Survival of adult spring/summer Chinook salmon from the mouth of the Columbia River to Bonneville Dam, 2011

A. Michelle Wargo Rub, Lyle G. Gilbreath, R. Lynn McComas, Benjamin P. Sandford, David J. Teel, and John W. Ferguson

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

November 2012

Contents

Introduction

Accurate estimates of freshwater mortality from all sources are critical to fishery management decisions. However, aside from mortality attributed to harvest, the proportion of adult migrants lost through any mechanism between the river mouth and Bonneville Dam (rkm 234) had not been measured in a scientifically rigorous manner. In spring 2010 and 2011, we conducted a pilot study of adult survival from the mouth of the Columbia River to Bonneville Dam. During these two study years, we collected and tagged a total of 962 adult spring Chinook salmon and released them to the Columbia River estuary near river kilometer (rkm) 45. This report details work conducted in 2011, the second year of the pilot study. Results from work conducted in 2010 are detailed in Wargo Rub et al. (2012).

Objectives of the pilot study were to:

- Establish protocols and equipment needs, including vessels and crews, 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 acoustic tagging with both gastric and surgical implantation methods and passive integrated transponder (PIT) tagging
- 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 inform sample-size selection for expanded survival studies

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, each fish with no obvious abnormalities on physical examination was placed individually into a custom, PVC fish tube (Figure 2) and then transported from the sample boat to a tagging vessel. Fish tubes were either hung over the side of the vessel so that fish remained in the river, or were placed into a holding tank with flow-through river water until fish could be tagged.

Fish that appeared compromised upon landing (e.g., those 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.

To facilitate transfer and tagging, all study fish were physically immobilized by placement in an on-board aluminum restraint device custom built for this purpose (Figure 3). Each treatment fish was measured and scanned for a preexisting PIT tag, and a small tissue sample was clipped from the pelvic fin for genetic stock identification. Following genetic sampling, each fish was injected subcutaneously in the region of the pelvic girdle with a 12-mm PIT tag (2.0 mm diameter; 0.1 g in air).

Figure 1. Commercial tangle-net crew hauling in a Chinook salmon.

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.

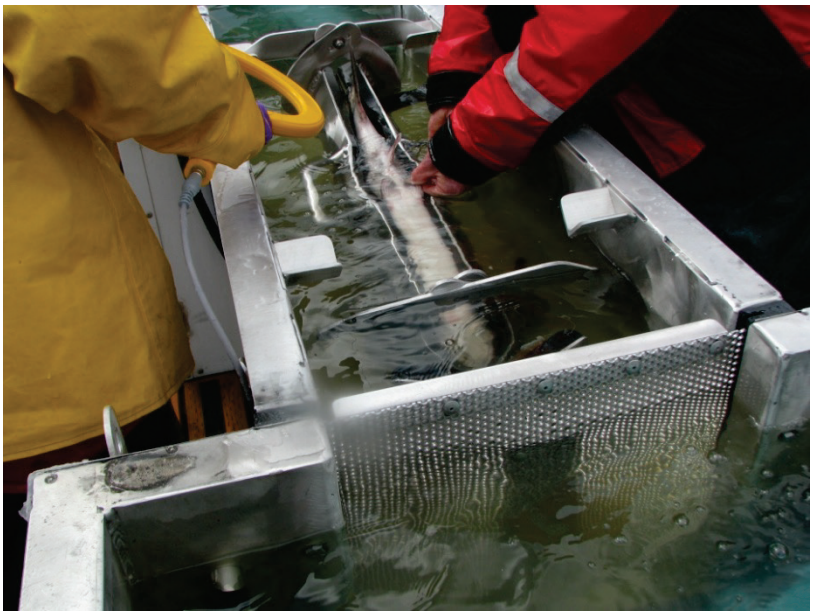

Figure 3. All study fish were physically immobilized in dorsal recumbency using a custom restraint for sample collection and tagging.

A subsample of 91 PIT-tagged fish were also implanted with an active acoustic transmitter equipped with a temperature sensor (VEMCO[1] V16 4L). Acoustic transmitters were 68 mm long, 16 mm in diameter, and weighed 24 g in air, producing an average tag burden well below 1%. Transmitters emitted a signal of 152 dB re 1μPa @ 1 m at 15 to 45-second intervals and were programmed for a tag life of 120 d. Acoustic transmitters were implanted either through gastric insertion into the stomach, or by surgical implant into the peritoneal cavity using a 1:1 ratio among the two attachment methods.

