Use of PIT tags to determine upstream migratory timing and survival of Columbia Basin sockeye salmon in 2006.

Technical Report 07-01

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ABSTRACT

A total of 503 sockeye salmon, *Oncorhynchus nerka*, were PIT-tagged at Bonneville Dam in 2006 and tracked upstream using detections at mainstem dam fish ladders. Based on these detections, upstream survival steadily declined as the migration progressed; Bonneville-Rock Island survival declined from 93.2% for sockeye salmon passing Bonneville Dam the week of June 11 to 63.8% for sockeye salmon passing the week of July 10. There was also a significant linear relationship between decreasing survival and decreasing flow as well as increasing water temperature. The estimated stock composition of sockeye passing Bonneville Dam was 72.8% Okanogan and 27.2% Wenatchee.

Sockeye salmon mean travel time between Bonneville and Rock Island dams was 14 days, indicating a mean travel speed of 34.9 km per day. Fish passing Bonneville Dam later in the migration traveled upstream faster than those earlier in the migration.

Mark-recapture techniques were used to estimate sockeye salmon abundance at upstream dams. These techniques estimated up to 17.8% more fish at McNary and Priest Rapids dams, but up to 14.3% fewer fish at Rock Island, Rocky Reach, and Wells dams when compared to those made by visual fish counts at mainstem dams. Estimated rates of sockeye salmon falling back over the dams after ascending and then reascending ranged from 0.2% at Bonneville Dam to 3.3% at Wells Dam.

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INTRODUCTION

Sockeye salmon, *Oncorhynchus nerka,* is one of the species of Pacific salmon native to the Columbia River Basin. Prior to white settlement of the region, it is estimated the Columbia Basin supported an annual sockeye salmon run averaging over three million fish (Northwest Power Planning Council 1986, Fryer 1995). Since the mid-1800's, however, this sockeye salmon population has severely declined. The estimated number of sockeye salmon entering the Columbia River over the most recent four year period (2003-2006) averaged 78,200 fish per year, though as recently as 1995-1998, the mean escapement was only 24,900 per year (DART 2005, Fish Passage Center 2005). The 2006 count of 37,066 sockeye salmon at Bonneville Dam was the lowest since 1999.

The Columbia Basin sockeye salmon run was once composed of at least eight principal stocks (Fulton 1970, Fryer 1995). Today, only two major stocks remain (Figure 1); the first originating in the Wenatchee River-Lake Wenatchee

Figure 1. Map of the Columbia Basin showing fishery Zones 1-5 and 6, mainstem dams, and the two major sockeye salmon production areas.

System (Wenatchee stock) and second in the Okanogan River-Osoyoos Lake System (Okanogan stock). A third remnant stock, comprising well under 0.1% of the run, returns to Snake River-Redfish Lake (Snake stock) and is listed under the Endangered Species Act.

The Okanogan run is the Columbia Basin's sole remaining transboundary stock. The fish spawn in the Canadian portion of the Okanogan River, then rear in Osoyoos Lake, through which runs the border between the United States and Canada. This run has persisted despite one of the longest, most difficult migrations of any salmon stock in the world. The stock migrates 986 km between the spawning grounds and the ocean through 13 irrigation control structures, one Okanogan River dam, and nine mainstem Columbia River dams. The production of this run is believed to be limited by upstream and downstream migration survival as well as habitat factors in the spawning and rearing areas (Fryer 1995).

The Wenatchee stock spawns in tributaries to Lake Wenatchee and rears in the lake. This stock migrates 842 km through two Wenatchee River dams and seven mainstem Columbia River dams. Since the spawning grounds and lake are relatively pristine, the production of this run is believed limited by upstream and downstream survival as well as the low productivity of the oligotrophic Lake Wenatchee (Fryer 1995).

Since both stocks are believed to be limited, at least in part, by upstream survival, this study was proposed to examine upstream survival and timing by inserting Passive Integrated Transponder (PIT) tags in sockeye sampled at Bonneville Dam as part of our annual Pacific Salmon Commission (PSC)-funded sockeye stock identification project. (We were also funded in 2006 by the PSC Letter of Agreement funding process to PIT tag summer Chinook [Fryer 2007a] which migrate at the same time as sockeye salmon, and we will be presenting some summer Chinook results for comparison purposes.) These PIT tags were then detected at upstream dam fish ladders with detection capability (McNary, Priest Rapids, Rock Island, Rocky Reach, and Wells dams on the Columbia River and Ice Harbor and Lower Granite dams on the Snake River).

The fact that there are only two significant Columbia Basin sockeye salmon stocks makes the species ideal for a PIT tag study because it is easier to determine migration timing and mortality since there are not multiple tributaries

without detection facilities where fish can escape undetected. The run timing of the adult Columbia Basin sockeye salmon migration is of particular interest because the migration has become earlier over the past 70 years (Fryer 1995, Quinn et al. 1997), and a 1997 radio-tagging study found high mortality of the latter portion of the run (Naughton 2005) as well as no difference in stock-specific migration timing. The radio tag study was conducted in an unusually high flow year that may not be typical of other years.

METHODS

Sampling

Sockeye salmon were sampled at the Adult Fish Facility located adjacent to the Second Powerhouse at Bonneville Dam (river km 235) in conjunction with steelhead *O. mykiss* and summer Chinook salmon *O. tshawytscha*. Sampling typically occurred between 0900 and 1500 three days per week. The facility uses a picket weir to divert fish ascending the Washington shore fish ladder into the adult sampling facility collection pool. An attraction flow is used to draw fish through a false weir where they then can be selected for sampling. Fish not selected and fish that have recovered from sampling then migrate back to the Washington Shore fish ladder above the picket weir.

Sockeye selected for sampling were examined for tags (including scanning for existing PIT tags), fin clips, wounds, and condition, measured for length, and four scales removed for later age analysis and measurement for our stock identification project (Fryer 2007b). PIT tags were inserted into the body cavity of the sockeye salmon using standard techniques (CBFWA 1999). The fish were scanned for the PIT tag number which was recorded. If no tag was detected due to either the tag being shed or a malfunctioning tag, another tag was implanted. All PIT tag and sampling information was uploaded to the Columbia Basin PIT tag information system (PTAGIS) database (www.ptagis.org).

PIT-tagged sockeye salmon were detected by existing PIT tag detection arrays in adult fish ladders at Bonneville, McNary, Priest Rapids, Rock Island, Rocky Reach, and Wells dams on the Columbia River; Ice Harbor and Lower Granite dams on the Snake River, as well as at several tributaries and hatcheries in the Columbia Basin (Appendix 1). PIT tag detection data was uploaded to the PTAGIS database, where it is accessible to registered users of the site. We also supplied a PIT tag reader to the Okanagan National Alliance to use on their Okanogan River spawning ground surveys and brood stock collection activities.

Stock classification

Sockeye salmon stock determinations were made by last detection point. For example, those individuals last observed at Rocky Reach or Wells dams were classified as being Okanogan stock, those last observed at Rock Island Dam (but not observed at Rocky Reach or Wells dams) were classified as

Wenatchee stock, while those last observed downstream of Rock Island were considered as unknown and were also considered mortalities. (Note that this will overestimate the proportion of the Wenatchee stock since any mortality of Okanogan-stock fish that occurs between Rock Island and Rocky Reach dams will be considered as a Wenatchee-stock sockeye salmon.) The sole exception to this rule were those fish never detected after release, which were considered to have shed their tags and were subtracted from the number of fish tagged.

Escapement

Escapement to McNary, Priest Rapids, Rock Island, Rocky Reach, and Wells dams was estimated as:

$$N = \sum_i \frac{B_i R_i}{T_i}$$

with variance:

$$Var(N) = \sum_i \frac{Var(B_i) R_i^{\,2}}{T_i^{\,2}}$$

where N was the estimated escapement at a particular upstream dam, B_i is the weekly visual count passing Bonneville Dam in week *i* (DART 2006, Fish Passage Center 2006), T_i is the number of fish PIT tagged at Bonneville Dam in week *i,* and R_i is the number of PIT tag detections at the dam where escapement is being estimated of those fish tagged in week *i.* For $Var(B_i)$, it was assumed that visual fish counts at Bonneville Dam are within 5% of the true count at α=0.05 (Fryer 1995).

Mortality

PIT-tagged sockeye salmon that were lost on the upstream migration (with the exception of those “lost” between Rock Island and Rocky Reach dams, which were considered to be Wenatchee stock) were recorded as mortalities. Mortality rates were computed by week of passage at Bonneville Dam between dams with detection capabilities and correlated with temperatures and flows at The Dalles Dam (for Bonneville to McNary mortality) and Priest Rapids Dam (for McNary to Rock Island mortality).

Detection Efficiencies

No previous studies have examined the effectiveness of mainstem Columbia Basin dam fish ladder PIT tag detectors in detecting PIT-tagged adult sockeye salmon. Therefore, the percentage of sockeye passing each dam, except Wells Dam (the uppermost dam), that were totally missed was estimated.

Any fish detected at an upstream dam should also be detected at lower dams (except at McNary Dam where it is possible that a fish could use the navigation locks). For example, the percentage missed at Rocky Reach Dam was calculated as:

$$P = \frac{W_m}{W_d + W_m}$$

where W_m is the number of fish detected at Wells Dam (the next dam upstream of Rocky Reach Dam) that were not detected at Rocky Reach Dam, and W_d is the number of fish detected passing Wells Dam.

Also compiled for placement in the appendix of this report was the probability of detection at the different sites, hereafter referred to as weirs, at dam fish ladders. PIT tag detection antennas in fish ladders are always placed at a minimum of two weirs in relatively close proximity. Therefore, if a fish is detected at one weir, it should also be detected at the rest of the weirs in that same ladder. This allows a probability of detection at the individual weirs to be calculated by comparing it with other weirs in that same ladder. Detection probabilities were calculated as:

$$Pi = \frac{N_i}{Max(N_i)}$$

where N_i is the number of fish detected at a given weir and $Max(N_i)$ is the total number of fish detected by any weir in that ladder.

Also calculated was the percentage of sockeye salmon using each ladder at dams with multiple ladders.

Migration timing and passage time

Run timing was estimated using the date and time of detection at the different dams. Migration rates were calculated between dam pairs as the time between the last detection at the lower dam and the first detection at the upper dam and correlated with temperatures and flows at The Dalles Dam (for Bonneville to McNary migration rates) and Priest Rapids Dam (for McNary to Wells migration rates).

The amount of time required to pass each dam was estimated as the difference between the first detection time at a dam and the last detection time at a dam.

Bonneville Stock composition estimates using PIT tag recoveries

The overall stock composition, P_i, for stock *i* (where *i* denotes the Wenatchee or Okanogan stock) at Bonneville Dam was estimated as:

$$P_i = \sum_j W_j * S_{ij}$$

where W_j is the proportion of the run passing Bonneville Dam in week *j*, and S_{ij} is the percentage of the run estimated in week *i* estimated to belong to stock *i* based on upstream recoveries.

The stock composition estimated by PIT tag recoveries was compared with that estimated by scale pattern analysis, visual interpretation of scale patterns, as well as by visual fish counts at dam fish ladders. Two visual counts are available, the first estimating the Wenatchee stock abundance as the difference between the Rock Island and Rocky Reach dam counts and the second using Tumwater Dam visual count to estimate the Wenatchee stock abundance.

