REVIEW OF SURVIVAL, FLOW, TEMPERATURE, AND MIGRATION DATA FOR HATCHERY-RAISED, SUBYEARLING FALL CHINOOK SALMON ABOVE LOWER GRANITE DAM, 1995-1998

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The National Marine Fisheries Service (NMFS), the U. S. Fish and Wildlife Service, and the Nez Perce Tribe have investigated migration characteristics of hatchery-raised, subyearling fall chinook salmon (*Oncorhynchus tshawytscha*) in the Snake River Basin from data collected from 1995 through 1998 (Muir et al., 1999). The studies showed that estimated survival from points of release to Lower Granite Dam could be correlated with three environmental variables: flow, water temperature, and turbidity. These correlations are being used in support of flow augmentation in the lower Snake River.

This report provides a review of the data used for comparing subyearling survival to flow rates, water temperature, time of release, and travel time. The principal conclusion of the review is that survival data and flow rates used by Muir et al. (1999), despite showing an apparent correlation between flow rates and survival, do not imply a cause and effect relationship between flow and survival of subyearlings and should not be used as a basis to justify flow augmentation. This is primarily because the experimental design did not address other factors that appear to have strongly influenced migration characteristics and survival.

There is a fourfold basis for this conclusion. First, although flow can be correlated with survival, there is a stronger correlation between estimated survival and release date. The NMFS experimental design assumed that sequential releases of hatchery-raised fall chinook would not influence survival independent of flow, temperature, and turbidity. The high correlation between time of release and survival makes this assumption questionable.

Second, travel times for hatchery-raised, subyearling fall chinook did not correspond with flow rates. For instance, travel times for the early percentile surviving fish (5^{th}, 10^{th}, and 25^{th} percentiles) were **less** at lower flows than at higher flows for most releases. Median travel time for the 5^{th} percentile surviving fish decreased from 33 days to 16 days between the 1^{st} and 6^{th} weekly releases, despite a decrease in the 5^{th} percentile flow indices during the same time from 122 thousand cubic feet per second (kcfs) to 63 kcfs. These travel times and arrival patterns were contrary to what would be expected if the higher flows resulted in significant improvements in survival.

The fact that travel times are inconsistent with flow rates may result from (1) the migration rate being weakly dependent on flow in the flow ranges considered or (2) other important non-flow factors influencing migration rate. An example of a non-flow factor is “readiness to migrate.” The NMFS study used hatchery-raised, subyearling fall chinook as surrogates for wild fish. Implicit in the use of these hatchery-raised subyearlings in sequential weekly releases is that the fish are equally “ready to migrate” when released. Longer travel times for portions of early-released subyearlings, and faster travel times for portions of later-released subyearlings, despite substantially decreasing flows, suggests that the fish in the weekly sequential releases may not have been equally “ready to migrate.” Differences in states of “readiness to migrate” would confound the analysis of flow and survival relationships. Correlations of flow and temperature with travel time and survival are only meaningful if the groups of fish studied are actively migrating or relatively similar in their state of “readiness to migrate. ”

Third, flow rates, velocity, temperature, and turbidity are closely correlated with one another (NMFS, 2000). The current data are insufficient to allow delineation of the effects of individual attributes of flow. Understanding the effects of individual attributes of flow, particularly the usefulness of flow augmentation to compensate for the effects of reservoir impoundment on these attributes, is fundamental to determining the effectiveness of flow augmentation efforts for increasing survival of subyearling fall chinook salmon.

Fourth, additional problems with existing studies must be addressed prior to making conclusions about the efficacy of flow augmentation. These include use of flow and temperature indices that do not represent overall migration conditions; release timing of hatchery-raised fish that is not representative of natural migration; relatively high post-release mortality; and the inability of reach survival estimates to reflect the full spectrum of potential effects from altered water velocities, temperatures, and turbidity during migration (e.g., altered migration timing, bioenergetics, and transition into the estuary and ocean).

In summary, this review does not suggest that flow, or the attributes of flow (water velocity, temperature, and turbidity), are unimportant to migration and survival of subyearling fall chinook salmon. However, existing correlations between survival of hatchery-raised, subyearling fall chinook salmon with flow rates and water temperatures do not support the postulation that augmenting mainstem Snake River flows improves subyearling survival.

Table of Contents

1. Introduction..1

2. Data Description..2

3. Analysis and Results..7

3.1. Flow Rates and Water Temperatures at Lower Granite Dam..7

3.2. Comparison of Estimated Survival and 5th Percentile Flow Indices..11

3.3. Comparison of Estimated Survival and 5th Percentile Water Temperature Indices...12

3.4. Comparison of Estimated Survival and Date of Release..13

3.5. Comparison of Estimated Survival and Release Groups by Release Site..16

3.6. Subyearling Fall Chinook Salmon Travel Times and Numbers of Detections..........18

3.6.1. Distribution curves for hatchery-raised, subyearling fall chinook salmon detected at Lower Granite Dam for the 1st, 3rd and 6th releases, 1996 through 1998..18

3.6.2. Cumulative detections of subyearling fall chinook salmon at Lower Granite Dam for the 1st , 3rd, and 6th releases, 1996 through 1998. 23

3.6.3. Flows Rates, Flow Indices, Travel Times, and Arrival Dates..25

4. Discussion..47

4.1. Limitations of Flow-Survival Studies Focusing on Reservoir Reaches..47

4.2. "Lumped Parameter" Characteristic of Flow..48

4.3. High Mortality Rates for Later Releases..48

4.4. Linear Regression Characteristics..49

4.5. Flow and Temperature Indices..49

4.6. Estimated Survival and Date of Release..50

4.7. Travel Times and Clustered Arrivals..51

4.8. Use of Hatchery-Raised Salmon as Analogues for Wild Fish..52

4.9. "Readiness to Migrate"..52

4.10. Other Factors Influencing Survival..53

4.11. Flow Augmentation and Salmon Survival..53

5. Conclusions..56

6. References..58

Appendix: NMFS Fall Chinook Data at Lower Granite Dam, 1995-1998

List of Figures

Figure 2-1: Map of release sites for hatchery-raised, subyearling fall chinook salmon (adapted from Muir et al., 1999). 3

Figure 2-2: Flow indices (kcfs) for 5^{th}, 50^{th}, and 25^{th} to 75^{th} percentile arrivals at Lower Granite Dam for the release made at the Pittsburg Landing site on June 13, 1996. 6

Figure 3.1-1: Outflow and water temperatures at Lower Granite Dam, 1995-1998. 8

Figure 3.1-2: Outflow, spill, flow augmentation, and water temperatures at Lower Granite Dam, 1995. 8

Figure 3.1-3: Outflow, spill, flow augmentation, and water temperatures at Lower Granite Dam, 1996. 9

Figure 3.1-4: Outflow, spill, flow augmentation, and temperatures at Lower Granite Dam, 1997 9

Figure 3.1-5: Outflow, spill, flow augmentation, and water temperature at Lower Granite Dam, 1998. 10

Figure 3.1-6: Outflows at Lower Granite Dam from approximately May 1 through October 31, 1995 through 1998. 10

Figure 3.1-7: Water temperatures at Lower Granite Dam from May 1 through October 31, 1995 through 1998. 11

Figure 3.2-1: Estimated survival of hatchery-raised, fall chinook salmon versus 5^{th} percentile flow indices. 12

Figure 3.3-1: Estimated survival of hatchery-raised, fall chinook salmon versus 5^{th} percentile water temperature indices. 13

Figure 3.4.1: Estimated survival versus release date, 1995-1998. 14

Figure 3.4-2: Estimated survival by release site, 1995. 14

Figure 3.4-3: Estimated survival by release site, 1996. 15

Figure 3.4-4: Estimated survival by release site and year, 1997 15

Figure 3.4-5: Estimated survival by release site and year, 1998 16

Figure 3.5-1: Estimated survival versus release groups for the Pittsburg Landing site, 1995-1998. 17

Figure 3.5-2: Estimated survival versus release groups for the Clearwater site, 1996-1998. 17

Figure 3.5-3: Estimated survival versus release groups for the Billy Creek site, 1995-1998. 18

Figure 3.6.1-1: Distribution of hatchery-raised, subyearling fall chinook salmon released at the Clearwater site in 1996 and detected at Lower Granite Dam. 19

Figure 3.6.1-2: Distribution of hatchery-raised, subyearling fall chinook salmon released at the Pittsburg Landing site in 1996 and detected at Lower Granite Dam. 20

Figure 3.6.1-3: Distribution of hatchery-raised, subyearling fall chinook salmon released at the Pittsburg Landing site in 1997 and detected at Lower Granite Dam. 20

Figure 3.6.1-4: Distribution of hatchery-raised, subyearling fall chinook salmon released at the Clearwater site in 1997 and detected at Lower Granite Dam.................................. 21

Figure 3.6.1-5: Distribution of hatchery-raised, subyearling fall chinook salmon released at the Billy Creek site in 1997 and detected at Lower Granite Dam.................................. 21

Figure 3.6.1-6: Distribution of hatchery-raised, subyearling fall chinook salmon released at the Pittsburg Landing site in 1998 and detected at Lower Granite Dam. 22

Figure 3.6.1-7: Distribution of hatchery-raised, subyearling fall chinook salmon released at the Clearwater site in 1998 and detected at Lower Granite Dam.................................. 22

Figure 3.6.1-8: Distribution of hatchery-raised, subyearling fall chinook salmon released at the Billy Creek site in 1998 and detected at detected at Lower Granite Dam. 23

Figure 3.6.2-1: Cumulative detections of hatchery–raised, fall chinook salmon at Lower Granite Dam released from the Pittsburg Landing and Clearwater sites in 1996........... 24

Figure 3.6.2-2: Cumulative detections of hatchery–raised, fall chinook salmon at Lower Granite Dam released from the Pittsburg Landing, Clearwater, and Billy Creek sites in 1997.. 24

Figure 3.6.2-3: Cumulative detections of hatchery–raised, fall chinook salmon at Lower Granite Dam released from the Pittsburg Landing, Clearwater, and Billy Creek sites in 1998.. 25

Figure 3.6.3-1: Travel times for the 5th, 10th, 25th, 50th, 75th, 90th, and 25th to 75th percentile surviving fish released from the Pittsburg Landing site in 1996 and corresponding 5th, 50th, and 25th to 75th percentile flow indices at Lower Granite Dam (LGD). 29

Figure 3.6.3-2: Arrival dates for the 5th, 50th, and 90th percentile surviving fish for the six releases from the Pittsburg Landing site in 1996. 30

Figure 3.6.3-3: Travel times for the 5th, 10th, 25th, 50th, 75th, 90th, and 25th to 75th percentile fish released from the Clearwater site in 1996 and corresponding 5th, 50th, and 25th through 75th percentile flow indices at Lower Granite Dam (LGD)............................... 31

Figure 3.6.3-4: Arrival dates for the 5th, 50th, and 90th percentile surviving fish for the six releases at the Clearwater site in 1996. 32

Figure 3.6.3-5: Travel times for the 5th, 10th, 25th, 50th, 75th, 90th, and 25th to 75th percentile surviving fish released from the Pittsburg Landing site in 1997 and corresponding 5th, 50th, and 25th to 75th percentile flow indices at Lower Granite Dam (LGD). 33

Figure 3.6.3-6: Arrival dates for the 5th, 50th, and 90th percentile surviving fish for the six releases at the Pittsburg Landing site in 1997. ... 34

Figure 3.6.3-7: Travel times for the 5th, 10th, 25th, 50th, 75th, 90th, and 25th to 75th percentile surviving fish released from the Clearwater site in 1997 and corresponding 5th, 50th, and 25 through 75th percentile flow indices at Lower Granite Dam (LGD). ... 35

Figure 3.6.3-8: Arrival dates for the 5th, 50th, and 90th percentile surviving fish for the six releases at the Clearwater site in 1997. ... 36

Figure 3.6.3-9: Travel times for the 5th, 10th, 25th, 50th, 75th, 90th, and 25th to 75th percentile surviving fish released from the Billy Creek site in 1997 and corresponding 5th, 50th, and 25th through 75th percentile flow indices at Lower Granite Dam (LGD). ... 37

Figure 3.6.3-10: Arrival dates for the 5th, 50th, and 90th percentile surviving fish for the six releases at the Billy Creek site in 1997. ... 38

Figure 3.6.3-11: Travel times for the 5th, 10th, 25th, 50th, 75th, 90th, and 25th to 75th percentile surviving fish released from the Pittsburg Landing site in 1998 and corresponding 5th, 50th, and 25th through 75th percentile flow indices at Lower Granite Dam (LGD). ... 39

Figure 3.6.3-12: Arrival dates for the 5th, 50th, and 90th percentile surviving fish for the five releases at the Pittsburg Landing site in 1998. ... 40

Figure 3.6.3-13: Travel times for the 5th, 10th, 25th, 50th, 75th, 90th, and 25th to 75th percentile fish released from the Clearwater site in 1998 and corresponding 5th, 50th, and 25th through 75th percentile flow indices at Lower Granite Dam (LGD). ... 41

Figure 3.6.3-14: Arrival dates for the 5th, 50th, and 90th percentile surviving fish for the six releases at the Clearwater site in 1998. ... 42

Figure 3.6.3-15: Travel times for the 5th, 10th, 25th, 50th, 75th 90th, and 25th to 75th percentile surviving fish released from the Billy Creek site in 1998 and corresponding 5th, 50th and 25th through 75th percentile flow indices at Lower Granite Dam (LGD). ... 43

Figure 3.6.3-16: Arrival dates for the 5th, 50th, and 90th percentile surviving fish for the six releases at the Billy Creek site in 1998. ... 44

Figure 3.6.3-17: Median travel times for the 50th percentile fish and median outflows for the 50th percentile flow indices by release groups (for all release series with five or more releases), 1995-1998. ... 45

List of Tables

Table 2-1: Release dates and numbers of fish released for hatchery-raised, subyearling fall chinook salmon, 1995-1998. 4

Table 3.6.3-1: Travel times (days) for the 5th, 25th, 50th and 75th percentile surviving fish from the 1st and 6th releases at the Pittsburgh Landing , Clearwater , and Billy Creek sites in 1996 through 1998 and the 5th and 50th percentile flow indices based on average daily flows at Lower Granite Dam. 46

1. INTRODUCTION

The effectiveness of flow augmentation[1] in aiding conservation and recovery of Snake River salmonid populations listed under the Endangered Species Act is questionable. The purpose of flow augmentation has been largely to increase the velocity and/or reduce the temperature of water flowing through mainstem reservoirs in the lower Snake and Columbia Rivers[2]. Although improved adult returns are generally associated with good water years (e.g., high natural flow and spill) during juvenile outmigration, the efficacy of flow augmentation as a substitute for good water years has not been defensibly established.

During the period from 1995 through 1998, the National Marine Fisheries Service (NMFS), the U.S. Fish and Wildlife Service, and the Nez Perce Tribe investigated migration characteristics of hatchery-raised, subyearling fall chinook salmon (*Oncorhynchus tshawytscha*) in the Snake River Basin (Muir et al., 1999). Hatchery-raised subyearlings were used as surrogates for wild subyearlings in the survival research. The studies showed that estimated survival from points of release to the tailrace of Lower Granite Dam could be correlated with all three environmental variables examined (flow rate, water temperature, and turbidity). Estimated survival decreased throughout the season, as flow volume and turbidity decreased and water temperature increased (Muir et al., 1999). These correlations have provided the primary basis for the continuation of flow augmentation from reservoirs in the Snake River and Clearwater River Basins (NMFS, 1999).

The purpose of this report is to provide a review of the data considered in the Muir et al. (1999) study within the context of determining the efficacy of flow augmentation for enhancing the survival of subyearling fall chinook. In particular, relationships between flow rates, water temperatures, travel times, and estimated survival of hatchery-raised, subyearling fall chinook salmon between points of release and detections at Lower Granite Dam are examined. This report includes analyses of: (1) flow rates and water temperatures at Lower Granite Dam; (2) estimated survival with 5th percentile flow indices; (3) estimated survival and 5th percentile water temperature indices; (4) estimated survival versus release dates; (5) estimated survival versus release groups; and (6) fall chinook travel times and numbers of detections. Finally, these comparisons are used to draw conclusions about flow rates, travel times, subyearling survival, and the effectiveness of flow augmentation.

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[1] Flow augmentation is defined as the use of water from storage reservoirs, or foregone water storage, to augment natural flows.

[2] For example, mainstem reservoirs in the lower Snake River have reduced average water velocities during the summer migration period to about 1/20 to 1/10 of the velocities that existed prior to construction of the dams forming the mainstem reservoirs (Dreher, 1998).

2. DATA DESCRIPTION

The data used in this review and evaluation consist of: (1) numbers of hatchery-raised, subyearling fall chinook salmon released from four sites along the Snake and Clearwater Rivers; (2) estimated subyearling survival rates from point of release to Lower Granite Dam[3] on the lower Snake River; (3) travel times of the surviving fish between point of release and Lower Granite Dam based on the date of release and date of detection; and (4) flow and temperature data from the lower Snake River at Lower Granite Dam. The data were collected as part of a study by NMFS, the U. S. Fish and Wildlife Service, and the Nez Perce Tribe (Muir et al., 1999) investigating migrational characteristics of hatchery-raised, subyearling fall chinook salmon as substitutes for wild subyearlings (Muir et al., 1999).

Hatchery-raised, subyearling fall chinook salmon were released at four locations into the Snake and Clearwater Rivers upstream of Lower Granite Dam from 1995 through 1998 to estimate survival in these reaches. Details about release methods were provided in Hockersmith et al. (1999). The release points on the Snake River were (1) Pittsburg Landing; (2) Asotin; and (3) Billy Creek. Subyearlings also were released into Big Canyon Creek (referred to as the "Clearwater" site), which flows into the Clearwater River near Peck (Figure 2-1). In addition, several large releases were made at Pittsburg Landing (PD) for tracking migration downstream of Lower Granite Dam. The released fish were all raised under similar conditions at the same time in the Lyons Ferry hatchery in the state of Washington. The subyearlings were released at approximate one-week intervals between early June and mid-July (Table 2-1). Most releases contained between 1,119 and 1,353 fish, although the PD releases contained about 7,000 fish. A passive integrated transponder (PIT tag) was inserted into each fish prior to release, allowing monitoring of its downstream progress and survival. The PIT-tagged fish were counted as they passed detectors in the fish bypass system at Lower Granite Dam. The release numbers and survival data are provided in Appendix A. Flow and temperature data also are available at www.cqs.washington.edu/dart/dart.html.

The apparent relationships between estimated subyearling survival to Lower Granite Dam, flow rate, and temperature in the lower Snake River (e.g., NMFS, 1999; Muir et al., 1999) are constructed using flow and temperature "indices." The flow and temperature indices consist of the average daily flow and temperature values, respectively, at Lower Granite Dam averaged over the interval between the release date and the date that a given percentile (e.g., 5th, 10th, 25th, 50th, 75th, or 90th percentile) of the surviving fish is detected at the dam. For example, the 5th percentile flow index corresponding to a release of 1,000 fish from which 500 survive would be the average flow rate between the release date and

[3] Survival estimates developed by NMFS were provided by Steve Smith of NMFS on November 18, 1999, and are included in Appendix A.

the date that the 5th percentile of the surviving fish (i.e., the 25th fish) is detected at Lower Granite Dam. The number of days used to calculate the flow and temperature indices varies by release depending on the travel time for each release.

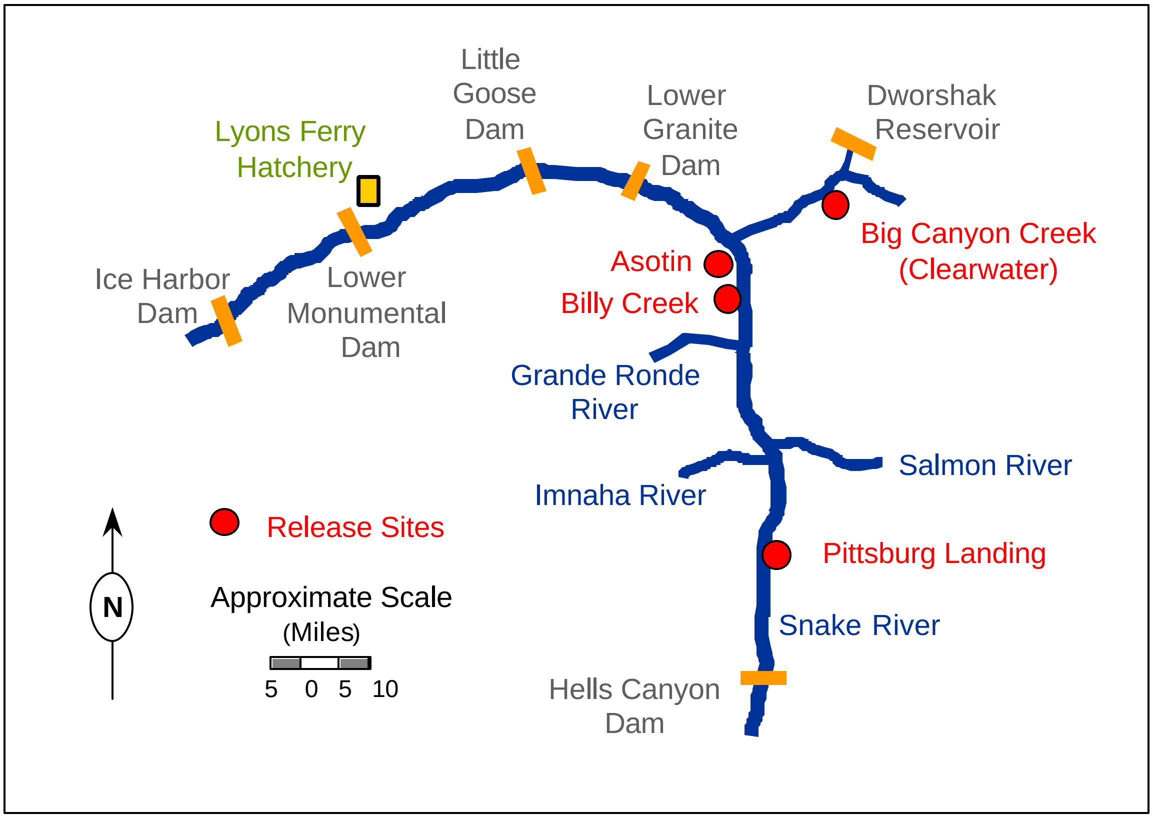


Figure 2-1: Map of release sites for hatchery-raised, subyearling fall chinook salmon (adapted from Muir et al., 1999).

The arrival dates for each percentile of surviving fish are determined by counting the arriving salmon as they are detected at the Lower Granite Dam fish bypass system. The travel time (in days) for each percentile of surviving fish is determined by using the release date and the arrival date at Lower Granite Dam. The estimated survival rates are based on numbers of PIT-tagged fish counted at Lower Granite Dam and at dams downstream of Lower Granite Dam. The estimated survival rates account for fish that successfully pass through the turbines at Lower Granite Dam or are spilled over the dam, which are not counted in the fish bypass system at Lower Granite Dam. The procedure for estimating survival is presented in Hockersmith et al. (1999).

A release group is defined as the releases that were made during a specific time period. For example, Release Group 1 contains data for the releases that were made between May

28 and June 6 in 1995 through 1998. There are six release groups defined for the data in this report (Table 2-1).

Release		1995			1996			1997			1998		
Site	Release Group*	Release Date	Julian Date	Number Fish	Release Date	Julian Date	Number Fish	Release Date	Julian Date	Number Fish	Release Date	Julian Date	Number Fish
Clearwater	1				6/6	157	1,198	6/3	153	1,253	6/2	152	1,254
	2				6/13	164	1,166	6/10	160	1,238	6/9	159	1,274
	3				6/20	171	1,218	6/17	167	1,250	6/16	166	1,271
	4				6/27	178	1,189	6/24	174	1,250	6/23	173	1,264
	5				7/3	184	1,161	7/1	181	1,267	6/30	180	1,254
	6				7/10	191	1,211	7/8	188	1,269	7/7	187	1,288
Pittsburg Landing	1	5/31	150	1,353	6/6	157	1,189	6/3	153	1,262	6/2	152	1,277
	2	6/7	157	1,341	6/13	164	1,119	6/10	160	1,245	6/9	159	1,274
	3	6/14	164	1,326	6/20	171	1,189	6/17	167	1,243	6/16	166	1,251
	4				6/27	178	1,214	6/24	174	1,239	6/23	173	1,279
	5				7/3	184	1,220	7/1	181	1,251	6/30	180	1,273
	6				7/10	191	1224	7/8	188	1,238			
Billy Creek	1	6/1	151	1,220				6/3	153	1,247	6/2	152	1,262
	2	6/8	158	1,317				6/10	160	1,250	6/9	159	1,273
	3	6/15	165	1,124				6/17	167	1,244	6/16	166	1,261
	4							6/24	174	1,250	6/23	173	1,259
	5							7/1	181	1,245	6/30	180	1,249
	6							7/8	188	1,238	7/7	187	1,266
Asotin	3	6/19	169	2,778									
	4	6/27	177	2,489									
	5	7/5	185	3,523									
PD	1							5/28	148	6,955	6/4	155	7,028
								5/30	150	6,941	6/6	157	7,086
	2				6/13	164	6,870						
	3				6/20	171	6,929						

* Release groups are defined in text.

Table 2-1: Release dates and numbers of fish released for hatchery-raised, subyearling fall chinook salmon, 1995-1998.

A release series is the set of sequential releases made at one release site during one year. For example, the six releases made at the Clearwater site in 1996 are referred to as a release series.

Flow indices are used to describe flows over a period of time. For example, the 5th percentile flow index for a given site and a given release is the average of the average daily flows at Lower Granite Dam between the time of release and the arrival of the 5th percentile of the surviving fish. The 25th to 75th percentile flow index is the average of the average daily flows between the time of arrival of the 25th percentile and the time of arrival of the 75th percentile fish.

Previous studies have used 25th to 75th percentile flow indices for comparisons with survival (Smith et al., 1998; Muir et al., 1999). However, 5th percentile flow indices were used by Muir et al. (1999) to compare flow and estimated survival for subyearling fall chinook salmon. The reason for this is stated by Muir et al. (1999, pg. 7):

> Smith et al. (1998a) 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.

The 5th percentile flow indices represent earlier portions of the hydrograph than the 25th to 75th percentile flow indices (Figure 2-2). The 5th percentile flow indices for earlier releases are therefore larger values (during the subyearling migration period) than corresponding 25th to 75th percentile flow indices.

