SURVIVAL ESTIMATES FOR THE PASSAGE OF JUVENILE CHINOOK SALMON THROUGH SNAKE RIVER DAMS AND RESERVOIRS

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EXECUTIVE SUMMARY

A pilot study was conducted to estimate survival of hatchery-reared yearling chinook salmon through dams and reservoirs on the Snake River. The goals of the study were to: 1) field test and evaluate the Single-Release, Modified-Single-Release, and Paired-Release Models for the estimation of survival probabilities through sections of a river and hydroelectric projects; 2) identify operational and logistical constraints to the execution of these models; and 3) determine the usefulness of the models in providing estimates of survival probabilities.

Field testing indicated that the numbers of hatchery-reared yearling chinook salmon needed for accurate survival estimates could be collected at different areas with available gear and methods. For the primary evaluation, seven replicates of 830 to 1,442 hatchery-reared yearling chinook salmon were purse-seined from Lower Granite Reservoir, PIT tagged, and released near Nisqually John boat landing (River Kilometer 726).

Secondary releases of PIT-tagged smolts were made at Lower Granite Dam to estimate survival of fish passing through turbines and after detection in the bypass system. Similar secondary releases were made at Little Goose Dam, but with additional releases through the spillway. Hatchery-reared yearling chinook salmon for the secondary releases came from juvenile collection and bypass facilities at each dam. For the secondary evaluations, replicates of 750 to 1,500 PIT-tagged fish were

released on three dates for each release site at each dam while primary release groups were passing.

PIT-tag slide gates at Lower Granite and Little Goose Dams returned 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 from PIT-tagged yearling chinook salmon released from hatcheries upstream from Lower Granite Dam. Although the majority of PIT-tagged fish were diverted, variability in diversion efficiency at the two dams influenced the precision of survival estimates.

Nevertheless, first year results indicated that detecting a fish at an upstream site did not influence the probability of its subsequent detection at downstream sites, that detection did not influence subsequent survival, that the chosen models accurately predicted sampling variability, and that treatment and reference fish were mixed at subsequent detection sites.

Thus, all Single-Release Model assumptions were satisfied, and precise survival estimates for a limited period of the hatchery-reared yearling chinook salmon migration were obtained. Results indicated that survival from the primary release site (31 km upstream from Lower Granite Dam) to the tailrace of Lower Granite Dam in river flows of approximately 60-70 kcfs was approximately 90%. Survival from the tailrace of Lower Granite Dam to the tailrace of Little Goose Dam was approximately 86%.

Based on the success of the 1993 pilot study, we believe that the Single-Release and Paired-Release Models will provide accurate estimates of juvenile salmonid passage survival for individual river sections, reservoirs, and hydroelectric projects in the Columbia and Snake Rivers.

CONTENTS

CONTENTS--Continued.

CONTENTS--Continued.

FIGURES

FIGURES--Continued.

TABLES

PAGE

PAGE

PAGE

PAGE

PAGE

INTRODUCTION

Problem

Reliable estimates of juvenile salmonid survival through the reservoirs, hydroelectric projects, and free-flowing sections of the Snake and Columbia Rivers are essential to effective management strategies. Present management strategies, however, rely upon outdated system survival estimates (Raymond 1979, Sims and Ossiander 1981) that lacked statistical precision and were derived in a river system that differs considerably from today's. The magnitude, locations, and causes of smolt mortality under present passage conditions and under conditions projected for the future are necessary to develop strategies for optimizing smolt survival.

Recent advances in statistical methodology have provided new approaches for the design and analysis of smolt passage studies. Burnham et al. (1987) proposed models for paired release recapture data [hereafter referred to as Paired-Release (PR) Models] that appeared appropriate for the estimation of survival through hydroelectric projects via turbines, bypasses, or spill. Valid estimation of survival in reservoirs and free-flowing sections has been more problematic, because the assumption of mixing and simultaneous downstream movement of fish from reference and treatment groups in the PR Model is difficult to satisfy as the distance between the release sites increases.

More recently, however, Hoffmann and Skalski proposed models for single release-recapture data for river and reservoir survival estimation hereafter referred to as the Single-Release (SR) and Modified-Single-Release (MSR) Models (Dauble et al. 1993). Satisfying the assumptions of these models appeared easier, thus making accurate estimates with quantitative measures of precision possible. However, the SR and MSR models combine river/reservoir and project survival into one estimate. To partition the survival among these areas requires expansion of the SR or MSR Models to include survival estimates based on the PR Model for dam passage.

To study the feasibility of using these models, the National Marine Fisheries Service (NMFS) and the University of Washington (UW) conducted a pilot study using hatchery-reared yearling chinook salmon (Oncorhynchus tshawytscha) during 1993 with the following goals: 1) field test and evaluate the Single-Release, Modified-Single-Release, and Paired-Release Models for the estimation of river/reservoir and project survival; 2) identify operational and logistical constraints that would limit the ability to collect data for the models; and 3) determine the usefulness of these models in providing estimates of river/reservoir and project survival with precision. The ultimate goal was to provide fisheries researchers and agencies with proven and reliable statistical methodologies for survival estimation of passage of juvenile salmonids through dams and reservoirs.

METHODS

Statistical Theory

A key assumption of the Paired-Release Model is that test fish mix randomly downstream from any given release site. (Our use of the term "Paired-Release Model" refers to the entire suite of models for paired-release studies analyzed by Burnham et al. (1987)). Thus, the model works well for point sources of mortality, such as turbine passage, where release sites for treatment and reference groups are close together geographically. However, the PR Model is not well suited for estimating survival through a section of a river or reservoir, as random mixing of reference and treatment fish becomes less likely as the distance between the release sites increases.

Survival probabilities through a section of a river or reservoir can be estimated using a single release of tagged fish upstream with multiple detection sites downstream. Data for such a Single-Release (SR) Model are the records of downstream detection of the tagged fish. Like the PR Model, the SR Model includes parameters for detection rates at the detection sites and survival probabilities between the detection sites. Technically, the SR Model is a special case of the PR Model, using data only from recaptures of the reference release group. The SR Model was first presented by Cormack (1964), Jolly (1965), and Seber (1965).

The SR model requires at least one release at the top of the river section of interest, a downstream dam with a detector and a mechanism to return detected fish to the river, and a second detection site farther downstream. This possibility now exists at some Snake River dams where most detected PIT-tagged fish can be returned to the river via slide gates in the bypass system. This allows the possibility for multiple downstream detections of at least some fish. Without multiple detections, survival probabilities cannot be separated from detection probabilities. When it is not feasible to return every fish detected at a site to the river, the SR model can be adjusted, provided that the identity of the removed fish is established.

A critical assumption of the Single-Release Model (and of the Paired-Release Model) is that survival and detection probabilities are homogeneous and independent among all fish in a release group. The statistical likelihood function of the SR Model is based on multinomial sampling which requires independent observations each with equal (homogeneous) probabilities of every possible outcome.

Hoffmann and Skalski (in Dauble et al. 1993) studied three different mechanisms by which the homogeneity assumption could be violated. They investigated the effects of these mechanisms on the performance of the SR Model. The results of their simulation showed that the SR Model is robust, even when survival probabilities are dissimilar due to inherent differences among **fish, and when mortality occurred in the bypass system prior to** detection.

However, the SR Model did not perform well when mortality occurred in the bypass system after fish had been detected but before they remixed with fish that had not been detected (hereafter referred to as post-detection bypass mortality). For example, discrepancies in survival estimates would occur if bypassed fish were subject to significant predation at the bypass outfall, while fish passing through turbines or spillways were not. In this case, survival probability to the next sampling site would no longer be equal for detected fish and nondetected fish, and both the survival estimate and the confidence interval around the estimate would be biased.

Hoffmann and Skalski (in Dauble et al. 1993) proposed the Modified-Single-Release (MSR) Model to adjust for the bias caused by post-detection bypass mortality. The MSR model calls for an additional pair of releases: one in the bypass system immediately below the detection site, and one in the river where bypassed fish remix with nondetected fish. This permits estimation of the post-detection bypass mortality rate, which in turn allows for an unbiased survival estimate. If post-detection bypass mortality is not significant, then the SR model is sufficient; no bias correction is needed.

Like the SR model, the MSR requires at least two detection sites downstream from the point of the primary release, and the first site must have the capability of returning detected fish to the river. Under this configuration, the MSR Model provides the following estimates: 1) survival probability from the point of primary release to the tailrace of the first downstream dam; 2) post-detection bypass mortality rate; 3) probability of detection at the first dam; and 4) the combined probability of survival between the tailraces of the two dams and of detection at the second dam.

The first estimate includes the probability for survival from the primary release site to the tailrace of the first dam. This estimate can be partitioned into its components by adding further paired releases to assess survival associated with turbine passage and spillway passage, where necessary, thus providing survival estimates from release to forebay and past the dam. Data from these paired releases are independently analyzed using the PR Model.

During the 1993 migration season, PIT-tag detectors were operational at Lower Granite, Little Goose, Lower Monumental, and McNary Dams. At Lower Granite and Little Goose Dams, slide gates were in operation to divert PIT-tagged fish from the bypass system back to the river. Under this configuration, a single release of PIT-tagged fish above Lower Granite Dam provided estimates of survival from the point of release to the Lower Granite Dam tailrace and from Lower Granite Dam tailrace to Little Goose Dam tailrace.

To determine if there was significant mortality to fish On release to the tailrace after they were detected by the PIT-tag detectors in the bypass system, paired releases in and below the bypass systems at Lower Granite and Little Goose Dams were required (MSR Model with two downstream detector/diverter sites). In addition, the survival probabilities were partitioned into the various components by fish releases through the dam passage routes.

Experimental Design

The 1993 NMFS/UW Smolt Survival Study consisted of the following (Tables 1 and 2; Figs. 1 and 2):

1) Study Area: PIT-tagged (Prentice et al. 1990a) fish were released in Lower Granite Reservoir near Nisqually John boat landing (River Kilometer (RKm) 726), at Lower Granite Dam (RKm 6951, and at Little Goose Dam (RKm 635). PIT-tagged fish were detected at Lower Granite Dam, Little Goose Dam, and Lower Monumental Dam (RKm 589) on the Snake River, and at McNary Dam (RKm 470) on the Columbia River (Fig. 1).

2) Primary release group (R_P): The R_P release groups consisted of hatchery-reared yearling chinook salmon captured by purse-seine in Lower Granite Reservoir and PIT tagged near the Nisqually John boat landing. There was one release per day for seven consecutive days. Recapture histories from each group were used in the SR Model to estimate survival from release to Lower Granite Dam tailrace, and from Lower Granite Dam tailrace to Little Goose Dam tailrace. If there was significant post-detection bypass mortality, the R_P group was combined in the

Table 1.--Release groups of PIT-tagged hatchery-reared yearling chinook salmon for the 1993 survival study.

Parameter	Definition
R_P	Primary release groups, Lower Granite Reservoir
R_{B1}	Post-detection bypass test release groups, Lower Granite Dam
C_{B1}	Post-detection bypass reference release groups, Lower Granite Dam
R_{T1}	Turbine test release groups, Lower Granite Dam
C_{T1}	Turbine reference release groups, Lower Granite Dam
R_{B2}	Post-detection bypass test release groups, Little Goose Dam
C_{B2}	Post-detection bypass reference release groups, Little Goose Dam
R_{T2}	Turbine test release groups, Little Goose Dam
R_{S2}	Spillway test release groups, Little Goose Dam
C_{T2}	Turbine/spillway reference release groups, Little Goose Dam
R_H	Hatchery release groups

Table 2.--Definition of parameters estimated from releases.

Parameter	Definition	Related to objective
S_{R1}	Probability of survival from point of primary release to tailrace of Lower-Granite Dam (Lower-Granite Dam "reach" survival).	Primary
S_{B1}	Probability of survival from just below PIT-tag diverter gate to bypass outfall at Lower Granite Dam (Lower Granite Dam post-detection bypass survival).	Primary
S_{T1}	Probability of survival through Lower Granite Dam turbines (Lower Granite Dam turbine passage survival).	Secondary
S_{P1}	Probability of survival from point of primary release to forebay of Lower Granite Dam (Lower Granite Dam reservoir survival).	Secondary
S_{D1}	Probability of surviving passage through Lower Granite Dam (Lower Granite Dam project survival).	Secondary
P_1	Probability of detection at Lower Granite Dam, given fish was alive at Lower Granite Dam forebay.	Primary
β_1	Vector of parameters for covariates affecting survival from primary release point to Lower Granite Dam tailrace.	Secondary
S_{R2}	Probability of survival from Lower Granite Dam tailrace to tailrace of Little Goose Dam (Little Goose Dam "reach" survival).	Primary
S_{B2}	Probability of survival from just below PIT-tag diverter gate to bypass outfall at Little Goose Dam (Little Goose Dam post-detection bypass survival).	Primary
S_{T2}	Probability of survival through Little Goose Dam turbines (Little Goose Dam turbine passage survival).	Secondary

Table 2.--Continued.

Parameter	Definition	Related to objective
S_{S2}	Probability of survival through Little Goose Dam spillway (Little Goose Dam spillway passage survival).	Secondary
S_{P2}	Probability of survival from Lower Granite Dam tailrace to forebay of Little Goose Dam (Little Goose Dam reservoir survival).	Secondary
S_{D2}	Probability of surviving passage through Little Goose Dam (Little Goose Dam project survival).	Secondary
P_2	Probability of detection at Little Goose Dam, given fish was alive at forebay of Little Goose Dam.	Primary
β_2	Vector of parameters for covariates affecting survival from Lower Granite Dam tailrace to Little Goose Dam tailrace.	Secondary
A	Probability that a fish alive below Little Goose Dam tailrace is eventually detected at either Lower Monumental or McNary Dams (includes probability of survival and probability of detection).	Both

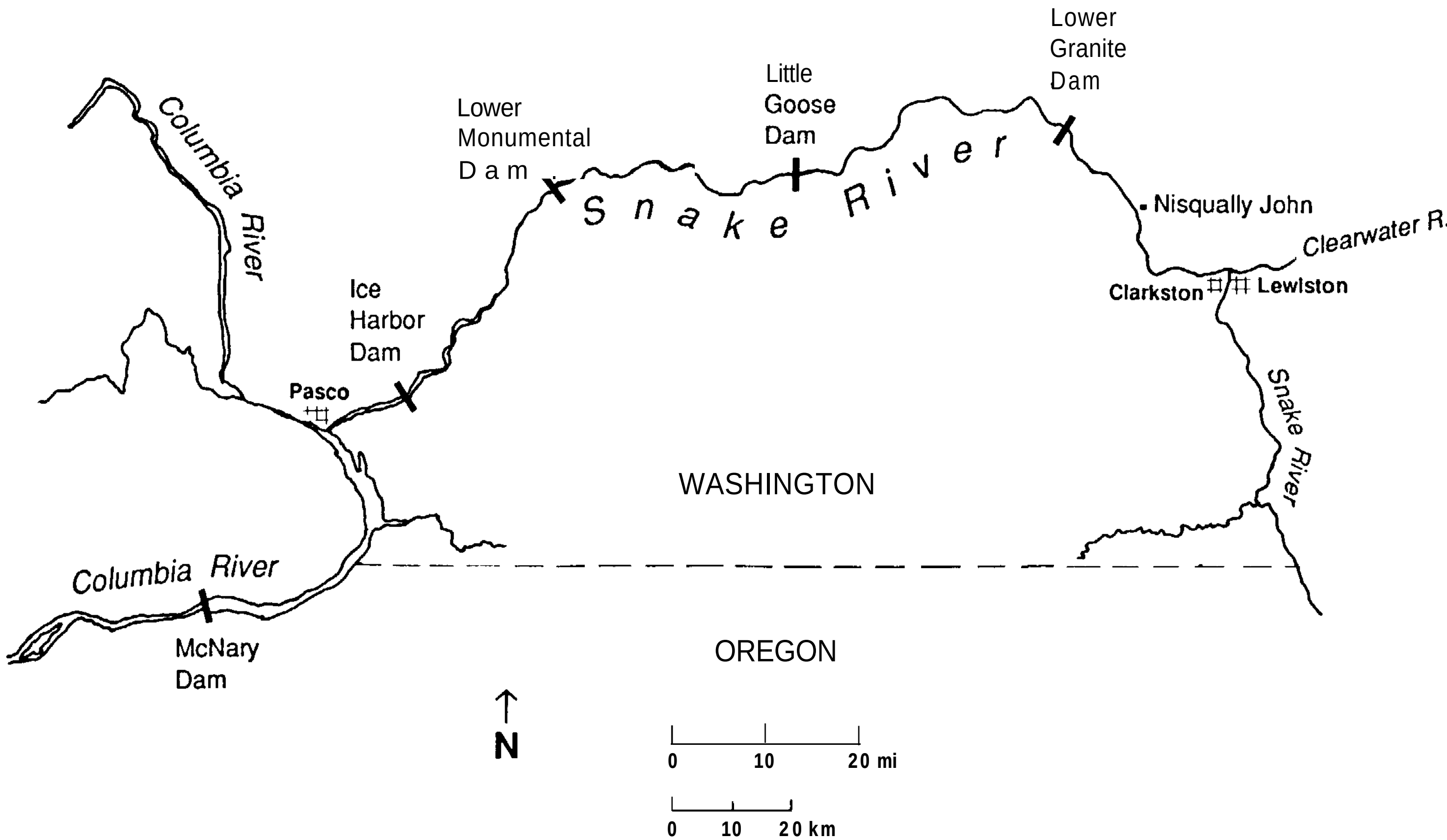

Figure l.--Study area showing release and recapture sites.

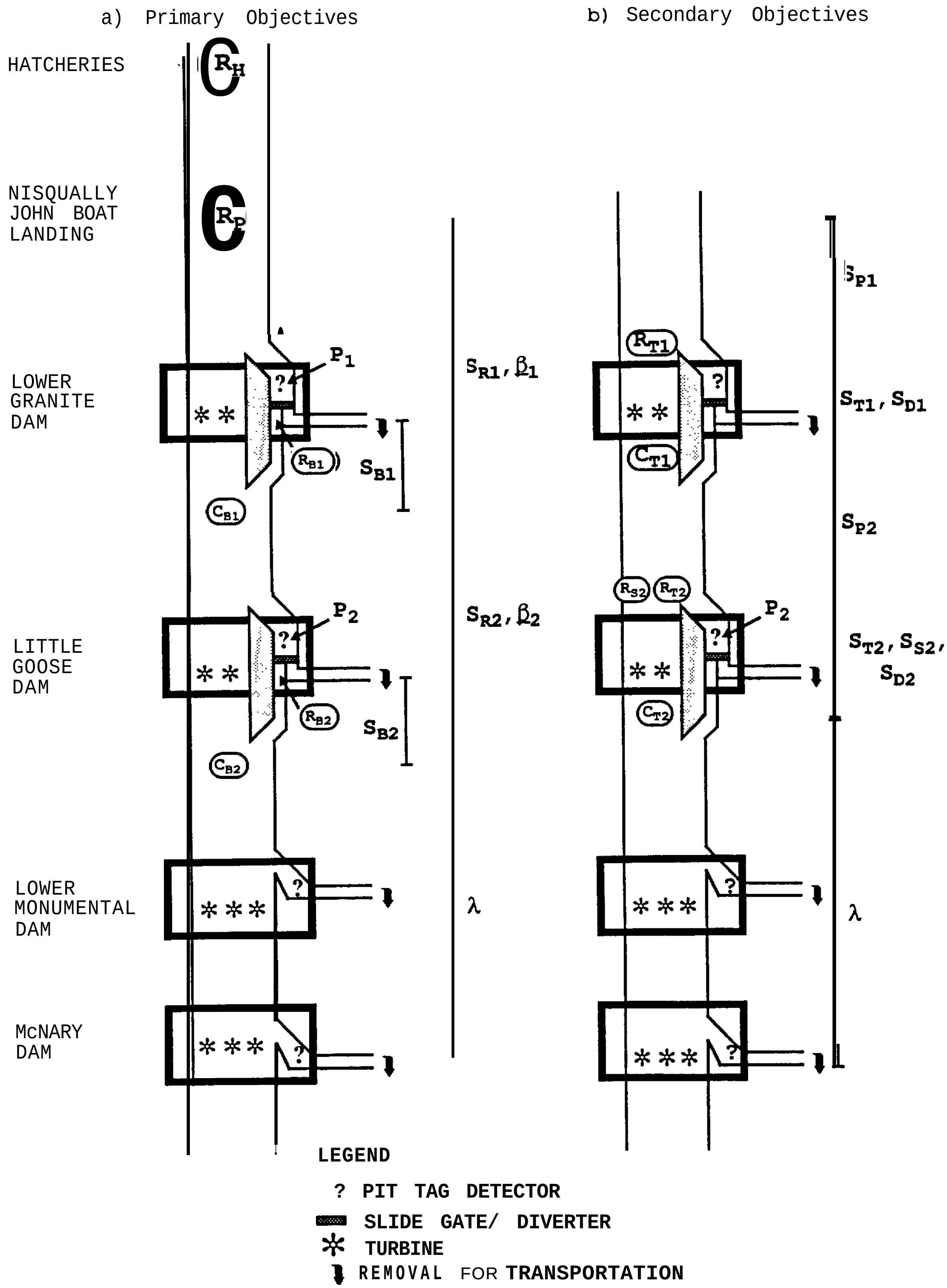

Figure 2.--Schematic of study area showing location of study sites, release groups (circled), and estimated parameters.

MSR model with paired releases for the Lower Granite Dam and Little Goose Dam bypass systems.

3) Post-detection bypass and tailrace release groups: These releases were made at Lower Granite Dam (R,,, C,,) and at Little Goose Dam (R,,, C_{B2}). The post-detection bypass test groups (R,,, R,,) were released in the bypass line at the juvenile collection facilities just downstream from the PIT-tag detector. Their reference groups (C,,, C,,) were released to the river at the point where detected fish could remix with non-detected fish.

Preliminary analyses of recapture histories from these releases were conducted separately, 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.

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.

4) Turbine passage treatment and reference groups at Lower Granite Dam (R_{T1}, C,,) and turbine and spill treatment and reference groups at Little Goose Dam (R,,, R_{S2}, C,,): These sets of releases were analyzed separately using the PR Model to obtain estimates of survival rates associated with the respective routes of passage. While spillway release studies were not part of the original research proposal, natural spill occurred at Little

Goose Dam during the study, and the releases into the spillway were added. A single tailrace reference group was used for both the turbine and spillway test releases at Little Goose Dam.

Only hatchery-reared yearling chinook salmon, determined by the absence of either adipose or ventral fins, were used for this study. Fish with injuries, excessive descaling, or obvious bacterial kidney disease (BKD) symptoms were excluded, as were previously PIT-tagged fish (identified by scanning **with a PIT-tag** detector). There were three replications of each set of releases at each dam for a total of 27 releases.

Table 2 lists the parameters defined for all releases, and Table 3 identifies which parameters were used with each release or set of releases. Survival probabilities were estimated for the following: 1) from the point of primary release to the tailrace of Lower Granite Dam (S,,), and 2) from the Lower Granite Dam tailrace to the Little Goose Dam tailrace (S,). Each estimate included reservoir and dam survival components (Fig. 2).

The dam survival or project survival estimate is the overall probability of surviving passage through a dam and includes survival associated with each of the three passage routes: spillway, turbine, and bypass.

Table 3.--Parameters estimated from each set of releases.

