Estimated survival of adult spring/summer Chinook salmon from the mouth of the Columbia River to Bonneville Dam, 2010

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Executive Summary

Aside from mortality attributed to harvest, the proportion of adult migrants lost through any mechanism between the river mouth and Bonneville Dam (rkm 234) has never been measured in a scientifically rigorous manner. Accurate estimates of freshwater mortality from all sources are critical to fishery management decisions. In preparation for conducting survival and behavior studies of adult salmon migrating through the estuary and lower Columbia River, NOAA Fisheries conducted a pilot study of adult survival to Bonneville Dam in spring 2010. A total of 333 adult spring Chinook salmon were collected, tagged, and released to the Columbia River estuary near river kilometer (rkm) 45.

Objectives of the pilot study were:

- Establish protocols and equipment needs, including boat and crew, for handling and tagging significant numbers of adult salmon (e.g., up to 100 fish per sampling day)
- Establish protocols for restraining fish to facilitate "best practices" for gastric and surgical tagging (acoustic tags) and injection of PIT tags
- Provide a cursory evaluation of the effects of tagging on adult fish
- Obtain estimates of PIT- and acoustic-tag retention for migrating fish over a period of 2 weeks or longer
- Obtain preliminary estimates of survival to Bonneville Dam for adult spring Chinook salmon to aid in sample-size selection for expanded survival studies

We marked 333 adult salmon using tangle-net sampling gear with custom PVC fish tubes for transport and holding and a custom aluminum restraint apparatus for tagging. This tagging protocol was successful, and all study fish appeared to have been in excellent condition upon release with no mortality observed during tagging.

Little or no evidence of tag loss was observed after release. Of the 22 acoustic-tagged fish detected at a PIT-tag interrogation site, 21 were also detected on one or more acoustic receivers immediately below Bonneville Dam (N = 19) or in the tailrace of Lower Granite Dam (N = 2). Mean travel time from release at rkm 44 to Bonneville Dam was similar between acoustic (16.1 d) and PIT-tagged (15.4 d) groups, while estimates of mean survival were higher for PIT (0.88) than acoustic-tagged fish (0.34).
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Introduction

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Methods

Fish were collected from vessels in the Columbia River estuary east of Astoria, Oregon near rkm 44. Adult fish were collected by commercial fishers with extensive experience in the use of 4.25-inch tangle-net gear (Figure 1). Upon landing, fish with no obvious abnormalities on physical examination were placed individually into custom, PVC fish tubes (Figure 2). Tubes were held in the river and transported from the sample boat to a tagging vessel, where they were either hung over the side of the vessel, so that fish remained in the river, or placed into a holding tank with flow-through river water until tagging. Fish that appeared compromised upon landing (e.g., fish that were lethargic or showed evidence of physical trauma such as an unhealed bite wound) were rejected for treatment. Excluded adults were allowed to recover in a "live box," equipped with high-flow river water, and were released (without tagging) after recovery. Bycatch species (such as steelhead and Chinook salmon jacks) were treated in a similar manner.

Figure 1. Commercial tangle-net crew hauling in a Chinook salmon in the lower Columbia River Estuary during 2010.
Figure 2. Custom fabricated PVC fish tube, which facilitated safe handling of adults and allowed study fish to be held individually in the river and within holding tanks.

To facilitate sampling and tagging, all study fish were physically restrained in a custom aluminum restraint built for this purpose (Figure 3). Treatment fish were measured and scanned for PIT tags, and a pelvic fin clip was obtained for genetic stock identification. Following genetic sampling, untagged fish were injected with a PIT tag subcutaneously in the region of the pelvic girdle. A subsample of 100 PIT-tagged fish were also implanted with acoustic transmitters (ATs) using either surgical (N = 50) or gastric (N = 50) insertion methods. Previously PIT-tagged fish were not excluded from the study; however, none of these fish were implanted with acoustic tags. After tagging, all study fish were placed back into their individual fish tubes, where they were allowed to recover in a tank with flow-through river water for a minimum of 20 minutes. Fish were then released from the tubes over the side of the vessel to resume migration.
Figure 3. All study fish were physically restrained in dorsal recumbency in a custom restraint for sample collection and tagging.

