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Fish Ecology Division

Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

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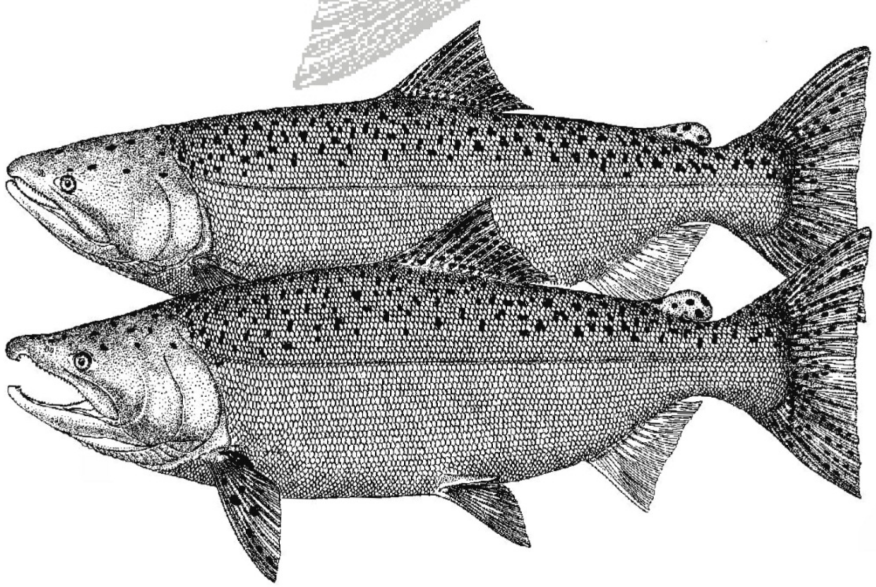

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Fish Ecology Division, Northwest Fisheries Science Center
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EXECUTIVE SUMMARY

Evaluation of Acoustic Tags in Migrating Yearling Chinook Salmon

Migration rates, detection and survival probabilities, and avian predation rates were compared between fish tagged with a passive integrated transponder (PIT) tag vs. those tagged with both a PIT-tag and Juvenile Salmonid Acoustic Telemetry System (JSATS) tag. During spring 2008, we collected migrating hatchery yearling Chinook salmon at Lower Granite Dam. We tagged 4,139 of these fish with both a JSATS tag and a PIT tag (JSATS-tagged fish) and 50,814 with a PIT tag only (PIT-tagged fish). Samples were designed to be of sufficient size to determine a minimum difference of 5% between tag groups in detection and survival over a distance of 348 km, and to provide statistical power of 80% ($\alpha = 0.05$). Fish were released to the tailrace of Lower Granite Dam on 10 d, from 24 April through 17 May.

Acoustic-tagged fish were implanted with the 2008 model JSATS acoustic tag, which weighed 0.42 g in air. Average tag burden experienced by JSATS-tagged fish was 2.3% of body weight (range 0.8-7.2%). For both tag treatments, travel times, detection probabilities, and survival were estimated from individual PIT-tag detections at Little Goose, Lower Monumental, McNary, John Day, and Bonneville Dam. For estimates of detection probability and survival, we also utilized detections of JSATS-tagged fish from acoustic arrays at multiple locations within the study area.

Mean detection probabilities were estimated for each PIT-tag detection site. Mean detection probability was higher for JSATS- than PIT-tagged fish at Little Goose, Lower Monumental, and John Day Dams. The difference in detection probability was 0.04 ($P = 0.005$) at Little Goose Dam, 0.05 ($P = 0.002$) at Lower Monumental, and 0.06 ($P = 0.006$) at John Day Dam. Mean detection probability at Ice Harbor Dam was 0.03 higher for JSATS- than PIT-tagged fish, and the difference approached significance ($P = 0.067$). There was no significant difference in detection probability between tag-treatment groups at McNary or Bonneville Dam ($P = 0.242$, and 0.174, respectively).

In the Snake River, relative survival (ratio of survival estimates for JSATS-tagged/PIT-tagged groups) was not significantly different than one from release to Little Goose or Ice Harbor Dam ($P = 0.107$ and 0.336 respectively). Relative survival was 0.95 from release to Lower Monumental Dam and approached significance ($P = 0.096$). In the Columbia River, relative survival was 0.91 ($P = 0.095$) to McNary Dam, 0.72 ($P = 0.001$) to John Day Dam, and 0.69 ($P = 0.021$) to Bonneville Dam. A significant difference in travel time to John Day Dam was observed ($P = 0.019$), with JSATS-tagged fish arriving 0.81 d (19.44 h) after PIT-tagged fish, but significant differences in travel time were not observed at any other detection site.

Overall mean PIT-tag recovery from upper river bird colonies was 2.0% for JSATS-tagged and 1.0% for PIT-tagged fish. Although this 1% difference in tag-recovery rate was statistically significant ($P = 0.016$), it was not likely to have been biologically meaningful. From estuarine bird colonies, the overall mean PIT-tag recovery was rate 3.0% for JSATS-tagged and 4.0% for PIT-tagged fish, and the difference was not significant ($P = 0.881$).

Gross Necropsy and Histological Evaluation of Migrating Yearling Chinook Salmon

To provide insight into the mechanism responsible for any tag effects observed, we subsampled study fish at two downstream sites for necropsy and histological evaluation. Up to 10 yearling Chinook salmon from each tag treatment and each release group were recaptured during migration using the separation-by-code (SbyC) systems in the juvenile bypass facilities at McNary and Bonneville Dams. Midway through the study, sampling at Bonneville Dam was discontinued due to extremely high flows, which resulted in high debris loads on the fish guidance screens. We resumed sampling for the Bonneville target groups at John Day Dam within approximately 48 h of this disruption. Respective subsamples from JSATS- and PIT-tagged release groups totaled 98 and 92 at McNary Dam, 29 and 67 at Bonneville Dam, and 57 and 53 at John Day Dam. John Day and Bonneville fish were combined in a single group for analysis.

Recaptured fish were euthanized and examined for tag loss, disease, and histological change due to tag implantation. Kidney tissue samples were also collected and examined for the antigen to *Renibacterium salmoninarum* (Rs), the causative agent of bacterial kidney disease (BKD). A group of 100 non-tagged reference fish was used to provide baseline data for comparisons of gross necropsy, histological evaluation, and assessments of Rs in JSATS- and PIT-tag treatment fish. Reference fish were hatchery yearling Chinook collected at Lower Granite Dam for evaluations of migrating fish.

The majority of fish subsampled at McNary Dam from both tag treatments were described as having either opaque, frayed, or missing fins (79% of PIT-tagged fish and 90% of JSATS-tagged fish). In contrast, a large majority of reference fish, and fish subsampled further downstream at Bonneville Dam, were described as having normal fins. Additionally, 13% of JSATS-tagged fish collected at McNary Dam were described as having eyes that were hemorrhagic. By comparison, 99% of the Lower Granite reference fish were described as having normal eyes. These observations indicated that fish might have experienced a trauma sometime between release and recapture. We also noted that in the McNary subsamples, the percentage of fish with hemorrhagic eyes was higher in JSATS-tagged than in PIT-tagged fish, and the difference between treatment groups was significant ($P = 0.003$).

For both tag treatments, gross necropsy revealed less caecal and mesenteric fat in fish collected at McNary and Bonneville Dam than in reference fish, although these metrics were rated similarly between treatment groups at both locations. Splenic engorgement/enlargement was more prevalent in Lower Granite reference fish than in tag-treatment fish of either type subsampled at either McNary or Bonneville Dam. Enlarged spleens were observed in a higher percentage of fish collected at McNary than at Bonneville Dam. In the Bonneville subsamples, the percentage of fish observed with food in the stomach was higher for PIT-tagged than JSATS-tagged fish, and the difference between treatment groups was significant ($P = 0.038$). However, there was no difference between treatments for this metric in the McNary subsamples. Greater than 99% of all reference fish and SbyC subsampled fish were rated as having normal kidneys on gross exam. Liver abnormalities were seen in both reference and SbyC fish, and were of similar prevalence among treatment groups.

Comparative histopathology metrics varied by recapture site and were mixed with respect to nutritional indicators, with some being higher in JSATS-tagged and others in PIT-tagged fish. However, histological indicators of inflammation and healing showed a consistent pattern of higher inflammation and slower healing in JSATS-tagged fish. For example, chronic inflammation within the mesentery was more prevalent in JSATS-tagged than in PIT-tagged fish subsampled at both McNary and Bonneville Dam ($P = 0.001$), and when present in both treatment groups, it was rated as more severe in JSATS-tagged fish at both recapture sites ($P < 0.001$). In Bonneville subsamples, chronic peritonitis was higher in JSATS-tagged than PIT-tagged fish ($P = 0.001$), and poor apposition of the incision was more common ($P = 0.006$), as were internal adhesions at the incision site ($P = 0.063$). Microscopic evidence of the incision/injection site was less prevalent in PIT-tagged than JSATS-tagged fish from both McNary and Bonneville Dams ($P = 0.001$), and the epidermis was more often observed to be "retracted" away from the incision/injection site in the JSATS-tagged fish from Bonneville Dam ($P = 0.015$).

Rs antigen levels were evaluated using enzyme-linked immunosorbent assay (ELISA). For hatchery yearling Chinook, the range of Rs antigen levels was 0.065-0.335 in reference fish (one outlier at 1.11), 0.069-0.289 in both JSATS and PIT treatments recaptured at McNary Dam, and 0.076-0.540 in both JSATS and PIT treatments recaptured at Bonneville Dam. Since ELISA values were considered low for all but two fish recaptured at McNary Dam (1 JSATS and 1 PIT), no statistical analyses were conducted to evaluate differences between treatments at this location. At Bonneville Dam, 13% of JSATS-tagged fish had ELISA values considered moderate, compared to 11% of PIT-tagged fish. However, there was no statistical difference in these values based on a Kruskal-Wallis test ($P = 0.830$; a nonparametric equivalent of analysis of variance).

Extended Holding of JSATS- vs. PIT-Tagged Yearling and Subyearling Chinook Salmon

Yearling Chinook Salmon—For extended holding and observation of yearling Chinook salmon, 10 replicate groups were collected at Lower Granite Dam, allocated to tag treatment groups, and transported to juvenile monitoring facilities at Bonneville Dam. For each replicate, approximately 40 fish each were injected with a PIT tag, surgically implanted with a PIT tag, or surgically implanted with both a JSATS and PIT tag. Approximately 40 additional fish per replicate were held as reference fish. Reference fish were collected and anesthetized in the same manner as surgically tagged fish, but were neither tagged nor treated with an injection, incision, or suture. All fish were transported to the juvenile monitoring facility at Bonneville Dam Second Powerhouse, where they were held in laboratory tanks for up to 120 d for observation and evaluation of long-term mortality.

The day of each mortality in each treatment group was recorded, and survival estimates were statistically evaluated at 14, 28, and 120 d of holding. Fish that had not died at 120 d were sacrificed and necropsied after the holding period had ended. Post-mortem, all fish were monitored for tag loss and tested for the antigen to *Renibacterium salmoninarum* (Rs) using ELISA. We also collected CWTs from hatchery marked fish in each sample group to examine survival trends within individual hatchery release groups.

For yearling Chinook salmon, mean survival was compared among fish surgically implanted with the JSATS tag, injected with a PIT tag, surgically implanted with a PIT tag, and reference fish (handled as surgically tagged fish). Among these four groups, survival rates did not differ significantly between the 0-14 d, 14-28 d, or 28-120 d holding periods (ANOVA $P = 0.333$, 0.282, and 0.947, respectively). Among fish that survived to 120 d, no significant differences were found between tag treatments in either mean growth (mm; $P = 0.628$) or mean weight gain (g; $P = 0.436$).

Of JSATS-tagged yearling Chinook that survived 120 d, 21 (8%) expelled or dropped an acoustic tag, but only 1 (0%) lost or expelled a PIT tag. No injected or surgically PIT-tagged fish that survived to termination dropped PIT tags. Both acoustic and PIT-tag losses were determined post-mortem at the time of necropsy. Due to the small number of tags recovered from holding tanks, it was not possible to determine the timing of tag loss.

In fish that died before termination of the study, prevalence of Rs based on ELISA values ranged from 0.064 to 3.738. There were no significant differences in Rs antigen levels among treatment groups ($P = 0.313$). Of fish that survived to termination, Rs antigen levels ranged from 0.28 to 0.44. There were also no significant differences in Rs levels among treatment groups for these fish ($P = 0.323$).

Evidence from CWTs collected from laboratory fish indicated that no single hatchery group contributed fish to our study that were obviously compromised in numbers sufficient to bias the results.

Subyearling Chinook Salmon—Subyearling Chinook were sampled and tagged on 10 occasions specifically for long-term holding and observation. Subyearling replicate groups were allocated to the same tag treatments as those of the yearling groups, except that an additional group of approximately 40 fish was tagged with a single-battery JSATS tag. The single-battery tag was designed specifically for use in the smaller subyearling Chinook. However, the tag was not delivered from the manufacturer until after the study had begun and the first 4 replicates had been collected and tagged.

Thus, for the first 4 replicates, approximately 40 fish each were injected with a PIT tag, surgically implanted with a PIT tag, or surgically implanted with both a JSATS and PIT tag. For the remaining 6 replicates, an additional treatment group was surgically implanted with a single-battery JSATS tag. A reference group of approximately 40 fish was collected for all 10 replicates. Reference fish were collected and anesthetized in the same manner as surgically tagged fish, but were neither tagged nor treated with an injection, incision, or suture.

After collection and tagging, subyearling Chinook salmon were transported from Lower Granite to the juvenile fish facility at Bonneville Dam, where they were held in laboratory tanks for up to 120 d and observed for long-term mortality. Post-mortem, fish were evaluated for tag loss and tested for the antigen to *Renibacterium salmoninarum* (Rs) using an ELISA. We also collected CWTs from hatchery marked fish in each sample group to examine survival trends within individual hatchery release groups.

Mean survival at 14 d was lower for JSATS-tagged (0.85) and surgically PIT-tagged fish (0.88) than for injected PIT-tagged (0.97) or reference fish (0.94), and the differences were significant ($P = 0.037$; Fisher's LSD, $P = 0.044$). Survival rates of fish in the later intervals of the holding periods were not significantly different among tag treatment groups ($P = 0.827$ for the 14-28 d interval, and $P = 0.515$ for the 28-120 d interval). Among fish that survived to 120 d, no significant differences were found between tag treatments in either mean growth (mm; $P = 0.194$) or mean weight gain (g; $P = 0.515$).

For subyearlings that survived to the end of the 120-d holding period, only 1 fish (single-battery JSATS tag) passively dropped or expelled a PIT tag. A total of 5 (2%)

JSATS-tagged fish and 2 (2%) single-battery JSATS-tagged fish dropped or expelled JSATS tags. Due to the small number of tags recovered from holding tanks, it was not possible to determine the timing of tag loss.

Rs antigen values as measured by an ELISA for subyearling laboratory fish that died before termination of the study ranged from 0.068 to 3.866. Fish with JSATS and surgically implanted PIT tags had lower ELISA values than those with injected PIT tags and reference fish, and the difference was significant (P <0.001). Rs antigen levels for fish that survived until experiment termination at 120 d ranged from 0.540 to 0.760. There was no significant difference in BKD ELISA values among fish that survived through termination (P = 0.401). Evidence from coded-wire tags collected from laboratory fish indicated that no single hatchery group contributed fish to our study that were obviously compromised in numbers sufficient to cause bias of any study results.

Evaluation of an Antibiotic Prophylactic Dip in Surgically Tagged Salmonids

Survival during the 2007 tag comparison study was lower than expected for acoustic-tagged subyearling Chinook salmon. For migrating fish, differences in relative survival between tag types increased as water temperature increased. One possible explanation for these low survival rates was that for surgically tagged fish, inflammation or infection at the incision site (both internal and external) was exacerbated as temperature increased, and this contributed to decreased fitness and higher rates of mortality. The following seven treatments were evaluated for potential use as prophylactics against bacterial infection during large-scale tagging operations: hydrogen peroxide at 25, 50, and 100 mg/L; PolyAqua™; salt at 10 and 30 ppt; and Argentyne (diluted 1:1 with water). For dip treatment in each of these chemicals or products, we collected additional fish during sampling for the long-term holding study.

Approximately 320 river-run subyearling Chinook salmon (40 fish each × 8 treatment groups) were sampled at Lower Granite Dam over 10 d during the subyearling Chinook migration period. These fish were all surgically implanted with PIT tags for individual identification. Similar to the long-term holding study fish, dip-treatment fish were held overnight at Lower Granite Dam after tagging and then transported by truck to the Bonneville Dam juvenile monitoring facility for observation. Dip treatment fish were held in freshwater for a total of 28 d. Mortality was recorded daily, and every 7 d post-tagging, treatment fish were anesthetized so that the incision could be examined and rated based on suture presence and incision appearance. A photographic record, including two full-body side views and a close-up of the incision was archived for each fish at 7, 14, 21, and 28 d.

Unfortunately, none of the treatments tested appeared to reduce inflammation or to produce cleaner or more rapid healing or greater survival than was observed in reference fish. In addition, although differences in survival rates were not statistically significant, reference fish were among the three prophylactic treatment groups with the best overall survival. This result indicated that aside from salt, the other chemical treatments tested may even be contraindicated when handling apparently healthy fish.

Results of the prophylactic dip-treatment analyses indicated that mortality could be most consistently predicted by either the presence of two secure ligatures or by foreign matter on one or more ligatures. Higher mortality was observed for fish with two sutures present at 7 d or longer after surgery. These mortalities may have occurred due to secondary infection from pathogens that had accumulated on the sutures, such as fungi or bacteria. When foreign matter had accumulated on sutures, there was often evidence of secondary dermal ulceration directly beneath the mass of foreign material. These ulcers could have facilitated and served as a route for internal infection. These results indicate that a component of tag effects, to the extent that they have been observed, may be driven in part by suture presence and/or secondary fouling.

CONTENTS

INTRODUCTION

Background

In 2001, NOAA Fisheries, in partnership with Battelle Pacific Northwest National Lab, began development of an acoustic telemetry system that would provide information on the migration and survival of juvenile salmonids through the hydropower system and into the estuary and ocean (McComas et al. 2005). Since that time, this system, known as the Juvenile Salmonid Acoustic Telemetry System (JSATS), has undergone extensive development. One notable accomplishment of this work to date has been production of a microacoustic transmitter suitable for implant into small fish, such as juvenile salmonid smolts. Since production and testing of its prototype, which measured 21 × 7 × 6 mm and weighed 0.9 g in air (Frost et al. 2010), the JSATS transmitter has been reduced in volume by nearly 75% and in mass by nearly 50%.

Each reduction in transmitter size increases the potential that this technology can be utilized to produce unbiased estimates of survival and behavior in small fish. Columbia River Chinook salmon *O. tshawytscha* measuring 92 mm FL or greater is the target species and size for JSATS development. This size threshold was chosen because nearly 85% of migrating Chinook salmon smolts are thought to be at least this size when they reach Bonneville Dam. Size at this location is targeted because Bonneville Dam is the proposed tagging and release site for evaluations of survival for fish migrating through the lower Columbia River and estuary.

Survival estimates of migrating fish generally rely on statistical models, which represent detection-history data for a single group of tagged fish as a multinomial distribution. Detection probability at any given location is a function of the underlying survival and detection probabilities for that fish at that location. Aside from the assumption that individuals tagged for a study must be representative of the population of inference, these models rely on several key assumptions to produce unbiased estimates.

One of these key assumptions is that all fish within a release group have common probabilities of detection and survival. A second is that for each individual fish within the group, these probabilities are independent from those of all other fish within the group. A third, that the survival/detection probability of each individual fish for a given event is conditionally independent of all other probabilities. These assumptions can be violated if downstream detection probabilities are affected by the presence of the tag itself, by the sampling or tagging procedure, or by the experience of prior detection (Skalski et al. 1998).

More complex statistical models that rely on multiple releases at a number of locations or on multiple dates require the additional assumption that any post-release mortality or tag loss is equal among comparison groups by the time all groups arrive at downstream detection sites (Skalski et al. 2009). If handling and/or tagging does indeed affect survival, or if tag loss does occur, then it must occur over a finite and predictable window of time and distance from the release sites, so that the effects can be accommodated *a priori* within the study design.

The validity of these assumptions has been studied extensively in the laboratory for active transmitters of all sizes and types (e.g. both radio and acoustic; Moore et al. 1990; Adams et al. 1998a, 1998b; Martinelli et al. 1998; Brown et al. 1999; Hall et al. 2009; Frost et al. 2010). In addition, researchers have attempted to identify meaningful relationships between transmitter attributes (e.g., length, mass, or volume) and the size of fish at tagging. Knowledge of such relationships would allow identification of fish that will not be affected by the presence of a transmitter (Perry et al. 2001; Lacroix et al. 2004; Brown et al. 2006; Chittenden et al. 2009). These researchers have most commonly recommended the appropriateness of implanting fish with transmitters based on laboratory evaluations of the maximum tolerable tag burden (with tag burden generally defined as tag weight/fish weight).

However, in addition to the considerable differences reported among studies, to date these recommendations have not undergone extensive field testing, where conditions influencing survival may be far more complex and challenging (Thorsteinsson 2002). Furthermore, regardless of transmitter size, the effects of handling and the general invasiveness of the surgical tagging procedure have not yet been evaluated sufficiently in the field.

In the early stages of JSATS development, three acoustic studies had been conducted in the Columbia River that offered insight into the performance of active tags in the field. In the mid-Columbia, Skalski et al. (2003, 2005) compared survival to Rock Island Dam between JSATS- and PIT-tagged yearling Chinook salmon released at Wells or Rocky Reach Dam and found no difference between treatment groups. However, during early JSATS field trials, McComas et al. (2005) released JSATS-tagged fish at Bonneville Dam (yearling and subyearling Chinook) and found a significant difference in mean size between fish subsequently detected on acoustic receivers in the lower river and estuary and fish that were never detected after release. The mean length at tagging of "never detected" groups was 2 mm less than that of fish detected at least once after release. In addition, McComas et al. (2005) found avian predation rates 2 and 3 times higher for JSATS-tagged fish than for PIT-tagged fish from the run at large. Although their study was not designed specifically to identify tag effects, these observations suggested that the JSATS tag/surgical tagging procedure were not without some effects.

Additionally, in the laboratory component of their study, McComas et al. (2005) observed suture retention in 42% of the yearling Chinook implanted with a JSATS transmitter and in 50% of those implanted with a sham transmitter after 30 d holding. Retained sutures appeared to abrade tissue and delay wound healing at entrance and exit points. Material that appeared to be filamentous fungi was also observed on trailing suture material, prompting these authors to express concern that "by presenting a disease entry point," the observed exposed tissue and presence of contaminated suture material might contribute to "study-induced survival reduction in free-roaming fish" (McComas et al. 2005).

To address concerns about potential tag effects in the field, and to explore the cause of these effects if observed, the USACE sponsored a series of studies on both yearling and subyearling river-run juvenile Chinook salmon. In these studies, fish were implanted with both a JSATS transmitter and a PIT tag as they migrated downstream through the Federal Columbia River Power System. This report describes results from the third study year of this series. Below we briefly summarize findings from the 2006 (Hockersmith et al. 2007a) and 2007 (Wargo-Rub et al. 2009) companion studies. These studies provide complete details of two independent evaluations of JSATS tag effects. For background on acoustic telemetry technology in general, see Winter (1996). Comprehensive background and detail on development of the JSATS system was reported by McComas et al. (2005).

In 2006, Hockersmith et al. (2007a) conducted a pilot study, including both field and laboratory components, to evaluate survival and behavior of yearling Chinook salmon tagged with JSATS transmitters. For their field experiments, migrating hatchery juvenile spring Chinook were collected and tagged either with both a JSATS and PIT tag or with a PIT tag only (Hockersmith et al. 2007b). At the time, JSATS acoustic transmitters were approximately 40% smaller than the radio and acoustic transmitters that had been used in prior research (Hockersmith et al. 2003; Skalski et al. 2003, 2005). For these field evaluations, the acoustic tag burden ranged from 1.5 to 7.3% (mean 2.7%) of fish body weight. Length of these study fish ranged from 105 to 240 mm FL (mean 137.2 mm) and weight from 10.5 to 50.1 g (mean 23.9 g).

Travel times from release to detection did not differ significantly between acoustic- and PIT-tagged fish at the majority of downstream detection sites evaluated (Hockersmith et al. 2007b). Differences in PIT-tag detection probability between tag treatments were less than 2% at each downstream site. Similarly, Hockersmith et al. (2007b) found no significant difference in estimated survival between tag types from release to each detection site, with the exception of the first reach evaluated (Lower Granite to Little Goose Dam tailrace), where acoustic-tagged fish had higher survival than PIT-tagged fish. However, less than 3% of the 3,500 JSATS tags secured for this field study were available for fish migrating in spring 2006. Thus, the impact of these results was seriously undermined by lack of replication and low sample sizes.

Concurrent laboratory studies in 2006 evaluated potential effects of the JSATS tag on growth, mortality, tag loss, and predator avoidance in yearling and subyearling Chinook salmon (Brown et al. 2007a,b; Liedtke et al. 2007). Similar to the field study, laboratory results indicated no significant differences in survival among acoustic- and PIT-tagged fish (Brown et al. 2007a). No significant differences were found between tag treatments at 21 or 90 d after tag implantation. The minimum fish length at which surgical implantation of a JSATS transmitter and a PIT tag did not negatively influence growth of juvenile Chinook salmon was 88 mm FL (Brown et al. 2007b). The minimum fish length at which surgical implantation of both a JSATS transmitter and PIT tag did not negatively influence survival was 95 mm FL (7.6% tag burden by weight). Predator avoidance was not significantly different between acoustic- and PIT-tagged subyearling Chinook, and there was no evidence of differential predation between study groups (Liedtke et al. 2007).

In 2007, the study continued with a basic design similar to that used in 2006: field evaluations were conducted concurrent with laboratory work on actively migrating yearling and subyearling Chinook salmon (Wargo-Rub et al. 2009). For the field portion of the 2007 study, detection and survival probabilities were again compared between fish tagged with JSATS vs. PIT tags, along with comparisons of migration rate and vulnerability to avian predation. Laboratory studies in 2007 were divided into two general evaluations. The first was a series of necropsies and histological examinations of actively migrating study fish recaptured at periodic intervals during the spring and summer migration periods. The second was a 90-d holding experiment to evaluate survival, tag retention, and disease prevalence.

For yearling and subyearling Chinook salmon, Wargo-Rub et al. (2009) examined relative survival, or the ratio of mean estimated survival rates between tag treatment groups (JSATS/PIT). In the Snake River, they found that survival from release to Little Goose and Ice Harbor Dam did not differ significantly ($\alpha = 0.05$) between the two tag treatments for yearling Chinook salmon. However, relative survival rates indicated slightly higher survival to Lower Monumental Dam for JSATS-tagged fish, and the difference approached significance ($P = 0.080$). In the Columbia River, survival of PIT-tagged yearling Chinook was higher than that of their JSATS-tagged cohorts at McNary, John Day, and Bonneville Dam. The difference in survival between tag treatments approached significance at McNary, and was significant at John Day and Bonneville Dam (P = 0.054, 0.010, and 0.001, respectively).

Detections from treatment groups of subyearling Chinook (95 mm FL or larger) implanted with JSATS tags were insufficient for estimates of survival to all downstream detection sites except Little Goose and McNary Dam (Wargo-Rub et al. 2009). Mean survival to both these locations was higher for PIT- than JSATS-tagged fish, and the difference between the treatment groups at both locations was significant (P = 0.003 and 0.001, respectively). In addition to their evaluation of actively migrating subyearling Chinook salmon at least 95 mm FL, Wargo-Rub et al. (2009) conducted a pilot study comparing tag treatments in smaller subyearlings (85-94 mm FL). However, pilot study fish implanted with JSATS tags were detected in such low numbers at all locations that detection and survival probabilities could not be estimated. The researchers concluded that the small number of detections was presumably due to high mortality in this group.

Gross necropsy of actively migrating fish during 2007 revealed that for both yearling and subyearling Chinook salmon, fish collected at downstream locations generally had less adipose tissue (visible fat) than fish observed at release (Wargo-Rub et al. 2007). In yearling Chinook, recaptured PIT-tagged fish had more adipose tissue and a higher percentage of stomachs containing food than JSATS-tagged fish. However, significant differences between tag treatments were not seen in subyearlings.

Histological examinations in 2007 revealed differences in measures of nutritional condition between JSATS- and PIT-tagged yearling Chinook, although the differences were not entirely consistent in direction. Differences in peritoneal inflammation and healing at incision or injection sites were observed in both yearling and subyearling Chinook. In both yearling and subyearling fish, inflammation within the peritoneal cavity at the incision site was greater in JSATS- than PIT-tagged groups, and healing had progressed further in PIT- than in JSATS-tagged groups. Analysis by size class of yearling Chinook tag treatments combined revealed a clear pattern in the amount of mesenteric adipose tissue present, with larger fish having more fat. A similar trend was observed in the subyearling Chinook examined at Bonneville Dam.

Changes in Study Design and River Conditions from 2007 to 2008

In 2008, we repeated the tagging experiments conducted in 2007 with yearling Chinook salmon, including both releases to the river and long-term holding. The JSATS transmitter in 2008 was lower in volume by ~40% and in weight by ~30% than the transmitter used in 2007. For subyearling Chinook study fish migrating in 2007, both detection probabilities and inriver survival were so poor for JSATS-tagged groups that comparisons of actively migrating smolts were not repeated in 2008. The reduction in transmitter size was favorable for smaller fish, but with no evaluation data, we could not assume the 2008 tag would reduce mortality/increase detection rates sufficiently for subyearling Chinook estimates. However, we did collect subyearling Chinook salmon for laboratory evaluations to evaluate progress towards minimizing tag effects through reduction in transmitter volume/weight, as well as to test the hypothesis that different handling and tagging techniques (e.g., injection vs. surgery) might affect survival in captivity independent of tag burden.

To help evaluate these hypotheses, in addition to laboratory replicates of reference fish, JSATS-tagged fish, and PIT-tagged fish, we added a laboratory replicate of fish surgically implanted with a PIT tag. For both the yearling and subyearling evaluations, this group was subjected to the surgical process (incision and suture placement) but not the additional burden of an acoustic tag. For the subyearling holding experiment, a fourth treatment was planned for fish to be tagged with a smaller, surgically implanted JSATS transmitter (miniaturized further by removing one of the two batteries from the 2008 JSATS tag). However, single-battery tags were not available until late in the study period, when replicates were influenced to a greater extent by higher water temperatures during tagging. Therefore, we excluded this group from statistical comparisons of survival or growth.

Thus, as in 2007, we transported a subset of each tagging group collected at Lower Granite Dam to the laboratory at Bonneville Dam for extended rearing studies. Detections of study fish released to the tailrace of Lower Granite Dam were obtained from downstream dams equipped with PIT-tag monitors (Figure 1) and from a trawl detection system operated in the upper Columbia River estuary (rkm 61-83).

As in the companion studies of 2006 and 2007, the study area in 2008 encompassed a 695-km reach of river, from Lower Granite Dam on the Snake River to the mouth of the Columbia River (Figure 1). Lower Granite Dam is the fourth dam upstream from the mouth of the Snake River and is located in Washington State, 173 km above the confluence of the Snake and Columbia Rivers.

Detections from acoustic transmitters were obtained from receiver arrays in the Columbia River and estuary (Appendix Table A1). In addition, we repeated the comparison between percentages of PIT tags recovered from piscivorous waterbird colonies to determine relative vulnerability to avian predation between tag treatments.

Field experiments in 2008 were, at least in part, conducted amid more normal river flow conditions than in 2007. In the Snake River, discharge at Lower Granite Dam ranged from 55 to 155 kcfs during the yearling Chinook collection period (Figure 2). Discharge during the majority of the yearling study period in 2008 fluctuated within about 27 kcfs of the 10-year average, swinging from lower- to higher-than-average midway through the yearling Chinook salmon tagging and release period. However, from 17 to 23 May, flows continued to rise above the 10-year average, ranging from 122 to 155 kcfs, and peaking at nearly 89 kcfs above average.

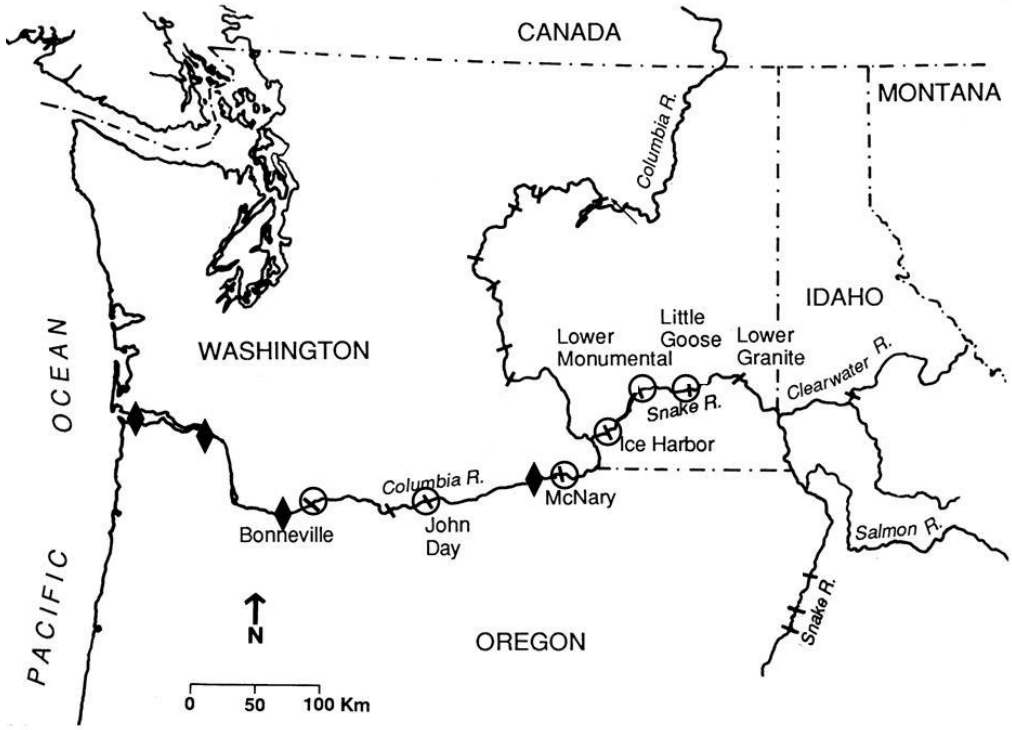

Figure 1. Study area showing fish collection and release location at Lower Granite Dam and downstream detection sites. Diamonds indicate locations of acoustic arrays (Appendix Table A1) and circles show locations of PIT-tag monitors.

Water temperatures in the Snake and Columbia Rivers were below the 10-year average during most of the study period for both yearling and subyearling Chinook (Figure 2). During collection and tagging periods at Lower Granite Dam, water temperature ranged 07.7-10.6°C for yearling Chinook and 10.2-17.8°C for subyearling Chinook. During the yearling collection period, these temperatures were below the 10-year average by 0.7-1.9°C (mean difference, 01.0°C). During the subyearling collection period, temperatures were 01.3-03.0°C lower than the 10-year average (mean difference, 02.2°C). At McNary Dam, water temperatures during 7-31 May ranged 10.6-13.0°C and were below the 10-year average by 0.03-01.0°C. Mean temperature at McNary during this period was 0.65°C below the 10-year average.

In 2008, we also photographed migrating acoustic-tagged fish prior to release and laboratory holding fish both before and after treatment. These photographs may help to identify external physical abnormalities, which in turn may provide information on how fish condition at the time of tagging (e.g., percentage of descaling) influences survival.

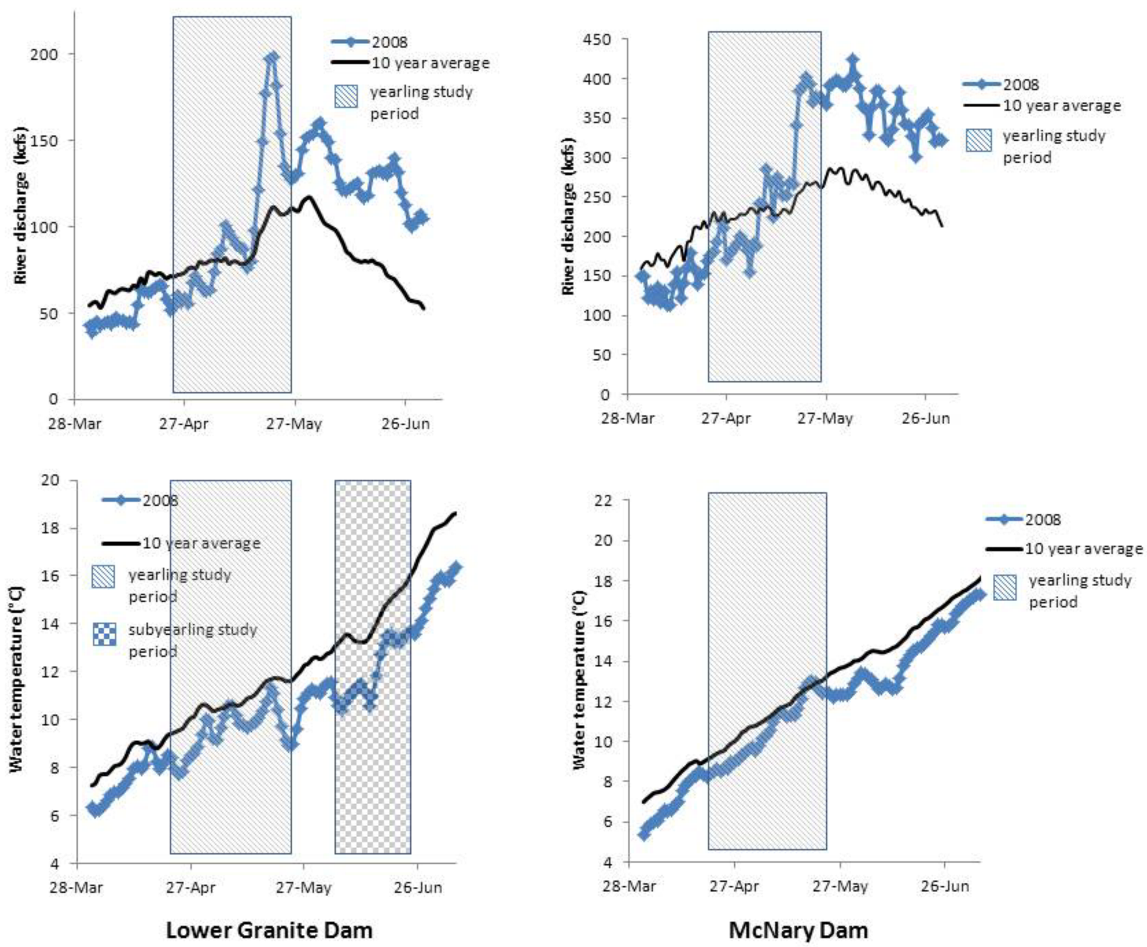

Figure 2. Upper charts show discharge at Lower Granite and McNary Dam during the study period in 2008 compared to the 10-year average (1998-2007). Lower charts show water temperature at Lower Granite and McNary Dams compared to the 10-year average (1998-2007).

Finally, for the 2008 study, we evaluated several prophylactic dip treatments. The hypothesis for this evaluation was that a chemical treatment applied postoperatively to the incision would promote healing by preventing fungal and/or bacterial organisms from immediately colonizing the incision or associated suture material. The poor survival observed in both migrating and laboratory subyearling fish during 2007 was thought to be related at least in part to inflammation and or infection (internal and externally) at the incision site (Wargo-Rub et al. 2009).

We suspected that increasing temperatures exacerbated the rates of infection and inflammation, and could have contributed to differences in survival between migrating JSATS- and PIT-tagged subyearlings. These differences became greater as water temperature increased. Others have also noted delayed incision healing and inflammation at the incision site at warm temperatures in surgically tagged fish. For example, delayed healing was observed at temperatures above 20°C for bluegills (Knights and Lasee 1996) and at temperatures above 22°C for striped bass (Walsh et al. 2000).

Several chemical treatments have been used in aquaculture facilities and during transport to prevent or treat bacterial, fungal, and parasitic infections in fish (Francis-Floyd 1995, 1996; Marking et al. 1994; Edgell et al. 1993; Lilley and Inglis 1997; Long et al. 1997; Fitzpatrick et al. 1995; Rach et al. 2000; Speare and Arsenault 1997; Lumsden and Ferguson 1998; Noga 2000). The dip portion of this study was designed to evaluate whether or not a subset of these chemicals (salt, hydrogen peroxide, Argentyne, and PolyAqua) would be efficacious in preventing or minimizing inflammatory reactions and infection, such as those observed during 2007.

For the chemical dip evaluation, a second set of subyearling fish was collected and surgically PIT-tagged at Lower Granite Dam before being transported to the juvenile monitoring facility at Bonneville Dam for observation. These subyearling fish were monitored for survival and progression of healing on a weekly basis for up to 28 d.

This report describes each separate evaluation and summarizes our conclusions to date based on the results. We include recommendations and guidelines for using acoustic telemetry technology to study survival and migration in juvenile Chinook salmon at the conclusion of this report based on information collected during the three studies described here. This information will aid in determining the suitability of acoustic telemetry to estimate short- and longer-term (up to 120 d) juvenile salmonid survival through Columbia and Snake River reservoirs and dams and the Columbia River estuary. This information may also contribute to future research and development of acoustic technology.

Statistical Significance in Reporting Results

Our proposal for this study included plans to test hypotheses at the $\alpha = 0.05$ significance level, and sample sizes were planned in an effort to achieve 80% power to detect differences using tests with that significance level. We noted in the proposal that for the field evaluation, the ability to detect differences would be highly dependent on spill and river flow patterns over the course of the study and on PIT-tag detection probabilities at Bonneville Dam. We expressed confidence that the sample sizes chosen would allow us to detect *biologically* important differences in survival. As will be seen, for many of the survival estimates for migrating juvenile Chinook salmon, we did not achieve the statistical precision anticipated for these estimates, or accordingly, the statistical power to discern real differences with the degree of sensitivity that we had sought. As a consequence, we reported any observed differences that had potential *biological* importance even though they did not result in *statistically* significant tests.

In addition, we reported *P* values for all statistical tests comparing metrics between PIT- vs. JSATS-tagged fish, regardless of statistical significance. These *P* values provide the actual level of statistical significance of each individual observed test statistic. In other words, the *P* value represents the risk of a type I error, or rejection of a true hypothesis, if the hypothesis is indeed rejected based on information provided by the observed test statistic. The choice to reject a hypothesis on the basis of a *P* value greater than 0.05 increases the chances of making a type I error to a level greater than that which was proposed (i.e., it increases the risk of concluding that observed differences in biological effects between tag types are real, when in fact they are due to chance variation).

However, more liberal rejection can be justified when the actual observed data failed to provide the anticipated statistical power because under these circumstances, an increase in the probability of either a type I or type II error (failing to reject a false hypothesis), or both, is unavoidable. As explained above, to accept a significance level greater than 0.05 will result in an increased risk of type I error. Conversely, if we maintain the significance level at $\alpha = 0.05$, we cannot avoid an increase in the probability of a type II error, that a false hypothesis will be accepted (i.e., the conclusion that differences between tag types are not real, but due to chance variation, when in fact they are real). Thus when anticipated power is not obtained, one or both types of errors are more likely.

Therefore, the meaning of the observed results can only be decided through *a posteriori* consideration of the relative costs—or the relative harm—of committing either type of error. Some may decide that it is prudent to accept a more liberal rejection of the hypothesis, such as when *P* values are moderately greater than 0.05, if the cost of a type II error is high enough. Others may conclude that the consequences of accepting a false hypothesis are the least harmful alternative, and thus choose to stick with the significance level that was planned. The *P* values reported here, along with results of an analysis of the power of the actual observed data reported at the end of the section, allow the reader to make such informed judgments.

Though *P* values give all the information required to make judgments regarding statistical significance, in summarizing large sets of data, we indicated general levels of significance by using a single term to refer to an entire range of *P* values. In these descriptions, we used the term "significant" to indicate *P* values ≤ 0.05, "not significant" to indicate *P* values > 0.10, and "approach significance" to indicate *P* values between 0.05 and 0.10. Every statement of general significance is accompanied with the actual corresponding *P* value, though not all *P* values are accompanied by such statements.

EVALUATION OF ACOUSTIC TAGS IN MIGRATING JUVENILE CHINOOK SALMON

Methods

Fish Collection, Tagging, and Release

River-run, hatchery yearling Chinook salmon smolts were collected from the run at large at Lower Granite Dam between 23 April and 16 May 2008. Between 1900 and 0700 PDT on these dates, study fish were diverted to a concrete raceway for holding. Within 12-18 h of collection, fish were sorted under light anesthesia using clove oil as an induction agent followed by tricaine methanesulfonate (MS-222; Marsh et al. 1996, 2001).

We tagged only hatchery yearling Chinook that had not been previously PIT tagged, had no visual signs of disease or injury, and measured at least 95 mm FL. Fish selected for PIT-tagging only (PIT-tagged fish) were tagged immediately following sorting. Collection and handling techniques followed the methods described by Marsh et al. (1996, 2001). Fish were measured and injected with PIT tags using a method similar to that of Prentice et al. (1990a,b). To reduce the likelihood of disease transmission, all needles and PIT tags were disinfected in 70% ethyl alcohol for a minimum of 10 minutes prior to use.

Fish selected for acoustic tagging (JSATS-tagged fish) were collected in 20-L plastic buckets directly after sorting and transferred to a 975-L holding tank, where they were allowed to recover from anesthesia. Fish were then held overnight in flow-through river water prior to tagging; as such, JSATS-tagged fish were held for 18-24 h longer than PIT-tagged fish.

Prior to surgery, fish designated for the JSATS-tag treatment were placed in an anesthetic bath containing MS-222 in concentrations ranging from 50 to 80 mg/L until they reached stage 4 anesthesia (loss of equilibrium; Summerfelt and Smith 1990). Temperature and pH of the anesthetic bath were monitored several times daily to ensure that temperature did not increase more than 2°C during a tagging session and that pH did not drop below 7.0. Frequent water/anesthetic changes and the addition of sodium bicarbonate as a buffering agent were used to maintain these conditions. After reaching stage 4 anesthesia, fish were removed from the anesthetic bath and transferred in 1-L plastic cups to a data station where they were weighed, measured and photographed using a Cannon Powershot G9[1] digital camera.

After pre-processing, fish were placed on a surgery table ventral side up and administered either additional anesthesia or river water over the gills. Either MS-222

(50 mg/L), pure river water, or a combination of both were delivered through gravity-fed rubber tubing. The decision to administer additional anesthetic or river water during surgery was left to the individual surgeon and based on achieving a balance between maintaining a level plane of stage 4 anesthesia throughout the surgical process and allowing for rapid post-operative recovery.

Surgical tagging was conducted simultaneously at up to four stations, with approximately 75-100 acoustic tags implanted per hour. All surgical tools were sterilized in a steam autoclave prior to the start of each tagging day. All acoustic transmitters and PIT tags were disinfected in 70% ethyl alcohol for a minimum of 10 min and rinsed in distilled water prior to use. Suture material and surgical tools were disinfected and rinsed in the same manner between consecutive surgeries.

Once the desired level of anesthesia was reached, a 6-8 mm incision was made 2-5 mm from and parallel to the mid-ventral line (linea alba) just anterior of the pelvic girdle of each fish. Incisions were made using either a 3.0-mm Micro-Unitome blade (BD Medical Supplies), a number 10 scalpel, or a combination of both. First a PIT tag and then an acoustic transmitter was inserted into the peritoneal cavity through the incision. Following tag insertion, each incision was closed with two 5-0 absorbable monofilament sutures placed in a simple interrupted pattern.

Immediately following tagging, JSATS-tagged fish were returned to their 1-L plastic cups (with anesthetic water) and transferred to a second data station, where post-operative photographs of the surgical incision were taken using a second Cannon Powershot G9 digital camera. After this final step, fish were placed into 75-L oxygenated containers and held for a minimum of 2 h for anesthetic recovery and to observe for post-tagging mortality. Implanted fish were then transferred water-to-water to an 18,500-L holding tank supplied with flow-through river water and commingled with PIT-tagged fish that had been tagged on the same day.

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

Following a post-tagging recovery period of 12-24 h, JSATS- and PIT-tagged fish tagged on the same day were released simultaneously into the tailrace of Lower Granite Dam. Fish were released by connecting their common holding tank to the juvenile bypass system outfall pipe with a 10.2-cm diameter flexible hose. All fish tagged and released for this study were assigned a "no transport" designation in the PTAGIS system (PSMFC 1996). This classification ensured that our study fish would not be diverted to barges if they were collected at downstream dams. Yearling Chinook salmon belonging to the PIT-tagged fish group served a dual purpose: they were used as both reference fish for our comparisons to acoustic-tagged fish and as "inriver migrants" for a latent mortality study (BPA Project 2003-041-00).

A total of 4,139 JSATS-tagged and 50,814 PIT-tagged fish were released to the tailrace of Lower Granite Dam on 10 release days (Table 1). Sample sizes were chosen based on the target of being able to estimate a 5% difference in survival from release to John Day Dam (approximately 348 km downstream) with 80% power, and at a significance level of $\alpha = 0.05$. The first release on 25 April coincided with detection of the 27th percentile of the cumulative smolt index for yearling Chinook salmon passing Lower Granite Dam in 2007, and the final release on 18 May coincided with the 82nd percentile (Figure 3).

Table 1. Number and mean fork length of JSATS- and PIT-tagged fish released at Lower Granite Dam in 2008.

