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Mortality and Long-Term Retention of Passive Integrated Transponder Tags by Spring Chinook Salmon

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Abstract.—I monitored long-term mortality and retention rates of passive integrated transponder (PIT) tags for 145,000 juvenile spring chinook salmon *Oncorhynchus tshawytscha* tagged as part of a large-scale tagging project. A total of 325 PIT tagged mortalities were collected during the 28-d study. Mortalities were collected, on average, 11 d after tagging, indicating that direct mortality due to tagging was rare. The mortality rate observed during the study was less than 1.0%. With the exception of the first day of tagging, 24-h retention was greater than 99.0%. A total of 113 shed tags were collected following the first day of tagging, corresponding to a 24-h retention rate of 98.1%. The overall retention rate for the study was 99.996%. I found no statistical relationship between the frequency of shedding and fish length or time of tagging. Although the relationship is not quantifiable, the frequency of sheds appeared to be linked to the experience of tagging personnel at the start of the tagging project and the continuity of personnel at a tagging station.

The use of passive integrated transponder (PIT) tags in large-scale survival studies involving fish passage through hydroelectric projects carries a number of assumptions and satisfying these assumptions is critical to accurately assessing survival (Burnham et al. 1987). Although PIT tags are commonly used in studies of salmonid migration and survival through hydroelectric projects on the Columbia and Snake rivers, little research has been conducted on tag retention since the technology was developed in the 1980s. As the technology became more routinely used, a number of studies were conducted by National Marine Fisheries Service (NMFS) personnel and published as technical reports and summarized during the American Fisheries Society Symposium, Fish Marking Techniques (Parker et al. 1990). Prentice et al. (1990) conducted a retention study using juvenile chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* under a variety of conditions. They found that retention in fish as small as 55 mm was 99–100%. Studies addressing PIT tag retention in adult fishes have also found retention rates were at or near 100% (Harvey and Campbell 1989; Jenkins and Smith 1990; Prentice 1990; Buzby and Deegan 1999).

Past retention research typically was encumbered by one of two shortcomings: (1) the study was conducted on a small number of fish, or (2) the study lacked a long-term temporal component. For example, the above-mentioned studies were conducted using relatively small numbers of fish: 22–300 per treatment group. More recently, Muir et al. (2001) published a survival study where PIT tag retention was evaluated on larger treatment groups of 119–1,405 chinook salmon and 148–4,009 steelhead. These fish were held for approximately 24 h before release; therefore, this study did not address long-term retention. According to Burnham et al. (1987) 12 assumptions are associated with release–recapture data. Three of these assumptions relate directly to PIT tag retention: (1) the number of fish released is exactly known, (2) tags are not lost, and (3) all fish in a release group have the same probability of capture (Burnham et al. 1987). Data for fish passage and survival studies is typically collected from large numbers of fish that can take several weeks to migrate to sea (Achord et al. 1996; Muir et al. 2001; Smith et al. 2002). These assumptions would be violated if tag retention was substantially less than 100% or if shedding occurred after release. Management actions that potentially increase survival of emigrating salmonids by as little as 1% are considered significant in the Columbia River basin (Skalski 1998). Because the time before release is the only time during a survival study that a researcher has direct control over the fish, controlling potential sources of error, including tag-shedding rates that could mask any measurable change in survival, should be a high priority.

During March and April 2002, I conducted a PIT tag retention study at the Leavenworth National Fish Hatchery (LNFH), using 145,000 PIT tagged spring chinook salmon. These fish were being tagged to evaluate the efficacy of transportation of juveniles through McNary Dam. The pur-

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pose of this study was to determine the mortality and long-term (3–4 weeks after tagging) retention of PIT tags implanted as part of a large-scale tagging project. I defined ''large-scale'' as any project where tagging rates exceeded 200/person/h. Additionally, I investigated potential causal factors in PIT tag losses, including tagging rate, tagging personnel, and feeding.

