SURVIVAL ESTIMATES FOR THE PASSAGE OF JUVENILE SALMONIDS THROUGH SNAKE RIVER DAMS AND RESERVOIRS, 1994

ANNUAL REPORT

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EXECUTIVE SUMMARY

In 1994, the National Marine Fisheries Service and the University of Washington completed the second year of a multi-year study to estimate survival of juvenile salmonids *(Oncorhynchus* spp.) passing through the dams and reservoirs of the Snake River. Actively migrating smolts were collected at selected locations above, at, and below Lower Granite Dam, tagged with passive integrated transponder (PIT) tags, and released to continue their downstream migration. Individual smolts were subsequently detected at PIT-tag detection facilities at Lower Granite, Little Goose, Lower Monumental, and McNary Dams. Survival estimates were calculated using the Single-Release, Modified Single-Release, and Paired-Release Models.

The specific research objectives in 1994 were: 1) to continue field testing and evaluating the Single-Release, Modified Single-Release, and Paired-Release Models for estimating survival probabilities of migrating juvenile salmonids, 2) to identify operational and logistical constraints that would limit the ability to collect data for the models, and 3) to begin collecting baseline information on smolt travel time and survival under extant river conditions and dam operations. In contrast to the 1993 study, which estimated survival only for hatchery yearling chinook salmon (0. *tshawytscha)* over a small fraction of the migration, the 1994 research was expanded to include releases of wild yearling chinook salmon and hatchery steelhead (0. *mykiss).* Releases of tagged fish in 1994 spanned a greater

portion of the juvenile outmigration period than in 1993, and survival probabilities were estimated for a larger stretch of the Snake River.

Primary releases consisted of 10 groups of hatchery yearling chinook salmon (542 to 1,196 per group), 1 group of 512 wild yearling chinook salmon, and 9 groups of hatchery steelhead (1,001 to 4,009 per group). Smolts were collected by purse seine near Silcott Island (about 37 km upstream from Lower Granite Dam), PIT tagged, and released at the same location.

Secondary releases consisted of replicate groups of hatchery yearling chinook salmon and steelhead released in the forebays, turbine intakes, collection channels of juvenile bypass facilities, and bypass flumes (downstream of the PIT-tag detectors) at Lower Granite, Little Goose, and Lower Monumental Dams. Release of these groups was timed to coincide with the approximate time of passage of the primary release groups at each dam. Fish for secondary releases were collected in the juvenile collection and bypass facilities at the dam where they were released. The one exception was forebay releases of steelhead at Lower Granite Dam; these fish were collected by purse seine in the Lower Granite Dam forebay.

During the spring outmigration, slide gates triggered by PIT-tag detectors at Lower Granite, Little Goose, and Lower Monumental Dams automatically returned most PIT-tagged smolts back to the Snake River. This allowed multiple detections at downstream dams of fish from the primary and secondary release groups and PIT-tagged salmonids released from hatcheries and trap sites upstream from Lower Granite Dam.

Operational and logistical constraints identified in 1993, which indicated the need for a juvenile separator at Lower Granite Dam and higher slide-gate efficiency, were both addressed during 1994 research. A temporary juvenile separator was used in 1994 at Lower Granite Dam, resulting in decreased handling and reduced mortality of nontarget species. Slide-gate efficiency was improved substantially at Lower Granite Dam, and operation of new slide gates at Lower Monumental Dam made possible survival estimates through an additional river section (Little Goose Dam tailrace to Lower Monumental Dam tailrace) of the Snake River.

PIT-tag detection rates varied widely in 1994, due at least in part to the effects of spill, particularly late in the season after a voluntary spill program was initiated. The increased spill resulted in lower detection rates and decreased precision in survival estimates.

As in 1993, assumptions of the Single-Release and Paired-Release Models were generally satisfied in 1994. The results indicated that 1) detecting a fish at an upstream site did not influence the probability of its subsequent detection downstream, 2) that detection did not influence subsequent survival, and 3) that, excluding forebay releases, treatment and reference fish were mixed at subsequent detection sites. Moreover, post-detection bypass releases indicated nonsignificant mortality occurred after bypass fish were detected in the bypass and before they remixed with fish using other passage routes. Accordingly, the Single-Release Model was used to estimate survival probabilities for the primary release groups.

Precise survival estimates for a large portion of the 1994 hatchery yearling chinook salmon and hatchery steelhead migrations were obtained. Results indicated that survival from the primary release site (37 km upstream from Lower Granite Dam) to the tailrace of Lower Granite Dam averaged about 92% for hatchery yearling chinook salmon and 90% for hatchery steelhead. Survival from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam was about 79% for hatchery yearling chinook salmon and 78% for hatchery steelhead. From Little Goose Dam tailrace to Lower Monumental Dam tailrace, survival was 89% and 83% for hatchery yearling chinook salmon and hatchery steelhead, respectively. Survival estimates for a single release of wild yearling chinook salmon in mid-April were 92% from the primary release site to the tailrace of Lower Granite Dam, 83% from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam, and 94% from the tailrace of Little Goose Dam to the tailrace of Lower Monumental Dam.

The river sections over which survival was estimated represent about 64% of the distance from the head of Lower Granite Reservoir to the confluence of the Snake and Columbia Rivers. The estimated survival probability from Silcott Island to Lower Monumental Dam tailrace (143 km) was 66% for hatchery chinook salmon, 73% for wild chinook salmon, and 60% for hatchery steelhead. These estimates are relatively high compared to those in the Snake River in earlier years (Raymond, 1979).

Mortality from the head of Lower Granite Reservoir to the tailrace of Lower Granite Dam was approximately 10% for hatchery and wild yearling chinook salmon and hatchery steelhead. Because this estimate included mortality associated with dam passage via turbines, bypass, and spill, as well as reservoir mortality, it appeared that relatively little mortality occurred in the reservoir.

Survival estimates from Lower Granite Dam tailrace to Little Goose Dam tailrace for primary releases and hatchery releases were lower in 1994 than in 1993. Moreover, they were the lowest estimates observed of the three river sections investigated in 1994. We believe that the low survival estimates may have resulted from adverse tailrace conditions at Little Goose Dam caused by the particular dam operations in 1994. During the spring migration, two or three turbine units were out of service due to maintenance or because of fish guidance research activities. As a result, spill occurred 24 hours per day throughout the season. The spill and turbine operations caused a large eddy to flow upstream into the tailrace just below the turbines. Most fish exiting the juvenile bypass system were carried upstream by the eddy. Moreover, all fish passing through turbines and some passing through spill were also subjected to the eddy conditions. We suspect the overall result was decreased survival in the Little Goose Dam tailrace and consequently, decreased survival between the tailrace of Lower Granite Dam and the tailrace of Little Goose Dam.

Based on the results of the 1993 and 1994 research, we conclude that the Single-Release, Modified Single-Release, and Paired-Release Models can be used to make precise estimates of juvenile salmonid passage survival through individual river sections, reservoirs, and hydroelectric projects in the Snake and Columbia Rivers.

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INTRODUCTION

Problem

Survival estimates for juvenile chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) that migrate through reservoirs, hydroelectric projects, and free-flowing sections of the Snake and Columbia Rivers are essential to develop effective strategies to recover depressed stocks. Many management strategies, however, rely upon outdated estimates of system survival (Raymond 1979, Sims and Ossiander 1981) that lacked statistical precision and were derived in a river system that differs considerably from today's. Knowledge of the magnitude, locations, and causes of smolt mortality under present passage conditions and under conditions projected for the future is necessary to develop strategies for optimizing smolt survival.

In 1993, the National Marine Fisheries Service (NMFS) and the University of Washington (UW) made significant progress in demonstrating the feasibility of using the Single-Release (Cormack 1964, Jolly 1965, Seber 1965), Modified Single-Release (Hoffmann and Skalski, statistical appendix in Dauble et al. 1993), and Paired-Release Models (Burnham et al. 1987) to estimate survival of hatchery yearling chinook salmon passing through Snake River dams and reservoirs (Iwamoto et al. 1994). Evaluation of model assumptions indicated that all were satisfied and precise survival estimates were obtained for a portion of the 1993 hatchery chinook salmon migration. No similar data have been collected for steelhead, the other abundant salmonid species in the Snake River.

In 1994, NMFS and UW completed the second year of the multi-year study. Specific research objectives were: 1) continue field tests and evaluation of the Single-Release, Modified Single-Release, and Paired-Release Models for estimating survival probabilities through river sections and hydroelectric projects with high precision, 2) identify operational and logistical constraints that would limit the ability to collect data for the models, and 3) provide baseline survival and travel time data for hatchery and wild yearling chinook salmon and juvenile hatchery steelhead.

METHODS

Experimental Design

General Strategy

The statistical methods used to estimate survival from PIT-tag data in 1994 were the Single-Release (SR), Modified Single-Release (MSR), and Paired-Release (PR) Models. Background information and statistical theory underlying these models can be found in Iwamoto et al. (1994).

During the 1994 migration season, PIT-tag detectors operated at Lower Granite, Little Goose, Lower Monumental, and McNary Dams (additional PIT-tag detectors were operational at John Day and Bonneville Dams, but interrogated only a small sample of fish passing through each project). At Lower Granite, Little Goose, and Lower Monumental Dams, slide gates diverted PIT-tagged fish detected in the bypass system back to the river. Under this configuration, using the SR Model, primary releases of PIT-tagged fish above Lower Granite Dam could provide estimates of survival from the point of release to Lower Granite Dam tailrace, from Lower Granite Dam tailrace to Little Goose Dam tailrace, and from Little Goose Dam tailrace to Lower Monumental Dam tailrace.

Three series of primary releases, using PIT-tagged hatchery and wild chinook salmon and hatchery steelhead juveniles, were conducted near the head of Lower Granite Reservoir. Paired secondary releases were conducted to estimate post-detection bypass mortality at Lower Granite, Little Goose, and Lower

Monumental Dams. Data from the paired releases were analyzed using the PR Model. If significant post-detection bypass mortality occurred, the MSR Model was used to analyze the releases above Lower Granite Dam. Otherwise the SR Model was used.

Further paired releases were conducted to evaluate passage survival through turbines and collection channels of the juvenile bypass facilities, and overall passage survival from the forebay to the tailrace of a dam. Data from these releases were also analyzed using the PR Model.

Study Area

The study area extended from Silcott Island near the head of Lower Granite Reservoir (River Kilometer (RKm) 732) downstream to McNary Dam, below the confluence of the Snake and Columbia Rivers (RKm 470) (Figs. 1 and 2). PIT-tagged (Prentice et al. 1990a) fish were released in Lower Granite Reservoir near Silcott Island, at Lower Granite Dam (RKm 695), at Little Goose Dam (RKm 635), and at Lower Monumental Dam (RKm 589) (Table 1). PIT-tagged fish were detected (Prentice et al. 1990b) and most were diverted back to the river at Lower Granite Dam, Little Goose Dam, and Lower Monumental Dam on the Snake River, and detected at McNary Dam on the Columbia River.

Primary Release Groups

The primary release groups consisted of hatchery yearling chinook salmon (R_P), wild yearling chinook salmon (R_{PW}), and

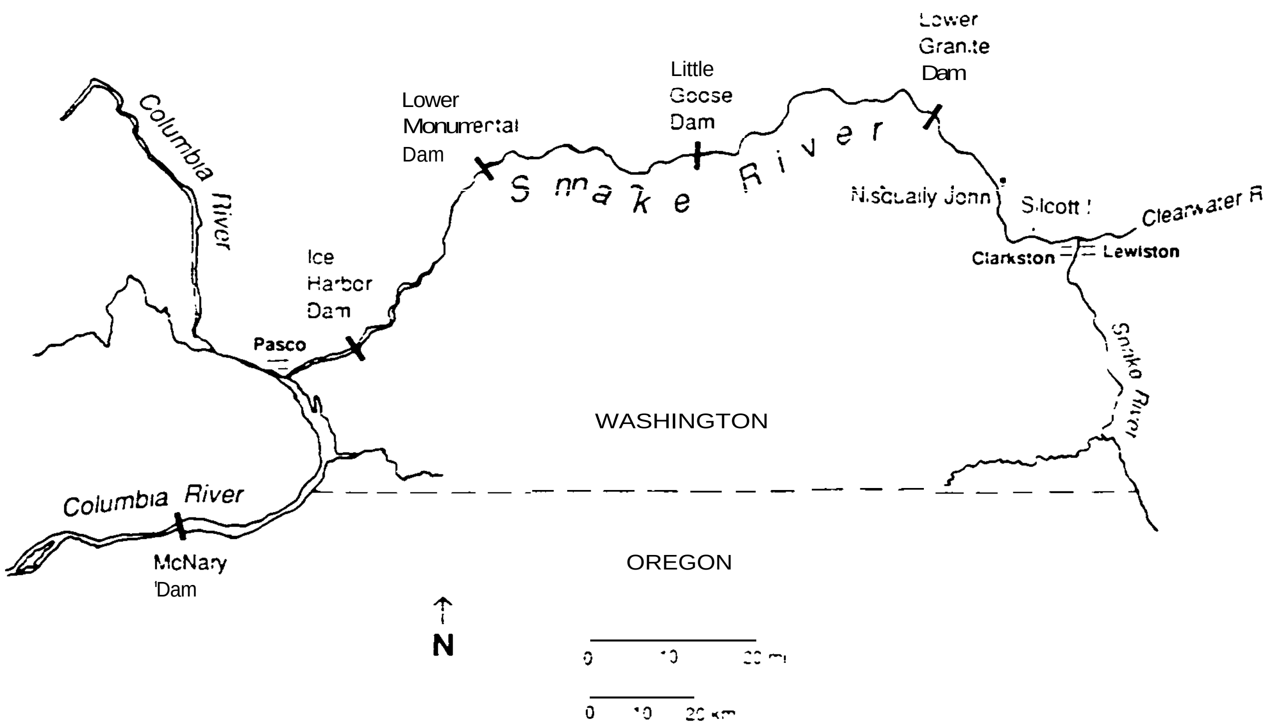

Figure 1. Study area showing release and recapture sites.

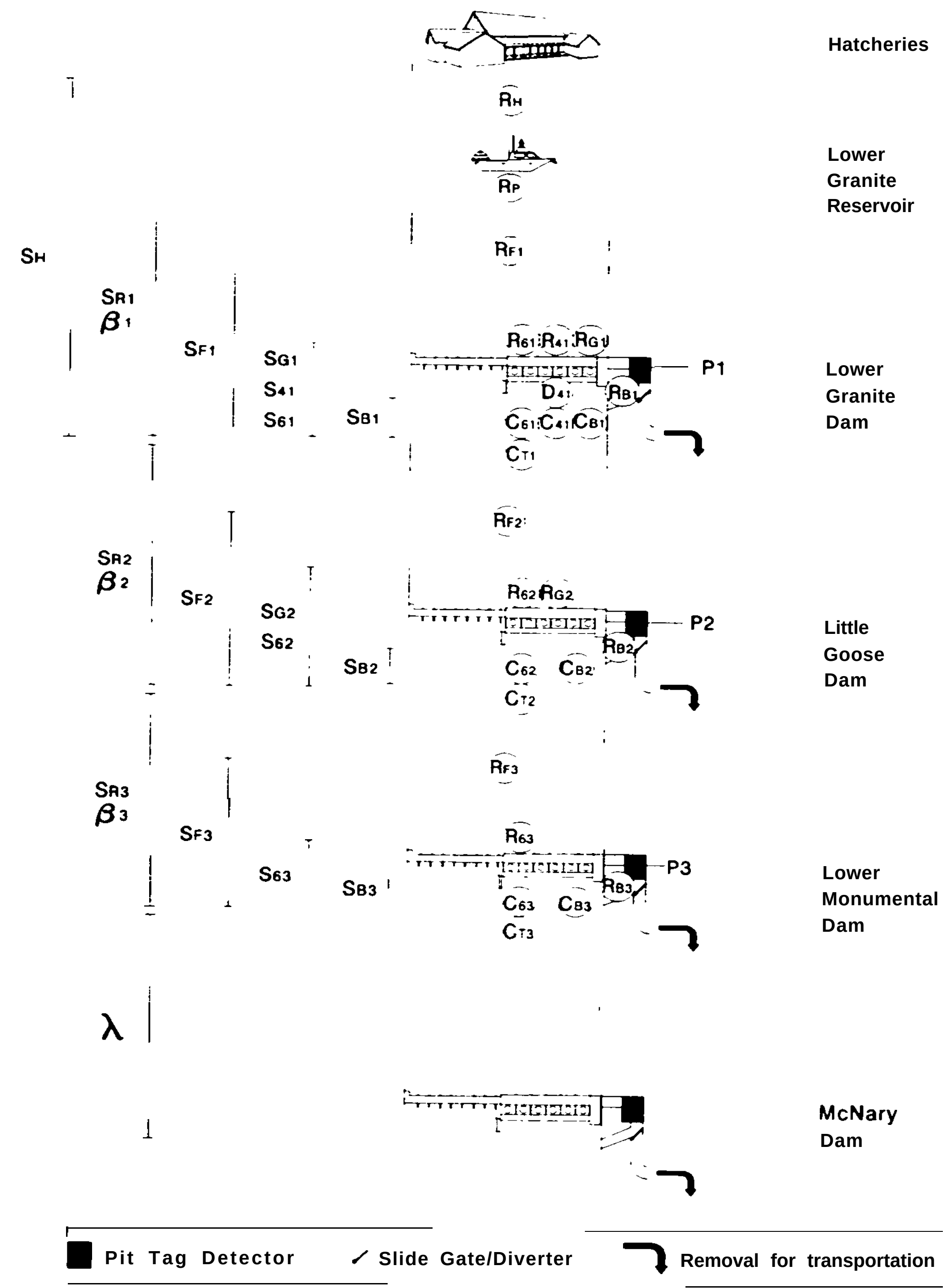

Figure 2. Schematic of study area showing location of study sites, release groups (circled), and estimated parameters. (See Tables 1 and 2 for release group and parameter definitions).

Table 1. Release groups of PIT-tagged yearling chinook salmon and steelhead for 1994 survival studies.

Release	Definition
R_P	Primary release groups of hatchery fish, Lower Granite Reservoir
R_{PW}	Primary release group of wild fish, Lower Granite Reservoir
R_{B1}	Post-detection bypass treatment release groups, Lower Granite Dam
R_{G1}	Collection channel (gallery) release groups, Lower Granite Dam
C_{B1}	Bypass reference release groups, Lower Granite Dam
R_{41}	Turbine Unit 4 treatment release groups, Lower Granite Dam
C_{41}	Turbine Unit 4 tailrace reference release groups, Lower Granite Dam
D_{41}	Turbine Unit 4 draft tube reference release groups, Lower Granite Dam
R_{61}	Turbine Unit 6 treatment release groups, Lower Granite Dam
C_{61}	Turbine Unit 6 tailrace reference release groups, Lower Granite Dam
R_{F1}	Forebay treatment release groups, Lower Granite Dam
C_{T1}	Tailrace reference release groups, Lower Granite Dam
R_{B2}	Post-detection bypass treatment release groups, Little Goose Dam
R_{G2}	Collection channel (gallery) release groups, Little Goose Dam
C_{B2}	Bypass reference release groups, Little Goose Dam
R_{62}	Turbine Unit 6 treatment release groups, Little Goose Dam
C_{62}	Turbine Unit 6 tailrace reference release groups, Little Goose Dam
R_{F2}	Forebay treatment release groups, Little Goose Dam
C_{T2}	Tailrace reference release groups, Little Goose Dam
R_{B3}	Post-detection bypass treatment release groups, Lower Monumental Dam
C_{B3}	Bypass reference release groups, Lower Monumental Dam
R_{63}	Turbine Unit 6 treatment release groups, Lower Monumental Dam
C_{63}	Turbine Unit 6 tailrace reference release groups, Lower Monumental Dam
R_{F3}	Forebay treatment release groups, Lower Monumental Dam
C_{T3}	Tailrace reference release groups, Lower Monumental Dam
R_H	Hatchery release groups

hatchery steelhead (R_P) captured by purse seine in Lower Granite Reservoir and PIT tagged near Silcott Island (Table 1). There were 10 releases of hatchery yearling chinook salmon, 1 release of wild yearling chinook salmon, and 9 releases of hatchery steelhead over the course of the spring migration. Recapture histories from each group were used in the SR Model to estimate survival for three river sections: from release to Lower Granite Dam tailrace, from Lower Granite Dam tailrace to Little Goose Dam tailrace, and from Little Goose Dam tailrace to Lower Monumental Dam tailrace. If-there was significant post-detection bypass mortality, the R_P group was combined in the MSR Model with paired releases for the Lower Granite, Little Goose, and Lower Monumental Dam bypass systems.

Post-detection Bypass Paired Release Groups

Releases were made at Lower Granite (R_{B1}, C_{B1}), Little Goose (R_{B2}, C_{B2}), and Lower Monumental Dams (R_{B3}, C_{B3}) (Table 1). The post-detection bypass treatment groups (R_{B1}, R_{B2}, R_{B3}) were released in the bypass flume at the juvenile collection facility at each dam just downstream from the PIT-tag detector. The reference groups (C_{B1}, C_{B2}, C_{B3}) were released into the river in the zone where detected fish remixed with nondetected fish.

Preliminary analyses of recapture histories from the paired post-detection bypass and tailrace releases were conducted, using the PR Model, to determine whether significant mortality occurred between the time of detection and the time of remixing. If post-detection mortality was not significant, primary releases were analyzed using the SR Model. Otherwise, the MSR Model was applied. The post-detection bypass releases at each dam were the secondary releases for the MSR Model.

Analysis of the bypass-system releases did not provide an estimate of overall mortality associated with the entire route through the juvenile bypass system. The purpose of these releases was solely to estimate post-detection bypass mortality.

Turbine, Collection Channel, and **Forebay** Paired Release Groups

Releases were made at Lower Granite (R_{41}, R_{61}, R_{G1}, R_{F1}, C_{41}, D_{41}, C_{61}, C_{B1}, C_{T1}), Little Goose (R_{62}, R_{G2}, R_{F2}, C_{62}, C_{B2}, C_{T2}), and Lower Monumental Dams (R_{63}, R_{F3}, C_{63}, C_{T3}) (Table 1). Each pair of releases at each dam was analyzed separately using the PR Model to obtain estimates of survival probabilities associated with the respective routes of passage.

Only hatchery yearling chinook salmon and hatchery steelhead, determined by the absence of either adipose or ventral fins, were used for releases at the dams. Fish with injuries, excessive descaling, or obvious signs of bacterial kidney disease (BKD) were excluded (generally less than 1%, details in the Results section), as were previously PIT-tagged fish (identified by scanning with a PIT-tag detector). At each dam, there were generally three replications of each set of releases using hatchery yearling chinook salmon, and two replications of each set of releases using hatchery steelhead.

Estimated Parameters

Table 2 gives the complete list of parameters estimated from all releases (also see Fig. 2), and Table 3 identifies which parameters were estimated from each release or set of releases. Survival probabilities were estimated for the following river sections: 1) from the point of primary release to the tailrace of Lower Granite Dam (S_{R1}), 2) from Lower Granite Dam tailrace to Little Goose Dam tailrace (S_{R2}), and 3) from Little Goose Dam tailrace to Lower Monumental Dam tailrace (S_{R3}) (Fig. 2). Paired releases were analyzed using the PR Model to estimate survival probabilities for the respective passage routes.

Fish Collection and Handling

Lower Granite Reservoir

For the primary release groups in Lower Granite Reservoir, fish were collected using two purse-seine vessels fished simultaneously upstream from Silcott Island (Durkin and Park 1967). Purse seines were approximately 229-m long and 11-m deep with 1- to 2-cm webbing (stretch measure). Effective fishing depth was about 6 m. Seines were towed upstream in a "U" shape for 10 to 30 minutes prior to closing the net bottom (pursing). Purse seining was conducted at dawn or occasionally at dusk when chinook salmon were the target species, and during mid-morning and afternoon when steelhead were the target species. Juvenile salmonids were removed from the purse seine with a sanctuary dip net to reduce stress. They were held in 120-L plastic containers

Table 2. Definition of parameters estimated from releases.

Parameter	Definition
S_{R1}	Probability of survival from point of primary release to tailrace of Lower Granite Dam (Lower Granite Dam "reach" survival).
S_{B1}	Probability of survival from just below slide gate to bypass outfall at Lower Granite Dam (Lower Granite Dam post-detection bypass survival).
S_{G1}	Probability of survival from release into collection channel (gallery) to bypass outfall at Lower Granite Dam (Lower Granite Dam collection channel survival).
S_{41}	Probability of survival from release into Turbine Unit 4 to tailrace of Lower Granite Dam (Lower Granite Dam Turbine Unit 4 survival).
S_{61}	Probability of survival from release into Turbine Unit 6 to tailrace of Lower Granite Dam (Lower Granite Dam Turbine Unit 6 survival).
S_{F1}	Probability of survival from release into forebay to tailrace of Lower Granite Dam (Lower Granite Dam passage survival).
P_1	Probability of detection at Lower Granite Dam, given that fish survived to Lower Granite Dam.
β_1	Vector of slope parameters for covariates affecting survival from primary release point to Lower Granite Dam tailrace.
S_{R2}	Probability of survival from Lower Granite Dam tailrace to Little Goose Dam tailrace (Little Goose Dam "reach" survival).
S_{B2}	Probability of survival from just below slide gate to bypass outfall at Little Goose Dam (Little Goose Dam post-detection bypass survival).
S_{G2}	Probability of survival from release into collection channel (gallery) to bypass outfall at Little Goose Dam (Little Goose Dam collection channel survival).
S_{62}	Probability of survival from release into Turbine Unit 6 to tailrace of Little Goose Dam (Little Goose Dam Turbine Unit 6 survival).
S_{F2}	Probability of survival from release into forebay to tailrace of Little Goose Dam (Little Goose Dam passage survival).
P_2	Probability of detection at Little Goose Dam, given that fish survived to Little Goose Dam.

Table 2. Continued.

Parameter	Definition
β_2	Vector of slope parameters for covariates affecting survival from Lower Granite Dam tailrace to Little Goose Dam tailrace.
S_{R3}	Probability of survival from Little Goose Dam tailrace to Lower Monumental Dam tailrace (Little Goose Dam "reach" survival).
S_{B3}	Probability of survival from just below slide gate to bypass outfall at Lower Monumental Dam (Lower Monumental Dam post-detection bypass survival).
S_{63}	Probability of survival from release into Turbine Unit 6 to tailrace of Lower Monumental Dam (Lower Monumental Dam Turbine Unit 6 survival).
S_{F3}	Probability of survival from release into forebay to tailrace of Lower Monumental Dam (Lower Monumental Dam passage survival).
P_3	Probability of detection at Lower Monumental Dam, given that fish survived to Lower Monumental Dam.
β_3	Vector of slope parameters for covariates affecting survival from Lower Granite Dam tailrace to Lower Monumental Dam tailrace.
λ	Probability that a fish surviving to Lower Monumental Dam tailrace is eventually detected at McNary Dam (includes reach survival and probability of detection at McNary Dam).
S_H	Probability of survival from release at hatchery to tailrace of Lower Granite Dam.

Table 3. Parameters estimated from each set of releases.

Set of releases	Parameters estimated	Model for analysis
R_P, R_{B1}, C_{B1}	S_{R1}, S_{B1}, P_1 β_1	Single-release (Modified if necessary)
R_{G1}, C_{B1}	S_{G1}	Paired-release (Complete capture history)
R_{41}, C_{41}	S_{41}	Paired-release (Complete capture history)
R_{41}, D_{41}	S_{41}	Paired-release (Complete capture history)
R_{61}, C_{61}	S_{61}	Paired-release (Complete capture history)
R_{F1}, C_{T1}	S_{F1}	Paired-release (Complete capture history)
R_P, R_{B2}, C_{B2}	S_{R2}, S_{B2}, P_2 β_2	Single-release (Modified if necessary)
R_{G2}, C_{B2}	S_{G2}	Paired-release (Complete capture history)
R_{62}, C_{62}	S_{62}	Paired-release (Complete capture history)
R_{F2}, C_{T2}	S_{F2}	Paired-release (Complete capture history)
R_P, R_{B3}, C_{B3}	S_{R3}, S_{B3}, P_3 β_3	Single-release (Modified if necessary)
R_{63}, C_{63}	S_{63}	Paired-release (First capture history)
R_{F3}, C_{T3}	S_{F3}	Paired-release (First capture history)
R_H, R_{B1}, C_{B1}	S_H	Single-release (Modified if necessary)

with flow-through water after each purse-seine set until transport back to a marking barge. Densities in the containers were kept at less than 100 fish/container. Adult steelhead and nonsalmonids were removed from the purse seine, counted, and returned to the reservoir as quickly as possible.

Fish sorting and marking were conducted on an 11-m marking barge anchored at the east end of Silcott Island. Fish transported from the purse-seine vessels were immediately transferred to 1.8 × 0.9 × 0.6 m aluminum tanks provided with flow-through water. Fish were held in these tanks until processing, then dipped from the tanks with a sanctuary dip-net (in which they were anesthetized with MS 222), and transferred into a 5-L dish pan. The anesthetized fish were then sorted.

Fish were rejected for tagging by the following criteria: non-target species or race, previously PIT tagged, excessively descaled, and obvious deformities and abnormalities. Rejected fish were counted, and held in net-pens (1.2 × 0.5 × 0.6 m) (Rottiers 1991) adjacent to the barge, and released after a minimum 4-hour recovery period.

Gill samples were collected periodically for gill Na^{+}-K^{+} ATPase assay from anesthetized fish (30 fish per group) by the National Biological Survey (NBS). Sampled fish were returned to their release group.

Lower Granite Dam

At Lower Granite Dam, fish were obtained from the juvenile collection facility. The sample gate was opened to direct fish into the upstream raceways. These raceways are normally used for transportation research or when lower raceways are filled to capacity. The collection rate was adjusted to obtain the target number of fish for marking. A portable wet separator was used at this site during 1994 to reduce handling of non-target species. The separator consisted of 1.6-cm inclined cylindrical bars with 1.6-cm spacing (173 cm in length) placed near the end of the flume leading to the raceways. The separator was continuously monitored when in use and removed after sufficient numbers of fish were collected.

Fish sorting and marking were conducted in the NMFS transportation marking trailer adjacent to the east bank of raceways. Fish were preanesthetized with benzocaine and alcohol, using the NMFS transportation marking procedures (Matthews et al. 1987). During sorting and marking inside the trailer, fish were anesthetized with MS 222 in a recirculating anesthetic system at a concentration of approximately 50 mg/L. Steelhead and chinook salmon rejected for tagging (same criteria used in the reservoir) were counted and returned to an adjacent raceway for loading onto the next available transport barge. Mortalities in the raceways before and after sorting were counted and apportioned between the facility (U.S. Army Corps of Engineers) and this study.

Hatchery steelhead used for forebay releases were either captured by purse seine near Silcott Island and transported via truck or barge in aluminum tanks to net-pens (1.8 × 0.9 × 0.7 m) anchored in the forebay, or purse seined in the forebay area near

Wawawai Boat Landing (RKm 698) and placed in net-pens. Hatchery yearling chinook salmon used in forebay releases were obtained from the collection facility and held in net-pens.

Little Goose and Lower **Monumental Dams**

At Little Goose and Lower Monumental Dams, all fish (including forebay releases) were obtained from the juvenile collection facilities. Both dams have permanent juvenile salmonid separators that sort fish on the basis of size into two tanks, with one tank receiving predominantly steelhead. Collection rates for each tank were adjusted to obtain the number of target species for marking. This reduced the number of non-target species handled unnecessarily.

Fish sorting and marking were conducted in the sample facilities at Little Goose and Lower Monumental Dams. Fish were preanesthetized with benzocaine and alcohol, using the NMFS transportation marking procedures (Matthews et al. 1987) and were conveyed to the sample facility by gra

Marking Procedures

PIT Tagging

Prior to tagging, each fish was prescanned during the sorting process to reduce the possibility of double tagging. Fish that were not previously tagged were PIT tagged using modified hypodermic syringes containing a push rod, terminal air hole, and 12-gauge needle (Prentice et al. 1990c, Nielsen 1992). To reduce the likelihood of disease transmission, all needles were soaked in 70% ethyl alcohol for a minimum of 10 minutes before loading with a PIT tag. The PIT-tag needle was inserted anteroventrally alongside the midventral line between the ventral and pelvic fins, and the tag was placed into the body cavity posterior to the pyloric caeca (Prentice et al. 1990c).

Each fish was then scanned to record the PIT-tag code and examined for injuries, descaling, brands, bleeding, or other abnormalities. Finally, length was measured, and comments were recorded on a digitizing board (Prentice et al. 1990c). Tagged fish were returned via pipe to a labeled holding tank until release. Because of the limited amount of space available for marking at the dams, fish were not randomized between treatment and reference groups during marking. Instead, fish were marked by groups into tanks containing one-half of a release group each. Tanks were then randomly designated as treatment or reference releases.

Tag Retention

Tag retention was estimated by rescanning a portion of fish tagged specifically for this purpose. Tagged fish were held in 120-L plastic containers at the dams (or in net pens in the reservoir) for 24 hours, anesthetized, and rescanned. The number tagged daily for tag-retention estimates ranged from 44 to 107.

Delayed Mortality

No samples of PIT-tagged fish were taken specifically to evaluate 24-hour delayed mortality. Instead, mortalities from all release containers were removed, scanned, and recorded prior to release, at least 24 hours after tagging. PIT-tag codes of mortalities were later deleted from tag files.

Release Procedures

Lower Granite Reservoir

Yearling chinook salmon PIT tagged and released in the reservoir as primary release groups were kept in net-pens (1.8 × 0.9 × 0.7 m) for 32 to 54 hours prior to release. The net-pens were anchored approximately 8 m offshore in a semi-protected area out of the main current. For release, they were towed farther offshore and downstream several hundred meters into the main current. Mortalities were removed, and the net-pens were rolled over to permit fish to escape. All releases were made between 2000 and 2200 hours.