In addition to the group implanted with active acoustic transmitter tags, we also implanted 92 PIT-tagged fish with an inactive or sham acoustic transmitter. Sham transmitters were of the same shape and size as the active transmitters, and they were implanted in the same manner and ratio as active tags. Previously PIT-tagged fish were not excluded from the study; however, no previously PIT-tagged fish was implanted with an acoustic tag. After tagging, all study fish were returned to their individual PVC tubes, where they were allowed to recover in a tank with flow-through river water for a minimum of 20 minutes. After recovery, fish were released from the vessel to resume migration. XXX from tube over side of vessel XXX

Fin tissue was analyzed to identify the most likely stock of origin based on genetic stock identification (GSI) analyses conducted in the manner of Teel et al. (2009). Fin tissues from tagged fish were genotyped for a set of 13 microsatellite DNA loci from a standardized database developed by nine West Coast salmon genetics laboratories (Seeb et al. 2007). Individual fish were then assigned to one of nine potential 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 six groups:

- Mid and Upper Columbia River spring Chinook
- Snake River spring/summer Chinook
- Upper Columbia River summer/fall Chinook
- Willamette River spring Chinook
- West Cascade tributary spring Chinook
- North Oregon Coast Chinook

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

Test of the GSI assignment conducted with fish of known origin showed that individuals were correctly assigned to stock groups with approximately 90% accuracy. Stock group originations above vs. below Bonneville Dam were assigned with approximately 99% accuracy (D. Teel, unpublished data). Tissues and extracted DNA from our samples will be archived for further analysis as new microsatellite or single-nucleotide polymorphisms (SNP) markers become available, permitting finer-scale and more accurate stock assignments (see Narum et al. 2008).

Survival and travel time to Bonneville Dam were estimated only for stocks originating upstream from the dam as identified by genetics testing. These estimates assume that permanent straying below Bonneville Dam was negligible. For fish that had originated above Bonneville Dam, we adjusted the survival estimate by dividing by the proportion of fish estimated to have escaped harvest (97.5%). This harvest rate was based on commercial and recreational harvest estimates during the study period, which averaged 2.5% overall (range 0-6%); these estimates were provided by the Washington and Oregon Departments of Fish and Wildlife.[2] Estimated survival was also adjusted by the proportion of fish estimated to have survived the sampling method (87.2%); sample mortality rate was provided by the Technical Advisory Committee to U.S. v Oregon and was based on the recommendation of Ashbrook (2008).[3] Estimated survival was adjusted one final time by dividing by adult detection efficiency at Bonneville Dam (99%; based on detections of study fish at Bonneville vs. McNary Dam).

After returns were complete, detections of PIT tags from our study fish in the Bonneville Dam fish ladders were downloaded from the PITAGIS database (www.ptagis.org). These detection numbers were used in the equation below to provide point estimates of survival to Bonneville Dam for releases of upriver fish. This estimate will be utilized to calculate precise sample-size requirements and to determine whether more precise estimates of harvest will be needed for future, more definitive studies.

Survival was estimated as follows:

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

Where S = survival to Bonneville Dam, N = number of fish detected at the 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 2011.

[2] Harvest estimates for spring 2011 were restricted to the study period and did not include potential tribal harvest below Bonneville Dam.

[3] Gear survival estimate did not include pre-landing mortality due to net suffocation or sea lion predation.

Movement of acoustic-tagged fish was monitored on 42 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 Inter-Tribal Fish Commission, NOAA, and the U.S. Geological Survey. Two additional acoustic receivers were deployed below Lower Granite Dam. However, these receivers were both lost to extreme high flows in the Snake River during spring 2011 before any data could be collected from them. Therefore, we planned to use detections on acoustic receivers below Bonneville Dam in conjunction with PIT-tag detections to estimate tag loss of both types in fish detected at Lower Granite Dam.

Results

A total of 629 adult spring Chinook salmon were tagged and released on 19 dates from 1 April through 16 May. Of these fish, 446 were marked with only a PIT tag, 91 were marked with both a PIT tag and active acoustic transmitter, and 92 were marked with both a PIT tag and an inactive or sham acoustic transmitter (Table 1).

Table 1. Adult Chinook salmon obtained from tangle-net fisheries in the Columbia River estuary, 2011. Previously PIT-tagged fish were included; non-tagged fish were injected with a PIT tag only or injected with a PIT tag and then surgically or gastrically implanted with an active or inactive acoustic transmitter (AT).

	Adult Chinook salmon (N)						
	PIT only		Gastric AT and PIT		Surgical AT and PIT		
Date	New	Previous	Active	Sham	Active	Sham	Totals
1 Apr	32	1	1	1	1	1	37
4 Apr	9		2	2	1	1	15
5 Apr	10				1	1	12
13 Apr	26	1	3	4	3	3	40
14 Apr	44	1	3	3	3	3	57
18 Apr	39	2	3	3	3	3	53
20 Apr	45	2	4	4	4	4	63
22 Apr	66		5	5	5	5	86
27 Apr	23	2	2	2	2	2	33
28 Apr	29	1	3	3	3	3	42
29 Apr	36	2	4	4	4	4	54
30 Apr	14		2	2	2	2	22
2 May	11		2	2	2	2	19
4 May	27		4	4	4	4	43
5 May	12		2	2	2	2	20
6 May	2		1	1	1	1	6
12 May	3		1	1	2	2	9
13 May	6		2	2	2	2	14
16 May			1	1	1	1	4
Totals	434	12	45	46	46	46	629

