Project survival of juvenile salmonids passing through the bypass system, turbines, and spillways with and without flow deflectors at Little Goose Dam, 1997

Fish Ecology Division

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Seattle, Washington

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EXECUTIVE SUMMARY

Studies were conducted to provide relative survival estimates through different routes of passage at Little Goose Dam. In 1997, only hatchery steelhead were used because too few hatchery yearling chinook salmon were available. Fish were collected and marked with PIT tags at the Lower Granite Dam smolt collection facility, and then transported to Little Goose Dam in aerated tanks mounted on trucks. After a 24-hour holding period, one group of 500 marked fish was released at each of five locations--into the bypass system, a turbine unit (Unit 6B), a spillbay equipped with a flow deflector ("flip lip," Spillbay 3), a spillbay without a flow deflector (Spillbay 1), and into the tailrace 1-2 km below Little Goose Dam. The bypass system groups were released through a hose attached to the trashrack so that fish would pass through the entire bypass system.

During the study, between 12 and 15 releases were made through each passage route. Survival was estimated from detections of individual PIT-tagged fish at the juvenile collection/detection facilities at Lower Monumental, McNary, John Day, and Bonneville Dams. Differences among detection percentages relative to tailrace groups were evaluated by analysis of variance (ANOVA). Survival was highest through Spillbay 1 without a flow deflector (1.004 relative to tailrace groups, s.e. 0.0150), followed by Spillbay 3 with a flow deflector (0.972, s.e. 0.0145), the bypass system (0.953, s.e. 0.0162), and turbine (0.934, s.e. 0.0156). ANOVA showed significant differences among treatment means ($F = 3.77$, $P = 0.016$). Survival for fish released into Spillbay 1 without a flow deflector was

significantly higher than for those released in the bypass or turbine locations (Fisher's Protected Least Significant Difference). No other contrasts of means were significant.

During the same period as our releases at Little Goose Dam, we also released hatchery steelhead into the tailrace of Lower Granite Dam, from which we made estimates of survival for various reaches, including from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam. By assuming a value for fish guidance efficiency (FGE) for steelhead at Little Goose Dam, we used our route-specific survival estimates at Little Goose Dam to partition the estimated reach survival into reservoir- and project-related components. Assuming 90% FGE, we partitioned the reach estimate (Lower Granite Dam tailrace to Little Goose Dam tailrace) of 0.954 into survival estimates of 0.994 through Little Goose Reservoir (Lower Granite Dam tailrace to Little Goose Dam forebay) and 0.960 through Little Goose Dam (forebay to tailrace). We also estimated hatchery steelhead Spill Efficiency (41% of fish passing via spill), Spill Effectiveness (1.24 ratio of proportion of fish passing via spill to proportion of water spilled), and Fish Passage Efficiency (94.0% of fish passing via nonturbine routes) through Little Goose Dam during the study period.

CONTENTS

INTRODUCTION

Route-specific estimates of survival for juvenile salmonids passing through dams are needed to determine dam operations that maximize smolt survival. Many dam operational decisions are based on fish passage models that use data collected many years ago using antiquated techniques. Precise estimates of fish survival under present conditions through all potential passage routes including bypass facilities, turbines, and spillways with and without flow deflectors are needed.

Juvenile salmonid passage facilities at Little Goose Dam were recently upgraded to include extended submersible bar screens, modified balanced-flow vertical barrier screens, and raised operating gates. Based on earlier fish guidance efficiency (FGE) research (Gessel et al. 1995), the majority of the yearling spring/summer chinook salmon (75%) and steelhead (86-90%) migration would pass via the bypass system in the absence of spill.

Previous studies indicated that, among the different passage routes through dams, passage survival was highest through spillways, followed by bypass systems and turbines. Spillway survival estimates have ranged from 73 to 100% (Holmes 1952, Schoeneman et al. 1961, Long et al. 1975, Ledgerwood et al. 1990, Muir et al. 1995a) and turbine survival estimates from 80 to 98% (Holmes 1952, Weber 1954, Schoeneman et al. 1961, Oligher and Donaldson 1966, Long et al. 1975, Raymond and Sims 1980, Giorgi and Stuehrenberg 1988, Ledgerwood et al. 1991, Mathur et al. 1996, Muir et al. 1996). However, few evaluations of bypass system survival have been conducted and most have not evaluated survival through the entire bypass system. Gilbreath et al. (1993) reported that overall recovery percentage for bypass-released groups was 7.6% less than for turbine-released groups and 8.3% less than for tailrace-released groups at Bonneville Dam Second Powerhouse. At Little Goose Dam, survival for PIT-tagged hatchery yearling chinook salmon was 99.4% (s.e. 2.3%) and for hatchery steelhead was 97.9% (s.e. 3.1%) for fish released into the collection channel (Muir et al. 1995b, 1996). However, these survival estimates do not include any mortality or injury incurred prior to entering the collection channel (i.e., from the submersible traveling screen, gatewell, or orifice passage).

The objective of this study was to obtain statistically sound survival estimates with known precision through the various passage routes at Little Goose Dam, including the juvenile bypass system, turbines, and spillbays with and without flow deflectors and to compare the survival of dam passage groups with fish released downstream from the dam. A second objective was to visually inspect the new bypass outfall pipe to ensure that it provides a safe route of passage.

METHODS

Tagging and Release Procedures

Fish were collected for PIT tagging at the Lower Granite Dam juvenile collection facility. Tagging was performed in the NMFS transportation marking facility adjacent to the east raceways. Only fish clearly identified as previously untagged hatchery-reared steelhead were used. Fish were pumped from the raceway into a preanesthetizer (benzocaine and MS222), sorted, and PIT tagged using 12-gauge hypodermic syringes. Sorting and tagging were done in a recirculating MS222 anesthetic system. Empty syringes were soaked in ethyl alcohol for a minimum of 10 minutes for sterilization before reloading with PIT tags. Fish for all release groups were tagged simultaneously and tagging personnel were rotated among tagging stations when half of each release group was tagged. Tagged fish were returned through a water-filled pipe to 2,000-L holding tanks mounted on trucks. Holding tanks were supplied with flow-through water during tagging and holding and aerated with oxygen during transport to Little Goose Dam. Fish were held at Little Goose Dam for a minimum of 24 hours with flow-through water for recovery and determination of post-tagging mortality. Holding density did not exceed 300 fish per tank.

Sample sizes for releases were determined by evaluating data from NMFS/UW 1995 survival studies and 1994 releases at Lower Monumental Dam (Muir et al. 1994). The release strategy called for five release locations: 1) bypass system, 2) turbine, 3) Spillbay 3 with flow deflector ("flip lip"), 4) Spillbay 1 without flow deflector, and 5) 1-2 km downstream from Little Goose Dam (Fig. 1). For a given total number of fish to be used in the evaluation, similar statistical power could be attained with a range of combinations of total numbers of releases and numbers of fish per group. Based on marking and transport constraints, we chose to mark and release 15 groups of 500 fish each in each of the passage routes, for a total of 7,500 fish released per location.

After the minimum recovery period, fish for the turbine, bypass system, and spill releases were transported in their recovery containers to the designated release areas on the dam deck. Fish were released from their holding tanks via hoses from the dam deck to their respective areas. Spillbays 1 (no flow deflector) and 3 (with flow deflector) were the release

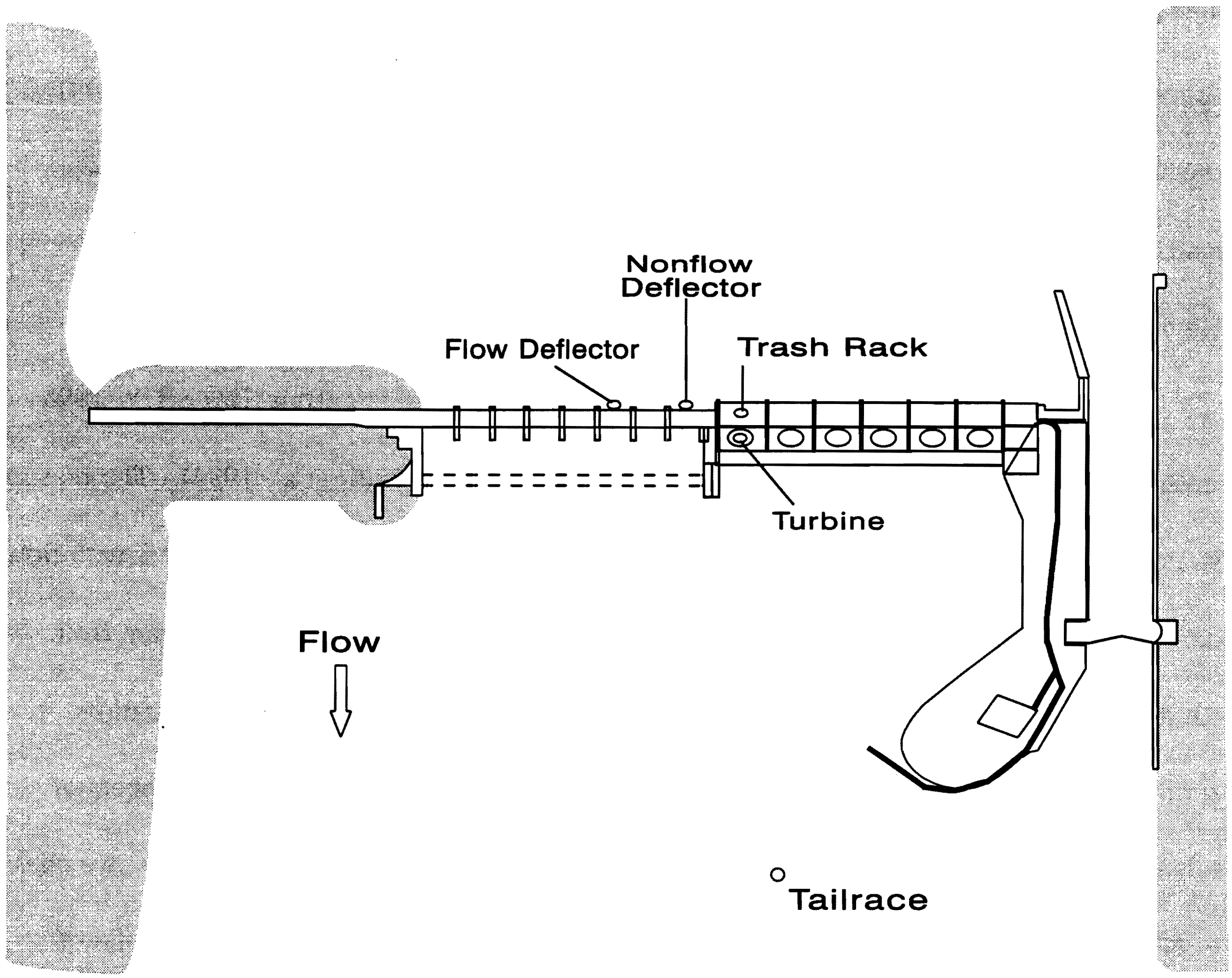

Figure 1. Schematic of Little Goose Dam showing release locations in 1997.

locations for spillway treatment releases, the same used by Normandeau Associates balloon tag studies at Little Goose Dam during 1997. Fish entered the designated spillbays via a 10.2-cm diameter hose supported within a 20.3-cm steel pipe anchored to the upstream face of the dam, with the terminal end of the hose set in the center of each spillbay, where flow velocity was about 1.5 m/sec (Normandeau Associates, Inc. et al. 1997). Flows through Spillbays 1 and 3 were kept equal during releases, with the spill level dependent on total project discharge.

The turbine groups were released through a 10.2-cm diameter hose 56.4 m in length attached to the bottom of the bar screen in Unit 6B (Fig. 2). The terminal end of the hose passed through a 90° bracket that directed the fish into the center of the turbine intake below the screen into flow with velocity of about 2.1 m/sec.

The bypass facility groups were released in front of the bar screen of Gatewell 6B with the expectation they would be diverted into the intake gatewell by normal intake flow. The release hose (10.2 cm x 27.4 m) passed through a 90° bracket attached to the bottom of the first trashrack section (Fig. 2). Several additional groups were released directly into the collection channel via 7.6 cm x 12.2 m hose. For all hose releases, sufficient water was added during and after release to ensure that all fish exited the hose alive.

Reference release groups were transferred to a small barge in the forebay, transported to the tailrace release site, and released water-to-water. To stabilize tailrace conditions, spill pattern, flow level, and powerhouse loading were kept constant from 30 minutes before release until 30 minutes after completion of all releases. However, total discharge, amount of spill,

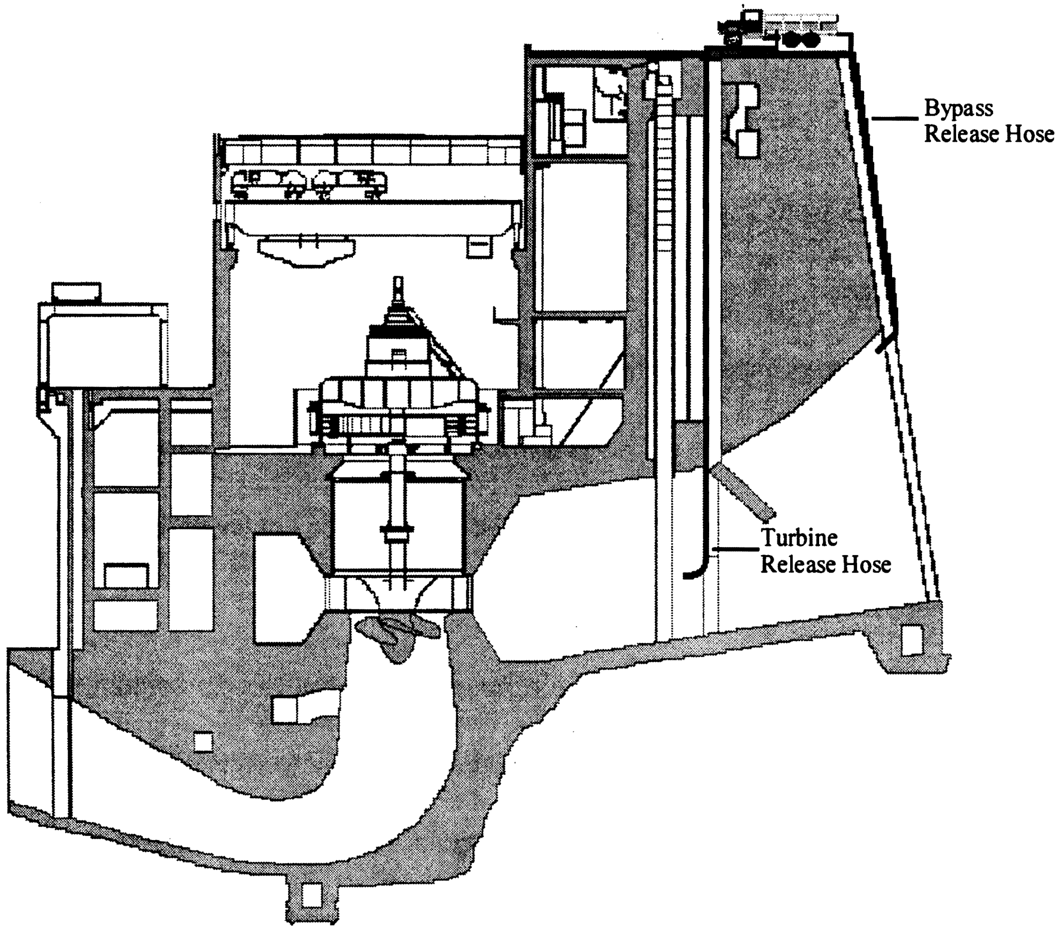

Figure 2. Location of the turbine and bypass release hoses in a turbine intake at Little Goose Dam, 1997

and number of turbine units operating varied between releases (Table 1). Spill levels through each spillbay ranged from 4,875 to 10,000 cfs with an average of 6,500 cfs during each spillbay release. All releases were made between 1600 and 1900 hours.

Statistical Analyses

Data for survival estimation were counts of detections of individual PIT-tagged fish at the juvenile collection/detection facilities at Lower Monumental, McNary, John Day, and Bonneville Dams. For a group released through a particular passage route on a particular day, survival was estimated by dividing the proportion of fish from the passage-route group that were detected downstream by the proportion detected of the corresponding tailrace reference group released the same day. For relative detection proportions to be interpreted as survival estimates, the probability of detection at downstream dams must be the same for surviving fish from each group released on a particular day. Even mixing of the groups as they move downstream is a sufficient, but not necessary, condition for equal probabilities of detection. Before conducting analyses of the detection proportions, we tested for mixing of release groups using chi-square contingency table tests on the daily distributions of detections at Lower Monumental and McNary Dams (i.e., daily counts of fish detected from each group). If counts appeared proportional throughout the period of passage, then the groups were assumed to be mixed.

The study design was planned initially as a randomized block design, with each release day considered a block. We planned to conduct Analysis of Variance (ANOVA) with 5 treatments over 15 blocks (days) using as data the proportion of fish detected from each release

Table 1. Dam operation and discharge conditions at Little Goose Dam during 1997 project survival studies.

Test date	Total discharge (kcfs)	Spill (kcfs)	Units in operation
15 April	89	50	1,6
16 April	102	45	1,4,5,6
17 April	111	45	1,4,5,6
18 April	106	45	1,2,5,6
19 April	130	45	1,2,4,5,6
20 April	177	55	1,2,3,4,5,6
21 April	170	50	1,2,3,4,5,6
22 April	177	55	1,2,3,4,5,6
23 April	167	45	1,2,3,4,5,6
24 April	180	59	1,2,3,4,5,6
25 April	161	39	1,2,3,4,5,6
26 April	160	80	1,2,3,4,6
27 April	145	44	1,2,3,4,5,6
28 April	175	52	1,2,3,4,5,6
29 April	184	71	1,2,3,4,5,6
30 April	173	61	1,2,3,4,5,6
1 May	170	50	1,2,3,4,5,6

group. However, not all turbine and bypass system releases were completed successfully, resulting in an incomplete block design with 17 days (blocks) of releases. Turbine and bypass system releases were "missing" from several early blocks, and spillbay releases were missing from the last two blocks.

