LOWER GRANITE POOL AND TURBINE

SURVIVAL STUDY, 1987

by

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ABSTRACT

Survival of yearling spring chinook salmon was estimated as they traversed Lower Granite Reservoir and passed through a turbine at Lower Granite Dam. Fish were PIT tagged at Rapid River Hatchery and transported to release sites near Asotin, Washington, and at Lower Granite Dam. Recovery ratios of treatment and control groups were used to estimate survival. Estimates were based on tags intercepted at both Lower Granite and Little Goose dams. Turbine survival was estimated to be 83.1% (95% CI= 74.1 to 92.2%). A qualified estimate of survival from Asotin to Lower Granite Dam for a single release group was calculated as 71.9%.

Uncertainties associated with satisfying certain key mark and recapture statistical assumptions are examined. As a result of these uncertainties, an alternate study design and analytical procedure are recommended for future investigations.

CONTENTS

INTRODUCTION

Reservoir related mortality is recognized as an important component affecting the overall survival of juvenile salmonids migrating through the Columbia-Snake River system. Several studies have estimated system mortality (Raymond 1979; Sims et al. 1983, 1984; McConnaha and Basham 1985; FPC 1986a) as well as mortality associated with dam passage (Schoeneman et al. 1961; Knapp et al. 1982). Long et al. (1968) and Nigro et al. (1985) presented evidence that predation related mortality can occur at discrete locations within the tailrace. However, direct estimates of reservoir related mortality are lacking.

The Northwest Power Planning Council, in their 1987 Columbia Basin Fish and Wildlife Program, stated that reservoir mortality is one of six research elements that should receive top priority and directed the Bonneville Power Administration (BPA) to fund research studies aimed at obtaining such data. They also directed BPA to fund a technical committee to develop a 5-year plan for obtaining the needed data on reservoir mortality and how the mortality fluctuates with flows. This report presents information on reservoir survival estimates generated with the Passive Integrated Transponder (PIT) tag. The research was funded by BPA under the 1987 Water Budget Measures Program. The primary objective was to estimate the survival rate of juvenile chinook salmon migrating through the Lower Granite Pool from a release site 16 miles upstream from Asotin, Washington, to Lower Granite Dam. Secondarily, turbine survival was to be estimated. Additionally, a separate group of PIT-tagged fish were released with the Rapid River Hatchery production release below Hell's Canyon Dam for the Fish Passage Center's evaluation of migration rates and timing.

METHODS AND MATERIALS

From 17 to 20 February 1987, a total of 13,147 spring chinook salmon from Rapid River Hatchery were PIT tagged. Personnel from the U.S. Fish and Wildlife Service assisted the National Marine Fisheries Service in this phase of the study. Tagged fish were held in a mesh net-pen (16 ft square X 5 ft deep of 0.5-in stretched measure web) in the hatchery pond until release. The net projected 3 feet above the waterline to prevent escapement. The Idaho Fish and Game personnel at the hatchery maintained the fish in the net-pen and removed and froze mortalities for later tag decoding. Ten separate groups were released from the net-pen population. One group was released at Hell's Canyon Dam (Fig. 1) as part of the Fish Passage Center's Water Budget Measures Program evaluation. For our survival study, three groups were released at each of the following locations: 1) 16 miles upstream from Asotin, Washington, into the Snake River; 2) into a turbine (Unit 3) at Lower Granite Dam; and 3) into the Lower Granite Dam tailrace. Tagged fish recovered from these releases were used to estimate reservoir and turbine survival. PIT tag monitors positioned in the bypass systems at Lower Granite and Little Goose dams provided recapture data for survival estimates.

Fish Handling

Juvenile chinook salmon were removed from the hatchery pond using a 4-foot square, 0.5-in stretched measure mesh net. The net was lowered to the bottom of the pond, fish were attracted into the water over the net by chumming, and then the net was pulled to the surface. Five-gallon buckets were used to transport the fish collected from the net to the tagging area. At the tagging area, they were placed into a vessel (6 X 2 X 1 ft) supplied with fresh circulating water. Each tagging team then netted fish from the vessel into plastic troughs of