Study fish were assigned to three lower-river and three upper-river stock groups based on genetic stock analysis (Table 2). Among fish assigned to upper-river stocks, 246 originated from the Mid/Upper Columbia River spring Chinook group and 199 from the Snake River spring/summer Chinook group (Table 2), with 2 additional fish from the Upper Columbia River summer/fall Chinook group. Lower river stock groups represented in the collection were the West Cascade tributary and Willamette River spring Chinook groups, along with one fish from the North Oregon Coast Chinook group. Fourteen fish could not be reliably identified to a specific stock. Figure 4 illustrates the proportion of each release group represented by the four largest stock groups identified in the overall sample.

Table 2. Genetic stock groups of adult Chinook salmon collected for evaluations of survival and behavior in the lower Columbia River and estuary, 2011.

Genetic stock group	N
Upper Columbia River	
Mid and Upper Columbia River spring Chinook	246
Snake River spring/summer Chinook	199
Upper Columbia River summer/fall Chinook	2
Lower Columbia River	
West Cascade tributary spring Chinook	44
Willamette River spring Chinook	125
North Oregon Coast Chinook	1
Unidentified stock group	14

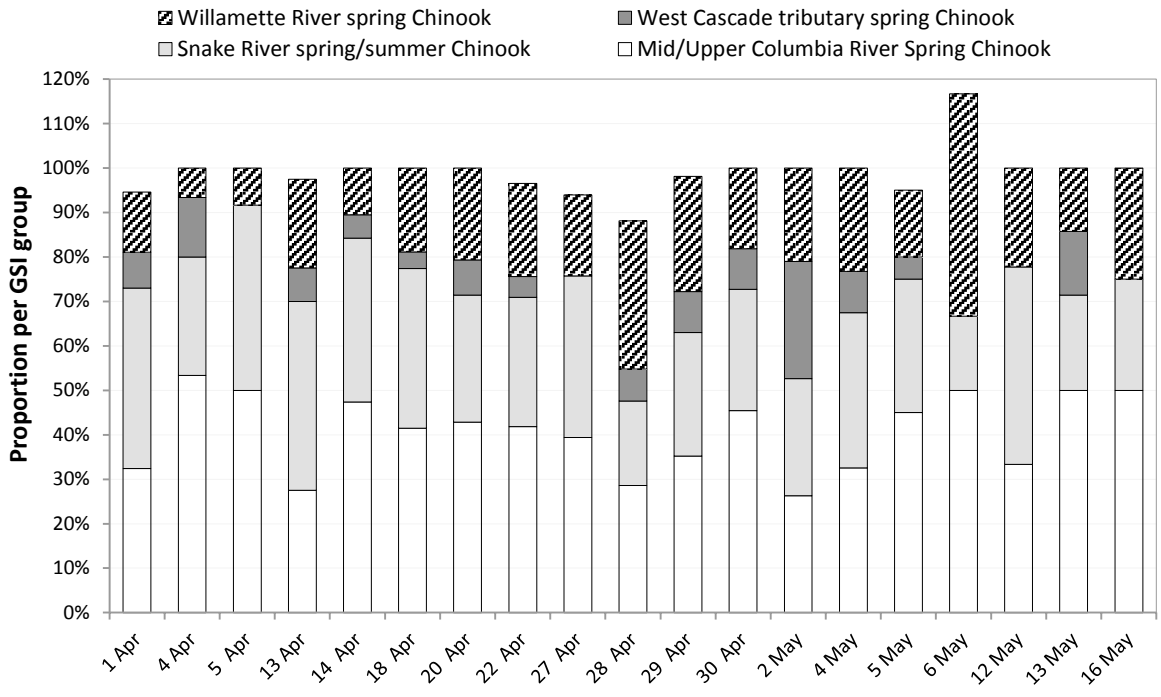

Figure 4. Proportion of fish identified to each of four genetic stock groups by date of release. Willamette River and West Cascade tributary groups originated below Bonneville Dam, while the Snake and Mid/Upper Columbia River groups originated above the dam. Note release dates were not consecutive.

Survival and Travel Time

Fish with PIT tags and sham acoustic tags

Among study fish assigned to stocks above Bonneville Dam, 307 were marked with a PIT-tag and 67 with both a PIT and sham acoustic tag. Exploratory analyses indicated that survival and travel times were similar among these two treatment groups; therefore, we combined these groups for subsequent analyses to increase statistical power. The mean probability that these fish were correctly identified as upriver stocks was 0.99 (range 0.57-1.0). These fish were further identified to Mid/Upper Columbia River or Snake River stock groups. The mean probability that these identifications were correct was 0.90 (range 0.34-1.0) for the Mid/Upper Columbia stock group and 0.92 (range 0.53-1.0) for the Snake River stock group.