We analyzed the incomplete block design using the S-PLUS 4 statistical analysis software package (MathSoft, Inc. 1997a), specifically functions for generalized linear models (function "glm") and linear mixed-effects models (function "lme") (MathSoft, Inc. 1997b).

Because we did not believe the mechanism leading to missing data (i.e., procedural errors--see Results) in the randomized block experimental design was related to patterns in treatment means (i.e., the mechanism was "ignorable"; Little and Rubin 1987), we conducted a simplified analysis in addition to the incomplete block analyses. For each group released into each of the four passage routes tested, the proportion of fish detected downstream was divided by the proportion detected of the corresponding tailrace reference group released the same day. These relative detection proportions (i.e., relative survival probabilities) were analyzed using ANOVA on a completely randomized design with four levels (i.e., passage routes) of one treatment. This method accounted for daily differences in detection probabilities by dividing by the detection proportion for the reference group instead of blocking by release day. Treatment means (i.e., mean relative survival for the four passage routes) were ranked by Fisher's protected least significant difference procedure if the F-test was significant. Model fits were checked by inspecting plots of residuals versus predicted values and normal q-q plots.

Bypass Outfall Pipe Evaluation

A new extended bypass outfall pipe was installed prior to the 1997 outmigration at Little Goose Dam. Prior to the juvenile salmonid outmigration, a video camera was used to inspect the pipe for obstructions or rough areas that could cause injury to fish. The camera was mounted on a wheeled cart and placed into the bypass pipe near the barge loading area, and slowly lowered through the pipe to its end. The camera was pulled through the pipe by passing a buoy and rope through the pipe to a waiting boat, which then pulled the camera assembly through the pipe. The camera was connected to a television monitor that allowed the camera operator to view the outfall pipe along its entire length.

RESULTS

Tagging and Release Procedures

Hatchery steelhead PIT tagging began at Lower Granite Dam on 14 April and was completed on 2 May (a small group of fish were tagged on 10 April to test the bypass release hose). Relatively few yearling chinook salmon were handled during tagging due to the small numbers released from Snake River Basin hatcheries in 1997 (Table 2). Tagging and handling mortality ranged from 0.1 to 0.2% for both species.

Because high levels of spill were forecast for late spring 1997 that would have reduced detection rates for our releases and thus reduced the precision of estimation, tagging and release began early in the migration, as soon as sufficient numbers of hatchery steelhead were available for tagging at Lower Granite Dam. Early in the season, fish released through the

Table 2. Numbers of fish handled (N) and mortalities (morts) during hatchery steelhead PIT tagging at Little Goose Dam for project survival studies during 1997. Overall percent mortality is also shown.

Date	Hat. steelhead		Wild steelhead		Hat. chinook		Wild chinook		Sockeye	
	N	Morts	N	Morts	N	Morts	N	Morts	N	Morts
10 Apr	211	1	0	0	0	0	0	0	0	0
14 Apr	3,092	2	171	0	15	0	102	0	1	0
15 Apr	2,884	2	191	0	38	0	3	0	0	0
16 Apr	2,730	3	135	0	70	0	120	0	2	0
17 Apr	2,766	3	142	0	45	0	39	0	1	0
18 Apr	2,117	2	210	0	167	0	142	0	3	0
19 Apr	2,446	1	207	0	287	0	96	0	6	0
20 Apr	2,246	0	537	0	1,092	0	175	0	5	0
21 Apr	2,189	3	261	0	0	0	2	0	2	0
22 Apr	2,764	0	301	0	111	0	31	0	0	0
23 Apr	2,649	6	291	0	30	2	24	1	1	0
24 Apr	2,684	3	478	0	41	1	3	0	0	0
25 Apr	2,669	3	155	0	28	0	15	0	0	0
26 Apr	2,707	17	243	0	62	0	12	0	0	0
27 Apr	2,805	1	278	0	49	1	17	0	0	0
28 Apr	2,676	3	202	0	56	0	6	0	0	0
29 Apr	1,755	0	101	0	22	0	5	0	0	0
30 Apr	1,648	2	103	0	72	0	8	0	1	0
2 May	429	2	16	0	9	0	2	0	0	0
Total	43,467	54	4,022	0	2,194	4	802	1	22	0
% Mort.	0.1		0.0		0.2		0.1		0.0	

trashrack into the bypass channel had protracted travel times through Little Goose Dam (Fig. 3). We discontinued trashrack releases for several days and instead made releases into the collection channel, several gatewells, and the head of the bypass flume to isolate where in the system the delay was occurring. Travel times were similar for fish released on 18 April in Gatewells 6A, 6B, and in the collection channel at 6B, showing that fish were not delaying in the gatewell (Fig. 4). Travel times from releases at various locations in the bypass system on 18 April indicated that most of the delay occurred in the upper bypass channel (Fig. 4). Releases at various locations in the bypass channel on 2 May also found the most delay for releases in the upper bypass channel; however, delay was minimal by this date regardless of release location. We speculate that the long delays in passage time for the early releases resulted from low water temperatures and poorly smolted fish early in the migration. Because of time spent investigating delay in the bypass system, only 12 of the 15 scheduled bypass system releases were completed.

After the third turbine release, we determined that the release hose attached to the bottom of the extended bar screen had separated. This required arranging for a turbine outage and raising the extended screen to repair the hose. Consequently, only 12 of the 15 scheduled turbine releases were completed.

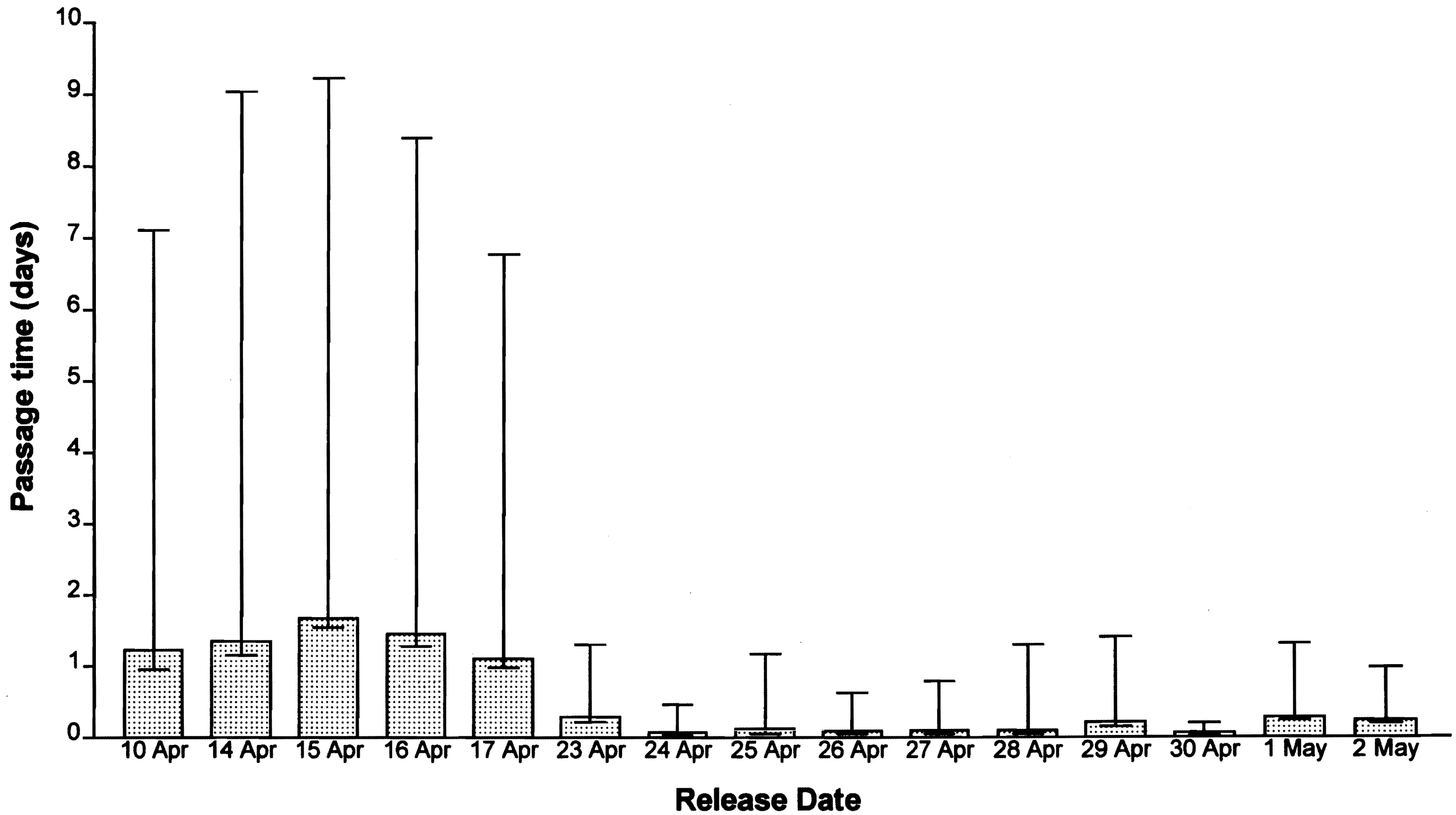

Figure 3. Median passage times (days) through Little Goose Dam for PIT-tagged hatchery steelhead released into the bypass system (trashrack releases). Ends of brackets show 20th and 80th percentiles.

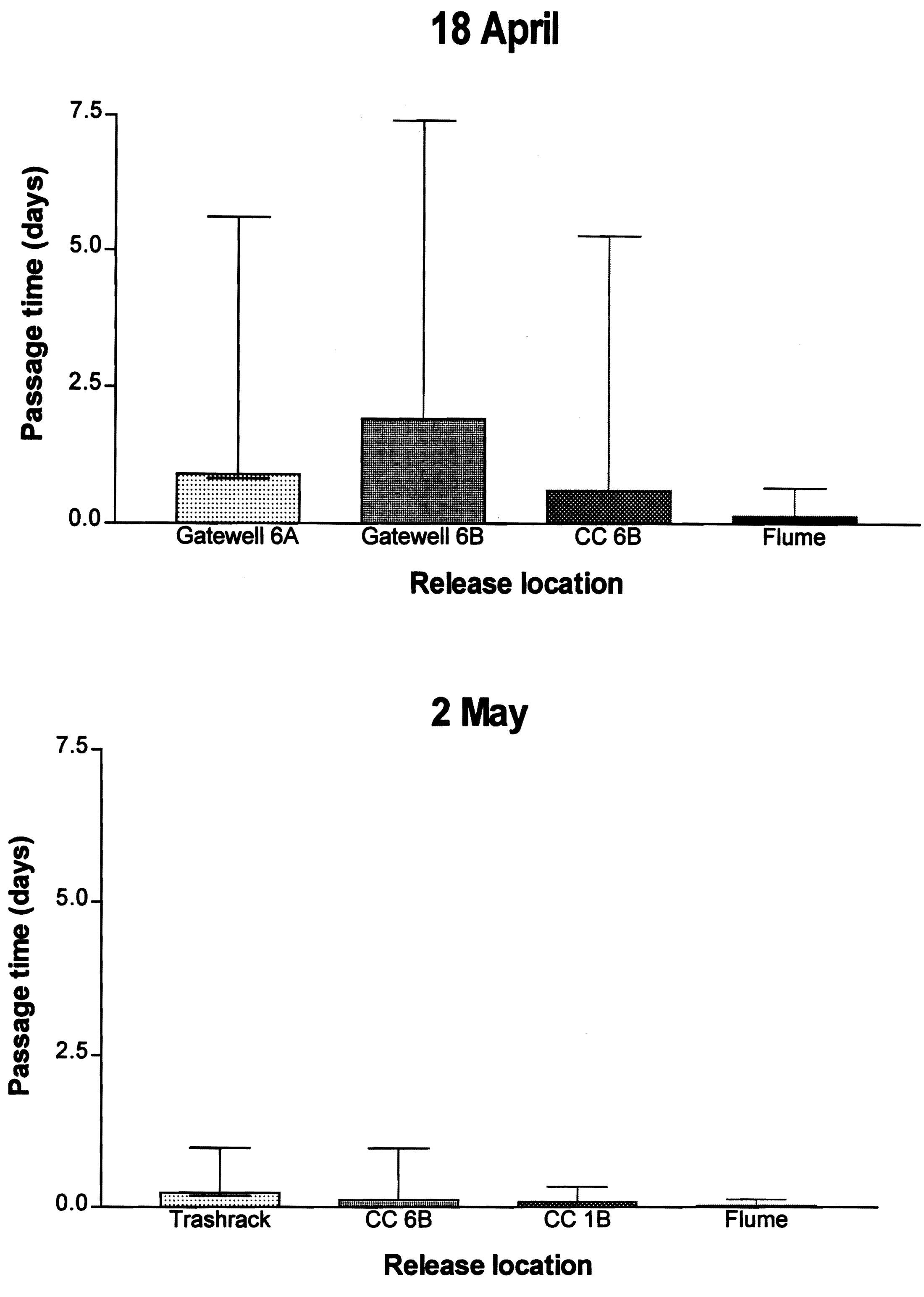

Figure 4. Median passage times (days) through Little Goose Dam for PIT-tagged hatchery steelhead released at various locations on 18 April and 2 May 1997. Ends of brackets show 20th and 80th percentiles. CC = collection channel, flume = upstream from primary dewaterer.

Statistical Analyses

Passage distributions at Lower Monumental Dam were often significantly different among groups of fish released on the same day from various locations at Little Goose Dam (Table 3 and Appendix Figs. 1-17). In all but one case, the differences were entirely due to later arrival of fish from the bypass release group, and the remaining release groups were mixed (Table 3). Also, in all but one case, all groups were mixed by the time they arrived at McNary Dam (Table 4). The effect of delay of bypass release groups on detection probabilities, and hence survival estimates, was probably minimal, since passage conditions (i.e., percent spill and discharge levels) were relatively constant during the entire period during which fish from our releases were passing.

Results of the simpler analysis (ANOVA of completely randomized design) of proportions of each release group detected relative to tailrace release groups were essentially the same as the analyses of incomplete block designs, supporting the conclusion that the mechanism leading to missing data was ignorable. Results presented here are for the simpler analysis.

Estimated survival was highest for PIT-tagged hatchery steelhead released into Spillbay 1 without a flow deflector (1.004, s.e. 0.0150), followed by Spillbay 3 with a flow deflector (0.972, s.e. 0.0145), the bypass system (0.953, s.e. 0.0162), and the turbine (0.934, s.e. 0.0156) (Table 5 and Fig. 5). ANOVA showed significant differences among treatment means ($F=3.77$, $P=0.016$), with survival for fish released into Spillbay 1 without a flow deflector significantly higher than for those released in the bypass and turbine locations. No

Table 3. Tests of homogeneity of Lower Monumental Dam passage distributions for groups of PIT-tagged yearling chinook salmon released at various locations at Little Goose Dam. P values calculated using a Monte Carlo approximation of the exact method. Tests for days including a bypass system release were repeated omitting the bypass data. Abbreviations: B-Bypass; Ta-Tailrace; Tu-Turbine; SD-Spillbay with deflector; SND-Spillbay with no deflector.

					Without Bypass Release Site		
Release Date	Release Site	χ^2	Degrees of freedom	P value	χ^2	Degrees of freedom	P value
15 April	B,Ta,SD,SND	121.7	87	0.0027	45.6	54	0.8193
16 April	B,Ta,SD,SND	157.4	90	<0.0001	60.4	56	0.3043
17 April	B,Ta,SD,SND	129.2	93	0.0040	58.7	60	0.5419
18 April	Ta,SD,SND	55.0	60	0.6899			
19 April	Tu,Ta,SD,SND	73.4	84	0.8161			
20 April	Tu,Ta,SD,SND	94.7	81	0.1167			
21 April	Tu,Ta,SD,SND	81.8	75	0.2540			
22 April	Tu,Ta,SD,SND	76.1	72	0.3294			
23 April	B,Tu,Ta,SD,SND	148.2	112	0.0069	85.7	81	0.3239
24 April	B,Tu,Ta,SD,SND	104.8	100	0.3452	72.5	72	0.4679
25 April	B,Tu,Ta,SD,SND	155.3	108	0.0006	82.7	78	0.3117
26 April	B,Tu,Ta,SD,SND	119.6	88	0.0068	66.2	66	0.4747
27 April	B,Tu,Ta,SD,SND	121.9	84	0.0025	64.1	60	0.3208
28 April	B,Tu,Ta,SD,SND	128.0	80	0.0003	61.3	60	0.4241
29 April	B,Tu,Ta,SD,SND	116.7	76	0.0010	65.6	57	0.1826
30 April	B,Tu,Ta	33.1	44	0.9383	17.7	19	0.5722
1 May	B,Tu,Ta	71.7	40	0.0004	33.0	20	0.0174

Table 4. Tests of homogeneity of McNary Dam passage distributions for groups of PIT-tagged yearling chinook salmon released at various locations at Little Goose Dam. P values calculated using a Monte Carlo approximation of the exact method. Abbreviations: B-Bypass; Ta-Tailrace; Tu-Turbine; SD-Spillbay with deflector; SND-Spillbay with no deflector.

Release Date	Release Site	χ^2	Degrees of freedom	P value
15 April	B,Ta,SD,SND	81.5	75	0.2516
16 April	B,Ta,SD,SND	97.7	84	0.1103
17 April	B,Ta,SD,SND	93.7	81	0.1167
18 April	Ta,SD,SND	51.2	52	0.5432
19 April	Tu,Ta,SD,SND	72.7	69	0.3546
20 April	Tu,Ta,SD,SND	70.6	69	0.4209
21 April	Tu,Ta,SD,SND	65.7	66	0.5070
22 April	Tu,Ta,SD,SND	67.0	72	0.6931
23 April	B,Tu,Ta,SD,SND	90.3	92	0.5440
24 April	B,Tu,Ta,SD,SND	99.0	96	0.3956
25 April	B,Tu,Ta,SD,SND	104.2	88	0.0684
26 April	B,Tu,Ta,SD,SND	107.0	72	0.0010
27 April	B,Tu,Ta,SD,SND	68.5	88	0.9805
28 April	B,Tu,Ta,SD,SND	83.1	76	0.2475
29 April	B,Tu,Ta,SD,SND	87.8	88	0.4995
30 April	B,Tu,Ta	40.0	38	0.3853
1 May	B,Tu,Ta	39.8	38	0.3821

Table 5. Complete release and detection data for 1997 study of passage route-specific survival at Little Goose Dam, including numbers released (Rel.), numbers (Det.) and proportions (Prop.) detected downstream, and proportion detected relative to tailrace reference group for PIT-tagged hatchery steelhead released at five locations at Little Goose Dam.