		Yearling Chinook salmon					
		JSATS-tagged fish			PIT-tagged fish		
Replicate	Release date	N	Fork length (mm)	SD	N	Fork length (mm)	SD
1	24 Apr	395	123.5	14.2	1,499	126.8	14.2
2	29 Apr	411	129.9	11.3	2,777	136.0	14.0
3	1 May	413	139.6	11.5	6,261	132.1	14.0
4	3 May	410	123.2	13.0	6,560	132.1	12.8
5	6 May	416	130.9	11.3	7,908	138.4	11.6
6	8 May	410	136.1	11.3	6,306	136.6	12.1
7	10 May	405	135.0	11.0	5,911	140.2	10.7
8	13 May	430	140.4	8.5	4,942	138.6	10.0
9	15 May	415	146.4	9.1	4,885	137.1	10.0
10	17 May	434	134.6	10.4	3,765	138.0	10.1
	Total	4,139	134.0	13.2	50,814	136.2	12.3

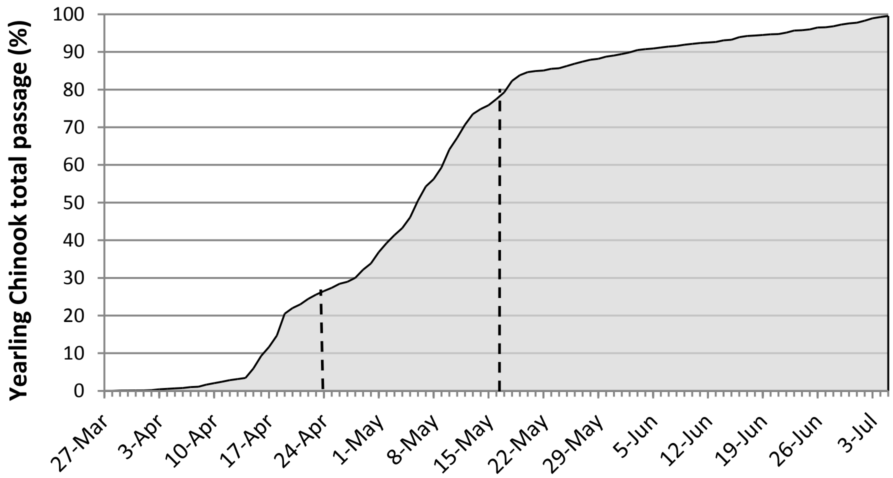


Figure 3. Cumulative passage distribution of yearling Chinook salmon at Lower Granite Dam, 2008. Collection period (23 Apr-16 May) shown between dotted lines .

Acoustic-tagged yearling Chinook had a mean fork length of 134 mm (range 92-202 mm), mean weight of 23.1 g (range 7.2-50.3 g), and experienced a mean tag burden of 2.3% from the combined presence of the acoustic transmitter and PIT tag. Mean tag burden from the acoustic tag alone was 1.8%. For PIT-tagged fish, mean fork length was 136.2 mm (range 84-303 mm). Weights were not obtained for fish tagged with a PIT-tag only. Fork lengths of both JSATS- and PIT-tagged fish were representative of the general population of river-run yearling Chinook salmon sampled by the smolt monitoring program (SMP) during the study period. Mean fork lengths among study fish and SMP sample fish were similar on most release days (Figures 4 and 5).

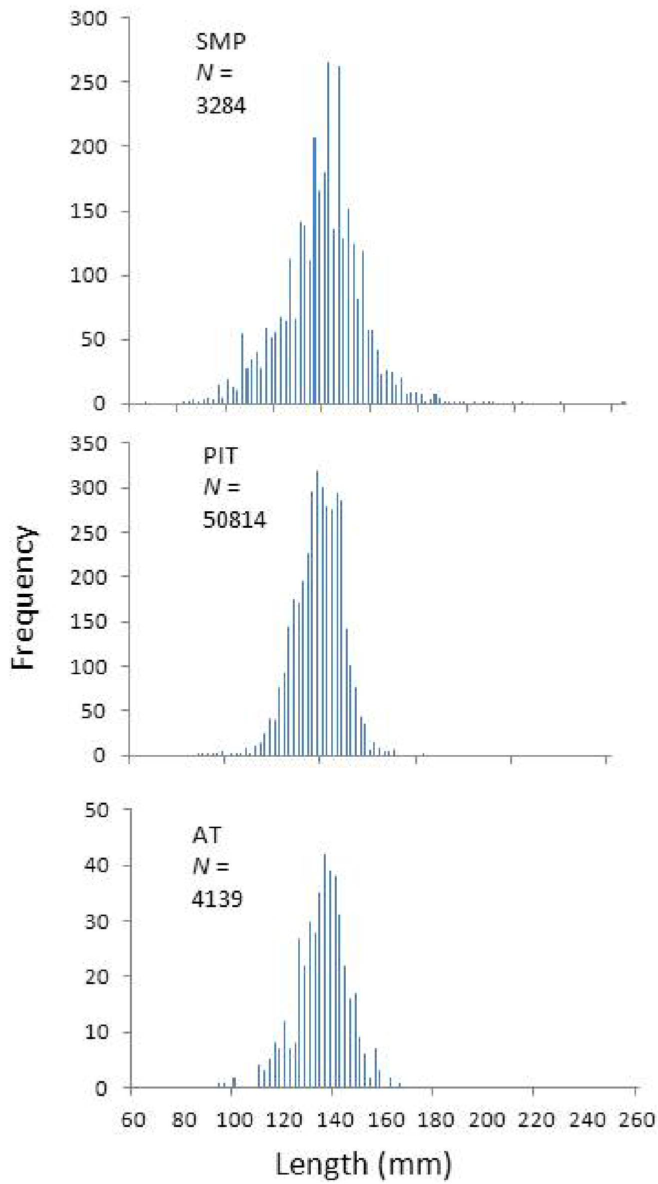


Figure 4. Length frequency histograms (2-mm bins) comparing fork lengths of yearling Chinook salmon sampled by the smolt monitoring program (SMP) to JSATS-tagged and PIT-tagged yearling Chinook salmon released at Lower Granite Dam in 2008. Smolt monitoring program data provided by the Fish Passage Center.

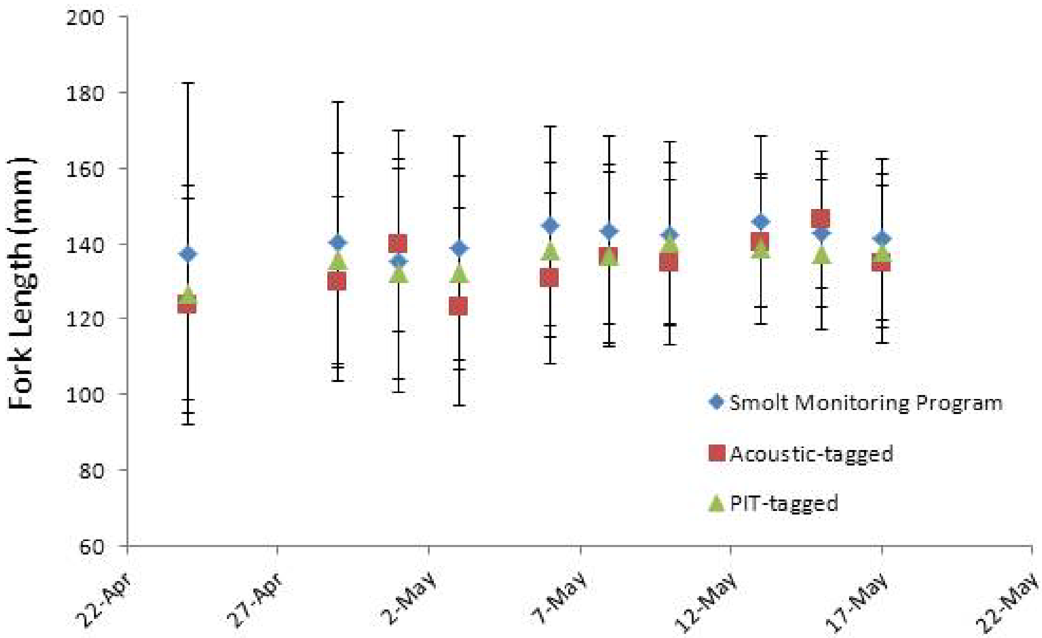


Figure 5. Mean fork length (whiskers represent 2 standard deviations from the mean) of JSATS- and PIT-tagged yearling Chinook salmon and yearling Chinook salmon sampled by the SMP at Lower Granite Dam in 2008. SMP data provided by the Fish Passage Center.

Individual PIT-tag detections at Little Goose, Lower Monumental, McNary, John Day, and Bonneville Dam were utilized to estimate travel time and detection and survival probabilities for PIT-tagged fish. A few study fish were also detected with the NMFS trawl detection system operated in the upper estuary (rkm 61-83). To estimate detection probabilities for JSATS-tagged fish, we used PIT-tag detections at these sites, along with acoustic detections from arrays near Irrigon, Oregon, downstream from Bonneville Dam, and in the lower Columbia River and estuary (Figure 1; Appendix Table A1). Travel times and avian predation rates for JSATS-tagged fish were based solely on PIT-tag detections.

Acoustic-tagged fish were implanted with Juvenile Salmonid Acoustic Telemetry System (JSATS) transmitters (2008 model; Advanced Telemetry Systems, Inc.; Table 2). Each acoustic tag transmitted a uniquely coded 31-bit binary phase-shift keyed signal at a frequency of 416.7 kHz and at a minimum source level of 150 dB (relative to 1 µPascal at 1 minute). The pulse rate interval was 10 seconds, and minimum tag life was 60 d. Tags were activated 1-2 d prior to tagging by placement in an electromagnetic activation dish. Dimensions of the 2008 JSATS acoustic tag model are shown in Table 2, along with dimensions of the 2006 and 2007 JSATS tags and the TX-1411SST (SST) PIT tag.

Table 2. Specifications of the 2006, 2007, and 2008 JSATS acoustic tag and TX-1411SST (SST) PIT tags used in tag comparison study of yearling Chinook salmon, 2008.

	JSATS acoustic tags			
Mean	2006	2007	2008	SST PIT tag
Length (mm)	17.0	16.1	12	12.48
Height (mm)	4.8	4.1	3.5	
Width (mm)	5.9	5.9	5.3	
Diameter (mm)				2.07
Weight in air (g)	0.64	0.6	0.42	0.1020
Mass in water (g)	0.36	0.38	0.3	
Volume (mL)	0.28	0.24	0.14	
Tag burden[a]	3.22	2.9	1.8	0.4
Range	(1.5-7.3)	(1.3-7.7)	(0.8-5.8)	(0.0-1.4)

[a] Defined as tag weight/fish body weight.

Detection and Survival Estimates

Detection data for all treatment groups were retrieved from PTAGIS and checked for errors (PSMFC 1996). Pre-release mortalities and fish that were determined to have lost tags before release were excluded from analyses. For yearling Chinook salmon, pre-release mortality rates were 0.2-4.1% (2-18 fish) per replicate for JSATS-tagged groups (mean 1.6%) and 0.2-3.2% (5-261 fish) per replicate for PIT-tagged groups (mean 1.1%).

Survival and detection probabilities were estimated for both JSATS- and PIT-tagged fish using the Cormack-Jolly-Seber (CJS) model (Cormack 1964; Jolly 1965; Seber 1965) and implemented using Survival with Proportional Hazards (SURPH) software (Smith et al. 1994). Detection-history data used with the model were records of individual detections at each downstream location. Detection histories also provided records of tagged study fish that were incidentally removed from the system due to transportation or other terminal sampling. These were also excluded from analyses.

Detection Probability—Acoustic- and PIT-tag detection sites are shown in Figure 1. For PIT-tag only fish, detection sites were Snake and Columbia River dams and the estuary trawl detection system. For JSATS-tagged fish, these same PIT detection sites were used, along with those from acoustic telemetry arrays listed in Appendix Table A1. Given the generally higher detection rates of acoustic transmitters, combining the PIT and JSATS data provided more precise estimates of survival than would have been possible using only PIT-tag detections of JSATS-tagged fish. In addition, combining technologies allowed us to avoid bias in the relative survival estimates that may have resulted from loss of PIT-tags in the JSATS-tagged fish.

For example, detection probabilities at Ice Harbor, Lower Monumental, and McNary Dam were estimated using downstream PIT-tag detections combined with downstream JSATS-tag detections from the acoustic array near Irrigon, Oregon. Likewise, detection probability at John Day Dam was estimated using downstream PIT-tag detections combined with downstream JSATS-tag detections from the acoustic array at Bonneville Dam tailrace. Detection probability at Bonneville Dam was estimated using PIT-tag detections in the estuary trawl system combined with acoustic detections from multiple arrays below Bonneville Dam (Appendix Table A1). A detailed description of how the CJS model was used with both types of data was reported by Wargo-Rub et al. (2009, Appendix C). Complete records of all JSATS-tag and PIT-tag detections are available with this report at www.nwfsc.noaa.gov/publications/index.cfm.

Tag treatment groups were paired by replicate release date at Lower Granite Dam. Detection probabilities at each downstream dam were compared using paired *t*-tests on the mean and standard error of estimated differences in detection probability between paired groups. The null hypothesis was that detection probability was equal between tag groups (i.e., the difference between detection probabilities is zero). We calculated the *t* statistic and computed the corresponding *P* value for a t-*distributed* statistic with degrees of freedom equal to the number of pairs minus one.

Relative Survival—Probabilities of survival from release to each downstream dam were compared between paired tag treatment groups. Relative survival was defined as the ratio of survival estimates for JSATS-tagged vs. PIT-tagged fish (JSATS/PIT). Thus, a ratio of 1.00 indicated no difference in survival between tag treatments, a ratio greater than 1.00 indicated higher survival for JSATS-tagged fish, and a ratio less than 1.00 indicated higher survival for PIT-tagged fish. The ratios of the paired groups were calculated and one-sample *t*-tests were computed. For these tests, we used log-transformed survival estimates of each ratio and assumed the transformed data were normally distributed (Snedecor and Cochran 1980). The mean and standard error were then back-transformed to provide estimates on the original scale (note that the back-transformed arithmetic mean of the log-transformed ratios is the geometric mean of the original paired survival differences). The null hypothesis tested was that survival did not differ (was equal) between tag treatment groups, or the ratio between tag treatments (JSATS/PIT) was equal to one (difference between mean log-transformed ratios was equal to zero). We calculated the *t* statistic and computed the corresponding *P* value for a *t*-distributed statistic with degrees of freedom equal to the number of pairs minus one.

Travel Time

Travel time was calculated for individual fish in PIT- and JSATS-tagged groups from PIT-tag detection data that was retrieved from PTAGIS and checked for errors (PSMFC 1996). Travel times were calculated from release in Lower Granite Dam tailrace to the following locations:

- Little Goose Dam (60 km)
- Lower Monumental Dam (106 km)
- Ice Harbor Dam (157 km)
- McNary Dam (225 km)
- John Day Dam (348 km)
- Bonneville Dam (460 km)

Travel time through a reach included delay in the forebay of a dam prior to passage and delay within the bypass system at a dam.

The true set of travel times for a release group would include the travel time of both detected and non-detected fish. However, travel time cannot be determined for a fish that traverses a reach of river but is not detected at one or both ends. Thus, travel-time statistics were estimated for detected fish only, with computations representing a sub-sample of the complete release group. For each detection site, we calculated travel time only for fish groups with a minimum of 10 detected fish. Travel time was estimated separately for each release date due to temporal differences in travel time associated with environmental (e.g. river flow) and biological (e.g. smoltification) factors. Detections that occurred 55 d after the tag-activation date (the minimum life of the acoustic transmitters) were excluded from these analyses.

Median travel time to each detection site was calculated for each release group. The median was more useful as an indicator of typical travel time due to the longer right tail of mean distributions by group (i.e., presence of "stragglers" within each group). For each release group, the 10th and 90th percentiles of travel time to each detection site were used to develop 90% CIs around the median. At each downstream detection site, the mean of all medians for all releases by tag type were calculated to obtain an average median travel time for each tag treatment. Average median travel times between release and each downstream detection site (and 95% CIs) were then used to test the null hypothesis that there was no difference in median travel time between JSATS- and PIT-tagged groups.

Avian Predation

Each year in the Columbia River and estuary, nesting colonies of avian predators are monitored for PIT tags by NOAA Fisheries and the Columbia Bird Research group. These agencies either electronically detect or physically recover PIT tags on the colonies during fall, after the birds have vacated their nests. Predation data collected during fall 2008 were provided by NOAA Fisheries (D. Ledgerwood, NOAA Fisheries personal communication) and Real Time Research, Inc. (A. Evans, Real Time Research, Inc., personal communication).

For analyses, PIT-tag detection data were grouped by colony location, with the upriver colony group consisting of pelican *Pelecanus erythrorhynchos*, gull *Larus* spp., tern *Hydroprogne caspia*, and cormorant *Phalacrocorax aurita* colonies. The estuary group was composed of detections from tern and cormorant colonies only. Upriver avian colonies were those located on Badger, Crescent, and Foundation Islands, Island 20, and Miller Rocks, Potholes, and Rock Island. Estuary colonies included only those on East Sand Island.

Differences in the percent of tags recovered (by location and colony) from JSATS- and PIT-tagged fish were compared using the methodology described above for comparisons of PIT-tag detection probability. To adjust for unequal survival downstream between the tag treatment groups, we multiplied the individual cohort release numbers by the survival rate of that cohort before calculating the proportion of fish known to be consumed within the cohort. For comparisons of predation on the upriver colonies, we used the survival rate from Lower Granite to Lower Monumental Dam, and for those on the estuary colonies, we used the survival rate to Bonneville or John Day Dam.

Results and Discussion

Detection Probability

Overall, PIT-tag detection probabilities varied among release groups and detection locations, ranging from a low of 0.09 to a high of 0.36 (Figure 6; Tables 3-4). The lowest PIT-tag detection probabilities were observed at Bonneville, John Day, and Ice Harbor Dam, where respective estimates were 0.09, 0.18, and 0.16 for JSATS-tagged fish and 0.12, 0.12, and 0.13 for PIT-tagged fish. The highest detection probabilities were observed at Little Goose, Lower Monumental, and McNary Dam, with respective estimates of 0.36, 0.25, and 0.25 for JSATS-tagged fish and 0.32, 0.20, and 0.23 for PIT-tagged fish (Figure 6).

Detection probabilities in this study (as well as those in the 2006 and 2007 companion studies) are essentially estimates of the proportion of migrating PIT-tagged fish that are guided into juvenile bypass systems at dams. Successful fish guidance varies with factors such as the type of equipment and engineering utilized at a particular facility, daily operations (e.g., the amount of spill that is occurring at the time of fish passage), and hydraulic conditions such as flow, turbidity, and debris load. Therefore, detection probabilities can vary among locations and over time at the same location.

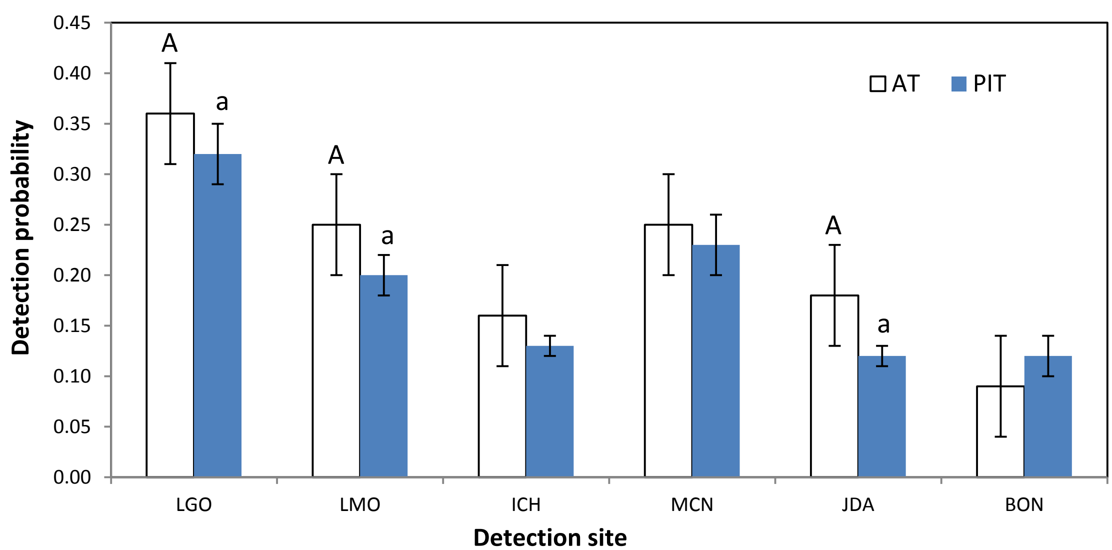


Figure 6. Mean PIT-tag detection probability of JSATS acoustic-tagged (AT) and PIT-tagged (PIT) yearling Chinook salmon at Snake and Columbia Rivers dams in 2008. Abbreviations: LGO, Little Goose; LMO, Lower Monumental; ICH, Ice Harbor; MCN, McNary; JDA, John Day; BON, Bonneville. Error bars denote SEs. Different letters indicate a significant difference between groups at each detection site (α = 0.05).

Table 3. Mean PIT tag detection probability and *t*-test results at each detection site in the Snake River for JSATS-tagged and PIT-tagged river-run yearling Chinook salmon released into the Lower Granite Dam tailrace in 2008. Standard errors are in parentheses.

		Mean probability of detection at Snake River dams			
Detection site	Release date	JSATS	PIT	*t*	*P*
Little Goose Dam	4/24/2008	0.34 (0.03)	0.29 (0.02)		
	4/29/2008	0.24 (0.02)	0.22 (0.01)		
	5/1/2008	0.22 (0.02)	0.2 (0.01)		
	5/3/2008	0.39 (0.03)	0.29 (0.01)		
	5/6/2008	0.41 (0.03)	0.36 (0.01)		
	5/8/2008	0.48 (0.03)	0.49 (0.01)		
	5/10/2008	0.48 (0.03)	0.43 (0.01)		
	5/13/2008	0.40 (0.03)	0.38 (0.01)		
	5/15/2008	0.35 (0.03)	0.33 (0.01)		
	5/17/2008	0.28 (0.02)	0.25 (0.01)		
Overall mean		**0.36 (0.03)**	**0.32 (0.03)**	**3.75**	**0.005**
Lower Monumental Dam	4/24/2008	0.20 (0.03)	0.20 (0.02)		
	4/29/2008	0.28 (0.03)	0.19 (0.01)		
	5/1/2008	0.22 (0.02)	0.20 (0.01)		
	5/3/2008	0.24 (0.03)	0.20 (0.01)		
	5/6/2008	0.23 (0.03)	0.15 (0.01)		
	5/8/2008	0.14 (0.02)	0.13 (0.01)		
	5/10/2008	0.19 (0.03)	0.13 (0.01)		
	5/13/2008	0.30 (0.03)	0.25 (0.01)		
	5/15/2008	0.34 (0.03)	0.28 (0.01)		
	5/17/2008	0.32 (0.03)	0.29 (0.01)		
Overall mean		**0.25 (0.02)**	**0.20 (0.02)**	**4.29**	**0.002**
Ice Harbor Dam	4/24/2008	0.16 (0.02)	0.19 (0.02)		
	4/29/2008	0.19 (0.02)	0.15 (0.01)		
	5/1/2008	0.15 (0.02)	0.14 (0.01)		
	5/3/2008	0.21 (0.03)	0.15 (0.01)		
	5/6/2008	0.14 (0.02)	0.11 (0.01)		
	5/8/2008	0.13 (0.02)	0.08 (0.01)		
	5/10/2008	0.12 (0.02)	0.11 (0.01)		
	5/13/2008	0.11 (0.02)	0.12 (0.01)		
	5/15/2008	0.15 (0.02)	0.16 (0.01)		
	5/17/2008	0.20 (0.02)	0.15 (0.01)		
Overall mean		**0.16 (0.01)**	**0.13 (0.01)**	**2.09**	**0.067**

Table 4. Mean PIT-tag detection probability and *t*-test results at each detection site in the Columbia River for JSATS-tagged and PIT-tagged river-run yearling Chinook salmon released into the Lower Granite Dam tailrace in 2008. Standard errors are in parentheses.

		Mean probability of detection at Columbia River dams			
Detection site	Release date	JSATS	PIT	*t*	*P*
McNary Dam	4/24/2008	0.34 (0.03)	0.34 (0.03)		
	4/29/2008	0.34 (0.03)	0.37 (0.02)		
	5/1/2008	0.36 (0.03)	0.32 (0.01)		
	5/3/2008	0.37 (0.03)	0.31 (0.01)		
	5/6/2008	0.34 (0.03)	0.28 (0.01)		
	5/8/2008	0.36 (0.03)	0.26 (0.01)		
	5/10/2008	0.15 (0.02)	0.15 (0.01)		
	5/13/2008	0.1 (0.02)	0.1 (0.01)		
	5/15/2008	0.09 (0.02)	0.09 (0.01)		
	5/17/2008	0.08 (0.02)	0.12 (0.01)		
Overall mean		**0.25 (0.04)**	**0.23 (0.03)**	**1.25**	**0.242**
John Day Dam	4/24/2008	0.16 (0.03)	0.11 (0.03)		
	4/29/2008	0.18 (0.03)	0.17 (0.02)		
	5/1/2008	0.19 (0.03)	0.11 (0.01)		
	5/3/2008	0.22 (0.03)	0.11 (0.01)		
	5/6/2008	0.24 (0.03)	0.11 (0.01)		
	5/8/2008	0.21 (0.03)	0.12 (0.02)		
	5/10/2008	0.20 (0.03)	0.14 (0.02)		
	5/13/2008	0.12 (0.02)	0.12 (0.02)		
	5/15/2008	0.13 (0.02)	0.14 (0.02)		
	5/17/2008	0.16 (0.02)	0.12 (0.02)		
Overall mean		**0.18 (0.01)**	**0.12 (0.01)**	**3.6**	**0.006**
Bonneville Dam	4/24/2008	0.10 (0.03)	0.13 (0.08)		
	4/29/2008	0.08 (0.02)	0.19 (0.05)		
	5/1/2008	0.13 (0.02)	0.23 (0.04)		
	5/3/2008	0.11 (0.02)	0.22 (0.04)		
	5/6/2008	0.07 (0.02)	0.11 (0.04)		
	5/8/2008	0.07 (0.02)	0.08 (0.05)		
	5/10/2008	0.06 (0.02)	0.05 (0.03)		
	5/13/2008	0.04 (0.01)	0.07 (0.05)		
	5/15/2008	0.13 (0.02)	0.05 (0.05)		
	5/17/2008	0.07 (0.02)	0.04 (0.04)		
Overall mean		**0.09 (0.01)**	**0.12 (0.02)**	**1.48**	**0.174**

Guidance efficiencies can also vary depending on the behavior and physiological condition of migrating fish (Giorgi et al. 1988; Gessel et al. 1991). Within a bypass system, detection efficiency for an individual antenna can vary depending on the configuration of fish with respect to the electronic field (proximity and angle), electromagnetic interference, and fish density (Stein et al. 2004). However, once a PIT-tagged fish has entered the bypass system at a dam, its probability of detection within the facility is generally very high ($\geq$ 98%, S. L. Downing, NMFS, personal communication).

Throughout the Federal Columbia River Power System, PIT-tag detections were lower than usual in 2008 due to higher-than-average river flows. These high flows were due to a late-season thaw in combination with above-average snowpack, and resulted in high debris loads, which threatened the condition of migrating fish. On 21 May 2008, the USACE initiated removal of the fish guidance screens at Bonneville Dam to ameliorate this threat. As a result, the ability to detect fish at Bonneville Dam was considerably reduced throughout a large portion of the yearling migration period.

Although the ability to guide fish into the bypass system remained intact at other study dams, heavy flow and river debris load similarly compromised PIT-detection capability at these sites. For the 4,139 JSATS-tagged and 50,814 PIT-tagged fish released at Lower Granite Dam, complete records of all downstream detections are available online with this report (www.nwfsc.noaa.gov/publications/index.cfm).

For yearling Chinook salmon, considerable variability in mean detection probability was observed among detection sites in 2008. This variability was likely due to differences in environmental and physical attributes at each detection site, and was to be expected. However, similar to findings from 2007 (Wargo-Rub et al. 2009), we also observed differences in detection probabilities between paired treatment groups at individual detection sites.

Mean PIT-tag detection probabilities between JSATS- and PIT-tagged fish differed significantly at three sites ($P < 0.01$) and approached significance at a fourth ($P = 0.067$), with JSATS-tagged fish having a higher likelihood of being detected at all four sites (Tables 3 and 4). At Little Goose Dam, overall mean PIT-tag detection probability of JSATS-tagged fish was 0.04 greater than that of PIT-tagged fish ($P = 0.005$; Table 3). Mean detection probability of JSATS-tagged fish was greater than that of PIT-tagged fish by 0.05 at Lower Monumental ($P = 0.002$), by 0.03 at Ice Harbor Dam ($P = 0.067$, Table 3), and by 0.06 at John Day Dam ($P = 0.006$; Table 4). In contrast to the 2007 findings, these differences were consistent in direction at each location.

Travel time differences between paired releases of tag-treatment groups (as reported below) were fairly small at most detection sites with only one exception. Therefore, we assumed that treatment groups were experiencing similar environmental conditions at each detection location as they migrated downstream. As such, with the possible exception of John Day Dam, subtle differences in behavior between treatment groups, such as vertical position in the water column, likely contributed to the observed differences in detection probability. This likelihood is supported by the small differences in travel time observed, as well as by the potential effect of internal tags on fish buoyancy.

For example, Perry et al. (2001) observed that changes in depth/pressure affected buoyancy to a greater extent in fish implanted with dummy radio transmitters (minus a trailing antenna) than in control fish. Based on these observations, they cautioned that tagged fish may expend more energy swimming in order to maintain buoyancy at depth compared to non-tagged fish, or tagged fish might travel at shallower depths in order to compensate for the higher costs of maintaining neutral buoyancy.

Another possibility is that if acoustic-tagged fish were physically compromised compared to PIT-tagged fish, they may have been less likely to resist flow entrainment into the bypass system than PIT-tagged fish. A similar phenomenon has been observed for small vs. large PIT-tagged salmonids, with smaller fish more likely to be bypassed (Zabel et al. 2005). Differential detection probabilities based on tag type (PIT tag vs. dual PIT and JSATS tag) and size at tagging were also evident in the covariable modeling analysis performed here (Appendix B).

Relative Survival

Our estimate of average relative survival was defined as the geometric mean of ratio estimates for JSATS-tagged vs. PIT-tagged fish (JSATS/PIT). Thus, a relative survival value of 1.00 indicated no difference in survival between tag treatments, while values greater than 1.00 indicated higher survival for JSATS-tagged fish and those less than 1.00 indicated higher survival for PIT-tagged fish. During 2008, overall average relative survival to detection sites throughout the hydrosystem ranged from 0.97 to 0.72 (Tables 5 and 6). Average estimated survival to all sites throughout the hydrosystem was higher for PIT-tagged than for JSAT-tagged fish (though not always statistically significantly different). In the Snake River, relative survival averaged 0.97 ($P = 0.107$) to Little Goose, 0.95 ($P = 0.096$) to Lower Monumental, and 0.96 ($P = 0.336$) to Ice Harbor Dam (Figure 7).

On the mainstem Columbia River, relative survival to McNary Dam was 0.91 ($P = 0.095$). Relative survival to John Day and Bonneville Dam was 0.72 and 0.75, respectively, indicating higher rates of survival for PIT-tagged fish, with a significant difference in estimated survival between tag types at both locations ($P = 0.001$ and 0.021). Among individual replicates, estimated survival was consistently higher for PIT-tagged fish throughout the study period at Little Goose (8 of 10 release groups), Lower Monumental (7 of 10), McNary (8 of 10), and John Day Dams (9 of 10).

In the 2006 and 2007 studies (Hockersmith et al. 2007b; Wargo-Rub et al. 2009), survival was higher for JSATS- than PIT-tagged fish at one Snake River detection location each study year. This location was Little Goose Dam in 2006 and Lower Monumental Dam in 2007. The difference observed at Little Goose Dam in 2006 was significant ($P = 0.004$), and the difference observed at Lower Monumental Dam in 2007 approached significance ($P = 0.080$). However, in both years, a trend toward higher survival for PIT-tagged fish subsequently developed, and the difference in survival between treatments appeared to increase over time/distance from release.

In 2008, survival was consistently higher for PIT-tagged than for JSATS-tagged fish at each detection location. Similar to 2006 and 2007, the difference in survival between treatments appeared to increase over time/distance from release. Differences in survival observed in 2008 approached significance at Lower Monumental ($P = 0.096$) and McNary Dam ($P = 0.095$), and were significant at John Day ($P = 0.001$) and Bonneville Dam ($P = 0.021$). Thus the trend towards higher survival for PIT-tagged fish persisted, despite reducing the mean tag burden from the JSATS tag to 1.8% in 2008 compared to 3.2% in 2006 and 2.9% in 2007.

Table 5. Mean survival probability and *t*-test results from release to downstream detection sites in the Snake River for JSATS-tagged and PIT river-run yearling Chinook salmon released into the Lower Granite Dam tailrace in 2008. The *t*-test was based on the geometric mean of the replicate survival ratio (JSATS/PIT) for each location. Standard errors are in parentheses.

Date of release at Lower Granite	Mean survival to Snake River dams for yearling Chinook salmon: JSATS-tagged	PIT-tagged	*t*	*P*	Relative survival (JSATS/PIT)
	Little Goose Dam				
4/24/2008	0.85 (0.04)	0.97 (0.04)			0.88 (0.05)
4/29/2008	0.96 (0.05)	0.97 (0.03)			1.00 (0.06)
5/1/2008	0.92 (0.04)	0.95 (0.02)			0.97 (0.04)
5/3/2008	0.94 (0.04)	0.96 (0.02)			0.98 (0.04)
5/6/2008	0.9 (0.04)	0.97 (0.02)			0.93 (0.04)
5/8/2008	0.96 (0.04)	0.94 (0.01)			1.03 (0.04)
5/10/2008	0.89 (0.03)	0.94 (0.02)			0.94 (0.04)
5/13/2008	0.88 (0.03)	0.91 (0.02)			0.98 (0.03)
5/15/2008	0.94 (0.03)	0.95 (0.02)			1.00 (0.04)
5/17/2008	1 (0.03)	0.96 (0.03)			1.05 (0.04)
Overall	0.92[a] (0.01)	0.95[a] (0.01)	1.79	0.107	0.97[b] (0.02)
	Lower Monumental Dam				
4/24/2008	0.93 (0.07)	0.84 (0.05)			1.12 (0.11)
4/29/2008	0.86 (0.04)	0.98 (0.04)			0.87 (0.05)
5/1/2008	0.9 (0.05)	0.91 (0.03)			1.00 (0.06)
5/3/2008	0.83 (0.05)	0.9 (0.02)			0.91 (0.06)
5/6/2008	0.81 (0.05)	0.97 (0.03)			0.83 (0.06)
5/8/2008	0.92 (0.09)	0.98 (0.04)			0.94 (0.10)
5/10/2008	0.81 (0.06)	0.94 (0.05)			0.86 (0.08)
5/13/2008	0.89 (0.04)	0.89 (0.04)			1.00 (0.06)
5/15/2008	0.89 (0.03)	0.89 (0.03)			1.01 (0.05)
5/17/2008	0.97 (0.03)	0.98 (0.04)			0.99 (0.05)
Overall	0.88[a] (0.02)	0.93[a] (0.02)	1.86	0.096	0.95[b] (0.03)
	Ice Harbor Dam				
4/24/2008	0.75 (0.06)	0.68 (0.04)			1.10 (0.11)
4/29/2008	0.76 (0.04)	0.85 (0.04)			0.89 (0.06)
5/1/2008	0.83 (0.05)	0.81 (0.03)			1.02 (0.08)
5/3/2008	0.74 (0.05)	0.86 (0.03)			0.87 (0.06)
5/6/2008	0.70 (0.06)	0.86 (0.04)			0.82 (0.08)
5/8/2008	0.72 (0.03)	0.90 (0.06)			0.80 (0.06)
5/10/2008	0.88 (0.1)	0.86 (0.06)			1.01 (0.13)
5/13/2008	0.93 (0.06)	0.82 (0.06)			1.14 (0.12)
5/15/2008	0.84 (0.05)	0.78 (0.05)			1.08 (0.10)
5/17/2008	0.83 (0.03)	0.86 (0.06)			0.95 (0.08)
Overall	0.80[a] (0.02)	0.83[a] (0.02)	1.02	0.336	0.96[b] (0.04)

[a] arithmetic mean
[b] geometric mean

Table 6. Mean survival probability and *t*-test results from release to each detection site on the Columbia River for JSATS-tagged and PIT tagged river-run yearling Chinook salmon released to the Lower Granite Dam tailrace in 2008. Standard errors are in parentheses. The *t*-test was based on the geometric mean of the replicate survival ratio (JSATS/PIT) for each location.

Date of release at Lower Granite	Mean survival to Columbia River dams for yearling Chinook salmon				Relative survival
	JSATS-tagged	PIT-tagged	*t*	*P*	(JSATS/PIT)
	McNary Dam				
4/24/2008	0.62 (0.03)	0.73 (0.06)			0.85 (0.08)
4/29/2008	0.7 (0.03)	0.75 (0.03)			0.93 (0.06)
5/1/2008	0.71 (0.03)	0.79 (0.03)			0.89 (0.05)
5/3/2008	0.62 (0.03)	0.84 (0.03)			0.74 (0.04)
5/6/2008	0.59 (0.03)	0.77 (0.03)			0.77 (0.05)
5/8/2008	0.63 (0.03)	0.78 (0.04)			0.81 (0.05)
5/10/2008	0.61 (0.04)	0.67 (0.05)			0.91 (0.09)
5/13/2008	0.71 (0.02)	0.57 (0.05)			1.25 (0.12)
5/15/2008	0.76 (0.02)	0.78 (0.08)			0.98 (0.11)
5/17/2008	0.87 (0.06)	0.78 (0.08)			1.12 (0.14)
Overall mean	0.68[a] (0.03)	0.75[a] (0.02)	1.87	0.095	0.91[b] (0.05)
	John Day Dam				
4/24/2008	0.51 (0.05)	0.89 (0.21)			0.58 (0.02)
4/29/2008	0.63 (0.05)	0.65 (0.07)			0.98 (0.13)
5/1/2008	0.56 (0.03)	0.82 (0.08)			0.69 (0.08)
5/3/2008	0.47 (0.03)	0.9 (0.09)			0.52 (0.06)
5/6/2008	0.47 (0.03)	0.91 (0.11)			0.52 (0.07)
5/8/2008	0.54 (0.04)	0.95 (0.15)			0.57 (0.10)
5/10/2008	0.59 (0.05)	0.69 (0.1)			0.85 (0.14)
5/13/2008	0.69 (0.05)	0.87 (0.13)			0.80 (0.14)
5/15/2008	0.75 (0.06)	0.69 (0.09)			1.09 (0.17)
5/17/2008	0.79 (0.06)	0.91 (0.15)			0.87 (0.16)
Overall mean	0.60[a] (0.04)	0.83[a] (0.03)	4.53	0.001	0.72[b] (0.06)
	Bonneville Dam				
4/24/2008	0.39 (0.03)	0.62 (0.41)			0.63 (0.41)
4/29/2008	0.67 (0.11)	0.61 (0.16)			1.09 (0.33)
5/1/2008	0.49 (0.02)	0.42 (0.07)			1.18 (0.21)
5/3/2008	0.43 (0.04)	0.42 (0.07)			1.04 (0.20)
5/6/2008	0.42 (0.02)	0.59 (0.23)			0.71 (0.27)
5/8/2008	0.52 (0.06)	0.44 (0.24)			1.19 (0.67)
5/10/2008	0.46 (0.03)	0.86 (0.59)			0.53 (0.37)
5/13/2008	0.57 (0.02)	0.84 (0.57)			0.69 (0.47)
5/15/2008	0.65 (0.04)	1.25 (1.22)			0.52 (0.51)
5/17/2008	0.62 (0.04)	1.43 (1.4)			0.43 (0.42)
Overall mean	0.52[a] (0.03)	0.75[a] (0.11)	2.79	0.021	0.75[b] (0.09)

[a] arithmetic mean
[b] geometric mean

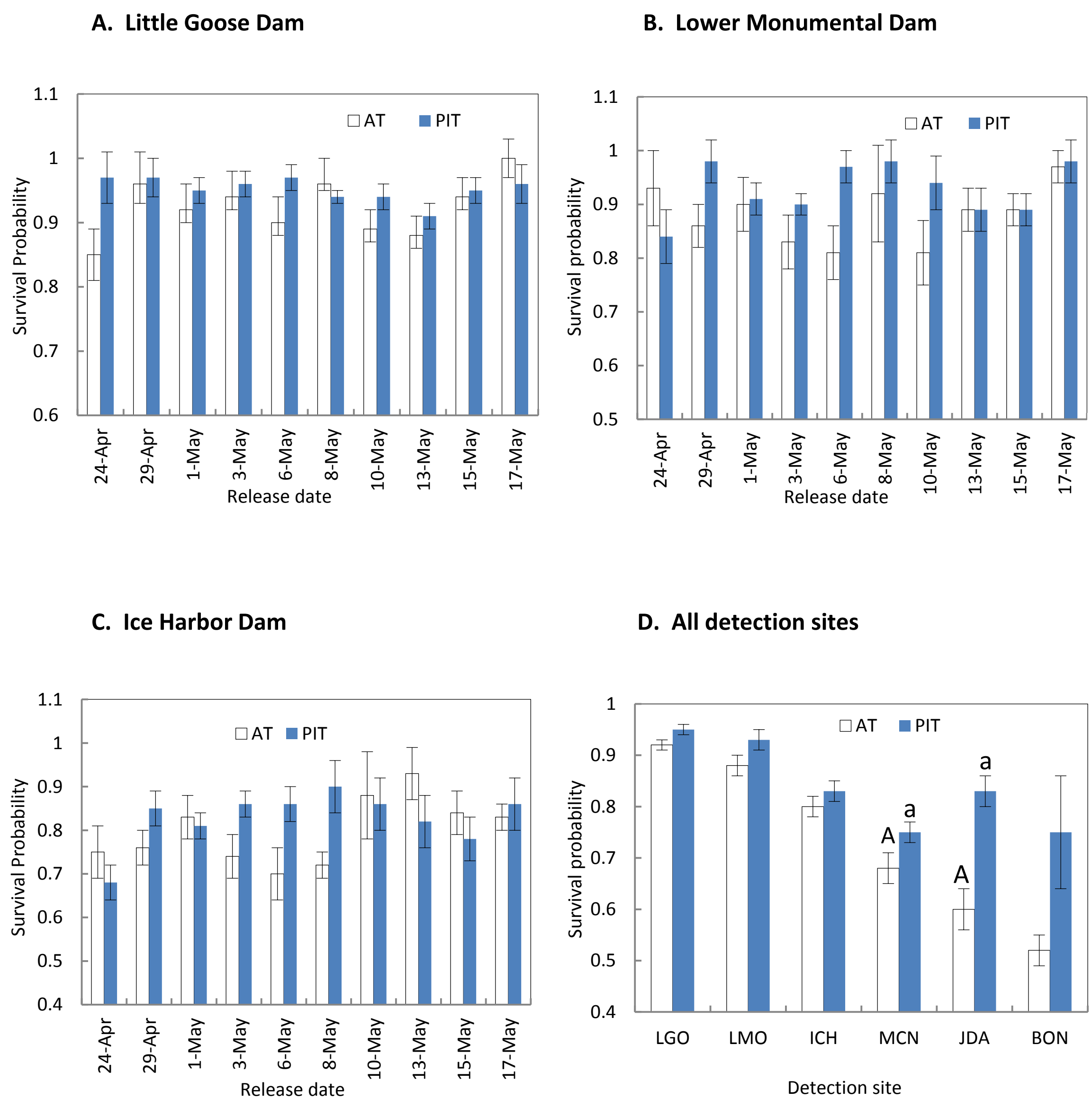
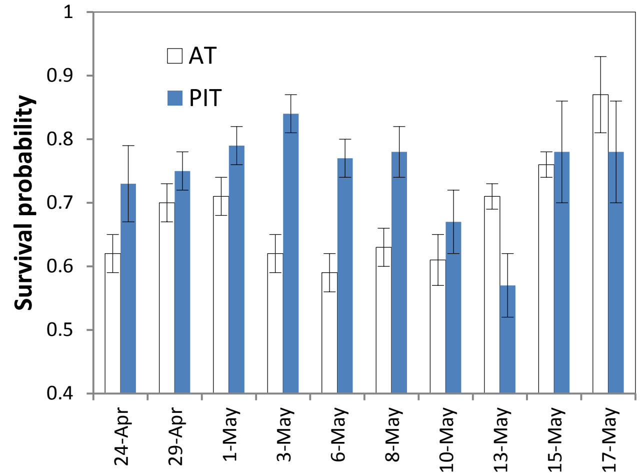
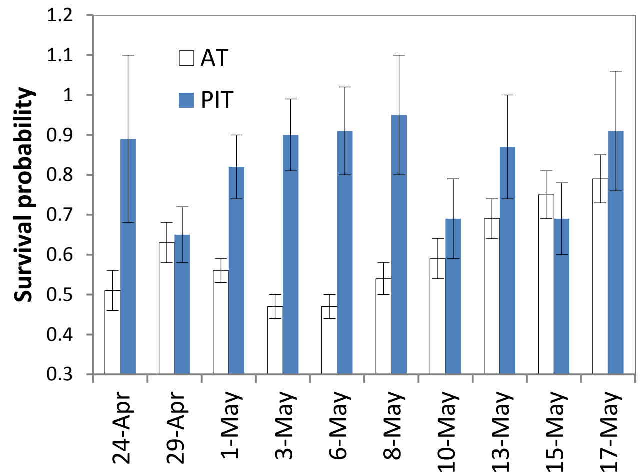


Figure 7. Mean survival probabilities by release date of JSATS-tagged and PIT-tagged yearling Chinook salmon from Lower Granite Dam tailrace to detection at A) Little Goose, B) Lower Monumental, C) Ice Harbor, and D) all detection sites (for the combined releases). Whisker bars denote standard errors. Dissimilar letters indicate a significant difference in estimated survival between tag treatments ($\alpha = 0.05$). Abbreviations: LGO, Little Goose; LMO Lower Monumental; ICH Ice Harbor, MCN McNary, JDA John Day, BON Bonneville.

A. McNary Dam



B. John Day Dam



C. Bonneville Dam

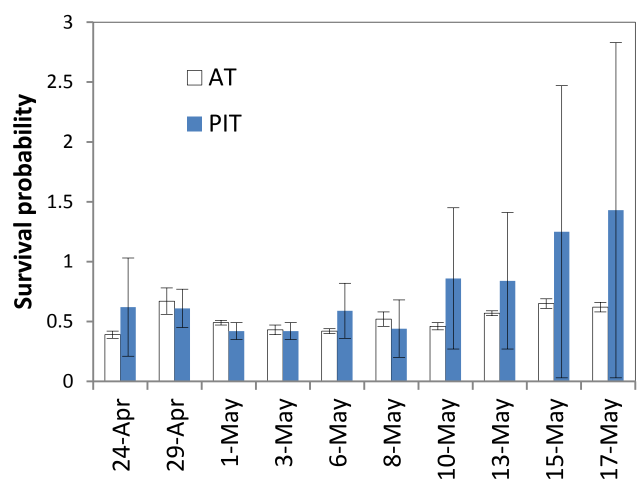


Figure 8. Mean survival probabilities of JSATS-tagged and PIT-tagged river-run yearling Chinook salmon from release at Lower Granite Dam to Columbia River detection sites at A) McNary, B) John Day, and C) Bonneville Dam in 2008. Whisker bars denote standard errors.

Statistical Power Analysis for Relative Survival

Relative survival (JSATS/PIT) from release at Lower Granite Dam to John Day Dam was the outcome variable used for sample size determination for study of yearling Chinook migrating in 2008. Sample sizes for this study were anticipated to be ample for comparison of recovery percentages, detection probabilities, and travel times. Although a stated objective of the study was to estimate relative survival from Lower Granite to Little Goose, Lower Monumental, Ice Harbor, McNary, and Bonneville Dam, sample sizes were planned for evaluation of survival from Lower Granite to John Day Dam, not for the other reaches.

The parameters and values listed below for yearling Chinook salmon were adapted from those listed in the Final Research Proposal for FY08. These parameters were used to develop the sample size and associated minimum detectable difference of 5% in survival between PIT- and JSATS-tagged hatchery yearling Chinook salmon with 80% statistical power ($\alpha = 0.05$, $\beta = 0.20$):

S = Estimated survival of PIT-tagged fish from release to John Day Dam (0.724)
p = Detection probability of PIT-tagged fish at John Day Dam (0.38)
λ = Detection probability of PIT tagged fish downstream from John Day Dam (0.25)
λ = Detection probability of JSATS-tagged fish downstream from John Day Dam (0.90)

Fish would be tagged at Lower Granite Dam and released through the bypass pipe. Proposed sample sizes of hatchery yearling Chinook totaled 4,200 JSATS-tagged fish and approximately 45,000 PIT-tagged fish.

An implicit assumption of the sample size calculations was that variability in relative survival between replicates would be negligible. In other words, we anticipated that by pairing replicate groups, we would account for temporal variability in absolute survival, since relative survival (i.e., a tag effect, if any) would remain near constant. These assumptions led to an expected standard error of 0.016 on the geometric mean ratio of replicate estimates of JSATS/PIT survival to John Day. The power of the tests is directly related to the precision of the estimate. As noted above, this level of precision would provide 80% statistical power to detect a minimum difference in survival of 5% between JSATS-tag and PIT-tag groups (JSATS/PIT ratio of 0.95) using a t-test at the $\alpha = 0.05$ significance level.

As reported in the previous section, under the actual conditions encountered in 2008, the detection probability at John Day Dam did not approach the anticipated 0.38 for any replicate release group. Detection probability at John Day in 2008 averaged 0.18 for JSATS-tagged and 0.12 for PIT-tagged fish. In addition, the observed data suggest that there was a non-negligible amount of temporal variability in relative survival. Because of these two factors, under the actual conditions of 2008, our estimated standard error on the geometric mean estimate of relative survival to John Day Dam was 0.062, almost 4 times larger than the anticipated 0.016. Estimated standard errors also exceeded 0.016 for relative survival to all the other downstream sites, except for Little Goose Dam.

Despite precision considerably lower than planned, relative JSATS/PIT survival to John Day was significantly different than 1.0 ($P = 0.001$). This was because the estimated difference (estimated relative survival was 0.72, or a 28% difference) in survival was much larger than the desired detectable difference of 5%. Had the true difference been only 5%, it is unlikely we would have detected it: with a standard error of 0.062 and $\alpha = 0.05$ there is only 20% power to detect a true difference of 5%, and the smallest difference that could be detected with 80% power would be 19% (relative survival 0.81). The table below gives the corresponding values for each of the reaches below Lower Granite Dam for survival estimation in the report:

Table 7. Values estimated vs. those required for various levels of statistical power for each of the reaches downstream from Lower Granite Dam that were evaluated for survival estimation during the tag comparison study of 2008.

Detection location after release at Lower Granite Dam	Actual estimated difference (%)	Actual estimated standard error	[a]Minimum difference that would have been declared significant at $\alpha = 0.05$ (%)	Power to detect true difference of 5% at α=0.05 (%)	Minimum detectable difference with 80% power at $\alpha = 0.05$ (%)	Power to detect true difference of 5% at $\alpha = 0.10$ (%)	Minimum detectable difference with 80% power at $\alpha = 0.10$ (%)
Little Goose	3	0.015	3.4	95	4.7	98	4.0
Lower Monumental	5	0.027	6.1	58	8.4	72	7.3
Ice Harbor	4	0.038	8.6	37	11.8	51	10.2
McNary	9	0.047	10.6	28	14.6	41	12.7
John Day	28	0.062	14.0	20	19.3	32	16.7
Bonneville	25	0.089	20.1	14	27.7	24	24.0

[a] Power to detect this difference was 50%, by definition.