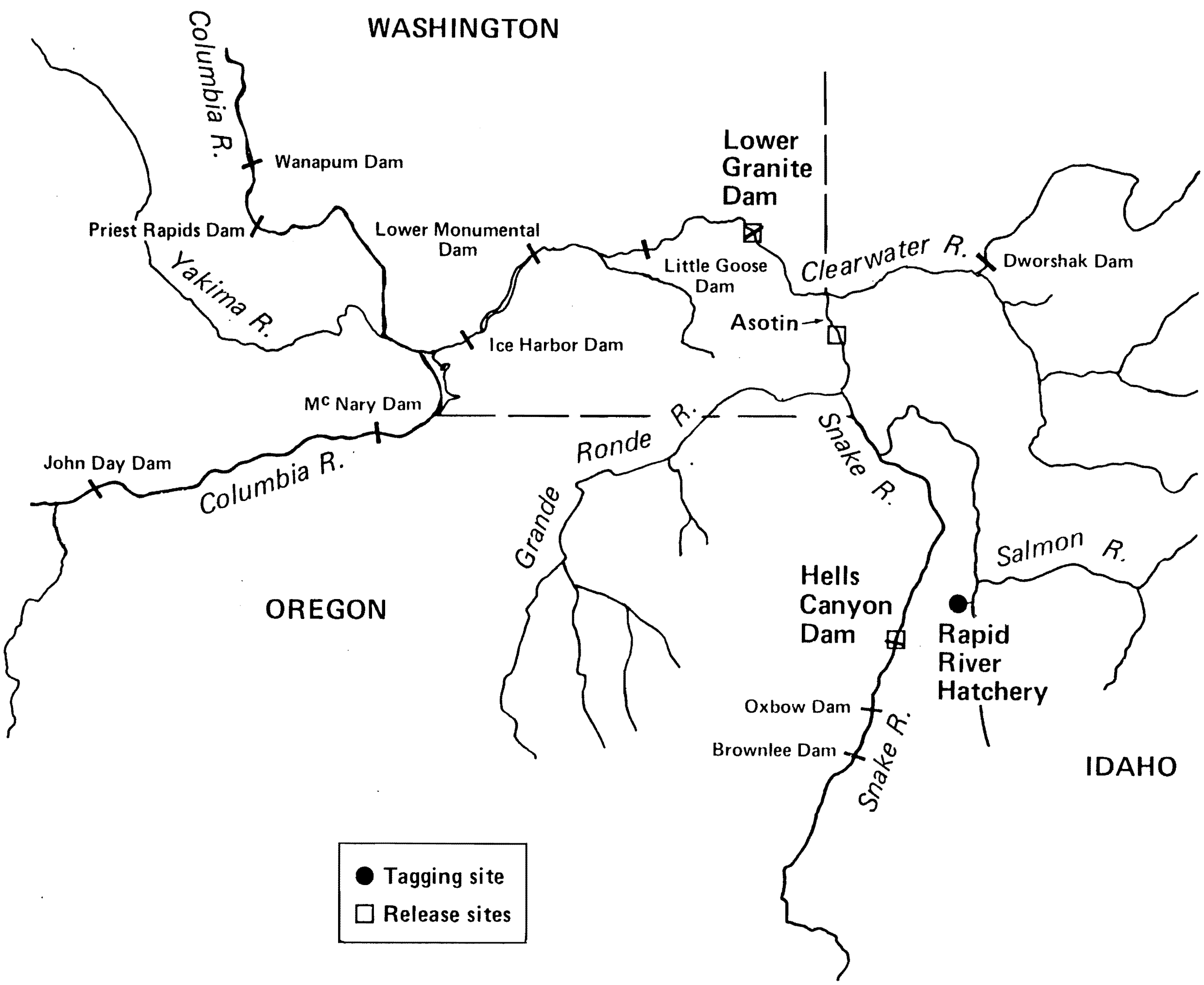

Figure 1.--Study area, 1987 yearling chinook salmon survival test, with tagging and release sites delineated.

MS-222 (50 ppm) as needed for tagging. After tagging, each fish's identification code and length were recorded (a subsample of every tenth fish was weighed) and fish were returned to the hatchery pond and net-pen via a flow of water in a 3-inch diameter pipe.

Tagging

Fish were tagged with either syringes fitted with individual tags or the newly developed auto-tagging gun. Detailed descriptions of the two procedures and associated equipment can be found in Prentice et al. (1987). The tagging station with individual syringes required three persons whereas only two were necessary at the auto-tagging station. Tagged fish were weighed and measured (fork length), and the data and the associated tag code were automatically entered in a computerized tagging file. Details regarding the hardware/software interfacing are noted in Prentice et al. (1987).

Release Procedures and Equipment

Each release group was removed from the net-pen by crowding the fish, dip netting a group, and then placing them into 5-gallon buckets of MS-222 (50 ppm). When anesthetized, fish were passed through a tag detector and the PIT tag codes recorded on a computer. The fish to be released below Hell's Canyon Dam were removed on 22 March and held in separate small net-pens (4 X 8 X 5 ft) over night and loaded with the hatchery production release the next day. Groups destined for Lower Granite Dam or reservoir (Asotin) were placed in the transport truck directly after decoding and taken to the release site. Gill Na^{+}-K^{+} ATPase samples were collected by U.S. Fish and Wildlife personnel prior to the Hell's Canyon release and before each series of survival releases. The Na^{+}-K^{+} ATPase levels from the samples were assayed by the NMFS and the U.S. Fish and Wildlife Service.

At Asotin, fish and water were released from the tanker through a 4-inch diameter hose directly into the river. Fish were released between 1400 and 1700 h. At Lower Granite Dam, fish and water were released from the tanker into Turbine Unit 3B just below the STS through a 3-inch diameter hose (Fig.2). Fish released in the Lower Granite Dam tailrace were transferred from the tanker to a 175-gallon tank on a 23-ft vessel. The boat was used to move the fish to a position just downstream from the Unit 3 turbine boil where they were released into the water through a 4-inch diameter hose. Tailrace releases were made at dusk (1930 to 2030 h), while light was still available for safe vessel operation. The turbine releases were made during darkness between 2100 and 2200 h.

Number of Fish Released and Prevailing Release Conditions

At the time fish were tagged, some fish in the hatchery system were displaying fungus infected tails, a symptom of "cold water disease." No fish exhibiting the symptom was tagged. Our target release number for the entire study was 12,000 fish. To compensate for expected disease related mortality between tagging and release, 13,147 fish were tagged. Subsequently, 1,566 fish were not released (1,048 which exhibited symptoms of disease, 87 sacrificed for Na^+-K^+ ATPase tests, and 43 fish which had rejected their tags). Table 1 details the number, date, time, and location of the 11,581 fish released.

To improve the probability that mixing would occur at the Little Goose Dam recapture site, we planned a 10-day delay between the test (Asotin) and control releases (Lower Granite Dam) for each replicate. However, due to the high disease related mortality and operational constraints at the hatchery, the release schedule was compressed. Pool and dam groups were released only 1 day apart (Table 1).