	Tailrace			Bypass				Turbine				Spill with Deflector				Spill w/o Deflector			
Date	Rel.	Det.	Prop.	Rel.	Det.	Prop.	Rel. to tailrace	Rel.	Det.	Prop.	Rel. to tailrace	Rel.	Det.	Prop.	Rel. to tailrace	Rel.	Det.	Prop.	Rel. to tailrace
15 Apr	453	252	0.556	552	299	0.542	0.974	NA	NA	NA	NA	500	259	0.518	0.931	499	302	0.605	1.088
16 Apr	498	290	0.582	565	297	0.526	0.903	NA	NA	NA	NA	499	306	0.613	1.053	497	287	0.577	0.992
17 Apr	497	290	0.584	584	327	0.56	0.96	NA	NA	NA	NA	497	272	0.55	0.943	497	272	0.547	0.938
18 Apr	500	272	0.544	NA	NA	NA	NA	NA	NA	NA	NA	501	260	0.519	0.954	498	287	0.576	1.059
19 Apr	501	243	0.485	NA	NA	NA	NA	201	93	0.463	0.954	500	245	0.49	1.01	250	132	0.528	1.089
20 Apr	499	257	0.515	NA	NA	NA	NA	506	248	0.49	0.952	501	255	0.509	0.988	500	267	0.534	1.037
21 Apr	501	270	0.539	NA	NA	NA	NA	508	259	0.51	0.946	500	240	0.48	0.891	501	288	0.575	1.067
22 Apr	499	246	0.493	NA	NA	NA	NA	500	203	0.406	0.824	501	257	0.512	1.041	500	256	0.512	1.039
23 Apr	500	245	0.49	590	286	0.485	0.989	501	227	0.453	0.925	488	251	0.514	1.05	497	252	0.507	1.035
24 Apr	500	294	0.588	584	317	0.542	0.923	500	282	0.564	0.959	512	312	0.609	1.036	500	285	0.57	0.969
25 Apr	500	304	0.608	591	332	0.562	0.924	500	267	0.534	0.878	500	282	0.564	0.928	499	253	0.507	0.834
26 Apr	501	290	0.579	591	334	0.565	0.976	499	278	0.557	0.962	498	260	0.522	0.902	500	286	0.572	0.988
27 Apr	503	291	0.579	587	319	0.543	0.939	498	254	0.51	0.882	501	265	0.529	0.914	498	281	0.564	0.975
28 Apr	501	309	0.617	597	349	0.585	0.948	502	293	0.584	0.946	496	293	0.591	0.958	500	290	0.58	0.94
29 Apr	500	298	0.596	584	302	0.517	0.868	499	294	0.589	0.989	500	292	0.584	0.98	NA	NA	NA	NA
30 Apr	500	267	0.534	591	321	0.543	1.017	500	267	0.534	1	NA	NA	NA	NA	NA	NA	NA	NA
01 May	500	313	0.626	431	274	0.636	1.016	501	289	0.577	0.921	NA	NA	NA	NA	NA	NA	NA	NA
Mean							0.953				0.934				0.972				1.004

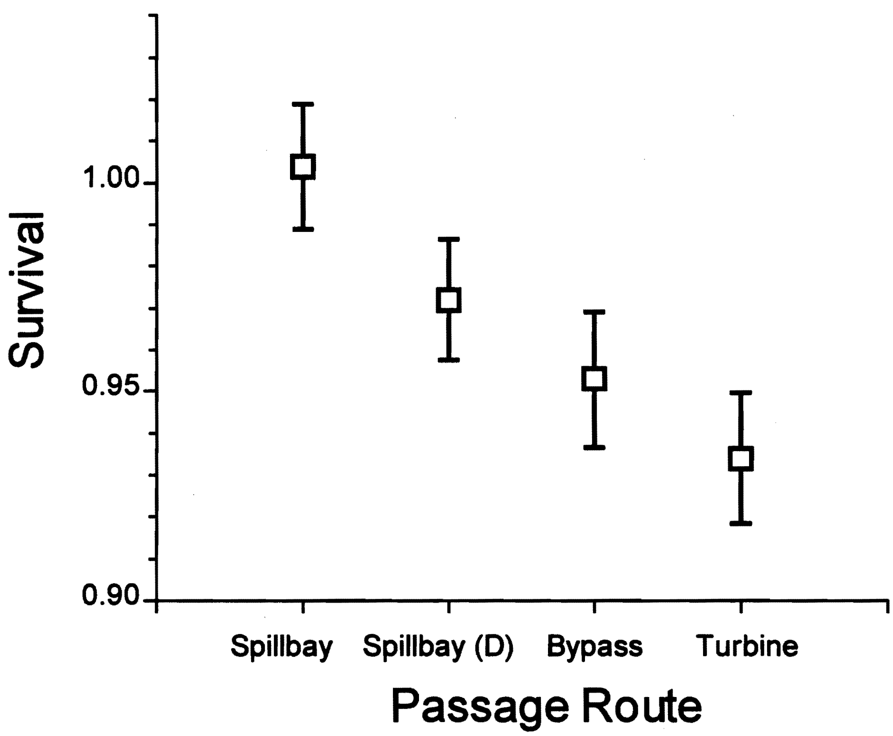

Figure 5. Survival estimates (with standard errors) for PIT-tagged hatchery steelhead released at various locations at Little Goose Dam in 1997. Spillbay 1 had no flow deflector and Spillbay 3 had a deflector (D).

other contrasts of treatment means were significant. It should be noted that only one spillbay with a flow detector and one spillbay without a flow deflector were evaluated. Observed differences in survival between the two spillbays could have been due to spillbay location (Spillbay 1 is located at the end of the spillway) or other differences other than the presence/absence of a flow deflector.

Bypass Outfall Pipe Evaluation

Video inspection of the bypass outfall on 10 April did not identify any problems in the new bypass outfall pipe.

Relationship to Other Research

During 1997, hatchery steelhead were PIT-tagged and released 5 days/week into the tailrace at Lower Granite Dam as part of a reach survival study funded by the Bonneville Power Administration. Survival for Lower Granite Dam releases was estimated through various reaches, including from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam. Using estimated detection probability from the Jolly-Seber model for these hatchery steelhead arriving at Little Goose Dam ($\hat{P}_{cjs}$), FGE estimates from Gessel et al. (1995), and the route-specific survival estimates from the 1997 Little Goose Dam research ($\hat{S}_{sp}$, $\hat{S}_{byp}$, and $\hat{S}_{turb}$), we estimated the proportion of hatchery steelhead passing via the spillbays ($\hat{P}_{sp}$). (Our survival estimates were for specific turbine units and spillbays. We assumed an equal survival estimate for all unevaluated turbine units and spill bays). We then partitioned passage survival through Little Goose Dam ($\hat{S}_{dam}$) from the overall survival ($\hat{S}_{res\cdot dam}$) for hatchery steelhead passing through this reach, using the formula:

$\hat{P}_{cjs} = (1 - \hat{P}_{sp}) \cdot FGE$. Assuming that FGE = 90% (Gessel et al. 1995) and $\hat{P}_{cjs} = 0.532$ (estimated detection probability at Little Goose Dam for hatchery steelhead released from Lower Granite Dam between 13 and 30 April), then $\hat{P}_{sp} = 1 - \hat{P}_{cjs}/FGE = 0.409$. $\hat{P}_{cjs}$ is also the estimate of the proportion of fish that passed via bypass, so $\hat{P}_{turb}$ (estimated proportion through the turbine) is $1 - \hat{P}_{cjs} - \hat{P}_{sp} = 0.059$.

For survival, $S_{dam} = P_{cjs} \cdot S_{byp} + P_{turb} \cdot S_{turb} + P_{sp} \cdot S_{sp}$ and $S_{res} = S_{res \cdot dam} / S_{dam}$ where $\hat{S}_{res \cdot dam}$ of 0.954 was estimated from releases of hatchery steelhead from Lower Granite Dam between 13 and 30 April.

Thus, $\hat{S}_{dam} = 0.532 \cdot 0.953 + 0.059 \cdot 0.934 + 0.409 \cdot 0.972 = 0.960$

and $\hat{S}_{res} = 0.954/0.960 = 0.994$ during the study period.

From the estimate of the proportion of fish using each route of passage during the study period, we estimated Spill Efficiency (the proportion of fish using the spillway), Spill Effectiveness (the proportion of fish using the spillway divided by the proportion of water spilled), and Fish Passage Efficiency (the proportion of fish using nonturbine routes of passage). Estimated Spill Efficiency was 40.9% for hatchery steelhead during the study period. Spill Effectiveness was estimated by dividing the proportion of fish spilled (0.409) by the proportion of water spilled (0.33, calculated from daily average project spill and discharge volumes). The estimated Spill Effectiveness was 1.24 during the study period. Fish Passage Efficiency at Little Goose Dam for hatchery steelhead during the study period was estimated to be 94%.

DISCUSSION

Estimated survival probability was highest for hatchery steelhead that passed through the spillways at Little Goose Dam, followed by the bypass system, and then the turbine. Our estimate of turbine survival is similar to that found in turbine survival studies at Snake and Columbia River dams using PIT tags (Iwamoto et al. 1994, Muir et al. 1996) and HI-Z Turb'N Tags (Normandeau Associates, Inc. et al. 1995, Mathur et al. 1996), but is generally higher than reported in past studies using other methods.

Long et al. (1975) found that turbine passage survival for yearling coho salmon at Lower Monumental Dam averaged 80% with a range of 76% to 83%. Turbine survival estimates at other mainstem dams equipped with Kaplan turbines has ranged from 81 to 95% for yearling chinook and coho salmon (Oligher and Donaldson 1966, Long et al. 1975, Schoeneman et al. 1961, Giorgi and Stuehrenberg 1988) and 85 to 98% for subyearling chinook salmon (Holmes 1952, Weber 1954, Schoeneman et al. 1961, Raymond and Sims 1980, Ledgerwood et al. 1991).

In more recent studies, Iwamoto et al. (1994) evaluated turbine survival at Little Goose Dam using PIT-tagged yearling chinook salmon and estimated turbine survival at 92% (s.e. 2.5%). Turbine survival for yearling chinook salmon at Lower Granite Dam was estimated at 92.7% (s.e. 2.7%) using PIT tags (Muir et al. 1996) and 94.8% using HI-Z Turb'N Tags (Nomandeau Associates Inc. et al. 1995). Turbine survival at Rocky Reach Dam was estimated at 93.0% using HI-Z Turb'N Tags (Mathur et al. 1996).

Spillway deflectors did not significantly affect survival through spillbays, although the estimate of survival was slightly higher without a flow deflector than with a flow deflector (1.004 and 0.972, respectively). Balloon tag studies in 1997 using hatchery steelhead released in the same spillbays at Little Goose Dam produced almost identical results. Survival probability (48 hours) through the spillbay without a flow deflector was estimated at 1.0 while survival through the spillbay with a deflector was significantly lower at 0.98 at a spill level of 5,600 cfs (Normandeau Associates, Inc. et al. 1997). Estimated survival probabilities between the two spillbays were more similar at other spill volumes tested. Balloon-tag estimates give direct estimates of survival (up to 48 hours) and do not include the additional mortality incurred farther downstream from injuries sustained during passage, while PIT-tag evaluations include both direct and indirect mortality.

Survival of steelhead after passage through spillways at Lower Monumental Dam without flow deflectors was estimated at 72.5% by Long et al. (1975). In comparison, estimated survival for steelhead passing through a spillway with a flow deflector in our 1997 study was much higher at 97.8%. Similar high estimates were reported by Holmes (1952) and Schoeneman et al. (1961) for subyearling chinook salmon at Bonneville Dam and McNary Dam. More recently, Ledgerwood et al. (1990) found no detectable mortality for subyearling chinook salmon passing via the spillway at Bonneville Dam. Iwamoto et al. (1994) evaluated spillway survival at Little Goose Dam using PIT-tagged yearling chinook salmon and estimated spillway survival at 100% (s.e. 2.6%).

Muir et al. (1995a) found high relative survival for PIT-tagged yearling chinook salmon released into spillbays equipped with flow deflectors (Spillbay 7; 92.7%, s.e. 2.3%)

and without flow deflectors (Spillbay 8; 98.4%, s.e. 3.3%) at Lower Monumental Dam. The relative survival estimates for the two spillbays were not significantly different ($P > 0.05$). In both the study at Lower Monumental Dam (Muir et al. 1995a) and the 1997 study at Little Goose Dam, only one spillbay of each type was evaluated. Furthermore, the evaluated spillbays without flow deflectors are located at the end of the spillway at both Little Goose and Lower Monumental Dams. Consequently, it was not possible to isolate differences in survival due to flow deflectors from differences due to spillbay location or other potential sources.

Few studies have evaluated survival through bypass systems and the few that have did not evaluate survival through the entire system. Gilbreath et al. (1993) reported that overall recovery percentage for bypass-released groups (releases made in the collection channel) of coded-wire-tagged fall chinook salmon was 7.6% less than for turbine-released groups and 8.3% less than for tailrace-released groups at Bonneville Dam. At Little Goose Dam, survival for PIT-tagged hatchery yearling chinook salmon was 99.4% (standard error 2.3%) and for hatchery steelhead was 97.9% (standard error 3.1%) for fish released into the collection channel (Muir et al. 1995b, 1996). However, these survival estimates did not include any mortality or injury incurred prior to entering the collection channel (i.e., from the submersible traveling screen, gatewell, or orifice passage). This study is the first to estimate survival through the entire bypass system, including the bypass outfall area where predation rates can be especially high (Reiman et al. 1991). However, the bypass survival estimate of 95.3% may have been affected to an unknown degree by poor mixing with reference releases at downstream dams, due to their delay in the bypass system at Little Goose Dam.

The turbine survival estimates in this study were obtained from releases through one turbine unit (Unit 6B) operating at a set turbine efficiency, and with one hose-outlet location. Likewise, the spillway releases were made during a limited range of spillbay settings and conditions. In this report, we have used the estimates to represent overall turbine or spillway passage survival at Little Goose Dam, which requires the assumption that survival probabilities would be the same under different hydraulic conditions or other release locations (both within the same turbine unit and spillbays we used in 1997, and in other turbine units and spillbays). To validate this assumption would require additional releases through other turbine units and spillbays under varying operating conditions. This would substantially increase the numbers of PIT-tagged fish needed for evaluation. However, researchers using balloon tags to evaluate turbine and spillway survival at Snake and Columbia River dams have evaluated a wider range of conditions and release locations and generally found little variation in the results (Normandeau Associates, Inc. et al. 1995, 1997; Mathur et al. 1996).

Decisions on how best to operate Snake and Columbia River dams will require accurate estimates of survival through each potential passage route as well as overall estimates of project and reservoir survival. This study provides these estimates for hatchery steelhead at Little Goose Dam, as well as estimates of Spill Effectiveness and Spill Efficiency.

SUMMARY

1. Survival relative to tailrace groups was highest through the spillbay without a flow deflector (1.004, s.e. 0.0150), followed by the spillbay with a flow deflector (0.972, s.e. 0.0145), the bypass (0.953, s.e. 0.0162), and turbine Unit 6 (0.934, s.e. 0.0156). ANOVA

showed significant differences among means (F = 3.77, P = 0.016). Survival for fish released into the spillbay without a flow deflector was significantly higher than for those released in the bypass or turbine locations (Fisher's Protected Least Significant Difference). No other contrasts of means were significant.

2. Tests to evaluate mixing of release groups at downstream dams showed significant violations of this assumption, primarily because groups released into the bypass system were delayed, especially early in the migration. However, this probably had little effect on the survival estimates obtained since conditions that might have affected survival at downstream dams (e.g., amount of spill or powerhouse discharge) changed little during the study.

3. During the same period as our releases at Little Goose Dam, we also released hatchery steelhead into the tailrace of Lower Granite Dam, from which we made estimates of survival from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam. By making an assumption for fish guidance efficiency (FGE) for steelhead at Little Goose Dam, we used our route-specific survival estimates at Little Goose Dam to partition the estimated reach survival into reservoir- and project-related components. The reach estimate (Lower Granite Dam tailrace to Little Goose Dam tailrace) of 0.954 was partitioned into a project survival estimate of 0.960 through Little Goose Dam and a reservoir survival estimate of 0.994 through Little Goose Reservoir.

4. Spill Efficiency was estimated at 41%, Spill Effectiveness at 1.24, and Fish Passage Efficiency at 94.0% through Little Goose Dam for hatchery steelhead during the study period.

RECOMMENDATIONS

1. This study should be repeated in 1998 using hatchery steelhead with releases starting later in the migration season to ensure better mixing of test groups at downstream dams.

2. This study should be conducted with hatchery chinook salmon in 1998 to provide route-specific estimates of survival for this species as well as hatchery steelhead.

