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# In-Stream Monitoring of PIT-tagged Wild Spring/Summer Chinook Salmon Juveniles in Valley Creek, Idaho

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*Abstract*.—Recent advances in passive integrated transponder (PIT) tag technology have allowed the development of in-stream fish-monitoring systems. We installed two such systems in Valley Creek near its confluence with the Salmon River in summer 2002. In the summers of 2003–2005 we collected and PIT tagged wild spring/summer Chinook salmon parr *Oncorhynchus tshawytscha* in natal rearing areas upstream from the monitors. Although subsequent detection numbers between fall 2003 and spring 2006 were low and variable, they were sufficient to determine timing and estimate survival. We defined migrational groups by period of detection: late summer and fall (August–October), winter (November–February), and the following spring (March–June). Combining 3 years of data, the mean proportions of fish detected during these three respective detection periods were 60.6, 27.7, and 11.7%. Mean probability estimates of survival from Valley Creek to Lower Granite or Little Goose Dams were 9.2, 23.4, and 40.8% for the respective late summer and fall, winter, and spring periods. Estimated overall mean probabilities of survival were 46.6% from tagging as parr to movement into the mouth of Valley Creek and 17.3% from Valley Creek to Lower Granite Dam. The overall mean parr-to-smolt survival estimate from tagging to arrival at Lower Granite Dam was 9.0%. The unexpectedly high proportion of fish migrating in winter has important implications for fish monitoring studies that use rotary screw or scoop traps: these traps are generally inoperable during winter near most natal rearing areas and thus may result in biased estimates of fish population status and migration timing. Advancements in technologies and methodologies to instream PIT-tag monitoring systems will improve data quality to assist recovery planning for threatened and endangered fish species.

## Introduction

Declines of several stocks of salmon and steelhead in the Columbia River basin over the last three decades have led to listings under the Endangered Species Act (ESA) and have prompted regional fish and wildlife programs to develop strategies to reverse these trends (NPPC 1980, 1994). Additionally, the National Marine Fisheries Service (NMFS) has issued biological opinions on actions

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taken by federal agencies to alleviate pressures on these stocks (NMFS 1995, 2001, 2004). These agencies have identified the importance of monitoring ESA-listed juvenile salmon to provide information needed for recovery of these stocks. Development and application of passive integrated transponder (PIT) tag technology (Prentice et al. 1990a, 1990b, 1990c), which permits identification of individual marked fish, has provided a tool to acquire some of this needed information. Many studies of juvenile fish migration timing, survival, biology, and behavior rely on PIT data, particularly in the Columbia River basin (Achord et al. 1996; Skalski et al. 1998; Muir et al. 2001a, 2001b; Achord et al. 2003; Zabel and Achord 2004; Achord et al. 2007; and Monzyk et al. 2009).

For example, in the Snake River portion of the Columbia River basin (Figure 1), many wild juvenile stream-type Chinook salmon *Oncorhynchus tshawytscha* are captured, PIT tagged, and released annually in their natal streams for long-term monitoring (Achord et al. 1996, 2007; Jonasson et al. 2006; Monzyk et al. 2009). Although in principle the PIT tag can be read at any time, previous monitoring opportunities for PIT-tagged fish have been restricted by the short read-range of early PIT tags. Until recently, detections were lim-