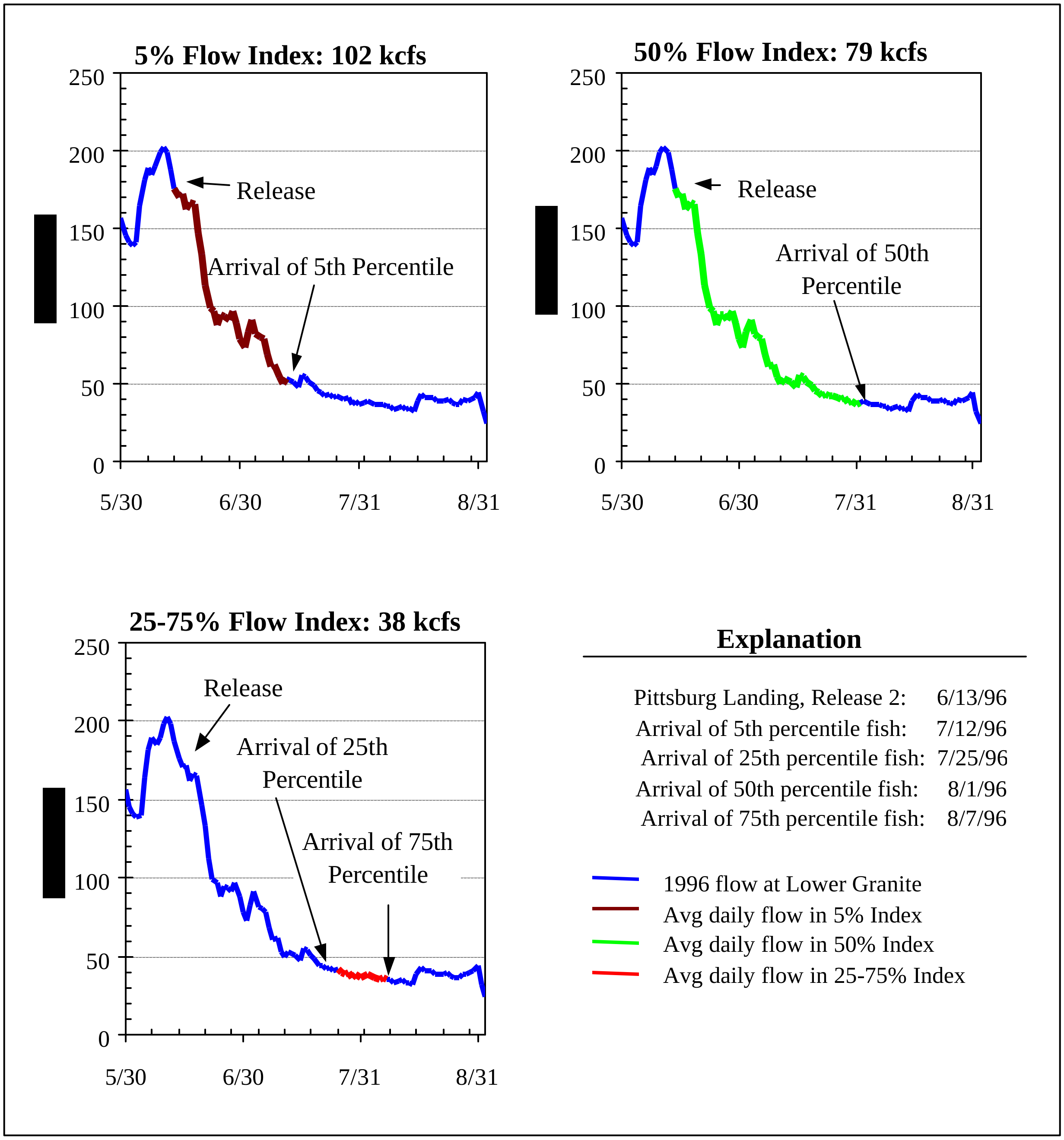


Figure 2-2: Flow indices (kcfs) for 5th, 50th, and 25th to 75th percentile arrivals at Lower Granite Dam for the release made at the Pittsburg Landing site on June 13, 1996.

3. ANALYSIS AND RESULTS

This section provides comparisons of various combinations of flow, estimated survival, flow and temperature indices, and travel times. The following figures and comparisons include data describing: (1) annual and seasonal hydrographs and water temperature histories; (2) estimated survival by release and 5th percentile flow indices; (3) estimated survival and 5th percentile temperature indices; (4) estimated survival versus release date; (5) estimated survival and release groups by release site; (6) travel times from release to Lower Granite Dam; and (7) arrival dates of subyearling fall chinook detected at Lower Granite Dam.

3.1. Flow Rates and Water Temperatures at Lower Granite Dam

A hydrograph and history of water temperatures at Lower Granite Dam are shown in Figure 3.1-1 for the period from 1995 through 1998. In general, peak flows occurred in May and June, and peak water temperatures occurred in August and early September.

Seasonal hydrographs, temperatures, and spill rates are presented in Figures 3.1-2 through 3.1-5 for the period 1995 through 1998. The hydrographs represent total flow at Lower Granite Dam, consisting of the controlled discharge through the dam as well as spill over the dam's spillway.

These hydrographs include water that is released to augment flows in the lower Snake River. The current annual level of flow augmentation consists of 427,000 acre-feet of water from the upper Snake River, 110,000 acre-feet from Brownlee Reservoir during the spring, 235,000 acre-feet from Brownlee Reservoir during the summer, and 1.2 million acre-feet from Dworshak Reservoir. Figures 3.1-2 through 3.1-5 show flow augmentation to the Clearwater and Snake Rivers.

The flow rates at Lower Granite Dam from 1995 through 1998 are compared in Figure 3.1-6. The largest peak flow, and the peak of longest duration, was experienced in 1997. The lowest peak flow occurred in 1995.

Water temperatures typically rise during May, June, and early July (Figure 3.1-7). The highest water temperatures occurred in mid-July of 1995, early September of 1997, and mid-August of 1998. A decline in water temperatures followed by a second peak occurred in 1995, 1996, and 1998, presumably reflecting the influx of colder water from Dworshak Reservoir in August.

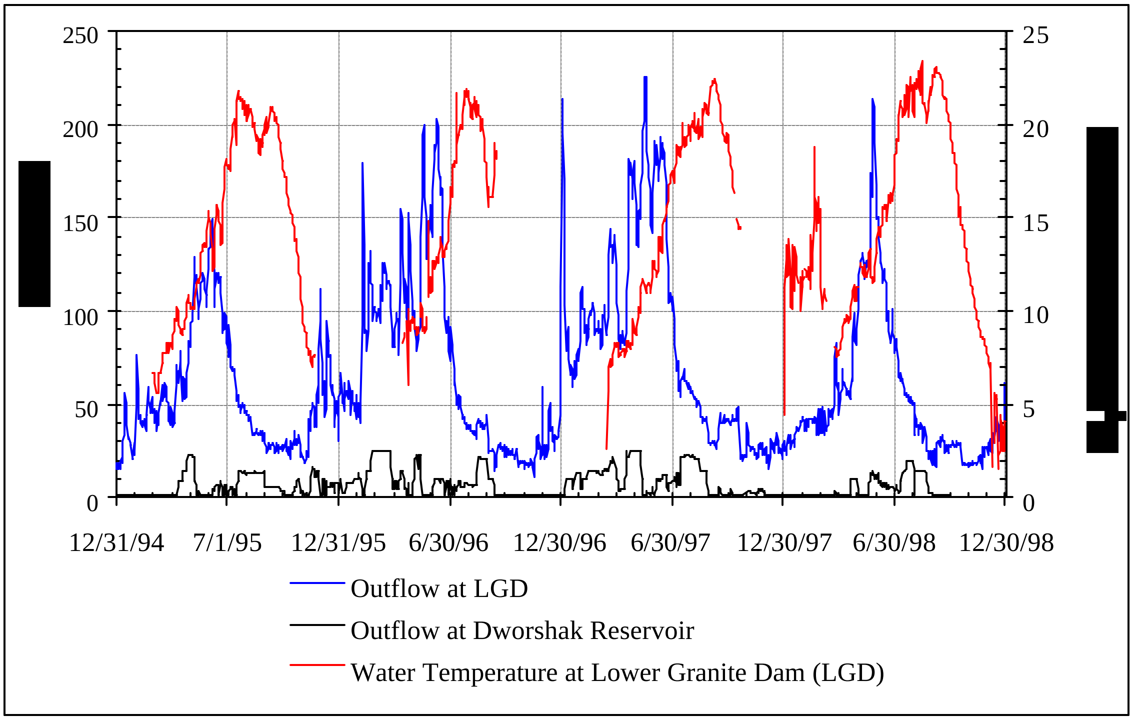


Figure 3.1-1: Outflow and water temperatures at Lower Granite Dam, 1995-1998.

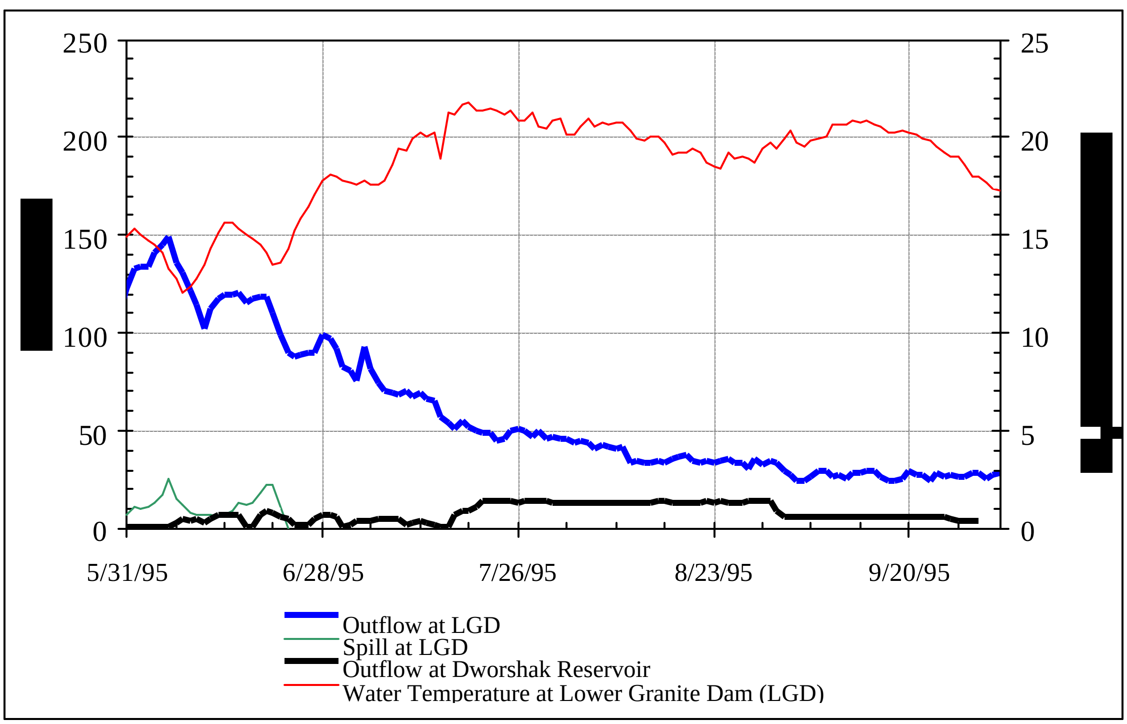


Figure 3.1-2: Outflow, spill, flow augmentation, and water temperatures at Lower Granite Dam, 1995.

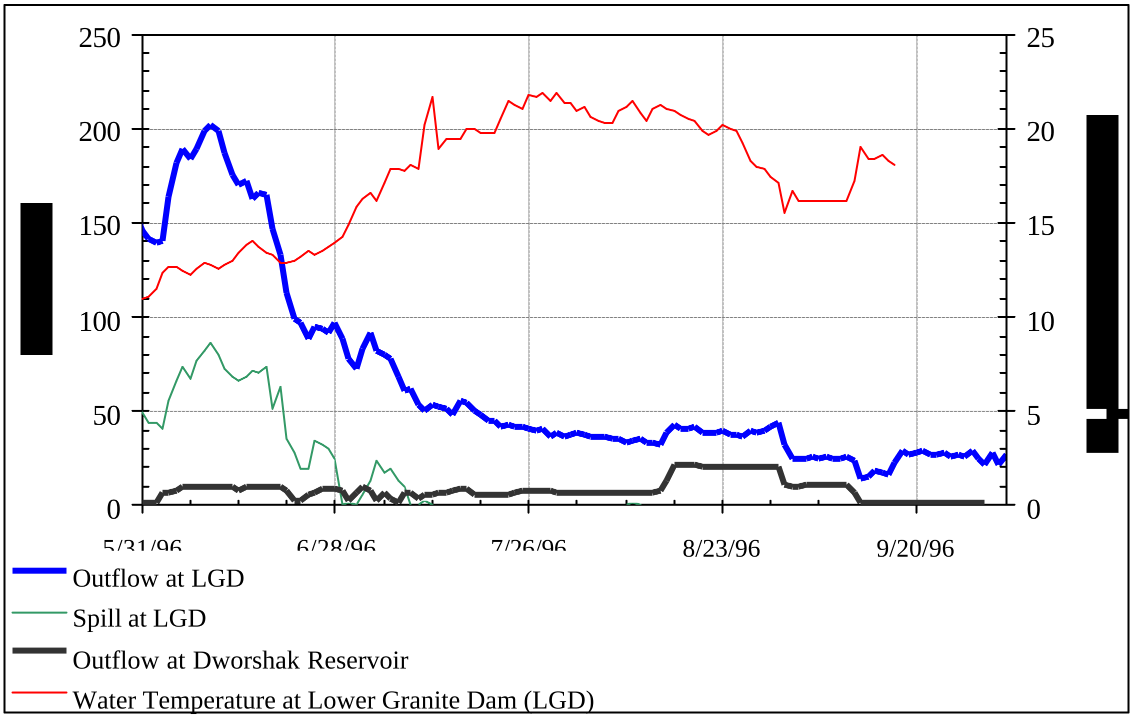


Figure 3.1-3: Outflow, spill, flow augmentation, and water temperatures at Lower Granite Dam, 1996.

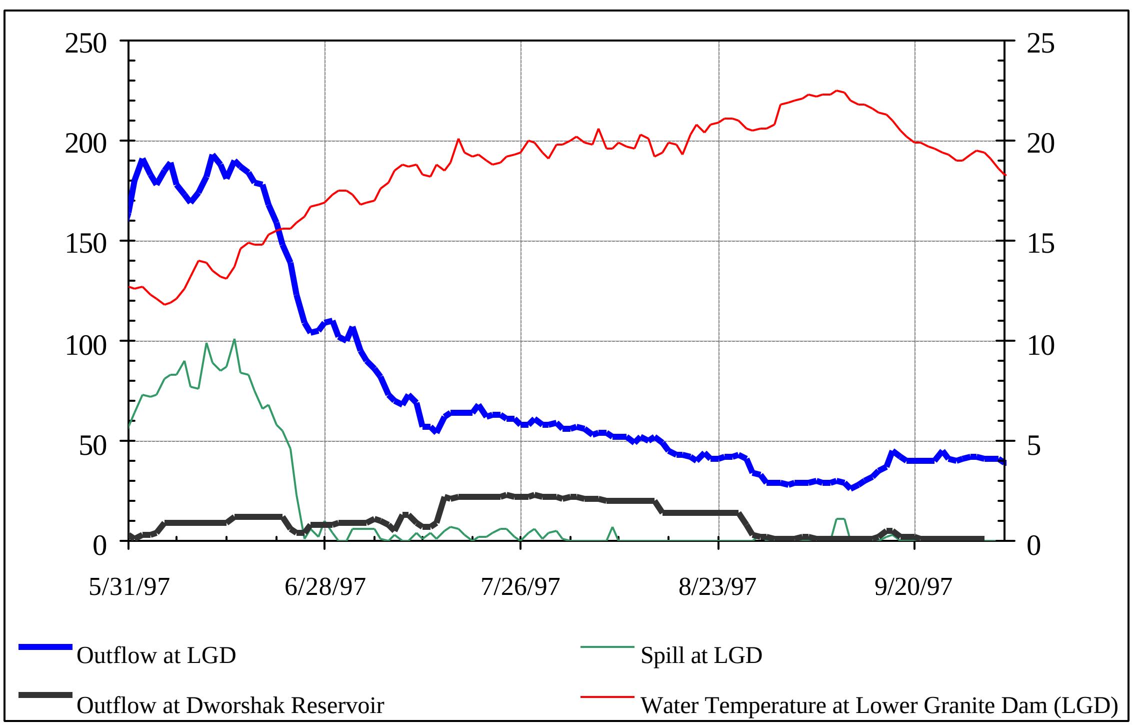


Figure 3.1-4: Outflow, spill, flow augmentation, and temperatures at Lower Granite Dam, 1997.

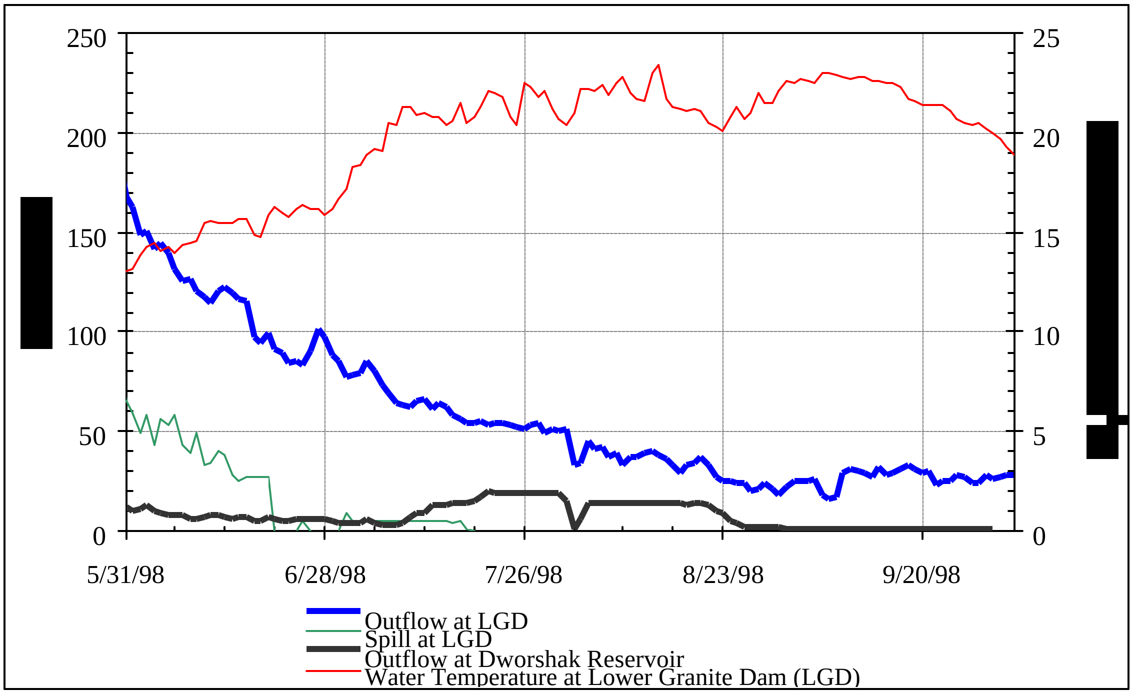


Figure 3.1-5: Outflow, spill, flow augmentation, and water temperature at Lower Granite Dam, 1998.

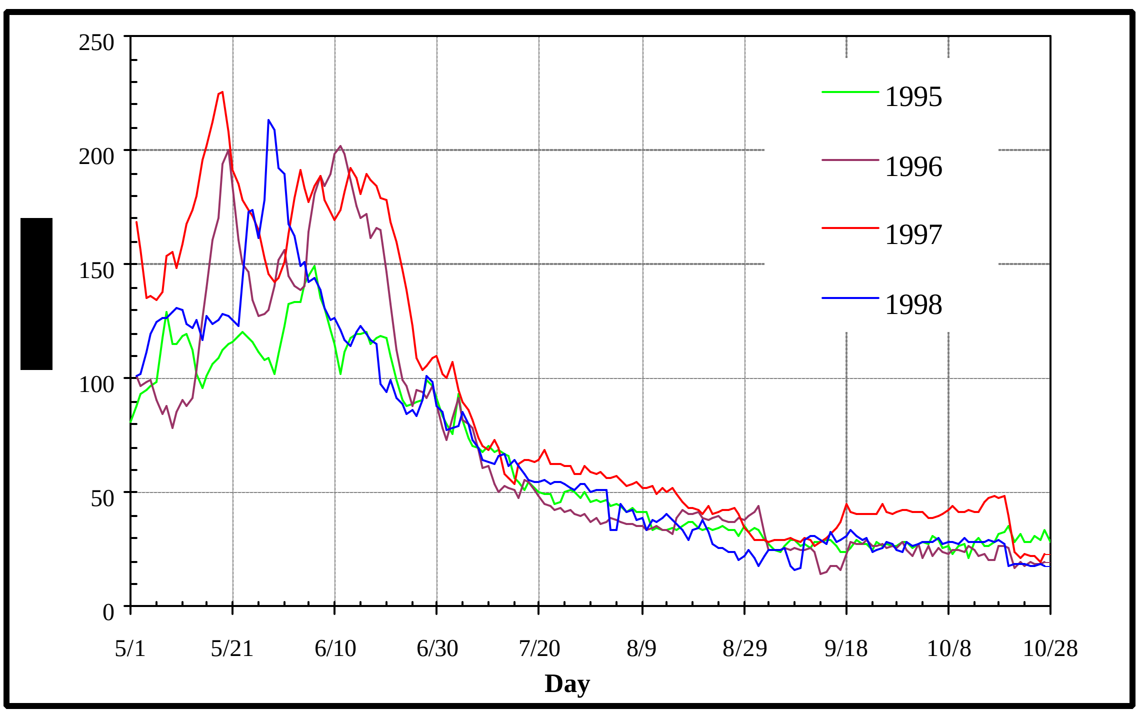


Figure 3.1-6: Outflows at Lower Granite Dam from approximately May 1 through October 31, 1995 through 1998.

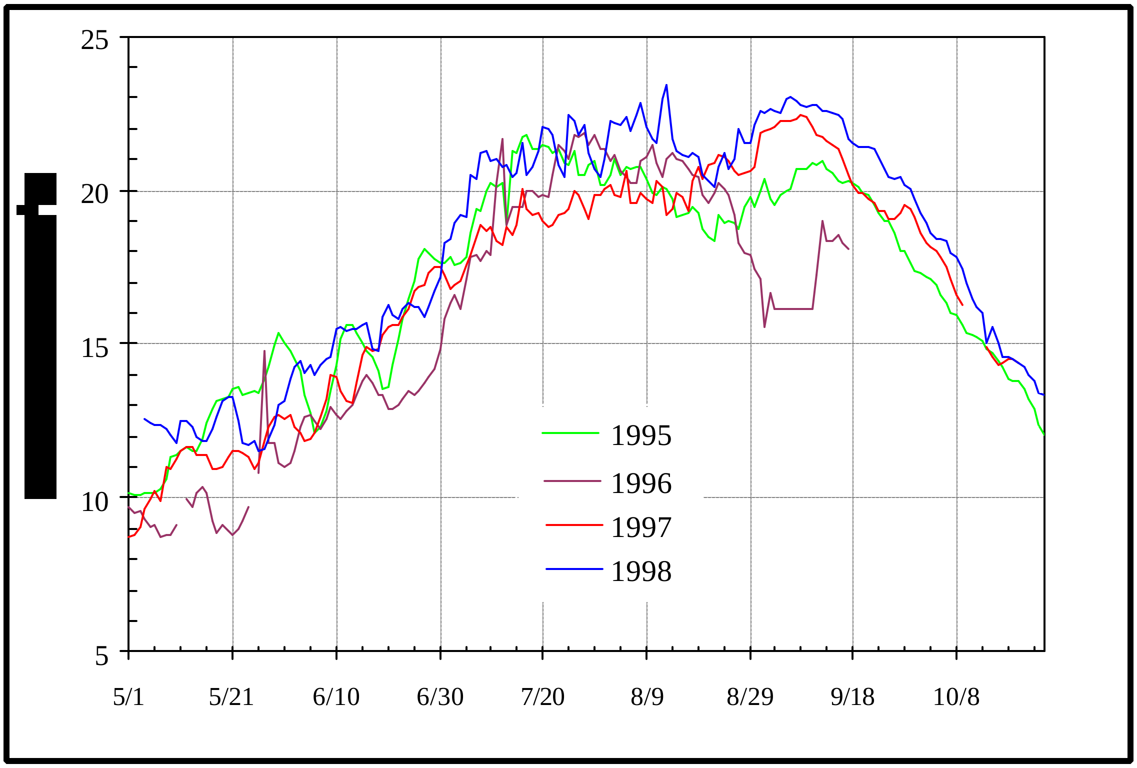


Figure 3.1-7: Water temperatures at Lower Granite Dam from May 1 through October 31, 1995 through 1998.

3.2. Comparison of Estimated Survival and 5^{th} Percentile Flow Indices

Although use of 5^{th} percentile flow indices is questionable (see Section 4.5), the evaluations herein use the 5^{th} percentile flow indices to be consistent with the NMFS analyses. Regressions between estimated survival rates for hatchery-raised, subyearling fall chinook salmon (from points of release to Lower Granite Dam) and the 5^{th} percentile flow indices for the 1995 through 1998 releases are shown in Figure 3.2-1. While there is an apparent positive correlation between estimated survival and outflow, additional analyses indicate this correlation may be strongly influenced by other factors and should not be used to infer a cause and effect relationship (see Section 4). Overall, the regression coefficient (R^2) for estimated survival correlated with 5^{th} percentile flow indices for the 1995 through 1998 time period is 0.49. This overall value is lower than coefficients for individual years because of the variability between years.

In 1997, the Snake River experienced the highest daily average peak outflow (225 kcfs at Lower Granite Dam) for the period from 1995 through 1998 (Figure 3.2-1), and the peak outflow period was of longer duration than the other years. The apparent relationship between 5^{th} percentile flow indices and estimated survival begins to have a different slope at flows greater than 120 kcfs. A second order polynomial regression was compared to the linear regression for the 1997 data. The second order polynomial regression results in a slightly larger correlation coefficient (R^2 = 0.80) than that of the linear regression (R^2 = 0.76).