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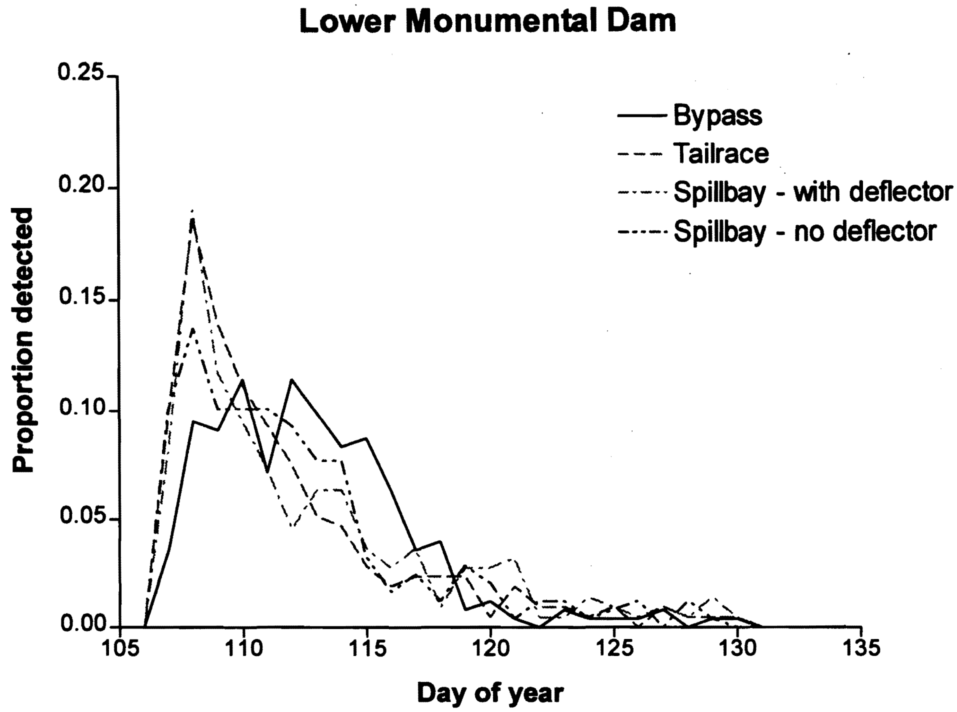
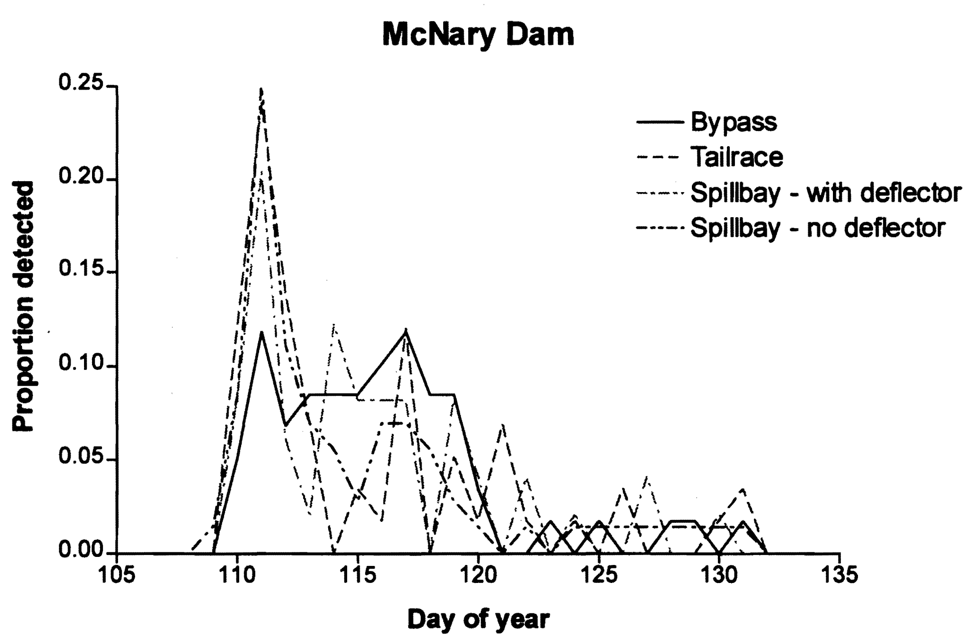
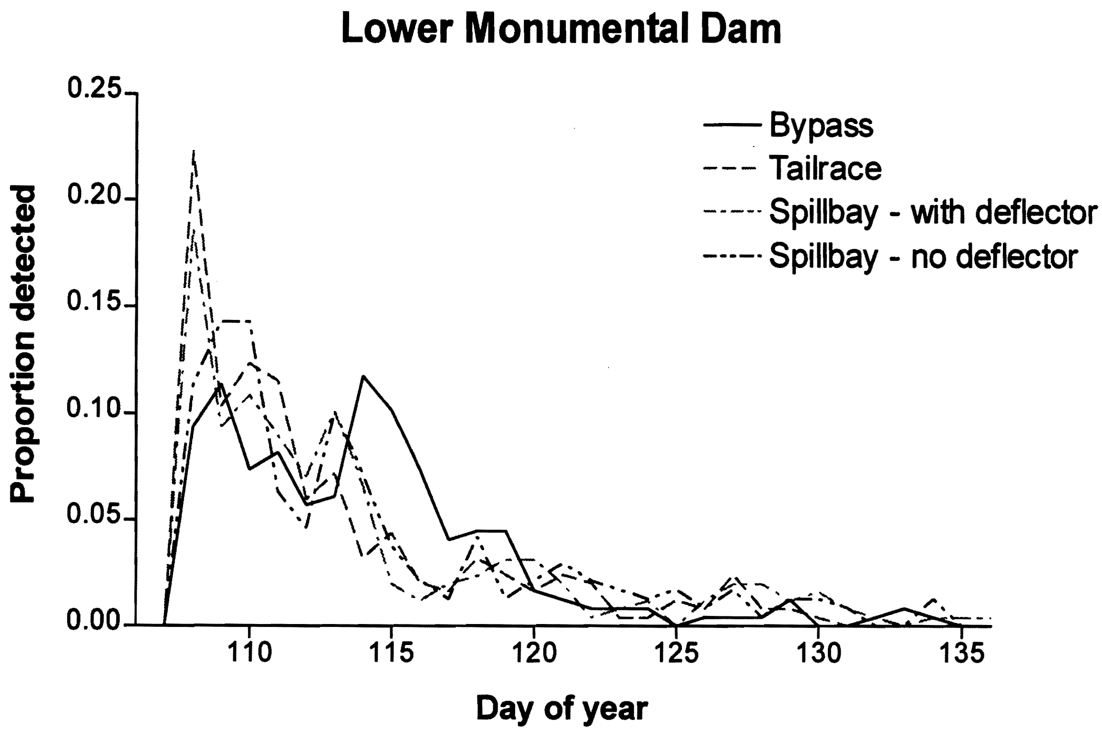
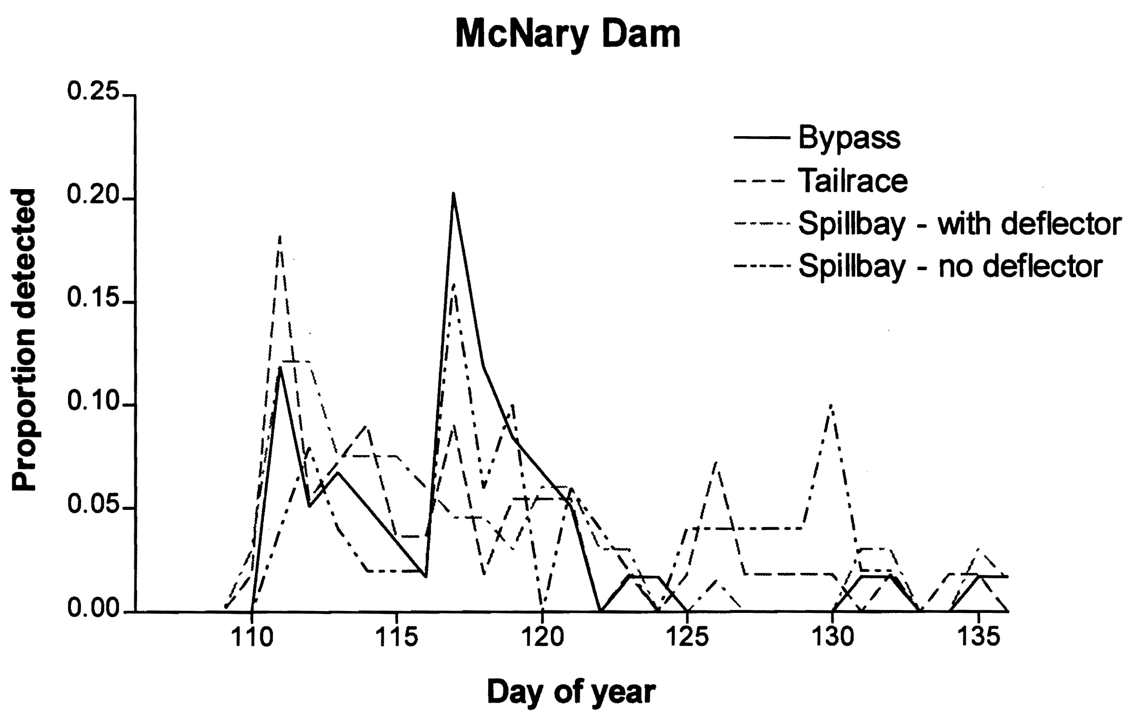


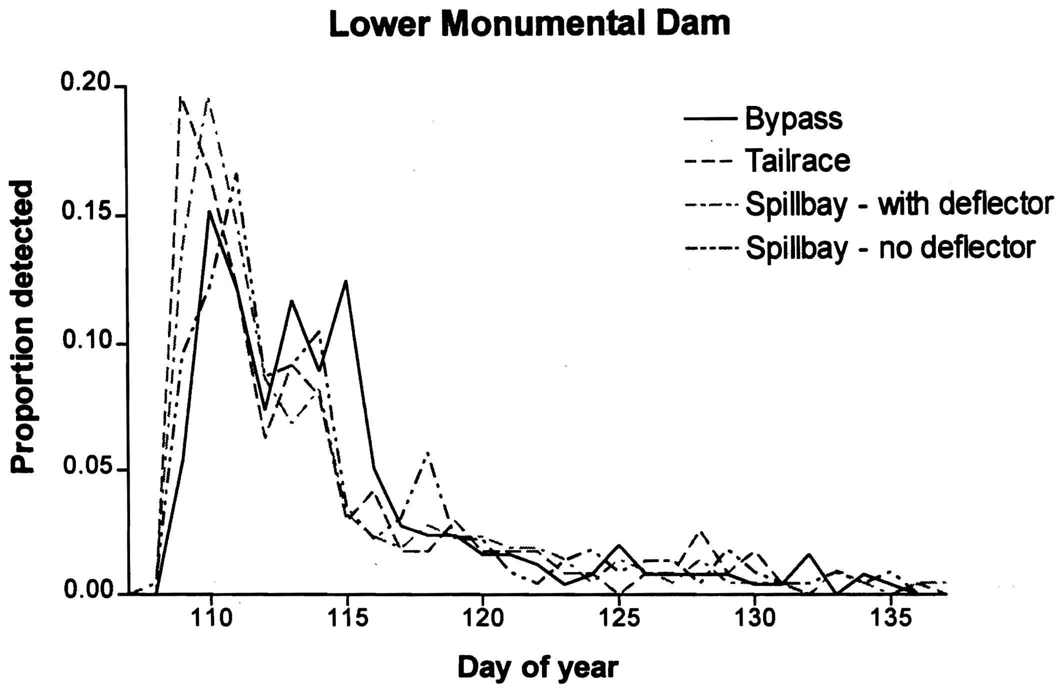


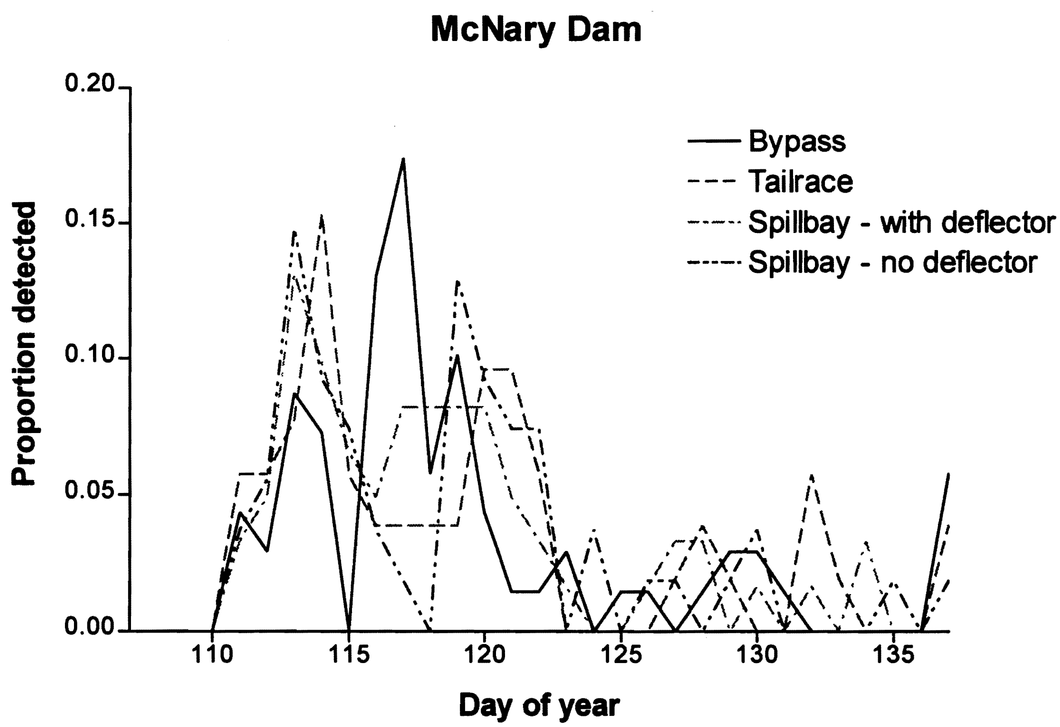
Appendix Figure 1. Passage distributions at Lower Monumental and McNary Dams for PIT-tagged hatchery steelhead released at Little Goose Dam on 15 April, 1997.



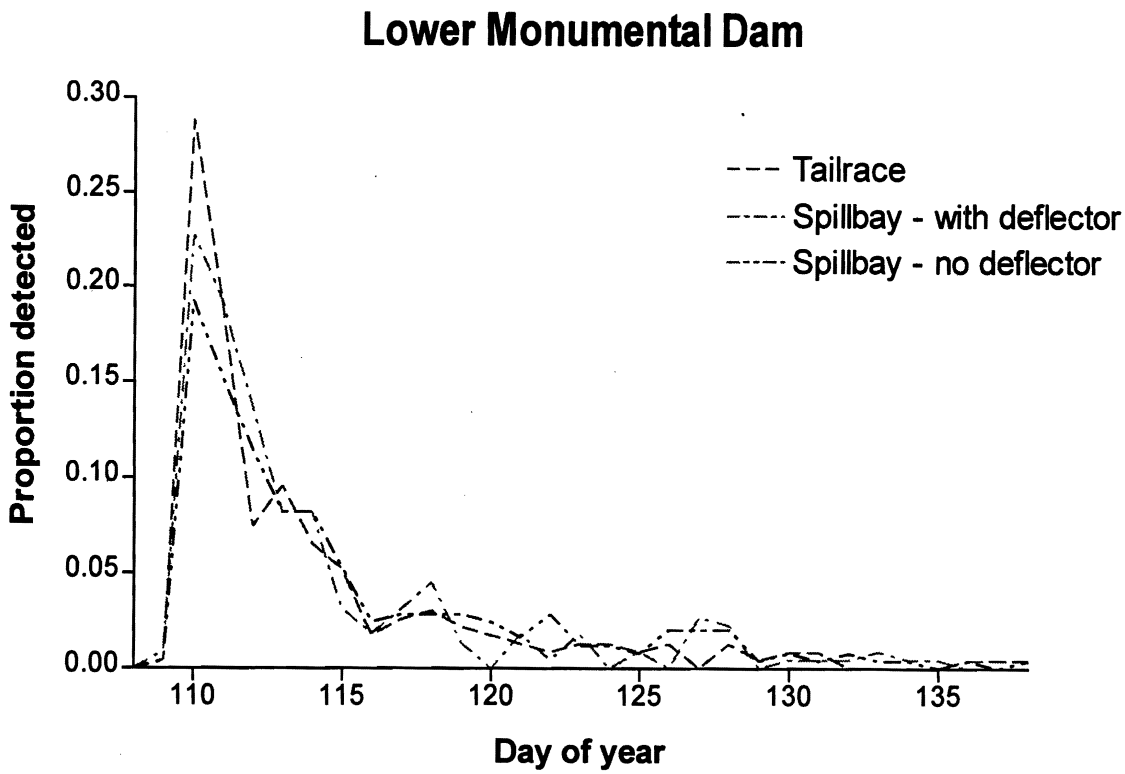


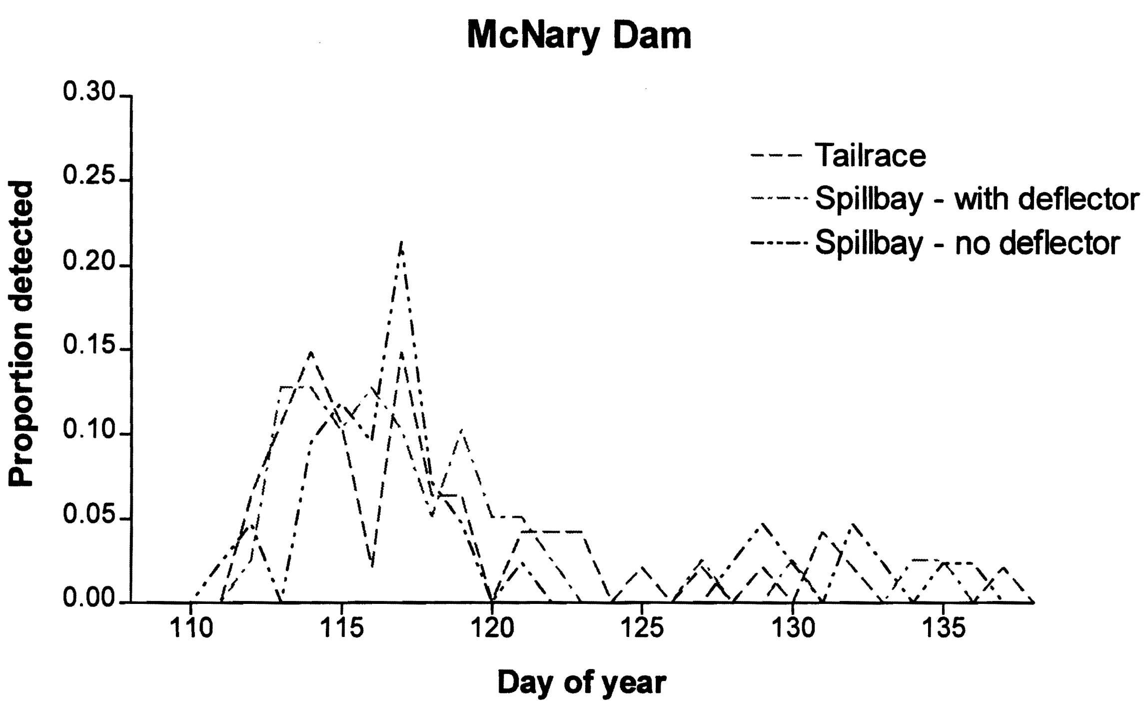
Appendix Figure 2. Passage distributions at Lower Monumental and McNary Dams for PIT-tagged hatchery steelhead released at Little Goose Dam on 16 April, 1997.