LOWER GRANITE DAM

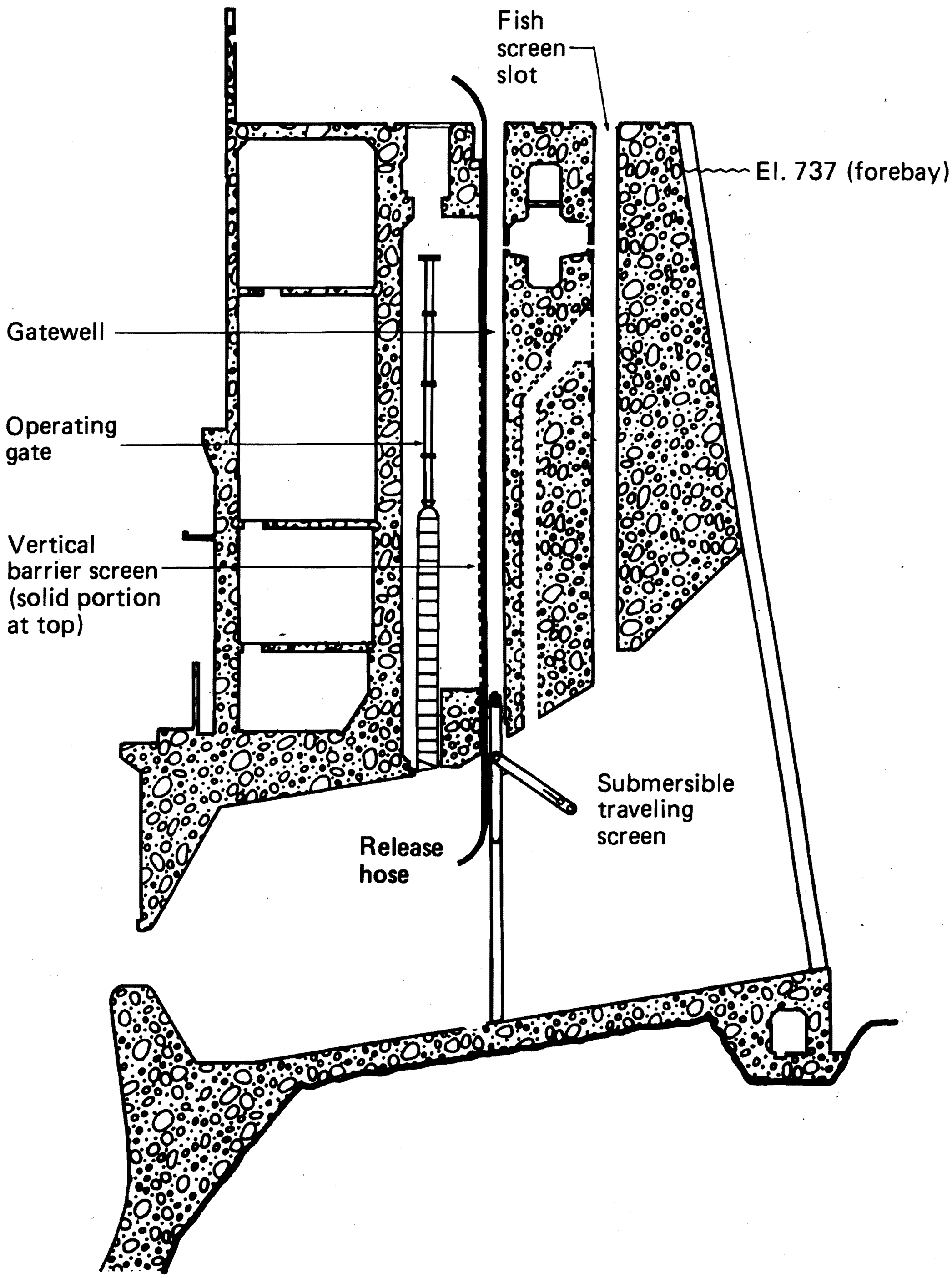

Figure 2.--Turbine release hose position, Lower Granite Dam, 1987.

Table 1. Release data for PIT-tagged chinook salmon from Rapid River Hatchery, 1987.

Release site	Date	Time (h)	Number released	Water temp. (^{o}F)	Tailrace elevation (ft)
Hell's Canyon	23 March	1500	2,997	--	
Asotin	27 March	1658	1,656	42	
	31 March	1415	1,537	50	
	4 April	1415	1,701	52	
Turbine	28 March	2200	625	42	636.5
	1 April	2200	621	50	636.2
	5 April	2105	749	47	637.4
Tailrace	28 March	2005	525	42	
	1 April	1930	525	50	
	5 April	1930	645	47	
Total			11,581		

Due to low river flows during the study, the load on Unit 3 was 100 MW when tagged fish were released into it. The load was a representative load for the period of the study; however, it was not the level (135 MW) normally prescribed in the Fish Transport Oversight Team's (FTOT) guidelines. The prescribed load did not occur during peak passage hours on the dates our tests were conducted (Fig. 3). River flow volumes at Lower Granite Dam from 3 April to 8 May ranged from 27.1 to 99.9 kcfs. These were near the record low flows recorded in 1977 (FPC 1988). Spill did not occur at either Lower Granite or Little Goose dams during the period the PIT-tagged smolts were passing the dams.

Data Analysis

The PIT tag data were recovered at Lower Granite and Little Goose dams by the monitoring systems described by Prentice (1987). Survival estimates were calculated from PIT-tagged fish recovered at Lower Granite and Little Goose dams. Survival(s) of a specified treatment group was defined as

$$s = \frac{R_t/N_t}{R_c/N_c}$$

where N_t = number of treatment fish released upstream for any estimate, N_c = number of control fish released downstream for any estimate, R_t = number of treatment fish recovered, and R_c = number of control fish recovered.

Since releases upstream from Lower Granite Dam had individuals removed at the dam due to transportation activities, certain survival estimates should reflect those removals. In those cases, survival was calculated as

