FALL CHINOOK SALMON SURVIVAL AND SUPPLEMENTATION STUDIES IN THE SNAKE RIVER AND LOWER SNAKE RIVER RESERVOIRS, 1997

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EXECUTIVE SUMMARY

In 1997, the National Marine Fisheries Service, the U.S. Fish and Wildlife Service, and the Nez Perce Tribe completed the third year of research to investigate migrational characteristics of subyearling fall chinook salmon in the Snake River Basin. Lyons Ferry Hatchery subyearling fall chinook salmon were PIT tagged and released weekly from early June to early July at Pittsburg Landing and Billy Creek on the Snake River and at Big Canyon Creek on the Clearwater River to collect data on survival, detection probabilities, and travel time. In spring and early summer 1997, we also captured natural subyearling fall chinook salmon by beach seine, PIT tagged them, and released them in the Snake River above and below the Salmon River.

For hatchery fish, survival probability estimates from release in the free-flowing reach of the Snake River at Pittsburg Landing to the tailrace of Lower Granite Dam ranged from 62% for the second release to14% for the latest release. For hatchery fish released at Billy Creek, survival probability estimates ranged from 75% for the earliest release to 9% for the latest release and for hatchery fish released at Big Canyon Creek, estimates ranged from 55% for the earliest releases to 9% for the latest release. Natural fish were PIT tagged and released early in the season in the vicinity of Pittsburg Landing (upper Snake River) with estimated 57% survival. Natural fish were released throughout the season in the vicinity of Billy Creek, with estimated 32% survival. A small proportion of hatchery subyearling fall chinook salmon residualized and migrated early in spring 1998; however, as with releases in 1995 and 1996, the number that overwintered in the river and migrated seaward as yearlings in spring was small and had minimal effect on survival estimates. A number of comparisons of characteristics of hatchery and natural fish were made. Results generally support the use of hatchery fall chinook salmon as surrogates for natural fall chinook salmon in survival research.

Combining the three years of data for hatchery fish, significant correlations were found between estimated survival from release to the tailrace of Lower Granite Dam and all three environmental variables examined (flow, water temperature, and turbidity). Estimated survival decreased throughout the season, as flow volume and turbidity decreased and water temperature increased.

In the reach from Lower Granite Dam tailrace to Lower Monumental Dam tailrace, ranges of exposures in 1995 and 1996 were too narrow to discern relationships with survival. However, significant relationships were observed between survival and the environmental variables in 1997, and the relationships were very similar in nature to those in the reach above Lower Granite Dam. The correlation with survival from Lower Granite Dam to Lower Monumental Dam was greatest with water temperature (higher survival with cooler water), followed by flow (higher survival with higher flow volumes), and turbidity (higher survival with more turbid water).

Survival was generally lower in 1997 between the tailrace of Lower Granite Dam and the tailrace of Lower Monumental Dam than in 1995 and 1996. We attribute this lower survival to a combination of factors most likely caused by the high flows observed during June and July of 1997. The high flows resulted in fish arriving at Lower Granite Dam earlier and at a smaller size than in past years. The higher flows also resulted in increased debris in the bypass systems at Snake River Dams.

CONTENTS

INTRODUCTION

Snake River fall chinook salmon (*Oncorhynchus tshawytscha*) were listed as threatened under the Endangered Species Act in April 1992 (NMFS 1992). The status was changed to endangered by emergency action in 1994, then restored to threatened in 1995. Before this study began, little was known about migrational characteristics of Snake River subyearling fall chinook salmon, including the proportion that survive passage through the Snake River dams and reservoirs, how flow volume and water temperature affect their survival, and the percentage of migrants collected and transported at the dams. As a result, operational strategies to maximize survival of subyearling chinook salmon in the Snake River have been largely based on data from studies of subyearling chinook salmon in the lower Columbia River. Information specific to Snake River migrants is necessary to develop and assess the effects of possible restoration strategies such as supplementation, dam modification, flow augmentation, spill, or reservoir drawdown.

For Snake River fall chinook salmon, it has been difficult to collect enough fish for experimental subjects. Although the number of natural subyearling fall chinook salmon collected by beach seine and PIT tagged upstream from Lower Granite Dam has increased in recent years (Connor et al. 1994a,b; 1997a,b), numbers are still too low to make sufficient releases within a single year to examine relationships among survival, travel time, and environmental conditions. Three options are available to increase the number of subyearling fall chinook salmon available for tagging: 1) collect more natural river migrants from the Snake River using available capture methods, 2) import fall chinook salmon collected in the Columbia River, where they are more abundant, or 3) use hatchery-reared subyearling fall chinook salmon of Snake River stock as surrogates for naturally produced migrants. The current population status of fall chinook salmon in the Snake River and concerns about inter-basin stock transfers limit the use of options 1 and 2.

Conclusions derived from studies of hatchery-reared fish (option 3) are applicable to natural fish only if hatchery fish are adequate surrogates. It is unlikely that fish taken directly from a hatchery, tagged, and released will behave similarly to natural migrants, especially immediately after release (Steward and Bjornn 1990). However, differences between hatchery-reared and natural migrants are lessened by acclimation to ambient environmental conditions prior to release, releasing fish of appropriate size, and timing of releases to coincide with the migration of natural fish. Moreover, survival information from hatchery fish can help guide future supplementation efforts using fall chinook salmon in the Snake River Basin.

This study represents an extension of earlier studies (1993-1997) of juvenile salmon and steelhead survival in the Snake River conducted by the National Marine Fisheries Service and the University of Washington (Iwamoto et al. 1994; Muir et al. 1995, 1996; Smith et al. 1998). In these studies, researchers estimated passage survival and PIT-tag detection probabilities (an approximation of fish guidance efficiency (FGE) at the dams when no water is spilled) for hatchery-reared and natural yearling spring/summer chinook salmon and hatchery-reared yearling steelhead (*O. mykiss*) using Single-Release (SR) and Paired-Release (PR) methodologies for survival estimation.

Here we report the results of the third year of releases of PIT-tagged hatchery subyearling fall chinook salmon in the Snake River and the second year of releases in the Clearwater River to estimate survival and travel time. Study objectives were to: 1) estimate detection and passage survival probabilities of hatchery subyearling fall chinook salmon released in the Snake and Clearwater Rivers, and 2) investigate relationships between travel times and passage survival probabilities of subyearling fall chinook salmon and environmental influences such as flow volume, water temperature, and turbidity.

METHODS

Study Area

The study was conducted from Billy Creek and Pittsburg Landing on the Snake River (Snake River Kilometer (RKm) 265 and 346, respectively) and Big Canyon Creek on the Clearwater River (Clearwater RKm 57) to McNary Dam on the Columbia River (Columbia RKm 470) (Fig. 1). The area included a 111-km free-flowing reach of the Snake River, a 57-km free-flowing reach of the Clearwater River (confluence at Snake RKm 224), and five reservoirs and dams: Lower Granite Dam (Snake RKm 173), Little Goose Dam (Snake RKm 113), Lower Monumental Dam (Snake RKm 67), Ice Harbor Dam (Snake RKm 16), and McNary Dam. The Snake River enters the Columbia River at RKm 522.

Primary Release Groups

All subyearling fall chinook salmon used in our study in 1997 were Snake River fall chinook stock from Lyons Ferry Hatchery (Snake RKm 95) (Washington Department of Fish and Wildlife). Our goal was to release experimental fish of approximately the same size as natural fall chinook salmon present in the Snake River at the time of release. On a given date, natural fall chinook salmon in the Clearwater River were generally smaller than those in the Snake River (Arnsberg et al. 1992). Target length for fish in primary release groups was 75 mm in fork length.

Primary groups were released into the Snake River at Billy Creek and Pittsburg Landing and into the Clearwater River at Big Canyon Creek. Fish for primary release groups were PIT tagged at Lyons Ferry Hatchery, using established techniques (Iwamoto et al. 1994). Fish were tagged weekly from 28 May to 8 July. At the hatchery, well water was supplied during tagging and loading for transportation at a near constant temperature averaging 11.5°C. Fork length of all fish tagged was measured, and about 10% of the fish were weighed. Fish were not coded-wire-tagged, fin clipped, or marked in any other way in 1997.

Immediately after tagging, we transported tagged fish in truck-mounted aerated tanks (approximately 1,000 L) to the three release sites. Elapsed time between departure from the hatchery and release was standardized at 8 hours for all three release sites. Actual transport to Billy Creek, Pittsburg Landing, and Big Canyon Creek release sites took about 3, 6, and 3 hours,

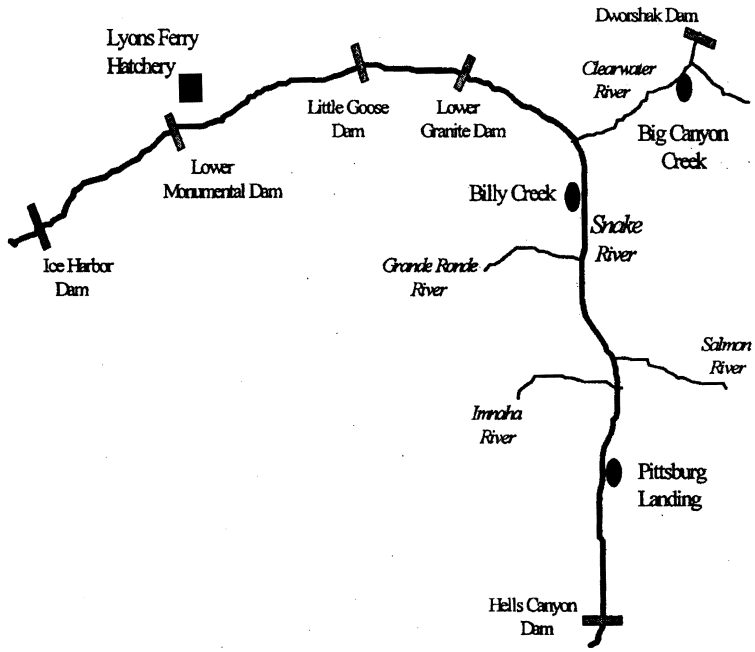

Figure 1. Study area showing location of Lyons Ferry Hatchery and release sites (Pittsburg Landing, Billy Creek, and Big Canyon Creek), 1997.

respectively. Immediately after arrival at Pittsburg Landing, fish were acclimated to ambient river temperature using a gasoline powered water pump that slowly replaced the hatchery water in the tank with river water. Upon arrival at Billy Creek and Big Canyon Creek, trucks were parked for about 3 hours before beginning in-tank acclimation to river temperature. After acclimation, fish were released directly into the Snake and Clearwater Rivers via flexible hose. Holding densities in the transport vehicles were kept below 8 kg fish/m^3 of water.

Secondary Release Groups

Secondary releases at Lower Granite Dam were used to assess mortality that may have occurred to fish in primary release groups between the point of detection at Lower Granite Dam and the point of remixing with nondetected fish in the tailrace. A pair of release groups is used: the treatment group released into the terminus of the juvenile bypass system at Lower Granite Dam, and the reference group released into the tailrace (Iwamoto et al. 1994). We PIT tagged hatchery subyearling fall chinook salmon on 28 and 30 May at Lyons Ferry Hatchery for eventual use as secondary release groups at Lower Granite Dam. The tagging and transport procedures were the same as those used for the primary release groups, and they were all released at Pittsburg Landing.

The fish from these release groups were subsequently recovered at Lower Granite Dam for use in secondary releases. Their PIT-tag codes were entered into the separation-by-code system at Lower Granite Dam at the time of their release, so that we could collect them when they were detected as they passed through the juvenile collection facility. Because fish for our secondary release groups were initially released at Pittsburg Landing and then recaptured at Lower Granite Dam, they were representative of the fish from our primary release groups as they passed Lower Granite Dam.

We released secondary groups in the period (3 to 18 July) during which most PIT-tagged fish from the primary release groups were passing Lower Granite Dam. Each day, fish were collected for the secondary group using the separation-by-code system with the PIT-tag codes retrieved from the system computer. Bypass and tailrace release groups were automatically sorted by the separation-by-code system into two tanks (alternated daily). Fish were loaded into 1.8 x 1.8 x 0.9-m (1,300-L) aluminum tanks mounted on trucks using sanctuary dipnets (without anesthesia). Holding densities were low, not exceeding 100 fish per tank. Tanks were aerated and supplied with at least 2 L/min of water per tank prior to release. Mortalities were recorded and loose tags recovered and recorded just before live fish were released. Treatment groups were released directly from the truck-mounted tank into a PVC pipe that ran parallel to the pipe used to return PIT-tagged fish diverted by the slide-gate to the river. Reference groups were transferred to similar-sized containers on board a vessel, transported to the tailrace release site, and released water-to-water. Fish were released between 12:00 and 3:00 PM.

Operation of PIT-Tag Interrogation and Slide-Gate Systems

Slide gates at Lower Granite, Little Goose, and Lower Monumental Dams automatically diverted most detected PIT-tagged fish back to the river in 1997 (details of slide-gate operation in Muir et al. 1995). PIT-tag interrogation was terminated in 1997 on 31 October at Lower Granite, Little Goose, Lower Monumental, and Bonneville Dams, and on 14 December at McNary Dam. In 1998, operations resumed on 26 March at Lower Granite, Little Goose, and Lower Monumental Dams, on 9 April at McNary Dam, and on 21 March at John Day and Bonneville Dams. To study growth, we recaptured a subsample of each release group using the separation-by-code system at Little Goose Dam.

Data Analyses

We used the methods described by Iwamoto et al. (1994) and Muir et al. (1995, 1996) for data collection and retrieval from the PIT Tag Information System (PTAGIS), database quality assurance/control, construction of capture histories, tests of assumptions, estimation of survival and detection probabilities, and travel time. The statistical models used to estimate survival from PIT-tag data were the Single-Release (SR) and Paired-Release (PR) Models. Background information and statistical theory underlying these models were described by Iwamoto et al. (1994).

Residualization and Interpretation of Model Parameters

The tendency of subyearling fall chinook salmon to residualize (some subyearling fish overwinter in the Snake River, then resume migration as yearlings the following spring) violates assumptions of the Single-Release Model (Smith et al. 1997). Fish released in the Snake and Clearwater Rivers that immediately migrated downstream would be expected to have higher survival probabilities than would fish released at the same time that residualized and spent the winter in the reservoir prior to migrating the following spring.

Because of effects of residualization on survival estimates, we first based our survival analyses solely on PIT-tag detections that occurred during the summer and fall following release, and ignored detections that occurred the following spring. This approach changed the interpretation of survival probabilities in the Single-Release Model. For example, the parameter previously defined as the probability of survival within a particular reach (Iwamoto et al. 1994; Muir et al. 1995, 1996), became the combined probability of migrating through the reach as a subyearling and the probability of surviving the reach for subyearling migrants (i.e., the product of the two probabilities). The detection probability at each dam was the probability for individuals that migrated as subyearlings, not for the entire group.

We then estimated the proportion of fish tagged in 1997 that residualized, based on the proportion detected in the spring of 1998 and detection probabilities of PIT-tagged hatchery fall chinook salmon released as yearlings in the spring of 1998. The probability of detecting in 1998 a fish that residualized and migrated as a yearling could not be estimated reliably from the residualized fish themselves because too few of them were detected in 1998.

Validity of Secondary Releases

We assessed the validity of our secondary releases by comparing detection rates and travel times downstream from Lower Granite Dam for fish from secondary release groups with those for fish from primary release groups.

Detection Probability vs. Fish Guidance Efficiency

Fish guidance efficiency (FGE) is the proportion of those fish entering the powerhouse that are successfully guided away from turbine intakes and into juvenile bypass facilities. The FGE at a particular dam can be expressed as:

$$FGE = \frac{A}{A + B} \times 100\% \qquad (1)$$

where: A = number of fish diverted into the bypass system; and
B = number of fish that passed through turbines.

The probability of detecting a PIT-tagged fish (P) estimated by the Single-Release Model is similar, but not equivalent to FGE:

$$P = \frac{C}{C + D} \qquad (2)$$

where: C = number of fish detected at the dam; and
D = number of fish that survived to the tailrace of the dam but were not detected as they passed.

The values A and C are nearly identical: a difference could be caused by a small amount of mortality that may occur in the bypass system between entry into the powerhouse and the point of detection and the negligible number of fish that pass through the bypass without being detected. The value B includes only fish that entered the powerhouse, while D also includes fish that passed via the spillway. However, even under conditions of no spill at the dam, the values of B and D differ, because B includes all fish that enter the turbines and D includes only those that survive turbine passage. Thus, when there is no spill, P is a larger value than FGE (and the estimate $\hat{P}$ generally overestimates FGE) because the numerators for FGE (Equation 1) and P (Equation 2) are essentially the same, but the denominator for FGE is larger than the denominator for P. The extent to which $\hat{P}$ overestimates FGE depends on the probability of surviving turbine passage (S_T) for the fraction of fish that pass through turbines. Assuming that A and C are equal, an estimate of FGE can be derived from:

$$\hat{FGE} = \frac{(\hat{P} \cdot S_T)}{\hat{P} \cdot S_T + (1 - \hat{P})} \times 100\%. \qquad (3)$$

Comparison of Natural and Hatchery Subyearling Chinook Salmon

To evaluate the efficacy of using hatchery fish as surrogates for natural fish we captured natural subyearling chinook salmon by beach seine between Snake River RKm 224 and 357 from April to July 1997. This stretch was divided into three sections, identified as upstream, midstream, and downstream. Natural fish were PIT tagged and released where they were captured to resume rearing and seaward migration. We compared fork length at release, travel times to Lower Granite Dam, time of passage at Lower Granite Dam, and survival to the tailrace of Lower Granite Dam between these PIT-tagged natural subyearlings and the hatchery subyearlings released at Pittsburg Landing, Billy Creek, and Big Canyon Creek. Natural fish released in the upstream reach were most comparable in release timing and location with the first release of the hatchery group at Pittsburg Landing. Natural fish were released in the downstream reach over a longer period of time, and were comparable in release timing and location to the first four release groups of hatchery fish at Billy Creek. We also recaptured a subsample of PIT-tagged natural and hatchery fish at Little Goose Dam to compare growth and condition factor (*K*).

Survival, Travel Time, and Environmental Variables

Subyearling fall chinook salmon migrate over prolonged periods, during which environmental conditions can change dramatically. Measures of environmental conditions relevant to migration performance must be chosen carefully. This is especially true for subyearlings taken directly from hatcheries and released into rivers, because both timing of onset of migration and migration rates can vary widely among individuals.

Smith et al. (1998) investigated relationships of environmental factors to survival of actively migrating yearling chinook salmon. Indices of exposure to factors at each dam for each group of PIT-tagged fish were defined as the average value of the factor during the period between the group's 25th and 75th percentiles of passage at the dam. However, indices defined over a "middle-of-passage" period were not appropriate to relate to survival to Lower Granite Dam tailrace for subyearling fall chinook salmon released in free-flowing river sections above Lower Granite Dam. For subyearlings, mortality was relatively high in this river section, and much of the mortality probably occurred prior to the date of the 25th percentile of passage at Lower Granite Dam, which was as long as 44 days after the date of release. Therefore, the middle-of-passage index is inappropriate, since many fish in the release group never experienced the conditions prevailing on the date of 25th percentile of passage; they were already dead.