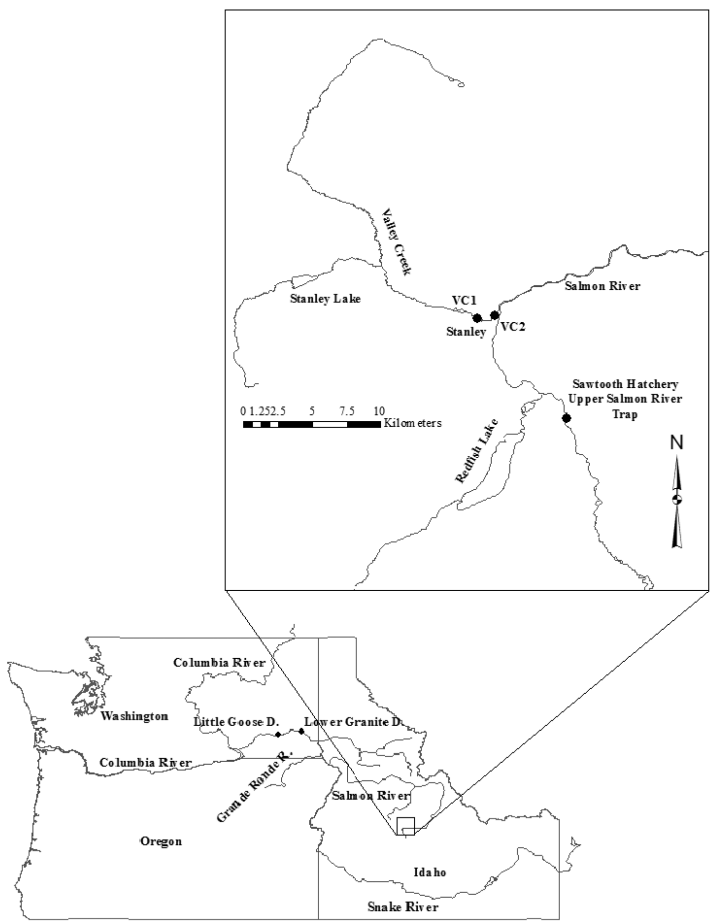


**Figure 1.** A study area map of the Pacific Northwest, USA with inset showing the Valley Creek in-stream PIT-tag monitoring sites study area.

ited to the juvenile fish bypass systems of some dams (Prentice et al. 1990a) and to a submerged PIT-tag detection trawl operating near the mouth of the Columbia River (Ledgerwood et al. 2004). These detection locations are often hundreds of kilometers from juvenile rearing areas. Thus, although these detections provide valuable information, large voids remain in our understanding of fish biology, behavior, and ecology between juvenile rearing areas and mainstem dams.

To obtain such information, NMFS began developing an in-stream monitor in 2000, when the full-duplex, 134.2-kHz PIT tag was introduced as the standard for basin-wide research. The PIT-tag is a type of RFID (radio frequency identification) tag developed and tested by NMFS during the mid-1980s (Prentice et al. 1990b). Using the standard PIT tag in 2000, a prototype in-stream system was developed at NMFS Manchester Research Station (Downing et al. 2004). In 2001, the first in-stream monitoring system was field tested in Rattlesnake Creek, a tributary of the Little White Salmon River in Washington State. Subsequent studies and development at this location occurred concomitantly with our studies in Valley Creek (Connolly et al. 2008).

In 2002, we continued work to improve this system and began development of a stand-alone system for use in remote areas lacking access to the power grid. Valley Creek near Stanley, Idaho, was selected for evaluation of the stand-alone system because of its year-round accessibility, moderate discharge, and climate extremes. Moreover, the stream constitutes natal rearing habitat for wild spring/summer Chinook salmon. The Chinook salmon population in Valley Creek has a long-term monitoring history (Achord et al. 1996, 2007) and is part of the evolutionarily significant unit (ESU) of Snake River spring/summer Chinook salmon, which was listed as threatened under the U.S. Endangered Species Act in 1992. In an interagency effort to monitor and recover these fish, NMFS, Oregon Department of Fish and Wildlife (ODFW), and Idaho Department of Fish and Game (IDFG) have PIT tagged fish from this ESU at the parr stage since 1988 (Achord et al. 1996, 2007; Jonasson et al. 2006; Kiefer and Lockhart 1997).

The goals of our in-stream PIT-tag monitoring work were to develop, install, and evaluate in-stream monitoring systems that could operate for weeks without service, and to investigate migration timing, travel time, and survival probabilities for juvenile Chinook salmon migrants that display various life history strategies in Valley Creek. In this paper, we describe in-stream PIT-tag monitoring systems and present methods for analyses of these systems. We report results from work during 2003–2006 and give a brief project update for work during 2007–2010.

## Methods

### *Study sites and equipment*

In the first week of August each year from 2003 to 2005, wild Chinook salmon parr were collected, PIT tagged, and released in Valley Creek in areas from stream km 4 to stream km 18 (Figure 1). For the duration of our study, we used the Digital Angel[1] "BE" PIT tag. Achord et al. (1996, 2007) provide details on collection, handling, and PIT tagging procedures.

