FINAL REPORT

PIT Tagging of Juvenile Salmon Smolts in the Lake Washington Basin: Second Year (2001) Pilot Study Results

U.S. Army Corps of Engineers, Seattle District
Lake Washington General Ecosystem
Restoration General Investigation Study

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R2 Resource Consultants

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3.5.2 Routes Through the Locks

Of the PIT tagged fish that passed through the smolt flumes, the majority passed through the two largest flumes when all four were operating during the time of peak chinook passage (June 10 to through June 17, 2001; see Figure 3-1). However, there was not as clear a preference for a specific spillway gate by all three species as in 2000, when proportionally more tagged fish passed through the Flumes 5C and 5B. In 2001, 63%, 48%, and 51% of detected chinook, coho, and sockeye, respectively, passed through gate 5 when all four flumes were operational, suggesting that only chinook salmon juveniles may have exhibited a partial preference that year.

Figure 3-32 depicts the possible passage routes through the Locks. As in 2000, the PIT tag data confirmed that recycling occurred through the Locks as indicated in the figure. For example, 91 PIT tagged chinook and 7 coho salmon were detected twice by the tunnel readers (Figure 3-33). They therefore had to have migrated back upstream through either the large or small lock. Several fish caught during seining in the large lock also passed through the tunnel detectors either prior or subsequent to capture (Table 3-4). With the exception of calibration test chinook, held at the Metro Laboratory prior to release, all but one coho juvenile exhibited a distribution in Figure 3-33 that was similar to that observed in the 2000 study. The behavior of the calibration test chinook was atypical of naturally produced fish and Issaquah Hatchery releases, possibly because they were held in chilled water, and were released directly into the flumes. As in the 2000 study, the intervening time between first and second detection shortened as the outmigration season progressed. There were no fish other than the calibration test chinook that were observed to recycle during the last two weeks of June 2001 when chinook passage was peaking (Figure 3-33).

The UW hatchery chinook exhibited the strongest recycling behavior of all the groups. This was manifest by 29 PIT tagged fish from that group that recycled more than twice (Figure 3-34). No fish from any of the other groups was observed to have exhibited this behavior. One of the UW Hatchery chinook recycled seven times. This difference in behavior from the other study fish may reflect their early release from the hatchery and rapid arrival at the Locks compared to the other test groups.

In summary, the PIT tag data indicate that a strong seasonal influence on outmigration existed in the LWSC, and that some chinook juveniles lingered in the upstream and downstream vicinity of the Locks before most actively making the transition to saltwater during the last two weeks of June 2001. There was no relation of recycling time between detections in the flumes to release group or size of fish at time of tagging.