Lower Granite Dam

Release locations for Lower Granite Dam are shown in Figure 3. Most release groups of PIT-tagged fish, except the post-detection bypass release group and the forebay release group, were held for at least 24 hours in aluminum tanks (1.8 × 1.2 × 0.6 m) mounted on flatbed trucks. Water quality was maintained with flow-through water until release time. The post-detection bypass release group was held in a 1.8 × 1.2 × 0.6-m aluminum tank with flow-through water located just above the slide gate on the main separator walkway. Dissolved oxygen and temperature in all containers were periodically checked with an electronic meter. Fish were released from the holding tank into the bypass flume tank located just upstream from the Diversion A and B PIT-tag detectors.

After switching from flow-through water to static oxygenated water, the turbine-treatment, collection-channel, and draft-tube release groups were transported by truck in their container to the forebay or tailrace deck where the tank was attached with a camlock fitting to a flexible hose. The turbine-release hoses (10.2 cm × 53.3 m) were attached to the submersible traveling screens (STS) in the B slots of Turbine Units 4 and 6. The other end of the release hose was approximately 1 m below the STS. The collection-channel release hose (7.6 cm × 12.2 m) extended from the intake deck, through an opening in Gatewell 6A into the

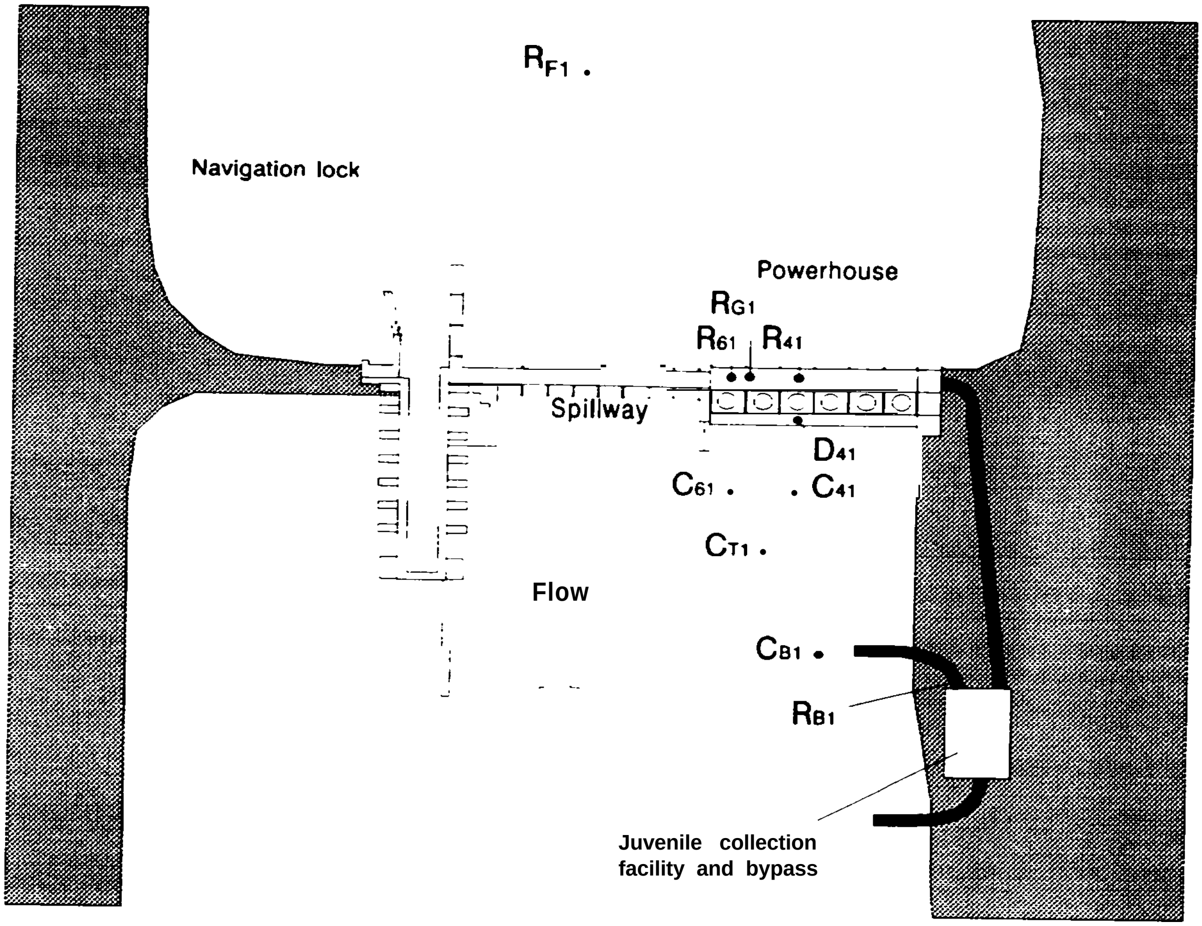

Figure 3. Schematic of Lower Granite Dam showing locations of bypass (R_{B1}), collection channel (R_{G1}), draft tube (D_{41}), forebay (R_{F1}), turbine (R_{41} and R_{61}) and reference (C_{B1}, C_{T1}, C_{41}, C_{61}) releases.

collection channel just below the water surface. The draft-tube release hose was 10.2-cm by 30.5-m. Emergency deck water was used to flush the hose after all releases.

Forebay releases were made after towing the net-pens upstream approximately 2 km. Mortalities were removed and the net-pens rolled over to permit fish to escape.

After switching from flow-through water to oxygen, reference releases were transported by truck in their containers either to a boat ramp located approximately 3.5 km downstream or to the fish transport barge storage area located north of the spillway. Fish were then transferred via 10.1-cm PVC pipe to aluminum tanks (1.8 × 0.9 × 0.6 m) mounted on board a small barge. The barge then motored (flow-through water was provided to the tanks) to the release site (Fig. 3), and fish were released through a 10.2-cm hose after mortalities were removed.

Little Goose and Lower Monumental Dams

Release locations for Little Goose and Lower Monumental Dams are shown in Figures 4 and 5. All release equipment and procedures were the same as those at Lower Granite Dam except for the post-detection bypass treatment groups, which were held in aluminum tanks until release. At release, fish in these groups were dip-netted with a sanctuary net into 19-L buckets, hauled up to the PIT-tag diverter tank, and released. Procedures for the turbine-released groups, including selection of Turbine Unit 6 as the test turbine, were identical to those at Lower Granite Dam

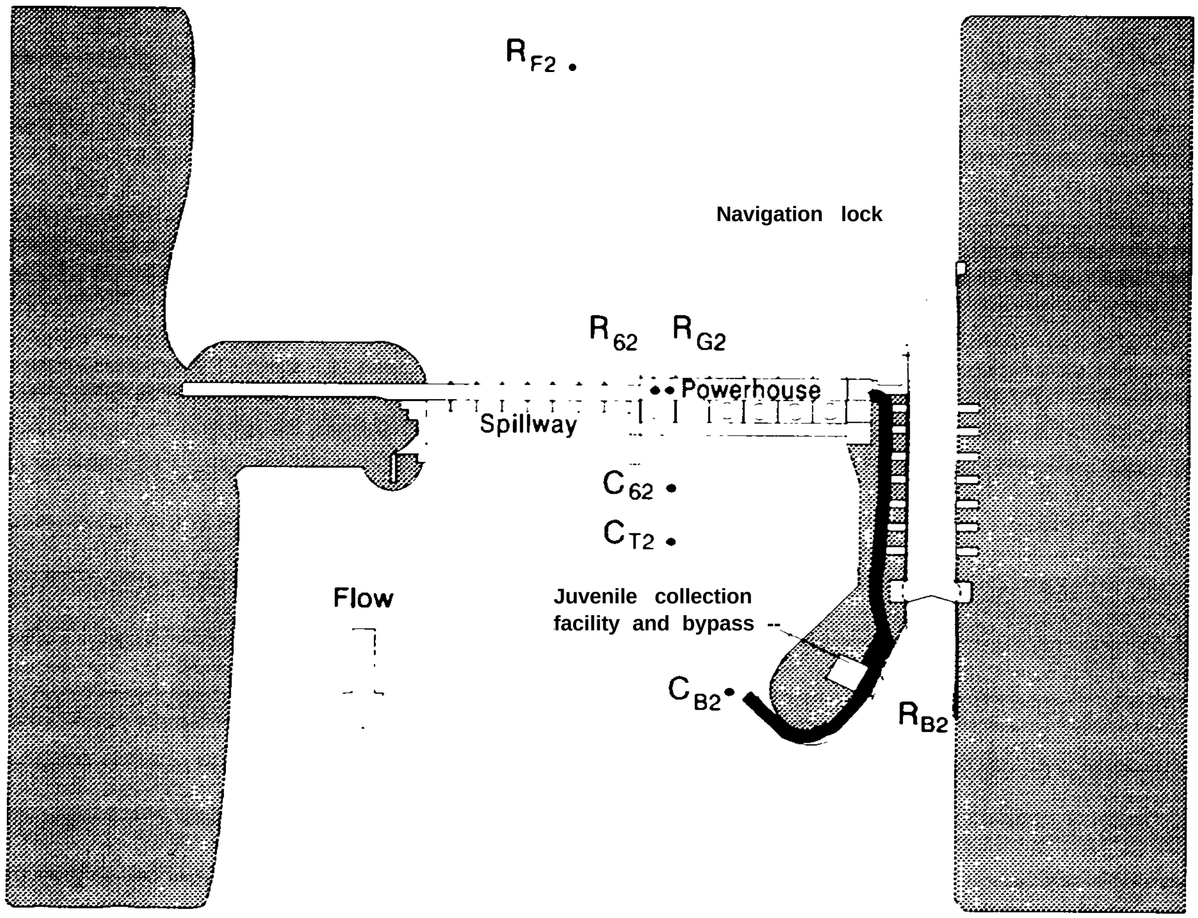

Figure 4. Schematic of Little Goose Dam showing locations of bypass (R_{B2}), collection channel (R_{G2}), forebay (R_{F2}), turbine (R_{62}) and reference (C_{B2}, C_{T2}, C_{62}) releases.

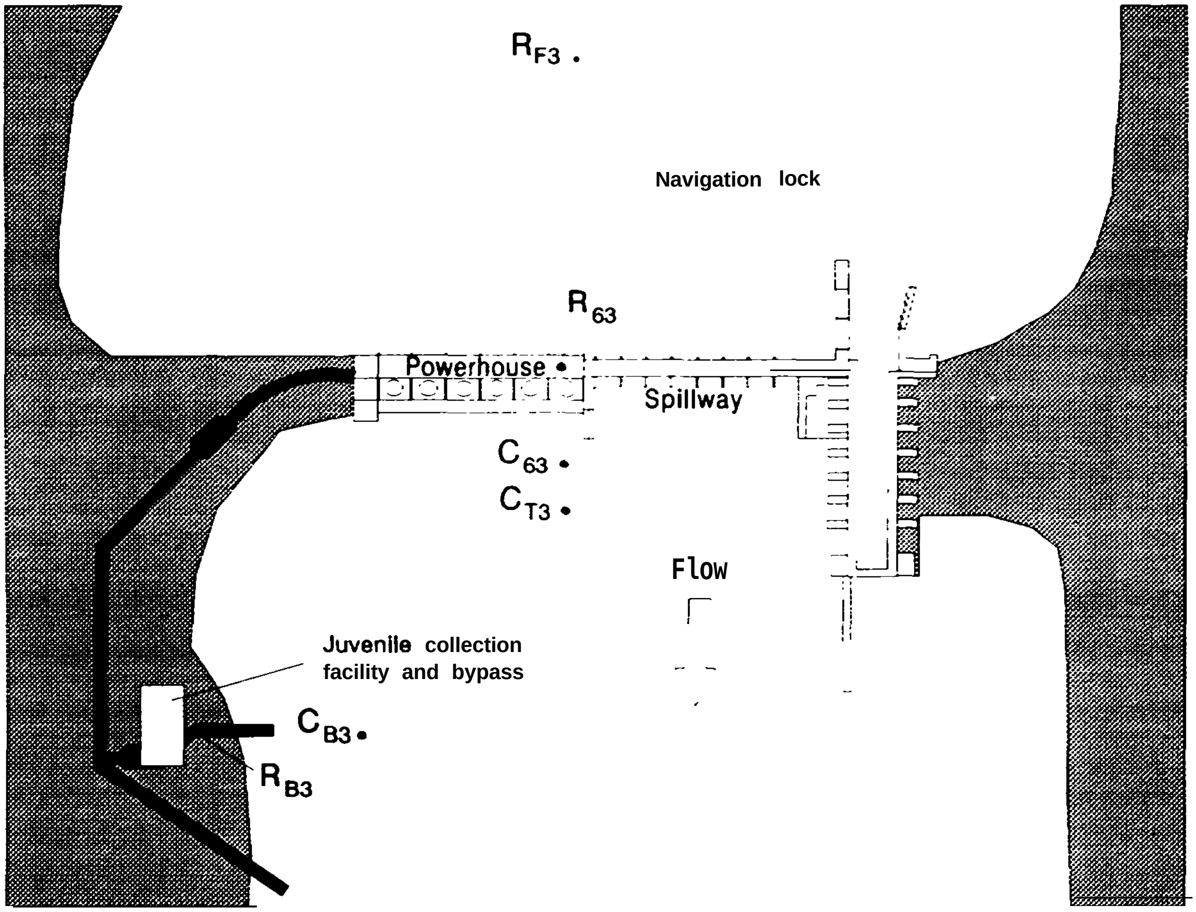

Figure 5. Schematic of Lower Monumental Dam showing locations of bypass (R_{B3}), forebay (R_{F3}), turbine (R_{63}) and reference (C_{B3}, C_{T3}, C_{63}) releases.

except that at Lower Monumental Dam, an additional tank of water was emptied after release to flush fish from the hose.

Project Operations

Slide-Gate Operation

To divert PIT-tagged fish back to the river, slide-gate systems at Lower Granite, Little Goose, and Lower Monumental Dams (Achord et al. 1992) were operated for the duration of the study. At Lower Granite Dam, operations began on 2 April; at Little Goose Dam, on 6 April; and at Lower Monumental Dam, on 7 April. Slide-gate or diversion efficiency (through the end of June) was determined by comparing the number of PIT-tagged smolts detected upstream with those detected downstream from the slide gate.

Turbine Load and Spill

Average daily flow and spill for each dam equipped with a PIT-tag detection system were obtained from Fish Passage Center weekly reports.[1] Turbine load, spill-gate settings, forebay elevation, and tailrace elevation during releases at Lower Granite, Little Goose, and Lower Monumental Dams were obtained from operators' logs.

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[1]Fish Passage Center, Suite 230, 2501 S. W. First Ave., Portland, OR 97201-4752.

Data Analysis

At the conclusion of each tagging session, data were electronically transferred to the PIT Tag Information System (PTAGIS) maintained by the Pacific States Marine Fisheries Commission[2]. Data were uploaded to a tagging file. The file contained information on the tagging session (e.g., tagging date, location, etc.), and individual records for each tagged fish, consisting of the PIT-tag code, species, rearing type, length (mm), and a comment field for miscellaneous information.

During the course of the season, detections at each site were automatically uploaded to observation files in PTAGIS. There were multiple detectors at each site, and each detector had two or more coils by which the PIT tag could be read. Therefore, each record in an observation file included PIT-tag codes of detected fish, the tagging file in which the PIT-tag code could be found, the observation site, the date and time of the detection, the number of coils, the ID codes for the coils, and the elapsed time in days between release and detection.

The first step of data analysis was retrieval of data from the PTAGIS tagging and observation files. For each release, a report in the comma-separated variable (CSV) format was generated from each file (Table 4). The report from the tagging file contained only tagging information (a single record for each

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[2] Pacific States Marine Fisheries Commission, PIT Tag Operations Center, 45 SE 82nd Drive, Suite 100, Gladstone, OR 97207.

Table 4. Variables in PTAGIS comma-separated-variable (CSV) list reports of tagging and observation information.

a) Tagging information

Variable name	Description
file_id	tagging file title
tag_id	PIT-tag code
t-species	species
t-rear-type	rearing type (hatchery or wild)
length	length of fish (mm)

b) Observation information

Variable name	Description
file-id	tagging file title
tag-id	PIT-tag code
obs site	code for site of observation
obs_date	date and time of observation
nreads	number of coils on which tag was read
coil1	coil ID of first coil
coil2	coil ID of second coil (blank if nreads = 1)
travel time	elapsed time (days) since release

fish), while the observation file report could generate multiple records of a fish, depending upon the number of times it was detected.

Database Quality Assurance/Control

Tagging and observation reports were examined for erroneous records, inconsistencies, and data anomalies. Records were eliminated where appropriate. A record was kept of all PIT-tag codes eliminated and the reasons for their elimination. Records were eliminated for the following reasons:

1) Fish was incorrect species (e.g., steelhead in a chinook salmon tagging file).

2) Fish was incorrect rearing type (e.g., wild fish in a hatchery fish tagging file).

3) Fish was detected at the release site. For example, a fish released into a turbine unit at a dam should not be detected in the bypass system at that same dam. On the other hand, some fish released in the collection channel or forebay treatment groups are expected to be detected at the dam at which they were released. Fish in collection channel and forebay test releases were eliminated from analysis only if the detection record indicated they were removed for transportation.

4) Fish had previously been PIT tagged.

5) Fish was later recaptured during fish-collection activities of the NMFS/UW study.

6) Length of the fish was not recorded, or recorded as zero millimeters.

7) The PIT-tag code appeared in tagging files for more than one release that occurred on the same day.

8) Detections were recorded "out of order." For example, PIT-tag codes were removed from the data base if a detection at Little Goose Dam was recorded at an earlier date than a detection at Lower Granite Dam.

9) A detection was recorded for a PIT-tagged fish before its recorded release date.

10) Fish died between the time of tagging and data uploading and the time of release (handling mortality).

As a result of the quality assurance/control process, all statistical analyses were based on fish of measured length that were known to be released alive in the intended release group. The process also ensured that fish were handled (and detained) only once, and that records of downstream detections were internally consistent and logical.

Capture Histories

The data for the SR, MSR, and PR Models are the capture histories for each tagged fish. The capture history for a tagged fish indicated the disposition of a fish at each monitoring site (Table 5).

The capture history for each fish in each tagging file was constructed by examining the coil ID codes for each record in the observation file. At each dam, fish first passed the "Gate" detector, which triggered the slide gate whenever a PIT tag was detected. Diverted fish could then be detected on their way back

Table 5. Potential capture histories for PIT-tagged juvenile salmonid migrants released above Lower Granite Dam. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-&Nary Dam.

History	Explanation
1111	Detected and returned to river at LGR, LGO, and LMN, detected at MCN.
1110	Detected and returned to river at LGR, LGO, and LMN, not detected at MCN.
1120	Detected and returned to river at LGR and LGO, detected and removed at LMO.
1101	Detected and returned to river at LGR and LGO, not detected at LMO, detected at MCN.
1100	Detected and returned to river at LGR and LGO, not detected at LMO or MCN.
1200	Detected and returned to river at LGR, detected and removed at LGO.
1011	Detected and returned to river at LGR, not detected at LGO, detected and returned to river at LMO, detected at HCN.
1010	Detected and returned to river at LGR, not detected at LGO, detected and returned to river at LMO, not detected at LMO.
1020	Detected and returned to river at LGR, not detected at LGO, detected and removed at LMO.
1001	Detected and returned to river at LGR, not detected at LGO or LMO, detected at MCN.
1000	Detected and returned to river at LGR, not detected at LGO, LMO, or MCN.
2000	Detected and removed at LGR.

Table 5. Continued.

History	Explanation
0111	Not detected at LGR, detected and returned to river at LGO and LMO, detected at McNary.
0110	Not detected at LGR, detected and returned to river at LGO and LMO, not detected at MCN.
0120	Not detected at LGR, detected and returned to river at LGO, detected and removed at LMO.
0101	Not detected at LGR, detected and returned to river at LGO, not detected at LMO, detected at MCN.
0100	Not detected at LGR, detected and returned to river at LGO, not detected at LMO, or MCN.
0200	Not detected at LGR, detected and removed at LGO.
0011	Not detected at LGR or LGO, detected and returned to river at LMO, detected at MCN.
0010	Not detected at LGR or LGO, detected and returned to river at LMO, not detected at MCN.
0020	Not detected at LGR or LGO, detected and removed at LMO.
0001	Not detected at LGR, LGO, or LMO, detected at MCN.
0000	Never detected after release.

to the river by one or more detectors on the diversion line, while fish not diverted could be detected again on their way to the transportation raceways.

Because the slide gates at all three dams were not 100% effective, some detected fish were not returned to the river. Rather, they were guided to raceways in the juvenile bypass facility and then transported downriver by truck or barge. Such fish gave no information regarding inriver survival or detection probabilities downstream from their removal. However, because the removed fish were known, the models could be adjusted to account for removals.

If a fish was detected only by the "Gate" detector, it was impossible to determine whether it was returned to the river or transported. Such fish were considered removed. This does not bias any of the estimated parameters, but does decrease the precision of estimation by decreasing the sample size.

There were three codes for capture history at each dam: capture history "1" --a fish detected and diverted back to the river; capture history "2" --a fish detected but removed from the system for sampling or transportation or unknown disposition; and capture history "0" --a fish not detected at the PIT-tag detection site. For example, a fish released in Lower Granite Reservoir had a capture history of "1020" if it were detected and diverted at Lower Granite Dam, not detected at Little Goose Dam, and detected and transported from Lower Monumental Dam.

At Lower Granite Dam, a fish was considered detected and diverted back to the river (capture history "1") if its tag was read by the "Diversion" detector, and detected and removed (capture history "2") if it was read by the "Main" or "Sub" detectors. At Lower Monumental and Little Goose Dams, the capture history was "1" if the fish was detected by the "Diversion" or "River Release" detectors and "2" if detected by the "Main" or "Sample Room" detectors. A detection on any coil at McNary Dam indicated a "1" for the final digit of the capture history.

Tests of Assumptions

A primary objective of the studies in 1994 was to test the statistical validity of the SR, MSR, and PR Models as applied to the data generated from PIT-tagged juvenile salmonids in the Snake River. Validity of the models was tested by evaluating their critical assumptions. For the SR Model the critical assumptions are:

A1) A fish's detection at a PIT-tag detection site does not affect its probability of subsequent detection at downstream sites.

A2) A fish's detection at a PIT-tag detection site does not affect its probability of subsequent survival through downstream river reaches.

A3) Detected fish suffer no significant post-detection bypass mortality before remixing with non-detected fish.

If Assumption A3 failed, the MSR Model was used in place of the SR Model to analyze the primary releases. Each release under the MSR Model is assumed to satisfy Assumptions A1 and A2. There is one additional critical assumption for the post-detection bypass releases:

A4) Treatment release groups and their corresponding reference groups mix evenly and travel together downstream from the source of mortality under investigation.

The PR Model shares the assumptions of the MSR Model.

Taken together, tests of Assumptions A1 and A2 can be thought of as general tests of the "goodness of fit" of the SR Model to the data. Burnham et al. (1987) gave a series of goodness of fit tests to be used for the SR Model (TESTs 2 and 3, Burnham et al. 1987, p. 71-77) and noted that factors that lead to rejection of the tests include heterogeneity of parameters across individuals, failure of the assumption of independent fish fates, and behavioral response to capture and subsequent release (i.e., passage through a juvenile bypass facility).

Assumptions Al and A2--A fish's detection at a PIT-tag detection site does not affect its probability of subsequent survival in downstream reaches or of subsequent detection at downstream sites.

Tests of Assumptions A1 and A2 were based on two main types of information: 1) daily passage distributions for groups or subgroups of tagged fish that were assumed to have traveled together, and 2) summaries of capture histories for groups or subgroups that were assumed to have had equal survival and detection probabilities.

Detected and non-detected fish took different routes of passage through a dam. If detected and nondetected fish did not subsequently move downriver in an evenly mixed group, Assumption A1 could be violated. For example, fish might reside in gatewells for a period of time before moving through the bypass facility, resulting in separation from fish that passed through the turbines or spillway with no such delay. If these subgroups of a release were not passing through downstream reaches together, they might experience different conditions in the reservoirs or at downstream dams. This could lead to differential survival or detection probabilities downstream.

When multiple groups or subgroups had homogeneous downstream passage distributions, the groups were assumed to have experienced similar downstream conditions and consequently to have had equal survival and detection probabilities. However, if river conditions were not changing greatly day to day, evidence of heterogeneous passage distributions did not necessarily imply that survival and detection probabilities were unequal. The statistical tests we used were sensitive to shifts of as little as 1 day in the distributions of fish groups. If river conditions changed only slightly from day to day, survival and detection probabilities were not significantly different even when the hypothesis of homogeneous distributions was rejected.

To test the assumption of homogeneous passage downstream from Lower Granite Dam for primary-release fish detected versus not detected at Lower Granite Dam, we used the following *K X 2* contingency table:

		Detected at Lower Granite Dam	
		Yes	No
Day of Little Goose Dam passage	1		
	2		
	.	.	.
	.	.	.
	.	.	.
	K		

Table entries were the numbers of PIT-tagged fish from each subgroup detected at Little Goose Dam on each day.

Similar tests of homogeneity were based on daily tag detections at Lower Monumental Dam for four subgroups defined by capture history at Lower Granite and Little Goose Dams (four subgroups: "11,", "10," "01," and "00"), and on daily tag detections at McNary Dam for eight subgroups defined by capture history at Lower Granite, Little Goose, and Lower Monumental Dams ("111," "110," "101," "100," "011," "010," "001," and "000").

For each contingency table, the Pearson's-χ^2 statistic (Sokal and Rohlf 1981) was computed. Because of the sparseness of many of the contingency tables, especially in the later parts of the groups' passage distributions, the exact method (Mehta and Patel 1992) was used to compute P values for contingency tables. The exact method consists of iteratively constructing all possible contingency tables with the same number of rows and columns (*K X 2*) as the observed table and with the same row and column totals. The χ^2 statistic is computed for each table. The P value for the observed table is the proportion of all possible tables that had a χ^2 statistic as large or larger than that observed. Because of the impractically large number of possible tables, the reported P values are based on a random sample of 10,000 of the possible tables. The P value computed from the random sample is called a "Monte Carlo approximation."

Goodness of fit tests based on capture histories were computed for primary releases from Silcott Island and for all releases from Lower Granite Dam. Detectors and slide gates at additional downstream sites would be required to properly test goodness of fit for releases from Little Goose and Lower Monumental Dams; the configuration in 1994 provided insufficient data.

The goodness of fit tests provided by Burnham et al. (1987) were used. For primary releases, the available tests were (notation of Burnham, et al. 1987) TESTs 2.C2, 2.C3, 3.SR3, 3.Sm3, and 3.SR4 (Table 6). For Lower Granite Dam releases, there are only two tests available: TESTs 2.C2 and 3.SR3 (Table 7).

Table 6. Tests of goodness of fit to the Single-Release Model that can be calculated for releases above Lower Granite Dam (notation of Burnham et al. 1987). Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam.

Test	Tests homogeneity of	degrees of freedom
TEST 2.C2	First detection location below LGR for two subgroups of a primary release group defined by capture history at LGR.	2
TEST 2.C3	First detection location below LGO for two subgroups of a primary release group defined by capture history at LGO.	1
TEST 2	Sum of TEST 2.C2 and TEST 2.C3.	3
TEST 3.SR3	"Seen again versus not seen again" for two subgroups of a primary release group detected at LGO, defined by capture history at LGR.	1
TEST 3.Sm3	"Seen next at LMO versus seen next at MCN" for two subgroups of a primary release group detected at LGO, defined by capture history at LGR.	
TEST 3.SR4	"Seen again versus not seen again" for two subgroups of primary release group detected at LMO, defined by "seen at LGR or LGO versus not seen at LGR or LGO."	
TEST 3	Sum of TEST 3.SR3, TEST 3.Sm3, and TEST 3.SR4	3
Overall	Sum of TEST 2 and TEST 3.	6

Table 7. Tests of goodness of fit to the Single-Release Model that can be calculated for releases at Lower Granite Dam (notation of Burnham et al. 1987). Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam.

Test	Tests homogeneity of	degrees of freedom
TEST 2.C2	First detection location below LGO for two subgroups of a LGR release group defined by capture history at LGO.	1
TEST 3.SR3	"Seen again versus not seen again" for two subgroups of a LGR release group detected at LMO, defined by capture history at LGO.	1
Overall	Sum of TEST 2.C2 and TEST 3.SR3.	2

For primary releases, TEST 2.C2 tests homogeneity of downstream parameters for fish detected and not detected at Lower Granite Dam. The test is based on the following contingency table:

	Site first detected below LGR		
	LGO	LMO	MCN
Not detected at LGR			
Detected at LGR			

TEST 2.C3 for primary releases and TEST 2.C2 for Lower Granite Dam releases are based on the following table:

	Site first detected below LGO	
	LMO	MCN
Not detected at LGO		
Detected at LGO		

This table tests homogeneity of downstream parameters for fish detected and not detected at Little Goose Dam. For primary releases, the rows of the contingency table are summed across all fish, regardless of whether they were detected at Lower Granite Dam.

For primary releases, TESTS 3.SR3 and 3.Sm3 are computed by dividing fish detected at Little Goose Dam into those also detected at Lower Granite Dam and those not detected at Lower Granite Dam. TEST 3.SR3 is based on the following contingency table:

	Detected again at LMO or MCN	
	Yes	No
Detected at LGO, not detected at LGR		
Detected at LGO, detected at LGR		

TEST 3.Sm3 subdivides the "Yes" column of TEST 3.SR3 into the site of detection. The test is based on the table:

	Site first detected below LGO	
	LMO	MCN
Detected at LGO, not detected at LGR		
Detected at LGO, detected at LGR		

TEST 3.SR4 for primary releases is the same as TEST 3.SR3 for Lower Granite Dam releases. The table divides the fish detected at Lower Monumental Dam into those detected previously and those not detected previously:

	Detected again at MCN	
	Yes	No
Detected at LMO, not detected previously		
Detected at LMO, also detected previously		

For primary releases, "detected previously" includes possible detection at Lower Granite or Little Goose Dams, while for Lower Granite Dam releases, it includes only Little Goose Dam detection.

All contingency tables for TESTs 2 and 3 were analyzed using Pearson's-χ^2 test. Because the tables had sufficient data in all cells, P values were computed from the asymptotic distribution (i.e., not the exact method).

Assumption **A3**--Detected fish suffer no significant post-detection bypass mortality before remixing with non-detected fish.

The paired releases in the bypass systems at Lower Granite, Little Goose, and Lower Monumental Dams were planned expressly to test for significant post-detection bypass mortality using the PR Model. If differences in mortality between the test and reference groups were statistically significant, the MSR Model was used to analyze the primary releases; if they were not significant, the SR Model was used.

Assumption **A4**--Treatment release groups and their corresponding reference groups mix evenly and travel together downstream from the source of mortality under investigation.

Mixing is a sufficient, but not necessary, condition for equal survival and detection probabilities. If passage conditions do not change substantially over a short period of time, complete mixing may not be required. Because conditions do change, however, the extent of mixing is a valid basis for testing the assumption of equal conditions downstream. If good mixing can be shown, the assumption is satisfied.

Assumption A4 was tested for each treatment and reference pair using contingency table analyses of the passage distributions for treatment and reference groups at downstream detection sites. Monte Carlo approximation of the exact method was used to compute P values, similar to the set of tests used to check Assumptions A1 and A2.

Experiment-wise Error Rate

Each series of contingency table tests was considered to be a separate and independent experiment (Table 8). Significance levels for individual tests (α_T) were selected to control the experiment-wise Type I error rate (α_{EX}) (Table 9). For a given experiment-wise Type I error rate, the test-wise significance level was computed as follows (Sokal and Rohlf 1981):

$$\alpha_T = 1-(1-\alpha_{EX})^{\frac{1}{k}}$$

where k was the number of tests in the experiment. For example, for a series of nine tests, setting the experiment-wise Type I error rate to $\alpha_{EX} = 0.05$ required a test-wise significance level of $\alpha_T = 0.0057$.

Table 8. Number of contingency table tests in each series used to test assumptions Of Single-Release and Paired-Release Models. Abbreviations: LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam.

	Tests of homogeneity of passage distributions			Goodness-of-fit tests				
Releases	LGO	LMO	MCN	2.C2	2.C3	3.SR3	3.Sm3	3.SR4
Primary releases of hatchery yearling chinook salmon	10	10	10	10	10	10	10	10
Primary releases of wild yearling chinook salmon	1	1	1	1	1	1	1	1
Primary releases of hatchery steelhead	9	9	9	9	9	9	9	9
Post detection bypass/collection channel/reference releases of hatchery yearling chinook salmon from Lower Granite Dam	3	3	3	3	---	3	---	---
Post detection bypass/reference releases of hatchery steelhead from Lower Granite Dam	2	2	2	2	---	2	---	---
Forebay/reference releases of hatchery chinook salmon from Lower Granite Dam	1	1	1	1	---	1	---	---
Forebay/reference releases of hatchery steelhead from Lower Granite Dam	5	5	5	5	---	5	---	---

Table 8. Cont hued.

Releases	Tests of homogeneity of passage distributions: LGO	LMO	MCN	Goodness-of-fit tests: 2.C2	2.C3	3.SR3	3.Sm3	3.SR4
Post detection bypass/collection channel/reference releases of hatchery yearling chinook salmon from Little Goose Dam	---	3	3	---	---	---	---	---
Post detection bypass/reference releases of hatchery steelhead from Little Goose Dam	---	2	2	---	---	---	---	---
Forebaylreference releases of hatchery steelhead from Lower Granite Dam	---	2	2	---	---	---	---	---
Post-detection bypass/reference releases of hatchery yearling chinook salmon from Lower Monumental Dam	mm-	---	3	---	---	---	---	---
Post-detection bypass/reference releases of hatchery steelhead from Lower Monumental Dam	---	---	2	---	---	---	---	---

Table 9. Test-wise Significance (α_T) levels corresponding to experiment-wise Type I error rates of 0.10, 0.05, 0.01.