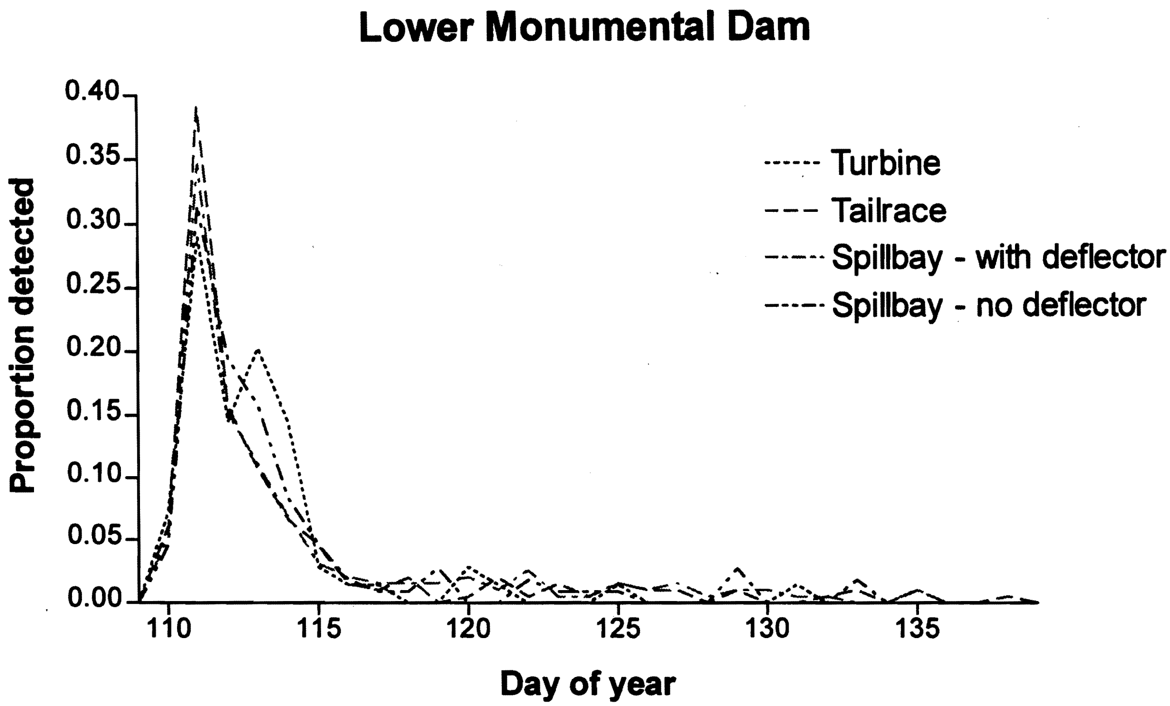


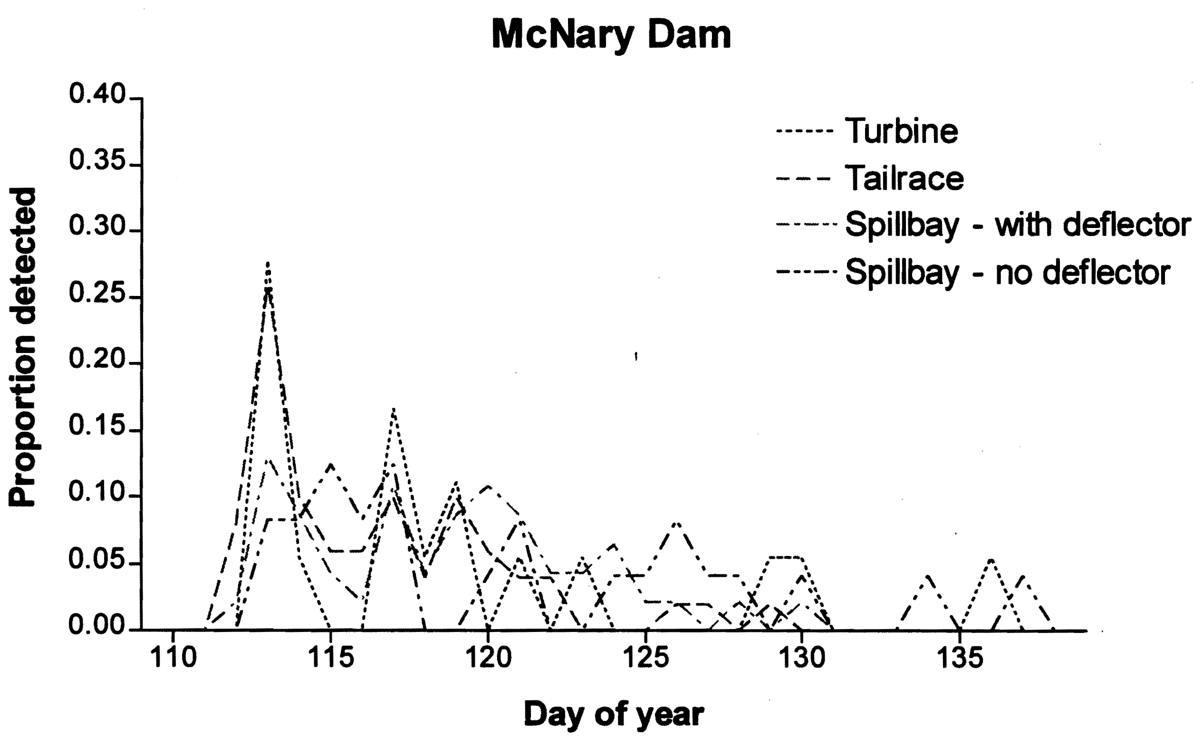
Appendix Figure 3. Passage distributions at Lower Monumental and McNary Dams for PIT-tagged hatchery steelhead released at Little Goose Dam on 17 April, 1997.



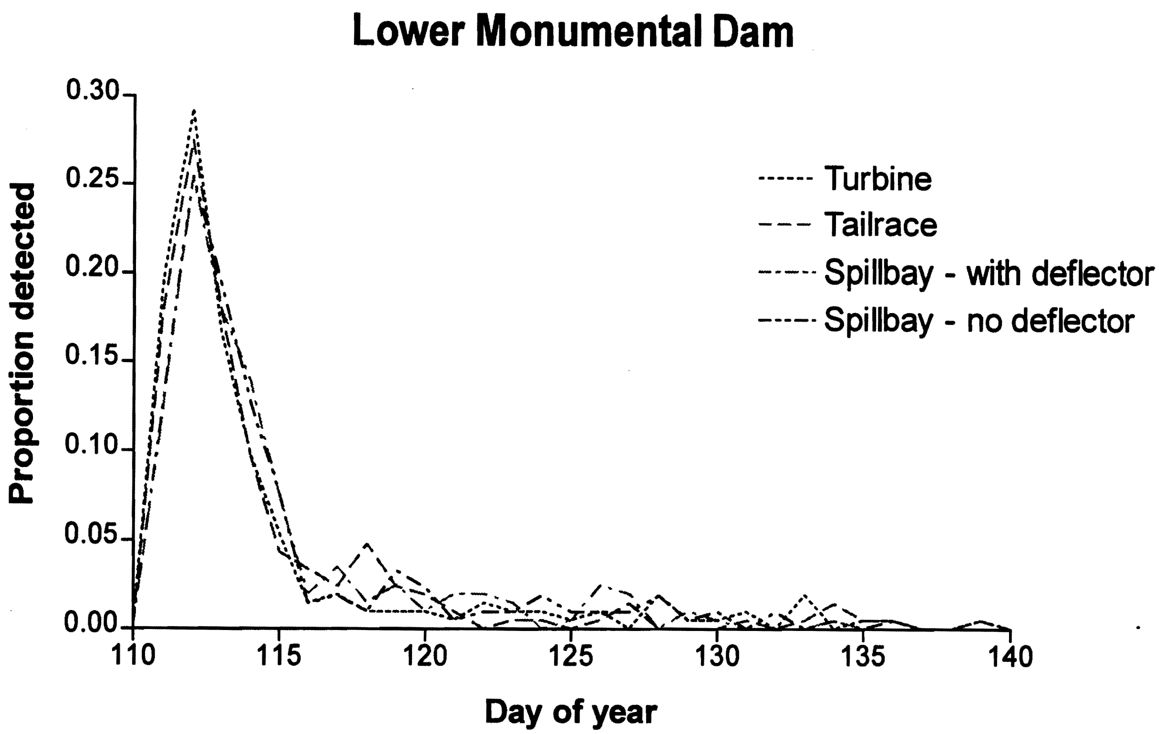


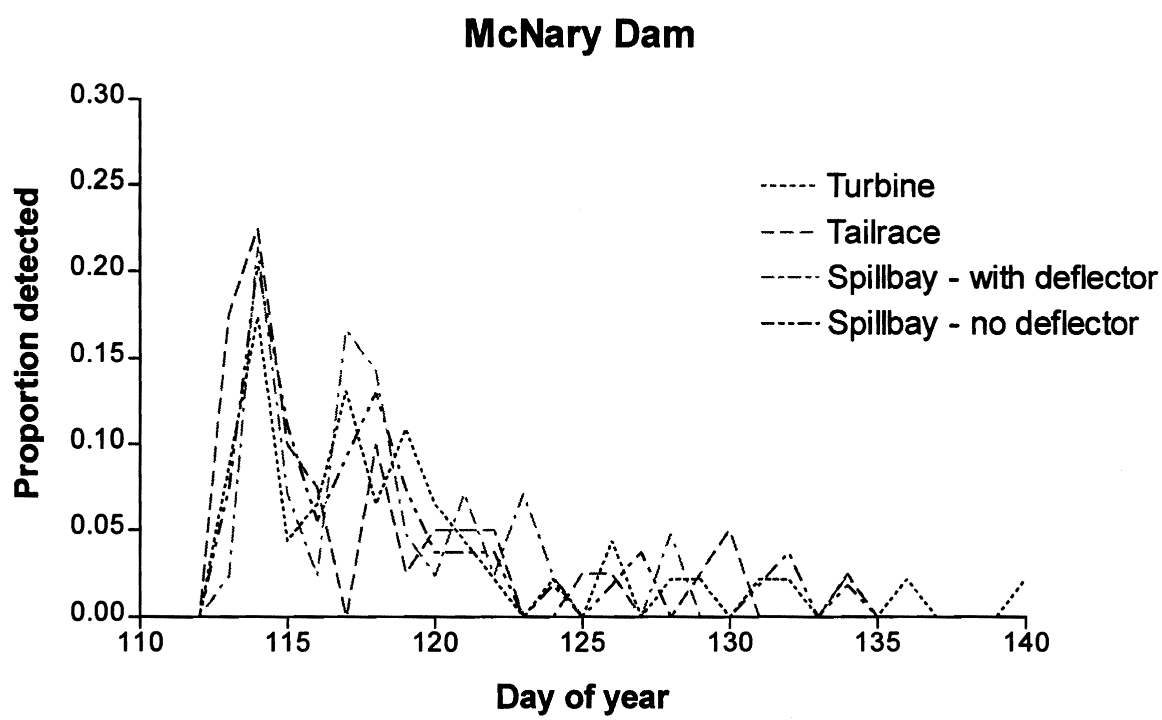
Appendix Figure 4. Passage distributions at Lower Monumental and McNary Dams for PIT-tagged hatchery steelhead released at Little Goose Dam on 18 April, 1997.



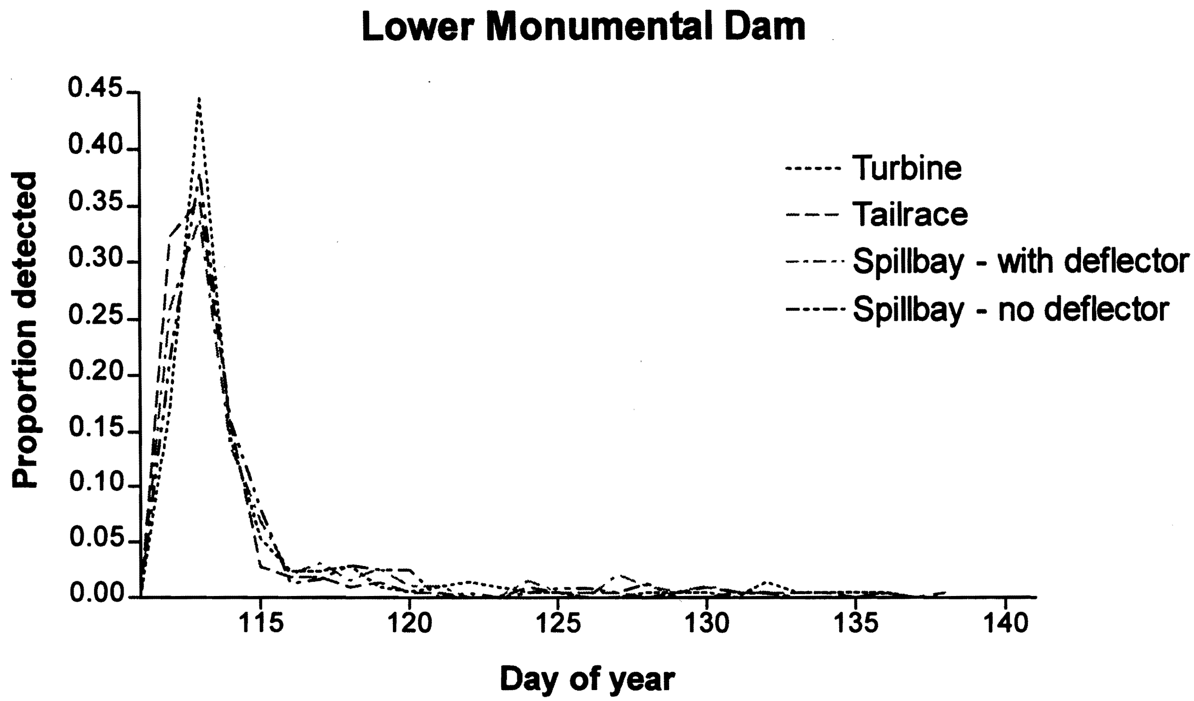


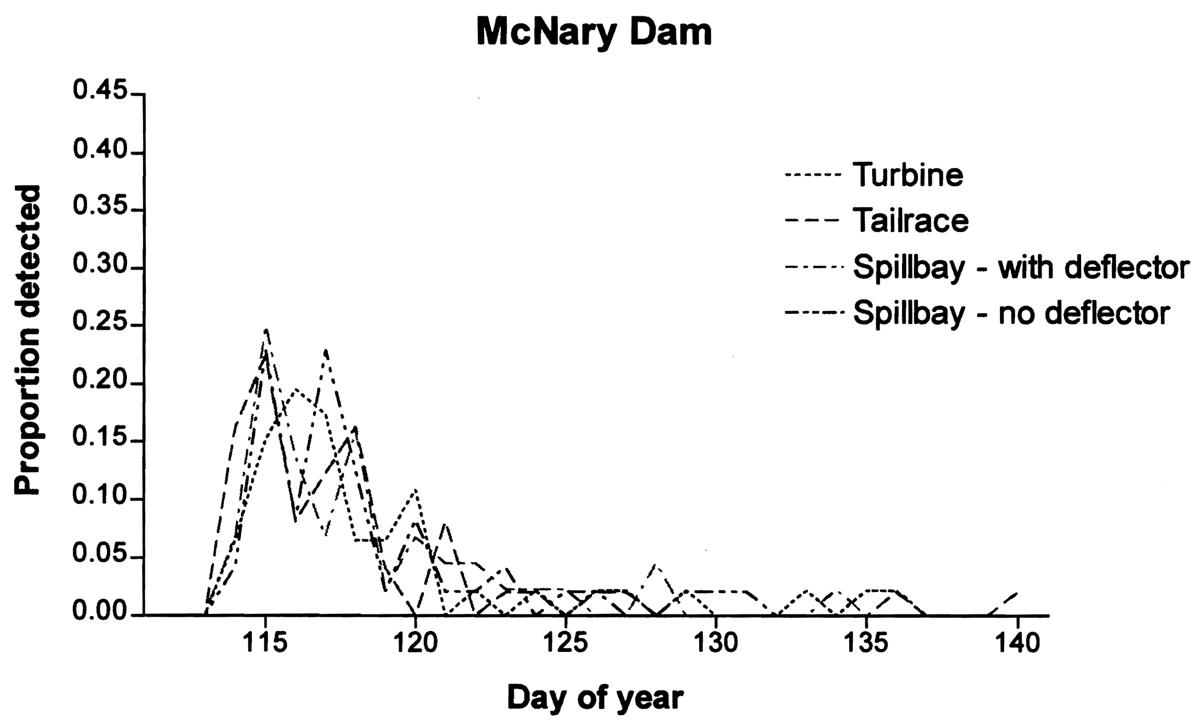
Appendix Figure 5. Passage distributions at Lower Monumental and McNary Dams for PIT-tagged hatchery steelhead released at Little Goose Dam on 19 April, 1997.