Instead, for release groups in free-flowing reaches above Lower Granite Dam, we defined indices of exposure to environmental factors as the average daily value measured at Lower

Granite Dam between the date of release and the date of the 5th percentile of passage at Lower Granite Dam. Using indices defined in the period immediately after release, we characterized conditions experienced by most of the fish after release and before initiation of migration. Relationships between exposure indices and survival and travel time from release to Lower Granite Dam tailrace were examined with linear regression using data for individual release groups from the Snake and Clearwater Rivers in 1995, 1996, and 1997.

To investigate relationships between environmental factors and survival and travel time in reaches below Lower Granite Dam, we redefined groups of PIT-tagged fish based on the date of passage at Lower Granite Dam, rather than based on the date and location of initial release. Using this approach, we identified groups of fish that actively migrated, and that had passed Lower Granite Dam within the same 24-hour period. The "post-Lower Granite" detection histories of all fish released to the tailrace of Lower Granite Dam on a particular day were tabulated, and the Single-Release Model was applied to estimate survival and travel time for the "daily-release group" from Lower Granite Dam tailrace to Lower Monumental Dam tailrace (i.e., through two reservoirs and two dams).

Using this approach it was difficult to obtain groups of sufficient size to estimate survival probabilities with high precision. To obtain reasonably sized groups, daily-release groups were made up of fish from all primary release groups in a particular year (e.g., in 1997 there were six each from Billy Creek, Pittsburg Landing, and Big Canyon Creek) and fish from secondary release groups from Pittsburg Landing (only those fish *not* handled at Lower Granite Dam via the separation-by-code system and used in post-detection bypass survival releases). Daily-release groups were further pooled by week. Thus, we estimated the survival probability and median travel time from Lower Granite Dam tailrace to Lower Monumental Dam tailrace for 13 groups of fish passing Lower Granite Dam during the following intervals in 1997: 9-15 June, 16-22 June, 23-29 June, 30 June-6 July, 7-13 July, 14-20 July, 21-27 July, 28 July-3 August, 4-10 August, 11-17 August, 18-24 August, 25-31 August, and 1-7 September. Indices of exposure to flow, water temperature, and turbidity for a weekly pooled group were the averages of the daily values at Lower Granite Dam during the period that fish for that group were detected at Lower Granite Dam. We obtained the mean daily value of each variable measured at each dam from sites on the World Wide Web maintained by the Columbia Basin Research group of the University of Washington School of Fisheries ("Data Access in Real Time," http://www.cqs.washington.edu/dart/dart.html) and by the Fish Passage Center (http://www.teleport.com/~fpc).

RESULTS

Primary Release Groups

A total of 7,474 subyearling fall chinook salmon were PIT tagged and released at Billy Creek, 7,478 fish at Pittsburg Landing, and 7,527 fish at Big Canyon Creek (Table 1). Tagging and handling mortality at the hatchery averaged 0.8% and transport mortality averaged 0.2%

Table 1. Information on individual groups of PIT-tagged hatchery subyearling fall chinook salmon released in 1997.

Site	Purpose of release	Release date	Number released	Water temp. (°C)	Mean length (mm)
Pittsburg Landing	Secondary	28 May	6,955	16.5	83
	Secondary	30 May	6,946	16.9	84
	Primary	3 Jun	1,262	16.6	80
	Primary	10 Jun	1,245	16.7	82
	Primary	17 Jun	1,243	18.1	82
	Primary	24 Jun	1,239	18.9	85
	Primary	1 Jul	1,251	18.9	85
	Primary	8 Jul	1,238	20.2	85
Billy Creek	Primary	3 Jun	1,247	12.5	80
	Primary	10 Jun	1,250	14.0	82
	Primary	17 Jun	1,244	15.0	80
	Primary	24 Jun	1,250	16.3	84
	Primary	1 Jul	1,245	16.4	82
	Primary	8 Jul	1,238	19.0	82
Big Canyon Creek	Primary	3 Jun	1,253	9.5	81
	Primary	10 Jun	1,238	13.0	82
	Primary	17 Jun	1,250	13.1	82
	Primary	24 Jun	1,250	13.9	85
	Primary	1 Jul	1,267	13.9	86
	Primary	8 Jul	1,269	15.1	85

(Table 2). Water temperatures at release ranged from 12.5 to 19.0°C in the Snake River at Billy Creek, 16.5 to 20.2°C in the Snake River at Pittsburg Landing, and from 9.5 to 15.1°C in the Clearwater River (Table 1).

Secondary Release Groups

A total of 13,901 subyearling fall chinook salmon were released at Pittsburg Landing in the Snake River for post-detection bypass evaluation (Table 1). Tagging mortality for these releases averaged 0.5% and transport mortality averaged 0.1% (Table 2). Post-detection bypass releases were made at Lower Granite Dam between 3 and 18 July (Table 3). During this time, release water temperatures were 18 or 19°C. Only 673 of the 13,901 fish (4.8%) released at Pittsburg Landing were recaptured at Lower Granite Dam by the separation-by-code system; 146 were eventually rereleased into the collection channel, 129 were rereleased into the tailrace, and 30 (12.8%) recaptured fish died before they could be released. The remaining 368 fish recaptured at Lower Granite Dam were radiotagged and used for evaluation of Ice Harbor Dam spillway passage (Eppard et al. 1998).

Data Analyses

Validity of Secondary Releases

Fish from primary and secondary release groups collected by the separation-by-code system at Little Goose Dam during the same period were of similar size. Both length and weight were measured for a total of 41 fish from secondary release groups and 162 fish from primary release groups. Fish from primary groups were sampled much later into the season: 38 of the 41 secondary-release fish were collected by 13 July, while only 74 of the 162 primary-release fish were collected by that date. The mean length for fish collected by 13 July was 119.7 mm for secondary-release fish and 115.6 for primary. Mean weights were 19.8 g and 18.2 g, respectively. Primary-release fish collected at Little Goose Dam later in the season were larger.

Fish released at Pittsburg Landing on 28 and 30 May for use in secondary releases from Lower Granite Dam arrived in large numbers at Lower Granite Dam earlier than primary-release fish. The median date of passage for secondary release groups was 2 July, by which date only 8% of the detections on primary-release fish had occurred. The median date of passage for primary release groups was 20 July, by which date over 87% of secondary-release fish had passed the dam.

Because of the high flows during June and July 1997, the majority of secondary release fish passed Lower Granite Dam during a short time period early in the summer migration, prior to the time the separation-by-code system was ready to capture them. Over half of the fish recaptured were then allocated to the Ice Harbor spillway evaluation. For this reason, we were able to release only 275 fish for post-detection bypass evaluation (Table 3). Paired groups were released on 3, 4, 11, 12, and 18 July. A higher percentage of fish collected, handled, and rereleased at Lower Granite Dam were detected downstream than fish detected at Lower Granite

Table 2. PIT-tagging and transport mortality for hatchery subyearling fall chinook salmon used in primary releases at Pittsburg Landing, Billy Creek, and Big Canyon Creek and secondary releases at Pittsburg Landing in 1997.

Release site	Release date	Tagging mortality		Transport mortality		Overall mortality	
		N	%	N	%	N	%
Pittsburg Landing	3 Jun	5	0.4	1	0.1	6	0.5
	10 Jun	5	0.4	0	0.0	5	0.4
	17 Jun	6	0.5	3	0.2	9	0.7
	24 Jun	17	1.4	1	0.1	18	1.4
	1 Jul	16	1.3	1	0.1	17	1.3
	8 Jul	16	1.3	3	0.2	19	1.5
Billy Creek	3 Jun	3	0.2	4	0.3	7	0.6
	10 Jun	6	0.5	1	0.1	7	0.6
	17 Jun	7	0.6	2	0.2	9	0.7
	24 Jun	6	0.5	2	0.2	8	0.6
	1 Jul	11	0.9	3	0.2	14	1.1
	8 Jul	15	1.2	1	0.1	16	1.3
Big Canyon Creek	3 Jun	4	0.3	2	0.2	6	0.5
	10 Jun	17	1.4	2	0.2	19	1.5
	17 Jun	7	0.6	3	0.2	10	0.8
	24 Jun	13	1.0	1	0.1	14	1.1
	1 Jul	13	1.0	0	0.0	13	1.0
	8 Jul	8	0.6	3	0.2	11	0.9
Primary release totals		175	0.8	33	0.2	208	0.9
	28 May	20	0.3	11	0.2	31	0.4
	30 May	44	0.6	1	0.1	45	0.6
Secondary release totals		64	0.5	12	0.1	76	0.5

Table 3. Information on individual secondary release groups of hatchery subyearling fall chinook salmon released at Lower Granite Dam in 1997.

Location	Release Date	Number collected	Mortalities	Number released	Temp. (°C)
bypass	3 Jul	47	2	45	18.0
tailrace	3 Jul	42	2	40	18.0
bypass	4 Jul	17	1	16	18.0
tailrace	4 Jul	20	0	20	18.0
bypass	11 Jul	39	9	30	18.9
tailrace	11 Jul	33	7	26	18.9
bypass	12 Jul	33	2	31	19.0
tailrace	12 Jul	23	1	22	19.0
bypass	18 Jul	27	3	24	19.0
tailrace	18 Jul	24	3	21	19.0

Dam and returned to the river without handling. Of 129 fish released into the tailrace of Lower Granite Dam, 58% were detected again at one or more dams downstream from Lower Granite Dam. Of a total 1,657 fish detected and returned to the river without handling on the same days that secondary groups were released into the tailrace, only 33% were detected again downstream.

The post-detection bypass survival estimate (weighted geometric mean of estimates for paired releases on 5 days) for fish released into the collection system at Lower Granite Dam was 0.867 (s.e. 0.115), suggesting post-detection bypass mortality occurred at this site. However, the small number of paired releases resulted in a large standard error for the estimate, and differences in post-release performance of fish handled at Lower Granite Dam compared to those not handled makes the post-detection survival estimate suspect. Therefore, we did not use the estimate of post-detection bypass survival, and used the SR model to estimate detection and survival probabilities for primary release groups. Potential effects of post-detection mortality on the SR Model survival estimates are evaluated in the Discussion section.

Tests of Model Assumptions

Only a few--no more than expected by chance alone--tests of assumptions showed significant ($\alpha < 0.10$) violations. For primary release groups, detected and nondetected fish at a particular dam were mixed as they passed dams farther downstream (Table 4), and detection history at upper dams did not affect probabilities of survival or detection at downstream dams (Table 5). On the basis of these results, we found no reason to reject the validity of parameter estimates from the Single-Release Model for primary release groups. For secondary release groups, detected and nondetected fish at one dam were not mixed farther downstream (Table 4), though serious lack of fit to the Single-Release Model did not result (Table 5).

Detection Probabilities

Overall, detection probabilities were lower at Lower Granite Dam in 1997 (Table 6) than in 1996, most likely due to the operation of the surface collector (and associated spill) (Fig. 2). Detection probabilities were higher at both Little Goose and Lower Monumental Dams than in 1996. At Little Goose Dam, this increase was most likely due to the extended bar screens installed prior to the 1997 migration. There were no apparent seasonal differences in detection probabilities nor between release locations.

Survival Probabilities

Because of problems with post-detection bypass releases described previously, for evaluation purposes we assumed post-detection bypass survival was 100%, and the SR Model was used to estimate survival for all primary release groups. If post-detection mortality occurred at all dams, then the SR Model would tend to overestimate survival from release to Lower Granite Dam. Survival estimates would also be biased for reaches below Lower Granite Dam, but the direction of the bias would depend on the relative degree of post-detection mortality at each dam.

Table 4. Tests of homogeneity of detection distributions at Little Goose, Lower Monumental, and McNary Dams for subgroups of primary (PL) and secondary (PD) release groups from Pittsburg Landing and primary release groups from Big Canyon Creek (CW) and Billy Creek (BC). Subgroups defined by detection histories at previous dams. P values calculated using Monte Carlo approximation of the exact method. P values significant at the 0.10 level are shaded.

	Little Goose Dam			Lower Monumental Dam			McNary Dam		
Release	χ^2	d.f.	P value	χ^2	d.f.	P value	χ^2	d.f.	P value
PL 1	58.65	53	0.232	114.3	120	0.785	224.4	217	0.338
PL 2	66.65	57	0.100	132.4	123	0.166	260.1	238	0.105
PL 3	69.60	61	0.140	132.9	132	0.504	309.2	315	0.771
PL 4	68.85	68	0.473	140.0	141	0.608	304.1	294	0.308
PL 5	48.11	46	0.386	53.10	57	0.723	171.7	162	0.288
PL 6	15.00	15	0.795	14.00	12	0.801	NA	NA	NA
PD 1	123.3	88	0.003	341.7	288	0.006	553.4	539	0.306
PD 2	118.8	86	0.005	303.1	270	0.058	683.9	588	0.002
CW 1	51.30	49	0.373	112.6	111	0.504	188.0	175	0.158
CW 2	32.40	31	0.394	62.29	60	0.453	24.00	20	0.999
CW 3	60.71	56	0.232	113.5	117	0.722	225.4	217	0.368
CW 4	41.95	47	0.898	79.07	81	0.755	149.4	154	0.938
CW 5	43.34	34	0.746	41.79	39	0.415	63.75	60	0.616
CW 6	9.00	8	0.999	NA	NA	NA	NA	NA	NA

Table 4. Continued.

	Little Goose Dam			Lower Monumental Dam			McNary Dam		
Release	χ^2	d.f.	P value	χ^2	d.f.	P value	χ^2	d.f.	P value
BC 1	47.26	41	0.189	105.9	105	0.524	133.0	126	0.471
BC 2	44.60	44	0.450	106.2	108	0.682	209.8	182	0.032
BC 3	66.98	76	0.873	182.6	168	0.108	286.6	294	0.803
BC 4	71.49	66	0.238	158.5	144	0.084	333.8	350	0.872
BC 5	55.32	53	0.357	53.33	57	0.874	133.5	140	0.971
BC 6	20.67	20	0.659	13.50	14	0.999	NA	NA	NA

Table 5. Results of tests of goodness of fit to the Single Release Model for primary (PL) and secondary (PD) release groups from Pittsburg Landing and primary release groups from Big Canyon Creek (CW) and Billy Creek (BC). P values significant at the 0.10 level are shaded.

	Overall		Test 2		Test 2.C2		Test 2.C3	
Release	χ^2	P value	χ^2	P value	χ^2	P value	χ^2	P value
PL 1	7.050	0.316	2.175	0.537	0.329	0.848	1.846	0.174
PL 2	3.780	0.706	0.672	0.880	0.654	0.721	0.018	0.893
PL 3	3.813	0.702	0.854	0.837	0.616	0.735	0.238	0.626
PL 4	6.571	0.362	2.816	0.421	0.940	0.625	1.876	0.171
PL 5	19.241	0.004	16.712	0.001	7.737	0.021	8.975	0.003
PL 6	4.080	0.538	2.430	0.488	2.252	0.324	0.178	0.673
PD 1	11.065	0.086	6.157	0.104	5.581	0.061	0.576	0.448
PD 2	5.517	0.479	4.468	0.215	4.274	0.118	0.194	0.660
CW 1	2.355	0.884	1.100	0.777	0.653	0.721	0.447	0.504
CW 2	3.412	0.756	1.845	0.605	1.279	0.528	0.566	0.452
CW 3	5.000	0.544	3.844	0.279	3.732	0.155	0.112	0.738
CW 4	3.253	0.776	1.121	0.772	0.915	0.633	0.206	0.650
CW 5	5.724	0.455	0.458	0.928	0.337	0.845	0.121	0.728
CW 6	NA	NA	NA	NA	NA	NA	NA	NA

Table 5. Continued.

	Overall		Test 2		Test 2.C2		Test 2.C3	
Release	χ^2	P value	χ^2	P value	χ^2	P value	χ^2	P value
BC 1	2.506	0.868	0.247	0.970	0.020	0.990	0.227	0.634
BC 2	9.287	0.158	1.362	0.714	0.330	0.848	1.032	0.310
BC 3	2.833	0.829	2.307	0.511	2.258	0.323	0.049	0.825
BC 4	11.377	0.077	9.696	0.021	2.618	0.270	7.078	0.008
BC 5	3.067	0.800	2.187	0.535	1.941	0.379	0.246	0.620
BC 6	1.559	0.459	NA	NA	NA	NA	NA	NA

Table 5. Continued.

	Test 3		Test 3.SR3		Test 3.Sm3		Test 3.SR4	
Release	χ^2	P value	χ^2	P value	χ^2	P value	χ^2	P value
PL 1	4.875	0.181	0.798	0.372	4.075	0.044	0.002	0.964
PL 2	3.108	0.375	0.505	0.477	0.078	0.780	2.525	0.112
PL 3	2.959	0.398	1.170	0.279	0.345	0.557	1.444	0.229
PL 4	3.755	0.289	0.098	0.754	0.509	0.476	3.148	0.076
PL 5	2.529	0.470	0.033	0.856	1.538	0.215	0.958	0.328
PL 6	1.650	0.438	0.900	0.343	0.750	0.386	NA	NA
PD 1	4.908	0.179	0.407	0.523	4.244	0.039	0.257	0.612
PD 2	1.049	0.789	0.404	0.525	0.460	0.498	0.185	0.667
CW 1	1.255	0.740	0.011	0.916	0.017	0.896	1.227	0.268
CW 2	1.567	0.667	0.205	0.651	1.362	0.243	0.000	1.000
CW 3	1.156	0.764	0.053	0.818	0.080	0.777	1.023	0.312
CW 4	2.132	0.545	1.229	0.268	0.676	0.411	0.227	0.634
CW 5	5.266	0.153	0.235	0.628	3.600	0.058	1.431	0.232
CW 6	NA	NA	NA	NA	NA	NA	NA	NA

Table 5. Continued.

	Test 3		Test 3.SR3		Test 3.Sm3		Test 3.SR4	
Release	χ^2	P value	χ^2	P value	χ^2	P value	χ^2	P value
BC 1	2.259	0.520	0.199	0.656	0.730	0.393	1.330	0.249
BC 2	7.925	0.048	4.835	0.028	0.034	0.854	3.056	0.080
BC 3	0.526	0.913	0.007	0.933	0.026	0.872	0.493	0.483
BC 4	1.681	0.641	0.007	0.933	1.671	0.196	0.003	0.956
BC 5	0.880	0.830	0.030	0.862	0.423	0.515	0.427	0.513
BC 6	1.559	0.459	0.929	0.335	NA	NA	0.630	0.427

Table 6. Detection probability estimates for subyearling fall chinook salmon PIT tagged at Lyons Ferry Hatchery and released in free-flowing sections of the Snake and Clearwater Rivers in 1997. Estimates based on the Single-Release Model. Standard errors in parentheses.