Travel Time

Median travel time to each downstream PIT-tag detection site was calculated only for release groups with 10 or more detections at a given downstream site. In 2008, this was true for every release group of yearling Chinook salmon from both the JSATS- and PIT-tag treatments. At each downstream detection site, the average median travel time for each release group was compared by tag treatment.

With only one exception, travel time from Lower Granite Dam to all downstream detection sites was not significantly different between tag treatment groups (Figure 9). To John Day Dam, the average median travel time was 0.81 d longer for JSATS-tagged than for PIT-tagged fish. This difference in travel time was significant ($P = 0.019$). Based on travel-time data, it is likely that JSATS- and PIT-tagged fish experienced similar environmental conditions and encountered similar hydropower operational modes at most detection locations, including locations where detection probabilities differed significantly between groups.

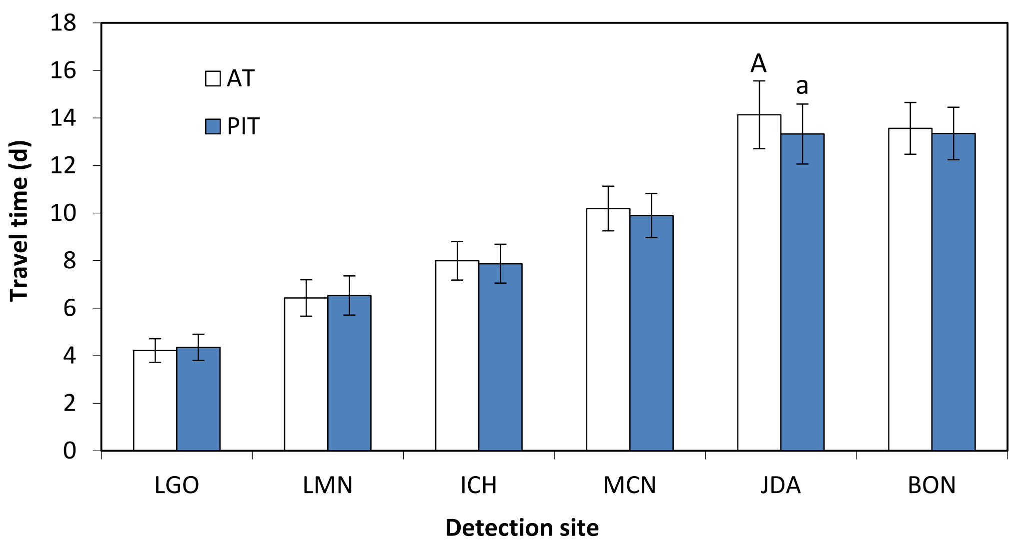


Figure 9. Average median travel time for combined release groups of JSATS acoustic-tagged (AT) and PIT-tagged (PIT) yearling Chinook salmon from release at Lower Granite Dam to detection at downstream dams on the Snake and Columbia Rivers, 2008. Whisker bars denote standard errors. Dissimilar letters indicate a significant difference in estimated survival between tag treatments ($\alpha = 0.05$). Abbreviations: LGO, Little Goose Dam; LMO, Lower Monumental Dam; ICH, Ice Harbor Dam; MCN, McNary Dam; JDA, John Day Dam; BON, Bonneville Dam.

Median travel time to each Snake River dam shortened sequentially for both JSATS-tagged and PIT-tag groups from the first release on 24 April to the sixth on 8 May (Figure 10). Travel time was slightly longer for groups released on 10 May than for those released on 8 May at all detection sites. However, the trend toward decreasing travel time resumed from 13 May through the end of the study. This trend was similar in the Columbia River, where we observed a sequential decrease in travel time at each dam, from the first to the tenth release group (with the exception of the 13 May release group at McNary Dam). In the Snake River, travel times for the last release group on 17 May were about one-third as long as those of the first release group on 24 April. In the mainstem Columbia River, travel times for the last release group were 50% shorter than those of the first.

In both 2007 (yearling and subyearling Chinook) and in 2008, we observed considerable variation in relative survival to a given location among sets of paired release groups. Environmental data indicated that treatment groups released during both the spring and summer study periods had been subjected to different environmental conditions. We suspected that Snake River flow in particular may have affected survival for yearling fish tagged in spring. To investigate whether or not there were indeed relationships between detection and survival probability and various environmental variables, we used SURPH (v2.2b) to estimate and fit models of detection and survival probabilities as functions of the following covariates: Flow, spill exposure, river temperature, and size (fork length) at tagging during 2007 and 2008 (Appendix B).

In general, the two models that best fit estimated detection and survival probability data both included an effect of tag type (JSATS vs. PIT) as well as an effect of size at tagging. Some models also indicated a small interaction between tag type and size. In addition, although the environmental covariates explained little variation between paired release groups or between treatment groups within pairs, models supported by the data included flow, spill proportion, water temperature, and travel time.

For yearling Chinook salmon in 2008, spill proportion (which was correlated with flow and travel time) appeared to be the most important of these variables influencing survival. However, for yearling Chinook in 2007, results of the covariate analyses were questionable from a biological perspective. This result highlighted the need for more than one year of data for this type of analysis and indicated that only tentative conclusions can be drawn from data produced within a single season, even from a series of release groups.

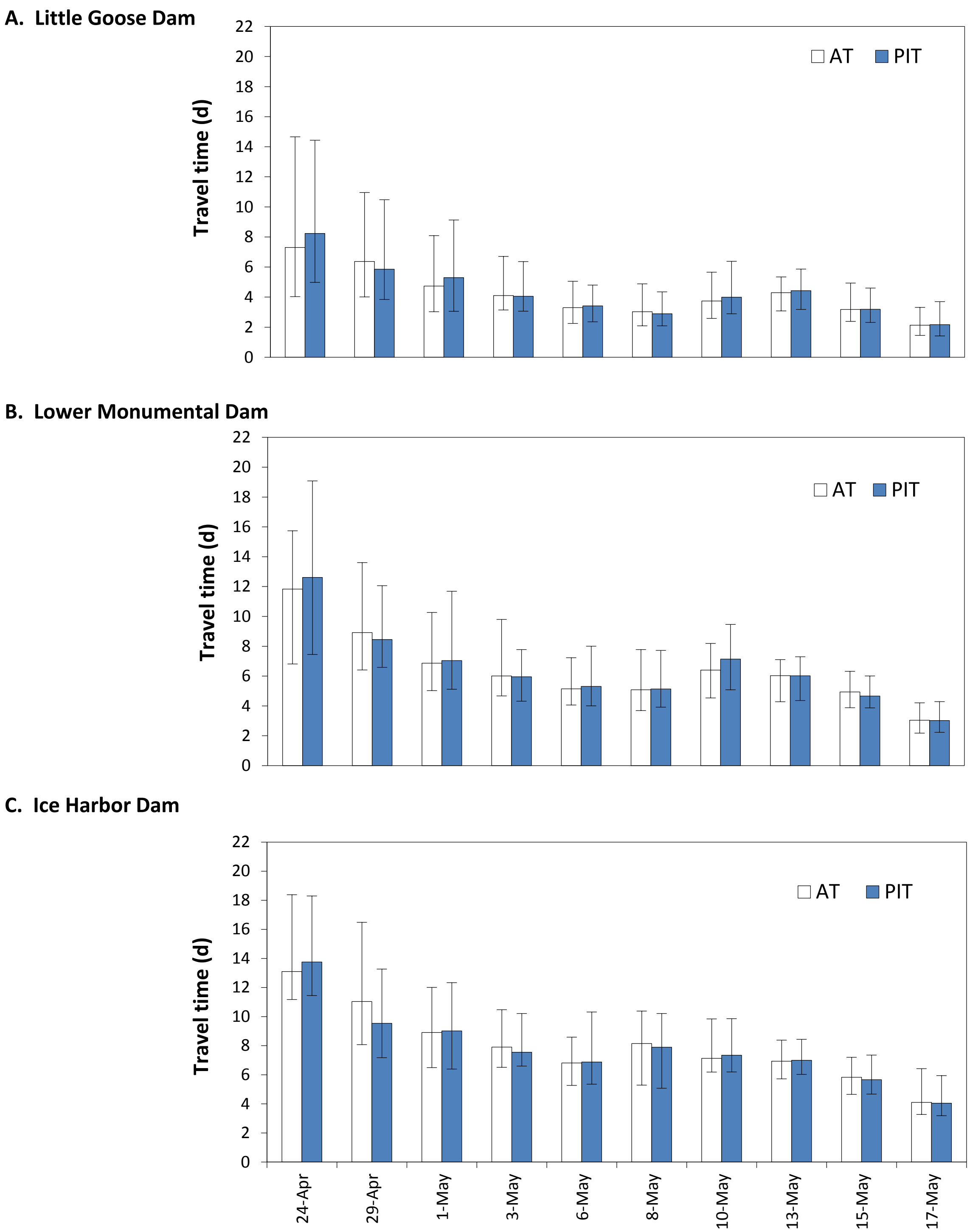


Figure 10. Median travel time by paired release group to A) Little Goose, B) Lower Monumental, and C) Ice Harbor Dam on the Snake River for JSATS-tagged and PIT-tagged yearling Chinook salmon released at Lower Granite Dam, 2008. Whisker bars denote 10th and 90th travel time percentiles from each release.

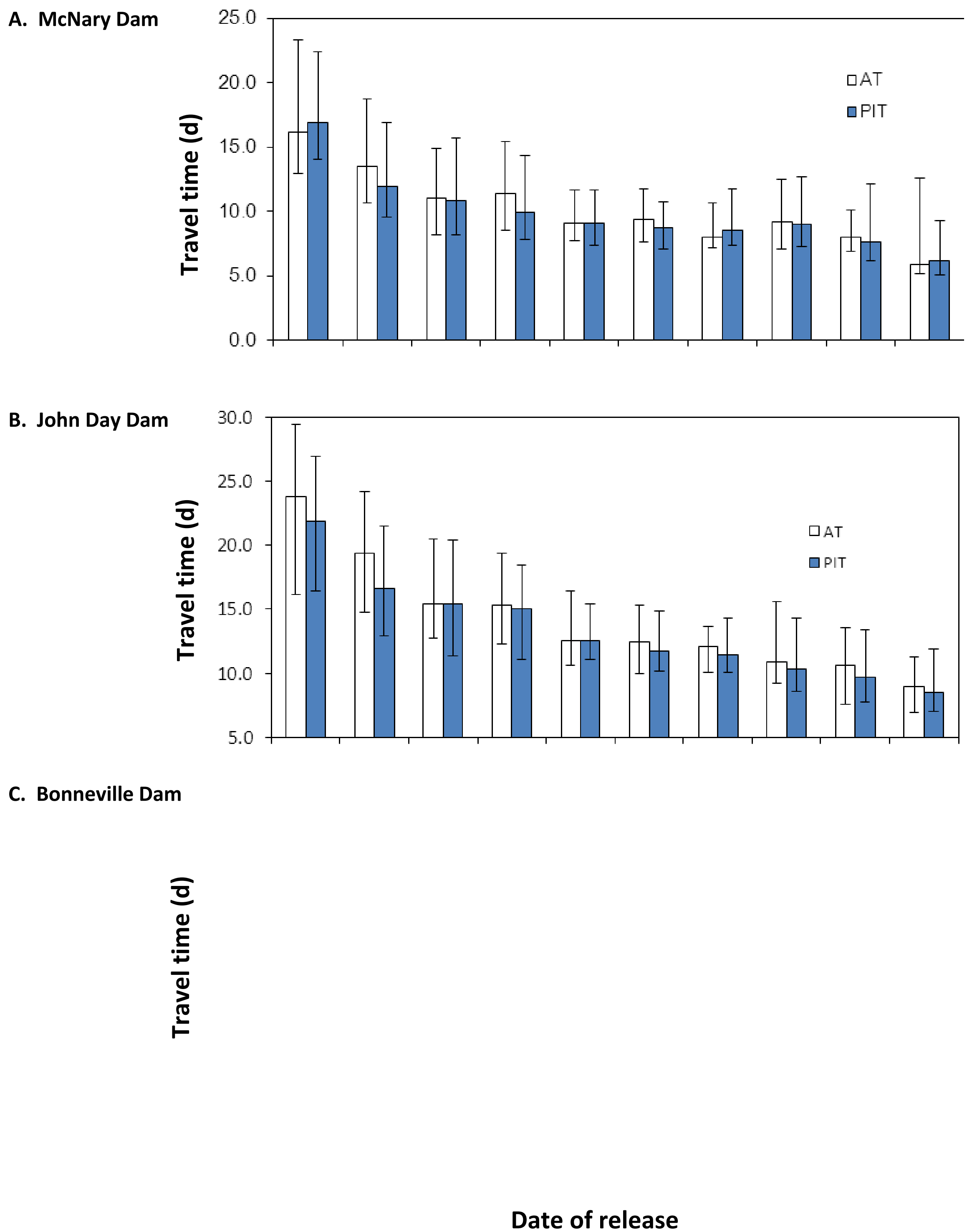


Figure 11. Median travel time by paired release group to A) McNary, B) John Day, and C) Bonneville Dam on the Columbia River for JSATS-tagged and PIT-tagged yearling Chinook salmon released at Lower Granite Dam in 2008. Whisker bars denote 10th and 90th travel time percentiles from each release.

Avian Predation

From the combined total recoveries from upriver colonies, predation rates averaged 2% (range 1-2%) for JSATS releases and 1% (consistent at 1%) for PIT releases (Table 8). Estuary colonies sampled included only the tern and cormorant colonies on East Sand Island. Total PIT-tag recoveries from all colonies on East Sand Island averaged 3% (range 2-5%) of JSATS-tagged releases and 4% (range 1-4%) of PIT-tagged releases).

The difference in proportion of PIT tags recovered on upriver colonies from JSATS-tagged compared to PIT-tagged fish was 0.005. Although this difference was statistically significant ($P = 0.016$), it was not likely to be biologically important. The difference in proportion of PIT tags recovered on downriver colonies was -0.001 and was not statistically significant ($P = 0.881$). Percentages of PIT tags recovered by individual colony and colony location were also similar between tag treatments (Table 9). These analyses were based on actual PIT detections and were not adjusted for detection efficiency rates. Since detection efficiency rates vary by colony, and none are 100%, the data shown in Tables 7 and 8 represent minimum estimates of predation.

Similar to the 2007 study, results from analyses of detection probability and relative survival indicated that JSATS-tagged fish were not likely behaving in the same manner, and were not surviving at the same rates as PIT-tagged fish. However, results from analysis of relative predation suggested that JSATS-tagged fish were no more vulnerable to avian predators than the PIT-tagged fish as they migrated through the upper river and estuary.

Table 8. Percentages of yearling Chinook PIT tags recovered from upriver and estuarine bird colonies in the Columbia River by tag treatment and release date. The actual number of tags recovered by colony is listed in parentheses.

		Yearling Chinook salmon			
Replicate	Release date	Upriver bird colonies (%)	SE	Estuarine bird colonies (%)	SE
		JSATS tag			
1	24 Apr	0.02 (9)	0.01	0.05 (8)	0.02
2	29 Apr	0.01 (3)	0.00	0.02 (5)	0.01
3	1 May	0.02 (7)	0.01	0.04 (9)	0.01
4	3 May	0.02 (8)	0.01	0.02 (3)	0.01
5	6 May	0.01 (4)	0.01	0.02 (4)	0.01
6	8 May	0.02 (7)	0.01	0.03 (6)	0.01
7	10 May	0.02 (6)	0.01	0.02 (3)	0.01
8	13 May	0.01 (2)	0.00	0.02 (6)	0.01
9	15 May	0.01 (5)	0.01	0.03 (8)	0.01
10	17 May	0.01 (4)	0.00	0.03 (8)	0.01
	Overall	0.02 (55)	0.00	0.03 (60)	0.00
		PIT tag			
1	24 Apr	0.01 (8)	0.00	0.03 (26)	0.02
2	29 Apr	0.01 (20)	0.00	0.04 (76)	0.01
3	1 May	0.01 (64)	0.00	0.04 (104)	0.01
4	3 May	0.01 (64)	0.00	0.04 (102)	0.01
5	6 May	0.01 (91)	0.00	0.03 (145)	0.01
6	8 May	0.01 (85)	0.00	0.03 (87)	0.02
7	10 May	0.01 (59)	0.00	0.01 (71)	0.01
8	13 May	0.01 (39)	0.00	0.02 (71)	0.01
9	15 May	0.01 (49)	0.00	0.01 (70)	0.01
10	17 May	0.01 (32)	0.00	0.01 (53)	0.01
	Overall	0.01 (511)	0.00	0.04 (805)	0.00
Difference between mean (JSATS - PIT)		0.005		-0.001	
SE		0.002		0.006	
T		2.95		-0.150	
P		0.016		0.881	

Table 9. Percentages of PIT tags from JSATS-tagged and PIT-tagged yearling Chinook salmon that were subsequently recovered on avian predator colonies in 2008 by colony location, tag treatment, and release date. Numbers of tags recovered are shown in parentheses.

Release date	Badger Island	Crescent Island			Foundation Island	Island 20	Miller Rocks		Potholes		Rock Island	East Sand Island	
	Pelican	Tern	Gull	Mixed	Cormorant	Gull	Gull	Mixed	Tern	Gull	Tern	Tern	Cormorant
	Proportion of PIT tags recovered from JSATS-tagged yearling Chinook salmon												
24 Apr	0.00 (0)	0.01 (3)	0.00 (1)	0.00 (1)	0.01 (4)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.04 (6)	0.01 (2)
29 Apr	0.00 (0)	0.00 (1)	0.00 (0)	0.00 (0)	0.01 (2)	0.00 (0)	0.01 (3)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.01 (4)	0.00 (1)
1 May	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.02 (7)	0.00 (0)	0 (1)	0.00 (0)	0.00 (0)	0.00 (0)	0.01 (2)	0.03 (6)	0.01 (3)
3 May	0.00 (0)	0.00 (0)	0.00 (1)	0.00 (0)	0.02 (7)	0.00 (0)	0 (1)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.02 (3)
6 May	0.00 (0)	0.01 (2)	0.00 (0)	0.00 (0)	0.01 (2)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.02 (4)	0.00 (0)
8 May	0.00 (0)	0.00 (1)	0.00 (1)	0.00 (0)	0.01 (5)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.01 (2)	0.02 (4)
10 May	0.00 (0)	0.01 (4)	0.01 (2)	0.00 (0)	0.00 (0)	0.00 (0)	0.01 (2)	0.00 (0)	0.00 (0)	0.00 (1)	0.00 (0)	0.02 (3)	0.00 (0)
13 May	0.00 (1)	0.00 (1)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.01 (3)	0.01 (3)
15 May	0.00 (0)	0.01 (2)	0.00 (1)	0.00 (0)	0.01 (2)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.01 (4)	0.01 (4)
17 May	0.00 (1)	0.00 (2)	0.00 (1)	0.00 (0)	0.00 (0)	0.00 (1)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.02 (5)	0.01 (3)
Overall	0.00 (2)	0.00 (16)	0.00 (7)	0.00 (1)	0.01 (29)	0.00 (1)	0.00 (7)	0.00 (0)	0.00 (0)	0.00 (1)	0.00 (2)	0.02 (37)	0.01 (23)
	Proportion of PIT tags recovered from yearling Chinook salmon												
24 Apr	0.00 (0)	0.00 (3)	0.00 (0)	0.00 (0)	0.00 (5)	0.00 (0)	0.00 (6)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (1)	0.02 (16)	0.01 (10)
29 Apr	0.00 (1)	0.00 (4)	0.00 (1)	0.00 (2)	0.00 (12)	0.00 (0)	0.00 (10)	0.00 (0)	0.00 (2)	0.00 (0)	0.00 (1)	0.03 (46)	0.02 (30)
1 May	0.00 (4)	0.00 (12)	0.00 (5)	0.00 (1)	0.01 (42)	0.00 (0)	0.00 (16)	0.00 (0)	0.00 (1)	0.00 (0)	0.00 (5)	0.03 (78)	0.01 (26)
3 May	0.00 (2)	0.00 (8)	0.00 (4)	0.00 (1)	0.01 (49)	0.00 (1)	0.00 (21)	0.00 (0)	0.00 (2)	0.00 (0)	0.00 (5)	0.02 (67)	0.01 (35)
6 May	0.00 (3)	0.00 (14)	0.00 (7)	0.00 (0)	0.01 (67)	0.00 (1)	0.00 (18)	0.00 (0)	0.00 (1)	0.00 (0)	0.00 (5)	0.02 (107)	0.01 (38)
8 May	0.00 (3)	0.00 (17)	0.00 (7)	0.00 (0)	0.01 (58)	0.00 (0)	0.00 (10)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (4)	0.02 (65)	0.01 (22)
10 May	0.00 (4)	0.00 (8)	0.00 (5)	0.00 (0)	0.01 (42)	0.00 (2)	0.00 (13)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.01 (37)	0.01 (34)
13 May	0.00 (0)	0.00 (11)	0.00 (2)	0.00 (0)	0.01 (26)	0.00 (0)	0.00 (6)	0.00 (1)	0.00 (0)	0.00 (0)	0.00 (1)	0.01 (28)	0.01 (43)
15 May	0.00 (0)	0.00 (5)	0.00 (12)	0.00 (2)	0.01 (30)	0.00 (0)	0.00 (13)	0.00 (1)	0.00 (0)	0.00 (0)	0.00 (2)	0.01 (37)	0.01 (33)
17 May	0.00 (0)	0.00 (12)	0.00 (1)	0.00 (0)	0.01 (19)	0.00 (0)	0.00 (9)	0.00 (1)	0.00 (0)	0.00 (0)	0.00 (0)	0.01 (31)	0.00 (22)
Overall	0.00 (17)	0.00 (94)	0.00 (44)	0.00 (6)	0.01 (350)	0.00 (4)	0.00 (122)	0.00 (3)	0.00 (6)	0.00 (0)	0.00 (24)	0.02 (512)	0.01 (293)

GROSS NECROPSY AND HISTOLOGICAL EVALUATIONS OF MIGRATING JUVENILE SALMON

Methods

Fish Collection

For gross necropsy, histological examination, and assessment of BKD, we used a subsample from each group released at Lower Granite Dam during spring 2008 for comparison of tag effects on behavior and survival (see *Evaluation of Acoustic Tags in Migrating Juvenile Salmon*). Treatment fish were subsampled from paired releases of JSATS- and PIT-tagged yearling Chinook salmon by recapture at McNary, Bonneville, and John Day Dam. Fish were recaptured using separation-by-code (SbyC) systems, which selectively recapture fish based on PIT-tag code (Marsh 1999; Downing 2001). In addition, we set aside 100 non-tagged hatchery yearling Chinook salmon as reference fish to provide baseline conditions for comparison with results from necropsy, histological exam, and BKD evaluations. Reference fish were anesthetized but not tagged.

Yearling Chinook salmon were subsampled from 20 unique groups based on release date (10 dates) and tag treatment (JSATS or PIT). The SbyC systems at McNary and Bonneville Dams were programmed to collect the first 10 fish detected from each paired release group. This would provide a maximum of 100 recaptures from each tag treatment, for a total of 200 treatment fish at each dam (10 fish/group × 2 tag treatments × 10 release groups). However, due to high debris load in the river and its potential threat to the condition of migrating fish, USACE removed the fish guidance screens at Bonneville Dam. On 21 May 2008, screen removal was initiated, rendering the fish collection and SbyC systems inactive. By this date, we had collected 29 of the 100 JSATS-tagged fish and 67 of the 100 PIT-tagged fish designated for recapture at Bonneville. On 23 May 2008, the SbyC system at John Day Dam was programmed to collect the remainder of our target fish.

Similar to 2007, targeting the first 10 fish to arrive at a downstream dam from each release/treatment may have biased recapture samples in favor of the 10 healthiest or strongest fish from each group. However, this protocol also provided for minimal collection impacts on study fish and bycatch, as well as consistent, systematic programming instructions for the SbyC systems.

At McNary Dam, we successfully recaptured a total of 190 hatchery yearling Chinook (98 JSATS-tagged and 92 PIT-tagged fish). At Bonneville Dam, we recaptured 96 hatchery yearling Chinook (29 JSATS-tagged and 67 PIT-tagged). At John Day Dam, we recaptured 110 hatchery yearling Chinook (57 JSATS-tagged and 53 PIT-tagged).

SbyC fish sampled at Bonneville and John Day Dam were combined by treatment for analyses (86 JSATS-tagged and 120 PIT-tagged). Treatment fish were sacrificed immediately after recapture at the respective dams, and reference fish were sacrificed immediately after collection at Lower Granite Dam. Variability in sample size between tag treatments may have resulted from differential survival, dissimilar routes of passage, or a combination of these variables.

Necropsy and Tissue Collection

Upon recapture in the SbyC system, study fish were humanely euthanized with an overdose of MS-222 (UFR Committee 2004). Each fish was measured, weighed, and evaluated for external abnormalities and gross visible injury, such as lesions, descaling, or hemorrhaging. Individual necropsies were performed at collection sites in the manner of Noga (2000). Fish were examined for gross tissue response to tagging, such as tag encapsulation. The following metrics were evaluated using a Goede index scoring system (Goede and Barton 1990): smolt index, eyes, fins, gills, pseudobranchs, caecal fat, mesenteric fat, spleen, food in stomach, hind gut, liver, gall bladder, sex, and kidney. A description of the numeric scale used to evaluate each metric is presented with the results. Goede index scores were compared between treatments by collection site using a Kruskal-Wallis non-parametric test (Hollander and Wolfe 1973).

Tissues for histological analyses were taken from each fish collected for gross necropsy (as described above). Tissue samples for histological examination were taken from the gill, heart, liver, head kidney, trunk kidney, spleen, upper intestine, lower intestine, skin in area of the incision/suture, and pyloric ceca. Tissues for histology were placed into one of three separate cassettes labeled gill (gill), soft tissue (heart, liver, head and trunk kidney, spleen, upper and lower intestine and pyloric ceca), and incision (skin in area of incision/suture). All tissue samples were placed directly into Davidson's solution for fixation and left undisturbed for 7-14 d.

After fixation, tissue samples were rinsed with distilled water and transferred to 70% ethyl alcohol for continued preservation until they were processed further. Fixed tissues were dehydrated, processed using a Shandon Hypercenter XP automated tissue processor, and embedded in Polyfin (Triangle Biomedical Sciences). Tissues sections (4-5µm thick) were stained with haematoxylin and eosin-phloxine (Luna 1968) and examined by light microscopy at the Ecotoxicology and Environmental Fish Health Program laboratory of the Northwest Fisheries Science Center in Seattle, WA (Appendix C lists specific indices evaluated and the scale used for scoring each index).

Tissue samples were evaluated using 49 histological metrics: five metrics were scored on an ordinal scale of 0 to 3, one on an ordinal scale of 1-5, two on an ordinal scale of 0 to 7, two on an ordinal scale of 1 to 7, and the remainder scored by presence/absence (Appendix C). After all tissue samples were evaluated, scores were coded and entered into a spreadsheet, and data were compared by treatment group, at each collection location using either a chi-square contingency table, a Fisher's exact test (presence/absence data), or a Kruskal-Wallis non-parametric test (ordinal data; Hollander and Wolfe 1973).

Prevalence of *Renibacterium salmoninarum*

Kidney tissue samples were also collected from each sampled and recaptured fish at the time of necropsy and examined for the antigen to *Renibacterium salmoninarum* (Rs), the causative agent of bacterial kidney disease (BKD). Fresh kidney samples were excised and placed into individually labeled sample bags (Nasco Whirlpak, 2 oz, #B01064). Samples were frozen and transported on ice to the Northwest Fisheries Science Center. In the laboratory, kidney samples were thawed, diluted in 0.01-M phosphate-buffered saline with 0.05% Tween 20 at 1:4 (w/v), homogenized using a print roller, and then frozen in screw cap tubes.

For each treatment and release group combination, the Rs antigen was determined based on enzyme-linked immunosorbent assay (ELISA) as described by Pascho and Mulcahy (1987) and modified by Pascho et al. (1991). Coating and conjugate antibodies (Kirkegaard and Perry Laboratories, Gaithersburg MD) were used at dilutions of 1:1500 and 1:4000 respectively. Optical densities were read at 405 nm using an automated 96-well absorbance microplate reader (Model ELx808 IU; BioTek Instruments, Inc., Winooski, VT). Negative controls and blanks, as well as substrate and conjugate controls, were run for each assay. ELISA values were reported as absolute readings, without subtracting values for blanks or negative controls.

Values obtained from ELISA testing represented an index of the magnitude of Rs bacteria present, and absolute values were not functionally related (e.g. the difference between 0.08 and 0.09 did not correspond to the difference between 2.5 and 2.7 via a mathematical function). Therefore, to construct metrics for measuring levels of BKD, it was prudent to map values with an indexing system to more robustly represent "distance" between ELISA values. We mapped values following the method of Pascho et al. (1991), who categorized infection levels based on the detection of Rs antigen using values of <0.199 as reflecting a low level of infection, 0.2 to 0.999 as a medium level, and values equal to or greater than 1.0 as indicating a high level of infection.

$$\{(0.000 - 0.199) \rightarrow 1; \quad (0.200 - 0.999) \rightarrow 2; \quad (1.000 - 4.000) \rightarrow 3\}$$

These values, which were used to group results as either low, medium, or high, reflect levels used in previous studies for broodstock segregation.

Results and Discussion

Gross Necropsy

Based on gross necropsies, yearling Chinook with both types of tags appeared to be within normal limits across all sampling sites for gills, pseudobranchs, hind gut, and kidney. Overall, both the JSATS- and PIT-tagged fish recaptured at McNary and Bonneville/John Day were described as more heavily smolted than reference fish sampled at Lower Granite Dam. Results from JSATS- and PIT-tagged fish necropsied at SbyC recapture sites, along with those of reference fish necropsied at Lower Granite Dam are displayed in Table 10.

Ninety-nine percent of reference fish were described as having normal eyes at Lower Granite Dam. Similarly, 99% of the JSATS-tagged fish collected at Bonneville/John Day, and 97% of the PIT-tagged fish collected at all recapture locations were described as having normal eyes. In contrast, 13% of the JSATS-tagged fish sampled at McNary Dam were described as having eyes that were hemorrhagic, and this was significantly different than the PIT-tagged fish at this location ($P = 0.003$) . Ninety-four percent of the reference fish were described as having normal fins at Lower Granite Dam, as were the majority of SbyC fish collected at Bonneville/John Day Dam (91% of JSATS-tagged and 87% of PIT-tagged fish). However, at McNary Dam, 79% of PIT-tagged and 90% of JSATS-tagged fish were described as having either opaque, frayed, or missing fins. Although the majority of fins for both treatment groups at McNary were not described as normal, they were significantly different from each other ($P < 0.001$), with the JSATS-tagged fish described as having "opaque" fins and the PIT primarily as "frayed."

Table 10. Gross necropsy results for yearling Chinook salmon sampled at Lower Granite Dam (reference) and recaptured at McNary and Bonneville/John Day Dam (acoustic and PIT tag treatments). Samples were scored following a Goede index and were evaluated for the metrics listed. Columns show the proportion of treatment fish corresponding to each metric score by location. Standard errors are in parentheses.

	Yearling Chinook Salmon sampled				
	Lower Granite Dam	McNary Dam		Bonneville/John Day Dam	
Metric	Reference (N = 100)	Acoustic tag (N = 98)	PIT tag (N = 92)	Acoustic tag (N = 86)	PIT tag (N = 120)
Smolt index					
0-Fully smolted	0.74 (0.04)	0.95 (0.02)	0.98 (0.02)	0.99 (0.01)	0.97 (0.02)
1-Moderately smolted	0.26 (0.04)	0.05 (0.02)	0.02 (0.02)	0.01 (0.01)	0.03 (0.02)
2-Weakly smolted	0.00	0.00	0.00	0.00	0.00
3-No smoltification observed	0.00	0.00	0.00	0.00	0.00
Eyes					
0-Normal	0.99 (0.01)	0.85 (0.04)	0.97 (0.02)	0.99 (0.01)	0.99 (0.01)
1-Diminutive	0.00	0.02 (0.01)	0.01 (0.01)	0.00	0 (0)
2-Hemorrhagic	0.00	0.13 (0.03)	0.01 (0.01)	0.00	0.01 (0.01)
3-Exopthalmic	0.00	0.00	0.00	0.00	0.00
4-Cataract	0.01 (0.01)	0.00	0.01 (0.01)	0.01 (0.01)	0.00
5-Blind or Missing	0.00	0.00	0.00	0.00	0.00
Fins					
0-Normal	0.94 (0.02)	0.10 (0.03)	0.21 (0.04)	0.91 (0.03)	0.87 (0.03)
1-Opaque	0.00	0.90 (0.03)	0.01 (0.01)	0.00	0.01 (0.01)
2-Frayed	0.06 (0.02)	0.00	0.77 (0.04)	0.03 (0.02)	0.11 (0.03)
3-Clubbed or Missing	0.00	0.00	0.01 (0.01)	0.06 (0.03)	0.01 (0.01)
Gills					
0-Normal	0.99 (0.01)	0.97 (0.02)	0.97 (0.02)	0.98 (0.02)	0.98 (0.01)
1-Pale	0.01 (0.01)	0.01 (0.01)	0.03 (0.02)	0.02 (0.02)	0.02 (0.01)
2-Marginate	0.00	0.01 (0.01)	0.00	0.00	0.00
3-Clubbed	0.00	0.01 (0.01)	0.00	0.00	0.00

Table 10. Continued.

	Yearling Chinook Salmon sampled				
	Lower Granite Dam	McNary Dam		Bonneville/John Day Dam	
Metric	Reference (N = 100)	Acoustic tag (N = 98)	PIT tag (N = 92)	Acoustic tag (N = 86)	PIT tag (N = 120)
Pseudobranchs					
0-Normal	1.00 (0)	0.99 (0.01)	1.00 (0)	1.00 (0)	1.00 (0.01)
1-Swollen	0.00	0.01 (0.01)	0.00	0.00	0.00
2-Lithic	0.00	0.00	0.00	0.00	0.00
3-Swollen and Lithic	0.00	0.00	0.00	0.00	0.00
4-Inflammed	0.00	0.00	0.00	0.00	0.00
Caecal fat					
0-None	0.19 (0.04)	0.85 (0.04)	0.81 (0.04)	0.73 (0.05)	0.71 (0.04)
1-Little, where less than 50% of caeca is covered	0.54 (0.05)	0.09 (0.03)	0.07 (0.03)	0.20 (0.04)	0.23 (0.04)
2-Normal, where 50% of caeca is covered	0.27 (0.04)	0.04 (0.02)	0.09 (0.03)	0.03 (0.02)	0.03 (0.02)
3-More than 50% of each caeca is covered	0.00	0.01 (0.01)	0.03 (0.02)	0.03 (0.02)	0.02 (0.01)
4-Excessive, where pyloric caeca are completely covered by large amount of fat	0.00	0.01 (0.01)	0.00	0.01 (0.01)	0.01 (0.01)
Mesenteric Fat					
0-No body fat present	0.16 (0.04)	0.80 (0.04)	0.79 (0.04)	0.71 (0.05)	0.71 (0.04)
1-Body fat less than diameter of caeca	0.00	0.11 (0.03)	0.08 (0.03)	0.19 (0.04)	0.23 (0.04)
2-Body fat equal in diameter to caeca	0.54 (0.05)	0.07 (0.03)	0.10 (0.03)	0.06 (0.03)	0.03 (0.02)
3-Body fat larger than diameter of caeca	0.30 (0.05)	0.02 (0.01)	0.03 (0.02)	0.02 (0.02)	0.02 (0.01)
4-Excessive fat, entire body cavity full of fat	0.00	0.00	0.00	0.02 (0.02)	0.01 (0.01)
Spleen					
0-Red	0.66 (0.05)	0.58 (0.05)	0.62 (0.05)	0.19 (0.04)	0.37 (0.04)
1-Black	0.00	0.25 (0.04)	0.27 (0.05)	0.74 (0.05)	0.56 (0.05)
2-Enlarged	0.34 (0.05)	0.17 (0.04)	0.10 (0.03)	0.07 (0.03)	0.07 (0.02)
3-Granular	0.00	0.00	0.01 (0.01)	0.00	0.00
4-Nodular	0.00	0.00	0.00	0.00	0.00
1,2-Black & Enlarged					

Table 10. Continued.

	Yearling Chinook Salmon sampled				
	Lower Granite Dam	McNary Dam		Bonneville/John Day Dam	
Metric	Reference (N = 100)	Acoustic tag (N = 98)	PIT tag (N = 92)	Acoustic tag (N = 86)	PIT tag (N = 120)
Food in stomach					
Absent	0.86 (0.03)	0.91 (0.03)	0.91 (0.03)	0.93 (0.03)	0.82 (0.03)
Present	0.14 (0.03)	0.09 (0.03)	0.09 (0.03)	0.07 (0.03)	0.18 (0.03)
Hind Gut					
0-No inflammation	1.00 (0)	0.96 (0.02)	0.93 (0.03)	1.00 (0)	0.97 (0.02)
1-Mild inflammation	0.00	0.04 (0.02)	0.07 (0.03)	0.00	0.03 (0.02)
2-Severe inflammation	0.00	0.00	0.00	0.00	0.00
Liver					
0-Normal; firm reddish brown color	0.84 (0.04)	0.84 (0.04)	0.86 (0.04)	0.78 (0.04)	0.79 (0.04)
1-Slight general discoloration	0.03 (0.02)	0.02 (0.01)	0.02 (0.02)	0.14 (0.04)	0.09 (0.03)
2-Pale	0.13 (0.03)	0.06 (0.02)	0.07 (0.03)	0.08 (0.03)	0.08 (0.03)
3-Fatty liver: coffee-cream color, greasy to touch	0.00	0.06 (0.02)	0.05 (0.02)	0.00	0.03 (0.01)
4-Nodules in liver	0.00	0.00	0.00	0.00	0.01 (0.01)
5-Focal discoloration	0.00	0.02 (0.01)	0.00	0.00	0.00
Gall Bladder					
0-Yellow or straw color; bladder empty or partially full	0.00	0.22 (0.04)	0.14 (0.04)	0.09 (0.03)	0.05 (0.02)
1-Yellow or straw color; bladder full, distended	0.02 (0.01)	0.13 (0.03)	0.19 (0.04)	0.12 (0.03)	0.15 (0.03)
2-light green to "grass" green	0.98 (0.01)	0.44 (0.05)	0.56 (0.05)	0.58 (0.05)	0.65 (0.04)
3-Dark green to dark blue-green	0.00	0.21 (0.04)	0.11 (0.03)	0.21 (0.04)	0.15 (0.03)
Kidney					
0-Normal	1.00 (0)	1.00 (0)	1.00 (0)	0.99 (0.01)	0.99 (0.01)
1-Pale	0.00	0.00	0.00	0.00	0.01 (0.01)
2-Swollen	0.00	0.00	0.00	0.00	0.00
3-Mottled	0.00	0.00	0.00	0.01 (0.01)	0.00
4-Granular	0.00	0.00	0.00	0.00	0.00

Twenty-seven percent of reference fish at Lower Granite had normal caecal fat, with the remaining reference fish described as having little or no caecal fat. In comparison, only 6% of the JSATS-tagged and 12% of the PIT-tagged fish collected at McNary Dam were described as having a normal (or greater than normal) amount of fat deposition in the caeca. At Bonneville/John Day Dam, 7% of JSATS-tagged and 6% of PIT-tagged fish were described as having a normal (or greater than normal) amount of fat deposition in the caeca. Eighty-four percent of reference fish had a fat deposition larger than the caeca within the mesentery. In contrast, 9% of JSATS-tagged and 13% of PIT-tagged fish at McNary Dam, as well as 8% of JSATS-tagged and 5% of PIT-tagged fish recaptured at Bonneville/John Day were described as having fat deposition larger than the caeca. There were no significant differences between JSATS- and PIT-tagged fish with respect to either caecal or mesenteric fat deposition.

Thirty-four percent of reference fish were described as having enlarged spleens compared to 17% of JSATS-tagged and 11% of PIT-tagged fish at McNary Dam. Seven percent of both the JSATS- and PIT-tagged fish collected at Bonneville/John Day were described as having enlarged spleens. The difference in splenic enlargement between treatments at McNary was not statistically significant. Food was present in the stomachs of 14% of reference fish sampled at Lower Granite Dam, and of 9% of both PIT- and JSATS-tagged fish at McNary Dam. At Bonneville/John Day Dam, PIT-tagged fish (18%) were described as having food in their stomachs more often than the JSATS-tagged fish (7%). The difference was significant ($P = 0.038$). The percent of livers described as normal was similar for all treatments between Lower Granite Dam and McNary Dam (84, 84, and 86% respectively for reference, JSATS-tagged, and PIT-tagged fish). At Bonneville/John Day Dam, 78% of JSATS-tagged and 79% of PIT-tagged fish were described as having normal livers.

As in 2007, the yearling Chinook salmon sampled as reference fish at Lower Granite Dam appeared healthy, and few abnormalities were noted on gross necropsy. In general, and similar to results from these examinations in 2007, the overall nutritional condition of both JSATS-tagged and PIT-tagged fish was inferior to that of reference fish. In addition, in 2008, there was some evidence that fish had been injured between release and collection at McNary Dam (13% of JSATS-tagged fish had hemorrhagic eyes, and high proportions of both PIT-tagged and JSATS-tagged fish (79 and 90%, respectively), were described as having opaque, frayed or missing fins.

These rates of injury were in sharp contrast to those of fish collected upstream at Lower Granite Dam, as well as to those collected further downstream at Bonneville/John Day Dam. Therefore, it is likely that something within the SbyC collection system at McNary was contributing to these abnormalities. In 2007, we saw a similar, though less extensive phenomenon at McNary Dam: approximately one-third of the tag-treatment fish were described as having fin abnormalities. Prevalence was 33% for JSATS-tagged and 26% for PIT-tagged fish, compared to <10% for reference fish and fish collected downstream at Bonneville/John Day Dam.

There are other possible explanations for the apparent difference in injury rates between fish subsampled at McNary Dam and reference fish or fish subsampled at Bonneville/John Day Dam. One possibility is that our reference sample at Lower Granite Dam was not representative of the tag-treatment groups due to small sample size, and that fin abnormalities were actually more common in fish collected and tagged at Lower Granite Dam than what we observed. Following this line of reasoning, attrition of affected fish may have occurred somewhere between McNary and Bonneville Dam. Similarly, fin regeneration could have occurred in affected fish between McNary and Bonneville Dam although this alternative is less likely due to the relatively short travel time of ~3.4 d between the two sites.

In 2008, 27% of reference fish at Lower Granite Dam were described as having normal caecal fat, and 84% were described as having fat deposition in the mesentery greater than or equal to the diameter of the caeca. In comparison, reference fish collected in 2007 were described as having slightly less lipid (e.g. 20% described as having normal caecal fat, and 10% with lipid deposits at least as thick as the diameter of the caeca), indicating that fish condition at tagging may have been better in 2008.

Similar to the trend observed in 2007, study fish appeared to rely on lipid reserves to fuel their downstream migration. Only 6% of the JSATS-tagged fish and 12% of the PIT-tagged fish collected at McNary Dam were described as having normal caecal fat deposits. Only 9 and 13%, respectively, of JSATS-tagged and PIT-tagged fish were described as having mesenteric fat deposits at least as large as the diameter of the caeca. These lipid levels were slightly higher than those observed in 2007, and were similar between tag treatments.

In the 2007 study, fish collected at Bonneville Dam were described as having more fat deposition than those collected upstream at McNary Dam. Possible explanations for these differences included attrition of fish that had failed to forage successfully, more favorable environmental conditions in the Columbia than in the Snake River, and hatchery fish transitioning to a more natural diet as they migrated seaward. However, this pattern was not observed again in 2008. Fish collected at Bonneville/John Day in 2008 were less frequently described in the "none" categories for both caecal and mesenteric fat than those collected at McNary Dam. However, the former were also less frequently described as having normal or greater-than-normal amounts of fat than their cohorts collected downstream.

Overall, very little difference in lipid deposition was observed between fish collected at the two locations. The differences observed in 2008 were more likely due to slight differences in scoring technique among examination sites than to Bonneville fish being more fit. Also of note is that a portion of the SbyC fish collected for the downstream examinations in 2008 were removed at John Day (~112 km upstream from Bonneville Dam), so these fish had actually travelled shorter distances than fish evaluated from the 2007 lower river subsamples.

Histopathological Evaluation—Table 11 shows results from the comparative histopathological analysis for yearling Chinook salmon by tag treatment (JSATS and PIT) at McNary and Bonneville/John Day Dams. Reference fish were generally healthy, indicating no systematic bias to between-treatment comparisons.

For fish recaptured at McNary Dam, comparative analysis showed significant differences between tag treatments in 6 of the 49 histopathological metrics evaluated. For fish recaptured at Bonneville/John Day Dam, these analyses showed significant differences between tag treatments in 11 of 49 metrics. Differences fell into four general categories of nutritional condition, peritoneal inflammation, infectious agents, and incision (JSATS) or injection site (PIT) healing (Table 11).

Differences in nutritional indicators were of mixed direction among treatments. The amount of mesenteric adipose was rated higher in JSATS-tagged than PIT-tagged fish at McNary Dam ($P = 0.003$), as were pancreatic zymogen granules (packets of digestive enzymes) at Bonneville/John Day Dam ($P = 0.035$). However, lower intestinal mucosal glycogen was rated higher in PIT-tagged fish at McNary Dam, and the difference was significant ($P = 0.004$).

When significant differences were observed in metrics indicating peritoneal inflammation, the scores were consistently higher (indicating more or greater inflammation) in JSATS-tagged than PIT-tagged fish. For both McNary and Bonneville/John Day recapture groups, inflammation within the mesentery was observed more often ($P < 0.001$), and when observed was rated as severe more often ($P < 0.001$) in JSATS than in PIT-tagged fish; differences were significant at both dams. Evidence of chronic peritonitis was also higher in JSATS-tagged than PIT-tagged fish at Bonneville/John Day Dam, and the difference between treatments was significant ($P = 0.001$).

In examining metrics of infectious indicators/agents, we found that all situations in which gastrointestinal trematode parasites were present were relatively minor, and there were no cases of significant host response (i.e. pathogenicity) associated with these parasites. A greater number of PIT-tagged fish had digenetic trematodes in the lower intestine at Bonneville/John Day Dam, and the difference was significant ($P = 0.047$).

Table 11. Results of comparative histopathology analysis by tag treatment (JSATS vs. PIT) for yearling Chinook salmon subsampled at McNary and Bonneville/John Day Dam. NSD indicates no significant difference; light shading indicates a significant difference ($\alpha = 0.05$); darker shading indicates a difference that approaches significance (*P* between 0.05 and 0.10), NO indicates not observed.

	Tag treatment (JSATS vs. PIT)			
	McNary Dam		Bonneville/John Day Dam	
	Higher prevalence/severity or amount	*P*	Higher prevalence/severity or amount	*P*
Nutritional Indicators				
Liver vacuolation	NO		NO	
Pancreatic zymogen	NSD		JSATS	0.035
Pancreatic atrophy	NO		NO	
Mesenteric adipose	JSATS	0.003	NSD	
pyloric caecae mucosal glycogen	NSD		NSD	
Small intestinal digesta presence	NSD		NSD	
Lower intestinal mucosal glycogen	PIT	0.004		
Lower intestinal digesta presence	NSD		NSD	
Liver hydropic vacuolation[a]	NSD		NSD	
Inflammatory Indicators				
Pancreatic inflammation	NO		NO	
Small intestinal inflammation	NO		NO	
Lower intestinal inflammation	NO		NSD	
Heart epi/myocarditis	NO		NO	
Spleen congestion	NSD		NSD	
Spleen lymphoid depletion	NO		NO	
Spleen fibrosis	NSD		NSD	
Mesenteric chronic inflammation	JSATS	0.001	JSATS	0.001
Mesenteric chronic inflammation severity	JSATS	<0.001	JSATS	<0.001
Peritonitis, chronic	NSD		JSATS	0.001
Degenerative Indicators				
Gill microaneurysms	NSD		NSD	
Liver coagulative necrosis	NO		NO	
Liver eosinophilic hypertrophy	NSD		NSD	
Kidney tubule epithelial necrosis	NO		NO	
Infectious Indicators/agents				
Liver lymphocytic infiltrates	NSD		NSD	
Liver BKD lesions	NO		NO	
Liver Ceratomyxa lesions	NO		NO	
Small intestinal digenetic trematodes	NO		NO	
Small intestinal Ceratomyxa	NO		NO	
Lower intestinal digenetic trematodes	NSD		PIT	0.047

Table 11. Continued.

	Tag treatment (Acoustic vs. PIT)			
	McNary Dam		Bonneville/John Day Dam	
	Higher prevalence/severity or amount	*P*	Higher prevalence/severity or amount	*P*
Infectious indicators/agents (continued)				
Kidney BKD lesions	NO		NO	
Kidney tubule Myxosporea	NO		NO	
Gill amoebiasis	JSATS	0.059	NSD	
Respiratory epithelial hyperplasia (REH)	NSD		NSD	
Coincidence of gill amoebiasis and REH	NSD		NSD	
Pylocric cecae digenetic trematodes	NSD		NSD	
Incision/injection site healing				
Incision closure	NSD		NSD	
Skin stratum compactum reknit	NSD[b]		NSD[b]	
Incision chronic inflammation	NSD		NSD	
Incision chronic inflammation severity	NSD		JSATS	0.059
Dermal muscular necrosis	NSD		NSD	
Dermal hemorrhage/fibrin	NSD		NSD	
Incision, poor apposition	NSD		JSATS	0.006
Incision, adhesions	NSD		JSATS	0.063
Internal organ evulsion via incision and presence of Saprolegnia	NSD[c]		ND	
Incision not visible	PIT	0.001	PIT	0.001
epidermis retracted	NSD		JSATS	0.015
Miscellaneous Indicators				
Kidney tubule HYDVAC	ND		ND	
Small intestinal mucosal glycogen	NSD		NSD	
Spleen macrophage aggregates	NSD		NSD	

[a] Can indicate inadequate diet in some mammals; unknown relation to diet in salmonids

[b] Detected in only 1 PIT-tagged and 1 JSATS-tagged fish at McNary and in 2 PIT-tagged fish at Bonneville/John Day Dam

[c] Organ evulsion detected in 1 JSATS-tagged fish only.