Number of tests	Experiment-wise significance levels (α_{EX})		
	0.10	0.05	0.01
1	0.1000	0.0500	0.0100
2	0.0513	0.0253	0.0050
3	0.0345	0.0170	0.0033
4	0.0260	0.0127	0.0025
5	0.0209	0.0102	0.0020
6	0.0174	0.0085	0.0017
7	0.0149	0.0073	0.0014
8	0.0131	0.0064	0.0013
9	0.0116	0.0057	0.0011
10	0.0105	0.0051	0.0010

Survival Estimation

The first task in estimating survival was to analyze bypass system releases at Lower Granite, Little Goose, and Lower Monumental Dams for significant post-detection mortality. Data from paired-releases at each site (R_{B1}, C_{B1}), (R_{B2}, C_{B2}), (R_{B3}, C_{B3}) were analyzed with the PR Model. The MSR Model was used to analyze the primary releases when the PR Model analysis indicated that post-detection bypass mortality was significant. The SR Model was used when the PR Model analysis did not indicate significant post-detection mortality.

Survival probabilities for paired collection channel, forebay, and turbine releases were also estimated using the PR Model. Each ($R_{[illegible]}$, $C_{[illegible]}$), ($R_{[illegible]}$, $C_{[illegible]}$), and ($R_{[illegible]}$, $C_{[illegible]}$) pair was analyzed independently. Because there were multiple detection sites downstream from Lower Granite and Little Goose Dams, the "complete capture history" protocol (Burnham et al. 1987) was used for paired releases from those two dams. For paired releases from Lower Monumental Dam, the "first capture history" protocol (Burnham et al. 1987) was used because there was only one downstream detection site.

Under the complete capture history protocol, the probability of survival for the passage route was estimated by applying the SR Model independently to treatment and reference groups. For reference groups, survival probability from the point of release to the next downstream dam was defined as S_R, and for test groups it was defined as the product of S_R and the probability of surviving the passage route under investigation (e.g., S_{G1} or S_{F2}). The passage survival probability was estimated as the ratio of the estimated survival probability for the treatment group to the estimate for the reference group. Under the first capture history protocol, the probability of survival for the passage route was estimated as the ratio of the proportion of the treatment group detected at McNary Dam to the proportion of the reference group detected ("relative recovery").

Estimates of survival probabilities under the SR, MSR and PR Models are random variables, subject to sampling variability. When true survival probabilities are close to 1.0 and/or when sampling variability is high, it is possible for estimates of survival probabilities to exceed 1.0. For practical purposes estimates should be considered equal to 1.0 in these cases.

When estimates for a particular river reach or passage route were available from more than one release or pairs of releases, the estimates were often combined using a weighted average. The weights were inversely proportional to the respective estimated variances, thus providing a weighted average with minimum standard error (Hunter et al. 1982).

A statistical program for analyzing release-recapture data was used to perform all survival analyses. The program was developed at the University of Washington and named SURPH, for "Survival with Proportional Hazards," (Skalski et al. 1993; Smith and Skalski, in press; Smith et al. 1994). This program extends the standard Single-Release Models (Cormack, 1964; Jolly, 1965;

Seber, 1965) to allow simultaneous analysis of release-recapture data from multiple release groups. Parameters can be constrained to be equal across release groups, while other parameters remain unique to a group. In addition, parameters can be modeled as functions of covariates, on both the individual (e.g., length) and group level (e.g., release date).

Hatchery Releases

In 1994, several hatcheries released PIT-tagged fish as part of experiments designed at the hatcheries. Data from hatchery releases of PIT-tagged fish were analyzed to demonstrate survival estimation methods using the PIT-tag detection and slide-gate systems for automatic data collection, and to evaluate the extent to which hatchery releases corroborated the results from our primary and secondary releases. In the course of characterizing the various releases, preliminary analyses were performed to determine whether data from multiple releases could be pooled to increase sample sizes. We neither intended nor attempted to analyze the experiments for which the hatchery releases were made.

Detections of PIT-tagged yearling chinook salmon and steelhead were analyzed from the following hatcheries (Table 10):

1) Dworshak National Fish Hatchery (United States Fish and Wildlife Service (USFWS)): As part of a study of release timing, approximately 2,000 PIT-tagged yearling chinook salmon were released from each of 3 raceways on 3 dates: 8 April,

Table 10. Hatchery releases of PIT-tagged yearling chinook salmon and steelhead during 1994 survival studies.

Hatchery	Date	Species	Number of releases	Approximate number/ release	Approximate total number released
Dworshak	8 Apr	Chinook	3	2,000	6,000
	14 Apr	Chinook	8	150	1,200
	15 Apr	Chinook	8	150	1,200
	22 Apr	Chinook	3	2,000	6,000
	6 Hay	Chinook	3	2,000	6,000
Dworshak	2-5 May	Steelhead	6	250	1,500
	4-6 May	Steelhead	3	750	2,250
Kooskia	18 Apr	Chinook	6	100	600
Lookingglass	10 Apr	Chinook	8	250	2,000
Lookingglass (Imnaha R. releases)	11 Apr	Chinook	6	500	3,000
McCall	9 Apr	Chinook	1	500	500
	11 Apr	Chinook	2	1,500	3,000
	12 Apr	Chinook	1	400	400
	14 Apr	Chinook	1	400	400
	22 Apr	Chinook	1	400	400
	28 Apr	Chinook	1	400	400
Rapid River	12 Apr	Chinook	1	1,500	1,500
	12 Apr	Chinook	1	1,500	1,500
Sawtooth	8 Apr	Chinook	5	300	1,500
	11 Apr	Chinook	2	350	700
Pahsimeroi	12 Apr	Chinook	2	500	1,000

22 April, and 6 May. Two additional releases of about 1,200 PIT-tagged yearling chinook salmon each were released on 14 and 15 April as part of a medicated feed experiment. Releases of about 250 PIT-tagged steelhead were made from each of 6 raceways between 2 and 5 May, and releases of about 750 PIT-tagged steelhead were made from 3 raceways between 4 and 6 May.

2) Kooskia National Fish Hatchery (USFWS): Releases of about 100 PIT-tagged yearling chinook salmon each were made from 6 different raceways on 18 April.

3) Lookingglass Hatchery (Oregon Department of Fish and Wildlife): Approximately 500 PIT-tagged yearling chinook salmon from each of 4 raceways were released from the hatchery on 10 April. Approximately 500 PIT-tagged yearling chinook salmon from each of 6 raceways were released in the Imnaha River on 11 April.

4) McCall Hatchery (Idaho Department of Fish and Game (IDFG)): Releases of 400 to 500 PIT-tagged yearling chinook salmon were made from 5 raceways between 9 and 28 April. Two groups of approximately 1,500 PIT-tagged fish each were released on 11 April; one group was tagged by hand, while the other was PIT tagged using an auto-injector.

5) Rapid River Hatchery (IDFG): Two groups of approximately 1,500 PIT-tagged yearling chinook salmon each were released on 12 April; one group was tagged by hand, while the other was PIT tagged using an auto-injector.

6) Sawtooth Hatchery (IDFG): Seven groups ranging from 155 to 374 PIT-tagged yearling chinook salmon were released on 8 and 11 April.

7) Pahsimeroi Hatchery (IDFG): Two releases of about 500 PIT-tagged yearling chinook salmon were made on 12 April.

For each hatchery, each set of releases was examined to determine suitability for survival analysis. The Single-Release Model was applied to each pooled data set to estimate the following parameters: 1) survival probability from release location to Lower Granite Dam tailrace, 2) detection probability at Lower Granite Dam, 3) survival probability from Lower Granite Dam tailrace to Little Goose Dam tailrace, 4) detection probability at Little Goose Dam, 5) survival probability from Little Goose Dam tailrace to Lower Monumental Dam tailrace, 6) detection probability at Lower Monumental Dam, and 7) combined probability of survival from Lower Monumental Dam tailrace to McNary Dam tailrace and detection probability at McNary Dam.

Survival estimates were not calculated for releases of PIT-tagged hatchery and wild chinook salmon parr because release numbers were too small.

Travel Time

Travel times were calculated for fish from primary releases through four river sections: 1) Silcott Island to Lower Granite Dam, 2) Lower Granite Dam to Little Goose Dam, 3) Little Goose Dam to Lower Monumental Dam, and 4) Lower Monumental Dam to

McNary Dam. Travel time from the release point to Lower Granite Dam was calculated for each fish detected at Lower Granite Dam as the number of days between the time of release and the time of first detection at Lower Granite Dam. Travel time between two dams was calculated for each fish detected at both dams as the number of days between first detection at the upstream dam and first detection at the downstream dam. Travel time included the time to move through the reservoir to the forebay of the downstream dam, and any delay associated with residence in the forebay before the fish passed into the bypass system and was detected.

To facilitate comparisons across the four river sections, rates of migration (kilometers per day) were also calculated for each fish. The lengths of the river sections are 37 km from Silcott Island to Lower Granite Dam, 60 km from Lower Granite Dam to Little Goose Dam, 43 km from Little Goose Dam to Lower Monumental Dam, and 119 km from Lower Monumental Dam to McNary Dam. Rate of migration through a river section was calculated as the length of the section (km) divided by the travel time (days) (which included any delay at dams as noted above). The minimum, 20th percentile, median, 80th percentile, and maximum travel times and migration rates were determined from the distributions for each release group.

The complete set of travel times for fish from a release group includes travel times of both detected and undetected fish. However, using PIT tags, travel times cannot be determined for fish that traverse a river section but are not detected at one or both ends of the section. Thus, travel time statistics are computed from travel times for detected fish only, which represent a sample of the complete set.

On 11 May 1994, substantial spill volumes began at most dams, resulting in lower detection rates. Some release groups had fish passing a particular dam both before and after spill began. For these groups, the faster migrants (early part of the passage distribution) were sampled more heavily than the slower migrants (late part of the distribution) because detection rates were higher before spill began. Thus, the distributions of observed travel times for these groups were biased toward shorter travel times, or faster migration rates. Travel time distributions were not biased for release groups that passed dams entirely before spill began or entirely after spill began.

Lower Granite Dam Bypass Pipe Evaluation

To evaluate the newly installed bypass pipe at Lower Granite Dam, releases of both hatchery and river-run hatchery steelhead were made. In mid-April, steelhead reared at Dworshak National Fish Hatchery were transported from McNary Dam, where they had been fin clipped (upper or lower caudal) and held for several weeks, to Lower Granite Dam. Prior to each test, fish were anesthetized and checked for descaling or injury so that only fish in good condition were used. Five releases of approximately 400 fish/release were made.

In late May, river-run hatchery steelhead were collected from the juvenile collection facility at Lower Granite Dam and fin clipped (upper and lower caudal fin) for additional bypass evaluation. Four releases of approximately 400 fish/release were made. Fish with prior injuries or descaling were not used.

Fish were released into the bypass pipe just downstream from the slide gate (test) or released into the net directly by boat (control). Fish were recovered in a large floating fyke net (7.6 m by 7.6 m with 5 mm knotless mesh), held in position by boat under the end of the bypass pipe. After the test fish had exited the pipe, the net was towed upstream to the tailrace deck and raised above the tailrace deck surface by crane to remove fish from the sanctuary cod-end. Fish were then checked for descaling or injury. A paired T-test was used to evaluate differences in descaling between test and control fish.

RESULTS

Logistics and Feasibility

Lower Granite Reservoir

Purse seining--Purse seining in Lower Granite Reservoir near Silcott Island began on 14 April and continued until 12 May, with one to nine sets made each day by the two purse seiners (Table 11). Species composition varied by time of day, with the highest percentage of chinook salmon captured near dusk and dawn. Steelhead were the predominant species during daylight hours. The time of purse-seining effort was adjusted to target whichever species was needed for tagging each day. When fish in excess of those needed for tagging were captured, they were released without handling.

A total of 12,349 yearling chinook salmon were captured and handled near Silcott Island, 89.3% of which were fin clipped indicating hatchery origin. Of the 22,586 juvenile steelhead captured and handled, 90.8% were of hatchery origin (Table 11). An additional 41 adult steelhead were also captured (Table 12). Handling mortality was low for all species in Lower Granite Reservoir, averaging less than 0.4% overall (Table 13).

The number of nonsalmonids (54) captured by purse seine near Silcott Island was small (Table 12) compared to the number of salmonids (34,982).

Additional purse seining was conducted near Wawawai from 14 May to 18 May for Lower Granite Dam forebay releases. Two to 10

Table 11. Number of juvenile salmonids captured by purse seine in Lower Granite Reservoir near Silcott Island and Wawawai, 1994. (Abbreviations: H-hatchery; W-wild).

Date	Sets	Chinook salmon H	Chinook salmon W	Steelhead H	Steelhead W	Sockeye salmon	Total
				Silcott Island			
14 Apr	9	517	257	83	105	0	962
15 Apr	9	812	263	66	84	0	1,225
16 Apr	4	1,339	196	16	33	0	1,584
17 Apr	2	1,222	71	9	7	0	1,309
20 Apr	2	1,211	47	10	10	0	1,278
22 Apr	4	835	95	1,221	247	0	2,398
24 Apr	3	145	16	1,208	124	0	1,493
25 Apr	4	1,048	75	1,369	200	0	2,692
27 Apr	3	343	32	338	24	0	737
28 Apr	3	309	40	1,340	58	0	1,747
29 Apr	3	609	46	296	25	0	976
30 Apr	4	475	22	1,165	56	15	1,733
2 May	4	269	25	1,204	96	7	1,601
3 May	5	546	35	1,295	20	1	1,897
4 May	1	8	2	1,632	42	2	1,686
6 May	1	13	2	1,227	44	0	1,286
9 May	2	1,051	60	1,533	155	17	2,816
10 May	3	156	17	1,230	155	2	1,560
11 May	4	56	13	2,826	332	2	3,229
12 May	4	59	12	2,434	267	1	2,773
Total	74	11,023	1,326	20,502	2,084	47	34,982
				Wawawai			
14 May	10	632	122	2,976	306	9	4,045
16 May	7	368	80	4,904	646	11	6,009
17 May	3	84	11	814	65	2	976
18 May	2	15	19	4,046	117	1	4,198
Total	22	1,099	232	12,740	1,134	23	15,228
Grand total	96	12,122	1,558	33,242	3,218	70	50,210

Table 12. Number of nonsalmonids and adult steelhead captured by purse seine in Lower Granite Reservoir near Silcott Island and Wawawai, 1994.

	Silcott Island 14 April - 12 May 74 purse-seine sets	Wawawai 14 May - 18 May 22 purse-seine sets	Total 14 April - 18 May 96 purse-seine sets
Adult steelhead	41	9	50
Chiselmouth	11	2	13
Peamouth	11	0	11
Northern squawfish	14	1	15
Black crappie	3	0	3
Largescale sucker	9	1	10
Carp	5	0	5
Yellow perch	0	4	4
Channel catfish	1	0	1
All species	95	17	112

Table 13. Number of fish handled and mortalities near Silcott Island in Lower Granite Reservoir during PIT tagging for the 1994 survival studies.

Date	Hatchery chinook Handled	Hatchery chinook Mort.	Wild chinook Handled	Wild chinook Mort.	Hatchery sthd. Handled	Hatchery sthd. Mort.	Wild sthd. Handled	Wild sthd. Mort.
14 Apr	517	12	257	0	83	0	105	0
15 Apr	812	8	263	1	66	0	84	0
16 Apt	1,339	5	196	0	16	0	33	0
17 Apt	1,222	6	71	9	9	0	7	0
20 Apr	1,211	6	47	0	10	0	10	0
22 Apr	835	9	95	0	1,221	1	247	0
24 Apr	145	0	16	0	1,208	0	124	0
25 Apr	1,048	3	75	0	1,369	4	200	0
27 Apr	343	1	32	0	338	0	24	0
28 Apr	309	1	40	0	1,340	0	58	0
29 Apr	609	0	46	0	296	1	25	1
30 Apr	475	0	22	0	1,165	1	56	0
2 May	269	8	25	0	1,204	0	96	0
3 May	546	11	35	0	1,295	0	20	0
4 May	8	0	2	0	1,632	0	42	0
6 May	13	0	2	0	1,227	0	44	0
9 May	1,051	0	60	0	1,533	0	155	0
10 May	156	0	17	0	1,230	1	155	0
11 May	56	1	13	0	2,826	16	332	0
12 May	59	0	12	0	2,434	1	267	0
Total	11,023	71	1,326	10	20,502	25	2,084	1

purse-seine sets were made each day and over 15,000 juvenile salmonids were captured (Table 14). The majority (83.7%) of these were hatchery steelhead, the target species for these releases. Only eight nonsalmonids were captured near Wawawai (Table 12).

PIT tagging--A total of 9,932 hatchery yearling chinook salmon, 522 wild yearling chinook salmon, and 13,735 hatchery steelhead were tagged for the primary releases. There were 10 groups of hatchery yearling chinook salmon released between 16 April-10 May, 1 group of wild yearling chinook salmon released on 17 April, and 9 groups of hatchery steelhead released between 23 April and 12 May.

Fish were in excellent condition, as indicated by the low mortality and small percentage rejected for tagging. Of the 11,023 fin-clipped chinook salmon and 20,502 fin-clipped steelhead captured, only 114 (1.0%) and 166 (0.8%), respectively, were rejected because of descaling or injuries, or because they were previously PIT tagged. Overall mortality in the reservoir (handling and post-tagging combined) averaged 0.6% for hatchery yearling chinook salmon, 0.7% for wild yearling chinook salmon, and 0.1% for hatchery steelhead (Table 13). One (usually) or 2 days of purse seining were needed to capture fish for each release group. After PIT tagging, fish were held from 32 to 54 hours before release.

Table 14. Number of fish handled and mortalities near Wawawai in Lower Granite Reservoir during PIT tagging for the 1994 survival studies.

Date	Hatchery chinook Handled	Hatchery chinook Mort.	Wild chinook Handled	Wild chinook Mort.	Hatchery sthd. Handled	Hatchery sthd. Mort.	Wild sthd. Handled	Wild sthd. Mort.
14 May	632	0	122	1	2,976	27	306	0
16 May	368	4	80	0	4,904	70	646	0
17 May	84	0	11	0	814	9	65	0
18 May	15	2	19	0	4,046	297	117	0
Total	1,099	6	232	1	12,740	403	1,134	0

Lower Granite Dam

PIT tagging--Fish were PIT tagged at Lower Granite Dam from 20 April to 8 June. A total of 40,767 hatchery yearling chinook salmon, 5,018 wild yearling chinook salmon, 34,340 hatchery steelhead, and 8,336 wild steelhead were handled (Table 15). Mortality from handling and tagging averaged 1.4% for hatchery yearling chinook salmon, 0.1% for wild yearling chinook salmon, 1.9% for hatchery steelhead, and 0.1% for wild steelhead (Table 15).

Project evaluation--Target numbers of PIT-tagged fish for each release at Lower Granite Dam were met on most release dates. Releases of hatchery yearling chinook salmon were made primarily during the early part of the hatchery chinook salmon migration, while releases of hatchery steelhead were made during the middle and later part of the hatchery steelhead migration (Fig. 6).

Little Goose Dam

PIT tagging--PIT tagging at Little Goose Dam began on 26 April and continued until 23 May. A total of 27,746 hatchery yearling chinook salmon, 5,562 wild yearling chinook salmon, 15,854 hatchery steelhead, and 5,260 wild steelhead were handled (Table 16). Mortality from handling and tagging averaged 2.1% for hatchery chinook salmon, 0.9% for wild yearling chinook salmon, 1.4% for hatchery steelhead, and 0.3% for wild steelhead (Table 16).

Project evaluation--Target numbers of PIT-tagged fish for each release at Little Goose Dam were not always met. Releases

Table 15. Number of fish handled and mortalities at Lower Granite Dam during PIT tagging for the 1994 survival studies.

Tag date	Hatchery chinook Handled	Hatchery chinook Mort.	Wild chinook Handled	Wild chinook Mort.	Hatchery sthd. Handled	Hatchery sthd. Mort.	Wild sthd. Handled	Wild sthd. Mort.
20 Apr	6,384	70	820	0	373	9	1,096	0
22 Apr	6,169	109	792	0	843	9	2,413	0
25 Apr	4,186	43	307	0	422	0	379	0
27 Apr	4,619	39	318	0	233	0	476	0
29 Apr	3,527	67	409	0	2,115	1	853	0
1 May	4,276	82	417	0	372	10	208	0
3 May	623	4	37	0	2,265	345*	160	4
5 May	656	4	85	0	1,635	8	105	2
10 May	564	0	37	0	3,936	37	131	0
11 May	3,328	152	246	0	878	0	181	0
12 May	196	0	40	0	3,425	9	177	0
14 May	307	6	61	0	2,833	65	149	0
16 May	1,380	6	467	0	4,876	36	360	0
18 May	1,635	2	302	0	2,969	8	196	0
27 May	399	0	92	4	2,792	61	523	3
4 June	1,348	0	281	0	2,745	35	596	0
8 June	1,170	1	307	0	1,628	16	333	0
Total	40,767	585	5,018	4	34,340	649	8,336	9

* An air stone malfunctioned during transport of steelhead from Silcott Island to Lower Granite Dam (forebay release), killing 342 hatchery steelhead.

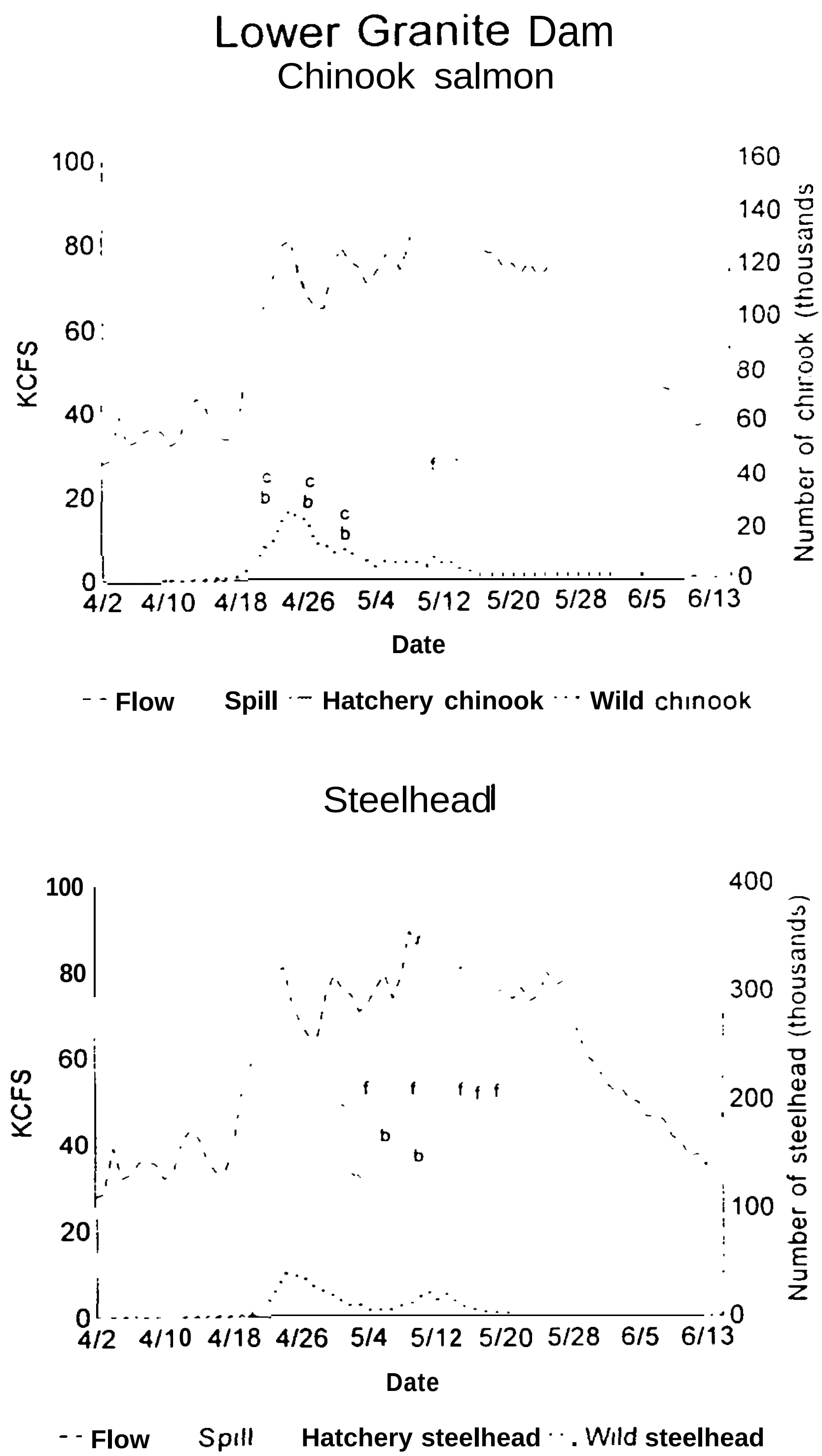


Figure 6. Yearling chinook salmon and steelhead passags at Lower Granite Dam during 1994 survival studies. Letters indicate paired releases (test and reference) for post-detection bypass (b), collection channel (c), and forebay (f) evaluation. Flow and spill are also shown.

Table 16. Number of fish handled and mortalities at Little Goose Dam during PIT tagging for the 1994 survival studies.

Tag date	Hatchery chinook Handled	Hatchery chinook Mort.	Wild chinook Handled	Wild chinook Mort.	Hatchery sthd. Handled	Hatchery sthd. Mort.	Wild sthd. Handled	Wild sthd. Mort.
26 Apr	3,834	59	2,417	7	972	2	1,660	1
28 Apr	3,921	103	976	10	237	1	844	4
2 May	3,855	78	516	10	425	1	471	5
4 May	3,906	63	443	4	350	0	252	1
6 May	3,902	111	431	8	814	7	320	1
9 May	3,531	99	371	3	911	4	249	1
13 May	2,714	22	216	4	2,693	33	239	0
15 May	918	17	69	0	2,714	41	512	1
17 May	511	7	52	1	2,956	23	328	0
23 May	654	34	71	3	3,782	113	385	1
Total	27,746	593	5,562	50	15,854	225	5,260	15

of hatchery yearling chinook salmon were made primarily during the first half of the hatchery chinook salmon migration, while releases of hatchery steelhead were made during the latter half of the migration (Fig. 7).

Lower Monumental Dam

PIT tagging--Fish were PIT tagged at Lower Monumental Dam from 3 May to 22 May. A total of 45,554 hatchery yearling chinook salmon, 4,293 wild yearling chinook salmon, 26,646 hatchery steelhead, and 2,789 wild steelhead were handled (Table 17). Mortality from handling and tagging averaged 0.8% for hatchery chinook salmon, 0.3% for wild yearling chinook salmon, 0.9% for hatchery steelhead, and 0.3% for wild steelhead (Table 17).

Project evaluation--Target numbers of PIT-tagged fish for each release at Lower Monumental Dam were not always met. Hatchery yearling chinook salmon releases were made during the middle of the migration, while hatchery steelhead releases were made during the latter half of the hatchery steelhead migration (Fig. 8).

Tag Retention

PIT-tag retention ranged from 96.0 to 100% for the various release groups at all sites during the study, with an average of 99.7% for all groups (Table 18). Because of the high tag-

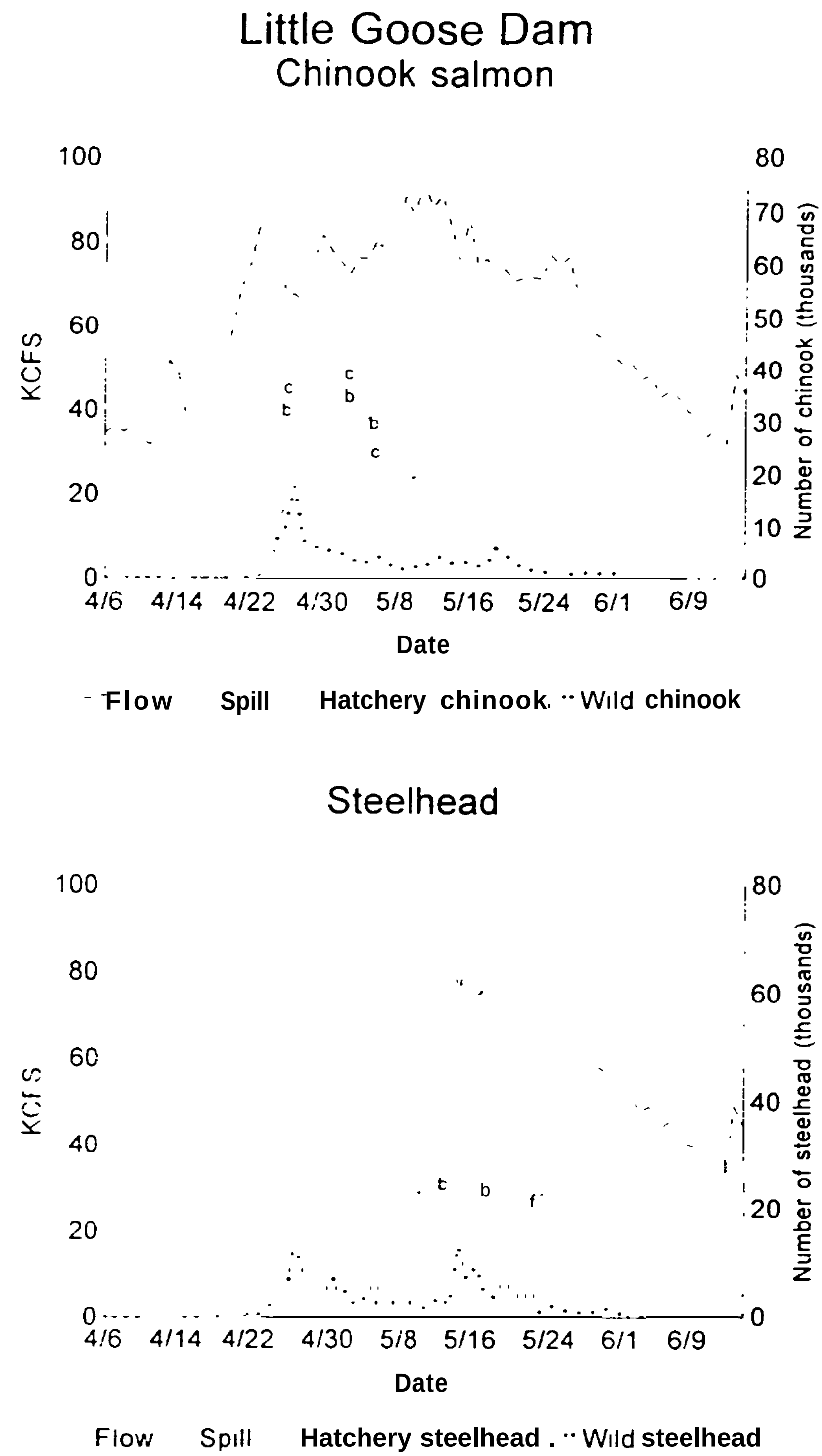


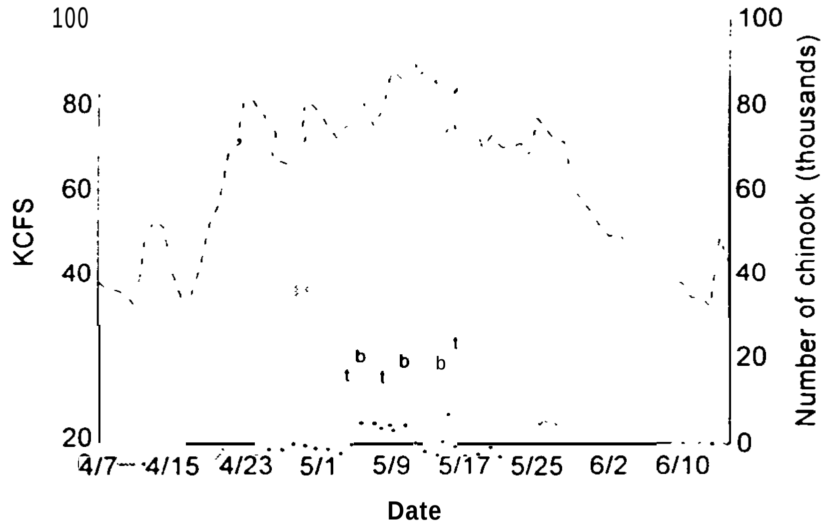
Figure 7. Yearling chinook salmon and steelhead passage at Little Goose Dam during 1994 survival studies. Letters indicate paired releases (test and reference) for post-detection bypass (b), collection channel (c), and forebay (f) evaluation. Flow and spill are also shown.

Table 17. Number of fish handled and mortalities at Lower Monumental Dam during PIT tagging for the 1994 survival studies.

Tag date	Hatchery chinook Handled	Hatchery chinook Mort.	Wild chinook Handled	Wild chinook Mort.	Hatchery sthd. Handled	Hatchery sthd. Mort.	Wild sthd. Handled	Wild sthd. Mort.
3 May	6,019	27	657	0	2,266	0	533	1
5 May	9,496	87	1,364	0	3,910	2	732	1
7 May	6,142	50	612	5	3,745	28	363	3
9 May	7,768	77	648	0	3,671	46	281	1
13 May	2,273	27	163	0	759	3	80	0
14 May	1,885	19	176	1	577	2	100	0
15 May	3,119	32	154	4	910	4	264	0
la May	4,397	26	239	1	4,489	60	166	2
20 May	3,320	11	225	1	3,667	46	154	0
22 May	1,135	4	55	0	2,652	53	116	0
Total	45,554	360	4,293	12	26,646	244	2,789	a

Lower Monumental Dam

Chinook salmon



Steelhead

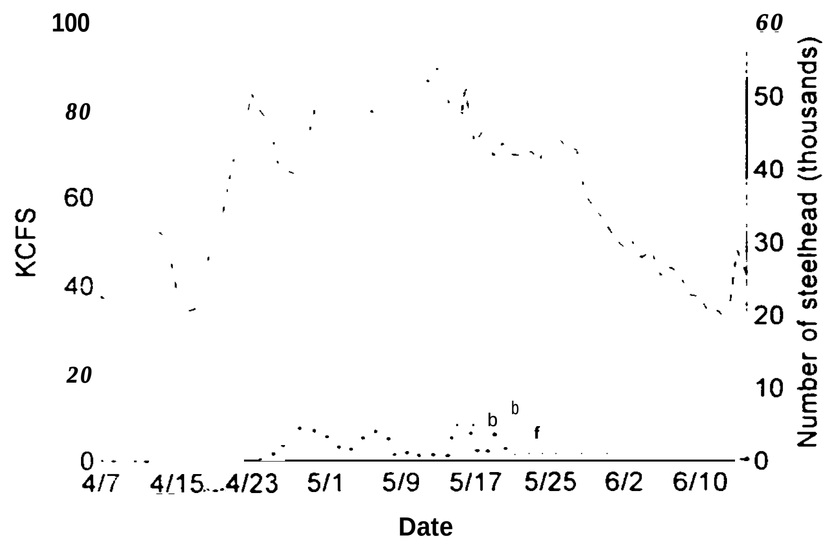


Figure 8. Yearling chinook salmon and steelhead passage at Lower Monumental Dam during 1994 survival studies. Letter indicate paired releases itest and reference) for post-detection bypass (b), turbine (t), and forebay (f) evaluation. Flow and spill are also shown.