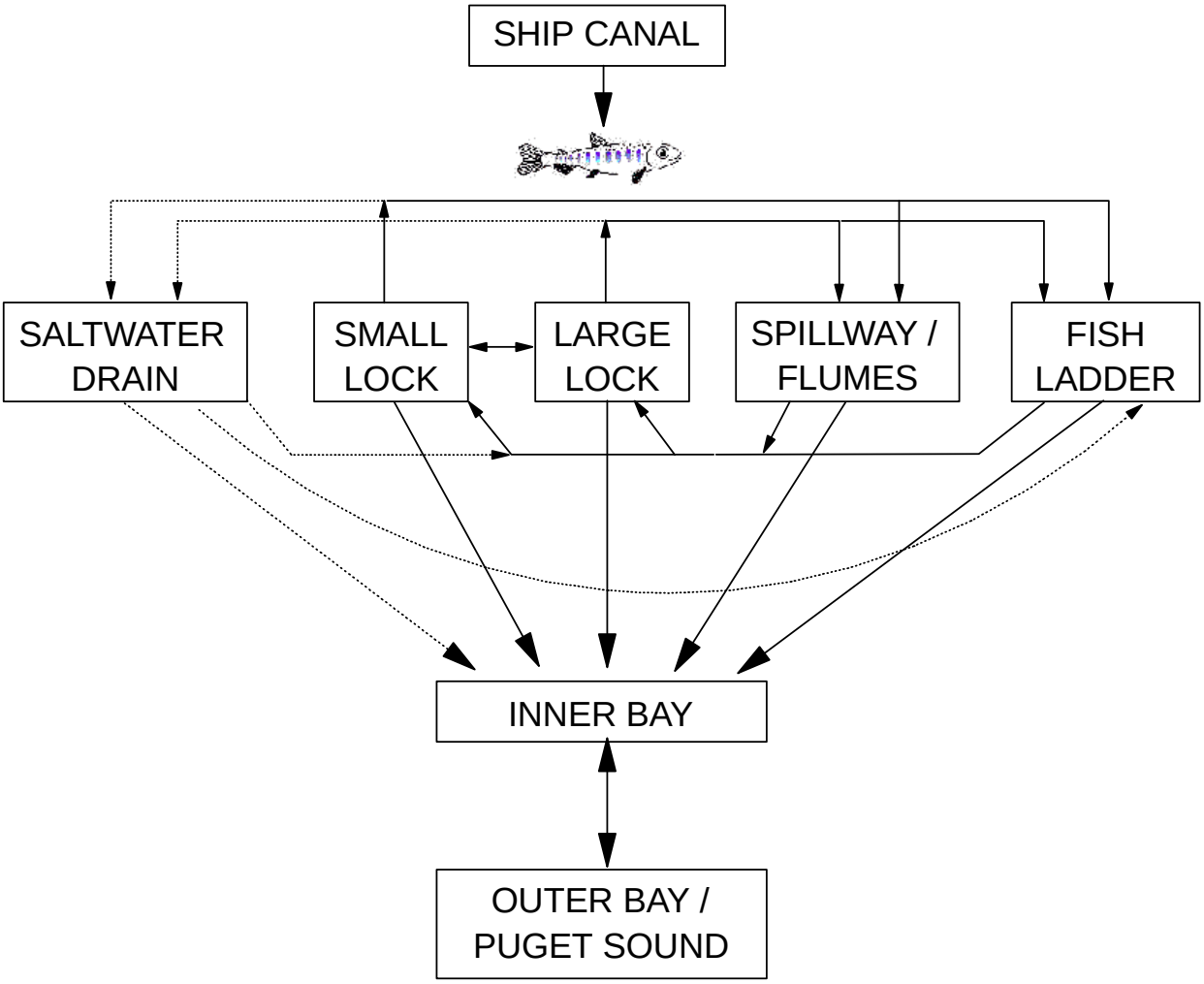


Figure 3-32. Possible migration routes of juvenile salmon through the Hiram M. Chittenden Locks to the saltwater beaches located below. The routes are indicated for fish after they have first encountered the Locks and have entered one of the five structural facilities indicated. For example, a fish entering the smolt flumes may subsequently move back upstream through either the small or large lock, and return downstream through any of the five routes. Alternatively, the fish may migrate directly to saltwater. The route through the saltwater drain is thought to be of lesser importance to smolt passage than the other four routes and is thus indicated by the dashed lines.