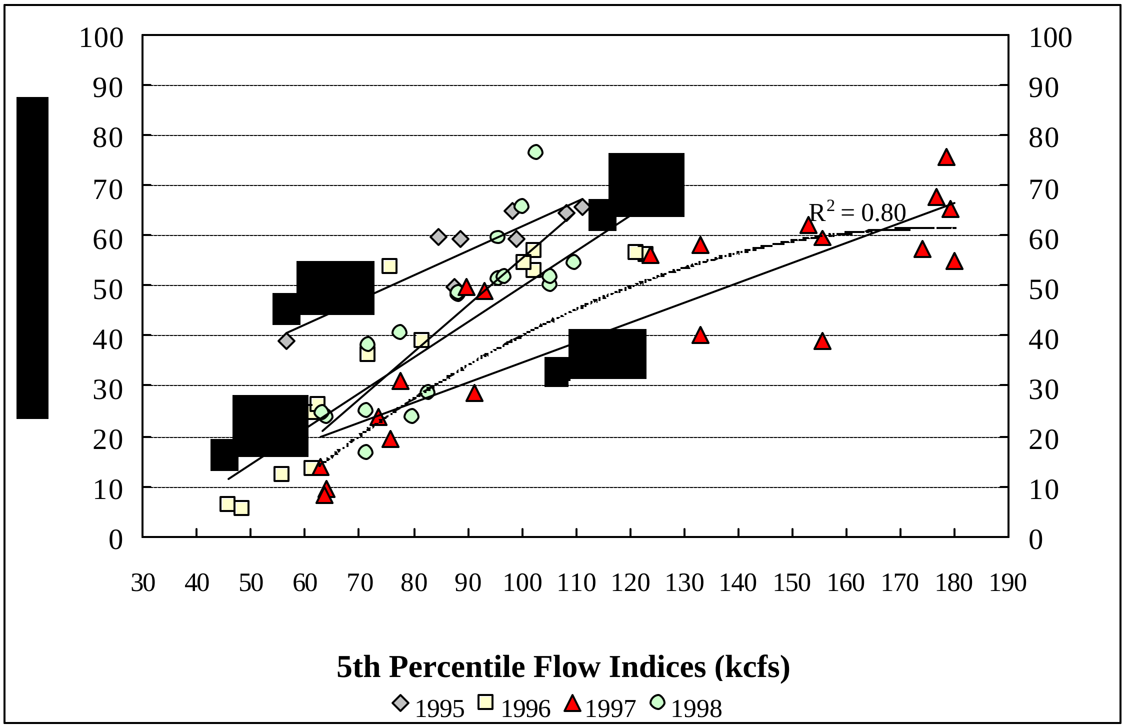


Figure 3.2-1: Estimated survival of hatchery-raised, fall chinook salmon versus 5th percentile flow indices.

3.3. Comparison of Estimated Survival and 5th Percentile Water Temperature Indices

Regressions between estimated survival (from points of release to Lower Granite Dam) and the 5th percentile water temperature indices are shown in Figure 3.3-1. The regression coefficients show a negative correlation between estimated survival and increasing water temperature; i.e., as water temperature increased, estimated survival decreased. The lowest temperatures were observed in 1997. Again, a second order polynomial regression resulted in a higher regression coefficient (R^2 = 0.82) than that of the corresponding linear regression (R^2 = 0.75) for the 1997 data. Overall, the regression coefficient for estimated survival correlated with 5th percentile water temperature indices for the 1995 through 1998 time period was 0.61. This overall value was lower than coefficients for individual years because of variability between years.

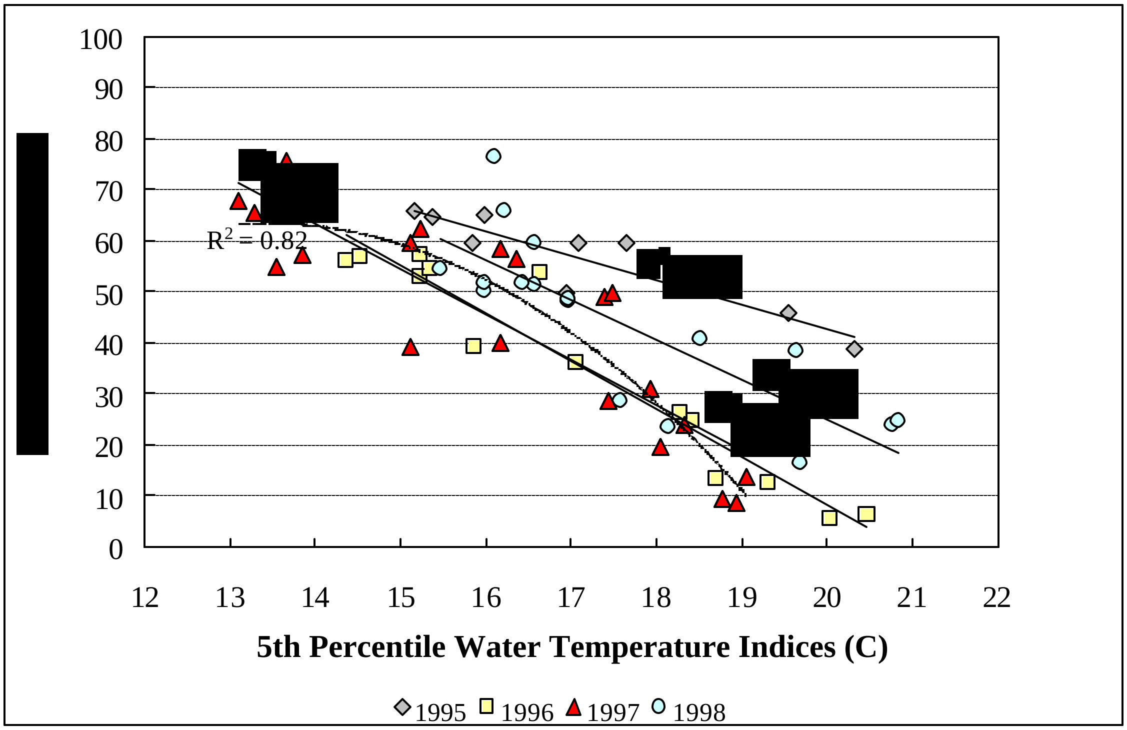


Figure 3.3-1: Estimated survival of hatchery-raised, fall chinook salmon versus 5th percentile water temperature indices.

3.4. Comparison of Estimated Survival and Date of Release

There is a strong negative correlation (Figure 3.4-1) between estimated survival to Lower Granite Dam and date of release for hatchery-raised, fall chinook salmon for all of the releases made in 1995 through 1998 (R^2 = 0.79). This value is considerably higher than the coefficients for estimated survival correlated with 5th percentile flow indices (R^2 = 0.49) and for estimated survival correlated with 5th percentile water temperature indices (R^2 = 0.61).

Estimated survival levels for 1995 are of limited significance because there were only nine releases that year (Figure 3.4-2). For 1996 releases in both the Snake and Clearwater Rivers, estimated survival rates are congruent (Figure 3.4-3). The rates are less congruent in 1997 when the Clearwater releases had lower survival rates than the Snake River releases (Figure 3.4-4), and in 1998 when some of the Clearwater releases had slightly higher survival rates than the releases on the Snake River (Figure 3.4-5). Although there are some differences in estimated survival rates between release sites, the correlation between estimated survival and date of release is the strongest overall relationship observed.

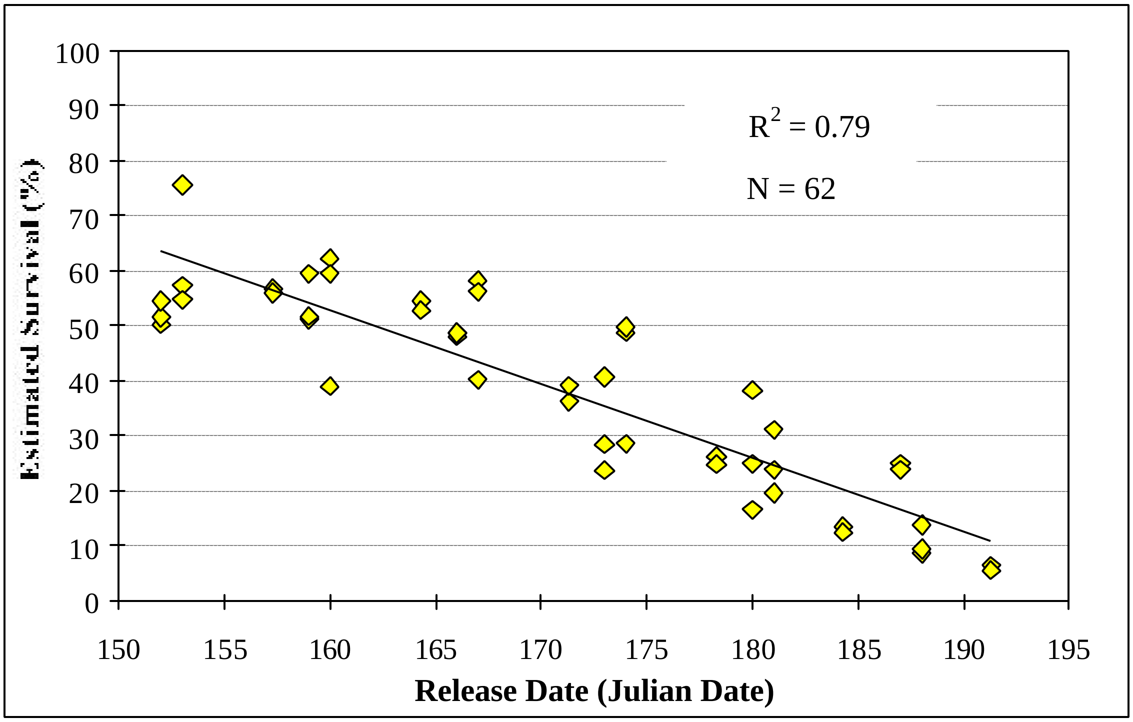


Figure 3.4.1: Estimated survival versus release date, 1995-1998.

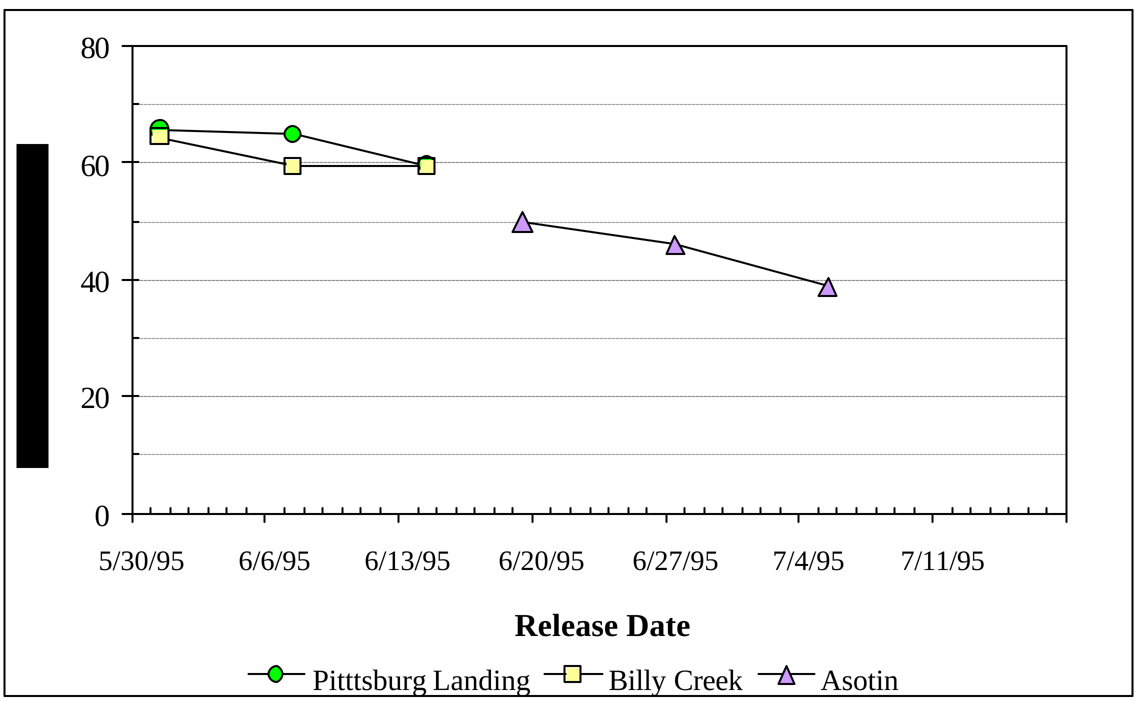


Figure 3.4-2: Estimated survival by release site, 1995.

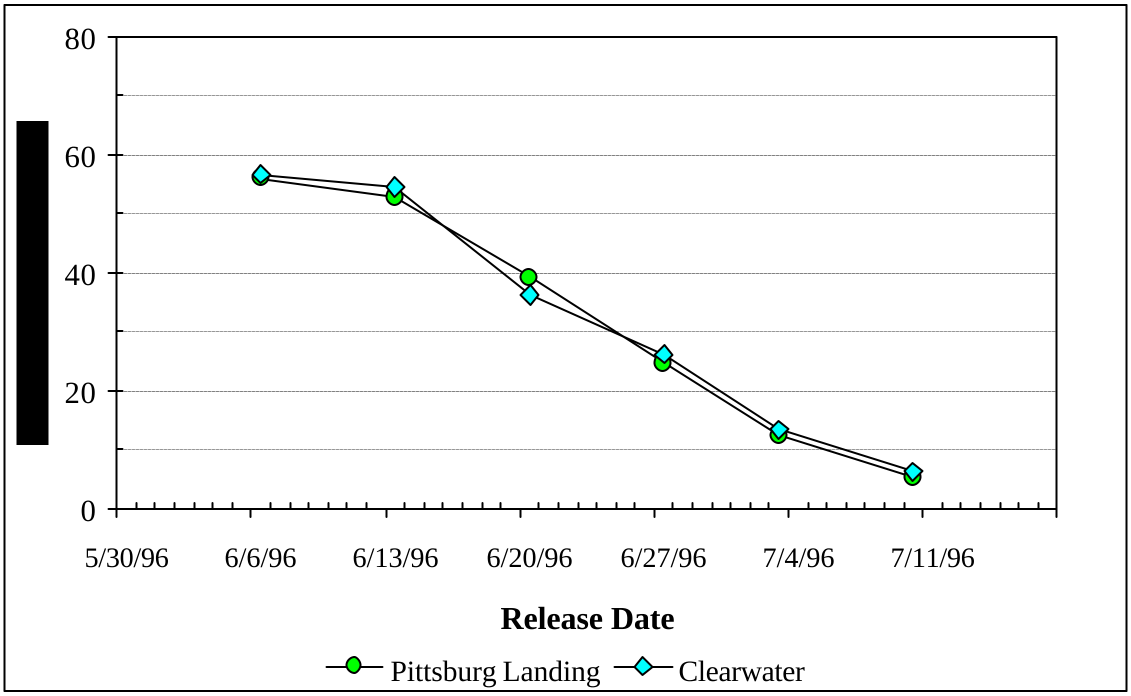


Figure 3.4-3: Estimated survival by release site, 1996.

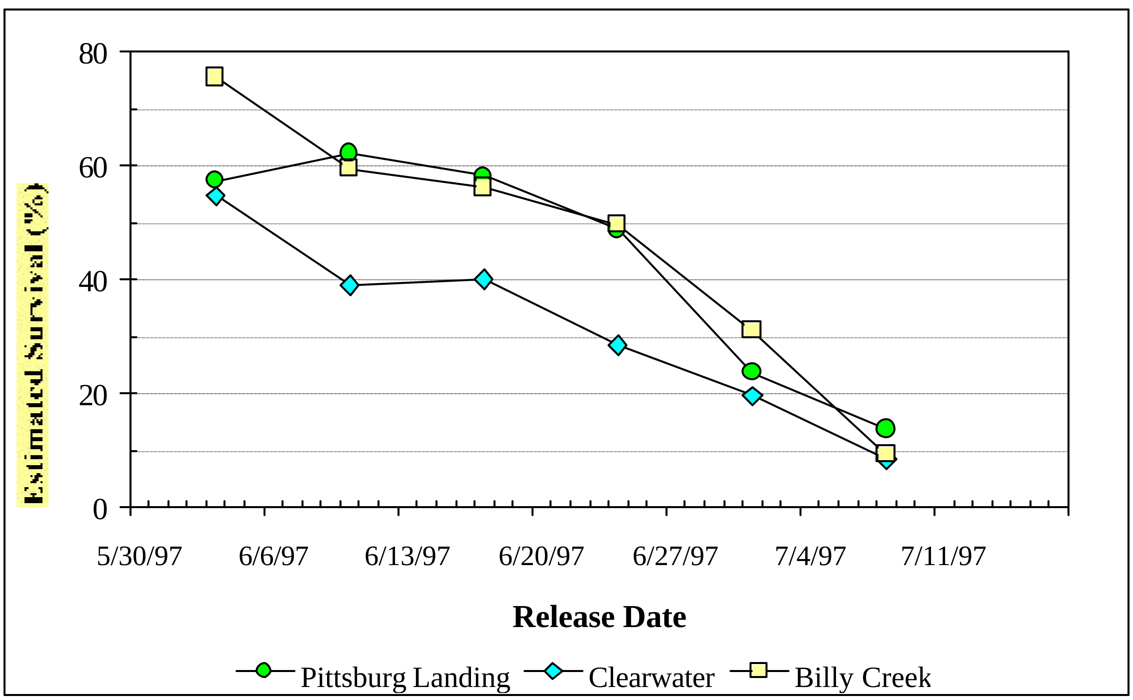


Figure 3.4-4: Estimated survival by release site and year, 1997.

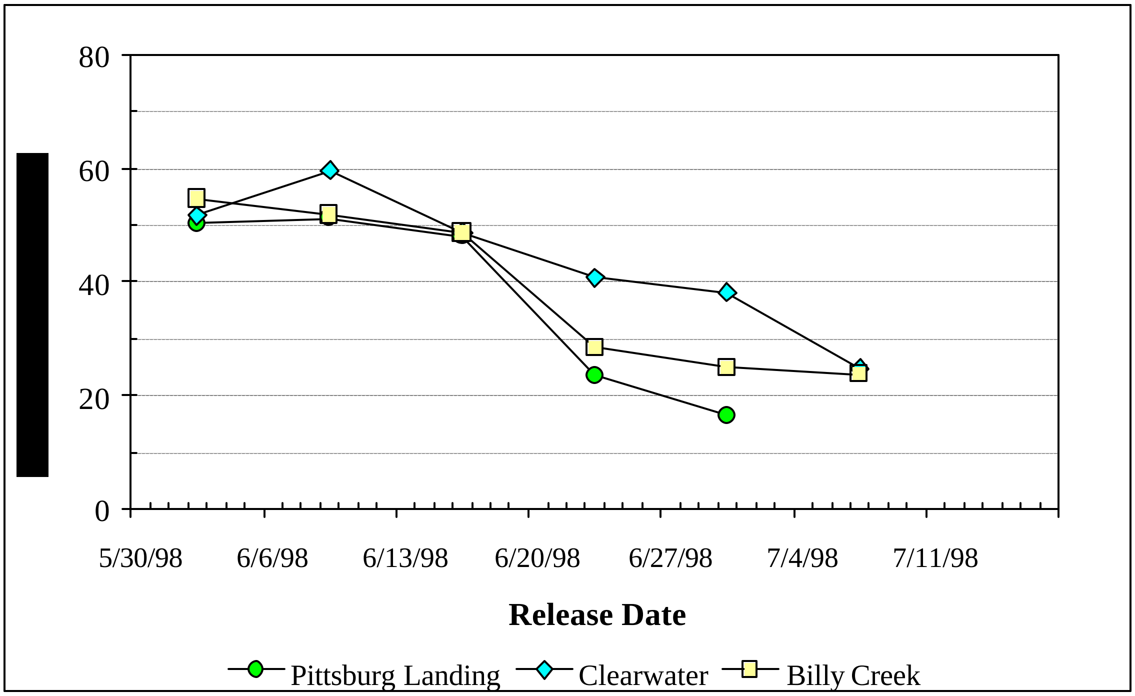


Figure 3.4-5: Estimated survival by release site and year, 1998.

3.5. Comparison of Estimated Survival and Release Groups by Release Site

The estimated survival by release group during the period 1995 through 1998 is shown in Figures 3.5-1 through 3.5-3. The estimated survival rates for the groups released at the Pittsburg Landing site were slightly higher in 1995[4] than in 1996 and 1997 (Figure 3.5-1). For all six release groups, the estimated survival rates from the 1997 releases at the Pittsburg Landing site were higher than the 1996 and 1998 releases.

Estimated survival rates for groups released at the Clearwater site were higher in 1998 than in 1996 and 1997 for 5 of the 6 releases (Figure 3.5-2). In general, the estimated survival rates for the releases at the Billy Creek site have similar patterns to the releases at the Pittsburg Landing site (Figure 3.5-3). Estimated survival rates were higher for 1995 and 1997 than for 1998 (there were no releases at the Billy Creek site in 1996).

These analyses show that there is some variation in estimated survival rates from year to year and between release sites. The reason(s) for the observed variations are not known.

[4] There were only three releases from the Pittsburg Landing site in 1995.

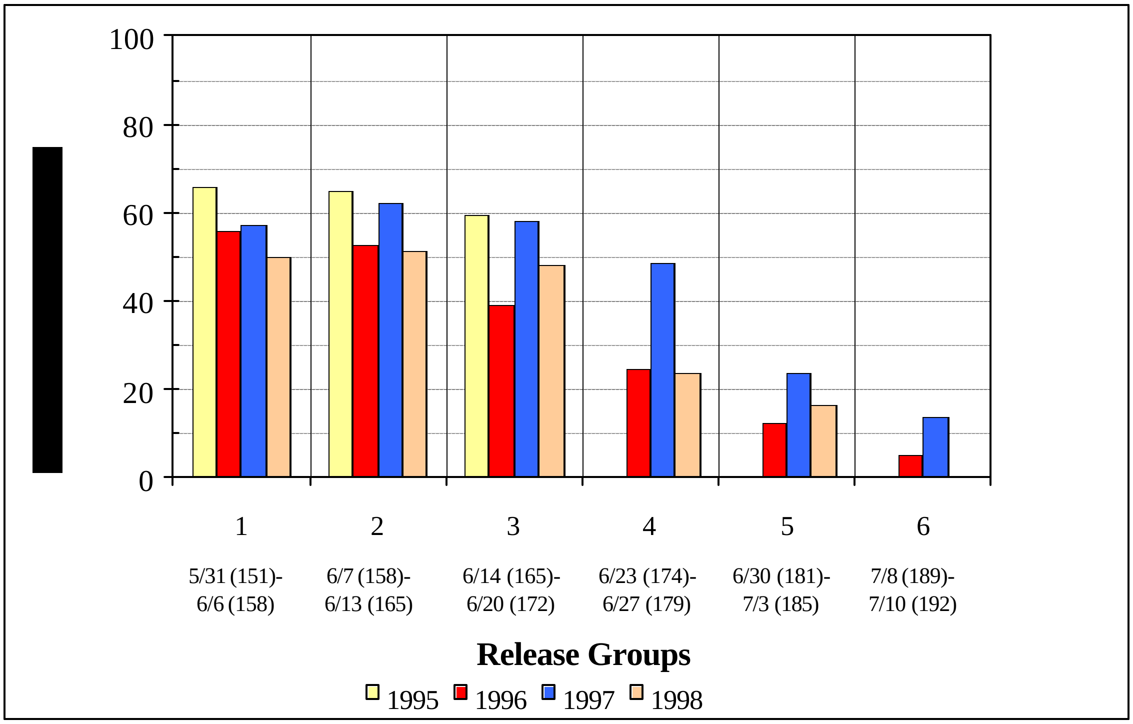


Figure 3.5-1: Estimated survival versus release groups for the Pittsburg Landing site, 1995-1998.

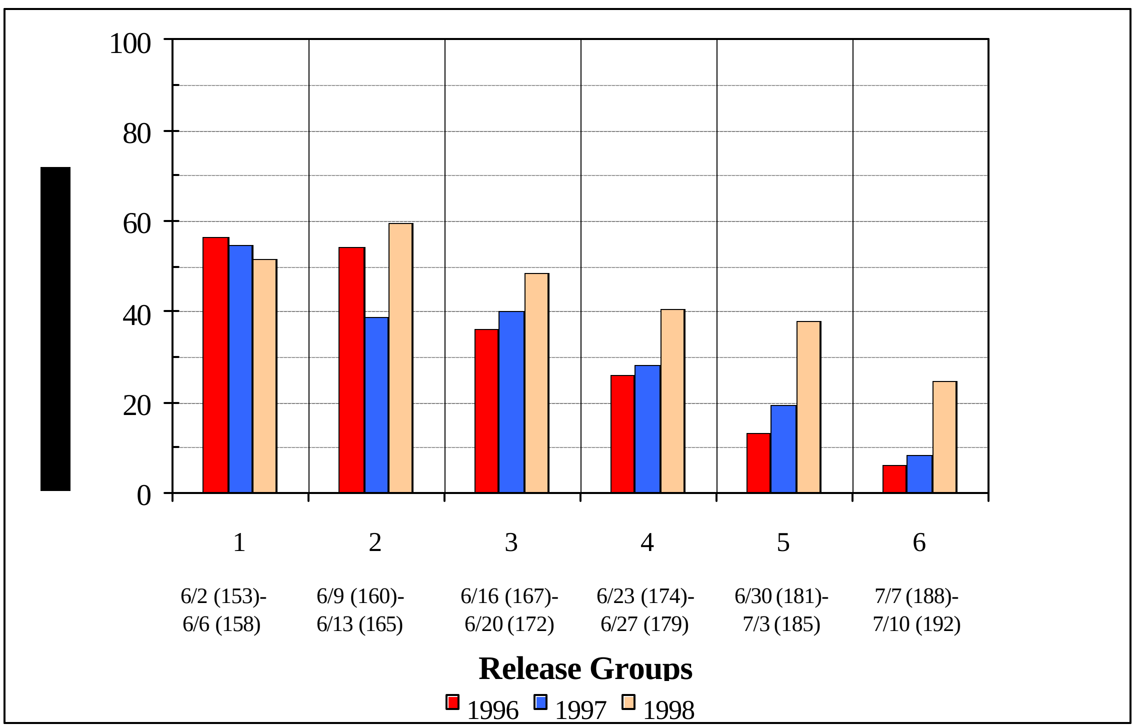
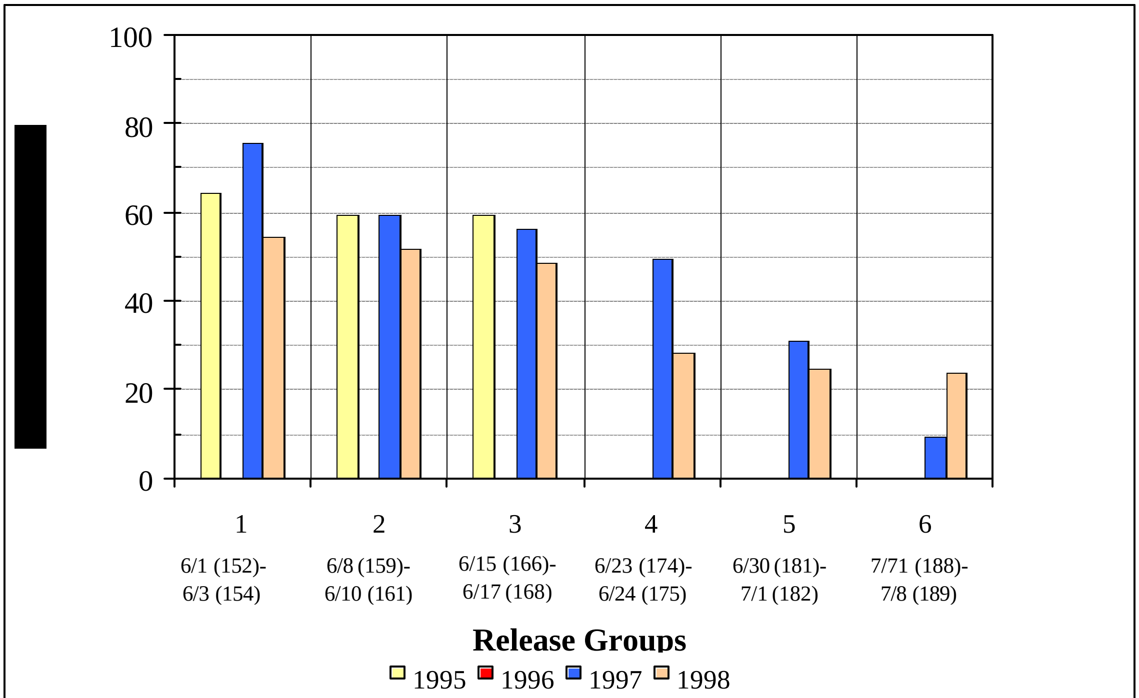


Figure 3.5-2: Estimated survival versus release groups for the Clearwater site, 1996-1998.



