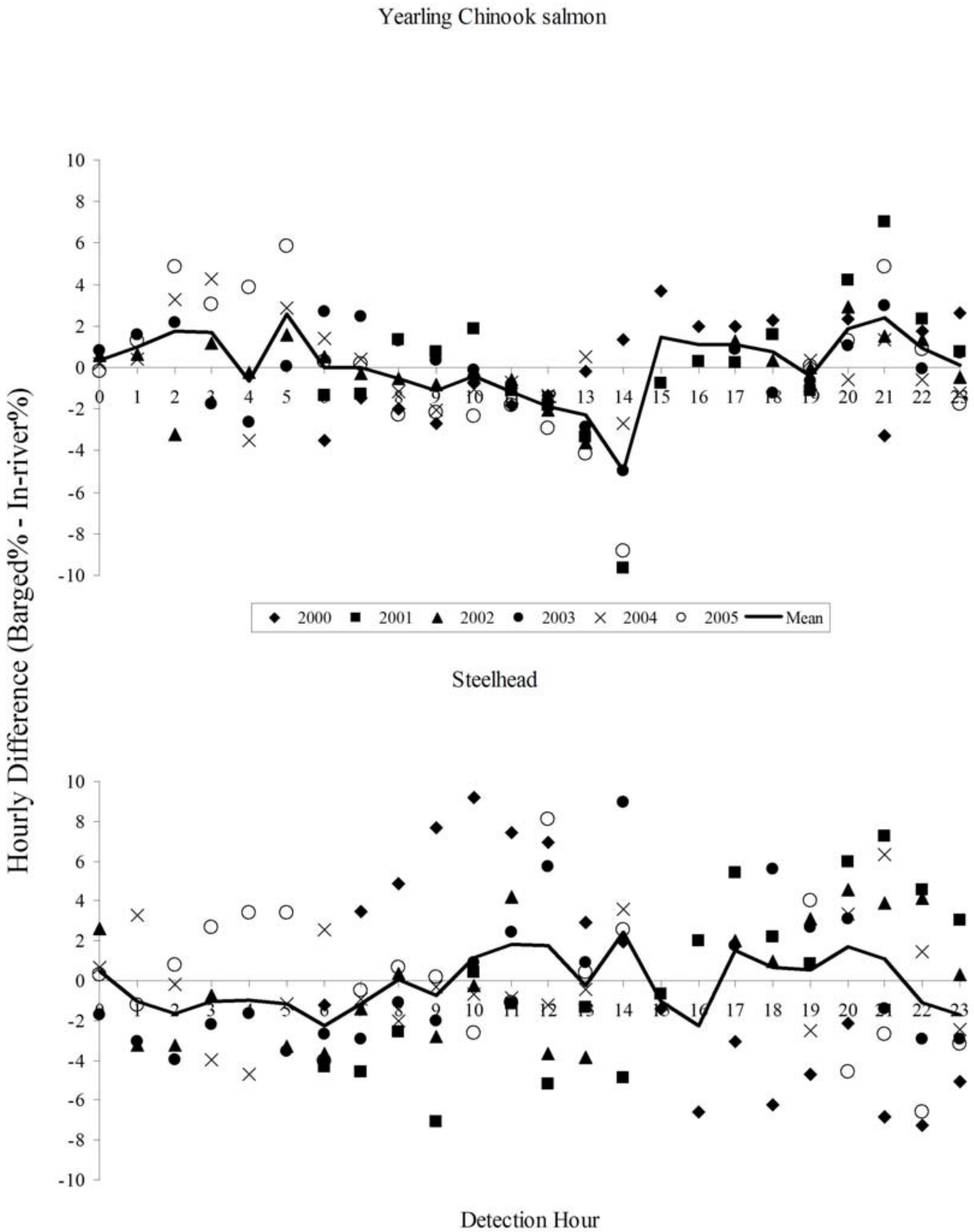


Figure 19. Hourly difference in estuarine detection percentages of barge-release fish compared to those fish previously detected at Bonneville Dam during two-crew sampling periods, 2000-2005. The pooled mean difference is plotted, and a mean difference greater than 0 indicates that a higher proportion of barged fish were detected during those hours and vice versa.

Transport Dam Assessment

There was no significant interaction between Snake River transport dam and barge release date for yearling Chinook salmon ($P = 0.465$; Figure 20, top). Detection rates for fish transported from all dams increased through the migration season from about 3.0% in late-April to about 4.5% by mid-June.

There was no significant interaction in the estimated estuarine detection rate between Snake River transported and barge release date for steelhead ($P = 0.720$, Figure 20, bottom) and no significant difference between fish transported from Lower Granite Dam versus the pooled rate from Little Goose and Lower Monumental Dams ($P = 0.235$). The detection rate was a consistent 2.1% through the season, regardless of dam of loading, and there was much variability in the data, probably associated with small sample size for steelhead.

There were 816 yearling Chinook salmon and 18,439 steelhead transported from McNary Dam, generally on alternating days. The majority of these fish (80% and 77%, respectively) were transported during our two-crew sample period. Though detection numbers for Chinook salmon (1.5%) were too low for meaningful evaluation, detection rates for steelhead (0.7%) were lower than for fish transported from the Snake River dams. Similar low detection rates for steelhead transported from McNary Dam were noted in 2003 and 2004 (Ledgerwood et al. 2006). Similarly, 59% of the Chinook salmon, primarily subyearlings transported from McNary Dam arrived in the estuary during mid-June to August, after we had reduced sampling to a single daily crew.