$$s = \frac{R_t/N_t}{R_c/N_c} + \frac{E}{N_t}$$

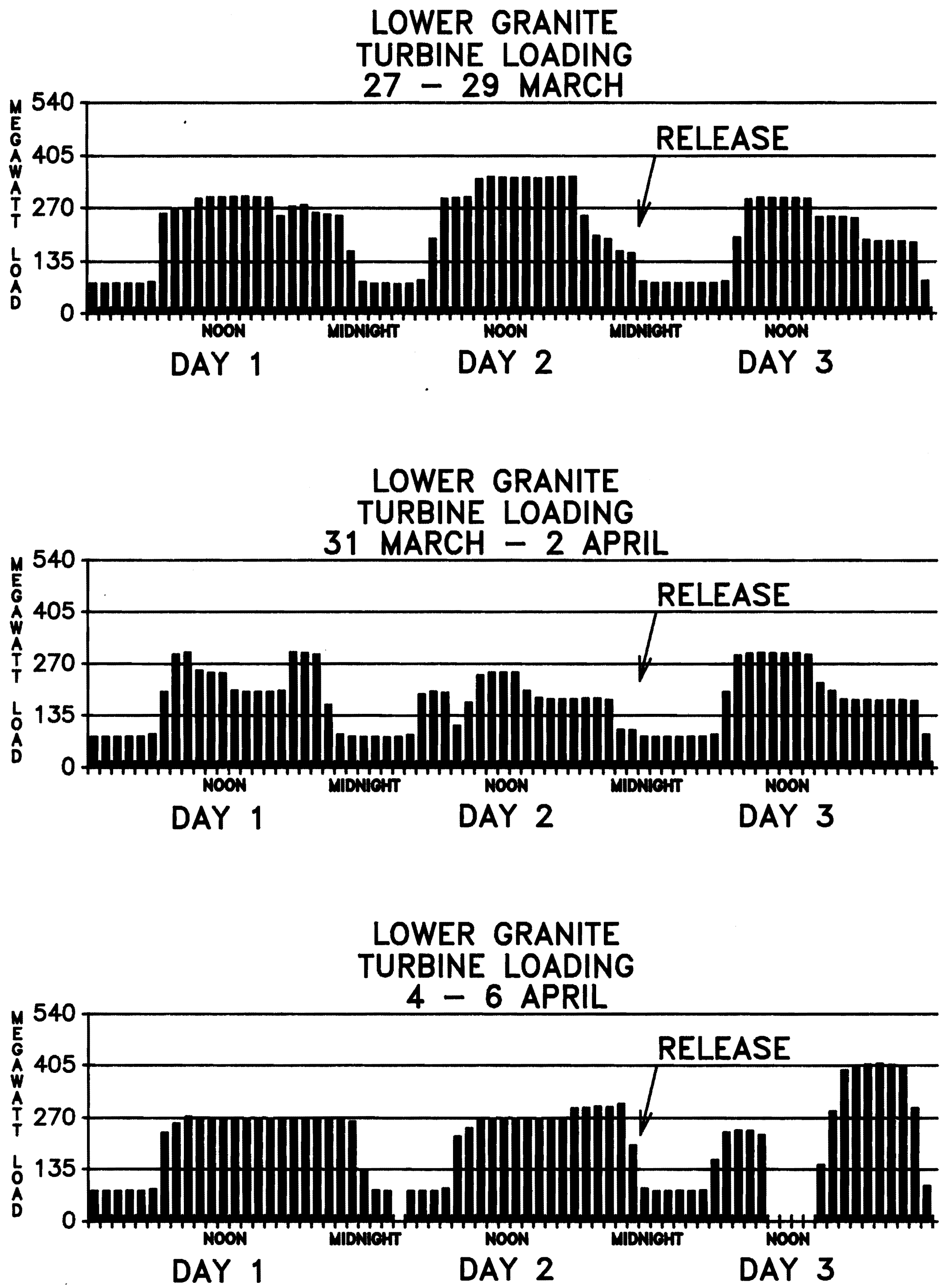

Figure 3.--Hourly megawatt (MW) load at Lower Granite Dam before, during, and after turbine releases. Megawatt loading increments in 135 MW (nameplate) steps are represented with horizontal lines.

where E = the number of fish in the treatment group extracted from the population.

RESULTS

A total of 1,958 and 1,090 tagged fish were recovered at Lower Granite and Little Goose dams, respectively. Specific recoveries from each release group appear in Table 2. Since nearly all yearling chinook salmon collected at Lower Granite and Little Goose dams were transported in 1987, no PIT-tagged fish were recaptured at more than one recovery site.

Arrival dates at Little Goose Dam are plotted for each release group in Figures 4 through 6. Visual assessment of the recovery data suggests that turbine and tailrace releases were generally mixed at Little Goose Dam, the designated recovery site for the analysis prescribed in the proposal. Mixing was statistically assessed with a chi-square test, where each day constituted a cell, except when the number of recoveries per cell was less than five. In those cases, the cell width was expanded until a minimum of five recoveries was achieved. Also, mixing was examined by visually assessing frequency distribution data at the recovery site. Results from the chi-square tests corroborate the visual assessment that turbine and tailrace releases were mixed at Little Goose Dam (Table 3).

Only the 27 March release at Asotin appeared to be mixed with any turbine or tailrace release at Little Goose Dam (Fig. 5). Chi-square tests suggest that only the first Asotin release (27 March) may have been mixed with any of the turbine or tailrace releases (Table 3).

A consideration when calculating survival estimates is that the treatment and control group are assumed to incur a similar degree of nontreatment related mortality as they travel from the control release site to the recapture site, otherwise referred to as the control zone. This is a difficult assumption to

Table 2. Recovery of PIT tags at Lower Granite (LGR) and Little Goose (LG) dams.

Release site	Release date	Number recovered LGR	LG	Total	% recovered LGR	LG	Total
Hell's Canyon	23 Mar	552	154	706	18.4	5.1	23.6
Asotin	27 Mar	488	126	614	29.5	7.6	37.1
	31 Mar	426	94	520	27.7	6.1	33.8
	4 Apr	484	103	587	28.5	6.1	34.5
Turbine	28 Mar	8	112	120	1.3	17.9	19.2
	1 Apr	-	92	92	-	14.8	14.8
	5 Apr	-	99	99	-	13.2	13.2
Tailrace	28 Mar	-	118	118	-	22.5	22.5
	1 Apr	-	94	94	-	17.9	17.9
	5 Apr	-	98	98	-	15.2	15.2
Total		1,958	1,090	3,048			