Note: there were only 3 releases in 1995 from the Billy Creek Site, and no releases in 1996

Figure 3.5-3: Estimated survival versus release groups for the Billy Creek site, 1995-1998.

3.6. Subyearling Fall Chinook Salmon Travel Times and Numbers of Detections

This section presents the following data:

1. Distribution curves for hatchery-raised, subyearling fall chinook salmon detected at Lower Granite Dam for the 1st, 3rd, and 6th releases for the years 1996 through 1998;

2. Cumulative detections of hatchery-raised, subyearling fall chinook salmon at Lower Granite Dam for the years 1996 through 1998; and

3. Flows, flow indices, travel times, and arrival dates for selected percentiles of surviving fish for the years 1996 through 1998.

3.6.1. Distribution curves for hatchery-raised, subyearling fall chinook salmon detected at Lower Granite Dam for the 1st, 3rd and 6th releases, 1996 through 1998

Distribution curves for surviving salmon detected from the 1st, 3rd, and 6th releases at the Pittsburg Landing, Clearwater, and Billy Creek release sites for the years 1996 through

1998 are shown in Figures 3.6.1-1 through 3.6.1-8. Flow and water temperatures at Lower Granite Dam as well as outflow from Dworshak Reservoir are also shown in these figures.

In general, the distribution curves for the early releases (1st and 3rd) are similar in shape. For example, compare the 1st and 3rd releases between the Clearwater and the Pittsburg Landing sites in 1996 (Figures 3.6.1-1 and 3.6.1-2). Detection data for the 1st and 3rd releases appear to be normally distributed to slightly skewed (either to the right or to the left). The 1st releases for 1997 appear to be more left-skewed than the 3rd releases (Figures 3.6.1-3 through 3.6.1-5).

The shapes of the distributions for the 6th releases are very different than the shapes of the distributions for the 1st and 3rd releases for all of the years. The 6th releases have distributions that are flat and elongated, indicating that migrations occur over long periods of time with fewer fish surviving than from the earlier releases.

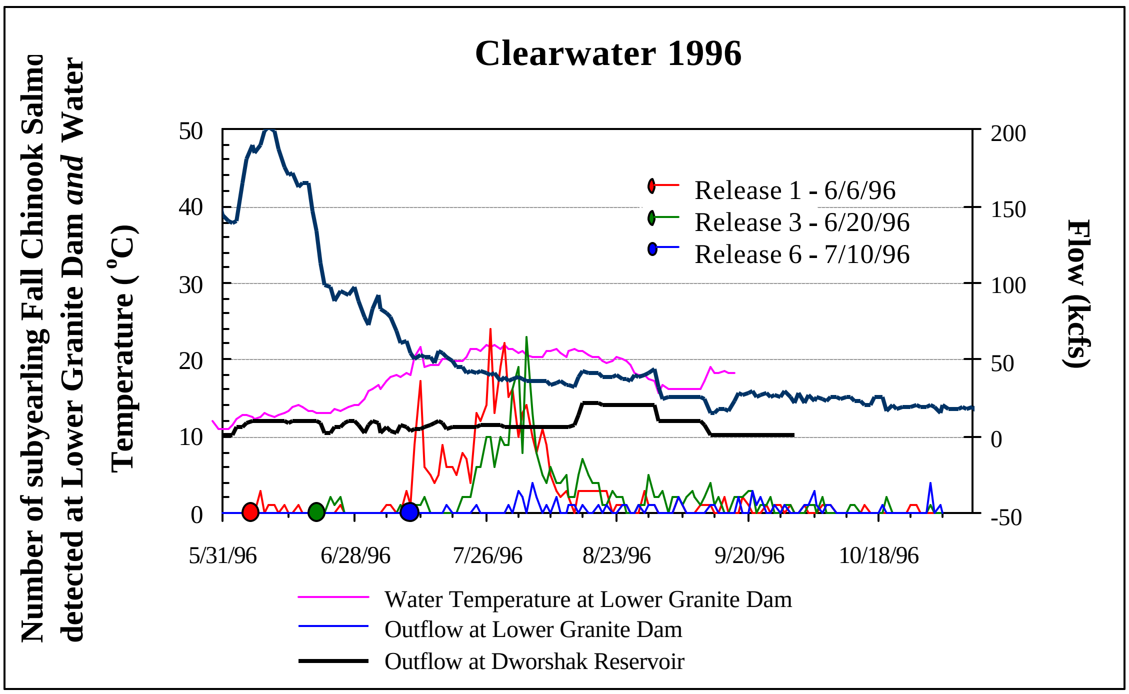


Figure 3.6.1-1: Distribution of hatchery-raised, subyearling fall chinook salmon released at the Clearwater site in 1996 and detected at Lower Granite Dam.

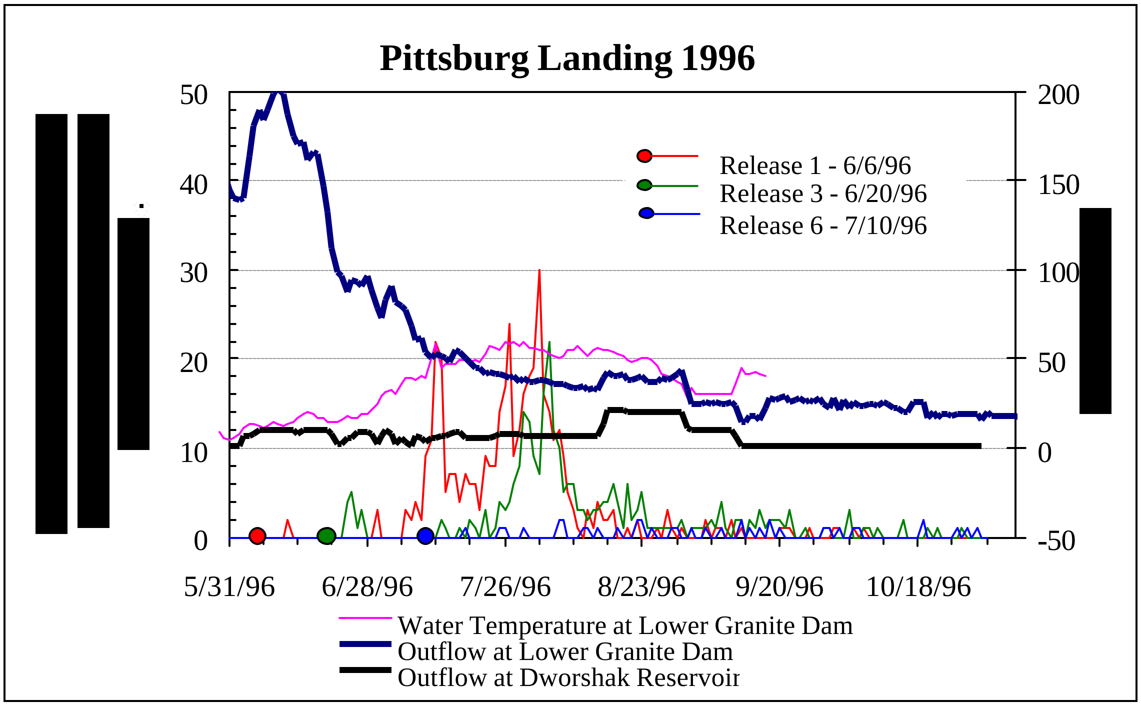


Figure 3.6.1-2: Distribution of hatchery-raised, subyearling fall chinook salmon released at the Pittsburg Landing site in 1996 and detected at Lower Granite Dam.

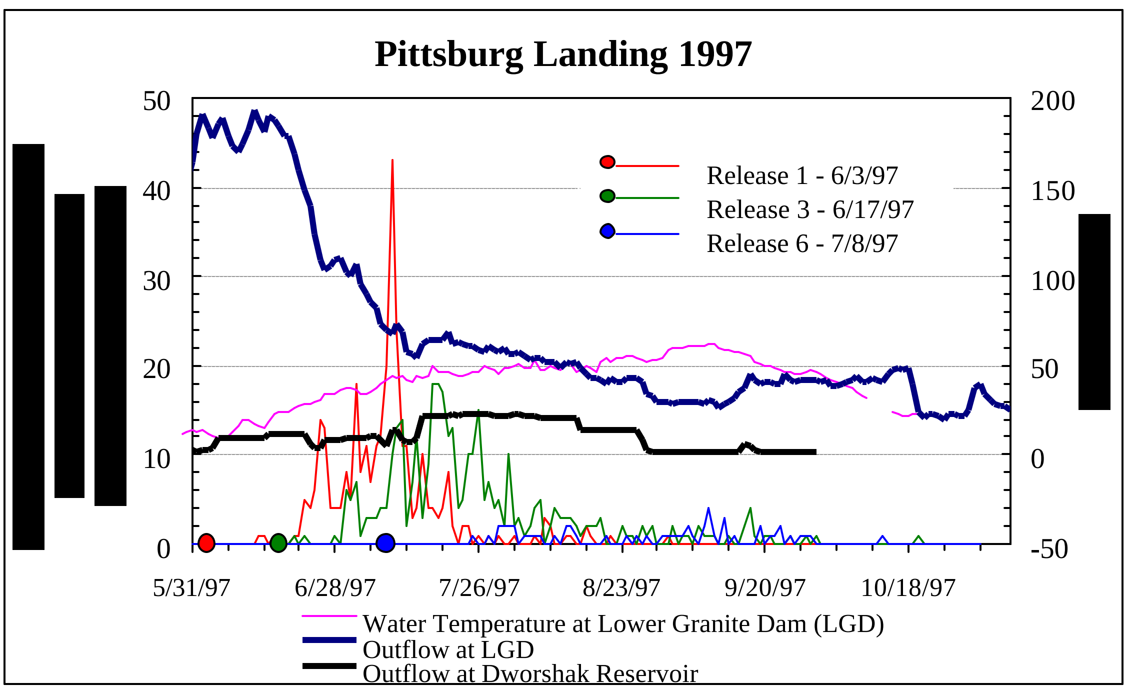


Figure 3.6.1-3: Distribution of hatchery-raised, subyearling fall chinook salmon released at the Pittsburg Landing site in 1997 and detected at Lower Granite Dam.

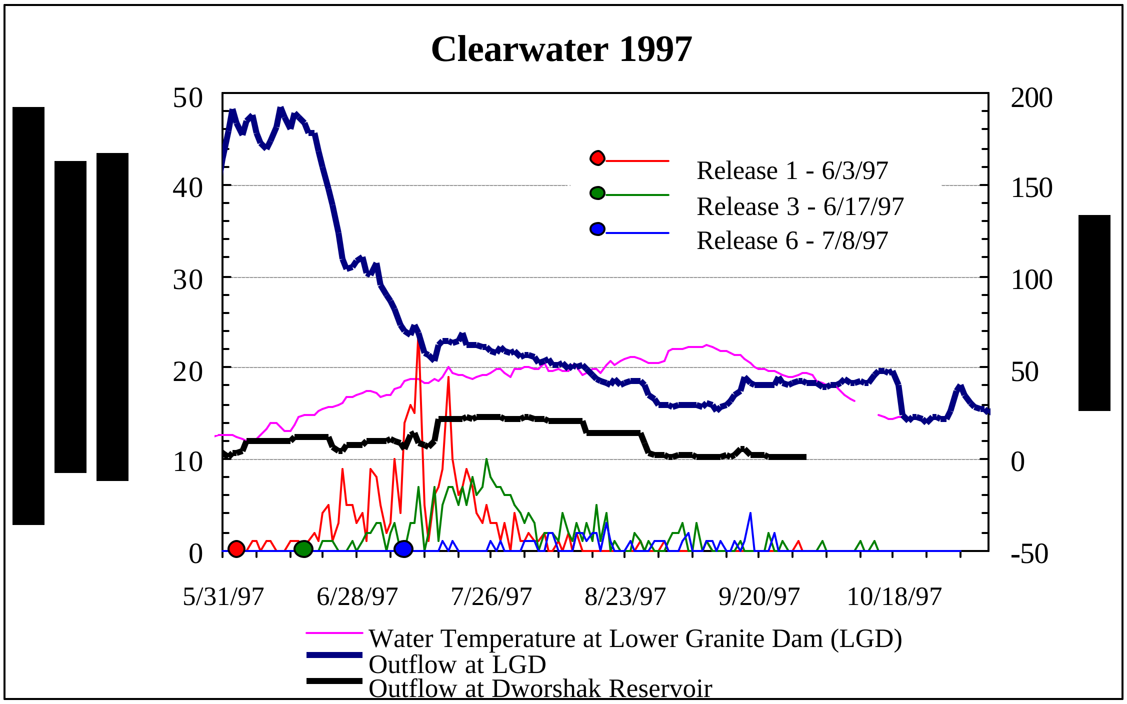


Figure 3.6.1-4: Distribution of hatchery-raised, subyearling fall chinook salmon released at the Clearwater site in 1997 and detected at Lower Granite Dam.

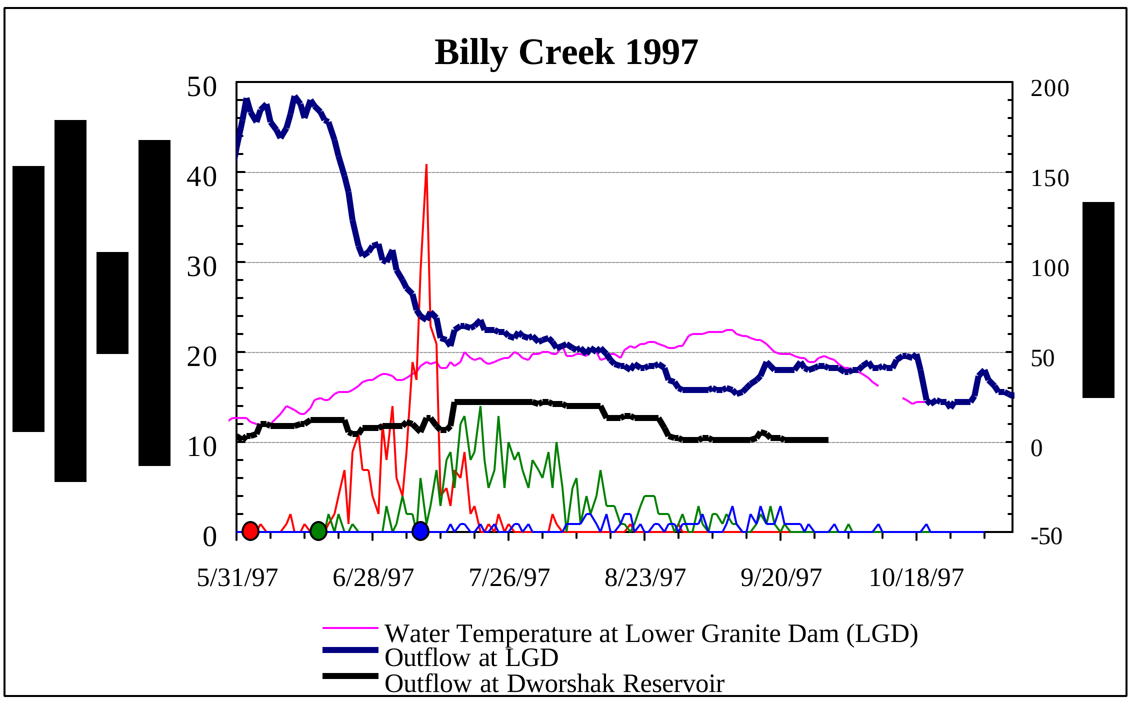


Figure 3.6.1-5: Distribution of hatchery-raised, subyearling fall chinook salmon released at the Billy Creek site in 1997 and detected at Lower Granite Dam.

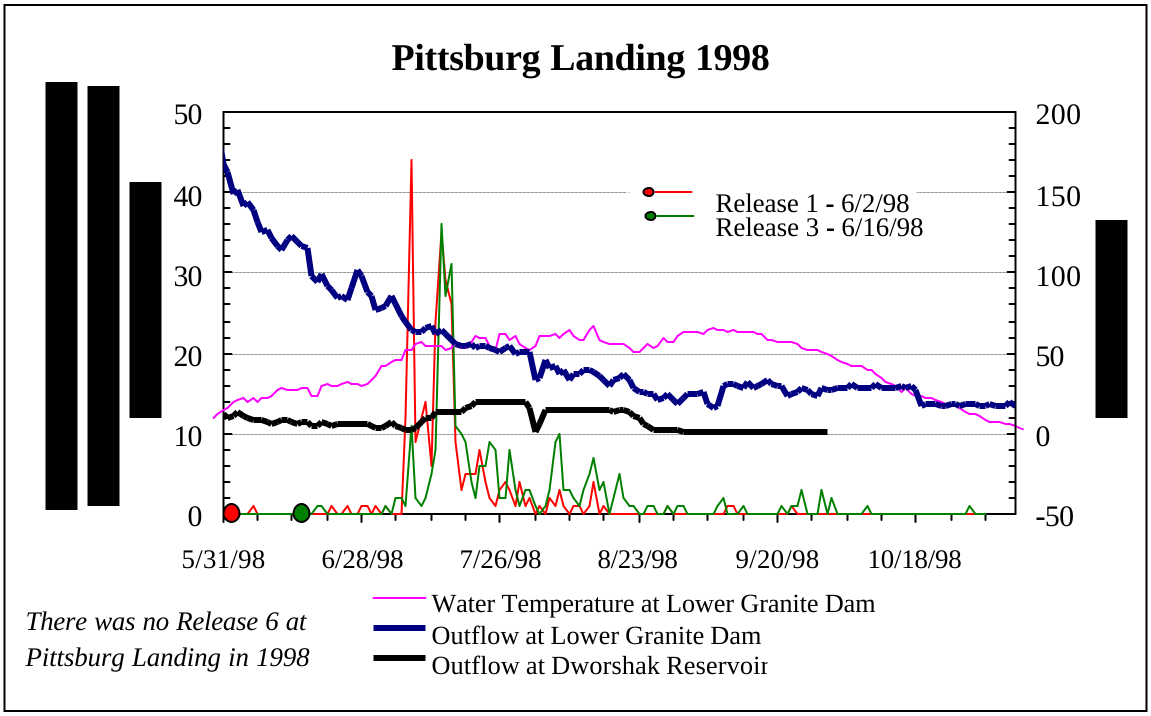


Figure 3.6.1-6: Distribution of hatchery-raised, subyearling fall chinook salmon released at the Pittsburg Landing site in 1998 and detected at Lower Granite Dam.

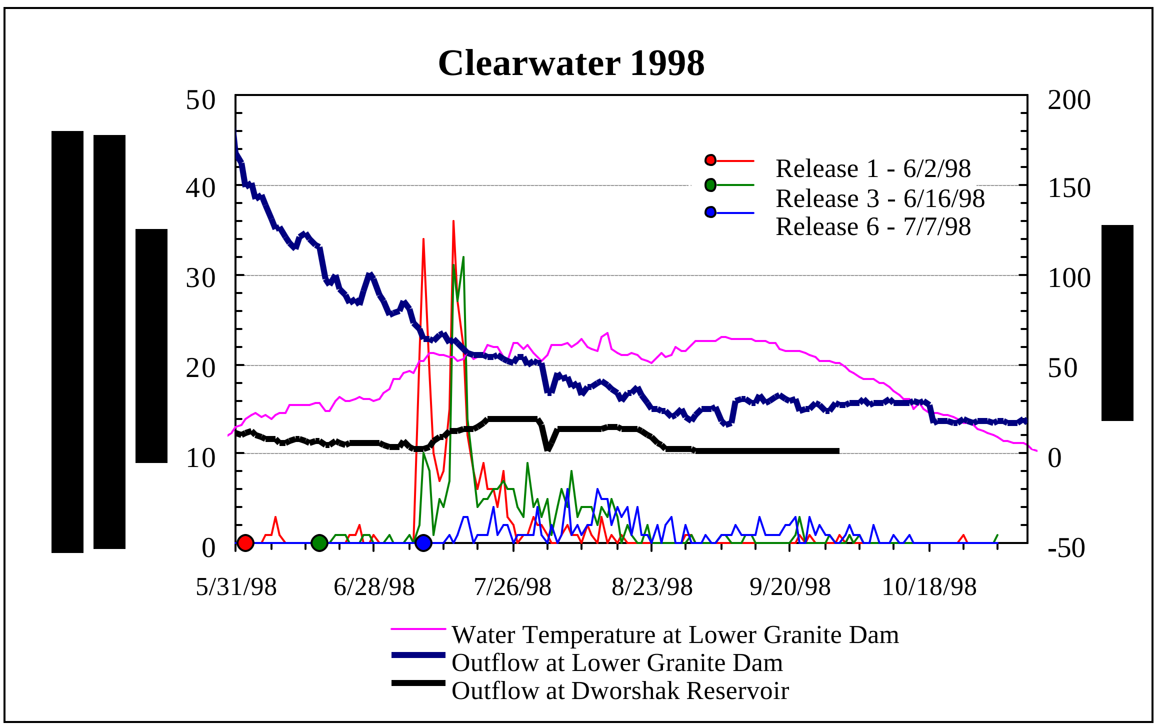


Figure 3.6.1-7: Distribution of hatchery-raised, subyearling fall chinook salmon released at the Clearwater site in 1998 and detected at Lower Granite Dam.

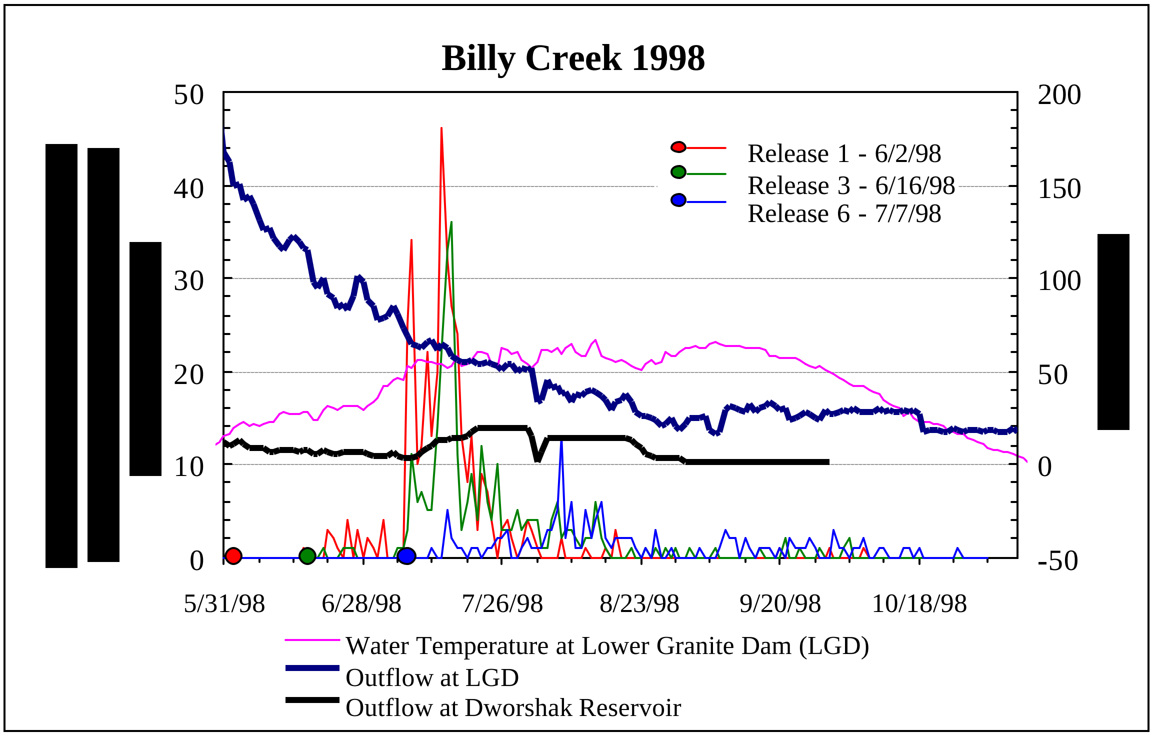


Figure 3.6.1-8: Distribution of hatchery-raised, subyearling fall chinook salmon released at the Billy Creek site in 1998 and detected at detected at Lower Granite Dam.