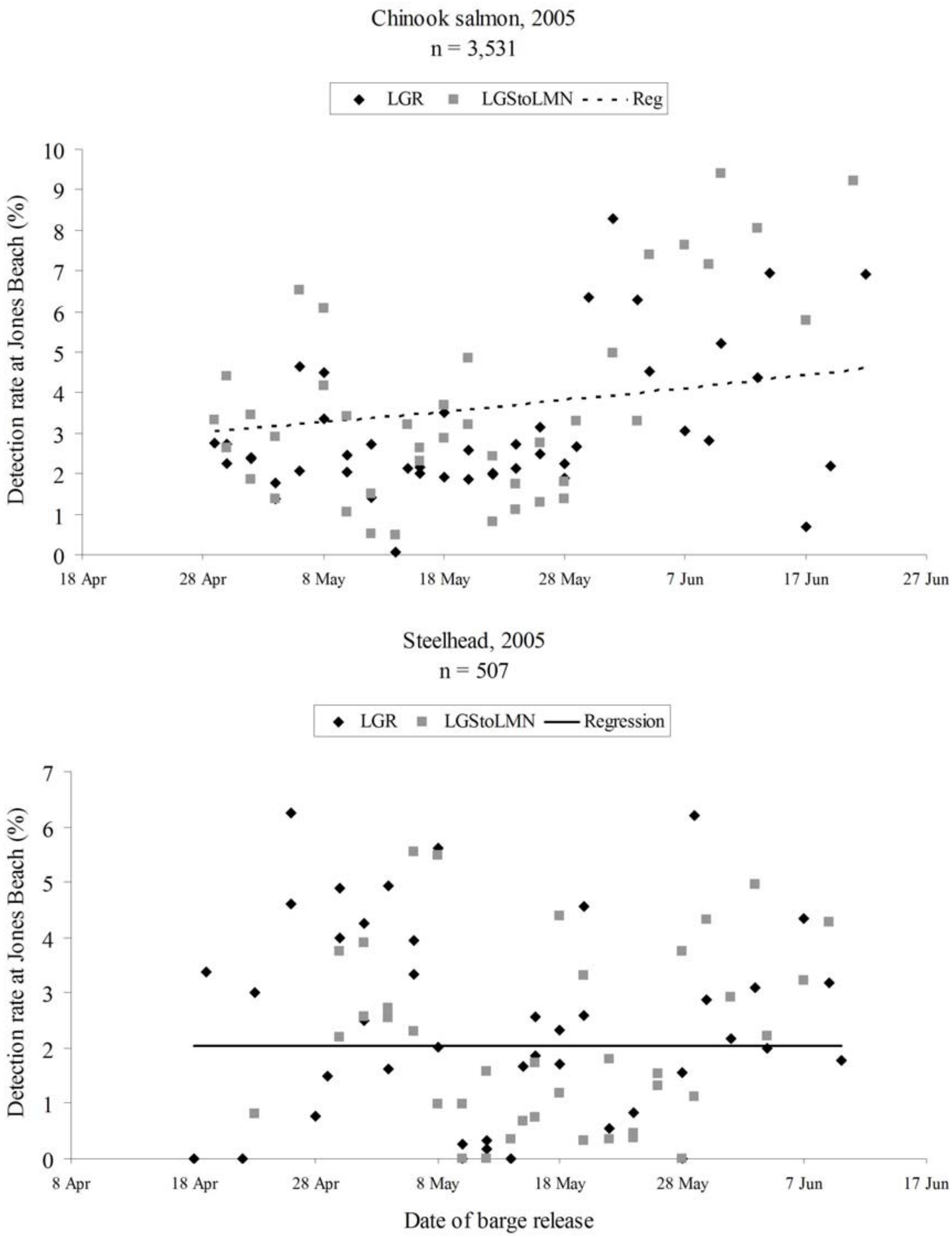


Figure 20. Daily detection rates of yearling Chinook salmon and steelhead released from barges loaded at Lower Granite (LGR) or other downstream dams (LGS, Little Goose Dam; LMN, Lower Monumental Dam), 2005.

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 1999-2005 (Figure 21). In some years there were insufficient PIT-tags released for one species or the other for a comparison between watersheds. However, there does not appear to be a general trend in survival between the two sources for either species. Annual estimates for yearling Chinook salmon ranged from 50.1% in 2001 (a drought year) to 76.3% in 2002 (71.5 in 2005). Steelhead survival was also lowest in 2001 (25%) but peaked at 77.0% in 1998 (53.3% in 2005).

Fish loaded aboard trucks and barges at Lower Granite Dam on the Snake River bypass a maximum of seven downstream dams. The effectiveness of fish transportation is evaluated in part by comparing adult return ratios of transported fish vs. inriver migrants. The annual benefit of transportation is sometimes related to river conditions experienced by fish left to migrate through the hydropower system. In 2005, seasonal average survival of inriver migrant yearling Chinook 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 (Table 7).

Survival probabilities for yearling Chinook salmon through the entire hydropower system downstream from Lower Granite Dam in 2005 were similar to those during 1998-2000 and 2002-2003, despite lower-than-average seasonal river flows. In 2001 and 2004, two years characterized by extremely low river flows due to regional drought, survival probabilities were about half that in 2005 and the other years, at 27.6 and 39.5%, respectively.

Table 6. Weekly average survival percentages from the tailrace of McNary Dam to the tailrace of Bonneville Dam for yearling Chinook salmon and steelhead, 2005. 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 for estimates of 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					
04 May-10 May	5,088	83.8	5.5	67.9	15.7	56.9	12.6
11 May-17 May	20,955	78.8	4.0	96.6	13.7	76.2	10.1
18 May-24 May	9,973	73.5	5.9	107.6	20.1	79.2	13.4
25 May-31 May	4,031	82.6	12.8	67.6	22.5	55.8	16.4
01 Jun-07 Jun	1,239	69.4	15.5	101.4	71.1	70.4	46.8
08 Jun-14 Jun	480	--	--	--	--	--	--
15 Jun-21 Jun	241	49.9	13.4	69.0	59.1	34.4	28.2
Weighted average	42,007	78.7	2.4	91.9	6.8	71.5	4.4
		Snake River steelhead					
27 Apr-03 May	80	45.0	14.3	--	--	--	--
04 May-10 May	790	54.2	12.2	--	--	--	--
11 May-17 May	2,591	69.6	12.9	--	--	--	--
18 May-24 May	2,907	59.7	9.8	--	--	--	--
25 May-31 May	980	67.1	22.1	--	--	--	--
Weighted average	7,348	60.7	3.8	--	--	--	--
		Mid-Columbia River yearling Chinook salmon					
27 Apr-03 May	6,328	71.5	24.8	--	--	--	--
04 May-10 May	4,350	83.0	13.4	--	--	--	--
11 May-17 May	7,463	82.3	15.8	--	--	--	--
18 May-24 May	4,166	61.4	19.7	--	--	--	--
25 May-31 May	2,148	116.7	76.1	--	--	--	--
Weighted average	24,455	80.1	5.6	--	--	--	--
		Mid-Columbia River steelhead					
13 Apr-19 Apr	5,123	82.8	11.8				
20 Apr-26 Apr	3,344	53.3	6.9	60.2	17.9	41.0	11.5
27 Apr-03 May	615	81.1	17.1				
04 May-10 May	3,447	83.9	9.9	133.0	131.0	110.8	108.4
11 May-17 May	4,957	92.1	13.7				
18 May-24 May	7,114	71.1	7.0	78.2	44.5	61.5	34.6
25 May-31 May	3,452	70.8	10.7				
01 Jun-07 Jun	611	49.5	25.1	127.4	89.3	86.0	59.0
Weighted average	28,663	74.9	4.7	75.5	16.7	53.3	11.9