Release site	Date	Number released	Lower Granite	Little Goose	Lower Monumental
Pittsburg Landing	3 Jun	1,262	0.436 (0.031)	0.555 (0.048)	0.474 (0.068)
Billy Creek	3 Jun	1,247	0.331 (0.036)	0.509 (0.060)	0.433 (0.094)
Big Canyon Creek	3 Jun	1,253	0.421 (0.039)	0.589 (0.056)	0.515 (0.087)
Pittsburg Landing	10 Jun	1,245	0.429 (0.033)	0.677 (0.043)	0.403 (0.067)
Billy Creek	10 Jun	1,250	0.458 (0.038)	0.563 (0.055)	0.523 (0.084)
Big Canyon Creek	10 Jun	1,238	0.470 (0.054)	0.586 (0.085)	0.509 (0.177)
Pittsburg Landing	17 Jun	1,243	0.478 (0.031)	0.495 (0.043)	0.473 (0.058)
Billy Creek	17 Jun	1,244	0.489 (0.030)	0.584 (0.040)	0.587 (0.055)
Big Canyon Creek	17 Jun	1,250	0.457 (0.042)	0.525 (0.053)	0.600 (0.069)
Pittsburg Landing	24 Jun	1,239	0.473 (0.032)	0.577 (0.041)	0.397 (0.058)
Billy Creek	24 Jun	1,250	0.507 (0.032)	0.474 (0.042)	0.505 (0.052)
Big Canyon Creek	24 Jun	1,250	0.427 (0.051)	0.621 (0.069)	0.633 (0.088)
Pittsburg Landing	1 Jul	1,251	0.515 (0.051)	0.481 (0.077)	0.400 (0.089)
Billy Creek	1 Jul	1,245	0.456 (0.046)	0.507 (0.077)	0.385 (0.095)
Big Canyon Creek	1 Jul	1,267	0.440 (0.075)	0.375 (0.099)	0.533 (0.129)
Pittsburg Landing	8 Jul	1,238	0.372 (0.099)	0.571 (0.168)	NA
Billy Creek	8 Jul	1,238	0.606 (0.086)	0.243 (0.195)	NA
Big Canyon Creek	8 Jul	1,269	0.428 (0.158)	NA	NA

Survival from the point of release to Lower Granite Dam tailrace for all three series of releases decreased with later release date within a year (Fig. 3). Survival estimates from the point of release to Lower Monumental Dam tailrace were similar between the Pittsburg landing and Billy Creek release sites with the Pittsburg Landing release site generally having slightly lower survival in 1997 (Table 7). Estimated survival from Big Canyon Creek on the Clearwater River to Lower Monumental Dam tailrace was lower than from the Snake River sites in 1997. There were no apparent differences between release sites in survival estimates in the reaches downstream from Lower Granite Dam in 1997 (Table 7).

Survival for the weekly passage groups leaving Lower Granite Dam to Lower Monumental Dam tailrace was highest at the beginning of the summer migration in 1997 (Table 8, Fig. 4). Estimated survival below Lower Granite Dam was substantially lower in 1997 than in previous years, especially in July.

Travel Time

The median elapsed travel time from release until detection at Lower Granite Dam was about the same for PIT-tagged hatchery subyearling chinook salmon released from Pittsburg Landing (173 km from Lower Granite Dam) as for those released at Big Canyon Creek (108 km from Lower Granite Dam) and Billy Creek (92 km from Lower Granite Dam) (Table 9). That is, migration rates (km/day) were higher for fish released at Pittsburg Landing than at Big Canyon or Billy Creek. Migration rates between each pair of dams (Lower Granite to Little Goose, Little Goose to Lower Monumental, and Lower Monumental to McNary) were more similar between release sites (Tables 10-13). For all groups, migration rates between Lower Monumental and McNary Dams were substantially higher than in the previous reaches (Table 12). From all release groups combined, a total of 20 fish were detected at both McNary Dam and Bonneville Dam. The median travel time for this 236 km stretch was 6.1 days (38.7 km/day).

Comparison of Natural and Hatchery Subyearling Chinook Salmon

Hatchery subyearling chinook salmon released at Pittsburg Landing, Billy Creek, and Big Canyon Creek averaged 3 to 8 mm longer at release than natural subyearling chinook salmon in 1997 (Table 14). Hatchery and natural fish both exhibited protracted travel times from release to Lower Granite Dam, with hatchery fish taking 1 to 4 days longer (Table 14). Both groups passed Lower Granite Dam primarily in the summer months of July and August (Fig. 5). The estimated survival probability from release to Lower Granite Dam was nearly identical for natural fish released in the upstream stretch of the Snake River and for the first group of hatchery fish released from Pittsburg Landing (Table 14). Estimated survival was substantially higher for the first four release groups of hatchery fish from Billy Creek than for natural fish released during the same time period. Hatchery fish were generally less in fork length and weight than natural fish when recaptured at Little Goose Dam. Both groups had similarly high condition factors when recaptured at Little Goose Dam (Table 14), while natural fish grew at a slightly higher rate than hatchery fish.

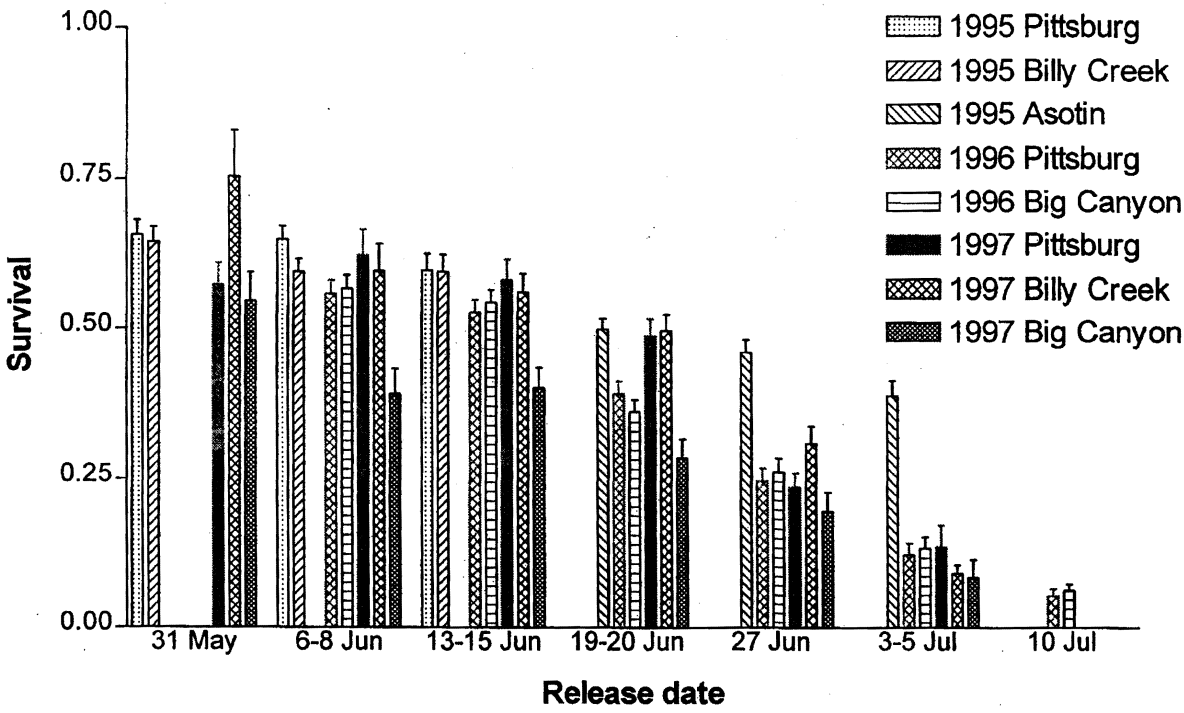

Figure 3. Estimated survival probabilities (with standard errors) from point of release in the Snake (Pittsburg Landing, Billy Creek, and Asotin) and Clearwater (Big Canyon Creek) Rivers to the tailrace of Lower Granite Dam in 1995, 1996, and 1997.

Table 7. Estimates of survival probabilities for subyearling fall chinook salmon PIT tagged at Lyons Ferry Hatchery and released in free-flowing sections of the Snake and Clearwater Rivers in 1997. Estimates based on the Single-Release Model. Standard errors in parentheses. Abbreviations: Rel-Release; LGR-Lower Granite Dam; LGO-Little Goose Dam; LMO-Lower Monumental Dam.

Release site	Date	Number released	Rel to LGR	LGR to LGO	LGO to LMO
Pittsburg Landing	3 Jun	1,262	0.573 (0.036)	0.520 (0.053)	0.496 (0.076)
Billy Creek	3 Jun	1,247	0.755 (0.075)	0.302 (0.046)	0.517 (0.120)
Big Canyon Creek	3 Jun	1,253	0.547 (0.046)	0.343 (0.044)	0.538 (0.094)
Pittsburg Landing	10 Jun	1,245	0.622 (0.043)	0.362 (0.035)	0.785 (0.122)
Billy Creek	10 Jun	1,250	0.595 (0.046)	0.332 (0.041)	0.572 (0.100)
Big Canyon Creek	10 Jun	1,238	0.390 (0.043)	0.262 (0.048)	0.483 (0.173)
Pittsburg Landing	17 Jun	1,243	0.582 (0.034)	0.529 (0.050)	0.590 (0.077)
Billy Creek	17 Jun	1,244	0.562 (0.030)	0.535 (0.043)	0.579 (0.060)
Big Canyon Creek	17 Jun	1,250	0.401 (0.034)	0.405 (0.050)	0.595 (0.077)
Pittsburg Landing	24 Jun	1,239	0.488 (0.029)	0.536 (0.045)	0.828 (0.114)
Billy Creek	24 Jun	1,250	0.497 (0.028)	0.583 (0.054)	0.582 (0.068)
Big Canyon Creek	24 Jun	1,250	0.285 (0.032)	0.345 (0.054)	0.512 (0.082)
Pittsburg Landing	1 Jul	1,251	0.237 (0.023)	0.515 (0.088)	0.489 (0.120)
Billy Creek	1 Jul	1,245	0.310 (0.029)	0.500 (0.085)	0.453 (0.122)
Big Canyon Creek	1 Jul	1,267	0.195 (0.032)	0.330 (0.095)	0.412 (0.129)
Pittsburg Landing	8 Jul	1,238	0.137 (0.035)	0.224 (0.089)	NA
Billy Creek	8 Jul	1,238	0.093 (0.014)	0.949 (0.756)	0.077 (0.074)
Big Canyon Creek	8 Jul	1,269	0.085 (0.031)	NA	NA

Table 8. Estimated survival probabilities from Lower Granite Dam tailrace to Lower Monumental Dam tailrace and average Lower Granite Dam flow, water temperature, and turbidity during release for Lower Granite Dam weekly passage groups, 1997.

Passage dates	N	Survival estimate	Average flow (kcfs)	Average turbidity (secchi)	Average temperature
9-15 June	79	0.668 (0.381)	182.4	1.2	13.5
16-22 June	722	0.658 (0.072)	172.1	1.3	15.1
23-29 June	1,459	0.570 (0.039)	114.2	1.8	16.5
30 June-6 July	1,877	0.456 (0.030)	94.7	2.0	17.2
7-13 July	2,931	0.289 (0.018)	67.0	2.3	18.5
14-20 July	3,075	0.283 (0.015)	63.1	4.0	19.2
21-27 July	1,671	0.240 (0.017)	61.0	4.7	19.2
28 July-3 August	1,219	0.341 (0.026)	58.2	4.4	19.7
4-10 August	799	0.380 (0.030)	53.2	4.5	19.8
11-17 August	644	0.392 (0.035)	48.7	4.5	19.7
18-24 August	433	0.295 (0.039)	41.9	4.6	20.5
25-31 August	274	0.314 (0.062)	36.2	4.9	20.7
1-7 September	143	0.131 (0.036)	29.2	5.0	22.1
8-14 September	162	0.123 (0.053)	29.3	5.0	22.0

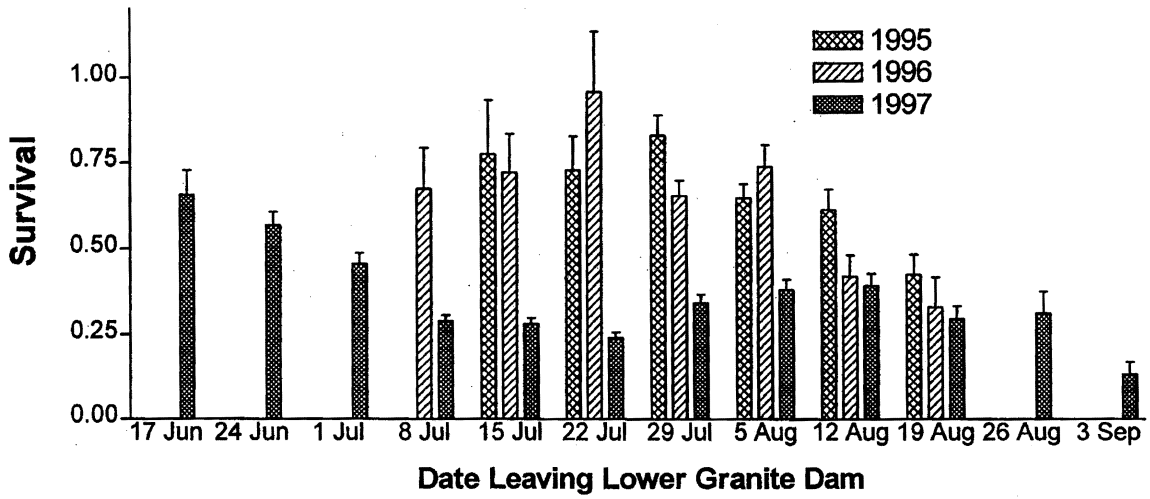

Figure 4. Estimated survival probabilities (with standard errors) to the tailrace of Lower Monumental Dam for PIT-tagged hatchery subyearling fall chinook salmon leaving Lower Granite Dam each week during 1995-1997.

Table 9. Travel times and migration rates between the point of release and Lower Granite Dam for hatchery subyearling fall chinook salmon released at Pittsburg Landing (PL, 173 km), Billy Creek (BC, 92 km), and Big Canyon Creek (CW, 108 km), 1997.

			Travel time (days)					Migration rate (km/day)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
CW1	3 Jun	288	2.9	27.6	37.2	47.4	116.1	0.9	2.3	2.9	3.9	37.6
CW2	10 Jun	227	5.1	27.0	30.4	37.8	85.6	1.3	2.9	3.6	4.0	21.3
CW3	17 Jun	229	3.2	28.4	38.4	57.2	118.9	0.9	1.9	2.8	3.8	33.3
CW4	24 Jun	152	7.3	30.7	42.4	66.4	129.5	0.8	1.6	2.5	3.5	14.8
CW5	1 Jul	109	8.1	24.4	39.7	63.2	118.5	0.9	1.7	2.7	4.4	13.3
CW6	8 Jul	46	7.7	30.0	42.4	70.4	82.9	1.3	1.5	2.5	3.6	14.1
PL1	3 Jun	315	9.7	26.3	34.9	40.2	101.5	1.7	4.3	5.0	6.6	17.9
PL2	10 Jun	332	2.7	26.1	31.0	39.2	112.5	1.5	4.4	5.6	6.6	64.8
PL3	17 Jun	346	2.8	23.4	32.5	49.9	124.5	1.4	3.5	5.3	7.4	62.5
PL4	24 Jun	286	4.2	22.5	35.9	57.5	119.9	1.4	3.0	4.8	7.7	41.5
PL5	1 Jul	153	4.7	29.6	45.4	69.7	122.5	1.4	2.5	3.8	5.9	37.0
PL6	8 Jul	63	16.2	29.7	59.0	75.2	96.5	1.8	2.3	2.9	5.8	10.7

Table 9. Continued.

			Travel time (days)					Migration rate (km/day)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
BC1	3 Jun	312	1.2	26.1	34.3	37.2	87.0	1.1	2.5	2.7	3.5	75.4
BC2	10 Jun	341	2.0	26.1	30.4	38.0	111.9	0.8	2.4	3.0	3.5	45.1
BC3	17 Jun	342	1.6	29.2	40.1	57.8	108.0	0.9	1.6	2.3	3.2	58.2
BC4	24 Jun	315	5.1	27.3	43.5	66.5	120.5	0.8	1.4	2.1	3.4	18.0
BC5	1 Jul	176	2.9	27.8	46.7	74.1	116.8	0.8	1.2	2.0	3.3	32.3
BC6	8 Jul	70	5.4	34.4	57.7	74.4	114.0	0.8	1.2	1.6	2.7	17.2

Table 10. Travel times and migration rates between Lower Granite Dam and Little Goose Dam (60 km) for hatchery subyearling fall chinook salmon released at Pittsburg Landing (PL), Billy Creek (BC), and Big Canyon Creek (CW), 1997.

			Travel time (days)					Migration rate (km/day)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
CW1	3 Jun	52	2.1	4.3	10.6	19.6	110.7	0.5	3.1	5.6	13.9	28.0
CW2	10 Jun	31	2.2	4.4	6.8	12.8	20.3	3.0	4.7	8.9	13.7	27.8
CW3	17 Jun	42	2.2	5.3	7.8	29.0	93.0	0.6	2.1	7.7	11.3	27.8
CW4	24 Jun	32	2.0	4.4	7.2	27.4	53.5	1.1	2.2	8.4	13.6	30.8
CW5	1 Jul	11	2.2	8.3	17.3	44.1	45.4	1.3	1.4	3.5	7.3	27.9
CW6	8 Jul	4	18.2	20.1	21.6	32.2	40.2	1.5	1.9	2.8	3.0	3.3
PL1	3 Jun	79	1.9	4.2	8.2	18.3	84.0	0.7	3.3	7.3	14.3	31.7
PL2	10 Jun	74	2.4	4.5	8.2	18.6	86.7	0.7	3.2	7.4	13.3	24.7
PL3	17 Jun	84	2.0	5.6	10.3	23.3	87.8	0.7	2.6	5.8	10.8	29.9
PL4	24 Jun	81	2.0	6.2	13.6	36.8	73.6	0.8	1.6	4.4	9.7	29.7
PL5	1 Jul	32	3.9	5.7	15.0	32.9	68.5	0.9	1.8	4.0	10.6	15.3
PL6	8 Jul	7	2.5	9.8	15.3	41.3	47.9	1.3	1.5	3.9	6.1	24.4

Table 10. Continued.