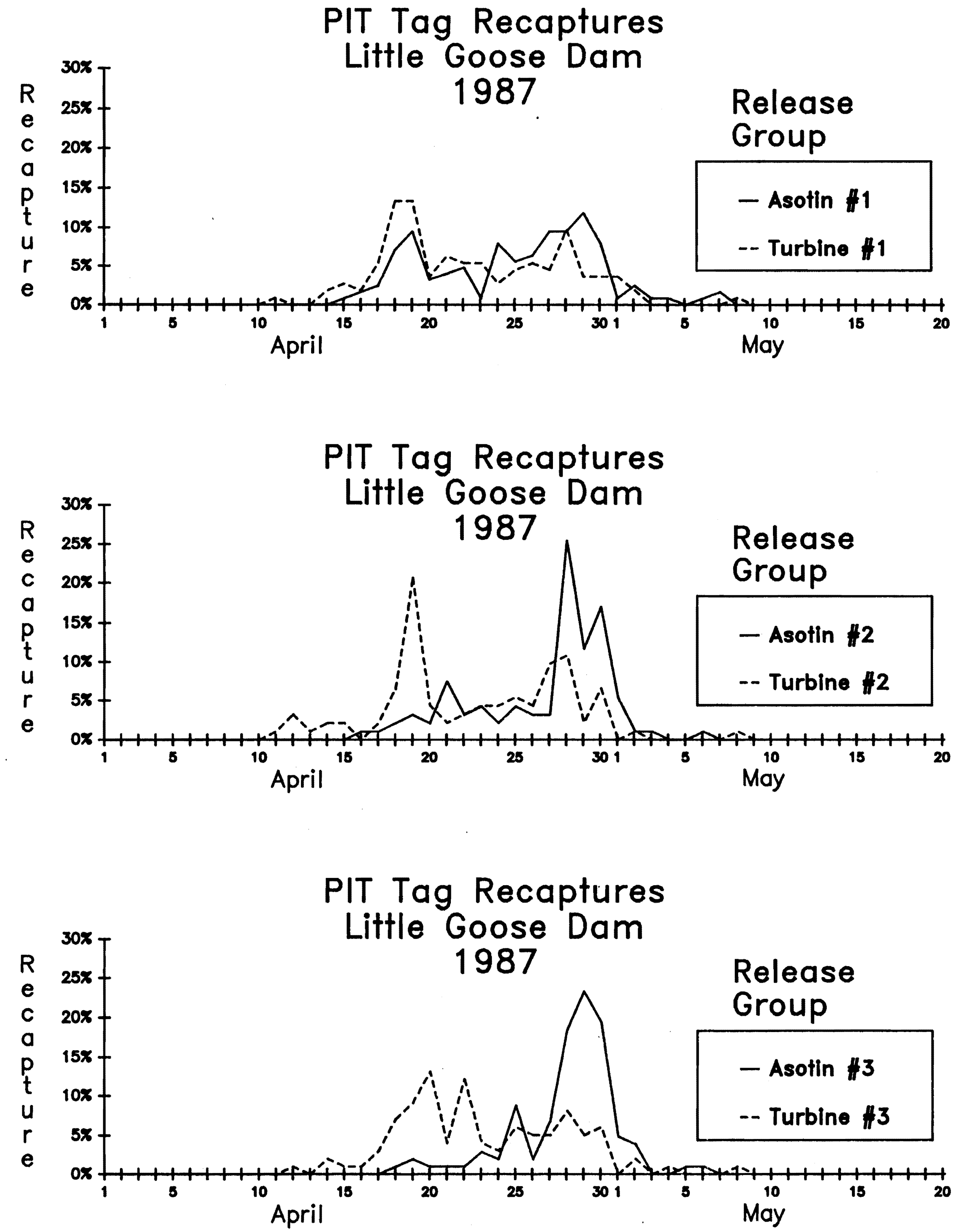

Figure 4.--Daily recapture percent of total PIT tags recaptured at Little Goose Dam from Asotin and turbine releases, 1987.