Methods

Study area.—Juvenile spring chinook salmon were held in covered, concrete raceways (30.8 m $\times$ 3.07 m $\times$ 1.5 m deep) supplied with stream water. Fish were tagged during 17 d from 11 March through 29 March 2002. Approximately 20,000 PIT tagged salmon were held in each raceway and this made up about one-third of the total population of each raceway.

Fish collection and tagging.—All tagging was done in a self-contained tagging trailer set up near the holding raceways. Fish were transported from raceways into a holding tank inside the trailer using buckets. Before tagging, fish were removed from the holding tank and placed in separate sinks containing tricaine methanesulfonate (MS-222) at a concentration of 52.8 mg/L. At this concentration, fish could be placed in the anesthetic for up to 30 min without causing mortality.

Fish were tagged with 12-mm Destron Fearing 134.2-kHz PIT tags using a 12-gauge hypodermic needle fitted onto modified syringes. The 13-person tagging crew consisted of six tagging personnel, three digitizers (digitizers interrogated each tagged fish, measured their fork length [FL], and noted external signs of disease), and four needle loaders. Fish were tagged using the techniques described in Prentice et al. (1990). This procedure involved piercing the body cavity at or near the ventral midline of a fish and inserting a tag into the body cavity. Fish were transferred from the tagging facility to the holding raceway via a 10-cm-diameter pipe. A secondary reader was placed on the outflow pipe to safeguard against missed tag interrogations at the tagging stations.

Mortality and shed-tag collection.—Mortalities were collected from raceways daily from 12 March through 6 April. Shed tags were collected daily until 8 April. Dead fish were examined for a tagging wound and signs of disease; PIT tags were removed from fish having a visible wound.

Shed tags were collected from raceways using a large rolling magnet. Each raceway could be ''swept'' in approximately 30 min. The magnet was checked and shed tags were removed at the approximate halfway point within each raceway. All PIT tags collected were placed in plastic bags labeled with the raceway number, date, total number of mortalities, and total number of PIT tagged mortalities.

The efficiency of the rolling magnet was tested by sweeping a raceway containing a known number of tags. Three trials were conducted using 100 tags/trial. Tags were distributed throughout the raceway; however, during the first trial an effort was made to place several tags in close proximity to corners and walls to determine the efficacy of the magnet in these parts of the raceway. During each trial, I collected 100, 92, and 94 tags, respectively. This represented an overall collection efficiency of 95.3%.

Data analysis.—To determine if mortality and shed rates were related to fish size, I compared the proportion of fish of a particular size-class that died or shed tags with the proportion of that size-class in the total tagged population using chi-square analysis. Specifically, I asked the question: for a given size-class of fish, were mortalities or shed rates greater than would be expected if proportional tag loss in every size-class of fish were identical?

I tested the influence of tagging rate, and continuity of tagging personnel on tag shedding. The relationship between tagging rate and shedding was examined using correlation and regression analysis. Lastly, I observed the frequency of shedding in relation to continuity of tagging personnel at a given station. Although it was not possible to quantitatively analyze these data, I discuss them as a plausible explanation for the increased shed rates that were documented at each tagging station.

Results and Discussion

Mortality

A total of 1,729 mortalities were collected over a 26-d period, representing substantially less than 1% of the fish within the tagged and untagged populations (Table 1). Of the 325 PIT tagged mortalities, fork length data were available for 287 (Figure 1). Of the PIT tagged mortalities 88% were less than 130 mm FL; however, 84% of the fish we tagged during this study were of this size-class. Mortality rate was significantly higher in these smaller fish ($\chi^2 = 4.075$, df = 1, $P = 0.044$).

On average, PIT tagged mortalities were collected 10.9 d (95% confidence interval: 10.0–11.8 d) after tagging, although 42 (15%) of the mortalities for which data were available died within

TABLE 1.—Proportion of mortalities in untagged and tagged (passive integrated transponder tags) populations of juvenile chinook salmon in seven raceways at Leavenworth National Fish Hatchery. Untagged population data represent numbers of total raceway population (inventory data tabulated by hatchery personnel on 5 March 2002) minus the total number of tagged fish in each raceway.