Okanogan and Wenatchee age and length-at-age composition

The age composition for the Okanogan and Wenatchee stocks was estimated as:

$$T_{i,j} = \sum_k A_{i,j,k} * W_k$$

where $T_{i,j}$ was the estimate for stock *i and age gro*up *j,* $A_{i,j,k}$ was the percentage of sockeye for stock *i* and age group *j* in week *k* (such that $\sum_j A_{i,j,k} = 1$) and W_k was the percentage of the run that passed Bonneville Dam in week *k.*

The variance was estimated as

$$Var(T_{i,j}) = \sum_k Var(A_{i,j,k}) * W_k^{\,2}$$

where

$$Var(A_{i,j}) = \frac{\sum_k A_{i,j,k}(1 - A_{i,j,k})}{n_{i,k}}$$

Night passage

Fish at Columbia Basin dams are not always counted using the same time period. Fish at Bonneville and McNary dam fish ladders are counted by observers only from 0400 to 2000 Pacific Standard Time for 50 minutes of each hour and the counts expanded by a factor of 1.2. Fish passing Priest Rapids,

Rock Island, Rocky Reach, and Wells dams are recorded 24 hours per day and the video later reviewed. Night passage rates (where night is defined as 2000 to 0400) were calculated by stock for all dams passed based on the last detection time for a given fish ladder. The last time detected was used as an approximation for passage time as the upper most weir was closer to the fish counting window than the lower most weir (where the first detection would be made) at all weirs except at BO4 near the Washington shore fish counting facility (Figure A1). (And at BO4, the distance between the upper most and lower most weirs is only about 25 meters.)

Fallback

There were two methods of determining fallback, which is defined as a fish that ascends a fish ladder into the reservoir above the dam, then "falls back" to the downstream side of the dam either over the spillway or through the turbines. The first was if an adult sockeye salmon was subsequently detected in the juvenile bypass system following upstream passage. However, on the Columbia River only Bonneville, John Day, and McNary dams have both juvenile bypass systems and PIT tag detection capability. Also, any sockeye salmon falling back over the spillway or through the turbines would not be detected. Therefore, I also considered sockeye salmon that had a detection at an "upper" detection weir followed by a detection at a "lower" detection weir that was separated by more than 12 hours as possible fallbacks. At McNary and Bonneville dam, the upper weir was that at the fish counting window (which is believed to detect all PIT-tagged fish passing) while the lower weirs were PIT tag detectors at lower weirs which have a lower passage efficiency for sockeye salmon[1]. At McNary and Bonneville dams, sockeye salmon that were detected at multiple ladders were also examined as possible fallbacks since "lower" detection weirs did not prove to detect sockeye very well. At Priest Rapids, Rock Island, Rocky Reach, and Wells dams, there are only two weirs with PIT tag detectors in each fish ladder so these two weirs were designated as the upper and lower detection weirs.

[1] Appendix 1 gives PIT tag detection array configurations for all mainstem Columbia Basin dams except Rocky Reach Dam. This information is also available at www.ptagis.org.

RESULTS

Sample Size

A total of 503 sockeye salmon were PIT-tagged between June 14, 2006 and July 21, 2006 (Table 1). This compares to 556 sockeye salmon sampled for our stock identification study. We had initially intended to PIT tag every sockeye salmon sampled; however we were unable to do so for several reasons. First, we started sampling prior to receiving the concurrence of National Oceanic and Atmospheric Administration-Fisheries (NOAA) to potentially PIT tag sockeye salmon listed under the Endangered Species Act (ESA). A total of 27 sockeye were sampled prior to our beginning PIT tagging. Additionally, since most ESA-listed sockeye salmon were expected to be adipose clipped, NOAA asked us not to PIT tag adipose clipped sockeye salmon[2]. Thus 16 adipose clipped sockeye were not tagged, although one was accidentally tagged[3]. An additional nine sockeye salmon were not PIT-tagged either due to the tag falling out (and later recovered) in the recovery tank or for operational reasons. Finally, we had one recapture (a fish tagged on July 5 was sampled again on July 7).

Table 1. Number of sockeye salmon PIT-tagged at the Bonneville Adult Fish Facility by statistical week in 2006.

Dates	Statistical Week	Tagged (n)
6/14,16	24	61
6/20,21,23	25	90
6/26,28,30	26	159
7/5,6,7	27	134
7/10,12	28	54
7/17,19,21	29	5
	Total	503

Upstream Recoveries, mortality, and escapement:

PIT tag detection data was obtained from PTAGIS on November 15, 2006. A total of 493 fish were detected subsequent to release, so we assume that 10 fish either shed their tags prior to detection at the Bonneville Dam, or did not pass Bonneville Dam. Most of the fish that were not detected at Rock Island Dam were lost between Bonneville and McNary dams (Table 2, Figure 2). This

[2] ESA-listed sockeye salmon are adipose clipped in the Snake Basin. However, the vast majority of adipose clipped sockeye salmon in the Columbia Basin are the product of a Lake Wenatchee supplementation program.

[3] This tagged adipose clipped fish was last detected at Rock Island Dam and thus was likely destined for Lake Wenatchee.

stretch of river is where the Zone 6 tribal fishery occurs, which was estimated to harvest 1,325 of the 4,513 sockeye estimated to have been lost between Bonneville and McNary dams. A total of 10 PIT-tagged sockeye salmon, out of 730 scanned, were detected by the Okanagan Nation Alliance in Okanogan River brood stock collection and spawning ground survey activities.

Table 2. Percentage of PIT-tagged sockeye salmon detected subsequent to tagging at upstream dams, the estimated mortality, and the percentage missed at mainstem Columbia Basin dams with PIT tag adult detection capability in 2006.

Dam	Estimated percentage reaching dam	Percent lost en route	Percent "missed" by PIT tag detectors at dam	Percent summer Chinook missed
Bonneville	100.0		0.2	0.6
McNary	88.4	11.6	3.1	0.2
Priest Rapids	84.8	2.9	0.0	0.2
Rock Island	81.1	4.4	1.3	0.7
Rocky Reach	58.8	NA	12.3	9.5
Wells	53.8	NA	NA	NA

Table 3. Sockeye salmon survival through selected reaches by Statistical Week as estimated by PIT tag detections in 2006.

Statistical Week at Bonneville Dam	Bonneville-McNary	Bonneville-Priest Rapids	Bonneville-Rock Island	Rocky Reach-Wells
24	94.9%	93.2%	93.2%	88.9%
25	91.1%	87.8%	81.1%	89.4%
26	88.3%	86.4%	79.9%	91.8%
27	82.7%	75.9%	71.9%	93.7%
28	75.9%	67.2%	62.7%	96.8%
Composite	88.4%	84.8%	80.0%	91.4%

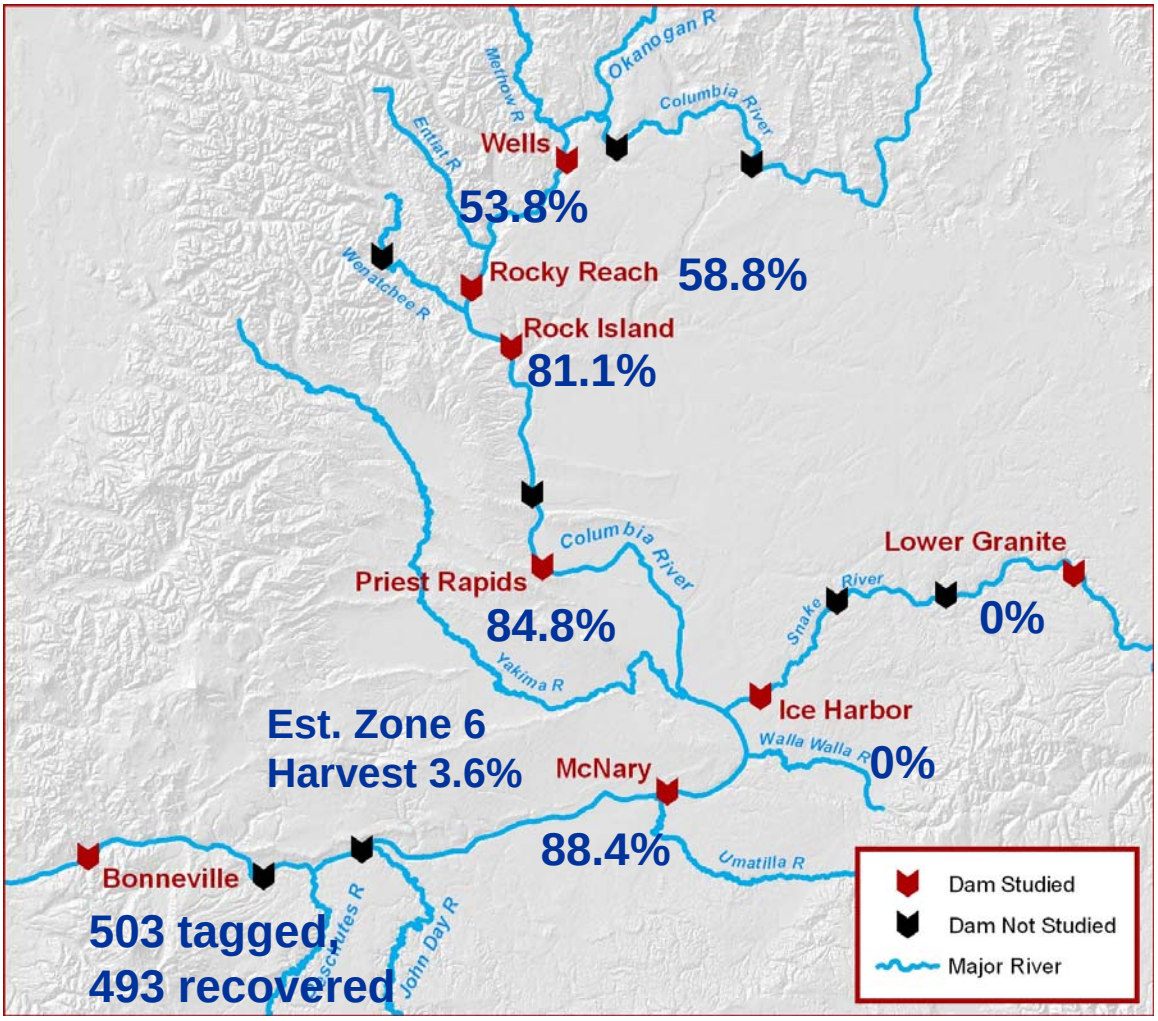

Figure 2. Map of the Columbia River Basin from Bonneville to Wells and Lower Granite dams showing the number of fish PIT-tagged at Bonneville Dam, and the percentage of the run estimated to pass McNary, Priest Rapids, Rock Island, Rocky Reach, Wells, Ice Harbor, and Lower Granite dams in 2006.

Sockeye salmon tagged at Bonneville Dam later in the migration had lower rates of survival to McNary, Priest Rapids, and Rock Island dams than fish tagged earlier in the migration (Table 3). However, these fish had higher survival rates between Rocky Reach and Wells dams.

Rocky Reach dam had the poorest detection rate with 12% of the tags not detected (Table 2). The second poorest detection rate was at McNary Dam, although the navigation locks provide a plausible means of passage that would avoid detection. No estimate could be made for Wells Dam, although all 10 fish recovered on the spawning grounds were detected at Wells Dam. Data on the

detection probability of individual weirs within ladders is found in Table A1, while data on the distribution of fish between ladders is found in Table A2.