In-stream PIT-tag monitoring systems were deployed in July 2002 at two sites in Valley Creek near the town of Stanley in central Idaho. Valley Creek is a medium-sized stream lying within the larger Salmon River drainage (36,000 km$^2$). Its drainage area is 381 km$^2$ with a mean annual discharge of 5.46 m$^3$/s, based on mean daily flows from 1993 to 2006 (U.S. Geological Survey, sta-

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

tion 13295000). Elevations of the two monitoring sites were 1,901 and 1,904 m, with the lower site located 739.4 km upstream from Lower Granite Dam and 1,434 km from the Pacific Ocean.

The two monitoring sites were located approximately 1.2 km apart. The upstream or "on-grid" site (VC1) was located approximately 1.6-km upstream from the confluence of Valley Creek with the Salmon River. The site had access to electric power and a land-line phone (Figure 2).

Following this initial deployment, the in-stream PIT-tag monitoring system was modified extensively from mid-2002 to mid-2003. Various antenna designs were constructed and evaluated, and details of this work are reported by Downing et al. (2004). Concurrent systems were reported by Zydlewski et al. (2006), Bond et al. (2007), Horton et al. (2007), and Connolly et al. 2008. Ultimately, we developed a "hybrid" system, which uses pivots to combined features of the earlier pass-through and pass-by models. After development and testing, we deployed rectangular antennas of 7.6-cm PVC pipe (3.0-m long × 0.6-m wide). At each site, one long side of the antenna was anchored to the substrate in the main thalweg (Figures 2 and 3) using a frame secured with four 0.9-m steel stakes. Pivoting devices on the antennas allowed the unanchored side of the rectangle to move up and down with the water level. Wetted width of the stream at both sites averaged about 17–21 m during low to medium flows, thus the antennas covered about 14–18% of the stream width.

The antennas were connected to transceivers via specially designed electrical cable, which was 15-m long at the upstream site and

**Figure 2.** The upper PIT-tag monitoring site (VC1) on Valley Creek, approximately 1.6 km from the confluence with the Salmon River.

**Figure 3.** The lower PIT-tag monitoring site (VC2) on Valley Creek, approximately 0.4 km from the confluence with the Salmon River. The eight solar panels obscure the view of the utility trailer.

35-m long at the downstream site. All electronics at both locations were housed in 2.4-m long enclosed trailers (Figure 2). Both systems were set up to automatically interrogate, store, and transmit data to the PIT Tag Information System (PTAGIS), a regional database operated by the Pacific States Marine Fisheries Commission (PSMFC 1996-). In addition, both systems could be monitored remotely via "timer" tags built into the systems, which constantly tested antenna function and sent electronic alerts if problems were detected.

The "off-grid" stand-alone system (VC2) was more complicated than the VC1 "on-grid" system because it was located where no power or communication utilities were available. After considerable development, its components included a model FS1000A 24-V DC transceiver, notebook computer, wireless Ethernet link to the VC1 computer, power inverter, DC power disconnect and breaker panel, generator relay, and data control board.

The stand-alone system relied on three areas of developing technology: the antenna system, power supply, and transceiver. For a power supply, we mounted eight solar panels on an outside frame on the trailer (Figure 3), along with two 284-L propane tanks and a generator. Inside the trailer were four 12-V DC 110-amp $h^{-1}$ glass-mat batteries, which were connected in series and shielded from other electronics. Complete details of the system and issues related to the tag, transceiver, and antenna are reported by Downing et al. (2004), Zydlewski et al. (2006), Horton et al. (2007), and Connolly et al. (2008).

During 2003–2004, 2004–2005, and 2005–2006, both systems were operational year-round, although work to improve their performance continued through 2006.

## Data Analysis

To evaluate detection efficiencies of the monitoring systems, we used an indirect method similar to that described by Connolly et al. (2008). Detection efficiencies of the two in-stream monitors were inferred from detection probabilities of fish released above the monitors. Fish detection probabilities were estimated from detection or nondetection at downstream monitors. Thus, for all tagged fish we compiled a detection history, which included the two in-stream monitors in Valley Creek as well as monitors in the juvenile collection facilities at downstream dams.

We estimated survival probabilities for the PIT-tagged population from release as parr in Valley Creek to arrival at Lower Granite Dam as smolts. This migration corridor was divided into two smaller segments: (1) stream segment, from the point of release to the lower in-stream PIT-tag monitor, and (2) river segment, from the lower stream monitor to Lower Granite or Little Goose Dam.