3.6.2. Cumulative detections of subyearling fall chinook salmon at Lower Granite Dam for the 1st , 3rd, and 6th releases, 1996 through 1998.

Cumulative detections of subyearling fall chinook salmon at Lower Granite Dam from the 1st, 3rd, and 6th releases are presented in Figures 3.6.2-1 through 3.6.2-3. Cumulative detections from early releases generally form steeper curves, indicating that migration occurs during a relatively short time period. First and 3rd releases show more delay for the arrival of the 5th percentile fish than the 6th releases, which possibly is associated with the time required to reach physiological “readiness” to migrate. Cumulative detections from 6th releases were spread over a larger time period, indicating a more dispersed migration pattern.

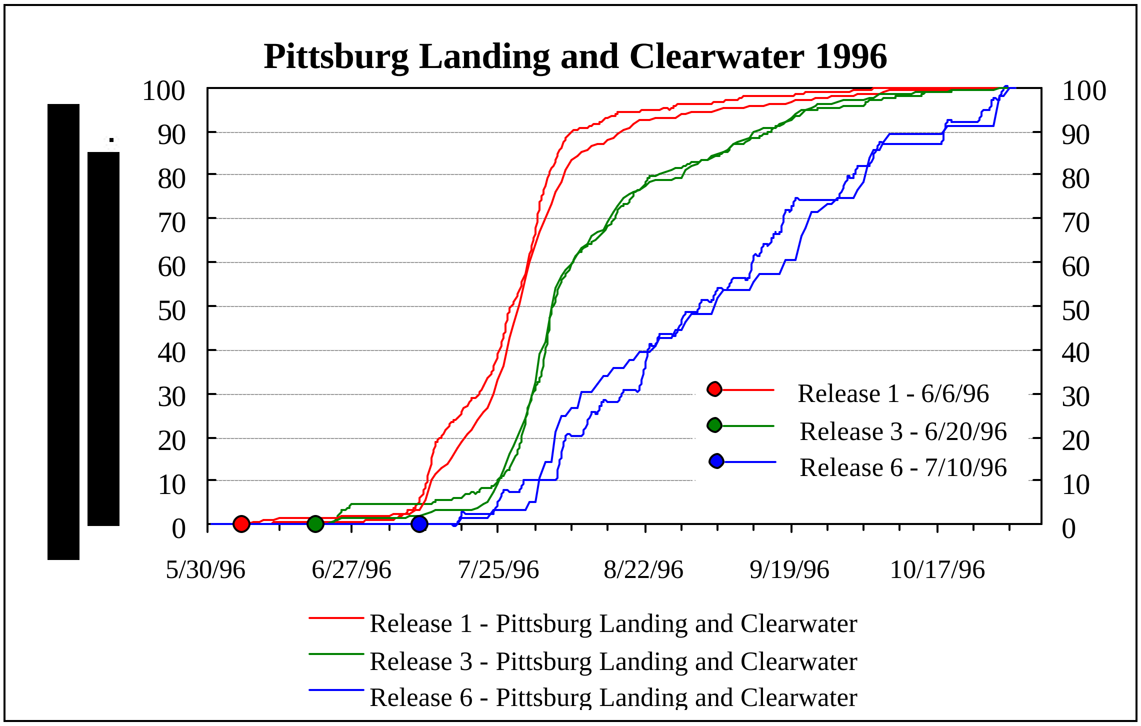


Figure 3.6.2-1: Cumulative detections of hatchery–raised, fall chinook salmon at Lower Granite Dam released from the Pittsburg Landing and Clearwater sites in 1996.

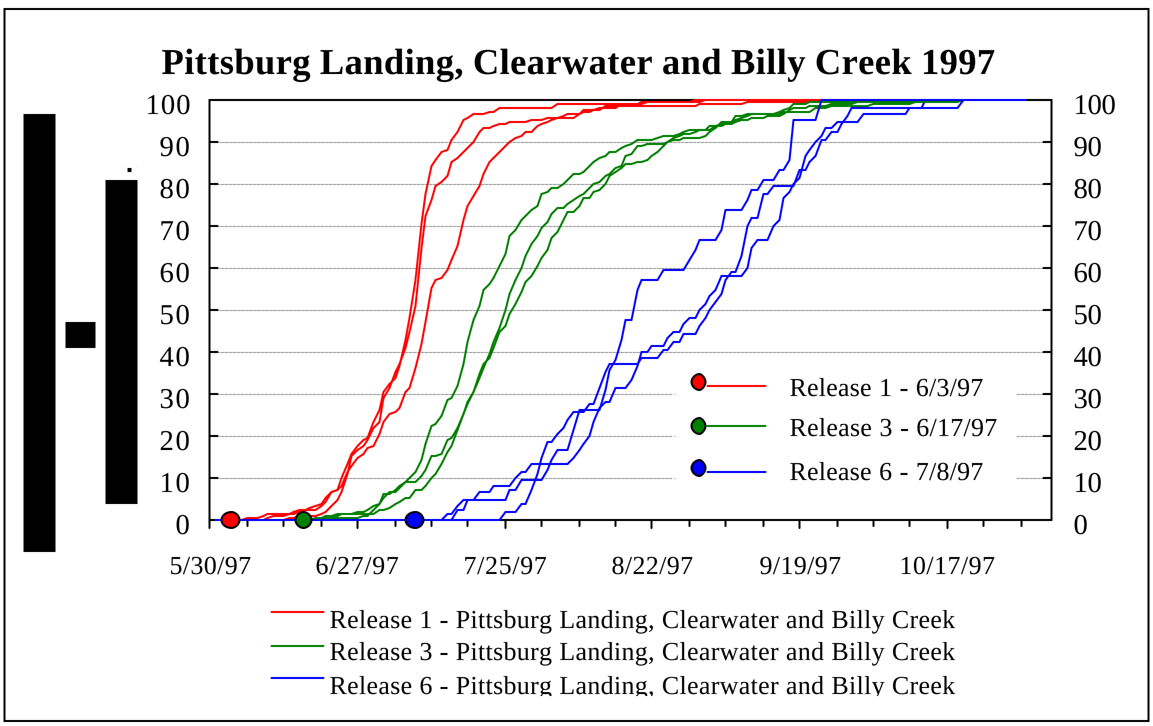


Figure 3.6.2-2: Cumulative detections of hatchery–raised, fall chinook salmon at Lower Granite Dam released from the Pittsburg Landing, Clearwater, and Billy Creek sites in 1997.

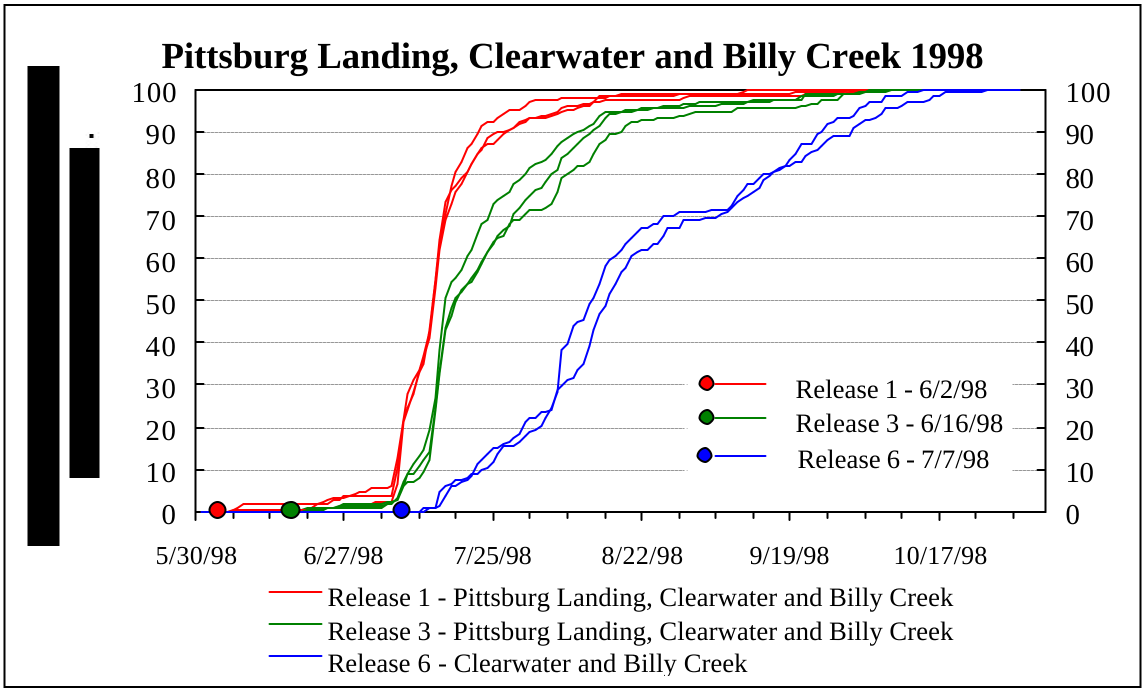


Figure 3.6.2-3: Cumulative detections of hatchery–raised, fall chinook salmon at Lower Granite Dam released from the Pittsburg Landing, Clearwater, and Billy Creek sites in 1998.

3.6.3. Flows Rates, Flow Indices, Travel Times, and Arrival Dates

This section presents a series of graphs showing flow rates, flow indices, travel times, and arrival dates for selected percentiles of surviving fish. Figures 3.6.3-1 through 3.6.3-16 display flows, flow indices, water temperatures, travel times, and arrival dates for selected percentiles of surviving fish for the Clearwater and Snake River releases for 1996 through 1998. These figures are arranged in sequences according to release site and year. For example, Figures 3.6.3-1 and 3.6.3-2 show the flows, flow indices, water temperatures, travel times, and arrival dates for releases at the Pittsburg Landing site in 1996. Figure 3.6.1-17 shows the median of the travel times for the 50th percentile fish and the median of the 50th percentile flow indices by release group. Travel times (in days) for the 5th, 25th, 50th, and 75th percentile fish in the 1st and 6th releases are presented in Table 3.6.3-1.

The following observations and interpretations are made from these graphs (discussion of each numbered point follows):

1) Travel times for the 5th and 10th percentile surviving fish decreased for each release series[5], despite decreasing flow rates. Travel times for the 25th percentile surviving

[5] The term "release series" refers to sequential releases during one year at one site.

fish decreased or remained nearly the same (except for the 1997 Billy Creek series, which experienced a slight increase in travel time).

2) There was no significant difference in the median travel times for the six weekly release groups for the 50th percentile surviving fish at the 95 percent confidence interval despite a decrease in the median 50th percentile flow indices of about 48 percent from the 1st to the 6th releases (99 kcfs to 51 kcfs).

3) The arrival dates for some of the surviving fish percentiles were nearly the same despite being released up to 14 days apart.

4) The effect of flow augmentation from Dworshak Reservoir on fall chinook salmon survival rates is unknown. An analysis of the 50th percentile fish, Releases 1 through 4 in 1996 (these fish arrived at Lower Granite Dam before augmentation from Dworshak began) with Releases 1 through 4, 1998 (flow augmentation from Dworshak took place during the migration of these fish) showed that there was no statistical difference in estimated survival between the two years at the 95 percent confidence level.

Travel times for the 5th and 10th percentile surviving fish decreased for each release series despite decreasing flow rates. For example, the 5th percentile surviving fish from the first Pittsburg Landing release arrived at Lower Granite Dam in 34 days (Figure 3.6.3-1). The 5th percentile flow index during this time was 123 kcfs. The 5th percentile surviving fish from the 6th release arrived in 15 days. The 5th percentile flow during these 16 days was 48 kcfs.

The median travel times for the 5th percentile surviving fish in the 1st releases[6] during the years 1996 through 1998 was 33 days (Table 3.6-1). The median travel time for the 5th percentile fish from the 6th releases was 16 days. **Thus, the median travel times for the 5th percentile surviving fish from the 1st releases was more than twice the median travel time of the 5th surviving percentile fish from the 6th releases, despite steadily decreasing flows.** This pattern was also observed for some of the 25th percentile surviving fish. For example, the median travel time for the 25th percentile surviving fish in the 1st releases was 39 days (Table 3.6-1). The median travel time of the 25th percentile surviving fish from the 6th releases was 31 days, despite steadily decreasing flows.

Travel times for the 50th percentile surviving fish generally decreased from the 1st to the middle (3rd or 4th) releases, despite decreasing flows, then increased for later releases (Figures 3.6.3-1, -3, -11, -13 and -15). This pattern was also observed by NMFS (2000): "Typically, groups released around 13-15 June had the shortest travel times, and groups released earlier or later had longer travel times," and that "flow generally decreased

[6] Includes those release series in which there were five or six weekly releases.

throughout the period of subyearling chinook salmon migration." Median travel times in 1997 were an exception; the shortest travel times for the 50^{th} percentile surviving fish were experienced by fish from the 2^{nd} release (Figures 3.6.3-5, -7, and –9).

A compilation of the release data for individual sites showed that median travel times for the 50^{th} percentile surviving fish from the six release groups had a much different pattern than the medians of the 50^{th} percentile flow indices for those groups. While the median flow indices dropped steadily from 99 kcfs (1^{st} release groups) to 51 kcfs (6^{th} release groups), median travel times remained nearly the same for the four release groups, and rose slightly for the last two release groups (Figure 3.6.3-17).

The arrival dates for some of the percentiles of surviving fish were clustered. Figures 3.6.3-2, -4, -6, -8, -10, -12, -14, and -16 show the survival, release date, and arrival times of the 5^{th}, 50^{th}, and 90^{th} percentile surviving fish. The 5^{th} percentile surviving fish from several sequential releases arrived on a similar date. For example, the 5^{th} percentile surviving fish from the first three weekly releases at the Pittsburg Landing site in 1998 (released on 6/2, 6/9, and 6/16) arrived within one day of each other (Figure 3.6.3-12). The arrivals of the 5^{th} percentile surviving fish from the last three Pittsburg Landing releases in 1996 occurred at approximately the same time (Figure 3.6.3-2). In fact, the arrival of the 5^{th} percentile surviving fish from the 6^{th} release actually occurred prior to the arrival of the 5^{th} percentile surviving fish from the previous two releases. This pattern of similar arrival times for the 5^{th} percentile surviving fish released up to 14 days apart was also observed in releases from the Clearwater site in 1996 and 1998, and the Billy Creek site in 1997 and 1998.

Some of the 50^{th} percentile surviving fish from sequential releases arrived in clusters despite different release times. This pattern was observed in the 1^{st} and 2^{nd} and in the 3^{rd} and 4^{th} releases from the Clearwater site in 1996 (Figure 3.6.3-4), the first two releases from the Clearwater site in 1997 (Figure 3.6.3-8), the first two releases from Billy Creek in 1997 (Figure 3.6.3-10), the first three releases from the Pittsburg Landing site in 1998 (Figure 3.6.3-12), the first three releases from the Clearwater site in 1998 (Figure 3.6.3-14), and the first three and the last two releases from the Billy Creek site in 1998 (Figure 3.6.3-16).

Some of the arrival dates for the 90^{th} percentile surviving fish from different releases were also aggregated despite weekly intervals between release times. Examples of this include the last two releases from the Pittsburg Landing site in 1997 (Figure 3.6.3-6) as well as the first two and the last two releases from the Clearwater site in 1997 (Figure 3.6.3-8). Conversely, some of the arrival dates for the 90^{th} percentile surviving fish were more spread out than the time intervals between releases. Examples of this include the arrivals of the 90^{th} percentile surviving fish from the 2^{nd} and 3^{rd} releases from the Clearwater site in 1996 (Figure 3.6.3-4), the 4^{th} and 5^{th} releases from the Pittsburg Landing site in 1997

(Figure 3.6.3-6), the 3rd and 4th releases from the Pittsburg Landing site in 1998 (Figure 3.6.3-10), and the 4th and 5th releases from the Billy Creek site in 1998 (Figure 3.6.3-16).

Finally, the effects of increased flow from Dworshak Reservoir in mid-August of 1996 and in mid-July of 1997 and 1998 could not be determined using available data. However, a portion of the data was analyzed by comparing releases that had reached Lower Granite Dam before flow augmentation began with releases that experienced, at least in part, flow augmentation from Dworshak Reservoir. In 1996, the 50th percentile surviving fish from the first four releases from the Clearwater and the Pittsburg Landing sites arrived at Lower Granite Dam before flow augmentation began at Dworshak Reservoir. In 1998, flow augmentation from Dworshak began earlier than in 1996. Thus, the 50th percentile surviving fish from the first four releases at the Clearwater and the Pittsburg Landing sites in 1998 migrated during the time period when flow augmentation from Dworshak Reservoir was in the Clearwater and Snake Rivers. Although the travel times for the 50th percentile fish for the first four releases were significantly greater in 1996 than in 1998 at the 95 percent confidence level, the 50th percentile flow indices, 50th percentile water temperature indices, and estimated survival were not significantly different between 1996 and 1998 at the 95 percent confidence level.

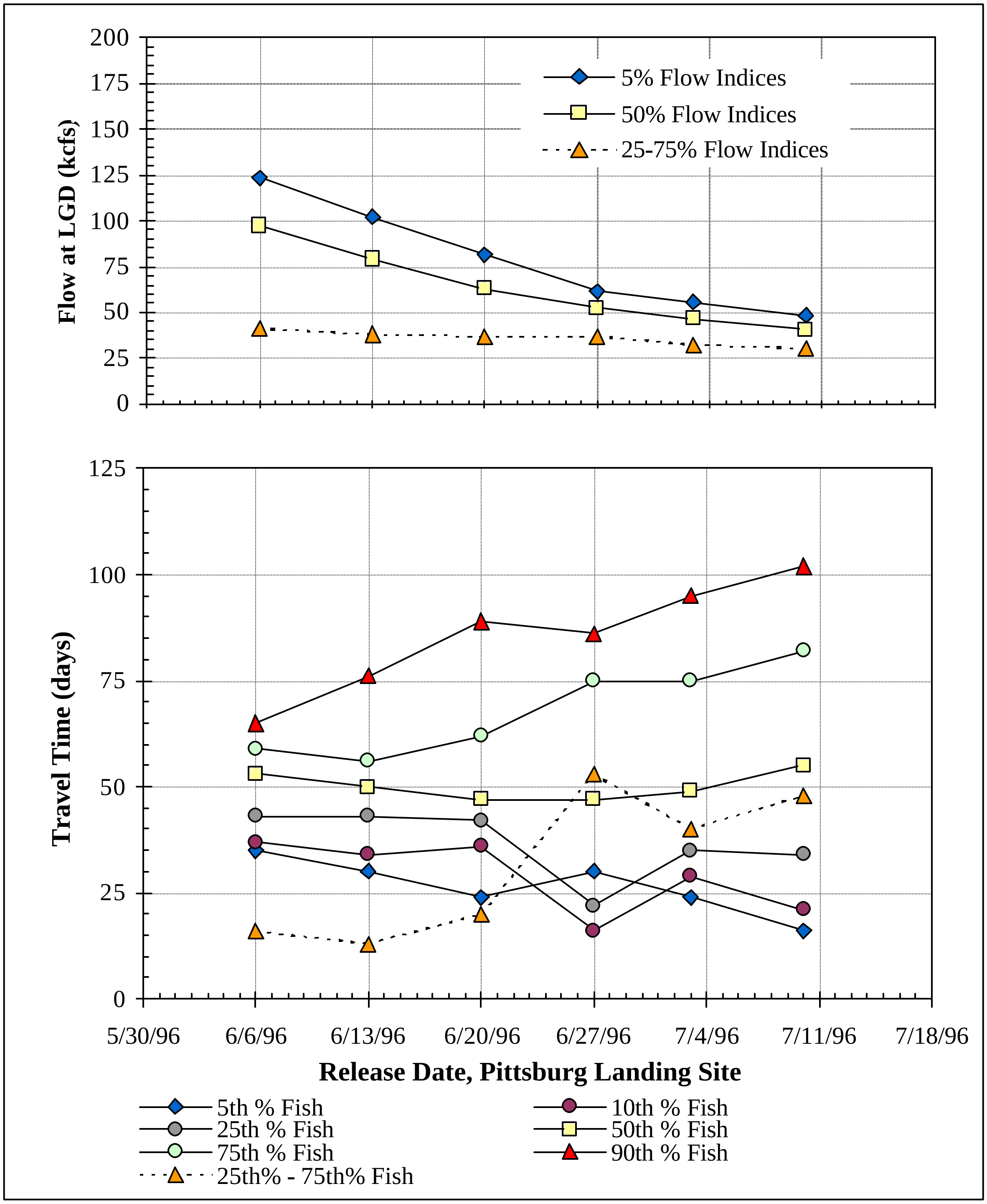


Figure 3.6.3-1: Travel times for the 5th, 10th, 25th, 50th, 75th, 90th, and 25th to 75th percentile surviving fish released from the Pittsburg Landing site in 1996 and corresponding 5th, 50th, and 25th to 75th percentile flow indices at Lower Granite Dam (LGD).

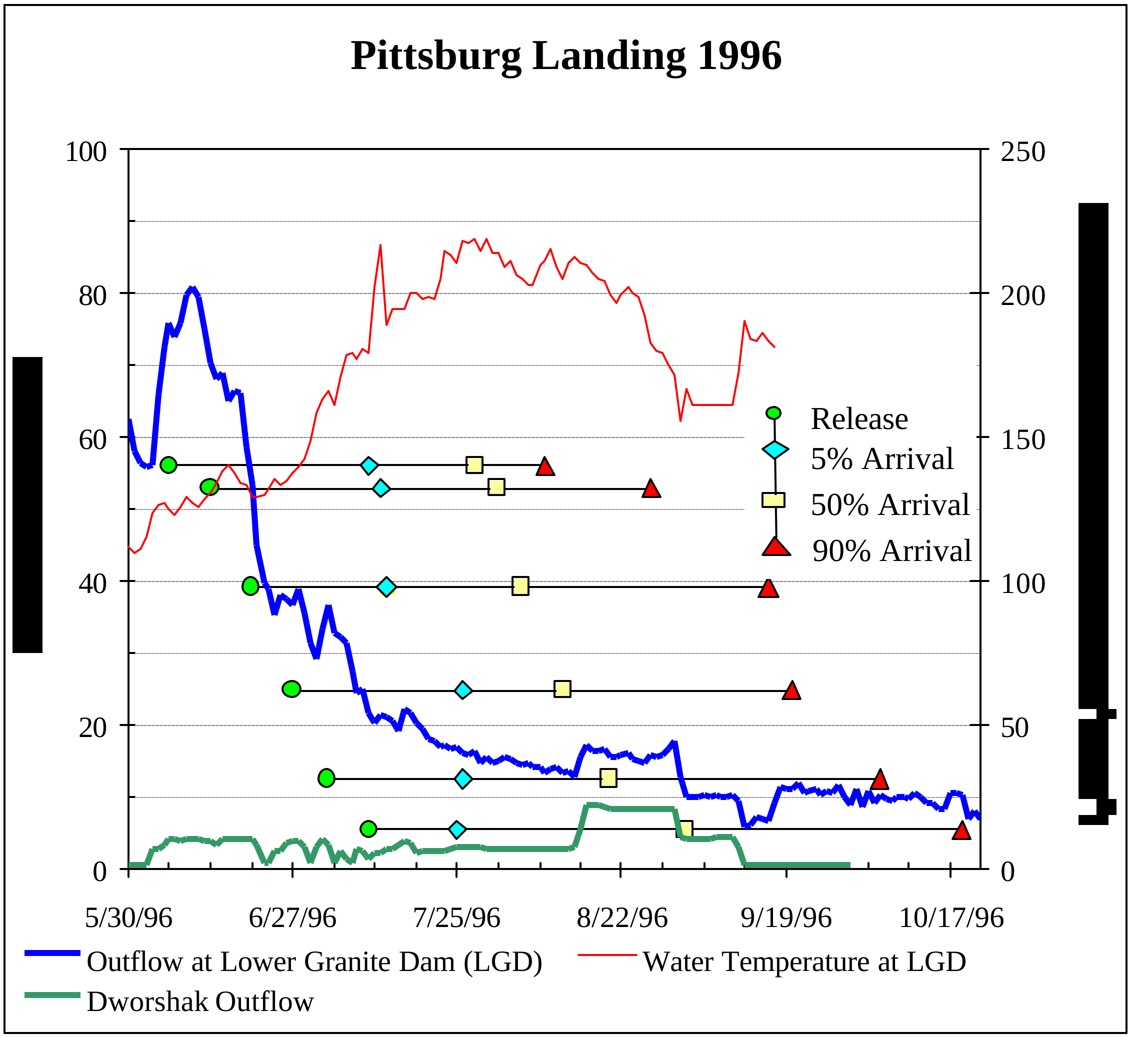


Figure 3.6.3-2: Arrival dates for the 5th, 50th, and 90th percentile surviving fish for the six releases from the Pittsburg Landing site in 1996.