Using PIT tag detections to estimate escapement at mainstem dams results in estimates that deviate from visual fish counts by 9% or more (Table 4). Visual fish counts at McNary and Priest Rapids dams both estimate fewer fish than those estimated using PIT tags, while Rock Island, Rocky Reach, and Wells dam visual fish counts all estimate a greater abundance than PIT tags. Unlike visual fish counts, PIT tag counts do not have the problem of more sockeye salmon being counted at an upstream dam than a downstream dam. In 2006, the visual fish count at Rock Island Dam was greater than that of any downstream dam and 32% greater than at the next downstream dam with visual fish counts, Priest Rapids Dam.

Table 4. Sockeye escapement at McNary, Priest Rapids, Rock Island, Rocky Reach, and Wells dams as estimated from both PIT tag recoveries and dam counts, and the difference between the two estimates in 2006.

Dam	Estimate	Standard Deviation	Visual Fish Count	Difference
McNary	32,553	425	29,304	10.9%
Priest Rapids	31,473	408	26,710	17.8%
Rock Island	30,106	392	35,132	-14.3%
Rocky Reach	21,793	294	25,377	-14.1%
Wells	20,012	272	22,075	-9.3%

Bonneville to McNary survival significantly decreases with decreasing flow (Figure 3), increasing temperature (Figure 4), and week of migration (Table 3) ($p<0.01$ for all linear regressions). All three variables are highly correlated with absolute correlation coefficients ranging from 0.94-0.99. McNary to Rock Island survival significantly decreases with decreasing flow as measured at Priest Rapids Dam ($p=0.03$, Figure 5) and week of migration ($p=0.03$, Figure 6), but there is not a significant linear relationship with temperature at Priest Rapids Dam ($p=0.21$, Figure 7). While week and flow are inversely correlated ($r=-0.91$), decreasing temperatures late in the migration result in a flow versus temperature correlation of -0.81, while the week-temperature correlation coefficient is 0.56.

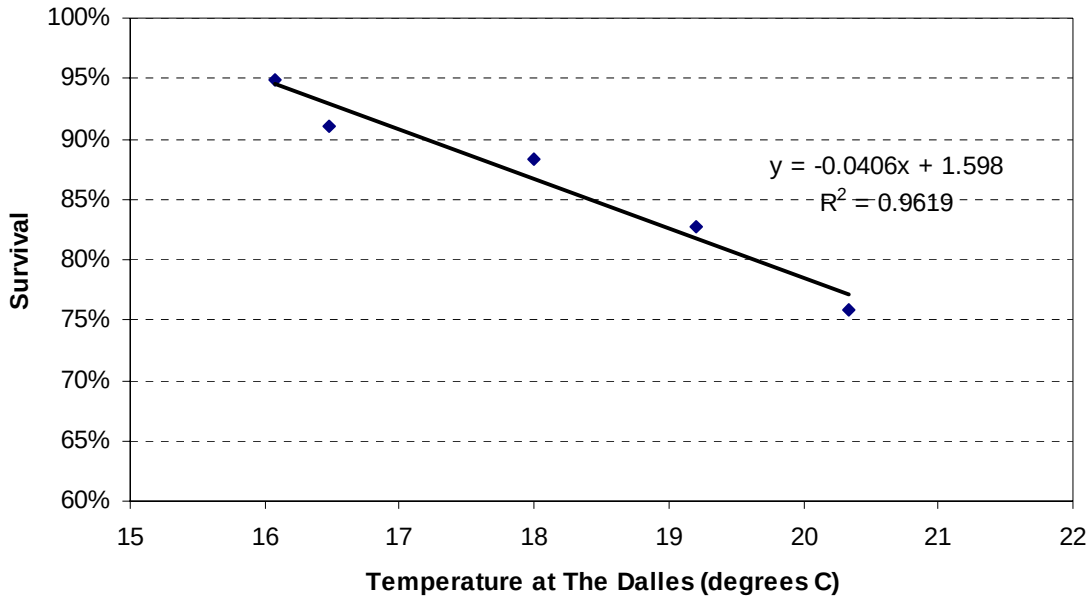

Figure 3. Figure showing the linear relationship between the survival of PIT-tagged sockeye salmon from Bonneville to McNary Dam and mean water temperature at The Dalles Dam by statistical week in 2006.

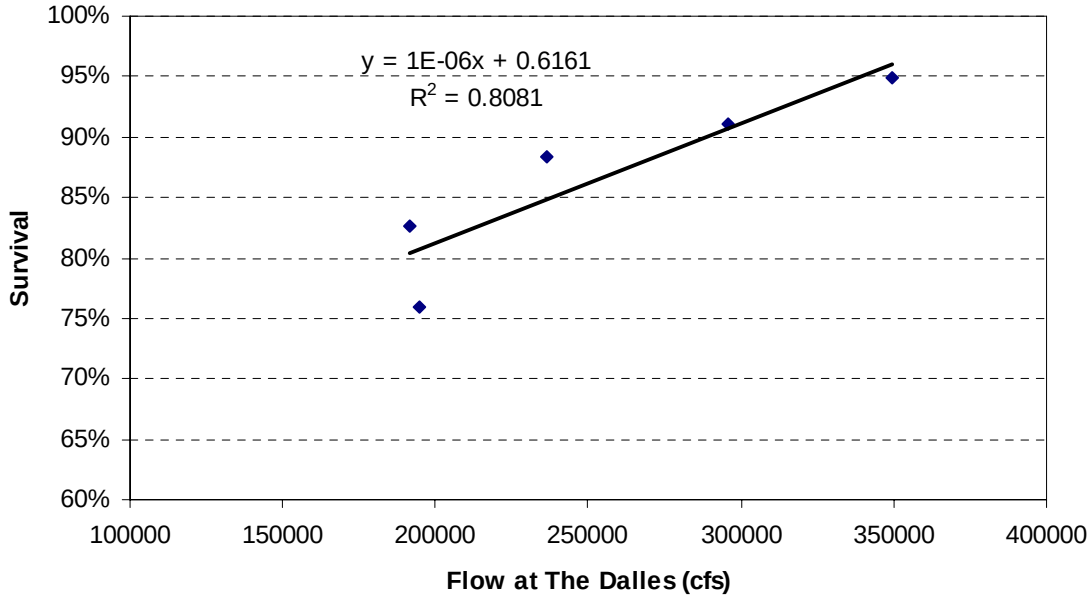

Figure 4. Figure showing the linear relationship between the survival of PIT-tagged sockeye salmon from Bonneville to McNary Dam and mean flow at The Dalles Dam by statistical week in 2006.

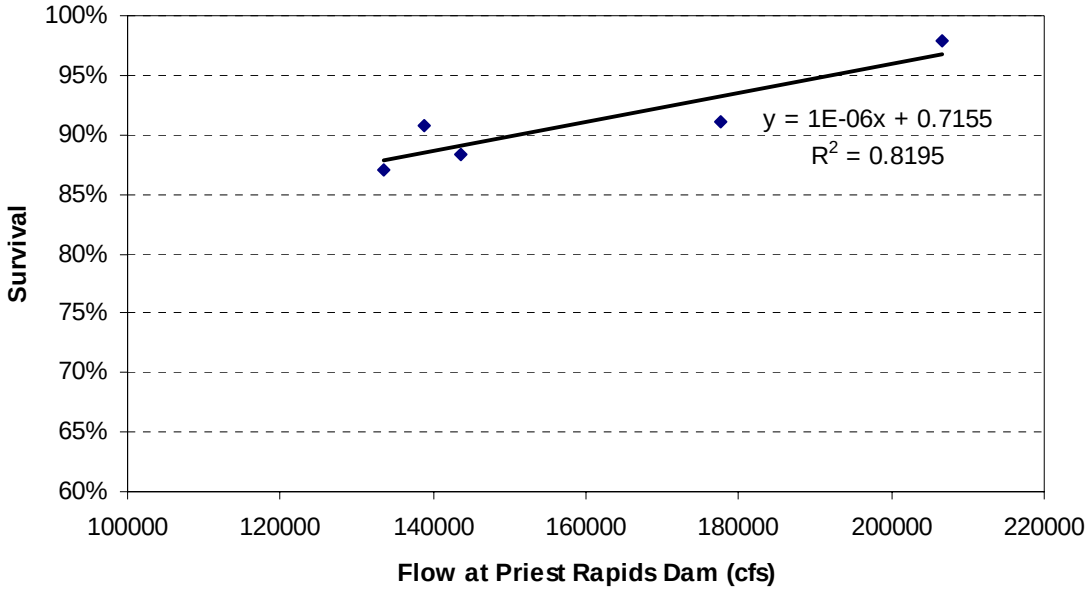

Figure 5. Figure showing the linear relationship between the survival of PIT-tagged sockeye salmon from McNary to Rock Island Dam and mean flow at Priest Rapids Dam by statistical week in 2006.

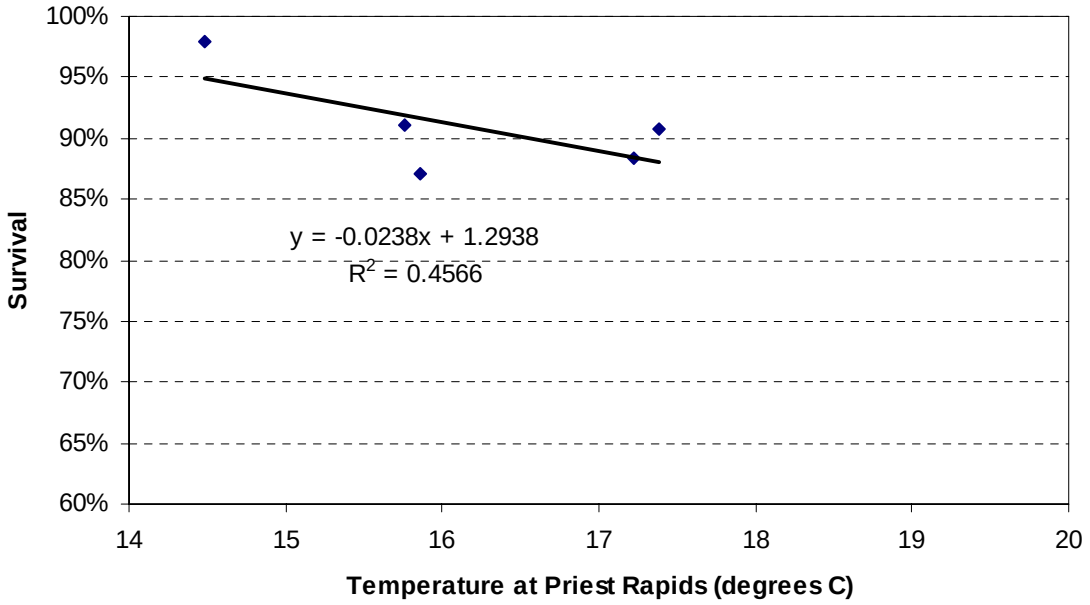

Figure 6. Figure showing the linear relationship between the survival of PIT-tagged sockeye salmon from McNary to Rock Island Dam and mean water temperature at Priest Rapids Dam by statistical week in 2006.