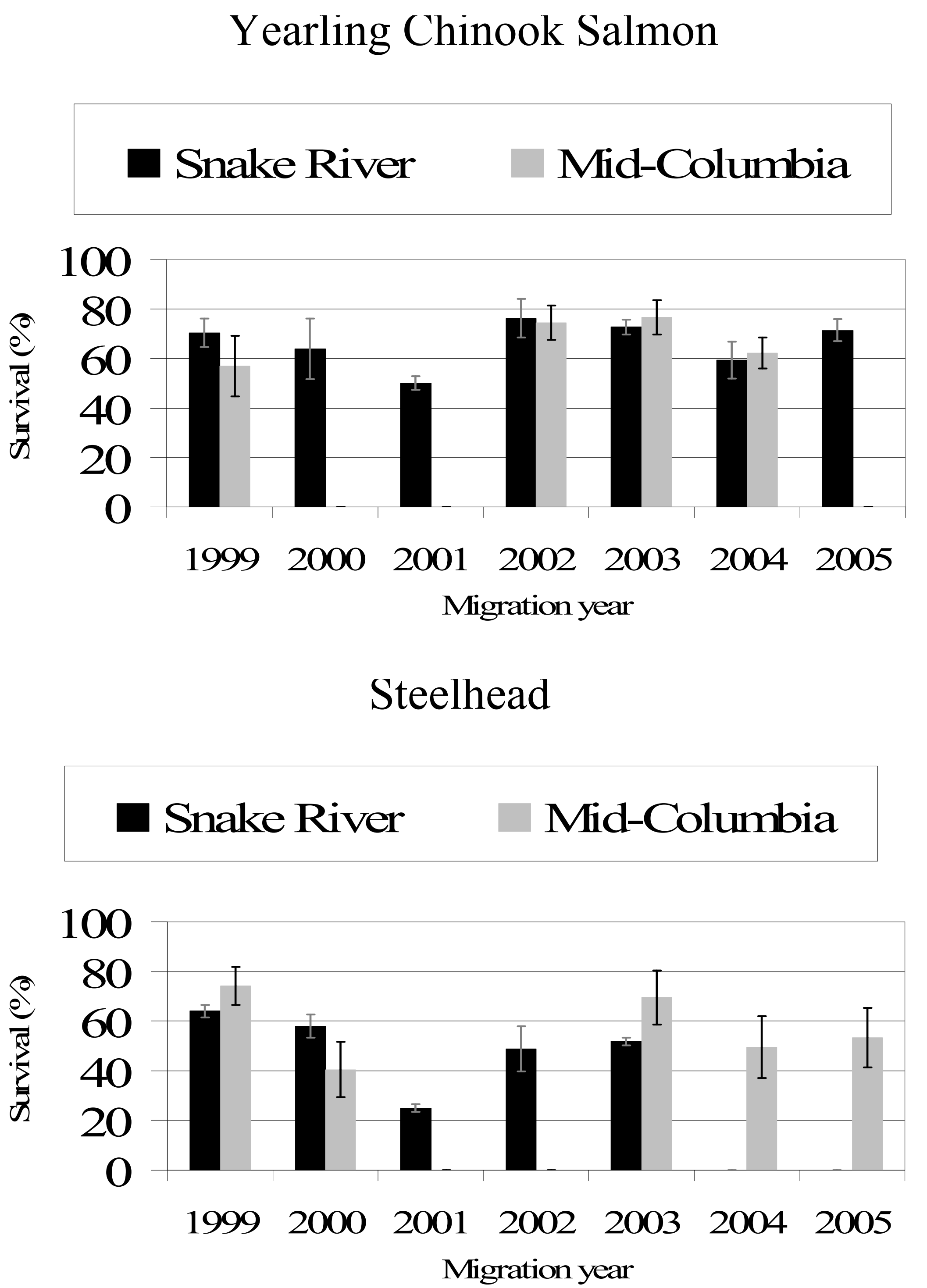


Figure 21. Weighted average annual survival and SE from the tailrace of McNary Dam to the tailrace of Bonneville Dam, 1999-2005.

Table 7. Estimated survival probabilities from the tailrace of Lower Granite Dam to the tailrace of Bonneville Dam for yearling Chinook salmon and steelhead, 1998-2005. SE is standard error; CI is 95% confidence interval for the respective means; dashes indicate data was insufficient for analysis.

	Yearling Chinook salmon			Steelhead		
Migration year	Estimated survival (%)	SE	CI	Estimated survival (%)	SE	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	52.6	3.5	45.7-59.5	--	--	--

DISCUSSION

The large and small pair trawl PIT-tag-detection systems deployed in 2005 represent a continuing effort to improve collection efficiency of PIT-tagged juvenile salmonids migrating through the Columbia River estuary. Operation of these systems provides data to PIT-tagging programs that release nearly two million fish annually, as well as increasing our understanding of juvenile salmon migrational behavior during the time they are traversing from fresh to saltwater.

Large colonies of predacious birds occur in the lower estuary and have a significant annual impact on migrating smolts. Data collected using the trawl detection systems provide context for smolt-to-adult return ratios that have shown substantial temporal variation in previous years. They enable freshwater effects to be separated from ocean effects when evaluating possible survival changes associated with factors like delayed mortality following barge release. 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.

In 2005, our sampling period coincided with the presence in the lower river and estuary of nearly 90% of all migrating PIT-tagged fish, and we detected over 2% of those passing through the upper estuary. Travel times from detection in the upper estuary to detection in the lower estuary in 2005 were similar to those observed in 2002 and 2004. Based on the collective observations from all 3 years, the differences in travel time were strongly correlated with the timing (and thus the number) of flood tides encountered by individual fish. These few observations of movement through the estuary and its relationship to tidal movement are consistent with those of Dawley et al. (1986) from beach- and purse-seine sampling in the late 1970s and early 1980s. They reported that yearling fish released upstream from Jones Beach showed no slowing of movement during passage through the estuary and into the ocean plume relative to travel speeds from the point of release to the estuary.

Detection rates with the small trawl in the lower estuary were disappointing. However, continued development of the more rigorous equipment and deployment techniques for the fast-flowing brackish-water of the lower estuary will have broad long-term benefits. For example, in 2005, we enlarged the antenna developed for use in brackish water, and the resulting antenna was too large for use with the electronics barge.

This problem was solved by using wireless data monitoring and transceivers, which in turn opened new possibilities for a larger (by an order of magnitude) antenna in the freshwater trawl.

A larger freshwater antenna will be required to take full advantage of the longer reading distances of the improved PIT-tags planned for release in 2006 and beyond. A larger antenna, and thus fish-passage opening, in the freshwater trawl will also result in lessened impacts to fish, since the potential for delay and impingement will be reduced. It will also improve sample efficiency by allowing faster tow speeds, as the larger opening will reduce drag on the net.

In 2004 and 2005, there was a major, albeit temporary, change in overall PIT-tag detection efficiency for juvenile salmonids passing Bonneville Dam. This change originated with the operation of a corner collector bypass system, which lacked PIT-tag detection capability. Detection numbers at Bonneville Dam dropped to about 40,000 in 2004 and to less than 30,000 in 2005, compared to about 140,000 in 2003. This reduction in efficiency at Bonneville Dam adversely impacted our ability to make survival estimates due to the reduced sample size of fish passing Bonneville Dam.

Survival probabilities for yearling Chinook salmon through the entire hydropower system downstream from Lower Granite Dam in 2005 were similar to those from 1998-2000 and 2002-2003, 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 50% 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.

The benefit to fish populations from transportation is evaluated by comparing ratios of smolt-to-adult returns (SARs) from transported and inriver groups. 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 also applied to fish loaded at different dams to the same barge (and released from the same barge).

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 2005, there were no obvious differences in daily detection rates between barged and inriver migrants, with steadily increasing detection rates through the season for yearling Chinook salmon and steady detection rates for steelhead. Comparisons of daily detection rates for fish loaded at various dams and released from the same barge showed no seasonal differences among dams of loading. 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 and loading densities, and for some years, loading site.

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 no PIT-tagged river-run fish using the shoreline system, and we generally observed few fish on the antenna-mounted camera. Electronic components of the shoreline detection system performed satisfactorily. However, 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. Use of the larger diameter antenna apparently did not appreciably improve passage through the net. Adaptation of a wireless data and video link from the antenna to shoreline receivers, similar to those used with the small trawl in the lower estuary, provided much improved monitoring of the system.

Snake River subyearling fall Chinook salmon (an ESA-listed stock) that do not migrate to sea in late summer or fall, but overwinter in the river basin and migrate the following spring are known as "residuals." From releases of PIT-tagged Snake River subyearling Chinook in 2004, we detected six residuals in the upper estuary during May 2005, none of which had been transported.

In summer 2005, spill rather than transportation was used for the first time as the primary dam-passage method for Snake River fall Chinook salmon. How this change in management strategy will affect smolt-to-adult returns remains to be seen. However, an obvious affect on juveniles is a much-extended exposure during migration to near-lethal high water temperatures. For example, between 1 July and 31 August, temperature in the forebay of Bonneville Dam averaged 20.9°C. We detected about equal numbers of transported and inriver migrant subyearling Chinook salmon; however, the majority of transported fish were detected prior to mid-June. After that, the majority of our detections were inriver migrants.

ACKNOWLEDGEMENTS

We thank the NOAA Dive Team for their low-visibility and cold-water dives in support of this research. Their efforts have been instrumental in helping develop new equipment, assure proper net configurations, antenna alignments, and ultimately low impacts to fish traversing our detection systems. Dave Marvin of PSMFC, Portland, Oregon, assisted in getting our interrogation data into the PTAGIS database. Special thanks as always to the boat operators and crews for their flexibility to keep us safe and underway, especially during the long days of the extended sampling period. We also gratefully acknowledge Rebecca Kalamasz of the U.S. Army Corps of Engineers, Walla Walla, District, as well as John Piccininni of the Bonneville Power Administration, for helping to fund this project.