Table 1a. Tag retention for hatchery yearling chinook salmon and steelhead PIT tagged in Lower Granite Reservoir (Res), at Lower Granite (LGR), Little Goose (LGC), and Lower Monumental (LMO) Dams during April and May, 1994. Fish were scanned for PIT tags after being held 24-36 hours.

Location	Species	Tag date	Number held	Number untagged	Retention (%)
Res	Chinook	15 April	107	0	100.0
Res	Chinook	20 April	60	0	100.0
Res	Chinook	28 April	100	0	100.0
Total			267	0	100.0
Res	Steelhead	3 May	101	0	100.0
Res	Steelhead	10 May	93	0	100.0
Total			194	0	100.0
LGR	Chinook	19 April	110	0	100.0
LGR	Chinook	24 April	110	0	100.0
Total			220	0	100.0
LGO	Chinook	26 April	56	0	100.0
LMO	Chinook	3 May	44	1	97.7
LMO	Chinook	5 May	53	0	100.0
LMO	Chinook	7 May	51	0	100.0
LMO	Chinook	9 May	49	0	100.0
LMO	Chinook	12 MAY	50	2	96.0
Total			247	3	98.8

retention rate, no adjustments were made to the release numbers, resulting in very slight underestimation of the true survival probability.

Project Operations

Slide-gate operation--Between 2 April and 1 July, 51,390 PIT-tagged salmonids (all species) were detected at Lower Granite Dam. Of these, 44,844 (87.3%) were bypassed back to the Snake River by the slide-gate diverter system (Table 19). The remainder were either missed by the slide gate and transported (9.5%), removed prior to the slide gate as part of the Smolt Monitoring Program sample (2.4%), or were not detected again and their fate unknown (0.8%).

At Little Goose Dam, 42,807 PIT-tagged salmonids were detected, with 35,377 (82.6%) bypassed back to the Snake River by the slide-gate diverter system (Table 19). The remainder were either missed by the slide gate and transported (10.5%), removed prior to passing the slide gate as part of the Smolt Monitoring Program sample (5.9%), or were not detected again and their fate unknown (1.0%).

At Lower Monumental Dam, 46,895 PIT-tagged salmonids were detected, with 36,924 (78.7%) bypassed back to the Snake River by the slide-gate diverter system (Table 19). The remainder were either missed by the slide gate and transported (8.9%), removed prior to passing the slide gate as part of the Smolt Monitoring Program sample (11.0%), or were not detected again and their fate unknown (1.4%).

Table 19. Number of PIT-tagged juvenile salmonids detected and diverted at Lower Granite (LGR), Little Goose (LGO), and Lower Monumental (LMO) Dams during the 1994 migration (up to 1 July). Diverted fish were returned to the Snake River; fish in the raceways and sample were transported out of the study area.

Dam	Total Number	Diverted Number (%)	Raceways Number (%)	Sample Number (%)
Chinook salmon				
LGR	26,694	22,688 (85.0)	3,137 (11.8)	570 (2.1)
LGO	21,078	17,124 (81.2)	2,291 (10.9)	1,426 (6.8)
LMO	28,327	21,720 (76.7)	2,873 (10.1)	3,312 (11.7)
Steelhead				
LGR	24,652	22,124 (89.7)	1,746 (7.1)	650 (2.6)
LGO	21,679	18,219 (84.0)	2,193 (10.1)	1,088 (5.0)
LMO	18,525	15,177 (81.9)	1,316 (7.1)	1,861 (10.0)
All species				
LGR	51,390	44,844 (87.3)	4,893 (9.5)	1,222 (2.4)
LGO	42,807	35,377 (82.6)	4,495 (10.5)	2,515 (5.9)
LMO	46,895	36,924 (78.7)	4,196 (8.9)	5,177 (11.0)

PIT-tagged chinook salmon were diverted back to the Snake River at a lower rate than steelhead at all three dams (Table 19).

Turbine load and spill--At Lower Granite Dam, all conditions except turbine discharge remained constant during the releases of PIT-tagged hatchery yearling chinook salmon (Table 20). Turbine operation in Units 4 and 6 was set at 135 MW (within 1% of the peak efficiency curve) during all releases. Total turbine discharge increased substantially during the releases. Spill began on 11 May, after the majority of PIT-tagged hatchery yearling chinook salmon releases were completed (Fig. 6).

Hatchery steelhead releases occurred at Lower Granite Dam during variable discharge levels both before and after spill began on 11 May (Fig. 6).

At Little Goose Dam, all conditions except turbine discharge remained constant during the releases (Table 21). Total turbine discharge increased during the hatchery yearling chinook salmon and steelhead releases while levels of spill remained fairly constant (Fig. 7).

At Lower Monumental Dam, all conditions except turbine discharge and spill remained constant during the releases (Table 22). Spill began on 9 May at this site and continued for the rest of the migration. Hatchery yearling chinook salmon releases were made before and after spill began, while hatchery steelhead releases were made only after spill began (Fig. 8).

Table 20. Conditions at Lower Granite Dam during release of PIT-tagged yearling chinook salmon and steelhead during 1994. Turbine loads were set at 135 MW for all releases. Daily average spill in parentheses.

Date	Turbine discharge (KCFS)	Spill (KCFS)	Forebay elevation (ft)	Tailrace elevation (ft)
Chinook salmon bypass and reference releases				
21 Apr	68.2	0.0 (0.0)	733.7	634.1
26 Apr	66.1	0.0 (0.0)	733.2	634.2
30 Apr	78.7	1.7 (0.0)	733.2	634.5
Chinook salmon collection channel releases				
21 Apr	68.4	0.0 (0.0)	733.7	634.2
26 Apr	65.9	0.0 (0.0)	733.3	634.2
30 Apr	80.5	0.0 (0.0)	733.2	634.4
Chinook salmon forebay and reference release				
12 May	80.1 •	0.0 (24.5)	733.4	634.6
Steelhead bypass and reference releases				
6 May	67.3	0.0 (0.0)	733.7	634.6
11 May	----	--- (17.1)	-----	-----
Steelhead forebay releases				
4 May	67.9	0.0 (0.0)	733.4	633.8
11 May	84.1	0.0 (17.1)	733.5	634.6
15 May	----	--- (29.0)	-----	-----
17 May	66.4	0.0 (26.4)	733.3	634.3
19 May	60.9	0.0 (27.7)	733.6	634.0
Steelhead forebay control releases				
15 May	----	---- (29.0)	-----	-----
19 May	16.4	47.0 (27.7)	733.7	632.4

• Dashed lines indicate information unavailable.

Table 21. Conditions at Little Goose Dam during release of PIT-tagged yearling chinook salmon and steelhead during 1994. Turbine loads were set at 135 MW for all releases. Daily average spill in parentheses.

Date	Turbine discharge (KCFS)	Spill (KCFS)	Forebay elevation (ft)	Tailrace elevation (ft)
Chinook salmon bypass and reference releases				
27 Apr	53.7	13.2 (12.8)	633.7	537.8
3 May	52.2	0.2 (18.2)	633.6	538.2
7 May	52.9	22.1 (23.4)	633.6	537.8
Chinook salmon collection channel releases				
27 Apr	53.7	13.2 (12.8)	633.7	537.8
3 May	58.2	0.0 (18.2)	633.7	537.7
7 May	52.9	22.1 (23.4)	633.6	537.8
Steelhead bypass and reference releases				
14 May	54.8	29.3 (28.7)	633.0	538.1
18 May	43.3	29.5 (26.7)	633.6	537.8
Steelhead forebay releases				
16 May	56.2	29.4 (29.4)	633.4	538.2
24 May	53.1	29.5 (27.9)	633.8	538.0
Steelhead forebay control releases				
16 May	47.0	29.4 (29.4)	633.1	538.1
24 May	49.5	29.6 (27.9)	633.6	538.1

Table 22. Conditions at Lower Monumental Dam during release of PIT-tagged yearling chinook salmon and steelhead during 1994. Turbine loads were set at 135 MW for all releases. Daily average spill in parentheses.

Date	Turbine discharge (KCFS)	Spill (KCFS)	Forebay elevation (ft)	Tailrace elevation (ft)
Chinook salmon turbine and reference releases				
4 May	65.4	0.0 (0.0)	537.4	439.4
8 May	75.1	0.0 (0.0)	537.5	439.8
15 May	66.4	0.0 (12.4)	537.4	439.3
Chinook salmon bypass and reference releases				
6 May	77.9	0.0 (0.0)	536.8	439.4
10 May	78.9	0.0 (0.0)	537.7	439.9
14 May	80.9	0.0 (15.1)	537.5	439.9
Chinook salmon downstream reference releases				
6 May	71.4	0.0 (0.0)	537.3	439.4
10 May	81.1	0.0 (0.0)	537.6	440.2
15 May	67.1	0.0 (12.4)	537.2	439.3
Steelhead bypass releases				
19 May	61.1	0.0 (11.5)	537.2	439.0
21 May	70.1	0.0 (15.7)	537.3	439.5
Steelhead bypass reference releases				
19 May	59.2	0.0 (11.5)	537.2	438.5
21 May	60.8	0.0 (15.7)	537.3	438.8
Steelhead forebay releases				
23 May	70.0	0.2 (16.0)	537.4	439.5
Steelhead forebay reference releases				
23 May	71.4	0.0 (16.0)	537.4	439.6

Turbine Releases

Two procedural changes for turbine releases during 1994 affected the results: 1) because of concern about releasing steelhead through the 7.6-cm flexible hose used for 1993 chinook salmon releases, 10.2-cm hoses were used for turbine releases at all three projects, and 2) at Lower Granite and Little Goose Dams, extra aluminum tanks were unavailable for hauling water to flush the release hoses after fish were released. Instead, emergency deck water was used to flush smolts from the turbine release hoses at these sites. These procedural changes apparently resulted in a portion of the smolts being stranded in the turbine release hoses at Lower Granite and Little Goose Dams, resulting in unreasonably low turbine survival estimates. At Lower Monumental Dam, sufficient water was provided by the extra tanks available. For this reason, only turbine survival estimates from Lower Monumental Dam are presented.

Data Analysis

Database Quality Assurance/Control

Beginning with the total number of fish in the PTAGIS tagging files, the data were edited by eliminating fish for the reasons discussed below. A complete record of fish eliminated from each release group can be found in Appendix Tables 1 through 14.

1) Three wild yearling chinook salmon were in tagging files for hatchery fish. One hatchery chinook salmon and one steelhead

were in the tagging file for wild chinook salmon primary releases. Eight fish in tagging files for hatchery steelhead were recorded as wild. Records for these fish were removed from tagging and observation files, leaving only fish of the correct species and rearing type.

2) There were records of detections earlier than the recorded release date and time for 34 hatchery chinook salmon and 75 steelhead. Additionally, 13 hatchery chinook salmon and 6 steelhead had detections "out of order."

3) Under certain circumstances, fish from paired releases at dams were eliminated if they were detected at the dam where they were released. For example, fish in the bypass or tailrace reference groups at Lower Granite Dam were not used in the analysis if there was a record of a detection at Lower Granite Dam. There were 13 such instances in chinook salmon files, and 11 in steelhead files.

Fish from collection channel and forebay test releases could be detected at the dam of release. Fish from these releases were eliminated from analysis only if the observation record indicated that they were removed at the dam of release (i.e., not diverted by the slide gate). At Lower Granite Dam, 526 hatchery chinook salmon from collection channel test releases and 18 from forebay test release were eliminated. From forebay test releases of hatchery steelhead, 424 fish were eliminated. At Little Goose Dam, 890 chinook salmon were eliminated from collection channel test releases, and 204 steelhead were eliminated from forebay test releases. At Lower Monumental Dam, 25 steelhead were removed from forebay test releases.

4) Finally, fish that died after their tagging records were uploaded but before they were released were eliminated. Of 41,127 fish in the hatchery chinook salmon tagging files, 585 (1.4%) were eliminated. Eight of 522 fish (1.5%) were eliminated from the wild chinook salmon tagging file. Of 61,554 fish in the hatchery steelhead tagging files, 991 (1.6%) were eliminated because of mortality.

Tests of Assumptions

As in 1993, the assumptions of the SR and MSR Models were generally met by most releases of PIT-tagged salmonids in the Snake River in 1994. The most notable exception was the failure of paired forebay test/tailrace reference releases to mix and travel together downstream. The presence of some violations of assumptions, emphasized the need to test assumptions to the furthest extent possible before proceeding to survival estimation.

Assumptions Al **and A2**--A fish's detection at a PIT-tag detection site does not affect its probability of subsequent survival in downstream reaches or of subsequent detection at downstream sites.

Inspection of passage distributions for subgroups of primary releases of hatchery chinook salmon (Tables 23, 24, and 25) showed few problems. None of the tests for passage distributions were significant at the α_{EW} = 0.05 level (10 tests). The lowest

Table 23. Tests of homogeneity of Little Goose Dam passage distributions for subgroups of primary releases of yearling chinook salmon defined by capture history at Lower Granite Dam. P values calculated using Monte Carlo approximation of the exact method.

Release	χ^2	Degrees of freedom	P value*
R_{P1}	32.42	24	0.102
R_{P2}	17.25	27	0.960
R_{P3}	41.50	26	0.011
R_{P4}	15.77	23	0.896
R_{P5}	17.20	21	0.762
R_{P6}	23.40	20	0.249
R_{P7}	14.75	16	0.594
R_{P8}	14.00	18	0.805
R_{P9}	12.18	12	0.471
R_{P10}	13.48	16	0.617
R_{PW1}	17.00	14	0.222

* To control experiment-wise Type I error rate (e.g., α_{EX} = 0.05), test-wise P values are compared to adjusted significance levels for 10 tests (e.g., α_T = 0.0051) for hatchery yearling chinook salmon releases (see Table 10).

Table 24. Tests of homogeneity of Lower Monumental Dam passage distributions for subgroups of primary releases of yearling chinook salmon defined by capture history at Lower Granite and Little Goose Dams. P values calculated using Monte Carlo approximation of the exact method.

Release	χ^2	Degrees of freedom	P value*
R_{P1}	75.54	72	0.355
R_{P2}	89.47	84	0.315
R_{P3}	54.80	69	0.901
R_{P4}	118.50	84	0.013
R_{P5}	54.78	63	0.738
R_{P6}	66.30	69	0.538
R_{P7}	37.05	45	0.781
R_{P8}	87.28	60	0.044
R_{P9}	61.40	48	0.178
R_{P10}	35.80	48	0.847
R_{PW1}	65.82	57	0.173

* To control experiment-wise Type I error rate (e.g., α_{EX} = 0.05), test-wise P values are compared to adjusted significance levels for 10 tests (e.g., α_T = 0.0051) for hatchery yearling chinook salmon releases (see Table 10).

Table 25. Tests of homogeneity of McNary Dam passage distributions for subgroups of primary releases of yearling chinook salmon defined by capture history at Lower Granite, Little Goose, and Lower Monumental Dams. P values calculated using Monte Carlo approximation of the exact method.

Release	χ^2	Degrees of freedom	P value*
R_{P1}	251.3	217	0.053
R_{P2}	228.4	210	0.188
R_{P3}	221.7	189	0.080
R_{P4}	248.9	217	0.134
R_{P5}	167.8	189	0.730
R_{P6}	181.1	175	0.341
R_{P7}	198.9	175	0.182
R_{P8}	124.0	154	0.815
R_{P9}	119.4	133	0.556
R_{P10}	171.6	144	0.201
R_{PW1}	224.3	210	0.213

* To control experiment-wise Type I error rate (e.g., α_{EX} = 0-05), test-wise P values are compared to adjusted significance levels for 10 tests (e.g., α_T = 0.0051) for hatchery yearling chinook salmon releases (see Table 10).

P values were for Little Goose Dam passage of the release R_{P3} (P value = 0.011) and Lower Monumental Dam passage of release R_{P4} (P value = 0.013). The P value for McNary Dam passage of R_{P3} was also relatively low (0.080).

Tests of goodness of fit of the SR Model (Table 26) suggested that the heterogeneity of passage distributions resulted in significant lack of fit for R_{P3}. In particular, the probability of detection at Lower Monumental and McNary Dams depended on capture history at Lower Granite Dam and Little Goose Dams (TESTs 3.Sm3 and 3.SR4). Goodness of fit tests did not indicate similar problems with R_{P4}.

For primary releases of hatchery steelhead, release R_{P1} showed the most evidence of heterogeneity of passage distributions (Tables 27, 28, and 29). However, goodness of fit tests (Table 30) indicated that the heterogeneity of passage did not result in unequal capture or survival probabilities for R_{P1}. The overall goodness of fit test was not significant at the α_{EX} = 0.05 level (9 tests) for any primary release of hatchery steelhead. TEST 3.SR4 produced relatively low P values (8 out of 9 P values less than 0.10), suggesting that the probability of detection at McNary Dam depended on capture history at Lower Granite and Little Goose Dams.

The goodness of fit tests for primary releases of yearling chinook salmon and hatchery steelhead suggest that problems with assumption violations, if any, occurred at downstream detection

Table 26. Results of tests of goodness of fit to the Single-Release Model for primary releases of yearling chinook salmon from Silcott Island (TEST 2 and TEST 3 of Burnham et al. 1987).

	Overall		TEST 2		TEST 2.C2		TEST 2.C3	
Release	χ^2	P value*	χ^2	P value*	χ^2	P value*	χ^2	P value*
R_{P1}	9.010	0.173	2.839	0.417	2.201	0.333	0.638	0.424
R_{P2}	6.142	0.407	4.354	0.226	3.208	0.201	1.146	0.284
R_{P3}	27.726	0.000	4.315	0.229	0.775	0.679	3.540	0.060
R_{P4}	7.966	0.241	3.625	0.305	1.747	0.417	1.878	0.171
R_{P5}	4.655	0.589	2.308	0.511	2.296	0.317	0.012	0.913
R_{P6}	6.395	0.380	2.901	0.407	0.186	0.911	2.715	0.099
R_{P7}	3.112	0.795	0.163	0.983	0.042	0.979	0.121	0.728
R_{P8}	2.395	0.880	1.475	0.688	0.552	0.759	0.923	0.337
R_{P9}	12.250	0.057	7.411	0.060	3.024	0.220	4.387	0.036
R_{P10}	9.522	0.146	2.147	0.542	1.952	0.377	0.195	0.659
R_{PW1}	15.578	0.016	6.171	0.104	5.697	0.058	0.474	0.491

* To control experiment-wise Type I error rate (e.g., α_{EX} = 0.05), test-wise P values are compared to adjusted significance levels for 10 tests (e.g., α_T = 0.0051) for hatchery yearling chinook salmon releases (see Table 10).

Table 26. Continued.

Release	TEST 3		TEST 3.SR3		TEST 3.Sm3		TEST 3.SR4	
	χ^2	P value*	χ^2	P value*	χ^2	P value*	χ^2	P value*
R_{p1}	6.171	0.104	2.681	0.102	0.106	0.745	3.384	0.066
R_{p2}	1.788	0.618	0.002	0.964	0.036	0.850	1.750	0.186
R_{p3}	23.411	0.000	0.040	0.841	9.578	0.002	13.793	0.000
R_{p4}	4.341	0.227	2.423	0.120	0.526	0.468	1.392	0.238
R_{p5}	2.347	0.504	0.464	0.496	0.869	0.351	1.014	0.314
R_{p6}	3.494	0.322	0.063	0.802	2.461	0.117	0.970	0.325
R_{p7}	2.949	0.400	2.790	0.095	0.054	0.816	0.105	0.746
R_{p8}	0.920	0.821	0.142	0.706	0.108	0.742	0.670	0.413
R_{p9}	4.839	0.184	1.542	0.214	0.286	0.593	3.011	0.083
R_{p10}	7.375	0.061	1.202	0.273	0.467	0.494	5.706	0.017
R_{pW1}	9.407	0.024	0.923	0.337	0.024	0.877	8.460	0.004

* To control experiment-wise Type I error rate (e.g., α_{EX} = 0.05), test-wise P values are compared to adjusted significance levels for 10 tests (e.g., UT = 0.0051) for hatchery yearling chinook salmon releases (see Table 10).

Table 27. Tests of homogeneity of Little Goose Dam passage distributions for subgroups of primary releases of hatchery steelhead defined by capture history at Lower Granite Dam. P values calculated Monte Carlo approximation of the exact method.

Release	χ^2	Degrees of freedom	P value*
R_{P1}	47.24	25	0.005
R_{P2}	21.37	25	0.660
R_{P3}	45.20	26	0.022
R_{P4}	24.38	22	0.334
R_{P5}	25.76	28	0.587
R_{P6}	41.85	29	0.051
R_{P7}	27.40	23	0.213
R_{P8}	30.51	37	0.779
R_{P9}	69.57	49	0.041

* To control experiment-wise Type I error rate (e.g., $\alpha_{EX} = 0.05$), test-wise P values are compared to adjusted significance levels for nine tests (e.g., $\alpha_T = 0.0057$) (see Table 10).

Table 28. Tests of homogeneity of Lower Monumental Dam passage distributions for subgroups of primary releases of hatchery steelhead defined by capture history at Lower Granite and Little Goose Dams. P values calculated using Monte Carlo approximation of the exact method.

Release	χ^2	Degrees of freedom	P value*
R_{P1}	79.40	81	0.533
R_{P2}	93.54	78	0.132
R_{P3}	163.70	93	0.002
R_{P4}	67.85	69	0.528
R_{P5}	86.03	90	0.588
R_{P6}	101.40	96	0.351
R_{P7}	120.20	105	0.178
R_{P8}	115.10	129	0.762
R_{P9}	140.50	162	0.829

* To control experiment-wise Type I error rate (e.g., $\alpha_{EX} = 0.05$), test-wise P values are compared to adjusted significance levels for nine tests (e.g., $\alpha_T = 0.0057$) (see Table 10).

Table 29. Tests of homogeneity of McNary Dam passage distributions for subgroups of primary releases of hatchery steelhead defined by capture history at Lower Granite, Little Goose, and Lower Monumental Dams. P values calculated using Monte Carlo approximation of the exact method.

Release	χ^2	Degrees of freedom	P value*
R_{p1}	414.1	224	<o-o01
R_{p2}	319.5	252	0.032
R_{p3}	192.9	217	0.711
R_{p4}	201.8	196	0.405
R_{p5}	207.6	245	0.950
R_{p6}	214.0	210	0.394
R_{p7}	242.6	196	0.045
R_{p8}	226.9	252	0.736
R_{p9}	336.6	322	0.324

* To control experiment-wise Type I error rate (e.g., α_{EX} = O-OS), test-wise P values are compared to adjusted significance levels for nine tests (e.g., α_T = 0.0057) (see Table 10).

Table 30. Results of tests of goodness of fit to the Single-Release Model for primary releases of hatchery steelhead from Silcott Island (TEST 2 and TEST 3 of Burnham et al. 1987).

Release	Overall		TEST 2		TEST 2.C2		TEST 2.C3	
	χ^2	P value*	χ^2	P value*	χ^2	P value*	χ^2	P value*
Rp_1	9.785	0.134	7.386	0.061	0.279	0.870	7.107	0.008
Rp_2	10.603	0.101	6.530	0.088	4.277	0.118	2.253	0.133
Rp_3	13.474	0.036	1.945	0.584	1.471	0.479	0.474	0.491
Rp_4	5.092	0.532	1.293	0.731	1.289	0.525	0.004	0.950
Rp_5	14.797	0.022	7.998	0.046	5.514	0.063	2.484	0.115
Rp_6	14.171	0.028	10.214	0.017	9.940	0.007	0.274	0.601
Rp_7	10.262	0.114	3.809	0.283	3.188	0.203	0.621	0.431
Rp_8	12.052	0.061	3.814	0.282	0.359	0.836	3.455	0.063
Rp_9	9.951	0.127	5.457	0.141	4.908	0.086	0.549	0.459

* To control experiment-wise Type I error rate (e.g., $\alpha_{EX} = 0.05$), test-wise P values are compared to adjusted significance levels for nine tests (e.g., $\alpha_T = 0.0057$) (see Table 10).

Table 30. Continued.

Release	TEST 3		TEST 3.SR3		TEST 3.Sm3		TEST 3.SR4	
	χ^2	P value*	χ^2	P value*	χ^2	P value*	χ^2	P value*
Rp_1	2.399	0.494	0.004	0.950	0.001	0.975	2.394	0.122
Rp_2	4.073	0.254	0.058	0.810	0.002	0.964	4.013	0.045
Rp_3	11.529	0.009	6.825	0.009	0.000	1.000	4.704	0.030
Rp_4	3.799	0.284	0.750	0.386	0.000	1.000	3.049	0.081
Rp_5	6.799	0.079	0.645	0.422	0.128	0.721	6.026	0.014
Rp_6	3.957	0.266	1.011	0.315	0.063	0.802	2.883	0.090
Rp_7	6.453	0.092	1.509	0.219	1.687	0.194	3.257	0.071
Rp_8	8.238	0.041	0.237	0.626	0.975	0.323	7.026	0.008
Rp_9	4.494	0.213	0.142	0.706	0.501	0.479	3.851	0.050

* To control experiment-wise Type I error rate (e.g., α_{EX} = 0-05), test-wise P values are compared to adjusted significance levels for nine tests (e.g., α_T = 0.0057) (See Table 10).

sites (Lower Monumental and McNary Dams). However, problems in lower reaches did not invalidate estimates for upper reaches.

TEST 2 and TEST 3 results indicated no model violations for releases of hatchery chinook salmon from Lower Granite Dam (Table 31). TEST 2.C2 was significant for the first post-detection bypass treatment release and for two forebay treatment releases of hatchery steelhead from Lower Granite Dam (Table 32), indicating that the location of next detection below Little Goose Dam was dependent on detection at Little Goose Dam. Two other forebay treatment releases had relatively low, but not significant P values.

Assumption A3--Detected fish suffer no significant post-detection bypass mortality before remixing with non-detected fish.

At Lower Granite Dam, estimates of post-detection survival for hatchery yearling chinook salmon ranged from 0.878 to 0.979 (Table 33a), with a weighted average of 0.962 (s.e. 0.022). For hatchery steelhead, the weighted average of two survival probability estimates was 0.997 (s.e. 0.068) (Table 34a). However, because one of the two releases had a survival estimate of only 0.905, post-detection bypass mortality was a possibility.

At Little Goose Dam, two of the three test release groups of hatchery yearling chinook salmon had greater survival estimates than their corresponding reference groups, leading to point estimates of post-detection bypass survival greater than 1.0 (Table 33b). The third estimate was 0.989, resulting in a

Table 31. Results of tests of goodness of fit to the Single-Release Model for post-detection bypass, collection channel, forebay, and corresponding reference releases of hatchery yearling chinook salmon from Lower Granite Dam (TEST 2 and TEST 3 of Burnham et al. 1987).

Release	Overall		TEST 2.C2		TEST 3.SR3	
	χ^2	P value*	χ^2	P value*	χ^2	P value*
R_{B11}	2.882	0.237	0.901	0.637	1.981	0.159
C_{B11}	4.640	0.098	3.374	0.185	1.266	0.261
R_{G11}	2.549	0.280	0.151	0.927	2.398	0.121
R_{B12}	1.868	0.393	1.045	0.593	0.823	0.364
C_{B12}	5.047	0.080	0.012	0.994	5.035	0.025
R_{G12}	1.685	0.431	0.951	0.622	0.734	0.392
R_{B13}	0.784	0.676	0.695	0.706	0.089	0.765
C_{B13}	1.295	0.523	0.744	0.689	0.551	0.458
R_{G13}	5.118	0.077	1.032	0.597	4.086	0.043
R_{F11}	1.204	0.548	0.002	0.999	1.202	0.273
C_{T11}	0.885	0.642	0.885	0.642	0.000	1.000

* To control experiment-wise Type I error rate (e.g., $\alpha_{EX} = 0.05$), test-wise P values for bypass releases are compared to adjusted significance levels for three tests (e.g., $\alpha_T = 0.017$) (see Table 10).

Table 32. Results of tests of goodness of fit to the Single-Release Model for post-detection bypass, forebay, and corresponding reference releases of hatchery steelhead from Lower Granite Dam (TEST 2 and TEST 3 of Burnham et al. 1987).

Release	Overall		TEST 2.C2		TEST 3.SR3	
	χ^2	P value*	χ^2	P value*	χ^2	P value*
R_{B11}	8.172	0.017	8.170	0.004	0.002	0.964
C_{B11}	5.567	0.062	3.557	0.059	2.010	0.156
R_{B12}	0.308	0.857	0.287	0.592	0.021	0.885
C_{B12}	2.668	0.263	1.009	0.315	1.659	0.198
R_{F11}	0.926	0.629	0.540	0.462	0.386	0.534
C_{T11}	2.287	0.319	1.229	0.268	1.058	0.304
R_{F12}	4.851	0.088	3.043	0.081	1.808	0.179
C_{T12}	0.054	0.973	0.031	0.860	0.023	0.879
R_{F13}	6.826	0.033	6.821	0.009	0.005	0.944
C_{T13}	0.647	0.724	0.479	0.489	0.168	0.682
R_{F14}	8.669	0.013	6.965	0.008	1.704	0.192
C_{T14}	2.368	0.306	0.397	0.529	1.971	0.160
R_{F15}	3.782	0.151	3.213	0.073	0.569	0.451
C_{T15}	0.425	0.809	0.044	0.834	0.381	0.537

* To control experiment-wise Type I error rate (e.g., α_{EX} = 0.05), test-wise P values for bypass and forebay releases are compared to adjusted significance levels for two (e.g., α_T = 0.0253) and and five tests (e.g., α_T = 0.0102), respectively (see Table 10).

Table 33. Post-detection bypass survival estimates for hatchery yearling chinook salmon released from Lower Granite, Little Goose, and Lower Monumental Dams. Standard errors in parentheses. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam.

a) Lower Granite Dam

Releases	Treatment group survival LGR to LGO tailrace	Reference group survival LGR to LGO tailrace	Post-detection bypass survival (S_{B1})
(R_{B11}, C_{B11})	0.806 (0.031)	0.823 (0.029)	0.979 (0.051)
(R_{B12}, C_{B12})	0.743 (0.043)	0.778 (0.047)	0.955 (0.080)
(R_{B13}, C_{B13})	0.770 (0.073)	0.877 (0.091)	0.878 (0.123)
Pooled*			0.962 (0.022)

b) Little Goose Dam

Releases	Treatment group survival LGO to LMO tailrace	Reference group survival LGO to LMO tailrace	Post-detection bypass survival (S_{B2})
(R_{B21}, C_{B21})	0.927 (0.031)	0.826 (0.024)	1.122 (0.050)
(R_{B22}, C_{B22})	0.867 (0.033)	0.865 (0.027)	1.002 (0.049)
(R_{B23}, C_{B23})	0.872 (0.052)	0.882 (0.051)	0.989 (0.082)
Pooled*			1.051 (0.043)

- Pooled estimates are weighted averages of the independent estimates, with weights inversely proportional to the respective variances.

Table 33. Continued.

c) Lower Monumental Dam

Releases	Treatment group proportion detected at MCN (%)	Reference group proportion detected at MCN (%)	Post-detection bypass survival (S_{B3})
(R_{B31}, C_{B31})	48.8	54.8	0.890 (0.044)
(R_{B32}, C_{B32})	43.9	47.9	0.916 (0.051)
(R_{B33}, C_{B33})	57.3	57.5	0.996 (0.044)
Pooled*			0.936 (0.033)

* Pooled estimates are weighted averages of the independent estimates, with weights inversely proportional to the respective variances.

Table 34. Post-detection bypass survival estimates for hatchery steelhead released at Lower Granite, Little Goose, and Lower Monumental Dams. Standard errors in parentheses. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam; MCN-McNary Dam.

a) Lower Granite Dam

Releases	Treatment group survival LGR to LGO tailrace	Reference group survival LGR to LGO tailrace	Post-detection bypass survival (S_{B1})
(R_{B11}, C_{B11})	0.899 (0.040)	0.859 (0.036)	1.047 (0.064)
(R_{B12}, C_{B12})	0.711 (0.050)	0.786 (0.052)	0.905 (0.087)
Pooled*			0.997 (0.068)

b) Little Goose Dam

Releases	Treatment group survival LGO to LMO tailrace	Reference group survival LGO to LMO tailrace	Post-detection bypass survival (S_{B2})
(R_{B21}, C_{B21})	0.864 (0.069)	0.900 (0.067)	0.960 (0.105)
(R_{B22}, C_{B22})	1.070 (0.130)	0.899 (0.094)	1.190 (0.191)
Pooled*			1.013 (0.097)

* Pooled estimates are weighted averages of the independent estimates, with weights inversely proportional to the respective variances.

Table 34. Continued.

c) Lower Monumental Dam

Releases	Treatment group proportion detected at MCN (%)	Reference group proportion detected at MCN (%)	Post-detection bypass survival (S_{B3})
(R_{B31}, C_{B31})	22.8	24.1	0.945 (0.062)
(R_{B32}, C_{B32})	23.9	23.6	1.015 (0.066)
Pooled*			0.977 (0.025)

* Pooled estimates are weighted averages of the independent estimates, with weights inversely proportional to the respective variances.

weighted average of three survival probability estimates greater than 1.0. The weighted average of two paired releases of hatchery steelhead was also greater than 1.0 (Table 34b). As in 1993, we concluded that there was no post-detection mortality at Little Goose Dam.

At Lower Monumental Dam, the three post-detection survival estimates for hatchery yearling chinook salmon ranged from 0.890 to 0.996, with weighted average of 0.936 (s.e. 0.033) (Table 33c). Survival estimates from the two paired releases of hatchery steelhead averaged 0.977 (s.e. 0.025) (Table 34c).