### *Stream segment*

To estimate survival in the stream segment, we collapsed the detection histories for each fish to include detection at VC1 and/or detection at VC2 and/or detection at a site downstream. This allowed eight possible detection histories (combinations of "detected" and/or "not detected" on three sites after release). Counts of fish with each detection history were fitted to a multinomial model, with cell probabilities parameterized as functions of detection and survival probability. The model was similar to the Cormack–Jolly–Seber (CJS) model (Cormack 1964; Jolly 1965; Seber 1965) used extensively for PIT-tagged fish survival estimation in the Columbia River basin, except that we assumed 100% survival over the 1.2-km stream segment between VC1 and VC2.

Evidence from detection data showed that detection at VC1 was not independent of detection at VC2; however, an independent probability of detection for each fish is a critical assumption required by the multiple recapture model. The assumption that survival was 100% between VC1 and VC2 allowed us to model the dependency between these detection probabilities.

To evaluate this dependency, two different models were possible, each distinguishable by the three estimable parameters for instream detection. The first model included an overall (mean) detection probability at VC1 and two separate detection probabilities at VC2, depending on whether or not the fish was detected at VC1. The second model was the reverse, with an overall detection probability at VC2 and two separate detection probabilities at VC1, depending on whether or not the fish was detected at VC2. The survival probability estimate from point of release to VC2 was the same for both models, as was the probability of detection somewhere downstream from VC2. We used both models and report detection probability estimates from both. Parameter estimates and associated standard errors for all models were calculated using program USER 2.1 (Lady et al. 2003).

### *River segment*

For the river segment, through the use of auxiliary data, we estimated separate probabilities of survival for each of the three periods when fish were detected by in-stream monitors: late summer and fall (August–October), winter (November–February), and spring (March–June). To obtain these estimates, we first grouped detected fish by seasonal period of in-stream detection in Valley Creek. Then, for each group, we compiled a temporal distribution of detections at Lower Granite Dam (i.e., the number of fish from each seasonal period detected at the dam on each day). Each daily count at the dam was then divided by the estimated probability of detection at Lower Granite Dam that day (see below) to derive an estimate of the total number of fish from each seasonal group that passed Lower Granite Dam on that day. Daily passage estimates were then summed to give an estimate of the total number of fish from each seasonal group that survived to Lower Granite Dam. This number was divided by the number in the group (i.e., total number detected at VC1 and VC2 during the seasonal period) to derive the estimate of survival from Valley Creek to Lower Granite Dam.

We summed the estimated numbers passing Lower Granite Dam from each seasonal detection period at Valley Creek to get an overall estimate of the number of fish detected at the stream that passed the dam. We divided this number by the total number of detections to estimate the overall probability of survival for PIT-tagged fish released in a given year.

Daily detection probabilities at Lower Granite Dam were estimated with auxiliary data using the method of Schaefer (1951) as modified by Sandford and Smith (2002). The auxiliary data were for all wild Chinook salmon tagged and released in the Snake River Basin upstream from the dam. For each day of the migration season, we estimated numbers of all wild Chinook salmon PIT-tagged and released upstream from the dam that passed the dam detected or undetected. Thus a series of daily probabilities of detection was developed as follows:

1) Fish detected on day *i* at Little Goose Dam that had previously been detected at Lower Granite Dam were tabulated according to day of passage at Lower Granite Dam.

2) Fish detected on day *i* at Little Goose Dam that had *not* previously been detected at Lower Granite Dam were assigned to an estimated day of passage at Lower Granite Dam, assuming that their passage distribution at Lower Granite Dam was proportionate to that of detected fish.

3) This process was repeated for all days with detections at Little Goose Dam.

4) Detected and nondetected fish passing Lower Granite Dam on day *i* were summed.

5) Detection probability on day *i* was estimated by dividing the number of fish detected on day *i* by the sum of detected and (estimated) nondetected fish passing that day.

We modified the method slightly (see Sandford and Smith 2002) for estimates in the tails of the passage distribution where the above process was not applicable (e.g., for days when no detections occurred at Little Goose Dam).

Bootstrap methods were used to derive standard errors for the estimated probability of survival from Valley Creek to Lower Granite Dam (Achord et al. 2007). Auxiliary data were used to derive bootstrap distributions of daily detection probability estimates. Lower Granite Dam detection data for each Valley Creek group were used for bootstrap distributions of passage at Lower Granite Dam.