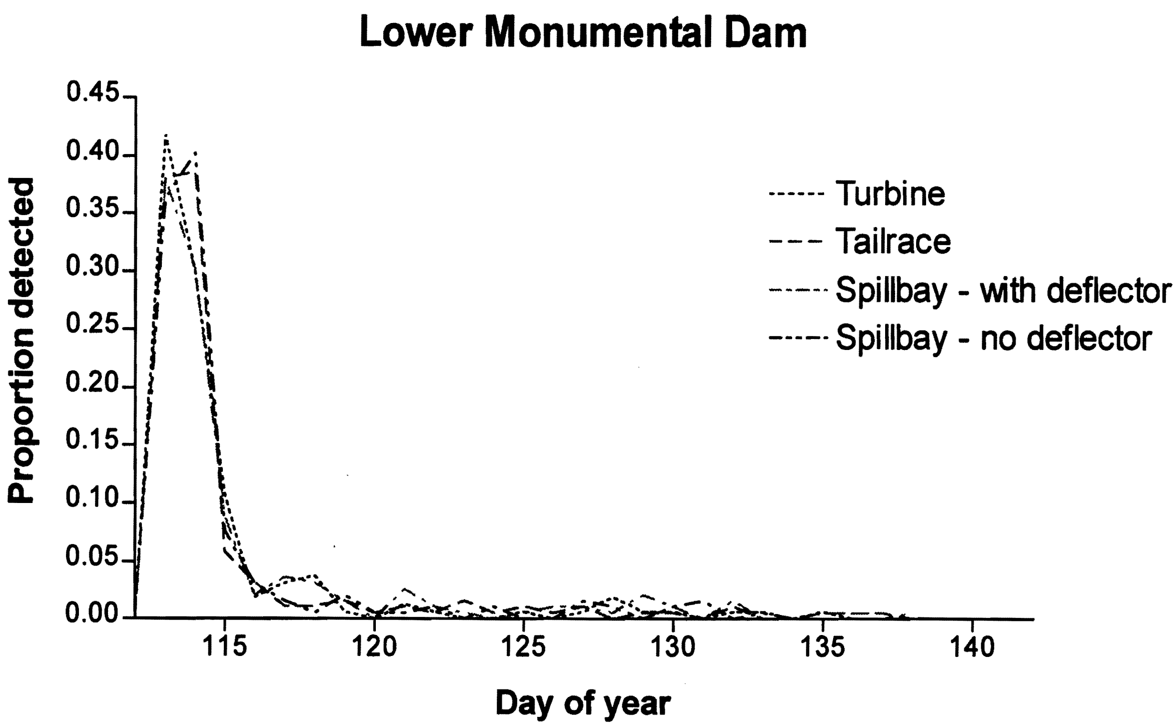


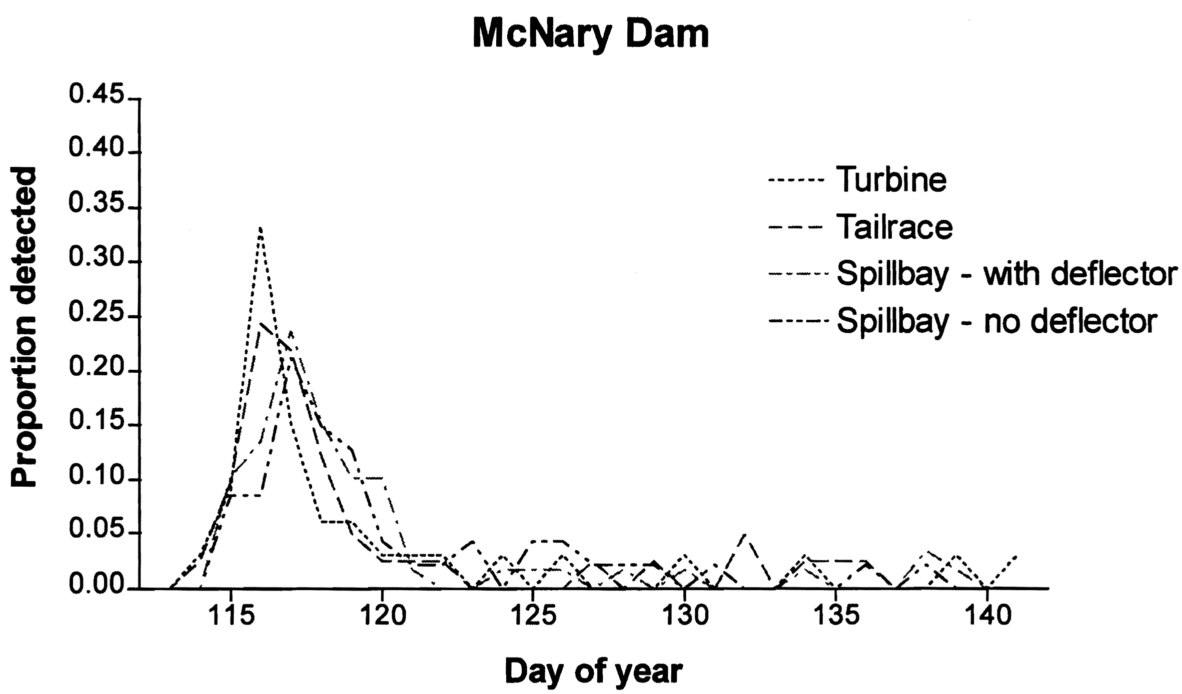
Appendix Figure 6. Passage distributions at Lower Monumental and McNary Dams for PIT-tagged hatchery steelhead released at Little Goose Dam on 20 April, 1997.



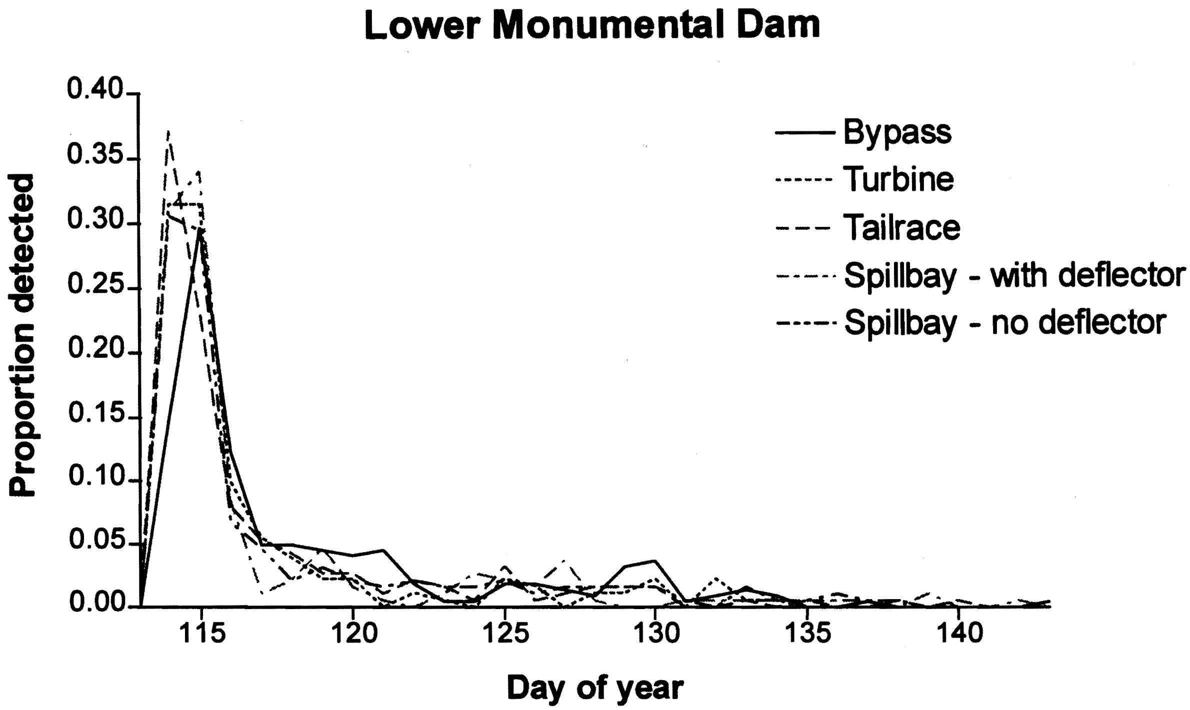


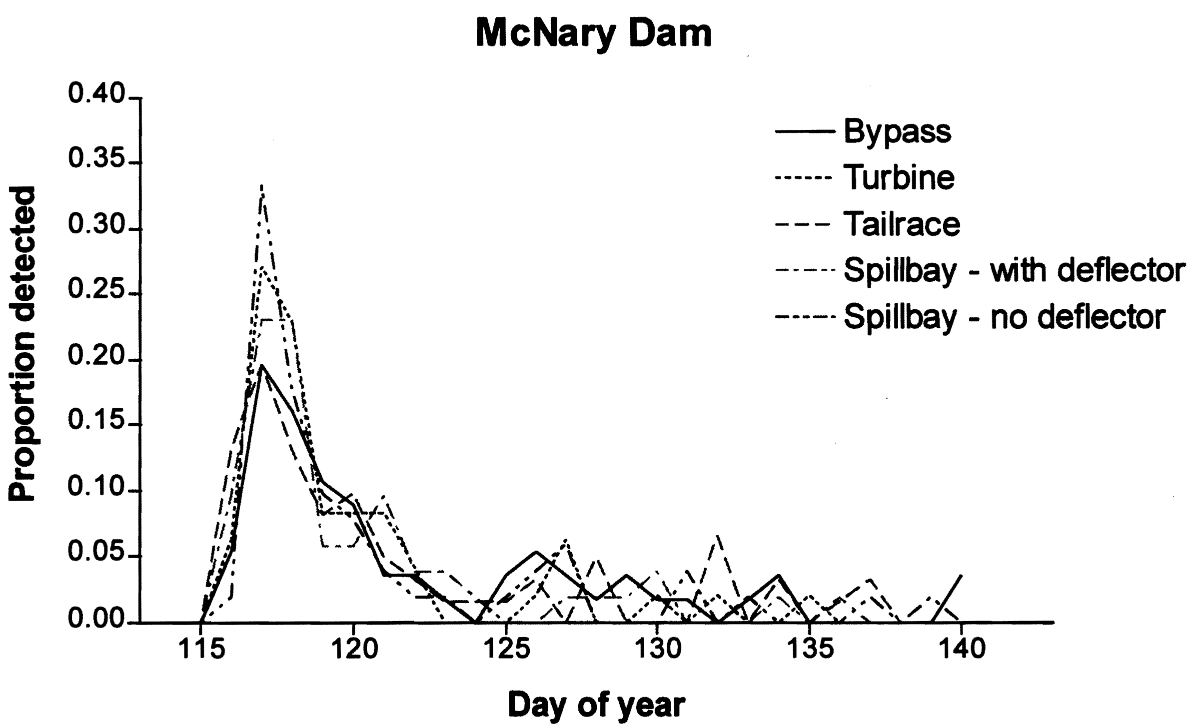
Appendix Figure 7. Passage distributions at Lower Monumental and McNary Dams for PIT-tagged hatchery steelhead released at Little Goose Dam on 21 April, 1997.



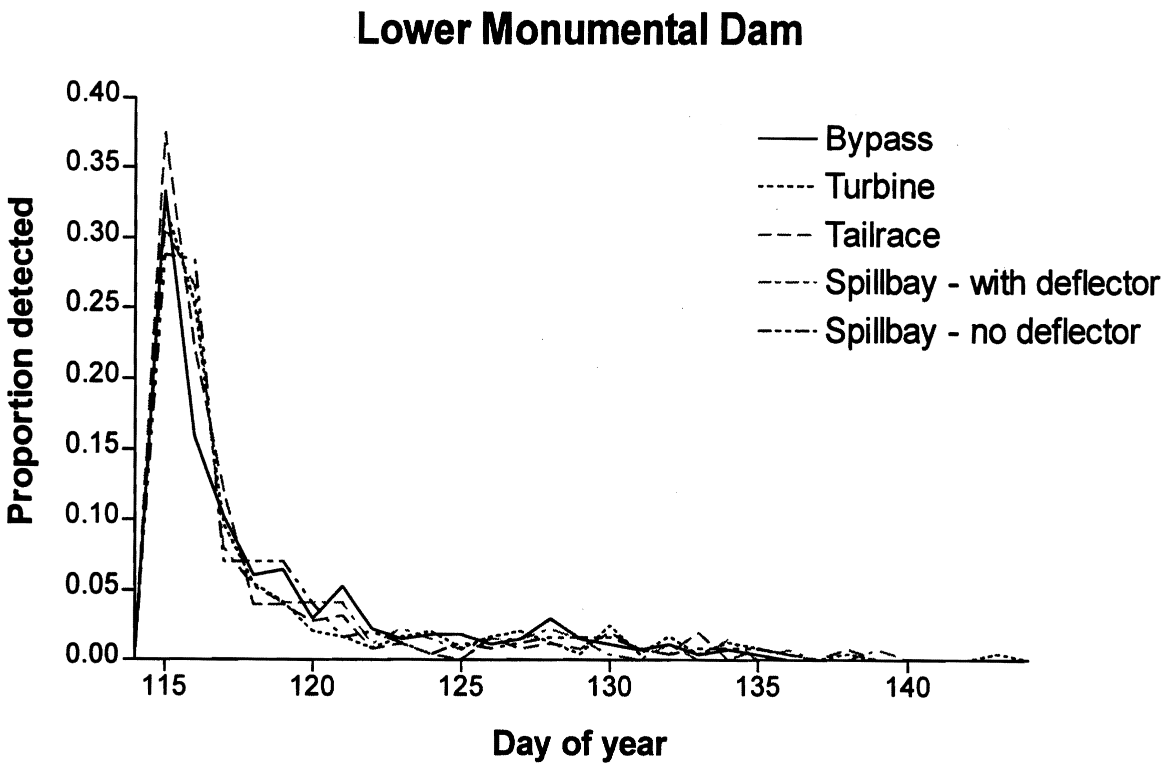


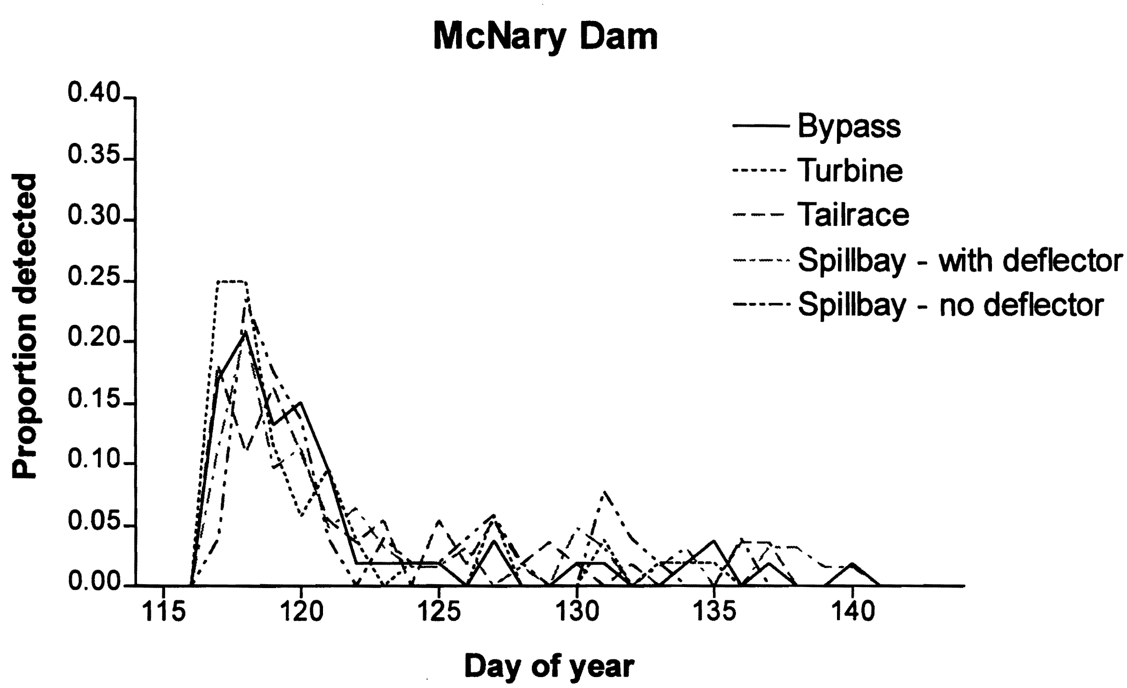
Appendix Figure 8. Passage distributions at Lower Monumental and McNary Dams for PIT-tagged hatchery steelhead released at Little GooseDam on 22 April, 1997.