			Travel time (days)					Migration rate (km/day)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
BC1	3 Jun	41	2.1	5.8	9.3	18.6	63.6	0.9	3.2	6.5	10.4	29.3
BC2	10 Jun	57	1.9	4.5	8.0	15.8	29.4	2.0	3.8	7.5	13.2	31.6
BC3	17 Jun	93	2.2	6.0	13.0	30.8	80.5	0.7	1.9	4.6	10.0	27.0
BC4	24 Jun	87	2.6	7.1	15.8	30.9	98.6	0.6	1.9	3.8	8.5	22.9
BC5	1 Jul	44	3.0	7.0	13.7	34.5	83.9	0.7	1.7	4.4	8.6	19.9
BC6	8 Jul	15	6.0	10.9	16.0	20.9	34.7	1.7	2.9	3.7	5.5	10.0

Table 11. Travel times and migration rates between Little Goose Dam and Lower Monumental Dam (46 km) for hatchery subyearling fall chinook salmon released at Pittsburg Landing (PL), Billy Creek (BC), and Big Canyon Creek (CW), 1997.

			Travel time (days)					Migration rate (km/day)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
CW1	3 Jun	35	1.8	3.1	4.7	8.8	34.2	1.3	5.2	9.8	15.0	26.0
CW2	10 Jun	16	1.8	2.6	4.6	10.8	18.1	2.5	4.3	9.9	18.0	25.7
CW3	17 Jun	34	1.9	2.8	4.9	11.4	26.5	1.7	4.0	9.3	16.7	24.6
CW4	24 Jun	24	1.7	3.7	4.7	11.0	25.4	1.8	4.2	9.9	12.5	26.9
CW5	1 Jul	6	3.2	5.0	9.6	13.7	13.9	3.3	3.4	4.8	9.1	14.3
CW6	8 Jul	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PL1	3 Jun	31	1.3	3.0	4.9	12.5	49.4	0.9	3.7	9.4	15.5	35.4
PL2	10 Jun	44	1.7	2.8	5.1	12.1	66.3	0.7	3.8	9.1	16.3	26.4
PL3	17 Jun	42	1.5	2.5	4.5	12.5	38.0	1.2	3.7	10.3	18.8	30.9
PL4	24 Jun	43	1.6	2.7	5.8	22.0	63.1	0.7	2.1	7.9	16.9	28.0
PL5	1 Jul	14	2.7	4.8	6.1	13.9	27.8	1.7	3.3	7.5	9.6	17.1
PL6	8 Jul	2	3.9	5.1	5.5	2.8	7.0	6.6	16.4	8.4	8.9	11.8

Table 11. Continued.

			Travel time (days)					Migration rate (km/day)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
BC1	3 Jun	23	1.4	3.6	6.3	11.4	24.9	1.8	4.0	7.3	12.7	31.9
BC2	10 Jun	26	1.8	3.1	5.4	9.2	56.2	0.8	5.0	8.6	14.8	26.1
BC3	17 Jun	58	1.0	3.0	6.0	15.6	40.5	1.1	3.0	7.7	15.3	44.7
BC4	24 Jun	45	1.0	2.8	4.3	18.5	49.0	0.9	2.5	10.8	16.5	46.5
BC5	1 Jul	10	2.0	3.5	4.8	10.7	13.3	3.5	4.3	9.6	13.0	22.8
BC6	8 Jul	2	4.1	10.6	12.2	8.2	20.4	2.3	5.6	3.8	4.3	11.3

Table 12. Travel times and migration rates between Lower Monumental Dam and McNary Dam (119 km) for hatchery subyearling fall chinook salmon released at Pittsburg Landing (PL), Billy Creek (BC), and Big Canyon Creek (CW), 1997.

			Travel time (days)					Migration rate (km/day)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
CW1	3 Jun	16	2.4	2.9	3.5	5.9	6.9	17.2	20.0	34.1	40.5	49.0
CW2	10 Jun	4	2.9	6.4	7.7	8.2	10.2	11.6	14.5	15.4	18.7	41.0
CW3	17 Jun	30	2.3	3.0	4.4	6.5	11.2	10.7	18.4	27.2	39.9	52.2
CW4	24 Jun	18	2.5	3.7	5.5	18.0	48.5	2.5	6.6	21.8	32.5	47.0
CW5	1 Jul	8	2.6	4.0	7.5	22.9	43.8	2.7	5.2	16.0	29.9	46.3
CW6	8 Jul	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
PL1	3 Jun	22	2.2	2.9	4.6	8.6	16.7	7.1	13.8	25.9	41.6	54.1
PL2	10 Jun	21	2.7	3.4	3.8	6.0	10.1	11.8	19.8	31.5	35.4	44.7
PL3	17 Jun	35	2.9	3.5	4.6	8.7	44.6	2.7	13.6	25.7	33.9	41.6
PL4	24 Jun	28	2.9	3.4	5.2	8.8	64.2	1.9	13.5	22.8	34.9	41.6
PL5	1 Jul	13	3.7	5.9	7.9	34.5	58.7	2.0	3.4	15.1	20.3	31.9
PL6	8 Jul	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table 12. Continued.

			Travel time (days)					Migration rate (km/day)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
BC1	3 Jun	11	2.2	3.2	3.9	6.3	7.8	15.3	19.0	30.8	37.1	53.1
BC2	10 Jun	17	2.7	3.2	3.7	5.9	6.9	17.3	20.2	32.4	37.7	44.4
BC3	17 Jun	46	2.2	3.1	4.2	14.7	87.7	1.4	8.1	28.6	38.8	54.6
BC4	24 Jun	45	2.4	3.3	5.4	10.0	77.5	1.5	11.9	22.2	36.2	49.4
BC5	1 Jul	9	2.6	6.0	9.0	19.2	36.7	3.2	6.2	13.2	19.8	46.7
BC6	8 Jul	3	6.2	6.6	6.9	4.6	7.6	15.7	26.1	17.3	18.0	19.2

Table 13. Travel times and migration rates between the point of release and McNary Dam for hatchery subyearling fall chinook salmon released at Pittsburg Landing (PL, 398 km), Billy Creek (BC, 317 km), and Big Canyon Creek (CW, 288 km), 1997.

			Travel time (days)					Migration rate (km/day)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
CW1	3 Jun	32	28.4	40.0	55.7	78.6	134.8	2.5	4.2	6.0	8.3	11.7
CW2	10 Jun	6	37.8	53.0	58.3	92.9	95.6	3.5	3.6	5.7	6.3	8.8
CW3	17 Jun	50	36.4	46.5	55.2	69.7	96.9	3.4	4.8	6.0	7.2	9.1
CW4	24 Jun	29	40.6	52.5	63.0	96.3	167.8	2.0	3.5	5.3	6.3	8.2
CW5	1 Jul	15	40.8	47.5	70.6	80.5	136.2	2.4	4.1	4.7	7.0	8.2
CW6	8 Jul	1	65.0	65.0	65.0	65.0	65.0	5.1	5.1	5.1	5.1	5.1
PL1	3 Jun	47	29.5	45.9	58.7	73.9	151.1	2.6	5.4	6.8	8.7	13.5
PL2	10 Jun	52	30.6	47.6	59.7	69.5	110.9	3.6	5.7	6.7	8.4	13.0
PL3	17 Jun	75	36.7	53.0	62.1	78.5	174.8	2.3	5.1	6.4	7.5	10.8
PL4	24 Jun	70	29.3	47.7	60.0	77.5	167.9	2.4	5.1	6.6	8.3	13.6
PL5	1 Jul	31	37.2	49.0	74.6	131.7	165.5	2.4	3.0	5.3	8.1	10.7
PL6	8 Jul	2	75.6	93.3	97.7	47.9	119.8	3.3	8.3	4.1	4.3	5.3

Table 13. Continued.

			Travel time (days)					Migration rate (km/day)				
Release	Date	N	Min.	20%	Median	80%	Max.	Min.	20%	Median	80%	Max.
BC1	3 Jun	24	27.7	37.1	59.0	73.7	96.1	3.3	4.3	5.4	8.5	11.4
BC2	10 Jun	34	29.0	47.1	60.2	71.5	93.8	3.4	4.4	5.3	6.7	10.9
BC3	17 Jun	77	37.8	52.0	60.7	86.3	171.4	1.8	3.7	5.2	6.1	8.4
BC4	24 Jun	89	38.5	49.6	64.5	90.8	172.5	1.8	3.5	4.9	6.4	8.2
BC5	1 Jul	25	38.0	64.7	77.7	113.7	157.7	2.0	2.8	4.1	4.9	8.3
BC6	8 Jul	3	31.6	52.2	65.9	40.4	67.3	4.7	7.8	4.8	6.1	10.0

Table 14. Pre- and post-release attributes of natural and hatchery subyearling fall chinook salmon by release location in 1997. Release groups of hatchery fish chosen to match release dates of natural fish. Survival to Lower Granite Dam is presented as probability, with standard error in parentheses. All other attributes are reported as medians with 25th and 75th percentiles in parentheses. Abbreviations: LGR = Lower Granite Dam and LGO = Little Goose Dam.

	Natural subyearlings			Hatchery subyearlings		
	Upstream	Midstream	Downstream	Pittsburg Landing	Billy Creek	Big Canyon Creek
Fork length at release (mm)	77 (71 - 85)	80 (68 - 89)	73 (66 - 82)	80 (76 - 83)	81 (77 - 85)	82 (78 - 86)
Travel time to LGR (days)	33.5 (21.2 - 47.8)	25.2 (15.4 - 37.5)	31.5 (20.5 - 43.4)	34.9 (28.3 - 37.4)	35.3 (28.4 - 45.4)	36.4 (29.0 - 45.2)
Est. survival to tailrace of LGR	0.565 (0.074)	0.305 (0.049)	0.317 (0.029)	0.573 (0.036)	0.573 (0.018)	0.407 (0.020)
Fork length at LGO (mm)	133 (127 - 141.5)	129 (119 - 136.5)	136 (123.5 - 151)	110 (106.5 - 116)	123 (116 - 137)	118 (107 - 120.5)
Weight at LGO (g)	25.6 (22.7 - 30.8)	26.0 (18.8 - 30.7)	29.0 (20.2 - 39.2)	15.7 (13.7 - 18.0)	22.4 (17.6 - 31.6)	18.5 (13.3 - 21.5)
Condition factor at LGO (K)	1.10 (1.06 - 1.16)	1.17 (1.09 - 1.22)	1.18 (1.09 - 1.22)	1.14 (1.10 - 1.19)	1.20 (1.14 - 1.27)	1.13 (1.09 - 1.22)
Growth rate release to LGO (mm/day)	1.15 (1.04 - 1.25)	1.42 (1.25 - 1.51)	1.35 (1.29 - 1.42)	1.11 (0.89 - 1.22)	1.22 (0.98 - 1.39)	1.13 (1.06 - 1.19)

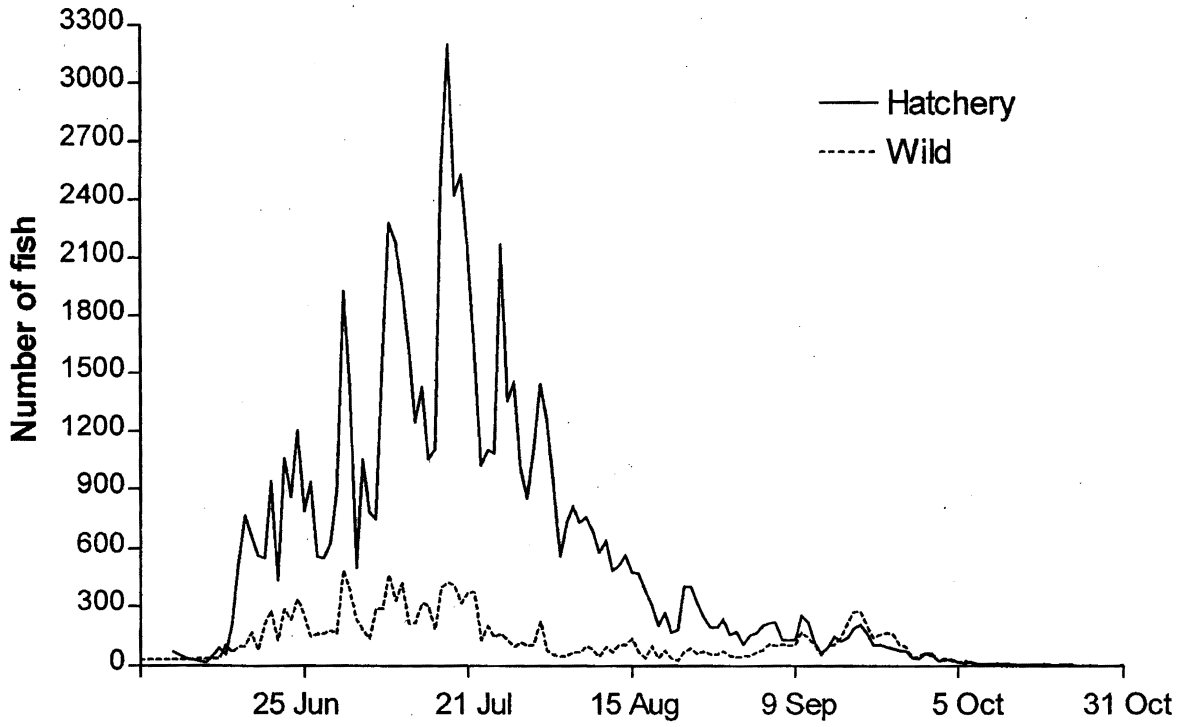

Figure 5. Passage distributions of wild and hatchery subyearling fall chinook salmon at Lower Granite Dam in 1997.

Residualization--PIT-Tag Detections in Spring 1998

A total of 461 fish (2.0%) from primary groups of hatchery fall chinook salmon released as subyearlings in 1997 were detected at Snake and Columbia River Dams in spring 1998 (Table 15). Detections of overwintered fall chinook salmon began soon after the juvenile bypass systems began operation in 1998 (Fig. 6), indicating that some hatchery fall chinook salmon probably migrated from rearing areas to the lower Snake River in 1997 and spent the winter in the reservoirs between dams. However, because detection systems at Snake and Columbia River dams were not operational until 26 March to 5 April, we were unable to determine exactly in which reservoir fish residualized or when the holdovers resumed migrating in 1998. Holdovers were detected into early May 1998. Among the three release sites, fish released at Big Canyon Creek were detected in 1998 at the lowest rate (0.9%), probably because of lower survival rates in 1997 (Table 7). Percentages of fish released at Pittsburg Landing (2.2%) and Billy Creek (3.1%) were slightly higher. The proportion of fish detected in 1998 was generally higher for groups released later in 1997 than for earlier release groups (Table 15).

In spring 1998, PIT-tagged yearling fall chinook salmon reared at Lyons Ferry Hatchery were released at Pittsburg Landing on the Snake River and at Big Canyon Creek on the Clearwater River. Of 9,942 yearlings released at Pittsburg Landing, about 70% were detected at least once as they migrated down the Snake River, and about 57% of 7,459 yearlings released at Big Canyon Creek were detected. We assumed fish from our 1997 primary release groups that overwintered were equally likely to be detected as yearlings released in 1998. That is, the 395 fish (Table 15) released in the Snake River and detected in 1998 represented 70% of the total that survived overwintering and migrated as yearlings, and the 66 fish from Clearwater River release groups detected in 1998 represented 57%. Thus, we estimated that 3.7% (2.6%/0.70) of subyearlings released in the Snake River in 1997 and 1.6% (0.9%/0.57) of those released in the Clearwater River actually migrated in spring 1998.

Little is known about the overwinter survival probability of residualizing subyearling fall chinook salmon. Most subyearlings that cease migrating probably remain in reservoirs where they likely have low metabolic needs because water temperatures are low. Low temperatures likely also result in low predation rates, resulting in higher overwinter survival. Assuming that winter survival for overwintering fish between 14 December 1997 and 1 April 1998 was about 65% regardless of release date or site, we estimated that 5.7% (3.7%/0.65) of the subyearlings released in the Snake River in1997 and 2.5% (1.6%/0.65) of those released in the Clearwater River did not migrate in 1997. That is, the proportions of fish that migrated from the Snake and Clearwater Rivers in 1997 were 94.3% and 97.5%, respectively.

Applying the adjustments for 1998 yearling detection probability and overwinter survival probability to the individual release groups (Table 15), the estimated proportion that migrated in 1997 ranges from 87.5 (24 June release from Billy Creek) to 99.5% (3 June release from Big Canyon Creek).

Table 15. Detections (percent) in spring 1998 of hatchery fall chinook salmon released as subyearlings in 1997 at Pittsburg Landing and Billy Creek on the Snake River and Big Canyon Creek on the Clearwater River. Standard errors is parentheses.

	Percent detected in spring 1998			
Release date	Big Canyon Creek	Billy Creek	Pittsburg Landing	Total
3 Jun	2 (0.2)	4 (0.3)	8 (0.6)	14 (0.4)
10 Jun	3 (0.2)	4 (0.3)	14 (1.1)	21 (0.6)
17 Jun	20 (1.6)	52 (4.2)	24 (1.9)	96 (2.6)
24 Jun	18 (1.4)	71 (5.7)	50 (4.0)	139 (3.7)
1 Jul	15 (1.2)	65 (5.2)	40 (3.2)	120 (3.2)
8 Jul	8 (0.6)	35 (2.8)	28 (2.2)	71 (1.9)
All dates	66 (0.9)	231 (3.1)	164 (2.2)	461 (2.0)

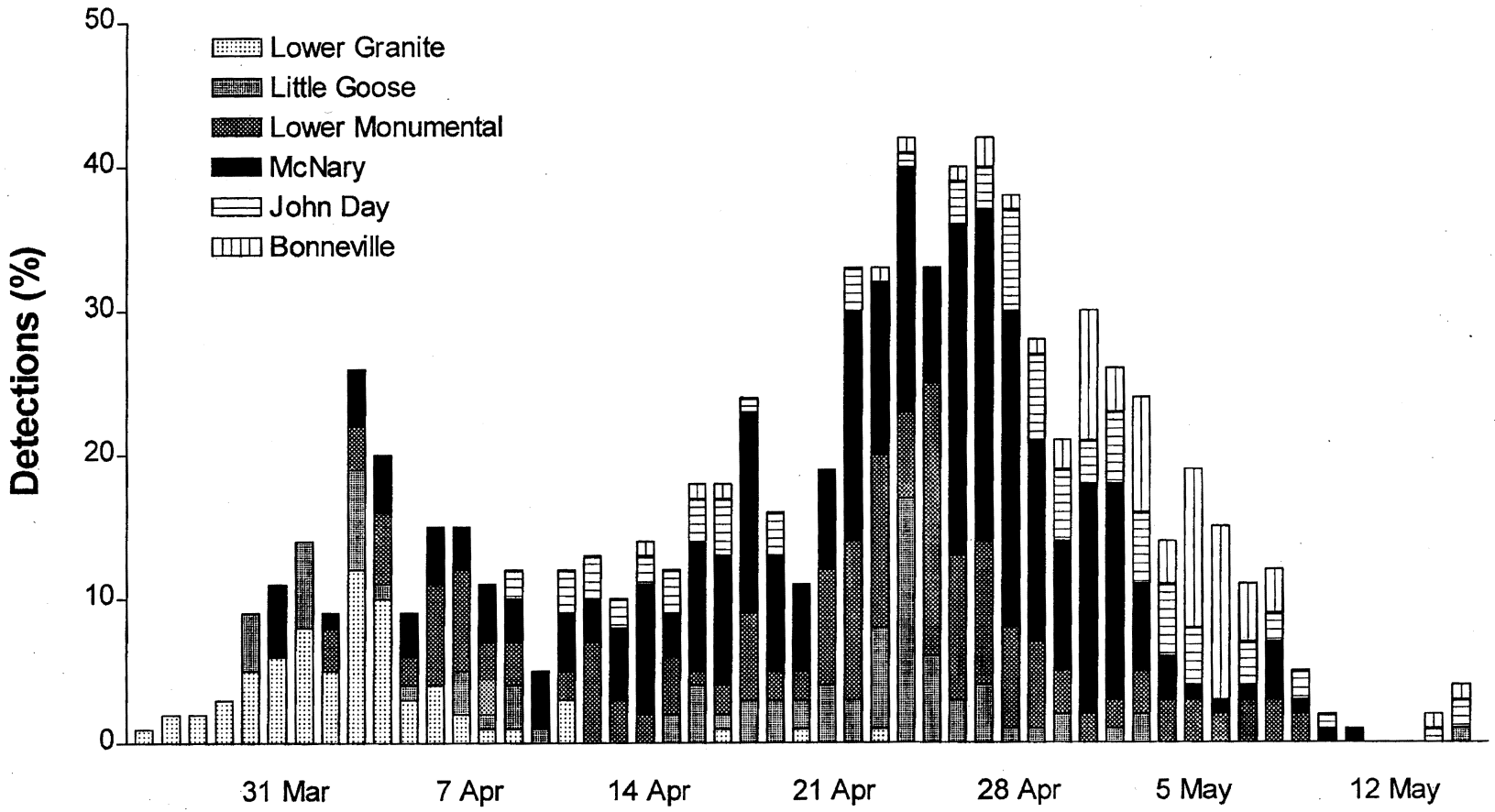

Figure 6. Detections and locations of detections in spring 1998 of PIT-tagged hatchery fall chinook salmon released above Lower Granite Dam in 1997.