For the combined PIT only and PIT plus sham acoustic tag treatments, estimated survival to Bonneville Dam was 0.85 (95% CI; 0.79-0.93); this estimate included a gear-related mortality rate of 0.13 and a mean harvest-related mortality rate of 0.025. By release group, survival estimates for these fish ranged from 0.70 to 1.01 (Figure 5) and were comparable between groups assigned to Upper/Middle Columbia (0.84) and Snake River (0.86) stocks. However, estimated survival was considerably lower for fish tagged and released during the middle of the study period (0.76) than for those released either earlier (0.89) or later in the season (0.98; Table 3 and Figure 5).

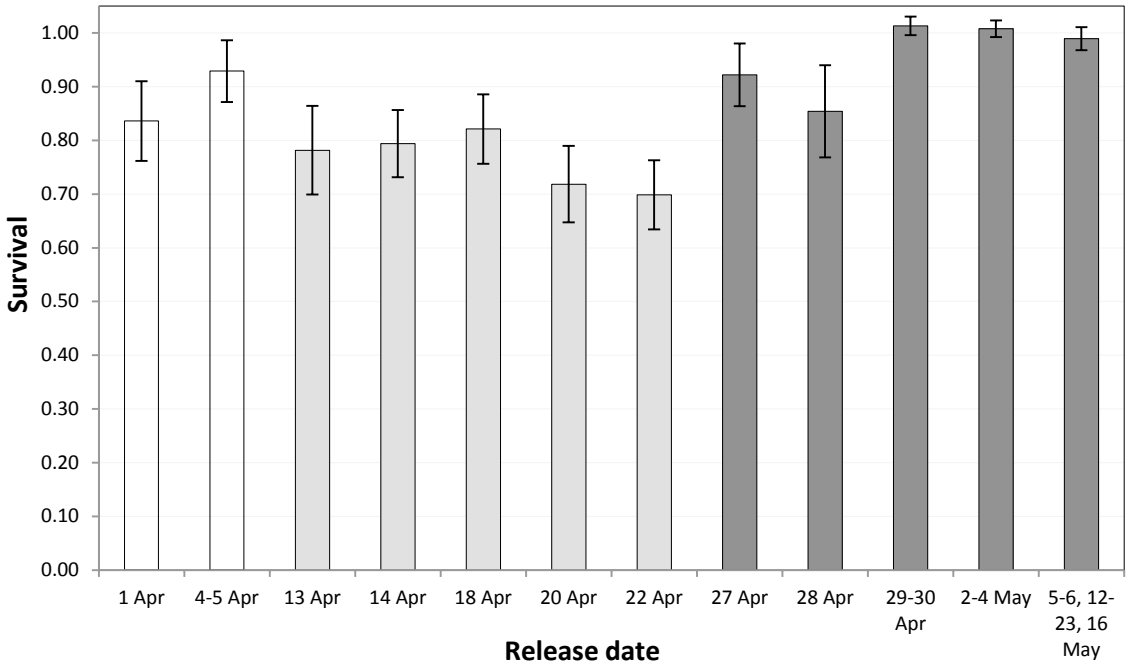

Figure 5. Survival by release date for early (white), middle (light), and late season (dark) study fish marked with either a PIT-tag or sham acoustic tag and PIT tag. Estimates include potential mortality from sampling gear and harvest. Error bars represent standard errors. Dates of release were not consecutive.

Table 3. Estimated survival from the lower estuary to Bonneville Dam for groups of adult spring Chinook salmon tagged with either a PIT tag only or a PIT tag and sham acoustic transmitter, 2011. Estimates of survival were lower for fish released during the middle of the study period, even after adjusting for variation in harvest estimate (range 0-6%).

	PIT only and PIT plus sham acoustic tag groups		
	Date range	Estimated survival	Total released (N)
Early season	1-5 April	0.89	45
Middle season	13-22 April	0.76	193
Late season	27 April-5 May	0.98	136

Median travel time from release to Bonneville Dam for PIT and sham-tagged fish was 22.2 d (range, 8.2-57.0 d). Median travel time to Bonneville Dam was similar for Upper/Middle Columbia (21.4 d; range, 9.0-53.2 d) and Snake River fish (21.0 d; range, 8.2-57.0 d. However, a general trend of faster travel times to Bonneville was observed through the beginning of May (Figure 6.).