Because 95% confidence intervals for the weighted average estimates of post-detection bypass survival of both hatchery yearling chinook salmon and steelhead included 1.0 at all dams, we used the SR Model to estimate survival rates for the primary releases. However, the post-detection mortality for hatchery yearling chinook salmon was nearly significant at the 0.05 level at both Lower Granite and Lower Monumental Dams. Moreover, two releases of steelhead at each dam were probably not enough to conclude definitively that there was no post-detection mortality for hatchery steelhead. Consequently, we also used the MSR Model to estimate survival probabilities and included the results in the Discussion section.

Assumption A1--Treatment release groups and their corresponding reference groups mix evenly and travel together downstream from the source of mortality under investigation.

Tests of homogeneity of passage distributions for paired bypass releases of hatchery yearling chinook salmon and steelhead from Lower Granite Dam (Figs. 9 and 10; Tables 35 and 36) showed no significant differences in passage distributions at any downstream dam (significance level α_{EW} = 0.05).

Paired forebay/reference releases of both hatchery yearling chinook salmon and steelhead from Lower Granite Dam (Tables 37 and 38) had highly significant differences in downstream passage distributions (P values typically less than 0.001). The two groups were not mixed for any of the six paired releases. Tailrace releases consistently arrived at downstream dams earlier than the corresponding forebay releases, had higher peaks in passage, and had less protracted passage distributions (Figures 11 and 12). Highly significant differences in passage distributions suggested that the two release groups of a pair did not experience the same reservoir and dam conditions downstream from release. Consequently, the survival estimates for Lower Granite Dam passage obtained from the ratio of estimated probabilities of survival to Little Goose Dam tailrace were not reliable.

Tests of passage homogeneity for Little Goose Dam paired bypass releases showed some significant differences (Tables 39 and 40). However, comparison of passage distributions shows that the actual differences were very small (Figures 13 and 14). The statistical significance of the difference was a reflection of

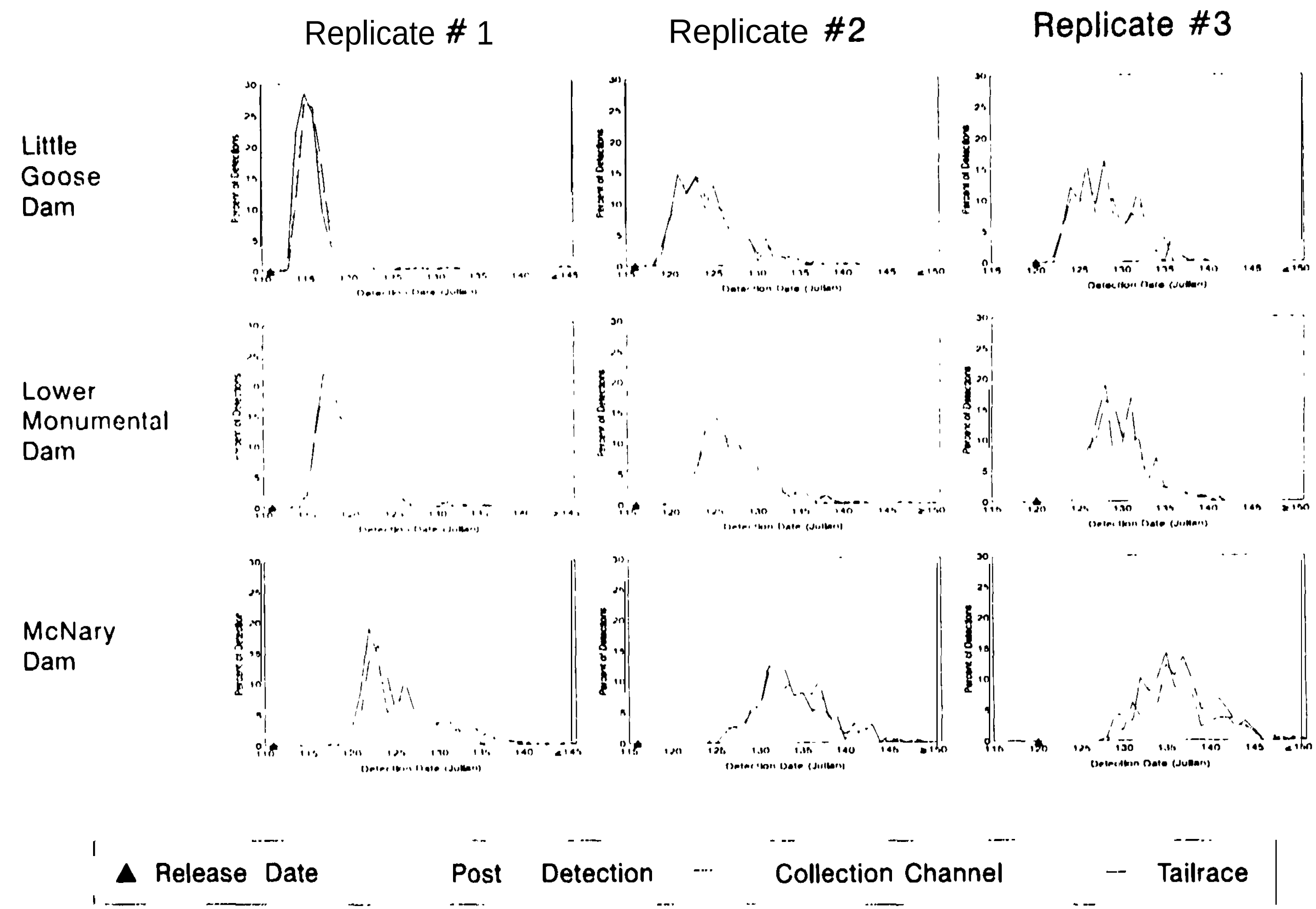


Figure 9. Passage distributions at downstream dams for Lower Granite Dam paired bypass releases of hatchery yearling chinook salmon.

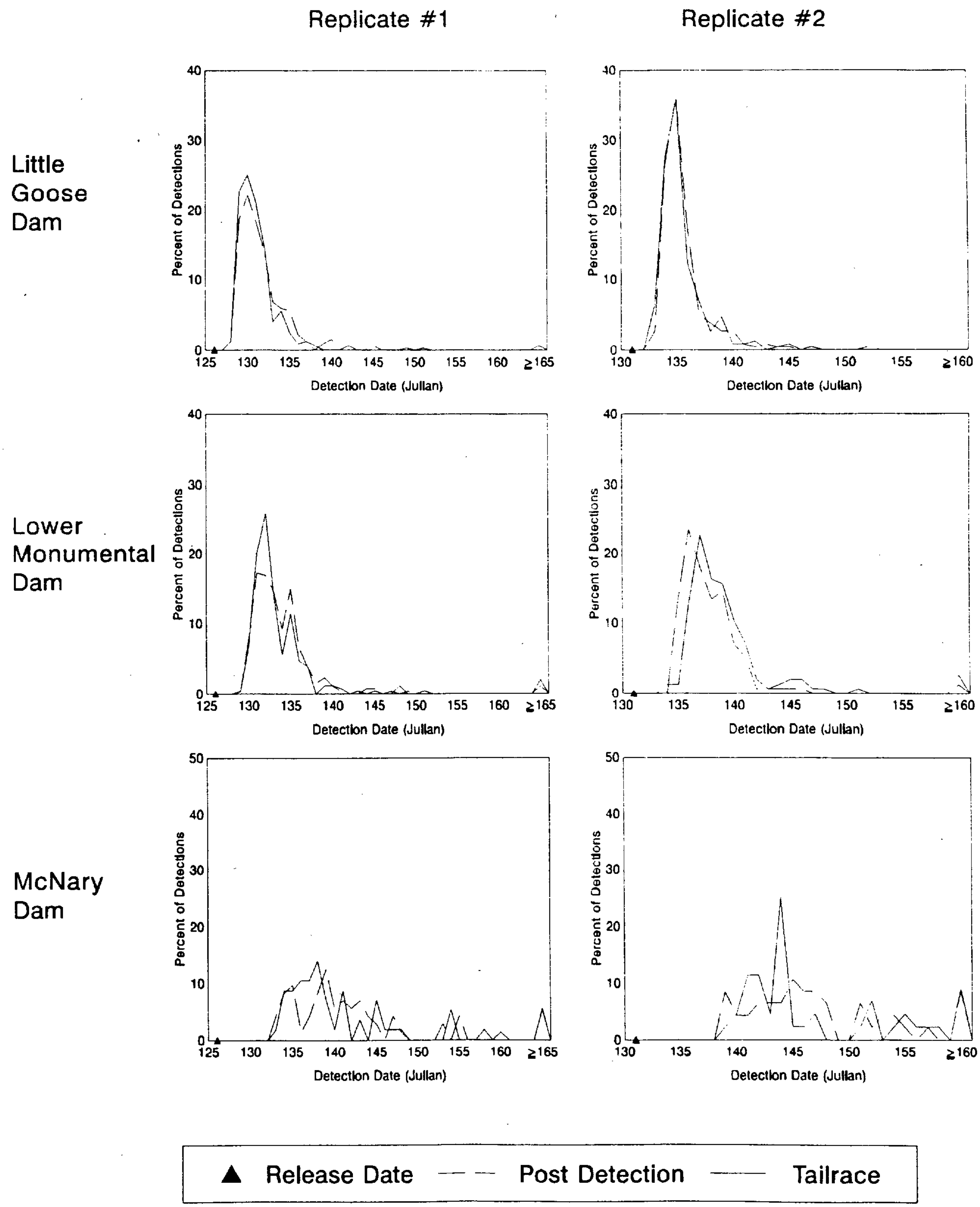


Figure 10. Passage distributions at downstream dams for Lower Granite Dam paired bypass releases of hatchery steelhead.

Table 35. Tests of homogeneity of passage distributions at downstream dams for Lower Granite Dam paired bypass releases of hatchery yearling chinook salmon. P values calculated using Monte Carlo approximation of the exact method.

Passage distribution	Releases	χ^2	Degrees of freedom	P value*
Little Goose Dam	$(R_{B11}, C_{B11}, R_{G11})$	49.22	38	0.072
	$(R_{B12}, C_{B12}, R_{G12})$	41.35	44	0.605
	$(R_{B13}, C_{B13}, R_{G13})$	32.98	32	0.416
Lower Monumental Dam	$(R_{B11}, C_{B11}, R_{G11})$	56.21	42	0.056
	$(R_{B12}, C_{B12}, R_{G12})$	55.67	48	0.181
	$(R_{B13}, C_{B13}, R_{G13})$	52.53	36	0.032
McNary Dam	$(R_{B11}, C_{B11}, R_{G11})$	63.73	56	0.190
	$(R_{B12}, C_{B12}, R_{G12})$	48.45	46	0.376
	$(R_{B13}, C_{B13}, R_{G13})$	56.84	46	0.115

* To control experiment-wise Type I error rate (e.g., α_{EX} = 0.05), test-wise P values are compared to adjusted significance levels for three tests (e.g., α_T = 0.017) (see Table 10).

Table 36. Tests of homogeneity of passage distributions at downstream dams for Lower Granite Dam paired bypass releases of hatchery steelhead. P values calculated using Monte Carlo approximation of the exact method.

Passage distribution	Releases	χ^2	Degrees of freedom	P value
Little Goose Dam	(R_{B11}, C_{B11})	25.54	18	0.072
	(R_{B12}, C_{B12})	16.72	14	0.254
Lower Monumental Dam	(R_{B11}, C_{B11})	30.64	26	0.174
	(R_{B12}, C_{B12})	14.26	20	0.910
McNary Dam	(R_{B11}, C_{B11})	34.68	26	0.068
	(R_{B12}, C_{B12})	23.49	21	0.296

* To control experiment-wise Type I error rate (e.g., α_{EX} = 0.05), test-wise P values are compared to adjusted significance levels for two tests (e.g., α_T = 0.0253) (see Table 10).

Table 37. Tests of homogeneity of passage distributions at downstream dams for Lower Granite Dam paired forebay/reference releases of hatchery yearling chinook salmon. P values calculated using Monte Carlo approximation of the exact method.

Passage distribution	Releases	χ^2	Degrees of freedom	P value*
Little Goose Dam	(R_{F11}, C_{T11})	43.23	9	<0.001
Lower Monumental Dam	(R_{F11}, C_{T11})	31.47	18	0.006
McNary Dam	(R_{F11}, C_{T11})	63.21	24	<0.001

- [illegible] single experiment, experiment-wise Type I error rate and test-wise significance levels are equal (e.g. $\alpha_{EX} = \alpha_T = 0.05$).

Table 38. Tests of homogeneity of passage distributions at downstream dams for Lower Granite Dam paired forebay/reference releases of hatchery steelhead. P values calculated using Monte Carlo approximation of the exact method.

Passage distribution	Releases	χ^2	Degrees of freedom	P value*
Little Goose Dam	(R_{F11}, C_{T11})	115.9	24	<0.001
	(R_{F12}, C_{T12})	93.91	32	<0.001
	(R_{F13}, C_{T13})	348.4	47	<0.001
	(R_{F14}, C_{T14})	491.1	52	<0.001
	(R_{F15}, C_{T15})	94.82	43	<0.001
Lower Monumental Dam	(R_{F11}, C_{T11})	106.8	26	<0.001
	(R_{F12}, C_{T12})	116.4	45	<0.001
	(R_{F13}, C_{T13})	176.1	52	<0.001
	(R_{F14}, C_{T14})	285.3	55	<0.001
	(R_{F15}, C_{T15})	289.1	53	<0.001
McNary Dam	(R_{F11}, C_{T11})	49.82	34	0.006
	(R_{F12}, C_{T12})	45.67	43	0.358
	(R_{F13}, C_{T13})	61.88	42	0.007
	(R_{F14}, C_{T14})	94.82	43	<0.001
	(R_{F15}, C_{T15})	80.80	45	<0.001

* To control experiment-wise Type I error rate (e.g., $\alpha_{EX} = 0.05$), test-wise P values are compared to adjusted significance levels for five tests (e.g., $\alpha_T = 0.0102$) (see Table 10).

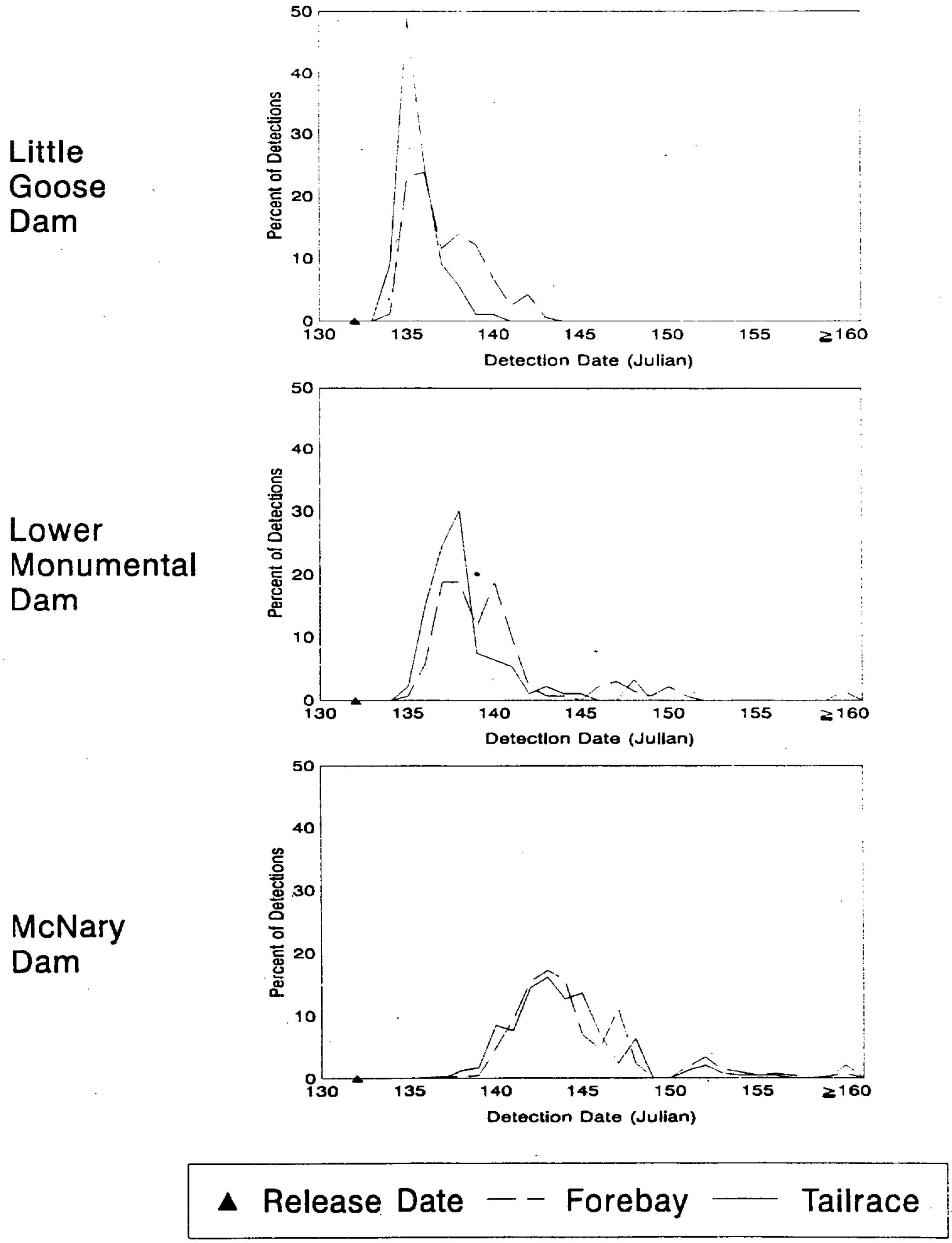


Figure 11. Passage distributions at downstream dams for Lower Granite Dam paired forebay/reference releases of hatchery yearling chinook salmon.

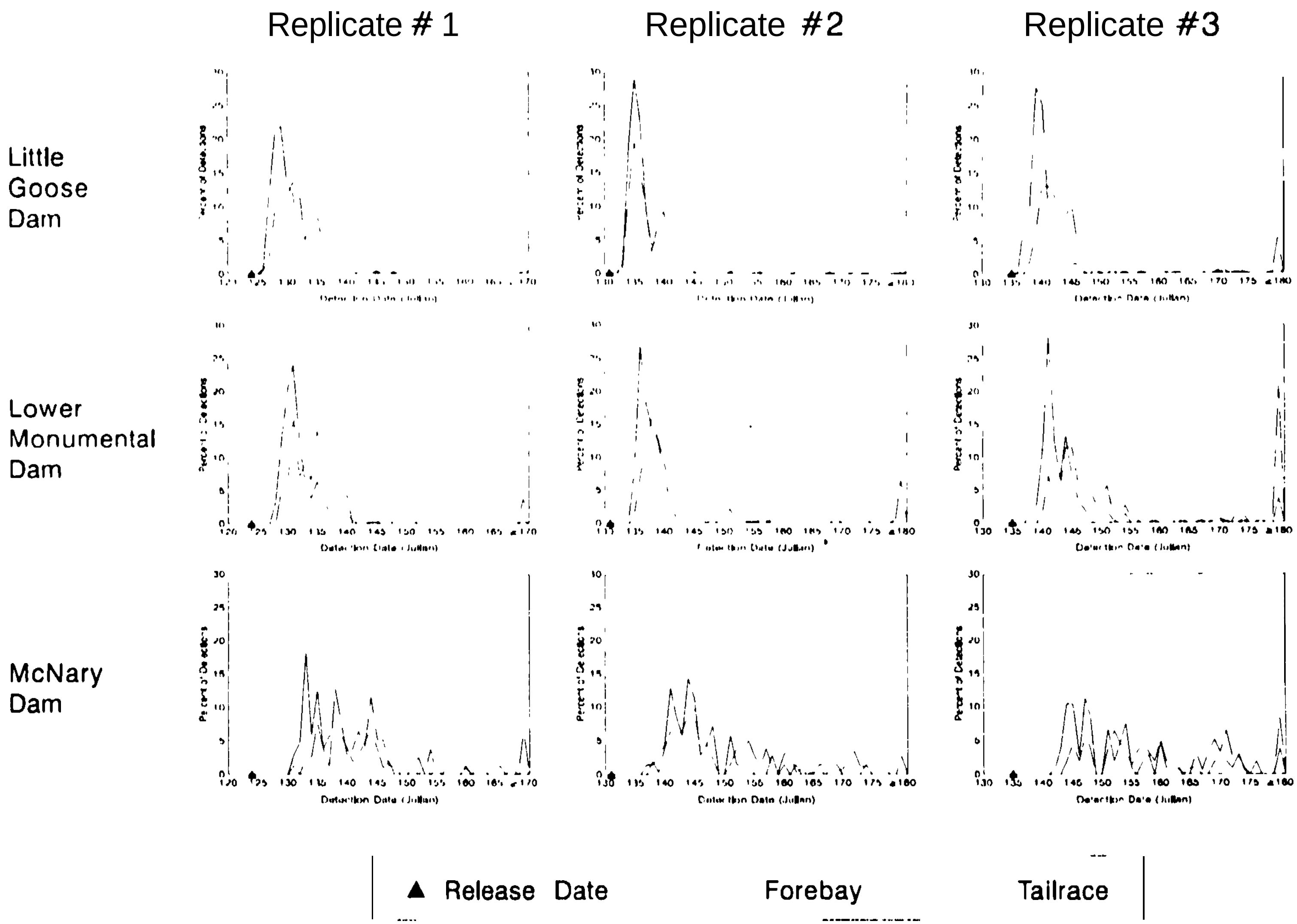


Figure 12. Passage distributions at downstream dams for Lower Granite Dam paired forebay/reference releases of hatchery steelhead.

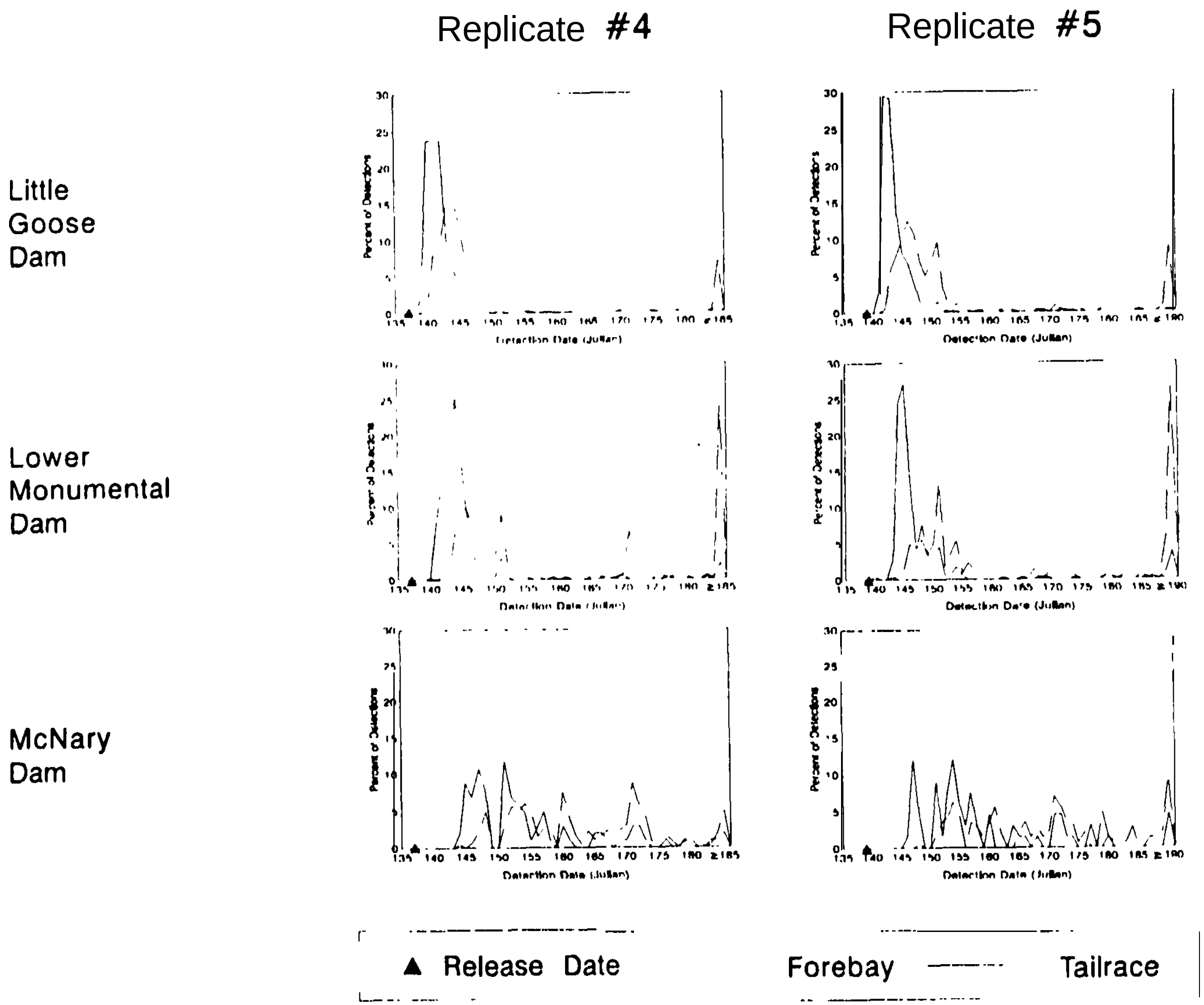


Figure 12. Continued.

Table 39. Tests of homogeneity of passage distributions at downstream for Little Goose Dam paired bypass releases of hatchery yearling chinook salmon. P values calculated using Monte Carlo approximation of the exact method.

Passage distribution	Releases	χ^2	Degrees of freedom	P value*
Lower Monumental Dam	(R_{B21}, C_{B21}, R_{G21})	55.56	32	0.004
	(R_{B22}, C_{B22}, R_{G22})	82.51	32	<0.001
	(R_{B23}, C_{B23}, R_{G23})	35.32	30	0.186
McNary Dam	(R_{B21}, C_{B21}, R_{G21})	34.05	48	0.972
	(R_{B22}, C_{B22}, R_{G22})	46.02	40	0.212
	(R_{B23}, C_{B23}, R_{G23})	35.50	42	0.802

* To control experiment-wise Type I error rate (e.g., $\alpha_{EX} = 0.05$), test-wise P values are compared to adjusted significance levels for three tests (e.g., $\alpha_T = 0.017$) (see Table 10).

Table 40. Tests of homogeneity of passage distributions at downstream dams for Little Goose Dam paired bypass releases of hatchery steelhead. P values calculated using Monte Carlo approximation of the exact method.

Passage distribution	Releases	χ^2	Degrees of freedom	P value*
Lower Monumental Dam	(R_{B21}, C_{B21})	32.14	14	0.001
	(R_{B22}, C_{B22})	13.47	18	0.849
McNary Dam	(R_{B21}, C_{B21})	26.36	19	0.072
	(R_{B22}, C_{B22})	26.03	26	0.480

* To control experiment-wise Type I error rate (e.g., $\alpha_{EX} = 0.05$), test-wise P values are compared to adjusted significance levels for two tests (e.g., $\alpha_T = 0.0253$) (see Table 10).

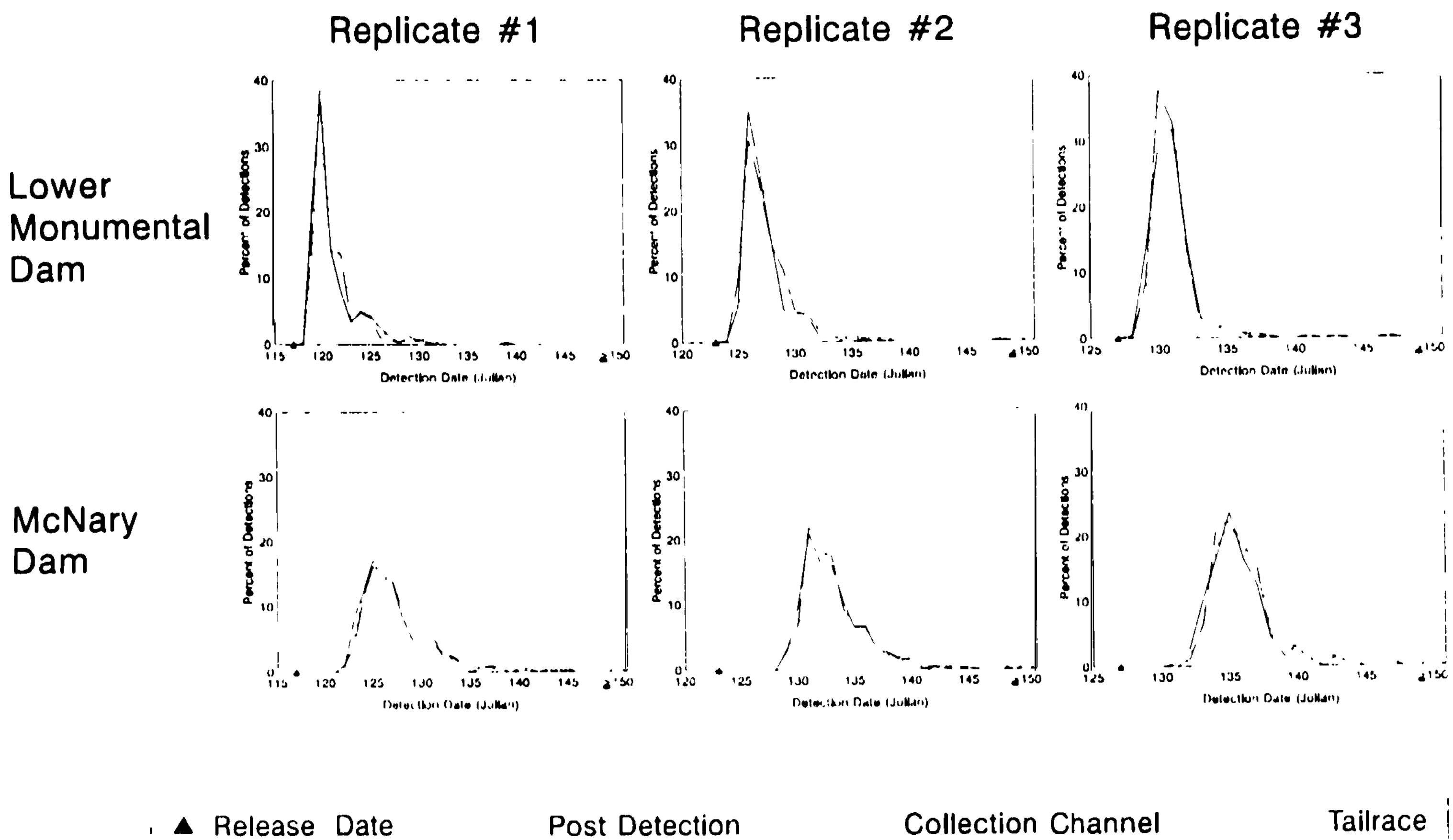


Figure 13. Passage distributions at downstream dams for Little Goose Dam paired bypass releases of hatchery yearling chinook salmon.

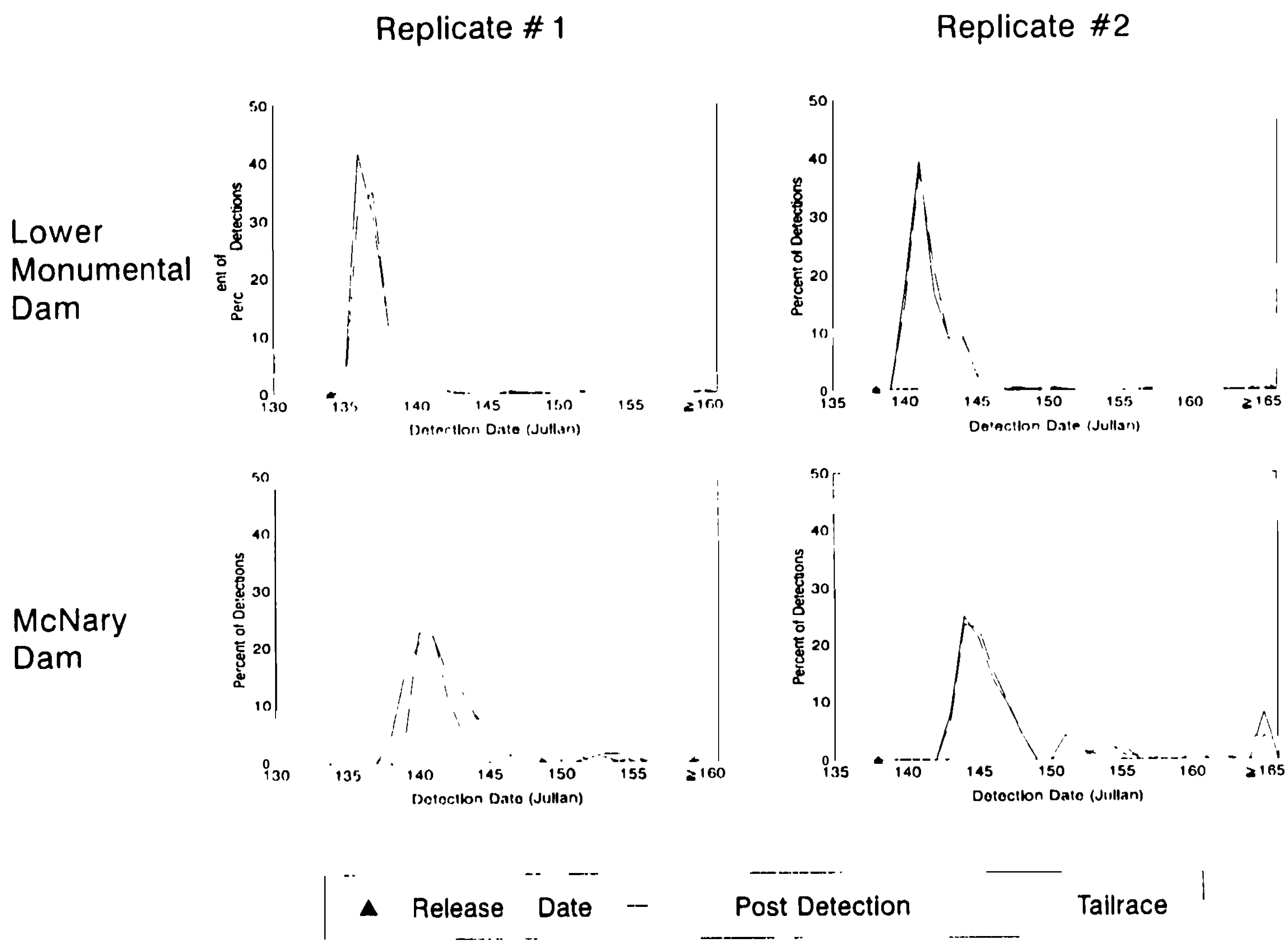


Figure 14. Passage distributions at downstream dams for Little Goose Dam paired bypass releases of hatchery steelhead.

the highly sensitive nature of the test; the small actual difference was not likely to result in differences in survival or capture probabilities downstream from release.