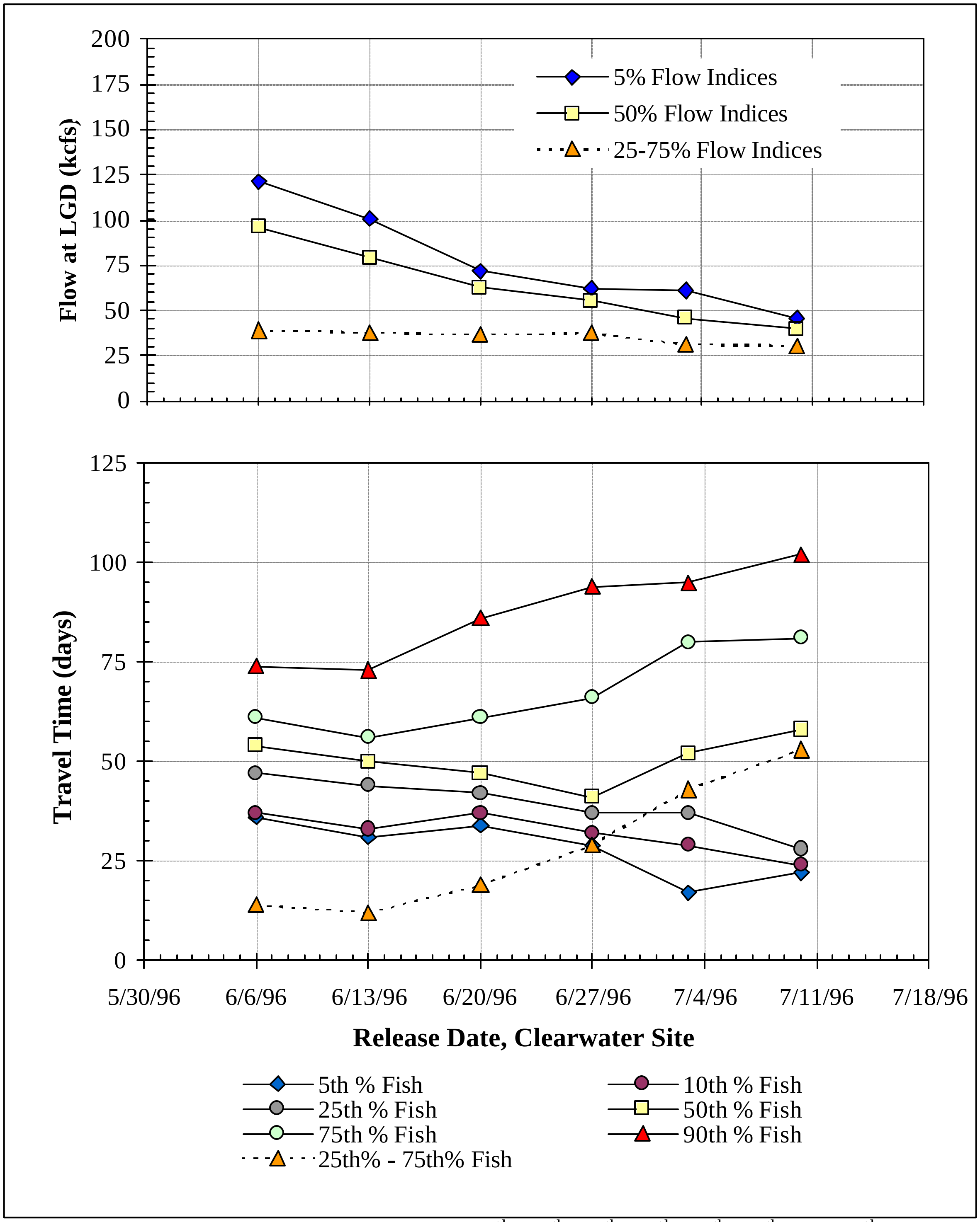


Figure 3.6.3-3: Travel times for the 5th, 10th, 25th, 50th, 75th, 90th, and 25th to 75th percentile fish released from the Clearwater site in 1996 and corresponding 5th, 50th, and 25th through 75th percentile flow indices at Lower Granite Dam (LGD).

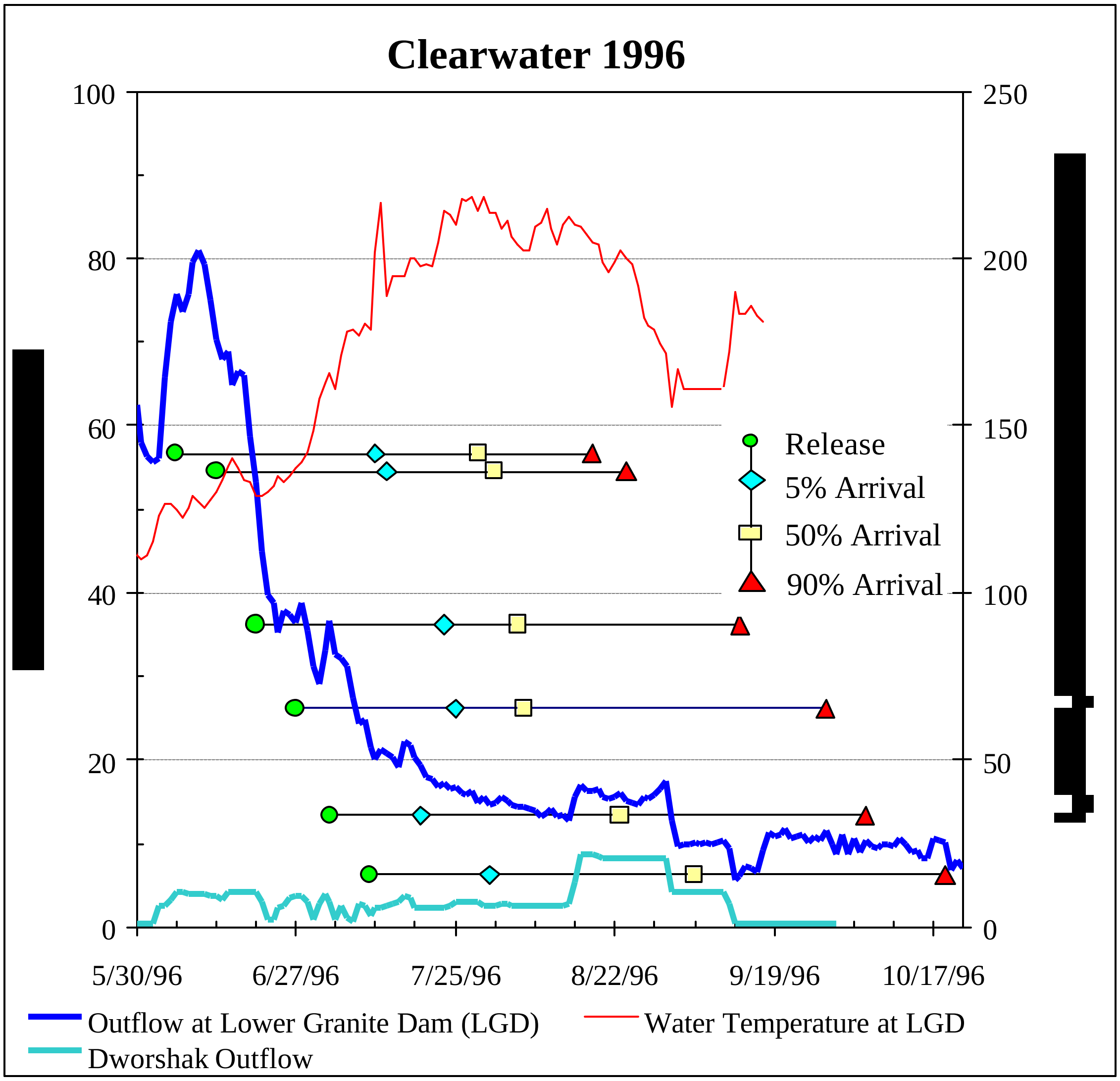


Figure 3.6.3-4: Arrival dates for the 5th, 50th, and 90th percentile surviving fish for the six releases at the Clearwater site in 1996.

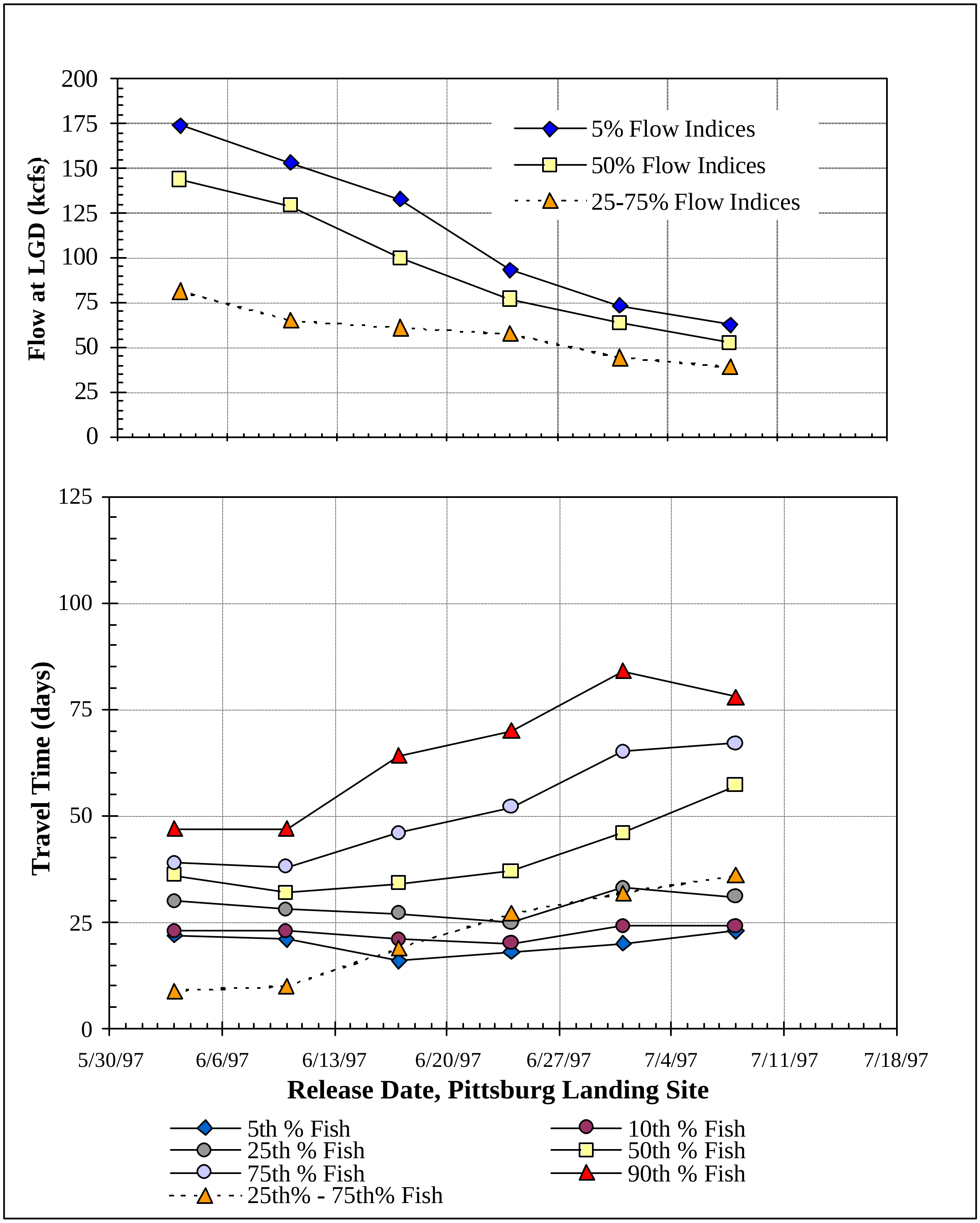


Figure 3.6.3-5: Travel times for the 5th, 10th, 25th, 50th, 75th, 90th, and 25th to 75th percentile surviving fish released from the Pittsburg Landing site in 1997 and corresponding 5th, 50th, and 25th to 75th percentile flow indices at Lower Granite Dam (LGD).

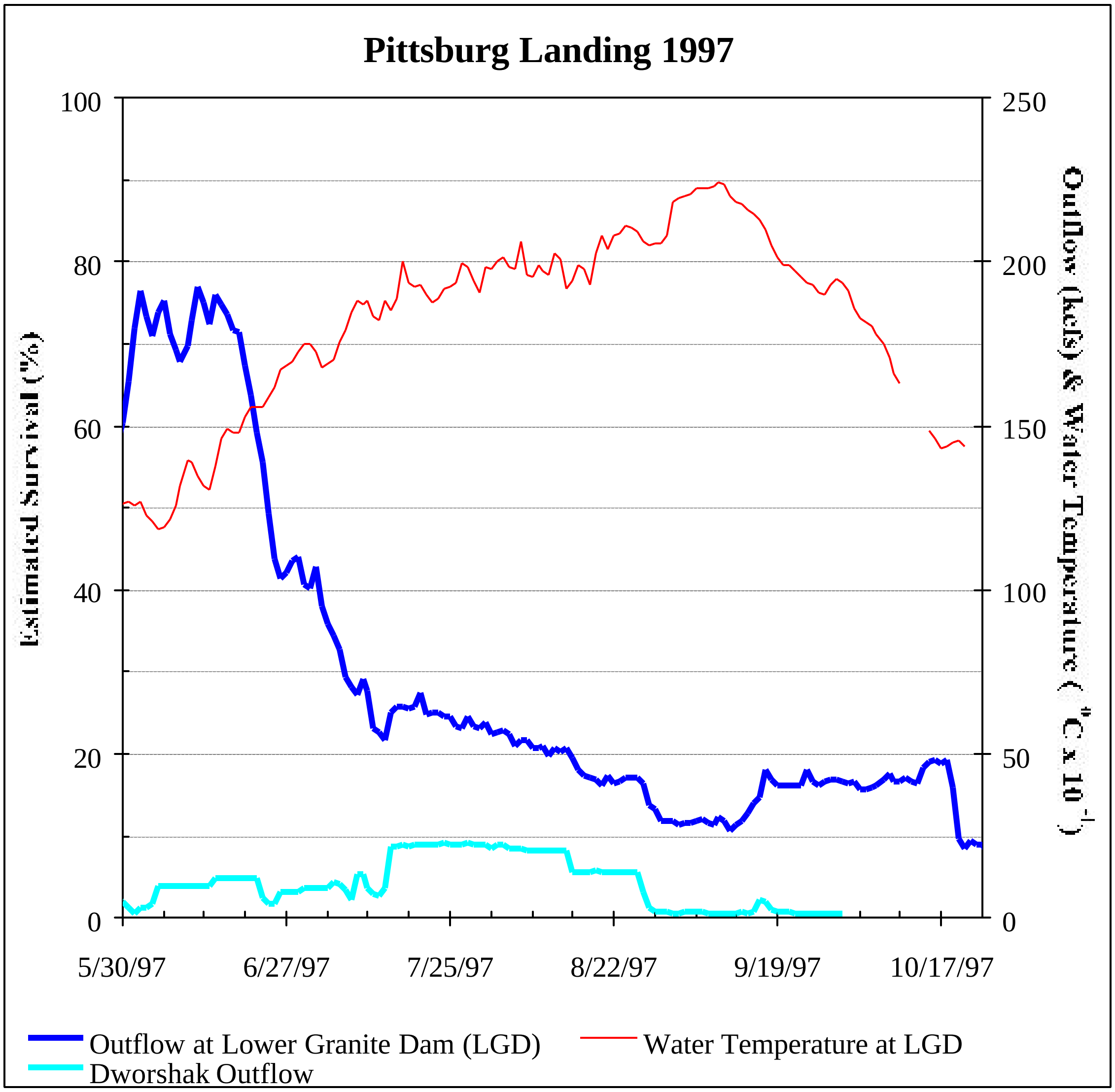


Figure 3.6.3-6: Arrival dates for the 5th, 50th, and 90th percentile surviving fish for the six releases at the Pittsburg Landing site in 1997.

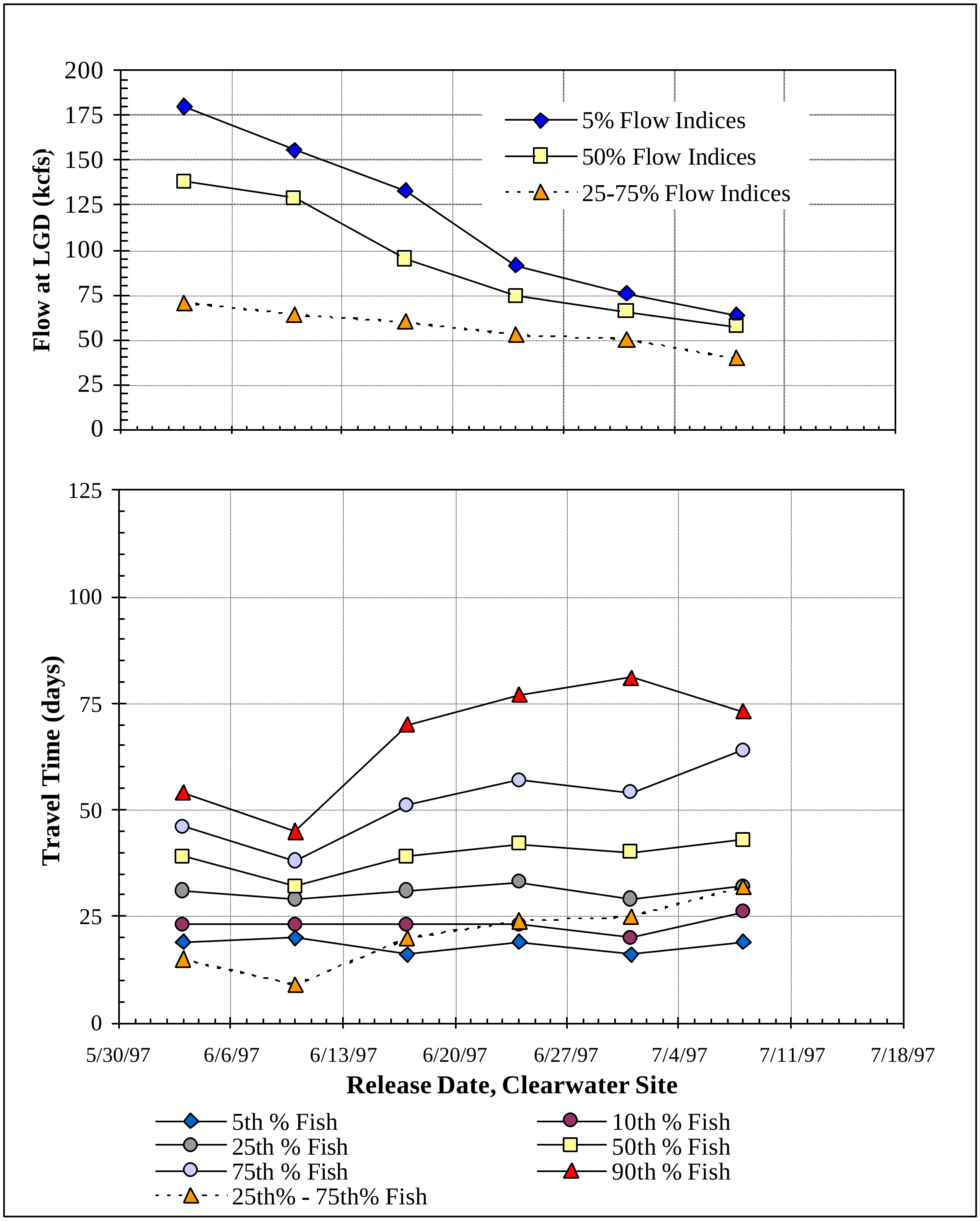


Figure 3.6.3-7: Travel times for the 5th, 10th, 25th, 50th, 75th, 90th, and 25th to 75th percentile surviving fish released from the Clearwater site in 1997 and corresponding 5th, 50th, and 25 through 75th percentile flow indices at Lower Granite Dam (LGD).

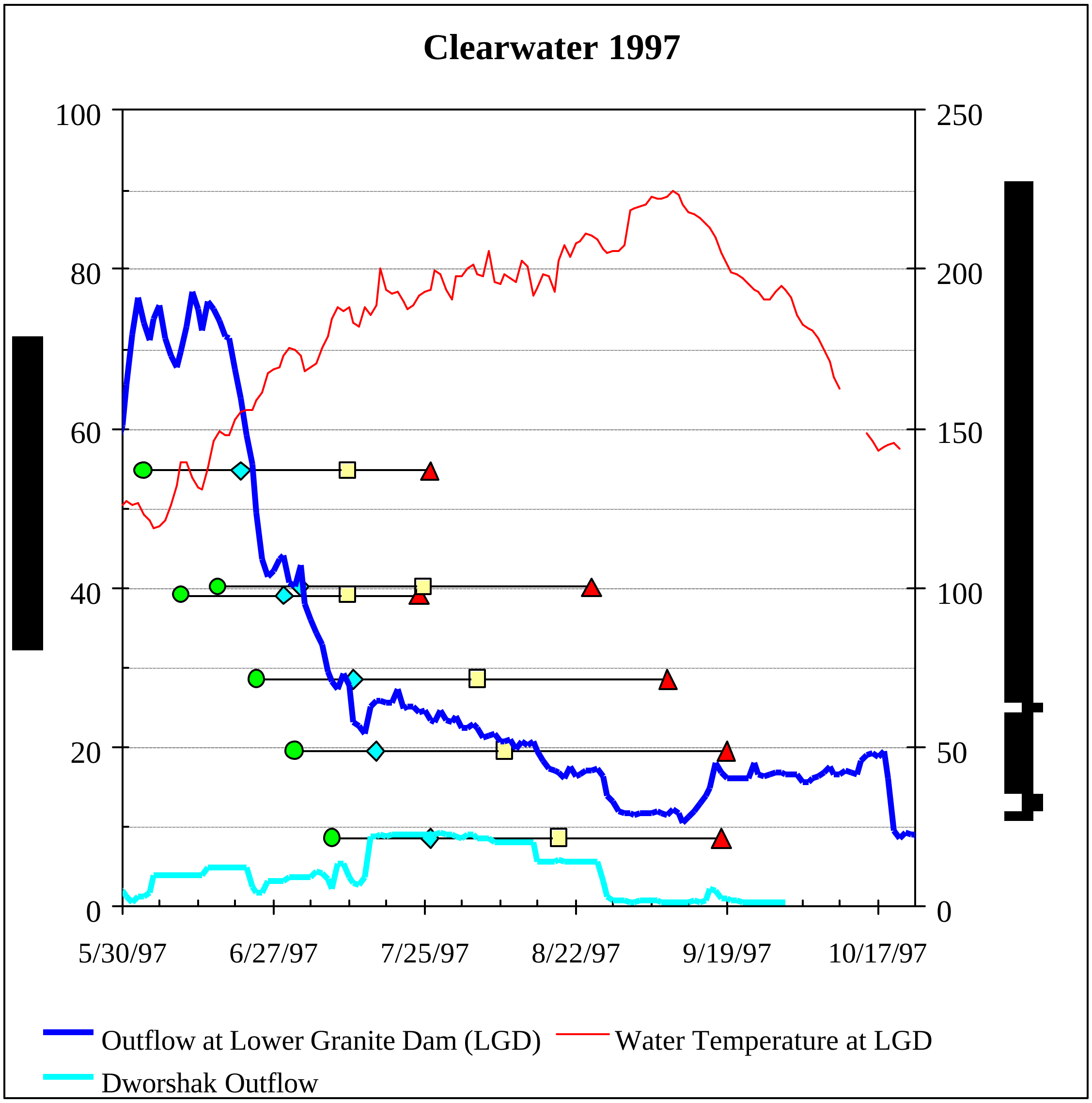


Figure 3.6.3-8: Arrival dates for the 5th, 50th, and 90th percentile surviving fish for the six releases at the Clearwater site in 1997.

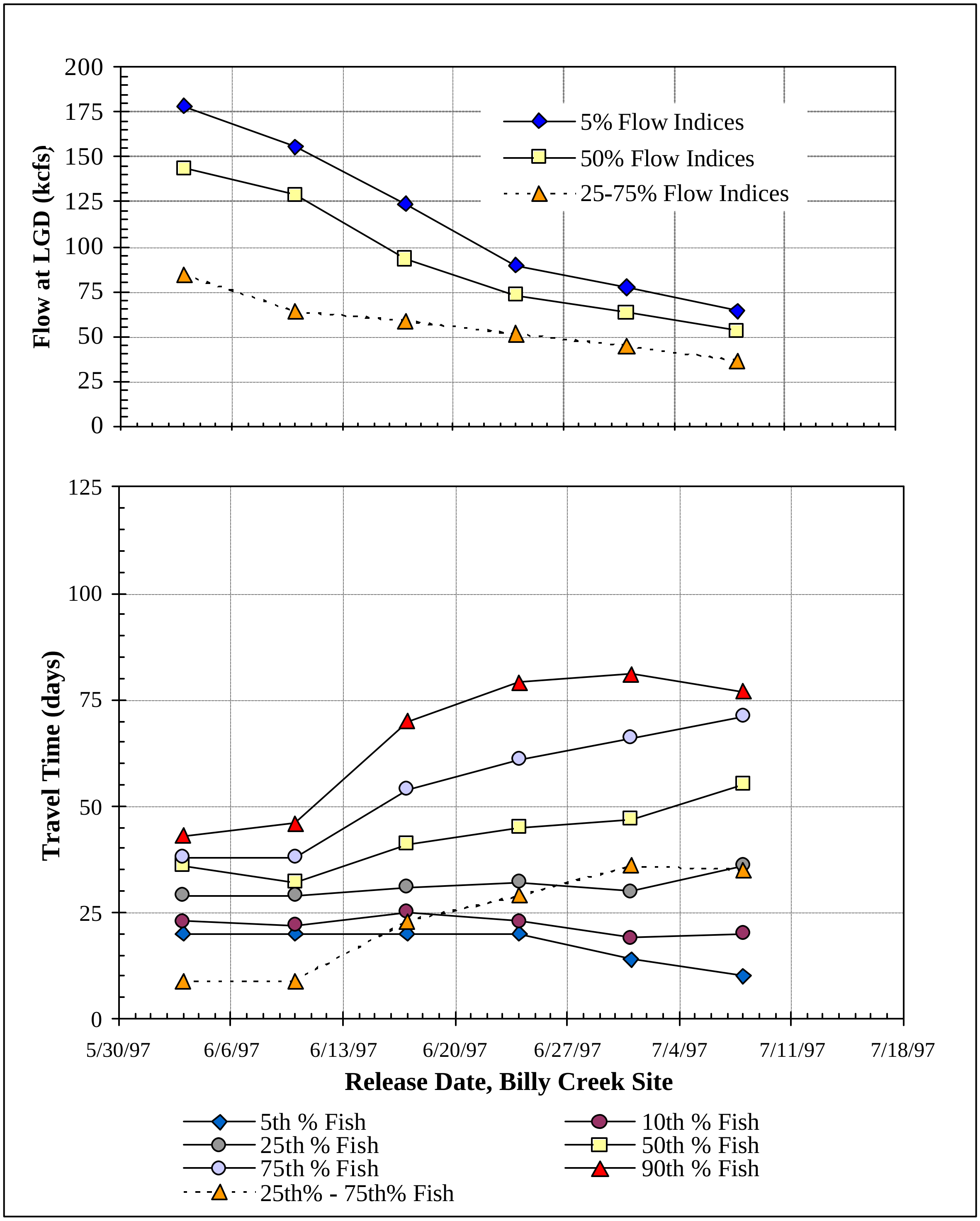


Figure 3.6.3-9: Travel times for the 5th, 10th, 25th, 50th, 75th, 90th, and 25th to 75th percentile surviving fish released from the Billy Creek site in 1997 and corresponding 5th, 50th, and 25th through 75th percentile flow indices at Lower Granite Dam (LGD).