A greater number of JSATS-tagged than PIT-tagged fish had gill amoebiasis at McNary Dam. The difference between treatment groups approached significance ($P = 0.059$). In observations of gill amoebiasis, the majority of cases were minor, with no visible host response or pathogenicity. However, the few cases of mild-to-moderate or severe gill amoebiasis were directly associated with at least a mild case of respiratory epithelial hyperplasia. Although the overall prevalence of this association appeared to increase as study fish moved downstream, ranging from a low of 2% at Lower Granite (both tag types) to a high of 19% at Bonneville/John Day Dam (11% PIT; 19% JSATS), differences among individual treatment groups were not statistically significant at any recapture site.

In the 2007 yearling Chinook salmon, internal indicators of inflammation and/or infection (discoloration in the liver and kidneys) and stress (splenic enlargement) were grossly visible in fish from both treatment at recapture. Furthermore, inflammatory lesions in the kidney and liver were more prevalent in fish recaptured at Bonneville than at McNary Dam, suggesting that as they moved downriver, affected fish from both tag treatments may have been responding to the implants or to previously latent or newly acquired pathogens and parasites. Notably, liver abnormalities were more prevalent in JSATS-tagged fish recaptured at both downstream sites, and splenic enlargement was more prevalent in JSATS-tagged than PIT-tagged fish recaptured at Bonneville Dam.

In contrast, in 2008, there was no evidence of hepatic or renal response to pathogens or irritants as fish from either tag treatment group moved downstream. Overall, very little histological or gross evidence of inflammation within either the liver or kidney was observed in any study fish. Furthermore, gross evidence of splenic enlargement was more prevalent in reference fish collected at Lower Granite Dam than in either of the tag treatment groups recaptured at McNary or Bonneville/John Day Dam.

For fish recaptured at McNary Dam, gross and histological examination both showed that liver abnormalities were equally prevalent in fish from both tag treatments and were similar to those reported for the reference fish. At Bonneville Dam, although the prevalence of liver abnormalities on gross examination was slightly higher than at McNary, there were no differences between tag treatment groups on either gross or histological examination. Similarly, for fish recaptured from all downstream sites, nearly all (>99%) of the kidneys examined during gross necropsy were described as normal, and there were no significant differences among tag treatment groups in the renal tissues that were evaluated during histological examinations.

Although there was no evidence in 2008 that study fish were mounting inflammatory responses within major organs, there was evidence that JSATS-tagged fish in particular were reacting either to the implants or to infectious agents or foreign bodies introduced during the tagging surgery. Inflammation within the mesentery was observed more often in JSATS- than in PIT-tagged fish, and significant differences were seen at all dams ($P = 0.001$). When present, inflammation within the mesentery was rated as more severe in JSATS- than in PIT-tagged fish, and significant differences were seen at all dams ($P = 0.001$). Evidence of chronic peritonitis was higher in JSATS- than PIT-tagged fish recaptured at Bonneville and John Day Dam, and the difference was significant ($P = 0.001$).

Similar to 2007, peritonitis was evaluated locally, at the site of the incision, and may have been a primary reaction to the tag. Although copious bacteria were not observed in the tissue sections examined, tissue reactivity may have been elicited by a secondary infection introduced either during the surgical procedure or post-operatively through the incision site. Either type of tag itself could have introduced bacteria directly into the peritoneal cavity as well. When present, chronic inflammation of the incision/injection site was rated more severe in JSATS- than PIT-tagged fish at Bonneville Dam, and the difference approached significance ($P = 0.059$). At Bonneville and John Day Dam, and incision adhesions were present more often in JSATS- than PIT-tagged fish, and the difference approached significance ($P = 0.063$).

Overall, incisions appeared more healed (not visible) in PIT- than JSATS-tagged fish from both the McNary and Bonneville/John Day recapture groups ($P = 0.001$). This would be expected based on the less invasive and traumatic nature of tag injection as compared to surgical implant. Poor apposition was described more often in JSATS-tagged than PIT-tagged fish recaptured at Bonneville/John Day Dam ($P = 0.006$). Similarly, the epidermis was rated as retracted more often in JSATS-tagged than PIT-tagged fish from these recapture groups ($P = 0.015$), as also would be expected based on the more invasive surgical implant procedure. When present, chronic inflammation of the incision was rated as more severe ($P = 0.059$; approaching significance), and incision adhesions were present more often ($P = 0.063$) in JSATS- vs. PIT-tagged fish recaptured at Bonneville/John Day Dam.

Poor or uneven apposition of the two sides of the incision would increase the vulnerability of surgically tagged fish to secondary infections by exposing the underlying dermal tissue to river water, which can be teeming with bacteria and fungi. Overall, and similar to the 2007 study results, these results suggest that PIT-tag injection sites healed cleaner and faster than the surgery incisions, and that a component of the JSATS tag effect that was observed inriver may have been related to this difference.

Prevalence of *Renibacterium salmoninarum*—Estimated Rs antigen levels in hatchery Chinook salmon, as measured by ELISA, ranged from 0.065 to 0.335 (with one outlier at 1.11) for fish sampled at Lower Granite Dam prior to tagging. Rs antigen was considered low in all but two fish from this group. ELISA values ranged from 0.069 to 0.289 for fish recaptured at McNary Dam, and from 0.076 to 0.540 for fish recaptured at Bonneville Dam. In fish recaptured at McNary Dam, ELISA values for all but two fish (1 JSATS- and 1 PIT-tag) were considered low; therefore, no statistical analyses were conducted to evaluate differences between treatments at this location. At Bonneville/John Day Dam, 13% of JSATS-tagged and 11% of PIT-tagged fish had moderate ELISA values. However, the difference was not statistically significant ($P = 0.830$), and the majority of fish from both groups had low levels of the Rs antigen (87% of JSATS-tagged and 89% of PIT-tagged fish).

EXTENDED HOLDING OF ACOUSTIC- AND PIT-TAGGED CHINOOK SALMON JUVENILES

Methods

Fish Collection and Tagging

Yearling Chinook Salmon—For extended holding evaluations, we used the same river-run, hatchery yearling Chinook salmon smolts collected at Lower Granite Dam for evaluations of migration behavior and survival. Yearling Chinook allocated for long-term holding and observation were subsampled from migration study fish after tagging. Methods for collection, handling, and tagging of these fish are detailed in this report (*Evaluation of Acoustic Tags in Migrating Juvenile Chinook Salmon*).

For extended holding at Bonneville Dam, subsamples of 160 fish each were obtained from each of the 10 yearling Chinook release groups, for a total of ~1,600 fish. From each subsample of 160, approximately 40 fish were surgically implanted with both a JSATS and PIT tag, 40 were injected with a PIT tag, 40 were surgically implanted with a PIT tag, and 40 were reserved as reference fish, for a total of ~400 fish per treatment group. Reference fish were anesthetized and handled in the same manner as acoustic-tagged fish; however, no incision, suture, or tag was placed in these fish.

Subyearling Chinook Salmon—River-run hatchery and wild subyearling Chinook salmon were collected from the smolt collection facility at Lower Granite Dam from 2 June to 9 July 2008 (Figure 12). Due to the high mortality of subyearling Chinook study fish in summer 2007, we did not collect subyearlings for tag evaluation in migrating fish during 2008. However, subyearling Chinook were sampled and tagged on 10 dates during 2008 for long-term holding and observation at Bonneville Dam. Approximately 1,840 subyearling Chinook salmon were sampled and treated for the long-term holding portion of this study. The temperature during tagging at Lower Granite Dam ranged from ~11 to 17°C for the subyearling portion of the study.

For the extended holding experiments, the 10 subyearling Chinook replicates totaled 405 reference, 403 JSATS , 408 injected PIT, 400 surgical PIT, and 240 single-battery JSATS treatment fish (Table 12).

Table 12. Number and mean fork length of subyearling Chinook tagged with a standard JSATS or single-battery JSATS transmitter or with a surgically implanted or injected PIT tag at Lower Granite Dam in 2008. After tagging, fish were transported, along with a reference group, to Bonneville Dam for long-term holding and observation.

		Treatment allocation of subyearling Chinook salmon collected for extended holding														
		Standard double-battery JSATS*			Single-battery JSATS*			Surgically implanted PIT			Injected PIT			Reference		
			Fork length			Fork length			Fork length			Fork length			Fork length	
Replicate	Date tagged	N	(mm)	SD	N	(mm)	SD	N	(mm)	SD	N	(mm)	SD	N	(mm)	SD
11	3 Jun	40	109.5	4.7				40	110.3	5.1	40	105.5	5.7	42	110.3	5.5
12	5 Jun	40	107.0	5.8				40	105.7	4.7	40	105.9	4.0	40	106.7	5.9
13	10 Jun	40	110.0	6.8				40	107.3	6.4	40	109.0	5.5	40	109.5	4.8
14	12 Jun	40	114.7	5.4				40	115.1	4.8	41	109.5	4.3	40	115	4.6
15	18 Jun	40	118.6	4.6	40	119.5	5.8	40	121.1	5.6	40	114.9	5.8	40	119.8	6.5
16	20 Jun	40	109.8	6.9	40	110.4	4.8	40	109.6	6.5	41	112.8	5.0	40	111.6	7
17	25 Jun	40	110.0	7.5	40	111.1	7.9	40	110.7	7.5	40	116.1	6.6	42	108.6	7.5
18	27 Jun	41	105.5	5.9	40	108.4	6.2	40	105.5	6.8	45	110.2	10.0	40	106.5	8
19	1 Jul	42	110.3	7.0	40	108.2	7.3	40	109.7	7.7	42	111.8	7.7	40	109.5	9.2
20	10 Jul	40	109.1	5.9	40	109.5	6.1	40	108.7	4.8	39	111.3	6.0	41	109	5.7
Total or mean		403	110.4	7.0	240	111.1	7.5	400	110.3	7.5	408	110.7	7.1	405	110.6	7.6
Avg tag burden (%)			4			2.8			0.8			0.7				

* Fish implanted with a secondary tag (PIT tag)

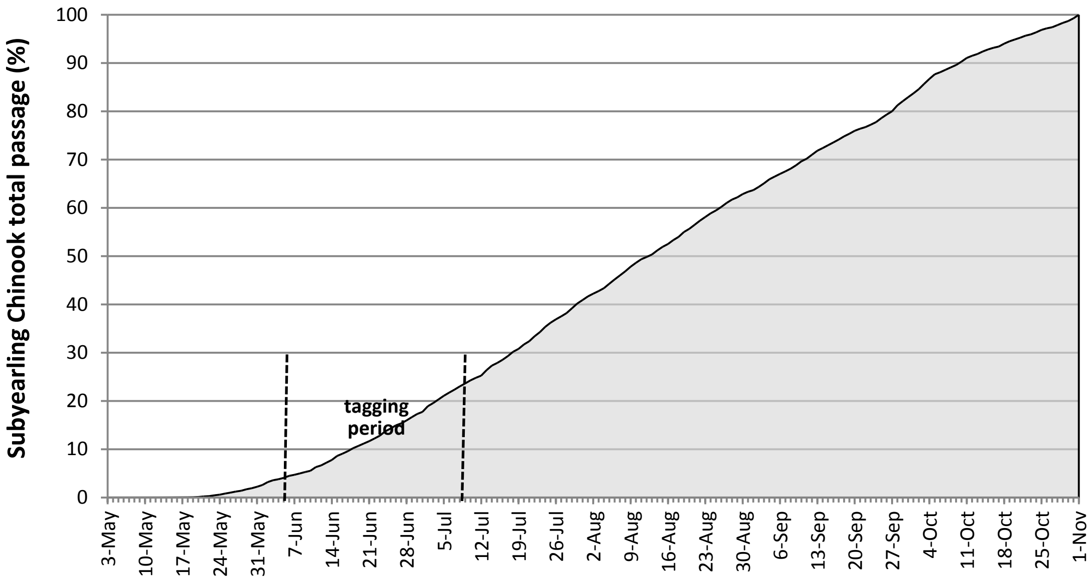


Figure 12. Cumulative passage distribution of subyearling Chinook salmon at Lower Granite Dam. Area between dotted lines indicates tagging period, 2 June to 9 July 2008.

Size-frequency distributions of subyearling Chinook in all tag treatment groups were similar to those of the run at large based on SMP samples (Figure 13). Mean fork length was similar between tag treatment groups and the SMP sample on most individual release days (Figure 8).

Acoustic-tagged (double-battery) subyearling Chinook had a mean fork length of 110.4 mm (range 95-131 mm), and a mean mass of 12.9 g (range 8.0-23.1 g; Table 12). These fish experienced a mean tag burden of 4% (range 2.3-6.5%) from the combined presence of the acoustic transmitter and PIT tag, and a mean tag burden of 3.3% from the JSATS tag alone (range 1.8-5.3%). For subyearlings implanted with both a single-battery JSATS tag and PIT-tag, mean fork length was 111.1 mm and mean weight was 13.4 g. These fish experienced a mean tag burden of 2.8% from the combined presence of the acoustic transmitter and PIT tag, and a mean tag burden of 2.0% from JSATS tag alone.

For fish injected with a PIT tag, mean fork length was 110.7 mm, mean weight was 14.0 g (range 5.3-28.2 g), and mean tag burden was 0.7% (Table 12). For the surgically PIT-tagged group, mean fork length was 110.3 mm, mean weight was 12.6 g (range 8-25.1 g), and mean tag burden was 0.8%. Mean fork length for the reference group was 110.6 mm, and mean weight was 13.4 g (range 8.0-31.2 g).

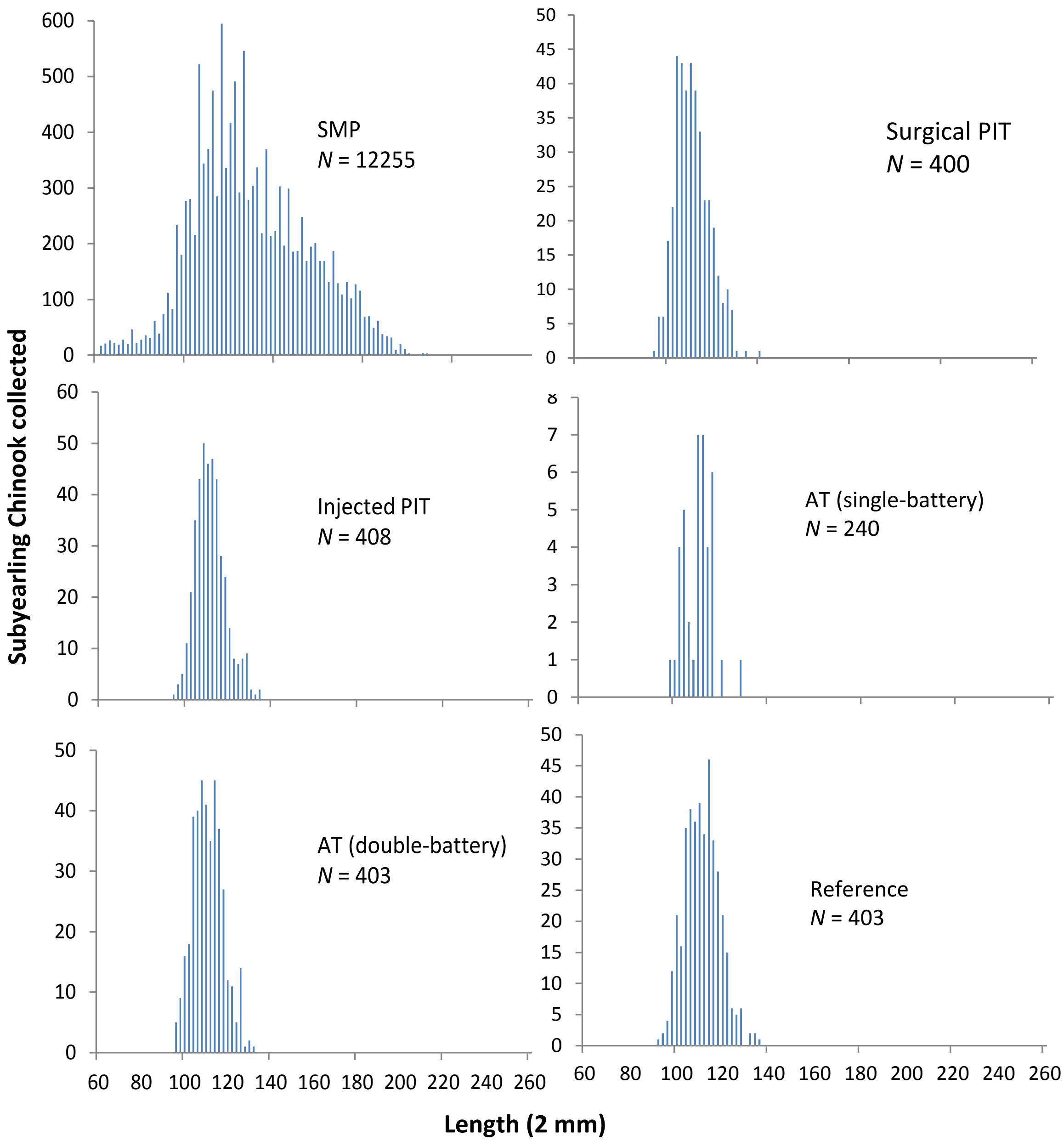


Figure 13. Length-frequency histograms (2-mm bins) comparing fork lengths of subyearling Chinook salmon from the SMP sample to fish surgically implanted with a standard JSATS or single-battery JSATS and a PIT tag, fish injected with a PIT tag, and reference fish. Fish were tagged at Lower Granite Dam in 2008, and transported to the JMF at Bonneville Dam for long-term observation. SMP data provided by the Fish Passage Center.

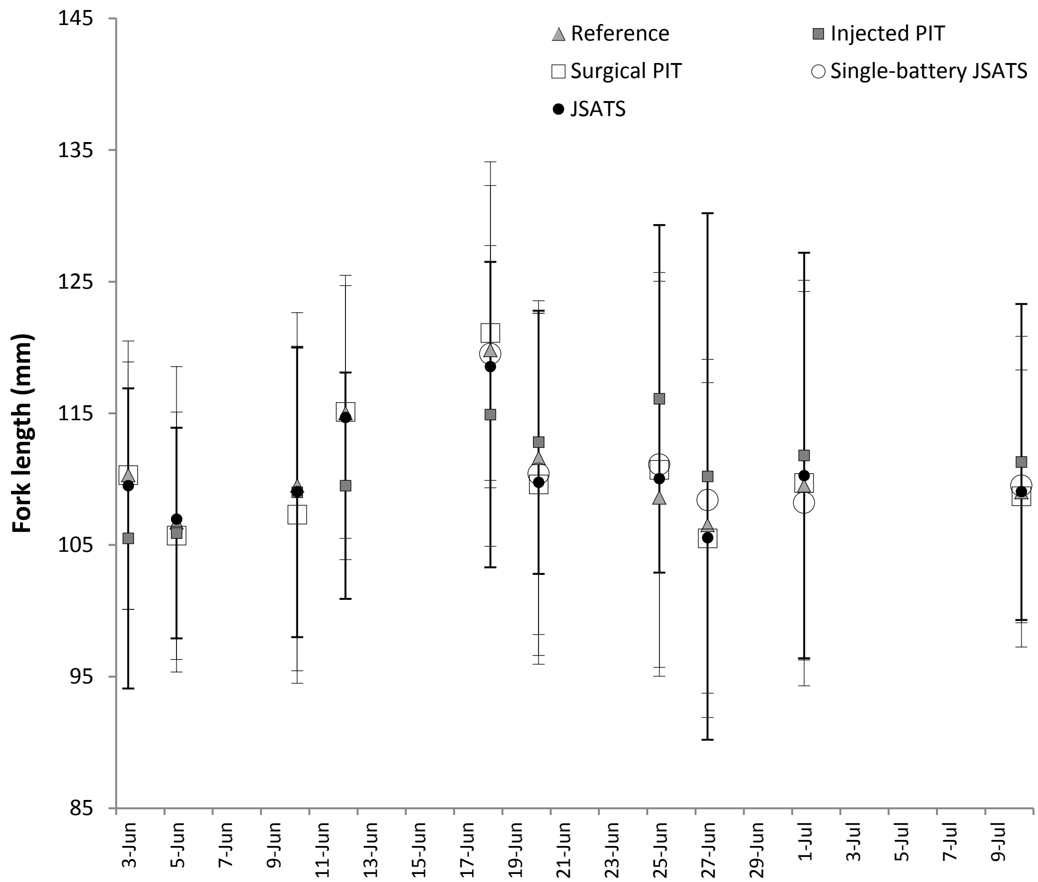


Figure 14. Mean fork length of subyearling Chinook salmon treated with a standard JSATS or a single-battery JSATS tag, injected and surgically implanted PIT tags, and those reserved as reference fish (whiskers indicate 2 SDs). All fish were sampled by the SMP at Lower Granite Dam in 2008.

Similar to the yearling Chinook, subyearling Chinook salmon were implanted with JSATS acoustic transmitter tags manufactured by Advanced Telemetry Systems, Inc. (Isanti, MN). Average tag dimensions (± SD) and subsequent tag burden experienced by subyearling fish are shown in Table 13, with PIT-tag dimensions for comparison. Aspects of the tag signal were similar to those described above for JSATS transmitters implanted in yearling Chinook salmon. Tags were activated 1-2 d prior to tagging by placement in an electromagnetic activation dish.

Subyearling groups were allocated for tag treatment in the same manner as yearling treatment groups, except for the addition of groups tagged with a single-battery JSATS tags. Single-battery JSATS transmitters were similar in length and width to the standard JSATS tag, but were approximately one-half the thickness at the wider end and weighed only 0.27 g in air. Single-battery JSATS transmitters were not available from the manufacturer until later in the study period. Therefore, they were not used in replicates 1-5 but only in replicates 6-10. Thus, the later replicates had 40 fish injected with a PIT tag, 40 surgically implanted with a PIT tag (using the same surgical procedure used for acoustic tag implantation), 40 surgically implanted with a standard JSATS tag, 40 surgically implanted with single-battery JSATS tag, and 40 reserved as reference fish. Reference fish were anesthetized and handled in the same manner as acoustic-tagged fish except that no incision, suture, or tag was placed in these fish.

Table 13. Dimensions of the JSATS acoustic tag implanted into subyearling Chinook salmon in 2007 and 2008 and of the TX-1411SST (SST) PIT tag (used in both years). Tag burden for 2008 is mean from extended holding fish. Mean for 2007 includes both migrating and extended holding fish.

	JSATS tag		
Mean	2007	2008	SST PIT tag
Length (mm)	15.8	12.0	12.48
Height (mm)	4.2	3.5	
Width (mm)	5.6	5.3	
Weight in air (g)	0.61	0.42	0.102
Mean mass in water (g)	0.37	0.3	
Mean volume (mL)	0.22	0.14	
Diameter (mm)			2.07
Mean tag burden*	5.6	3.3	0.8
(range)	(1.7-11.3)	(1.8-5.3)	(0.4-1.3)

* Defined as tag weight/fish body weight.

Transport and Tissue Sampling

Following tagging, all fish were held in one of two 75-L (19.8 gal) stainless steel holding tanks supplied with flow-through river water for 12-24 h. At the end of the holding period, fish were transferred (water-to-water) to a 1,817-L (480 gal) trailer tank containing saline river water (10 ppt) and transported by truck to the juvenile monitoring facility at Bonneville Dam Second Powerhouse. Mean transport time was 6 h, 14 min.

During individual transports, we added jugs containing frozen river water to the transport tank in an attempt to keep water temperatures within 1°C of the temperature at departure. For yearling Chinook, transport temperatures were 8-9°C for replicate 1, and were maintained at 10°C and 11°C respectfully for replicates 2-9 and 10 (Table 14). For subyearling Chinook replicates 1-4, transport temperatures were maintained within 1°C of the temperature at departure from Lower Granite Dam and did not exceed 13°C. However, for subyearling replicates 15, 17, and 18, temperatures varied from 3 to 5°C above the temperature at departure, despite the use of ice during transport, (Table 14). Water temperatures were maintained within 1°C for replicates 16, 19, and 20.

Upon arrival at the Bonneville facility, fish were transferred (water-to-water) to 1,893-L (500 gal) circular tanks and held by transport group (e.g., 160 fish per tank in spring and 160-200 fish per tank in summer). In an attempt to mimic the physical conditions experienced by migrating fish, the circular tanks were maintained with flow-through river water at ambient temperature for 14 d. Temperature at entry to the circular tanks varied 9.1-13.1°C for yearling replicates and 13.2-18.6°C for subyearling replicates (Table 14).

Table 14. Temperatures during post-tagging recovery at Lower Granite Dam, transport, and upon entry to holding tanks at Bonneville Dam for yearling and subyearling Chinook salmon tagged with JSATS acoustic and PIT tags for laboratory holding evaluations, 2008.

		Mean temperature (°C)		
Replicate	Date of Collection	Lower Granite Dam (°C)	Maximum during transport	Bonneville Dam holding tanks
		Yearling Chinook		
1	24 Apr	8	9	9
2	29 Apr	10	10	10
3	1 May	10	10	10
4	3 May	10	10	11
5	6 May	10	10	11
6	8 May	10	10	11
7	10 May	10	10	12
8	13 May	10	10	12
9	15 May	10	10	12
10	17 May	10	11	13
		Subyearling Chinook		
11	3 Jun	12	13	13
12	5 Jun	11	11	14
13	10 Jun	11	12	13
14	12 Jun	11	12	13
15	18 Jun	14	17	15
16	20 Jun	14	15	16
17	25 Jun	14	17	16
18	27 Jun	14	19	17
19	1 Jul	16	17	18
20	10 Jul	17	17	19

Overall, freshwater temperature varied from 8.8 to 13.4°C during the yearling period of the study, and from 12.9 to 19.7°C during subyearling period. During both periods, temperatures followed a temporal trend from low to high (Figure 2). For all replicates, study tanks were converted to a closed artificial seawater system (to mimic ocean conditions) on holding day 15, and this system was maintained through the remainder of the 120-d holding period. Seawater holding temperature ranged from 11.1 to 13.3°C throughout both seasons and did not vary by more than 1°C within a 24-h period.

The timing of transfer to seawater was based primarily on yearling travel times (Hockersmith et al. 2007). For all yearling Chinook salmon replicates in 2008, combined average median travel time from Lower Granite to Bonneville Dam was 13.6 d (range 9-21 d) for JSATS-tagged fish and 13.3 d (range 9-21 d) for PIT-tagged fish. For yearling Chinook detected in the estuary pair trawl in 2008, average median travel time to the lower river (rkm 61-83) was 16.1 d (12-21.7 d) for JSATS-tagged fish and 15 d (10.7-22.5 d) for PIT-tagged fish. For subyearling Chinook, travel time during the summer migration varies considerably (Connor et al. 2005). However, we also transferred these groups to seawater at 15 d holding for comparison purposes. For subyearling Chinook released at Lower Granite Dam in 2007, median travel time to Bonneville Dam was 24.1 d for JSATS-tagged and 15.5 d for PIT-tagged groups (Wargo-Rub et al. 2009).

During the 120-d holding period, fish were fed ad libitum a diet consisting of a mixture of appropriately sized *BioDiet Grower*, a semi-moist pelleted commercial fish food (Bio-Oregon). Waste food and fish excrement were removed from holding tanks on a continuous basis by self-cleaning flow within the tanks. Tanks were monitored for dropped tags and mortalities at least twice daily.

After 120 d of holding and observation, surviving fish were humanely euthanized with an overdose of MS-222 (UFR Committee 2004) and weighed and measured. Gross necropsies were performed following the methods outlined by Noga (2000) to evaluate gross tissue response to tagging, such as tag encapsulation. Kidney tissue was collected from each laboratory fish and placed in individually labeled sample bags (Nasco Whirlpak, 2 oz, #B01064). These samples were frozen and transported on ice for analysis to labs at the Northwest Fisheries Science Center, Seattle, WA,. Kidney samples were processed and Rs antigen levels determined for each fish in the same manner described above for migrating fish recaptured for necropsy and histological exam. Coded-wire tags were collected from the snouts of individual fish when present, and their respective codes were recorded in a database for future reference.

Data Analysis

We recorded the day of each mortality in each treatment group, and computed the empirical survivor functions through 120 d. We tested for differences in laboratory survival estimates from 0 to 14 d, from 14 to 28 d, and from 28 to 120 d post-treatment. Day 14 corresponded with the end of the freshwater holding phase, while day 28 was included to identify residual mortality from handling or tagging that may have been obscured by background mortality at 120 d.

A two-factor ANOVA was conducted, with replicate release date as a random factor and tag treatment as a fixed factor. Mean growth in mm (yearling and subyearling Chinook) and mean weight gain in g (subyearling Chinook) were calculated by replicate for JSATS- and PIT-tagged fish that survived 120-d holding. Paired *t*-tests were used to compare differences between treatments and across replicates. In separate and conditionally independent analyses, mean survival between day 0 and day 14, mean survival between day 14 and day 28, and mean survival between day 28 and day 120 were compared among treatment groups using Fisher's LSD.

Paired *t*-tests were also used to compare differences in Rs antigen levels between treatments and across replicates. Levels of post-mortem Rs antigen were compared among treatment groups both for fish that died prematurely and for those that survived the entire 120-d holding period. Comparisons of Rs antigen levels followed the methods described for migrating fish recaptured for necropsy and histological exam.

Differences in the percentage of PIT tags lost between tag treatments (JSATS vs. PIT) for spring and summer groups were evaluated statistically using chi-square tests. Both acoustic and PIT-tag losses were determined at the time of necropsy. Tag loss was compared only for fish that survived to the end of the holding period because for those that died earlier, it was not always possible to determine whether tag loss had occurred pre- or post-mortem. Due to the small number of tags recovered from the bottom of holding tanks, it was not possible to determine the timing of tag loss. Missing tags could have been dropped through an open wound or could have been actively expelled through the body wall.

Results and Discussion

Yearling Chinook Salmon

Survival—Yearling Chinook salmon in all tag treatments exhibited a decline in survival over time throughout the 120-d holding period (Figure 15; Table 15). For all treatments (reference, JSATS, surgical PIT, and injected PIT), the slope of the survival curve became more gradual after fish were transferred to seawater on day 15. Mortality began to accelerate again after ~56 d of holding and then increased steadily through 120 d for all treatments. Survival was similar among groups through the first 15 d of observation, but afterwards and for the remainder of the study period, the survival function for the injected PIT-tag group remained higher than either the JSATS, surgical PIT, or reference group. Also, the reference and surgical JSATS-tag groups had higher survival than the surgically PIT-tagged group. Differences in survival functions observed at day 28 and at day 120 were largely determined by mortality in the first 14 days, as estimated survival for the sub-intervals 14-28 and 28-120 varied less among the tag treatment groups than for the first 14 days (Table 15). However, no differences we tested for were statistically significant (P = 0.333, 0.282, and 0.947 for 0-14, 14-28, and 28-120 d, respectively).

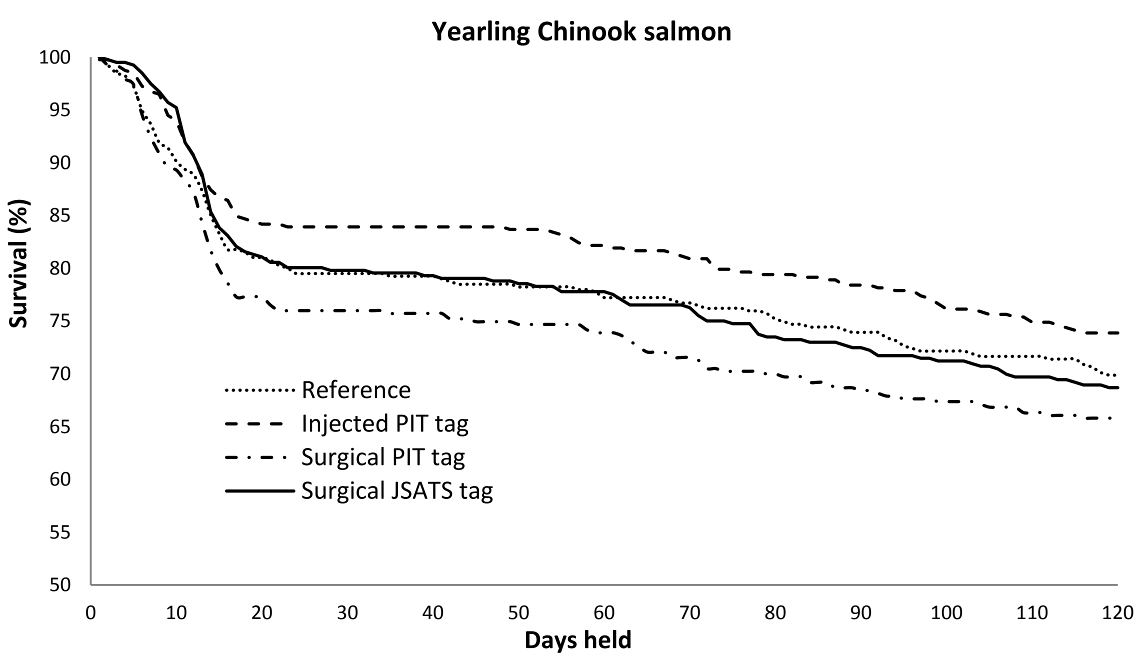


Figure 15. Percentage survival of yearling Chinook salmon by tag treatment through 120 d of laboratory holding at Bonneville Dam

Table 15. Proportions surviving of yearling Chinook salmon by tag treatment after 14, 28, and 120 d and during d 14-28 and d 28-120 of the 120-day laboratory holding period at Bonneville Dam. Total indicates mean by replicate date for all treatment groups combined. Mean indicates average of all replicate means. Standard errors are shown in parentheses.

Yearling Chinook Salmon					
Treatment date	Reference	Injected PIT tag	Surgical PIT tag	Acoustic tag	Total
			Survival to day 14		
23-Apr	1.00 (0.00)	1.00 (0.00)	0.88 (0.05)	0.85 (0.06)	0.93 (0.02)
28-Apr	0.93 (0.04)	0.98 (0.02)	1.00 (0.00)	0.93 (0.04)	0.96 (0.02)
30-Apr	0.90 (0.05)	1.00 (0.00)	0.88 (0.05)	0.83 (0.06)	0.90 (0.02)
2-May	0.87 (0.05)	0.85 (0.06)	0.77 (0.07)	0.82 (0.06)	0.83 (0.03)
5-May	0.83 (0.06)	0.78 (0.07)	0.43 (0.09)	0.68 (0.08)	0.70 (0.04)
7-May	0.87 (0.05)	0.80 (0.06)	0.72 (0.07)	0.87 (0.05)	0.82 (0.03)
9-May	0.67 (0.08)	0.72 (0.07)	0.76 (0.07)	0.84 (0.06)	0.75 (0.04)
12-May	0.85 (0.06)	0.86 (0.05)	0.95 (0.04)	0.83 (0.06)	0.87 (0.03)
14-May	0.78 (0.07)	0.84 (0.06)	0.82 (0.06)	0.95 (0.04)	0.85 (0.03)
16-May	0.83 (0.06)	0.90 (0.05)	0.87 (0.05)	0.93 (0.04)	0.88 (0.03)
Mean	0.85 (0.03)	0.87 (0.03)	0.81 (0.05)	0.85 (0.02)	0.85 (0.03)
			Survival to day 28		
23-Apr	0.95 (0.04)	1.00 (0.00)	0.88 (0.05)	0.73 (0.07)	0.89 (0.03)
28-Apr	0.90 (0.05)	0.98 (0.02)	1.00 (0.00)	0.90 (0.05)	0.94 (0.02)
30-Apr	0.90 (0.05)	1.00 (0.00)	0.83 (0.06)	0.80 (0.06)	0.88 (0.03)
2-May	0.84 (0.06)	0.83 (0.06)	0.77 (0.07)	0.71 (0.07)	0.79 (0.03)
5-May	0.73 (0.07)	0.72 (0.07)	0.37 (0.09)	0.63 (0.08)	0.63 (0.04)
7-May	0.79 (0.06)	0.76 (0.07)	0.59 (0.08)	0.82 (0.06)	0.74 (0.03)
9-May	0.56 (0.08)	0.62 (0.08)	0.65 (0.08)	0.76 (0.07)	0.65 (0.04)
12-May	0.79 (0.06)	0.81 (0.06)	0.85 (0.06)	0.78 (0.07)	0.81 (0.03)
14-May	0.75 (0.07)	0.82 (0.06)	0.79 (0.06)	0.95 (0.04)	0.83 (0.03)
16-May	0.73 (0.07)	0.86 (0.05)	0.77 (0.07)	0.88 (0.05)	0.81 (0.03)
Mean	0.80 (0.04)	0.84 (0.04)	0.75 (0.06)	0.80 (0.03)	0.80 (0.03)
			Survival to day 120		
23-Apr	0.87 (0.05)	0.97 (0.03)	0.83 (0.06)	0.61 (0.08)	0.82 (0.03)
28-Apr	0.80 (0.06)	0.83 (0.06)	0.85 (0.06)	0.76 (0.07)	0.81 (0.03)
30-Apr	0.75 (0.07)	0.95 (0.03)	0.70 (0.07)	0.68 (0.07)	0.77 (0.03)
2-May	0.76 (0.07)	0.60 (0.08)	0.74 (0.07)	0.63 (0.08)	0.68 (0.04)
5-May	0.61 (0.08)	0.72 (0.07)	0.37 (0.09)	0.55 (0.08)	0.57 (0.04)
7-May	0.74 (0.07)	0.71 (0.07)	0.51 (0.08)	0.77 (0.07)	0.68 (0.04)
9-May	0.49 (0.08)	0.59 (0.08)	0.46 (0.08)	0.71 (0.07)	0.56 (0.04)
12-May	0.77 (0.07)	0.63 (0.07)	0.74 (0.07)	0.68 (0.07)	0.70 (0.04)
14-May	0.58 (0.08)	0.63 (0.08)	0.67 (0.08)	0.82 (0.06)	0.67 (0.04)
16-May	0.63 (0.08)	0.76 (0.07)	0.62 (0.08)	0.66 (0.07)	0.67 (0.04)
Mean	0.70 (0.04)	0.74 (0.04)	0.65 (0.05)	0.69 (0.03)	0.69 (0.03)

Table 15. Continued.

	Yearling Chinook Salmon				
Treatment date	Reference	Injected PIT tag	Surgical PIT tag	Acoustic tag	Total
	Survival from day 14 to day 28				
23-Apr	0.95 (0.04)	1.00 (0.00)	1.00 (0.00)	0.86 (0.06)	0.95 (0.02)
28-Apr	0.97 (0.03)	1.00 (0.00)	1.00 (0.00)	0.97 (0.03)	0.99 (0.01)
30-Apr	1.00 (0.00)	1.00 (0.00)	0.94 (0.04)	0.97 (0.03)	0.98 (0.01)
2-May	0.97 (0.03)	0.97 (0.03)	1.00 (0.00)	0.87 (0.06)	0.95 (0.02)
5-May	0.88 (0.06)	0.93 (0.05)	0.85 (0.10)	0.92 (0.05)	0.9 (0.03)
7-May	0.91 (0.05)	0.94 (0.04)	0.82 (0.07)	0.94 (0.04)	0.91 (0.03)
9-May	0.85 (0.07)	0.86 (0.07)	0.86 (0.07)	0.91 (0.05)	0.87 (0.03)
12-May	0.94 (0.04)	0.95 (0.04)	0.89 (0.05)	0.94 (0.04)	0.93 (0.02)
14-May	0.97 (0.03)	0.97 (0.03)	0.97 (0.03)	1.00 (0.00)	0.98 (0.01)
16-May	0.88 (0.06)	0.95 (0.04)	0.88 (0.06)	0.95 (0.04)	0.92 (0.02)
Mean	0.93 (0.02)	0.96 (0.01)	0.92 (0.02)	0.93 (0.01)	0.94 (0.01)
	Survival from day 28 to day 120				
23-Apr	0.92 (0.04)	0.97 (0.03)	0.94 (0.04)	0.83 (0.07)	0.92 (0.02)
28-Apr	0.89 (0.05)	0.85 (0.06)	0.85 (0.06)	0.84 (0.06)	0.86 (0.03)
30-Apr	0.83 (0.06)	0.95 (0.03)	0.85 (0.06)	0.84 (0.06)	0.87 (0.03)
2-May	0.91 (0.05)	0.73 (0.08)	0.97 (0.03)	0.89 (0.06)	0.87 (0.03)
5-May	0.83 (0.07)	1.00 (0.00)	1.00 (0.00)	0.88 (0.07)	0.91 (0.03)
7-May	0.94 (0.04)	0.94 (0.04)	0.87 (0.07)	0.94 (0.04)	0.92 (0.02)
9-May	0.86 (0.07)	0.96 (0.04)	0.71 (0.09)	0.93 (0.05)	0.87 (0.03)
12-May	0.97 (0.03)	0.77 (0.07)	0.88 (0.06)	0.87 (0.06)	0.87 (0.03)
14-May	0.77 (0.08)	0.77 (0.08)	0.84 (0.07)	0.86 (0.06)	0.81 (0.03)
16-May	0.86 (0.06)	0.89 (0.05)	0.80 (0.07)	0.75 (0.07)	0.82 (0.03)
Mean	0.88 (0.02)	0.88 (0.03)	0.87 (0.03)	0.86 (0.02)	0.87 (0.01)

In general, and similar to 2007, the largest decline in survival for all yearling Chinook study fish was observed from day 0 through day 15, after which the survival curve stabilized through about day 60. Similar to 2007, this trend indicated that treatment fish possibly received a therapeutic benefit from transfer to seawater (Noga 2000). Near day 60 of holding, mortality began to accelerate again, and from 60 d through the end of the study, mortality rates were similar for all fish regardless of treatment.

In the 2007 tag comparison (Wargo Rub et al. 2009), yearling Chinook salmon held in the laboratory fared better overall than their counterparts migrating in the river. Respective post-tagging survival rates for JSATS- and PIT-tagged fish were 0.85 and 0.92 at d 14 for fish held in the laboratory vs. 0.50 and 0.63 at d 12 for fish that passed Bonneville Dam. In addition, relative survival between the two tag-treatment groups (JSATS/PIT) was lower for fish migrating inriver (0.79) than for their laboratory counterparts (0.92). A similar trend was observed in 2008.

In 2008, respective post-tagging survival rates for JSATS- and PIT-tagged yearling Chinook were 0.85 and 0.87 at 14 d for fish held in the laboratory vs. 0.60 and 0.83 for fish passing John Day and 0.52 and 0.75 for fish passing Bonneville Dam. Average median travel times to both locations was ~14 d for JSATS-tagged and 13.3 d for PIT-tagged fish. Relative survival (JSATS/PIT) was 0.98 at 14 d for laboratory, 0.72 from release to John Day, and 0.75 from relase to Bonneville Dam. These results indicate that rigorous field evaluations should not be replaced or dropped in lieu of laboratory studies when evaluating tag effects.

In contrast to the holding study results during 2007, where PIT-tagged and reference fish survived at significantly higher rates through d 28, we saw no significant differences in survival among tag treatments for yearling Chinook during 2008. Overall results from 2008 indicated no effect of tagging on survival in the laboratory conditions under which these fish were held. Tag effects may have been eliminated with the reduction in tag size in 2008, which reduced tag burden for yearling Chinook salmon by nearly 33%.

Growth—At the end of the 120-d holding period, survivors were measured (FL) and weighed, and growth was calculated for individual fish based on fork length at the time of tagging. Table 16 shows average growth (mm) and weight gain (g) for yearling Chinook by tag treatment and date of tagging.

Table 16. Mean growth in length and weight for yearling Chinook by tag treatment group and treatment date for laboratory fish that survived 120 d of holding at Bonneville Dam. Means are overall mean by treatment. Standard errors are shown in parentheses.

	Yearling Chinook salmon growth over 120 d		
	Injected PIT tag	Surgically implanted PIT tag	JSATS acoustic tag
Treatment date	Mean increase in length (mm)		
23 Apr	73.79 (2.51)	72.03 (2.77)	69.96 (4.13)
28 Apr	67.76 (3.54)	70.66 (2.84)	63.16 (2.95)
30 Apr	63.08 (2.33)	53.63 (2.72)	51.54 (3.51)
2 May	59.13 (3.64)	65.29 (4.9)[a]	63.04 (4.65)
5 May	56.73 (3.16)	69.64 (5.12)	66.24 (3.71)
7 May	57.31 (3.22)	62.85 (4.28)	65.93 (1.88)
9 May	67.52 (2.37)	69.76 (3.9)	59.11 (3.49)
12 May	55.37 (3.33)	54.28 (2.71)	54.89 (3.84)
14 May	59.67 (2.77)	49.15 (3.11)	57 (2.96)
16 May	60.81 (3.01)	58.25 (3.47)	55.7 (3.48)
Mean	62.67 (1.01)	62.34 (1.22)	60.51 (1.16)
	Mean increase in weight (g)		
23 Apr	NA (0)	89.6 (3.66)	83.14 (5.3)
28 Apr	NA (0)	87.73 (4.04)	81.04 (3.55)
30 Apr	81.49 (3.65)	76.9 (5.11)	77.77 (5.52)
2 May	73.26 (5.45)	75.69 (6.76)[c]	73.93 (5.94)
5 May	81.66 (5.03)[b]	85.96 (8.13)	84.82 (6.56)
7 May	76.76 (5.34)	91.82 (5.82)[d]	84.75 (2.56)
9 May	85.6 (3.29)	102.98 (5.8)	77.7 (6.36)[e]
12 May	73.84 (4.93)	74.68 (4.38)	75.04 (7.46)
14 May	76.22 (3.64)	65.76 (5.43)	82.91 (5.56)
16 May	80.39 (5.87)	77.1 (6.65)[f]	73.51 (5.62)[g]
Mean	78.77 (1.72)	82.99 (1.79)	79.19 (1.81)

[a] N = 28
[b] N = 23
[c] N = 28
[d] N = 19
[e] N = 26
[f] N = 17
[g] N = 26

Average growth for pooled treatment groups of yearling Chinook that survived to the end of the 120-d holding period was 60.51 mm for JSATS-tagged fish, 62.67 mm for injected PIT-tagged fish, and 62.34 mm for surgically PIT-tagged fish (Table 16). These were similar to the averages of the replicate means, at 60.7 mm for JSATS, 62.1 mm for injected PIT, and 62.6 for surgical PIT fish. By either method of calculation, the differences among treatment means were not significant (Fisher's LSD ANOVA $P = 0.628$).

Average weight gain by pooled treatment was 79.19 g for JSATS, 78.77 for injected PIT, and 82.99 for surgical PIT groups of yearling Chinook that survived to the end of the 120-d holding period. These were similar to the average of the replicate means, at 79.5 g for JSATS-tagged, 79.7 g for injected PIT-tagged, and 82.8 g for surgically PIT-tagged fish. Differences among treatment means were not significant (ANOVA $P = 0.436$).

In 2007, average growth was 2.6 mm greater for PIT-tagged than JSATS-tagged fish and this difference approached significance (P = 0.068). However, the holding time was only 90 d in 2007, compared to 120 days in 2008, and the additional 30 d may have allowed for compensatory growth of the JSATS-tagged fish. This growth pattern has been observed in other acoustic tagging studies (Lacroix 2004, Adams 1998a, and Chittenden et al. 2009).

Tag Expulsion—Yearling Chinook that survived to the end of the 120-d holding period rarely expelled or dropped PIT tags, as shown in Table 17, and there was no difference in PIT-tag loss between treatments. For acoustic-tagged fish, PIT-tag loss was lower in 2008 (0%; N = 1 tag) than it had been in 2007 (2%; N = 5 tags). Of the yearling Chinook treated with JSATS tags that survived to the end of the 120-d holding period, 8% (N = 21) expelled or dropped acoustic tags. The number of tags lost by replicate is also shown in Table 17. This was in contrast to 0 acoustic tags lost in 2007. The timing of tag loss during this study was unknown because study fish were not disturbed by handling during the holding period, and very few tags were recovered from the bottom of the holding tanks. However, the literature is replete with reports of acoustic transmitter loss from fish, and tag loss is more often reported as an active phenomenon that occurs several days to weeks after surgery, rather than as passive loss through unhealed incisions (Marty and Summerfelt, 1986 , 1990; Moore 1990, Chisholm and Hubert, 1985; Lucas, 1989; Welch et al. 2007; Lacroix 2004).

Table 17. Percentage of dropped or expelled tags by JSATS-tagged and PIT-tagged fish held 120 d at Bonneville Dam. Actual number of tags lost is in parentheses.

Yearling Chinook salmon			
	Tag loss or expulsion (%)		
	Injected PIT tag	Surgically implanted PIT tag	JSATS acoustic tag
Lost PIT tag	0.00 (0)	0.00 (1)	0.00 (1)
Lost JSATS tag	NA	NA	0.08 (21)

Total tags lost by replicate										
Replicate	1	2	3	4	5	6	7	8	9	10
Tags lost	1	3	5	1	6	2	1	0	2	0

Estimates of survival for actively migrating fish in this study were determined primarily based on detections of PIT tags. Therefore, inriver survival estimates for double-tagged fish were not affected by acoustic tag loss. However, these findings and others show that caution should be applied to interpreting results from field studies that have been designed to rely solely on detection of acoustic transmitters for estimates of detection and survival. Such a design may result in estimates that are biased low due to the potential for transmitter loss or expulsion.

Prevalence of *Renibacterium salmoninarum*—Of the hatchery yearling Chinook salmon held in the laboratory at Bonneville, 480 died before termination of the study. For these fish, overall ELISA coded values ranged from 0.064 to 3.738. Samples taken from individual mortalities were averaged by replicate and treatment (Table 18), and among the ELISA coded values from these samples, no significant differences were found in BKD levels among the four tag treatments (Kruskal-Wallis, P = 0.313). In addition, no significant difference was found in BKD levels among surgical and non-surgical treatments (Kruskal-Wallis P = 0.684), with ELISA values ranging from 0.28 to 0.44 across treatments. Mean ELISA values by period of mortality during the holding period were as follows:

Mortality period (d)	Mean ELISA value
0-24	0.165
25-48	1.310
49-72	0.584
73-96	0.446
97-120	0.996

For the 1,095 hatchery yearling Chinook salmon that survived beyond termination of the study, the range of ELISA values was similar (0.067-3.697). Mean coded values for individual ELISA samples were calculated by replicate and treatment (Table 18), and no significant differences were found among reference, JSATS, injected PIT, or surgical PIT treatment fish (Kruskal-Wallis $P = 0.323$). Mean coded ELISA values ranged from 0.12-0.19 across treatments. Similar to results from our previous laboratory study in 2007, a comparison of Rs antigen between treatment groups showed no evidence that JSATS-tagged fish were more predisposed to developing BKD than PIT-tagged fish or reference fish. This was evident in both the earlier mortalities and in fish that survived to study termination.