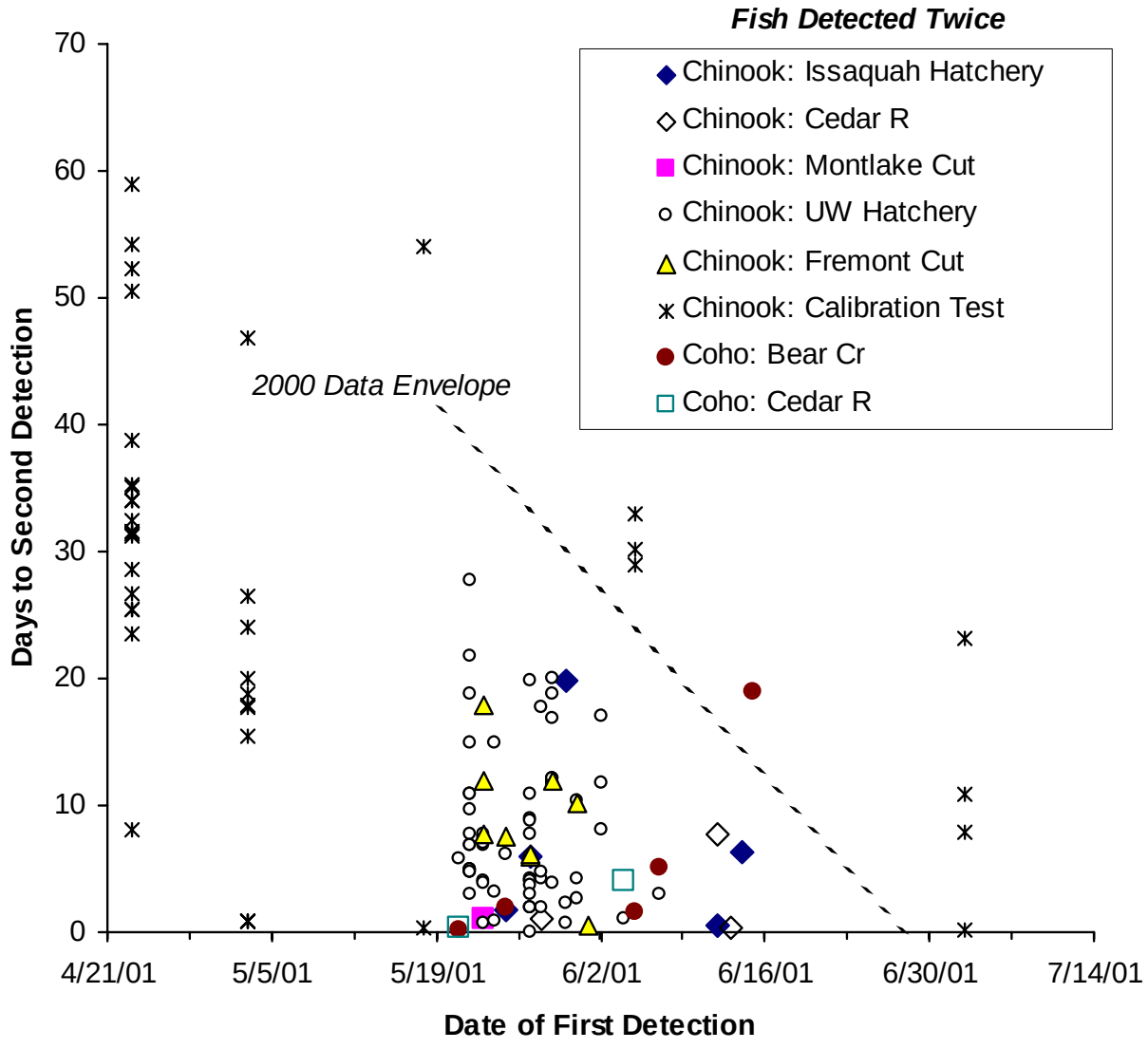


Figure 3-33. Recycling times of PIT tagged juvenile chinook and coho salmon passing downstream twice through the smolt flumes at the Locks, 2001 Lake Washington GI study. The upper data envelope from the 2000 study is indicated by the diagonal dashed line.

Table 3-4. Summary of Large Lock Purse Seine Recapture Data, 2001 PIT Tag Study

				Large Lock		Flumes			
Species	**Release Location**	**Release Date**	**Tag No.**	**Date Captured**	**Time Captured**	**Date Detected**	**Time Detected**	**Hatchery/ Natural**	**Comments**
Chinook	Tunnel	5/3/01	3D9.1BF1125A6E	5/24/01		*Not Detected Again*		H	Tags Not Recorded on Data Sheets
	Reader	5/18/01	3D9.1BF113314F	5/24/01		*Not Detected Again*		H	Tags Not Recorded on Data Sheets
	Calibration	5/18/01	3D9.1BF113D0AE	6/7/01	11:00	*Not Detected Again*		H	
	Testing	6/5/01	3D9.1BF113C058	6/20/01	9:30	*Not Detected Again*		H	
		7/3/01	3D9.1BF1129E67	7/11/01	16:30	7/14/01	7:24:26	H	
		7/3/01	3D9.1BF111D5B4	7/11/01	16:30	*Not Detected Again*		H	
	Issaquah	5/15/01	3D9.1BF113BC24	6/6/01	11:30	*Not Detected*		H	
	Hatchery	5/15/01	3D9.1BF113CD32	6/7/01	12:30	*Not Detected*		H	
	"	5/15/01	3D9.1BF113C623	6/13/01	17:30	*Not Detected*		H	
	"	5/15/01	3D9.1BF1135491	6/14/01	15:30	*Not Detected*		H	
	"	5/15/01	3D9.1BF11396D0	6/14/01	15:30	*Not Detected*		H	
	"	5/15/01	3D9.1BF112A28E	6/14/01	15:30	*Not Detected*		H	
	"	5/15/01	3D9.1BF113C142	6/14/01	17:30	*Not Detected*		H	
	"	5/15/01	3D9.1BF1133201	6/20/01	9:30	*Not Detected*		H	
	Montlake	5/29/01	3D9.1BF11110B7	6/14/01	16:30	6/14/01	10:36:14	H	
	Lake Union	5/22/01	3D9.1BF1112F1C	5/23/01	13:00	*Not Detected*		H	
	"	5/22/01	3D9.1BF10D8A10	6/6/01	10:00	*Not Detected*		H	
	"	5/22/01	3D9.1BF1107BA5	6/6/01	11:30	*Not Detected*		H	
	"	6/19/01	3D9.1BF0E295C7	6/20/01	11:30	*Not Detected*		**N**	
	"	6/19/01	3D9.1BF10CDA56	6/20/01	11:30	*Not Detected*		**N**	
	"	6/19/01	3D9.1BF0DD3858	6/21/01	9:30	*Not Detected*		H	