## Results

Released numbers of PIT-tagged Chinook salmon parr from tagging years 2003 to 2005 in Valley Creek ranged from 2,218–2,511 (Table 1). Mean fork lengths of these fish at tagging ranged from 62.8 to 64.9 mm. Overall, 20% of the tagged fish were held for 24 h in live cages to measure post tagging mortality and tag loss. Mortality averaged 0.3% and tag loss was zero.

The total number of individual tagged fish detected at one or both in-stream monitoring sites between August of the tagging year

**Table 1.** Tagging and release numbers of wild Chinook salmon parr and estimated survival probabilities from release to the mouth of Valley Creek and the detection probabilities at both in stream PIT-tag monitoring sites for tagging years 2003–2005.

| Tagging Year | Total tagged and released | Estimated survival probability (%) from release to detection at Valley Cr (SE) | Estimated detection probability | |
|---|---|---|---|---|
| | | | VC1 (SE) | VC2 (SE) |
| 2003 | 2,498 | 44.9 (7.1) | | |
| Overall | | | 0.060 (0.012) | 0.182 (0.031) |
| Fish detected on other | | | 0.098 (0.021) | 0.299 (0.056) |
| Fish not detected on other | | | 0.051 (0.012) | 0.175 (0.031) |
| 2004 | 2,511 | 41.3 (4.9) | | |
| Overall | | | 0.105 (0.016) | 0.267 (0.034) |
| Fish detected on other | | | 0.105 (0.018) | 0.266 (0.042) |
| Fish not detected on other | | | 0.105 (0.020) | 0.267 (0.038) |
| 2005 | 2,218 | 53.7 (7.6) | | |
| Overall | | | 0.045 (0.009) | 0.119 (0.019) |
| Fish detected on other | | | 0.099 (0.025) | 0.259 (0.060) |
| Fish not detected on other | | | 0.038 (0.008) | 0.113 (0.019) |
| Average 2003–2005 | | 46.6 (3.7) | | |
| Overall | | | 0.070 (0.018) | 0.189 (0.043) |
| Fish detected on other | | | 0.101 (0.002) | 0.275 (0.012) |
| Fish not detected on other | | | 0.065 (0.021) | 0.185 (0.045) |

and June of the following year ranged from 182 to 357 (Table 2). Based on detections at downstream dams, overall efficiency of the two monitoring systems was 22.6% in 2003, 34.4% in 2004, and 14.9% in 2005. Migration from the release site to the in-stream monitors was protracted; significant numbers of fish were detected in late summer and fall the year of release and during the following winter and spring. The CJS model and the similar model used in our study typically rely on the assumption that probabilities of survival and detection are equal for all tagged animals. This assumption is not likely valid for the protracted migrations we observed. However, the data indicated that detection probabilities at the in-stream sites were relatively stable among the three migration periods. Therefore, our overall estimated survival probabilities were reasonable estimates of *average* survival for each annual group comprised of all three seasonal migration timing groups.

The estimated overall probability of detection was lower at VC1 (the on-grid site) than at VC2 (the stand-alone site) in all three years (Table 1). The average estimated detection probability was 0.070 at VC1 and 0.189 at VC2. Estimated detection probability at VC2 averaged 0.275 for fish detected at VC1 and 0.185 for fish not detected at VC1 (Table 1). Estimated detection probability at VC1 averaged 0.101 for fish detected at VC2 and 0.065 for fish not detected at VC2. For annual groups of tagged wild Chinook salmon parr released upstream, estimated survival from the point of release to the mouth of Valley Creek (as migrants) ranged from 41.3 to 53.7% and averaged 46.6% (Table 1).

**Table 2.** Numbers and proportions (by season) of wild Chinook salmon juveniles detected at the Valley Creek monitors and the estimated survival probabilities of Valley Creek (VC) detected fish to Lower Granite (LGR) or Little Goose (LGO) Dams and the overall survival probabilities from release to the dam(s).