Survival, Travel Time, and Environmental Variables

From release to Lower Granite Dam tailrace, survival estimates were highest for the earliest release groups, and declined for groups released on later dates. A similar trend of decreasing survival over time was also observed in 1995 and 1996 (Fig. 3). During sampling times within these years, flows and turbidity generally decreased and water temperatures generally increased (Fig. 7). Relationships between survival and environmental variables from point of release to Lower Granite Dam tailrace within years were strong and consistent from year to year (Table 16, Figs. 8,-10). For the years combined (1995, 1996, and 1997), the correlation was greatest with water temperature (higher survival with cooler water), followed by flow (higher survival with higher flow volumes), and turbidity (higher survival with more turbid water).

The relationship between estimated survival and median travel time for the release groups has not been consistent from year to year (Fig. 11). The correlation between survival and travel time was not significant within 1995 and 1996, but was highly significant in the high-flow year 1997. Median travel time was also highly significantly correlated with the environmental variables in 1997, and was not within 1995 and 1996 (Table 16, Figs. 12-14). In 1997, travel times from release to Lower Granite Dam tended to increase (migration rate tended to decrease) throughout the season, as flow decreased, temperature increased, and turbidity decreased. Travel time relationships in previous years suggested a curved response, with the shortest travel times (fastest migration rates) occurring at intermediate levels of the environmental variable.

In the reaches below Lower Granite Dam, narrow ranges of exposure levels within 1995 and 1996 made examination of relationships among survival and travel time and environmental variables difficult (Table 17, Figs. 15-18). However, PIT-tagged subyearling chinook salmon leaving Lower Granite Dam experienced wider ranges of environmental exposures in 1997. Relationships between estimated survival and environmental variables from Lower Granite Dam tailrace to Lower Monumental Dam tailrace were highly significant within 1997, and very similar in nature to the relationships for the reach above Lower Granite Dam. As in the upper reach, the correlation was greatest with water temperature (higher survival with cooler water), followed by flow (higher survival with higher flow volumes), and turbidity (higher survival with more turbid water). Relationships between environmental variables and survival have not been consistent between years, partly because of narrow ranges of exposures in 1995 and 1996, so that when the years are combined in a single analysis, no significant linear correlation exists in this reach.

Relationships with environmental exposures have been stronger and more consistent between years for median travel time between Lower Granite and Lower Monumental Dams than for survival (Figs. 19-21). Travel time relationships also tended to be stronger in 1997, but the directions of the correlation were the opposite of those seen in the upper reach; travel times from Lower Granite Dam to Lower Monumental Dam tended to decrease (migration rate increased) throughout the season, while flow decreased, temperature increased, and turbidity decreased. Between Lower Granite Dam and Lower Monumental Dam, the longest travel times in 1997 were associated with the highest flows.

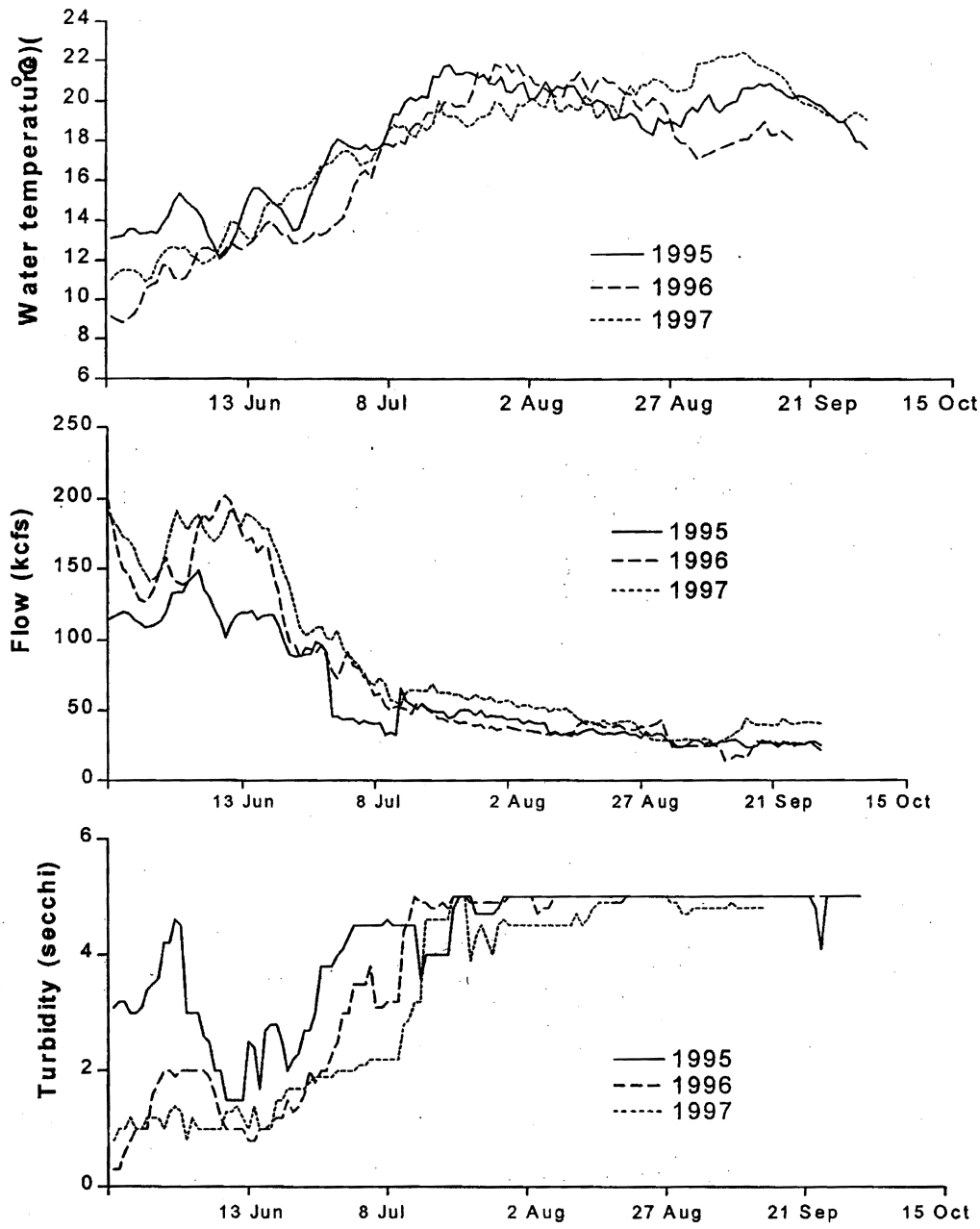

Figure 7. Environmental variables measured at Lower Granite Dam during the subyearling fall chinook migration, 1995-1997.

Table 16. Coefficient of determination (r^2) for relationships among travel time, flow, water temperature, turbidity, and survival from point of release to Lower Granite Dam tailrace for 1995, 1996, and 1997 release groups within single years and combined in single analysis.

		Correlation with			
Variable	Groups	Flow	Temperature	Turbidity	Travel time
Travel Time	1995	25.3	31.3	16.6	---
	1996	0.4	1.3	0.4	---
	1997	57.3***	56.3***	65.8***	---
	1995 to 1997 (combined)	37.4**	21.5*	48.7***	---
Survival	1995	86.3***	83.9***	79.7***	30.9
	1996	81.2***	92.2***	89.6***	4.8
	1997	70.0***	70.9***	75.8***	55.9***
	1995 to 1997 (combined)	48.3***	60.1***	32.3**	3.3

* $P < 0.05$
** $P < 0.01$
*** $P < 0.001$

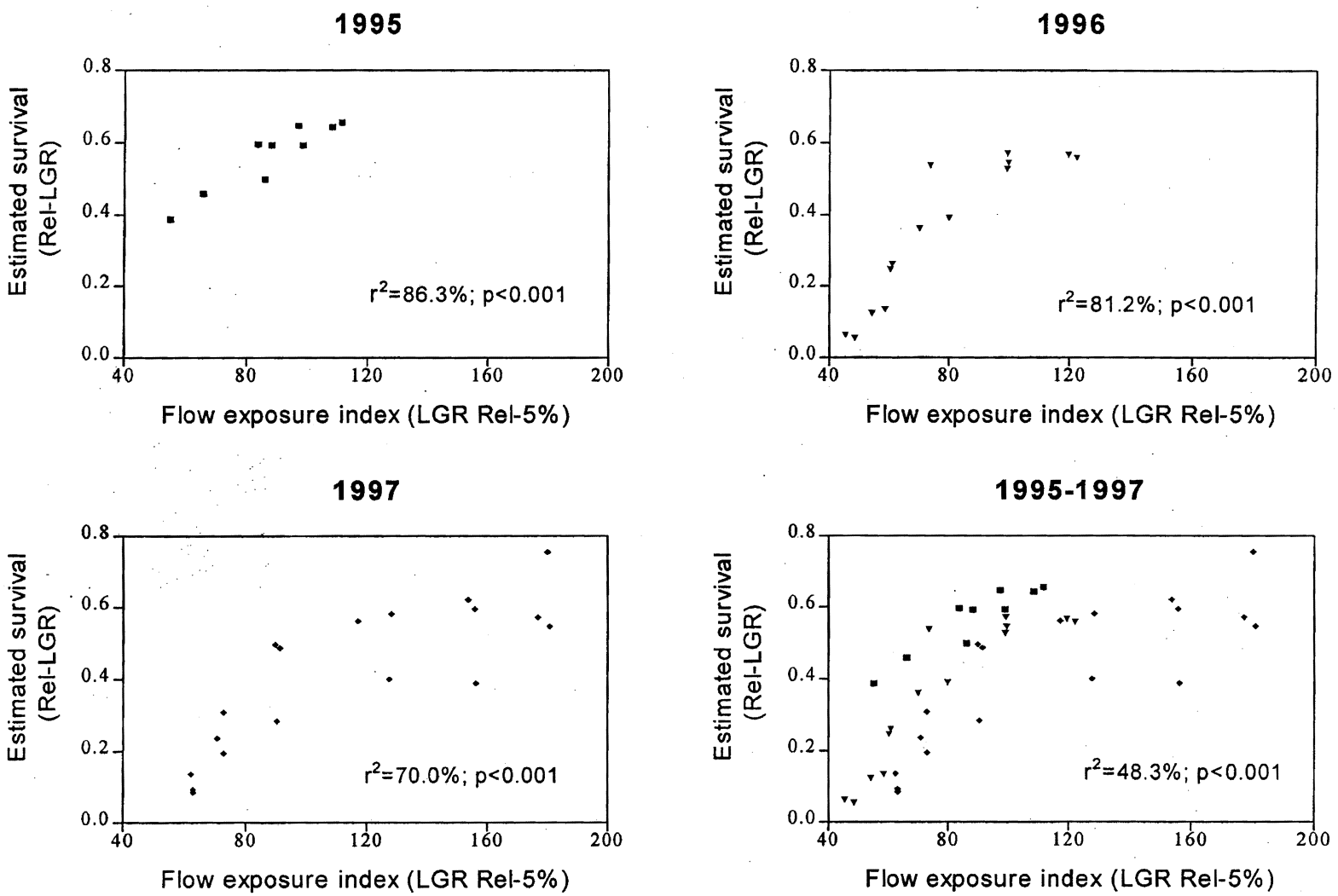

Figure 8. Estimated survival probability from point of release to Lower Granite Dam tailrace (Rel-LGR) vs. mean daily flow measured at Lower Granite Dam from release date to 5% passage date at Lower Granite Dam (LGR REL-5%) for 1995, 1996, and 1997.

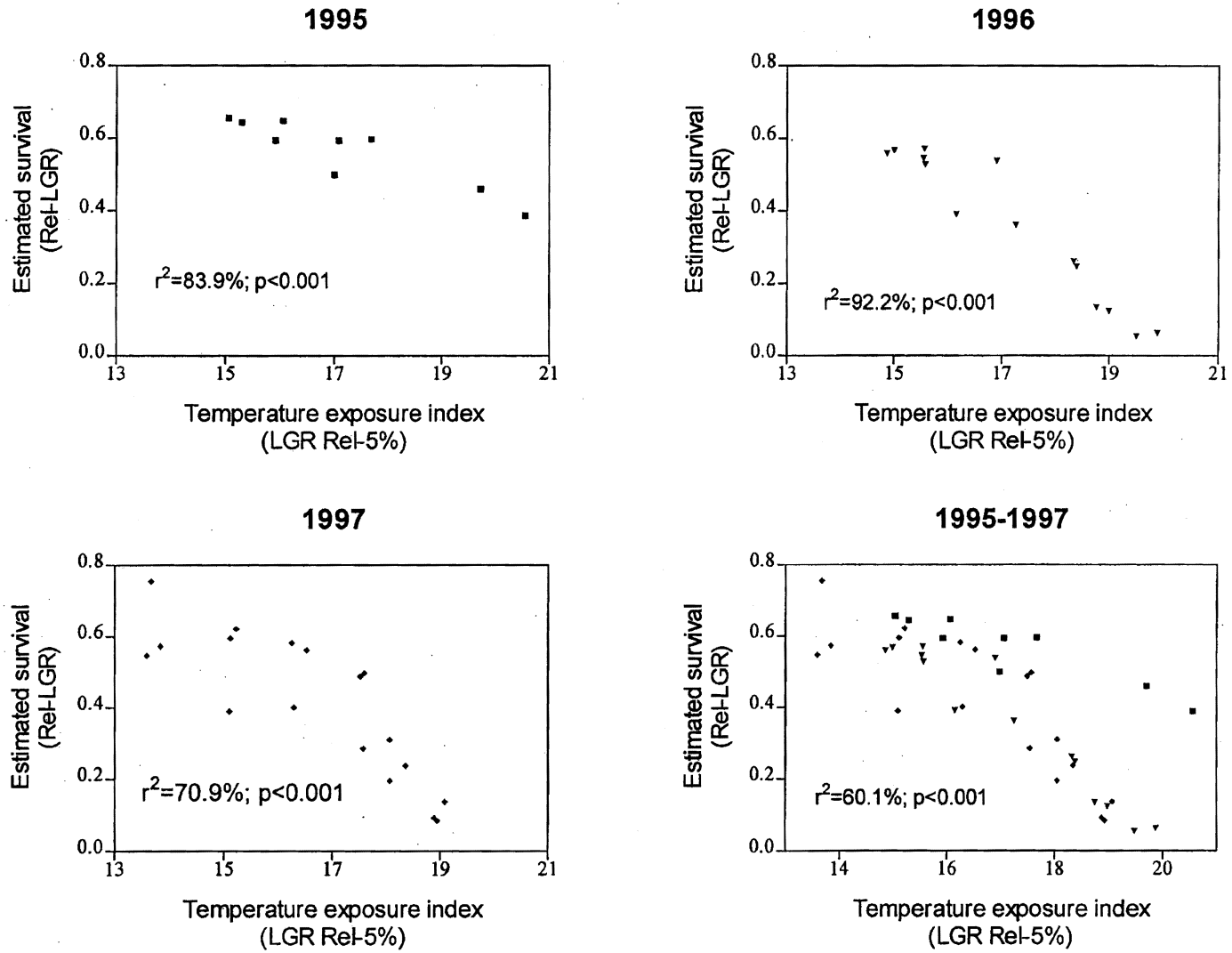

Figure 9. Estimated survival probability from point of release to Lower Granite Dam tailrace (Rel-LGR) vs. mean daily water temperature measured at Lower Granite Dam from release date to 5% passage date at Lower Granite Dam (LGR REL-5%) for 1995, 1996, and 1997.