Table 3-4. Summary of Large Lock Purse Seine Recapture Data, 2001 PIT Tag Study

				Large Lock		Flumes			
Species	**Release Location**	**Release Date**	**Tag No.**	**Date Captured**	**Time Captured**	**Date Detected**	**Time Detected**	**Hatchery/ Natural**	**Comments**
	"	6/19/01	3D9.1BF0E16B29	6/21/01	9:30	*Not Detected*		H	
	"	6/19/01	3D9.1BF0E14960	7/11/01	15:30	*Not Detected*		H	
	UW Hatchery	5/21/01	3D9.1BF11344AA	5/23/01	10:00	5/31/01	19:52:11	H	First Set; Assume Time
	"	5/21/01	3D9.1BF1125A0E	6/6/01	10:00	*Not Detected*		H	
	"	5/21/01	3D9.1BF113066D	6/6/01	11:30	5/23/01	15:17:10	H	
	"	5/21/01	3D9.1BF1123CF4	6/6/01	11:30	5/22/01	16:52:01	H	Recycling
	"		"			6/5/01	11:00:18	H	Recycling
	"		"			6/15/01	9:47:44	H	Recycling
	"	5/21/01	3D9.1BF11252FB	6/6/01	11:30	*Not Detected*		H	
	"	5/21/01	3D9.1BF1134723	6/6/01	11:30	5/23/01	16:55:59	H	Recycling
	"		"			5/26/28		H	Recycling
	"	5/21/01	3D9.1BF1130FA0	6/6/01	11:30	5/25/01	17:59:52	H	
	"	5/21/01	3D9.1BF112AD6E	6/7/01	12:30	*Not Detected*		H	
	"	5/21/01	3D9.1BF113ACC1	6/7/01	12:30	*Not Detected*		H	
	"	5/21/01	3D9.1BF11356CD	6/14/01	16:30	5/28/01	12:10:33	H	
	"	5/21/01	3D9.1BF112477F	6/14/01	16:30	*Not Detected*		H	
	"	5/21/01	3D9.1BF112CA4A	6/14/01	16:30	5/22/01	12:18:18	H	Recycling
	"		"			6/4/01	8:52:36	H	Recycling
	"		"			6/5/01	13:42:14	H	Recycling
	"		"			6/6/01	10:45:48	H	Recycling