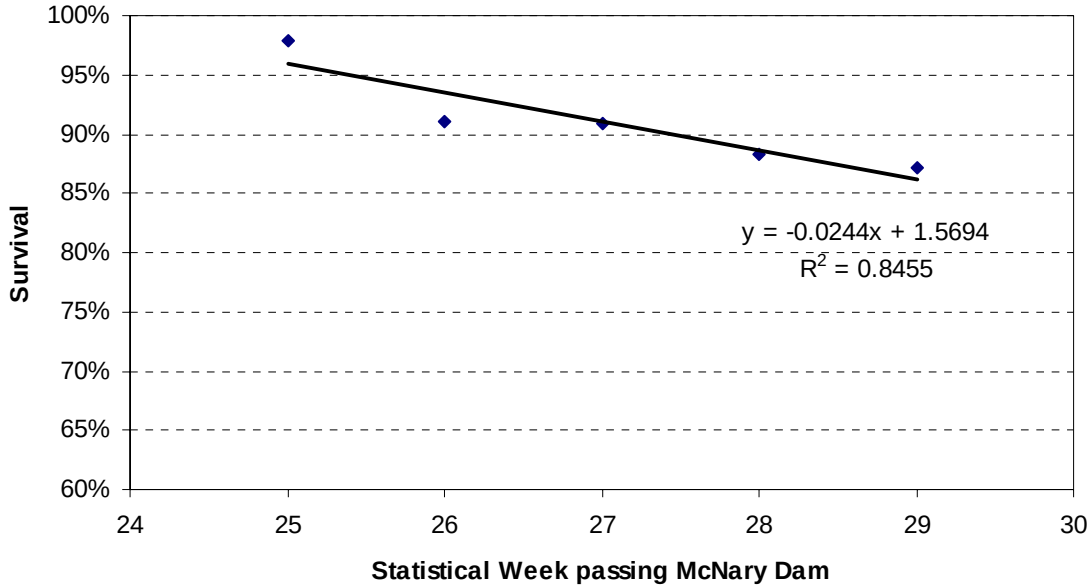

Figure 7. Figure showing the linear relationship between the survival of PIT-tagged sockeye salmon from McNary to Rock Island Dam and statistical week in 2006.

Migration Timing and Passage Time

Sockeye salmon travel quickly upstream, with a median travel time between Bonneville and Rock Island Dam of only 14 days (Table 5). Sockeye salmon passing Bonneville Dam later in the migration travel upstream faster than those earlier in the migration. There is a significant (α=0.05) linear relationship between statistical week passing Bonneville Dam and passage time for Bonneville-Rock Island and Priest Rapids-Rock Island, but all other relationships tested in Table 6, with the exception of Rocky Reach to Wells, are significant at the α=0.10 level. The median travel time for Wenatchee stock fish is greater than that for Okanogan stock fish for those dam pairs in Table 6 that both stocks pass.

Table 5. Median sockeye salmon migration time and travel rates between mainstem dams as estimated by PIT tag recoveries in 2006.

Dam pair	Distance (km)	Median time (days)	Median travel time (km/day)	Summer Chinook median km/day
Bonneville-McNary	231	5.0	46.1	37.4
McNary-Priest Rapids	167	4.5	37.2	42.8
Priest Rapids-Rock Island	89	3.9	22.6	28.6
Rock Island-Rocky Reach	33	1.4	24.4	29.0
Rocky Reach-Wells	65	2.9	22.7	11.9
Bonneville-Rock Island	487	14.0	34.9	35.3
Bonneville-Wells	585	18.3	32.2	28.1

Table 6. Median adult sockeye salmon travel time in days between dam pairs by statistical week passing Bonneville Dam, the F-statistic for a linear regression between travel time and statistical week, and mean travel time by stock as estimated using PIT tags in 2006.

Statistical Week at Bonneville Dam	Bonneville- McNary	Bonneville-Priest Rapids	Bonneville-Rock Island	Bonneville-Rocky Reach	Bonneville-Wells	McNary-Priest Rapids	Priest Rapids-Rock Island	Rock Island-Rocky Reach	Rocky Reach-Wells
24	5.8	11.6	16.8	18.0	20.8	5.5	4.4	1.5	3.0
25	5.3	10.6	14.6	15.0	19.1	4.9	4.0	1.3	2.8
26	4.7	8.9	13.1	14.9	18.6	4.0	4.1	1.4	2.7
27	4.7	9.5	13.2	14.8	17.3	4.3	3.8	1.4	3.0
28	4.8	9.1	12.4	13.6	18.4	4.2	3.1	1.2	2.8
F-Statistic	0.081	0.071	0.025	0.053	0.082	0.097	0.042	0.093	0. 970
Stock									
Okanogan	4.9	9.5	13.6	14.9	18.3	4.3	3.8	1.4	2.9
Wenatchee	5.3	10.5	15.1	NA	NA	4.9	4.3	NA	NA
Unknown[4]	5.1	10.5	NA	NA	NA	5.1	NA	NA	NA

The median time between first detection and last detection is less than two hours at all dams except Bonneville Dam (Table 7.)

Table 7. Sockeye salmon median travel time from time of first detection at a dam to last detection at a dam and the percentage of sockeye salmon taking greater than 12 hours between first detection and last detection in 2006.

Dam	Median Passage Time (Minutes)	Taking more than 12 hours-sockeye (%)	Taking more than 12 hours-summer Chinook (%)
Bonneville	367	6.8	1.0
McNary	2	3.2	0.6
Priest Rapids	110	2.4	2.7
Rock Island	51	1.8	13.0
Rocky Reach	16	2.7	3.7
Wells	34	4.8	3.7

Bonneville Stock composition estimates using PIT tag recoveries

The percentage of Okanogan stock sockeye salmon at Bonneville Dam steadily increased as the run progressed while the Wenatchee portion of the run decreased (Table 8). The overall stock composition estimate of 27.2% Wenatchee and 72.8% Okanogan was very similar to that estimated using dam counts and visual estimates of scale patterns (Table 8).

[4] Unknown stock sockeye salmon are those that were not detected at Rock Island Dam and are likely mortalities on the upstream migration.

Table 8. Weekly and composite sockeye salmon stock composition at Bonneville Dam as estimated by PIT tags in 2006 and a comparison to other total stock composition estimates.

Statistical Week	Percent Wenatchee	Percent Okanogan	Percent Unclassified
24	33.9	66.1	
25	37.0	63.0	
26	23.6	76.4	
27	16.7	83.3	
28	15.8	84.2	
Composite	27.2	72.8	
Visual Fish Counts at dams-(using difference between Rock Island and Rocky Reach for Wenatchee estimate)	27.4	72.6	
Visual Fish Counts at dams -(Tumwater count as Wenatchee estimate)	18.1	81.9	
Scale Pattern Analysis (Fryer 1997b)	13.3	52.4	34.1
Visual Estimate from scale patterns	27.5	72.5	

Okanogan and Wenatchee age and length-at-age composition

Age composition estimates based on upstream PIT tag detections were similar to those from sampling at Tumwater Dam on the Wenatchee River and at Wells Dam (Table 9). The sole exception was for the Wenatchee stock where PIT tags had a higher estimate of the Age 1.3 component and a lower estimate of the Age 2.2 component. Length-at-age composition estimates are also similar, with mean lengths estimated by the two methods not differing by more than 1.0 cm for estimates where 10 or more PIT-tagged fish were recovered (Table 10).

Table 9. Age composition (%) of Wenatchee and Okanogan stock sockeye salmon in 2006 as estimated by upstream detection of PIT tags (with standard deviations in parentheses) as well as by sampling at Tumwater and Wells dams.

	Age							
Estimate	**1.1**	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**	**3.1**	**3.2**
Wenatchee PIT tag	-	34.3 (4.4)	50.9 (4.8)	2.3 (1.5)	9.2 (3.1)	-	3.4 (1.8)	-
Wenatchee-Tumwater	-	36.4 (2.5)	40.9 (2.5)	-	21.2 (2.1)	<0.1 (0.3)	1.2 (2.5)	-
Okanogan-PIT tag	0.7 (0.1)	75.1 (2.8)	7.3 (1.8)	2.3 (1.0)	13.4 (2.2)	-	1.2 (0.7)	-
Okanogan-Wells Dam	0.4 (0.6)	72.4 (3.2)	8.4 (2.1)	1.7 (0.8)	14.8 (2.4)	<0.1 (0.2)	0.1 (0.7)	0.1 (0.3)

Table 10. Length-at-age composition of Wenatchee and Okanogan stock sockeye salmon in 2006 as estimated by upstream detection of PIT tags as well as by sampling at Tumwater and Wells dams.

		Age							
Stock	**Statistic**	**1.1**	**1.2**	**1.3**	**2.1**	**2.2**	**2.3**	**3.1**	**3.2**
Bonneville mixed stock	Mean	40.7	49.6	55.0	41.9	49.9	54.0	49.5	
	St. Dev.	5.1	2.3	2.6	2.6	3.0	-	3.7	
	N	5	328	98	12	74	1	7	
Okanogan (PIT tags)	Mean	41.6	49.6	53.6	42.3	49.1		47.8	
	St. Dev.	5.4	2.3	2.8	2.6	2.6		5.1	
	N	4	207	22	9	39		3	
Okanogan (Wells sampling)	Mean	40.0	50.2	53.6	41.6	50.1		50.5	50.9
	St. Dev.	1.4	2.6	3.6	1.3	2.8		4.3	4.8
	N	2	160	20	5	42		3	4
Wenatchee (PIT tags)	Mean		50.5	55.6	42.3	51.8		51.5	
	St. Dev.		2.3	2.5	2.5	2.9		2.2	
	N		29	49	2	10		3	
Wenatchee (Tumwater Sampling)	Mean		51.3	55.4		50.8	58.5	50.4	
	St. Dev.		2.8	2.5		2.4	-	2.9	
	N		144	155		86	1	4	

Fallback

Estimated fallback rates for sockeye salmon ranged from 0% at Bonneville to 3.3% at Wells Dam (Table 11).

Table 11. Estimated sockeye salmon fallback at mainstem Columbia River dams in 2006 as estimated by PIT tag detections with summer Chinook estimates for comparison purposes.

Dam	Sockeye (%)	Summer Chinook (%)
Bonneville	0.2	0.9
McNary	1.5	0.4
Priest Rapids	0.5	0.9
Rock Island	0.8	0.4
Rocky Reach	1.0	1.7
Wells	3.3	5.1

Night Passage

Okanogan stock sockeye salmon passed dams at night (2000-0400) at a higher rate than Wenatchee stock sockeye salmon (Table 12) and sockeye salmon passed at a higher rate than summer Chinook salmon. The Bonneville Dam estimate of night time passage is likely biased low due to the fact that tagging occurred between about 0900 and 1500. If a “night” passing sockeye salmon at one dam is more likely to pass subsequent dams at night, our time of sampling could bias low all nighttime passage estimates. However, among the sockeye salmon that did pass at night, there did not appear to be a tendency for fish to pass multiple dams at night (Table 13).

Table 12. Estimated sockeye salmon nighttime passage (2000-0400) in 2006 at mainstem Columbia River dams as estimated by PIT tag detections with summer Chinook estimates for comparison purposes.