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.

Cormack, R. M. 1964. Estimates of survival from the sightings of marked animals. Biometrika 51:429-438.

Dawley, E. M., R. D. Ledgerwood, T. H. Blahm, C. W. Sims, J. T. Durkin, R. A. Kirn, A. E. Rankis, G. E. Monan, and F. J. Ossiander. 1986. Migrational characteristics, biological observations, and relative survival of juvenile salmonids entering the Columbia River Estuary, 1966-1983. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Downing, S. L., E. F. Prentice, R.W. Frazier, J. E. Simonson, and E. P. Nunnallee. 2001. Technology developed for diverting passive integrated transponder (PIT) tagged fish at hydroelectric dams in the Columbia River Basin. Aquacultural Engineering 25(2001):149-164.

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., 375 pp.

Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and Immigration--stochastic model. Biometrika 52:225-247.

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. 2004a. A surface trawl to detect migrating juvenile salmonids tagged with passive integrated transponder tags. North American Journal of Fisheries Management (or In Press scheduled for May 2004a).

Ledgerwood, R. D., S. W. Naman, B. A. Ryan, B. P. Sandford, C. Z. Banks, and J. W. Ferguson. 2004b. Detection of PIT-tagged juvenile salmonids in the Columbia River estuary using a pair-trawl, 2000-2001. 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. 2005. Detection of PIT-tagged juvenile salmonids in the Columbia River estuary using a pair-trawl, 2002. 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. 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

Marsh, D. M., J. R. Harmon, K. W. McIntyre, K. L. Thomas, N. N. Paasch, B. P. Sandford, D. J. Kamikawa, and G. M. Matthews. 1996. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 1995. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Marsh, D. M., J. R. Harmon, N. N. Paasch, K. L. Thomas, K. W. McIntyre, B. P. Sandford, and G. M. Matthews. 1997. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 1996. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Marsh, D. M., J. R. Harmon, N. N. Paasch, K. L. Thomas, K. W. McIntyre, B. P. Sandford, and G. M. Matthews. 1998. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 1997. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Marsh, D. M., J. R. Harmon, N. N. Paash, K. L. Thomas, K. W. McIntyre, B. P. Sandford, and G. M. Matthews. 2000. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 1998. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Marsh, D. M., J. R. Harmon, N. N. Paasch, K. L. Thomas, K. W. McIntyre, B. P. Sandford, and G. M. Matthews. 2005. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 2001: final report for the 2001 spring/summer chinook salmon juvenile migration. 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). 2005. The Columbia Basin PIT-Tag-Information System (PTAGIS). Online interactive database, Pacific States Marine Fisheries Commission, Gladstone, Oregon (available via the internet at www.psmfc.org/pittag).

Seber, G. A. F. 1965. A note on the multiple recapture census. Biometrika 52:249-259.

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

Appendix Table 1. Design of the tape measure used to test antenna performance in 2005.

Position on tape measure (ft)	Orientation (°)	Distance from previous tag (ft)[a]	PIT-tag code[b]
117	0	0	3D9.1BF1A1CD75
119	0	2	3D9.1BF1A1CE16
121	0	2	3D9.1BF1A1D0F8
123	45	2	3D9.1BF1A1D20B
125	45	2	3D9.1BF1A1DFA6
128	0	3	3D9.1BF1A24A29
131	0	3	3D9.1BF1A6CCF5
134	0	3	3D9.1BF1A71C32
137	45	3	3D9.1BF1A71E13
140	45	3	3D9.1BF1A72BFD
143	45	3	3D9.1BF1A73F3A
145	0	2	3D9.1BF1A76D70
147	0	2	3D9.1BF1A78B35
149	0	2	3D9.1BF1A78FC4
150	0	1	3D9.1BF1A974D4
151	0	1	3D9.1BF1A98D9C
152	0	1	3D9.1BF1A9919F
155	0	3	3D9.1BF1A99324
158	0	3	3D9.1BF1A99327
159	0	1	3D9.1BF1A9953C
162	0	3	3D9.1BF1A99BA6
163	0	1	3D9.1BF1A99C8B
166	0	3	3D9.1BF1A9ADDC
169	45	3	3D9.1BF1A9B578
170	45	1	3D9.1BF1CF5456
172	0	2	3D9.1BF1CF5C8B
173	0	1	3D9.1BF1CF694C
175	0	2	3D9.1BF1F721C4
177	0	2	3D9.1BF1F7268D
181	0	4	3D9.1BF1F729AF
183	0	2	3D9.1BF1F73E67
185	0	2	3D9.1BF1F7C65E
188	45	3	3D9.1BF1F7CD88

Appendix Table 1. Continued.

Position on tape measure (ft)	Orientation (°)	Distance from previous tag (ft)[a]	PIT-tag code[b]
189	45	1	3D9.1BF1F7CDF7
191	45	2	3D9.1BF1F7D35F
192	45	1	3D9.1BF1F7D65D
194	45	2	3D9.1BF1F7D8EA
196	45	2	3D9.1BF1F7E04E
200	45	4	3D9.1BF1F7E85D
202	45	2	3D9.1BF1F80AF7
204	45	2	3D9.1BF1F81389
206	0	2	3D9.1BF1F84E01
208	0	2	3D9.1BF1F85701
210	0	2	3D9.1BF1F88FAD
212	0	2	3D9.1BF1F8B965
214	45	2	3D9.1BF1F8B9A4
216	45	2	3D9.1BF1F8CAB0
218	45	2	3D9.1BF1F8D5BE
220	45	2	3D9.1BF1F8DA09
225	0	5	3D9.1BF1F8F0C1

a. Distance from previous tag as measured in the direction from 117 to 225 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, 2005.

Date	Total time under-way (h)	Pit-tag detections (N)						
		Unknown	Chinook salmon	Coho salmon	Steelhead	Sockeye salmon	Sea-run Cutthroat	Total
20 Apr	1.9	0	0	0	5	0	0	5
21 Apr	4.2	1	0	0	1	0	0	2
22 Apr	4.6	0	0	0	27	0	0	27
23 Apr	3.9	0	5	0	1	0	0	6
24 Apr	0.0	0	0	0	0	0	0	0
25 Apr	4.8	0	6	0	3	0	0	9
26 Apr	4.2	0	2	0	15	0	0	17
27 Apr	8.6	2	12	0	12	0	0	26
28 Apr	11.4	2	20	0	21	0	0	43
29 Apr	10.3	4	23	0	5	0	0	32
30 Apr	4.7	3	22	0	38	0	0	63
01 May	5.4	0	30	0	43	0	0	73
02 May	12.0	2	130	1	199	0	0	332
03 May	13.2	5	185	0	100	0	0	290
04 May	13.0	2	112	0	70	0	0	184
05 May	13.0	1	112	0	62	0	0	175
06 May	11.1	3	114	1	26	0	0	144
07 May	10.2	2	111	0	27	0	0	140
08 May	13.8	1	161	0	44	0	0	206
09 May	15.2	1	336	0	57	0	0	394
10 May	14.3	2	402	2	80	0	0	486
11 May	16.5	1	462	1	23	0	0	487
12 May	16.9	4	272	1	49	0	1	327
13 May	15.7	0	184	3	70	0	0	257
14 May	17.1	6	295	1	102	0	0	404
15 May	8.5	0	62	0	21	0	0	83
16 May	10.2	3	223	1	100	0	0	327
17 May	15.6	3	157	3	153	0	0	316
18 May	15.8	5	259	2	138	2	0	406
19 May	16.2	5	440	4	228	0	0	677
20 May	12.7	9	498	4	208	2	0	721
21 May	13.7	8	470	19	176	1	0	674
22 May	16.9	16	567	17	303	1	0	904
23 May	11.1	5	276	5	101	0	0	387
24 May	15.6	15	373	20	318	2	0	728

Appendix Table 2. Continued.