Fin tissue collected from study fish was analyzed to identify the most likely stock of origin based on genetic stock identification analysis (GSI). Genetic analysis was conducted in the manner of Teel et al. (2009). Fin tissues from tagged fish were genotyped for a set of 13 microsatellite DNA loci recently standardized among several west coast genetics labs (Seeb et al. 2007). Individual fish were then assigned to one of nine genetic-stock identification groups for the Columbia River basin (Seeb et al. 2007; Teel et al. 2009). Based on this analysis, all study fish were assigned to one of the following four groups:

- Willamette River spring Chinook
- West Cascade tributary spring Chinook
- Mid and Upper Columbia River spring Chinook
- Snake River spring/summer Chinook
Assignment tests conducted on fish of known origin showed that individuals were correctly assigned to these groups with approximately 90% accuracy, and were assigned to groups originating above or below Bonneville Dam with approximately 99% accuracy (D. Teel, unpublished data). Tissues and extracted DNA from our samples will be archived for re-analysis as new microsatellite or single nucleotide polymorphisms (SNPs) markers become available, permitting finer-scale and more accurate stock assignments (see Narum et al. 2008).

Survival and travel time were estimated only for fish originating upstream from Bonneville Dam, as identified by genetics testing. These estimates assumed that permanent straying below Bonneville Dam was negligible. After first identifying fish that had originated from upriver stocks, the number of study fish that had been tagged and released in the estuary was further adjusted by dividing by the proportion of fish estimated to have escaped harvest (97% based on WDFW and ODFW commercial and recreational harvest estimates for the study period\(^1\)) and the proportion of fish estimated to have survived the sampling method (87.2% based on recommendations for tangle-net gear (Ashbrook 2008\(^2\) and U.S. v Oregon Technical Advisory Committee). The survival estimate was further adjusted by detection efficiency of our study fish at Bonneville Dam in 2010 (98% based on comparing detections of study fish at Bonneville and McNary Dam).

Detections of PIT tags from our study fish in the Bonneville Dam fish ladders were downloaded from PTAGIS after returns were complete. These detections were used in the equation below to provide a point estimate of lower river survival for upriver fish. This estimate will be utilized to calculate precise sample-size requirements for future, more definitive studies, and to determine whether more precise estimates of harvest will be needed in the future.

Survival was estimated as follows:

\[
S = \frac{N}{R(1 - p_h)(1 - p_g)p_d}
\]

Where \(S\) = survival, \(N\) = number of fish detected at Bonneville Dam, \(R\) = number of fish released, \(p_h\) = mortality attributed to harvest, \(p_g\) = mortality attributed to the gear, and \(p_d\) = detection efficiency at Bonneville Dam for study fish in 2010.

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\(^1\) Estimates of harvest were restricted to the study period and did not include tribal harvest that may have occurred below Bonneville Dam in spring of 2010.

\(^2\) This estimate does not include pre-landing mortality due to net suffocation and sea lion predation.
Movement of acoustic-tagged fish was monitored on 72 stationary acoustic receivers located in the estuary and lower Columbia River. These receivers were deployed and maintained by a collaborative group of researchers from the Columbia River Intertribal Fish Commission and the U.S. Geological Survey. Two additional receivers were deployed below Lower Granite Dam by NOAA Fisheries researchers. Detections on this array were used in conjunction with PIT-tag detections at Lower Granite Dam to estimate tag loss (AT and PIT) for fish detected at this location. Surgically acoustic-tagged fish were recaptured using the separation-by-code system at Lower Granite Dam. These fish were photographed and examined for incision healing.
Results

A total of 333 adult spring Chinook salmon were tagged and released on 14 dates from 14 April through 5 June. A total of 233 study fish were marked with only a PIT tag, while 100 were marked with both a PIT tag and acoustic transmitter (Table 1). Study fish were identified and assigned to one of two lower-river and two upper-river genetic stock identification groups. These groups were the West Cascade tributary spring Chinook, Willamette River spring Chinook, Mid and Upper Columbia River spring Chinook, and Snake River spring/summer Chinook. Figure 4 illustrates the proportion of each release group represented by these stock identification groups.

Table 1. Adult Chinook salmon obtained from tangle-net fisheries in the Columbia River estuary during 2010 and tagged with PIT tags alone or in combination with surgically or gastrically implanted acoustic tags (AT).