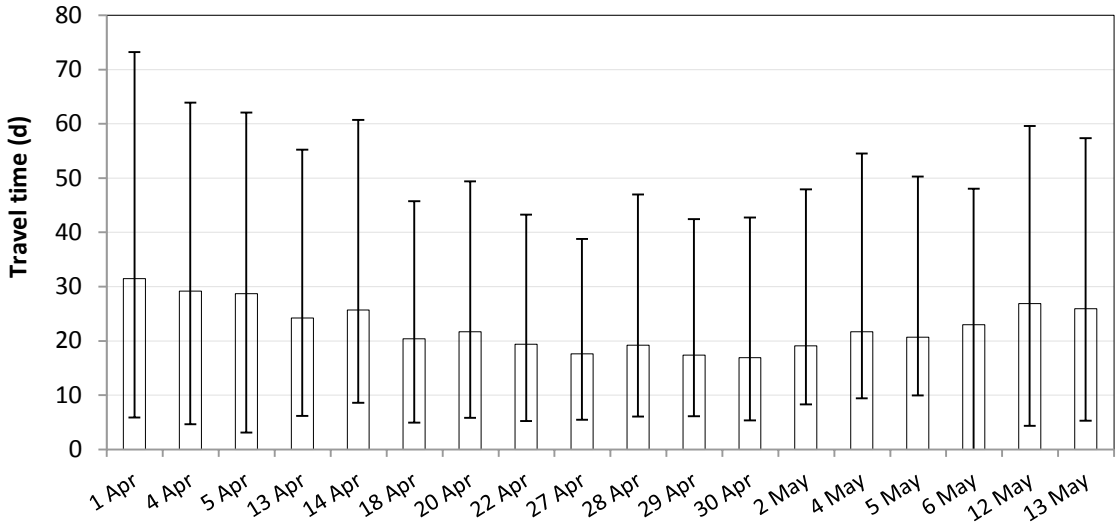

Figure 6. Median travel time to Bonneville Dam by release date for fish either PIT-tagged or implanted with both a sham acoustic tag and PIT tag. Error bars represent 10th and 90th percentile passage time. Note dates are not consecutive.

Fish with active acoustic tags

Results from genetic stock identification showed that of the 91 study fish tagged with both an active acoustic transmitter and PIT tag, 71 had originated from stocks above Bonneville Dam. The mean probability that these 71 fish were correctly assigned to upriver stocks was 0.98 (range 0.75-1.0). These fish were further identified as either Mid/Upper Columbia River or Snake River stock groups, and the mean probability that these assignments were correct was 0.92 (range 0.56-1.0) for Mid/Upper Columbia stocks and 0.87 (range 0.51-1.0) for the Snake River stock group.

In total, 10 acoustic-tagged fish were detected at one or more locations within the hydrosystem, and all of these fish were first detected at Bonneville Dam. Survival to Bonneville for these 10 fish (upriver stock only) was estimated at 0.17 (95% CI, 0.04-0.24) after accounting for gear-related mortality (0.13) and mortality due to harvest (mean 0.025). Survival by release group ranged from 0.00 to 0.40 (Figure 6). Median overall travel time to Bonneville Dam for these fish was 18.1 d (range 14-26.2 d).

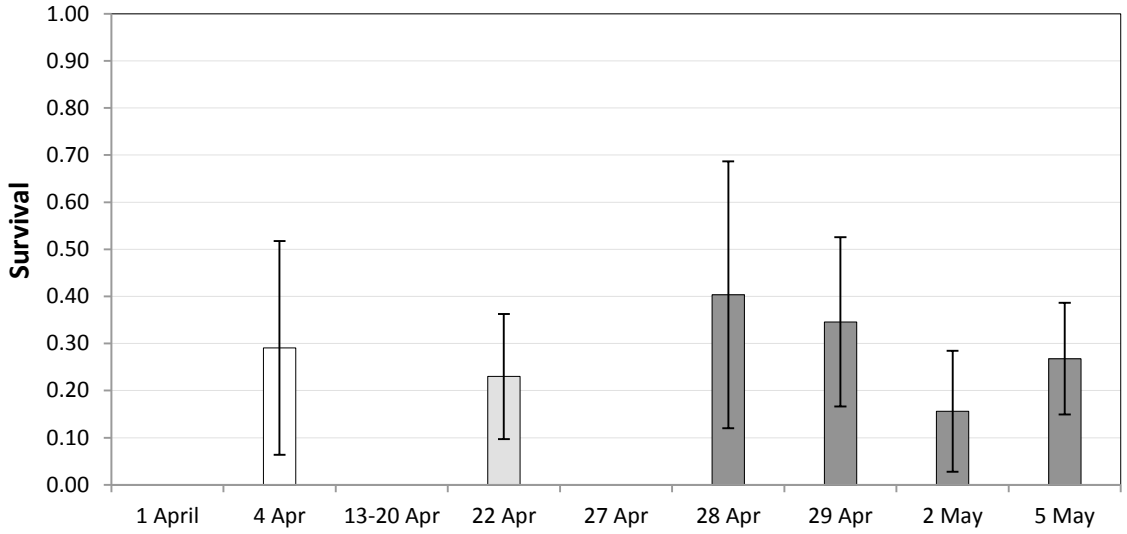

Figure 6. Survival by early (white), middle (light), or late season (dark) release date for acoustic-tagged study fish after accounting for potential mortality from sampling gear and from harvest. Error bars represent standard errors. Dates or date ranges with no bar represent groups with 0% survival.