Date	Total time under-way (h)	Pit-tag detections (N)						
		Unknown	Chinook salmon	Coho salmon	Steelhead	Sockeye salmon	Sea-run Cutthroat	Total
25 May	16.5	14	316	22	221	4	0	577
26 May	16.3	1	125	4	31	0	0	161
27 May	14.8	2	99	1	62	2	0	166
28 May	14.9	7	157	10	181	3	1	359
29 May	15.5	6	128	6	152	3	2	297
30 May	14.6	5	140	8	127	5	0	285
31 May	14.9	2	149	6	105	9	0	271
01 Jun	13.3	7	200	6	133	7	0	353
02 Jun	15.1	1	132	2	56	3	0	194
03 Jun	17.7	1	56	4	34	2	0	97
04 Jun	16.7	5	83	3	56	9	0	156
05 Jun	16.3	10	83	7	53	1	0	154
06 Jun	12.6	5	36	9	53	0	0	103
07 Jun	14.3	5	100	8	62	8	0	183
08 Jun	11.6	6	49	3	80	4	0	142
09 Jun	12.1	3	44	7	51	1	1	107
10 Jun	12.0	3	30	7	34	1	0	75
11 Jun	12.4	5	52	3	25	2	0	87
12 Jun	12.3	1	32	3	41	0	0	77
13 Jun	12.2	3	77	4	30	0	0	114
14 Jun	11.6	5	45	3	15	1	0	69
15 Jun	12.0	4	73	4	21	2	0	104
16 Jun	11.4	6	29	1	16	0	0	52
17 Jun	11.0	2	70	2	30	1	0	105
18 Jun	6.9	1	17	1	9	0	0	28
19 Jun	5.3	1	32	0	7	1	0	41
20 Jun	0.2	0	0	0	0	0	0	0
21 Jun	4.1	3	14	0	2	0	0	19
22 Jun	7.3	3	14	0	2	0	0	19
23 Jun	8.6	13	62	1	4	1	1	82
24 Jun	6.0	6	22	0	4	0	0	32
25 Jun	4.9	1	46	0	1	0	0	48
26 Jun	0.0	0	0	0	0	0	0	0
27 Jun	2.9	0	0	0	0	0	0	0
28 Jun	10.6	4	14	0	4	0	0	22
29 Jun	9.1	7	11	0	1	0	0	19
30 Jun	6.1	6	18	0	1	1	0	26

Appendix Table 2. Continued.

Date	Total time under-way (h)	Pit-tag detections (N)						
		Unknown	Chinook salmon	Coho salmon	Steelhead	Sockeye salmon	Sea-run Cutthroat	Total
01 Jul	2.1	1	3	0	0	1	0	5
02 Jul	0.0	0	0	0	0	0	0	0
03 Jul	0.0	0	0	0	0	0	0	0
04 Jul	0.0	0	0	0	0	0	0	0
05 Jul	4.9	2	19	0	0	0	0	21
06 Jul	7.1	0	2	0	0	0	0	2
07 Jul	7.2	5	13	0	1	0	0	19
08 Jul	7.0	3	16	0	0	0	0	19
09 Jul	0.0	0	0	0	0	0	0	0
10 Jul	0.0	0	0	0	0	0	0	0
11 Jul	5.0	2	12	0	0	0	0	14
12 Jul	7.2	0	8	0	0	0	0	8
13 Jul	6.5	0	9	0	1	0	0	10
14 Jul	5.4	0	9	0	0	0	0	9
15 Jul	0.9	0	0	0	0	0	0	0
16 Jul	0.0	0	0	0	0	0	0	0
17 Jul	0.0	0	0	0	0	0	0	0
18 Jul	2.9	0	2	0	0	0	0	2
19 Jul	5.5	0	3	0	0	0	0	3
20 Jul	5.3	0	1	0	0	0	0	1
21 Jul	7.2	1	2	0	0	0	0	3
22 Jul	1.3	0	2	0	0	0	0	2
23 Jul	0.0	0	0	0	0	0	0	0
24 Jul	0.0	0	0	0	0	0	0	0
25 Jul	5.3	1	0	0	0	0	0	1
26 Jul	7.0	1	3	0	0	0	0	4
27 Jul	5.3	0	0	0	0	0	0	0
28 Jul	5.7	0	0	0	0	0	0	0
29 Jul	0.9	0	0	0	0	0	0	0
30 Jul	0.0	0	0	0	0	0	0	0
31 Jul	0.0	0	0	0	0	0	0	0
01 Aug	4.5	0	1	0	0	0	0	1
02 Aug	5.9	0	1	0	0	0	0	1
03 Aug	6.4	0	0	0	0	0	0	0
04 Aug	6.2	0	0	0	0	0	0	0
05 Aug	0.6	0	0	0	0	0	0	0
Totals	909.2	281	8,982	220	4,532	80	6	14,101

Appendix Table 3. Daily total sample time and detections for each salmonid species using a salt-water-tolerant PIT-tag antenna and small pair-trawl in the lower Columbia River estuary, 2005.

Date	Total time underway (h)	Pit-tag detections (N)				
		Unknown	Chinook salmon	Coho salmon	Steelhead	Total
16 May	4.7	0	0	0	1	1
17 May	4.3	0	0	0	1	1
18 May	3.8	0	0	0	0	0
19 May	3.2	0	0	0	1	1
20 May	4.7	0	0	0	1	1
21 May	4.9	1	0	0	1	2
22 May	0.0	0	0	0	0	0
23 May	4.9	0	1	0	1	2
24 May	4.8	0	0	0	2	2
25 May	4.6	0	5	0	3	8
26 May	2.8	0	2	0	3	5
27 May	5.0	0	3	0	5	8
28 May	0.0	0	0	0	0	0
29 May	0.0	0	0	0	0	0
30 May	0.0	0	0	0	0	0
31 May	3.6	0	0	0	0	0
01 Jun	4.2	0	1	1	2	4
02 Jun	1.7	0	0	0	0	0
03 Jun	2.2	0	0	0	0	0
04 Jun	0.0	0	0	0	0	0
05 Jun	0.0	0	0	0	0	0
06 Jun	4.8	0	0	0	0	0
07 Jun	5.3	0	1	1	1	3
08 Jun	3.5	0	0	0	0	0
Totals	72.9	1	13	2	22	38

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, 2005.

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

Appendix Table 4. Continued.

Date	Chinook salmon		Coho salmon	Steelhead	Sockeye
	Yearling	Subyearling			
26 May	0	0	0	0	0
27 May	0	0	0	0	0
28 May	0	0	0	0	0
29 May	0	0	0	0	0
30 May	1	1	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	0	0	0	0	0
06 Jun	0	0	0	0	0
07 Jun	1	2	0	1	0
08 Jun	2	2	0	1	0
09 Jun	0	0	0	0	0
10 Jun	0	0	0	0	0
11 Jun	0	0	0	0	0
12 Jun	0	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	6	0	2	0
23 Jun	4	6	0	2	0
24 Jun	9	12	1	4	0
25 Jun	0	0	0	0	0
26 Jun	0	0	0	0	0
27 Jun	16	22	2	8	0
28 Jun	0	0	0	0	0
29 Jun	3	4	0	1	0
30 Jun	20	28	2	10	0
01 Jul	0	0	0	0	0
02 Jul	0	0	0	0	0
03 Jul	0	0	0	0	0

Appendix Table 4. Continued.