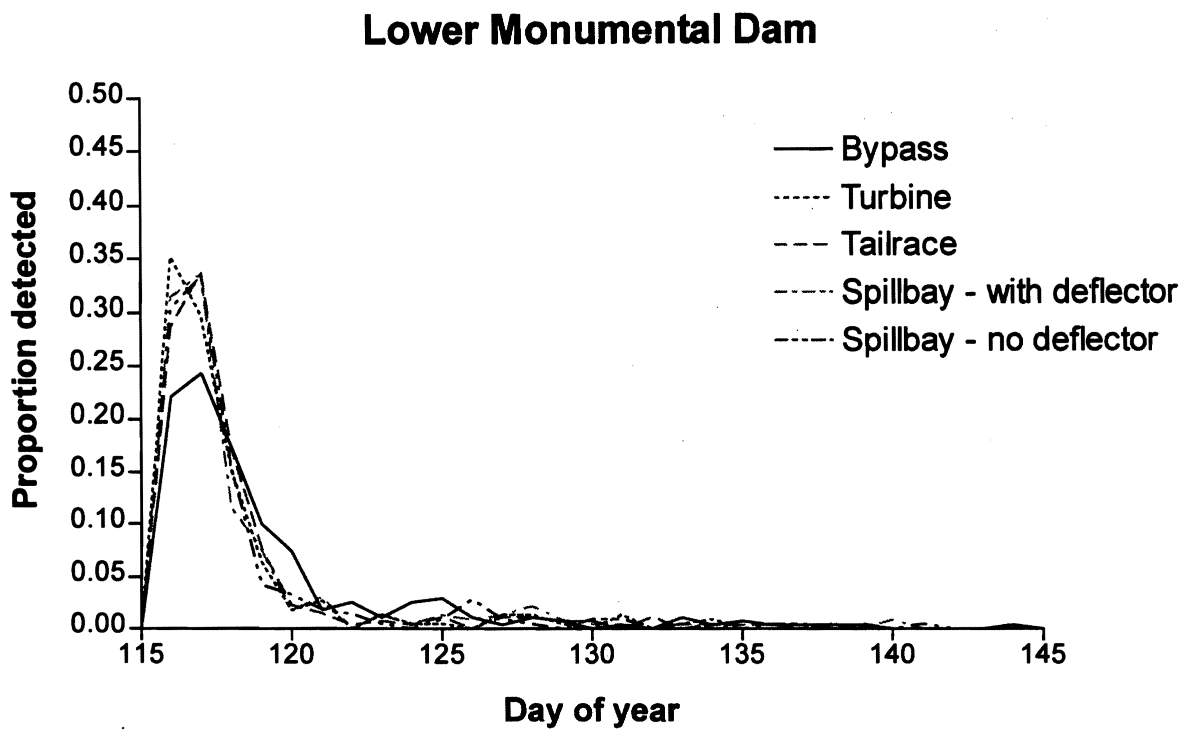


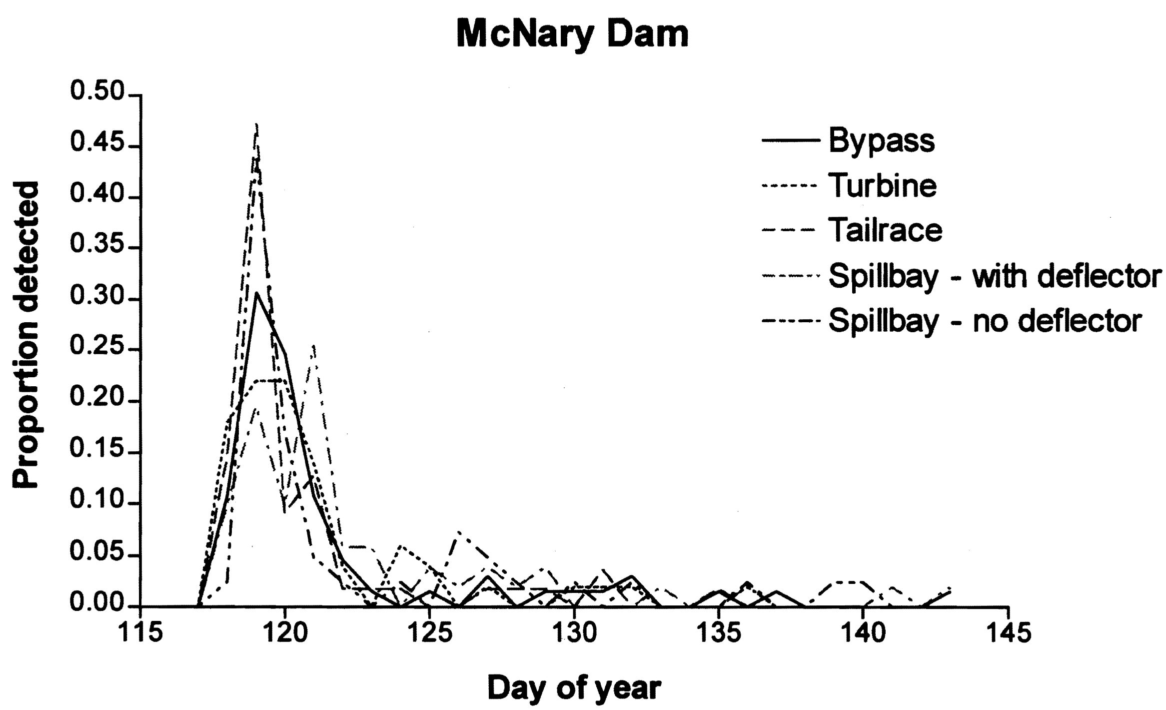
Appendix Figure 9. Passage distributions at Lower Monumental and McNary Dams for PIT-tagged hatchery steelhead released at Little Goose Dam on 23 April, 1997.



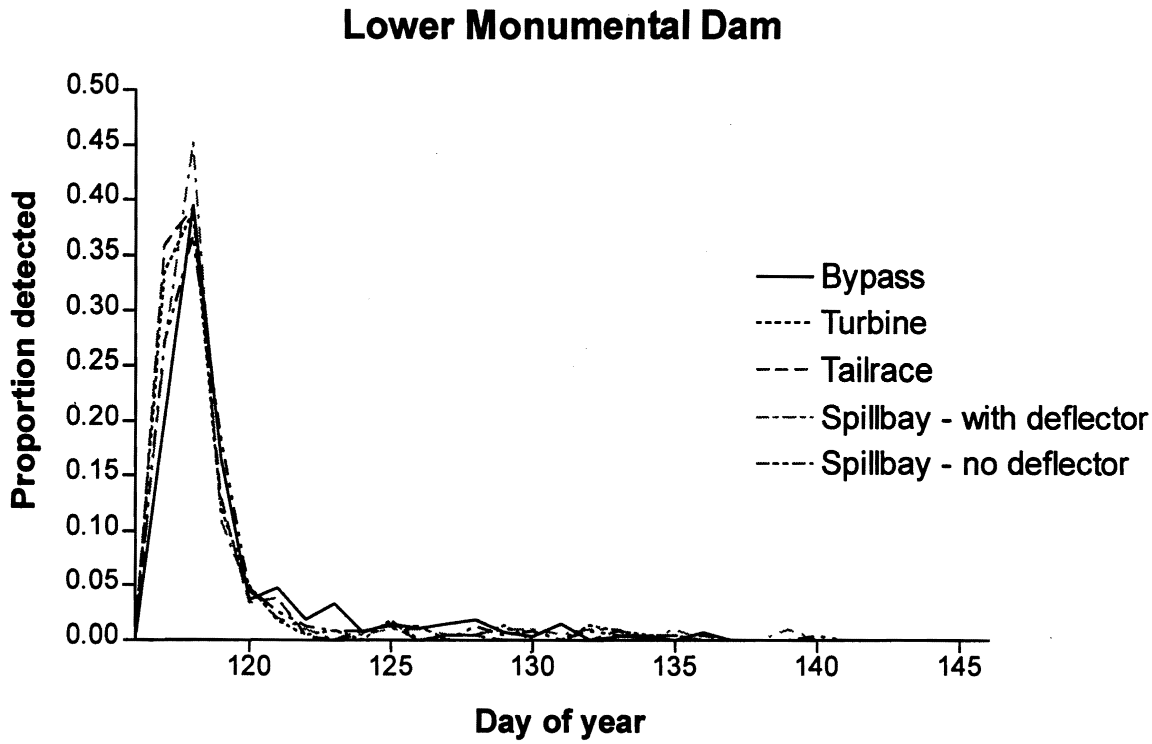


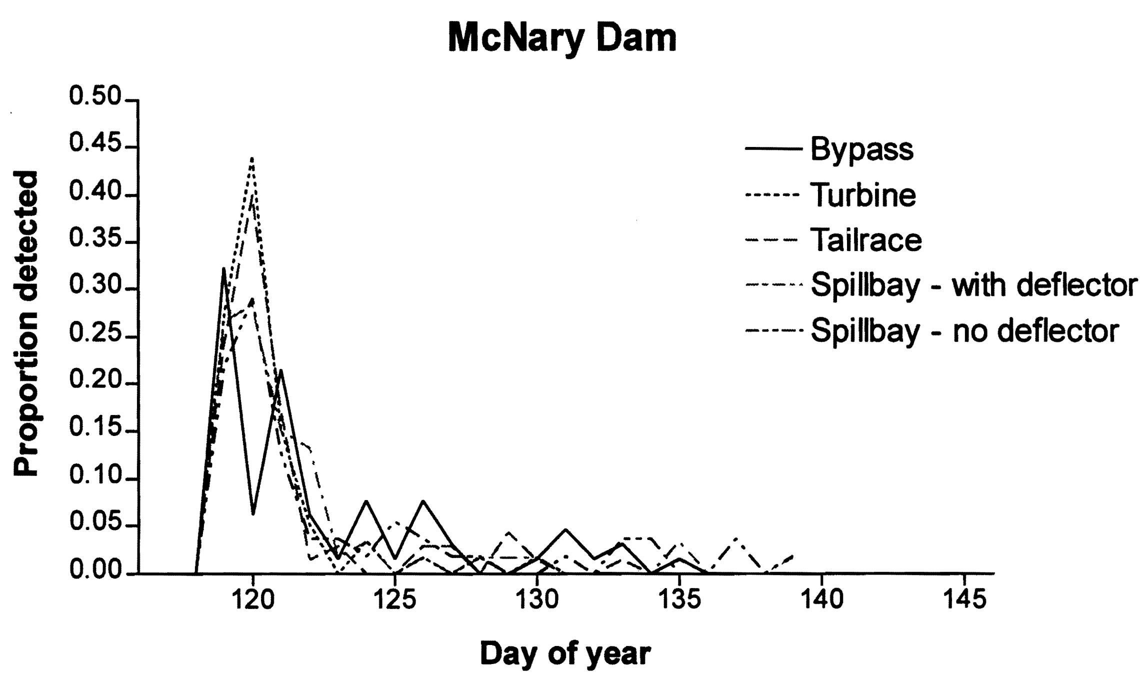
Appendix Figure 10. Passage distributions at Lower Monumental and McNary Dams for PIT-tagged hatchery steelhead released at Little Goose Dam on 24 April, 1997.



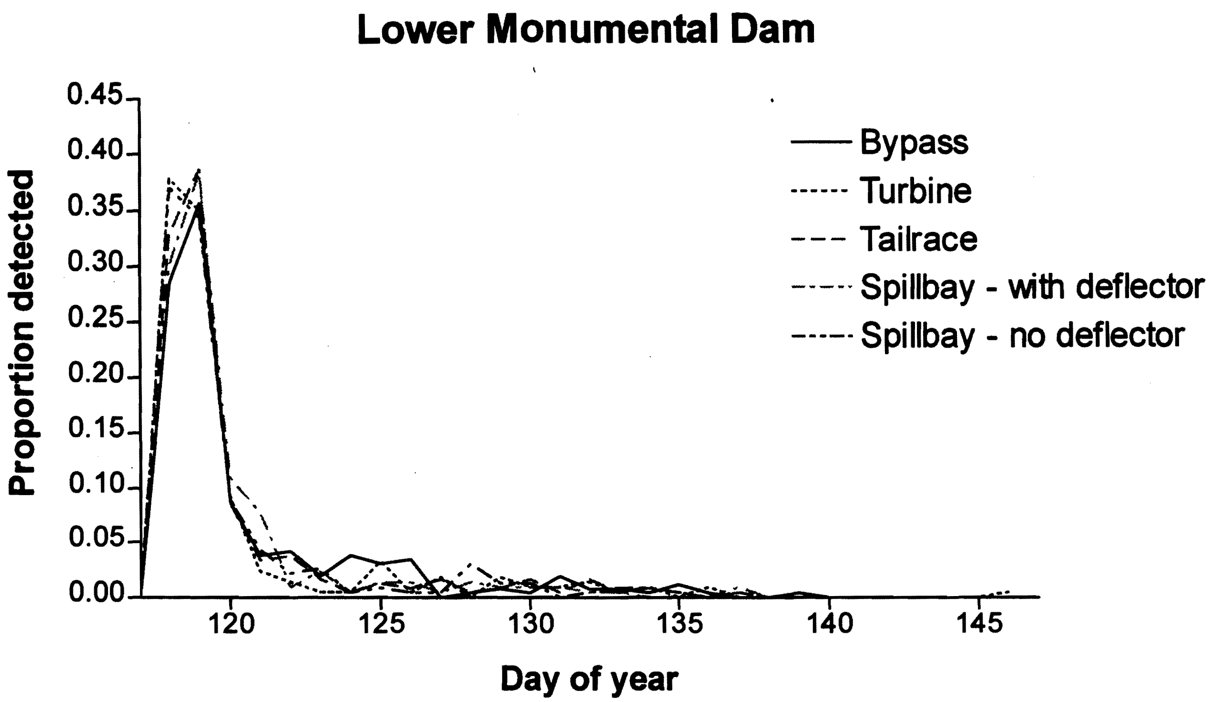


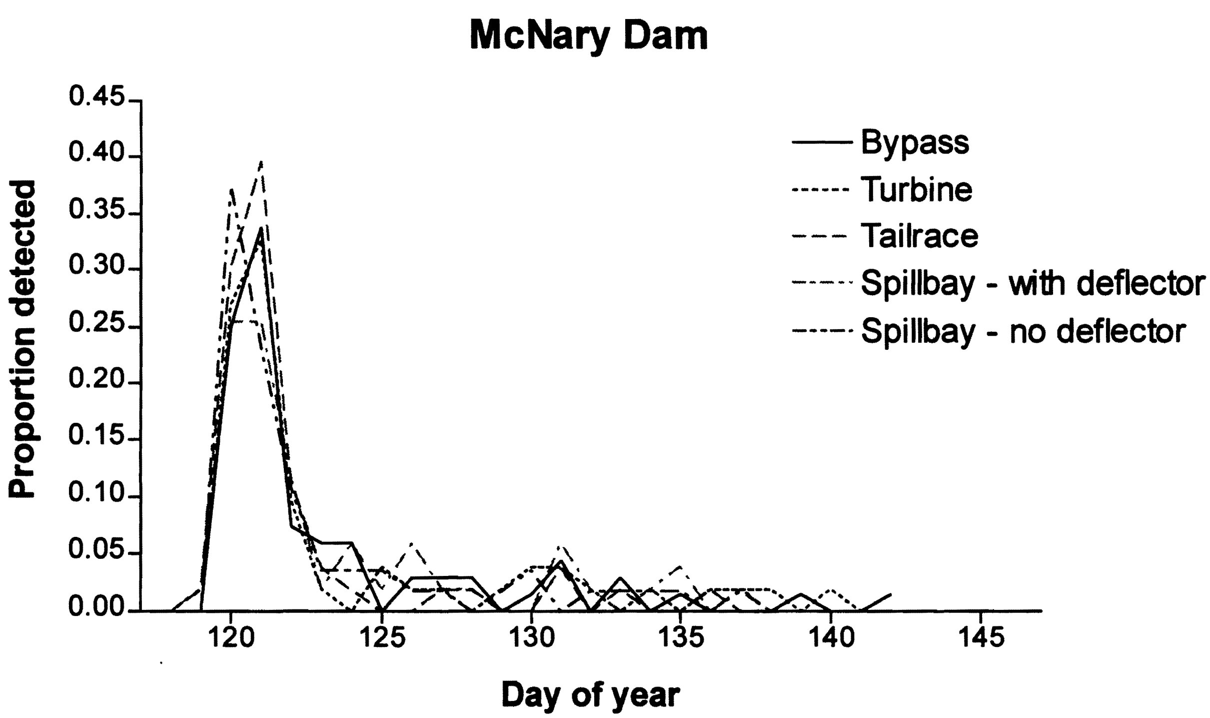
Appendix Figure 11. Passage distributions at Lower Monumental and McNary Dams for PIT-tagged hatchery steelhead released at Little Goose Dam on 25 April, 1997.