Dam	All Sockeye (includes unknown)	Okanogan Stock	Wenatchee Stock	Summer Chinook
Bonneville	0.2%	0.0%	0.0%	0.7%
McNary-Oregon Shore	10.0%	5.0%	4.3%	1.5%
McNary-Washington Shore	7.1%	8.7%	4.0%	4.0%
Priest Rapids	6.6%	4.8%	2.0%	1.3%
Rock Island	3.4%	4.9%	1.0%	3.8%
Rocky Reach	11.7%	10.9%	NA	1.5%
Wells	15.1%	15.9%	NA	3.7%
Mean McNary, Priest Rapids and Rock Island	6.2%	5.5%	2.4%	2.7%

Table 13. Number of dams passed at night (2000-0400) by PIT-tagged Okanogan and Wenatchee sockeye salmon in 2006.

Total Dams passed at night	Okanogan	Wenatchee	Unknown
1	88	7	8
2	15	0	0
3	1	0	0

DISCUSSION

This study demonstrates the feasibility of using PIT tags to assess adult sockeye salmon migration, timing, escapement, age composition, stock composition, length composition, mortality, and fallback rates.

This study potentially offers a more accurate method of estimating stock composition at Bonneville Dam than the scale pattern studies that CRITFC has conducted over the past 21 years (Fryer 2007b). PIT tags do not have the problem of having insufficient samples to classify some age classes (resulting in 32.6% of the run being unclassified by scale pattern analysis in 2006), nor is there the problem of scale patterns being too similar between stocks to allow accurate classification. However, PIT tags do not allow classification of sockeye salmon at Bonneville Dam that do not appear at Rock Island Dam, which made up of 20.9% of the run. Our estimate of 27.2% Wenatchee and 72.8% Okanogan assumes that these unknown fish have a similar classification. (The estimates derived from visual fish counts at dams also make this assumption.) If one stock suffers a higher rate of mortality than the other on the upstream migration, then our estimates are biased. Given that we have weighted mortality estimates by week, this is only a problem if the stock composition of the unknowns differs from that of the classified fish on a weekly basis. For example, during Week 28 the estimated run composition was 15.8% Wenatchee and 84.2% Okanogan (Table 7). If mortality among the estimated 37.3% of the run from Week 28 that did not survive to Rock Island Dam (Table 2) is distributed similarly, then our overall stock composition estimate is still valid. However, if the stock composition of that 37.3% was, for example, 50% Wenatchee, and 50% Okanogan, then we would be underestimating the Wenatchee run component at Bonneville Dam.

Our stock composition estimate may also be biased because we classified all sockeye detected at Rock Island Dam, but not Rocky Reach or Wells dams as Wenatchee stock. It is likely that some of these fish were in fact Okanogan fish that were mortalities. This may explain the 2.3% of the Wenatchee stock that were estimated to be of Age 2.1. This is an age class that we have almost never seen in our Wenatchee known stock in the 22 years of the stock identification study, but which is more frequently observed for the Okanogan stock.

The results of this study differ from those of Naughton (2005) with respect to run timing. Naughton found that there was no difference in run timing between the two stocks, while we found a significant relationship between run timing and stock composition, with a higher percentage of the Wenatchee stock migrating in the early portion of the run. This finding was similar to what we have found in most years of our stock identification study (e.g. Fryer 1995, 2006). A later migrating Okanogan stock, combined with a higher mortality for later migrating fish suggests that the Okanogan stock has higher upstream migration mortality than the Wenatchee stock. Indeed, combining our weekly stock composition and mortality rates results in 75.2% of the Bonneville-Rock Island mortality being allocated to the Okanogan stock with the remainder allocated to the Wenatchee stock; resulting in an estimated stock composition at Rock Island Dam of 72.3% Okanogan and 27.7% Wenatchee stock. This compares to a Bonneville Dam stock composition of 72.8% Okanogan and 27.2% Wenatchee (Table 8).

The upstream survival rate estimated by this study was consistently higher than that estimated by Naughton (2005)-88.4% to McNary versus 81.2%, 84.8% to Priest Rapids versus 76.9%, and 81.1% to Rock Island versus 74.2%. This study also estimated a Bonneville-McNary mean migration speed of 46.1 km/day versus 33.8 km/day for Naughton. The differences between the results of this study and those of Naughton are likely, to a large extent, explained by the unusually high flows (and possibly the unusually low temperatures) in 1997 (Figure 7). Higher flows would be expected to slow the upstream migration and increase mortality. High, but declining, flows might also affect the overall timing of the components of the run, slowing the early (Wenatchee) portion of the run more than the later (Okanogan) portion and making more difficult to differentiate stock-specific run timing.

PIT tags provide an easier, much cheaper, and less intrusive method of monitoring the upstream migration than radio tags used in past studies (e.g. Naughton (2005). However, PIT tags do not always provide as much data as can be collected in a radio tag study. For example, PIT tag detectors are not installed at all mainstem dams, nor are they present in many tributaries. However, new detection sites, particularly at dams, are continually being added. Adult ladders at John Day and The Dalles dams are scheduled to be added in 2008. Ultimately, it seems likely all dams in the Columbia Basin with upstream

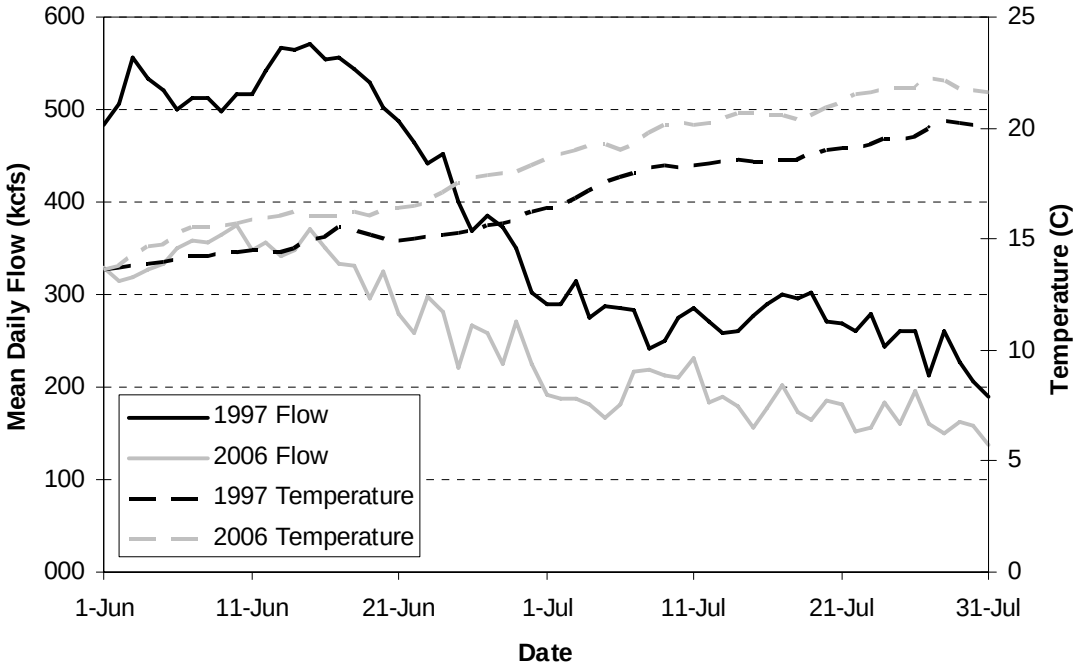

Figure 8. Comparison of flow and temperature at The Dalles Dam between June 1 and July 31 for 1997 and 2006.

passage facilities will be wired with PIT tag detectors. Key dams for sockeye salmon would be Tumwater Dam on the Wenatchee River and would be Zosel Dam on the Okanogan River near the Canadian border. PIT tag detection capability at Zosel dam would allow mortality to be estimated on the reach from Wells Dam to Lake Osoyoos, where mortality is believed to be high.

Using PIT tag data to estimate in ladder passage statistics, for which the PIT tag system was not designed, exposes some of the disadvantages of PIT tags when compared to radio tags. At Bonneville and McNary dams, there a number of detectors in underwater orifices; however sockeye salmon commonly swim over the weirs and thus go undetected (D. Marvin, PTAGIS, personal communication). At Priest Rapids, Rock Island, Rocky Reach, and Wells Dams due to the fact that there are only two weirs at each ladder with PIT tag detectors and those weirs are in close proximity to each other, making it difficult to estimate direction of movement and impossible to estimate total fish ladders passage time. Additional detectors at these ladders would make it easier to determine ladder passage time and direction of movement, and thereby more accurately estimate fallback

Sockeye salmon PIT tag detection rates at mainstem dams in 2006 were close to 100% at dams except for Rocky Reach dam where 12.3% of sockeye salmon detected at Wells Dam were not detected passing Rocky Reach. A similar (9.5%) percentage of summer Chinook were also missed at Rocky Reach. PIT tag detection was installed at Rocky Reach Dam prior to the beginning of the 2006 migration season and it appears there were equipment problems in 2006 that should be addressed for 2007 (Thad Mosey, Chelan PUD, January 19, 2007 e-mail, personal communication).

In 2007, we expect to be able to PIT tag adipose-clipped sockeye salmon which are overwhelmingly of Wenatchee stock. We had also hoped that this tagging project would benefit by the planned installation of detection facilities at Tumwater Dam in 2007; however we recently found that this will not occur until 2008 (Chuck Peven, Chelan County Public Utility District, personal communication, February 20, 2007). Such a facility would allow for a better estimate of the fate of fish which pass Rock Island Dam but not Rocky Reach Dam. We also suspect that we would find that some sockeye salmon detected at Rocky Reach or Wells dams ultimately fall back over the dams and end up in the Wenatchee River (where they may be detected at Tumwater Dam). In 2006, we looked into retrofitting the Tumwater Dam fish trap (though which all sockeye are diverted for a Chinook salmon research program) with a PIT tag detector but high flows made this impossible. We will revisit this issue in 2007.

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APPENDIX

Table A1. Probability of detection at PIT tag detectors by weir at mainstem Columbia Basin fish ladders, and the overall probability of detection, for sockeye salmon in 2006.