Date	Chinook salmon Yearling	Chinook salmon Subyearling	Coho salmon	Steelhead	Sockeye
04 Jul	0	0	0	0	0
05 Jul	3	5	0	2	0
06 Jul	5	7	1	2	0
07 Jul	4	6	0	2	0
08 Jul	1	1	0	0	0
09 Jul	0	0	0	0	0
10 Jul	0	0	0	0	0
11 Jul	2	3	0	1	0
12 Jul	0	0	0	0	0
13 Jul	1	1	0	0	0
14 Jul	7	9	1	3	0
15 Jul	0	0	0	0	0
16 Jul	0	0	0	0	0
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	0	0	0	0	0
22 Jul	0	0	0	0	0
23 Jul	0	0	0	0	0
24 Jul	0	0	0	0	0
25 Jul	0	0	0	0	0
26 Jul	0	0	0	0	0
27 Jul	0	0	0	0	0
28 Jul	0	0	0	0	0
29 Jul	0	0	0	0	0
30 Jul	0	0	0	0	0
31 Jul	0	0	0	0	0
01 Aug	0	0	0	0	0
02 Aug	0	0	0	0	0
03 Aug	0	0	0	0	0
04 Aug	0	0	0	0	0
Total	101	138	11	49	1

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), 2005. Effort, rounded to the nearest tenth, is presented as a decimal hour.

		Yearling Chinook salmon				Steelhead			
Diel	Effort	Hatchery		Wild		Hatchery		Wild	
hour	(h)	n	n/h	n	n/h	n	n/h	n	n/h
0	48.2	646	13.4	119	2.5	202	4.2	55	1.1
1	43.5	624	14.3	127	2.9	168	3.9	38	0.9
2	29.9	541	18.1	108	3.6	146	4.9	31	1.0
3	18.5	462	25.0	69	3.7	73	4.0	21	1.1
4	14.3	274	19.2	56	3.9	68	4.8	15	1.0
5	17.9	171	9.5	50	2.8	22	1.2	7	0.4
6	35.4	153	4.3	54	1.5	70	2.0	22	0.6
7	42.7	251	5.9	64	1.5	114	2.7	31	0.7
8	45.8	247	5.4	77	1.7	173	3.8	53	1.2
9	43.8	204	4.7	57	1.3	148	3.4	42	1.0
10	43.2	229	5.3	57	1.3	203	4.7	42	1.0
11	39.2	250	6.4	64	1.6	231	5.9	74	1.9
12	29.6	314	10.6	44	1.5	211	7.1	71	2.4
13	16.3	225	13.8	39	2.4	184	11.3	50	3.1
14	5.8	81	14.0	10	1.7	45	7.8	14	2.4
15	1.0	10	10.5	0	0.0	4	4.2	0	0.0
16	0.0	0	0.0	0	0.0	0	0.0	0	0.0
17	0.0	0	0.0	0	0.0	0	0.0	0	0.0
18	0.4	0	0.0	0	0.0	1	2.7	2	5.5
19	14.9	58	3.9	16	1.1	48	3.2	14	0.9
20	45.5	373	8.2	121	2.7	260	5.7	59	1.3
21	48.0	707	14.7	149	3.1	476	9.9	100	2.1
22	48.0	545	11.4	120	2.5	446	9.3	81	1.7
23	49.7	628	12.6	83	1.7	251	5.1	56	1.1
Total	681.4	6,993		1,484		3,544		878	

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 were 9 April-2 August; trawl detector was operated 20 April-5 August, with intensive sampling 28 April-17 June, 2005. Totals for the entire season are shown.

Release date	Numbers loaded at each dam and total fish loaded (n)*					Numbers detected from each dam and total numbers detected (n)					
and time	LGR	LGO	LMN	MCN	n	LGR	LGO	LMN	MCN	n	(%)
9 Apr–15 Apr	1,203	1	0	0	1,204	0.0	0.0	0.0	0.0	0	0.0
18 Apr 1:22	626	1	0	0	627	0.2	0.0	--	--	1	0.2
19 Apr 23:40	451	2	0	3	456	0.7	0.0	--	0.0	3	0.7
22 Apr 2:35	1,409	11	0	5	1,425	0.9	0.0	--	0.0	13	0.9
23 Apr 23:58	1,058	9	3	3	1,073	0.9	0.0	0.0	0.0	10	0.9
26 Apr 3:45	1,263	57	1	3	1,324	1.5	1.8	0.0	0.0	20	1.5
26 Apr 22:40	470	39	4	0	513	0.9	0.0	0.0	--	4	0.8
28 Apr 3:10	1,043	61	9	1	1,114	1.3	0.0	0.0	0.0	14	1.3
29 Apr 0:45	2,391	88	20	0	2,499	2.8	2.3	5.0	--	69	2.8
30 Apr 2:15	3,347	186	18	1	3,552	2.7	2.7	0.0	0.0	96	2.7
30 Apr 21:35	3,064	159	40	0	3,263	2.3	4.4	2.5	--	77	2.4
02 May 9:30	2,881	191	36	2	3,110	2.4	2.1	5.6	0.0	75	2.4
02 May 23:35	1,860	235	44	0	2,139	2.4	4.3	4.5	--	56	2.6
04 May 4:45	4,397	491	40	2	4,930	1.8	1.4	0.0	0.0	85	1.7
04 May 21:27	1,582	402	28	0	2,012	1.4	2.5	7.1	--	34	1.7
06 May 1:45	3,143	471	64	5	3,683	2.1	5.5	4.7	0.0	94	2.6
06 May 23:55	6,066	813	95	0	6,974	4.6	7.0	6.3	--	345	4.9
08 May 2:15	5,928	1,388	81	8	7,405	3.4	5.8	11.1	12.5	290	3.9
08 May 22:20	9,153	1,290	58	0	10,501	4.5	4.3	1.7	--	466	4.4
10 May 0:45	5,478	1,692	152	61	7,383	2.5	3.6	0.7	0.0	197	2.7
10 May 21:10	5,504	1,637	0	0	7,141	2.0	1.0	--	--	129	1.8
12 May 0:30	2,455	1,515	23	70	4,063	2.7	1.1	8.7	2.9	87	2.1
12 May 21:20	1,856	781	0	0	2,637	1.4	0.5	--	--	30	1.1
14 May 0:10	1,377	623	0	46	2,046	0.1	0.5	--	0.0	4	0.2
15 May 0:20	705	618	196	0	1,519	2.1	3.4	2.6	--	41	2.7
16 May 4:00	1,113	800	198	74	2,185	2.2	2.4	2.0	0.0	47	2.2
16 May 21:50	843	1,026	183	0	2,052	2.0	2.8	1.6	--	49	2.4
18 May 0:20	853	737	270	104	1,964	3.5	3.0	2.6	2.9	62	3.2
18 May 20:10	208	620	219	0	1,047	1.9	2.9	5.9	--	35	3.3
20 May 2:05	804	406	127	57	1,394	1.9	3.9	0.8	10.5	38	2.7
20 May 20:20	1,012	388	108	0	1,508	2.6	3.9	8.3	--	50	3.3
22 May 0:10	735	304	66	104	1,209	1.9	1.0	0.0	1.0	18	1.5