Raceway	Untagged population	Untagged mortalities	Proportion	Tagged population	Tagged mortalities	Proportion
2	51,672	257	0.005	13,829	68	0.005
3	47,946	194	0.004	18,010	85	0.005
4	48,832	230	0.005	17,658	51	0.003
5	39,962	252	0.006	26,328	55	0.002
9	32,891	196	0.006	25,196	50	0.002
10	33,085	119	0.004	25,889	11	0.0004
11	40,407	156	0.004	17,540	5	0.0002
Total	294,795	1,404	0.005	144,450	325	0.002

24 h of tagging. Most untagged mortalities displayed external signs of bacterial kidney disease, particularly bloating. Several PIT tagged mortalities were bloated; however, the tagging crew culled 1,009 fish that had obvious signs of bacterial kidney disease during the tagging operation. Because of the substantial delay between tagging and mortality, disease and other stressors probably related to the hatchery environment were the primary factor in most of these mortalities. However, I could not determine the extent to which the stress associated with PIT tagging contributed to these mortalities.

Retention

Over a 28-d period, I collected 575 shed tags, which corresponded to an overall retention rate of 99.996% (Table 2). If 5% of the shed tags were missed over the course of the study, approximately 29 additional tags were missed. Based on the total number of fish tagged during the project, the corrected overall retention rate remained at 99.996%. This level of retention is similar to that reported during previous studies (Prentice 1990; Achord et al. 1996; Buzby and Deegan 1999; Muir et al. 2001). Estimates of 24-h retention rates were similar to those in previous studies. The 24-h retention rate was only less than 99% for the first day when it was 98.1%.

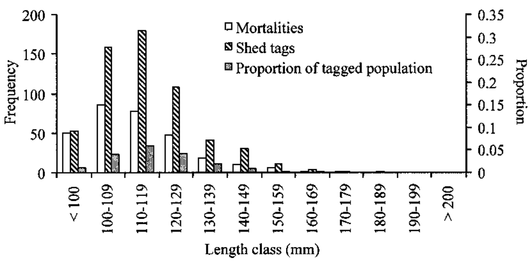

FIGURE 1.—Frequency distribution of size-classes within the population of chinook salmon juveniles tagged with passive integrated transponder (PIT) tags, of tagged-fish mortalities, and of shed tags collected during a 26-d PIT tag retention study.

Length data were available for 563 of the fish that shed tags (Figure 1). Of the shed tags that were recovered, 85% came from fish that were less than 130 mm FL; however, shed rates were not significantly higher for this size-class ($\chi^2 = 1.45$, df = 1, $P = 0.228$).

Most shed tags were collected during the first 2 d of sampling (Table 2). The high shedding rates observed during the first 2 d of the tagging project were most likely attributable to the learning process of the tagging crew, which is associated with the start of a tagging project. Six of the 12 tagging personnel had no experience with PIT tagging, and their inexperience is the most plausible explanation for why 159 shed tags were collected on 12 and 13 March; shed rates declined substantially by day 3 of the tagging project as the skill of the tagging crew improved (Table 2).

Shed tags were collected, on average, 9 d (95% confidence interval: 8.7–10.1 d) after tagging. Because of the high efficiency of the rolling magnet, most tags were probably collected the day after they were shed. Therefore, these data suggest that shedding continued after the termination of sampling on 8 April, or 4 weeks after tagging.

Hourly tagging rate was not strongly related to the frequency of shedding (Figure 2). Tagging rate was negatively correlated to the number of shed tags that originated at a particular tagging station ($r = -0.357$, df = 46, $P = 0.01$); however, when the three highest shed values were removed, the strength of the correlation dropped significantly ($r = -0.112$, 46 df, $P = 0.447$). Most shed tags were traced to stations 1 and 2 during the first 2 d of tagging. Four of the six tagging personnel

TABLE 2.—Distribution of passive integrated transponder tags shed by juvenile chinook salmon in seven raceways at the Leavenworth National Fish Hatchery in March and April 2002. Tags were collected with a special rolling magnetic device. Asterisks denote the day when feeding was resumed in each raceway.