<table>
<thead>
<tr>
<th>Date</th>
<th>PIT tag only</th>
<th>Surgical implant</th>
<th>Gastric implant</th>
<th>Totals</th>
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<td>50</td>
<td>333</td>
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</tbody>
</table>
Fish Tagged with only a PIT Tag

Genetic stock identification methods determined that we had PIT-tagged 174 adult Chinook salmon destined for tributaries above Bonneville Dam. The mean probability that these fish were correctly identified as upriver stock was 0.99 (range 0.91-1.0). These fish were further identified as either Mid/Upper Columbia River or Snake River stocks. The mean probability that these stock identifications were correct was 0.95 (range 0.54-1.0) for fish not detected within the hydrosystem and 0.92 (range 0.48-1.0) for fish that were detected at Bonneville or McNary Dam.

In total, 129 PIT-tagged fish were detected within the hydrosystem at one or more locations. The majority of these fish (N = 126) were first detected at Bonneville Dam. However, three additional fish were first detected at McNary Dam. Based on these detections, detection efficiency at Bonneville Dam for PIT-tagged study fish was estimated at 0.98 (126/129). Survival to Bonneville for PIT-tagged study fish was estimated at 0.88 (95% CI, 0.83-0.93) after accounting for gear-associated mortality (0.13) and mortality due to harvest (0.03).
Survival by release date for PIT-tag only study fish after accounting for potential mortality from sampling gear and from harvest. Error bars represent standard errors.

Mean travel time from release to Bonneville Dam for PIT tagged fish was 15.4 d (range, 6.2-31.3 d). Survival by release group ranged from 0.69 to 1.15 (Figure 5). Survival to Bonneville was comparable for fish identified as originating from Upper/Middle Columbia River genetic stocks (0.87) vs. those originating from Snake River stocks (0.89). Mean travel time to Bonneville was also similar for Upper/Middle Columbia (15.3 d; range, 6.2-26.2 d) and Snake River fish (15.4 d; range, 7.1-31.3 d).

Fish Tagged with a PIT-Tag and Acoustic Transmitter

Genetic stock identification determined that of the 100 adult Chinook salmon implanted with both an acoustic transmitter and PIT tag, 76 had originated in tributaries above Bonneville Dam. In total, 22 acoustic-tagged fish were detected within the hydrosystem at one or more locations, and all of these fish were first detected at Bonneville Dam. Survival to Bonneville for acoustic-tagged study fish (upriver stock only) was estimated at 0.34 (95% CI, 0.23-0.45) after accounting for gear-related mortality (0.13) and mortality due to harvest (0.03). Survival by release group ranged from 0.00 to 0.62 (Figure 6). Mean travel time to Bonneville Dam for acoustic-tagged fish was 16.1 d (range 6.9-30.2 d; with one outlier at 39.2 d).
Figure 6. Survival by release date for groups of acoustic-tagged study fish after accounting for potential mortality from sampling gear and from harvest. Error bars represent standard errors; asterisks denote groups with 0.0% survival.

Of the 100 acoustic-tagged fish released, 51 were detected in the lower estuary below the point of release at rkm 44 (Figure 7). Forty-two were detected only at or above the release site, and 7 were not detected after release. Thirty-six acoustic-tagged fish were eventually detected at or above Tenasillahe Island (rkm 56) near the upper extent of the estuary. All 36 of these fish were determined to be of either Middle/Upper Columbia or Snake River origin. Of these fish, 29 (81%) were detected at or above the Lewis River (rkm 140), 26 (89%) were detected at or above the Bonneville Dam tailrace (rkm 232), and 22 (85%) were eventually detected in the Bonneville adult ladders.
Figure 7. Map of the Columbia River below Bonneville Dam (rm 236) shows survival by reach (denoted by arrows) from release at rm 44 for acoustic-tagged study fish (N = 100). Circles represent acoustic receivers where study fish were detected. The larger the circle, the higher the proportion of study fish detected at a given location.
Tag Loss

Twenty-one of the 22 acoustic-tagged fish detected at PIT-tag interrogation sites within the hydrosystem were also detected on one or more acoustic receivers immediately below Bonneville Dam (N = 19) or above Bonneville in the tailrace of Lower Granite Dam (N = 2). These dual detections suggest very high acoustic-tag retention for these fish. Only one fish was detected on a PIT-tag interrogation system but not on an acoustic receiver immediately below or above Bonneville Dam. This fish was last detected on an acoustic receiver near the Lewis River approximately 96 km below Bonneville Dam. However, this did not necessarily indicate that the transmitter was lost or expelled. It is also possible that the transmitter had failed to produce a signal before the stated life of 120 days, or that acoustic receivers stationed in the reach between the Lewis River and Bonneville Dam had failed to detect the signal. All 10 acoustic-tagged fish detected at Lower Granite Dam had been detected on acoustic receivers below the dam as well as within the PIT-tag interrogation system at the dam, suggesting that there was no acoustic or PIT-tag loss for fish surviving to this location.
Discussion