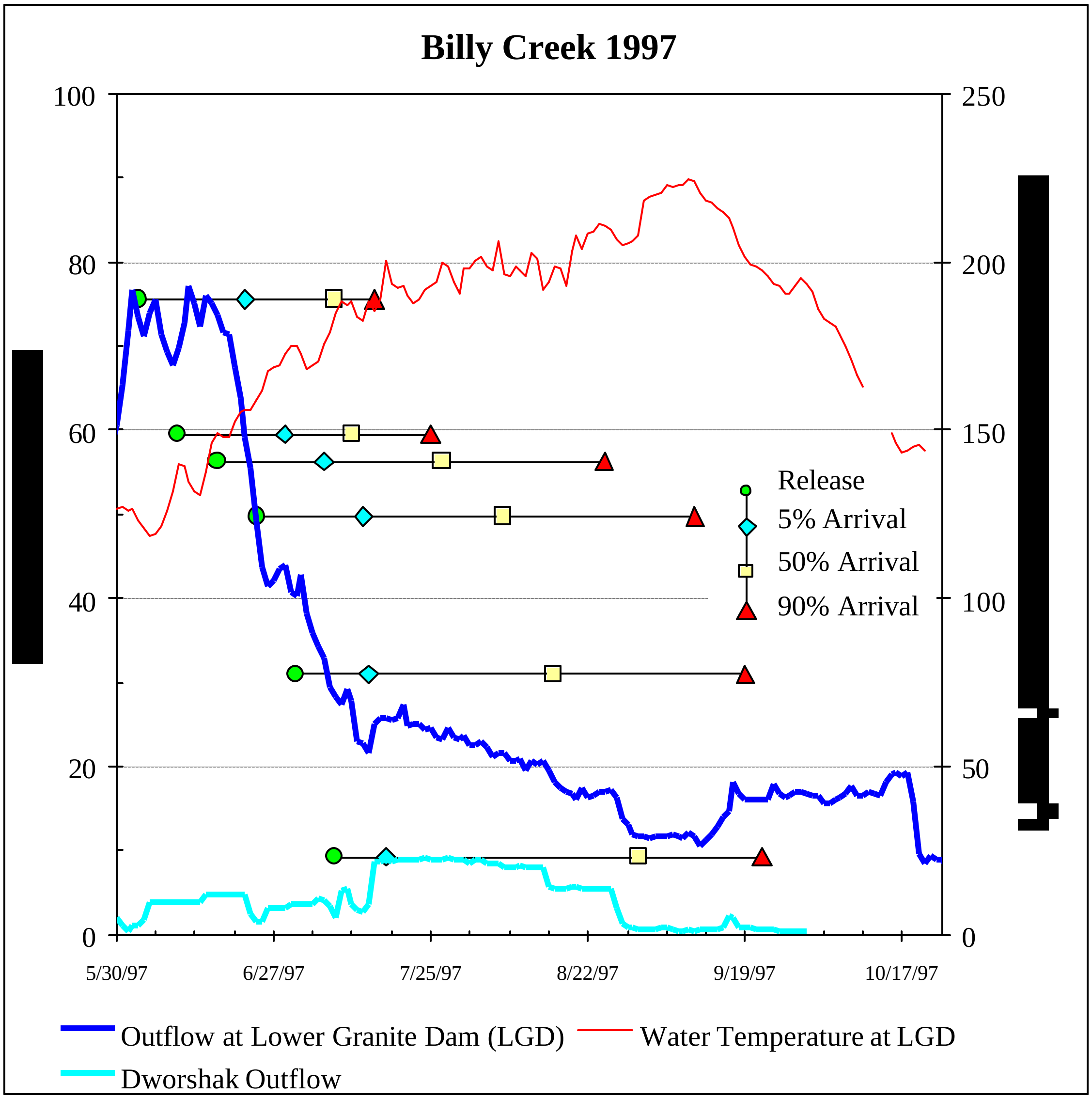


Figure 3.6.3-10: Arrival dates for the 5th, 50th, and 90th percentile surviving fish for the six releases at the Billy Creek site in 1997.

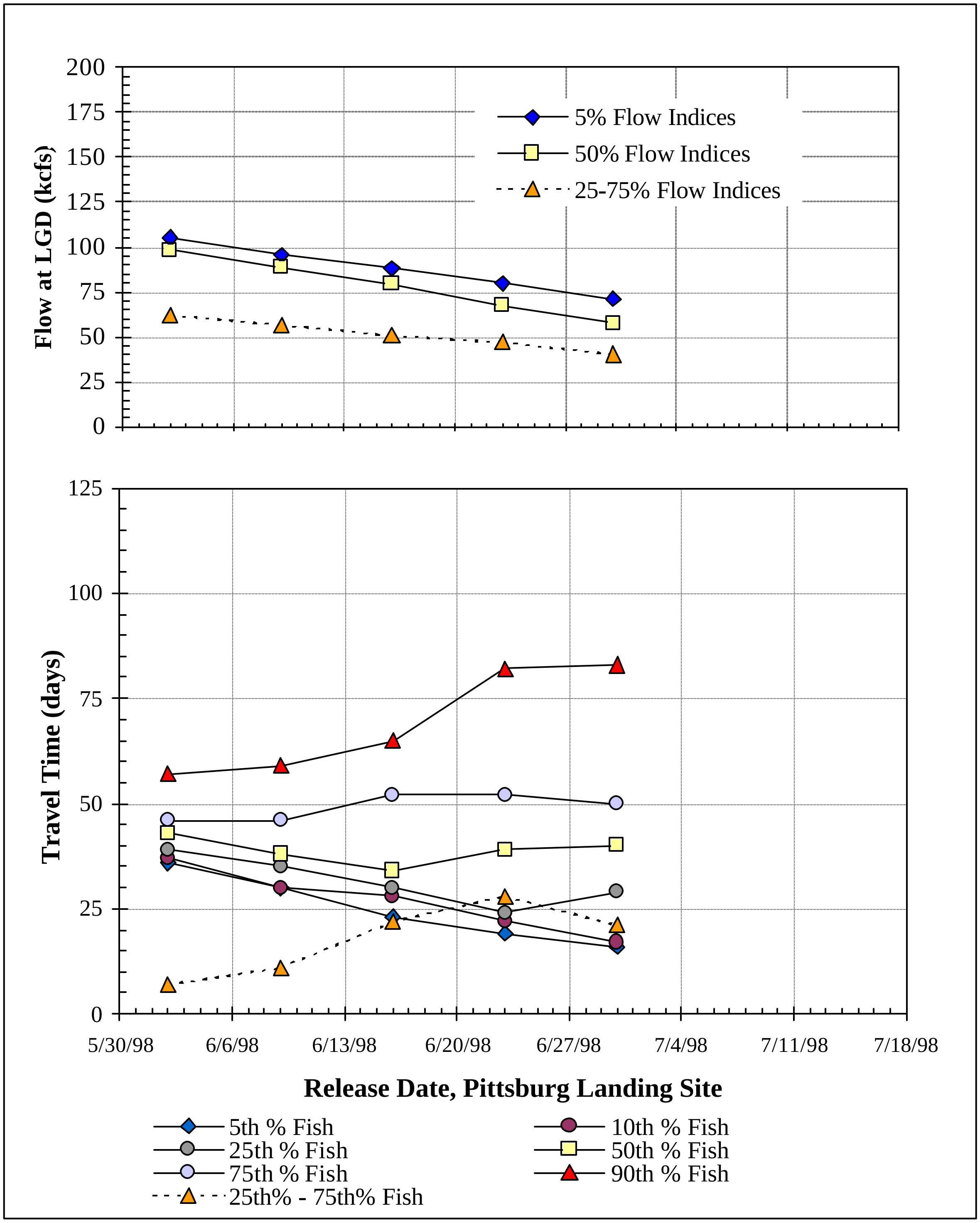


Figure 3.6.3-11: Travel times for the 5th, 10th, 25th, 50th, 75th, 90th, and 25th to 75th percentile surviving fish released from the Pittsburg Landing site in 1998 and corresponding 5th, 50th, and 25th through 75th percentile flow indices at Lower Granite Dam (LGD).

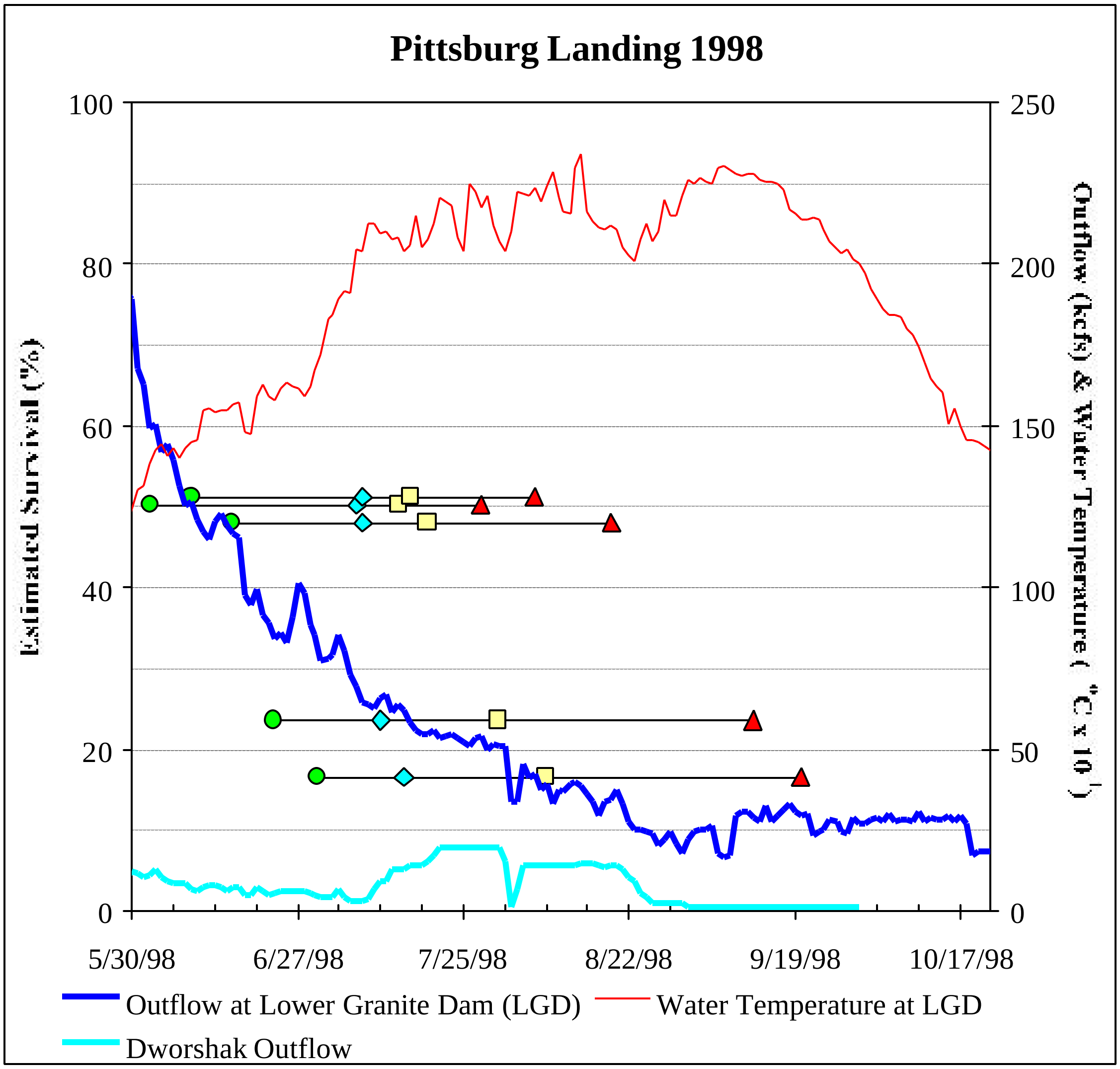


Figure 3.6.3-12: Arrival dates for the 5th, 50th, and 90th percentile surviving fish for the five releases at the Pittsburg Landing site in 1998.

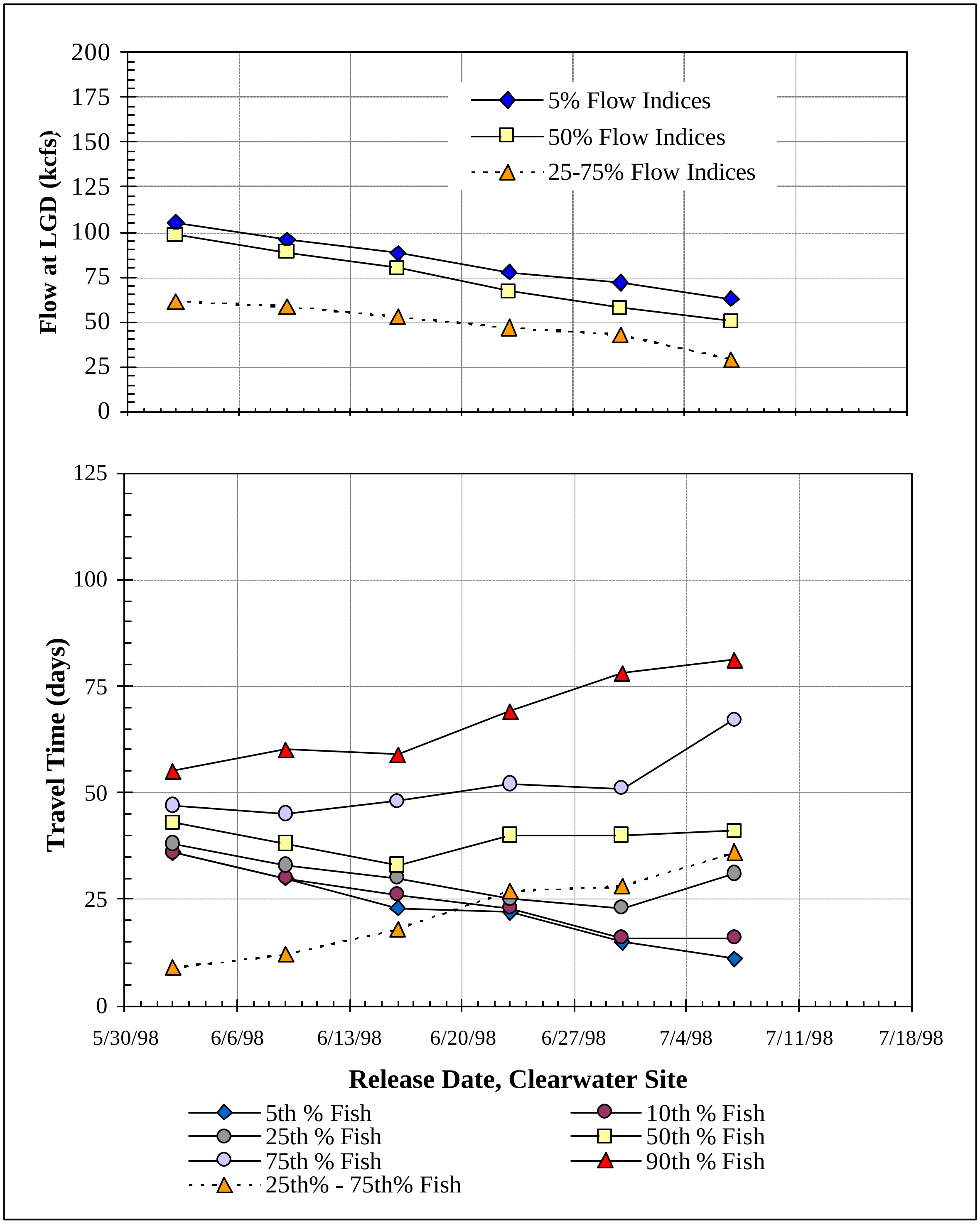


Figure 3.6.3-13: Travel times for the 5th, 10th, 25th, 50th, 75th, 90th, and 25th to 75th percentile fish released from the Clearwater site in 1998 and corresponding 5th, 50th, and 25th through 75th percentile flow indices at Lower Granite Dam (LGD).

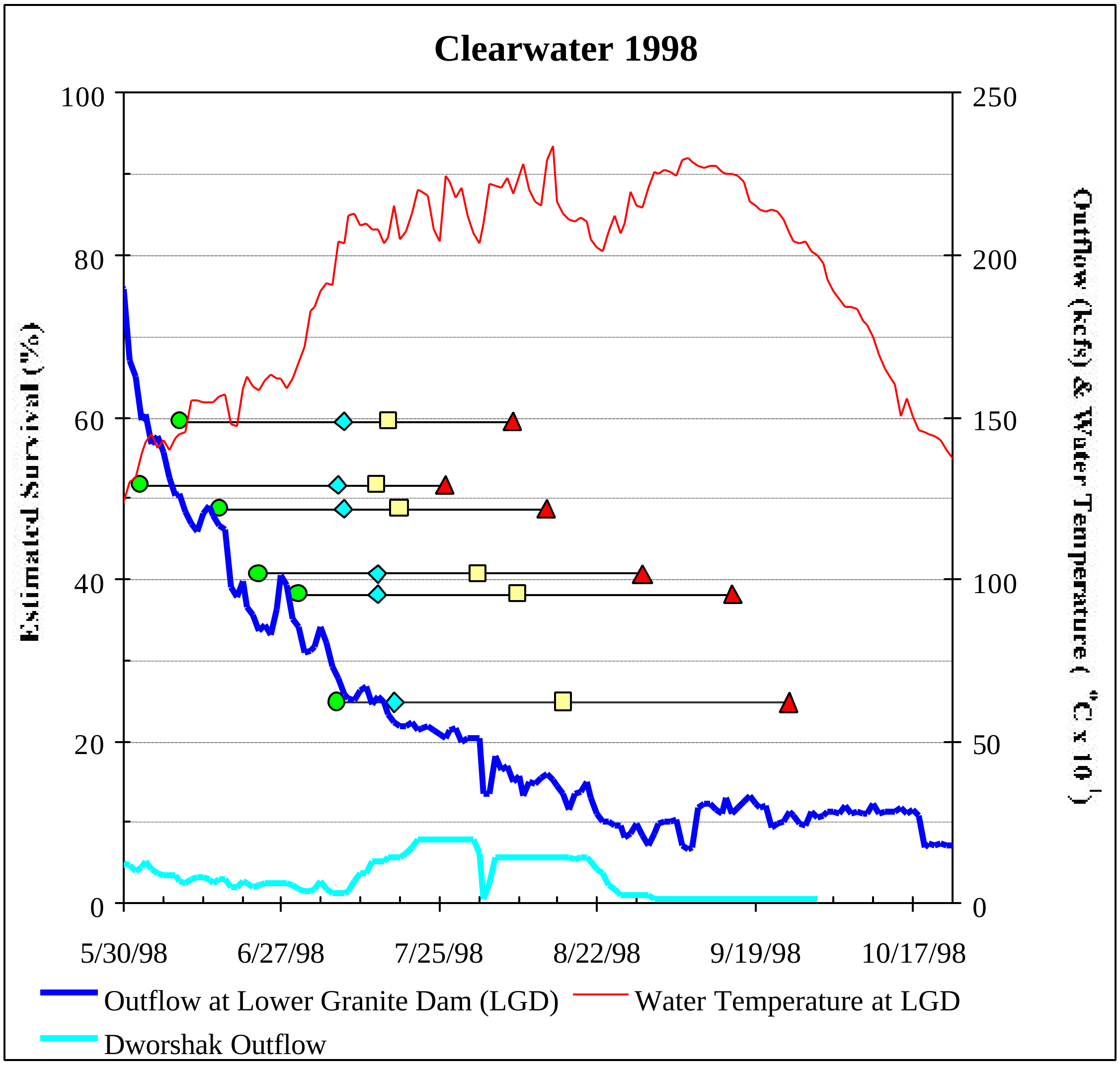


Figure 3.6.3-14: Arrival dates for the 5th, 50th, and 90th percentile surviving fish for the six releases at the Clearwater site in 1998.

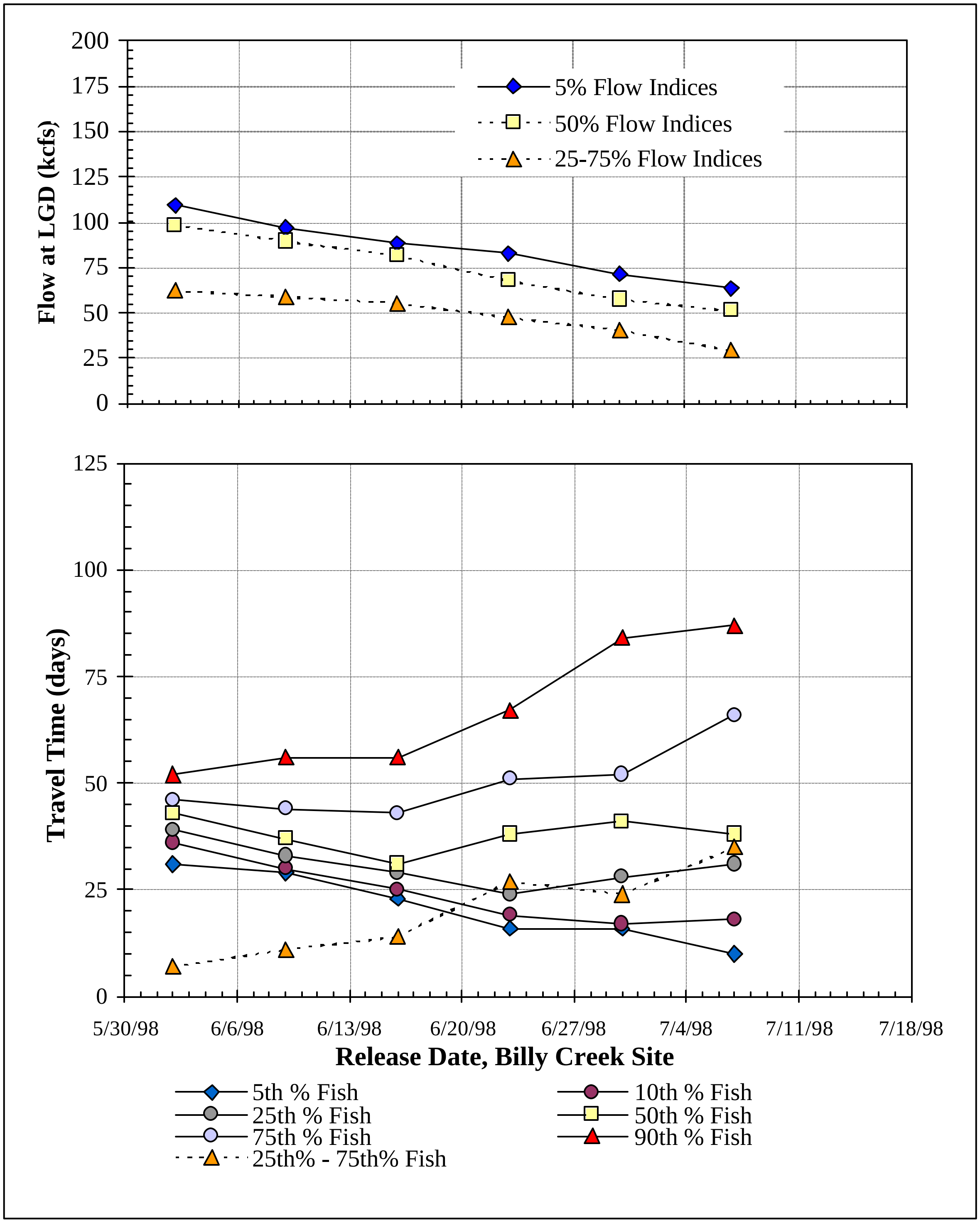


Figure 3.6.3-15: Travel times for the 5th, 10th, 25th, 50th, 75th 90th, and 25th to 75th percentile surviving fish released from the Billy Creek site in 1998 and corresponding 5th, 50th and 25th through 75th percentile flow indices at Lower Granite Dam (LGD).

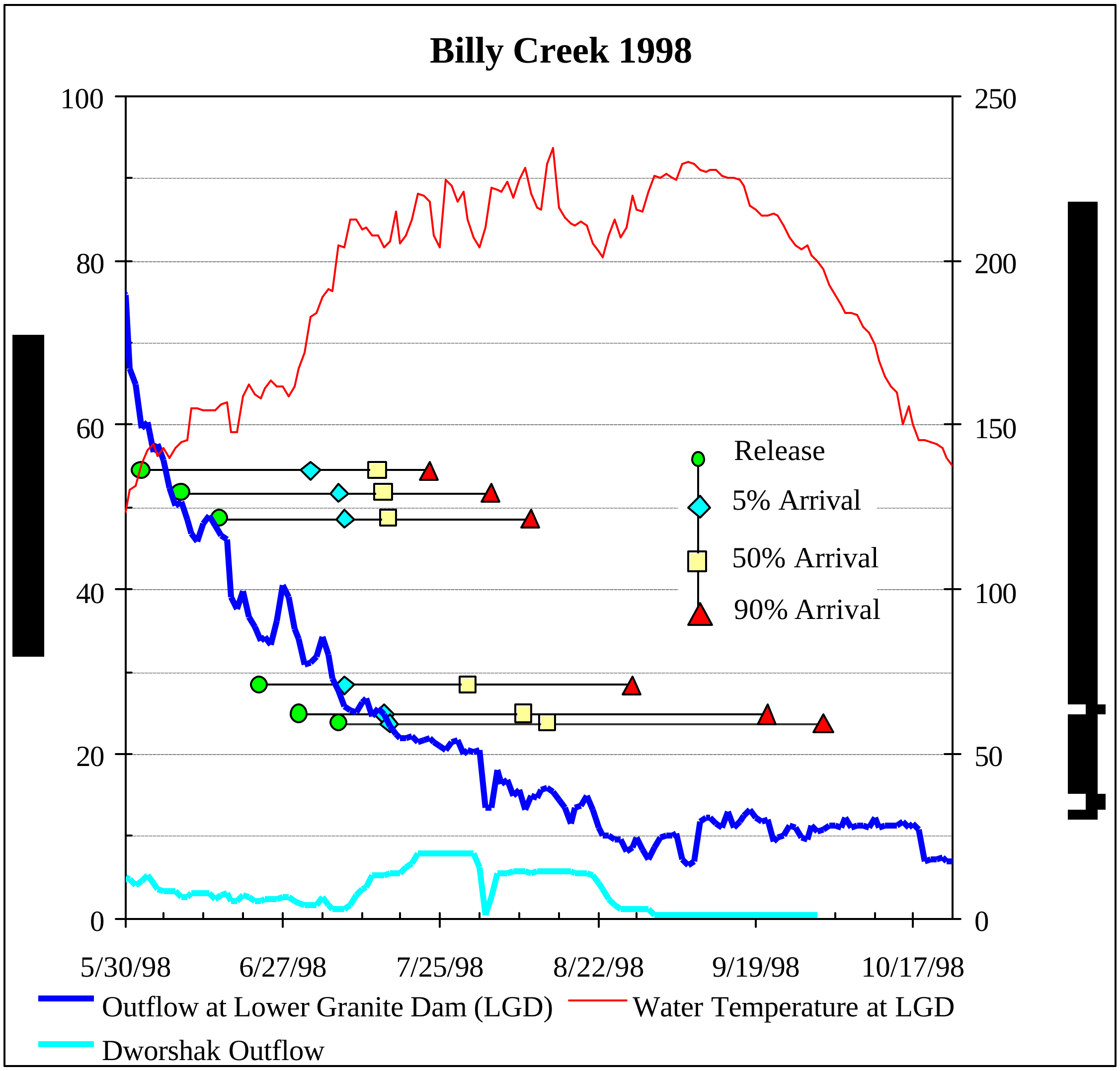


Figure 3.6.3-16: Arrival dates for the 5th, 50th, and 90th percentile surviving fish for the six releases at the Billy Creek site in 1998.