Dam and site	Weir and probability of detection at weir											Overall Detection Probability
Bonne-ville	**N**	**1**	**2**	**3**	**4**							
BO4	424	100.0	99.1	99.8	99.5							100.0
BO1	10	100.0	100.0	100.0	100.0							100.0
		45	**46**	**47**	**48**	**49**	**50**	**51**	**52**			
BO2	5	60.0	80.0	100.0	60.0	40.0	60.0	80.0	80.0			100.0
McNary		**1**	**2**	**312**	**311**	**309**	**308**	**306**	**305**	**303**	**302**	
MC1	209	97.1	98.1	10.5	8.6	11.0	6.7	11.5	2.9	8.6	6.2	100.0
		1	**2**	**3**	**312**	**311**	**309**	**308**	**306**	**303**	**302**	
MC2	210	98.6	100.0	100.0	8.6	7.6	6.7	6.2	6.7	10.0	7.1	100.0
Priest Rapids		**3**	**7**									
East	350	92.[a]0[b]	100.0									100.0
		3	**5**									
West	**61**	85.2	100.0									100.0
Rock Island		**1-2**	**3-4**									
Left	55	100.0	100.0									100.0
		5-6	**7-8**									
Middle	80	100.0	98.8									100.0
		09-0A	**0B-0C**									
Right	253	99.2	51.4									99.6
Rocky Reach		**1-2**	**3-4**									
	256	78.9	71.1									93.9
Wells		**1-2**	**3-4**									
Left	69	100.0	100.0									100.0
		5-6	**7-8**									
Right	206	100.0	99.5									100.0

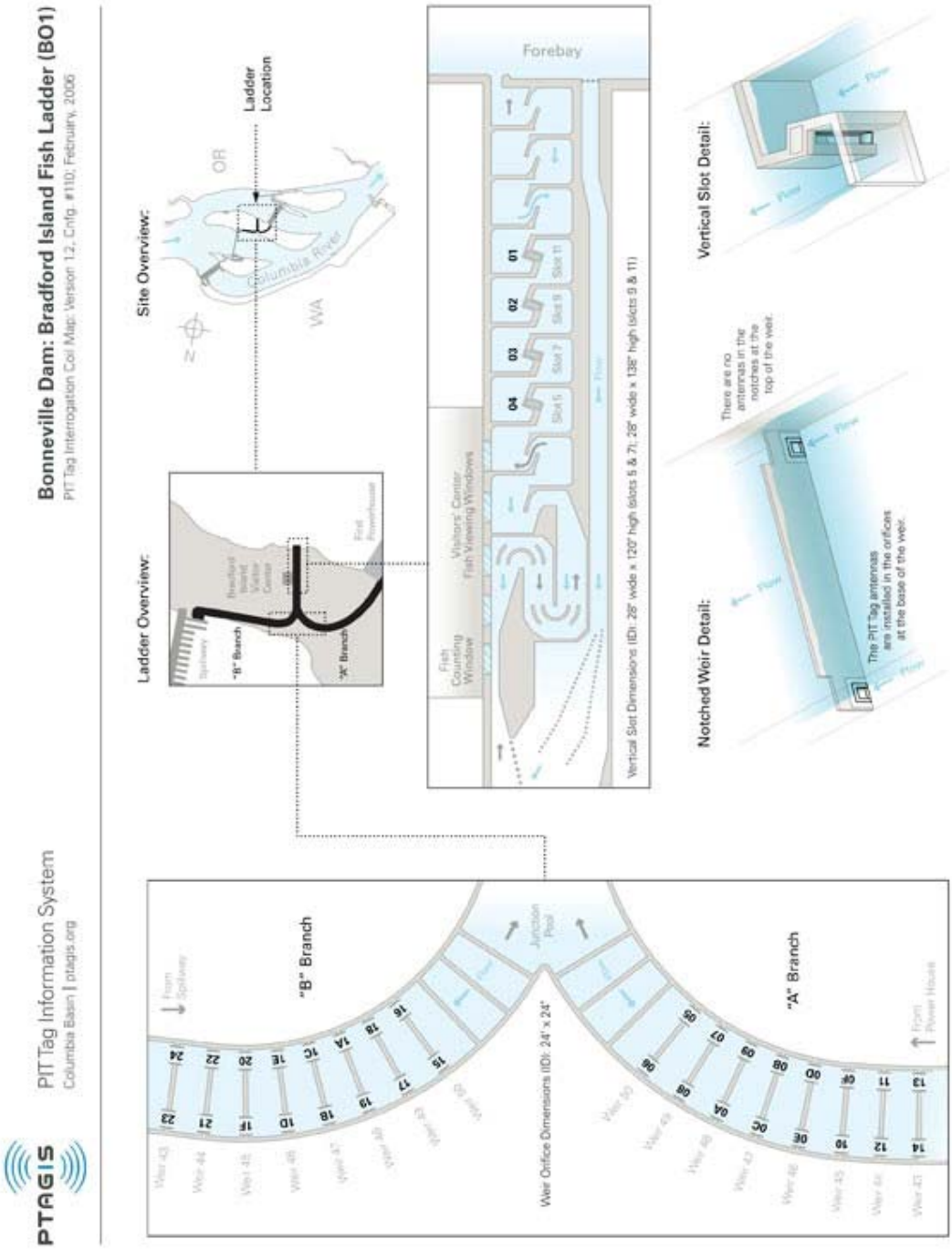
[a] Fish bypass this weir when the Priest Rapids adult fish trap is in operation.

Table A2. Distribution of sockeye salmon by fish ladder for dams with multiple fish ladders as estimated by PIT tag detections in 2006.

Dam	Right Bank[a]	Left Bank	Center
Bonneville	97.8%	2.2%	
McNary	50.1%	49.9%	
Priest Rapids	14.9%	85.1%	
Rock Island	14.2%	65.2%	20.6%
Wells	25.1%	74.9%	

[a] Right or left is determined by looking downstream at the dams, thus the right bank at Wells would be the west bank, at McNary it would be the Washington shore.

Figure A1. PIT Tag detection configurations in adult fish ladders at Bonneville, McNary, Priest Rapids, Rock Island, and Wells dams. All images provided by PTAGIS (2007) and available at http://www.ptagis.org. Reprinted with permission.



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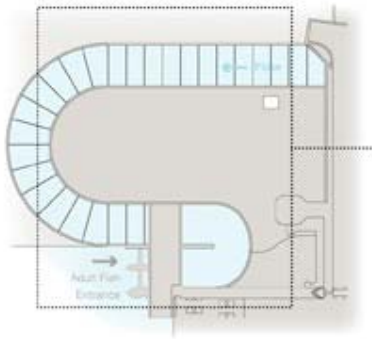
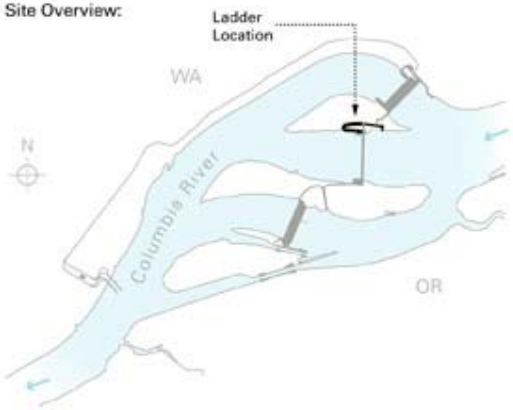
Bonneville Dam: Cascades Island Fish Ladder (BO2)

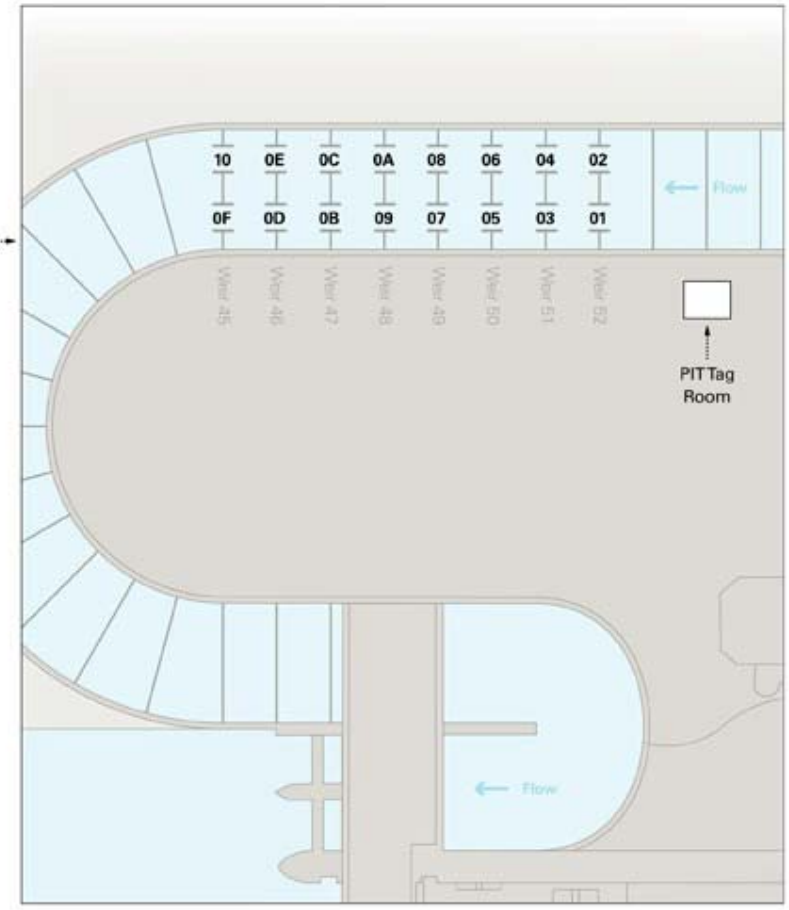
PIT Tag Interrogation Coil Map: Version 1.1, Cnfg. #100; February, 2002
Orifice Dimensions: 24" wide x 24" high

Ladder Overview:



Site Overview:





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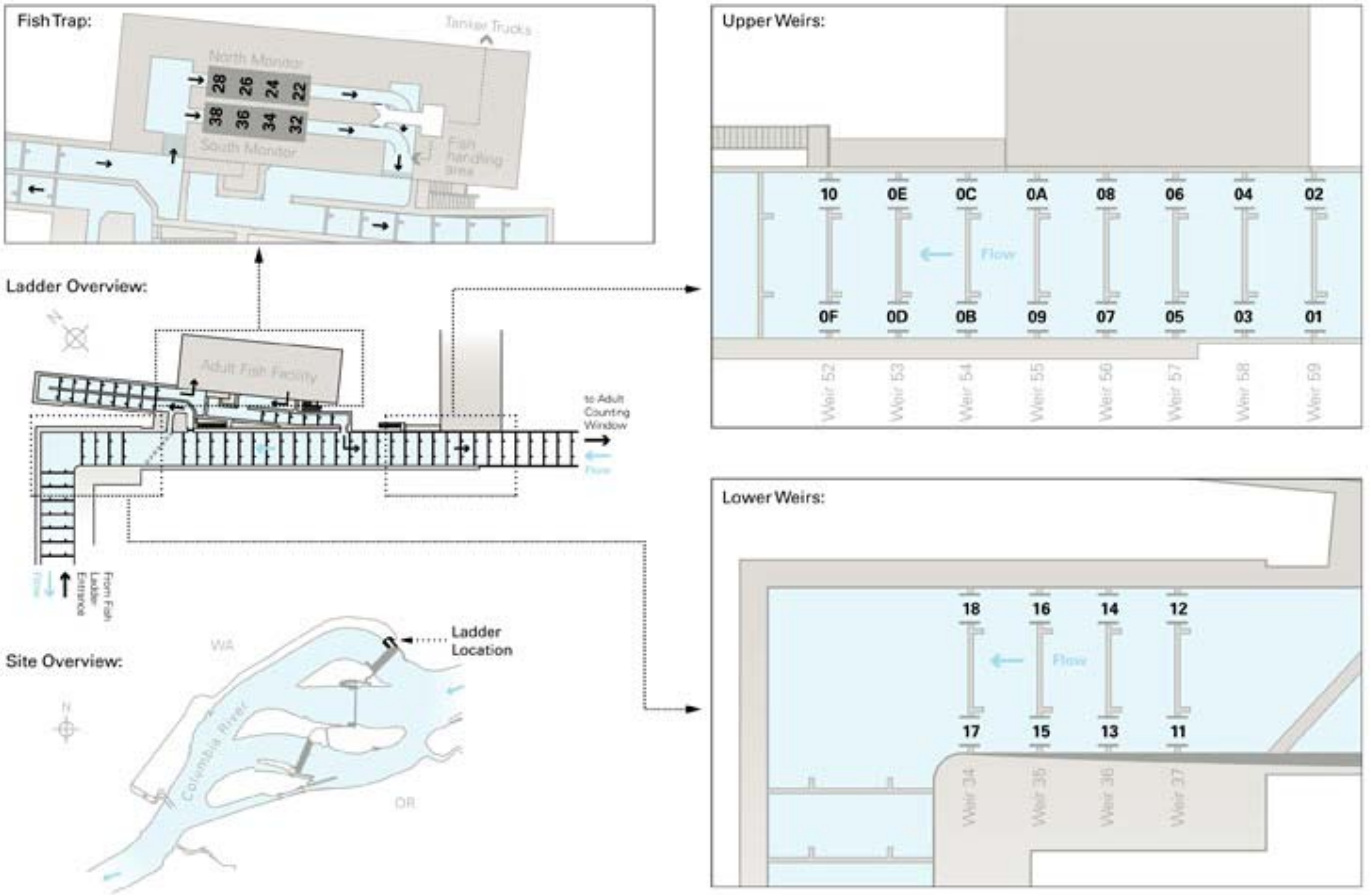
Bonneville Dam: Washington Shore Fish Ladder and AFF (BO3)