Table 3-4. Summary of Large Lock Purse Seine Recapture Data, 2001 PIT Tag Study

				Large Lock		Flumes			
Species	**Release Location**	**Release Date**	**Tag No.**	**Date Captured**	**Time Captured**	**Date Detected**	**Time Detected**	**Hatchery/ Natural**	**Comments**
	"		"			6/13/01	6:33:10	H	Recycling
Coho	Bear Cr	5/17/01	3D9.1BF1114ADA	6/6/01	10:00	*Not Detected*		**N**	
	"	5/25/01	3D9.1BF111298C	6/14/01	15:30	*Not Detected*		**N**	
	"	5/9/01	3D9.1BF1132C9C	6/14/01	16:30	6/7/01	15:51:48	**N**	
	Cedar R	5/11/01	3D9.1BF113BC8F	6/7/01	11:00	*Not Detected*		**N**	
	"	5/15/01	3D9.1BF11309F1	6/14/01	18:30	*Not Detected*		**N**	
	Montlake	6/5/01	3D9.1BF10D1D0D	6/7/01	10:00	*Not Detected*		**N**	First Set; Assume Time
	Lake Union	6/5/01	3D9.1BF0DD9032	6/6/01	10:00	*Not Detected*		H	
	"	6/5/01	3D9.1BF0DD903E	6/6/01	10:00	*Not Detected*		H	
	"	6/5/01	3D9.1BF0E3B39E	6/6/01	10:00	*Not Detected*		H	
	"	6/5/01	3D9.1BF1114AF4	6/6/01	10:00	*Not Detected*		H	
	"	6/5/01	3D9.1BF0DDA333	6/6/01	10:00	*Not Detected*		H	
	"	6/5/01	3D9.1BF1020DFA	6/6/01	10:00	*Not Detected*		H	
	"	6/5/01	3D9.1BF10D8CAA	6/6/01	10:00	*Not Detected*		H	
	"	6/5/01	3D9.1BF1025B2E	6/6/01	11:30	*Not Detected*		H	
	"	6/6/01	3D9.1BF0E24030	6/7/01	11:00	*Not Detected*		H	
	"	6/6/01	3D9.1BF111AED2	6/7/01	12:30	*Not Detected*		**N**	
	"	6/5/01	3D9.1BF10D75B7	6/7/01	14:00	6/6/01	13:03:13	**N**	

Table 3-4. Summary of Large Lock Purse Seine Recapture Data, 2001 PIT Tag Study

				Large Lock		Flumes			
Species	**Release Location**	**Release Date**	**Tag No.**	**Date Captured**	**Time Captured**	**Date Detected**	**Time Detected**	**Hatchery/ Natural**	**Comments**
Sockeye	Lake Union	5/8/01	3D9.1BF1112EBF	5/9/01	13:30	*Not Detected*		**N**	
	"	5/8/01	3D9.1BF1113627	5/9/01	13:30	*Not Detected*		**N**	
	"	5/8/01	3D9.1BF11145DB	5/9/01	13:30	*Not Detected*		**N**	
	"	5/8/01	3D9.1BF11106AB	5/9/01	13:30	*Not Detected*		**N**	
	"	6/5/01	3D9.1BF10F0203	6/6/01	10:00	*Not Detected*		**N**	
	"	6/5/01	3D9.1BF10B1E27	6/6/01	10:00	*Not Detected*		**N**	
	"	6/5/01	3D9.1BF1020302	6/7/01	10:00	*Not Detected*		**N**	First Set; Assume Time
	"	6/12/01	3D9.1BF0E143A4	6/21/01	11:30	*Not Detected*		**N**	