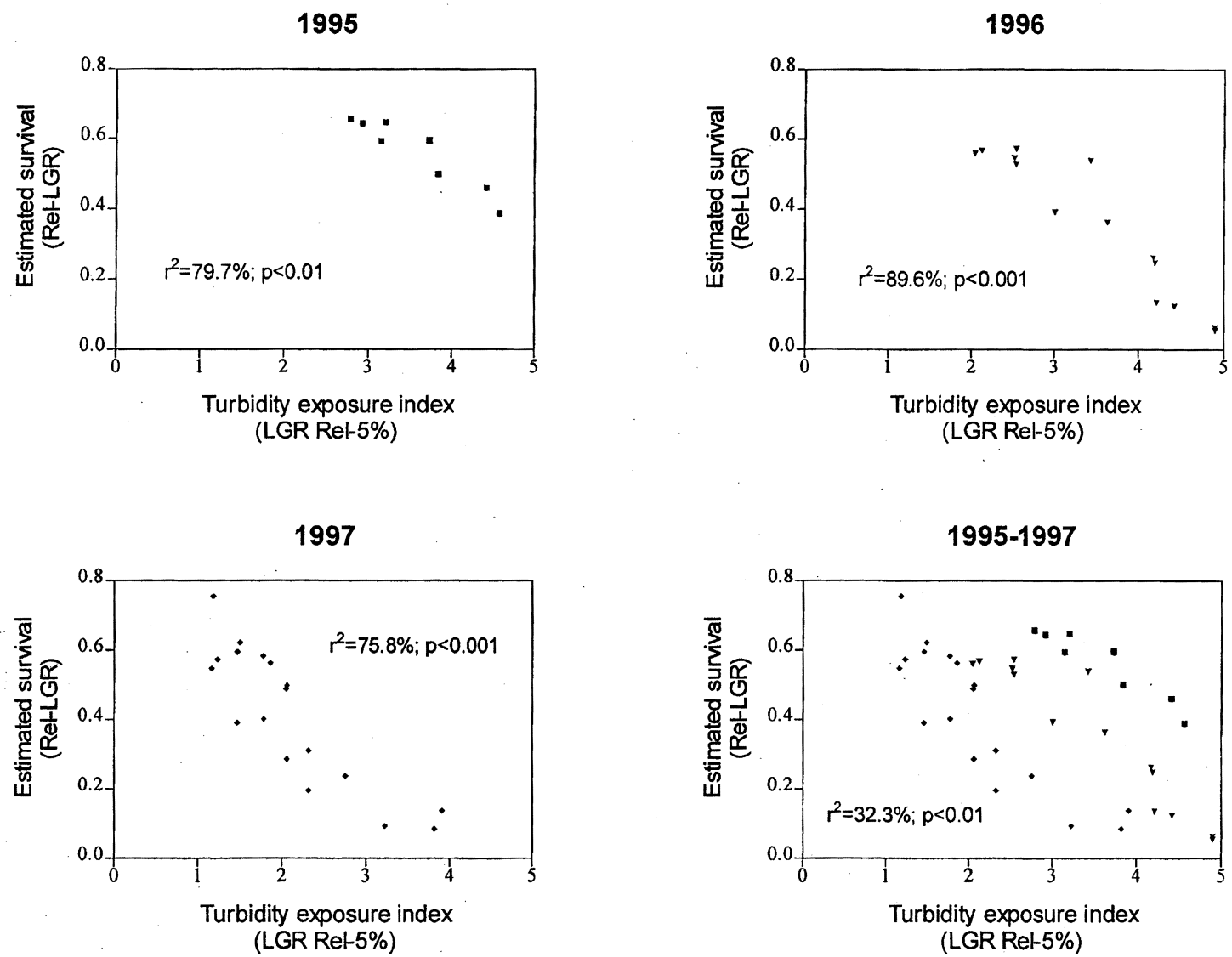

Figure 10. Estimated survival probability from point of release to Lower Granite Dam tailrace (Rel-LGR) vs. mean daily turbidity measured at Lower Granite Dam from release date to 5% passage date at Lower Granite Dam (LGR REL-5%) for 1995, 1996, and 1997.

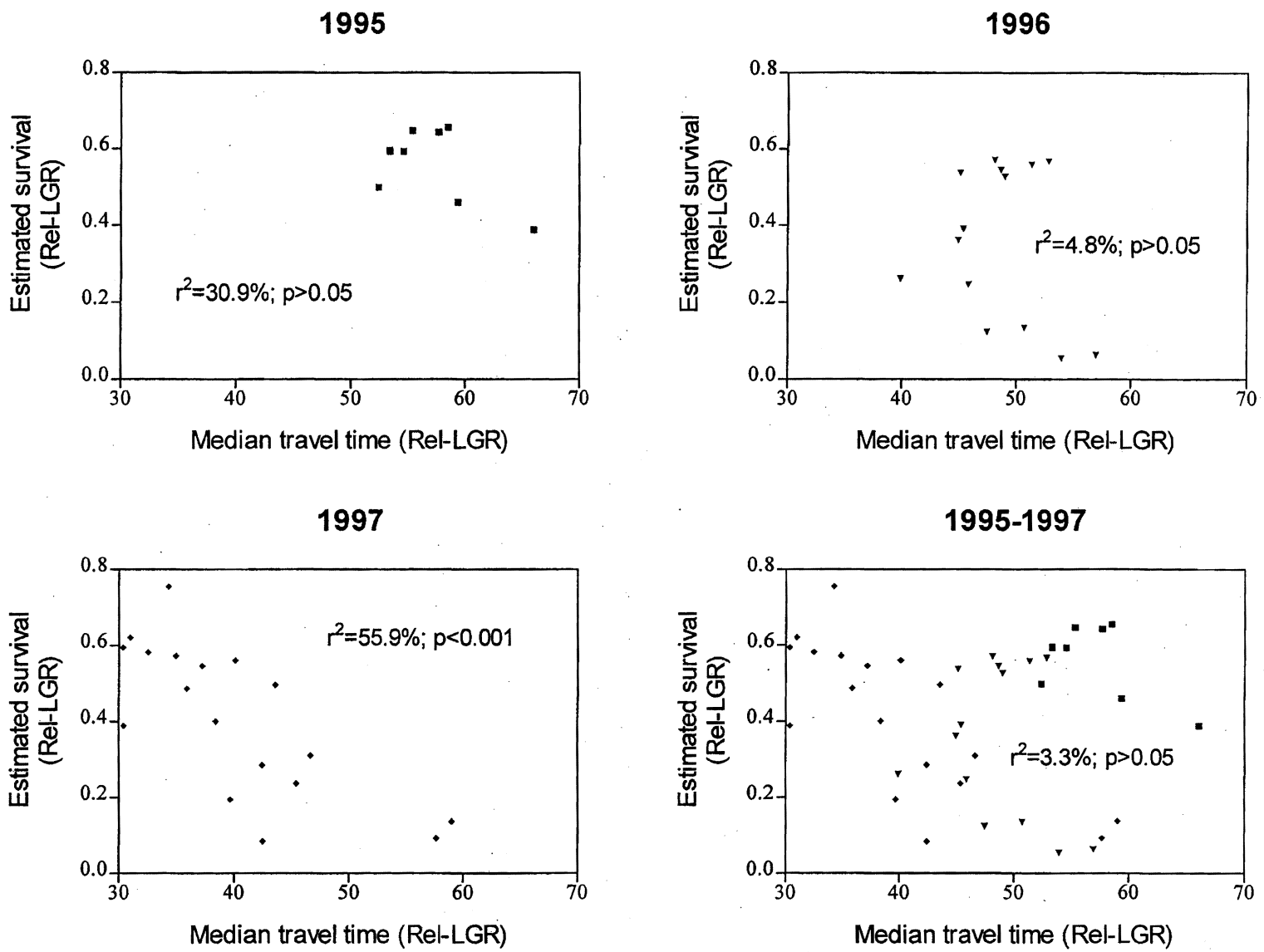

Figure 11. Estimated survival probability from point of release to Lower Granite Dam tailrace (Rel-LGR) vs. median travel time for 1995, 1996, and 1997.

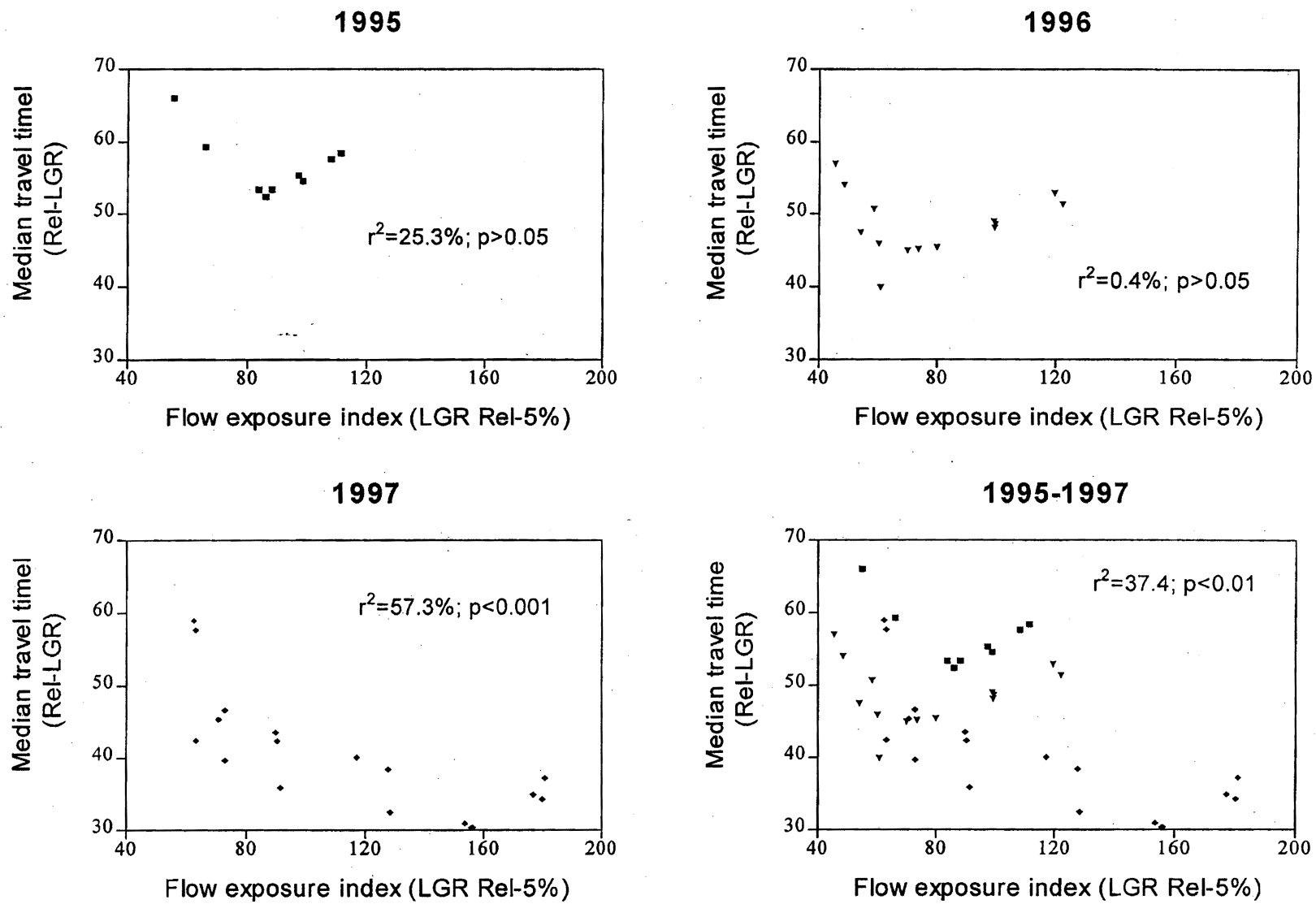

Figure 12. Median travel time from point of release to Lower Granite Dam tailrace (Rel-LGR) vs. mean daily flow measured at Lower Granite Dam from release date to 5% passage date at Lower Granite Dam (LGR REL-5%) for 1995, 1996, and 1997.

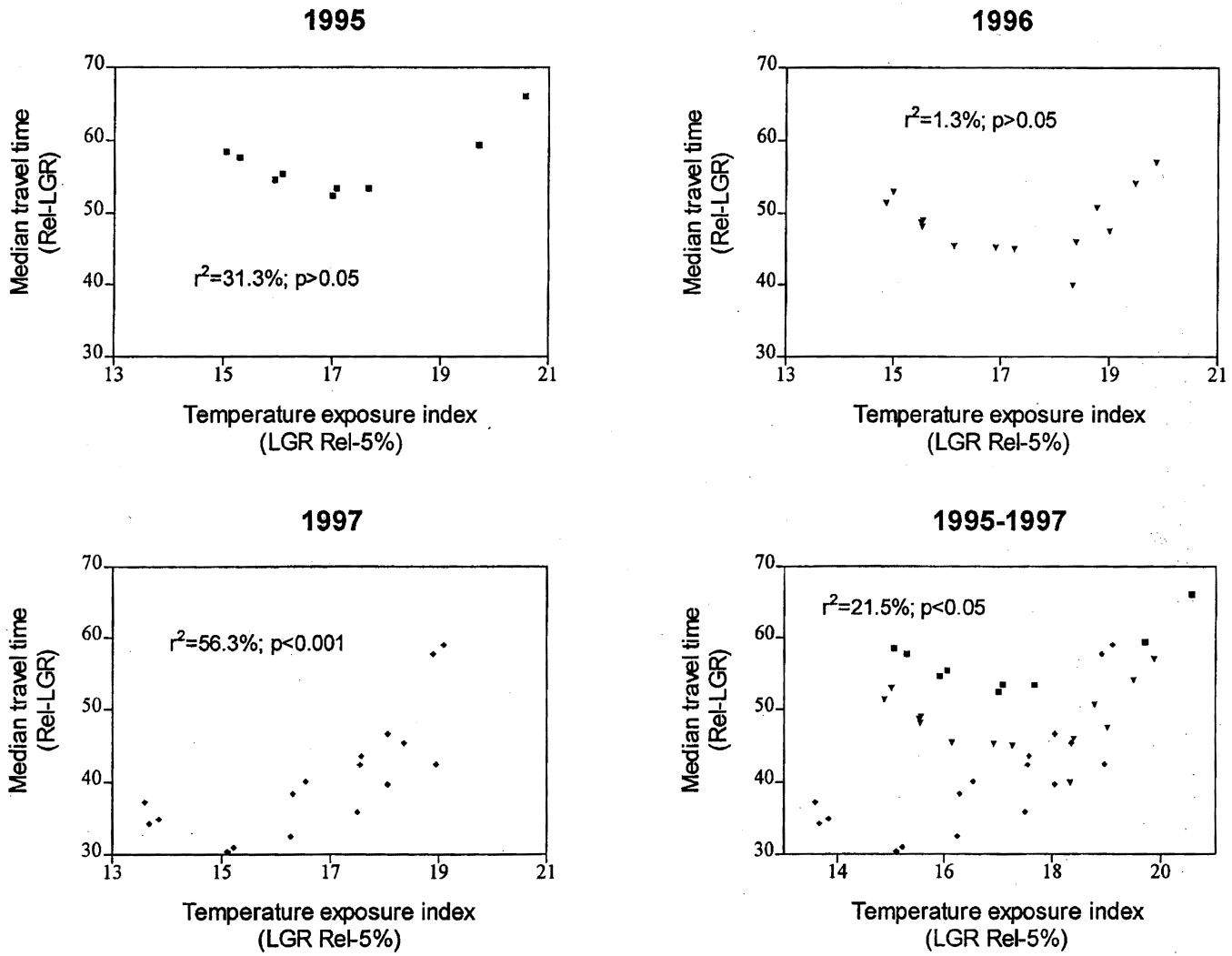

Figure 13. Median travel time from point of release to Lower Granite Dam tailrace (Rel-LGR) vs. mean daily water temperature measured at Lower Granite Dam from release date to 5% passage date at Lower Granite Dam (LGR REL-5%) for 1995, 1996, and 1997.

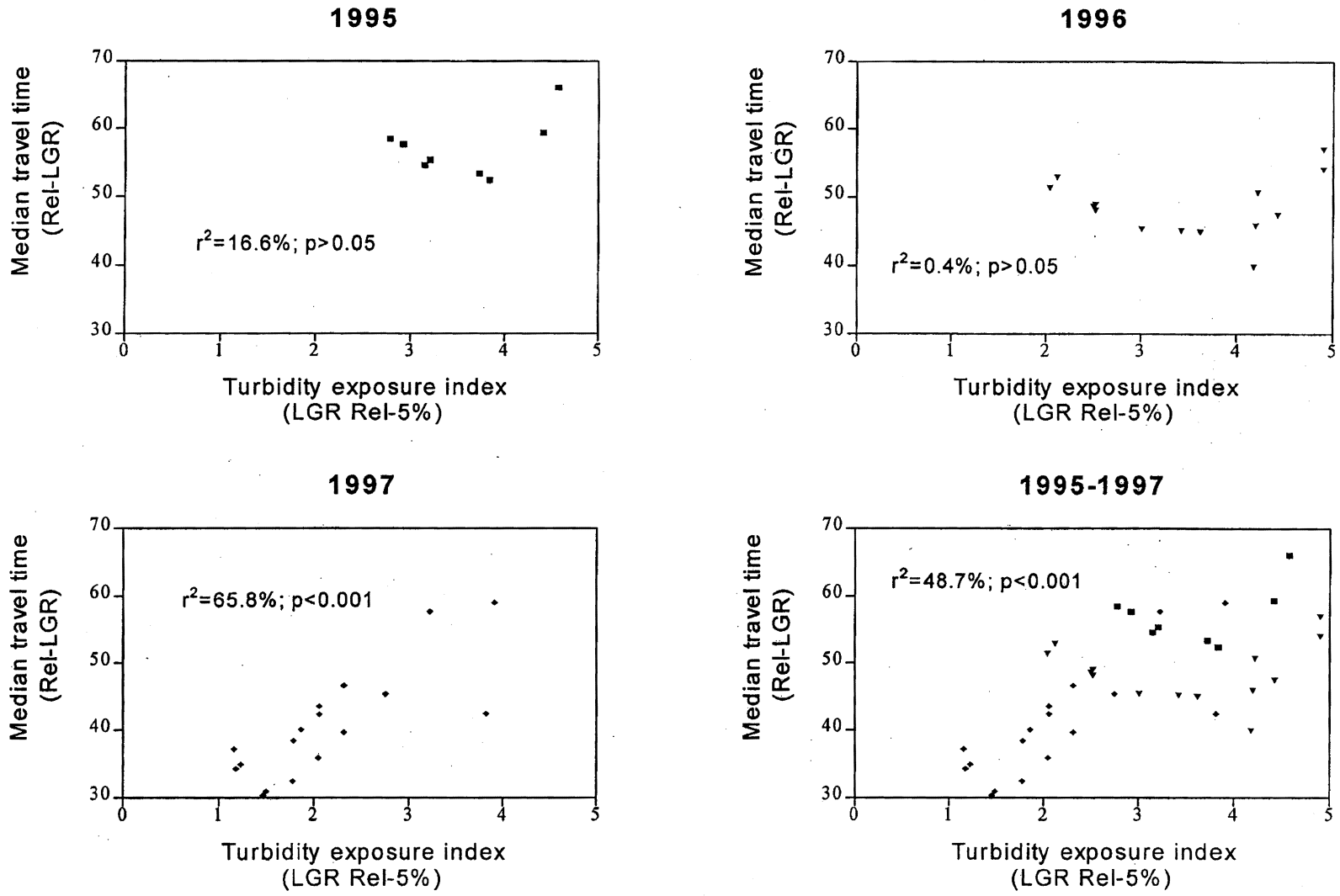

Figure 14. Median travel time from point of release to Lower Granite Dam tailrace (Rel-LGR) vs. mean daily turbidity measured at Lower Granite Dam from release date to 5% passage date at Lower Granite Dam (LGR REL-5%) for 1995, 1996, and 1997.

Table 17. Coefficient of determination (r^2) for relationships among travel time, flow, water temperature, turbidity, and survival from Lower Granite Dam tailrace to Lower Monumental Dam tailrace for 1995, 1996, and 1997 release groups within single years and combined in single analysis.