Set of releases	Parameters estimated	Model of analysis
R_P, R_{B1}, C_{B1}	S_{R1}, S_{B1}, P_1 β_1	Single-Release (Modified if necessary)
R_{T1}, C_{T1}	S_{T1} S_{R2}, P_2 β_2, λ	Burnharn (Complete Capture History)
	S_{P1}, S_{D1}	Calculated from Eqs. 1,2
R_P, R_{B2}, C_{B2}	S_{R2}, S_{B2}, P_2 β_2, λ	Single-Release (Modified if necessary)
R_{T2}, C_{T2}	S_{T2}, λ	Burnham (First Capture History)
R_{S2}, C_{T2}	S_{S2}, λ	Burnham (First Capture History)
	S_{P2}, S_{D2}	Calculated from Eqs. 1,2

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 (Durkin and Park 1967). Purse seines were approximately 229 m long and 11 m deep with l- 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).

Juvenile salmonids were removed from the purse seine with a sanctuary dip-net to reduce stress. They were held in 120-L plastic containers with flow-through water until transport back to shore. Densities in the containers were kept at less than 100 fish/container. A 12-V air pump system was available for use for larger densities of fish, but was never needed. Catches were usually transported back to shore by seine skiff after each purse-seine set. Adult steelhead (0. mykiss) and nonsalmonids were removed from the net, counted, and returned to the reservoir as quickly as possible.

Fish sorting and marking were conducted in a portable marking trailer set up at the Nisqually John boat landing. Fish transported from the purse-seine vessels were immediately transferred to a 1.8 x 0.9 x 0.6-m aluminum tank provided with flow-through water. Fish were held in this tank until processing when they were dipped from the tank with a sanctuary dip-net into a 19-L bucket containing 30 mL of MS 222 stock solution (100 gm/L). The anesthetized fish were then dip-netted into marking troughs in the trailer for sorting and marking.

The trailer contained a recirculating anesthetic (MS 222) and chiller system to keep the fish anesthetized at a dosage of approximately 50 ppm. Fish rejected for tagging (criteria included wrong species or race, previously PIT tagged, excessive descaling, obvious deformities and abnormalities) were counted, placed into 19-L buckets containing fresh water, hand carried to net-pens (1.8 x 0.9 x 0.7 m) (Rottiers 1991) tied to the boat dock, and released after a minimum 4-hour recovery period.

Sixty fish per tag group were sacrificed for disease and physiological assays by the U.S. Fish and Wildlife Service (USFWS). Coded-wire-tags (CWT) were extracted from these fish and decoded to determine their origin, and the fish were examined for BKD and general disease, and assayed for gill Na^+-K^+ ATPase and plasma cortisol levels.

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, which 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 hatchery-reared yearling chinook salmon for marking.

Since there is no juvenile separator at Lower Granite Dam, large numbers of steelhead were incidentally collected at this site.

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 kept anesthetized with MS 222 in a recirculating anesthetic system at a dosage of approximately 50 ppm. Steelhead and chinook salmon rejected for tagging were counted and returned by pipe to an adjacent raceway for loading onto the next available transport barge. Mortalities in the raceways before and after sorting were counted.

Little Goose Dam

At Little Goose Dam, fish were also obtained from the juvenile collection facility. Little Goose Dam has a juvenile salmonid separator that sorts fish on the basis of size into two tanks (A and B), with the larger "B" tank containing predominantly steelhead. We increased the collection rate for the "A" tank to a level sufficient to obtain the necessary number of hatchery chinook salmon needed for marking. By collecting only fish in the "A" tank, we reduced the number of steelhead handled unnecessarily.

Fish sorting and marking were conducted in the sample facility at Little Goose Dam. Fish were preanesthetized in tank "A" with benzocaine and alcohol, using the NMFS transportation marking procedures (Matthews et al. 1987) and were conveyed to the sample facility by gravity feed (Monk et al. 1992). During sorting and marking, fish were kept anesthetized with MS 222 in a recirculating anesthetic system at a dosage of approximately 50 ppm. Steelhead and chinook salmon rejected for tagging were counted and returned by pipe to a raceway adjacent to the sampling facility for loading onto the next available transport barge.

Marking Procedures

PIT Tagging

Hatchery-reared yearling chinook salmon 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 incidence of disease transmission, all needles were suspended 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 for the presence of a PIT tag 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, and randomly designated as a treatment or reference release group.

Tag Retention

Tag retention was estimated by rescanning a portion of fish tagged each day approximately 24 hours after tagging. In the reservoir, fish sampled by the USFWS for disease and physiological assays were rescanned (60 fish samples). At the dams, a separate group of fish were tagged and held in 120-L plastic containers for 24 hours, anesthetized and scanned (n > 80).

Delayed Mortality

Since mortalities from all release containers were removed, scanned, and recorded prior to release, no 24-hour delayed mortality samples were necessary. The codes of mortalities were deleted from the tag files.

Release Procedures

Lower Granite Reservoir

Yearling chinook salmon PIT tagged and released to the reservoir as a primary release group were kept in net-pens for about 24 hours prior to release. The net-pens were anchored approximately 50 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, live fish samples taken for disease/physiological assay, and the net-pen was rolled over to permit escape. All releases were made between 2000 and 2200 h.

Lower Granite Dam

Release locations for Lower Granite Dam are shown in Figure 3. All release groups of PIT-tagged fish, except the bypass release group, were held for 24 hours in 1.8 x 0.9 x 0.6-m aluminum tanks mounted on flatbed trucks. Water quality was maintained with flow-through water until release time. The bypass release group was held in a 1.8 x 1.2 x 0.6-m aluminum tank with flow-through water located just above the slide gate on the main separator walkway. Oxygen level and temperature in all containers were periodically checked with an oxygen meter. Fish were released from the holding tank into the bypass line tank located just upstream from the Diversion A and B detectors. (Fig. 4)

After switching from flow-through water to oxygen, the turbine-treatment release groups were transported by truck in their container to the forebay deck where the tank was attached with a camlock fitting to a 7.6-cm x 30.5-m flexible hose attached to the submersible traveling screen (STS) in Turbine Unit 6B (Fig. 5). The other end of the release hose was approximately 1 m below the STS. An additional tank of water was used to flush smolts from the hose. Turbine Unit 6B was selected

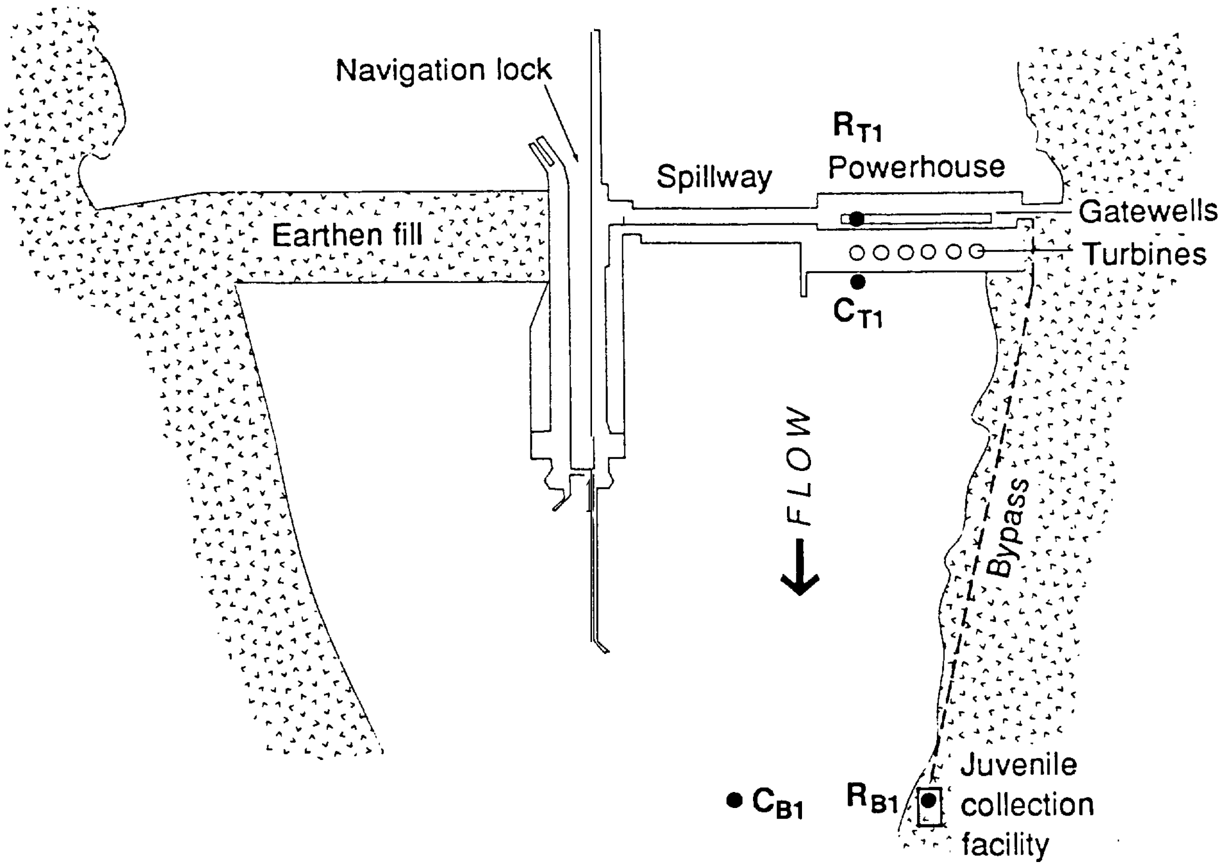

Figure 3.--Schematic of Lower Granite Dam showing location of the turbine (R_{T1}), bypass (R_{B1}), and reference (C_{T1}, C_{B1}), releases of PIT-tagged hatchery-reared yearling chinook salmon.

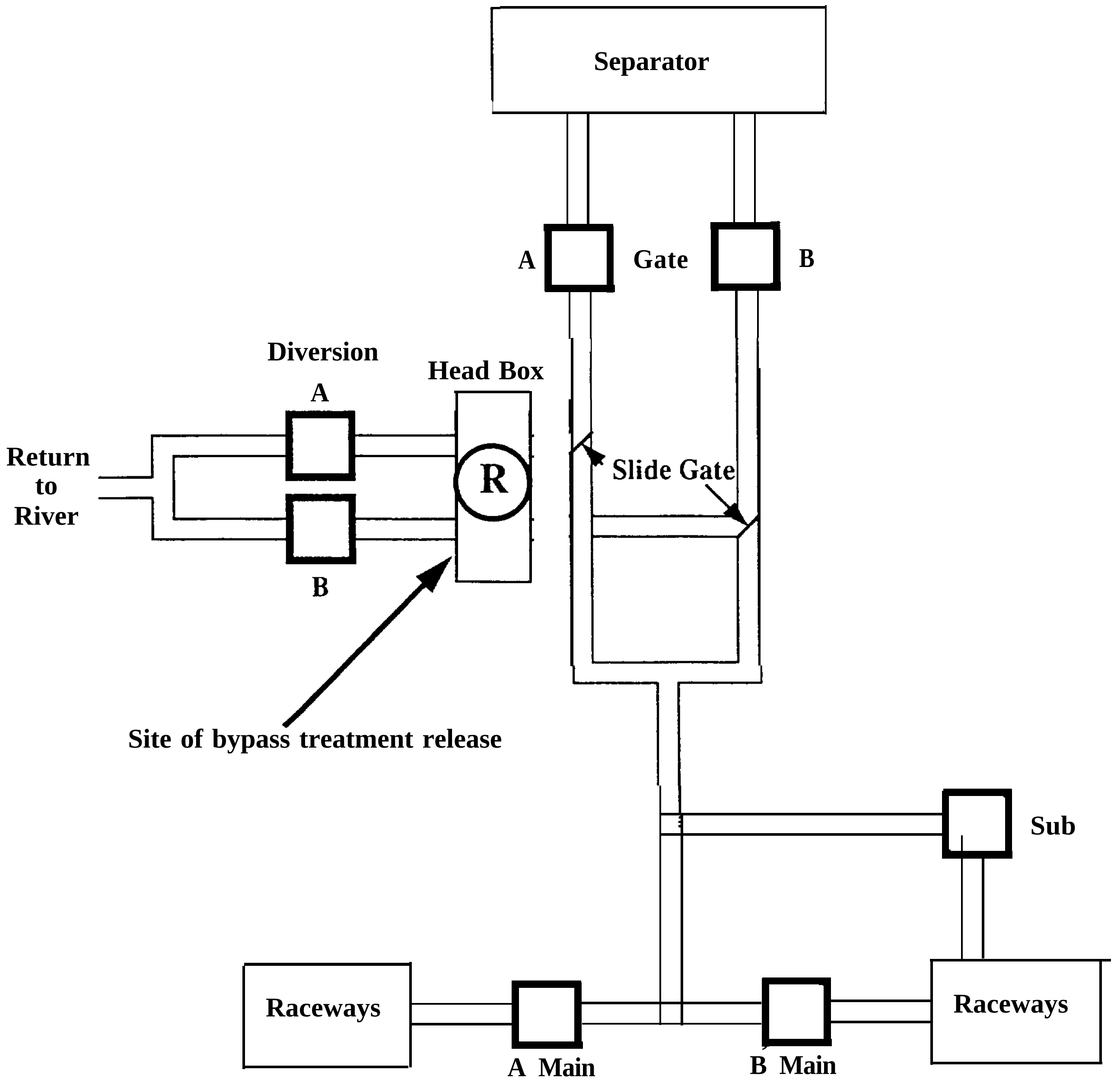

Figure 4.--Schematic of the Lower Granite Dam juvenile bypass system showing location of post-detection bypass treatment releases and PIT-tag detectors (black-outlined boxes).

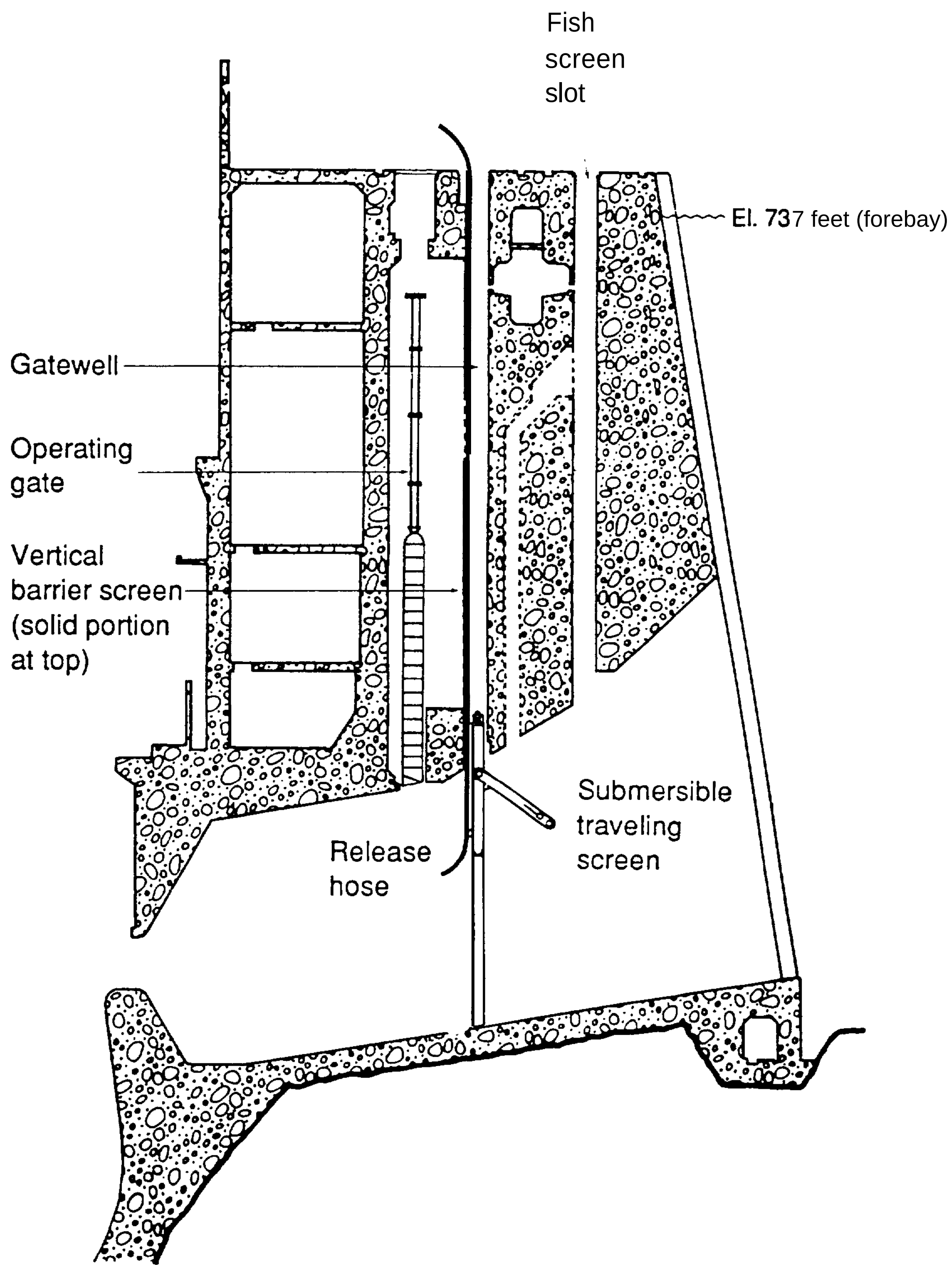

Figure 5.--Schematic of Lower Granite Dam showing location of the hose used for turbine releases of PIT-tagged hatchery-reared yearling chinook salmon.

for two reasons: 1) Large numbers of salmonids pass through Unit 6B, particularly at night, and 2) Unit 6B was also available at Little Goose Dam making comparisons between dams possible.

After switching from flow-through water to oxygen, reference releases were transported by truck in their container to a boat ramp located approximately 3.5 km downstream, and then transferred by sanctuary dip-net (and flexible hose for the last remaining fish) to 120-L containers. These containers were then loaded on a boat, supplied with a 12-V aeration system, and transported to the release site upstream (Fig. 3). Just prior to release, mortalities were removed, and a sample was taken from the reference release group for disease/physiological assay.

Little Goose Dam

Release locations for Little Goose Dam are shown in Figure 6. Spill caused turbulent conditions in the tailrace. Therefore, turbine and spill reference releases were combined.

All release equipment and procedures were the same as at Lower Granite Dam except for the post-detection bypass treatment group, which was held in an aluminum tank until release. At release, fish in this group were dip netted with a sanctuary net into 19-L buckets, hauled up to the PIT-tag diverter tank, and released (Fig. 7). Procedures for the turbine-released groups, including selection of Turbine Unit 6 as the test turbine, were identical to those at Lower Granite Dam. An additional release was made at Little Goose Dam to evaluate spillway survival. After switching from flow-through water to oxygen, the spillway

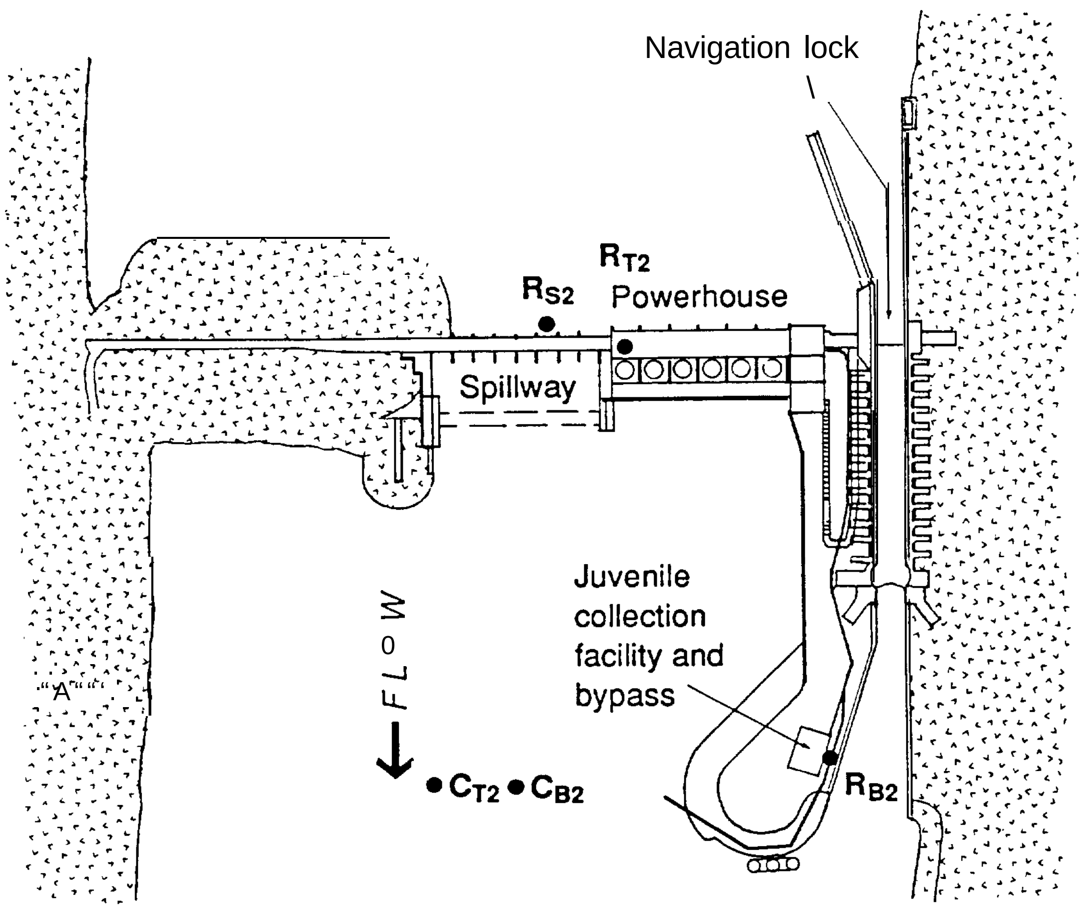

Figure 6.--Schematic of Little Goose Dam showing location of the turbine (R_{T2}), bypass (R_{B2}), spillway (R_{S2}), and reference (C_{T2}, C_{B2}) releases of PIT-tagged hatchery-reared yearling chinook salmon.