Appendix Table 6. 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	(%)
22 May 19:20	324	414	81	0	819	1.9	2.4	2.5	--	18	2.2
24 May 1:45	640	372	151	18	1,181	2.7	2.2	0.7	0.0	26	2.2
24 May 20:05	292	381	70	0	743	1.7	1.3	0.0	--	10	1.3
26 May 5:20	522	926	166	43	1,657	2.3	2.9	1.8	0.0	42	2.5
26 May 18:50	201	464	241	0	906	2.5	1.5	0.8	--	14	1.5
28 May 1:25	535	475	182	27	1,219	2.2	1.7	1.1	0.0	22	1.8
28 May 19:30	629	337	56	0	1,022	1.9	1.8	1.8	--	19	1.9
29 May 23:30	794	244	65	24	1,127	2.5	2.9	4.6	0.0	30	2.7
30 May 16:35	706	254	59	0	1,019	5.5	2.8	3.4	--	48	4.7
01 Jun 1:35	377	247	26	20	670	5.6	7.3	7.7	0.0	41	6.1
03 Jun 0:30	1,087	325	44	0	1,457	3.7	3.4	4.5	0.0	53	3.6
04 Jun 23:55	1,373	349	75	2	1,799	3.0	5.4	6.7	0.0	65	3.6
07 Jun 0:01	1,768	191	54	1	2,014	2.7	7.3	0.0	0.0	62	3.1
09 Jun 1:25	1,544	129	44	0	1,717	3.0	4.7	4.5	--	55	3.2
10 Jun 23:55	1,526	211	35	1	1,773	3.6	5.2	0.0	0.0	66	3.7
13 Jun 2:00	781	169	40	1	991	3.7	5.3	2.5	0.0	39	3.9
14 Jun 23:25	861	318	80	0	1,259	3.7	4.7	3.8	--	50	4.0
17 Jun 0:20	1,023	209	87	2	1,321	1.7	3.3	5.7	0.0	29	2.2
19 Jun 1:30	567	118	38	0	723	2.1	1.7	0.0	--	14	1.9
21 Jun 0:01	1,497	242	70	3	1,812	2.5	2.5	4.3	0.0	47	2.6
22 Jun 22:30	566	269	75	0	910	2.1	5.9	5.3	--	32	3.5
25 Jun 5:35	72	5	5	30	112	0.0	0.0	0.0	0.0	0	0.0
27 Jun 5:20	85	13	5	51	154	0.0	0.0	0.0	2.0	1	0.6
29 Jun 4:55	95	32	7	122	256	1.1	0.0	0.0	0.0	1	0.4
01 Jul 4:45	189	54	25	240	508	0.5	0.0	0.0	0.0	1	0.2
03 Jul 4:10	66	244	52	196	558	3.0	2.0	0.0	0.0	7	1.3
05 Jul 3:55	27	190	25	77	319	0.0	1.1	0.0	0.0	2	0.6
07 Jul 3:45	29	18	26	73	146	0.0	0.0	0.0	0.0	0	0.0
09 Jul 2:50	9	50	15	40	114	0.0	4.0	0.0	2.5	3	2.6
11 Jul 2:30	16	37	19	16	88	0.0	0.0	5.3	0.0	1	1.1
13 Jul 1:35	31	31	7	10	79	0.0	0.0	0.0	0.0	0	0.0
15 Jul 2:25	12	104	18	8	142	0.0	0.0	0.0	0.0	0	0.0
17 Jul 3:05	5	57	23	15	100	0.0	1.8	0.0	0.0	1	1.0
19 Jul-2 Aug	36	96	87	68	287	0.0	0.0	0.0	0.0	0	0.0
Totals	92,563	24,617	4,136	1,638	122,954	2.7	3.0	2.8	0.9	3,338	2.7

* 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 9 April-2 August; trawl detector was operated 20 April-5 August, with intensive sampling 28 April-17 June, 2005. Totals for the entire season are shown.

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	(%)
9 Apr-15 Apr	220	2	26	0	248	0.0	0.0	0.0	0.0	0	0.0
18 Apr 1:22	96	0	12	161	269	0.0	--	8.3	1.9	4	1.5
19 Apr 23:40	59	2	10	2,058	2,129	3.4	0.0	0.0	1.3	28	1.3
22 Apr 2:35	272	3	33	1,254	1,562	0.0	0.0	0.0	0.1	1	0.1
23 Apr 23:58	200	8	16	514	738	3.0	0.0	0.0	0.8	10	1.4
26 Apr 3:45	239	33	35	275	582	4.6	0.0	2.9	0.7	14	2.4
26 Apr 22:40	64	25	6	0	95	6.3	0.0	0.0	--	4	4.2
28 Apr 3:10	129	19	9	192	349	0.8	0.0	0.0	0.5	2	0.6
29 Apr 0:45	135	16	22	0	173	2.2	0.0	0.0	--	3	1.7
30 Apr 2:15	125	32	48	138	343	4.8	0.0	6.3	2.2	12	3.5
30 Apr 21:35	184	19	72	0	275	4.9	0.0	2.8	--	11	4.0
02 May 9:30	306	17	60	77	460	4.2	5.9	3.3	1.3	17	3.7
02 May 23:35	400	38	79	0	517	2.8	0.0	3.8	--	14	2.7
04 May 4:45	308	49	98	53	508	1.6	2.0	3.1	0.0	9	1.8
04 May 21:27	81	44	74	0	199	4.9	4.5	1.4	--	7	3.5
06 May 1:45	330	42	45	271	688	3.3	2.4	2.2	1.1	16	2.3
06 May 23:55	480	96	102	0	678	4.0	9.4	2.0	--	30	4.4
08 May 2:15	764	269	186	597	1,816	5.8	7.4	2.7	2.0	81	4.5
08 May 22:20	789	92	110	0	991	2.0	2.2	0.0	--	18	1.8
10 May 0:45	342	102	177	829	1,450	0.0	0.0	0.0	0.1	1	0.1
10 May 21:10	742	305	0	0	1,047	0.3	1.0	--	--	5	0.5
12 May 0:30	910	107	20	1,304	2,341	0.3	0.9	5.0	0.2	7	0.3
12 May 21:20	1,093	129	0	0	1,222	0.2	0.0	--	--	2	0.2
14 May 0:10	616	291	0	1,050	1,957	0.0	0.3	--	0.2	3	0.2
15 May 0:20	179	221	226	0	626	1.7	0.0	1.3	--	6	1.0
16 May 4:00	934	215	188	921	2,258	2.6	1.9	1.6	1.6	46	2.0
16 May 21:50	961	138	131	0	1,230	1.9	0.7	0.8	--	20	1.6
18 May 0:20	817	79	174	606	1,676	1.7	1.3	1.1	0.3	19	1.1
18 May 20:10	129	70	158	0	357	2.3	1.4	5.7	--	13	3.6