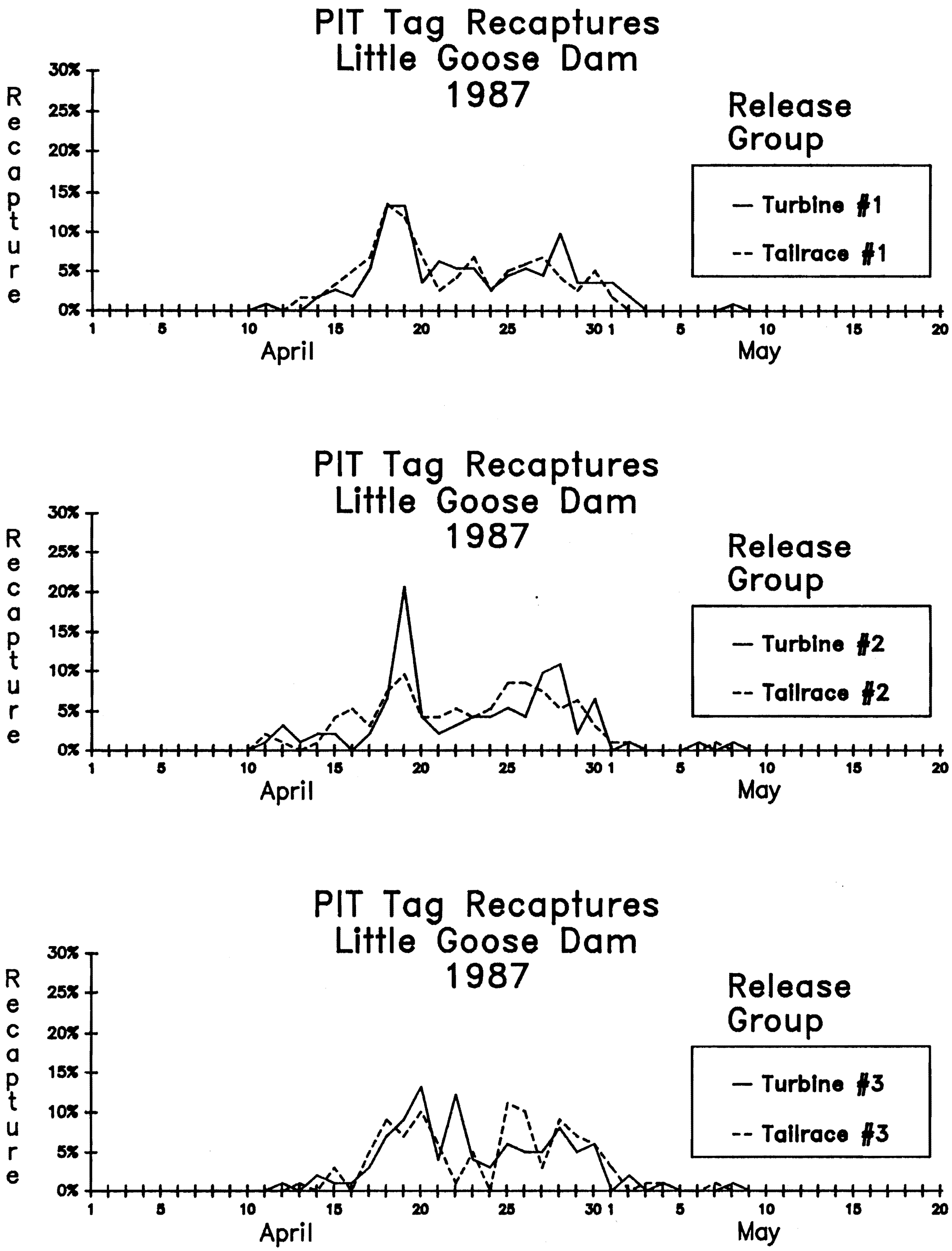

Figure 5.--Daily recapture percent of total PIT tags recaptured at Little Goose Dam from turbine and tailrace releases, 1987.

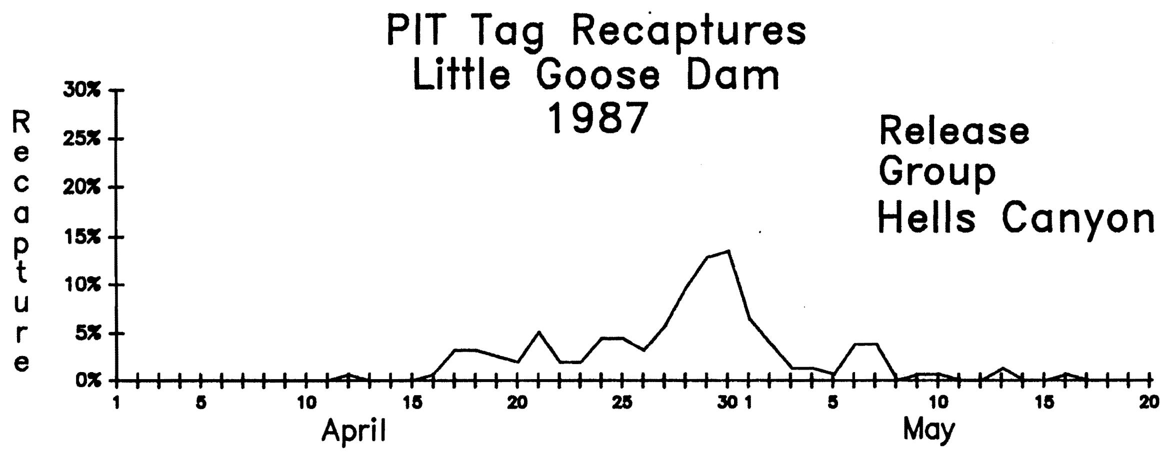

Figure 6.--Daily recapture percent of total PIT tags recaptured at Little Goose Dam from Hells Canyon release, 1987.

Table 3. Results of chi-square (X^2) analysis of mixing at Little Goose Dam, 1987. Probabilities ($\geq$0.05) marked by asterisks indicate that mixing of the paired groups was achieved, as assessed by the X^2 test.

Release		Hell's	Asot.	Asot.	Asot.	Turb.	Turb.	Turb.
Loc.	Date	Canyon	1	2	3	1	2	3
Asot. 1	27							
X^2	Mar.	23.92						
P		0.0209						
df		12						
Asot. 2	31							
X^2	Mar.	18.95						
P		0.0151						
df		8						
Asot. 3	4							
X^2	Apr.	23.62						
P		0.0027						
df		8						
Turb. 1	28							
X^2	Mar.	53.16	17.22	44.09	74.57			
P		0.0	0.1015*	0.0	0.0			
df		10	11	7	6			
Turb. 2	1							
X^2	Apr.	48.96	15.20	41.61	64.18			
P		0.0	0.0553*	0.0	0.0			
df		8	8	6	5			
Turb. 3	5							
X^2	Apr.	45.19	16.09	33.91	64.53			
P		0.0	0.1379*	0.0	0.0			
df		10	11	7	6			
Tailr. 1	28							
X^2	Mar.	69.92	26.48	63.52	92.27	5.939	16.34	16.76
P		0.0	0.0031	0.0	0.0	0.8774*	0.0378	0.0798*
df		9	10	6	5	11	8	10
Tailr. 2	1							
X^2	Apr.	47.50	16.14	47.49	69.24	7.640	6.830	12.54
P		0.0	0.1359*	0.0	0.0	0.7452*	0.5551*	0.3241*
df		10	11	7	6	11	8	11
Tailr. 3	5							
X^2	Apr.	37.86	10.89	28.64	50.95	10.98	13.11	8.740
P		0.0	0.3664*	0.0004	0.0	0.2774*	0.1082*	0.5570*
df		10	10	8	7	9	8	10

assess. However, we may make general inferences based on the time frame and duration that treatment and control fish reside within the control zone. The more disparate their exposure periods in the control zone, the greater the possibility they may have incurred different levels of mortality due to biological and environmental factors (e.g., predation or water temperature). This uncertainty means that the accompanying survival estimate will need to be qualified. This uncertainty was not a concern for the turbine (treatment) and tailrace (control) releases since they were released into the head of Little Goose pool a few hundred meters apart and within 3 h of each other (Table 1), and they were in Little Goose pool over the same time frame. However, for the 27 March Asotin release (treatment) which exhibited mixing with several turbine or tailrace releases, the uncertainty of mortality through the control zone was a concern. Generally, turbine and tailrace releases traversed the control zone in an average of 21 days whereas fish from the 27 March Asotin release were in the control zone an estimated average 7 days (Table 4, Fig. 7). This equates to a 2-week difference in the amount of time these groups were in the control zone.