		Correlation with			
Variable	Groups	Flow	Temperature	Turbidity	Travel time
Travel Time	1995	57.2*	50.4*	43.7	---
	1996	78.8**	67.7*	44.4	---
	1997	53.0**	43.9**	38.5**	---
	1995 to 1997 (combined)	50.1***	48.6***	45.9***	---
Survival	1995	62.3*	64.6*	31.7	51.8
	1996	6.5	0.1	1.6	2.8
	1997	83.2***	85.6***	69.6***	27.6*
	1995 to 1997 (combined)	4.7	2.2	0.8	6.8

* $P < 0.05$
** $P < 0.01$
*** $P < 0.001$

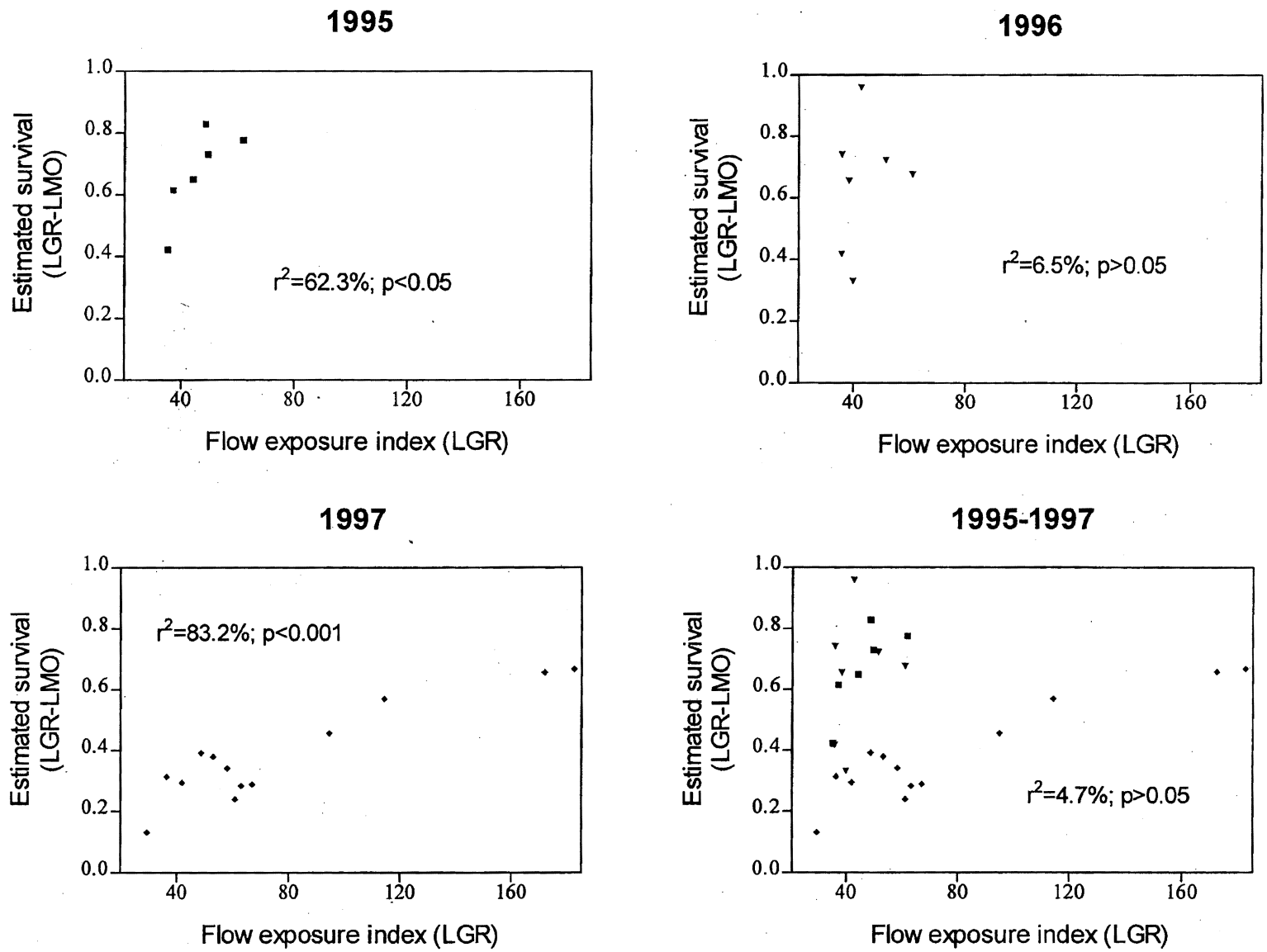

Figure 15. Estimated survival probability from Lower Granite Dam tailrace to Lower Monumental Dam tailrace (LGR-LMO) vs. mean daily flow measured at Lower Granite Dam during the weekly release period for 1995, 1996, and 1997.

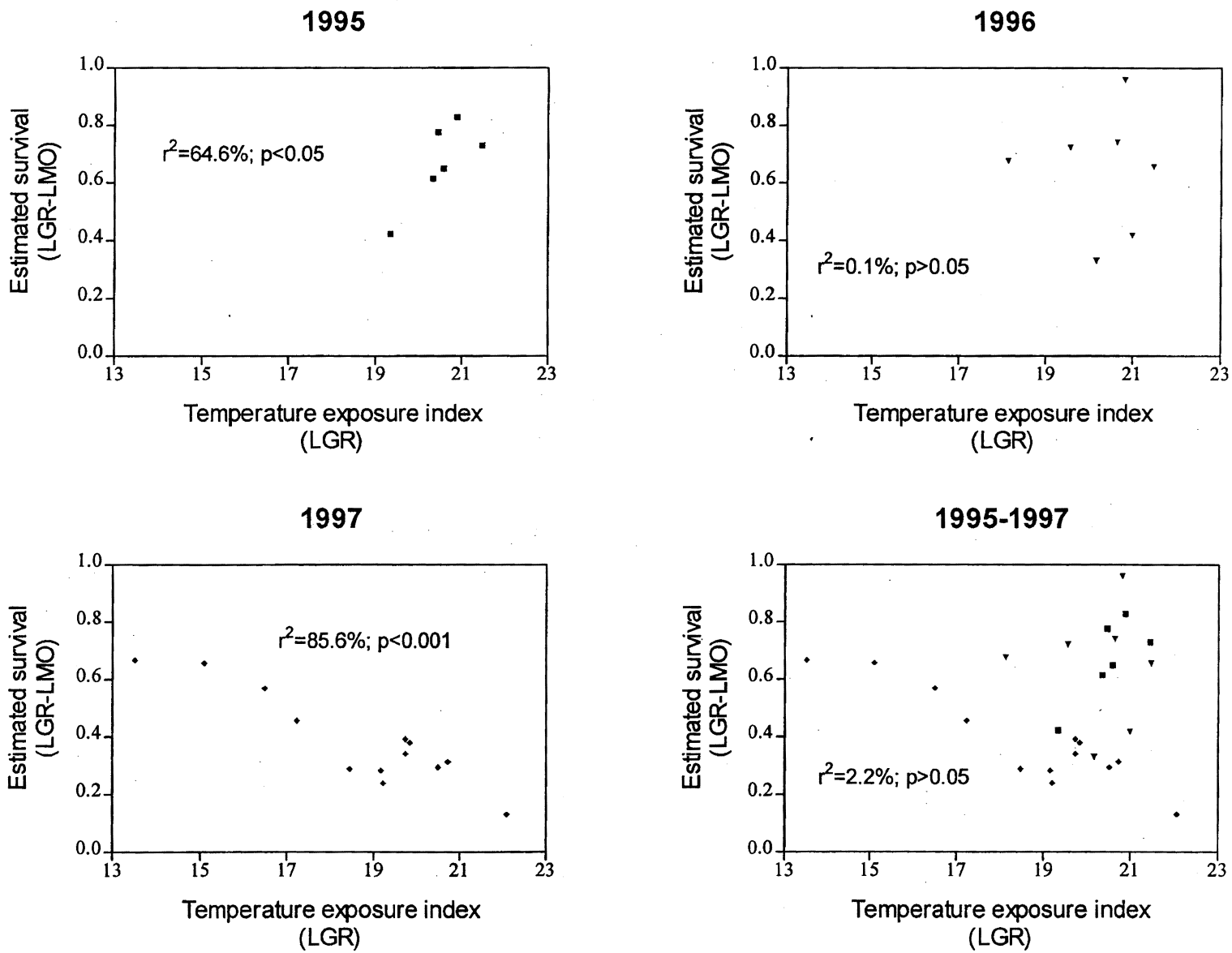

Figure 16. Estimated survival probability from Lower Granite Dam tailrace to Lower Monumental Dam tailrace (LGR-LMO) vs. mean daily water temperature measured at Lower Granite Dam during the weekly release period for 1995, 1996, and 1997.

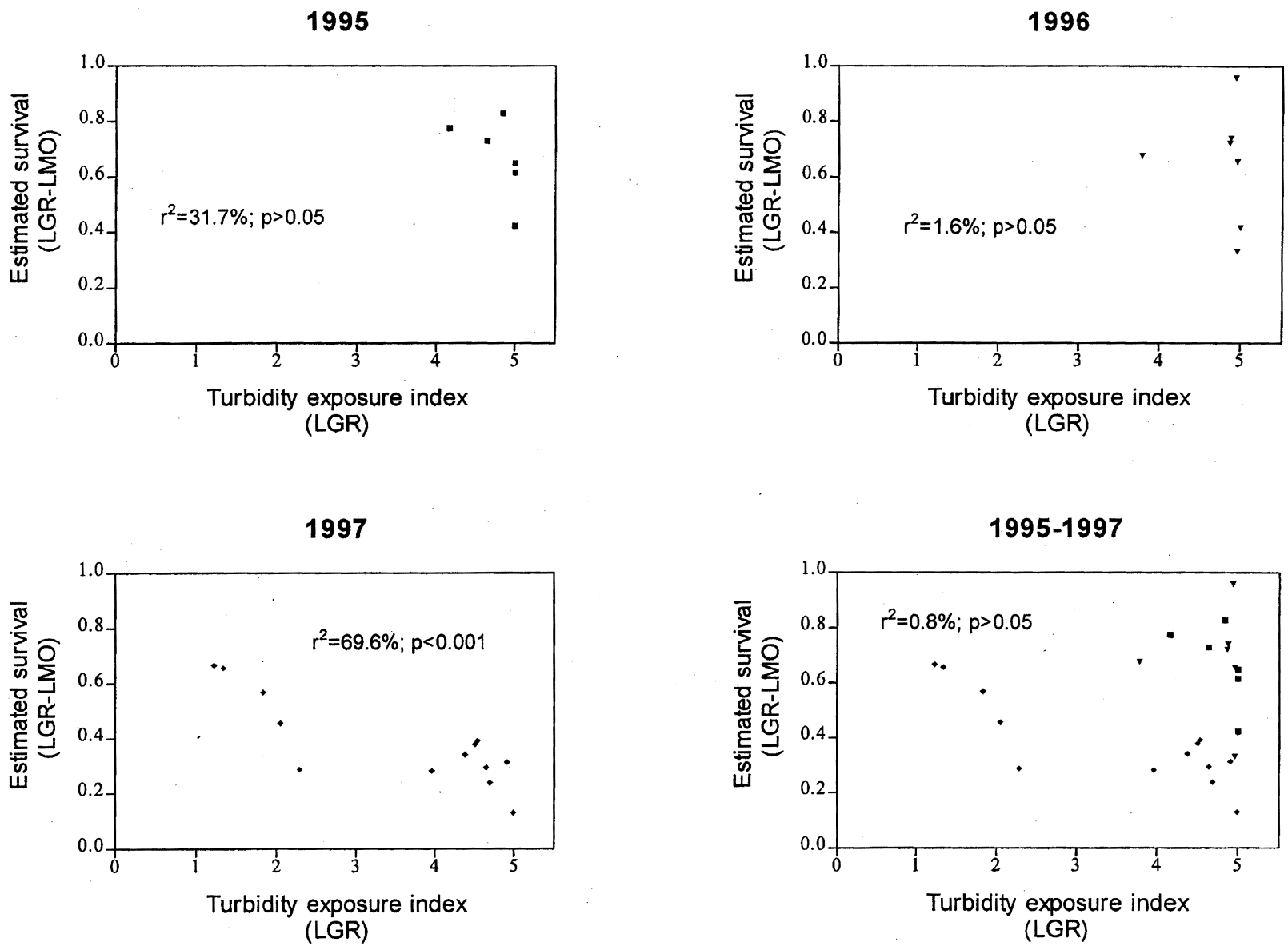

Figure 17. Estimated survival probability from Lower Granite Dam tailrace to Lower Monumental Dam tailrace (LGR-LMO) vs. mean daily turbidity measured at Lower Granite Dam during the weekly release period for 1995, 1996, and 1997.

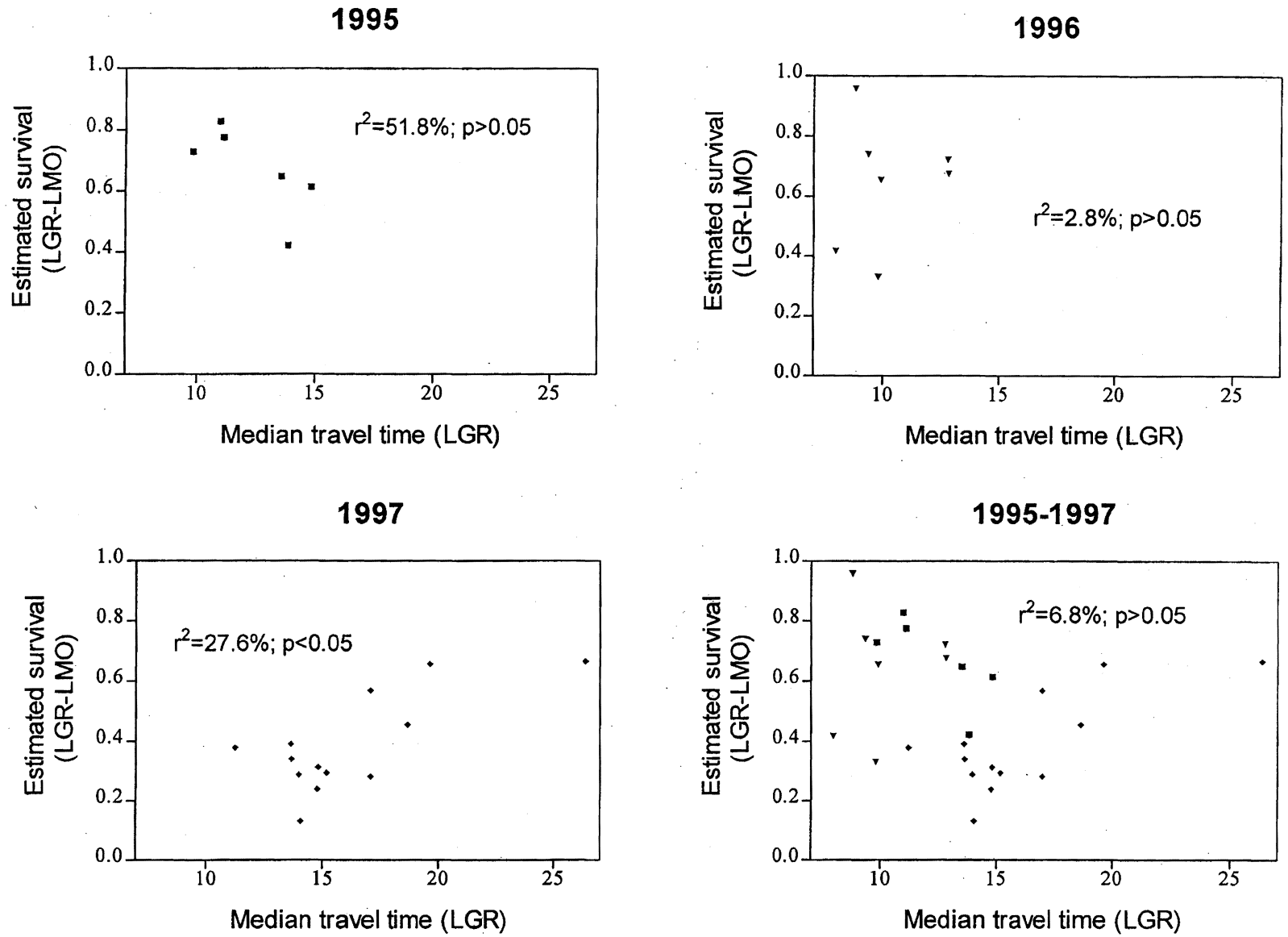

Figure 18. Estimated survival probability from Lower Granite Dam tailrace to Lower Monumental Dam tailrace (LGR-LMO) vs. median travel time for 1995, 1996, and 1997.

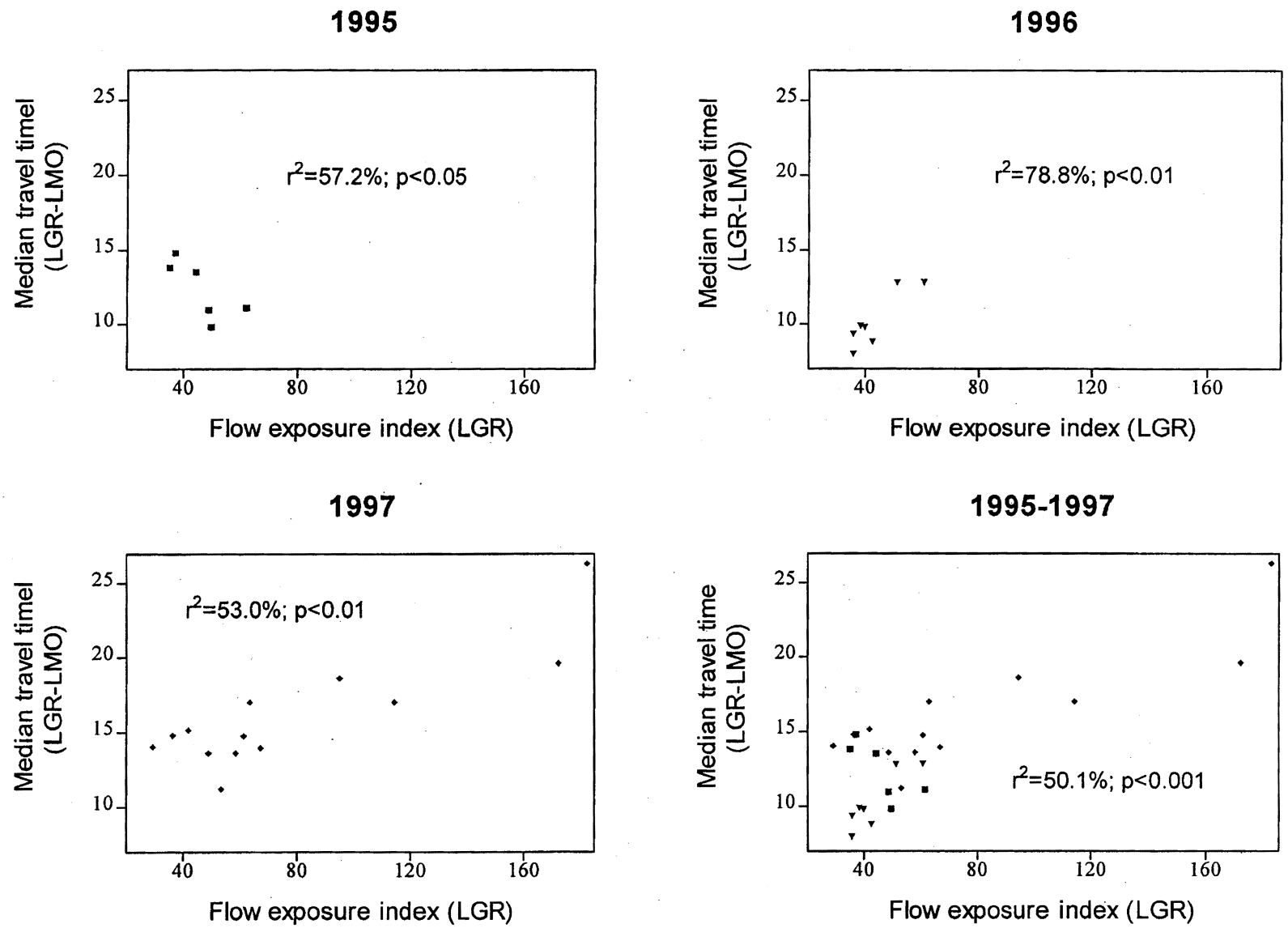

Figure 19. Median travel time from Lower Granite Dam tailrace to Lower Monumental Dam tailrace (LGR-LMO) vs. mean daily flow measured at Lower Granite Dam during the weekly release period for 1995, 1996, and 1997.