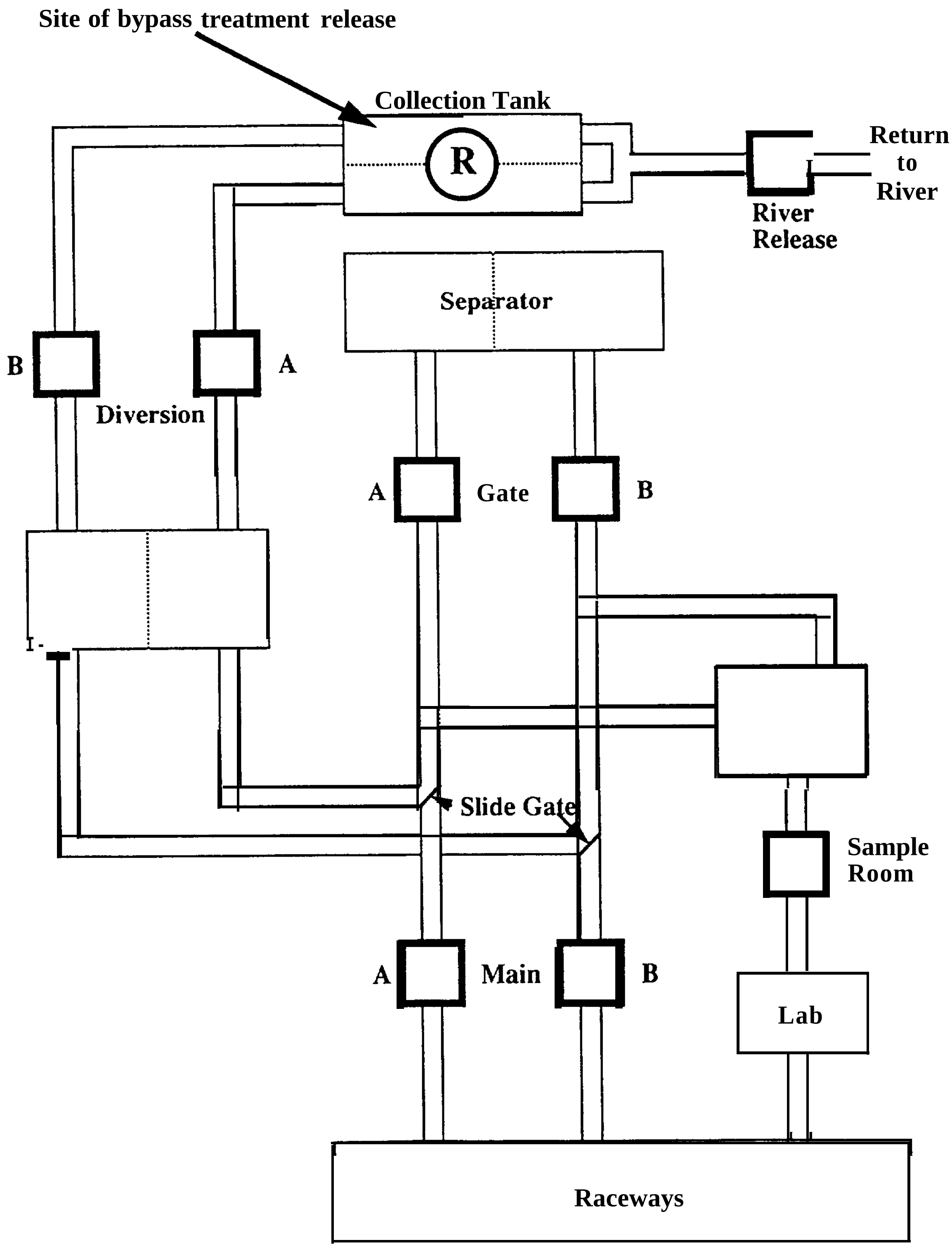

Figure 7.--Schematic of the Little Goose Dam PIT-tag bypass system showing location of post-detection bypass treatment releases and PIT-tag detectors (black-outlined boxes).

treatment release groups were transported by truck in their aluminum container to the forebay deck where the tank was attached with a camlock fitting to 7.6-cm x 25-m flexible hose attached to the suspended stoplog (with approximately 1 m extending through the stoplog) in spillway Gate 3 (Fig. 8). The other end of the release hose was approximately 2 m above the ogee. The spillway gate was opened approximately 66 cm during release.

Hatchery Releases

In 1993, several hatcheries released PIT-tagged fish as part of experiments designed at the hatchery level for travel time estimation to Lower Granite Dam. Hatchery data were analyzed to demonstrate survival estimation methods using the detector 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. We neither intended nor attempted to analyze the experiments for which the releases were made. 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. The results of these preliminary analyses cannot take the place of more rigorous examination by those more familiar with the experiments for which the releases were made.

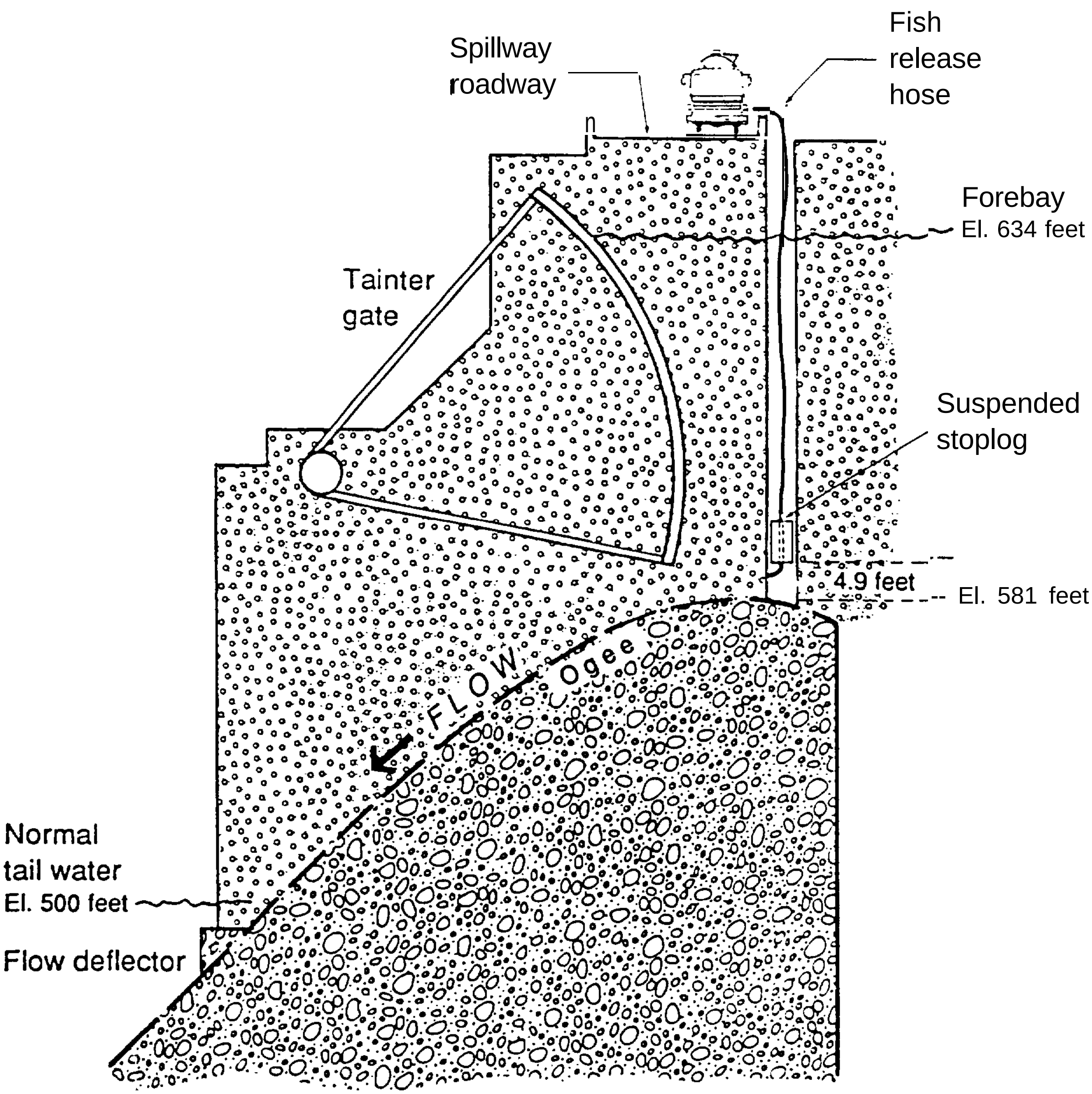

Figure 8.--Schematic of Little Goose Dam showing location of the hose used for spillway releases of PIT-tagged hatchery-reared yearling chinook salmon.

Tag detections were made of yearling chinook salmon from the following hatcheries (Table 4):

1) Dworshak National Fish Hatchery (USFWS): As part of a study of release timing, approximately 250 PIT-tagged fish were released from each of six raceways on the three dates: 8 April, 22 April, and 6 May.

2) Kooskia National Fish Hatchery (USFWS): Releases of just under 200 PIT-tagged fish each were made from six different raceways on 19 April, as part of a rearing-density study.

3) Lookingglass Hatchery (Oregon Department of Fish & Wildlife): Approximately 500 PIT-tagged fish from each of four raceways were released from the hatchery on 7 April. Two raceways had normal fish densities and two had low densities.

4) Lookingglass Hatchery: Approximately 500 PIT-tagged fish from each of four raceways were released in the Imnaha River on 12 April. In two raceways, fish weighed 25 to the pound. In the remaining two raceways, fish weighed 15 to the pound.

5) McCall Hatchery (Idaho Department of Fish & Game (IDFG)): Releases of approximately 500 fish each were made from the hatchery on the three dates: 9 April, 22 April, and 5 May.

6) McCall Hatchery: Two groups of approximately 1,500 PIT-tagged fish each were released on 3 April. One group was tagged by hand, while the other was PIT tagged using an auto-injector.

7) Rapid River Hatchery (IDFG): Two groups of approximately 1,500 PIT-tagged fish each were released on 3 April. One group

Table 4.--Hatchery releases of PIT-tagged yearling chinook salmon examined during the 1993 survival study.

Hatchery	Number of replicates	Approximate number/ replicate	Approximate total number released
Dworshak	6	250	1,500
	6	250	1,500
	6	250	1,500
	6	250	1,500
Kooskia	6	200	1,200
Lookingglass	4	500	2,000
Lookingglass (Imnaha River releases)	4	500	2,000
McCall	3	500	1,500
	2	1,500	3,000
Rapid River	2	1,500	3,000
Sawtooth	1	800	800

was tagged by hand, while the other was PIT tagged using an auto-injector.

8) Sawtooth Hatchery (IDFG): A single release of 799 PIT-tagged fish was made from the hatchery on 20 April.

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; and 5) detection probability at Lower Monumental or McNary Dams.

Project Operations

Slide Gate Operation

To divert PIT-tagged fish back to the river, slide gate systems at Lower Granite and Little Goose Dams (Achord et al. 1992) were operated for the duration of the study. At Lower Granite Dam, operations continued from 18 April to 13 July; at Little Goose Dam from 19 April to 4 July; and at Lower Monumental Dam, the slide gate was not operated during the 1993 migration. Slide gate or diversion efficiency 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'. Turbine load, spill-gate settings, forebay elevation, and tailrace elevation during releases at Lower Granite and Little Goose Dams were obtained from the operators' logs.

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. Data was uploaded to two files: 1) the tagging file--it contained information on the tagging session (date, location, etc.) and individual records for each tagged fish, consisting of the PIT-tag code, species, rearing type, length (mm)I and a comment field for miscellaneous information; and 2) the observation file--it contained records of PIT-tag detections that were collected automatically at the various monitoring sites. 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 the PIT-tag code, the tagging file in which the PIT-tag code could be found, the observation site, the date and time of

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'Fish Passage Center, Suite 230, 2501 S. W. First Ave., Portland, OR 97201-4752. Pers. commun. April-June 1993.

the observation, the number of coils, the ID codes for the coils, and the elapsed time in days between release and detection.

The first step of the 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 5). The report from the tagging file contained only tagging information, while the observation file report could generate multiple records of a fish, depending upon the number of times it was detected.

Quality Assurance/Quality Control (QA/QC)

Both reports were examined for erroneous records, inconsistencies, and data anomalies. Records were eliminated where appropriate. However, a record was kept of all PIT-tag codes eliminated and the reasons for their elimination. Records were eliminated by the following criteria:

1) Rearing type was wild rather than hatchery.

2) Species was steelhead rather than chinook salmon.

3) Fish had previously been PIT tagged.

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

5) The length of the fish was not recorded, or recorded as zero millimeters.

6) The PIT-tag code appeared in tagging files for more than one release that occurred on the same day ("tank jumpers").

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

Table 5.--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)
flags	coded comment field

b) Observation information

Variable name	Description
tag_id	PIT-tag code
obs_site	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

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 prior to a detection at Lower Granite Dam.

9) Fish was sacrificed for disease and physiological sampling by the USFWS.

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

As a result of the QA/QC process, all statistical analyses were based on hatchery-reared chinook salmon 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 data were internally consistent and logical as to downstream detections.

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 6). Because detected fish were not returned to the river at Lower Monumental Dam, which precluded estimates of the Little Goose Dam to Lower Monumental Dam survival probability, detections at Lower Monumental and McNary Dams were pooled as if they were a single site. Pooling is valid, since under release-recapture models, the only function of the final detection site is to make survival estimates possible for the river section between Lower Granite and Little Goose Dam tailraces.

Table 6.--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-McNary Dam).

History	Explanation
111	Detected and returned to river at LGR and LGO, detected at LMO or MCN.
110	Detected and returned to river at LGR and LGO, not detected at LMO or MCN.
120	Detected and returned to river at LGR, detected and removed at LGO.
101	Detected and returned to river at LGR, not detected at LGO, detected at LMO or MCN.
100	Detected and returned to river at LGR, not detected at LGO, not detected at LMO or MCN.
200	Detected and removed at LGR.
011	Not detected at LGR, detected and returned to river at LGO, detected at LMO or MCN.
010	Not detected at LGR, detected and returned to river at LGO, not detected at LMO or MCN.
020	Not detected at LGR, detected and removed at LGO.
001	Not detected at LGR, not detected at LGO, detected at LMO or MCN.
000	Never detected after release.

Capture histories were constructed from the observation files for each fish in each tagging file by examining the coil codes for each observation. Figures 4 and 7 show schematics of the juvenile bypass facilities at Lower Granite and Little Goose Dams, respectively. These indicate the relative positions of the various PIT-tag detectors.

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 to the river by the "Diversion" detector, while fish not diverted could be detected again on their way to the barge transport raceways.

At both Lower Granite and Little Goose Dams, if a fish was detected only by the "Gate" detector, it was impossible to determine whether it was returned to the river or removed. Such fish were considered removed. This does not bias any of the estimated parameters, but does decrease the precision of estimation, because the effect is to decrease the sample size.

There were three codes for capture history: 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 transport downstream by barge; and capture history "0" --a fish not detected at one of the PIT-tag sites. For example, a fish released in the Lower Granite Reservoir would have a capture history of "101" if it was detected and diverted at Lower Granite Dam, not detected at Little Goose Dam, and finally detected at either Lower Monumental or McNary Dam. The capture history for a fish released at Lower Granite Dam and never again detected would be 1100"; with the first "0" indicating no detection at Little Goose Dam and the second indicating no detection at Lower Monumental/McNary Dams.

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 Little Goose Dam, 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 Lower Monumental or McNary Dams indicated a "1" for the final digit of the capture history.

Because the slide gates at Lower Granite and Little Goose 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 barge. Such fish can give no information concerning in-river survival or detection probabilities downstream from their removal. Because the removed fish were known, the models could be adjusted to account for removed fish.

Tests of Assumptions

A primary objective of this study was to test the statistical validity of the Single-Release, Modified-Single-Release, and Paired-Release Models for smolt survival studies on the Snake River by evaluating their critical assumptions. For the SR Model there are three critical assumptions:

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

A2) A fish's detection at a PIT-tag detection site does not affect the probability of its subsequent survival at downstream sites. Specifically, no significant post-detection bypass mortality occurs differentially to detected fish compared with non-detected fish.

A3) The Single-Release Model accurately **estimates** sampling variability.

If Assumption A2 fails, the MSR Model **must be** used in **place** of the SR Model. The MSR Model shares Assumptions Al and A3 and **has** one additional critical assumption:

A4) Treatment and reference groups **mix** evenly downstream from the source of mortality under investigation.

The Paired-Release Model shares the assumptions of the MSR Model.

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

Using data from the seven releases into the Lower Granite Reservoir, Assumption Al was analyzed in two ways. One analysis was based on temporal passage distribution for subgroups of fish, as defined by their migration histories up to a specified point.

Another evaluation was based on the history of capture at each site for two groups with similar migration histories.

By definition, detected and non-detected fish take different routes of passage through Lower Granite Dam. If the detected and non-detected fish did not move downriver in a mixed group, it would violate Assumption Al. For example, fish guided through the bypass facility might reside in the gatewells for a period of time such that upon re-entry into the river, they might be separated from that passed through the turbines with no such delay. If these groups were not passing through downstream sections together, they might experience different conditions in the reservoirs or at the downstream dams. This could lead to differential survival or detection probabilities downstream, depending on whether or not a fish had been detected at Lower Granite Dam.

The hypothesis of homogeneous passage distributions implies that groups experience the same downstream conditions and consequently have equal survival and capture probabilities. However, if river conditions were not changing greatly day to day, evidence against this hypothesis would not necessarily imply that capture and survival 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 capture probabilities would not be significantly different even when the hypothesis of homogeneous distributions was rejected.

To test the assumption of equal capture probabilities for detected and non-detected fish, we used the Pearson χ^2-test (Sokal and Rohlf, 1981). This test is based on a K X 2 contingency table:

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

Table entries were the numbers of PIT-tagged fish from each subgroup passing Lower Granite Dam that were 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 detection records at Lower Granite and Little Goose Dams. The four groups were: 1) those not detected at either Lower Granite or Little Goose Dam; 2) those detected only at Lower Granite Dam; 3) those detected only at Little Goose Dam; and, 4) those detected at both upstream dams. Pooling over days was necessary on occasion to insure that no cells in the table had zeros.

The second method for checking Assumption Al was presented by Burnham et. al (1987), and called TEST3. This test checked the internal consistency of survival and capture probabilities by dividing a single release group into subgroups based on their capture histories up to a specified point. Generally speaking, long capture histories (multiple detection times/sites) are required to make extensive use of TEST3. Our two detection/diversion sites and two detection-only sites provided enough data to perform one contingency table analysis under TEST3.

For this analysis, the two subgroups of a particular reservoir release were defined by their capture history codes including Little Goose Dam. All fish detected at Little Goose Dam were divided into those detected at Lower Granite Dam and those not detected at Lower Granite Dam. All fish in these two groups were known to be alive at Little Goose Dam. Therefore, according to Assumptions Al and A2, the two groups should be detected proportionally at the downstream monitoring sites at Lower Monumental and McNary Dams.

Fish released at the primary site and detected at both Lower Granite and Little Goose Dams had a capture history code "11," while those detected at Little Goose Dam but not Lower Granite Dam were denoted "01." For TEST3, homogeneity of subsequent survival and capture probabilities were tested based on the following contingency table:

Capture history to Little Goose Dam	Capture history at Lower Monumental and McNary Dams			
	00 (Not detected at LMO or MCN)	01 (Detected only at MCN)	10 (Detected only at LMO)	11 (Detected at LMO and MCN)
17				
01				

Entries in the contingency table were the numbers of PIT-tagged fish in each group with each of the potential capture histories at Lower Monumental and McNary Dams. Assumption Al was violated if the two groups did not have equal proportions across the possible downstream capture histories.

Assumption A2--A fish's detection at a PIT-tag detection site does not affect the probability of its subsequent survival at downstream sites.

The paired releases in the bypass systems at Lower Granite and Little Goose Dams were planned expressly to test Assumption A2. Data from these releases were used to test differences in post-detection bypass mortality using the PR Model. If differences in mortality were statistically significant, the MSR Model was used to analyze the primary releases; if they were not significant, the SR Model was used.

Assumption A3--The Single-Release Model accurately estimates sampling variability.

Assumption A3 is not needed to estimate survival or detection probabilities, although it is needed to show that the estimates of precision associated with these estimates are satisfactory.

The seven replicates released to Lower Granite Reservoir were clustered in time as closely as possible so that variability in the respective point estimates of survival was almost exclusively the result of sampling variability. Assumption A3 was checked using the seven Lower Granite Reservoir releases. The empirical variance among the seven point estimates was compared with the average variance estimated from the model. There was no formal test; however, large differences between the empirical variance and the average variance predicted by the model, particularly if the empirical variance was greater than the average variance predicted by the model, would imply that: 1) the model was missing a substantial source of variability, and 2) the estimate of sampling variability provided by the model was not reliable.

Theoretically, the empirical variance would contain more sources of variability (e.g., day-to-day variability) in survival than the average variance estimated by the model, and would be expected to be greater in magnitude. However, because both quantities are imprecise estimates, it is possible that the empirical variance could be smaller than the model-predicted average by chance alone. In any case, if the variance from the model prediction exceeds the empirical variance, then true variability is not underestimated by the model. At worst, the estimated variance from the model provides a reliable, though conservative (upper bound), estimate of the true variance.

Assumption A4--Treatment and reference groups mix evenly downstream from the source of mortality under investigation.

Mixing is sufficient for survival and detection probabilities to be equal but not necessary. 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 chi square (χ^2) analyses of the passage distributions at detection sites. This test was similar to the first set of tests used to check Assumption Al.

Experiment-wise Error Rate

Each series of contingency table tests was considered to be a separate and independent experiment. Table 7 shows the complete list of contingency table tests performed to test model assumptions. Significance levels for individual tests (α_T) were selected to control the experiment-wise Type I error rate (α_{EX}) (Table 8). For a given experiment-wise Type I error rate, the

Table 7.--Series of contingency table tests used to test assumptions of Single-Release and Paired-Release Models.

Test Series	Number of Tests
Little Goose Dam passage for subgroups of primary releases	7
Lower Monumental Dam passage for subgroups of primary releases	7
TEST3 for subgroups of primary releases	7
Little Goose Dam passage for Lower Granite Dam paired bypass releases	3
Lower Monumental Dam passage for Lower Granite Dam paired bypass releases	3
McNary Dam passage for Lower Granite Dam paired bypass releases	3
Little Goose Dam passage for Lower Granite Dam paired turbine releases	3
Lower Monumental Dam passage for Lower Granite Dam paired turbine releases	3
McNary Dam passage for Lower Granite Dam paired turbine releases	3
Lower Monumental Dam passage for Little Goose Dam paired bypass releases	3
McNary Dam passage for Little Goose Dam paired bypass releases	3
Lower Monumental Dam passage for Little Goose Dam turbine/spill/reference releases	3
McNary Dam passage for Little Goose Dam turbine/spill/reference releases	3

Table 8. --Test-wise significance levels corresponding to experiment-wise Type I error rates of 0.10, 0.05, 0.01.

Experiment-wise error rate (a,)	Test-wise significance levels (α_T)	
	7 tests	3 tests
0.10	0.0150	0.0350
0.05	0.0073	0.0170
0.01	0.0014	0.0033

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 seven tests, setting the experiment-wise Type I error rate to α_{EX} = 0.05 requires a test-wise significance level of α_T = 0.0073.

Survival Estimation

The first task in estimating survival was to analyze bypass system releases at Lower Granite and Little Goose Dams for significant post-detection mortality. The results of these tests determined the selection of the SR or MSR Model for analysis of the primary release data. Data from paired-releases at each site (R_{B1}, C_{B1} and R_{B2}, C_{B2}) were analyzed with the PR Model. If the PR analysis indicated that the post-detection bypass mortality was significant, the MSR Model would have to be used to analyze the primary releases. If the PR analysis did not indicate significant post-detection mortality, the SR Model could be used.

Survival probabilities for passage through the turbines and spillway were also estimated using the PR Model with (R_{T1}, C_{T1}), (R_{T2}, C_{T2}), and (R_{S2}, C_{S2}) pairs analyzed independently. Because there were multiple detection sites downstream from Lower Granite Dam, the complete capture history protocol was used (Burnham et al. 1987) for the PR analysis of paired releases into Little

Goose Dam reservoir (detections at Lower Monumental and McNary Dams were pooled). For paired releases from Little Goose Dam, the PR "first capture history" protocol was used because detected fish were not returned to the river at Lower Monumental Dam.