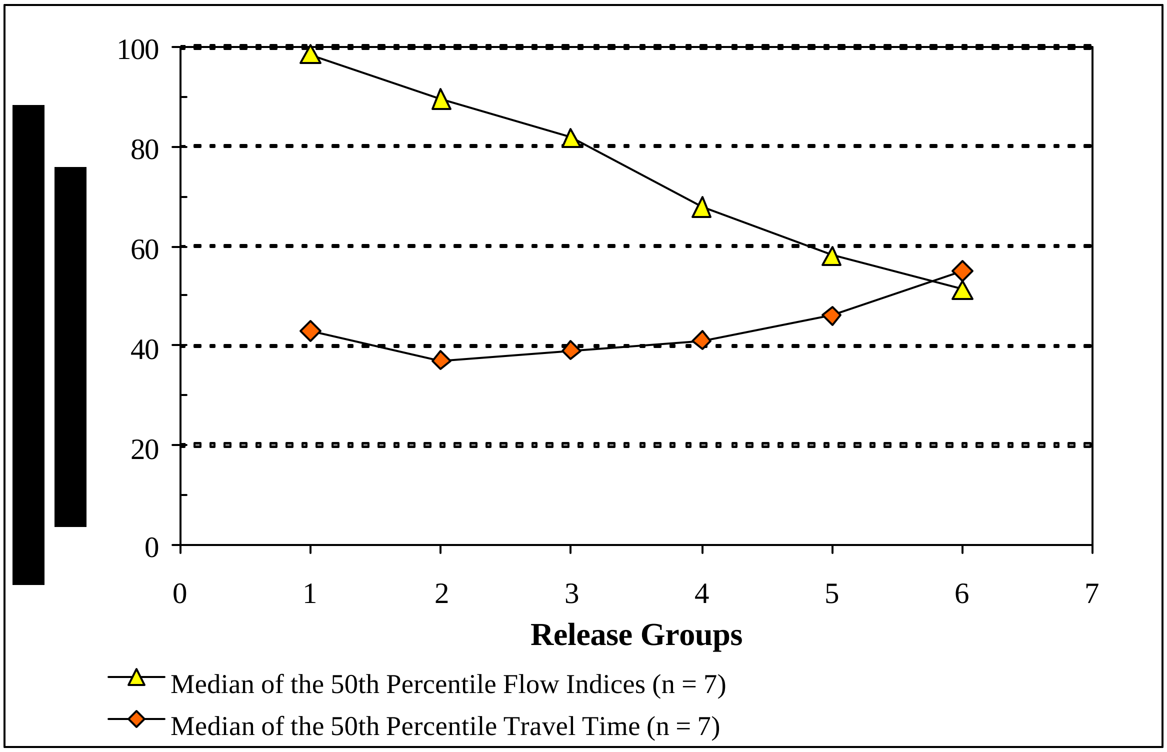


Figure 3.6.3-17: Median travel times for the 50th percentile fish and median outflows for the 50th percentile flow indices by release groups (for all release series with five or more releases), 1995-1998.

Release	1st Releases						6th Releases					
	5% Flow Indices (kcfs)	50% Flow Indices (kcfs)	Travel Time (days)				5% Flow Indices (kcfs)	50% Flow Indices (kcfs)	Travel Time (days)			
			5%	25%	50%	75%			5%	25%	50%	75%
Pittsburgh Landing, 1996	123	97	35	43	53	59	48	41	16	34	55	82
Clearwater, 1996	121	96	36	47	54	61	46	40	22	28	58	81
Pittsburgh Landing, 1997	174	144	22	30	36	39	63	52	23	31	57	67
Billy Creek, 1997	178	144	20	29	36	38	64	53	10	36	55	71
Clearwater, 1997	180	138	19	31	39	46	63	57	19	32	43	64
Pittsburgh Landing, 1998 *	105	99	36	39	43	46						
Billy Creek, 1998	110	99	31	39	43	46	64	51	10	31	38	66
Clearwater, 1998	105	99	36	38	43	47	63	50	11	31	41	67
Average:	137	114	29	37	43	48	59	49	16	32	50	71
Median:	122	99	33	39	43	46	63	51	16	31	55	67
Maximum:	180	144	36	47	54	61	64	57	23	36	58	82
Minimum:	105	96	19	29	36	38	46	40	10	28	38	64
n:	8	8	8	8	8	8	7	7	7	7	7	7

* There was no 6th release from the Pittsburg Landing site in 1998.

Table 3.6.3-1: Travel times (days) for the 5th, 25th, 50th and 75th percentile surviving fish from the 1st and 6th releases at the Pittsburgh Landing , Clearwater , and Billy Creek sites in 1996 through 1998 and the 5th and 50th percentile flow indices based on average daily flows at Lower Granite Dam.

4. DISCUSSION

Various data distributions and comparisons were described in the preceding sections regarding estimated survival, flow rates, water temperatures, release and arrival dates, and travel times for hatchery-raised, subyearling fall chinook salmon between points of release and Lower Granite Dam. This section provides a discussion of these data distributions and comparisons in the context of the following topics:

(1) Limitations of flow-survival studies focusing on reservoir reaches;

(2) "Lumped parameter" characteristic of river flow;

(3) High mortality rates for some of the releases;

(4) Validity of linear regression analyses between flow indices and estimated survival;

(5) Use of the 5^{th} percentile flow and temperature indices in comparisons with estimated survival;

(6) Relationship between estimated survival and date of release;

(7) Differences in travel times and clustered arrival dates;

(8) Use of hatchery-raised, fall chinook salmon as substitutes for wild fall chinook;

(9) "Readiness to migrate" characteristics;

(10) Other factors that may influence subyearling fall chinook survival between point of release and Lower Granite Dam; and

(11) Relationship between flow augmentation and survival of hatchery-raised, subyearling fall chinook salmon between points of release and Lower Granite Dam.

4.1. Limitations of Flow-Survival Studies Focusing on Reservoir Reaches

Adult returns are the best, and only complete, way to assess whether increased flow improves fish survival. The reservoir-reach survival studies conducted by NMFS are inadequate to address the primary survival factors hypothesized to be influenced by flow. Studying the survival of subyearlings through reservoir reaches may address some mortality issues, such as increased exposure to predators, but it does not address the cumulative effect of delayed migration, altered timing of ocean entry, and loss of energy reserves. Patterns detected through juvenile survival studies should be characterized within the context of observed adult returns. For example, preliminary information indicates that low in-river survival of late-migrating juvenile fall chinook did not necessarily correspond with low adult returns (B. Sanford, NMFS, personal communication; IDFG unpublished data).

4.2. "Lumped Parameter" Characteristic of Flow

A number of factors may influence survival and travel time of hatchery-raised, subyearling fall chinook salmon during the course of a migration season. Physical factors include time of release, photoperiod, water velocity, temperature, turbidity, and dissolved gas concentrations. There are also biological factors influencing migration such as fish size, health, smoltification, and degree of acclimation to migration conditions. Some of the physical factors are closely related to flow – e.g., average water velocity through Lower Granite Reservoir is closely related to flow at Lower Granite Dam. Other physical factors, such as temperature, dissolved gas concentrations, and turbidity, are indirectly related to flow. Flow rates and other environmental conditions, such as photoperiod or release date, may also influence biological factors. Thus, flow is a "lumped parameter" because flow encompasses several variables that affect salmon migration and survival, and the significance of these variables can not be distinguished by merely evaluating changes in responses under various flow conditions. It is important to understand and quantify the influence of the various individual attributes of flow on salmon survival. The 1995 through 1998 survival and flow data are insufficient to provide for such evaluation.

4.3. High Mortality Rates for Later Releases

Current data do not provide a sufficient basis for concluding that the relatively high mortality occurring after the release of hatchery-raised fish, especially from later releases, is related to flow rate. An inability to transition from a cultured environment to a natural environment may result in high mortality shortly after release. This post-release mortality is incorporated into survival estimates. If it is relatively high, this initial mortality could strongly influence observed survival patterns, even when the cause of mortality can not be shown to be related to flow conditions. For example, water temperature differentials between the hatchery and the rivers were not constant among release groups. The temperature differential was relatively minor for early releases, but more dramatic for later release groups. Although fish were acclimated prior to release, and acute mortality monitored in net pens, the additional thermal stress on later release groups may have contributed to lower observed survival at Lower Granite Dam than for earlier release groups.

4.4. Linear Regression Characteristics

Linear regressions between estimated survival and river flows and temperatures were presented by Muir et al. (1999) as an indication of the relationship between flow and survival. The linearity of this relationship seems questionable.[7] Additionally, the use of flow indices adds uncertainty to the regression calculations because the indices represent average flows and may not reflect flow conditions during which actual migration occurred (see next section).

4.5. Flow and Temperature Indices

Subyearling fall chinook survival data were described as a single survival percentage for a given release (Muir et al, 1999). To compare the single survival number to flow or temperature, a single number must also be used for the flow rate or temperature. The flow rates and water temperatures, however, are changing during the time that the subyearling fall chinook are migrating from points of release to Lower Granite Dam. Consequently, flow and temperature indices were used in the correlations between estimated survival and flow and water temperature (Muir et al, 1999). The flow and temperature indices are single numbers – the average flow and temperature during a certain time period. In this case, NMFS calculated flow indices based on average daily flow rates, or temperatures, from the time of release to the time of detection of the 5th percentile surviving fish at Lower Granite Dam (Muir et al., 1999).

NMFS (2000) stated the rationale for using the 5th percentile flow indices as follows:

> The 5th passage percentile was chosen to increase contrast among the release groups in the indices of exposure, as the protracted residence time above Lower Granite Dam for subyearling chinook salmon released in the Snake and Clearwater Rivers makes use of the middle 50% exposure index inappropriate for analyses of survival and travel time to Lower Granite Dam.

Furthermore, NMFS stated that:

> Nearly all fish within a group experienced environmental conditions up to the 5th passage percentile date. Using a higher percentile resulted in less contrast in flow and temperature indices among groups, and was not representative for many fish within a group since many had already died because mortality was relatively high for these releases…. To calculate exposure indices based on the week-long period

[7] The recent white paper (NMFS, 2000) acknowledges this observation: "Over the entire range of flow exposures in 1997, the relationship between flow and survival appeared to curve, with a shallower slope at higher than at lower flows" (page 37). Between Lower Granite Dam and Lower Monumental Dam, flow and survival data in the year with the widest range of flow exposure (1998) "strongly suggested that the relationship is curved" (page 41).

> of the 25th to 75th passage percentile would ignore the preceding 5 weeks of common exposure period between the time of release and the 25th passage percentile at the bottom of the reach (NMFS, 2000, page 26).

The appropriateness of 5th percentile flow and temperature indices is questionable. Although fish in early release groups experienced higher flows and lower temperatures (corresponding with the time from release to arrival of the 5th percentile surviving fish), many surviving fish experienced different flow rates and water temperatures during their migration to Lower Granite Dam. Previous studies have used 25th to 75th percentiles (e.g., Smith et al., 1998). Researchers associated with the fall chinook study are aware of this concern, and may recalculate more representative flow and temperature indices (B. Muir, NMFS, personal communication).

The use of 5th percentile flow indices accentuates early season high flows (Figure 2-2). However, the longer travel times (Table 3.6.3-1) of fish from early releases compared to the much shorter travel times for fish from later releases suggest that fish in early releases may not be taking advantage of increased channel velocities during higher, early-season flows to migrate downstream (see Section 4.7). If the fish did not take advantage of increased channel velocities during higher, early-season flows to migrate, then use of the 5th percentile flow indices probably is not appropriate for the early releases. Furthermore, the median travel time for the 75th percentile surviving fish from the last releases is 67 days; the 5th percentile median travel time is only 16 days. Therefore, the 5th percentile flow indices represent only 24 percent of the flow conditions experienced by the 75th percentile fish. For these reasons, the use of other flow indices that more fully reflect actual flows during migration probably would be more appropriate for evaluating flow and survival relationships.

4.6. Estimated Survival and Date of Release

There is a strong relationship between estimated survival and date of release. Muir et al. (1999) also noted this relationship. During the 1995 through 1998 time period, survival rates from early season releases were as high as 76 percent; survival rates from later releases were as low as approximately 5 percent. The correlation between estimated survival and release date is stronger (R^2 = 0.79) than the correlation between estimated survival and 5th percentile flow indices (R^2 = 0.49), and between estimated survival and 5th percentile water temperature indices (R^2 = 0.61) using all of the data (1995-1998). The total survival of hatchery-raised, subyearling fall chinook salmon likely would have been much higher if they had all been released during the first week of June.

The NMFS experimental design assumed sequential releases of hatchery-raised fall chinook would not influence survival independent of flow, temperature, and turbidity. The high correlation between time of release and survival makes this assumption questionable.

4.7. Travel Times and Clustered Arrivals

One benefit attributed to flow augmentation is the resulting increase in channel velocities at higher flows (NMFS, 2000):

> Flow directly affects water velocity and indirectly affects water temperature and turbidity. These factors can in turn influence fish travel time and survival.[8]

However, travel times of hatchery-raised, subyearling fall chinook salmon between point of release and Lower Granite Dam did not appear to be substantially influenced by flow rate. Median travel times (travel times for the 50th percentile surviving fish) in 1996 and 1998 were lowest (i.e., faster travel) for fish in the middle (3rd or 4th) releases, despite the occurrence of larger flows that were experienced by fish in the earlier releases. In 1997, there was more of a correlation between median travel times to Lower Granite Dam and flow rates – although the median travel time was lowest for the 2nd release. The faster median travel times to Lower Granite Dam in 1997 were likely the result of high flows "flushing" the fish out of rearing areas (NMFS, 2000):

> Of the four years of study, the lowest survival estimates and longest travel times between Lower Granite and Lower Monumental Dams were observed in 1997…. A possible cause for the anomaly is that high flows in June and early July prematurely flushed subyearling chinook salmon from their rearing areas in free-flowing river stretches, and the fish continued to rear extensively after they passed Lower Granite Dam. Moreover, the longest travel times in 1997 were observed for the earliest groups passing Lower Granite Dam, despite higher flows.

The 5th percentile travel times decreased steadily from the 1st to the 6th releases in all years, despite decreasing flows. In fact, the median 5th percentile travel time decreased from 33 to 16 days between the 1st and 6th releases, despite an approximately 48 percent decrease in 5th percentile flow indices. The 25th percentile travel times decreased in 1996 and 1998 between the 1st and 6th releases, and remained relatively constant in 1997, despite steadily decreasing flows. Median travel times remained relatively constant for most releases, despite decreasing flow rates. Thus, higher velocities associated with higher early-season flows did not appear to influence median subyearling travel times. While the premise of faster travel at higher flows may apply to inert particles, it did not appear to apply to hatchery-raised, subyearling salmon. Factors in addition to, or other than, channel velocities appear to affect migration rate.

NMFS (2000, pg. 29) also recognized this point:

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[9] Actually, flow does not "affect" temperature – although changes in temperature may be coincident with changes in flow.

> Typically, groups released around 13-15 June had the shortest travel times, and groups released earlier or later had longer travel times . . . flow generally decreased throughout the period of subyearling chinook salmon migration … Consequently, relationships between indices of exposure to environmental variables and median travel time from release to Lower Granite Dam were not strong or consistent…

Other researchers have observed a lack of relationship between travel time, or migration rate, and flow. Giorgi et al. (1997) found that fall chinook salmon did not respond to increased flow in impounded portions of the mid-Columbia River. Migration rates "showed no response to flow over a broad range of discharge (1,500–5,000 m^3/s)" (Giorgi et al., 1997).

Finally, some arrivals of surviving fish at Lower Granite Dam were clustered in ways that appear inconsistent with the postulation that flow rates significantly influence fish travel time. In some cases, the same percentile of surviving fish from several different release groups (at the same release site) arrived on nearly the same day despite being released up to 14 days apart. For example, the 5th percentile surviving fish from the first three releases at the Clearwater site arrived at Lower Granite Dam within one day of each other in 1998 (Figure 3.6.3-14). Similarly, the 50th percentile surviving fish from the first three releases at the Billy Creek site arrived within two days of each other in 1998 (Figure 3.6.3-16). Clustered arrivals were observed in all of the release series in 1996 and 1998, and in some of the 1997 releases. Again, factors other than channel velocities appear to have a greater effect on migration patterns and rates for the hatchery-raised, subyearling fall chinook used in this study.

4.8. Use of Hatchery-Raised Salmon as Analogues for Wild Fish

The hatchery-raised, subyearling fall chinook salmon raised at the Lyons Ferry Hatchery between 1995 and 1998 may not be appropriate analogues for wild fish in survival and flow experiments. Hatchery releases begin in early June and end in mid-July. Wild fall chinook migration typically begins in late June and extends into September. Thus, wild subyearlings experience different flow, temperature, and other factors than fish raised at the Lyons Ferry Hatchery. There is also valid concern that hatchery and naturally-produced fish may respond differently to the same environmental cues relating to migration conditions.

4.9. "Readiness to Migrate"

Another variable – that is termed herein as "readiness to migrate" – may have influenced hatchery-raised, fall chinook migration rates and survival. Fish from the early release groups may have been released prior to the time of optimal physiological conditions for migration and, therefore, migrations were delayed. Evidence for this possibility is the delay between dates of release and dates of detections at Lower Granite Dam for early releases as compared to later releases (see Figures 3.6.2-1 through –3). Subyearlings from the later release groups may have been released at the end of, or after, their optimal physiological time for migration, although a few of the fish from late releases appeared to "catch up," as shown by faster travel times, despite lower flow conditions, as compared with earlier releases.

If hatchery-raised fish are used to evaluate the relationship between reach survival and flow rate, then "readiness to migrate" (including, but not limited to, fish size) must be further investigated under controlled studies. One approach that could perhaps be considered for future studies would be to use smolt traps to collect and mark *actively* migrating fish and then evaluate survival across a range of flow and temperature conditions. Data from such studies might be useful in addressing whether or not flow is related to survival for fish at equivalent conditions of "readiness to migrate."

4.10. Other Factors Influencing Survival

Other factors, in addition to those described in the above paragraphs, also may confound existing data and should be addressed in future studies. These include relatively high, post-release mortality that may be unrelated to temperature or flow; hatchery releases that are not temporally representative of the primary migration period for wild fall chinook salmon; the ability of flow augmentation to compensate for the physical realities associated with water velocity in mainstem reservoirs; the ability of reach survival studies to address effects of altered migration timing, bioenergetics, and the transition into the estuary and ocean caused by reduced water velocity in the mainstem; and the ability of reach survival estimates to reflect survival patterns observed for the entire smolt-to-adult life stage. These factors need to be addressed with and without flow augmentation to determine whether flow augmentation, particularly from the Upper Snake River Basin, provides significant survival benefits.

4.11. Flow Augmentation and Salmon Survival

It has been assumed that flow augmentation provides some of the benefits associated with high natural flows, including higher channel velocities that aid downstream migration. However, the impact of achievable levels of flow augmentation on water velocities through the lower Snake River reservoirs is insignificant compared to natural water velocities that occurred in these reaches before impoundments following the construction of the lower Snake River dams (Dreher, 1998). Even at higher augmentation levels, flow augmentation cannot compensate for the fundamental effect that mainstem reservoirs of the Federal Columbia River Power System (FCRPS) in the lower Snake River have on the velocity of flow (Dreher, 1998; IDFG, 1999; State of Idaho, 1999). Although other factors may have influenced the relationship, the analyses presented in this report show that higher, early-season flows did not appear to correspond with reductions in average subyearling travel times, as would be expected if there were incremental travel time benefits associated with increased water velocities.

The relationships between survival of wild fall chinook salmon and flow and temperature can not be accurately inferred using current data estimating survival of hatchery-raised subyearlings, nor can benefits of flow augmentation be accurately inferred from these data. Even though survival of hatchery-raised, subyearling fall chinook can be correlated with flow, the data do not show a good correlation between flow and median travel times of these fish to Lower Granite Dam. Increasing velocity through flow augmentation may not be a significant factor in migration and in improving the survival of hatchery-raised fish.

Discharges from Dworshak Reservoir, which provide the largest contribution to augmented flows in the lower Snake River, are shown in Figures 3.6.3-2, -4, -6, -8, -10, -12, -14, and –16. In 1996 the majority of surviving fish from the early releases (the releases with the highest estimated survival rates) had already passed Lower Granite Dam by the time flow releases from Dworshak Reservoir began. Flow augmentation from Dworshak began earlier in 1997 and 1998, but fish from the later releases still experienced very low survival rates.

Flow augmentation from Dworshak Reservoir increased flow and decreased water temperatures experienced by a portion of the surviving fish from later releases. Nonetheless, survival of hatchery-raised fish from the later releases continued to decline relative to earlier releases, despite flow augmentation with cooler water from Dworshak Reservoir. If there was improved survival because of temperature reductions associated with flow augmentation from Dworshak releases, the survival improvements may be reduced by simultaneously augmenting flows using warmer water from the Snake River. There currently are no sources of consistently cooler water for augmenting lower Snake River flows other than Dworshak Reservoir.

The existing survival, flow, and temperature data should not be used to conclude that flow augmentation improves survival of outmigrating, subyearling fall chinook salmon in the Snake River above or below Lower Granite Dam. To determine whether there are survival benefits attributable to flow augmentation, future studies must analyze augmentation flows within the context of the specific attributes of flow that are important to fish, i.e., water velocity, temperature, and turbidity. The analyses must delineate the extent that flow augmentation improves water velocity, temperature, and turbidity in the lower Snake River, and the extent (if any) that these improvements increase survival. Future evaluations of subyearling fall chinook survival as related to flow augmentation must also include analysis of other factors, such as “readiness-to-migrate” maturation.

In summary, the importance of flow on the survival of hatchery-raised, subyearling fall chinook between points of release and Lower Granite Dam and the survival benefits (if any) from flow augmentation cannot be determined from the NMFS data and analyses reviewed in this report. The correlation between flow and estimated survival does not imply cause and effect. Other factors, such as date of release and "readiness-to-migrate," may have greater impacts than flow on outmigration and survival of hatchery-raised, subyearling fall chinook salmon. Obviously water velocity, temperature, and turbidity are important to migrating fish. However, the existing correlations between hatchery-raised, subyearling fall chinook survival and flow rates do not support or refute the assumption that augmenting mainstem Snake River flows improves subyearling survival.

5. CONCLUSIONS

Data describing the estimated survival of hatchery-raised, subyearling fall chinook salmon from release to Lower Granite Dam have been correlated with flows in the lower Snake River (Muir et al., 1999). These correlations have been used to justify flow augmentation in the lower Snake River. The principal conclusion of the review of survival data and flow rates presented in this report is that the existing data, despite showing an apparent correlation between flow and survival, do not imply a cause and effect relationship between flow and survival of subyearlings and should not be used as a basis to justify flow augmentation. This is primarily because the experimental design did not address other factors that appear to have strongly influenced migration characteristics and survival. This conclusion is not inconsistent with a conclusion reached recently by NMFS (2000):

> Because environmental variables were highly correlated with each other, determining which variable was most important to subyearling fall chinook salmon survival was not possible.

The following observations support this principal conclusion:

1. The survival of subyearling fall chinook appears to be dependent on multiple factors, and the NMFS study did not separate the effects on survival of individual attributes of flow (i.e., velocity, turbidity, and temperature). Furthermore, the experimental design and resulting data are insufficient to imply that velocity improvements associated with flow augmentation increase survival.

2. There is a strong correlation between estimated survival and date of release. Survival rates from early releases (late May or early June) were as high as 76 percent. Estimated survival decreased with each successive release. Survival rates from final releases (e.g., second week of July) were as low as approximately 5 percent. The high correlation between date of release and survival brings into question the inherent assumption that sequential releases of hatchery-raised, fall chinook would not influence survival independent of flow, temperature, and turbidity.

3. Muir et al. (1999) reported a positive correlation between subyearling survival and the 5th percentile flow indices, and a negative correlation between subyearling survival and the 5th percentile water temperature indices. However, these analyses raise at least three concerns. First, the correlations do not imply cause and effect relationships. Second, the flow and temperature indices were not representative of overall migration conditions experienced by most of the fish in the various release groups. Third, the correlations may be strongly influenced by other factors such as "readiness to migrate" and date of release.

4. Migration of hatchery-raised, subyearling fall chinook from early releases appeared to be delayed. The travel times for the 5th, 10th, and 25th percentile surviving fish were consistently greater (longer) for the early releases than for the late releases, despite the occurrence of higher flows and lower temperatures experienced by fish in early releases.

5. There was no significant difference between the median travel times of 50th percentile surviving fish for the six weekly release groups at the 95 percent confidence level, even though the median values for the 50th percentile flow indices decreased from 99 kcfs (1st release) to 51 kcfs (6th release). This implies that factors other than, or in addition to, flow substantially affect outmigrating fall chinook.

6. Clustered arrival times for the same percentiles of surviving fish from different releases also suggest that outmigration is influenced by factors other than flow.

7. “Readiness to migrate” may be a significant factor influencing the outmigration of hatchery-raised, subyearling fall chinook. However, this variable and its relationship to survival and flows cannot be evaluated with current data.

In summary, until the specific factors influencing survival are better understood, the flow and survival data reviewed in this report should not be used as a basis to justify flow augmentation.

6. REFERENCES

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