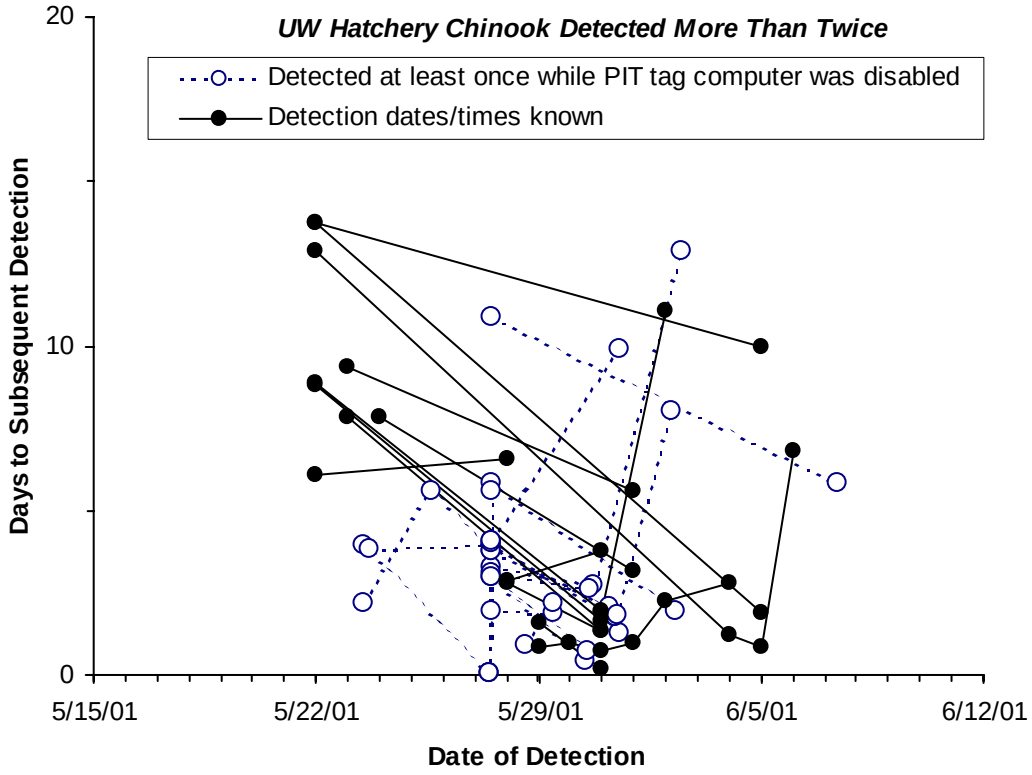


Figure 3-34. Recycling times of PIT tagged juvenile chinook salmon from the UW Hatchery passing downstream more than two times through the smolt flumes at the Locks, 2001 Lake Washington GI study. The open circles represent fish that were detected during times when the PIT tag computer was disabled (see Figure 3-1), and thus the recycling time is approximate to within a day for those fish.

3.5.3 Influence of Lock Operations on Passage Through Flumes

Figures 3-35 and 3-36 indicate that there was a tendency for PIT tagged fish to pass through the flumes at a higher rate during the fill period than during the between-fill period. It was not possible to determine if this was related to diurnal differences in behavior near the large lock culverts (Johnson et al. 2001) as the majority of PIT tag detections occurred during daylight hours. To evaluate this statistically, the data in the figures were filtered and cases identified where fish were detected during consecutive fill and between-fill periods. A ratio was calculated of the passage rate during fill to the passage rate during the subsequent between-fill period. Two-tailed t-tests of the ratio indicated that it was significantly greater than 1.0 on average ($p<0.05$). In other words, the mean passage rates through the flumes were significantly greater during the fill period than afterwards for both the small and the large locks.

3.6 ESTUARINE BEHAVIOR

Beach sampling was conducted at the railroad bridge and downstream where salinity appears to be usually equal to or greater than 15 ppt. Captures of PIT tagged fish in the beach seine samples thus provide temporal and spatial information regarding the transition to saltwater. Table 3-5 summarizes the tagging and capture histories of PIT tagged fish caught in beach seine samples that were collected below the Locks. There was a large fraction of the PIT tagged fish that was caught in the inner bay within a few days of detection in the smolt flumes. One chinook salmon juvenile was recaptured during beach seining near the railroad bridge within 10 minutes of having passed through the flumes. A coho juvenile was also recaptured at that location within 45 minutes of passage (Table 3-5).

One of the calibration test chinook was captured at the railroad bridge, and later passed through the flumes again in mid-July 2001 (Table 3-5). However, as described previously, this unique behavior may not necessarily be representative of other chinook salmon juveniles passing through the LWSC and the Locks.

3.7 SURVIVAL ESTIMATES

The PIT tag data were used to estimate relative differences in survival over discrete segments of the outmigration route in the LWSC and the Lake Washington system. However, the precision of the results was adversely influenced by the variation in tunnel reader detection efficiency, and because the proportion using the flumes could not be estimated consistently or with satisfactory precision as described in Section 2.6.5. Only two estimates could be made of the proportion using the flumes, based on the recapture data below the Locks: 39% for Lake Union coho