For each group released to the Lower Granite Dam turbines, the PR Model was used to estimate the probability of survival from the point of release to the tailrace of Little Goose Dam. For the reference groups released to the Lower Granite Dam tailrace, survival probability was defined as S_{R2} (Table 2), and for test groups, it was defined as the product of S_{R2} and turbine passage survival probability (S,,). Estimated turbine survival was then the ratio of the survival estimated for the treatment group to that of the reference group. For each of the Little Goose Dam releases, the PR Model estimated the probability of detection at Lower Monumental or McNary Dams. For the reference groups, this was λ (see Table 2), and for the test groups, the product of λ and the turbine survival probability (S_{T2}), or spillway survival probability (S_{S2}).

The analyses of the primary releases provided the following survival estimates: 1) from the point of primary release to the tailrace of Lower Granite Dam (S,,) and 2) from the Lower Granite Dam tailrace to the Little Goose Dam tailrace (S,). These estimates included both reservoir and dam passage survival components. The dam passage, or project survival, was the overall probability of surviving passage through a dam, and included survival associated with the three possible passage routes: spillway, turbine, and bypass. Paired releases at each of the dams gave estimates of turbine passage survival at both Lower Granite and Little Goose Dams, and spillway passage survival at Little Goose Dam.

The project survival probabilities (S_{Di}) were expressed as functions of the constituent parameters as follows:

$$S_{Di} = P_{Si}S_{Si} + (1-P_{Si})\left[(FGE_i)S_{Byp_i} + (1-FGE_i)S_{Ti}\right] \qquad \textbf{(1)}$$

where

P_{Si} = the probability of passing over the spillway,

S_{Si} = the probability of surviving passage over the spillway,

FGE_i = the fish guidance efficiency,

$S_{Byp\,i}$ = the probability of surviving passage through the bypass system, and

S_{Ti} = the probability of surviving passage through the turbines.

Survival probability (S,) was the product of reservoir and dam survival probabilities ($S_{Pi}S_{Di}$); thus the following expression was used for reservoir survival:

$$S_{P_i} = \frac{S_{Ri}}{S_{Di}} = \frac{S_{Ri}}{P_{Si}S_{Si} + (1-P_{Si})\left[(FGE_i)S_{Byp_i} + (1-FGE_i)S_{Ti}\right]}. \qquad \textbf{(2)}$$

Fish guidance efficiency (FGE_i) was the conditional probability that a fish was guided to the bypass system, given that it entered the powerhouse (i.e., did not pass through the spillway). Assuming that all guided fish were detected, the estimate of FGE_i could be expressed informally as:

$$FGE_i = \frac{\text{no. fish detected}}{\text{no. fish entering intake}}, \quad (3)$$

Probability of detection (P_i), in contrast, was the conditional probability that a fish was detected, given that it survived to the tailrace of the dam. The estimate of detection probability could be informally expressed as:

$$P_i = \frac{\text{no. fish detected}}{\text{no. fish surviving to tailrace}}, \quad (4)$$

Thus, P_i and FGE_i are not equivalent; equations (3) and (4) differ in the denominators. In terms of the probabilities defined above, the expression linking the detection probability to FGE when spill occurred was:

$$P_i = \frac{(1 - P_{Si})FGE_i}{S_{Di}} \quad (5)$$

Substituting Equation (1) for S_{Di} in Equation (5) and solving for FGE_i, we have:

$$FGE_i = \frac{P_i[P_{Si}S_{Si} + (1 - P_{Si})S_{Ti}]}{(1 - P_{Si})[1 - P_i(S_{Byp_i} - S_{Ti})]}. \quad (6)$$

When there was no spill, Equations (1), (2), and (6) simplified to the following:

$$S_{Di} = FGE_i S_{Byp_i} + (1 - FGE_i)S_{Ti}, \quad (7)$$

$$S_{P_i} = \frac{S_{Ri}}{S_{Di}} = \frac{S_{Ri}}{FGE_i S_{Byp_i} + (1 - FGE_i) S_{Ti}}, \quad (8)$$

and

$$FGE_i = \frac{P_i S_{Ti}}{1 - P_i (S_{Byp_i} - S_{Ti})}. \quad (9)$$

When no spill occurred, Equations (7) through (9) were used to partition the survival probability (S,) into its components.

In the absence of data on the overall bypass system survival probabilities for Lower Granite Dam or Little Goose Dam (S_{Bypi}, as distinct from S_{Bi}), we used the widely-applied value of 98% bypass survival. When spill occurred, Equations (1), (2) and (6) should be used to compute the components of survival. A critical parameter in these equations was P_{Si}, the proportion of fish passing over the spillway. This proportion depended both on the volume of flow over the spillway and on the spill efficiency. Unfortunately, spill efficiency at the dams had not been sufficiently studied and documented to provide reliable values for P_{Si} in Equations (1) through (6). Therefore, where spill occurred, no attempt was made to compute the survival components.

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). This program extends the standard Cormack (1964), Jolly (1965), and Seber (1965) models 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).

RESULTS AND DISCUSSION

Logistics and Feasibility

Lower Granite Reservoir

Purse seining--Purse seining in Lower Granite Reservoir began on 13 April and continued daily until 20 April, with 6 to 16 sets made daily by the two purse-seiners (Table 9). 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 the day. After the first 2 days, seining effort was adjusted to target the time periods when chinook salmon were most abundant. Thus, the number of sets needed each day to capture the target number of chinook salmon declined.

A total of 10,403 chinook salmon were captured in Lower Granite Reservoir, and 8,738 (84%) of these were fin clipped, indicating hatchery origin. Coded-wire-tags were removed from the subsamples of smolts from each release that were assayed for disease and physiological assessment. Tags indicated that the majority of yearling chinook salmon PIT tagged for reservoir releases originated from Lookingglass Hatchery (Fig. 9), but fish from Rapid River Hatchery and Dworshak National Fish Hatchery also contributed. Approximately 20% of the 1,665 chinook salmon without finclips appeared to have partial or regenerated fin

Table 9.--Number of juvenile salmonids captured by purse seine in Lower Granite Reservoir near Nisqually John boat landing, 13-20 April 1993. Handling mortalities are also shown. (Abbreviations: H-Hatchery; W-Wild).

Date	Sets	Chinook salmon H	Chinook salmon W	Steelhead H	Steelhead W	Sockeye salmon	Total
13 Apr	13	225	30	11	64	1	331
14 Apr	16	894	179	13	127	0	1,213
15 Apr	16	1,406	227	159	120	0	1,912
16 Apr	15	1,269	237	799	83	1	2,389
17 Apr	10	1,320	207	1,513	82	0	3,122
18 Apr	13	1,218	260	2,148	158	,0	3,784
19 Apr	7	894	186	700	72	0	1,852
20 Apr	6	1,512	339	796	114	0	2,761
Totals	96	8,738	1,665	6,139	820	2	17,364
Mortality (number)		4	1	7	0	0	12
Mortality (%)		0.1	0.1	0.1	0.0	0.0	0.1

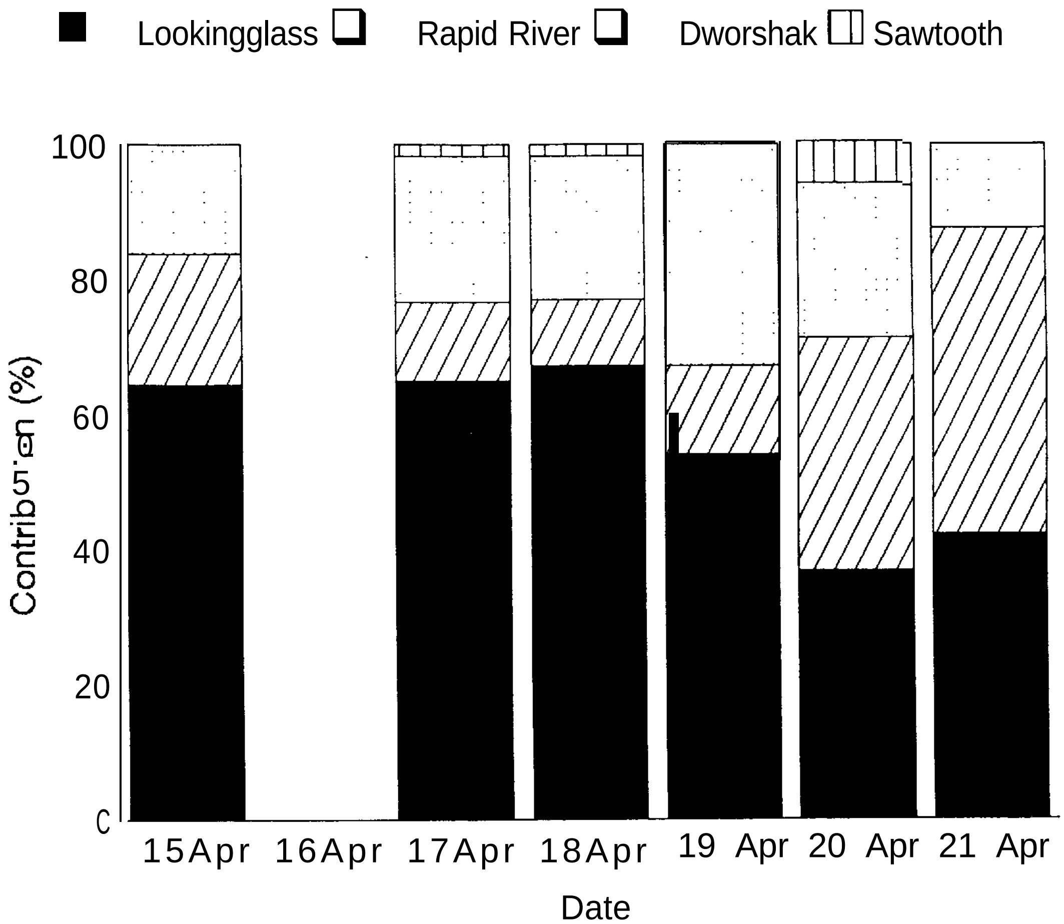

Figure 9.--Origin of hatchery-reared yearling chinook salmon sacrificed for disease/physiological assay in Lower Granite Reservoir.

clips, or were outside the typical size range for wild migrants. Fin-clipped hatchery chinook salmon with no detectable coded-wire-tags were assumed to be from Rapid River Hatchery since fish with non-magnetized tags were released from that hatchery in 1993. Therefore, the percentage of wild fish (16%) was probably overestimated. Of 6,959 juvenile steelhead captured, 88.2% were of hatchery origin (Table 9). An additional 116 adult steelhead were also captured (Table 10). Handling mortality was low for all species in Lower Granite Reservoir, averaging less than 0.1% overall (Table 9).

The numbers of nonsalmonids captured by purse seine (120) were small compared to the number of salmonids (17,364). Chiselmouth (*Acrocheilus alutaceus*) was the most frequently captured nonsalmonid, followed by peamouth (*Mylocheilus caurinus*) and northern squawfish (*Ptychocheilus* oregonensis). Small numbers of other nonsalmonids were captured including carp ***(Cyprinus carpio),*** largescale sucker ***(Catostomus macrocheilus),*** black crappie ***(Pomoxis nigromaculatus),*** channel catfish (*Ictalurus* ***punctatus),*** and brown bullhead ***(I. nebulosus)*** (Table 10).

PIT tagging--A total of 8,542 hatchery-reared yearling chinook salmon were tagged for release into Lower Granite Reservoir (Table 11). These fish were marked in seven replicate groups of 830 to 1,442 fish. Fish appeared to be in excellent condition as indicated by the low mortality and small percentage rejected for tagging. Of the 8,738 fin-clipped chinook salmon

Table 10.--Number of nonsalmonids and adult steelhead captured by purse seine in Lower Granite Reservoir near Nisqually John boat landing, 13-20 April 1993.

Sample date	13	14	15	16	17	18	19	20	13-20
Number of sets	13	16	16	15	10	13	7	6	96
Adult steelhead	25	17	15	16	12	12	17	2	116
Chiselmouth	9	11	7	21	1	5	1	5	60
Peamouth		5	2	9	1		5	3	25
Northern squawfish	2	1	4	5	2	4			18
Black crappie		2	1	2		3			a
Largescale sucker				1	1	4			6
Carp					1				1
Brown bullhead					1				1
Channel catfish						1			1

Table 11.--Number of hatchery-reared yearling chinook salmon PIT tagged and released in Lower Granite Reservoir near Nisqually John boat landing, 13-21 April 1993. Fish removed from tag files for various reasons, and post-tagging mortalities, are also shown.

Replicate	R_{P1}	R_{P2}	R_{P3}	R_{P4}	R_{P5}	R_{P6}	R_{P7}	Total
Release date	15 Apr	16 Apr	17 Apr	18 Apr	19 Apr	20 Apr	21 Apr	
Total fish in tagging files	1,086	1,392	1,255	1,315	1,215	832	1,447	8,542
Wild fish	1	0	2	6	4	4	5	22
Previously handled	0	0	21	23	28	27	36	135
Handled again later	21	27	23	14	10	0	0	95
Length not recorded	0	0	0	3	0	0	0	3
Detections out of order	0	0	0	1	0	0	0	1
USFWS sample	49	59	58	58	60	1	0	285
Handling (number)	0	1	0	2	0	3	2	8
mortality (%)	0.0	0.1	0.0	0.1	0.0	0.4	0.1	0.1
Total fish in analysis	1,015	1,305	1,152	1,208	1,113	797	1,405	7,995

captured, only 216 (2.5%) were rejected because of descaling, or injuries, or because they were previously PIT tagged. From all seven replicates combined, only 15 fish died after PIT tagging and before release (0.2%) (Table 11). Reservoir releases were made on seven consecutive days between 15 April and 21 April. All replicates except the first (R_{P1}) required **a** l-day purse-seine effort. After PIT tagging, fish were held from 24 to 33 hours before release. Fish for the first replicate were collected over a 2-day period and held from 24 to 54 hours.

Lower Granite Dam

PIT tagging--Hatchery-reared yearling chinook salmon were PIT tagged on three dates at Lower Granite Dam, beginning on 27 April (Tables 12 and 13). Of 14,628 hatchery-reared yearling chinook salmon handled, 7.4% were rejected for tagging because of injury, descaling, disease, or previous PIT tagging (Table 14). Mortality from handling and tagging averaged 2.9%. Overall, 5,931 wild yearling chinook salmon were handled (28.8% of total) with a 1.5% mortality rate (Table 14). Large numbers of hatchery steelhead were also handled with little mortality (Table 15). However, they contributed to the higher mortality rate for yearling chinook salmon. Post-tagging mortality ranged from 1.6 to **5.7%** at Lower Granite Dam, with an average of 3.5% (Tables 12 and 13).

Table 12.--Number of hatchery-reared yearling chinook salmon PIT tagged and released at Lower Granite Dam to evaluate post-detection survival in the bypass during 1993. Fish removed from tag files for various reasons, and post-tagging mortalities, are also shown. The first numeral in the two-digit release code identifies the release site (Lower Granite Dam = 1; Little Goose Dam = 2), and the second numeral identifies the replicate.

Release Code	R_{B11}	C_{B11}	R_{B12}	C_{B12}	R_{B13}	C_{B13}	
Release date	28 Apr	28 Apr	30 Apr	30 Apr	12 May	12 May	Total
Total fish in tagging files	758	786	724	755	781	761	4,565
Wild fish	0	1	0	0	0	0	1
Steelhead	0	0	1	0	0	0	1
Previously handled	0	0	0	1	0	0	1
Length not recorded	0	0	0	0	0	1	1
Detections recorded before release	0	0	0	0	0	0	2
Detections out of order	0	0	0	0	1	0	1
Handling (number)	30	25	27	12	32	15	141
mortality (%)	4.0	3.2	3.7	1.6	4.1	2.0	3.1
Total fish in analysis	728	760	696	742	748	743	4,417

Table 13.--Number of hatchery-reared yearling chinook salmon PIT tagged and released at Lower Granite Dam to evaluate turbine passage survival during 1993. Fish removed from tag files for various reasons, and post-tagging mortalities, are also shown.

Release Code	R_{T11}	C_{T11}	R_{T12}	C_{T12}	R_{T13}	C_{T13}	Total
Release date	28 Apr	28 Apr	30 Apr	30 Apr	12 May	12 May	
Total fish in tagging files	1,545	1,509	1,519	1,579	1,256	1,292	8,700
Wild fish	2	2	0	1	0	0	5
Steelhead	0	1	0	2	0	0	3
Previously handled	1	0	1	0	0	0	2
Handled again later	0	1	0	1	0	0	2
Length not recorded	2	0	1	1	1	0	5
Tank jumpers	8	8	0	0	0	0	16
Detections recorded before release	0	0	1	0	4	0	5
Detections out of order	0	0	0	1	2	1	4
USFWS sample	0	15	0	14	0	15	44
Handling mortality (number)	58	86	29	34	63	51	321
Handling mortality (%)	3.7	5.7	1.9	2.1	5.0	3.9	3.7
Total fish in analyses	1,474	1,396	1,487	1,525	1,186	1,225	8,293

Table 14.--Number of yearling chinook salmon handled, handling mortalities, and tag rejections during PIT tagging at Lower Granite Dam in 1993. Post-tagging mortalities are not included. Percentages are shown in parentheses.

	Hatchery chinook salmon					Wild chinook salmon		
Date	Handled	Rejected		Mortalities		Handled	Mortalities	
27 April	4,910	313	(6.4)	162	(3.3)	2,728	58	(2.1)
29 April	4,811	232	(4.8)	64	(1.3)	2,336	28	(1.2)
11 May	4,907	537	(10.9)	202	(4.1)	867	3	(0.3)
Total	14,628	1,082	(7.4)	428	(2.9)	5,931	89	(1.5)

Table 15.--Number of steelhead handled and mortalities during PIT tagging at Lower Granite Dam in 1993. Percentages are shown in parentheses.

	Hatchery steelhead		Wild steelhead	
Date	Handled	Mortalities	Handled	Mortalities
27 April	4,129	7 (0.2)	396	1 (0.2)
29 April	15,220	48 (0.3)	659	1 (0.2)
11 May	14,590	20 (0.1)	1,816	4 (0.2)
Total	33,939	75 (0.2)	2,871	6 (0.2)

Project Evaluation--The target numbers of PIT-tagged fish for each release at Lower Granite Dam (1,500 each for the R_{T1} and C_{T1} releases and 750 each for the R_{B1} and C_{B1} releases) were met or exceeded on most release dates (Tables 12 and 13). Releases generally encompassed the time periods of yearling chinook salmon migration as planned (early, middle, and late spring outmigrations) (Fig. 10). Coded-wire-tag data indicated that the majority of smolts PIT tagged at Lower Granite Dam were from Rapid River Hatchery (Fig. 11).

Little Goose Dam

PIT tagging--At Little Goose Dam, hatchery-reared yearling chinook salmon for three sets of releases were PIT tagged on five dates, beginning 5 May (Tables 16, 17, and 18). Of 16,475 hatchery-reared yearling chinook salmon handled, mortality was 0.4%; of 1,605 wild yearling chinook salmon (8.9% of total), mortality was 0.5% (Table 18). Because of the juvenile separator used at this site, only small numbers of steelhead were handled, and mortality for all species was low (Table 19). The mortality rate for yearling chinook salmon was lower at Little Goose Dam than at Lower Granite Dam.

Post-tagging mortality ranged from 0 to 35.0%, averaging 6.8% for individual releases at Little Goose Dam (Table 16). This average was skewed due to the high mortality (35.0%) that

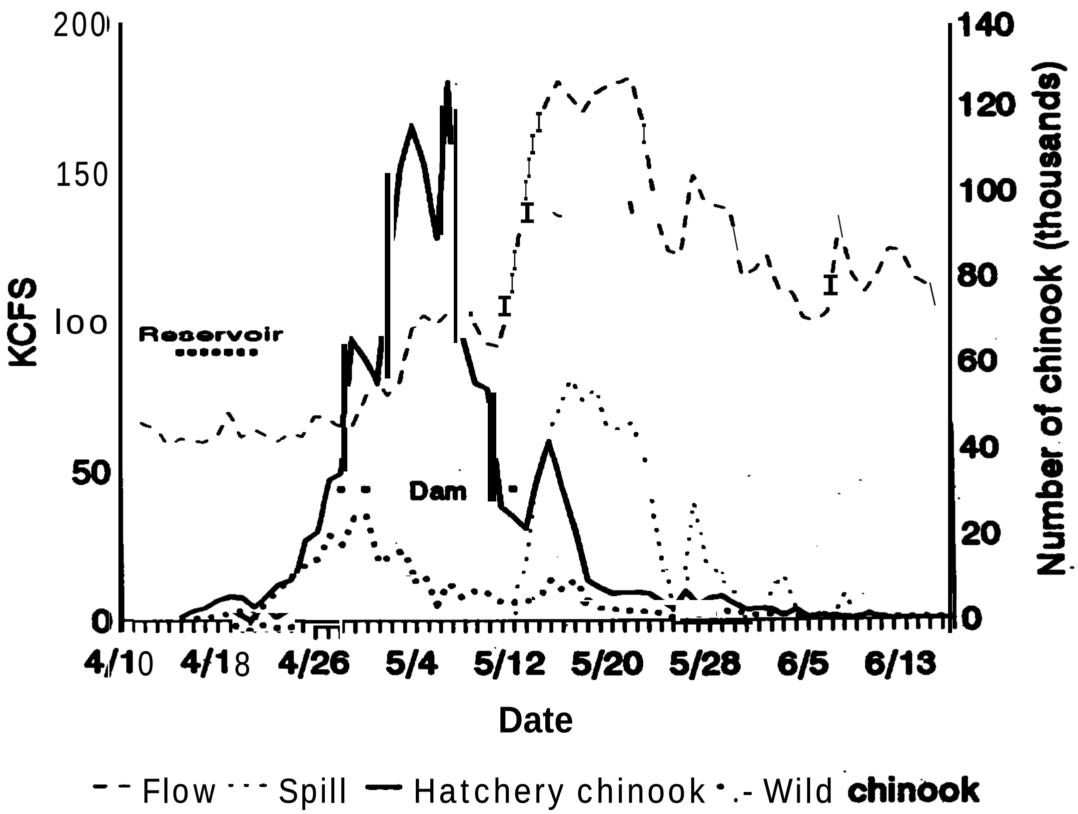

Figure 10.--Hatchery-reared and wild yearling chinook salmon passage at Lower Granite Dam during the 1993 survival study. Squares indicate release dates of PIT-tagged hatchery-reared yearling chinook salmon in Lower Granite Reservoir and at Lower Granite Dam.. Flow and spill. are also shown.