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	(%)
20 May 2:05	853	134	171	1,219	2,377	4.6	0.0	0.6	0.6	47	2.0
20 May 20:20	1,743	96	176	0	2,015	2.6	3.1	4.0	--	55	2.7
22 May 0:10	742	165	129	2,472	3,508	0.5	0.6	0.0	0.3	13	0.4
22 May 19:20	33	160	175	0	368	0.0	1.9	1.7	--	6	1.6
24 May 1:45	171	113	152	767	1,203	1.2	0.0	0.7	0.9	10	0.8
24 May 20:05	42	74	143	0	259	0.0	1.4	0.0	--	1	0.4
26 May 5:20	328	60	166	1,013	1,567	1.5	5.0	0.0	0.7	15	1.0
26 May 18:50	24	18	242	0	284	0.0	0.0	2.5	--	6	2.1
28 May 1:25	385	32	99	863	1,379	1.6	0.0	0.0	0.0	6	0.4
28 May 19:30	423	24	56	0	503	0.0	4.2	3.6	--	3	0.6
29 May 23:30	193	34	56	704	987	6.2	0.0	1.8	1.3	22	2.2
30 May 16:35	278	40	99	0	417	2.9	5.0	4.0	--	14	3.4
01 Jun 1:35	46	30	73	392	541	2.2	0.0	4.1	0.5	6	1.1
03 Jun 0:30	97	23	118	247	485	3.1	13.0	3.4	1.6	14	2.9
04 Jun 23:55	50	23	112	115	300	2.0	0.0	2.7	1.7	6	2.0
07 Jun 0:01	92	22	40	109	263	4.3	4.5	2.5	0.9	7	2.7
09 Jun 1:25	63	16	26	91	196	3.2	6.3	0.0	5.5	8	4.1
10 Jun 23:55	112	7	21	26	166	1.8	14.3	4.8	0.0	4	2.4
13 Jun 2:00	90	9	13	19	131	1.1	0.0	7.7	0.0	2	1.5
14 Jun 23:25	90	6	15	13	124	3.3	0.0	6.7	0.0	4	3.2
17 Jun 0:20	3	7	11	12	33	0.0	14.3	0.0	0.0	1	3.0
19 Jun 1:30	5	2	2	7	16	0.0	0.0	0.0	0.0	0	0.0
21 Jun 0:01	7	11	11	4	33	14.3	0.0	9.1	0.0	2	6.1
22 Jun 22:30	3	7	7	0	17	0.0	14.3	0.0	--	1	5.9
25 Jun 5:35	0	0	0	13	13	--	--	--	0.0	0	0.0
27 Jun 5:20	0	0	1	30	31	--	--	0.0	6.7	2	6.5
29 Jun 4:55	0	0	0	6	6	--	--	--	0.0	0	0.0
01 Jul 4:45	1	0	0	11	12	0.0	--	--	0.0	0	0.0
03 Jul 4:10	0	0	1	5	6	--	--	0.0	0.0	0	0.0
11 Jul 2:30	1	0	0	1	2	0.0	--	--	100.0	1	50.0
Totals	17,559	3,574	4,206	18,439	44,026	2.1	2.0	2.0	0.7	659	1.5

* 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 8. Detection rates in the Columbia River estuary of PIT-tagged juvenile Chinook salmon and steelhead previously detected at Bonneville Dam, 2005. The juvenile bypass system at Bonneville Dam operated 4 March-4 August; the trawl was operated 20 April-5 August, with intensive sampling between 28 April and 7 June, 2005.

Detection at Bonneville Dam	Bonneville Dam detections		Jones Beach detections			
	Chinook salmon (n)	steelhead (n)	Chinook salmon (n)	steelhead (n)	Chinook salmon (%)	steelhead (%)
4 Mar-15 Apr	28	25	0	0	0.0	0.0
16 Apr	14	2	1	0	7.1	0.0
17 Apr	147	2	3	0	2.0	0.0
18 Apr	138	3	3	0	2.2	0.0
19 Apr	92	3	2	0	2.2	0.0
20 Apr	46	2	2	0	4.3	0.0
21 Apr	43	1	0	0	0.0	0.0
22 Apr	102	5	2	0	2.0	0.0
23 Apr	51	8	0	0	0.0	0.0
24 Apr	48	67	0	2	0.0	3.0
25 Apr	46	87	0	0	0.0	0.0
26 Apr	156	56	3	1	1.9	1.8
27 Apr	200	41	4	1	2.0	2.4
28 Apr	149	60	6	5	4.0	8.3
29 Apr	76	100	2	1	2.6	1.0
30 Apr	69	377	2	12	2.9	3.2
01 May	123	210	7	7	5.7	3.3
02 May	112	201	2	9	1.8	4.5
03 May	113	245	2	6	1.8	2.4
04 May	145	106	2	0	1.4	0.0
05 May	152	79	5	1	3.3	1.3
06 May	169	95	4	3	2.4	3.2
07 May	154	81	7	1	4.5	1.2
08 May	215	85	4	1	1.9	1.2
09 May	261	140	5	1	1.9	0.7
10 May	233	219	3	2	1.3	0.9
11 May	278	159	7	0	2.5	0.0
12 May	579	187	4	0	0.7	0.0
13 May	845	291	16	0	1.9	0.0

Appendix Table 8. Continued.

Detection at Bonneville Dam	Bonneville Dam detections		Jones Beach detections			
	Chinook salmon (n)	steelhead (n)	Chinook salmon (n)	steelhead (n)	Chinook salmon (%)	steelhead (%)
14 May	627	185	11	0	1.8	0.0
15 May	538	276	16	5	3.0	1.8
16 May	640	445	16	6	2.5	1.3
17 May	887	244	47	9	5.3	3.7
18 May	1182	149	52	3	4.4	2.0
19 May	1091	198	38	5	3.5	2.5
20 May	941	140	42	3	4.5	2.1
21 May	764	157	18	0	2.4	0.0
22 May	799	170	25	3	3.1	1.8
23 May	752	428	33	3	4.4	0.7
24 May	956	169	31	1	3.2	0.6
25 May	840	116	8	2	1.0	1.7
26 May	841	103	16	2	1.9	1.9
27 May	560	92	16	2	2.9	2.2
28 May	522	128	11	3	2.1	2.3
29 May	385	221	18	4	4.7	1.8
30 May	303	212	9	7	3.0	3.3
31 May	164	130	4	4	2.4	3.1
01 Jun	205	67	11	5	5.4	7.5
02 Jun	168	39	5	3	3.0	7.7
03 Jun	226	107	4	5	1.8	4.7
04 Jun	137	61	5	3	3.6	4.9
05 Jun	92	38	2	1	2.2	2.6
06 Jun	79	43	1	4	1.3	9.3
07 Jun	47	71	1	4	2.1	5.6
08 Jun	48	29	1	1	2.1	3.4
09 Jun	65	19	3	2	4.6	10.5
10 Jun	77	61	1	0	1.3	0.0
11 Jun	96	22	3	1	3.1	4.5
12 Jun	104	15	3	0	2.9	0.0
13 Jun	54	5	1	0	1.9	0.0
14 Jun	32	14	1	1	3.1	7.1
15 Jun	12	10	0	1	0.0	10.0

Appendix Table 8. Continued.

Detection at Bonneville Dam	Bonneville Dam detections		Jones Beach detections			
	Chinook salmon (n)	steelhead (n)	Chinook salmon (n)	steelhead (n)	Chinook salmon (%)	steelhead (%)
16 Jun	20	26	0	0	0.0	0.0
17 Jun	35	11	0	0	0.0	0.0
18 Jun	228	13	0	0	0.0	0.0
19 Jun	13	4	0	0	0.0	0.0
20 Jun	54	2	2	0	3.7	0.0
21 Jun	38	1	2	0	5.3	0.0
22 Jun	50	5	0	0	0.0	0.0
23 Jun	65	2	0	0	0.0	0.0
24 Jun	38	2	0	0	0.0	0.0
25 Jun	275	6	0	0	0.0	0.0
26 Jun	39	2	0	0	0.0	0.0
27 Jun	36	1	0	0	0.0	0.0
28 Jun	67	0	0	0	0.0	--
29 Jun	73	0	0	0	0.0	--
30 Jun	77	2	0	0	0.0	0.0
01 Jul	84	0	0	0	0.0	--
02 Jul	302	1	0	0	0.0	0.0
03 Jul	58	0	0	0	0.0	--
04 Jul	26	0	0	0	0.0	--
05 Jul	40	2	0	0	0.0	0.0
06 Jul	74	1	1	0	1.4	0.0
07 Jul	59	0	0	0	0.0	--
08 Jul	86	0	1	0	1.2	--
09 Jul	282	0	3	0	1.1	--
10 Jul-28 Sep	503	0	0	0	0.0	--
Totals	21,640	7,182	560	146	2.6	2.0