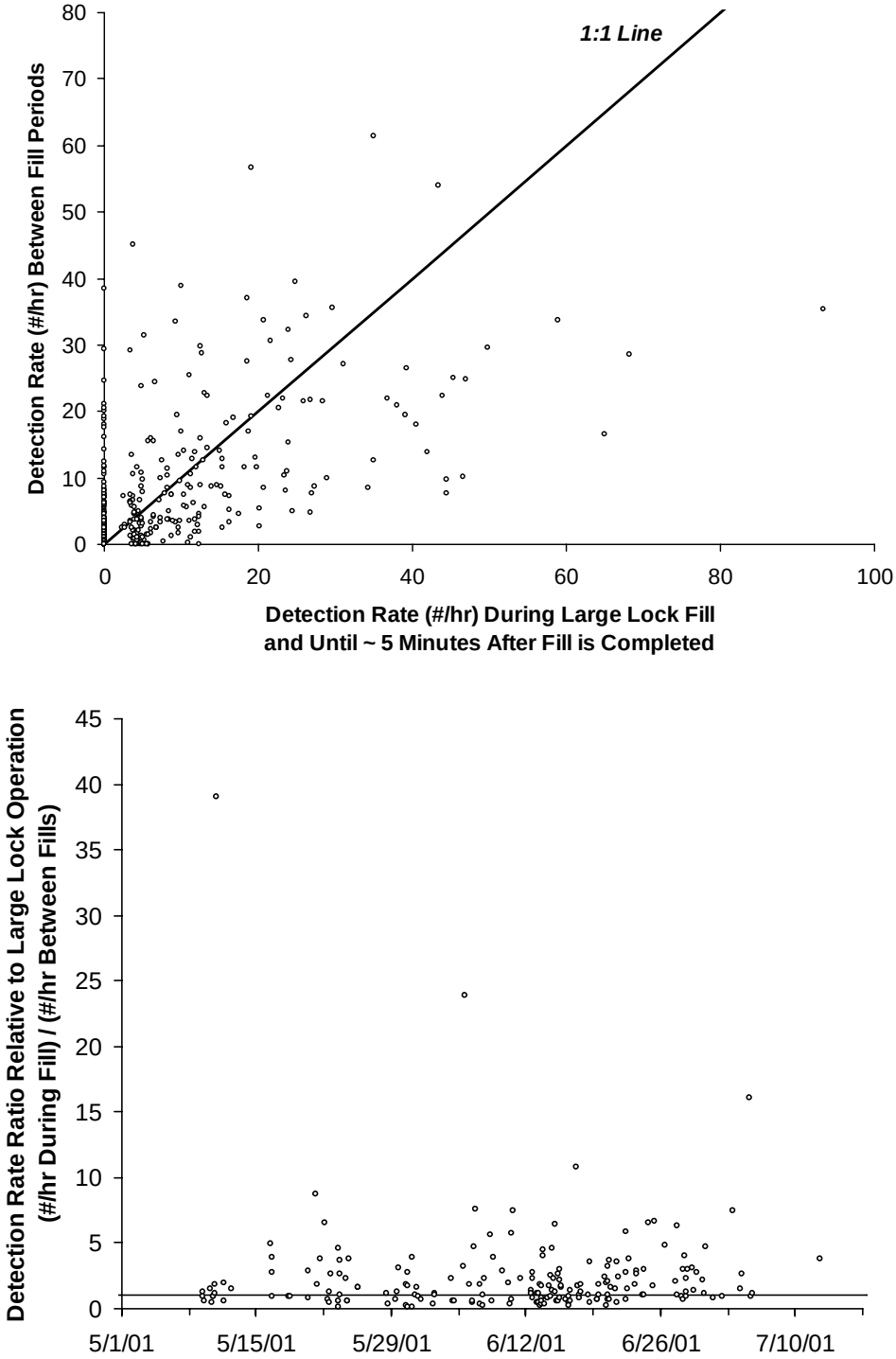
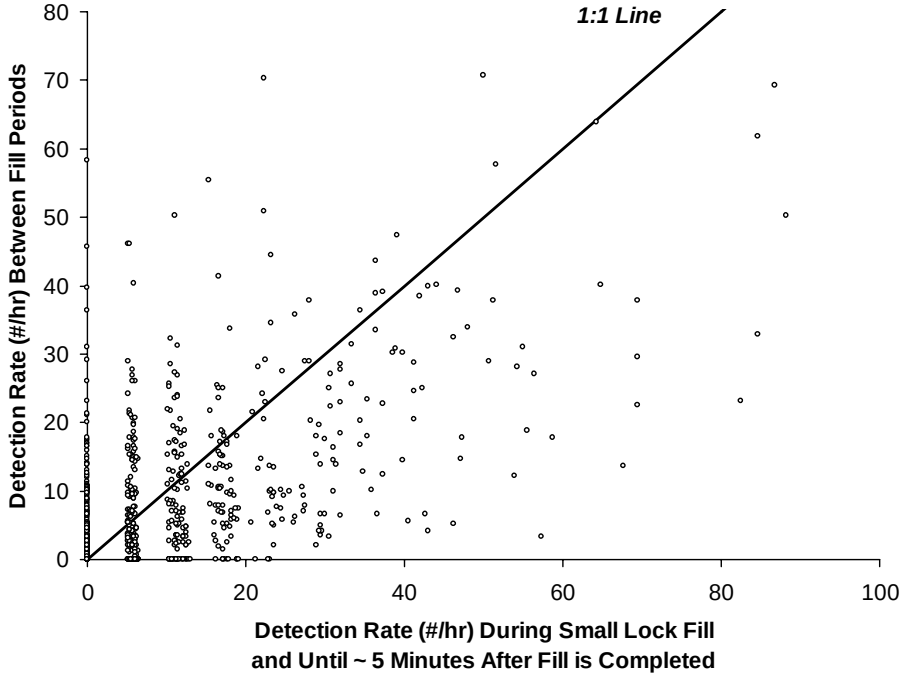