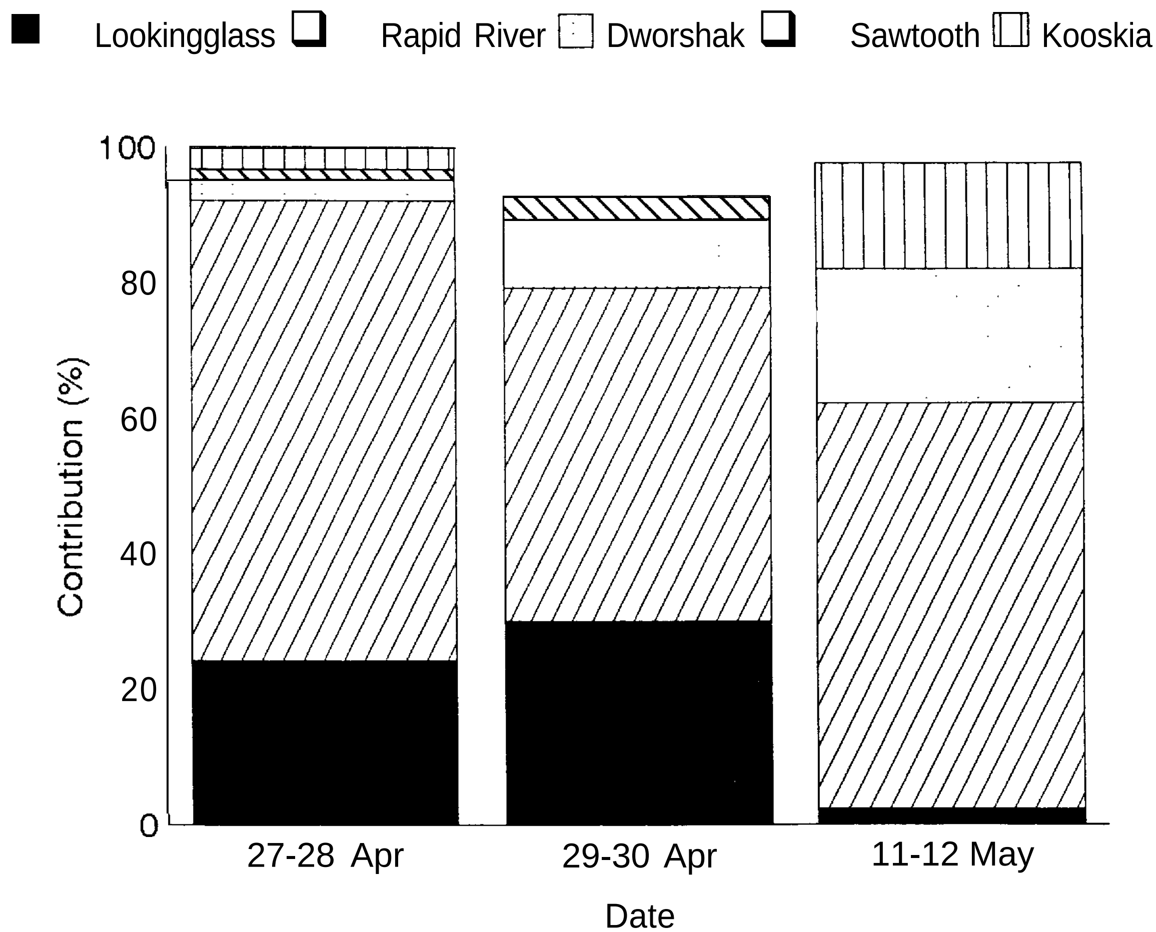

Figure 11.--Origin of hatchery-reared yearling chinook salmon sacrificed for disease/physiological assay at Lower Granite Dam.

Table 16.--Number of hatchery-reared yearling chinook salmon PIT tagged and released at Little Goose Dam to evaluate post-detection bypass survival during 1993. Fish removed from tag files for various reasons, and post-tagging mortalities, are also shown.

Release	R_{B21}	C_{B21}	R_{B22}	C_{B22}	R_{B23}	C_{B23}	Total
Release date	7 May	7 May	8 May	8 May	13 May	13 May	
Total fish in tagging files	755	734	752	753	756	759	4,509
Previously handled	1	0	0	1	2	0	4
Detections recorded before release	0	0	0	2	0	2	4
USFWS sample	31	30	0	14	0	14	89
Handling (number)	264	12	15	6	3	8	308
mortality (%)	35.0	1.6	2.0	0.8	0.4	1.0	6.8
Total fish in analyses	459	692	737	730	751	735	4,104

Table 17.--Number of hatchery-reared yearling chinook salmon PIT tagged and released at Little Goose Dam to evaluate turbine and spillway passage survival during 1993. Fish removed from tag files for various reasons, and post-tagging mortalities, are also shown.

Release	R_{T21}	R_{S21}	C_{T21}	R_{T22}	R_{S22}	C_{T22}	R_{T23}	R_{S23}	C_{T23}	Total
Release date	6 May	6 May	6 May	8 May	8 May	8 May	14 May	14 May	14 May	
Total fish in tagging files	756	813	754	751	780	758	749	751	752	6,864
Previously handled	1	0	2	0	0	0	1	1	1	6
Length not recorded	0	0	0	0	0	0	2	0	0	2
Tank jumpers	0	1	0	1	0	0	0	0	0	2
Detections recorded before release	2	0	0	0	0	2	4	1	1	10
Detections out of order	1	0	0	0	0	0	0	0	0	1
USFWS sample	0	0	15	0	0	0	0	0	15	30
Handling (number)	0	0	1	3	10	3	5	3	23	48
mortality (%)	0.0	0.0	0.1	0.4	1.3	0.4	0.7	0.4	3.1	0.7
Total fish in analysis	752	812	736	747	770	753	737	746	712	6,765

Table 18.--Number of yearling chinook salmon handled and handling mortalities during PIT tagging at Little Goose Dam in 1993. Post-tagging mortalities are not included. Percentages are shown in parentheses.

	Hatchery chinook salmon		Wild chinook salmon	
Date	Handled	Mortalities	Handled	Mortalities
5 May	3,591	38 (1.1)	384	2 (0.5)
6 May	1,881	8 (0.4)	139	2 (1.4)
7 May	4,833	10 (0.2)	449	2 (0.4)
12 May	3,484	0 (0.0)	375	0 (0.0)
13 May	2,686	18 (0.7)	258	2 (0.8)
Total	16,475	74 (0.4)	1,605	8 (0.5)

Table 19.--Number of steelhead handled and mortalities during PIT tagging at Little Goose Dam in 1993. Percentages are shown in parentheses.

	Hatchery steelhead		Wild steelhead	
Date	Handled	Mortalities	Handled	Mortalities
5 May	288	0 (0.0)	123	0 (0.0)
6 May	101	0 (0.0)	85	1 (1.2)
7 May	303	0 (0.0)	288	0 (0.0)
12 May	798	0 (0.0)	488	0 (0.0)
13 May	855	0 (0.0)	344	0 (0.0)
Total	2,345	0 (0.0)	1,328	1 (0.1)

occurred in one release group when over 200 smolts were overdosed with anesthetic in the preanesthetizer.

Project Evaluation--Target numbers of PIT-tagged fish for each release at Little Goose Dam (1,500 each for the R_{T2}, R_{S2}, and C_{T2} releases and 750 each for the R_{B2} and C_{B2} releases) were not met because of concerns about handling too many wild yearling chinook salmon. Therefore, the turbine and spillway release-group sizes were halved at this site (Tables 16 and 17). Releases generally bracketed the yearling chinook salmon migration as planned (early, middle, and late) (Fig. 12). Coded-wire-tag data indicated that the majority of smolts PIT-tagged at Little Goose Dam were from Rapid River Hatchery (Fig. 13).

Tag Retention

PIT-tag retention (24 hours) ranged from 96.7 to 100% for the various release groups during the study, with an average of 99.2% for all groups (Table 20). Because of the high tag-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 18 April and 13 July, 29,501 PIT-tagged salmonids (chinook salmon and steelhead) were detected at Lower Granite Dam. Of these, 19,292 (65.4%) were bypassed back to the Snake River by the slide-gate diverter system (Table 21). The remainder were either missed by the slide gate and

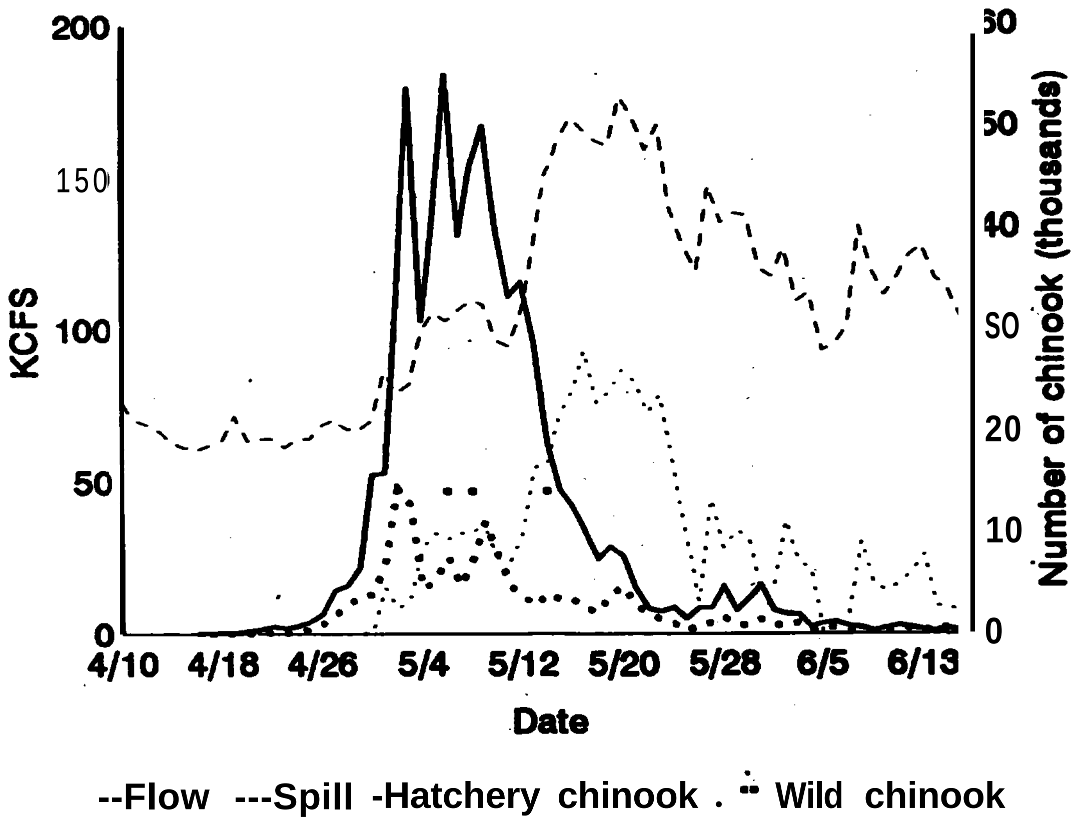

Figure 12.--Hatchery-reared and wild yearling chinook salmon passage at Little Goose Dam during the 1993 survival study. Squares indicate release dates of PIT-tagged hatchery-reared yearling chinook salmon at Little Goose Dam. FLOW and spill are also shown.

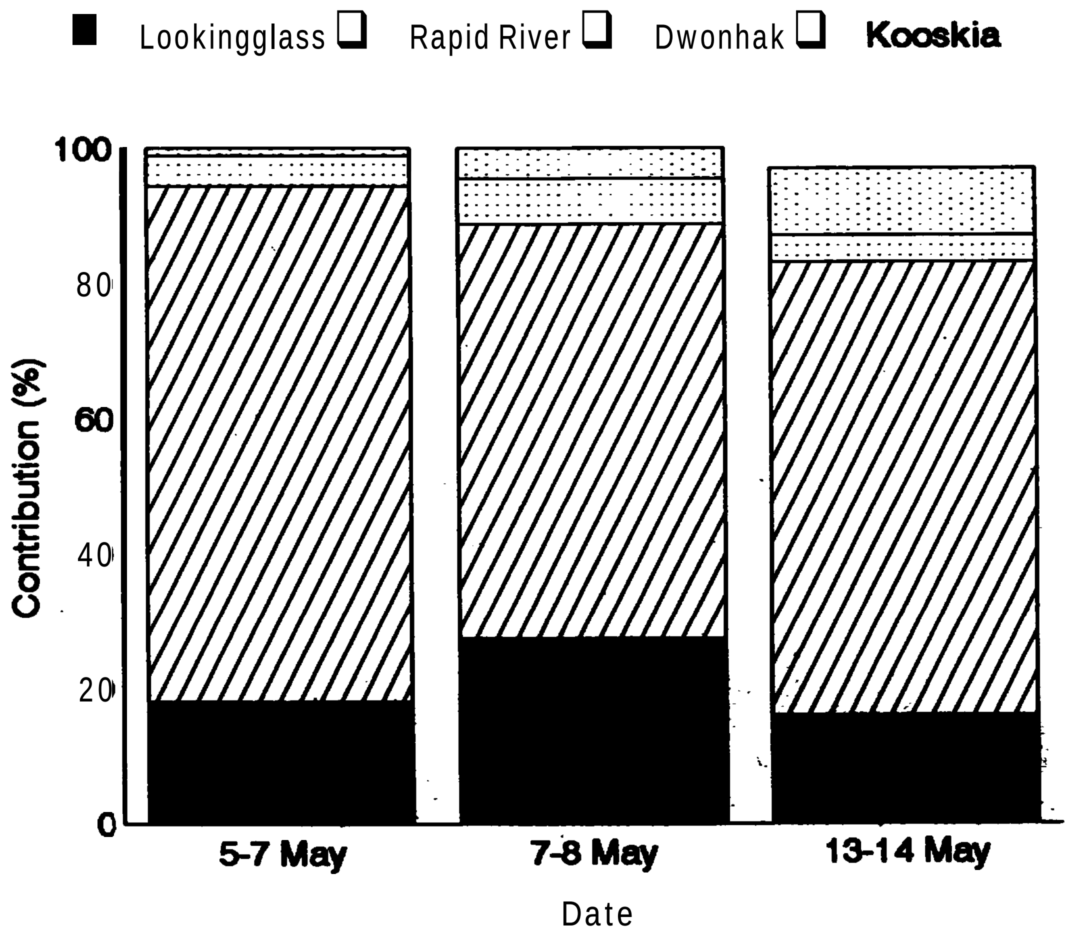

Figure 13.--Origin of hatchery-reared yearling chinook salmon sacrificed. for disease/physiological assay at Little Goose Dam.

Table 20.--Tag retention for hatchery-reared yearling chinook salmon PIT tagged in Lower Granite Reservoir (Res), at Lower Granite Dam (LGR), and at Little Goose Dam (LGO), during April and May 1993. Fish were scanned for tags after being held 20-29 hours.

Location	Tag date	Number held	Number untagged	Retention (%)
Res	14 Apr	59	0	100.0
Res	15 Apr	59	0	100.0
Res	16 Apr	60	1	96.7
Res	17 Apr	60	1	96.7
Res	18 Apr	60	0	100.0
Res	19 Apr	60	0	100.0
Res	20 Apr	64	2	96.9
		422	4	99.1
LGR	27 Apr	150	0	100.0
LGR	29 Apr	159	0	100.0
LGR	11 May	80	2	97.5
		389	2	99.5
LGO	6 May	290	1	99.7
LGO	12 May	91	2	97.8
		382	3	99.2
Overall		1,193	9	99.2

Table 21.--Number of PIT-tagged juvenile salmonids detected and diverted at Lower Granite (LGR), Little Goose (LGO), and Lower Monumental (LMO) Dams during the 1993 migration. Diverted fish were returned to the Snake River. Fish in the raceways and Smolt Monitoring Program sample were transported out of the study area. Other fish (unknown) were detected at the dams, but no information was available on disposition.

Dam	Total number detected	Diverted		Raceways		Sample		Unknown	
		Number	(%)	Number	(%)	Number	(%)	Number	(%)
LGR	29,501	19,292	(65.4)	9,095	(30.8)	770	(2.6)	344	(1.2)
LGO	20,818	16,244	(78.0)	2,900	(13.9)	736	(3.5)	938	(4.5)
LMO	27,699	0	(0.0)	27,699	(100.0)	0	(0.0)	0	(0.0)

transported (30.8%), removed prior to the slide gate as part of the Smolt Monitoring Program sample (2.6%), or were not detected again and their fate unknown (1.2%).

At Little Goose Dam, 20,819 PIT-tagged salmonids were detected, with 16,244 (78.0%) bypassed back to the Snake River by the slide-gate diverter system (Table 21). The remainder were either missed by the slide gate and transported (13.9%), removed prior to passing the slide gate as part of the Smolt Monitoring Program sample (3.5%), or were not detected again and their fate unknown (4.6%).

At Lower Monumental Dam, the slide-gate diverter system was not operated during 1993. Most PIT-tagged smolts collected at this site were transported out of the study area (Table 21).

Turbine load and spill--At Lower Granite Dam, all conditions except turbine discharge remained constant during the releases of PIT-tagged hatchery-reared yearling chinook salmon smolts (Table 22). Turbine operation in Unit 6 was set at 135 MW (within 1% of the peak efficiency curve) during all releases. Total turbine discharge increased substantially during the releases, although spill did not occur until after all releases had been made (Fig. 10).

At Little Goose Dam, all conditions except turbine discharge and spill remained constant during the releases (Table 23).

Table 22.--Conditions at Lower Granite Dam during release of PIT-tagged hatchery-reared yearling chinook salmon into turbine and reference release areas at 2000 hours on three dates during 1993.

Date	28 Apr	30 Apr	11 May
Turbine discharge (KCFS)	64.2	78.9	95.0
Spill (KCFS)	0.0	0.0	0.0
Unit 6 turbine load (MW)	135	135	135
Forebay elevation (ft)	733.2	733.7	733.7
Tailrace elevation (ft)	633.8	634.9	635.0

Table 23.--Conditions at Little Goose Dam during release of PIT-tagged hatchery-reared yearling chinook salmon into turbine, spill, and reference release areas at 2000 h on three dates during 1993.

Date	6 May	8 May	14 May
Turbine discharge (KCFS)	68.6	70.5	90.4
Spill (KCFS)	25.8	25.9	67.9
Unit 6 turbine load (MW)	135	135	135
Forebay elevation (ft)	636.7	637.4	637.4
Tailrace elevation (ft)	539.1	539.1	539.3

Total turbine discharge increased, while spill occurred in increasing amounts with the exception of the 8 May releases (Fig. 12).

At Lower Monumental Dam (Fig. 14) and McNary Dam (Fig. 15), spill began during the first week of May and continued during the majority of the outmigration.

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:

1) Twenty-eight wild chinook salmon and four hatchery steelhead were present in the PTAGIS tagging files. These records were eliminated, leaving only hatchery-reared yearling chinook salmon for the analyses.

2) Some fish were collected on more than one occasion and were included in more than one tagging file. Because fish were held for a period of time in net-pens for the reservoir releases and in tanks for releases at the dams, travel time and passage information for fish collected more than once was not reliable. Moreover, though handling mortality was low, a fish handled multiple times was suspected to have altered survival probabilities. Therefore, fish that had previously been PIT tagged (total of 148) or that were later recaptured (total of 97) were eliminated. Multiple handling was most prevalent during

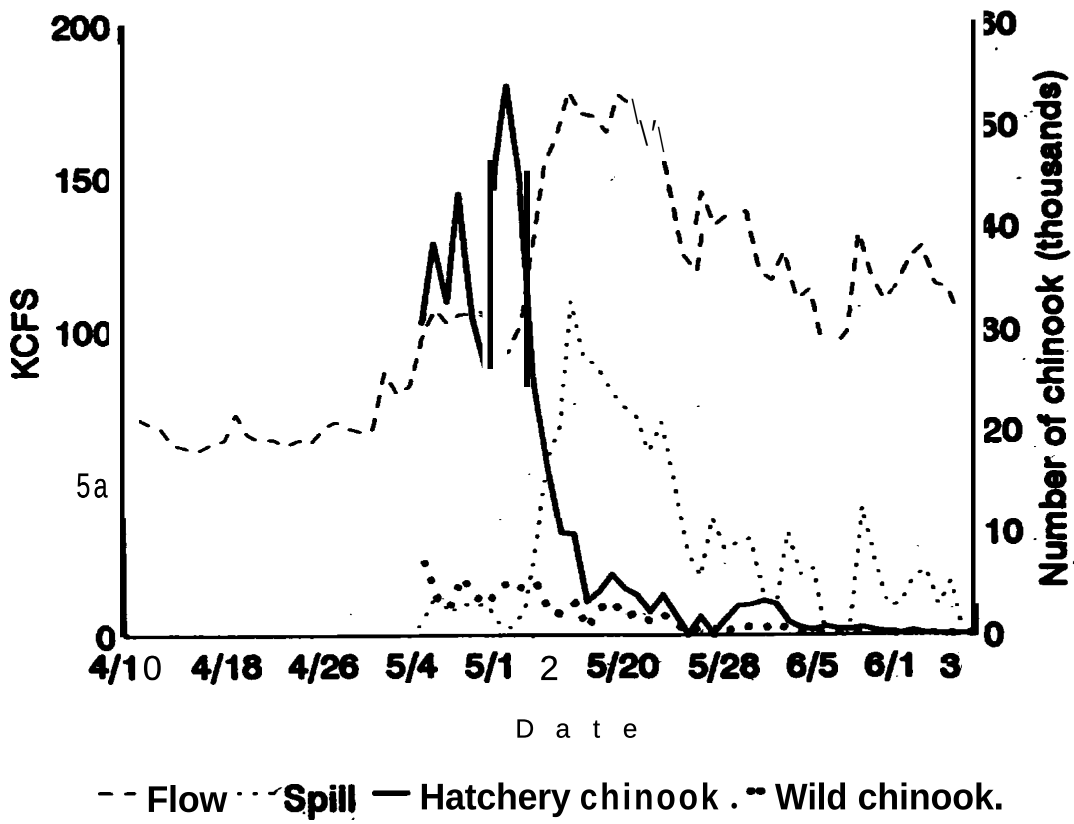

Figure 14.--Hatchery-reared and wild yearling chinook salmon passage at Lower Monumental Dam during the 1993 survival study. Fish counts did not begin until the first week of May. Flow and spill are also shown.

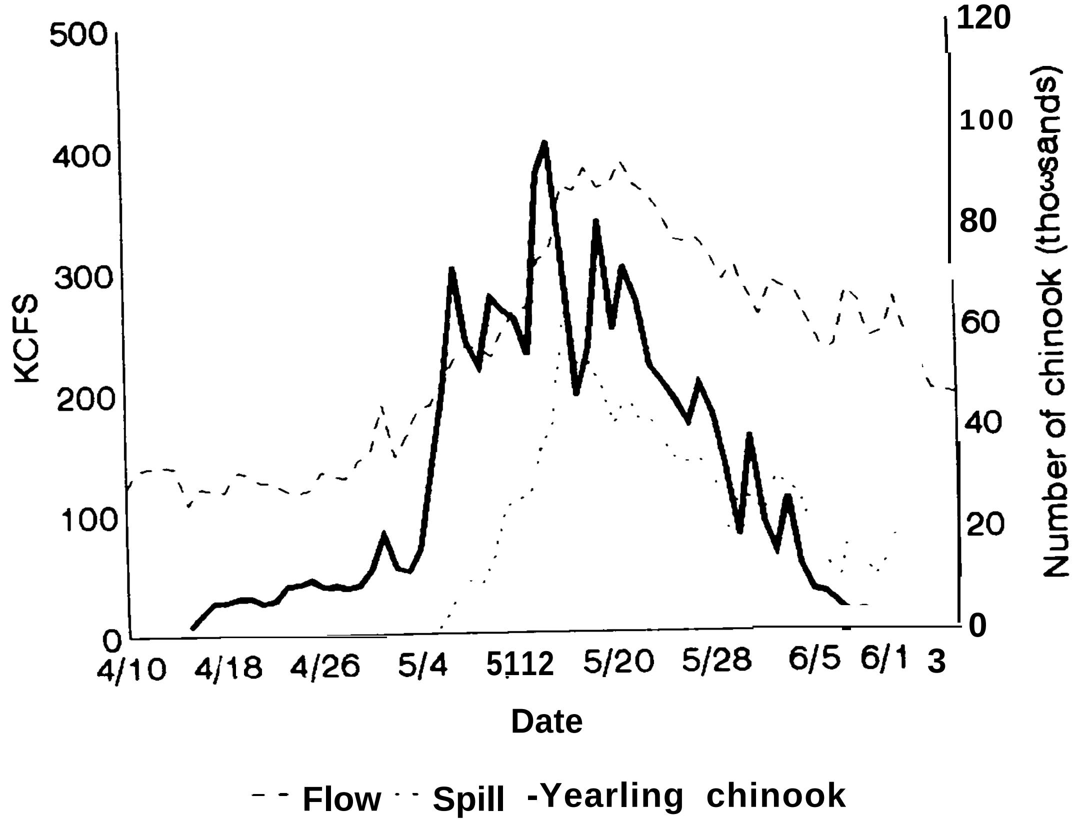

Figure 15.--Hatchery-reared yearling chinook salmon passage at McNary Dam during the 1993 survival study. Flow and spill are also shown.

purse-seining in the Lower Granite Reservoir, as **fish** that milled in the reservoir were susceptible to multiple capture.