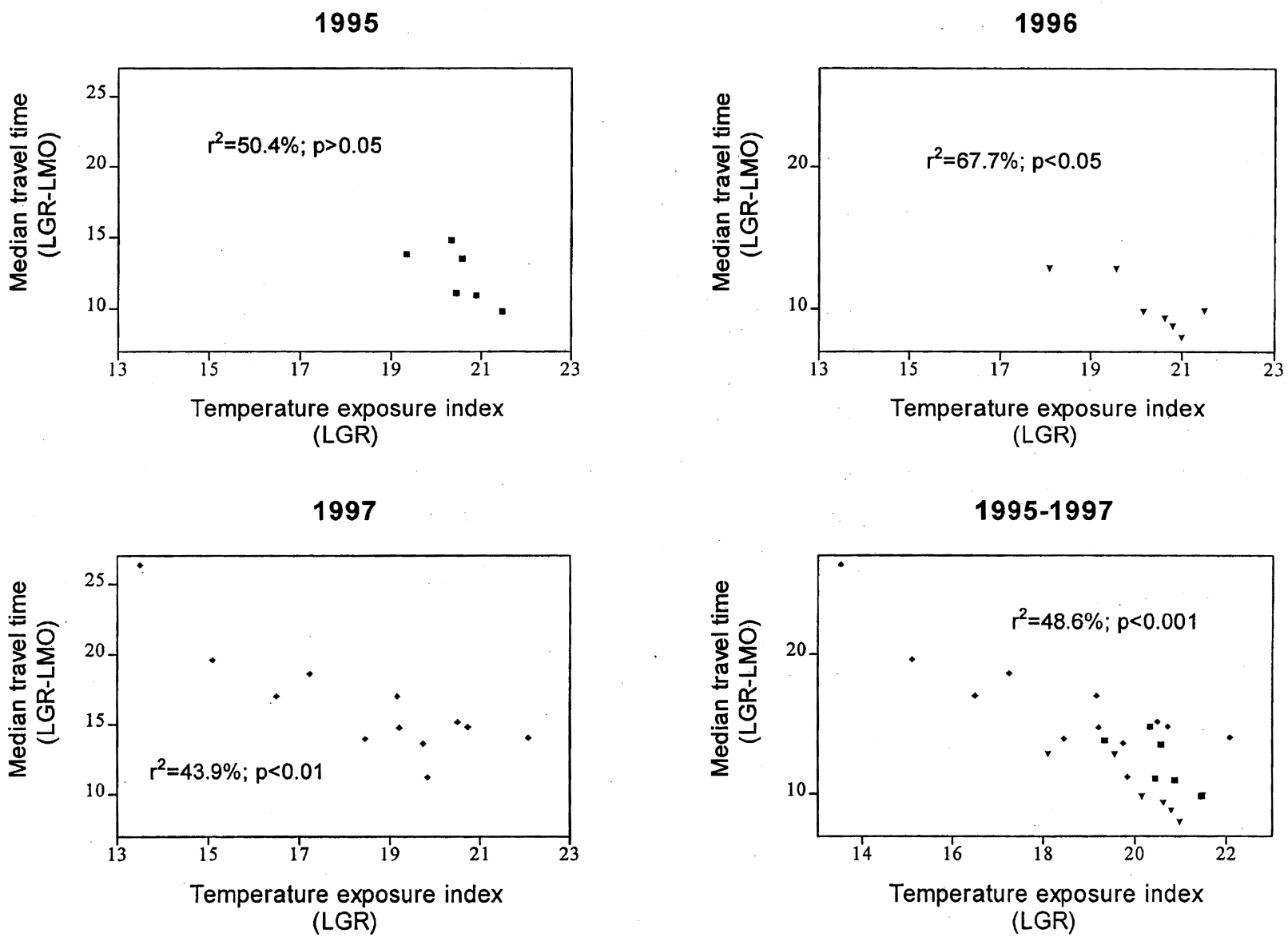

Figure 20. Median travel time from Lower Granite Dam tailrace to Lower Monumental Dam tailrace (LGR-LMO) vs. mean daily water temperature measured at Lower Granite Dam during the weekly release period for 1995, 1996, and 1997.

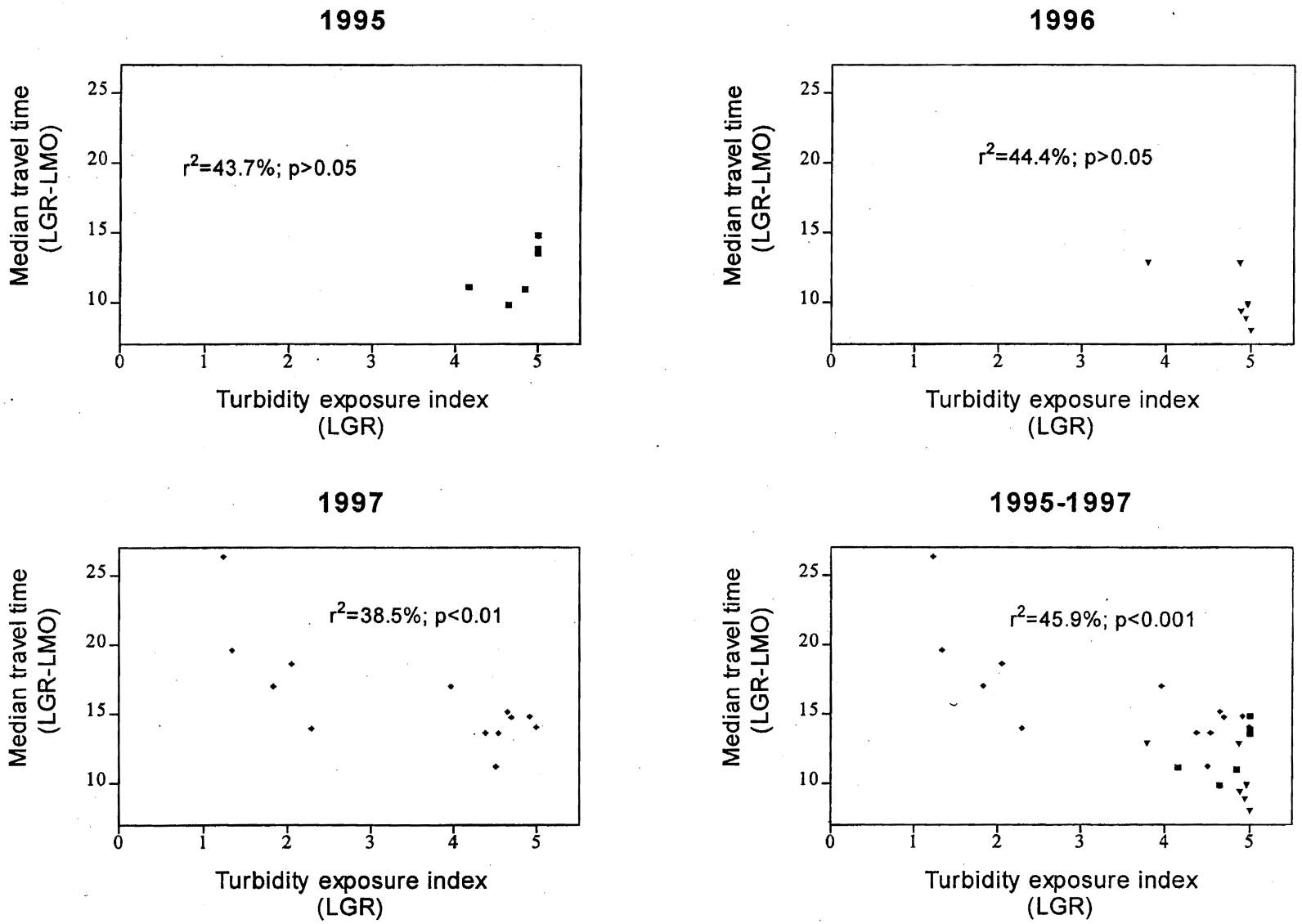

Figure 21. Median travel time from Lower Granite Dam tailrace to Lower Monumental Dam tailrace (LGR-LMO) vs. mean daily turbidity for 1995, 1996, and 1997.

DISCUSSION

As in past years, our release strategy resulted in hatchery subyearling chinook salmon with post-release attributes and survival probability estimates similar to natural fish migrating from the free-flowing Snake River. Use of hatchery subyearling fall chinook salmon as surrogates for natural subyearling fall chinook salmon appears feasible when hatchery fish are provided for research in a timely manner and are released at the appropriate size and time. Fish reared above Lower Granite Dam for an extended period after release, migrated past Lower Granite Dam during the summer months, and increased their rate of migration as they migrated downstream. Therefore, estimated survival probability for hatchery subyearling fall chinook salmon released in early June can be used as an index of survival for fall chinook salmon produced naturally in the Snake River. Estimated survival probability for hatchery fish released in mid-to-late June and early July can be used as an index of survival for late-hatching subyearling fall chinook salmon produced naturally in the Grande Ronde and Clearwater Rivers.

The life history of juvenile fall chinook salmon, particularly prolonged migrations and the tendency to residualize, presents some unique challenges for statistical analysis of capture-recapture data. Survival probability estimates we obtained were actually estimates of the joint probability of migrating before the PIT-tag interrogation system was shut down at McNary Dam on 14 December and the probability of surviving migration in that period. However, the small percentage that did not migrate as subyearlings (less than 6% estimated annually for 1995-1997) had minimal effect on subyearling survival estimates. An exact estimate would require operation of detection systems essentially year around. However, the shape of the distribution of yearling detections in the spring following the year of release indicates that relatively few migrating fish passed while detection systems were dewatered. An exception might occur during winter flood events when some winter passage has been documented (Connor et al. 1997a,b).

We estimated survival probabilities in 1997 for two segments of the Snake River fall chinook salmon migration corridor: 1) release to the tailrace of Lower Granite Dam, and 2) the reservoir reaches between Snake River Dams. We found survival probability estimates from release to the tailrace of Lower Granite Dam decreased markedly from early to late release dates. This trend was also evident for releases of hatchery subyearling chinook salmon made from all upstream release sites in 1995 and 1996. Based on data collected in all three years, the estimated survival from release to the tailrace of Lower Granite Dam was highly significantly correlated with flow, water temperature, and turbidity. Since the three environmental variables were also highly correlated with each other, determining which variable was most important to subyearling fall chinook salmon survival is difficult. Therefore, fishery managers are presented with a complex problem when implementing summer flow augmentation, since releases of water from Brownlee Reservoir increase flow through the free-flowing Snake River and Lower Granite Reservoir, but increase water temperature at the same time (Connor et al. 1997b). In contrast, flow augmentation from Dworshak Reservoir increases flow while decreasing water temperature. Also, fishery managers have notably little control of the turbidity of Lower Granite Reservoir, since in most years turbidity in all rivers upstream from Lower Granite Dam is low prior to the initiation of summer flow augmentation.

River flow, water temperature, and turbidity may affect survival probability estimates for hatchery subyearling fall chinook salmon in a number of ways. Delays in passage may occur under lower flows experienced by hatchery fish released late in the season, compared to those released early in the season. Hypothesized causes for lower survival are disorientation of migrants, increased exposure time to predators, reversal of smoltification, and disease (Park 1969, Raymond 1988, Berggren and Filardo 1993). Warmer water during later releases of hatchery subyearling fall chinook salmon would result in increased predation due to increased metabolic demands of predators (Vigg et al. 1991, Vigg and Burley 1991, Curet 1993). Vulnerability to sight-feeding predators would also be expected to increase as turbidity decreases (Hobson 1979, Zaret 1979) by decreasing predator reactive distance and increasing predator encounter rates (Vinyard and O'Brien 1976), as Shively et al. (1991) observed in Lower Granite Reservoir. Higher turbidity could reduce predation on juvenile salmonids by providing protective cover during rearing (Simenstad et al. 1982, Gregory 1993, Gregory and Levings 1998).

Predator abundance and feeding selectivity, in concert with decreasing flow and increasing water temperature, may have caused the steady decline in survival probability estimates from early to late release dates. Isaak and Bjornn (1996) found that the peak abundance of northern squawfish (*Ptychocheilus oregonensis*) in the tailrace of Lower Granite Dam occurred in July, during the subyearling fall chinook salmon migration. Poe et al. (1991) and Shively et al. (1996) found that predation rates depended on the size of juvenile salmonids, with smaller fish more vulnerable to predation. Fish size is one of the variables known to affect migration rates in fall chinook salmon, with smaller fish rearing longer in upstream areas before initiating migration (Connor et al. 1994a). Thus, small hatchery subyearling fall chinook salmon released late in the year may experience higher predation and lower survival. A similar fate is expected for later emerging natural fall chinook salmon and could account for the low survival probability estimates to the tailrace of Lower Granite Dam (17%) reported for fish from the Clearwater River (Connor et al. 1997a,b).

However, this low survival estimate may be confounded by unseasonably cold water releases from Dworshak Dam during the Clearwater River wild fall chinook salmon rearing period. Summer flow augmentation to cool the Snake River in July and August may have adverse affects on wild fall chinook salmon growth and may delay or inhibit subyearling smolt development in the Clearwater River (Arnsberg and Statler 1995).

Our findings regarding survival through the reservoirs between Snake River Dams have been less clear than those above Lower Granite Dam, primarily because the range of observed environmental exposures were too narrow in 1995 and 1996. However, a wider range of exposures was observed in 1997, and the relationships between estimated survival and environmental factors were very similar to those observed in all three years above Lower Granite Dam.

Estimated survival through reaches below Lower Granite Dam was lower in 1997 than in the two previous years of the study. We believe this was due to the higher flows observed in June and July 1997 that resulted in fish migrating sooner in the year, and consequently arriving at

the Snake River dams at a substantially smaller size than in 1995 and 1996 (from 30 to 40 mm smaller). The higher flows also increased the amount of debris at the Snake River Dams, resulting in blockages within the bypass systems. In particular, blockages in the PIT-tag portions of the bypass systems required additional dewatering. Delayed mortality was higher for natural subyearling fall chinook salmon at Little Goose Dam during 1997 (7.7%) compared to 1995 (2.2%) and 1996 (1.4%), and higher than normal levels of columnaris were observed (Rex Baxter, U.S. Army Corps of Engineers, pers. commun., November 1998).

Relating travel time of actively migrating subyearling fall chinook salmon to environmental variables through reservoir reaches has proven difficult for researchers and has produced conflicting results (Berggren and Filardo 1993, Giorgi et al.1994). Giorgi et al. (1997) found that PIT-tagged subyearling chinook salmon in the mid-Columbia River showed no response to flow or temperature, although there was a significant positive correlation between fish length and migration rate. Fish in their analysis were substantially smaller than migrant Snake River subyearling chinook salmon. Additional years of data with variable environmental conditions will help define the relationships between survival of hatchery subyearling fall chinook salmon and travel time, flow, water temperature, and turbidity.

Although we assumed that post-detection bypass survival was 100%, based on evaluations during the spring migration in the Snake River (Iwamoto et al. 1994; Muir et al. 1995, 1996), some mortality might have occurred. To resolve this issue in the future will require releases of fish that are of the appropriate size and physiological condition that have not had their future performance compromised by handling prior to rerelease. If post-detection bypass mortality occurred at Lower Granite Dam, then the SR Model overestimated survival probabilities for the reach from release to Lower Granite Dam tailrace and underestimated survival probabilities for the reach from Lower Granite Dam tailrace to Little Goose Dam tailrace.

For example, based on the SR Model, the survival estimates were 0.573, 0.520, and 0.496 for the first Pittsburg Landing release group from release to Lower Granite Dam tailrace, Lower Granite Dam tailrace to Little Goose Dam tailrace, and Little Goose Dam tailrace to Lower Monumental Dam tailrace, respectively. If post-detection bypass mortality were 13% at each dam, then the Modified Single Release (MSR) Model (Dauble et al. 1993) would have been appropriate. Survival probability estimates based on the MSR Model would have been 0.531, 0.563, and 0.531 for the respective reaches. The overall survival probability estimate from release to Lower Monumental Dam tailrace was 0.148 under the SR Model and would have been 0.159 under the MSR Model assuming 13% post-detection mortality at each dam.

RECOMMENDATIONS

Based on the results of three years of this study, we recommend the following:

1) To release groups of appropriate-sized, PIT-tagged hatchery subyearling fall chinook salmon weekly from release locations upstream from Lower Granite Dam in the free-flowing

Snake River and in the Clearwater River. Groups should be released over as long a time period as practicable, to help determine relationships between travel time, survival, and environmental factors.

2) To release groups weekly at Billy Creek in the Snake River for comparison to the Pittsburg Landing releases to determine where mortality occurs en route to Lower Granite Dam.

3) To release fish from an upstream site, collect them at Lower Granite Dam using the separation-by-code system, divide collected fish into two paired release groups, and rerelease them into the bypass and tailrace (with as little handling as possible) to estimate post-detection bypass survival. This method should provide fish that are comparable in size and physiological status to PIT-tagged fish from primary release groups as they pass the dams.

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