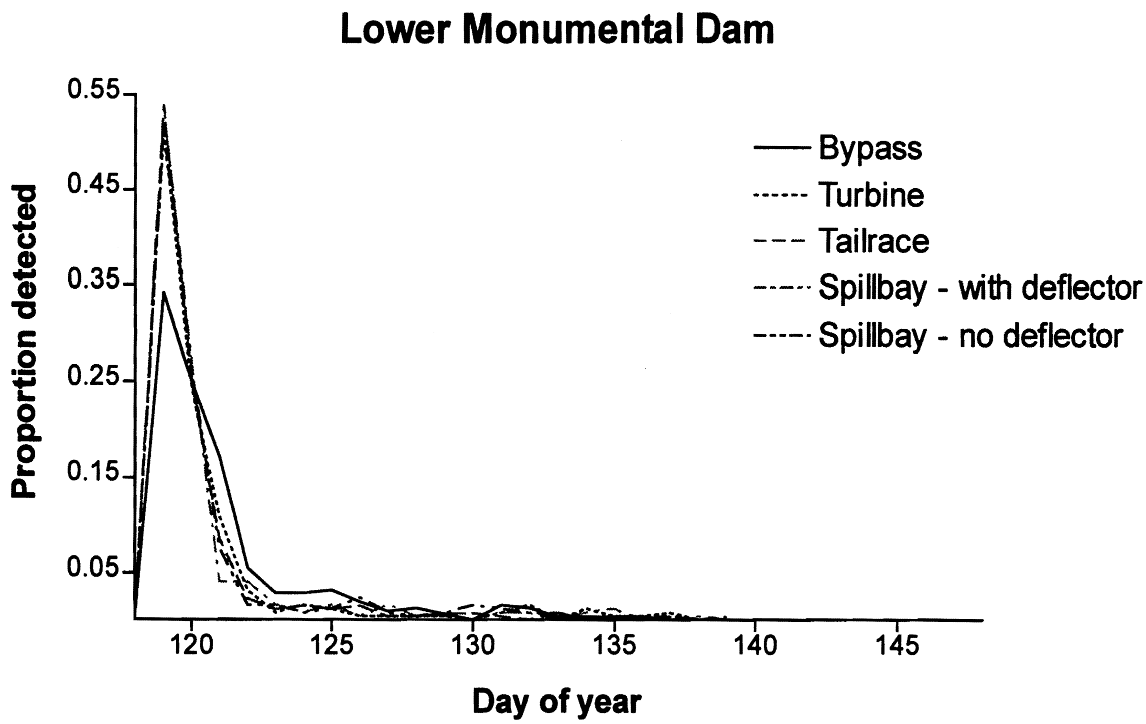


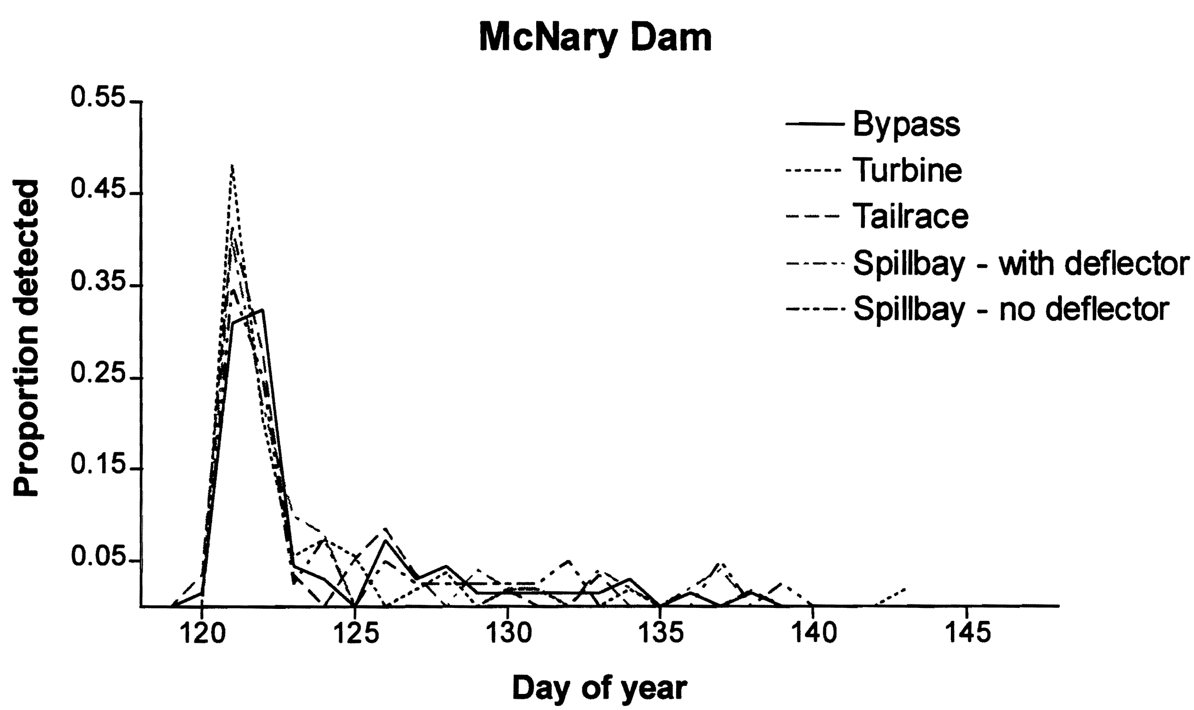
Appendix Figure 12. Passage distributions at Lower Monumental and McNary Dams for PIT-tagged hatchery steelhead released at Little Goose Dam on 26 April, 1997.



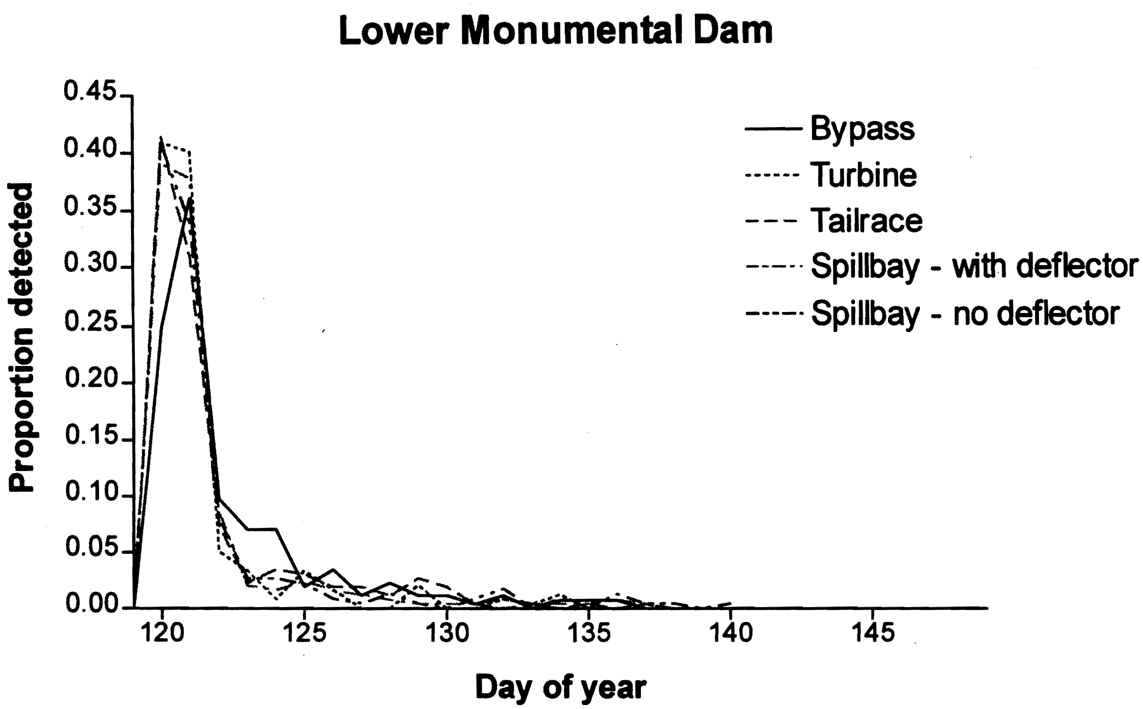


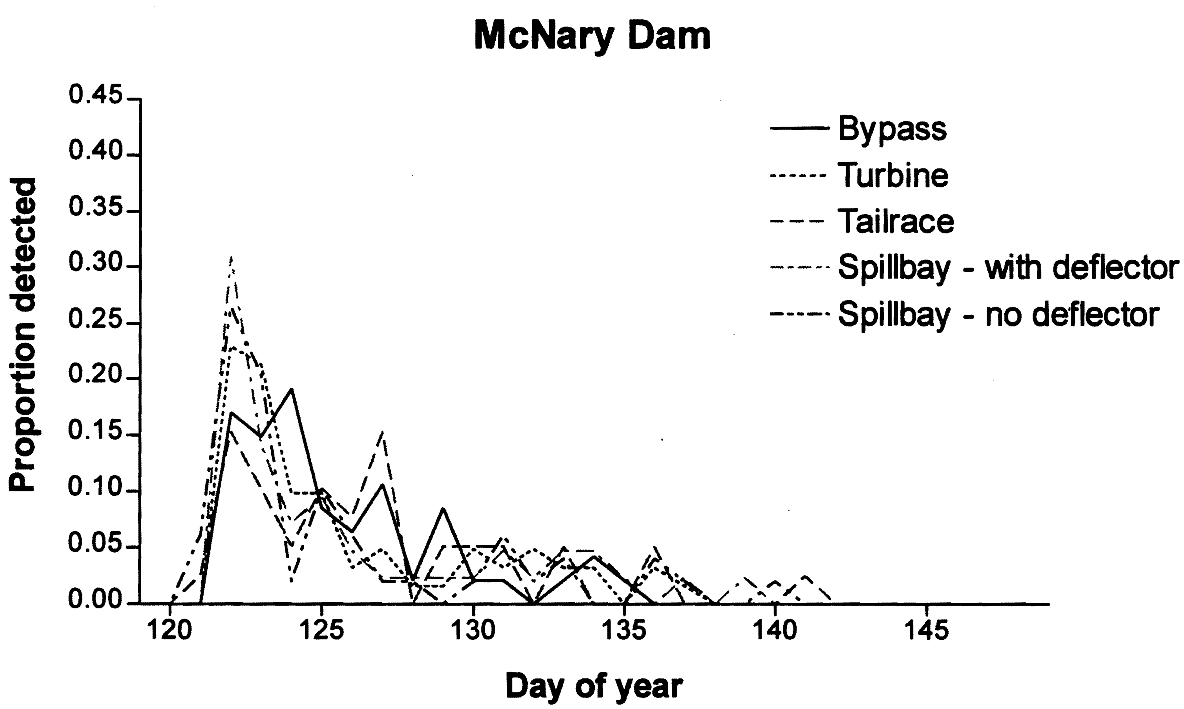
Appendix Figure 13. Passage distributions at Lower Monumental and McNary Dams for PIT-tagged hatchery steelhead released at Little Goose Dam on 27 April, 1997.



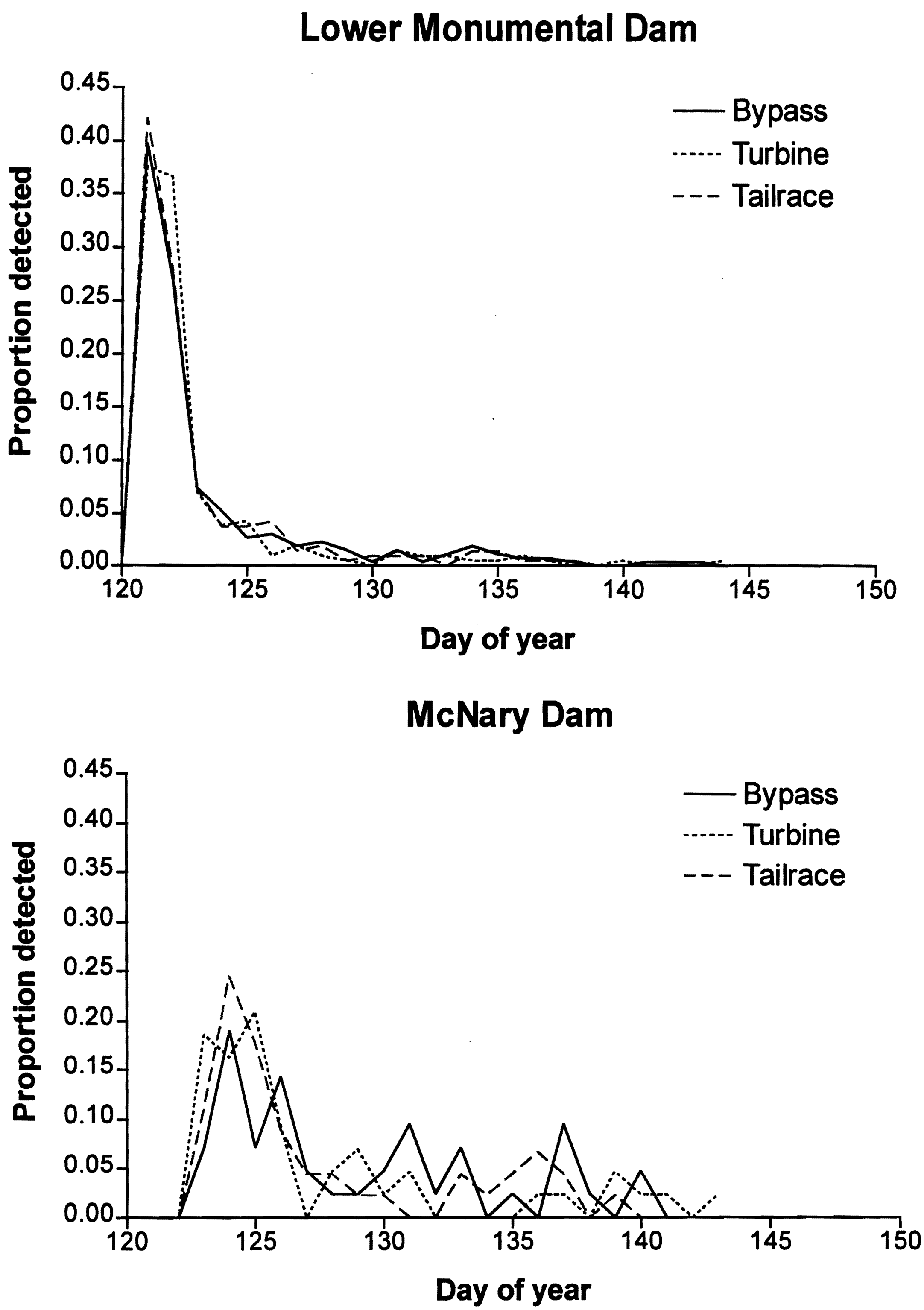


Appendix Figure 14. Passage distributions at Lower Monumental and McNary Dams for PIT-tagged hatchery steelhead released at Little Goose Dam on 28 April, 1997.

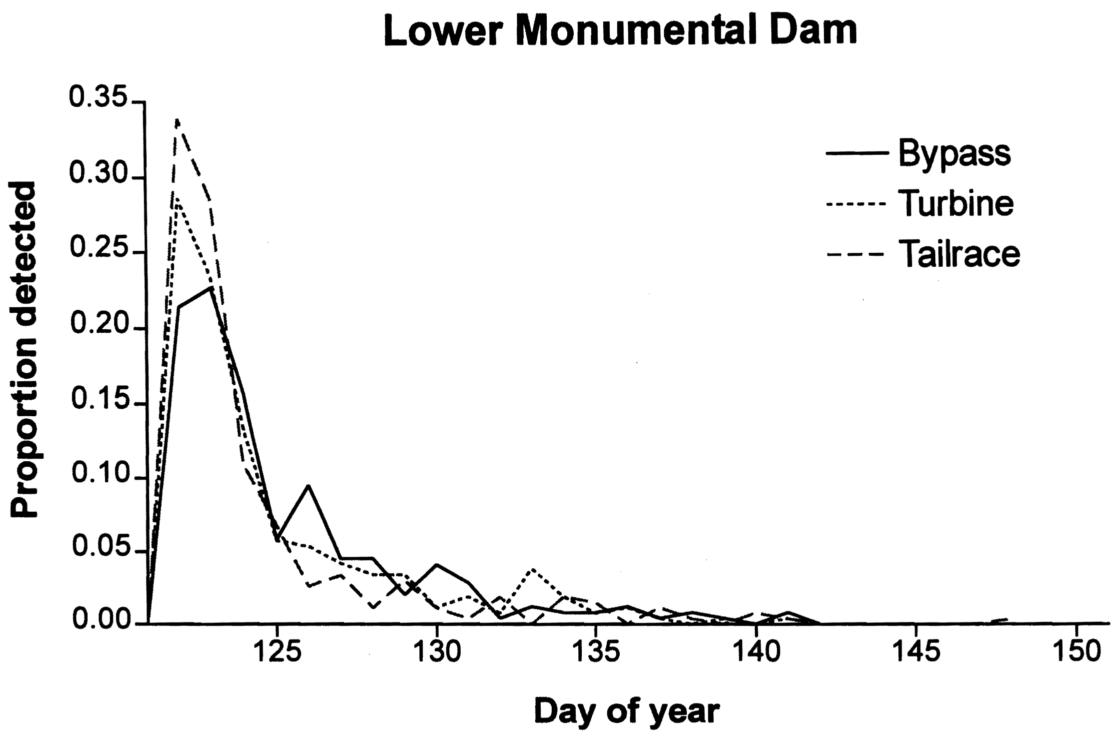


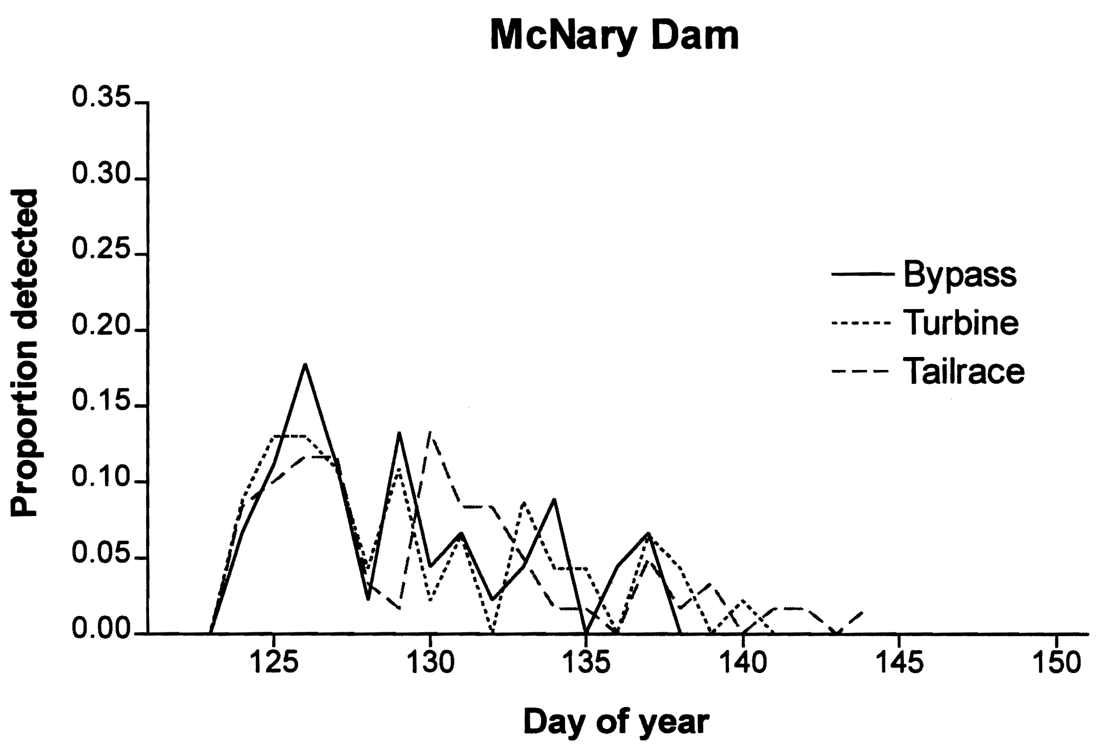


Appendix Figure 15. Passage distributions at Lower Monumental and McNary Dams for PIT-tagged hatchery steelhead released at Little Goose Dam on 29 April, 1997.



Appendix Figure 16. Passage distributions at Lower Monumental and McNary Dams for PIT-tagged hatchery steelhead released at Little Goose Dam on 30 April, 1997.





Appendix Figure 17. Passage distributions at Lower Monumental and McNary Dams for PIT-tagged hatchery steelhead released at Little Goose Dam on 1 May, 1997.