Influence of Hatchery Origin—All yearling Chinook salmon held at Bonneville were scanned for CWTs post-mortem. Overall, CWTs were identified in 21% of the yearling laboratory fish (N = 337 tags), and represented 12 hatchery groups. Table 19 shows the number of CWTs collected by hatchery of origin along with proportions of CWT-tagged fish by hatchery with low, medium, or high levels of BKD antigen, as indicated by ELISA value. Figure 19 shows comparative survival for yearling laboratory fish with CWTs by hatchery of origin, and Table 20 shows the number of CWT-tagged fish by hatchery of origin and replicate.

Survival for CWT-tagged yearling fish ranged from 33 to 100%. For the most part, hatchery fish of similar origin did not appear to be clustered by sample (Table 20), and this included McCall and Rapid River hatchery fish, of which less than 60% survived. The other two hatchery groups that had less than 60% survival were Oxbow-ID, and Sawtooth. Although these hatchery fish were more clustered in time (Sawtooth fish were collected only in replicates 7, 9, and 10, and Oxbow in replicates 2 and 10), both hatcheries were represented by very few fish overall.

We know that the total contribution by Sawtooth hatchery was the total in our sample of 13, since 100% of these fish were marked with CWTs in 2008. Approximately 92% of Oxbow Hatchery Chinook salmon were marked with CWTs in 2008. However, assuming equal survival rates to Lower Granite Dam for Oxbow Hatchery fish with or without CWTs, the total number in our sample could not have exceeded three. Furthermore, Oxbow Hatchery released only fall Chinook in 2008, and this was not our target species. Overall, the CWT sample numbers were too low for meaningful statistical analysis. However, they indicate that it is unlikely that our study results were biased due to any one particular hatchery group that may have released fish in poor condition in either 2007 or 2008.

Table 18. Hatchery yearling Chinook salmon ELISA coded values averaged by replicate and treatment for fish that died prior to the end of 120-d holding and those that survived to the end of 120 d at Bonneville juvenile monitoring facility.

	Replicate										
Tag treatment	1	2	3	4	5	6	7	8	9	10	Total/mean
	Fish that survived 120 d										
Injected PIT											
N	38	32	38	24	26	29	23	27	24	32	293
ELISA	0.09	0.27	0.09	0.10	0.09	0.53	0.09	0.13	0.33	0.14	0.18
Surgical PIT											
N	32	34	28	29	11	20	17	29	26	24	250
ELISA	0.08	0.16	0.10	0.09	0.08	0.10	0.12	0.27	0.39	0.21	0.17
JSATS											
N	25	31	27	24	21	30	27	27	32	27	271
ELISA	0.09	0.09	0.10	0.09	0.09	0.18	0.10	0.12	0.19	0.10	0.12
Reference											
N	34	31	30	29	24	28	19	30	23	25	273
ELISA	0.12	0.20	0.09	0.09	0.11	0.35	0.09	0.15	0.52	0.28	0.19
	Fish that died before 120 d										
Injected PIT											
N	1	7	2	16	10	11	15	15	14	10	101
ELISA	0.06	0.15	0.25	0.15	0.13	0.22	0.22	0.44	0.55	0.49	0.3
Surgical PIT											
N	6	6	12	6	19	18	19	10	13	15	124
ELISA	0.65	0.71	0.16	0.27	0.2	0.16	0.65	0.93	0.65	0.37	0.44
JSATS											
N	16	10	13	13	17	9	9	13	7	14	121
ELISA	0.25	0.53	0.26	0.15	0.31	0.1	0.1	0.29	0.29	0.5	0.28
Reference											
N	5	8	10	7	17	9	19	9	17	15	116
ELISA	0.14	0.15	0.19	0.39	0.38	0.66	0.21	0.46	1.01	0.15	0.4

Table 19. Survival rates of yearling laboratory fish with CWTs by hatchery of origin. The percentage of these fish by hatchery that had either a low, medium, or high ELISA value is also indicated along with the total number of CWTs collected.

Hatchery of origin	Survival	ELISA value Low	ELISA value Med	ELISA value High	Number of CWTs
Clearwater	0.81	1.00	0.00	0.00	47
Nez Perce Tribal	0.86	0.91	0.05	0.05	43
Dworshak	1.00	1.00	0.00	0.00	21
Kooskia	0.81	0.87	0.09	0.04	47
Lookingglass	0.66	0.81	0.10	0.10	73
Lyons Ferry	0.70	1.00	0.00	0.00	9
McCall	0.55	0.60	0.35	0.05	20
Oxbow-ID	0.33	1.00	0.00	0.00	3
Pahsimeroi	0.88	0.88	0.09	0.03	34
Rapid River	0.58	0.89	0.05	0.05	19
Sawtooth	0.54	0.77	0.08	0.15	13
Wallowa	0.88	0.75	0.13	0.13	8

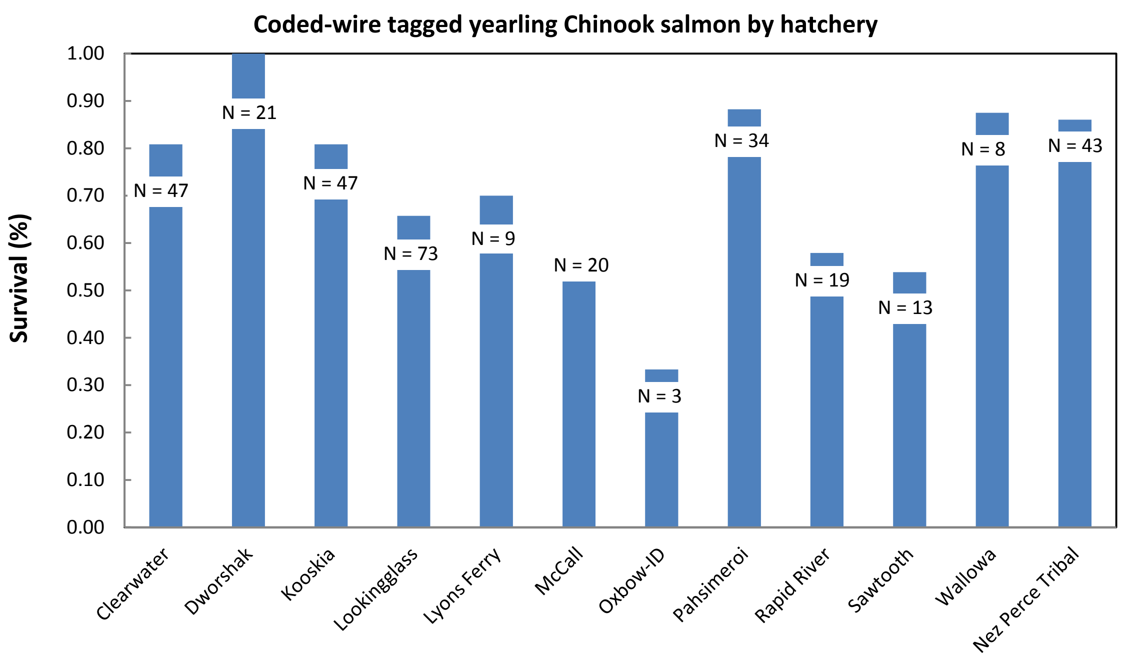


Figure 19. Percent survival during 120-d holding at Bonneville Dam for yearling Chinook with Coded-wire tags by hatchery of origin. The number of CWTs collected by hatchery is noted above each bar.

Table 20. Number of CWT-tagged fish by hatchery of origin and replicate during 120-d holding at Bonneville Dam for yearling Chinook. Shaded cells denote survival rates of less than 60%.

	Yearling Chinook replicate										
Hatchery of origin	1	2	3	4	5	6	7	8	9	10	Total
Clearwater	7	6	10	5	5	5	5		3	1	47
Nez Perce Tribal	7	4	15	2	1	6	1	1	3	3	43
Dworshak	4	2	2	5	2	2	1	3			21
Kooskia	6	10	4	13	4	3	3	1	1	2	47
Lookingglass	6	7	5	5	10	12	9	6	6	7	73
Lyons Ferry	3	1	1	1	1	1				1	9
McCall	1	1	2	1	3	1	2	2	3	4	20
Oxbow-ID		1								2	3
Pahsimeroi	1		1	2	6	3	5	8	2	6	34
Rapid River		3	1	2	1	2	1	2	6	1	19
Sawtooth							1		10	2	13
Wallowa		1			1		1	1	4		8
Total	35	36	41	36	34	35	29	24	38	30	337

Although average coded ELISA values by treatment were slightly higher for fish that died during holding than for fish that survived to termination, it is unlikely that BKD was driving accelerated mortality for these fish. Study fish contributing to the steepest decline in survival (0-24 d) had the lowest mean ELISA value (0.165), study fish that died during the most stable period (25-48 d) had the highest mean ELISA value (1.310). In CWT fish, although survival as well as Rs antigen levels differed by hatchery of origin, there was no evidence that overall survival across replicates was biased or negatively influenced by one or more hatchery group.

Subyearling Chinook Salmon

Survival—Much more mortality was observed from day 0 to 18 in subyearling Chinook salmon for all surgical treatment groups (JSATS, single-battery JSATS surgical PIT) than for the injected PIT or reference groups (Figure 20; Table 21). The lower rate of mortality observed in the first 18 days for the injected and reference groups remained relatively constant throughout the entire 120-d holding period. After 18 d, the survival function for the surgical groups exhibited a steady decline similar to that for the other groups.

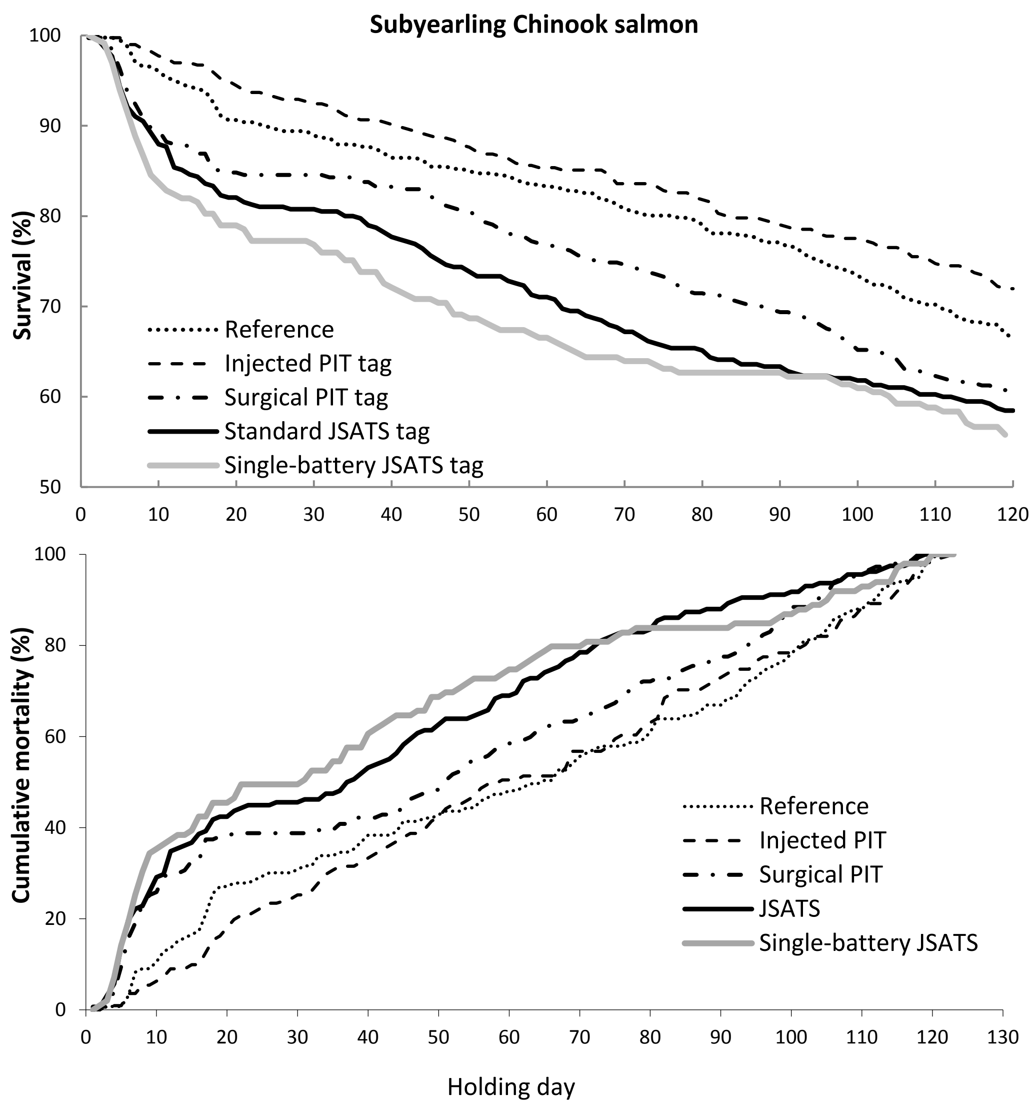


Figure 20. Survival (upper panel) and cumulative mortality for reference fish and injected PIT, surgical PIT, JSATS, and single-battery JSATS tag treatment groups during 120 d holding at Bonneville Dam.

Table 21. Proportions surviving of subyearling Chinook salmon by tag treatment after 14, 28, and 120 d and during d 14-28 and d 28-120 of the 120-day laboratory holding period at Bonneville Dam. Total indicates mean by replicate date for all treatment groups combined (excluding single-battery acoustic). Mean indicates average of all replicate means. Standard errors are shown in parentheses.

Treatment	**Subyearling Chinook salmon**					
date	Reference	Injected PIT tag	Surgical PIT tag	Acoustic tag	Single-battery acoustic	Total
			Survival to day 14			
3 Jun	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	NA	1.00 (0.00)
5 Jun	0.93 (0.04)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	NA	0.98 (0.01)
10 Jun	0.97 (0.03)	1.00 (0.00)	0.98 (0.02)	0.95 (0.03)	NA	0.97 (0.01)
12 Jun	0.98 (0.02)	1.00 (0.00)	1.00 (0.00)	0.90 (0.05)	NA	0.97 (0.01)
18 Jun	0.98 (0.02)	1.00 (0.00)	0.97 (0.03)	0.90 (0.05)	1.00 (0.00)	0.96 (0.02)
20 Jun	1.00 (0.00)	1.00 (0.00)	0.95 (0.04)	0.93 (0.04)	0.95 (0.04)	0.97 (0.01)
25 Jun	0.98 (0.02)	0.97 (0.03)	0.90 (0.05)	0.84 (0.06)	0.97 (0.03)	0.92 (0.02)
27 Jun	0.95 (0.04)	0.98 (0.02)	0.93 (0.04)	0.83 (0.06)	0.95 (0.03)	0.92 (0.02)
1 Jul	0.86 (0.05)	0.95 (0.03)	0.82 (0.06)	0.88 (0.05)	0.76 (0.07)	0.88 (0.03)
10 Jul	0.79 (0.07)	0.78 (0.07)	0.22 (0.07)	0.26 (0.07)	0.28 (0.07)	0.51 (0.04)
Mean	0.94 (0.02)	0.97 (0.02)	0.88 (0.08)	0.85 (0.07)	0.82 (0.11)	0.91 (0.05)
			Survival to day 28			
3 Jun	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	NA	1.00 (0.00)
5 Jun	0.90 (0.05)	1.00 (0.00)	0.97 (0.03)	1.00 (0.00)	NA	0.97 (0.01)
10 Jun	0.95 (0.04)	0.95 (0.04)	0.98 (0.02)	0.90 (0.05)	NA	0.94 (0.02)
12 Jun	0.98 (0.02)	0.98 (0.02)	1.00 (0.00)	0.88 (0.05)	NA	0.96 (0.02)
18 Jun	0.93 (0.04)	0.97 (0.03)	0.97 (0.03)	0.90 (0.05)	1.00 (0.00)	0.94 (0.02)
20 Jun	1.00 (0.00)	1.00 (0.00)	0.92 (0.04)	0.85 (0.06)	0.90 (0.05)	0.94 (0.02)
25 Jun	0.95 (0.03)	0.97 (0.03)	0.87 (0.05)	0.79 (0.07)	0.92 (0.04)	0.90 (0.02)
27 Jun	0.90 (0.05)	0.89 (0.05)	0.83 (0.06)	0.75 (0.07)	0.90 (0.05)	0.84 (0.03)
1 Jul	0.62 (0.07)	0.83 (0.06)	0.72 (0.07)	0.80 (0.06)	0.74 (0.07)	0.74 (0.03)
10 Jul	0.71 (0.07)	0.70 (0.08)	0.19 (0.06)	0.23 (0.07)	0.18 (0.06)	0.46 (0.04)
Mean	0.89 (0.04)	0.93 (0.03)	0.85 (0.08)	0.81 (0.07)	0.77 (0.12)	0.87 (0.05)

Table 21. Continued.

Treatment date	Subyearling Chinook salmon					
	Reference	Injected PIT tag	Surgical PIT tag	Acoustic tag	Single-battery acoustic	Total
	Survival to day 120					
3 Jun	0.76 (0.07)	0.88 (0.06)	0.87 (0.06)	0.83 (0.06)	NA	0.83 (0.03)
5 Jun	0.25 (0.07)	0.45 (0.08)	0.32 (0.08)	0.15 (0.06)	NA	0.29 (0.04)
10 Jun	0.79 (0.06)	0.56 (0.08)	0.53 (0.08)	0.73 (0.07)	NA	0.65 (0.04)
12 Jun	0.90 (0.05)	0.85 (0.06)	0.90 (0.05)	0.83 (0.06)	NA	0.87 (0.03)
18 Jun	0.63 (0.07)	0.79 (0.06)	0.79 (0.06)	0.62 (0.08)	0.76 (0.07)	0.71 (0.04)
20 Jun	0.90 (0.05)	0.85 (0.06)	0.82 (0.06)	0.78 (0.07)	0.74 (0.07)	0.84 (0.03)
25 Jun	0.74 (0.07)	0.77 (0.07)	0.62 (0.08)	0.63 (0.08)	0.69 (0.07)	0.69 (0.04)
27 Jun	0.67 (0.08)	0.66 (0.07)	0.75 (0.07)	0.65 (0.08)	0.78 (0.07)	0.68 (0.04)
1 Jul	0.31 (0.07)	0.69 (0.07)	0.36 (0.08)	0.45 (0.08)	0.18 (0.06)	0.45 (0.04)
10 Jul	0.68 (0.08)	0.70 (0.08)	0.14 (0.06)	0.21 (0.06)	0.18 (0.06)	0.43 (0.04)
Mean	0.66 (0.07)	0.72 (0.04)	0.61 (0.08)	0.59 (0.08)	0.56 (0.12)	0.64 (0.06)
	Survival from day 14 to day 28					
3 Jun	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	NA	1.00 (0.00)
5 Jun	0.97 (0.03)	1.00 (0.00)	0.97 (0.03)	1.00 (0.00)	NA	0.99 (0.01)
10 Jun	0.97 (0.03)	0.95 (0.04)	1.00 (0.00)	0.95 (0.04)	NA	0.97 (0.01)
12 Jun	1.00 (0.00)	0.98 (0.02)	1.00 (0.00)	0.97 (0.03)	NA	0.99 (0.01)
18 Jun	0.95 (0.03)	0.97 (0.03)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	0.98 (0.01)
20 Jun	1.00 (0.00)	1.00 (0.00)	0.97 (0.03)	0.92 (0.04)	0.95 (0.04)	0.97 (0.01)
25 Jun	0.98 (0.02)	1.00 (0.00)	0.97 (0.03)	0.94 (0.04)	0.95 (0.04)	0.97 (0.01)
27 Jun	0.95 (0.04)	0.91 (0.04)	0.89 (0.05)	0.91 (0.05)	0.95 (0.04)	0.91 (0.02)
1 Jul	0.72 (0.07)	0.88 (0.05)	0.88 (0.06)	0.91 (0.05)	0.97 (0.03)	0.85 (0.03)
10 Jul	0.90 (0.05)	0.90 (0.06)	0.88 (0.12)	0.90 (0.09)	0.64 (0.15)	0.90 (0.03)
Mean	0.94 (0.03)	0.96 (0.02)	0.96 (0.02)	0.95 (0.01)	0.91 (0.05)	0.95 (0.02)

Table 21. Continued.

Treatment date	Subyearling Chinook salmon					
	Reference	Injected PIT tag	Surgical PIT tag	Acoustic tag	Single-battery acoustic	Total
	Survival from day 28 to day 120					
3 Jun	0.76 (0.07)	0.88 (0.06)	0.87 (0.06)	0.83 (0.06)	NA	0.83 (0.03)
5 Jun	0.28 (0.07)	0.45 (0.08)	0.32 (0.08)	0.15 (0.06)	NA	0.3 (0.04)
10 Jun	0.84 (0.06)	0.59 (0.08)	0.54 (0.08)	0.81 (0.07)	NA	0.69 (0.04)
12 Jun	0.92 (0.04)	0.88 (0.05)	0.90 (0.05)	0.94 (0.04)	NA	0.91 (0.02)
18 Jun	0.68 (0.07)	0.82 (0.06)	0.82 (0.06)	0.69 (0.08)	0.76 (0.07)	0.75 (0.04)
20 Jun	0.90 (0.05)	0.85 (0.06)	0.89 (0.05)	0.91 (0.05)	0.83 (0.06)	0.89 (0.03)
25 Jun	0.78 (0.06)	0.79 (0.07)	0.71 (0.08)	0.80 (0.07)	0.75 (0.07)	0.77 (0.04)
27 Jun	0.74 (0.07)	0.74 (0.07)	0.91 (0.05)	0.87 (0.06)	0.86 (0.06)	0.81 (0.03)
1 Jul	0.50 (0.10)	0.83 (0.06)	0.50 (0.09)	0.56 (0.09)	0.25 (0.08)	0.61 (0.04)
10 Jul	0.96 (0.04)	1.00 (0.00)	0.71 (0.17)	0.89 (0.10)	1.00 (0.00)	0.94 (0.03)
Mean	0.74 (0.07)	0.78 (0.05)	0.72 (0.06)	0.74 (0.07)	0.74 (0.11)	0.75 (0.06)

Single-battery JSATS fish were not included in the comparisons described below because they were marked only in replicates 6-10, and environmental conditions during collection and treatment were inconsistent over time. After 14 d holding, mean survival differed significantly among reference, injected PIT, surgical PIT, and JSATS tag treatment groups (ANOVA, $P = 0.037$). Further testing based on Fisher's LSD revealed that mean survival was significantly lower for JSATS (0.85) and surgical PIT (0.88) groups than for injected PIT (0.97) and reference (0.94; $P = 0.044$) groups, although survival between the latter two was not different.

At 14 d holding, survival for both individual and combined treatment groups by replicate date was fairly consistent among replicates 1-9 (combined: mean 0.95, range 0.86-1.00), but was far lower for replicate 10 (0.46). The difference in survival between earlier replicates and replicate 10 was much larger in surgically treated fish (replicate 10: surgical PIT 0.22; JSATS 0.26; single-battery JSATS 0.28) than in those injected with a PIT tag (0.78) or reference fish (0.79). This may have been related to increasing temperatures later in the 2008 season: replicate 10 was the only replicate collected and tagged during a period when temperatures were above 17°C. During an average year, Snake River temperatures increase steadily from about 7°C in March up to nearly 15°C by early July, and continue to rise through the end of August. Thus during the subyearling migration period, average water temperature is often well above 15°C, and may rise to 20°C during July and August.

Regardless of the reason for the difference, because replicate 10 was an outlier with respect to the other replicates, we repeated this comparison with replicate 10 excluded. Mean survival at 14 d was still significantly different among reference fish, injected PIT, surgical PIT, and JSATS tag treatment groups (ANOVA, $P = 0.001$). Further testing based on Fisher's LSD revealed that mean survival was lower for JSATS and surgical-PIT treatment groups than for injected-PIT and reference groups, and the difference was significant ($P = 0.017$). Mean survival between injected PIT and reference groups was not significantly different.

Differences in survival functions observed at day 28 and at day 120 were largely determined by mortality in the first 14 days, as estimated survival for the sub-intervals 14-28 and 28-120 varied less among the tag treatment groups than for the first 14 days (Table 21). Survival estimates for the later sub-intervals were not statistically significantly different among treatment groups ($P = 0.827$ and 0.515 for 14-28 d, and 28-120 d, respectively, using all 10 replicates; $P = 0.770$ and 0.735 excluding replicate 10).

In both the 2007 and 2008 holding studies, it appeared that either most of the tag effect for surgically treated fish had run its course by 18 d post-tagging, or that treatment fish had received a survival benefit from transfer to seawater. In terms of survival, JSATS-tagged fish benefitted from seawater transfer to a greater extent than PIT-tagged and reference fish. In 2008, we observed a drop in the mortality curve for the surgical PIT-tag group from ~18 to 30 d, with mortality rate remaining relatively constant after 30 d. Over this period, the mortality curve for the surgical PIT group approached and mirrored that of the reference and injected PIT groups (Figure 20). Survival in the JSATS tag treatment group appeared to stabilize a few days later (~21 d) although not to the extent of the surgical PIT-tag group, and also remained relatively stable through ~30 d.

A pronounced change in mortality of single-battery JSATS-tagged fish occurred from around 78 to 98 d post-tagging (Figure 20). Over time, this curve stabilized and approached that of the injected PIT, reference, and surgical PIT treatment groups. For standard JSATS-tagged fish, mortality approached that of the other treatment groups only after ~100 d post-tagging. The 2008 mortality curves suggest that a component of the tag effect was driven by the effects of surgery, and that this component was manifest in the laboratory predominately during the first 18 d post-tagging (the freshwater holding period). After this point, the larger tag burden experienced by standard JSATS-tagged fish may have continued to drive differences in survival between standard and single-battery JSATS and PIT-tagged fish. As in 2007, reference fish survived at an intermediate rate between injected and surgically PIT-tagged fish, although the difference was not significant.

As described above, the increase in tagging temperature over time was thought to have affected survival of laboratory fish, particularly those treated surgically. A cursory comparison of survival between single-battery JSATS fish and the other groups for replicates 4-10 is shown in Table 22. When environmental conditions for sampling, tagging, and transport were held constant among groups, survival of single-battery JSATS-tagged fish was most similar to that of surgically PIT-tagged fish. However, these relationships were not evaluated statistically due to the truncated period for which single-battery tags were available.

Table 22. Mean survival of subyearling Chinook by treatment group after 14, 28, and 120 d holding for replicates 4-10 only (12 June-10 July) and for 2007 and 2008 overall. Mean is average of all replicate means.

	Mean survival of subyearling Chinook salmon								
	Replicates 4-10 only (2008)			2008			2007		
Treatment	14 d	28 d	120 d	14 d	28 d	120 d	14 d	28 d	90 d
Reference	0.96	0.92	0.95	0.94	0.89		0.88	0.82	
Injected PIT	0.98	0.95	0.90	0.97	0.93		0.94	0.89	
Surgical PIT	0.87	0.80	0.75						
JSATS	0.86	0.77	0.72	0.85	0.81		0.53	0.41	
1-battery JSATS	0.89	0.82	0.77						
JSATS/PIT				0.88	0.87	0.82	0.56	0.46	0.43

Survival was higher in 2008 than in 2007 for JSATS-tagged, PIT-tagged, and reference fish at both 14 and 28 d, although this improvement was more pronounced in JSATS-tagged fish (Table 22). Relative survival ratios (JSATS/PIT) were less than one at 14, 28, and 90/120 d in both years, indicating higher survival of PIT-tagged fish. However, these ratios were considerably higher in 2008 than in 2007 (Table 22).

Growth—In subyearling Chinook that survived to the end of the 120-d holding period, mean growth was 65.28 mm for JSATS-tagged fish, 67.25 mm for fish with an injected PIT tag, 66.86 mm for fish surgically implanted with a PIT tag, and 62.54 mm for fish surgically implanted with the single-battery JSATS tag (Table 23) . The average of the replicate means was 66.3 mm for JSATS fish, 67.4 mm for injected PIT-tagged fish, 68.7 mm for surgically PIT-tagged fish, and 65.2 mm for single-battery JSATS fish. Differences among these means were not statistically significant ($P = 0.194$).

Mean weight gain for subyearling Chinook surviving to the end of the120-d holding period was 63.85 g for standard JSATS-tagged fish, 64.83 g for injected PIT-tagged fish, 66.2 g for surgically PIT-tagged fish, and 59.52 for single-battery JSATS fish (Table 23). The average of the replicate means was 66.1 g for standard JSATS fish, 65.0 g for injected PIT-tagged fish, 67.0 g for surgically PIT-tagged fish, and 63.2 g for single-battery JSATS fish. Differences among these means were not statistically significant ($P = 0.515$).

Table 23. Mean growth in length and weight for subyearling Chinook by treatment group (Injected PIT, Surgical PIT, JSATS (two-battery model), and JSATS (one-battery model) treatment date for laboratory fish that survived 120d of holding at Bonneville Dam. Means are overall mean by treatment.

Treatment	Subyearling Chinook salmon growth			
	PIT tag		JSATS acoustic tag	
Date	Injected	Surgical implant	Standard (2 battery)	Prototype (1 battery)
	Mean increase in length (mm)			
3 Jun	72.30 (2.01)	70.35 (2.59)[a]	69.64 (2.02)[b]	NA
5 Jun	73.29 (2.89)	80.00 (2.23)	81.50 (4.41)	NA
10 Jun	64.40 (2.22)	68.35 (2.59)[c]	70.40 (1.61)	NA
12 Jun	72.43 (1.75)	66.19 (1.8)	63.76 (1.42)	NA
18 Jun	65.00 (1.68)	58.13 (1.35)	55.79 (1.79)	54.48 (1.63)
20 Jun	65.49 (1.78)	63.88 (1.82)	61.81 (1.95)	63.86 (2.09)
25 Jun	65.17 (2.7)	66.54 (1.84)	61.33 (2.21)	60.58 (2.16)
27 Jun	67.89 (2.06)	70.2 (2.27)	70.58 (1.82)	68.61 (2.28)
1 Jul	62.79 (3.31)	66.64 (4.43)	64.22 (3.33)	62.57 (4.32)
10 Jul	64.73 (3.2)	71.2 (4.28)	64.38 (5.39)	65.14 (3.1)
Mean	67.25 (0.77)	66.86 (0.8)	65.28 (0.78)	62.54 (1.06)
	Mean increase in weight (g)			
3 Jun	68.00 (3.11)	72.13 (3.61)	65.41 (3.14)	
5 Jun	70.91 (4.29)	86.78 (6.02)	93.95 (5.41)	
10 Jun	60.1 (3.35)	64.6 (3.85)	70.52 (2.83)[d]	
12 Jun	72.39 (3.00)	70.5 (2.37)	67.42 (2.37)	
18 Jun	66.13 (2.97)	63.5 (1.93)	61.28 (2.67)	59.84 (2.63)
20 Jun	59.62 (2.96)	59.32 (2.72)	56.77 (2.95)	58.94 (2.73)
25 Jun	69.4 (3.92)	64.93 (2.37)	54.67 (2.92)	55.64 (2.49)
27 Jun	63.53 (2.68)	62.55 (2.91)	64.27 (2.35)	63.45 (2.99)
1 Jul	57.44 (4.11)	62.09 (4.91)	63.09 (4.71)	55.87 (3.67)
10 Jul	61.91 (4.00)	63.82 (7.94)	60.66 (7.82)	61.29 (6.11)
Mean	64.83 (1.12)	66.2 (1.11)	63.85 (1.17)	59.52 (1.13)

[a] N = 26
[b] N = 28
[c] N = 20
[d] N = 28

Tag Expulsion—Subyearling Chinook salmon that survived to the end of the 120-d holding period rarely expelled or dropped a PIT tag (Table 24). The percentage of lost PIT tags was 0.0% for JSATS, single-battery JSATS, injected PIT, and surgical PIT tag treatment groups. Differences in PIT-tag loss between treatment groups were not significant.

Loss of acoustic tags was somewhat higher. Of fish that survived to the end of the120-d holding period, percentages of expelled or dropped acoustic tags lost were 2% for both JSATS and single-battery JSATS fish. Acoustic tags were lost from standard JSATS fish in replicates 13 (2 fish), 14 (1 fish), 16 (1 fish), and 20 (1 fish). Acoustic tags were lost from single-battery JSATS fish in replicate 16 (2 fish) only.

During the 2008 holding experiment overall, we observed an improvement in tag retention for subyearling Chinook salmon with both PIT and acoustic tags. Such an improvement was not seen in yearling fish during 2008. In 2007, subyearling acoustic-tagged fish lost PIT tags at a rate of 3.4% (4 fish) and acoustic tags at a rate of 7.6% (9 fish). In contrast, during 2008, no subyearling acoustic-tagged fish dropped or expelled a PIT tag, and only 2% (5 fish) dropped or expelled an acoustic transmitter.

Table 24. Percentage of tags dropped or expelled by tag treatment from subyearling Chinook salmon held 120 d at Bonneville Dam. Number of tags lost is shown in parentheses.

	Percent tag loss or expulsion at 120 d (n)			
	PIT tag		JSATS tag	
	Injected	Surgical	Standard	Single-battery
Lost PIT tag	0.00 (0)	0.00 (0)	0.00 (0)	0.01 (1)
Lost JSATS tag	NA	NA	0.02 (5)	0.02 (2)

Prevalence of *Renibacterium salmoninarum*—For the 677 hatchery subyearling Chinook salmon that died before termination of holding, ELISA values ranged from 0.068 to 3.866 (Table 25). Among these fish, mean coded ELISA values were 2.49 for injected PIT, 1.99 for surgical PIT, 1.82 for JSATS, and 1.66 for single-battery JSATS tag treatments and 2.37 for reference fish. Mean coded ELISA values for fish from the reference and injected PIT tag treatment were higher than those of fish from the surgical PIT, JSATS, and single-battery JSATS treatments, and the differences between treatments were significant (Kruskal-Wallis, $P < 0.001$). In a direct comparison of surgically and non-surgically treated fish, a significant difference was found in BKD levels, with the surgical group having lower values (Kruskal-Wallis, $P = 0.036$). Mean ELISA values batched by time of mortality were 0.480 for fish 0-24 d, 2.86 for fish 25-48 d, 2.79 for fish 49-72 d , 3.02 for fish 73-96 d, and 3.23 for fish 97-120 d to mortality.

For the 1143 hatchery subyearling Chinook salmon held at Bonneville Dam that did not die before termination of the study, ELISA values ranged from 0.066 to 3.441. Mean coded ELISA values by tag treatment ranged from 0.54 to 0.76, and no significant difference was found among tag treatments (Kruskal-Wallis $P = 0.401$).

Based on ELISA values, subyearling Chinook in 2008 had a higher prevalence of the Rs antigen than yearling Chinook in 2008 or than subyearling Chinook in 2007 (all treatment groups). Additionally, and unlike the comparisons performed in 2007 and spring 2008, significant differences in levels of BKD antigen were found among treatment groups for subyearling fish that died during holding in 2008. Mean coded ELISA values for reference and injected PIT treatment groups were higher than those of surgical PIT, single-battery JSATS, or standard JSATS groups, and the differences among the treatment groups were significant (Kruskal-Wallis $P < 0.001$). In addition, there was a trend toward higher mean ELISA values in fish that died progressively later in the holding period. These results suggest that while mortality in non-surgically treated fish may have been driven by BKD advancing through time, mortality in surgically tagged fish, which tended to die sooner after tagging and at higher rates, was unlikely to have been related to BKD.

Table 25. Hatchery subyearling Chinook salmon ELISA coded values for RS antigen averaged by replicate and treatment for mortalities of fish held at the juvenile monitoring facility at Bonneville Dam.

	Replicate										
Tag treatment	11	12	13	14	15	16	17	18	19	20	Total/mean
	Fish that survived 120 d										
Injected PIT											
N	4	23	17	6	8	6	9	16	13	9	111
ELISA	3.6	3.35	2.45	2.38	2.91	2.26	2.56	2.61	1.99	0.16	2.49
Surgical PIT											
N	3	26	19	4	8	7	15	10	23	32	147
ELISA	3.19	3.24	2.3	3.33	3.00	1.66	2.02	1.4	2.34	0.24	1.99
JSATS											
N	6	33	10	7	14	9	13	14	22	30	158
ELISA	2.57	3.29	1.93	1.47	2.37	0.63	1.55	1.31	2.39	0.14	1.82
Single-battery JSATS											
N					9	10	12	8	29	31	99
ELISA					3.23	1.82	1.85	2.19	2.33	0.31	1.66
Reference											
N	9	30	8	4	15	4	11	14	28	11	134
ELISA	3.41	3.06	2.4	2.47	2.99	3.4	2.42	2.42	1.6	0.24	2.37
	Fish that died before 120 d										
Injected PIT											
N	30	17	22	35	29	34	30	27	29	26	279
ELISA	0.48	0.68	0.4	0.29	0.9	0.88	0.53	0.51	0.89	0.08	0.57
Surgical PIT											
N	27	12	21	35	31	32	24	30	14	5	231
ELISA	0.33	0.69	0.39	0.46	0.44	0.49	0.84	0.8	0.67	0.08	0.54
JSATS											
N	29	6	29	33	24	30	24	26	18	8	227
ELISA	0.58	0.26	0.51	0.42	0.59	0.78	0.48	0.72	0.45	0.08	0.54
Single-battery JSATS											
N					29	29	26	31	7	7	129
ELISA					0.95	0.49	1.18	0.7	0.55	0.09	0.76
Reference											
N	32	10	31	36	27	36	32	25	13	26	268
ELISA	0.67	0.79	0.48	0.37	0.68	0.74	1.07	0.6	0.55	0.08	0.6

Influence of Hatchery Origin—All subyearling laboratory fish were scanned for CWTs post-mortem. Overall, CWTs were identified in 43% of the laboratory fish (789 tags), representing 7 hatcheries. Table 26 shows the number of coded-wire tagged fish collected by hatchery of origin along with the percentage of these fish with low, medium, or high ELISA values. Table 27 shows the number of coded-wire tagged fish by hatchery of origin and replicate.

Table 26. Survival rates of subyearling laboratory fish with CWTs by hatchery of origin. The percent of CWT-tagged fish by hatchery that had either a low, medium, or high BKD ELISA value is also indicated along with the total number of tags collected.

		ELISA value			
Hatchery Origin	Survival	Low	Med	High	Number of CWTs
Irrigon	0.83	0.47	0.17	0.36	70
Lookingglass	0.00	0.00	0.00	1.00	1
Lyons Ferry	0.65	0.46	0.15	0.39	312
McCall	0.00	0.00	0.00	1.00	2
Nez Perce Tribal	0.60	0.53	0.14	0.33	214
Oxbow-ID	0.77	0.45	0.15	0.40	65
Umatilla	0.66	0.38	0.23	0.38	125

Table 27. Number of CWT-tagged fish by hatchery of origin and replicate during 120-d holding at Bonneville Dam for yearling Chinook. Shaded rows denote survival by hatchery of less than 60%.

	Replicate										
Hatchery Origin	11	12	13	14	15	16	17	18	19	20	Total
Irrigon	3	5	3	7	6	12	11	15	5	3	70
Lookingglass		1									1
Lyons Ferry	39	31	30	32	25	36	31	36	35	17	312
McCall			1		1						2
Nez Perce Tribal		1	2	1	3	5	50	47	40	65	214
Oxbow-ID	26	7	12	13	3	3	1				65
Umatilla	4	12	12	15	33	21	15	4	9		125
Total	72	57	60	68	71	77	108	102	89	85	789

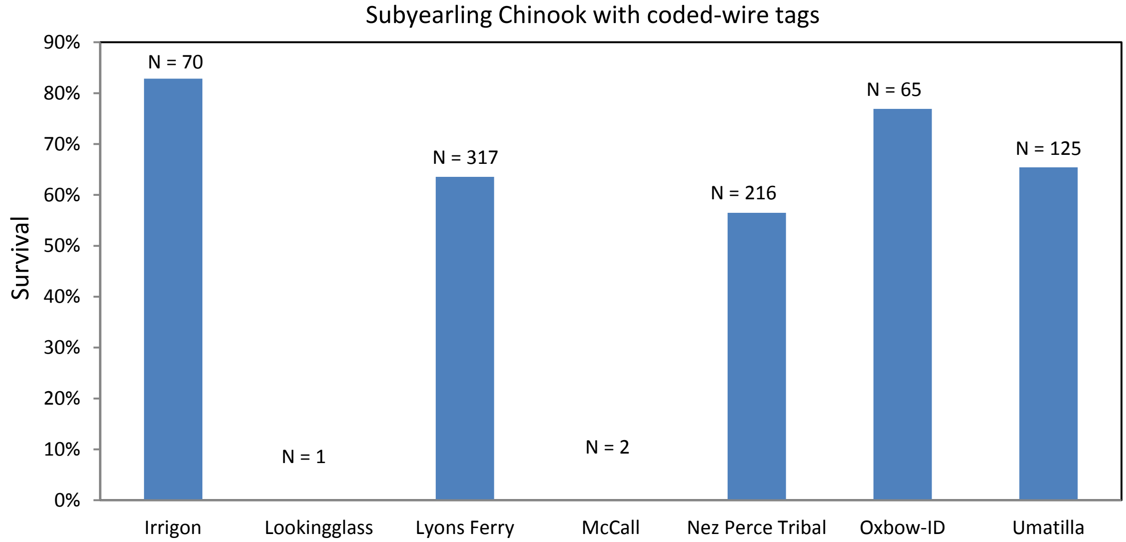


Figure 22. Percent survival during 120-d holding at Bonneville Dam for subyearling Chinook with CWTs by hatchery of origin. The actual number of CWTs collected by hatchery is noted above each bar.

Survival for CWT-tagged subyearling fish ranged from 60 to 83% with two outliers at 0% (Figure 22). Study fish from outlier hatcheries were clustered in time, with one Lookinglass fish collected with replicate 12 and two McCall fish collected with replicates 13 and 15. These comprised a total of only 3 fish.

Approximately 30% of McCall Hatchery subyearling Chinook salmon were marked with CWTs in 2008. Assuming equal survival rates to Lower Granite Dam for hatchery fish with and without CWTs, the total number of McCall Hatchery fish in our sample would not have exceeded 7 fish. Approximately 70% of Lookingglass Chinook salmon were marked with CWTs in 2008. Following the assumptions above, the total number of fish from this hatchery would not have exceeded 2 fish. Furthermore, Lookingglass Hatchery released only yearling spring Chinook in 2008, and this was not our target species. Other coded-wire tagged hatchery fish did not appear to be clustered through time (Table 27).

Overall, our CWT sample numbers were too low for meaningful statistical analysis. However, similar to the yearling study, these low numbers indicated that our study was unlikely to have been biased due to contributions from any one particular hatchery that may have released fish in poor condition during 2008. Similarly, although survival and Rs antigen levels both differed by hatchery of origin, there was no evidence that overall laboratory survival across replicates was biased or negatively influenced by one or more hatchery groups.

Overall results of laboratory holding suggest multi-faceted effects of acoustic vs. PIT-tagging for subyearling fish. Tag effects were hierarchical, with acoustic tag burden contributing to differences in growth and survival over a longer period than incision presence, additional handling, or exposure to anesthetic. Finally, these effects appear to have been enhanced by warm temperatures, particularly those above 15°C.

No significant differences in growth were identified among treatment groups in 2008 ($P = 0.194$), but in 2007 we found a difference in growth between JSATS and PIT treatment groups of 4.5-mm that approached significance (P = 0.061). Differences in weight gain among treatment groups were not significant in either year. For JSATS-tagged subyearling Chinook, an improvement in retention of both PIT and JSATS tags was observed in 2008, although such an improvement was not seen in yearling Chinook. In 2007, JSATS-tagged subyearling fish lost PIT tags at a rate of 3.4% (N = 4) and acoustic tags at a rate of 7.6% (N = 9 tags). In 2008, no JSATS-tagged subyearling dropped or expelled a PIT tag, and only 2% (N = 5) of these fish dropped or expelled an acoustic transmitter.

Lessened tag effects observed in 2008 may be partly attributed to the reduction in transmitter size and subsequent reduction in tag burden, which was ~30% less than in 2007. However, in addition to the smaller tag burden, water temperatures were cooler in 2008 during both tagging and freshwater holding. Anomalously cool river conditions may have contributed to better survival in general, as well as to reduced tag effects. Average river temperatures during the 2008 subyearling study period were 2.2°C lower than the 10-year average (range 1.3-3.0°C).

In 2007, temperatures at Lower Granite Dam were generally similar to the 10-year average. Of the 10 replicates released during 2007, temperatures at tagging exceeded 15°C for 9 replicates and 17°C for 4 replicates. In 2008, temperatures exceeded 15°C during tagging for only 2 of 10 replicates, with temperatures exceeding 17°C during one of these. Total survival at 14 d for this replicate was 0.46 compared to a mean total survival of 0.95 for the other nine.

In our covariate analysis of factors affecting survival for subyearling Chinook, the models that best fit detection and survival probability data from 2007 included an effect of tag type (JSATS or PIT) as well as size of an individual fish at tagging (Appendix B). Environmental variables explained little of the variation observed between paired release groups or between treatment groups within pairs. However, models that included flow, spill exposure, water temperature, and travel time were among those supported by the data. Of these environmental factors, temperature appeared to have the strongest influence on subyearling survival.

EVALUATION OF ANTIBACTERIAL PROPHYLACTIC DIP TREATMENTS IN SURGICALLY TAGGED SUBYEARLING CHINOOK SALMON

Methods

Fish Collection, Tagging, and Assignment to Treatment Groups

A total of 3,200 subyearling fish were collected from the juvenile facility at Lower Granite Dam for evaluation of antibacterial prophylactic dip treatments. Study fish were collected on 10 dates from 2 June through 15 July during the subyearling Chinook migration, and 9 of these 10 dates coincided with collection dates for the long-term holding study. Thus, the size and condition of these fish was similar to that reported for subyearling Chinook collected on the same dates for the long-term holding study (Table 12).

After collection, subyearling fish were sorted under light anesthesia (clove oil and MS-222), transported by bucket to a 975-L holding tank, and held overnight before tagging. On the day of tagging, fish were anesthetized, measured, weighed, and photographed. Surgical protocol was similar to that described for fish in the long-term holding study, except that dip study fish were implanted with only a PIT tag (no JSATS transmitters were used).

The following seven dip treatments were evaluated: hydrogen peroxide at 25, 50, and 100 mg H_2O_2/1 L river water, PolyAqua™, Instant Ocean (salt) at 10 and 30 ppt, and Argentyne™ (iodine diluted 1:1 with water for 100-ppm solution). A group of reference fish was also dipped in untreated river water. Dip treatments were evaluated in terms of potential prophylaxis for incision healing.

Fish were assigned to treatment groups before they were tagged. Treatment assignment followed a predetermined rotation, which ensured that individual surgeons working on a given day would contribute to each treatment group equally, and that each treatment group would have an equal number of fish in recovery at any given time. Each dip treatment fish was photographed again after tagging. Upon completion of this step, fish were sorted by treatment into one of six 75-L containers and allowed to recover from anesthesia. Containers were supplied with flow-through river water and oxygen. The one exception to this protocol was for the Argentyne treatment fish. These fish had Argentyne (diluted 1:1 with water) applied to their incision topically, using a squirt bottle, prior to transfer into recovery buckets (and after the second photo was complete).

Dip treatment baths were prepared after all study fish had been tagged and transferred to their respective recovery containers. Chemical treatments were prepared by adding pre-measured amounts of each chemical to polyethylene pans filled with 36 L of fresh river water. Treatment pans were dark blue and non-porous, and they measured 66.0 × 45.7 × 25.4 cm (Polylewton; U.S. Plastic Corp., Lima, OH). Argentyne and reference baths were filled only with fresh river water. All baths were oxygenated throughout the treatment.

Salt baths were made using Instant Ocean (Spectrum Brands, Inc., Madison WI) to prepare solutions of 360 and 1,080 g/10 L river water for the respective 10- and 30-ppt salt baths. Salt baths were mixed early in the day to allow for maximum dissolution. Just prior to treatment, salt solutions were transferred to the blue treatment bins, and fresh river water was added to bring the entire volume up to 36 L. Salinity was then measured using a handheld refractometer, and additional Instant Ocean was added in 100-g increments as needed to bring them up to 10 and 30 ppt. Salinity level was also verified using a Hanna no. 19828 multi-parameter instrument meter (Hanna Instruments, Woonsocket, RI) and a YSI salinity meter (YSI Inc., Yellow Springs, OH).

Peroxide baths of 25-, 50-, and 100-mg/L were prepared by adding 2.6, 5.1, and 10.3 mL respectively of 35% hydrogen peroxide (Perox-Aid, Eka Chemicals, Inc., Marietta, GA) to 36 L of river water. Activity of each bath was verified using Quantofix Peroxide 100 test strips (Macherey-Nagel, Dueren, Germany). These test strips were only semi-quantitative, with color codes indicating concentrations of 1, 3, 10, 30, and 100 mg H_2O_2/L river water. However, they were used to determine if the concentration of each respective bath fell within the appropriate ranges of 10-30, 30-100, and 100 mg/L for the respective peroxide concentrations of 25, 50, and 100 mg/L.

PolyAqua treatment baths were prepared at the recommended dose of 1 teaspoon per 10 gal water by adding one-half teaspoon PolyAqua concentrate to 36 L river water. Baths for both the reference and Argentyne treatment fish were prepared with 36 L fresh river water only.

Temperature, pH, and dissolved oxygen were measured in each treatment bath at 0, 15, and 30 min (and at 0 and 10 min for 30-ppt salt bath) using the Hanna meter. Total dissolved solids were also measured in the reference bath at time zero using the Hanna meter, and total water hardness was measured using SofChek water quality test strips (Hach Company, Loveland, CO). The Hanna instrument was recalibrated weekly for conductivity (80,000 μS/cm), pH (3 point; 4.01, 7.01, and 10.1), and DO (% saturation), according to the manufacturers recommendations. The temperature of each treatment bath did not vary by more than 0.5°C throughout the 10-30 minute treatments. Dissolved oxygen ranged from 7.11 to 19.0 mg/dL at the start of treatment (mean 9.8 mg/dL) and generally increased through the end of the treatment (mean 12.8 mg/dL; range 7.44-23.0 mg/dL). The pH generally dropped slightly from the beginning (mean 7.9) to the end of treatment (mean 7.3). During the following replicate treatment groups, pH dropped below 7.0 by the end of the treatment:

Replicate 6: H_2O_2 at 25, 50, and 100 mg/L; PolyAqua; and salt at 10 ppt
Replicate 7: reference; H_2O_2 at 25, 50, and 100 mg/L; PolyAqua; and Argentyne
Replicate 9: reference, PolyAqua, and Argentyne

After all seven baths had been prepared, teams of 2-3 people transferred fish from each respective recovery bucket to the appropriate treatment bath using soft nylon dip nets. Time of entry for the first and last fish to each treatment bath was recorded, and treatment time for each group started when the last fish had entered the bath. Among treatments, average time between recovery of the last fish from surgery and the beginning of treatment was 24 min (range 17-43 min).