As per the primary objectives of this study, we successfully established protocols for large-scale sampling of adult spring Chinook salmon in the estuary upon return to freshwater. We marked 333 adult salmon using tangle-net sampling gear with custom PVC fish tubes for transport and holding and a custom aluminum restraint apparatus for tagging. Fish were released back to the river, and subsequent detections of these fish were used to estimate upstream survival and travel time to Bonneville Dam in 2010. All study fish appeared to have been in excellent condition upon release, and we observed no mortality during tagging of these fish.

To evaluate stress levels and survival in fish handled and tagged using these protocols, we conducted a captive pilot study using steelhead as a surrogate to Chinook salmon. Results of this work are currently being evaluated; however, no mortality was observed in steelhead injected with PIT-tags and bled using our restraint apparatus through 14 days post-tagging. A more comprehensive captive study is planned for 2011 to further evaluate these protocols.

Preliminary survival estimates for adult spring Chinook salmon bound for tributaries above Bonneville Dam indicated that mean survival through the lower river to Bonneville Dam was 88% in spring 2010 (after accounting for potential mortality from harvest and gear effects). The 95% CI for this estimate ranged from 83-93%. However, we likely marked only the late-returning portion of the 2010 spring Chinook adult return group, and a more representative sampling/tagging effort would be necessary in order to make survival inferences for the run at large.

Although mean travel time to Bonneville Dam was similar for acoustic vs. PIT-tagged fish, survival of acoustic-tagged fish in the lower river was approximately 39% that of the PIT-tagged fish. The vast majority of acoustic-tagged fish (74%) were never detected above the upper estuary (rkm 560). This difference in survival may have been due to the longer restraint time required for acoustic tagging, the more invasive acoustic-tagging procedure, or the higher tag burden experienced by acoustic-tagged fish. These factors could have resulted in higher direct mortality of acoustic-tagged fish, or they could have rendered acoustic-tagged fish more vulnerable to predators than their PIT-tagged counterparts.

In addition, a recent report by Bowles et al. (2010a,b) suggests that acoustic tags may have been "heard" by some pinnipeds, making these fish more vulnerable to capture. The frequency of coded "pings" emitted by the 69-kHz tags is within the upper audible
range of harbor seals, and a relatively low-frequency "click" associated with amplitude envelope of the ping may be audible at very close distances to both harbor seals and sea lions. Future laboratory and field studies are being designed to address these possibilities.

Our goals in 2011 include repeating the 2010 pilot work with a sample that is more representative of the run over time. We will continue to evaluate acoustic tagging methods by incorporating "dummy" or silent acoustic transmitters into the study design. These should help to determine whether potential differences in survival between acoustic- and PIT-tagged fish are due to different tagging methods or are related in part to the "sound" emitted by acoustic transmitters. In addition, we plan to utilize temperature-sensitive transmitters in 2011 to determine whether active tags are in fish or mammals when they are detected.

Because there is a possibility that the transmitters may be audible to pinnipeds independent of frequency (e.g. through the amplitude envelope), we would also like to begin testing a group of fish surgically implanted with transmitters that operate at a frequency well above the audible range of harbor seals. As mentioned previously, captive stress studies using steelhead as a surrogate for Chinook salmon are also planned to evaluate whether or not the methods of restraint that we are using are more stressful than traditional methods, which include anesthesia.

Once robust methods for estimating survival of adult salmon are established, we will work closely with pinniped biologists to establish circumstantial evidence of predation. Pinniped behavior is currently being tracked for a select group of individuals that frequent the dam. We would like to see more emphasis placed on the behavior of estuary residents as well. In addition, hybrid transmitter/receivers are currently available for deployment on pinnipeds. This technology would allow us to document direct predator/prey interactions. Future goals (2012 and beyond) include expanding the acoustic infrastructure, incorporating a gear-comparison component, and extending investigations of lower river mortality to include fall Chinook and coho salmon.
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References