Paired forebay and reference releases of hatchery steelhead from Little Goose Dam were not mixed at Lower Monumental Dam, but were mixed by the time they reached McNary Dam (Table 41). However, comparison of passage distributions indicates that the actual differences were small (Figure 15). Because of the highly significant test results, we again conclude that the survival estimates for Little Goose Dam passage obtained from the ratio of estimated probabilities of survival to Lower Monumental Dam tailrace were not reliable.

McNary Dam passage distributions were significantly different (α_{EX} = 0.05) for the second paired bypass and reference releases of hatchery yearling chinook salmon and the second release of hatchery steelhead (Tables 42 and 43). However, comparison of passage distributions shows a maximum difference of 1 day in the passage of the 2 groups (Figures 16 and 17). The effects of such a small difference on the survival and detection rates below Lower Monumental Dam were probably negligible.

Tests of homogeneity of passage at McNary Dam for paired forebay/reference (Table 44) and Turbine Unit 6 (Table 45) releases of hatchery steelhead from Lower Monumental Dam showed significant heterogeneity for the first turbine/reference pair (P value 0.003). The P value for the forebay/reference pair was

Table 41. Tests of homogeneity of passage distributions at downstream dams for Little Goose Dam paired forebay/reference releases of hatchery steelhead. P values calculated using Monte Carlo approximation of the exact method.

Passage distribution	Releases	χ^2	Degrees of freedom	P value*
Lower Monumental Dam	(R_{F21}, C_{T21})	84.54	20	<0.001
	(R_{F22}, C_{T22})	33.75	21	0.007
McNary Dam	(R_{F21}, C_{T21})	28.06	25	0.261
	(R_{F22}, C_{T22})	19.08	19	0.486

* To control experiment-wise Type I error rate (e.g., α_{EX} = 0.05), test-wise P values are compared to adjusted significance levels for two tests (e.g., α_T = 0.0253) (see Table 10).

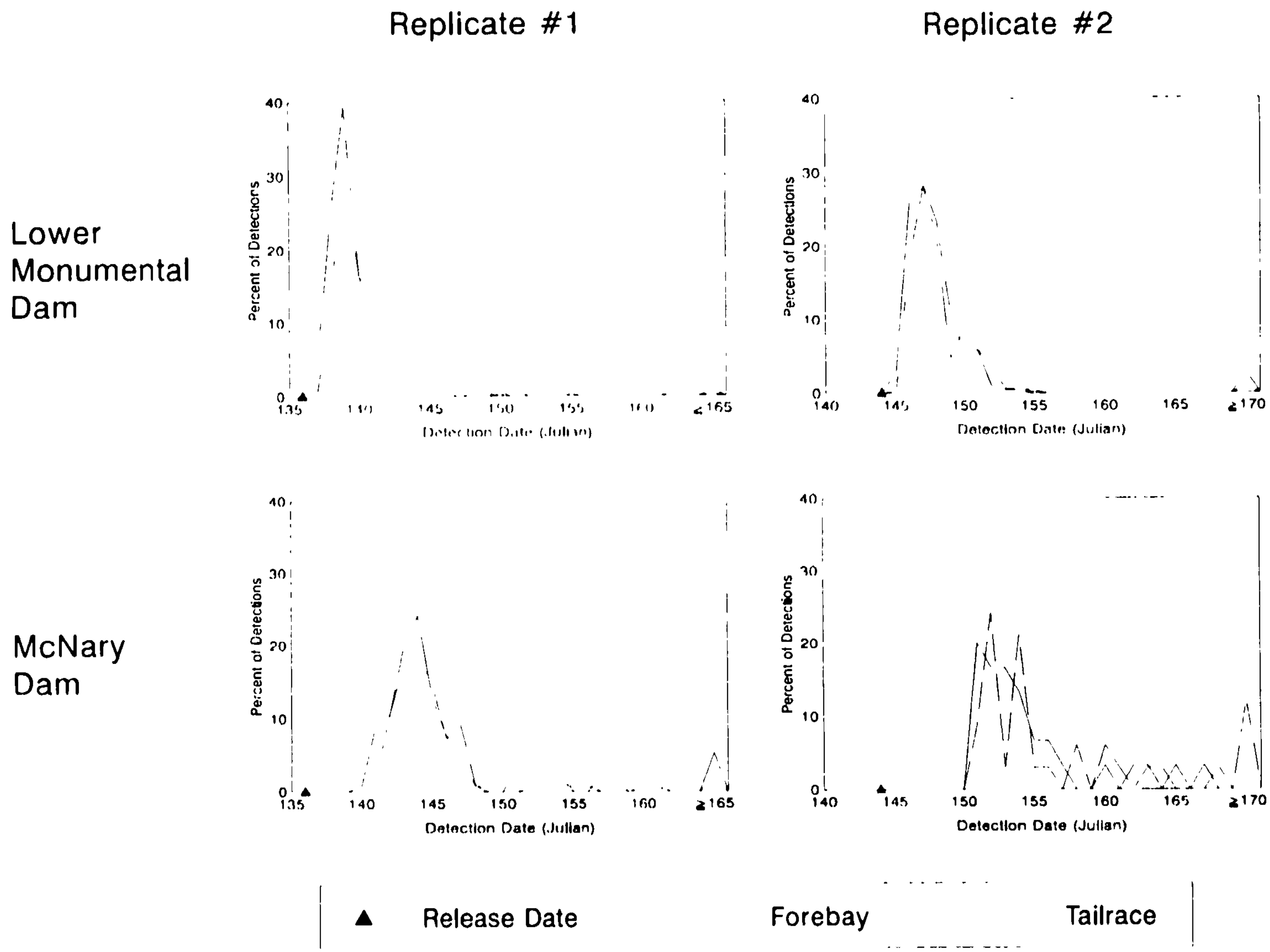


Figure 15. Passage distributions at downstream dams for Little Goose Dam paired forebay/reference releases of hatchery steelhead.

Table 42 Tests of homogeneity of passage distributions at McNary Dam for Lower Monumental Dam paired bypass releases of hatchery yearling chinook salmon. P values calculated using Monte Carlo approximation or the exact method.

Passage distribution	Releases	χ^2	Degrees of freedom	P value*
McNary Dam	(R_{B31}, C_{B31})	5.40	14	0.992
	(R_{B32}, C_{B32})	29.46	11	0.001
	(R_{B33}, C_{B33})	8.15	9	0.547

* To control experiment-wise Type I error rate (e.g., α_{EX} = 0.05), test-wise P values are compared to adjusted significance levels for three tests (e.g., UT = 0.017) (see Table 10).

Table 43. Tests of homogeneity of passage distributions at McNary Dam for Lower Monumental Dam paired bypass releases of hatchery steelhead. P values calculated using Monte Carlo approximation of the exact method.

Passage distribution	Releases	χ^2	Degrees of freedom	P value*
McNary Dam	(R_{B31}, C_{B31})	22.37	17	0.128
	(R_{B32}, C_{B32})	62.41	14	<0.001

- To control experiment-wise Type I error rate (e.g., $\alpha_{EX} = 0.05$), test-wise P values are compared to adjusted significance levels for two tests (e.g., $\alpha_T = 0.0253$) (see Table 10).

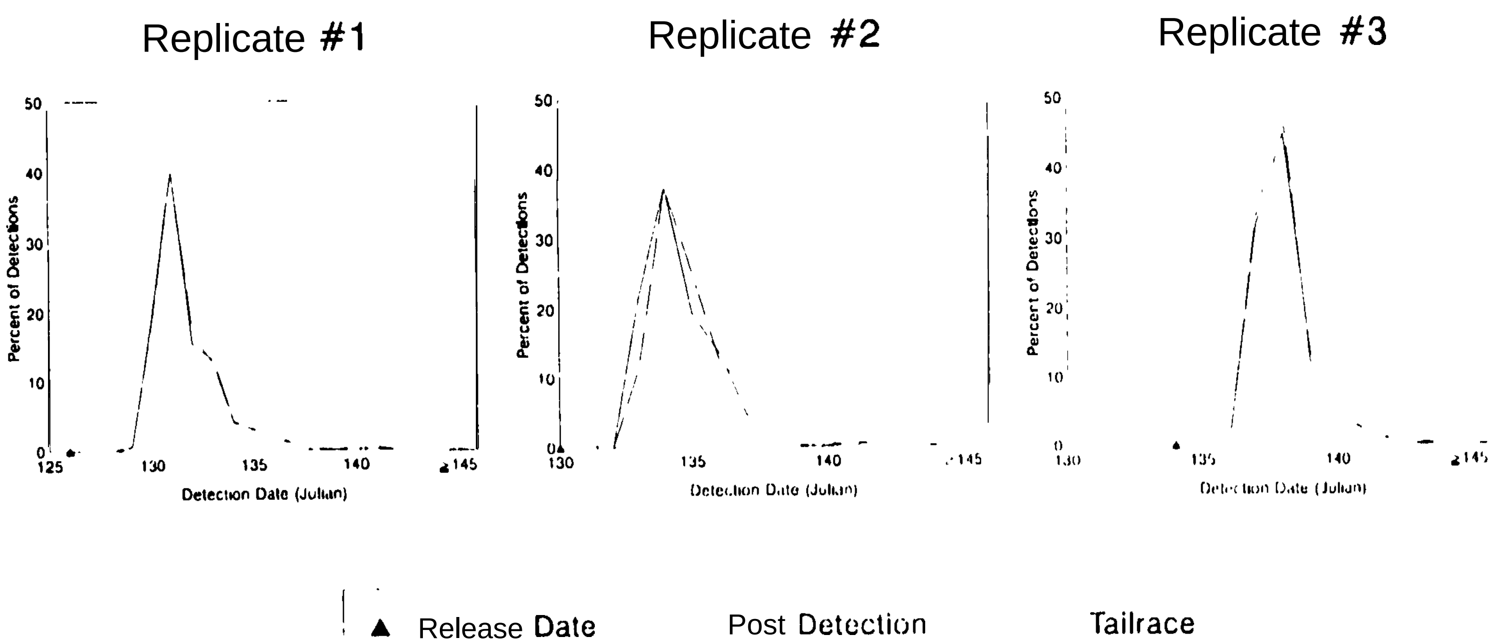


Figure 16. Passage distributions at McNary Dam for Lower Monumental Dam paired bypass releases of hatchery yearling chinook salmon.

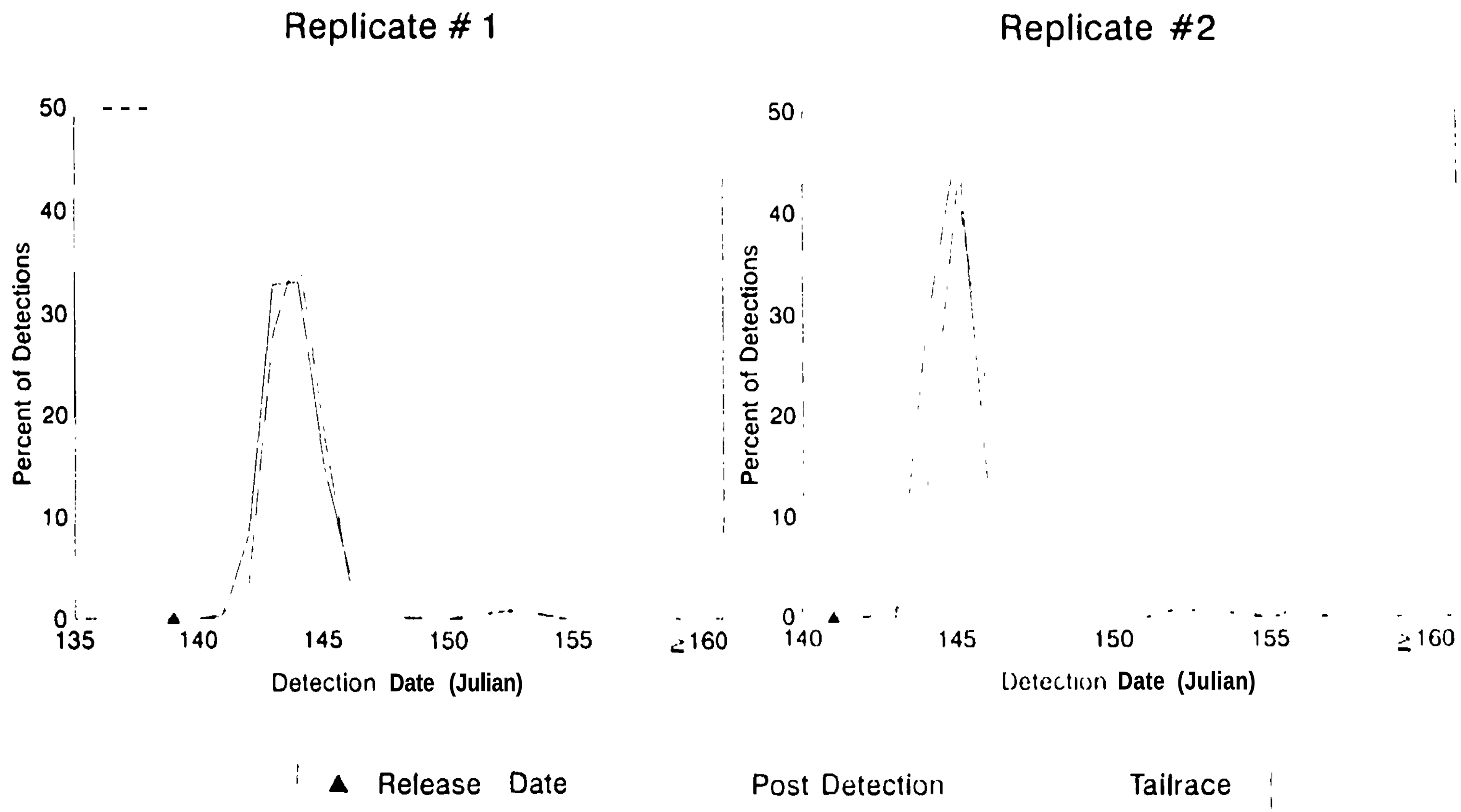


Figure 17. Passage distributions at McNary Dam for Lower Monumental Dam paired bypass releases of hatchery steelhead.

Table 44. Tests of homogeneity of passage distributions at McNary Dam for Lower Monumental Dam paired forebay/reference releases of hatchery steelhead. P values calculated using Monte Carlo approximation of the exact method.

Passage distribution	Releases	χ^2	Degrees of freedom	P value*
McNary Dam	(R_{F31}, C_{T31})	17.44	12	0.069

- For single experiment, experiment-wise Type I error rate and test-wise significance levels are equal (e.g. $\alpha_{EX} = \alpha_{T} = 0.05$).

Table 45. Tests of homogeneity of passage distributions at McNary Dam for Lower Monumental Dam paired turbine releases of hatchery yearling chinook salmon. P values calculated using Monte Carlo approximation of the exact method.

Passage distribution	Releases	χ^2	Degrees of freedom	P value*
McNary Dam	(R_{631}, C_{631})	32.58	16	0.003
	(R_{632}, C_{632})	19.11	13	0.093

- To control experiment-wise Type I error rate (e.g., α_{EX} = 0.05), test-wise P values are compared to adjusted significance levels for two tests (e.g., α_T = 0.0253) (see Table 10).

also relatively small (0.069). Given the extremely sensitive nature of the test and the minor differences in distributions (Figs. 18 and 19), we concluded that the paired forebay and turbine groups were sufficiently mixed to validate the estimates of survival derived from relative recoveries of the groups.

Survival Estimation

Survival estimates for primary releases of hatchery yearling chinook salmon from Silcott Island to Lower Granite Dam tailrace ranged from 0.841 to greater than 1.0 (Table 46). The weighted average of the 10 survival estimates was 0.922 (s.e. 0.010). The weighted average survival estimate for Lower Granite Dam tailrace to Little Goose Dam tailrace was 0.794 (s.e. 0.026). The weighted average survival estimate from Little Goose Dam tailrace to Lower Monumental Dam tailrace was 0.891 (s.e. 0.023).

For the single primary release of wild yearling chinook salmon, the survival estimates were 0.923 (s.e. 0.030) from Silcott Island to Lower Granite Dam tailrace, 0.827 (s.e. 0.044) from Lower Granite Dam tailrace to Little Goose Dam tailrace, and 0.944 (s.e. 0.054) from Little Goose Dam tailrace to Lower Monumental Dam tailrace (Table 46).

Survival estimates for primary releases of hatchery steelhead from Silcott Island to Lower Granite Dam tailrace ranged from 0.865 to 0.925 with weighted average of 0.904 (s.e. 0.007) (Table 47). The weighted average survival estimates from Lower Granite Dam tailrace to Little Goose Dam tailrace and

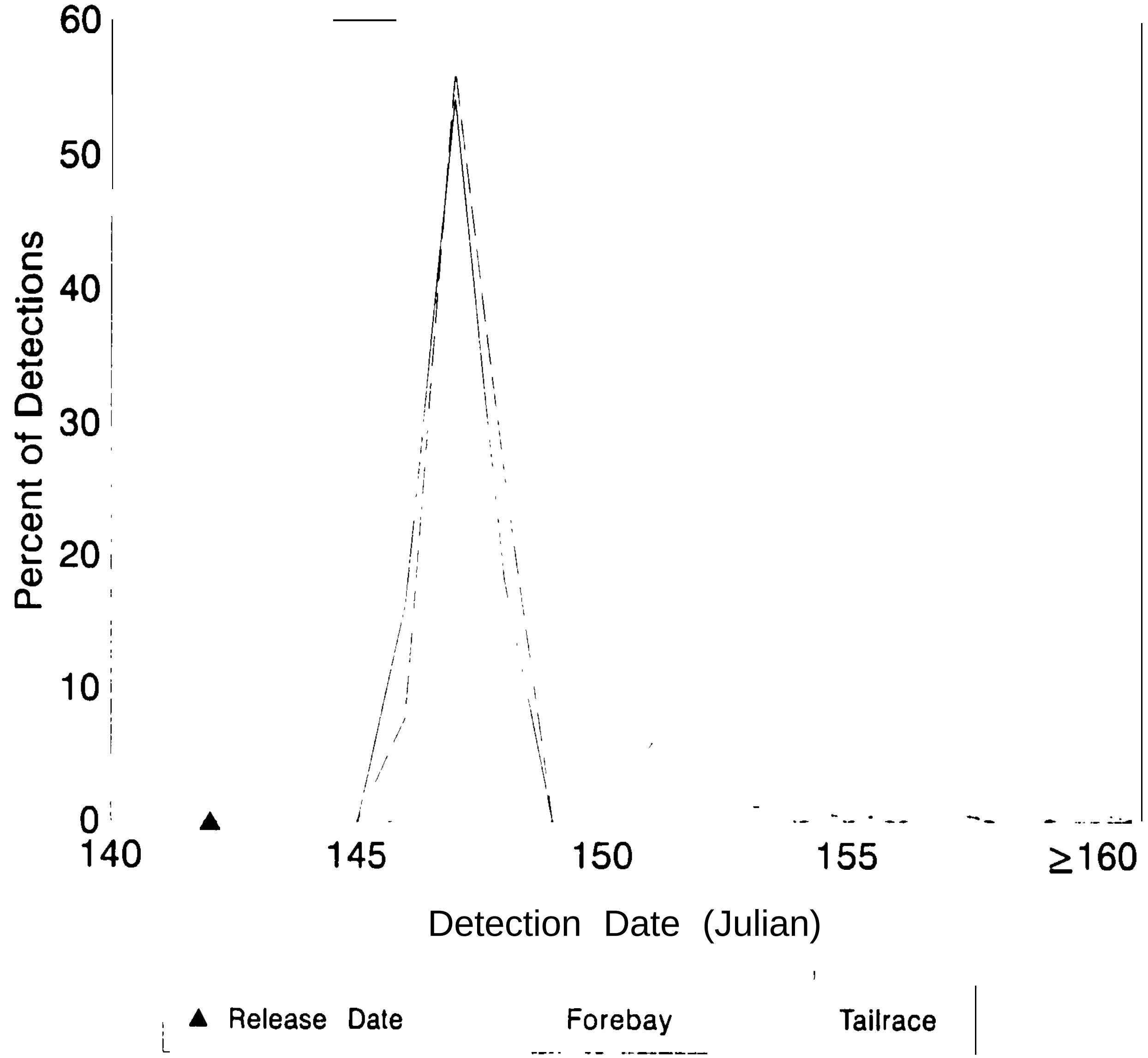


Figure 18. Passage distribution at McNary Dam for Lower Monumental Dam paired forebay/reference releases of hatchery steelhead.

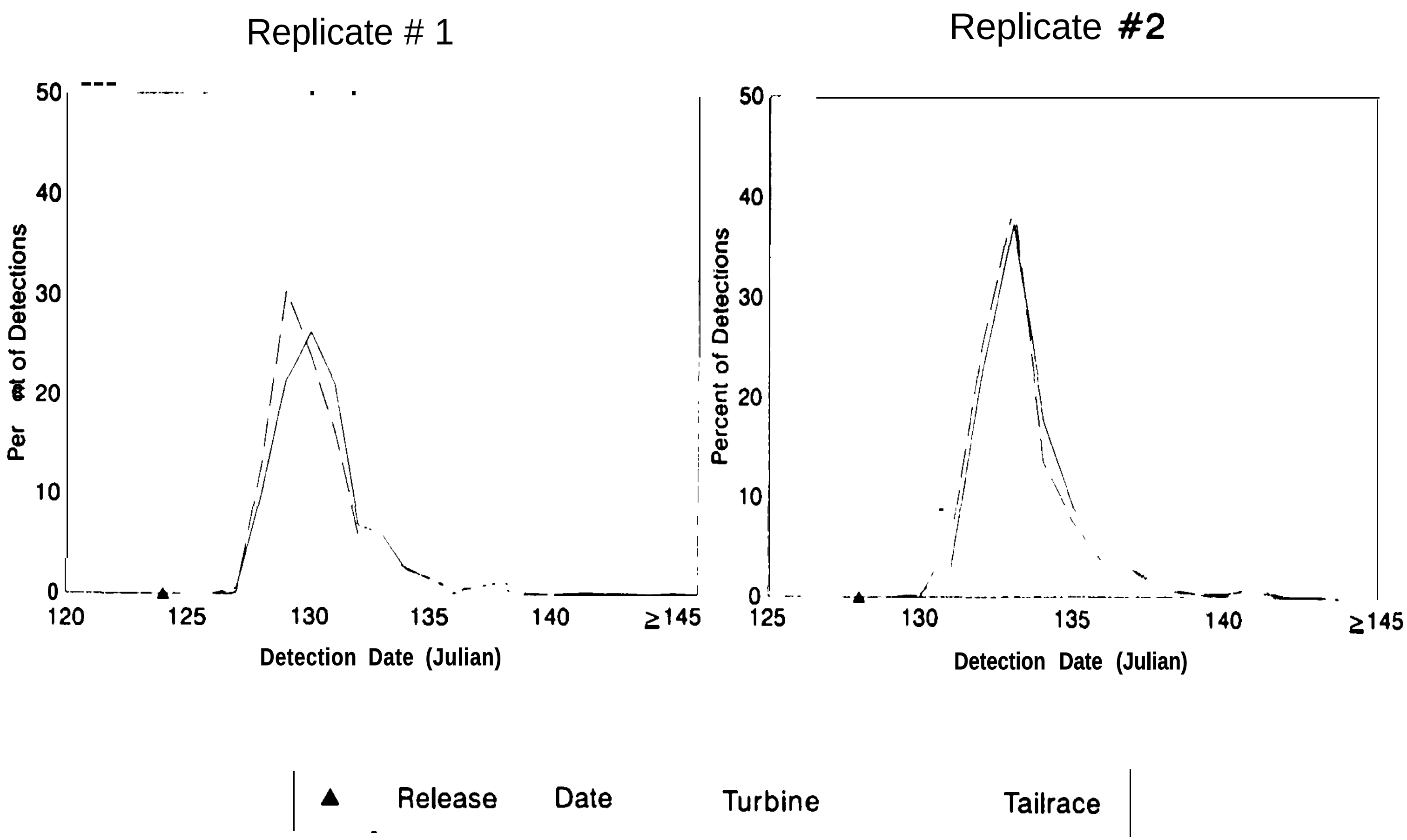


Figure 19. Passage distributions at McNary Dam for Lower Monumental Dam paired turbine releases of hatchery yearling chinook salmon.

Table 46. Estimates of survival probabilities for primary releases of yearling chinook salmon near Silcott Island. Estimates based on Single-Release Model. Standard errors in parentheses. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam.

Release	Date	Release to LGR (S_{R1})	LGR to LGO (S_{R2})	LGO to LMO (S_{R3})	Release to LMO
R_{P1}	16 Apr	0.893 (0.024)	0.882 (0.038)	0.874 (0.045)	0.688 (0.027)
R_{P2}	17 Apr	0.948 (0.029)	0.739 (0.038)	0.950 (0.049)	0.666 (0.028)
R_{P3}	18 Apr	0.925 (0.028)	0.782 (0.045)	0.876 (0.053)	0.634 (0.027)
R_{P4}	21 Apr	0.941 (0.033)	0.723 (0.047)	1.014 (0.076)	0.690 (0.040)
R_{P5}	23 Apr	1.028 (0.058)	0.723 (0.085)	0.816 (0.103)	0.606 (0.047)
R_{P6}	26 Apr	0.927 (0.038)	0.913 (0.101)	0.744 (0.095)	0.630 (0.048)
R_{P7}	29 Apr	0.896 (0.044)	0.756 (0.081)	0.919 (0.131)	0.623 (0.069)
R_{P8}	1 May	0.903 (0.037)	0.963 (0.098)	0.777 (0.098)	0.676 (0.056)
R_{P9}	4 May	0.933 (0.074)	0.688 (0.110)	1.036 (0.199)	0.665 (0.094)
R_{P10}	10 May	0.841 (0.081)	1.022 (0.146)	0.839 (0.148)	0.721 (0.101)
Pooled*		0.922 (0.010)	0.794 (0.026)	0.891 (0.023)	0.659 (0.009)
R_{PW1}	17 Apr	0.923 (0.030)	0.827 (0.044)	0.944 (0.054)	0.728 (0.036)

* Pooled estimates are weighted averages of the independent estimates, with weights inversely proportional to the respective variances.

Table 47. Estimates of survival probabilities for primary releases of hatchery steelhead near Silcott Island. Estimates based on Single-Release Model. Standard errors in parentheses. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam.

Release	Date	Release to LGR (S_{R1})	LGR to LGO (S_{R2})	LGO to LMO (S_{R3})	Release to LMO
R_{P1}	23 Apr	0.925 (0.011)	0.793 (0.022)	0.824 (0.028)	0.604 (0.019)
R_{P2}	25 Apr	0.912 (0.012)	0.801 (0.027)	0.819 (0.040)	0.598 (0.025)
R_{P3}	26 Apr	0.915 (0.010)	0.804 (0.027)	0.832 (0.049)	0.612 (0.032)
R_{P4}	1 May	0.916 (0.014)	0.812 (0.040)	0.885 (0.092)	0.658 (0.061)
R_{P5}	3 May	0.873 (0.014)	0.742 (0.044)	0.907 (0.115)	0.588 (0.068)
R_{P6}	5 May	0.865 (0.016)	0.749 (0.049)	0.832 (0.111)	0.539 (0.064)
R_{P7}	7 May	0.880 (0.017)	0.776 (0.053)	0.918 (0.148)	0.627 (0.092)
R_{P8}	10 May	0.878 (0.068)	0.701 (0.081)	0.718 (0.120)	0.442 (0.063)
R_{P9}	12 May	0.917 (0.052)	0.682 (0.054)	1.004 (0.143)	0.628 (0.082)
Pooled*		0.904 (0.007)	0.784 (0.012)	0.831 (0.013)	0.598 (0.012)

* Pooled estimates are weighted averages of the independent estimates, with weights inversely proportional to the respective variances.

from Little Goose Dam tailrace to Lower Monumental Dam tailrace were 0.784 (s.e. 0.012) and 0.831 (s.e. 0.013), respectively.

The product of the three survival probability estimates provided an estimate of the probability of cumulative survival from point of release to Lower Monumental Dam tailrace. The weighted average estimates were 0.659 (s.e. 0.009), 0.728 (s.e. 0.036), and 0.598 (s.e. 0.012) for hatchery yearling chinook salmon, wild yearling chinook salmon, and hatchery steelhead, respectively (Tables 46 and 47).

Detection rates varied widely in 1994, particularly late in the season after the spill program began (Tables 48 and 49). Detection rates for hatchery steelhead at Lower Granite Dam were as high as 0.880 (s.e. 0.012) before spill began, and dropped to as low as 0.158 (0.011) during the spill program. The chief effect of lower detection rates on the SR and MSR Models is decreased precision in estimating survival probabilities.

The weighted average survival estimate for passage of hatchery yearling chinook salmon through the collection channel was 0.994 (s.e. 0.030) at Lower Granite Dam and 0.994 (0.023) at Little Goose Dams (Table 50). The survival estimates for the collection channel releases were higher than those for the post-detection releases, despite passing through a longer stretch of the bypass system. The collection channel survival estimates near 1.0 supported the use of the SR Model for the primary

Table 48. Estimates of detection probabilities for yearling chinook salmon released near Silcott Island. Estimates based on Single-Release Model. Standard errors in parentheses. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam.

Release	Date	LGR (P_1)	LGO (P_2)	LMO (P_3)
R_{p1}	16 Apr	0.400 (0.018)	0.368 (0.020)	0.536 (0.027)
R_{p2}	17 Apr	0.398 (0.019)	0.320 (0.020)	0.476 (0.026)
R_{p3}	la Apr	0.420 (0.020)	0.259 (0.019)	0.474 (0.026)
R_{p4}	21 Apr	0.402 (0.020)	0.241 (0.019)	0.340 (0.026)
R_{p5}	23 Apr	0.333 (0.026)	0.170 (0.023)	0.314 (0.032)
R_{p6}	26 Apr	0.403 (0.023)	0.138 (0.018)	0.256 (0.026)
R_{p7}	29 Apr	0.436 (0.030)	0.192 (0.026)	0.191 (0.029)
R_{p8}	1 May	0.377 (0.022)	0.152 (0.019)	0.223 (0.024)
R_{p9}	4 May	0.307 (0.032)	0.134 (0.026)	0.177 (0.032)
R_{p10}	10 May	0.128 (0.017)	0.151 (0.020)	0.112 (0.020)
R_{pW1}	17 Apr	0.490 (0.027)	0.406 (0.029)	0.548 (0.036)

Table 49. Estimates of detection probabilities for hatchery steelhead released near Silcott Island. Estimates based on Single-Release Model. Standard errors in parentheses. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam.

Release	Date	LGR (P_1)	LGO (P_2)	LMO (P_3)
R_{P1}	23 Apr	0.827 (0.014)	0.530 (0.021)	0.803 (0.026)
R_{P2}	25 Apr	0.829 (0.014)	0.473 (0.022)	0.700 (0.035)
R_{P3}	26 Apr	0.880 (0.012)	0.519 (0.023)	0.619 (0.040)
R_{P4}	1 May	0.792 (0.018)	0.457 (0.028)	0.434 (0.049)
R_{P5}	3 May	0.829 (0.017)	0.394 (0.029)	0.391 (0.053)
R_{P6}	5 May	0.787 (0.019)	0.376 (0.029)	0.323 (0.044)
R_{P7}	7 May	0.740 (0.020)	0.367 (0.029)	0.308 (0.052)
R_{P8}	10 May	0.199 (0.019)	0.300 (0.029)	0.245 (0.039)
R_{P9}	12 May	0.158 (0.011)	0.294 (0.018)	0.155 (0.022)

Table 50. Survival estimates for hatchery yearling chinook salmon released in collection channels at Lower Granite and Little Goose Dams. Standard errors in parentheses. Abbreviations: LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam.

a) Lower Granite Dam

Releases	Treatment group survival LGR to LGO tailrace	Reference group survival LGR to LGO tailrace	Collection channel survival (S_{G1})
(R_{G11}, C_{B11})	0.795 (0.025)	0.823 (0.029)	0.966 (0.046)
(R_{G12}, C_{B12})	0.831 (0.036)	0.778 (0.047)	1.068 (0.079)
(R_{G13}, C_{B13})	0.893 (0.064)	0.877 (0.091)	1.018 (0.128)
Pooled*			0.994 (0.030)

b) Little Goose Dam

Releases	Treatment group survival LGO to LMO tailrace	Reference group survival LGO to LMO tailrace	Collection channel survival (S_{G2})
(R_{G21}, C_{B21})	0.847 (0.022)	0.826 (0.024)	1.025 (0.040)
(R_{G22}, C_{B22})	0.849 (0.025)	0.865 (0.027)	0.982 (0.042)
(R_{G23}, C_{B23})	0.823 (0.036)	0.882 (0.051)	0.933 (0.068)
Pooled*			0.994 (0.023)

- Pooled estimates are weighted averages of the independent estimates, with weights inversely proportional to the respective variances.

releases and suggested that the greater mortality experienced by the post-detection treatment releases was related to release procedures.

The weighted average survival estimate for passage of hatchery yearling chinook salmon through Turbine Unit 6 at Lower Monumental Dam was 0.865 (s.e. 0.018) (Table 51).

Of the 1,026 hatchery steelhead in the single forebay release at Lower Monumental Dam, only 10.1% were detected at McNary Dam, while 14.8% of the 1,047 fish in the tailrace reference group were detected (Table 52). The relative recovery method gave a survival estimate for passage through Lower Monumental Dam of 0.684 (s.e. 0.081). However, the low recovery rates led to an imprecise estimate; the 95% confidence interval around the weighted average ranged from 0.525 to 0.843.