| Tagging and detection years | Detected in Valley Creek | | Estimated number passing LGR (spring after tagging) | Estimated survival probability (%) | |
|---|---|---|---|---|---|
| | *N* | (%) | | Detection at VC to LGR or LGO (SE) | Release to LGR or LGO (SE) |
| **2003–2004** | | | | | |
| Total | 251 | | 33.1 | 13.2 (2.7) | 5.7 (1.5) |
| Late summer/fall (Aug–Oct) | 148 | 59.0 | 9.5 | 6.4 (3.0) | |
| Winter (Nov–Feb) | 81 | 32.3 | 14.1 | 17.4 (6.1) | |
| Spring (Mar–Jun) | 22 | 8.8 | 9.5 | 43.1 (12.5) | |
| **2004–2005** | | | | | |
| Total | 357 | | 53.2 | 14.9 (2.4) | 8.6 (1.6) |
| Late summer/fall (Aug–Oct) | 276 | 77.3 | 32.0 | 11.6 (2.4) | |
| Winter (Nov–Feb) | 50 | 14.0 | 12.2 | 24.4 (8.8) | |
| Spring (Mar–Jun) | 31 | 8.7 | 9.0 | 29.0 (12.6) | |
| **2005–2006** | | | | | |
| Total | 182 | | 43.1 | 23.7 (4.2) | 12.7 (2.9) |
| Late summer/fall (Aug–Oct) | 83 | 45.6 | 7.9 | 9.6 (4.1) | |
| Winter (Nov–Feb) | 67 | 36.8 | 19.1 | 28.4 (7.6) | |
| Spring (Mar–Jun) | 32 | 17.6 | 16.1 | 50.3 (13.6) | |
| **Average 2003–2006** | | | | 17.3 (3.3) | 9.0 (2.0) |
| Late summer/fall (Aug–Oct) | | 60.6 | | 9.2 (1.5) | |
| Winter (Nov–Feb) | | 27.7 | | 23.4 (3.2) | |
| Spring (Mar–Jun) | | 11.7 | | 40.8 (6.3) | |

The highest proportion of in-stream detections of tagged fish occurred in late summer or fall (August through October) in all years and averaged 60.6% of the total detections (Table 2). The average proportion of detections that occurred in winter (November through February) was 27.7%, and the average in spring (March through June) was 11.7%. Although lower detection efficiencies were expected during higher flows, almost all fish were detected from August to early May under low to moderate flow conditions, prior to peak flows from mid-May to June.

By seasonal detection period, estimates of average annual survival in the river segment were 9.2% for late summer or fall, 23.4% for winter, and 40.8% for spring (Table 2). In 2006 (tagging year 2005), we based survival estimates on detections at Little Goose Dam because of the low number of detections at Lower Granite Dam. Since survival estimates between the two dams were high in 2006 for all PIT-tagged wild Chinook salmon (95.6%; Faulkner et al. 2007), we did not adjust these estimates. Overall annual estimated survival from detection at the mouth of Valley Creek to arrival at either lower Snake River dam ranged from 13.2 to 23.7% and averaged 17.3% (Table 2).

To estimate overall annual survival from point of release in August to arrival at either lower Snake River dam the following spring, we multiplied the stream segment survival estimate by the river segment estimate (Table 1). Overall estimated annual survival ranged from 5.7 to 12.7% and averaged 9.0% (Table 2).

Juvenile Chinook salmon passed the stream monitors predominately during hours of darkness in all years (2003–2006). The overall mean annual proportion of fish passage from 1800 to 0600 was 93.5% (range 91.7–94.7%).

Juvenile Chinook salmon traveled predominately in a downstream direction. Total numbers detected at both monitoring sites during 2003–2004, 2004–2005, and 2005–2006, were 20, 29, and 14, respectively. The overall mean yearly travel time for these fish between upstream and downstream monitors was 8 h and 21 min (range 19 min-110.4 d). Based on travel times, these fish appeared to actively migrate from Valley Creek. Only one fish likely overwintered between the monitors.

## Discussion

This project had both technical and biological goals. While we accomplished the technical goal of producing a stand-alone monitoring system that could operate for several weeks without service, further years of study will be required to meet the biological objectives. The project has provided initial data on migration timing and duration, travel time, and survival probability for juvenile Chinook salmon migrants from Valley Creek. However, only 8–14% of the tagged juvenile Chinook salmon was detected at these monitors during these 3 study years. By increasing coverage or efficiency of the antennas, fish should be detected at higher rates.

To produce adequate precision for estimates of biological parameters will require either more antennas, larger antennas, or greater numbers of fish tagged. The low precision of our estimates to date precludes meaningful analyses relating finer scale fish movement and survival to water quality parameters such as temperature, pH, conductivity, dissolved oxygen, turbidity, and flow. Nevertheless, these data are collected near the monitors and will be available for such analyses in future years.