Fish behavior was monitored, and deviations from normal swimming behavior and spatial distribution were noted. Normal behavior was defined as calm but continuous swimming as opposed to resting on the bottom, jumping, or gulping air at the surface. A group was considered to have normal spatial distribution if individuals were distributed throughout the water column, rather than being clustered at or near the bottom or at the surface. Isolated jumping, some flashing, nosing and gulping were observed in all treatment groups at some point during the study. However, for the most part there was no evidence that group behavior was influenced by a particular treatment or environmental parameter such as acidic pH levels.

Fish were removed after 10 min from the 30-ppt salt treatment and after 30 min from the reference, 10-ppt salt, Argentyne, and hydrogen peroxide (25-, 50-, and 100-mg) treatments. Study fish were removed from baths with dip nets and divided equally between one of two 75-L (19.8 gal) stainless steel holding tanks supplied with flow-through river water, where they were held for an additional 12-24 h.

At the end of the holding period, fish were transferred (water-to-water) to a 1,817-L (480-gal) trailer tank containing pure river water, and transported by truck to the juvenile monitoring facility at Bonneville Dam. Subyearling fish were transported along with long-term holding study fish tagged on the same day. Details of transport were the same as those reported above in the long-term holding section of this report, with the exception that fish were transferred in freshwater. Upon arrival at the Bonneville juvenile monitoring facility, fish were transferred (water-to-water) to 1,893-L (500 gal) circular tanks, where they were held for the remainder of the study.

Dip treatment fish tagged on the same day as fish for the long-term holding study were held separately at the Bonneville Dam facility. Study tanks were maintained with flow-through river water at ambient temperature for 28 d. For subyearling dip-treatment replicates, water temperatures at transfer to the circular tanks varied from 13.2 to 19.4°C. For dip treatment replicates 1-6, temperatures were similar to those shown in Table 14 for long-term holding study replicates 11-16. For the remaining dip study replicates, temperature at transfer to holding tanks was 16.5°C for replicate 7, 17.5°C for replicate 8, 18.6°C for replicate 9, and 19.4°C for replicate 10. Overall, temperatures varied from 13.2 to 20.7°C during the dip test period and followed a temporal trend, increasing over time (Figure 2).

Subyearling dip treatment fish were fed ad libitum a diet consisting of *BioDiet Grower*, a semi-moist pellet (Bio-Oregon) in a mixture of appropriate pellet sizes. Waste food and excrement were continually removed from holding tanks by the self-cleaning action of flow within the tanks. Holding tanks were checked daily for mortalities. Individual dip treatment fish were anesthetized and examined on holding days 7, 14, 21, and 28, and a suite of metrics (Table 28) were rated and recorded by one of two examiners. During this process, right and left lateral full-body photographs were taken of each fish with a Cannon Powershot G9 digital camera, and a close-up photograph of the incision was taken with a Nikon D80 Digital SLR camera. After 28 d of holding, survivors were released to the river to resume migration.

Data Analysis

Relative effects of dip treatments were evaluated three ways. First, to assess overall survival effects, cumulative survival by treatment group was compared at 7, 14, 21 and 28 d using two-factor ANOVA, where replicate "block" was considered a random factor and dip treatment a fixed factor. Following ANOVA, multiple comparisons were conducted using Fisher's LSD.

Second, to examine survival patterns over time, a non-parametric Kaplan-Meier (K-M) "time-to-event" analysis (Hosmer et al. 2008; Lawless 1982) was used. Because fish were released after 28 d, data from more than 28 d were right-censored for this analysis. Kaplan-Meier curves for replicates pooled across treatments were observed to assess seasonal patterns in survival, and curves for treatments pooled across replicates were observed to assess temporal survival patterns. Differences between curves were compared using a log-rank test.

Finally, after confirming where scores for each metric were similar among treatments (both in magnitude and distribution), these metrics were combined, and Kruskal-Wallis non-parametric tests (Hollander and Wolfe 1973) were used to compare mortality between scores for each of metric (Table 29).

Table 28. List of metrics used to evaluate the external appearance of the incision site for subyearling Chinook treatment and reference fish during the dip study, 2008.

Metrics scored at incision site of subyearling Chinook		
Metric	**Definition**	**Scale**
Total sutures present	Total number of sutures present	0, 1, 2
Total knots present	Total number of knots present (number of "throws" remaining is not reflected here)	0, 1, 2
Suture tearing	Evidence that either suture has torn through tissue	Presence/absence
Foreign material present on sutures	Evidence of foreign material	Presence/absence
Inflammation at suture site*	Presence of inflammation associated with sutures (does not describe degree of inflammation, just whether tissue is swollen, pink, or red)	0 = None, 1 = Present (at suture entry, exit, or between), 2 = Present at 2 or more sites (entry, exit, between), 3 = Present at all sites (entry, exit, and between)
Ulceration at suture site*	Presence of ulceration associated with sutures (does not describe the degree of ulceration, just whether underlying dermis is exposed and red)	0 = None, 1 = Present at suture entry, suture exit, or between, 2 = Present at 2 or more sites (entry, exit, between), 3 = Present at all sites (entry, exit, and between)
Incision Healing	Degree to which incision is healed	0 = Completely healed, no scar visible, 1 = Healed but scar still visible, 2 = Incision not healed
Incision apposition	Describes how well the two parallel sides of the incision are approximated (rated by % of total length of incision)	0 = Perfect apposition for entire length of incision, 1 = >50% of incision length perfectly apposed, 3 = <50% of the length of incision perfectly apposed
Incision inflammation	Presence of inflammation by the length of the incision	0 = none, 1 = inflammation on ≤25% of incision length, 2 = inflammation on 26-49% of length, 3 = inflammation on >50% of length

* For inflammation and ulceration at the suture site, the highest scores from the anterior and posterior suture were used for analyses.

Results and Discussion

Survival

Post-treatment mortality for fish (i.e., prior to ponding during holding at Lower Granite Dam or during transport) was low overall, but was not equal among treatment groups (Table 29). Mortality after 24 h was highest for the three peroxide treatment groups (3-8%) and lower for the other dip treatments (<2%). Overall, mortality prior to ponding at the JMF was highest for replicates 7 (8%) and 10 (5%) tagged on 27 June and 16 July respectively, and was 2% or less for all other replicates. Fish that died within 24 of tagging were excluded from analyses.

Preliminary examination of the data showed higher mortality for fish tagged progressively later in the study period, with mortality increasing sharply in the final replicates. Notably, for the last two replicates, mortality exceeded 80% for all treatment groups and occurred very soon after holding began. Due to the high degree of early mortality, fish from these replicates were omitted from analyses.

Table 29. Proportions of fish by dip treatment and replicate that died before ponding at the Bonneville Dam juvenile monitoring. Numbers of fish are shown in parentheses.

		Percent mortality by treatment for subyearling Chinook salmon (n)								
	Dip		Peroxide (H_2O_2)				Salt (ppt)			
	replicate	Argentyne	25 mg/L	50 mg/L	100 mg/L	PolyAqua	10	30	Reference	Total
3 Jun	1	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)
5 Jun	2	0.00 (0)	0.00 (0)	0.05 (2)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.001 (2)
10 Jun	3	0.00 (0)	0.00 (0)	0.00 (0)	0.03(1)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (1)
12 Jun	4	0.00 (0)	0.05 (2)	0.08 (3)	0.00 (0)	0.00 (0)	0.00 (0)	0.03(1)	0.00 (0)	0.002 (6)
18 Jun	5	0.00 (0)	0.00 (0)	0.03 (1)	0.05 (2)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.001 (3)
20 Jun	6	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)
27 Jun	7	0.00 (0)	0.03 (1)	0.30 (12)	0.33 (13)	0.10(4)	0.00 (0)	0.00 (0)	0.03 (1)	0.10 (31)
1 Jul	8	0.03 (1)	0.05 (2)	0.03 (1)	0.05 (2)	0.00 (0)	0.00 (0)	0.03 (1)	0.00 (0)	0.02 (7)
10 Jul	9	0.00 (0)	0.05 (2)	0.03 (1)	0.13 (5)	0.03(1)	0.00 (0)	0.00 (0)	0.00 (0)	0.03 (9)
16 Jul	10	0.08 (3)	0.10 (4)	0.10 (4)	0.23 (9)	0.00 (0)	0.00 (0)	0.03 (1)	0.00 (0)	0.07 (21)
Total		0.01 (4)	0.03 (11)	0.06 (24)	0.08 (32)	0.01 (5)	0.00 (0)	0.01 (3)	0.00 (1)	0.03 (80)

We compared survival only among fish that survived transport to the juvenile monitoring facility at Bonneville Dam. The trend in survival among replicate groups was similar to that observed in fish immediately following recovery from dip treatments, with lower survival in the later replicates. Although none of the treatments produced significantly different survival than the reference group throughout the holding period, at seven days, there were some significant differences in cumulative mortality among the different groups ($F = 2.61$, $P = 0.023$, LSD = 4%). Average mortality was lower for the 30-ppt Salt treatment than for the PolyAqua or the three H_20_2 treatment groups. Average mortality was lower for the Argent treatment group than for the PolyAqua or the 50 and 100 mg/L H_20_2 groups, and was lower for the reference group than for the 50 mg/L H_20_2 group. We found no significant difference in cumulative mortality among treatments at 14 d ($F = 1.74$, $P = 0.122$, LSD = 6%), 21 ($F = 1.81$, $P = 0.107$, LSD = 6%), or 28 d ($F = 1.36$, $P = 0.244$, LSD = 8%). Diagnostics showed good model fit for ANOVA, with high R^2 values (range 83-92 for the four comparisons). Overall, average mortality was fairly high for all groups after 7 d, ranging 17-23% at 14 d, 24-32% at 21 d, and 33-41% at 28 d (Table 30).

Table 30. Average mortality by treatment for combined test replicates at 7, 14, 21, and 28 d for subyearling Chinook salmon held at Bonneville Dam in 2008.

	Average mortality of subyearling Chinook (%)			
Treatment	7d	14 d	21d	28 d
Salt-10 ppt	5.0	17.8	24.4	32.7
Salt-30 ppt	2.8	16.5	25.8	32.8
PolyAqua	8.2	23.3	29.7	37.9
Argentyne	4.1	19.6	27.9	38.1
H_2O_2 25 mg/>	6.7	21.6	31.3	40.9
H_2O_2 50 mg/L	9.0	21.7	30.7	40.2
H_2O_2 100 mg/L	8.6	22.3	31.7	40.2
Reference	4.7	17	26.2	34.2
SE for all	2.0	2	3.2	2.9

The non-parametric K-M curves for replicates over time showed dissimilar temporal patterns (Figure 23). The first two replicates had very little mortality, and the last two had fairly high mortality that primarily occurred in the first 2 weeks. The middle four replicates had intermediate mortality, but did not follow an increasing trend. The K-M curves showed similar temporal patterns of somewhat constant mortality and were not significantly different among treatments (log-rank $\chi^2 = 11.08$, $P = 0.135$, Figure 24).

The objective of these experiments was to identify a treatment that might augment healing and survival in surgically tagged fish. Unfortunately, the results indicate no such benefit from any treatment tested, including a product advertised as a "health aid in aquariums for bruised and lacerated fish" (Novalek Inc. 2010), which produced no "cleaner" or more rapid healing or greater survival than observed in reference fish. In addition, reference fish were among the three treatment groups with highest overall survival, though the differences were not significant. However, these results indicate the possibility that aside from salt, the other chemical treatments tested may even be contraindicated when handling apparently healthy fish.

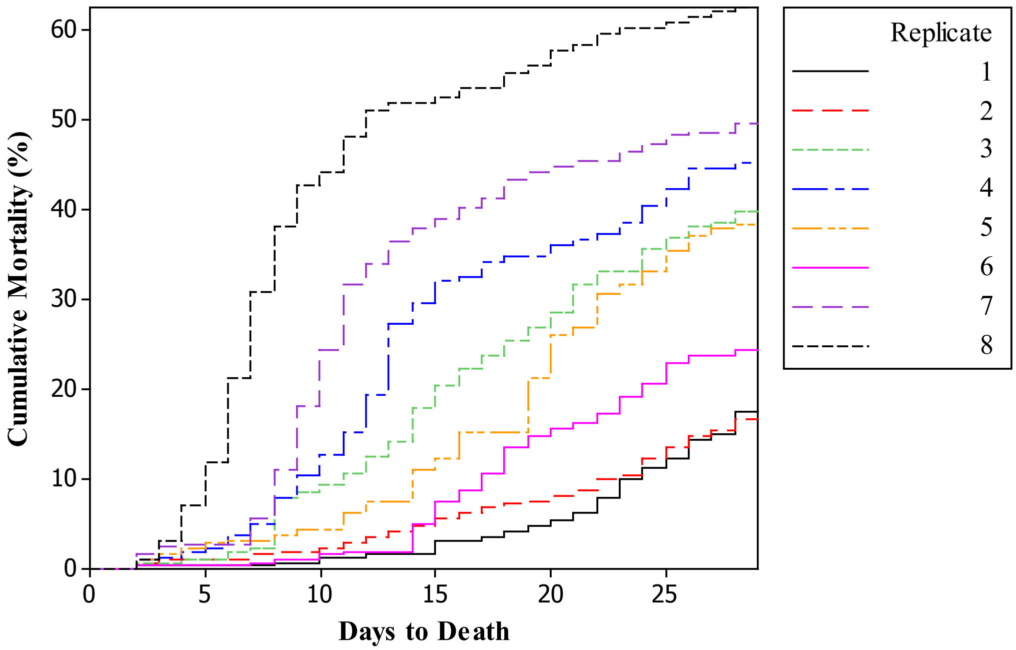


Figure 23. Nonparametric Kaplan-Meier estimated mortality for dip study replicates 1-8 pooled across treatments. Data are right-censored at 28 d.

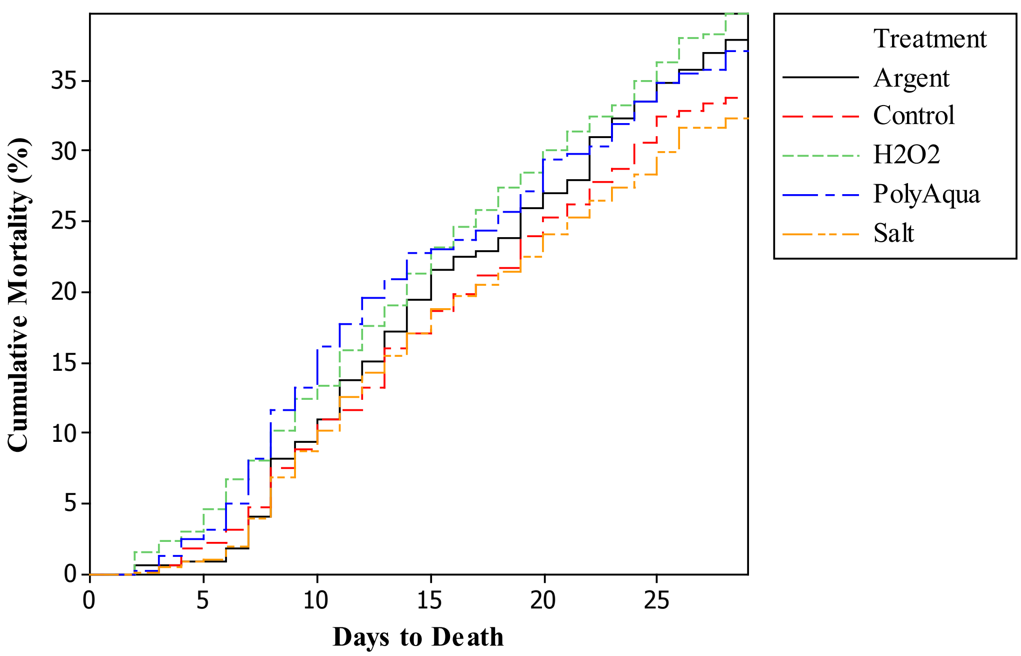


Figure 24. Nonparametric Kaplan-Meier estimated mortality for dip study treatments pooled across replicates 1-8. Data were right-censored at 28 d; the 3 peroxide and 2 salt treatments were very similar and so were pooled for analysis.

Non-parametric K-M curves for survival of individual replicates over time showed a pattern similar to that observed in the long-term holding study wherein the first two replicates experienced little mortality and the last two experienced fairly high mortality. The most obvious variable that changed over time was temperature, and survival differed between fish that were tagged earlier in the study, when water temperature was below ~16°C, to those tagged later at temperatures above 16°C. The higher temperatures at tagging (as well as during transport and holding) likely contributed to mortality for these fish.

Incision Evaluations

Kaplan-Meier testing indicated that aside from suture tearing in replicate 2 of the reference fish, there were no significant differences in incision metric scores among dip treatments. More sutures were torn in reference fish replicate 2 than in other replicates of reference fish or of treatment fish, and the difference among treatments was significant. However, this was only found at the 7-d exam. Therefore, we combined the results of incision metric scoring for all groups to evaluate whether or not these metrics had value in predicting survival. This increased statistical power for the Kruskal-Wallis comparison of mortality between scores for each metric.

Results of these comparisons are reported along with the *P*-values in Table 31. These results showed that at 7 d, fish with 2 sutures intact had higher mortality than those with only 1 suture, and this difference in survival was significant (P <0.001) or with no sutures intact ($P = 0.019$). The difference in mortality between fish with 1 vs. 0 sutures was not significant ($P = 0.261$). At both the 14- and 21-d exams, a pattern was found of increasing mortality with an increasing number of sutures. However, the only significant differences observed in mortality rates was between fish with 2 vs. 0 sutures ($P = 0.001$ and $P = 0.002$ at 14 and 21 d respectively; Table 31). The relationship between mortality and the number of ligatures with intact knots followed a pattern very similar to that seen for numbers of sutures present (Table 31).

The accumulation of foreign matter on suture material, was higher for fish that died before the end of the holding period and this distinction between fish that ultimately lived or died at 28d was significant in examinations at 7 ($P < 0.001$), 14 ($P = 0.004$), and 21 d ($P < 0.001$). In total, foreign matter was identified on sutures in 238 of 2,087 fish examined at 7 d (11.4%), 186 of 1,589 fish examined at 21 d (11.7%), 273 of 1,474 fish examined at 21 d (18.5%), and 159 of 1,496 fish that survived to 28 d (10.6%).

Table 31. Percent mortality for each incision metric score as rated by examiners at 7, 14, and 21 d for all treatments combined. *P*-values for Kruskal-Wallis statistical comparisons are reported for each comparison.

Metric evaluated	Score or comparison	Pooled mortality of dip treatment subyearlings (%) 7 d	14 d	21 d
Number of sutures present	0	27.7	18.0	11.5
	1	23.4	22.6	14.1
	2	35.1	24.8	17.8
	0 vs. 1 vs. 2	$P < 0.001$	$P = 0.003$	$P = 0.011$
	0 vs. 1	$P = 0.261$	$P = 0.095$	$P = 0.254$
	0 vs. 2	$P = 0.019$	$P = 0.001$	$P = 0.002$
	1 vs. 2	$P = 0.000$	$P = 0.443$	$P = 0.257$
Number of knots intact	0	29.6	18.2	11.5
	1	22.2	22.6	14.5
	2	35.1	24.8	17.3
	0 vs. 1 vs. 2	$P < 0.001$	$P = 0.004$	$P = 0.018$
	0 vs. 1	$P = 0.043$	$P = 0.102$	$P = 0.231$
	0 vs. 2	$P = 0.069$	$P = 0.001$	$P = 0.008$
	1 vs. 2	$P < 0.001$	$P = 0.473$	$P = 0.420$
Fungus present	0	30.1	19.3	12.0
	1	54.6	31.5	18.7
		$P < 0.001$	$P < 0.001$	$P = 0.004$
Suture tearing	0	32.2	22.3	13
	1	32.8	21.1	13.1
		$P = 0.787$	$P = 0.564$	$P = 0.999$
Inflammation at suture entrance/exit site	0	27.6	20.0	12.2
	1	34.8	17.8	12.5
	2-3	38.1	23.8	13.6
	0 vs. 1 vs. 2	$P < 0.001$	$P = 0.105$	$P = 0.811$
	0 vs. 1	$P = 0.006$		
	0 vs. 2-3	$P < 0.001$		
Ulceration at suture entrance/exit site	0	29.9	20.7	12.5
	1	33.5	18.4	
	2, 4	40.4	23.6	
	1, 2, 3, 4			12.6
	0 vs. 1 vs. 2	$P < 0.001$	$P = 0.458$	$P = 0.999$
	0 vs. 1	$P = 0.271$		
	0 vs. 2, 4	$P < 0.001$		
Incision apposition	0	32.4	20.5	12
	1	32.1	18.0	
	2	30.4	23.4	
	1, 2			17.6
	0 vs. 1, 2			$P = 0.043$
	0 vs. 1 vs. 2	$P = 0.646$	$P = 0.375$	

Table 31. Continued.

Metric evaluated	Score or comparison	Post-surgery mortality 7 d	14 d	21 d
Incision inflammation	0	28.6	20.2	13.0
	1	30.0	21.3	10.6
	2	31.7	23.0	
	3	39.9	19.9	
	2-3			12.8
	0 vs. 1 vs. 2 vs. 3	*P* = 0.002	*P* = 0.784	
	0 vs. 1 vs. 2	*P* = 0.532		
	0 vs. 1 vs. 2, 3			*P* = 0.518
Incision healing	0, 1	28.7	20.8	12.2
	2	32.8		13.4
	2, 3		20.7	
	0, 1 vs. 2	*P* = 0.115		*P* = 0.560
	0, 1 vs. 2, 3		*P* = 0.999	

Examination at 7 and 14 d showed evidence that inflammation at suture entrance and exit sites was correlated with survival (*P* <0.001 at 7 d and *P* = 0.105 at 14 d), and a trend toward higher mortality in fish with higher levels of inflammation was observed. Fish with higher ulceration scores at 7 d were also more likely to die before the end of the observation period (*P* <0.001). Poor incision apposition was found to be positively correlated with mortality only in the exam at day 21 (*P* = 0.043). Finally, the degree of inflammation at the incision site on d 7 was correlated with morality: fish were more likely to die during the observation period if evidence of inflammation was found along more than 50% of the length of the incision at the d 7 examination (*P* = 0.002). Metrics for evidence of suture tearing and for evaluation of incision healing did not appear to be significantly related to mortality.

Examination of mortality by surgeon did show trends in survival related to tagging personnel, both among the primary surgeons and those who tagged periodically throughout the study period (designated as other). Eight primary surgeons implanted PIT tags in a total of 2,297 dip treatment and reference fish (range 127-451 each) evaluated over the eight replicates. Five of these eight surgeons generally tagged ~64 fish each on replicate days when they were present. The number of replicate days attended by primary surgeons ranged from 2 to 7. Four other surgeons tagged a total of 262 fish (range 34-99 each) over the 8 replicates, with each surgeon attending 1-2 replicate tagging sessions and each marking 4-66 fish.

Least-square means for mortality ranged from 28.2 to 54.8% among surgeons, but ranged widely among replicates (21.0-66.8%). Because individual taggers were not present consistently throughout the study period, comparisons of mortality cannot be used to draw definitive conclusions. However, when survival to 28 d was compared among surgeons ranked within individual replicates, there was evidence of differential survival among surgeons (Table 32), and individual surgeons were consistently ranked as having higher or lower survival relative to their cohorts.

Table 32. Mortality ranked among surgeons for the 5 present at each of 8 dip study replicates (2 of 10 replicates excluded). Totals show cumulative rank scores, and mean rank shows cumulative rank divided by number of sessions attended. Lower ranks indicate higher mortality, and vice versa.

	Rank among the 5 surgeons per replicate										
Surgeon	1	2	3	4	5	6	7	8	Total	Mean rank per session (1-5)	Rank of means among all surgeons (1-9)
A	2	1			2	3		3	11.0	2.2	5
B	5	2	5		5	4	5	4	30.0	4.3	8
C				2			1		3.0	1.5	2
D	1	3	1.5	3	1				9.5	1.9	3
E		5		4			3	2	14.0	3.5	7
F				1	3				4.0	2.0	4
G	4	4	4	5	4	5		5	31.0	4.4	9
H			1.5			1	2	1	5.5	1.4	1
Other*	3		3			2	4		12.0	3.0	6

* Combined rank for four surgeons who tagged on a periodic basis.

When we examined the mean number of sutures remaining at 7 d by surgeon, we found that surgeons achieving high mean suture retention (1.9-2.0 sutures) also had higher mortality relative to peers at 28 d than those with the lowest mean suture retention (1.1-1.3 sutures). Figures 25 and 26 show a representative selection of photographs at 7 d from surgeons that were consistently ranked as having either the highest (B and G) or lowest survival relative to cohorts (C, D, and H). At 28 d, survival data revealed that surgeons with the highest relative mortality (and highest suture retention) generally tied more concise, secure knots/ligatures compared to surgeons with the lowest mortality (and lowest suture retention). In general, by 7 d post-surgery, any remaining ligatures tied by surgeons with the lowest relative mortality at 28 d, were loose and beginning to pull out of the skin.

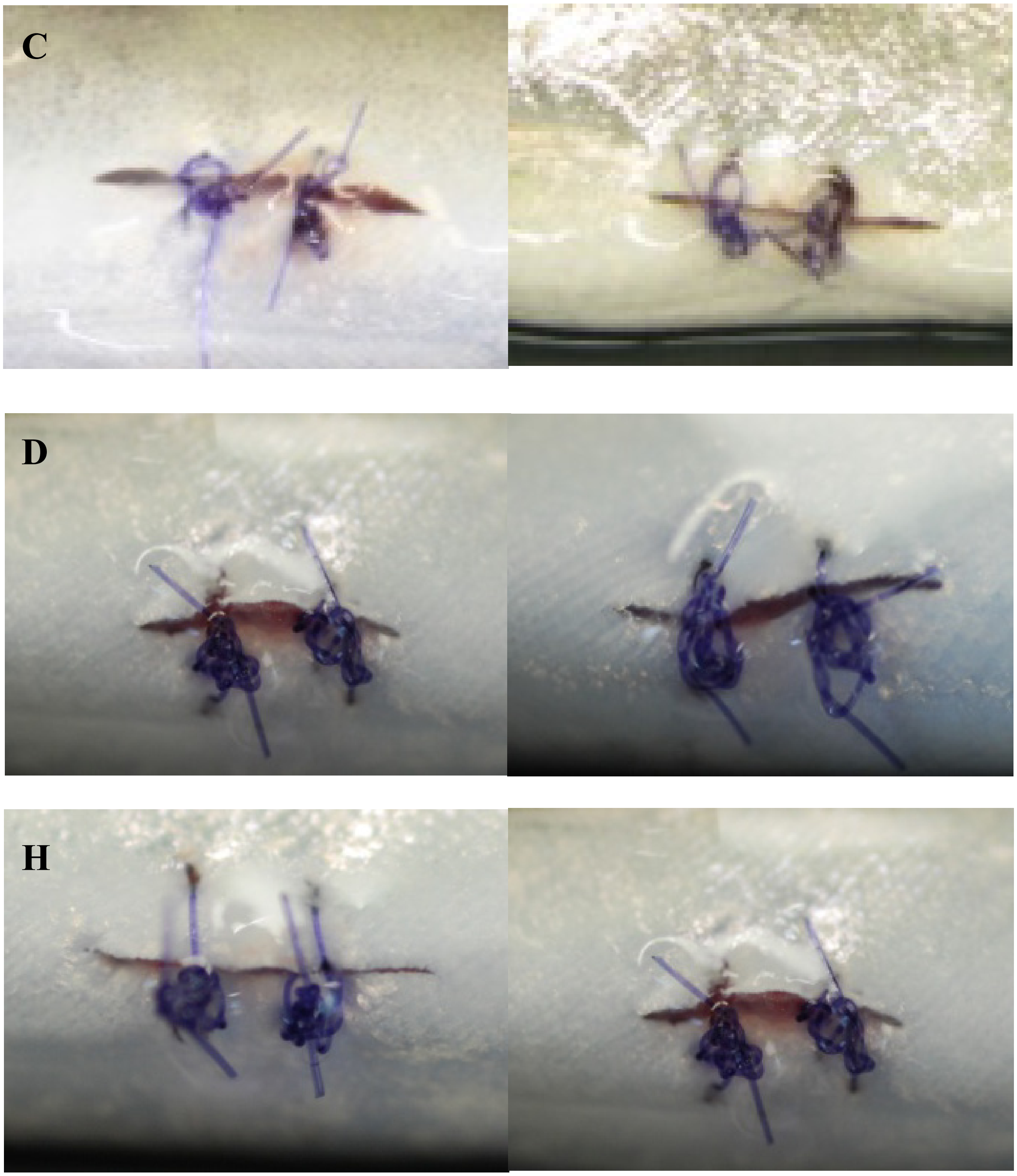


Figure 25. Representative photos of sutures from the three surgeons with the lowest survival relative to cohorts (Table 32). All photos were taken at the 7 d exam. Fish shown were tagged on 3, 10, and 12 June 2008.

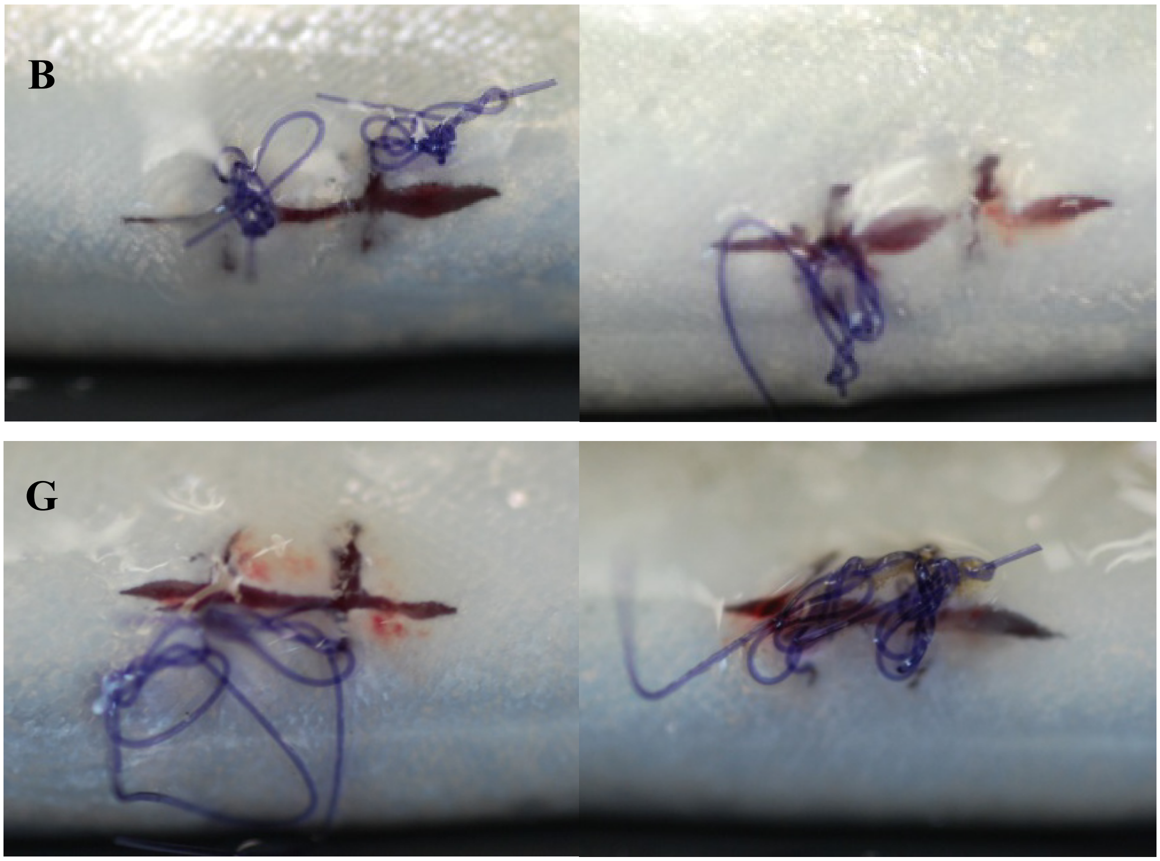


Figure 26. Representative photos of sutures made by the two surgeons with the highest survival relative to cohorts . All photos were taken at the 7 d examination of fish tagged 3 June 2008.

Results of these analyses indicated that the most consistent predictor of mortality through 28 d (e.g. significant at 7, 14, and 21 d) was either the presence of two secure ligatures or the presence of foreign matter on one or more of the ligatures. These results indicate that a component of the tag effects observed during study years 2007 and 2008 may have been driven in part by suture presence and/or secondary fouling. Similar observations were made during preliminary JSATS studies by McComas et al. (2005), who expressed concern over the potential for secondary infection in surgically tagged fish due to long-term retention of sutures.

For fish with sutures persisting until the 7 d exam or later, higher mortality may have occurred due to secondary infection from pathogens such as bacteria or fungi that had accumulated on the sutures. Where foreign matter had accumulated on sutures, there was often evidence of secondary dermal ulceration directly beneath the mass of foreign material. These ulcers could have facilitated infection.

We observed a relationship between suture presence and survival only in subyearling fish transported directly from Lower Granite Dam after tagging. A similar phenomenon was not seen in fish subsampled (SbyC) from the inriver migrant releases of yearling Chinook in 2007 and 2008 or of subyearling Chinook in 2007. However, the SbyC sampling technique was biased towards the 10 most robust fish, or those that arrived first, from each release and treatment group. Furthermore, in 2007 we were able to recapture only 9 of the 100 acoustic-tagged subyearling Chinook salmon targeted by the SbyC systems. This was presumably due to high inriver mortality for this treatment group in 2007.

Finally, it is important to note that dip study fish were tagged only with PIT-tags rather than with both PIT- and acoustic- tags. Therefore, although it appears that suture retention was correlated with mortality during this study; we cannot predict whether or not their presence would have been necessary for acoustic tag retention.

CONCLUSIONS AND RECOMMENDATIONS

Synthesis of Study Results from 2008

Major advancements in acoustic tag construction, including miniaturization, have been made in recent years. These developments prompted the current investigation to compare the performance of acoustic-tagged and PIT-tagged juvenile salmon. The purpose of this comparison was to inform regional discussions of model assumptions, such as whether the models are valid for use with the JSATS acoustic tag technologies in large-scale studies over long distances and in relatively small fish, such as juvenile yearling and subyearling Chinook salmon. Survival estimation models that rely on releases at multiple locations or on multiple dates require validation of the assumption that the likelihood of post-release mortality and tag loss over the reach in question is equal among all individuals (Skalski et al. 2009).

The Columbia River hydropower system is an ideal area for these studies because it can be subdivided into smaller study reaches between dams. Our evaluations were based on detections at three dams on the mainstem Columbia River and three on the lower Snake River. Each of these six dams is equipped with juvenile bypass systems and PIT-tag detection capability, which allow direct comparison of survival and behavior between tag treatment groups. Using these and other facilities at the dams, we compared groups of migrating juvenile Chinook salmon either injected with a PIT tag or surgically implanted with both a JSATS tag and a PIT tag.

In 2006, we conducted a pilot study to compare the effects of acoustic vs. PIT tagging on migrating yearling Chinook salmon. However, results were inconclusive due to lack of replication among acoustic-tagged release groups and inadequate sample sizes of acoustic-tagged fish (JSATS tags were not available in time for the spring migration). In 2007, field and laboratory studies were again conducted to identify differences among tag treatment groups in behavior, survival, growth, and tag loss.

Results of field work conducted in 2007 suggested that both yearling and subyearling Chinook with acoustic implants may experience lower survival and may behave differently and/or be guided into bypass systems at dams differently than PIT-tagged fish. Estimated survival varied with distance from release and travel conditions (e.g., flow volume, temperature). Results of laboratory diagnostic work conducted in tandem with field studies in 2007 also showed that there may be adverse effects related to stress, possibly induced by the higher tag burden (tag weight/body weight) experienced by fish tagged with both the JSATS and PIT tag compared to those tagged only with a PIT tag.

We also observed a tendency for the presence of the acoustic transmitter to elicit inflammatory reactions within the peritoneal cavity, as well as direct effects of the surgical tagging procedure. Slower healing was observed at JSATS surgical incision sites than at PIT-tag injection wounds. These effects were likely greater in subyearling than in yearling Chinook because of their smaller size, more metabolically active status, and typical experience of less favorable river conditions during migration (i.e., warmer temperatures and lower flow volumes).

Tagging experiments were repeated in 2008 and included replicates of yearling Chinook collected both for tagging and release to the river and for tagging and long-term holding in the laboratory. Replicates of subyearling Chinook were collected in 2008 only for long-term holding. Actively migrating subyearling Chinook salmon were excluded from field experiments using the JSATS tag in 2008 because of low detection probabilities observed in these fish in 2007 at some dams, combined with their poor survival to McNary Dam.

Additional replicates of reference fish were collected for both the yearling and subyearling long-term holding experiments to evaluate the effects of surgery. These fish were subjected to the surgical process (incision and suture placement) and were implanted with a PIT tag, but were not subjected to the additional burden of a JSATS tag. A subsample of subyearling Chinook from this experimental group was also taken for tests to identify whether potential dip treatments, such as hydrogen peroxide, salt, Argentyne, or Polyaqua would promote surgical incision healing. The JSATS transmitter in 2008 was reduced in volume by ~40% and in weight by ~30% compared to the transmitter used in 2007.

In 2008, JSATS-tagged yearling Chinook had a mean fork length of 134 mm (range 92-202 mm), a mean weight of 23.1 g (range 7.2-50.3 g), and experienced a mean tag burden of 2.3% from the combined presence of the acoustic transmitter and PIT tag. Mean tag burden from the acoustic tag alone was 1.8%. In 2008, JSATS-tagged subyearling Chinook had a mean fork length of 110.4 mm (range 95-131 mm) and a mean mass of 12.9 g (range 8.0-23.1 g). These fish experienced a mean tag burden of 4% (range 2.3-6.5%) from the combined presence of the acoustic transmitter and PIT tag and a mean tag burden of 1.8-5.3% from the acoustic transmitter alone. In the lists below, we summarize the major findings by life history type from field and laboratory evaluations conducted in 2008. We then discuss our interpretations and conclusions based on these findings.

Yearling Chinook salmon

1. Mean detection probability was higher for JSATS-tagged than PIT-tagged fish at Little Goose, Lower Monumental, and John Day Dam. Differences in mean detection probability were 0.04 at Little Goose, 0.05 at Lower Monumental, and 0.06 at John Day Dam, and these differences were all significant ($\alpha = 0.05$). Mean detection probability at Ice Harbor Dam was 0.03 higher for JSATS-tagged fish than PIT-tagged fish, and the difference approached significance ($P = 0.067$). Mean detection probabilities were not significantly different between tag treatment groups at McNary and Bonneville Dams ($P = 0.242$ and 0.174, respectively).

2. In the Snake River, mean relative survival (ratio of estimates for JSATS-tagged/PIT-tagged fish) was 0.97 to Little Goose ($P = 0.107$), 0.95 to Lower Monumental ($P = 0.096$), and 0.96 to Ice Harbor Dam ($P = 0.336$). In the Columbia River, mean relative survival was 0.91 to McNary ($P = 0.095$), 0.72 to John Day ($P = 0.001$), and 0.75 to Bonneville Dam ($P = 0.021$). Thus, we observed lower estimated survival rates in JSATS-tagged than in PIT-tagged fish at all dams, with differences that were statistically significant at John Day and Bonneville Dam and that approached significance at Lower Monumental and McNary Dam.

3. Significant differences in travel time between tag groups were observed only to John Day Dam ($P = 0.019$), with JSATS-tagged fish taking 0.81 d longer to reach this detection site.

4. Overall mean PIT-tag recovery from upper river bird colonies was 2.0% for JSATS-tagged fish and 1.0% for PIT-tagged fish. From estuarine colonies, overall mean PIT-tag recovery was 3.0% for JSATS-tagged fish and 4.0% for PIT-tagged fish. Although the 1% difference in tag-recovery rate at the upriver colonies was statistically significant ($P = 0.016$), the difference was not likely of biological importance. The difference in recovery rate at estuarine colonies was not significantly different between tag treatments ($P = 0.881$).

5. The majority of inriver migrating fish recaptured at McNary Dam using separation-by-code (SbyC) were described as having opaque, frayed, or missing fins. This was seen in fish from both tag treatments and included 79% of recaptured PIT-tagged fish and 90% of recaptured JSATS-tagged fish. In contrast, a majority of reference fish, both from initial collections at Lower Granite Dam and from recaptures downstream at Bonneville Dam, were described as having normal fins. Additionally, 13% of the JSATS-tagged fish recaptured at McNary Dam were described as having eyes that were hemorrhagic. In contrast, 99% of the reference fish collected at Lower Granite Dam were described as having normal eyes. These observations indicated that study

fish had experienced trauma sometime between release and recapture. In addition, of the study fish recaptured at McNary Dam, a larger proportion of JSATS- than PIT-tagged fish had hemorrhagic eyes , and the difference was significant (*P* = 0.003).

6. For both tag treatments, gross necropsy revealed less caecal and mesenteric fat in fish collected at McNary and Bonneville Dam than in reference fish that had been collected at Lower Granite Dam at the time of tagging. However, both caecal and mesenteric fat were rated similarly among treatment groups at these locations. Splenic engorgement/ enlargement was more prevalent in reference fish than in treatment fish of either tag type recaptured at McNary or Bonneville Dam. Enlarged spleens were observed in a higher percentage of fish collected at McNary than at Bonneville Dam. However, comparisons based on gross necropsy between reference fish and treatment fish collected downstream were not evaluated statistically.
   The percentage of fish observed with food in the stomach was higher in PIT-tagged than in JSATS-tagged fish at Bonneville Dam, and this difference was significant (*P* = 0.038). However, there was no difference in this metric between tag treatments at McNary Dam. More than 99% of all reference fish and recaptured (SbyC) fish were rated as having normal kidneys upon gross examination. Liver abnormalities were seen in both the reference and recaptured fish, and were of similar prevalence among treatment groups.

7. Comparative histopathology metrics varied by recapture site and were mixed with respect to nutritional indicators, with some being higher in JSATS-tagged and others in PIT-tagged fish. However, histological indicators of inflammation and healing showed a consistent pattern of higher inflammation and slower healing in JSATS than PIT-tagged fish. For example, chronic inflammation within the mesentery was more prevalent in JSATS- than PIT-tagged fish recaptured (SbyC) at both McNary and Bonneville Dams (*P* = 0.001). While chronic inflammation of the mesentery was present in both tag treatment groups, it was rated as more severe in JSATS-tagged fish at both recapture sites (*P* < 0.001).

   Microscopic evidence of chronic inflammation within the mesentery was more prevalent in JSATS- than in PIT-tagged fish recaptured at both McNary and Bonneville Dams (*P* = 0.001). Chronic peritonitis was higher in JSATS- than PIT-tagged fish recaptured at Bonneville Dam (*P* = 0.001). Poor apposition of the incision was also more common in JSATS- than PIT-tagged fish at Bonneville Dam (*P* = 0.006), as were internal adhesions at the incision site (*P* = 0.063). Microscopically, incisions/injection wounds were more often rated as "not visible" in PIT- than in JSATS-tagged fish at both McNary and Bonneville Dams *P* = 0.001).

8. Rs antigen levels were evaluated using enzyme-linked immunosorbent assay. For hatchery yearling Chinook, the range of Rs antigen levels was 0.065-0.335 in reference fish (with one outlier at 1.11), 0.069-0.289 in both JSATS- and PIT-tagged fish recaptured (SbyC) at McNary Dam, and 0.076-0.540 for fish of both tag treatments recaptured at Bonneville Dam. For fish recaptured at McNary Dam, ELISA values were quite low for all but one JSATS-tagged and one PIT-tagged fish; therefore, no statistical analyses were conducted to evaluate differences between treatments. At Bonneville Dam, 13% of JSATS-tagged and 11% of PIT-tagged fish had moderate ELISA values, and the difference was not significant ($P = 0.830$).

9. For yearling Chinook salmon held in the laboratory, mean survival was not significantly different among fish surgically implanted with the JSATS tag, injected with a PIT tag, surgically implanted with a PIT tag, and or handled and anesthetized but not tagged (reference fish). Among these four groups, survival rates did not differ significantly after 14 d, between 14 and 28 d, or between 28 and 120 d ($P = 0.333$, 0.282, and 0.947, respectively). Among fish that survived to termination of holding at 120 d, neither mean growth (mm) nor gain (g) were significantly different among treatments ($P = 0.628$, and $P = 0.436$ respectively).

10. Of the JSATS-tagged yearling Chinook that survived to termination of the holding experiment at 120 d, 21 (8%) expelled or dropped acoustic tags, but only 1 (0%) lost or expelled a PIT tag. Of fish either injected or surgically implanted with only a PIT tag that survived to 120 d, none dropped or expelled a tag. Both acoustic and PIT-tag losses were determined post-mortem at the time of necropsy.

11. In fish of both tag types that died before termination of the laboratory-holding study at 120 d, prevalence of Rs based on ELISA values ranged from 0.064 to 3.738. There were no significant differences in Rs antigen levels among tag treatment groups (Fisher's LSD, $P = 0.313$). In fish of both tag types that survived to study termination, Rs antigen levels ranged from 0.28 to 0.44, and there were no significant differences in Rs levels among tag treatment groups ($P = 0.323$).

12. Assessment of Rs prevalence in laboratory-holding fish marked with a coded-wired tag indicated that no single hatchery group contributed fish to our samples that were obviously compromised in numbers sufficient to influence the study results.

Subyearling Chinook Salmon

1. In the laboratory, mean survival at 14 d was significantly different for JSATS-tagged (0.85) and surgically PIT-tagged subyearling Chinook salmon (0.88) than for their injected PIT-tagged (0.97) or non-tagged cohorts (0.94)($P = 0.037$). Fish with a single-battery JSATS tag were excluded from these comparisons due to the low number of replicates for this treatment. Survival estimates were not significantly different among treatment groups in the 14-28 d period ($P = 0.827$) or in the 28-120 d period ($P = 0.515$). Among fish that survived to 120 d, neither mean growth (mm) nor mean weight gain (g) was significantly different among treatment groups ($P = 0.194$ for length and $P = 0.515$ for weight).

2. For subyearling Chinook salmon that survived to the end of the 120-d holding period, only one fish (single-battery JSATS tagged) passively dropped or expelled a PIT tag. A total of 5 (2%) standard JSATS and 2 (2%) single-battery JSATS-tagged fish dropped or expelled acoustic tags. Due to the small number of tags recovered from holding tanks, it was not possible to determine the timing of tag loss.

3. Rs antigen values as measured by ELISA for subyearling Chinook that died before termination of the laboratory holding study ranged from 0.068 to 3.866. Fish with JSATS and surgically implanted PIT tags had lower ELISA values than those with injected PIT tags and reference fish. These values were significantly different ($P < 0.001$). Rs antigen levels for fish that survived until termination of the experiment at 120 d ranged from 0.540 to 0.760. There was no significant difference in ELISA values among fish that survived through termination ($P = 0.401$).

4. Assessment by ELISA of Rs antigen levels in subyearling laboratory fish marked with coded-wire tags indicated that no single hatchery group contributed fish to our samples that were compromised in numbers sufficient to influence study results.

5. Of the seven dip treatments tested for potential use as a prophylactic against bacterial infection, none appeared to reduce inflammation or to produce cleaner or more rapid healing or greater survival than observed in reference fish. However, results of these analyses indicated that the two most consistent predictors of mortality at 28 d were the presence of either two secure ligatures or of foreign matter on one or more of the ligatures. These results indicated that a component of JSATS-tag effects, to the extent that effects have been observed, may be driven in part by suture presence and/or secondary fouling.

Conclusions Based on Results from 2006 to 2008

Despite continued success in miniaturization of the JSATS acoustic tag, results of research conducted in 2006, 2007, and 2008 indicated that yearling and subyearling Chinook salmon surgically implanted with this tag behaved differently at some locations within the Columbia River hydropower system and survived at different rates through the system than their counterparts injected with only a PIT tag. Some of the differences between treatment groups were statistically significant at the first detection site (i.e., at Little Goose Dam), indicating differences had developed within 4-5 d of release.

Inriver Survival

Significant differences in survival over varying distances from release were observed between tag treatment groups in all study years for both yearling and subyearling fish, with the majority of comparisons showing higher survival for PIT- than JSATS-tagged fish. In both 2006 and 2007, estimated survival to one detection site was higher for JSATS- than PIT-tagged yearling Chinook. In 2006 this site was Little Goose Dam ($P = 0.004$), and in 2007 estimated survival was higher for JSAT-tagged yearling Chinook to Lower Monumental Dam, and the difference approached significance ($P = 0.080$). However, in 2007, estimated survival to all other detection sites was higher for PIT- than JSATS-tagged fish. These differences approached significance at McNary ($P = 0.054$), and were significant at John Day ($P = 0.010$) and Bonneville Dam ($P = 0.001$).

In 2008, estimated survival to all downstream detection sites was higher for PIT- than JSATS-tagged yearling Chinook salmon. These differences approached significance at Lower Monumental ($P = 0.096$) and McNary Dam ($P = 0.095$) and were significant at John Day ($P = 0.001$) and Bonneville Dam ($P = 0.021$). Differences in estimated survival between the 2008 tag treatment groups were not significant at Little Goose or Ice Harbor Dam. In both the 2007 and 2008 studies, difference in survival between JSATS- and PIT–tagged fish tended to increase with increasing distance from release, and estimated survival was higher for PIT-tagged fish.

In 2007, mean survival of larger (mean length = 107 mm) subyearling Chinook salmon was significantly higher for PIT-tagged than AT subyearling Chinook from Lower Granite Dam to both Little Goose ($P = 0.003$) and McNary Dams ($P = 0.001$).

Covariate Analysis of Factors that Effected Survival

In both 2007 and 2008, we observed considerable variation in relative survival to a given location among sets of paired-release tag treatment groups of Chinook salmon. Environmental data indicated that different release groups were subjected to different environmental conditions during both the spring and summer study periods in 2007. In the Snake River, we suspect that flow affected the survival of yearling Chinook tagged in spring, and temperature affected the survival of subyearlings tagged in summer. To investigate potential relationships between environmental variables and detection and survival probability estimates, we included environmental variables in our analysis of the effects of tag type and fish size on these probabilities. Variables evaluated were flow, spill proportion, and water temperature (Appendix B).

In general, the best-fitting models for both detection and survival probabilities were those that included an effect of tag type (JSATS or PIT) and of size (FL) at tagging. Some models showed that there may have also been a small interaction effect between tag type and size at tagging (i.e., the effect of the tag depended on the size of the fish). In addition, although the environmental covariates explained little variation between paired release groups or between treatment groups within pairs, all of the explanatory variables (flow, spill proportion, water temperature, and travel time) were included in models that were supported by the data.