PIT Tag Interrogation Coil Map: Version 1.2, Cnfg. #110; Revised December, 2003
Orifice Dimensions: 18" wide x 18" high



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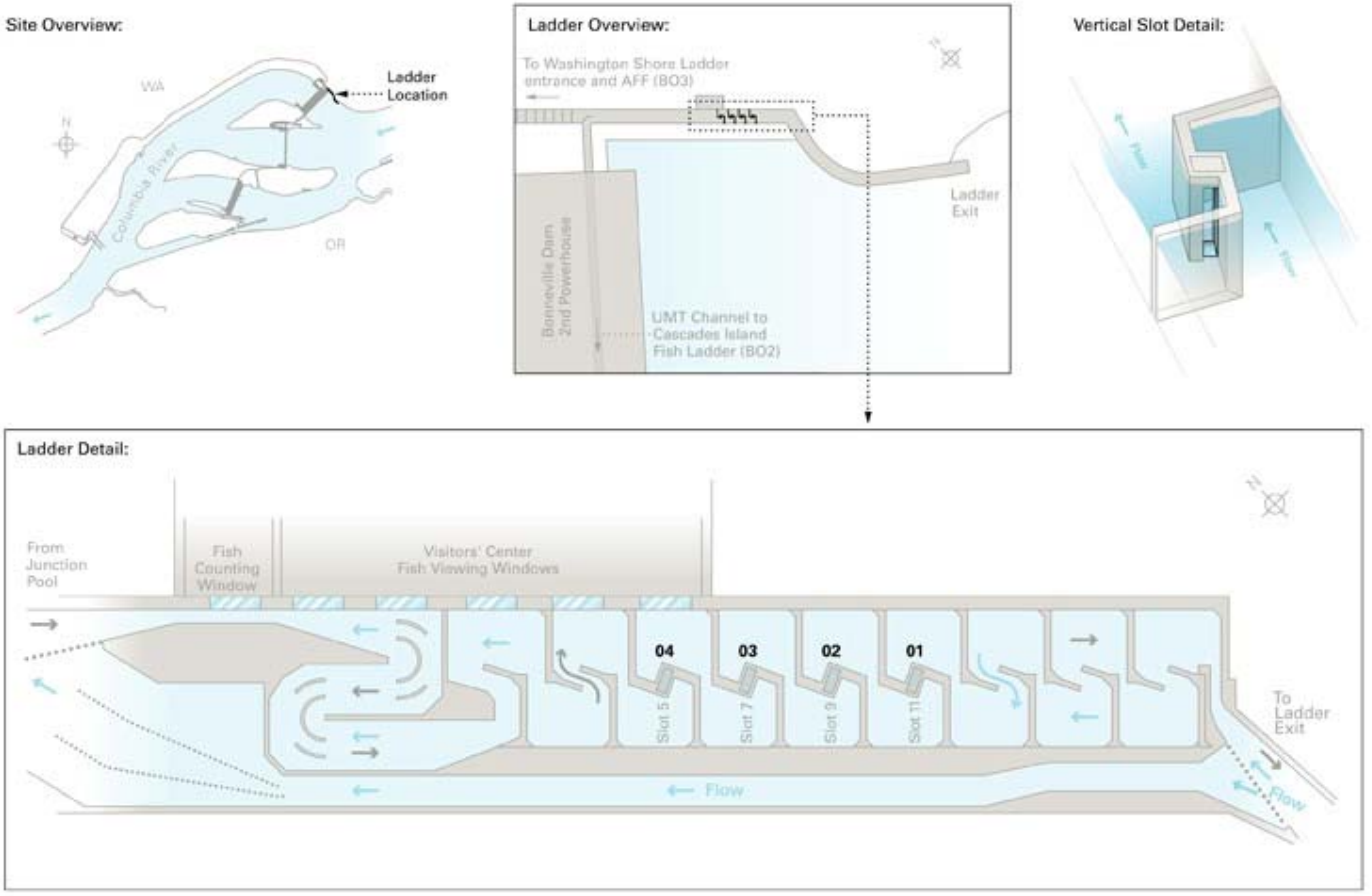
Bonneville Dam: Washington Shore Ladder Vertical Slots (BO4)

PIT Tag Interrogation Coil Map: Version 1.0, Cnfg. #100; Created March, 2005

Antenna Dimensions (ID): 28" wide x 120" high (slots 5 & 7); 28" wide x 138" high (slots 9 & 11)



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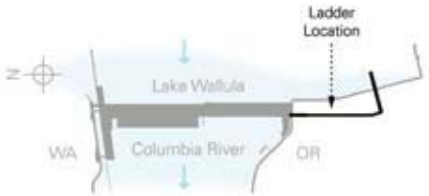
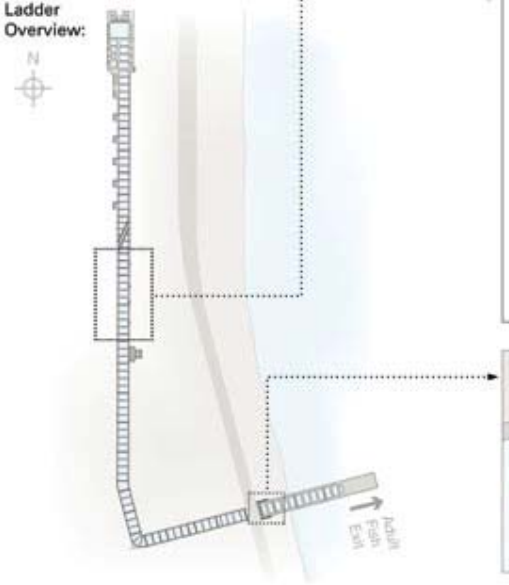
McNary Dam: Oregon Shore Ladder (MC1)

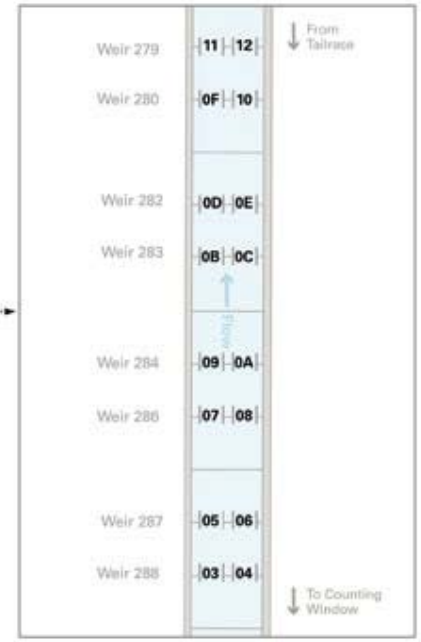
PIT Tag Interrogation Coil Map: Version 1.2, Cnfg. #100; February 2002

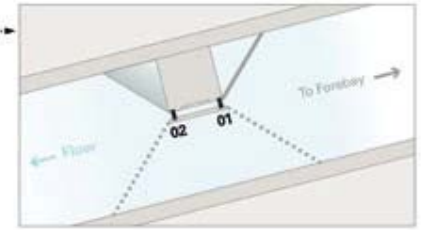
Site Overview:



Ladder Overview:

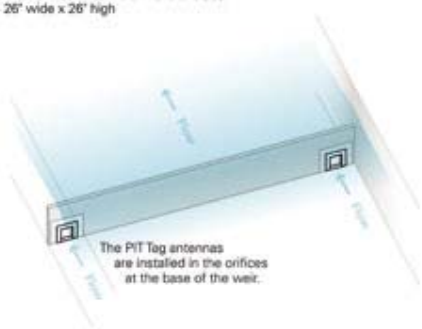






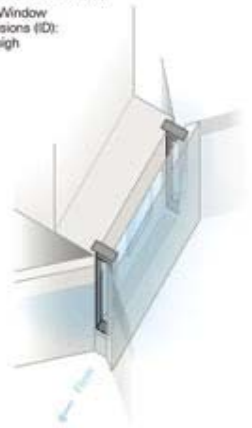
Overflow Weir Detail:

Weir Orifice Antenna Dimensions (ID):
26" wide x 26" high



Counting Window Detail:

Adult Counting Window
Antenna Dimensions (ID):
20" wide x 62" high



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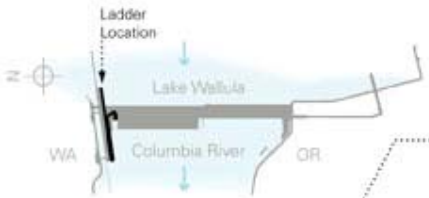
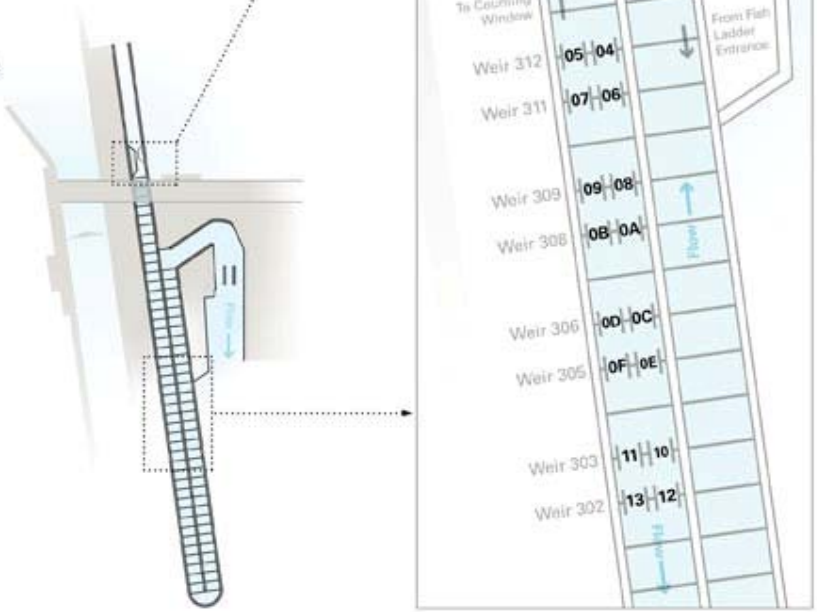
McNary Dam: Washington Shore Ladder (MC2)