We observed extremely low 24-h post-tagging mortality and no tag loss in all three tagging years. Actual parr-to-smolt tag loss in our study could have been similar to the 2.0% observed by Knudsen et al. (2009) in hatchery spring Chinook salmon presmolts held 70–125 d after tagging. However, even if this were the case, it would not have changed the accuracy of our survival estimates substantially. Dare (2003) found less tag loss (less than 1.0%) than Knudsen et al. in similar fish held for a shorter time after tagging (28 d). We are not aware of any study of long-term tag retention and delayed mortality during the parr-to-smolt life stage for wild Chinook salmon in natural conditions.

Investigators from ODFW using screw traps near natal rearing areas in streams of the Grande Ronde River drainage (Figure 1) found that most wild juvenile Chinook salmon migrations occur in fall and spring, with few observed in winter (Jonasson et al. 2006). However, winter trapping operations have been intermittent for various reasons, including harsh environmental conditions. Studies by the IDFG using traps in the upper Salmon River (8 km upstream from Valley Creek; Figure 1) have also found that parr, presmolts, and smolts migrate in summer, fall, and spring (Walters et al. 1999; Venditti et al. 2005, 2006); however, trapping generally did not occur in winter (~November–February) in the Salmon River drainage. We believe our study provides the first evidence of significant migration of presmolts from this ESU during winter (proportional average 28%). This downstream movement was probably not an effort to reach the ocean, but rather to search out warmer water temperatures and better feeding conditions prior to initiation of the smolt stage in spring.

Regardless of the motivation, this behavior was unexpected, and has important implications for fish monitoring studies throughout Idaho and the Pacific Northwest. Because rotary screw and scoop traps are inoperable during winter in most areas, considerable proportions of fish that move downstream during winter may be passing undetected. At some locations, agencies may consider using a combination of traps and in-stream monitors to improve fish monitoring studies. The varied life history strategies displayed by this species probably act as a survival mechanism by spreading the population spatially and temporally throughout downstream areas of the Salmon River.

In the upper Salmon River, significant numbers of parr/presmolts migrate in late summer and fall (Walters et al. 1999; Venditti et al. 2005, 2006). Migration behavior of Valley Creek fish is similar to that of fish in the upper Salmon River. We observed migratory behavior during early August and November in a substantial proportion of these fish. Migration in early August, as well as in November prior to trap removal, has also been observed in upper Salmon River fish (Kiefer and Lockhart 1995, 1997). We believe the migration patterns observed for these fish in the upper Salmon River indicate that a considerable number probably migrate during winter in this stream. However, as in Valley Creek, migration behavior during a given season probably varies from year to year.

Because of the low sample sizes obtained with instream monitoring systems to date, we are continuing work to improve performance of tags, antennas, transceivers, and power supply systems. Future research needs include development of standardized procedures to measure tag-reading efficiencies and to evaluate the effectiveness of antennas placed in streams under variable conditions. These protocols are in turn tied to behavioral responses of various fish species to these structures, as well as differing stream habitats and flow conditions. An example of standardized protocol for in-stream monitoring of detection efficiencies and effectiveness in small streams is presented by Zydlewski et al. (2006). This might be translated for use in moderate-sized streams. There is also a need to develop additional statistical methodologies for PIT-tag monitoring systems in streams and rivers.

## Project Update

Monitoring results from 2007 to 2010 have not substantially changed the biological results presented in this paper. What has changed is the explosion of in-stream PIT tag monitoring systems usage throughout the Pacific Northwest. Most in-stream monitoring systems, including the Valley Creek systems, now use multiplex transceivers, which can power and decode data from multiple antennas. Technological advancements in both tags and monitoring systems have increased detection range, bringing a new set of challenges for successful in-stream PIT tag monitoring. Most of these issues were related to mechanical and electro-magnetic interference, and most have been rectified. In 2007–2008, the first year of using multiple antennas, in-stream monitors operated intermittently. Presently, we have two full years of analyzed data from the Valley Creek monitors using the new system with multiple antennas. In 2008–2009 and 2009–2010, overall detection efficiencies of the two monitoring systems were 45.6% and 37.7%, respectively, compared to a yearly average of 24% from 2003 to 2006. Migration patterns of juvenile fish (groups) moving out of Valley Creek and their estimated survival rates to the dams in 2008–2009 and 2009–2010 were similar to earlier years. Development and improvements to the Valley Creek monitoring systems will continue.

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