Of the 71 upriver fish implanted with active acoustic transmitters, 44 were detected on acoustic receivers below Bonneville Dam. These detections were assumed to have been from live fish when 1) commensurate temperatures were within range of ambient river water (8-10°C), and 2) detection did not persist over several hours in a stationary location, as would occur if a transmitter had been deposited/dropped on the river bottom. Detections were assumed to have been from marine mammals if their commensurate temperatures were within the range of the body temperature of a warm-blooded animal (36-38°C).

Only 11 (15%) transmitters were eventually detected at Tenasillahe Island (rkm 56) or further upstream, and all of these were deemed to be in fish. The remaining transmitters were detected only on acoustic receivers at or below the point of release or not at all. Of the 11 fish detected upstream from the release site, 10 were subsequently detected at or above the Lewis River (rkm 140), and all of these fish were eventually detected at Bonneville Dam. These results indicated high survival for fish in river reaches above rkm 56.

In total, 9 of the 71 transmitters implanted into upriver fish were detected in marine mammals. Eight of these transmitters were first detected at ambient water temperatures and thus assumed to have been within fish. After release, the average time until these transmitters were detected in a warm-blooded animal, such as a sea lion or harbor seal, was 1.9 d (range = 0.59-2.73 d), excluding one outlier at 42 d.

Tag Loss

Eight of the 10 acoustic-tagged fish detected at PIT-tag interrogation sites within the hydrosystem were also detected on one or more acoustic receivers deployed immediately below Bonneville Dam (rkm 212-234). All 10 acoustic-tagged fish were detected on acoustic receivers near the Lewis River (rkm 140) prior to being detected at a PIT-tag interrogation site. These dual detections suggested high retention rates for both acoustic and PIT tags. However, we were not able to obtain data for evaluations of tag retention further upstream in 2011. Unfortunately, the acoustic receivers deployed at Lower Granite Dam were lost due to unusually high river flows, and none of our acoustic-tagged fish were detected on a PIT-tag monitor at Lower Granite Dam.

Discussion

During pilot studies of adult survival in 2010 and 2011, we successfully established a protocol for large-scale collection of migrating adult Chinook salmon in the estuary, successfully meeting a primary study objective. Our protocol relies on tangle-net sampling gear, custom PVC fish tubes for transport and holding, and a custom aluminum restraint apparatus for tagging. Using this protocol, we marked 333 adult salmon in 2010 and 629 in 2011 for studies of survival and travel time to Bonneville Dam. All fish were released back into the river after tagging and appeared to have been in excellent condition upon release; we observed no mortality during tagging.

To date, adult mortality through the estuary and lower river below Bonneville Dam has been assumed negligible due to lack of information about this segment of the adult migration. As such, mortality that occurs before adults reach Bonneville Dam has been attributed by default to the ocean phase of the life cycle. Our estimates of survival in 2011 for adult spring Chinook salmon from stock groups originating above Bonneville Dam indicated that beyond harvest or gear effects, mortality through the estuary and lower river was considerable (e.g. 24%) for fish tagged during the peak of the run from 13-22 April. Mortality for fish that arrived in the estuary early was somewhat lower (e.g. 11%), and was the lowest (e.g. 2%) for the tail end of this run. These patterns of mortality were consistent with those observed during our study of adult survival in 2010.

There was direct evidence in 2011 that this mortality included predation by warm-blooded animals; however, this evidence was obtained from acoustic transmitters, which themselves may have affected passage success through the estuary. In 2011, estimated survival for acoustic-tagged treatment fish was approximately 20% of the estimated survival for PIT-tagged and sham acoustic-tagged fish. This large difference suggested a treatment effect related to tag type. Although we had observed a similar phenomenon in 2010, we had implanted study fish with only active acoustic tags. At the time, we hypothesized that the difference in survival may have been related to biological effects from the longer restraint time, more invasive attachment procedure, or higher tag burden associated with acoustic tags as opposed to PIT tags.

In our second year of evaluation, we designed the study to provide insight into the causes of any observed differences in mortality among tag treatments. We used both gastric and surgical implantation methods for the acoustic tags, and we added a sham acoustic tag group. Results in 2011 showed that survival for fish implanted with a sham acoustic tag was similar to that of fish tagged only with a PIT-tag. This result did not support our hypothesis that biological effects such as tag burden or invasive attachment

procedure were responsible for differences in survival. We revised our hypothesis to include the possibility that pinnipeds were able to detect signals from active acoustic transmitters in fish and to use these signals to assist them in depredation of adult salmon runs.

Bowles et al. (2010a,b) recently reported that acoustic tags may be "heard" by some pinnipeds, and that harbor seals demonstrated an aversion to the ping emitted by a 69-kHz transmitter. If pinnipeds are able to detect acoustic transmitters in fish, then tagged fish would clearly be more vulnerable to these predators. In an informal study at the Oregon Coast Aquarium in Newport, Oregon, a similar aversion to 69-kHz transmitters was observed in both a harbor seal and a young sea lion (L. Weitkamp, NWFSC, personal communication).