PIT Tag Interrogation Coil Map: Version 1.1, Cnfg. #120; Revised March, 2006

Site Overview:

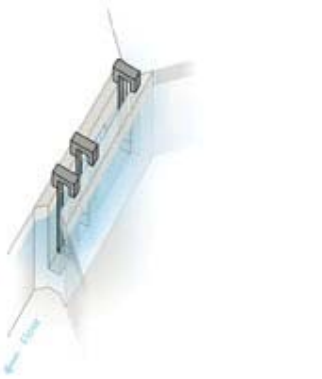


Ladder Overview:



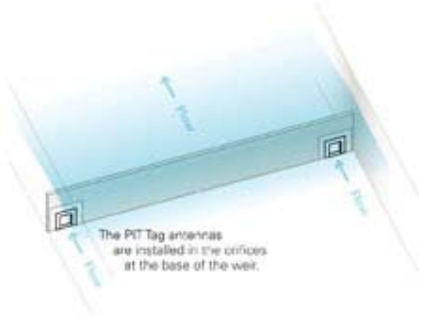
Counting Window Detail:

Adult Counting Window Antenna Dimensions (ID): 20" wide x 62" high



Overflow Weir Detail:

Weir Orifice Antenna Dimensions (ID): 21" wide x 23" high



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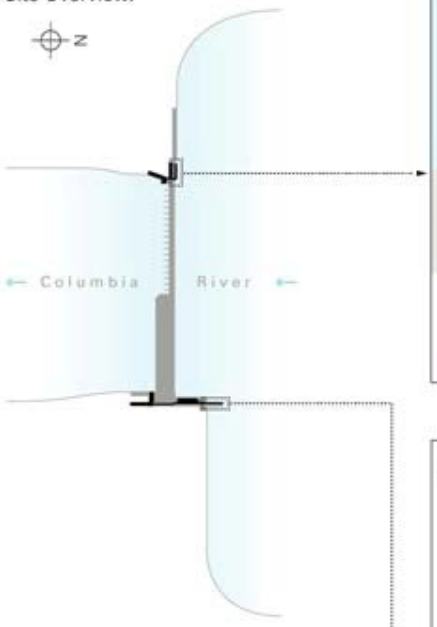
Priest Rapids Dam Fish Ladders (PRA)

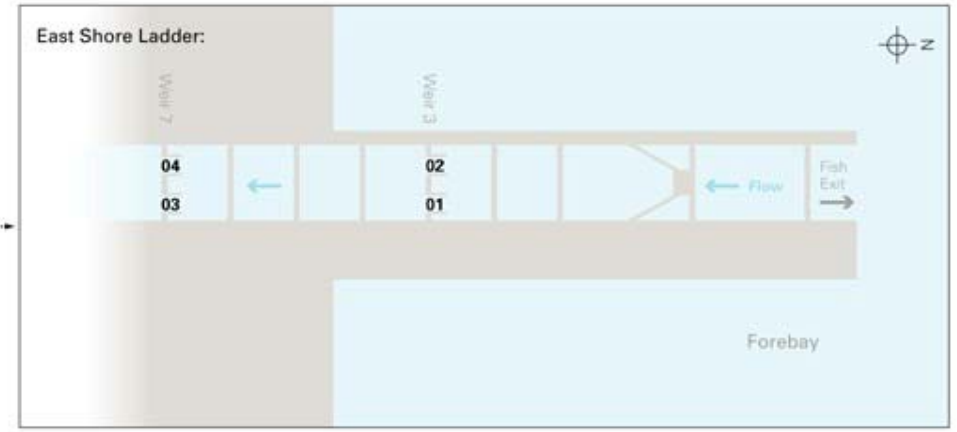
Interrogation Coil Map Revised: May, 2003 v.1.0, Cnfg. #100

Site Overview:



West Shore Ladder:

East Shore Ladder:



PIT Tag Antenna Dimensions
two antennas per weir

West Shore (Right) Ladder
- Weir 3: 22.5" wide x 43.0" high (ID)
- Weir 5: 22.0" wide x 50.0 high (ID)

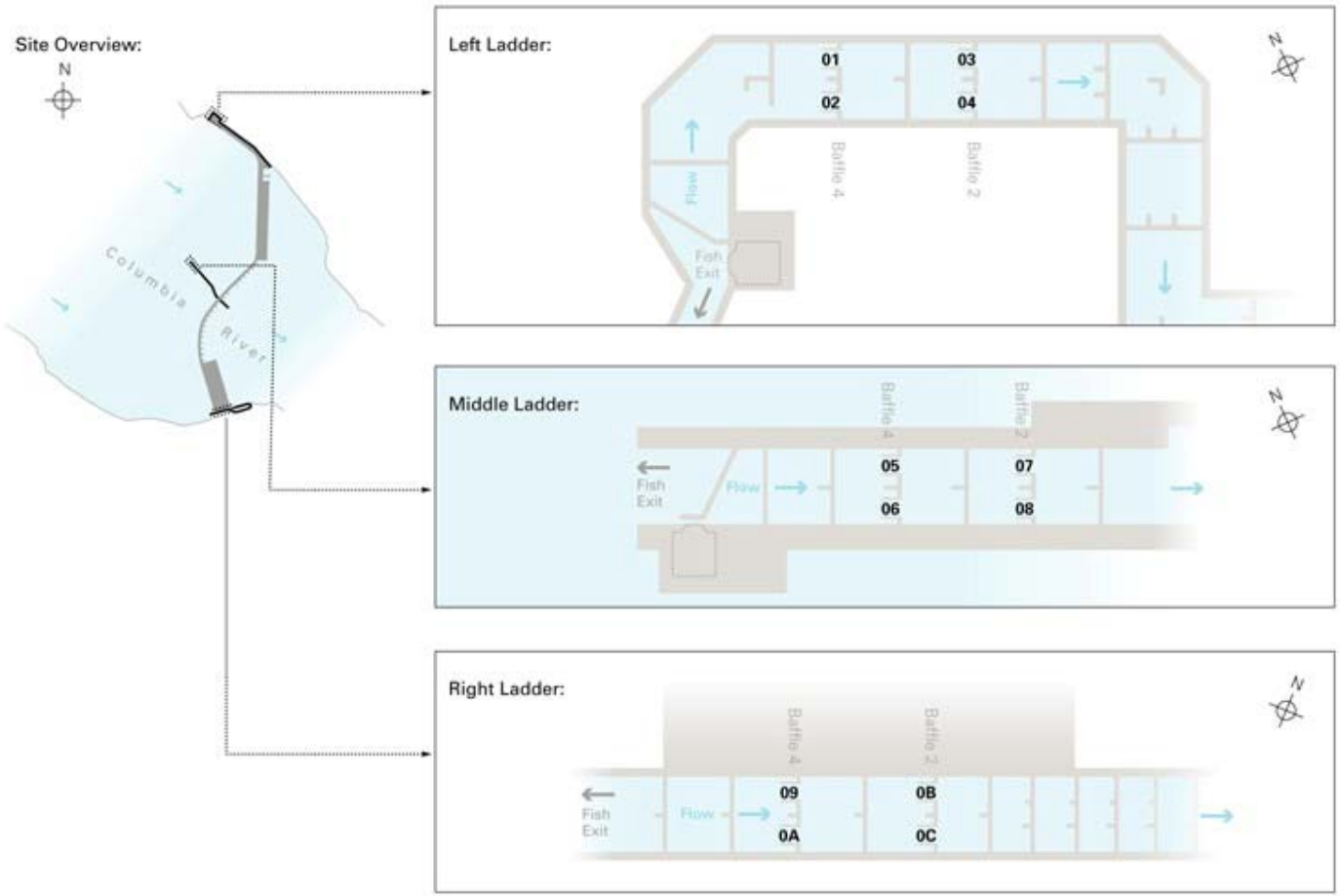
East Shore (Left) Ladder
- Weir 3: 24.0" wide x 55.0" high (ID)
- Weir 7: 24.5" wide x 45.0" high (ID)

PTAGIS

PIT Tag Information Systems
Columbia Basin

Rock Island Dam Fish Ladders (RIA)

Interrogation Coil Map Revised: May, 2003 v.1.0, Cnfg. #100
PIT Tag Antennae Dimensions: 21.5" wide x 36.5" high (ID)



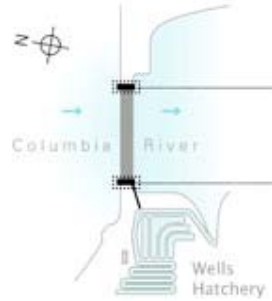
PTAGIS

PIT Tag Information Systems
Columbia Basin

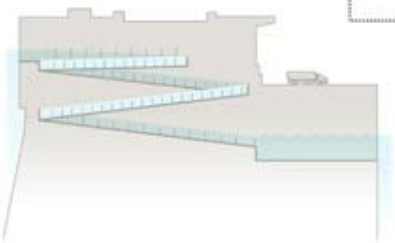
Wells Dam Fish Ladders (WEA)

PIT Tag Interrogation Map: Version 1.1, Cnfg. #110; Revised June, 2004
Ladder Orifice Dimensions: 21" wide x 34.5" high

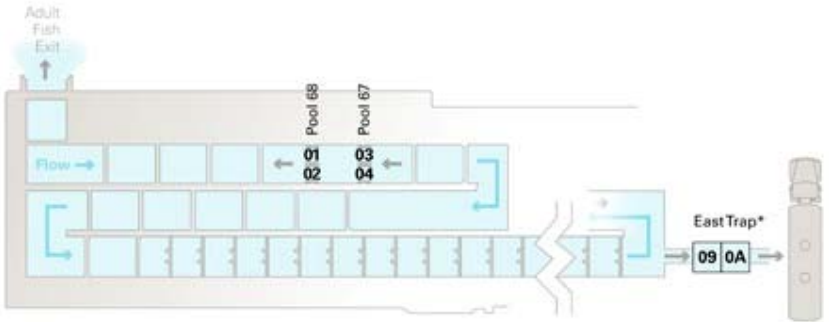
Site Overview:



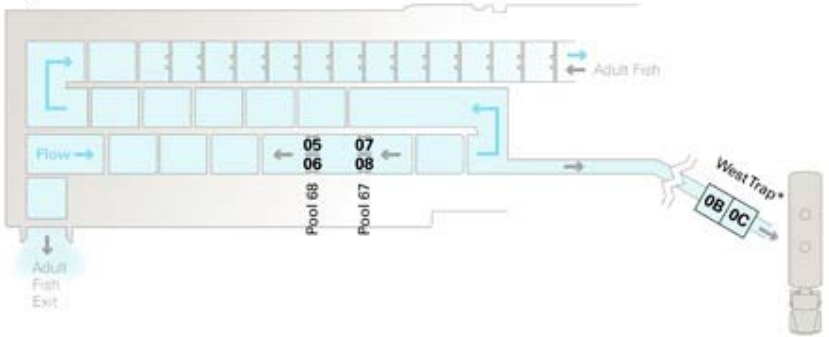
Elevation View:



Left Ladder



Right Ladder



*Trap fish are removed to the hatchery or trucked off-site.