3) Records for fish with a length of zero were eliminated. In some cases, records in the tagging file that had no length recorded appeared to be erroneous, including a nonsensical PIT-tag code, for example. A total of 11 tagging records had length of zero.

4) Some PIT-tag codes were listed in the tagging files for more than one group released on the same day. These were attributed not to recapture but to fish jumping from one tank to another. Because it was impossible to determine in which release the tank jumpers were ultimately included, these fish were eliminated from both tagging files. A total of nine fish were identified as tank jumpers.

5) A fish was eliminated when its record of observations was illogical or internally inconsistent. Detection dates were recorded for a total of 21 PIT-tagged fish prior to the date of release. Seven additional fish had detections "out of order." That is, a detection was recorded at Little Goose Dam prior to a detection at Lower Granite Dam, or a detection was recorded at Lower Monumental Dam prior to a detection at Little Goose Dam. The cause of such inconsistencies is uncertain.

6) The USFWS sacrificed a number of fish from selected groups just prior to release for disease and physiology assessment. Many of the PIT-tag codes for the sacrificed fish

remained in the PTAGIS tagging files and had to be eliminated before analysis.

7) Finally, tagged fish that died before release (handling mortalities) were eliminated. Of 32,074 fish tagged, 1,052 (3.3%) were omitted from analysis because of handling mortality.

Tests of Assumptions

The data provided no evidence that the assumptions of the Single-Release and Paired-Release Models could not be met using the field methods detailed in the previous section. Nothing in the analyses suggested that these models were not valid tools for estimation of survival rates for river sections and dams on the Snake and Columbia Rivers.

Assumption Al: Upstream detection does not affect the probability of downstream detection--For each of the seven Lower Granite Reservoir release groups, Figure 16 shows the passage distributions at Little Goose Dam for the two subgroups that passed via either the turbines (non-detected) or through the bypass facility (detected). The passage distributions of the two groups varied among releases (Table 24). (The contingency tables for these analyses and all other such analyses in this section are in Appendix Tables l-8.)

Figure 17 shows the passage distributions at Lower Monumental **Dam** for four subgroups of reservoir releases, defined by the records of detection at Lower Granite and Little Goose Dams. The results of these contingency table analyses **are given** in Table 25.

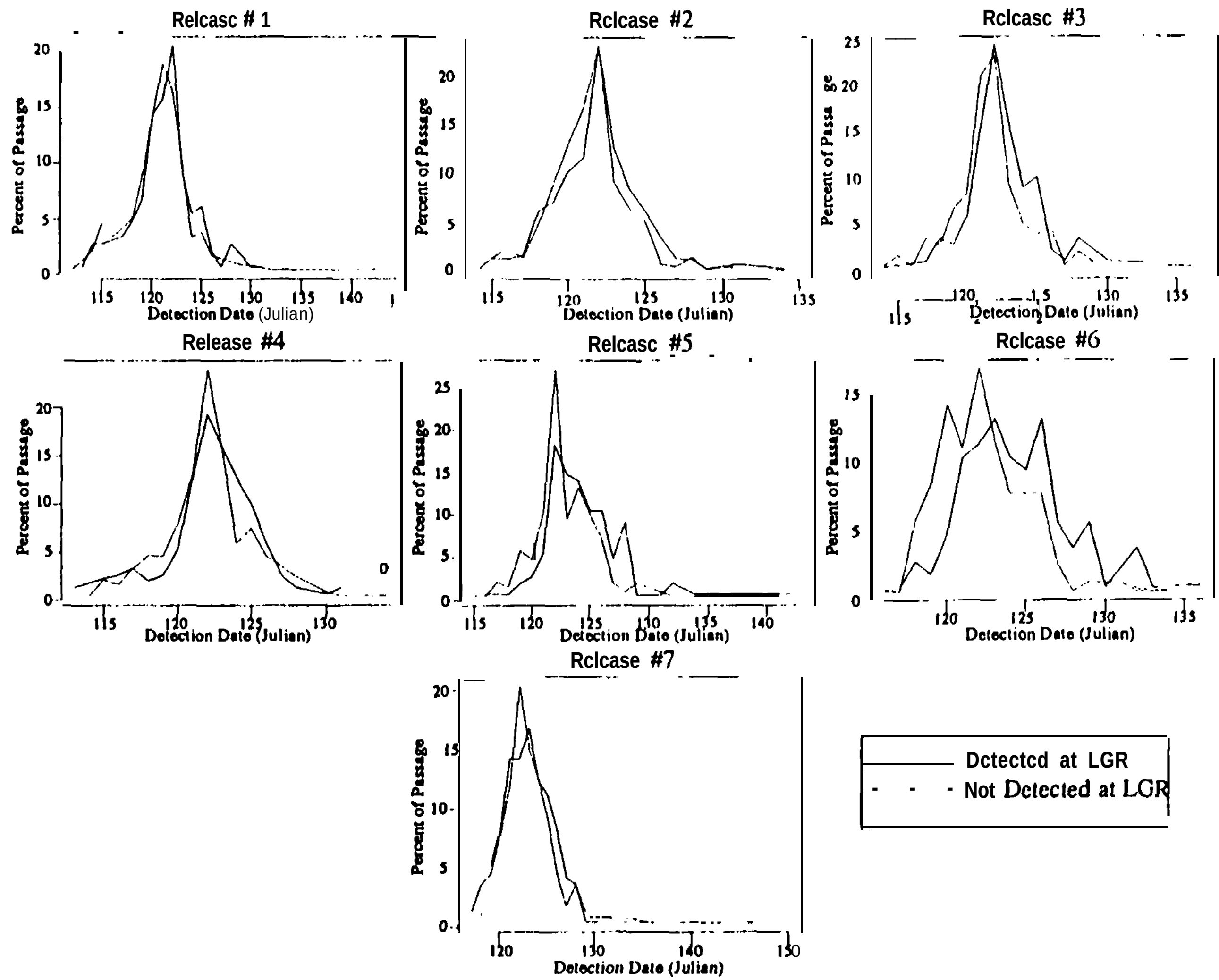

Figure 16.--Passage distributions at Little Goose Dam for primary release fish detected and not detected at Lower Granite Dam.

Table 24.--Tests of homogeneity of Little Goose Dam passage distributions for subgroups of primary releases defined by capture history at Lower Granite Dam.

Release	χ^2	Degrees of freedom	P value*
R_{P1}	11.31	15	0.730
R_{P2}	13.50	15	0.564
R_{P3}	24.75	14	0.037
R_{P4}	12.68	14	0.552
R_{P5}	31.74	15	0.007
R_{P6}	28.74	15	0.017
R_{P7}	13.39	13	0.418

* To control experiment-wise Type I error rate (e.g., α_{EX} = 0.051, test-wise P values are compared to adjusted significance levels (e.g., α_T = 0.0073) for seven tests (see Table 8).

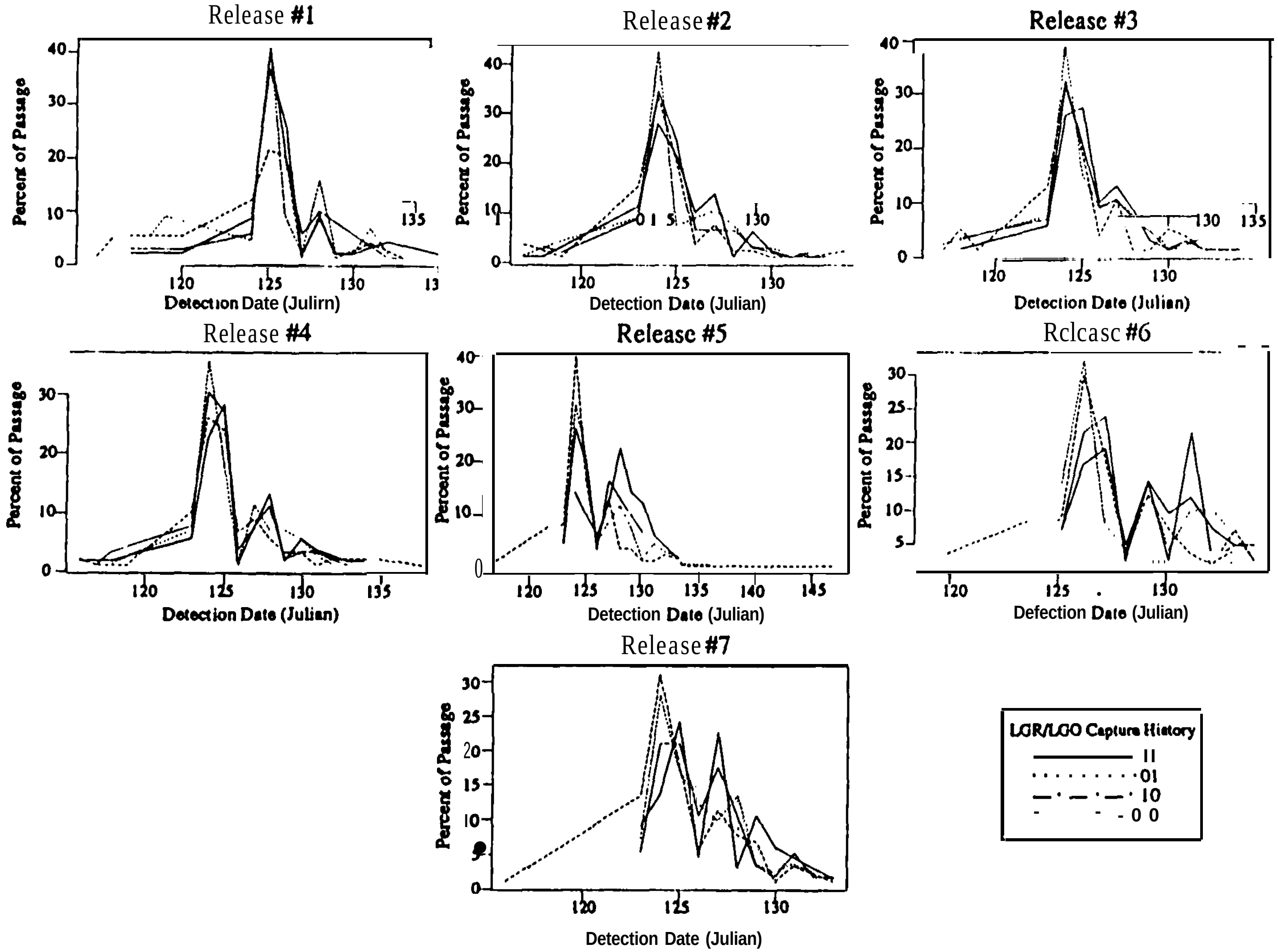

Figure 17.--Passage distributions at Lower Monumental Dam for four subgroups of primary release fish defined by capture history at Lower Granite and Little Goose Dams.

Table 25.--Tests of homogeneity of Lower Monumental Dam passage distributions for subgroups of primary releases defined by capture history at Lower Granite and Little Goose Dams.

Release	χ^2	Degrees of freedom	P value*
R_{P1}	26.57	24	0.325
R_{P2}	25.19	24	0.395
R_{P3}	26.47	30	0.651
R_{P4}	24.49	30	0.749
R_{P5}	38.18	18	0.004
R_{P6}	25.48	24	0.380
R_{P7}	33.08	24	0.102

* To control experiment-wise Type I error rate (e.g., $\alpha_{EX} = 0.05$), test-wise P values are compared to adjusted significance levels (e.g., $\alpha_T = 0.0073$) for seven tests (see Table 8).

We established a test-wise significance level of $\alpha_T = 0.0073$ as required for experiment-wise Type I error rate $\alpha_{EX} = 0.05$ (Table 7). The null hypothesis of homogeneity between detection distributions of primary release groups was rejected for the fifth release group at both Little Goose and Lower Monumental Dams. In addition, detection distributions at Little Goose Dam for the third release group were significantly different at the $\alpha_{EX} = 0.10$ level, but this difference disappeared by the time fish reached Lower Monumental Dam (P = 0.65).

Data shown in Figure 16 suggest that the reason for differences in Little Goose Dam passage is that fish detected at Lower Granite Dam were delayed by a day or two (the distribution for detected fish is shifted slightly to the right). However, river conditions over the peak days of passage for both groups were sufficiently stable so that a difference of 1 day in passage time was not likely to cause a significant change in detection probabilities at Little Goose Dam. Survival and capture probabilities of fish with different routes of passage at Lower Granite Dam did not vary (Table 26). For all seven primary releases, the distribution of capture histories at Lower Monumental and McNary Dams did not depend on the capture history at Lower Granite and Little Goose Dams (significance level $\alpha_{EX} = 0.10$).

Assumption A2: Upstream detection does not affect the probability of downstream survival--Most treatment groups had

Table 26.--Tests of homogeneity of downstream capture histories for two subgroups of primary release groups detected at Little Goose Dam, defined by capture history at Lower Granite Dam (TEST3 of Burnham et al. 1987).

Release	χ^2	Degrees of freedom	P value*
R_{P1}	2.049	3	0.562
R_{P2}	4.038	3	0.257
R_{P3}	3.617	3	0.306
R_{P4}	2.164	3	0.539
R_{P5}	4.328	3	0.228
R_{P6}	6.534	3	0.088
R_{P7}	5.517	3	0.089

* To control experiment-wise Type I error rate (e.g., $\alpha_{EX} = 0.05$), test-wise P values are compared to adjusted significance levels (e.g., $\alpha_T = 0.0073$) for seven tests (see Table 8).

higher survival estimates than their corresponding reference groups (Table 27). This led to point estimates of post-detection bypass survival that were greater than one. The pooled estimates were a weighted average of the three independent estimates, with weights inversely proportional to the respective estimated variances. None of the confidence intervals excluded 100% survival, which indicated that the assumption of no post-detection bypass mortality was satisfied. Consequently, we concluded that the Single-Release Model could be used to analyze the primary releases.

Assumption A3: The Single-Release Model accurately estimates the measurement error associated with point estimates-- For survival estimates at Lower Granite and Little Goose Dams, the average estimated variance was similar to the empirical variance (Tables 28 and 29, respectively). There was no evidence that the model failed to adequately measure any significant source of variability.

Assumption A4: In a paired-release, treatment and reference groups mix evenly downstream from the source of mortality being investigated-- Figures 18 and 19 show the passage distributions at downstream dams for Lower Granite Dam bypass and turbine paired-release groups, respectively. None of the paired-bypass releases from Lower Granite Dam had significantly different (significance level α_{EX} = 0.05) passage distributions at any of the downstream dams (Table 30). The first set of paired turbine releases from Lower Granite Dam had significantly different passage

Table 27.--Post-detection bypass survival estimates for Lower Granite and Little Goose Dams (standard errors in parentheses).

a) Lower Granite Dam

Releases	Treatment group survival	Reference group survival	Post-detection bypass survival ($\hat{S}_{B1}$)
(R_{B11}, C_{B11})	0.733 (0.030)	0.790 (0.029)	0.928 (0.051)
(R_{B12}, C_{B12})	0.857 (0.046)	0.787 (0.029)	1.140 (0.072)
(R_{B13}, C_{B13})	1.092 (0.178)	1.029 (0.158)	1.051 (0.238)
Pooled*			1.001 (0.041)

b) Little Goose Dam

Releases	Treatment group detection rate (%)	Reference group detection rate (%)	Post-detection bypass survival (S_{B1})
(R_{B21}, C_{B21})	59.3	59.7	0.997 (0.049)
(R_{B22}, C_{B22})	61.3	57.9	1.058 (0.045)
(R_{B23}, C_{B23})	15.5	13.3	1.168 (0.148)
Pooled*			1.022 (0.035)

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

Table 28.--Empirical variance and average estimated variance of the estimated survival probability from release to Lower Granite Dam tailrace based on primary releases.

Release	Point estimate of survival ($\hat{S}_{R1i}$)	Estimated variance
R_{P1}	0.920	0.000576
R_{P2}	0.500	0.000351
R_{P3}	0.911	0.000484
R_{P4}	0.903	0.000529
R_{P5}	0.901	0.000484
R_{P6}	0.855	0.000575
R_{P7}	0.886	0.000400
Empirical variance of $\hat{S}_{R1i}$		0.000119
Average estimated variance		0.000487

Table 29.--Empirical variance and average estimated variance of the estimated survival probability from Lower Granite Dam tailrace to Little Goose Dam tailrace based on primary releases.

Release	Point estimate of survival ($\hat{S}_{R2i}$)	Estimated variance
R_{P1}	0.888	0.00152
R_{P2}	0.889	0.00084
R_{P3}	0.831	0.00096
R_{P4}	0.818	0.00116
R_{P5}	0.831	0.00137
R_{P6}	0.902	0.00194
R_{P7}	0.869	0.00130
Empirical variance of $\hat{S}_{R2i}$		0.000115
Average estimated variance		0.000130

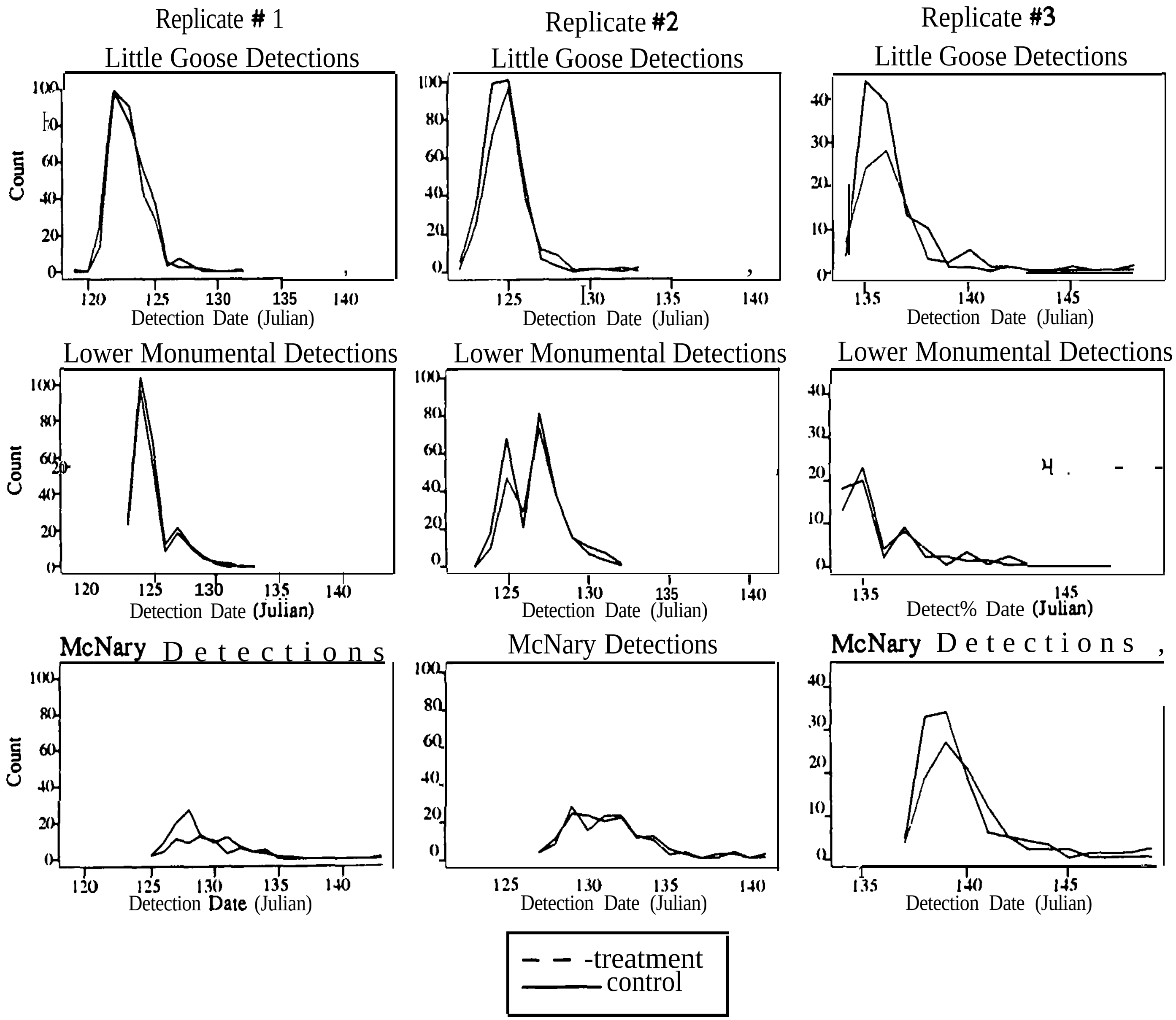

Figure 18. --Passage distributions at downstream dams for Lower Granite Dam paired bypass releases.