The physiological status of the fish at release indicates the fish were still in the early stages of smolt development and not prepared to initiate downstream migration. Gill Na^+-K^+ ATPase values averaged 8.9 to 10.2 units (Table 5). By comparison, gill Na^+-K^+ ATPase in active migrant yearling chinook salmon intercepted at Lower Granite Dam are more typically near 20 to 35 units (Swan et al. 1987). These data indicate that the failure of the tagged fish to migrate upon release may be, in large part, a result of inadequate smolt development.

Turbine survival was estimated to be 79.7, 82.7, and 87.0% for releases made on 28 March and 1 and 5 April, respectively. The pooled estimate for the three releases was 83.1% survival with a 95% confidence interval of 74.1 to 92.2%.

Using the tagged group released at Asotin on 27 March paired with the 28 March turbine release group as the control, we estimated 71.9% of the fish survived through Lower Granite Pool. This estimate must be qualified since the control group resided in Little Goose Pool 2 weeks longer than the treatment group and as a consequence may have incurred some higher rate of mortality within the control zone. Also, the degree of mixing attained at the recovery site was uncertain. Consequently, the estimated survival in Lower Granite Pool may be biased.

DISCUSSION

Results from this study identify specific problems associated with experimental design. Our inability to generate reliable estimates of pool survival was due to the failure of the design to satisfy two key assumptions or conditions. Treatment and control groups were neither adequately mixed, nor did they reside in the control zone for the same length of time. These failures cloak any accompanying pool survival estimates in uncertainty. Why did these failures occur? We believe the answer lies in the source of fish utilized to conduct the study. The spring chinook salmon released from Rapid River Hatchery were not prepared to migrate, as evidenced by their protracted post-release travel times (Fig. 7, Table 4) and low gill Na^{+}-K^{+} ATPase activity at release (Table 5).

Regardless of release site (Asotin or Lower Granite Dam), it took about 18 to 21 days for the tagged fish to arrive at the first downstream dam. As a result, control groups were in the control zone about 2 weeks longer than treatment groups (Fig. 7). As a consequence, mixing either did not occur or was

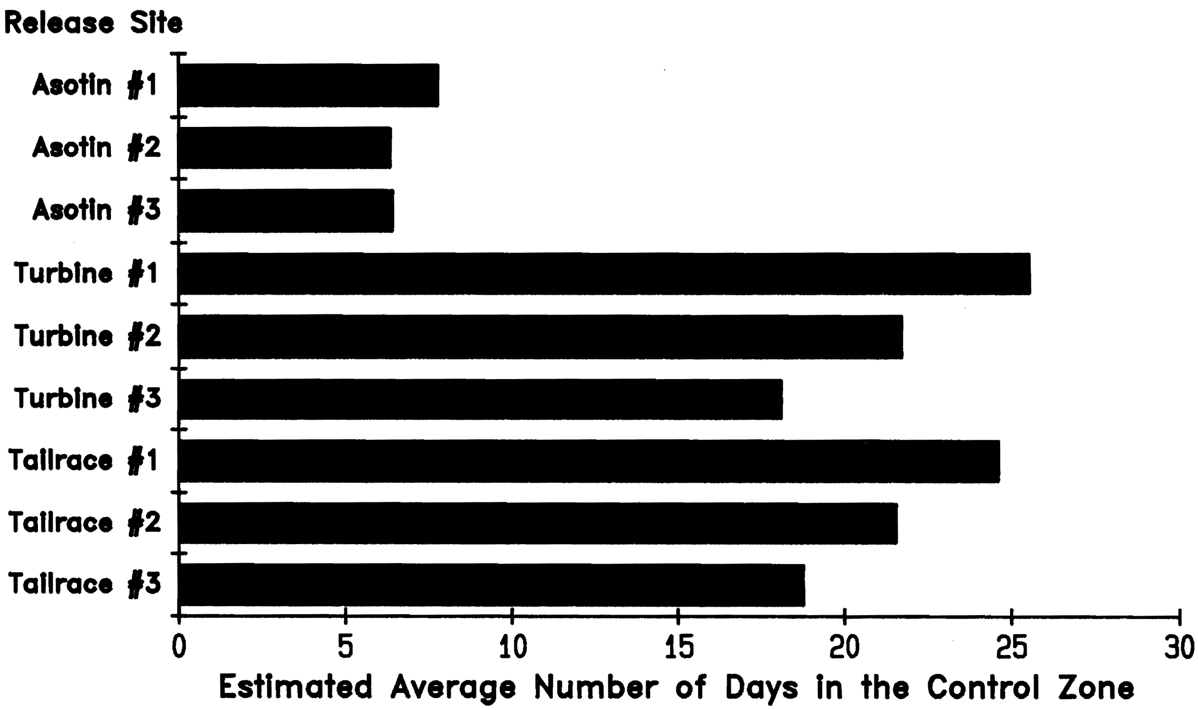

Figure 7.--Estimated average number of days PIT-tagged chinook salmon from the Asotin, turbine, and tailrace release groups resided in the Little Goose pool (Control Zone), 1987. Control zone time for fish released above Asotin was estimated from the fiftieth percentile recapture dates at Lower Granite and Little Goose Dams.

Table 4. Mean travel time (in days) between release and recapture sites for the Rapid River PIT-tagged population, 1987.

Site		Release	Average travel time	
Release	Recapture	date	Days	SD
Lower Granite turbine	Little Goose			
		28 March	25.57	5.104
		1 April	21.75	5.506
		5 April	18.14	4.845
Lower Granite tailrace	Little Goose			
		28 March	24.65	5.013
		1 April	21.59	5.194
		5 April	18.80	4.962
Asotin	Lower Granite	27 March	21.18	5.515
		31 March	20.26	4.876
		4 April	17.53	4.517
Asotin	Little Goose	27 March	29.00	4.871
		31 March	21.59	5.194
		4 April	24.00	4.962

Table 5. Gill Na^+-K^+ ATPase levels in PIT-tagged release groups from Rapid River Hatchery, 1987.

Sample date	Na^+-K^+ ATPase	
	Mean	SD
22 March	8.9	1.9
28 March	10.2	2.8
31 March	9.2	1.4
4 April	9.8	1.4

uncertain and controls may have incurred high rates of mortality in the control zone relative to the treatment groups released at Asotin.