These observations prompted a collaborative effort with researchers at the NMFS Southwest Fisheries Science Center and the Long Marine Lab of the UC Santa Cruz Institute of Marine Sciences to recreate pinniped hearing curves at frequencies and intensities similar to those produced by VEMCO 69 kHz acoustic transmitters. Early tests have indicated that harbor seals are likely able to detect contemporary 69-kHz transmitters at distances of up to 2,930 m in freshwater, and sea lions are able detect these transmitters at distances of up to 630 m (Colleen Reichmuth, UCSC, personal communication). Additional work is being conducted to evaluate pinniped hearing at higher frequencies (e.g., 180 kHz).

In 2011, we used transmitters with temperature sensors to determine whether detections on our acoustic arrays were from fish or sea lions. For this purpose, these hybrid transmitters were very effective. Not only were we able to discern the difference between detections of fish and mammals, in many cases we were able to document the time between release and each predation event. For one fish, we were even able to document a specific predation event as temperatures associated with its tag signal increased over several minutes from levels that reflected ambient water to those that reflected a warm-blooded animal.

Of the 13 transmitters detected in marine mammals, average time between release and detection in a marine mammal was 2.2 d (range 0.4-8.2 d) excluding one outlier at 42 d. Of the 13 marine mammal tracks we obtained, none extended above rkm 44. Tag detections in marine mammals also indicated that these predators resided in the estuary during the entire study period (April-June). Five of the 13 transmitters detected in a marine mammal were detected only between rkm 4.8 and 38, and 8 were detected between rkm 4.8 and 44. The duration of these marine mammal tracks ranged from a few hours to 73 d. The average detection period for tags in marine mammals was 22 d.

An additional objective for using the temperature sensors was to see if these tags could be used to determine decisively whether predation by marine mammals was indeed the primary cause of the mortality that had been observed in 2010. Unfortunately, the only transmitters detected within marine mammals in 2011 were from the gastric-tag treatment group, indicating an additional bias in the data based on tagging method. It is possible that gastric-tagged fish were more vulnerable to predation than those with surgical implants; however, this is not likely given the similarity in survival and travel time estimates among gastric and surgical tag treatments in both study years.

We suspect the reason gastric tags were observed in warm-blooded animals while surgical tags were not is more likely related to differences in tag placement within the fish or differences in surface roughness of gastric vs. surgical implants. Tags implanted gastrically were seated within the stomach, while tags implanted surgically could potentially shift position within the abdominal cavity. As such, the surgically implanted tags would have been more likely to shake loose or drop from the fish during capture or consumption.

Of course, one would not expect variation in transmitter placement to contribute to this difference for fish that were consumed whole. Therefore, because we did not observe a single surgically implanted transmitter within a marine mammal, it is more likely that retention in marine mammals was related to the difference in surface roughness between the tags themselves. Two-2 mm wide silica bands were placed around each gastrically inserted tag (Figure 7). These bands were added to promote transmitter retention in fish stomachs per Keefer et al. 2004a, and they may have increased tag retention in pinnipeds as well. In contrast, the surgically implanted tags were not banded and thus had a smooth surface.

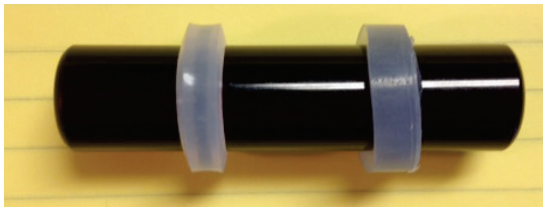

Figure 7. VEMCO V-16 acoustic transmitter with two-2 mm wide silica bands added to promote transmitter retention within fish stomachs after esophageal implant.

Overall, results from acoustic tagging in 2011 established that some portion of gastrically tagged fish were consumed by marine mammals. However, they also indicated that using acoustic tags with temperature sensors may not be a reliable method to estimate or rule out predation, since the only transmitters observed in marine mammals were from gastric-tagged fish. Furthermore, although the detection data from acoustic-tagged fish did indicate that mortality occurred below rkm 56, it did not indicate the source of mortality. The vast majority of transmitters from fish that were not detected

at Bonneville Dam were either detected only in fish or never detected at all, leaving the cause of their demise unknown.

In the future we plan to expand the overall study design to include one or more strategically located sampling and release sites. The addition of these sites may help to ensure that estimates of survival are not biased by the release location. As mentioned earlier, captive studies to investigate questions about pinniped hearing acuity are ongoing, and future field studies are being designed to determine if the marine mammal tracks that we observed in 2011 were from sea lions, harbor seals, or both. In addition, although not a primary goal of the pilot study, we believe that the results of our sampling and tagging effort will be useful to fisheries managers in the future as they attempt to make in-season adjustments to run forecasts.