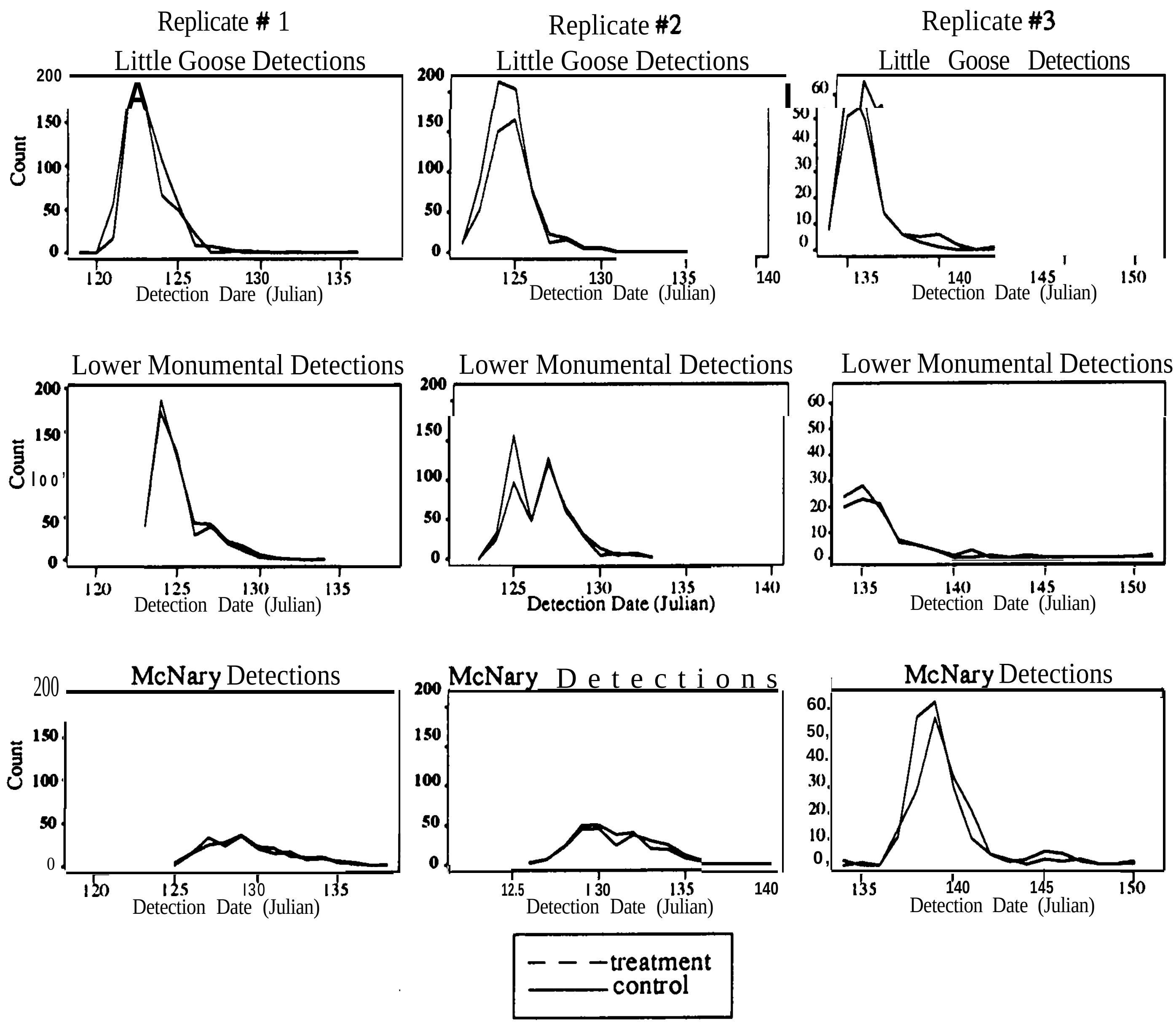

Figure 19.--Passage distributions at downstream dams for Lower Granite Dam paired turbine releases.

Table 30.--Tests of homogeneity of passage distributions at downstream dams for Lower Granite Dam paired bypass releases.

Passage distribution	Releases	χ^2	Degrees of freedom	P value*
Little Goose Dam	(R_{B11}, C_{B11})	10.978	8	0.203
	(R_{B12}, C_{B12})	IO.383	9	0.320
	(R_{B13}, C_{B13})	13.419	7	0.063
Lower Monumental Dam	(R_{B11}, C_{B11})	2.243	8	0.973
	(R_{B12}, C_{B12})	10.700	7	0.152
	(R_{B13}, C_{B13})	2.875	6	0.824
McNary Dam	(R_{B11}, C_{B11})	16.458	9	0.058
	(R_{B12}, C_{B12})	4.200	10	0.938
	(R_{B13}, C_{B13})	8.641	8	0.373

* To control experiment-wise Type I error rate (e.g., $\alpha_{EX} = 0.051$, test-wise P values are compared to adjusted significance levels (e.g., $\alpha_T = 0.017$) for three tests (see Table 8).

distributions at Little Goose Dam, but the difference was not evident at Lower Monumental or McNary Dams (Table 31). The estimated capture probabilities for the treatment and reference releases of the first pair were 0.494 (standard error 0.020) and 0.505 (0.020), respectively, and this difference was not significant (χ^2 = 0.157, 1 degree of freedom (df), P = 0.692). The differences in the passage distributions did not result in differences in detection probabilities. The second and third paired releases from Lower Granite Dam had no significantly different passage distributions at any of the downstream dams.

Figures 20 and 21 show the passage distributions at downstream dams for release groups at Little Goose Dam including turbine, bypass, spillway, and reference groups. None of the downstream passage distributions were significantly different (α_{EX} = 0.05) for the Little Goose Dam paired bypass releases (Table 32). The passage distributions at Lower Monumental Dam for the first set of bypass releases were significantly different at the α_{EX} = 0.10 level, but not at the a, = 0.05 level. No disparity was evident at McNary Dam.

Tests of homogeneity of downstream passage for the Little Goose Dam turbine/spillway/reference release sets show several significant differences (Table 33). Data presented in Figure 21 suggest that tests based on contingency tables were sensitive to very small differences among the distributions. There was no independent method to test differences among parameters for the various paired releases.

Table 31.--Tests of homogeneity of passage distributions at downstream dams for Lower Granite Dam paired turbine releases.

Passage distribution	Releases	χ^2	Degrees of freedom	P value'
Little Goose Dam	(R_{T11}, C_{T11})	35.319	8	<0.0001
	(R_{T12}, C_{T12})	16.912	10	0.076
	(R_{T13}, C_{T13})	9.063	6	0.170
Lower Monumental Dam	(R_{T11}, C_{T11})	4.671	8	0.862
	(R_{T12}, C_{T12})	16.858	9	0.051
	(R_{T13}, C_{T13})	2.029	7	0.958
McNary Dam	(R_{T11}, C_{T11})	6.985	11	0.800
	(R_{T12}, C_{T12})	9.000	11	0.622
	(R_{T13}, C_{T13})	17.378	10	0.056

• To control experiment-wise Type I error rate (e.g., $\alpha_{EX} = 0.05$), test-wise P values are compared to adjusted significance levels (e.g., $\alpha_T = 0.017$) for three tests (see Table 8).

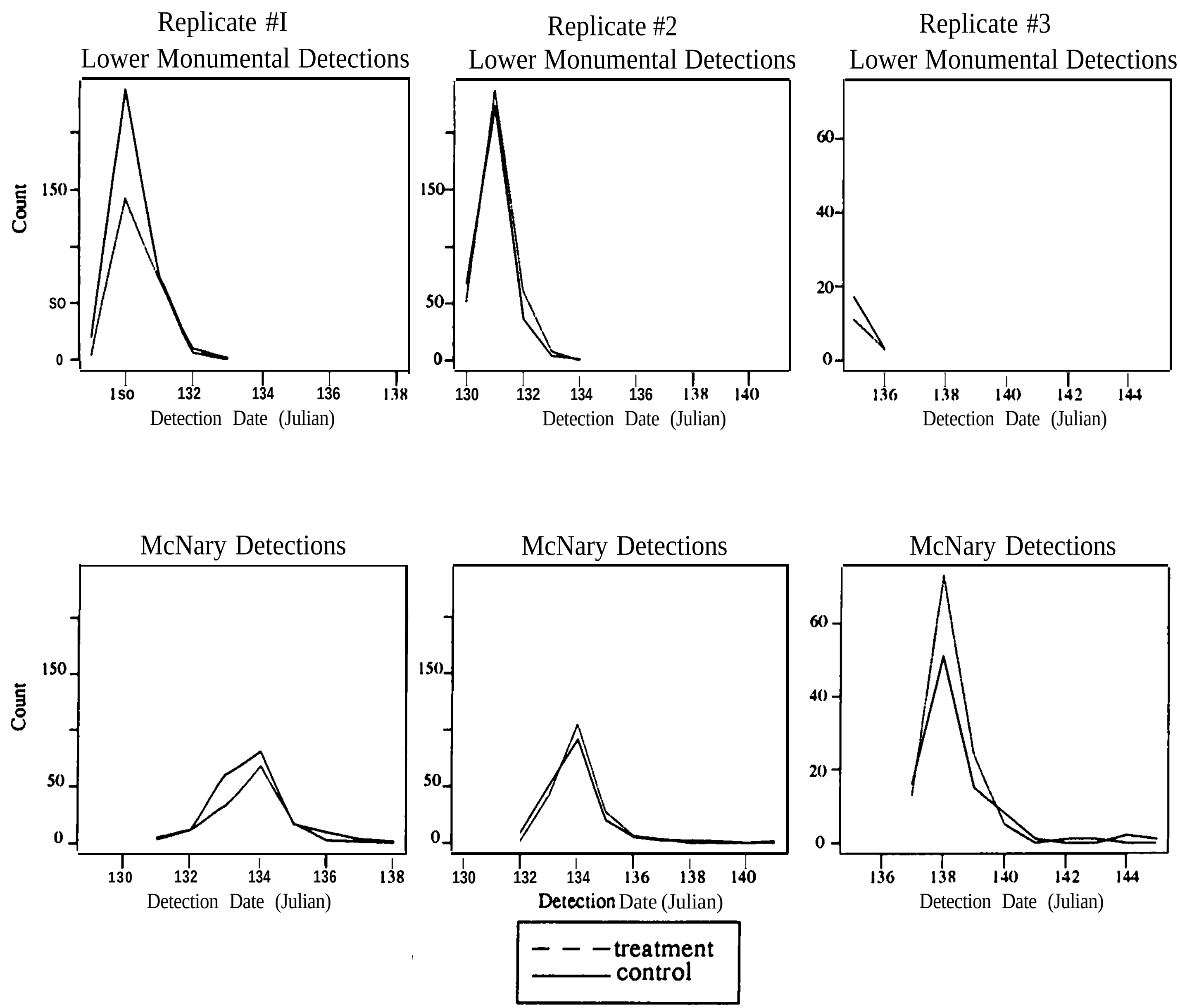

Figure 20.--Passage distributions at downstream dams for Little Goose Dam paired bypass releases.

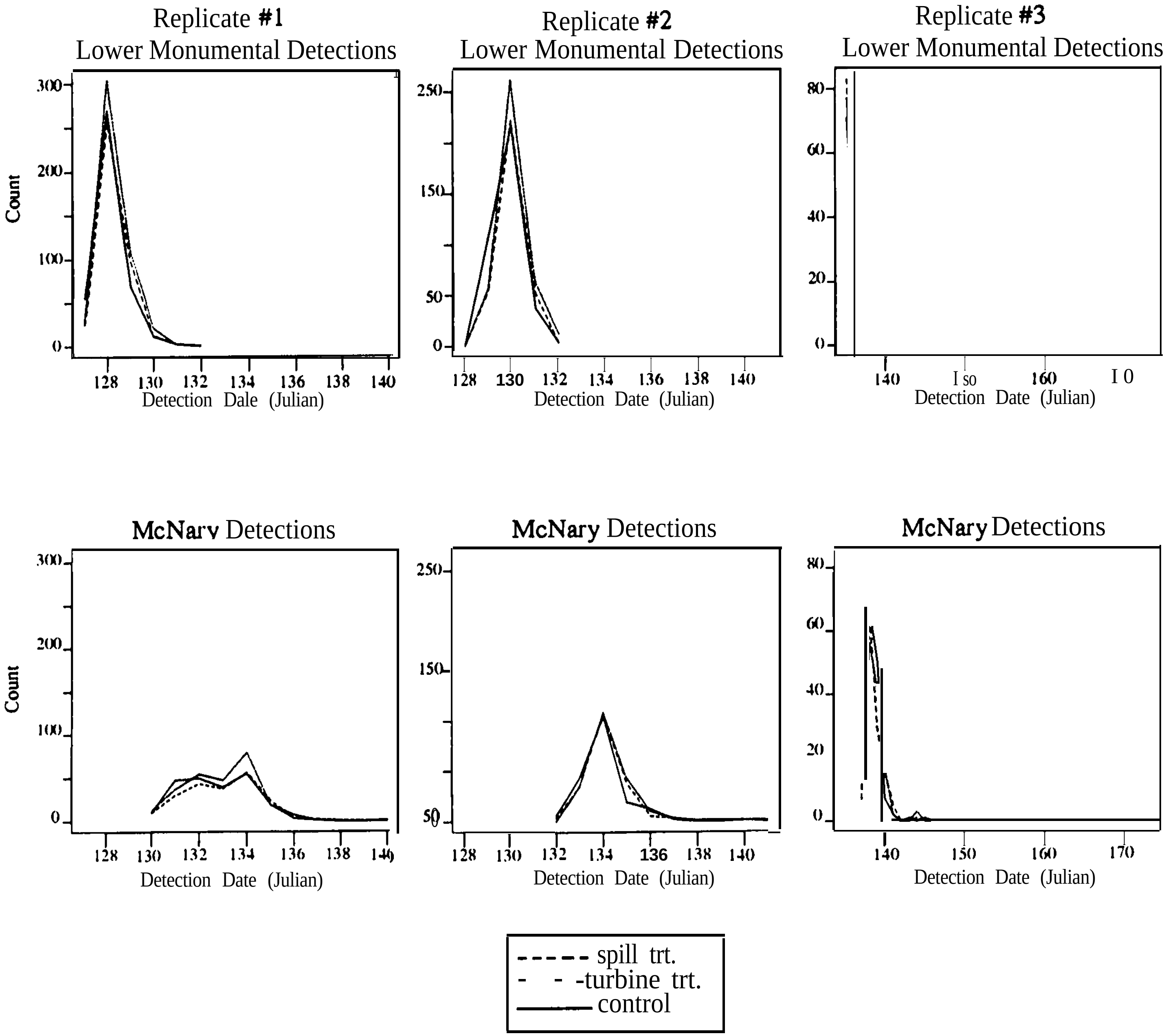

Figure 21.--Passage distributions at downstream dams for Little Goose Dam turbine and spillway release groups.

Table 32.--Tests of homogeneity of passage distributions at downstream dams for Little Goose Dam paired bypass releases.

Passage distribution	Releases	χ^2	Degrees of freedom	P value*
Lower Monumental Dam	(R_{B21}, C_{B21})	11.439	3	0.010
	(R_{B22}, C_{B22})	8.236	3	0.041
	(R_{B23}, C_{B23})	0.234	1	0.628
McNary Dam	(R_{B21}, C_{B21})	8.208	6	0.223
	(R_{B22}, C_{B22})	8.435	5	0.134
	(R_{B23}, C_{B23})	5.542	5	0.353

* To control experiment-wise Type I error rate (e.g., $\alpha_{EX} = 0.05$), test-wise P values are compared to adjusted significance levels (e.g., $\alpha_T = 0.017$) for three tests (see Table 8).

Table 33.--Tests of homogeneity of passage distributions at downstream dams for Little Goose Dam turbine/spillway/reference releases.

Passage distribution	Releases	χ^2	Degrees of freedom	P value*
Lower Monumental Dam	$(R_{T21}, R_{S21}, C_{T21})$	25.358	8	0.0014
	$(R_{T22}, R_{S22}, C_{T22})$	38.383	6	<0.0001
	$(R_{T23}, R_{S23}, C_{T23})$	2.166	2	0.339
McNary Dam	$(R_{T21}, R_{S21}, C_{T21})$	11.599	14	0.638
	$(R_{T22}, R_{S22}, C_{T22})$	16.954	10	0.075
	$(R_{T23}, R_{S23}, C_{T23})$	19.575	10	0.032

* To control experiment-wise Type I error rate (e.g., $\alpha_{EX} = 0.05$), test-wise P values are compared to adjusted significance levels (e.g., $\alpha_T = 0.017$) for three tests (see Table 8).

In conclusion, analyses of the data collected during the 1993 study indicated no major statistical problems with applying the Single-Release Model or Paired-Release Model for paired releases to survival studies using PIT-tagged hatchery-reared yearling chinook salmon through river sections and hydroelectric projects on the Snake River.

Survival Estimation

Obtaining preliminary estimates of survival and detection probabilities was a secondary objective of the 1993 study. The study was not designed to characterize survival for a variety of river conditions or throughout the migration season. While the estimates obtained suggest future research directions, the results do not characterize the entire 1993 hatchery chinook salmon migration.

Survival estimates for the primary releases in Lower Granite Reservoir from the Nisqually John boat landing to the tailrace of Lower Granite Dam ranged from 0.886 to 0.920 (Tables 34 and 35). The SR Model was used for analysis, because PR Model analyses of paired bypass and tailrace releases at Lower Granite and Little Goose Dams showed no significant post-detection bypass mortality, obviating the need for the MSR Model.

The survival estimates from release to Lower Granite Dam tailrace were not significantly different among the replicate releases (χ^2 = 1.53, 6 df, P = 0.957), so a model using a common survival probability for all seven releases was used to obtain the pooled estimate of 0.902. The standard error using the pooled model was extremely small (0.008). The 95% confidence

Table 34.--Estimated survival probability from primary release site to Lower Granite Dam tailrace and detection probability at Lower Granite Dam based on primary releases (standard errors in parentheses).

Release	Survival from release to Lower Granite Dam tailrace (S_{Ri})	Detection probability at Lower Granite Dam (P_i)
R_{P1}	0.920 (0.024)	0.458 (0.020)
R_{P2}	0.500 (0.019)	0.488 (0.017)
R_{P3}	0.911 (0.022)	0.475 (0.019)
R_{P4}	0.504 (0.023)	0.474 (0.015)
R_{P5}	0.901 (0.022)	0.532 (0.020)
R_{P6}	0.895 (0.024)	0.507 (0.022)
R_{P7}	0.886 (0.020)	0.531 (0.018)
Pooled	0.902[a] (0.008)	0.495[b] (0.007)

[a] Pooled estimate of survival probability computed using SURPH program to estimate a single survival probability for all populations.

[b] Pooled estimate of detection probability computed as weighted average of the seven independent estimates, with weights inversely proportional to the respective estimated variances.

Table 35.--Estimated survival probability from Lower Granite Dam tailrace to Little Goose Dam tailrace and detection probability at Little Goose Dam based on primary releases (standard errors in parentheses).

Release	Survival from Lower Granite Dam tailrace to Little Goose Dam tailrace (S_{R2})	Detection probability at Little Goose Dam (P_1)
R_{P1}	0.888 (0.039)	0.520 (0.025)
R_{P2}	0.889 (0.029)	0.564 (0.021)
R_{P3}	0.831 (0.031)	0.557 (0.022)
R_{P4}	0.818 (0.034)	0.492 (0.022)
R_{P5}	0.831 (0.037)	0.465 (0.024)
R_{P6}	0.902 (0.044)	0.463 (0.027)
R_{P7}	0.869 (0.036)	0.449 (0.022)
Pooled	0.862" (0.013)	0.505[b] (0.009)

[a] Pooled estimate of survival probability computed using SURPH program to estimate a single survival probability for all populations.

[b] Pooled estimate of detection probability computed as weighted average of the seven independent estimates, with weights inversely proportional to the respective estimated variances.

interval for the survival probability from release to Lower Granite Dam tailrace was 0.886 to 0.918.

Detection probabilities at Lower Granite Dam varied significantly between the seven primary releases (χ^2 = 13.97, 6 df, P = 0.030), but suggested a trend toward increasing probability of detection over time. The pooled estimate (0.495) was a weighted average of the individual estimates. Using weights equal to the inverse of the respective estimated variances provides a weighted average with minimum standard error (Hunter et al. 1982).

Estimated survival probabilities from Lower Granite Dam tailrace to Little Goose Dam tailrace ranged from 0.818 to 0.902 but were not significantly different as measured by SURPH (χ^2 = 5.50, 6 df, P = 0.482). The pooled estimate was 0.862, with a standard error of 0.013. Detection probabilities were significantly different (χ^2 = 25.82, 6 df, P < 0.001) and appeared to be decreasing over time at Little Goose Dam. The pooled estimate of the detection probability at Little Goose Dam (0.505) was obtained by the weighted average approach.

The weighted average of turbine survival estimates for the paired releases at Lower Granite and Little Goose Dams were 0.823 and 0.920, respectively (Table 36). The weighted average of the spillway survival estimate at Little Goose Dam was 1.021 (Table 37). There was no spill at Lower Granite Dam until most of the primary release groups had already passed. Therefore,

Table 36.--Turbine passage survival estimates for Lower Granite and Little Goose Dams based on paired turbine releases (standard errors in parentheses).

a) Lower Granite Dam

Releases	Treatment group survival	Reference group survival	Turbine passage survival (S_{T1})
(R_{T11}, C_{T11})	0.689 (0.021)	0.844 (0.021)	0.816 (0.034)
(R_{T12}, C_{T12})	0.739 (0.025)	0.864 (0.027)	0.855 (0.039)
(R_{T13}, C_{T13})	0.797 (0.107)	1.308 (0.186)	0.609 (0.119)
Pooled*			0.823 (0.025)

b) Little Goose Dam

Releases	Treatment group detection rate (%)	Reference group detection rate (%)	Turbine passage survival (S_{T2})
(R_{T21}, C_{T21})	61.0	66.0	0.924 (0.036)
(R_{T22}, C_{T22})	57.7	60.4	0.955 (0.041)
(R_{T23}, C_{T23})	30.1	31.5	0.957 (0.075)
Pooled*			0.920 (0.025)

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

Table 37.--Spillway passage survival estimates for Little Goose Dam based on paired spillway releases (standard errors in parentheses).

Releases	Treatment group detection rate (%)	Reference group detection rate (%)	Spillway passage survival (S_{S2})
(R_{S21}, C_{S21})	66.7	66.0	1.011 (0.037)
(R_{S22}, C_{S22})	63.6	60.4	1.053 (0.042)
(R_{S23}, C_{S23})	30.3	31.5	0.963 (0.075)
Pooled*			1.021 (0.026)

* Pooled estimate Is weighted average of the three independent estimates, with weights inversely proportional to the respective estimated variances.

results of the Single-Release Model and Paired-Release Model analyses were combined to derive the Lower Granite Dam reservoir and project components of survival using Equations (4), (5), and (6). We assumed a bypass survival probability of 0.98. The pooled estimates of survival probability from release to Lower Granite Dam tailrace and detection probability at Lower Granite Dam (Table 34) and turbine survival (Table 36), were used to compute estimates of survival components and fish guidance efficiency for Lower Granite Dam (Table 38).

Spill occurred at Little Goose Dam during nearly the entire passage of all upstream releases of survival study fish, so it would have been necessary to use Equations (1) through (3) to derive the Little Goose Dam reservoir and project components of survival. However, without information on the percent of fish passed over the spillway per unit of spill, we did not partition the survival estimate from Lower Granite Dam tailrace to Little Goose Dam tailrace.

Hatchery Releases

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

1) Dworshak National Fish Hatchery: Parameters did not vary significantly for releases made on the same date. Therefore, release groups from the six raceways on each date were pooled, providing three releases of about 1,500 fish each. Survival and detection rates differed among the pooled groups.

Table 38.--Estimates of Lower Granite Zam reservoir and project survival probabilities and fish guidance efficiency at Lower Granite Dam, based on primary releases and paired releases at Lower Granite Dam (standard errors in parentheses).

Parameter	Estimate
Survival Probability, Release to Lower Granite Dam Forebay (S_{P1})	1.011 (0.531)
Lower Granite Dam Project Survival Probability (S_{D1})	0.892 (0.026)
Lower Granite Dam Fisk Guidance Efficiency (FGE_1)	0.442 (3.925)

2) Kooskia National Fish Hatchery: No significant differences were found for parameters among the six release groups. They were pooled to provide a single group of 1,171 fish.

3) Lookingglass Hatchery releases: The normal-density and low-density raceway release groups were found to differ in survival and detection probabilities. However, the probabilities between the two replicates within each density were not significantly different. Attempting to characterize a "typical" release from the hatchery, we used the pooled data from the two normal-density raceways for a total of 999 fish.