We believe that these shortcomings may be averted if in-river migrants, rather than hatchery fish, are used in studies of this nature. Under a preferred design, river-run fish would be collected upstream from the dam, tagged, and returned to the pool. Upon arrival of that release group at Lower Granite Dam (as indicated by the tag recovery system there), fish would be removed from the collection system, tagged, and released in the tailrace and/or turbine, depending on the survival estimate of interest. This design would provide the best mixing at Little Goose Dam and similar exposure periods in the control zone. Thereby, the uncertainty of differential mortality of treatment and control groups within the control zone would be reduced.

The use of the chi-square test to assess mixing of treatment and control groups follows analytical precedent established by Schoeneman et al. (1961). Whether or not this is the most appropriate measure of mixing is uncertain. The FPC (1986) relied on visual interpretation of passage frequency plots, such as those appearing in Figures 4 through 6. We too considered such patterns in our assessment but were uncomfortable using them as the only measure since visual interpretation can be so subjective. In the past, we have employed a Kolmogorov-Smirnov Test but found that minor deviations in the passage distribution of paired groups often resulted in the rejection of the null hypothesis. We suggest this issue receive attention in the development of future research plans dealing with survival estimation.

When recapture data from the Asotin and turbine releases were compared, only one pair (27 March at Asotin with 28 March through the turbine at Lower Granite Dam) appeared to be mixed based on both visual inspection (Fig. 4) and a chi-square test (Table 3). Yet, on the average, the Asotin fish were in the control zone for only 7 days whereas fish released at the dam were there for 21 days. The travel time and mixing data seem to be contradictive. We offer two possible explanations: either our methods for assessing the extent of mixing are inappropriate or the mean residence time in the control zone can not be used to predict the extent of mixing.

Mixing, or the synchronous passage of treatment and control groups, is a concern when the sampling efficiency of the collection device changes through time. Such changes can result from the proportion of water spilled or intraseasonal fluctuations in fish guiding efficiency (FGE) (Swan et al. 1987). These changes in sampling efficiency are, to some extent, inherent to all collection systems in the basin. However, FGE has been found to be relatively stable at Little Goose Dam and no spill occurred in 1987; thus, mixing should not have been necessary. Unfortunately, the efficiency of the PIT tag detectors at the dam fluctuated over the course of the spring outmigration (Prentice, pers. comm.). This was the first year of operation at this site and interference between the PIT detector and the electronic fish counters caused erratic fluctuations in tag detection efficiency. As a consequence, mixing of treatment and control groups was necessary. Herein lies the dilemma--mixing is often difficult to achieve, yet it is required to some degree at perhaps all collection sites or collection efficiency must be accurately estimated and recoveries adjusted accordingly. The questions of concern then, for future investigators are as follows:

1) How can studies be better designed to accomplish mixing?

2) How can collection efficiency be accurately estimated?

3) How much deviation from mixing is acceptable statistically?

4) What are appropriate statistical methodologies?

The turbine survival estimates presented in this report include an undefined amount of mortality incurred by treatment fish entrained in the backroll. All of this backroll mortality may not be directly associated with turbine related injury, but likely includes predation on fish having passed through the turbine into the predator occupied backroll (Long 1968).

Our turbine survival estimates are lower than those estimated at other sites in the Columbia-Snake River system. Based on adult returns, Holmes (1952) estimated turbine survival at 85-89% for subyearling fall chinook salmon at Bonneville Dam. At McNary Dam, Schoeneman et al. (1961) estimated that subyearling chinook salmon survived at an average 89% when passed through the turbines. There are several possible explanations as to why our turbine survival estimates appear lower. First, the species we used in our experiment, spring chinook salmon, may be more sensitive to turbine passage than the fish examined by other investigators. Secondly, it may be that the passage conditions (e.g., megawatt load or sigma) prevailing during the conduct of the experiment were different for each study--it is suspected that fish incur a higher rate of mortality at reduced turbine loading. Another possibility may be that the treatment fish in our study traveled longer and farther to their recovery site than was the case for Schoeneman et al. (1961). On the average, our release groups were in the river 18 to 21 days prior to recovery at Little Goose Dam. Such a protracted period would permit any delayed mortality associated with turbine passage ample time for expression. Unfortunately, time-to-recovery-data were not provided by Schoeneman et al. (1961) and a comparison is not possible. Since Holmes (1952) based his estimates on adult returns and ours were based on juvenile recoveries, fundamental differences in sampling procedures and associated assumptions may preclude any direct comparisons of results.

The survival estimates provided in this study are calculated using tagged fish recaptured at Little Goose Dam. Alternative estimation models have been developed by investigators at Colorado State University. These models utilize recaptures from all available downstream sites and require tags similar to the PIT tag. A monograph (Burnham et al. 1987) describing the analytical procedures was recently released. An accompanying software package should be released soon. We recommend that this information be considered in the design of future survival studies.

CONCLUSIONS

1. The mean survival associated with turbine passage of spring chinook salmon at Lower Granite Dam was estimated to be 83.1% (95% CI= 74.1 to 92.2%). This estimate is based only on tag recoveries at Little Goose Dam and thus only reflects mortality manifested prior to arrival at that recovery site.

2. A qualified survival estimate for spring chinook salmon from Asotin to Lower Granite Dam was estimated at 71.9%.

3. There were difficulties or uncertainties satisfying assumptions inherent in calculating some survival estimates. We conclude that these problems are attributable to the fish source and release schedule employed in this experiment.

4. We suggest that Burnham et al.'s (1987) design and analysis be considered for future studies of this nature.

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APPENDIX

Budget Summary

BUDGET SUMMARY

		$K
Labor		54,661.18
Travel and transportation of persons		6,638.56
Transportation of things		2,184.96
Rent, communications, and utilities		2,836.36
Printing and reproduction		0.00
Contract services		3,752.50
Supplies, materials, and equipment		5,791.02
SLUC		3,408.82
NOAA and DOC overhead		21,428.08
	TOTAL	100,701.48