Among these variables, spill proportion (which was correlated with flow) appeared to be the most important factor affecting estimated survival for yearling Chinook in 2008, while water temperature appeared to have the strongest influence on survival of subyearling Chinook in 2007. However, for yearling Chinook in 2007, results for models that included environmental variables were biologically counterintuitive, with survival dropping at greater exposures to spill/higher flows. We concluded that since analyses of environmental covariates to date have suffered from correlated and potentially confounded predictor variables, multiple years of data would be required for these analyses to produce more definitive results.

Statistical Power and Detectable Differences

The downstream migration portion of this study was designed to identify differences in survival of at least 5% between tag treatments from Lower Granite to McNary Dam in 2007 and to from Lower Granite to John Day Dam in 2008. Sample sizes were determined for 80% power to detect the 5% difference using significance levels of $\alpha = 0.10$ in 2007 and $\alpha = 0.05$ in 2008. However, despite this robust study design, we were unable to achieve statistical power of 80% at these locations and many others. This failure resulted from different problems in acquiring data that were encountered in each of the three study years.

In 2006, less than 30% of the 3,500 JSATS tags intended for the migration study were available when fish began migrating, which resulted in forfeiture of nearly 60% of the acoustic-tag study replicates. Thus, we made no inference based upon the 2006 results and treated this study year as exploratory rather than conclusive.

In 2007, detection probabilities were lower than anticipated, and this affected our ability to detect differences as small as 5% at each detection location. However, the estimated differences in survival to John Day and Bonneville Dam were still statistically significant because they were much greater than 5%, and the estimated difference in survival to McNary Dam of 8% approached significance ($P = 0.054$). In the Snake River, estimated differences in survival were either equal to or less than 5% at each detection location (e.g. 1% at Little Goose, 5% at Lower Monumental, and 4% at Ice Harbor) and not significant at $\alpha = 0.05$.

In 2008, midway through the yearling Chinook study period, the Snake and Columbia Rivers experienced unusually high flows and heavy debris loads. These heavy flows and debris loads compromised PIT-detection capability at the dams, and we failed to achieve 80% power to identify differences of 5% at every detection location except Little Goose Dam. High variability in estimated relative survival among replicate release groups also compromised statistical power in 2008. The minimum detectable difference with 80% power at $\alpha = 0.05$ was approximately 8% at Lower Monumental, 12% at Ice Harbor, 15% at McNary, 19% at John Day, and 28% at Bonneville Dam.

Nonetheless, observed differences in estimates of survival to John Day and Bonneville Dams were sufficiently large to achieve statistical significance ($\alpha = 0.05$) in 2008. Similar to 2007, the observed difference in survival to McNary Dam of 9% approached significance ($P = 0.095$), and within the Snake River, the observed differences were either equal to or less than 5% at each detection location (e.g. 3% at Little Goose, 5% at Lower Monumental, and 4% at Ice Harbor) and not significant at $\alpha = 0.05$.

Detection Probability

For yearling Chinook released to the river in 2007, detection probabilities were significantly different between tag treatments at Little Goose ($P = 0.004$) and McNary Dam ($P = 0.018$) and approached significance at Bonneville Dam ($P = 0.010$). Estimated detection probability for JSATS-tagged fish was higher than for PIT-tagged fish at Little Goose Dam, but lower than for PIT-tagged fish at McNary and Bonneville Dams. For JSATS-tagged fish released to the river, we utilized detections from both PIT and acoustic tags to adjust for potential tag loss. Adjustments were made in detection probability at the dams for JSATS-tagged fish due to suspected PIT tag loss from this group in 2007. This was evident because we recorded detections of some fish on JSATS receiver arrays but not on PIT detectors just upstream of these arrays.

In 2008, differences in detection probability between JSATS- and PIT-tagged yearling Chinook released to the river were significant at Little Goose (P = 0.005), Lower Monumental (P = 0.002), and John Day Dams (P = 0.006). Unlike 2007, estimated detection probability was higher for JSATS-tagged fish at all these sites in 2008. In 2008, no adjustment in detection probability was needed since no loss of PIT tags was apparent observed in fish tagged with both JSATS and PIT tags. In addition, a covariate analysis of factors affecting detection and survival found that for yearling Chinook salmon in both 2007 and 2008, tag type was a factor in both models that best fit the detection data from (Appendix B).

For subyearling fish released to the river in 2007, data were insufficient for estimates of detection probability or survival at all sites except Little Goose Dam and McNary Dam. At Little Goose Dam, detection probabilities were significantly different, with JSATS-tagged fish more likely to be detected than PIT-tagged fish (P = 0.001). There was no significant difference in mean detection probabilities between groups at McNary Dam.

Travel Time

Travel times for paired releases of yearling Chinook for 2007 and 2008 were similar in all but one case where detection probability differed significantly. These results suggested that yearling fish from the two treatment groups were likely approaching the bypass systems at each dam under similar spill conditions. This led us to conclude that differences in detection probability, when present, more likely arose from differences in behavior between JSATS- and PIT-tagged than from differences in exposure to environmental conditions at a given detection site while fish were passing.

Behavioral differences may have been caused by AT-tagged fish residing higher in the water column and being more likely to be guided into the bypass system, or being physically compromised somehow and less likely to resist flow entrainment into the bypass system. However, the exact cause for the observed differences is unknown. A similar phenomenon has been observed for small vs. large PIT-tagged salmonids, with the smaller fish more likely to be bypassed (Zabel et al. 2005).

Differential detection probability based on size at tagging was also evident from the covariate analysis (Appendix B). The general trend observed in the covariable analyses was for smaller fish to have a higher detection probability, and this was particularly evident at Little Goose Dam. However, in yearling fish there was no difference between length classes at Ice Harbor or McNary Dam, and for subyearlings there was no difference between length classes at McNary Dam.

Unlike the comparisons of yearling Chinook, travel times to Little Goose Dam for subyearling Chinook were significantly different between JSATS- and PIT-tagged groups, with JSATS fish taking longer to reach Little Goose Dam. Therefore, study fish from the two tag treatment groups could have experienced different environmental conditions as they approached and passed the dam, and this alone could explain the differences in detection probability observed at this site. However, a significant difference in travel time between fish from the two treatment groups could also have resulted from behavioral differences. Similar to yearling Chinook, covariate analysis of factors affecting survival for subyearlings also included tag type as a variable in both models that best fit the data describing variation in detection probabilities (Appendix B).

Necropsy and Histological Examination

Etiologies behind the effects observed in inriver-migrating JSATS-tagged fish relative to PIT-tagged fish appeared to be consistent in both yearling and subyearling Chinook salmon in both 2007 and 2008. Acoustic tags were more likely than PIT tags to elicit an inflammatory response, both within the peritoneal cavity and at the incision site. In addition, injection sites appeared to be more healed in PIT-tagged fish than incision sites in JSATS-tagged fish at recapture, and poor or uneven apposition of the two sides of the injection/incision site was observed more often in JSATS-tagged than in PIT-tagged fish.

Large amounts of bacteria or fungi were not apparent in the histological exams in either year. Thus, an apparent cause of the inflammatory response was not identified. We suggest that an infectious cause for the observed inflammation cannot be ruled out as a potential cause of the lowered performance of JSATS-tagged fish relative to PIT-tagged fish, since prolonged exposure of the underlying dermal tissue to river-borne bacteria and fungi could have predisposed surgically tagged fish to secondary infection. Also, the inflammation may have placed a higher metabolic demand on the JSATS-tagged fish than on the PIT-tagged fish and may have affected performance of the former.

While the proximate cause of the inflammation is unknown, we suggest that any effects of slow or delayed healing would likely be larger in subyearling than in yearling Chinook because of the smaller size and more metabolically active status of subyearling fish and because these fish experience less favorable river conditions during migration (e.g., warmer temperatures and lower flow volumes).

Apparent causes of differences in performance between JSATS- and PIT-tagged fish were not directly identified. We theorized that differences could have been from reduced fitness in JSATS-tagged fish due to mechanical appetite suppression or simply to the additional tag burden experienced by this group. However, the technique employed to sample tagged fish released to the river and collected at dams for re-examination could have affected the results. The first 10 fish to arrive at a dam were used for these experiments. If the first fish arriving represented the strongest and healthiest fish in the replicate, the sampling technique used may have resulted in conservative estimates of gross and microscopic differences between the two tag treatments, or vice versa.

Laboratory Holding Experiments

Laboratory holding studies conducted in tandem with releases to the river (yearlings and subyearlings in 2007 and yearlings in 2008) were useful for evaluating tag loss and long-term survival, neither of which were directly measurable in the field. However, clear disparities emerged between survival comparisons among laboratory treatment groups and those among treatment groups migrating in the river. In all comparisons, laboratory fish fared better than their inriver counterparts over a similar time frame, and relative survival between tag treatment groups (JSATS/PIT) was lower for migrating fish. Thus, laboratory studies may have underestimated the secondary effect of marking as well as the direct effect of tag implants. However, we did observe significant differences in laboratory-holding survival at 14 d between subyearling study fish that had been surgically implanted with tags (either with both JSATS tags and PIT tags or only a PIT tag), and those injected with a PIT tag and reference fish, indicating a surgical effect independent of tag burden.

Transmitter loss in the laboratory was not consistent between 2007 and 2008 for either subyearling or yearling Chinook salmon. Acoustic tags were dropped or expelled from yearling fish at a rate of 8% (N = 21 tags) over 120 d in 2008, while only one tag was lost in 2007 over a 90-d period. Subyearling Chinook tagged with a JSATS and PIT-tag dropped or expelled the JSATS tag at a rate of 2% in 2008 (N = 5 tags) and 7.6% in 2007 (N = 9 tags). We also observed differences in PIT-tag loss between years and among treatment groups. Yearling Chinook tagged with both a JSATS- and PIT-tag lost PIT tags at a rate of 2% in 2007 (N = 5) and <0.01% in 2008 (N = 1 tag). Double-tagged subyearling Chinook lost PIT tags at a rate of 3.4% in 2007 (N = 4 tags) and 0% in 2008.

We were able to correct for tag loss in our inriver detection probability estimates (both PIT and JSATS) because both types of telemetry detections were available. However, these results also suggested that tag loss in JSATS-tagged fish may be an issue in studies where PIT detection is not available, as survival will be underestimated when tag loss is indistinguishable from mortality.

Experiments were conducted to evaluate whether or not a subset of chemicals used in aquaculture would be efficacious for preventing or minimizing inflammatory reactions and possible infection at incision sites in subyearling Chinook salmon. These studies did not identify a treatment that improved survival over that seen in reference fish. However, results of these analyses indicated that in addition to tagging temperature, the presence of foreign material on sutures, and the presence of 2 secure ligatures (compared to 0 or 1) were the most consistent variables predicting 28-d survival for these fish (e.g., survival was lower for these fish at 7, 14, and 21 d).

These results indicate that a component of the tag effect may be driven at least in part by suture presence, similar to observations made during studies to develop the JSATS by McComas et al. (2005) where the authors expressed concern over the potential for secondary infection in surgically tagged fish due to long-term retention of sutures. Survival by replicate for individual surgeons further indicated that suture presence at 7 d was related to surgeon, and that surgeons with the lowest survival by replicate appeared to have had the best knot-tying technique as exemplified by concise, secure knots. Conversely and unexpectedly, the ligatures placed by surgeons associated with the highest post-surgical survival were found absent or loose and pulling from the incision at the 7-d exam.

Higher mortality for fish with sutures present at 7 d or more after surgery may have occurred due to secondary infection from pathogens that accumulated on sutures such as fungi or bacteria. When foreign matter had accumulated on sutures, there was often evidence at gross exam of secondary dermal ulceration directly beneath the mass of foreign material. These ulcers could have facilitated and served as a route for internal infection. We did not see evidence of a similar phenomenon in inriver migrating yearling Chinook recaptured in 2007 and 2008 or in inriver migrating subyearling Chinook recaptured in 2007 using the SbyC system. However, we were able to recapture only 9 of the 100 JSATS-tagged subyearling Chinook targeted for SbyC in 2007, presumably due to overall high inriver mortality for this treatment group.

It is important to note that surgically tagged study fish used for the dip treatments were implanted with only a PIT-tag, rather than with both a PIT and JSATS tag. Therefore, although it appears that suture retention was correlated with mortality, we have no information to inform the question of whether or not JSATS tags of the size tested would have been retained in the absence of sutures.

Recommendations

1. Based on the results presented here, as well as those from the two previous years of study (Hockersmith 2007; Wargo-Rub et al. 2009), we recommend that researchers using surgically implanted transmitters for studies of survival and behavior in yearling Chinook salmon of the size range tested use caution when interpreting their results, especially if the evaluations cover long distances and the results are not paired with concomitant PIT-tag data. Researchers should consider the results reported here, in conjunction with other studies based on tag technologies and hardware developed since 2008, when designing future field studies and interpreting results.

We base this recommendation on several lines of evidence. First, in 2008 differences in survival that approached significance ($P = 0.095$) were found between JSATS-tagged and PIT-tagged river-run fish to McNary Dam, 225 km downstream from release. Differences in survival increased as fish moved downstream, and were significant even with low power to detect differences (e.g., JSATS/PIT = 0.72, $P = 0.001$ to John Day Dam and 0.75, $P = 0.021$ to Bonneville Dam). A small difference in estimated survival was also seen at Little Goose Dam (JSATS/PIT = 0.97), the first detection site downstream from release (60 km); however, this difference was not statistically significant ($P = 0.107$).

Second, a finding of differences in detection probability between tag treatments at Little Goose Dam during both 2007 and 2008 may indicate a real difference in behavior or fitness between JSATS and PIT-tagged fish. Average median travel time for each replicate release group to this detection site was approximately 3.5 d in 2007 and approximately 4 d in 2008 for both JSAT- and PIT-tagged yearling fish. This result indicated that for most fish, tag effects (i.e. differences in detection probabilities) had developed within 4 d of release. If JSATS-tagged fish are more likely to be bypassed, then it is likely that either the surgical tagging procedure or the tag burden affected their susceptibility to entrainment into bypass systems.

Third, the covariate analysis of factors affecting survival and detection probabilities indicated that aside from tag type, size at tagging had the greatest influence on detection probability and survival (Appendix B). A comparison of separate fitted survival curves for JSATS- and PIT-tagged fish at McNary Dam indicated that relative survival (JSATS/PIT) for yearling Chinook salmon in 2007 approached 1 at fork lengths of 147 mm. This result indicates that researchers should use caution in tagging yearling Chinook salmon smaller than approximately 150 mm. However, we also note that the covariate analysis of from yearling Chinook in 2008 indicated that survival differences were present at all fork lengths in the data set.

Fourth, although survival of yearling fish tagged with the contemporary JSATS tag was statistically indistinguishable from that of PIT-tagged fish in the laboratory, 8% of the yearling fish surviving to termination at 120 days had dropped or expelled the acoustic implant.

2. Based on the size range of fish and JSATS equipment tested, the results reported here suggest that a number of serious aspects should be addressed if surgically implanted transmitters are to be used to study survival and behavior of small subyearling Chinook salmon. These include observations of lower survival, slower travel times, and higher detection probabilities for JSATS- than PIT-tagged fish at some locations where detections were adequate to make comparisons between the two treatment groups. These observations also lead us to recommend incorporation of a reference group into future study designs to further explore how these performance metrics behave within a migration season and across years.

We base this recommendation on several lines of evidence. First, for subyearling fish released to the river in 2007, differences in detection probability and survival were significant at Little Goose Dam, the first detection site downstream from release (estimated detection probability was higher for JSATS-tagged fish and estimated survival was higher for PIT-tagged fish). Average median travel times for each release group to this site was 5.2 d for JSATS-tagged fish and 3.9 d for PIT-tagged fish, indicating that tag effects had developed within 4-5 d of release. Significant differences in survival among JSATS-tagged, PIT-tagged, and reference fish were also observed after 14 d of holding in the laboratory in 2007. In addition, acoustic tag loss for JSATS-tagged fish was 7.6% for fish that had survived to 90 d in 2007.

Second, despite a reduction in size of the JSATS tag from 2007 to 2008, we again observed significant differences in mean survival between JSATS-tagged, injected PIT-tagged, and reference groups after 14 d holding in the laboratory. Acoustic-tag loss in 2008 was 2% for fish that survived to 120 d. No subyearling Chinook were released to the river in 2008.

Third, our covariate analysis of factors affecting survival and detection probability of subyearling Chinook migrating in 2007 indicated that similar to the findings for yearling Chinook, aside from tag type, size at tagging had the greatest influence on detection probability and survival (Appendix B). We also note that a comparison of separate fitted survival curves for JSATS- and PIT-tagged subyearling fish detected at McNary Dam indicated that relative survival was lower for JSATS-tagged than PIT-tagged subyearling Chinook at all lengths in the data set.

Fourth, results of the 2008 holding study indicated that a component of the tag effect observed in subyearling Chinook salmon may have been the surgical procedure itself. This needs to be explored further for future applications. If true, then reducing tag burden alone will not completely eliminate the observed tag effects. Furthermore, observations of subyearling fish in 2007, results of the dip treatment work conducted in 2008, and exploratory JSATS work conducted in 2003 (McComas et al. 2005) have indicated that this "surgical" effect may be in part due to retention of sutures. Unfortunately, suture retention is a product of good, rather than poor, surgical technique. This would suggest that relying on improved training of surgeons may not fully eliminate such an effect.

Although rapidly dissolving sutures are being investigated for use in an aqueous environment, their performance has not been fully evaluated. An alternative for minimizing surgical effects could be to hold fish until the incision has healed enough to remove the sutures. However, researchers would have to consider whether the fish then represented the migrating population and passage conditions experienced by their cohorts. Another alternative would be to develop acoustic transmitters that are miniaturized sufficiently so as to allow injection rather than surgical implantation.

Fifth, higher temperatures appeared to exacerbate the survival differences between treatments in subyearling fish during both the dip (2008) and long-term holding studies (2007 and 2008). For the most part, tagging temperatures at Lower Granite Dam in 2007 were similar to the 10-year average: of the 10 replicates tagged and released to the river in 2007, temperatures exceeded 15°C for 9 replicates and exceeded 17°C for 4 replicates. For migrating subyearling Chinook in 2007, mean relative survival (JSATS/PIT) was 0.80 to Little Goose Dam and 0.41 to McNary Dam, and the difference in survival between treatments was significant at both locations. In 2008, temperature exceeded 15°C for only 2 of the 10 replicates and exceeded 17°C for only 1 of these replicates during tagging for the long-term holding study. Relative survival (JSAT/PIT) for fish tagged at 17.3°C was 0.33 compared to a mean relative survival of 0.93 for replicates tagged at the lower temperatures.

In the 2008 dip treatment study, Non-parametric K-M curves for survival of individual replicates over time showed a pattern similar to that observed in the long-term holding study, wherein the first two replicates experienced relatively low mortality and the last two experienced relatively high mortality. The variable that changed most obviously over the study period was temperature, and survival differed between fish that were tagged earlier in the study, when water temperature was below ~16°C, and those tagged later, when temperatures exceeded 16°C. The higher temperatures at tagging (as well as during transport and holding) likely contributed to mortality for these fish.

3. Researchers should be aware of potentially large differences in survival and behavior when conducting field studies using surgical implants in subyearling Chinook salmon when water temperature is above 15°C. Results reported under Recommendation 2 above indicate that the JSATS tag tested is not likely to yield accurate data at high temperatures for subyearling fish of the size we tested.

This cautionary recommendation with respect to temperature thresholds is similar to guidelines currently in place for less invasive tagging methods. A maximum temperature threshold of 17°C is recommended for PIT-tagging procedures in field manuals of both the Columbia Basin Fish and Wildlife Authority (CBPTSC 1999), and the Bonneville Power Administration (Nelle and Ward 2008). Both field manuals include a cautionary statement that this threshold should be lowered under circumstances where additional stressors may be present, in one instance stating that "as temperature increases above 15°C, fish become stressed very easily" (CBPTSC 1999). Based on our observations, the acoustic-tagged fish did experience additional stressors compared to PIT-tagged fish, from the presence of the acoustic tag as well as from the surgical procedure. In this regard, results of non-controlled studies of yearling Chinook salmon survival and behavior conducted at water temperatures above 15°C should also be interpreted carefully.

4. Differences in survival and performance among treatment groups can vary considerably both within and among years. Additional multi-year field and laboratory evaluations are needed in order to interpret findings within a context that captures at least some of this variation. Researchers using acoustic technology to study survival in salmonids should be aware that variation in environmental conditions can affect their results both within a given season and among years.

In both 2007 (yearling and subyearling Chinook) and in 2008 (yearling Chinook salmon), we observed considerable variation in relative survival to a given location among sets of paired release groups. Environmental data indicated that treatment groups released during both the spring and summer study periods had been subjected to different environmental conditions. To investigate whether or not there were indeed relationships between detection and survival probability and various environmental variables for fish migrating in 2007 and 2008, we used SURPH (v2.2b) to estimate and fit models of these probabilities as functions of the following covariates: flow, spill exposure, river temperature, and size (fork length) at tagging (Appendix B). Although based on limited data, our analysis suggested that survival through the hydropower system was influenced by environmental variables, particularly by levels of exposure to spill and flow for yearling Chinook salmon and exposure to warmer temperatures for subyearling Chinook (Appendix B).

5. Development of strict operational rules for when and under what circumstances researchers should use the technology tested is premature, based on the observations presented here.

We base this on several lines of evidence. First, it was not feasible to make operational rules in light of the variability in results we observed (e.g., variable effects of environmental conditions discussed above). Second, circumstances experienced in all 3 years of field-testing resulted in reduced power in tests. Third, the distance over which observed differences developed was variable. We found evidence to suggest that tag effects developed over long distances in the significantly lower survival estimates for JSATS-tagged vs. PIT-tagged yearling Chinook to John Day and Bonneville Dams in 2007 and 2008. These differences were extremely large in 2008, when survival to John Day Dam (348 rkm from release) was 28% lower for JSATS-tagged than PIT-tagged fish and survival to Bonneville Dam (460 rkm from release) was 25% lower for JSATS-tagged fish.

Based on these data one might postulate that testing over shorter distances, such as the 225 km distance from Lower Granite to McNary Dam, could be acceptable. However, we also observed differences that developed within days of release. For example, at Little Goose Dam, differences were observed between tag treatments in detection probability for yearling Chinook salmon during both 2007 and 2008, and in survival probability for subyearling Chinook salmon during 2007. There were also differences in estimated survival at intermediate distances and times; for example, differences in survival estimates for yearling Chinook salmon approached significance at Lower Monumental and McNary Dams in 2008.

In general, we observed that survival among replicates within a season changed with river flow volumes and thus travel time. These observations were supported by the covariate analysis discussed in Recommendation 5, above. Therefore, distance alone may be a poor basis for developing JSATS implementation rules. Survival of test fish appeared to be more affected by river environmental conditions and the resultant travel time. Overall, we found it difficult to develop exact operational recommendations based on these data and suggest that further testing will be needed before implementation guidelines can be developed. Finally, we were concerned that operational guidelines based on these data may be too prescriptive for future researchers using newer technologies and conducting tests outside the range of environmental conditions we evaluated.

6. Researchers using multiple-recapture census to estimate survival in acoustic-tagged fish will have to address some implications of our findings in future model derivations. Foremost of these is that differences in survival between tag treatments generally increased with increasing distance from release for both yearling and subyearling Chinook salmon. Furthermore, it is hard to predict the direction that some comparisons between acoustic- and PIT-tagged fish will follow, given variable environmental conditions and the percentage of active tags lost or shed during an experiment. Because of these factors, Recommendations 1 and 2 above include considering the use of reference groups when designing future research, including releases of PIT-tagged fish.

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APPENDIX A

Acoustic Receiver Arrays

Appendix Table A1. Locations of acoustic receiver arrays used for passage and survival estimates in comparison of the JSATS and PIT tag, 2008.

Acoustic receiver arrays		
Abbreviation	Site description	Location (rkm)
IRR1	Irrigon primary array	452
BON0	Bonneville egress, 14 km ds of Bonneville Dam	225.2
BON1	Bonneville primary, Sand Island	210.4
BON2	Bonneville secondary, Reed Island	204.0
BON3	Bonneville tertiary, Lady Island	199.1
KLM1	Kalama primary, Cottonwood Island	112.6
KLM2	Kalama secondary, Cottonwood Island	110.7
EIS1	Estuary islands primary, Oak Pt	86.2
EIS2	Estuary islands secondary, downstream from Oak Pt	83.6
EIS3	Estuary islands tertiary, Tenasillahe Island	58.4
EST1	Estuary primary, W. Sand Island	8.3
EST2	Estuary secondary, between N and S Jetties	2.8

APPENDIX B

Covariate Analysis of Factors Affecting Survival

Analysis of Effects on Detection and Survival Probabilities of Tag Type, Fish Size, and Environmental Variables

Steven G. Smith and A. Michelle Wargo Rub

Internal Report
Fish Ecology Division, Northwest Fisheries Science Center
National Marine Fisheries Service, National Oceanic and Atmospheric Administration
2725 Montlake Blvd. E., Seattle, WA 98136

Introduction

The purpose of this analysis was to investigate the relationships between covariates and the probability of PIT-tag detection at dams and between covariates and survival probabilities through stretches of the Snake and Columbia Rivers. To investigate how these relationships might change as migration time and distance increased, we investigated survival probabilities over these successively longer stretches of river:

1) Lower Granite to Little Goose Dam (60 km);
2) Lower Granite to Lower Monumental Dam (106 km);
3) Lower Granite to Ice Harbor Dam (157 km); and
4) Lower Granite to McNary Dam (225 km).

Methods

Tagged Fish and Release Groups

Tagged fish were released in the tailrace of Lower Granite Dam in paired released groups; one group consisted of fish tagged only with PIT tags and the other consisted of fish dually tagged with PIT tags and active acoustic (JSATS) tags. Paired groups of yearling Chinook salmon were released on 10 distinct days between 24 April and 14 May 2007 (Appendix Table B1) and on 10 days between 23 April and 16 May 2008 (Appendix Table B3). Paired groups of subyearling Chinook salmon were released on 27 days between 4 June and 13 July 2007. For adequate sample sizes, the daily paired groups of subyearlings were pooled into 6 weekly paired groups (Appendix Table B2). Because fish length at tagging was to be used as a potential explanatory variable in modeling detection and survival probabilities, fish that did not have recorded length were omitted from analysis.

Detection Histories

The PIT-tag detection history for each tagged fish consisted of a record of whether the PIT tag was detected at the following locations: Little Goose Dam (LGO), Lower Monumental Dam (LMN), Ice Harbor Dam (IHR), McNary Dam (MCN), John Day Dam (JDA), Bonneville Dam (BON), and the estuary PIT-tag trawl (TWX). In addition, for each dual-tagged fish, we recorded whether the acoustic signal was detected by at least one acoustic array located downstream of McNary Dam.

We used the program SURPH (Smith et al. 1994, v2.2b) for all detection and survival probability estimation and for fitting models of probabilities as functions of covariates. SURPH implements the Cormack-Jolly-Seber model (CJS model; Cormack 1964; Jolly 1965; Seber 1965) for estimation and provides a few choices of forms for extension of the CJS for modeling probabilities. SURPH requires input in the form of detection histories, from which the probability of survival through a single hydroelectric "project" is estimated (where one "project" entails one reservoir and one dam).

Thus to estimate detection and survival probabilities from Lower Granite Dam tailrace to Little Goose Dam tailrace, we compiled from detection records a two-digit detection history for each individual. The first of these digits indicated whether the fish had been detected (and its record censored) at Little Goose Dam, and the second digit indicated whether the fish was detected anywhere downstream from Little Goose Dam.

Appendix Table B1. Yearling Chinook salmon released in 2007 for tag comparison study. Shown are release date, type of tag, number released, group indices of exposure to flow (kcfs), spill percentage, and water temperature, and median travel time between release in tailrace of Lower Granite Dam (LGR) and detection at McNary Dam (MCN). Summary statistics of individual fork length are also included.

Yearling Chinook 2007

				Exposure indices			Median travel time (d)	Length statistic (mm)				
Pair	Release date	Tag type	N	Flow (kcfs)	Spill (%)	Temp. (°C)	LGR to MCN	Mean	sd	Median	5th	95th
1	24 Apr	Dual	403	88.5	18.8	11.2	12.3	130.7	11.6	131	112	150
	23 Apr	PIT	4,434	85.4	19.5	11.0	12.1	134.0	12.6	135	113	152
2	25 Apr	Dual	396	88.8	19.4	11.2	12.2	131.4	11.1	133	112	148
	25 Apr	PIT	3,733	87.3	19.3	11.2	10.9	129.6	11.2	130	112	148
3	27 Apr	Dual	403	91.0	18.7	11.3	10.2	133.4	11.5	134	115	151
	27 Apr	PIT	3,273	89.8	20.3	11.3	9.9	129.3	11.9	128	112	148
4	30 Apr	Dual	403	78.4	27.3	11.5	9.2	130.9	10.4	131	114	149
	30 Apr	PIT	3,771	79.4	27.0	11.5	9.0	132.2	10.0	132	116	148
5	2 May	Dual	405	64.6	34.3	12.1	9.1	132.7	10.3	133	116	150
	3 May	PIT	7,944	72.9	27.7	12.0	8.5	132.1	10.4	132	115	148
6	4 May	Dual	412	94.0	18.3	11.6	10.6	135.0	8.1	135	121	149
	4 May	PIT	5,487	93.6	19.0	11.6	10.0	135.0	10.0	136	118	150
7	8 May	Dual	405	96.8	15.9	11.5	8.9	133.4	9.6	135	116	148
	7 May	PIT	3,555	96.9	15.9	11.5	9.7	133.9	9.7	135	117	149
8	9 May	Dual	273	95.1	20.1	12.0	8.9	135.6	7.8	136	123	149
	9 May	PIT	4,741	96.8	18.1	11.7	9.0	134.2	9.2	135	118	148
9	11 May	Dual	303	86.6	25.0	13.3	8.9	133.7	8.6	134	120	148
	11 May	PIT	4,788	85.2	25.3	13.2	8.6	135.1	8.3	136	121	148
10	14 May	Dual	363	86.0	26.9	13.1	9.2	133.7	8.3	134	120	146
	14 May	PIT	4,540	85.9	26.9	13.1	9.2	135.0	9.1	136	119	149

Appendix Table B2. Subyearling Chinook salmon released in 2007 for tag comparison study and grouped for analysis. Shown are release date, type of tag, number released, group indices of exposure to flow (kcfs), spill percentage, and water temperature, and median travel time between release in tailrace of Lower Granite Dam (LGR) and detection at McNary Dam (MCN). Summary statistics of individual fork length are also included.

Subyearling Chinook Salmon 2007												
				Exposure indices			Median travel time (d)	Length statistic (mm)				
Pair	Release date	Tag type	N	Flow (kcfs)	Spill (%)	Temp. (°C)	LGR to MCN	Mean	sd	Median	5th	95th
1	5-9 Jun	Dual	1,321	56.6	41.0	16.2	13.2	103.9	5.8	103	96	114
	5-9 Jun	PIT	5,607	56.9	39.9	15.9	11.4	105.7	6.2	105	96	116
2	12-16 Jun	Dual	1,428	33.1	50.7	17.2	20.9	103.2	5.7	103	95	113
	12-16 Jun	PIT	5,419	34.5	48.3	16.4	15.8	106.8	6.4	106	97	118
3	19-23 Jun	Dual	1,467	32.9	51.6	18.3	15.5	106.5	7.1	106	96	118
	19-23 Jun	PIT	4,724	32.6	52.0	17.9	12.3	109.6	7.8	110	97	122
4	26-30 Jun	Dual	1,382	35.1	48.1	20.2	15.1	106.8	6.4	107	96	117
	26-30 Jun	PIT	4,458	35.4	47.5	19.4	11.5	109.1	7.0	109	98	121
5	3-7 Jul	Dual	936	35.1	48.3	20.4	14.6	109.0	8.0	110	96	122
	3-7 Jul	PIT	3,783	33.3	50.7	20.8	11.2	110.9	8.0	111	98	124
6	10-14 Jul	Dual	1,184	21.4	30.0	21.2	22.3	111.9	9.1	111	99	128
	10-14 Jul	PIT	2,243	21.1	28.2	21.2	18.4	111.2	8.7	110	98	126

Appendix Table B3. Yearling Chinook salmon released in 2008 for tag comparison study and summarized by weekly paired release group. Summaries include release date, type of tag, number released, group indices of exposure to flow (kcfs), spill percentage, and water temperature, and median travel time between release in tailrace of Lower Granite Dam (LGR) and detection at McNary Dam (MCN). Summary statistics of individual fork length are also included.

Yearling Chinook 2008

				Exposure indices			Median travel time (d)	Length statistic (mm)				
Pair	Release date	Tag type	N	Flow (kcfs)	Spill (%)	Temp. (°C)	LGR to MCN	Mean	sd	Median	5th	95th
1	24 Apr	Dual	394	78.6	27.8	10.3	18.3	123.5	14.2	122	103	146
	24 Apr	PIT	1,498	87.9	24.7	10.6	18.8	126.8	14.2	128	105	150
2	29 Apr	Dual	409	93.2	24.1	10.7	15.4	129.9	11.3	131	112	148
	29 Apr	PIT	2,772	94.5	23.3	10.7	13.8	136.0	14.0	137	111	157
3	1 May	Dual	413	96.0	23.3	10.7	12.8	139.7	11.5	141	117	156
	1 May	PIT	6,251	95.5	24.5	10.6	12.7	132.1	14.0	133	110	154
4	3 May	Dual	410	92.6	27.5	10.6	13.2	123.2	13.0	122	104	146
	3 May	PIT	6,542	93.4	26.9	10.6	11.8	132.1	12.8	133	111	151
5	6 May	Dual	416	86.2	30.8	11.1	11.0	130.9	11.3	132	112	147
	6 May	PIT	7,781	85.6	29.9	11.1	11.0	138.4	11.6	140	117	155
6	8 May	Dual	409	78.4	29.8	10.9	11.2	136.1	11.3	136	119	155
	8 May	PIT	6,275	76.7	30.8	10.9	10.6	136.6	12.1	137	116	155
7	10 May	Dual	405	116.5	23.0	11.0	9.8	135.0	11.0	136	115	150
	10 May	PIT	5,886	136.2	24.2	11.2	10.4	140.2	10.7	141	122	157
8	13 May	Dual	430	182.2	37.5	11.7	11.1	140.4	8.5	141	124	152
	13 May	PIT	4,890	188.7	39.7	11.7	10.8	138.6	10.0	139	122	154
9	15 May	Dual	415	198.5	43.1	11.9	9.8	146.4	9.1	147	130	159
	15 May	PIT	4,873	197.6	42.8	11.9	9.5	137.1	10.0	138	121	151
10	17 May	Dual	434	198.1	43.2	11.8	7.7	134.6	10.4	135	116	150
	17 May	PIT	3,736	198.0	43.3	11.8	8.0	138.0	10.1	139	121	153

In other words, the second digit "collapsed" information from PIT-tag detections at Lower Monumental, Ice Harbor, McNary, John Day, and Bonneville Dams, as well as from detections in the estuary trawl, and for dual-tagged fish, detections on acoustic receiver arrays downstream from McNary Dam.

The two-digit detection history was sufficient to estimate survival between release in Lower Granite Dam tailrace and Little Goose Dam tailrace. For estimates of survival in stretches that encompass more than one hydroelectric project, it would be necessary to construct detection histories that included all detection sites within the stretch. For example, for survival from Lower Granite Dam to McNary Dam, the customary detection history would include five digits, indicating whether detection occurred at Little Goose, Lower Monumental, Ice Harbor, and McNary Dam, as well as any detection downstream from McNary Dam. Using the CJS model, survival would then be estimated for each of these component reaches: Lower Granite to Little Goose, Little Goose to Lower Monumental, Lower Monumental to Ice Harbor, and Ice Harbor to McNary Dam. The estimate of overall survival probability from Lower Granite to McNary Dam would be calculated as simply the product of these four component survival estimates.

However, modeling this overall survival probability (product of component probabilities) as a function of covariates is problematic. In multi-reach data sets, SURPH allows regression-like modeling of each component survival estimate, but does not provide a simple, natural, and direct way to model the overall survival probability as a function of covariates. Thus, for each stretch that encompassed two or more projects, we modeled survival probability by constructing two-digit detection histories that ignored intermediate detection sites. For example, in the estimate of survival from Lower Granite to McNary Dam, the detection history consisted of one digit indicating whether the fish was detected at McNary (and whether it was censored at McNary after detection), and a second digit indicating whether the fish was detected anywhere downstream from McNary. Detections at Little Goose, Lower Monumental, and Ice Harbor Dam were not considered.

When censoring does not occur at intermediate sites, the survival estimate for the overall stretch (e.g., Lower Granite to McNary) will be identical whether it is calculated as the product of component estimates, made using the customary detection histories, or using the two-digit history that ignores intermediate sites. However, when censoring does occur at intermediate sites, the two-digit detection history will result in a lower survival estimate (negative bias) than the product of estimates from the complete detection history.

In our data sets, censoring did occur at intermediate sites when a study fish was either inadvertently transported from Little Goose or Lower Monumental Dam, or was diverted to the sample room at Little Goose, Lower Monumental, or Ice Harbor Dam. However, the censor rate was low enough that survival estimates were affected only slightly. More importantly, there was no reason to suspect that the censor rate was related to any of the covariates considered in our analyses. That is, the relative effect of censoring was the same on all survival estimates, and the relationships between the slightly biased estimates and the covariates are an accurate (unbiased) reflection of the relationships between the true survival probabilities and the covariates.

All study fish were released to the tailrace of Lower Granite Dam. Thus for survival estimation and modeling from Lower Granite to any point downstream, there were five possible two-digit detection histories, indicated as follows:

1 1 Detected at dam at the downstream end of survival reach, returned directly to tailrace of that dam, and detected again at least once downstream from there;

1 0 Detected at dam at the downstream end of survival stretch, returned directly to tailrace of that dam, but not detected anywhere downstream from there;

2 0 Detected at dam at the downstream end of survival stretch, censored at that dam;

0 1 Not detected at dam at downstream end of survival stretch, but detected at least once downstream from there;

0 0 Not detected anywhere after release.

Covariates

Covariates considered as potential explanatory variables for detection and survival probabilities were defined at either the group or individual level. Descriptors of each group's migration experience comprised one type of group-level covariate. These included typical travel time and indices of exposure to environmental conditions such as flow volume (*Flow*), percentage of flow that was spilled (*Sp%*), and water temperature (*Temp*). Each index was calculated as the mean of the daily average of the variable for the group during the period between the 25th and 75th percentile passage dates at Lower Monumental Dam. Travel time (*TT*) for the group was measured as the median time between release and detection at the downstream end of the stretch for which survival was estimated. Group-level covariates had group-specific values (Appendix Tables B1-B3) and allowed modeling of variation among group means of detection and survival probabilities.

Fork-length (mm) at the time of tagging (*Len*) was considered as an explanatory variable. This variable was defined at the individual level and allowed modeling of variation among individuals. Group-level summary statistics for *Len* for each group are included in Appendix Tables B1-B3, but modeling was done using the individual covariates.

The next factor, *Tag*, was considered to explain variation in detection and survival probabilities between tag types. To work as a covariate in SURPH models, tag effect was coded as a binary "indicator" variable, where a *Tag* value of 0 was PIT-tagged and 1 was dual tagged (both JSATS and PIT tag). As a binary coded variable, *Tag* could be represented as either a group-or individual-level covariate. However, in order to more easily explore the interaction between fish length and tag type using SURPH machinery, we modeled *Tag* as an individual-level covariate.

Finally, models included binary indicator variables to account for the "pair" or "block" effect in the experimental design.

Modeling Detection and Survival Probabilities

Group-level mean detection and survival probabilities are estimated simultaneously from a single mark-recapture data set in the CJS model. From a two-digit detection history, such as the one from Lower Granite to McNary Dam, three parameters are estimated:

1. *Survival probability*: Probability of survival from release in Lower Granite tailrace to McNary tailrace.
2. *Detection probability*: Probability of detection at McNary for fish that survive to that site.
3. *Downstream probability*: Probability that a fish alive in McNary tailrace is detected at least once downstream from McNary (this third probability encompasses both survival and downstream detection probability, as they cannot be separated mathematically using the available data).

We refer to these three parameters in describing the methods below and in subsequent results and discussion sections.

Likewise, covariate ("regression") models are estimated simultaneously for detection and survival probabilities in SURPH (downstream probability can also be represented by a regression function). Even if more interest lies in factors affecting one of these three probabilities (survival, say) than in factors affecting the others, it is important to simultaneously consider covariate effects on all three. This is because neglecting to account for a covariate effect on one probability can cause bias in modeling the others. For example, if an individual covariate such as fish length affects detection probability, but the statistical model does not include a parameter to account for this effect (i.e., the model has a single common detection probability for all fish), then the effect on detection can erroneously be identified as an effect on survival.

We used SURPH (Smith et al. 1994, v2.2b) to estimate all covariate models. We used the logistic link for detection probabilities (and downstream probabilities) and the hazard link for survival probabilities. That is, the portion of the model for the detection probability that includes both group- and individual-level covariates can be written as follows (full model including pair effect, length effect, tag effect, and the interaction between them):

$$logit(P_{ijP}) = \beta_0 + \beta_j + Len_{ijP}\beta_{Len} + X'_{\mathrm{jP}}\underline{\beta}_{\mathrm{g}}$$

$$logit(P_{ijD}) = \beta_0 + \beta_j + \beta_{Tag} + Len_{ijD}(\beta_{Len} + \beta_{Len*Tag}) + X'_{\mathrm{jD}}\underline{\beta}_{\mathrm{g}}$$

where P_{ijP} is the detection probability for the *i*th PIT-tagged individual in pair j, LN_{ijP} is the length of the *i*th PIT-tagged individual in pair j, β_{Len} is the regression coefficient for length, $X_{j\mathrm{P}}$ is the vector of group-level covariates for the PIT-tagged group in pair j, $\underline{\beta}_{\mathrm{g}}$ is the vector of regression coefficients for group covariates, P_{ijD} is the detection probability for the ith dual-tagged individual in pair j, Len_{ijD} is the length of the *i*th dual-tagged individual in pair j, $X_{j\mathrm{D}}$ is the vector of group-level covariates for the dual-tagged group in pair j, β_j is the "effect" of pair j, and β_0 is an intercept parameter.

The portion of the model for the survival probability can be written as follows:

$$S_{ijP} = S_0^{\exp(\delta_0 + \delta_j + Len_{ijP}\delta_{Len} + X'_{\mathrm{jP}}\underline{\delta}_{\mathrm{g}})}$$

$$S_{ijD} = S_0^{\exp(\delta_0 + \delta_j + \delta_{TAG} + Len_{ijD}(\delta_{Len} + \delta_{Len\times Tag}) + X'_{\mathrm{jD}}\underline{\delta}_{\mathrm{g}})}$$

where S_{ijP} is the survival probability for the ith PIT-tagged individual in pair j, δ_{Len} is the regression coefficient for length, $\underline{\delta}_{\mathrm{g}}$ is the vector of regression coefficients for group covariates, S_{ijD} is the survival probability for the ith dual-tagged individual in pair j, δ_j is the "effect" of pair j, and S_0 is an "intercept" parameter.

Investigation of models for detection and survival probabilities proceeded in three phases, described in detail below. We originally planned only the first two phases; however, results of the second phase led to the development of a third. In each phase, a pre-identified set of candidate models was fitted to the data, and assessment and selection of models was done using information-theoretic methods (Burnham and Anderson, 2002). Specifically, all models in the candidate set were fitted using the maximum-likelihood method, Akaike's information criterion (AIC) was computed for each model, and AIC weights were computed for the models.

Three phases of analysis were repeated for each of three data sets for migrating fish (yearling Chinook salmon in 2007, subyearling Chinook in 2007, and yearling Chinook in 2008) and for each of four dams at the downstream end of a survival reach (Little Goose, Lower Monumental, Ice Harbor, and McNary), for a total of 12 separate analyses.

Phase 1: Detection Probability

The first phase of model selection was to determine the most appropriate model to describe detection probability at McNary Dam for the various release groups. In this phase, detection probabilities were modeled simultaneously with a model structure that included a different mean survival and a different downstream probability for each release group. Candidate models for detection probability were as follows:

1.1 *CJS*: Detection probability at McNary is different for every release group.

1.2 *Null*: Detection probability at McNary is equal among all release groups.

1.3 *Pair*: Detection probability is equal for PIT- and dual-tagged groups within a pair, but varies between pairs.

1.4 *Pair + Tag*: Detection probability varies between pairs and between release groups within a pair according to a tag effect, which is common for all pairs.

1.5 *Pair + Tag + Len*: Detection probability varies between pairs, between release groups within a pair according to a tag effect common to pairs, and among individuals within a release group according to a length effect, which is common between pairs and tag types.

1.6 *Pair + Tag × Len*: Detection probability varies between pairs, between groups within a pair according to a tag effect common to pairs, and among individuals within a group according to a length effect common to pairs but dependent on tag type (interaction between tag effect and length effect).

We inspected the AIC results for detection probabilities to determine the most appropriate model to use for detection probabilities in the second phase of the modeling, which was focused on investigating effects on survival. We assumed that the most appropriate model for the detection probability would also be a reasonable model to use for the downstream probability, thus providing the context for unbiased evaluation of survival effects.

Phase 2: Survival Probability

In the second phase of modeling, we used SURPH (Smith et al. 1994, v2.2b) to fit a set of candidate models to explore effects on the survival probability, in the context of the models for detection and downstream effects that we selected in phase 1. The following large set of candidate survival probability models was considered in phase 2 (though all were considered in conjunction with selected models for detection and downstream probabilities):

CJS: Different survival probability from Lower Granite to McNary Dam for every release group.

CJS + Len: Different mean survival probability for every release group; survival for individuals within group varies according to length effect common to all groups.

2.1 *Pair*: Survival probability equal for PIT- and dual-tagged groups within a pair; varies between pairs.

2.2 *Pair + Len*: Survival probability varies between pairs, not between groups within a pair according (i.e. no tag effect), and varies among individuals within a group according to a length effect that is common between pairs and tag types.

2.3 *Pair + Tag + Len*: Survival probability varies between pairs, between groups within a pair according to a tag effect common to pairs, and among individuals within a group according to a length effect that is common between pairs and tag types.

2.4 *Pair + Tag × Len*: Survival probability varies between pairs, between groups within a pair according to tag effect common to pairs, and among individuals within a group according to a length effect common to pairs but dependent on tag type (interaction between tag effect and length effect).

2.5 *Null*: Equal survival probability for all release groups.

2.6 *Len*: Equal intercept for all release groups; survival depends only on individual length.

2.7 *Tag + Len*: Equal intercept for all release groups; survival depends on tag type and a length effect common to both tag types.

2.8 *Tag × Len*: Equal intercept for all release groups; survival depends on tag type and a length effect that depends on tag type (interaction between tag effect and length effect).

2.9 *Flow*: Equal "intercept" for all release groups; survival depends only on group flow exposure.

2.10 *Flow + Len*: Equal "intercept" for all release groups; survival depends on group flow exposure and a length effect common to both tag types.

2.11 *Flow + Tag + Len*: Equal "intercept" for all release groups; survival depends on group flow exposure, tag type, and a length effect common to both tag types.

2.12 *Flow* + *Tag* × *Len*: Equal "intercept" for all release groups; survival depends on group flow exposure, tag type and a length effect that depends on tag type (interaction between tag effect and length effect).

2.13-2.16: Four "spill percentage exposure" models analogous to those for flow exposure above, i.e., *Sp%*, *Sp%* + *Len*, *Sp%* + *Tag* + *Len*, and *Sp%* + *Tag* × *Len*.

2.17-2.20: Four "water temperature exposure" models analogous to those for flow exposure above, i.e., *Temp*, *Temp* + *Len*, *Temp* + *Tag* + *Len*, and *Temp* + *Tag* × *Len*.

2.21-2.24: Four "travel time" models analogous to those for flow exposure above, i.e., *TT*, *TT* + *Len*, *TT* + *Tag* + *Len*, and *TT* + *Tag* × *Len*.

Because the two models with "CJS baseline survival" do not admit any modeling of group-level covariates (including tag effects), we did not include them in the calculation of AIC weights for assessment of models in phase 2. The CJS models are, in a sense, fully parameterized for group variation. They are useful for describing group-level variation but not for explaining it. They are included as benchmarks for comparison to the reduced models. The remaining models used reduced parameter structures to describe group-level variation, either with no group variation (*Null*, *Len*, *Tag* + *Len*, and *Tag* × *Len*), with simple block effects (*Pair* models), or with explanatory group-level variables.

As will be seen in results for phase 2, AIC weights overwhelmingly favored survival models with tag and length effects, to the almost complete exclusion of models with group-level covariates. This led to consideration of a third phase of modeling, originally unplanned, to determine whether data supported models that included group-level environmental effects beyond the effects of tag type and length. That is, we fit a suite of candidate group-covariate models, all of which included the *Tag*/*Len* interaction term described above (and also the same model for detection probability and downstream probability as described above for phase 2).

Phase 3

Phase 3 was limited to modeling survival over the longest reach possible: from Lower Granite to McNary Dam. The following list describes candidate models in the survival probability suite in Phase 3 (all in conjunction with selected model for detection and downstream probabilities, and also with interaction between tag type and fish length (*Tag* × *Len*) included in the survival model):

3.1 *Null Group Cov*: Survival probability depends only on *Tag* × *Len*; no group covariates.

3.2 *Flow*: Survival probability depends on *Tag* × *Len*, and group-level flow exposure.

3.3 *Sp%*: Survival probability depends on *Tag* × *Len*, and group-level spill percentage exposure.

3.4 *Temp*: Survival probability depends on *Tag* × *Len*, and group-level water temperature exposure.

3.5 *TT*: Survival probability depends on *Tag* × *Len*, and group-level median travel time.

3.6 *Flow* + *Sp%*: Survival probability depends on *Tag* × *Len*, and flow and spill percentage exposures.

3.7 *Flow* + *Temp*: Survival probability depends on *Tag* × *Len*, and flow and water temperature exposures.

3.8 *Flow* + *TT*: Survival probability depends on *Tag* × *Len*, flow exposure, and median travel time.

3.9 *Sp%* + *Temp*: Survival probability depends on *Tag* × *Len*, and spill percentage and water temperature exposures.

3.10 *Sp%* + *TT*: Survival probability depends on *Tag* × *Len*, spill precentage exposure, and median travel time.

3.11 *Temp* + *TT*: Survival probability depends on *Tag* × *Len*, water temperature exposure, and median travel time.