4) Imnaha River releases: The four releases of Lookingglass Hatchery-reared fish were not found to have significant differences among parameters. The four groups were pooled to provide a single group of 1,991 fish.

5) McCall Hatchery timing study releases: The three releases did not have significant differences in parameters, and so were pooled to provide a single release of 1,501 fish.

6) McCall Hatchery tagging study releases: Fish from the two tagging groups did not have significant differences in parameters. The data were pooled to provide a single release of 2,993 fish.

7) Rapid River Hatchery: Fish from the two tagging groups did not have significant differences in parameters. The data were pooled and treated as a single release of 2,985 fish.

8) Sawtooth Hatchery: Only one release of 799 fish was available.

Results of analyses of the pooled data sets using the Single-Release Model are reported in Table 39. Sample sizes and standard errors for the survival probability **estimates from** release to Lower Granite Dam tailrace were comparable to those for our primary releases. Survival probability estimates to Lower Granite Dam for hatchery-releases were lower than for our primary releases and appeared to be inversely proportional to the distance from the hatcheries to Lower Granite Dam. Detection probabilities at Lower Granite **Dam** were generally lower for the hatchery release groups, especially for those passing the dam later in the season, when water was spilled.

Survival probabilities from Lower Granite Dam tailrace to the tailrace of Little Goose Dam for the hatchery releases are directly comparable to those for the primary releases, because the section of the river is the same. The pooled estimate from the hatchery releases for Lower Granite Dam tailrace to Little **Goose Dam** tailrace was 0.791, compared to the pooled estimate obtained from our primary releases (0.862). Releases with the lowest survival probability between the hatchery and Lower Granite Dam tailrace often had the higher probability of survival between the tailraces of Lower Granite and Little Goose Dams. Detection probabilities at Little Goose Dam were lower for the

Table 39.--Estimates of survival from hatchery release site to Lower Granite Dam tailrace and from Lower Granite Dam tailrace to Little Goose Dam tailrace and detection rates at Lower Granite and Little Goose Dams. Based on selected Spring 1993 hatchery releases of yearling chinook salmon (standard errors in parentheses).

Hatchery	Release date	Release size	Lower Granite Dam		Little Goose Dam	
			Survival probability	Detection probability	Survival probability	Detection probability
Dworshak	4/08	1,467	0.657 (0.027)	0.438 (0.023)	0.746 (0.048)	0.497 (0.028)
Dworshak	4/22	1,460	0.739 (0.031)	0.476 (0.024)	0.790 (0.065)	0.330 (0.028)
Dworshak	5/06	1,445	0.835 (0.061)	0.334 (0.028)	0.616 (0.074)	0.283 (0.029)
Kooskia	4/19	1,171	0.668 (0.043)	0.436 (0.032)	0.708 (0.086)	0.299 (0.034)
Lookingglass	4/07	999	0.672 (0.023)	0.492 (0.023)	0.870 (0.041)	0.574 (0.028)
Lookingglass (Imnaha River releases)	4/12	1,991	0.669 (0.025)	0.432 (0.020)	0.759 (0.047)	0.405 (0.024)
McCall	4/03	2,993	0.503 (0.017)	0.457 (0.018)	0.804 (0.044)	0.399 (0.022)
McCall	4/09-5/05	1,501	0.563 (0.028)	0.403 (0.024)	0.731 (0.052)	0.468 (0.029)
Rapid River	4/17	2,985	0.680 (0.017)	0.494 (0.015)	0.866 (0.041)	0.355 (0.019)
Sawtooth	4/20	799	0.264 (0.021)	0.440 (0.042)	1.153 (0.147)	0.248 (0.028)

hatchery releases than for our primary releases, because most of the fish from primary releases passed Little Goose Dam before spill began, while the hatchery-released fish passed later in the season.

SUMMARY/CONCLUSIONS

The 1993 NMFS/UW survival study was able to meet the primary goals which were to:

1) field test and evaluate the SR, MSR, and PR Models for the estimation of survival probabilities through sections of a river and hydroelectric projects;

2) identify operational and logistical constraints that would limit the ability to collect data for the models; and

3) determine the usefulness of the models in providing estimates of survival probabilities.

Results of the 1993 NMFS/UW survival study satisfied the assumptions of the Single-Release and Paired-Release Models for survival estimation in the Snake River. We demonstrated the feasibility of collecting, PIT tagging, and releasing large numbers of hatchery-reared yearling chinook salmon into Lower Granite Reservoir, at Lower Granite Dam, and at Little Goose Dam. Collection by purse seine in the reservoir and by juvenile collection facilities at Lower Granite and Little Goose Dams were successfully executed as were the releases for the turbine, bypass, spill, and tailrace survival evaluations. Bypass systems at Lower Granite and Little Goose Dams successfully detected and diverted PIT-tagged fish back to the river, and detector systems at Lower Monumental Dam and McNary Dam were operational.

We were unable to document any major statistical problems. Evaluation of model assumptions indicated that all were 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; detected fish at Lower Granite and Little Goose Dams did not suffer significant post-detection bypass mortality; and the Single-Release Model provided accurate estimates of sampling variability associated with point estimates.

Survival estimates were obtained during validation of these model assumptions. These estimates do not reflect temporal or seasonal variability and were based on a limited segment of the hatchery-reared yearling chinook salmon migration. However, where valid comparisons could be made (e.g., survival from Lower Granite Dam tailrace to Little Goose Dam tailrace), results from our releases were similar to results from hatchery releases made over the entire outmigration.

As part of the logistical evaluation, two areas were identified for improvement in future survival studies at Lower Granite and Little Goose Dams:

1) Handling and tagging mortalities of chinook salmon in 1993 at Lower Granite Dam were higher than at other sites. Higher mortalities were attributed to lack of a juvenile separator which resulted in stress and injury from the commingling of chinook salmon with steelhead in raceways when the fish were crowded together for tagging. Until a permanent juvenile fish separator is installed for the Lower Granite Dam collection facility, a temporary separator should be used in the flume diverting fish to raceways. It would separate larger

steelhead from smaller chinook salmon prior to tagging and should minimize mortalities when handling fish for marking.

2) The diversion systems at both Lower Granite and Little Goose Dams functioned at less than 80% efficiency. Higher diversion efficiencies will increase the precision of survival estimates obtained with current sample sizes or permit reductions in sample sizes without loss of precision.

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.

RECOMMENDATIONS

Successful validation of field and statistical methodologies in 1993 formed the basis for the following recommendations for 1994 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, and expanded study areas on additional species of salmonids.

2) The significantly different survival estimates for turbine passage at Lower Granite and Little Goose Dams emphasize the need for further evaluation of all sources of passage mortality. Future studies should also attempt to determine direct and indirect effects of passage using available technologies such as the PIT tag and balloon tags.

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

4) If prospects for a Lower Granite Reservoir drawdown continue on the present track, we recommend that the SR and PR methodologies 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, temporary measures to separate juvenile salmonids by size should be investigated to minimize handling during collection and tagging.

8) Survival investigations will be improved by increasing the number of detection facilities in the Columbia River Basin. 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.--Contingency tables used to test homogeneity of Little Goose Dam passage for two subgroups of primary releases. Some contingency table cells were pooled over days to provide sufficient cell totals. Days that were pooled are marked with an "x," with the pooled total at the beginning of a sequence of pooled days.

	RP1		RP2		RP3		RP4		RP5		RP6		RP7	
Julian	let.	LGR	let.	LGR	let.	LGR	iet.	LGR	let.	LGR	let.	LGR	let.	LGR
Day	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
112	1	1	x	x	x	x	x	x	x	x	x	x	x	x
113	x	x	x	x	x	x	2	i	x	x	x	x	x	x
114	4	5	3	5	1	7	x	x	x	x	x	x	x	x
115	4	11	x	x	x	x	4	9	1	2	x	x	x	x
116	x	x	3	8	2	12	x	x	x	x	1	2	x	x
117	5	18	4	5	x	x	5	8	1	4	x	x	10	21
118	7	12	14	16	5	8	3	11	1	3	3	9	x	x
119	10	21	16	29	5	19	4	11	3	11	2	13	x	x
120	21	34	23	42	10	23	8	19	4	9	5	22	16	17
121	23	45	26	54	26	57	19	31	8	20	11	17	28	27
122	30	39	51	73	40	63	29	57	26	51	12	25	28	46
123	14	24	28	30	26	26	24	38	21	18	14	18	33	34
124	8	8	19	21	15	14	19	14	20	25	11	12	24	28
125	9	9	14	17	17	11	15	18	15	19	10	12	22	21
126	3	4	8	3	4	13	9	11	15	14	14	12	16	10
127	5	2	3	2	2	2	5	5	7	4	6	4	8	4
128	x	x	3	5	5	9	x	x	13	2	4	1	7	8
129	x	x	1	3	x	x	x	x	1	4	5	2	1	3
130	1	2	x	x	2	4	1	2	x	x	1	2	1	2
131	1	3	3	3	x	x	2	2	5	1	x	x	1	2
132	x	x	x	x	x	x	x	x	x	x	5	1	x	x
133	x	x	x	x	1	1	x	x	x	x	x	x	x	x
134	x	x	x	x	x	x	x	x	x	x	x	x	x	x
135	x	x	x	x	x	x	x	x	x	x	1	1	1	3
136	x	x	x	x	x	x	x	x	x	x	x	x	x	x
137	x	x	x	x	x	x	x	x	x	x	x	x	x	x
138	x	x	x	x	x	x	x	x	x	x	x	x	x	x
139	x	x	x	x	x	x	x	x	x	x	x	x	x	x
140	x	x	x	x	x	x	x	x	x	x	x	x	x	x
141	x	x	x	x	x	x	x	x	1	1	x	x	x	x

Appendix Table 2.--Contingency tables used to test homogeneity of Lower Monumental Dam passage for four subgroups of primary releases. Some contingency table cells were pooled over days to provide sufficient cell totals. 3ays that were pooied are marked with an "x," with the pooled total at the beginning of a sequence of pooled days.

	R_{P1}				R_{P2}				R_{P3}			
Julian	GR/LGO detection				GR/LGO detection				GR/LGO detection			
Day	00	01	10	11	co	01	10	11	03	01	10	11
116	1	4	2	9	x	x	x	x		[illegible]	[illegible]	[illegible]
117	x	x	x	x	2	3	1	5	x	x	x	x
118	x	x	x	x	x	x	x	x	x	x	x	x
119	2	2	4	8	9	10	9	13	x	x	x	x
120	x	x	x	x	x	x	x	x	x	x	x	x
121	x	x	x	x	x	x	x	x	x	x	x	x
122	x	x	x	x	x	x	x	x	x	x	x	x
123	x	x	x	x	x	x	x	x	4	5	5	11
124	4	4	2	9	22	31	28	26	18	27	26	25
125	17	28	18	16	17	22	5	15	19	18	10	15
126	12	14	4	15	8	5	5	3	7	8	5	3
127	1	4	[illegible]	1	11	5	7	5	9	9	7	8
128	4	[illegible]	7	[illegible]	1	6	5	2	5	5	5	1
129	2	4	2	3	5	3	2	2	2	4	4	1
130	x	x	x	x	4	3	3	5	1	1	1	4
131	3	2	4	5	x	x	x	x	2	2	1	3
132	x	x	x	x	x	x	x	x	1	3	1	2
133	x	x	x	x	x	x	x	x	x	x	x	x
134	x	x	x	x	x	x	x	x	x	x	x	x
135	x	x	x	x	x	x	x	x	x	x	x	x

Appendix Table 2.--Continued.

Julian Day	R_{P4} LGR/LGO detection 00	01	10	11	R_{P5} LGR/LGO detection 00	01	10	11	R_{P6} LGR/LGO detection 00	01	10	11
116	2	4	1	3	x	x	x	x	x	x	x	x
117	x	x	x	x	x	x	x	x	x	x	x	x
118	x	x	x	x	x	x	x	x	x	x	x	x
119	x	x	x	x	x	x	x	x	x	x	x	x
120	x	x	x	x	x	x	x	x	x	x	x	x
121	x	x	x	x	x	x	x	x	x	x	x	x
122	x	x	x	x	x	x	x	x	x	x	x	x
123	3	7	5	10	7	19	24	44	3	3	7	5
124	12	27	25	23	x	x	x	x		9	16	17
125	15	24	13	21	5	12	14	14	8	10	4	10
126	2	1	1	5	3	2	3	4	2	1	2	2
127	4	7	8	8	5	10	5	11	6	5	7	7
128	7	10	5	5	11	8	8	3	4	1	2	4
129	1	2	5	3	7	5	5	3	5	9	5	2
130	3	3	4	3	10	4	8	5	3	1	5	1
131	2	3	2	1	x	x	x	x	4	2	2	7
132	2	[illegible]	1	5	x	x	x	x	x	x	x	x
133	x	x	x	x	x	x	x	x	x	x	x	x
134	x	x	x	x	x	x	x	x	x	x	x	x
135	x	x	x	x	x	x	x	x	x	x	x	x
136	x	x	x	x	x	x	x	x	x	x	x	x
137	x	x	x	x	x	x	x	x	x	x	x	x
138	x	x	x	x	x	x	x	x	x	x	x	x
139	x	x	x	x	x	x	x	x	x	x	x	x
140	x	x	x	x	x	x	x	x	x	x	x	x
141	x	x	x	x	x	x	x	x	x	x	x	x
142	x	x	x	x	x	x	x	x	x	x	x	x
143	x	x	x	x	x	x	x	x	x	x	x	x
144	x	x	x	x	x	x	x	x	x	x	x	x
145	x	x	x	x	x	x	x	x	x	x	x	x
146	x	x	x	x	x	x	x	x	x	x	x	x
147	x	x	x	x	x	x	x	x	X	X	x	x

Appendix Table 2.--Continued.

	R_{P7}			
Julian Cay	LGR/LGO detection			
	00	01	10	11
123	6	3	6	13
124	9	12	23	28
125	15	12	14	15
125	3	6	l0	5
127	15	10	8	**10**
128	2	5	11	7
129	7	2	3	5
1 33	4	12		1
131	4	5	5	4
i32	x	x	x	x
133	x	x	x	x

Appendix Table 3.--Ccntingency tables used to test homogeneity of downstream capture histories for two subgroups of primary release groups detected at Little Goose Dam, defined by capture history at Lower Granite Dam (TEST3 of Burnham, et al. 1987).

Release	Capture history to Little Goose Dam	Capture history at Lower Monumental and McNary Dams			
		00	01	10	11
R_{P1}	11	71	45	56	9
	01	46	22	42	4
R_{P2}	11	95	61	77	5
	01	53	43	69	5
R_{P3}	11	57	45	74	8
	01	33	26	57	8
R_{P4}	11	48	36	73	11
	01	42	25	43	6
R_{P5}	11	52	24	55	5
	01	33	27	40	8
R_{P6}	11	37	30	34	4
	01	28	12	33	7
R_{P7}	11	80	43	50	4
	01	53	33	54	9

Appendix Table 4.--Contingency tables used to test homogeneity of Little Goose Dam passage for paired releases from Lower Granite Dam. Some contingency table cells were pooled over days to provide sufficient cell totals. Days that were pooled are marked with an "x," with the pooled total at the beginning of a sequence of pooled days.

a) First set of releases:

Julian Cay	Bypass releases		Turbine releases	
	R_{B11}	C_{B11}	R_{T11}	C_{T11}
121	27	13	57	16
122	98	99	196	187
123	81	90	167	154
124	56	43	135	65
125	38	29	55	49
126	5	3	8	21
127	2	7	11	3
128	2	3	x	x
129	1	1	x	x
133	x	x	1	1
131	x	x	x	x
132	x	x	1	1
133	x	x	x	x
134	x	x	x	x
135	x	x	x	x
135	x	x	x	x

Appendix Table 4.--Continued.

b) Second set of releases:

Julian Day	Bypass releases		Turbine releases	
	R_{B12}	C_{B12}	R_{T12}	C_{T12}
122	6	2	11	13
123	36	25	89	54
124	99	72	212	150
125	101	57	203	155
126	45	39	73	77
127	7	12	12	23
128	3	9	15	18
129	1	2	5	6
130	x	x	5	7
131	1	1	x	x
132	2	2	1	2
133	x	x	x	x
134	x	x	1	1
135	x	x	x	x

c) Third set of releases:

Julian Day	Bypass releases		Turbine releases	
	R_{B13}	C_{B13}	R_{T13}	C_{T13}
134	4	7	8	9
135	44	24	65	51
135	35	28	49	56
137	13	15	14	14
138	10	3	6	6
139	1	2	3	5
140	1	5	1	9
141	x	x	x	x
142	3	1	x	x
143	x	x	x	x
144	x	x	x	x
145	x	x	x	x
146	x	x	x	x
147	x	x	x	x
148	x	x	x	x

Appendix Table 5.--Contingency tables used to test homogeneity of Lower Monumental Dam passage for paired releases from Lower Granite Dam. Some contingency table cells were pooled over days to provide sufficient cell totals. Days that were pooled are marked with an "x," with the pooled total at the beginning of a sequence of pooled days.

a) First set of releases:

Julian Day	Bypass releases		Turbine releases	
	R_{B11}	C_{B11}	R_{T11}	C_{T11}
123	28	24	43	C0
124	i05	58	186	172
125	70	58	[illegible]	123
125	13	5	43	29
127	22	19	42	35
128	12	11	22	19
125	5	5	15	11
130	2	3	6	3
131	1	3	2	2
132	x	x	2	1
133	x	x	x	x
134	x	x	x	x

b) Second set of releases:

Julian Day	Bypass releases		Turbine releases	
	R_{B12}	C_{B12}	R_{T12}	C_{T12}
124	19	10	33	25
125	68	47	155	97
126	21	29	49	48
127	81	73	128	121
128	38	38	60	65
125	15	15	30	32
130	5	10	5	14
131	3	8	7	5
132	x	x	5	8
133	x	x	3	2

Appendix Table 5.--Continued.

c)Third set of releases:

Julian Day	Bypass releases		Turbine releases	
	R_{B11}	C_{B11}	R_{T11}	C_{T11}
134	18	13	24	20
135	20	23	28	23
135	2	4	19	21
137	9	8	7	6
138	2	4	5	5
139	4	3	3	4
140	x	x	x	x
141	x	x	1	3
142	1	2	x	x
143	x	x	x	x
144	x	x	1	1
145	x	x	x	x
145	x	x	x	x
147	x	x	x	x
148	x	x	x	x
148	x	x	x	x
150	x	x	x	x
151	x	x	x	x

Appendix Table 6.--Contingency tables used to test homogeneity of McNrary Dam passage for paired releases from Lower Granite Dam. Some contingency table cells were pooled over days to provide sufficient cell totals. Days that were pooled are marked with an "x," with the pooled total at the beginning of a sequence of pooled days.

a) First set of releases:

Julian Day	Bypass releases		Turbine releases	
	R_{B13}	C_{B13}	R_{T13}	C_{T13}
125	2	2	4	1
125	5	4	15	14
127	23	11	32	24
128	27	9	23	27
129	12	13	34	35
130	13	9	20	22
131	3	12	14	20
132	5	7	16	11
133	4	4		5
134	6	5	8	10
135	x	x	5	3
135	x	x	4	2
137	x	x	x	x
138	x	x	x	x
135	x	x	x	x

Appendix Table S.--Continued.

b) Second set of releases:

Julian Day	Bypass releases		Turbine releases	
	R_{B12}	C_{B12}	R_{T12}	C_{T12}
127	4	4	5	5
128	11	8	21	20
129	24	28	47	42
130	23	15	48	43
131	20	23	35	22
132	22	23	38	35
133	11	12	18	28
134	12	10	17	23
135	5	2	6	10
135	4	3	2	3
137	x	x	2	4
138	x	x	x	x
135	4	3	2	1
140	x	x	x	x
141	x	x	x	x

c) Third set of releases:

Julian Day	Bypass releases		Turbine releases	
	R_{B11}	C_{B11}	R_{T11}	C_{T11}
134	x	x	1	2
135	x	x	x	x
135	x	x	x	x
137	5	4	11	14
138	33	19	57	29
135	34	27	63	57
140	19	21	30	34
141	5	12	10	21
142	5	5	4	4
143	2	4	2	3
144	2	3	x	x
145	2	5	2	5
146	x	x	1	4
147	x	x	2	2
148	x	x	x	x
145	x	x	x	x
150	x	x	x	x

Appendix Table 7.--Contingency tables used to test homogeneity cf Lower Monumental Dam passage for paired releases from Little Goose Dam. Some contingency table cells were pooled over days to provide sufficient cell totals. Days that were pooled are marked with an "x," with the pooled total at the beginning of a sequence of pooled days.

a) First set of releases:

Julian Day	Bypass releases		Turbine/Spillway releases		
	R_{B21}	C_{B21}	R_{T21}	R_{S21}	C_{T21}
127	x	x	55	31	25
128	x	x	[illegible]	335	255
129	20	4	53	113	97
130	238	142	41	21	12
131	73	70	3	2	3
132	[illegible]	5	x	x	x
133	x	x	x	x	x

b) Second set of releases:

Julian Day	Bypass releases		Turbine/Spillway releases		
	R_{B22}	C_{B22}	R_{T22}	R_{S22}	C_{T22}
125	x	x	107	57	54
130	58	52	218	252	222
131	223	237	38	53	52
132	37	51	3	12	3
133	5	8	x	x	x
134	x	x	x	x	x

c) Third set of releases:

Julian Day	Bypass releases		Turbine/Spillway releases		
	R_{B23}	C_{B23}	R_{T23}	R_{S23}	C_{T23}
135	17	11	71	47	83
136	3	3	27	35	24
137	x	x	x	x	x

Appendix Table 8. --Contingency tables used to test homogeneity of McNary Dam passage for paired releases from Little Goose Dam. Some contingency table cells were pooled over days to provide sufficient cell totals. Days that were pooled are marked with an "x," with the pooled total at the beginning of a sequence of pooled days.

a) First set of releases:

Julian Day	Bypass releases		Turbine/Spillway releases		
	R_{B21}	C_{B21}	R_{T21}	R_{S21}	C_{T21}
130	x	x	9	12	9
131	5	3	47	36	29
132	11	11	49	54	43
133	60	32	39	47	37
134	81	58	55	79	55
135	15	17	18	18	23
136	9	2	3	7	3
137	4	1	1	2	3
138	x	x	x	x	x
139	x	x	x	x	x
140	x	x	x	x	x

b) Second set of releases:

Julian Day	Bypass releases		Turbine/Spillway releases		
	R_{B22}	C_{B22}	R_{T22}	R_{S22}	C_{T22}
132	9	2	50	35	38
133	51	42	x	x	x
134	91	102	104	109	106
135	20	27	19	43	38
136	5	5	12	10	5
137	6	3	2	5	4
138	x	x	x	x	x
139	X	X	x	x	x
140	X	X	1	2	1
141	x	X	x	x	x

Appendix Table 8.-- Continued.

c) Third set of releases:

Julian Day	Bypass releases		Turbine/Spillway releases		
	R_{B23}	C_{B23}	R_{T23}	R_{S23}	C_{T23}
137	16	13	21	14	7
138	51	73	58	55	65
139	15	24	50	42	30
140	8	5	7	17	16
141	1	1	3	2	5
142	x	x	x	x	x
143	3	1	x	x	x
144	x	x	1	4	1
145	x	x	x	x	x