Hatchery Releases

Preliminary analyses to determine the composition of pooled release groups are summarized below.

1) Dworshak National Fish Hatchery (NFH): Parameters did not vary significantly for releases made on the same date. Therefore, for the test groups from the release-timing study, the releases from the 3 raceways on each date were pooled, providing 3 releases of about 6,000 yearling chinook salmon each on 8 April, 22 April, and 6 May. Releases on 14 and 15 April of about 1,200 yearling chinook salmon each for the medicated feed study were analyzed separately. Survival and detection rates differed among the pooled groups.

Table 51. Survival estimates for hatchery yearling chinook salmon released in Turbine Unit 6 at Lower Monumental Dam. Abbreviation: MCN-McNary Dam.

Releases	Treatment group proportion detected at MCN (%)	Reference group proportion detected at MCN (%)	Turbine survival (S_{63})
(R_{631}, C_{631})	44.5	52.5	0.848 (0.033)
(R_{632}, C_{632})	44.9	50.8	0.884 (0.034)
Pooled*			0.865 (0.018)

* Pooled estimates are weighted averages of the independent estimates, with weights inversely proportional to the respective variances.

Table 52. Survival estimate of hatchery steelhead for Lower Monumental Dam passage derived from paired forebay/reference release. Abbreviation: MCN-McNary Dam.

Releases	Treatment group proportion detected at MCN (%)	Reference group proportion detected at MCN (%)	Dam passage survival (S_{F3})
(R_{F31}, C_{T31})	10.1	14.8	0.684 (0.081)

There were two series of juvenile steelhead releases from Dworshak NFH. One series consisted of 6 releases of about 250 fish each between 2 and 5 May, and the second consisted of 3 releases of about 750 fish each between 4 and 6 May. The two series were pooled for these analyses.

2) Kooskia National Fish Hatchery: No significant differences were found among the parameters for the 6 releases of 100 yearling chinook salmon each. Therefore, the releases were pooled to provide a single release of 600 fish.

3) Lookingglass Hatchery: No significant differences were found among the parameters for the four releases of yearling chinook salmon on 10 April. Therefore, the releases were pooled into a single release of 1,993 fish.

The six releases from Imnaha River had significant differences in survival from release to Lower Granite Dam tailrace. A single, weighted average survival estimate was calculated.

4) McCall Hatchery: Hand- and auto-tagged release groups on 11 April were analyzed separately. The releases between 9 and 14 April were significantly different from those on 22 and 28 April. The three "early" releases were pooled into one release of 1,295 yearling chinook salmon, and the "late releases into one release of 797.

5) Rapid River Hatchery: Hand- and auto-tagged release groups on 11 April were analyzed separately.

6) Sawtooth Hatchery: Because the parameters for the 7 release groups of yearling chinook salmon were not significantly different, the groups were pooled to make 1 release group of 2,155 fish.

7) Pahsimeroi Hatchery: Parameters for the two releases were not significantly different. The 2 releases were pooled into a single release group of 997 yearling chinook salmon.

Results of analyses of the pooled data sets using the SR Model are reported in Table 53. Sample sizes and standard errors for the survival probability estimates from release to Lower Granite Dam tailrace were similar to those for our primary releases. Survival probability estimates to Lower Granite Dam tailrace for hatchery releases were lower than for our primary releases and generally appeared to be inversely proportional to the distance from the hatcheries to Lower Granite Dam.

Survival probability estimates from Lower Granite Dam tailrace to Little Goose Dam tailrace and from Little Goose Dam tailrace to Lower Monumental Dam tailrace for the hatchery releases are directly comparable to those for our primary releases, because the sections of the river are the same. The weighted average estimate from the hatchery releases of yearling chinook salmon from Lower Granite Dam tailrace to Little Goose Dam tailrace was 0.826 (s.e. 0.010), compared to the pooled estimate obtained from our primary releases of 0.794 (s.e. 0.026).

Table 53. Survival estimates for yearling chinook salmon and steelhead released from hatcheries. Estimates based on Single-Release Model. Standard errors in parentheses. Abbreviations: Ch-yearling chinook; St-steelhead; LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam.

Hatchery	Species	Date	Release Size	Release to LGR (S_H)	LGR to LGO (S_{R2})	LGO to LMO (S_{R3})	Release to LMO
Dworshak	Ch	a Apr	5,987	0.697 (0.016)	0.846 (0.033)	0.887 (0.039)	0.523 (0.017)
	Ch	14 Apr	1,198	0.799 (0.028)	0.848 (0.053)	0.872 (0.057)	0.591 (0.026)
	Ch	15 Apr	1,200	0.789 (0.029)	0.788 (0.058)	0.993 (0.083)	0.617 (0.036)
	Ch	22 Apr	5,992	0.829 (0.021)	0.861 (0.041)	0.836 (0.047)	0.597 (0.024)
	Ch	6 May	5,985	0.815 (0.028)	0.856 (0.042)	0.905 (0.053)	0.631 (0.029)
Dworshak	St	2-5 May	1,468	0.749 (0.016)	0.829 (0.040)	0.919 (0.105)	0.571 (0.060)
		4-6 May	2,309	0.687 (0.013)	0.792 (0.029)	0.929 (0.072)	0.505 (0.036)
Kooskia	Ch	18 Apr	600	0.739 (0.049)	0.845 (0.109)	0.913 (0.150)	0.570 (0.072)
Looking-glass	Ch	10 Apr	1,993	0.758 (0.024)	0.770 (0.036)	0.989 (0.057)	0.577 (0.028)
Looking-glass[a]	Ch	11 Apr	2,973	0.700 (0.020)	0.840 (0.046)	0.899 (0.062)	0.529 (0.028)
McCall[b]	Ch	9-14 Ap	1,295	0.576 (0.040)	0.756 (0.075)	1.097 (0.163)	0.478 (0.064)
		11 Apr[c]	1,498	0.421 (0.026)	0.918 (0.096)	0.796 (0.109)	0.308 (0.034)
		11 Apr[d]	1,497	0.688 (0.046)	0.862 (0.096)	0.640 (0.078)	0.380 (0.033)
		22-28 Ap	797	0.453 (0.059)	0.657 (0.108)	1.026 (0.216)	0.305 (0.060)

Table 53. Continued.

Hatchery	Species	Date	Release Size	Release to LGR (S_H)	LGR to LGO (S_{R2})	LGO to LMO (S_{R3})	Release to LMO
Rapid R.	Ch	12 Apr[c]	1,498	0.547 (0.029)	0.873 (0.114)	0.644 (0.103)	0.308 (0.033)
		12 Apr[d]	1,497	0.525 (0.039)	0.802 (0.134)	0.787 (0.172)	0.331 (0.053)
Sawtooth	Ch	a-ii Ap	2,155	0.213 (0.019)	0.816 (0.115)	0.689 (0.100)	0.120 (0.012)
Pahsimeroi	Ch	12 Apr	997	0.324 (0.031)	0.721 (0.126)	0.758 (0.148)	0.177 (0.024)
Pooled[e]	Ch			-----	0.826 (0.010)	0.868 (0.022)	-----

[a] Released in Imnaha River.

[b] Released at Knox Bridge.

[c] Hand-injected PIT tags.

[d] Auto-injected PIT tags.

[e] Pooled estimates are weighted averages of the independent. estimates from each release of yearling chinook salmon, with weights inversely proportional to the respective variances.

From Little Goose Dam tailrace to Lower Monumental Dam tailrace the weighted average survival estimates were 0.868 (s.e. 0.022) and 0.891 (s.e. 0.023) for the hatchery releases and our primary releases, respectively. Releases with the lowest survival probability between the hatchery and Lower Granite Dam tailrace often had higher probability of survival between the tailraces of Lower Granite and Little Goose Dams.

Travel Time

Travel time and migration rate statistics are given for all primary releases in Appendix Tables 15 through 24.

For the 10 primary releases of hatchery yearling chinook salmon, the median migration rates from time of release at Silcott Island to detection at Lower Granite Dam (37 km) ranged from 3.7 to 6.9 km/day (Fig. 20). From Lower Granite Dam to Little Goose Dam (60 km), median migration rates ranged from 7.1 to 12.4 km/day (Fig. 21). From Little Goose Dam to Lower Monumental Dam (46 km), median migration rates from 11.7 to 18.1 km/day (Fig. 22). From Lower Monumental Dam to McNary Dam (119 km), median migration rates ranged from 18.9 to 29.3 km/day (Fig. 23). For the entire river section from release at Silcott Island to the final PIT-tag detector at McNary Dam, median migration rates ranged from 10.6 to 17.9 km/day (Fig. 24). The number of fish used to calculate travel times decreased after the spill program began.

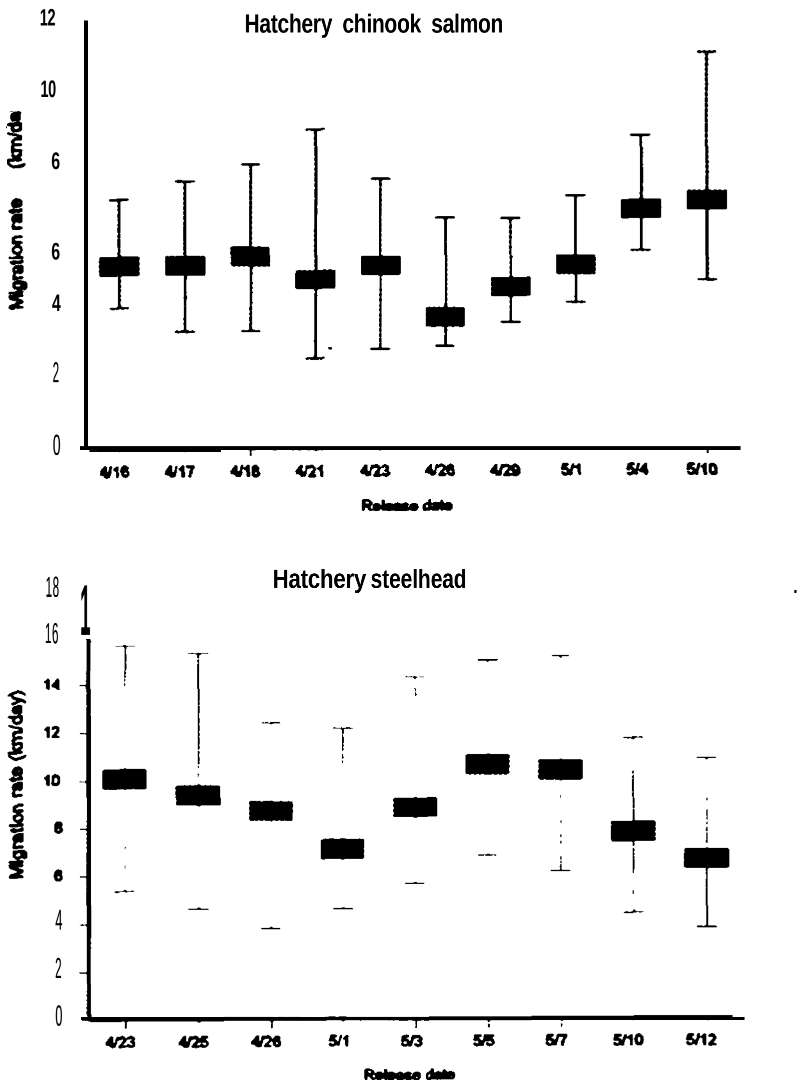


Figure 20. Median migration rate (km/day) from release at Silcott Island to Lower Granite Dam (37 km) for PIT-tagged hatchery chinook salmon and steelhead. The 20th and 80th percentiles are also shown.

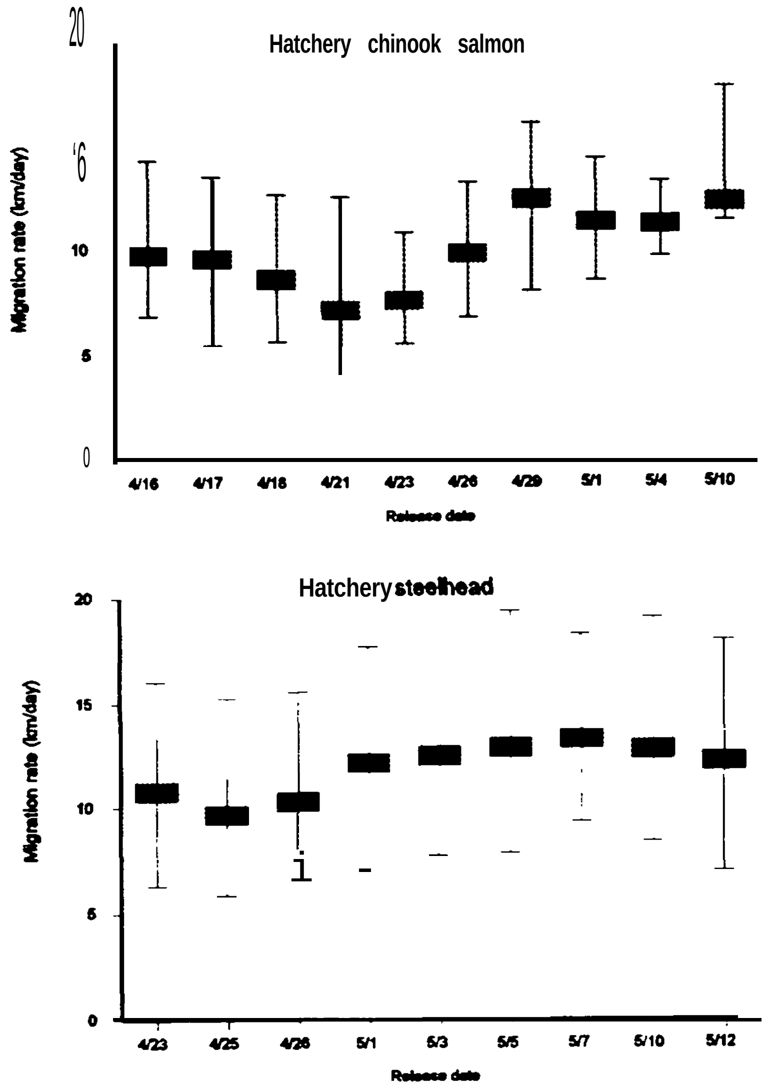


Figure 21. **Median migration rate (km/day) from Lower Granite Dam to Little Goose Dam (60 km) for PIT-tagged hatchery chinook salmon and steelhead. The 20th and 80th percentiles are also shown.**

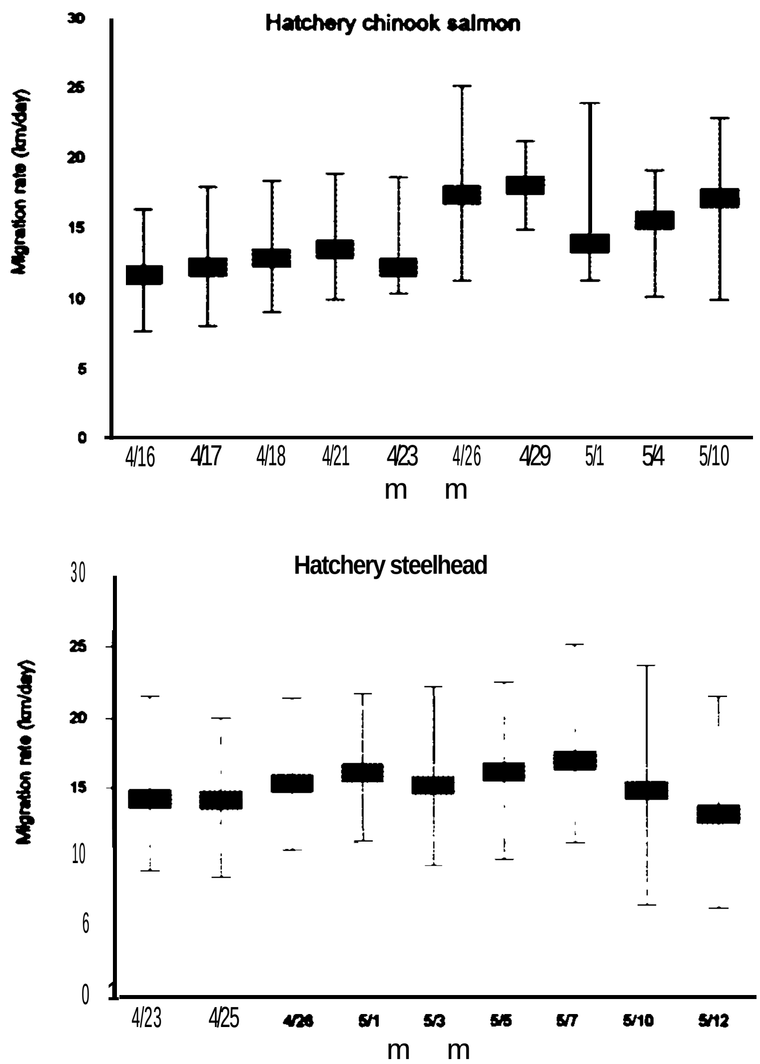


Figure 22. Median migration rate (km/day) from Little Goose Dam to Lower Monumental Dam (46 km) for PIT-tagged hatchery chinook salmon and steelhead. The 20th and 80th percentiles are also shown.

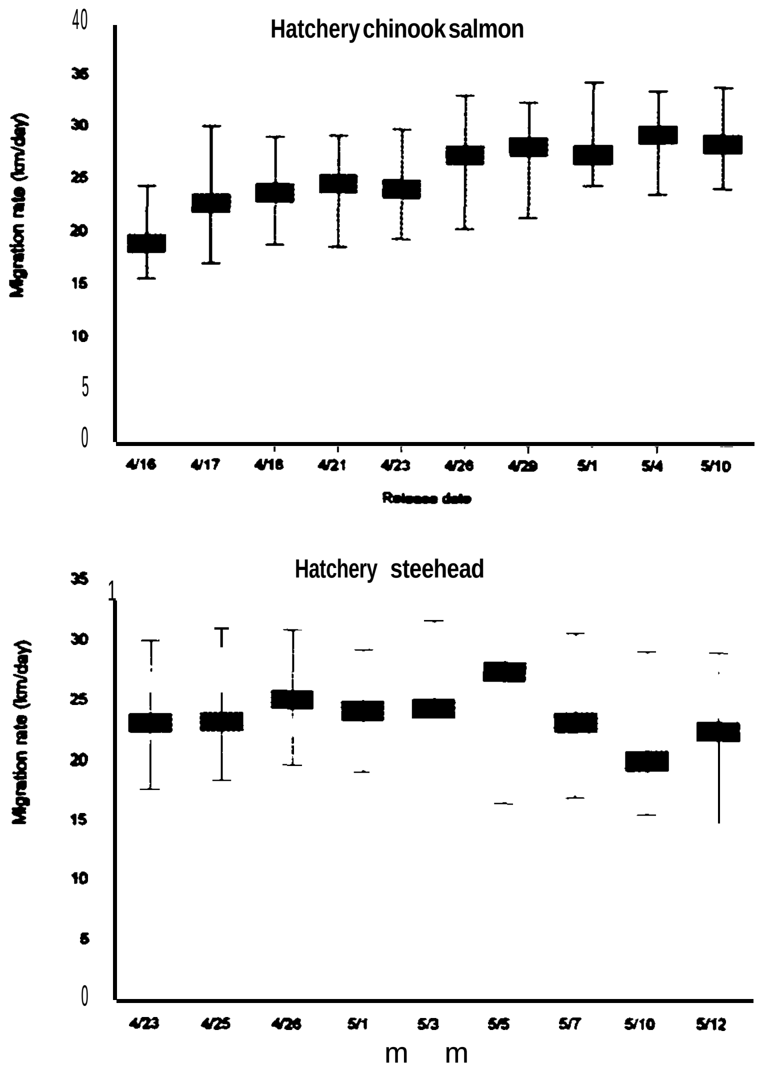


Figure 23. Median migration rate (km/day) from Lower Monumental Dam to McNary Dam (119 km) for PIT-tagged hatchery chinook salmon and steelhead. The 20th and 80th percentiles are also shown.

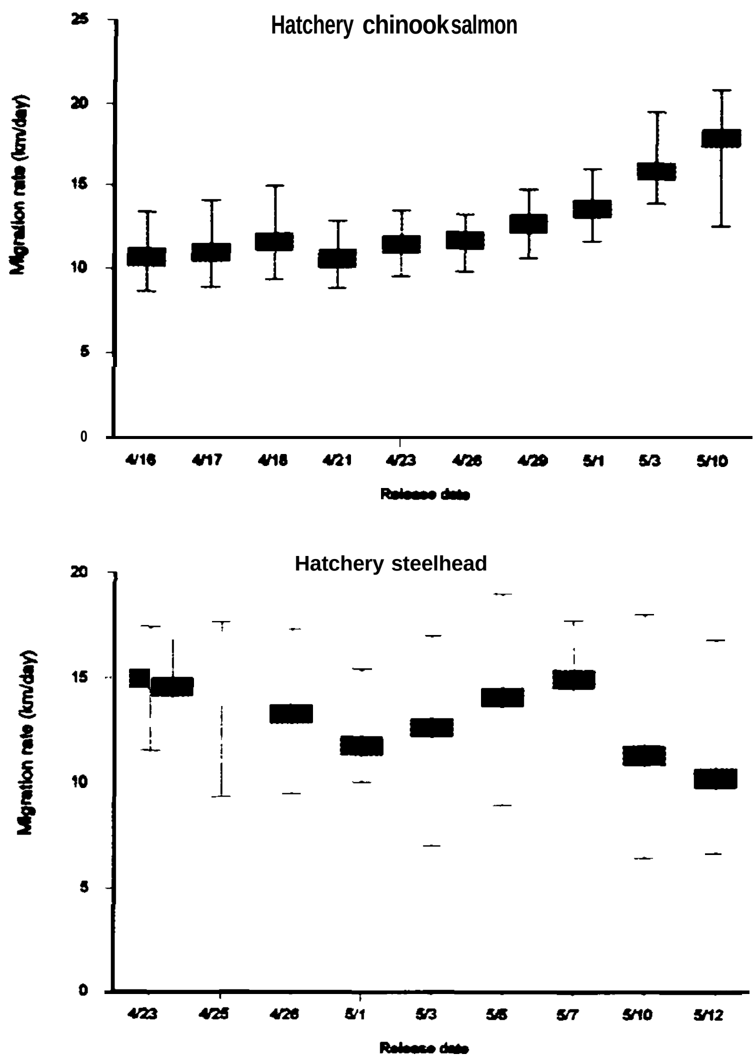


Figure 24. Median migration rate (km/day) from release at Silcott Island to McNary Dam (262 km) for PIT-tagged hatchery chinook salmon and steelhead. The 20th and 80th percentiles are also shown.

A comparison of median migration rates for yearling chinook salmon released on 17 April at Silcott Island (Fig. 25) showed that wild yearling chinook salmon traveled faster than hatchery yearling chinook salmon through the first three reservoirs after release. From Lower Monumental to McNary Dam, they traveled at the same rate. No test of statistical significance was done.

For the 9 primary releases of PIT-tagged hatchery steelhead, migration rates from Silcott Island to Lower Granite Dam ranged from 6.7 to 10.6 km/day (Fig. 20). From Lower Granite to Little Goose Dam, median migration rates ranged from 9.7 to 13.2 km/day (Fig. 21). From Little Goose to Lower Monumental Dam, median migration rates ranged from 13.1 to 17.0 km/day (Fig. 22). From Lower Monumental to McNary Dam, median migration rates ranged from 20.0 to 27.4 km/day (Fig. 23). For the entire river section from release at Silcott Island to the final PIT-tag detector at McNary Dam, median migration rates ranged from 10.3 to 15.0 km/day (Fig. 24).

For both hatchery chinook salmon and steelhead, the calculated migration rates were highest in the downstream reaches. With this study, we were unable to differentiate between migration rates through individual reservoirs and delay before passing a dam. Some preliminary information gathered from radio-tagged hatchery chinook salmon and steelhead in Lower Granite Reservoir (Dennis Rondorf, National Biological Service, Cook, WA, pers. commun., January 1995) indicates that migration rates within the reservoir were substantially higher than the

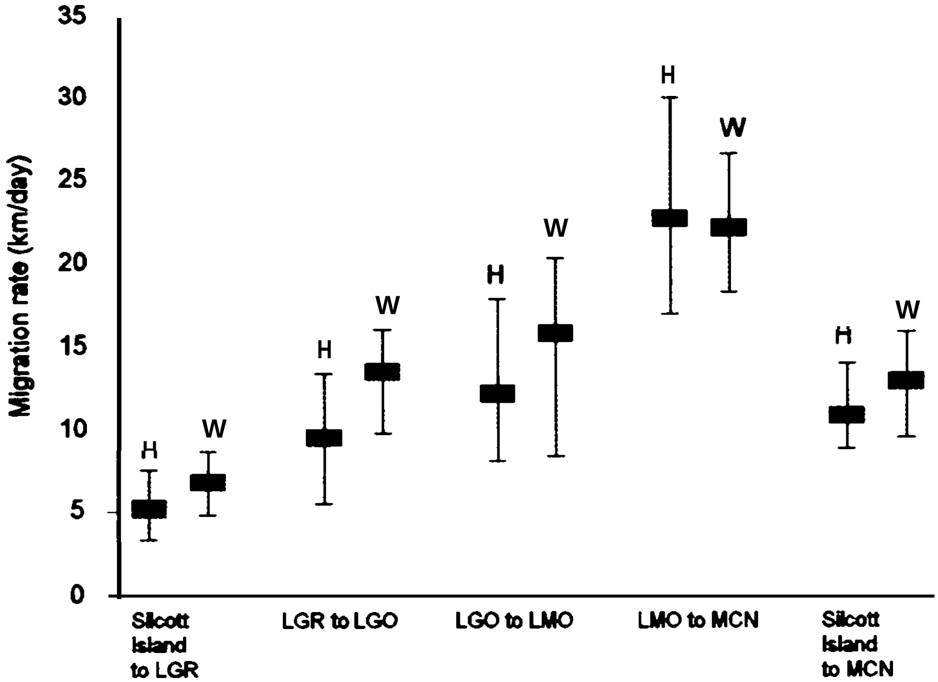


Figure 25. Median migration rate (km/day) from release at Silcott Island to Lower Granite Dam (LGR), LGR to Little Goose Dam (LGO), LGO to Lower Monumental Dam (LMO), and from LMO to McNary Dam (MCN) for hatchery and wild yearling chinook salmon released at Silcott Island on 17 April. The 20th and 80th percentiles are also shown.

time between detections suggested. Delay in the forebay at Lower Granite Dam led to longer overall travel time past the dam.

Lower Granite Dam Bypass Pipe Evaluation

Descaling of river-run hatchery steelhead released into the bypass pipe was significantly higher ($t = 4.74$, 3 d-f., $p < 0.05$) than descaling of fish released directly into the recovery net. However, the descaling rate was low for both the test (4.4%) and control (1.6%) groups (Table 54), indicating that the bypass pipe was not causing excessive descaling or injury.

Tests using the Dworshak NFH steelhead were inconclusive because of background levels of descaling in fish used for this portion of the evaluation. However, the observed 7.0% descaling rate in fish released into the bypass system was not excessive (includes passage through the bypass pipe as well as any additional descaling from being in the collection net).

Table 54. Descaling for river-run steelhead released into the new bypass pipe at Lower Granite Dam on 24 May 1994. Fish were released into the bypass pipe (test) or into the recovery net (control).

Replicate	Test # fish	Test # descaled	Test % descaled	Control # fish	Control # descaled	Control % descaled
1	189	12	6.3	199	10	5.0
2	183	7	3.8	198	0	0.0
3	185	8	4.3	184	1	0.5
4	187	6	3.2	150	1	0.7
Total	744	33	4.4	731	12	1.6

DISCUSSION

The results of the 1994 NMFS/UW survival study met the following specific research objectives: 1) field test and evaluate the Single-Release, Modified Single-Release, and Paired-Release Models for estimating survival probabilities through sections of a river and hydroelectric projects with high precision; 2) identify operational and logistical constraints that limit the ability to collect data for the models; and 3) obtain, under extant river conditions and dam operations, estimates of survival of juvenile chinook salmon and steelhead from their point of release to the tailrace of Lower Monumental Dam.

Although we generally met the study objectives in 1994, we were unable to collect sufficient numbers of wild yearling chinook salmon for the planned multiple primary releases. Because wild fish comprise only a small percentage of the daily yearling chinook salmon catch, capturing sufficient numbers of wild fish would require purse-seining and fish-handling efforts that are not feasible. Under current practices, fish caught over several days could be pooled into a single release. However, pooling over days limits the number of releases that can be made during an outmigration season. Perhaps future studies should be designed to include one release of wild yearling chinook salmon early and one release late in the season.

Releases of fish for bypass, forebay, and tailrace evaluations were successfully executed at all dams. However, difficulties were encountered in turbine releases at Lower Granite and Little Goose Dams. It appeared that some portion of the smolts were stranded in the turbine release hoses due to inadequate flushing. In future years, stranding can be avoided by providing sufficient water to flush smolts through the release hose after all smolts have left the release tank.

Over the course of the data analyses, we did not document any major statistical problems. Evaluation of model assumptions indicated that all except the equal mixing assumption for forebay-released fish and their reference releases were generally satisfied. Detection rates and survival probabilities for downstream river sections and sites were not dependent on the history of survival and capture at upriver sites, and with the exception of forebay releases, treatment release groups in paired releases mixed with their corresponding reference release groups as they moved downstream.

Post-detection bypass mortality for hatchery yearling chinook salmon was nearly significant at the 0.05 level at both Lower Granite and Lower Monumental Dams. (At Little Goose Dam, no post-detection bypass mortality was found in either 1993 or 1994). However, survival estimates for the collection channel treatment release groups were higher than those for the post-detection releases, despite passing through a longer segment of the bypass system. Collection channel survival estimates near 1.0 supported the use of the SR Model for the primary releases and suggested that the greater mortality experienced by the post-detection treatment releases were related to release procedures.

Survival estimates were calculated for Smolt Monitoring Program (SMP) releases of hatchery yearling chinook salmon from the Snake and Clearwater River traps over the same time period of the 1994 NMFS/UW releases. For the Snake River trap the pooled survival estimate from release to Lower Granite Dam tailrace was 0.957 (s.e. 0.031), and for the Clearwater River trap the survival estimate was 0.878 (s.e. 0.042). For Smolt Monitoring Program trap releases of hatchery steelhead from 23 April to 12 May, survival estimates from the Snake River and Clearwater River traps to Lower Granite Dam tailrace were 0.856 (s.e. 0.017) and 0.830 (s.e. 0.019), respectively.

The similarity between survival probability estimates for trap releases and for our primary releases suggested that effects of handling, marking, and release procedures are similar for SMP trap and NMFS/UW purse seining operations. The standard errors associated with the pooled survival estimates for the trap releases are similar to those for our primary releases. However, the trap releases were pooled over approximately 3 weeks. Over the same period, by purse seining, the NMFS/UW study obtained 9 or 10 survival estimates, each with comparable precision to the single estimate for trap releases. To relate survival probabilities with changing conditions throughout a migration season, multiple survival estimates with high precision are essential.

The survival estimates for hatcheries upstream from Lower Granite Dam, Smolt Monitoring Program traps, and releases from Silcott Island indicated that most of the mortality documented between the hatcheries and Lower Granite Dam forebay probably occurred soon after release, in the river sections upstream from Lower Granite Reservoir.

Overall, results indicated that the mortality from the head of Lower Granite Reservoir to the tailrace of Lower Granite Dam was approximately 10% for hatchery and wild yearling chinook salmon and hatchery steelhead. Because this estimate included mortality associated with dam passage as well as reservoir mortality, it appeared that relatively low mortality occurred in the reservoir. For example, if turbine passage mortality is 15% and 40% of fish pass Lower Granite Dam via turbines, then turbine passage alone can account for 6% overall mortality. Because there is also some mortality associated with spillway and bypass system passage, it appears that little of the 10% overall mortality can be attributed to the reservoir. Similar results indicated that relatively low mortality occurred in the other reservoirs investigated.

The river sections over which survival probabilities were estimated represent about 64% of the distance from the head of Lower Granite Reservoir to the confluence of the Snake and Columbia Rivers. (Silcott Island to Lower Granite Dam tailrace--37 km, Lower Granite Dam tailrace to Little Goose Dam tailrace--60 km, and Little Goose Dam tailrace to Lower Monumental Dam tailrace--46 km). The estimated survival probability from Silcott Island to Lower Monumental Dam tailrace (143 km) was 66% for hatchery chinook salmon, 73% for wild chinook salmon, and 60% for hatchery steelhead. Smolts migrating to Bonneville Dam tailrace encounter 5 more dams and approximately 360 km of additional reservoir.

Survival estimates from Lower Granite Dam tailrace to Little Goose Dam tailrace for primary releases and hatchery releases were lower in 1994 than in 1993. They were also the lowest estimates observed of the three river reaches investigated in 1994. We believe that the low survival estimates may have resulted from adverse tailrace conditions at Little Goose Dam caused by the particular dam operations in 1994. During the spring migration, two or three turbine units were out of service due to maintenance or because of fish guidance research activities. As a result, spill occurred 24 hours per day throughout the season. The spill and turbine operations caused a large eddy to flow upstream into the tailrace just below the turbines. Most fish exiting the juvenile bypass system were carried upstream by the eddy. Moreover, all fish passing through turbines and some passing through spill were also subjected to the eddy conditions. We suspect that the eddy conditions caused decreased survival in the Little Goose Dam tailrace and, consequently, decreased survival between the tailrace of Lower Granite Dam and the tailrace of Little Goose Dam.

The system survival estimates from this study were higher than those reported by Raymond (1979) and Sims and Ossiander (1981). However, their estimates were made using different methods, and in a river system that differs substantially from today's. Management strategies should not rely on outdated system survival estimates. Knowledge of the magnitude, locations, and causes of smolt mortality under present passage conditions, and under conditions projected for the future is essential to develop strategies for optimizing smolt survival.