3.12 *Flow* + *Sp%* + *Temp*: Survival probability depends on *Tag* × *Len*, and flow, spill percentage, and water temperature exposures.

3.13 *Flow* + *Sp%* + *TT*: Survival probability depends on *Tag* × *Len*, flow and spill percentage exposures, and median travel time.

3.14 *Flow* + *Temp* + *TT*: Survival probability depends on *Tag* × *Len*, flow and water temperature exposures, and median travel time.

3.15 *Sp%* + *Temp* + *TT*: Survival probability depends on *Tag* × *Len*, spill percentage and water temperature exposures, and median travel time.

3.16 *Flow* + *Sp%* + *Temp* + *TT*: Survival probability depends on *Tag* × *Len*, flow, spill percentage, and water temperature exposures, and median travel time.

More so than in phases 1 and 2, results in phase 3 featured multiple non-nested models in the candidate set receiving substantial AIC weight. Consequently, beyond identifying the best-supported model using AIC weights, we chose to illustrate the models using model-averaging techniques.

For each model with AIC weight exceeding 0.0, we calculated the fitted survival probabilities for an average-sized fish across a range of indices for *Flow* and *Sp*%, while holding *Temp* and *TT* constant at a "typical" value. The model-averaged fitted survival probability from Lower Granite to McNary Dam was then calculated as the weighted average of the model-specific fitted values, with weights equal to respective AIC weights. We then constructed one plot of model-averaged survival probability vs. a *Flow* index for minimum, average, and maximum levels of the *Sp*% index and one plot of model-averaged survival probability vs. *Sp*% index for minimum, average, and maximum levels of *Flow* exposure index.

Results

Phase 1—Modeling Detection Probabilities

In all cases, data supported only detection probability models that included fish length (Appendix Table B4). Two models were supported, as indicated by AIC weights, and both of these included both fish length (*Len*) and tag type (*Tag*) as explanatory factors. One of these models included an interaction between these two effects (interpretation: the relationship between length and detection probability was different for the different tag types), and the second did not (i.e., tag effect and length effect were independent). The small difference in respective AIC values for these two "nested" models suggest that the interaction term itself is not strongly supported, but is rather a "tag-along" variable (Burnham and Anderson 2002).

If the purpose of this analysis was to determine a single best model for detection probabilities, we would recommend the use of the model without interaction. However, we were focused on identifying the best detection-probability model structure to use for unbiased investigation of patterns in survival probabilities. Including a tag-along variable in the detection-probability part of the model has little effect on precision of estimation of survival probabilities, and the additional generality of the detection model may protect against bias if the interaction effect on detection is real. Therefore, for the subsequent survival modeling phases of the analyses, we adopted a detection probability model that included the block (*Pair*), tag, and length effects, and the interaction between *Tag* and *Len*. We also adopted this model for the downstream probability.

Appendix Table B4. Summary of results from Akaike's information criterion (AIC) for Phase 1 models for detection probabilities. Information shown for each model includes the number of parameters (k), delta AIC (Δ), and AIC-weight (w). Shaded cells indicate AIC weight > 0.05.

Model	Description	k	Little Goose Δ	Little Goose w	Lower Monumental Δ	Lower Monumental w	Ice Harbor Δ	Ice Harbor w	McNary Δ	McNary w
					Yearling Chinook 2007					
1.1	*Group*	60	530.2	0.000	208.4	0.000	208.0	0.000	103.2	0.000
1.2	*Null*	41	1493	0.000	1545	0.000	365.4	0.000	161.4	0.000
1.3	*Pair*	50	539.4	0.000	201.8	0.000	199.4	0.000	95.4	0.000
1.4	*Pair + Tag*	51	525.8	0.000	206.8	0.000	201.2	0.000	92.8	0.000
1.5	*Pair + Tag + Len*	52	***0.0***	0.646	***0.0***	0.731	***0.0***	0.622	***0.0***	0.731
1.6	*Pair + Tag × Len*	53	1.2	0.354	2.0	0.269	1.0	0.378	2.0	0.269
					Subyearling Chinook 2007					
1.1	*Group*	36	48.8	0.000	13.0	0.001	11.8	0.002	10.9	0.002
1.2	*Null*	25	152.2	0.000	91.8	0.000	30.8	0.000	65.3	0.000
1.3	*Pair*	30	99.4	0.000	21.8	0.000	24.8	0.000	18.5	0.000
1.4	*Pair + Tag*	31	49.0	0.000	14.8	0.000	11.2	0.003	16.3	0.000
1.5	*Pair + Tag + Len*	32	***0.0***	0.646	***0.0***	0.524	***0.0***	0.708	0.4	0.449
1.6	*Pair + Tag × Len*	33	1.2	0.354	0.2	0.474	1.8	0.288	***0.0***	0.548
					Subyearling Chinook 2008					
1.1	*Group*	60	28.6	0.000	36.4	0.000	11.4	0.002	4.8	0.045
1.2	*Null*	41	1144	0.000	516.2	0.000	137.8	0.000	701.4	0.000
1.3	*Pair*	50	31.2	0.000	53.8	0.000	15.0	0.000	7.2	0.013
1.4	*Pair + Tag*	51	38.0	0.000	39.4	0.000	10.8	0.003	9.0	0.005
1.5	*Pair + Tag + Len*	52	***0.0***	0.786	***0.0***	0.574	***0.0***	0.596	0.2	0.445
1.6	*Pair + Tag × Len*	53	2.6	0.214	0.6	0.426	0.8	0.399	***0.0***	0.492

Phase 2—Modeling Survival Probabilities, Part 1

Results for the first set of candidate models for survival probabilities are provided in Appendix Table B5 for 2007 yearling Chinook, Appendix Table B6 for 2007 subyearling Chinook, Appendix Table B7 for yearling Chinook salmon in 2008. With the single exception of survival from Lower Granite to Little Goose Dam for yearlings in 2007 (Appendix Table B5), models with block (*Pair*) effects were much better supported than models with any group-level covariate (almost no support for group-level effects compared to *Pair* or block effects). This means that none of the group-level environmental covariates was a particularly good descriptor of the pattern of variation observed in survival probabilities between paired release groups.

With the single exception of the stretch from Lower Granite to Little Goose Dam for yearling Chinook in 2008 (Appendix Table B7), nearly 100% of the AIC weight was put on models that included both a tag and a length effect on survival probability. Some of the minimum AIC models included an interaction between the tag and length effects and some did not (Appendix Tables B5-B7). As with most of the detection probability models described in Phase 1, the interaction term may have been a "tag along" variable in some of these models. However, there was strong support for the interaction effect in some data sets (e.g., survival from Lower Granite to McNary Dam for subyearling Chinook in 2007; Appendix Table B6).

Respective fitted survival and detection probabilities from the best-supported (greatest AIC weight) model are illustrated in Appendix Figures B1 and B2, for each Chinook salmon data set and each successive river reach. In almost every case, survival increased with length at tagging. In 11 of 12 cases there was an effect related to tag type (the one exception was in survival from Lower Granite to Little Goose Dam for yearling Chinook in 2008). Dual-tagged fish had higher fitted survival in four cases: from Lower Granite to Lower Monumental and Ice Harbor Dam for yearling Chinook in 2007, and again from Lower Granite to Lower Monumental and Ice Harbor for yearlings in 2008.

In three of these four cases (the exception was the reach from Lower Granite to Lower Monumental Dam for yearling Chinook in 2007), the best-support model result contradicted the result from CJS estimates. That is, the mean survival estimate from the CJS model was lower for dual-tagged than for PIT-tagged fish, but the fitted model indicated the opposite. To fully understand this unexpected result would require further investigation of numerical aspects of the routine used by SURPH v2.2b to fit these complex models. For subyearlings in 2007, fitted survival was substantially lower for dual-tagged fish in all reaches and at all lengths. Survival for dual-tagged fish was 76-78% that of PIT-tagged fish throughout the size range in the very first reach, from Lower Granite to Little Goose Dam.

Appendix Table B5. Summary of results from Akaike's information criterion (AIC) for Phase 2 modeling of reach survival probability for paired releases of yearling Chinook salmon in 2007. Information shown for each model includes number of parameters (k), delta AIC (Δ), and AIC weight (w). Shaded cells indicate AIC weight > 0.05; bold italic figures indicate delta AIC minimum AIC model.

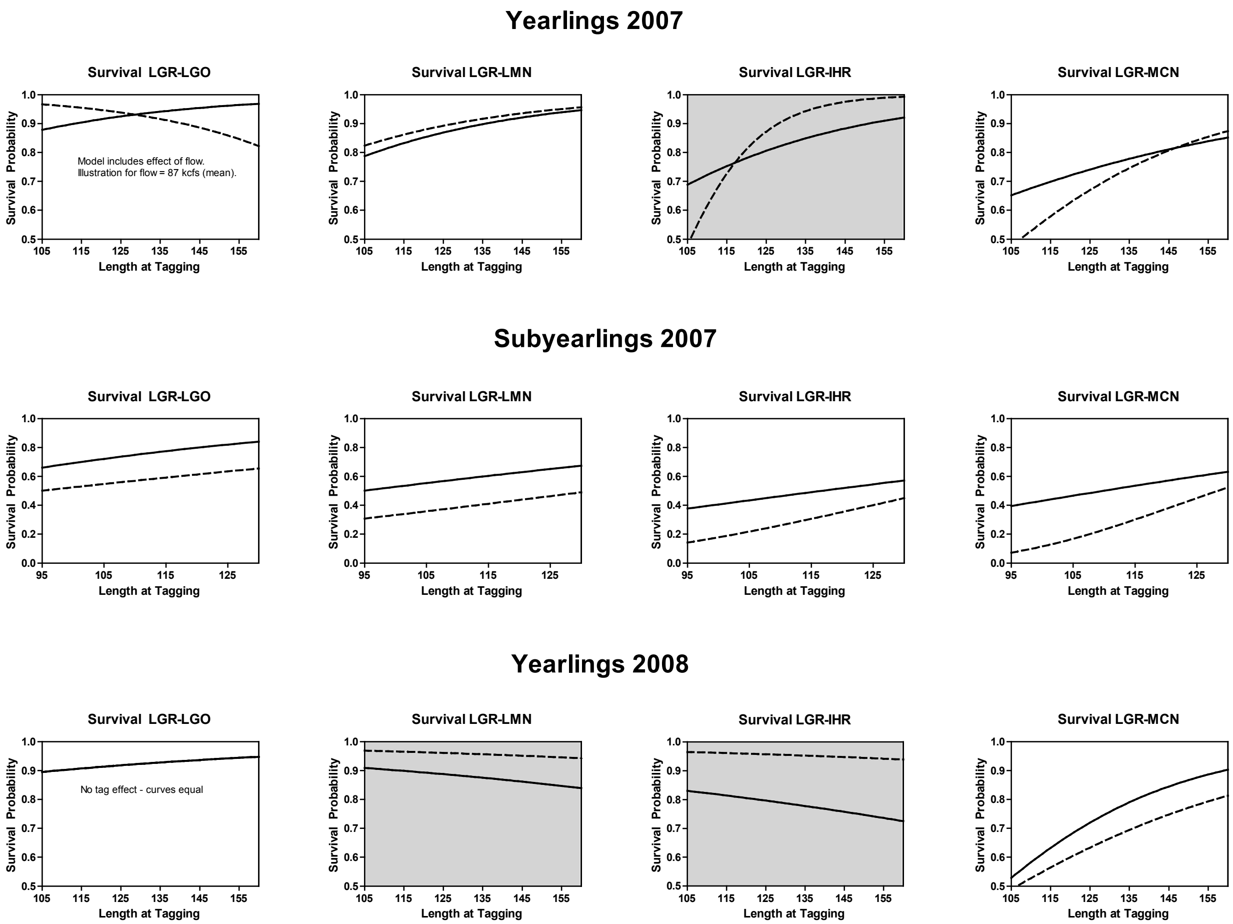
Yearling Chinook salmon 2007										
			Tailrace-to-tailrace survival from Lower Granite Dam							
			to Little Goose		to Lower Monumental		to Ice Harbor		to McNary	
Model	Description	k	Δ	w	Δ	w	Δ	w	Δ	w
2.1	*Pair*	30	14.1	0.001	16.5	0.000	34.9	0.000	54.4	0.000
2.2	*Pair + Tag*	31	5.8	0.032	29.8	0.000	12.1	0.002	18.8	0.000
2.3	*Pair + Tag + Len*	32	5.4	0.040	***0.0***	1.000	13.7	0.001	2.6	0.214
2.4	*Pair + Tag × Len*	33	1.4	0.292	25.9	0.000	***0.0***	0.994	***0.0***	0.786
2.5	Null	21	83.2	0.000	53.0	0.000	53.9	0.000	116.0	0.000
2.6	*Len*	22	66.9	0.000	35.9	0.000	25.7	0.000	76.6	0.000
2.7	*Tag + Len*	23	65.8	0.000	37.8	0.000	19.4	0.000	52.9	0.000
2.8	*Tag × Len*	24	66.2	0.000	37.4	0.000	16.2	0.000	52.2	0.000
2.9	*Flow*	22	11.2	0.002	55.0	0.000	50.7	0.000	113.8	0.000
2.10	*Flow + Len*	23	8.0	0.011	37.9	0.000	50.1	0.000	74.8	0.000
2.11	*Flow + Tag + Len*	24	7.7	0.013	39.7	0.000	50.8	0.000	53.5	0.000
2.12	*Flow + Tag × Len*	25	***0.0***	0.589	67.6	0.000	34.7	0.000	52.4	0.000
2.13	*Sp%*	22	17.0	0.000	54.6	0.000	54.3	0.000	116.1	0.000
2.14	*Sp% + Len*	23	16.6	0.000	37.8	0.000	25.9	0.000	76.7	0.000
2.15	*Sp% + Tag + Len*	24	17.6	0.000	39.7	0.000	21.4	0.000	51.4	0.000
2.16	*Sp% + Tag × Len*	25	6.7	0.021	34.7	0.000	41.9	0.000	51.2	0.000
2.17	*Temp*	22	78.5	0.000	53.6	0.000	53.6	0.000	87.6	0.000
2.18	*Temp + Len*	23	64.3	0.000	37.4	0.000	26.9	0.000	48.3	0.000
2.19	*Temp + Tag + Len*	24	63.7	0.000	39.4	0.000	20.5	0.000	25.5	0.000
2.20	*Temp + Tag × Len*	25	64.4	0.000	34.1	0.000	17.3	0.000	24.7	0.000
2.21	*TT*	22	75.0	0.000	50.6	0.000	50.8	0.000	117.0	0.000
2.22	*TT + Len*	23	68.6	0.000	29.4	0.000	19.0	0.000	78.4	0.000
2.23	*TT + Tag + Len*	24	67.5	0.000	31.1	0.000	18.3	0.000	53.5	0.000
2.24	*TT + Tag × Len*	25	67.9	0.000	30.6	0.000	13.1	0.001	52.5	0.000

Appendix Table B6. Summary of results from Akaike's information criterion (AIC) for Phase 2 modeling of reach survival probability for paired releases of subyearling Chinook salmon in 2007. Information shown for each model includes number of parameters (k), delta-AIC (Δ), and AIC-weight (w). Shaded cells are those with AIC weight > 0.05. Delta-AIC indicating minimum-AIC model is underlined bold italic.

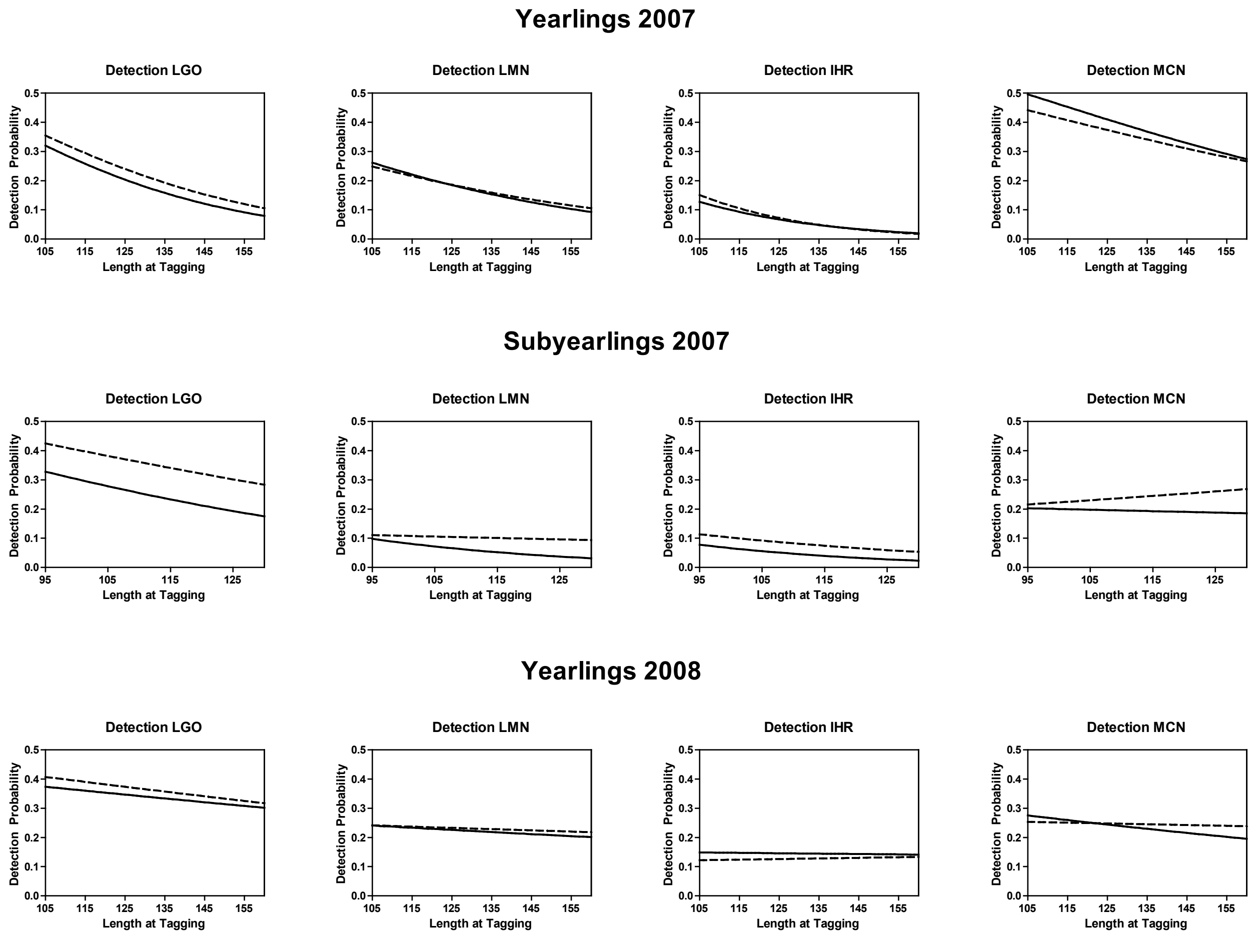
Subyearling Chinook salmon 2007										
			Tailrace-to-tailrace survival from Lower Granite Dam							
			to Little Goose		to Lower Monumental		to Ice Harbor		to McNary	
Model	Description	k	Δ	w	Δ	w	Δ	w	Δ	w
2.1	*Pair*	22	199.7	0.000	130.2	0.000	118.7	0.000	335.3	0.000
2.2	*Pair + Tag*	23	174.4	0.000	128.2	0.000	115.1	0.000	311.4	0.000
2.3	*Pair + Tag + Len*	24	0.3	0.463	<u>***0.0***</u>	0.668	2.7	0.206	12.6	0.002
2.4	*Pair + Tag × Len*	25	<u>***0.0***</u>	0.537	1.4	0.332	<u>***0.0***</u>	0.794	<u>***0.0***</u>	0.998
2.5	Null	17	654.6	0.000	714.1	0.000	723.8	0.000	760.9	0.000
2.6	*Len*	18	656.6	0.000	710.9	0.000	722.0	0.000	756.0	0.000
2.7	*Tag + Len*	19	657.5	0.000	696.2	0.000	713.5	0.000	710.9	0.000
2.8	*Tag × Len*	20	645.7	0.000	673.3	0.000	622.5	0.000	658.5	0.000
2.9	*Flow*	18	313.3	0.000	248.5	0.000	255.7	0.000	473.0	0.000
2.10	*Flow + Len*	19	296.4	0.000	248.0	0.000	248.1	0.000	464.0	0.000
2.11	*Flow + Tag + Len*	20	150.7	0.000	186.5	0.000	200.2	0.000	278.8	0.000
2.12	*Flow + Tag × Len*	21	147.3	0.000	188.4	0.000	199.5	0.000	277.5	0.000
2.13	*Sp%*	18	355.4	0.000	309.1	0.000	327.1	0.000	606.9	0.000
2.14	*Sp% + Len*	19	347.8	0.000	310.9	0.000	328.0	0.000	605.0	0.000
2.15	*Sp% + Tag + Len*	20	216.7	0.000	284.1	0.000	317.3	0.000	564.5	0.000
2.16	*Sp% + Tag × Len*	21	209.0	0.000	283.7	0.000	318.8	0.000	565.6	0.000
2.17	*Temp*	18	387.9	0.000	662.9	0.000	273.8	0.000	436.1	0.000
2.18	*Temp + Len*	19	373.3	0.000	256.3	0.000	246.5	0.000	412.7	0.000
2.19	*Temp + Tag + Len*	20	103.6	0.000	77.5	0.000	138.7	0.000	179.7	0.000
2.20	*Temp + Tag × Len*	21	87.5	0.000	79.4	0.000	139.9	0.000	180.5	0.000
2.21	*TT*	18	444.5	0.000	404.1	0.000	418.7	0.000	503.1	0.000
2.22	*TT + Len*	19	443.0	0.000	404.7	0.000	420.2	0.000	504.6	0.000
2.23	*TT + Tag + Len*	20	300.1	0.000	305.0	0.000	321.4	0.000	499.9	0.000
2.24	*TT + Tag × Len*	21	307.3	0.000	306.7	0.000	320.8	0.000	497.1	0.000

Appendix Table B7. Summary of results from Akaike's information criterion (AIC) for Phase 2 modeling of reach survival probability for paired releases of yearling Chinook salmon in 2007. Information shown for each model includes number of parameters (k), delta-AIC (Δ), and AIC weight (w). Shaded cells indicate AIC weight > 0.05; bold italic figures indicate delta AIC minimum AIC model.

Yearling Chinook salmon 2008										
			Tailrace-to-tailrace survival from Lower Granite Dam							
			to Little Goose		to Lower Monumental		to Ice Harbor		to McNary	
Model	Description	k	Δ	w	Δ	w	Δ	w	Δ	w
2.1	*Pair*	30	18.7	0.000	60.0	0.000	132.5	0.000	97.6	0.000
2.2	*Pair + Tag*	31	***0.0***	0.651	40.2	0.000	118.9	0.000	28.2	0.000
2.3	*Pair + Tag + Len*	32	1.9	0.252	***0.0***	0.550	0.4	0.450	3.1	0.175
2.4	*Pair + Tag × Len*	33	3.8	0.097	0.4	0.450	***0.0***	0.550	***0.0***	0.825
2.5	*Null*	21	301.3	0.000	452.1	0.000	720.4	0.000	220.2	0.000
2.6	*Len*	22	258.0	0.000	379.4	0.000	621.9	0.000	120.6	0.000
2.7	*Tag + Len*	23	259.1	0.000	380.7	0.000	621.4	0.000	101.3	0.000
2.8	*Tag × Len*	24	251.7	0.000	373.6	0.000	623.2	0.000	92.9	0.000
2.9	*Flow*	22	303.2	0.000	341.3	0.000	465.3	0.000	214.9	0.000
2.10	*Flow + Len*	23	256.2	0.000	310.4	0.000	421.8	0.000	110.9	0.000
2.11	*Flow + Tag + Len*	24	255.8	0.000	279.8	0.000	307.8	0.000	84.7	0.000
2.12	*Flow + Tag × Len*	25	242.6	0.000	275.0	0.000	309.8	0.000	68.0	0.000
2.13	*Sp%*	22	279.1	0.000	416.3	0.000	623.5	0.000	208.9	0.000
2.14	*Sp% + Len*	23	215.5	0.000	369.0	0.000	565.4	0.000	99.4	0.000
2.15	*Sp% + Tag + Len*	24	211.2	0.000	367.6	0.000	525.0	0.000	71.1	0.000
2.16	*Sp% + Tag × Len*	25	201.9	0.000	365.3	0.000	527.0	0.000	56.3	0.000
2.17	*Temp*	22	299.6	0.000	323.5	0.000	452.4	0.000	222.1	0.000
2.18	*Temp + Len*	23	259.6	0.000	307.5	0.000	429.5	0.000	121.0	0.000
2.19	*Temp + Tag + Len*	24	260.5	0.000	269.8	0.000	286.0	0.000	99.3	0.000
2.20	*Temp + Tag × Len*	25	251.5	0.000	266.1	0.000	288.0	0.000	85.8	0.000
2.21	*TT*	22	302.1	0.000	440.8	0.000	679.0	0.000	220.1	0.000
2.22	*TT + Len*	23	255.7	0.000	381.4	0.000	619.9	0.000	120.8	0.000
2.23	*TT + Tag + Len*	24	256.8	0.000	382.7	0.000	616.2	0.000	102.4	0.000
2.24	*TT + Tag × Len*	25	247.1	0.000	375.0	0.000	622.3	0.000	92.8	0.000



Appendix Figure B1. Illustration of survival component of best-supported models for each data set and survival reach. Fitted curve for survival vs. length at tagging was calculated for each release group by tag type. Solid lines indicate average curves across PIT-tagged groups and dashed lines indicate average for dual-tagged groups. Shaded panels indicate fitted models that estimate higher survival for dual-tagged fish, despite lower average survival estimates from CJS model.



Appendix Figure B2. Illustration of detection component of best-supported models for each data set and each survival reach. Fitted curve for detection vs. length at tagging was calculated for each release group of PIT-tagged or dual-tagged fish. Solid lines indicate average curves across PIT-tagged groups and dashed lines indicate average for dual-tagged groups.

For all three data sets, dual-tagged fish had lower fitted survival from Lower Granite to McNary Dam tailrace, the longest reach for which we estimated survival. For yearlings in 2007, average fitted survival for 110-mm dual-tagged fish was 78% that of PIT-tagged fish (0.528 vs. 0.782). The ratio increased with larger fish, and the two averages were equal at a length of 147 mm (91% of all tagged fish were smaller than 147 mm). For the other two data sets, survival of dual-tagged fish was less than that of PIT-tagged fish at all sizes. For subyearlings in 2007, relative survival ranged from 26.5% for 100-mm fish to 82.8% for 130-mm fish. For yearlings in 2008, relative survival was near constant at 88-90% throughout the range of sizes.

In almost all cases, fitted detection probabilities for both tag-type groups were higher for smaller fish than for larger fish (Appendix Figure B2). For yearlings in both 2007 and 2008, detection probabilities were similar at all dams for both tag types. Dual-tagged fish had slightly higher fitted detection probabilities at Little Goose Dam, but at the other dams there was no consistent pattern of one tag type being more detectable than the other. For subyearlings in 2007 there was a bit more difference between tag types, with dual-tagged fish more likely to be detected (i.e., more likely to pass via the juvenile bypass system) at all sizes and at all dams.

Phase 3 – Modeling Survival Probabilities, Part 2

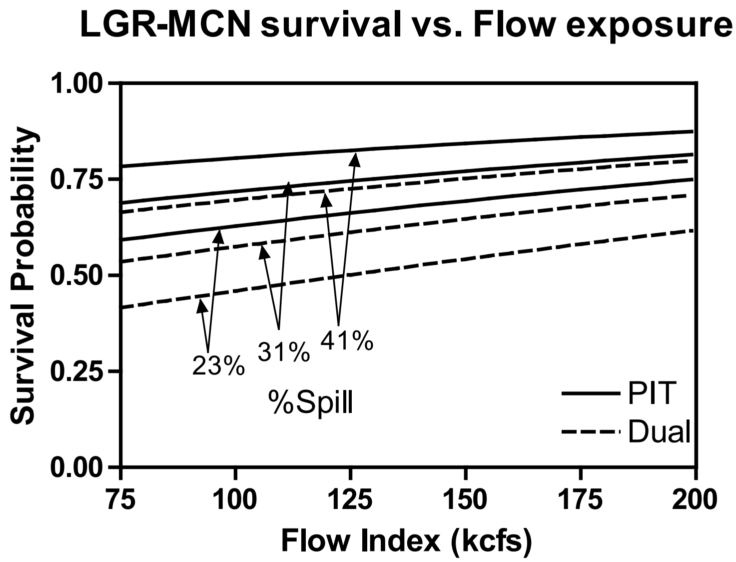
The analysis of river-environment covariates was not successful for yearling Chinook salmon in 2007, probably because the range of covariates was too narrow (Appendix Table B1). However, the 2007 yearling results suggest a caveat to all the results of this phase. Namely, that a single series of releases in a single year is not sufficient for a thorough and unequivocal analysis of environmental covariates. There are too many confounding factors, and the environmental factors are typically too correlated to derive definitive information on environmental effects from a single season of data. In future analyses, it will likely be beneficial to combine yearling data from 2007 and 2008 in one analysis.

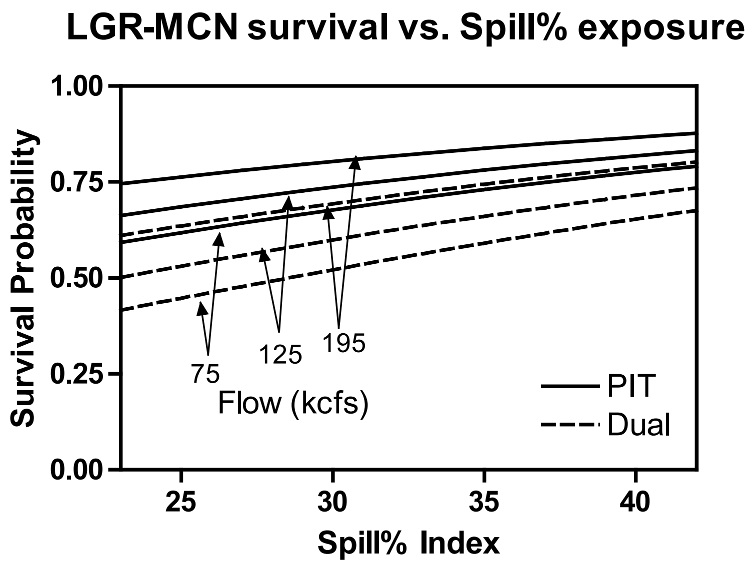
For yearlings in 2008, two models in the phase 3 candidate set received considerable AIC weight: the first included all three group-level exposure variables fork length (*Len*), percent spill (*Sp*%), and temperature (*Temp*; AIC weight 0.598). The second included those three variables plus travel time (*TT*; AIC weight 0.402; Appendix Table B8). Model-averaged fitted survival probabilities from Lower Granite to McNary Dam for an average-sized fish (135 mm fork length at tagging) with a temperature exposure index of 11.5°C and travel time of 10.9 d is illustrated in Appendix Figure B3.

Appendix Table B8. Summary of AIC results for Phase 3 models of group-level environmental effects on survival probability between Lower Granite Dam and McNary Dam. Information for each model is: number of parameters (k), delta AIC (Δ), and AIC weight (w). Cells with AIC weight greater than 0.05 are shaded; delta-AIC indicating minimum-AIC model is underlined bold italic.

		Yearling Chinook 2007			Subyearling Chinook 2007			Yearling Chinook 2008		
Model	Description	k	Δ	w	k	Δ	w	k	Δ	w
3.1	Null Gp Cov	24	49.1	0.000	20	627.3	0.000	24	63.9	0.000
3.2	*Flow*	25	49.3	0.000	21	246.3	0.000	25	39.0	0.000
3.3	*Sp%*	25	48.1	0.000	21	534.4	0.000	25	27.3	0.000
3.4	*Temp*	25	21.6	0.000	21	149.3	0.000	25	56.8	0.000
3.5	*TT*	25	49.4	0.000	21	465.9	0.000	25	63.8	0.000
3.6	*Flow + Sp%*	26	3.5	0.098	22	103.9	0.000	26	29.1	0.000
3.7	*Flow + Temp*	26	17.1	0.000	22	74.1	0.000	26	32.9	0.000
3.8	*Flow + TT*	26	47.4	0.000	22	244.1	0.000	26	38.3	0.000
3.9	*Sp% + Temp*	26	21.9	0.000	22	66.2	0.000	26	13.2	0.001
3.10	*Sp% + TT*	26	50.0	0.000	22	392.9	0.000	26	23.8	0.000
3.11	*Temp + TT*	26	18.2	0.000	22	19.9	0.000	26	58.9	0.000
3.12	*Flow + Sp% + Temp*	27	5.3	0.040	23	1.1	0.294	27	***0.0***	0.598
3.13	*Flow + Sp% + TT*	27	***0.0***	0.566	23	57.8	0.000	27	24.6	0.000
3.14	*Flow + Temp + TT*	27	16.7	0.000	23	19.6	0.000	27	34.8	0.000
3.15	*Sp% + Temp + TT*	27	20.0	0.000	23	1.9	0.197	27	15.2	0.000
3.16	*Flow + Sp% + Temp +TT*	28	1.3	0.295	24	***0.0***	0.509	28	0.8	0.401

All models included a detection component that included block (*Pair*) effects and an interaction between fish length and tag type, and a survival component that also included an interaction between length and tag type. Block effects on survival were not included in these models – differences between groups were modeled through the environmental covariates (though as seen in Phase 2, relatively little variation between pairs was explained by these variables. Though *Flow* and *Sp*% indices were strongly correlated in the 2008 yearling dataset (Appendix Table B3), the supported models included both these terms and also the third correlated covariate, *Temp* (Appendix Table B8). The range of fitted survival across the range of covariates was similar, but slightly greater for *Sp*% than for *Flow* (Appendix Figure B3). The range of flow was wide, 75-200 kcfs, while the range in percent spill was relatively narrow, 23-43% (41% was selected for illustration because the fitted curve for dual-tagged fish at 43% was indistinguishable from that for PIT-tagged fish at 31%), indicating that the effect of spill exposure on survival was greater than that of flow exposure.





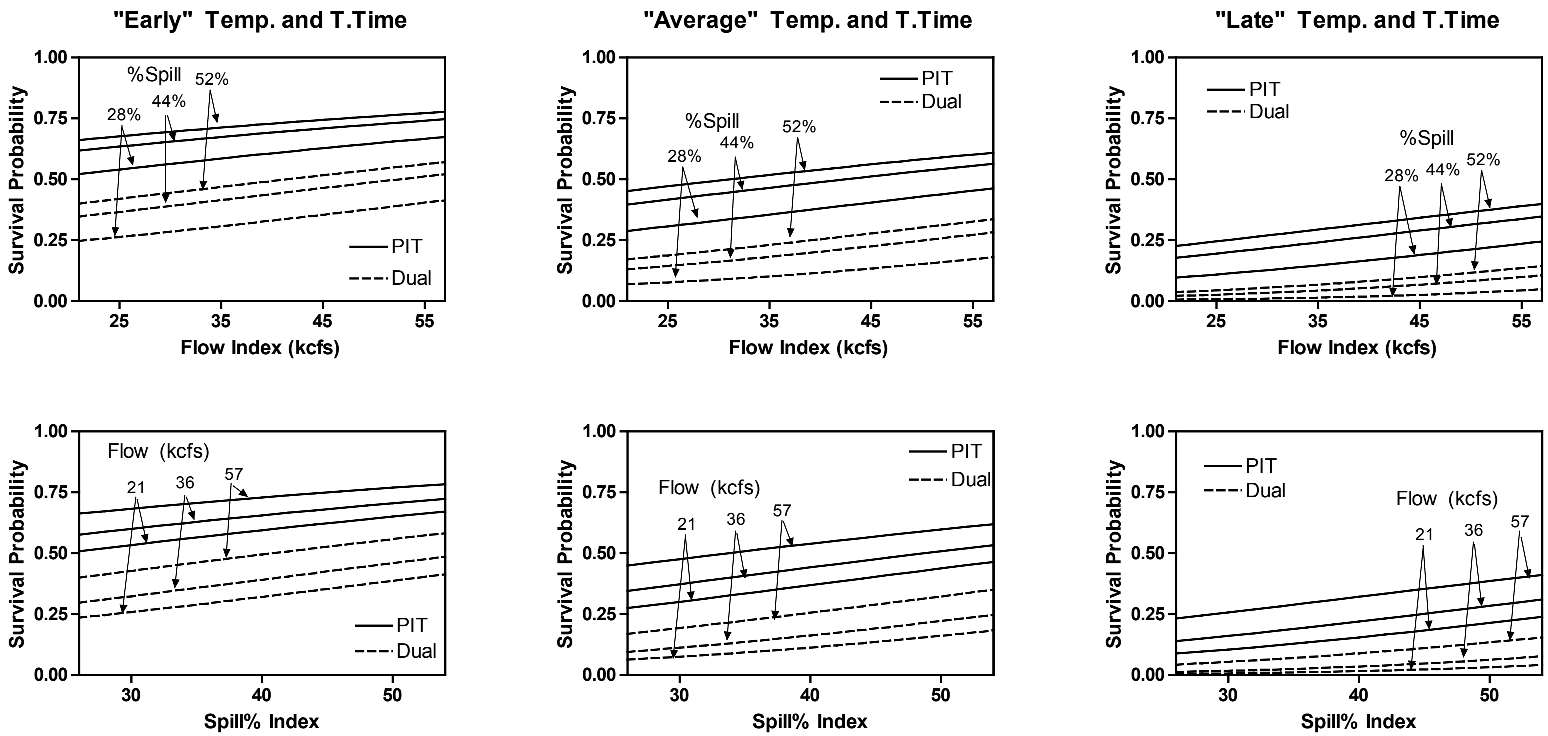
Appendix Figure B3. Illustration of model-averaged fitted survival probabilities from Lower Granite to McNary Dam for yearling Chinook salmon in 2008. Upper panel shows survival vs. flow exposure index at three levels of spill% exposure by tag type. Lower panel shows survival vs. spill% exposure index at three levels of flow exposure by tag type. Selected exposure levels were minimum, average, and maximum within the dataset. Curves are for 135-mm fork-length fish migrating in 11.5°C water and with a travel time of 10.9 d. Tag effect is evident in the distance between corresponding solid (PIT) and dashed (dual) lines.

For subyearlings released in 2007, three models were reasonably well-supported by data. The first two were the same two models that best fit the data for yearlings in 2008. The third was a three-variable model, which included *Sp*%, *Temp*, and *TT* (but not *Len*; Appendix Table B8). The best-supported model included all four variables. Model-averaged fitted survival probabilities from Lower Granite to McNary Dam for an average-sized fish (108 mm FL at tagging) are illustrated in Appendix Figure B4.

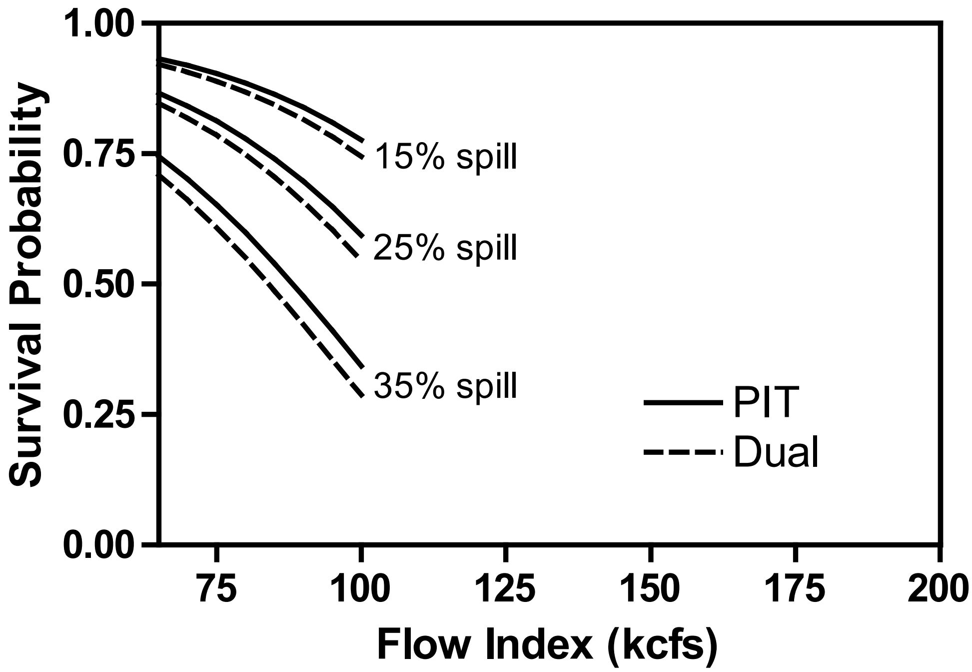
Subyearlings in 2007 had much greater ranges of temperature exposure and travel time from Lower Granite to McNary Dam than did yearlings in 2008. Accordingly, instead of a single "typical" combination of temperature and travel time, for subyearlings we illustrated three separate combinations, which correspond to temperature and travel times experienced by early, middle or "average," and late release groups of subyearlings in 2007. For each combination, the relationships between fitted survival and flow and spill exposure were similar for subyearlings in 2007 as for yearlings in 2008.

For subyearlings in 2007, flow and spill exposure were not strongly correlated (Appendix Table B2), and appear to have had roughly equal effect on survival (judged by range of fitted values). The range of fitted survival was greater across the three temperature/travel time combinations than across either flow or spill. Water temperature was the most important predictor of survival for subyearlings in 2007; all supported models included temperature and spill exposure, while the range of survival across observed water temperatures was greater.

Returning to yearlings released in 2007, four models had AIC weight exceeding 0.000, and all of them included flow and spill exposure. Model-averaged fitted survival probabilities from Lower Granite to McNary Dam for an average-sized fish (135 mm fork length at tagging) with temperature exposure index of 11.5°C and travel time of 10.9 d is illustrated in Appendix Figure B5. All four supported models showed similar severe decreases in survival as flow and spill proportion increased over their relatively narrow ranges. We rejected this analysis because of its biologically implausible result.



Appendix Figure B4. Illustration of model-averaged fitted Lower Granite-to-McNary survival probabilities for subyearling Chinook salmon in 2007. Upper panels show survival vs. flow exposure index at three levels for spill% exposure for each tagging type. Lower panels show survival vs. spill exposure index at three levels of flow exposure for each tagging type. Three selected flow and spill exposure levels are minimum, average, and maximum within the dataset. Curves are for fish of 108-mm FL. Left panels show water at 16.0°C and travel time of 12.0 d; middle panels show 18.8°C and 15.2 d; right panels show 21.2°C and 20.4 d. Tag effect is evident in the distance between corresponding solid (PIT) and dashed (dual) lines.



Appendix Figure B5. Illustration of model-averaged fitted survival probabilities for yearling Chinook salmon from Lower Granite to McNary Dam in 2007. Survival is plotted vs. flow exposure index at three levels of spill exposure for each tagging type. The selected spill exposure levels are minimum, average, and maximum within the dataset. Curves are for 135-mm fork-length fish migrating in conditions of 11.5°C temperature with a total travel time of 10.9 d. This analysis was rejected, as the fitted curves are biologically implausible; there is no mechanism to explain severe decrease in survival as flow and spill% increase over their relatively narrow ranges. Narrow ranges are the likely cause of this mathematical result.

Conclusions

In general, the best models for both detection and survival probabilities included block (pair) effects, an effect for tag type (PIT tag vs. dual PIT and JSATS tag), and an effect of individual fish size (fork length at tagging). Models for detection probability that included an interaction between tag and length were often supported by data, but the interaction effect was small at best, and appeared to most frequently appear as a "tag-along" variable in the information-theoretic analysis. For models of survival probability, there were a few more data sets in which the tag-length interaction was strongly supported, beyond the "tag-along variable" phenomenon.

Thus, fish length and tag type clearly had the strongest effects on survival in these analyses. Environmental covariates explained little of the variation between paired groups or between groups within pairs. Part of the difference in strength of evidence for effects results from the nature of the data sets: there is more statistical power to detect effects of factors measured at the individual level (e.g., for fork length or tag type, the sample size is counted as total number of tagged individuals) than those measured at the group level (e.g., for flow and spill exposure indices, which by their nature cannot be measured on individuals, the sample size is the number of groups).

When we attempted to model the portion of the between-group variation that could be explained by environmental covariates, supported models included all the covariates we considered (flow, spill proportion, water temperature, and travel time). For yearlings in 2008, percent spill and flow were correlated with each other, but effects of both were supported by data. Spill proportion was probably the most important factor; the range of observed spill% was associated with a larger range of fitted survival probabilities than any of the other variables. For subyearlings in 2007, water temperature appeared to have the strongest influence on survival.

However, all of our analyses of environmental covariates suffered from correlated and potentially confounded predictor variables. More definitive analyses of these types of variables typically require multiple years of data. Only tentative conclusions can be drawn from a series of release groups within a single season. These difficulties are best illustrated by our results for yearlings released in 2007, which were biologically nonsensical. Continued investigation of the complexities of the 2007 yearling data set will result in a better understanding of these results, and these analyses should be pursued if definitive answers are to be obtained.

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APPENDIX C

Histological Metrics

Appendix Table C. Description of metrics used in histological evaluations. Except where otherwise noted, all metrics are evaluated by presence/absence.

Metric	Description/biological meaning
Liver	
Liver vacuolation	Measure of the normal glycogen (energy) or lipid/fat stores in liver; primarily glycogen. This is a nutritional measure. Measured on ordinal scale of 1-7.
Liver lymphocytic infiltrates and PV cuffing	Infiltrates of mononuclear inflammatory cells and/or perivascular cuffing (aggregates of mononuclear inflammatory cells around blood vessels). Can be indicative of a host response to BKD or other infectious agents.
Liver hydropic vacuolation (abbr. Liver HYDVAC):	Water vacuoles in the liver cell. Occurrence may be related to previous exposure to chlorinated hydrocarbons (marine fish) or changes in pH. Measured on an ordinal scale of 1-7.
Liver coagulative necrosis:	Coagulative necrosis in hepatocytes of liver
Liver eosinophilic hypertrophy (abbr. Liver eosin. Hypertrophy):	Phenomena where hepatocytes stain more eosinophilic than usual, and are hypertrophied; occurrence is often related to degenerative changes.
Liver BKD lesions:	Lesions suggestive of bacterial kidney disease in liver.
Liver Ceratomyxa lesions:	Ceratomyxa shasta-like myxosporeans in liver.
Pancreas	
Pancreatic zymogen	A digestive enzyme measured on an ordinal scale of 0-3. Low or absent pancreatic zymogen indicates that a fish has stopped eating.
Pancreatic atrophy	Evidence that pancreatic cells have shrunk. This metric also indicates that a fish has stopped eating.
Pancreatic Inflammation	Inflammatory cell infiltrates in and around the exocrine pancreas.
Stomach	
Pyloric caecae mucosal glycogen	Glycogen reserves in the pyloric caecae; rated on an ordinal scale from 0-3.
Small intestine	
Small intestinal mucosal glycogen	Glycogen reserves in the small intestine. This is generally not a good indicator or nutritional status; rated on an ordinal scale from 0-3.
Small intenstinal digesta	Presence/absence of food in the small intestine. This metric is a nutritional measure.
Small intestinal trematode content	When present, small intestinal trematodes appeared to be at commensal levels.
Small intestinal inflammation	Presence of intestinal inflammation.
Small intestinal Ceratomyxa	Organisms resembling Ceratomyxa shasta in mucosa of small intestine.
Lower intestine	
Lower intestinal mucosal glycogen levels	Glycogen stores in the lower intestine; rated on an ordinal scale from 0-3. This metric is a nutritional indicator.
Lower intestinal digesta	Presence/absence of food in the large intestine. This metric is a nutritional measure.
Lower intestinal trematodes	If present, levels did not appear higher than normal, and there was no indication that trematodes were causing problems for these fish.
Lower intestinal inflammation	Inflammation in the lower intestine.

Appendix Table C. Continued.

Metric	Description/biological meaning
Heart epicarditis/myocarditis	Either inflammation of the epicardium (epicarditis) or myocardium (myocarditis) in the heart.
Kidney	
Kidney BKD lesions	Indication of a host response to BKD infection.
Kidney tubule epithelial necrosis	Coagulative necrosis of the epithelium lining the tubules of the kidney nephrons.
Kidney tubule Myxosporea	Unidentified myxosporean infection of the epithelium lining the kidney tubules.
Kidney tubule hydropic vacuolation	Water vacuoles in the kidney tubule cells.
Spleen	
Splenic congestion	Typically indicates a generalized response to stress.
Splenic macrophage aggregates	Normal structures, indicating activity of reticuloendothelial system; rated on ordinal scale from 1-7.
Spleen lymphoid depletion	Reduction in normal proportion of white pulp (lymphoid tissue) to red pump (erythropoietic tissue) in the spleen.
Peritoneum	
Mesenteric chronic inflammation	Inflammation in mesentery; rated as presence/absence.
Mesenteric chronic inflammation severity	Inflammation in mesentery; rated on an ordinal scale from 0-7.
Mesenteric adipose content	Fat reserves in the mesentery; measured on an ordinal scale from 0-3. This metric is a nutritional measure.
Peritonitis, chronic	Internal adhesions at the site of the incision. When present, there were no obvious signs of an infectious cause such as the presence of large amounts of bacteria; however, an infectious cause could not be ruled out.
Wound healing	
Incision closure	Describes whether or not the incision appears closed over by epidermal cells; 1= closure, 0 = open, no closure.
Skin stratum compactum reknitting	Reknitting or reconnection of the stratum compactum layer in the dermis, where the stratum compactum layer on either side of surgical incision has joined together.
Incision, poor apposition	This parameter shows whether or not there was a poor, uneven apposition between the two sides of the incision; essentially describes poor or uneven (i.e. overlapping, rather than evenly apposed) closure of the two body wall surfaces by the sutures. Poor apposition creates a larger entry point for secondary pathogens to enter the wound site and the peritoneal cavity: 1 = poor 0 = good
Incision, chronic inflammation	Measure of presence/absence of chronic inflammatory infiltrates (e.g. macrophages, lymphocytes) at the incision site.
Incision, chronic inflammation severity	Ordinal measure (0-7) of degree of cellular infiltrates in region of incision, as above.
Dermal musculature necrosis	Measure of residual muscle necrosis at incision site.
Dermal hemorrhage fibrin	Measure of residual hemorrhage or fibrin deposition in area of incision.
Incision adhesions	Adhesions between mesenteries associated with internal organs and the peritoneum in the area of the incision and suture site. Adhesions are usually associated with chronic peritonitis.
Internal organ evulsion through incision and presence of saprolegnia	Evaluated internally and externally; measured as presence/absence.