Towards this end, we plan to work closely with state and tribal resource managers to provide real-time information on catch numbers and fish movement to the research and management community. At present we are able to estimate only stock-specific survival for upriver Chinook salmon. However, based on newly developed single nucleotide polymorphism (SNP) genetic markers (Steele and Campbell 2011), we will soon be able to estimate cohort-specific survival as well for Snake River hatchery stocks.

Acknowledgements

We thank Susan Hinton and Paul Bentley of the NOAA Point Adams Research Station; George McCabe, Dave Caton, Christopher Lloyd, Joel Holcomb, and Brian Fite of Pacific States Marine Fisheries Commission; and Jim Simonson and crew of NOAA Fisheries Pasco Research Station. Thanks also to Doug Hatch and Ryan Brandstetter of the Columbia River Inter-Tribal Fish Commission, Jason Romine and Mike Parsley of the U.S. Geological Survey, and Chris Kern of the Oregon Department of Fish and Wildlife. We are also grateful for assistance from Brian, Frank, and Stephanie Tarabochia and Dan Marvin of Astoria, Oregon, and from JoAnne Butzerin of the Northwest Fisheries Science Center. This work was funded by NOAA through a regional cooperative fishing grant under the Magnuson-Stevens Fishery Conservation and Management Act.

References

Ashbrook, C. E. 2008. Selective fishing and its impacts on salmon: a tale of two test fisheries. MS Thesis, University of Washington, Seattle.

Bowles, A.E., S.L. Denes, and M. Shane. 2010. Acoustic characteristics of ultrasonic coded transmitters for fishery applications: could marine mammals hear them? Journal of the Acoustical Society of America 128(5):3,223-3,231.

Bowles, A.E., S.K. Graves, M. Shane, and S.L. Denes. 2010. Harbor seals respond with aversion to 69-kHz pings: Implications for weighting procedures for marine mammal noise metrics. Abstract *in* 159th Meeting of the Acoustical Society of America, 19-23 May 2010, Baltimore, MD. Journal of the Acoustical Society of America 127(3):1803.

Keefer, M. L., Peery, C. A., Ringe, R. R., and Bjornn, T. C. 2004a. Regurgitation rates of intragastric radio transmitters by adult Chinook salmon and steelhead during upstream migration in the Columbia and Snake Rivers. North American Journal of Fisheries Management 24:47-54.

Keefer, M. L., Peer, C. A., Jepson, M. A., Tolotti, K. R., Bjornn, T., and Stuehrenberg, L. C. 2004b. Stock-specific migration timing of adult spring-summer Chinook salmon in the Columbia River Basin. North American Journal of Fisheries Management 24:1145-1162.

Narum, S.R., Banks, M., Beacham, T.D., Bellinger, M.R., Campbell, M.R., Dekoning, S.J., Eliz, A., Guthrie III, C.M., Kozfkay, C., Miller, K.M., Moran, P., Phillips, R., Seeb, L.W., Smith, C.T., Warheit, K., Young, S.F., Garza, J.C. 2008. Differentiating salmon populations at broad and fine geographic scales with microsatellite and single nucleotide polymorphisms. Molecular Ecology 17:3464-3477.

Seeb, L. W., Antonovich, A., Banks, M. A., Beacham, T. D., Bellinger, M. R., Blankenship, S. M., Campbell, M. R., Decovich, N. A., Garza, J. C., Guthrie III, C. M., Lundrigan, T. A., Moran, P., Narum, S. R., Stephenson, J. J., Supernault, K. J., Teel, D. J., Templin, W. D., Wenburg, J. K., Young, S. F., and Smith, C. T. 2007. Development of a standardized DNA database for Chinook salmon. Fisheries 32(11):540-552.

Steel, C. and Campbell, M. 2011. Parentage based tagging of Snake River hatchery steelhead and Chinook salmon. Report of the Idaho Department of Fish and Game and Columbia Inter-Tribal Fish Commission to the Bonneville Power Administration, Portland, Oregon. Report IDFG 11-111 available from https://research.idfg.idaho.gov (November 2012).

Teel, D. J., Baker, C., Kuligowski, D. R., Friesen, T. A., and Shields, B. 2009. Genetic stock composition of subyearling Chinook salmon in seasonal floodplain wetlands of the Lower Willamette River, Oregon. Transactions of the American Fisheries Society 138:211-217.

A. Michelle Wargo Rub, Lyle G. Gilbreath, R. Lynn McComas, Benjamin P. Sandford, David J. Teel, and John W. Ferguson. 2012. A study to evaluate survival of adult spring/summer Chinook salmon migrating from the mouth of the Columbia River to Bonneville Dam. Report of the National Marine Fisheries Service Northwest Fisheries Science Center, Fish Ecology Division. Seattle, Washington. Available from www.nwfsc.noaa.gov/publications/scientificpubs.cfm (November 2012).