	Raceway							
Day	2	3	4	5	9	10	11	Total
1	113							113
2	46							46
3	1	11						12
4	7	2						9
5	*		3					3
6			1					1
7	1	*						1
8	1			11				12
9	2	5	*	1				8
10	1	1						2
11	2	1	3	1	38			45
12	4	3	11					18
13				*				0
14			1	2	3			6
15	3	1	4	7	1			16
16	5			3	3*	1		12
17	4	5	3	4				16
18	3	3	1	5	3			15
19	7	8	4		6	1	11	37
20	1	11	7		6	*		25
21	2	4		3	10	1	2	22
22	21	3	4	2	2		*	32
23	18	5	2	6	2		2	35
24	20	11	4	2	1	1	2	41
25	7	1	3	1	1	1	3	17
26	7	4	1		1	1	3	17
27	2	1	2		3		2	10
28	1	3					2	6
Total	279	83	54	48	80	6	27	577

working at those stations on those dates had never PIT-tagged before. These data suggest that experience of tagging personnel is a greater contributor to the probability of tag shedding than is the rapid tagging pace associated with large-scale PIT tagging projects.

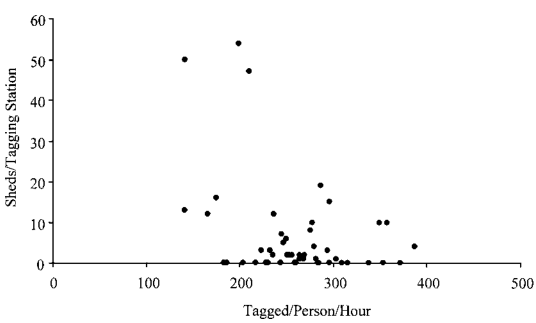

FIGURE 2.—Frequency of passive integrated transponder tags shed per tagging station in relation to tagging rate of individual personnel tagging juvenile chinook salmon. Three observations exerted significant influence on the correlation between these two variables; removing them resulted in nonsignificant linear regression (see text for details).

Of the shed tags collected, 85% came from fish tagged at station 1 (Table 3). Tagging rates differed significantly at the three stations ($F_{2,48} = 4.13$, $P = 0.022$); however, tagging rate was not significantly related to the frequency of shedding (see above). Nine different tag personnel tagged fish at station 1 and eight tagged at station 2; 84% of the shed tags that were collected came from these two stations. These data suggest that continuity at a tagging station is related to the frequency of shedding. The same tagging personnel worked at station 3 for the duration of the project and only 16%

TABLE 3.—Hourly tagging rates and standard deviation per tagging station for 150,000 spring chinook salmon tagged 11–29 March 2002 at the Leavenworth National Fish Hatchery. Personnel is the total number of workers that tagged fish at each station during the tagging project.

Tagging station	Personnel (number)	Mean (SD)	Range	Total sheds
1	9	278.8 (60.0)	141.5–357.2	310
2	8	266.5 (57.9)	165.6–387.3	163
3	2	229.8 (33.1)	141.2–284.7	90

of the sheds tags that were collected originated at that station.

This study has corroborated previous research by showing that despite the occurrence of PIT tag shedding for several weeks after tagging, the overall retention rate for juvenile salmonids tagged via conventional large-scale tagging methods is greater than 99.0%. Water temperatures during this study were consistently below 5°C during the tagging project. Consequently, fish activity within the raceways was minimal, which could have contributed to the very high retention I observed. Shed rates may have been elevated had water temperatures been above 5°C and the posttagging activity of fish been greater. However, under similar conditions, holding fish for 24–48 h following PIT tagging is sufficient to account for most shedding.

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