During the spring of 1994, a voluntary spill program was begun on 11 May at Lower Granite, Lower Monumental and McNary Dams (spill occurred throughout the migration season at Little Goose and Ice Harbor Dams). When the spill program began, all but 1 of our 10 primary release groups of hatchery yearling chinook had largely finished passing Lower Granite Dam. While only the final release group passed all dams entirely after the spill program began, several of the later releases passed the lower-river dams primarily after the spill program began. The general trend for the 10 primary releases was toward faster migration rates (shorter travel times) from Silcott Island to McNary Dam. No such trend was evident in the survival estimates for release to Lower Monumental Dam, though the estimate for the final release group was the highest of the 10.

For our primary releases of hatchery steelhead, there was no evidence of increased migration rates or survival probabilities associated with larger spill volumes. The final 2 steelhead releases passed all dams after 11 May, and had longer median travel times to McNary Dam than any of the first 7 releases. One of the final two releases had the lowest of the 9 survival estimates to Lower Monumental Dam. At most, the effect of the voluntary spill program on steelhead may have been to ameliorate the effects of increasing residualization.

In conclusion, we believe that accurate and precise estimates of system survival from an upstream release site in the Snake River Basin to the tailraces of Lower Granite, Little Goose, or Lower Monumental Dams are now possible using the SR, MSR, and PR methodologies with the PIT-tag diversion systems in place and with sufficient release numbers. The methodologies should also work to extend survival estimates over a larger stretch of river once PIT-tag detectors are installed at additional downstream dams. This will permit exploration of the relationships among smolt survival, smolt travel time, smolt quality, and environmental conditions encountered during migration. Moreover, the data collected in the first 2 years of this study provide valuable baseline information for evaluation of future management strategies.

SUMMARY

1) The SR, MSR, and PR Models were evaluated for use in estimating survival probabilities through reservoirs and dams on the Snake River.

2) No major logistical constraints were identified in collecting data for execution of these models. In general, target numbers of hatchery yearling chinook salmon and steelhead were PIT tagged and released for primary releases at Silcott Island and secondary releases at dams. However, we were unsuccessful in collecting sufficient numbers of wild chinook salmon for PIT tagging and release in Lower Granite Reservoir.

3) Constraints identified in 1993, including the need for a juvenile separator at Lower Granite Dam and increased slide-gate efficiency, were addressed during 1994 research. A temporary juvenile separator was used during 1994 at Lower Granite Dam, resulting in decreased handling of non-target species and decreased mortality. Slide-gate efficiency was improved substantially at Lower Granite Dam, and a slide gate was operational at Lower Monumental Dam, resulting in increased precision and survival estimates through an additional Snake River reach. Slide gates diverted from 78.7 to 87.3% of PIT-tagged smolts detected at Lower Granite, Little Goose, and Lower Monumental Dams back to the Snake River, permitting multiple detections during migration.

4) Incomplete mixing occurred for most forebay/tailrace paired releases resulting in significantly different passage distributions at downstream dams.

5) Precise survival estimates were obtained for primary releases of hatchery yearling chinook salmon and steelhead from Silcott Island to the tailraces of Lower Granite, Little Goose, and Lower Monumental Dams. Survival rates from Silcott Island to Lower Granite Dam tailrace were approximately 92% for hatchery yearling chinook salmon and 90% for hatchery steelhead. Survival from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam was approximately 79% for hatchery yearling chinook salmon and 78% for hatchery steelhead, and from Little Goose Dam tailrace to Lower Monumental Dam tailrace, 89% and 83% for hatchery yearling chinook salmon and hatchery steelhead, respectively.

6) Survival estimates from Silcott Island to Lower Monumental Dam tailrace (weighted average) were 0.659, 0.728, and 0.598 for hatchery yearling chinook salmon, wild yearling chinook salmon, and hatchery steelhead, respectively. The Silcott Island to Lower Monumental migration corridor represents about 64% of the distance from the head of Lower Granite Reservoir to the confluence of the Snake and Columbia Rivers.

7) Survival and travel time data collected during this study can be used as baseline data for evaluation of future drawdowns or other management strategies.

RECOMMENDATIONS

Successful validation of field and statistical methodologies in 1994 formed the basis for the following recommendations for 1995 and future years:

1) The SR (MSR when appropriate) and PR methodologies should be adopted for survival estimation. Future protocols should be designed to evaluate the effects of seasonal and environmental variation, differing capture and release protocols, expanded study areas, and additional salmonid stocks.

2) Additional post-detection bypass releases at Lower Granite and Lower Monumental Dams are warranted because of the mortality observed during 1994 for some releases. We recommend increasing the number of releases and moving the release location into the collection channel.

3) Hatcheries should be provided with minimum release-size requirements for their PIT-tag studies so that survival estimates from hatcheries to detection sites at dams can be made with known precision.

4) If plans for a Lower Granite Reservoir drawdown continue, the SR and PR methodologies should be applied to collect survival data during both the baseline data-collection period and the drawdown test.

5) Future survival studies should be coordinated with other inriver projects to maximize the data-collection effort and minimize study effects on salmonid resources.

6) Improved statistical precision should be accomplished by maximizing the return of PIT-tagged juveniles to the river through increased detector and diverter efficiency.

7) Until a permanent juvenile fish separator is constructed at Lower Granite Dam, the temporary separator should be used to minimize handling during collection and tagging.

8) Increasing the number of detection facilities in the Columbia River Basin will improve survival investigations. This would include installation of detectors and diversion systems at John Day, The Dalles, Bonneville, and Priest Rapids Dams.

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Appendix Table 1. Number of hatchery yearling chinook salmon PIT tagged and released in Lower Granite Reservoir near Silcott Island, 16 April-11 May 1994. Fish removed from analyses for various reasons, and post-tagging mortalities are shown.

Release	RP1	RP2	RP3	RP4	RP5	RP6	RP7	RP8	RP9	RP10	Total
Release date	16 Apr	17 Apr	18 Apt	21 Apr	23 Apr	26 Apr	29 Apr	1 May	4 May	11 May	
Total fish in tagging files	1,204	1,200	1,200	1,198	782	1,036	646	1,072	546	1,048	9,932
wild fish	0	0	0	1	0	0	2	0	0	0	3
Detections "out of order"	3	0	1	0	0	1	0	1	0	0	6
Detection before release	0	1	0	1	1	0	1	2	0	0	6
Handling (number	12	3	5	6	5	3	0	0	4	0	38
mortality (%)	1.0	0.3	0.4	0.5	0.6	0.3	0.0	0.0	0.7	0.0	0.4
Total (number)	15	4	6	8	6	4	3	3	4	0	53
rejected (%)	1.2	0.3	0.5	0.7	0.8	0.4	0.5	0.3	0.7	0.0	0.5
Total fish in analysis	1,189	1,196	1,194	1,190	776	1,032	643	1,069	542	1,048	9,879

Appendix Table 2. Number of wild yearling chinook salmon PIT tagged and released in Lower Granite Reservoir near Silcott Island, 16-17 April 1994. Fish removed from analyses for various reasons, and post-tagging mortalities are shown.

Release	RPW1	RPW2	Total
Release date	16 Apr	11 May	
Total fish in tagging files	522	52	574
Hatchery fish	1	0	1
Steelhead	1	0	1
Handling (number)	8	0	8
mortality (%)	1.5	0.0	1.4
Total (number)	10	0	10
rejected (%)	1.9	0.0	1.7
Total fish in analysis	512	52	564

Appendix Table 3 Number of hatchery steelhead PIT tagged and released in Lower Granite Reservoir near Silcott Island, 23 April-12 May 1994. Fish removed from analyses for various reasons, and post-tagging mortalities are shown.

Release	RP1	RP2	RP3	RP4	RP5	RP6	RP7	RP8	RP9	Total
Release date	23 Apr	25 Apr	26 Apr	1 May	3 May	5 May	7 May	10 May	12 May	
Total fish in tagging files	1,199	1,201	1,222	1,002	1,195	1,210	1,223	1,523	4,010	13,785
Wild fish	2	0	0	0	0	0	0	0	0	2
Detections *out of order"	0	0	1	0	2	0	0	0	0	3
Detection before release .	0	1	0	1	33	1	1	2	0	39
Handling (number	1	0	4	0	0	0	0	0	1	6
mortality (%)	0.1	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total (number)	3	1	5	1	35	1	1	2	1	50
rejected (%)	0.3	0.1	0.4	0.1	2.9	0.1	0.1	0.1	0.0	0.4
Total fish in analysis	1,196	1,200	1,217	1,001	1,160	1,209	1,222	1,521	4,009	13,735

Appendix Table 4. Number of hatchery yearling chinook salmon PIT tagged and released at Lower Granite Dam to evaluate collection channel and post-detection survival in the bypass during 1994. Fish removed from analyses for various reasons, and post-tagging mortalities are shown.

Release	RB11	CB11	RG11	RB12	CB12	RG12	RB13	CB13	RG13	Total
Release date	21 Apr	2 Apt	21 Apr	26 Apr	26 Apr	26 Apr	30 Apr	30 Apr	30 Apr	
Total fish in tagging files	751	752	1,501	749	750	1,486	751	756	1,499	8,995
Detected at release site	2	0	179	0	0	157	0	0	190	528
Detectiona "out of order"	0	0	1	0	0	1	0	0	0	2
Handling (number	16	16	32	9	21	14	17	27	16	168
mortality (%)	2.1	2.1	2	1.2	2.8	0.9	2.3	3.6	1.1	1.9
Total (number)	18	16	212	9	21	172	17	27	206	698
rejected (%)	2.4	2.1	14	1.2	2.8	11.6	2.3	3.6	13.7	7.8
Total fish in analysis	733	736	1,289	740	729	1,314	734	729	1,293	8,297

Appendix Table 5. Number of hatchery steelhead PIT tagged and released at Lower Granite Dam to evaluate post-detection survival in the bypass during 1994. Fish removed from analyses for various reasons, and post-tagging mortalities are shown.

Release	Poll	C_{B11}	R_{B12}	C_{B12}	Total
Release date	6 May	6 May	11 May	11 May	
Total fish in tagging files	758	752	758	778	3,046
Detections "out of order"	0	0	0	0	0
Detection before release	0	0	0	0	0
Handling mortality (number)	0	2	16	2	20
Handling mortality (%)	0.0	0.3	2.1	0.3	0.7
Total rejected (number)	0	2	16	2	20
Total rejected (%)	0.0	0.3	2.1	0.3	0.7
Total fish in analysis	758	750	742	776	3,026

Appendix Table 6. Number of hatchery yearling chinook salmon PIT tagged and released at Lower Granite Dam to evaluate total project (forebay release) survival during 1994. Fish removed from analyses for various reasons, and post-tagging mortalities are shown.

Release	RF11	CT11	Total
Release date	12 May	12 May	
Total fish in tagging files	1,989	1,017	3,006
Detected at release site	18	0	18
Detection before release	1	0	1
Handling (number)	68	84	152
mortality (%)	3.4	8.3	5.1
Total (number)	87	84	171
rejected (%)	4.4	8.3	5.7
Total fish in analysis	1,902	933	2,835

Appendix Table 7. Number of hatchery steelhead PIT tagged and released at Lower Granite Dam to evaluate total project (forebay release) survival during 1994. Fish removed from analyses for various reasons, and post-tagging mortalities are shown.

Release		Roll	CT11	RF12	CT12	RF13	CT13
Release date		4 May	4 May	1 May	11 May	15 May	15 May
Total fish in tagging files		1,205	1,007	2,422	1,000	2,929	2,408
Wild fish		0	0	0	0	0	0
Detected at release site		60	3	74	0	59	2
Detections "out of order"		1	0	0	1	0	0
Detection before release		O	0	0	0	0	3
Handling mortality	(number)	342*	2	0	3	24	13
	(%)	28.4	0.2	0.0	0.3	0.8	0.5
Total rejected	(number)	61	5	74	4	83	18
	(%)	5.1	0.5	3.1	0.4	2.8	0.7
Total fish in analysis		802	1,002	2,348	996	2,846	2,390

* An air stone malfunctioned during transport from Silcott Island to Lower Granite Dam forebay, killing 342 steelhead.

Appendix Table 7. Continued.

Release	R_{F14}	C_{T14}	R_{F15}	C_{T15}	Total
Release date	17 May	17 May	19 May	19 May	
Total fish in tagging files	4,799	2,404	4,610	2,400	25,184
Wild fish	0	5	0	0	5
Detected at release site	89	0	142	1	430
Detections "out of order"	0	0	0	1	3
Detection before release	6	3	6	5	23
Handling mortality (number)	61	9	287	1	742
Handling mortality (%)	1.3	0.4	6.2	0.0	2.9
Total rejected (number)	156	17	435	8	1,203
Total rejected (%)	3.3	0.7	9.4	0.3	4.8
Total fish in analysis	4,643	2,387	4,175	2,392	23,981

Appendix Table 8. Number of hatchery yearling chinook salmon PIT tagged and released at Little Goose Dam to evaluate collection channel and post-detection survival in the bypass during 1994. Fish removed from analyses for various reasons, and post-tagging mortalities are shown.

Release	R_{B21}	C_{B21}	R_{G21}	R_{B22}	C_{B22}	R_{G22}	R_{B23}	C_{B23}	R_{G23}	Total
Release date	27 Apr	27 Apr	27 Apr	3 May	3 May	3 May	7 May	7 May	7 May	
Total fish in tagging files	770	765	1,498	802	793	1,461	665	707	1,393	8,854
Detected at release site	0	1	336	0	3	330	1	0	224	895
Detections "out of order"	0	1	0	1	0	2	0	0	0	4
Detection before release	1	1	2	1	3	2	1	1	1	13
Handling (number	18	13	13	15	11	17	14	6	18	125
mortality (%)	2.3	1.7	0.9	1.9	1.4	1.2	2.1	0.8	1.3	1.4
Total (number)	19	16	351	17	17	351	16	7	243	1,037
rejected (%)	2.5	2.1	23.4	2.1	2.1	24.0	2.4	1.0	17.4	11.7
Total fish in analysis	751	749	1,147	785	776	1,110	649	700	1,150	7,817

Appendix Table 9. Number of hatchery steelhead PIT tagged and released at Little Goose Dam to evaluate post-detection survival in the bypass during 1994. Fish removed from analyses for various reasons, and post-tagging mortalities are shown.

Release	RB21	CB21	RB22	CB22	Total
Release date	14 May	14 May	18 May	18 May	
Total fish in tagging files	1,174	1,363	1,513	1,424	5,474
Wild fish	0	0	0	1	1
Detected at release site	0	1	0	1	2
Detections "out of order"	0	0	0	0	0
Detection before release	0	2	0	1	3
Handling mortality (number)	8	9	11	3	31
Handling mortality (%)	0.7	0.7	0.7	0.2	0.6
Total rejected (number)	8	12	11	6	37
Total rejected (%)	0.7	0.9	0.7	0.4	0.7
Total fish in analysis	1,166	1,351	1,502	1,418	5,437

Appendix Table 10. Number of hatchery steelhead PIT tagged and released at Little Goose Dam to evaluate total project (forebay release) survival during 1994. Fish removed from analyses for various reasons, and post-tagging mortalities are shown.

Release Release date	RF21 16 May	CT21 16 May	RF22 24 May	CT22 24 May	Total
Total fish in tagging files	2,003	907	2,006	999	5,915
Detected at release site	107	0	97	2	206
Detections "out of order"	0	0	0	0	0
Detection before release	O	1	3	1	5
Handling (number) mortality (%)	21 1.0	9 1.0	60 3.0	26 2.6	116 2.0
Total (number) rejected (%I	128 6.4	10 1.1	160 8.0	29 2.9	327 5.5
Total fish in analysis	1,875	897	1,846	970	5,588

Appendix Table 11. Number of hatchery yearling chinook salmon PIT tagged and released at Lower Monumental Dam to evaluate post-detection survival in the bypass during 1994. Fish removed from analyses for various reasons, and post-tagging mortalities are shown.

Release Release date	RB31 6 May	CB31 6 May	RB32 10 May	CB32 10 May	RB33 14 May	CB33 14 May	Total
Total fish in tagging files	771	761	783	773	767	758	4,613
Detected at release site	0	1	1	0	0	1	3
Detections "out of order"	0	0	0	0	0	0	0
Detection before release	0	0	3	1	1	1	6
Handling (number	15	12	12	7	10	10	66
mortality (%)	1.9	1.6	1.5	0.9	1.3	1.3	1.4
Total (number)	15	13	16	8	11	12	75
rejected (%)	1.9	1.7	2.0	1.0	1.4	1.6	1.6
Total fish in analysis	756	748	767	765	756	746	4,538

Appendix Table 12. Number of hatchery steelhead PIT tagged and released at Lower Monumental Dam to evaluate post-detection survival in the bypass during 1994. Fish removed from analyses for various reasons, and post-tagging mortalities are shown.

Release Release date		RB31 19 Way	CB31 19 May	RB32 21 May	CB32 21 May	Total
Total fish in tagging files		1,504	1,508	1,507	1,508	6,027
Detected at release site		0	2	0	1	3
Detections "out of order"		0	0	0	0	0
Detection before release		1	1	0	0	2
Handling mortality	(number)	17	7	16	11	51
	(%)	1.1	0.5	1.1	0.7	0.8
Total rejected	(number)	18	10	16	12	56
	(%)	1.2	0.7	1.1	0.8	0.9
Total fish in analysis		1,486	1,498	1,491	1,496	5,971

Appendix Table 13. Number of hatchery steelhead PIT tagged and released at Lower Monumental Dam to evaluate total project (forebay release) survival during 1994. Fish removed from analyses for various reasons, and post-tagging mortalities are shown.

Release	RF31	CT31	Total
Release date	22 May	22 Hay	
Total fish in tagging files	1,061	1,062	2,123
Detected at release site	25	0	25
Detections "out of order"	0	0	0
Detection before release	0	0	0
Handling (number	10	15	25
mortality (%)	0.9	1.4	1.2
Total (number)	35	15	50
rejected (%)	3.3	1.4	2.4
Total fish in analysis	1,026	1,047	2,073

Appendix Table 14. Number of hatchery yearling chinook salmon PIT tagged and released at Lower Monumental Dam to evaluate passage survival through Turbine Unit 6 during 1994. Fish removed from analyses for various reasons, and post-tagging mortalities are shown.

Release	R631	C631	R632	C632	Total
Release date	4 May	4 May	8 May	8 May	
Total fish in tagging files	1,375	1,405	1,489	1,458	5,727
Detected at release site	0	0	2	1	3
Detections "out of order"	1	0	0	0	1
Detection before release	1	3	2	2	8
Handling (number)	10	5	10	11	36
mortality (%)	0.7	0.4	0.7	0.8	0.6
Total (number)	12	8	14	14	48
rejected (%)	0.9	0.6	0.9	1.0	0.8
Total fish in analysis	1,363	1,397	1,475	1,444	5,679

Appendix Table 15. Travel times and migration rates between Silcott Island and Lower Granite Dam (37 km) for primary releases of yearling chinook salmon.

Release	Date	Number	Travel time (days)					Migration rate (km/day)				
			Minimum	20%	'Median	80%	Maximum	Minimum	20%	Median	80%	Maximum
Rp1	16 Apt	425	2.36	5.62	7.21	8.76	70.85	0.52	4.22	5.13	6.58	15.70
Rp2	17 Apr	451	2.39	5.41	7.16	10.15	23.53	1.57	3.65	5.16	6.84	15.51
Rp3	18 Apr	464	1.13	5.13	6.85	10.11	29.11	1.27	3.66	5.40	7.21	32.85
Rp4	21 Apr	450	1.67	4.45	7.79	13.70	45.89	0.81	2.70	4.75	8.31	22.16
Rp5	23 Apr	266	2.28	5.23	7.20	12.25	20.68	1.79	3.02	5.14	7.08	16.20
Rp6	26 Apr	386	2.32	6.28	10.07	12.23	19.64	1.88	3.03	3.67	5.89	15.95
Rp7	29 Apt	251	2.10	6.73	8.18	10.14	22.37	1.65	3.65	4.52	5.50	17.66
Rp8	1 May	364	2.65	5.57	7.21	8.93	17.96	2.06	4.14	5.13	6.64	13.96
Rp9	4 May	155	1.63	4.35	5.53	6.34	11.36	3.26	5.83	6.69	8.51	22.74
Rp10	10 May	113	1.77	3.61	5.33	7.44	19.09	1.94	4.98	6.94	10.25	20.91
RpW1	17 Apt	234	2.58	4.30	5.49	7.68	22.27	1.66	4.82	6.74	8.61	14.33

Appendix Table 16. Travel times and migration rates between Silcott Island and Lower Granite Dam (37 km) for primary releases of hatchery steelhead.

			Travel time (days)					Migration rate (km/day)				
Release	Date	Number	Minimum	20%	Median	80%	Maximum	Minimum	20%	Median	80%	Maximum
Rp1	23 Apr	915	0.26	2.45	3.67	6.28	54.12	0.68	5.89	10.08	15.11	141.83
Rp2	25 Apr	907	2.02	2.55	3.93	6.74	28.33	1.31	5.49	9.41	14.50	18.35
Rp3	26 Apr	980	1.33	3.16	4.24	8.19	80.78	0.46	4.52	8.72	11.72	27.79
Rp4	1 May	727	0.90	3.39	5.20	7.46	24.58	1.51	4.96	7.12	10.91	40.93
Rp5	3 May	839	1.31	2.78	4.19	6.07	21.67	1.71	6.10	8.84	13.31	28.34
Rp6	5 May	823	1.33	2.67	3.48	5.00	70.72	0.52	7.41	10.62	13.87	27.73
Rp7	7 May	796	0.22	2.57	3.56	5.25	65.61	0.56	7.04	10.38	14.41	168.02
Rp8	10 May	266	2.09	3.36	4.74	7.51	71.36	0.52	4.93	7.81	11.02	17.68
Rp9	12 May	583	1.90	3.55	5.54	8.46	78.52	0.47	4.37	6.67	10.41	19.43

Appendix Table 17. Travel times and migration rates between Lower Granite Dam and Little Goose Dam (60 km) for primary releases of yearling chinook salmon.

Release	Date	Number	Travel time (days)					Migration rate (km/day)				
			Minimum	20%	Median	80%	Maximum	Minimum	20%	Median	80%	Maximum
Rp1	16 Apr	113	2.55	4.49	6.16	8.11	23.41	2.56	7.39	9.74	13.37	23.51
Rp2	17 Apr	83	1.99	4.91	6.27	9.62	23.87	2.51	6.23	9.56	12.21	30.13
Rp3	18 Apr	77	2.20	5.16	6.97	10.35	26.80	2.24	5.80	8.60	11.64	27.26
Rp4	21 Apr	61	2.84	5.40	8.42	14.41	22.16	2.71	4.16	7.12	11.11	21.12
Rp5	23 Apr	24	3.29	5.76	7.90	10.54	21.27	2.82	5.69	7.60	10.42	18.24
Rp6	26 Apt	40	3.29	4.74	6.14	7.93	15.63	3.84	7.57	9.78	12.66	18.26
Rp7	29 Apr	32	3.46	3.97	4.86	6.95	9.78	6.14	8.65	12.36	15.10	17.32
Rp8	1 May	44	3.30	4.49	5.32	6.44	10.84	5.53	9.31	11.28	13.35	18.20
Rp9	4 May	9	3.94	4.66	5.32	5.82	9.91	6.05	10.34	11.27	12.89	15.22
Rp10	10 May	17	2.72	3.47	4.87	5.13	9.10	6.60	11.69	12.33	17.29	22.02
Rpw1	17 Apr	61	2.93	3.73	4.43	6.09	14.20	4.22	9.85	13.53	16.08	20.45

Appendix Table 18. Travel times and migration rates between Lower Granite Dam and Little Goose Dam (60 km) for primary releases of hatchery steelhead.

			Travel time (days)					Migration rate (km/day)				
Release	Date	Number	Minimum	20%	Median	80%	Maximum	Minimum	20%	Median	80%	Maximum
RP1	23 Apr	353	2.06	3.98	5.60	8.31	23.07	2.60	7.22	10.72	15.07	29.19
RP2	25 Apr	322	2.02	4.17	6.21	9.19	30.32	1.98	6.53	9.66	14.41	29.77
RP3	26 Apr	383	1.85	4.19	5.84	8.35	53.95	1.11	7.19	10.27	14.30	32.51
RP4	1 May	248	1.56	3.69	4.95	7.46	43.81	1.37	8.05	12.13	16.26	38.51
RP5	3 May	220	1.73	3.48	4.82	6.69	71.20	0.84	8.97	12.45	17.23	34.60
RP6	5 May	219	1.93	3.32	4.67	6.82	81.65	0.73	8.80	12.84	18.08	31.05
RP7	7 May	214	1.69	3.39	4.53	5.86	63.02	0.95	10.24	13.24	17.68	35.54
RP8	10 May	53	1.68	3.35	4.71	6.69	54.57	1.10	8.97	12.74	17.89	35.64
RP9	12 May	118	1.59	3.68	4.89	7.14	69.41	0.86	8.40	12.28	16.32	37.70

Appendix Table 19. Travel times and migration rates between Little Goose Dam and Lower Monumental Dam (46 km) for primary releases of yearling chinook salmon.

			Travel time (days)					Migration rate (km/day)				
Release	Date	Number	Minimum	20%	Median	80%	Maximum	Minimum	20%	Median	80%	Maximum
Rp1	16 Apr	125	1.90	2.99	3.93	5.56	17.00	2.71	8.27	11.70	15.38	24.18
Rp2	17 Apr	96	1.57	2.79	3.76	5.14	75.36	0.61	8.94	12.23	16.48	29.26
Rp3	18 Apr	78	1.66	2.67	3.57	4.67	9.41	4.89	9.86	12.89	17.25	27.67
Rp4	21 Apr	55	1.65	2.50	3.40	4.31	25.95	1.77	10.66	13.53	18.38	27.82
Rp5	23 Apt	21	1.67	2.54	3.76	3.96	7.26	6.34	11.63	12.25	18.13	27.60
Rp6	26 Apr	16	1.58	2.06	2.65	3.84	4.78	9.63	12.01	17.38	22.32	29.10
Rp7	29 Apr	12	1.63	2.27	2.55	3.03	3.32	13.84	15.20	18.05	20.28	28.25
Rp8	1 May	22	1.65	2.18	3.31	3.83	12.12	3.80	12.02	13.91	21.17	27.84
Rp9	4 May	11	2.04	2.53	2.96	4.50	5.47	8.41	10.23	15.53	18.21	22.58
Rp10	10 May	13	1.73	2.13	2.70	4.23	6.01	7.65	10.95	17.07	21.60	26.54
Rpw1	17 Apr	59	1.66	2.26	2.91	5.48	11.35	4.05	8.40	15.82	20.35	27.77

Appendix Table 20. Travel times and migration rates between Little Goose Dam and Lower Monumental Dam (46 km) for primary releases of hatchery steelhead.

			Travel time (days)					Migration rate (km/day)				
Release	Date	Number	Minimum	20%	Median	80%	Maximum	Minimum	20%	Median	80%	Maximum
Rp1	23 Apr	261	1.19	2.30	3.25	4.78	79.71	0.58	9.63	14.17	19.98	38.65
Rp2	25 Apr	199	1.21	2.45	3.27	4.79	35.73	1.29	9.60	14.09	18.78	38.10
Rp3	26 Apr	198	1.18	2.31	3.01	4.09	71.34	0.64	11.24	15.31	19.94	38.83
Rp4	1 May	105	0.98	2.17	2.86	3.86	18.78	2.45	11.91	16.10	21.16	47.05
Rp5	3 May	95	1.14	2.37	3.03	4.20	13.74	3.35	10.96	15.20	19.42	40.25
Rp6	5 May	67	1.27	2.23	2.85	4.44	55.29	0.83	10.35	16.12	20.64	36.20
Rp7	7 May	74	1.04	1.89	2.71	3.79	67.50	0.68	12.13	16.97	24.33	44.39
Rp8	10 May	47	1.60	2.12	3.12	5.98	53.81	0.85	7.70	14.76	21.69	28.77
Rp9	12 May	105	1.57	2.61	3.53	6.11	61.92	0.74	7.53	13.05	17.61	29.31

Appendix Table 21. Travel times and migration rates between Lower Monumental Dam and McNary Dam (119 km) for primary releases of yearling chinook salmon.

			Travel time (days)					Migration rate (km/day)				
Release	Date	Number	Minimum	20%	Median	80%	Maximum	Minimum	20%	Median	80%	Maximum
Rp1	16 Apr	158	2.72	5.28	6.31	7.36	11.80	10.08	16.16	18.87	22.56	43.68
Rp2	17 Apr	158	2.71	4.23	5.23	6.51	17.03	6.99	18.29	22.74	28.15	43.95
Rp3	18 Apr	154	2.82	4.21	5.03	6.04	13.35	8.91	19.71	23.67	28.25	42.21
Rp4	21 Apr	114	2.68	4.20	4.84	5.97	22.67	5.25	19.92	24.61	28.32	44.33
Rp5	23 Apr	67	2.92	4.13	4.94	5.89	12.47	9.55	20.19	24.10	28.84	40.74
Rp6	26 Apr	73	2.46	3.65	4.35	5.59	15.00	7.93	21.28	27.37	32.62	48.45
Rp7	29 Apr	34	2.86	3.68	4.21	5.36	6.61	18.00	22.22	28.24	32.30	41.57
Rp8	1 May	60	2.72	3.54	4.34	4.67	7.32	16.26	25.48	27.41	33.60	43.75
Rp9	4 May	23	3.03	3.55	4.06	4.85	6.57	18.11	24.52	29.34	33.49	39.27
Rp10	10 May	30	3.08	3.63	4.18	4.68	7.71	15.42	25.42	28.48	32.77	38.62
RpW1	17 Apr	90	2.93	4.48	5.36	6.49	18.64	6.38	18.33	22.19	26.59	40.65

Appendix Table 22. Travel times and migration rates between Lower Monumental Dam and McNary Dam (119 km) for primary releases of hatchery steelhead.

			Travel time (days)					Migration rate (km/day)				
Release	Date	Number	Minimum	20%	Median	80%	Maximum	Minimum	20%	Median	80%	Maximum
Rp1	23 Apr	159	2.81	4.06	5.16	6.14	27.08	4.39	19.38	23.05	29.28	42.35
Rp2	25 Apr	110	2.65	4.08	5.12	6.31	12.92	9.21	18.85	23.22	29.20	44.89
Rp3	26 Apr	82	3.04	4.00	4.74	5.80	10.04	11.85	20.53	25.09	29.78	39.18
Rp4	1 May	41	3.48	4.13	4.94	6.01	9.79	12.15	19.80	24.09	28.82	34.19
Rp5	3 May	31	2.80	3.81	4.89	7.01	23.53	5.06	16.97	24.33	31.23	42.46
Rp6	5 May	33	2.83	3.82	4.34	6.74	61.25	1.94	17.66	27.41	31.16	42.04
Rp7	7 May	26	2.92	4.10	5.14	6.68	20.60	5.78	17.80	23.17	29.01	40.81
Rp8	10 May	25	3.61	4.18	5.95	7.02	24.99	4.76	16.94	20.01	28.49	32.93
Rp9	12 May	42	3.30	4.22	5.30	7.43	27.27	4.36	16.01	22.44	28.19	36.08

Appendix Table 23. Travel times and migration rates between Silcott Island and McNary Dam (262 km) for primary releases of yearling chinook salmon.

			Travel time (days)					Migration rate (km/day)				
Release	Date	Number	Minimum	20%	Median	80%	Maximum	Minimum	20%	Median	80%	Maximum
RP1	16 Apr	330	11.59	20.69	24.63	28.77	45.84	5.72	9.11	10.64	12.67	22.60
RP2	17 Apr	370	11.97	19.96	24.03	28.38	47.45	5.52	9.23	10.90	13.13	21.90
RP3	18 Apr	365	11.69	18.72	22.65	26.67	39.43	6.64	9.82	11.57	14.00	22.42
RP4	21 Apr	352	10.87	21.22	24.78	28.08	51.63	5.07	9.33	10.57	12.35	24.10
RP5	23 Apr	222	12.15	20.18	22.93	26.19	52.73	4.97	10.01	11.43	12.98	21.57
RP6	26 Apr	306	11.41	20.63	22.37	26.46	49.71	5.27	9.90	11.71	12.70	22.96
RP7	29 Apr	201	11.56	17.93	20.64	24.17	52.71	4.97	10.84	12.69	14.61	22.66
RP8	1 May	315	11.38	16.55	19.25	21.94	42.64	6.14	11.94	13.61	15.83	23.01
RP9	4 May	150	8.88	13.59	16.50	18.45	35.55	7.37	14.20	15.88	19.28	29.51
RP10	10 May	276	8.51	12.75	14.63	17.39	62.13	4.22	15.06	17.91	20.56	30.80
RPW1	17 Apr	583	1.90	3.55	5.54	8.46	78.52	0.47	4.37	6.67	10.41	19.43

Appendix Table 24. Travel times and migration rates between Silcott Island and McNary Dam (262 km) for primary releases of hatchery steelhead.

			Travel time (days)					Migration rate (km/day)				
Release	Date	Number	Minimum	20%	Median	80%	Maximum	Minimum	20%	Median	80%	Maximum
Rp_1	23 Apr	206	10.40	15.59	17.53	20.60	76.43	3.43	12.72	14.94	16.81	25.19
Rp_2	25 Apr	164	10.08	15.48	18.00	26.38	81.49	3.22	9.93	14.55	16.92	25.98
Rp_3	26 Apr	142	10.04	15.58	19.70	26.10	76.50	3.43	10.04	13.30	16.82	26.11
Rp_4	1 May	103	10.40	17.95	22.28	24.48	75.47	3.47	10.70	11.76	14.59	25.19
Rp_5	3 May	86	7.57	16.41	20.77	34.89	69.48	3.77	7.51	12.61	15.97	34.63
Rp_6	5 May	118	10.62	14.88	18.56	28.27	70.65	3.71	9.27	14.12	17.61	24.67
Rp_7	7 May	86	10.05	15.39	17.49	25.58	62.50	4.19	10.24	14.98	17.02	26.08
Rp_8	10 May	124	9.48	16.36	23.15	34.12	66.39	3.95	7.68	11.32	16.02	27.63
Rp_9	12 May	305	9.61	19.15	25.53	37.17	78.92	3.32	7.05	10.26	13.68	27.26