Figure 3-35. Comparison of passage rates of PIT tagged juvenile salmon (all species) through the smolt flumes at the Locks during filling of the large lock and until the next fill, 2001 Lake Washington GI study. The bottom plot shows the ratio of the two passage rates over time. The line of equality is indicated by the solid diagonal (top) and horizontal (bottom) line.



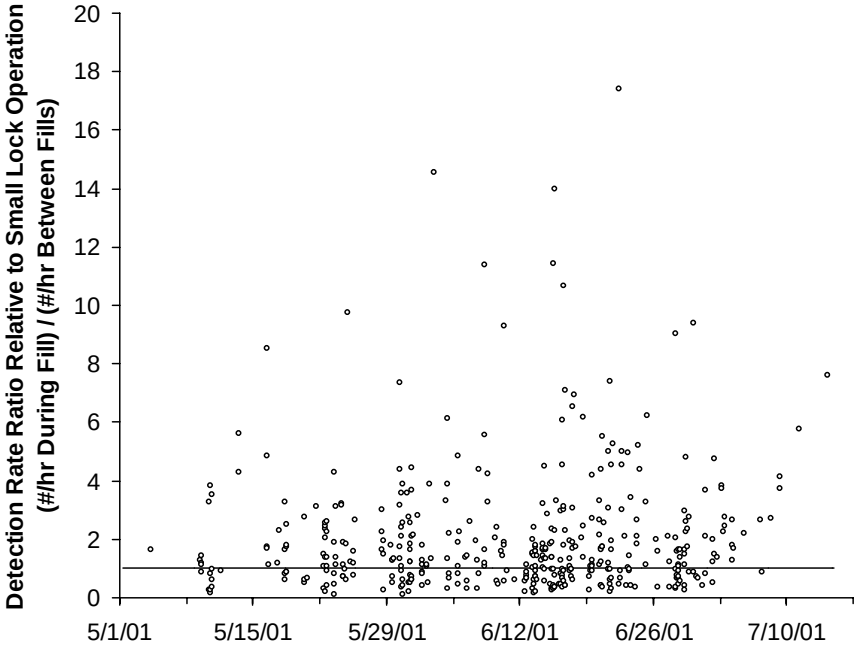


Figure 3-36. Comparison of passage rates of PIT tagged juvenile salmon (all species) through the smolt flumes at the Locks during filling of the small lock and until the next fill, 2001 Lake Washington GI study. The bottom plot shows the ratio of the two passage rates over time. The line of equality is indicated by the solid diagonal (top) and horizontal (bottom) line.

Table 3-5. Summary of Beach Seine Recapture Data Below Locks, Lake Washington GI 2001 PIT Tag Study

					Saltwater				Flumes			
Species	**Release Location**	**Release Date**	**Tag No.**	**Capture Location**	**Date Captured**	**Time Captured**	**Salinity (ppt)**	**Days in Saltwater**	**Date Detected**	**Time Detected**	**Hatchery/ Natural**	**Comments**
Chinook	Tunnel	*Same*	3D9.1BF1131777	Groundswell	5/31/01	13:00	-	38.1	4/23/01	10:37	H	
	Reader	*as*	3D9.1BF113C8B5	Statue of Liberty	6/6/01	13:45	-	1.2	6/5/01	9:36	H	Capture Date/Location Assumed
	Calibration	*Date*	3D9.1BF11325BE	Statue of Liberty	6/6/01	13:45	-	1.2	6/5/01	9:36	H	Capture Date/Location Assumed
	Testing	*Detected*	"	Railroad	6/18/01	14:00	15.9	-	*Saltwater Recap*		H	
	"	*in*	3D9.1BF1276EE5	Statue of Liberty	6/6/01	13:45	-	1.2	6/5/01	9:34	H	Capture Date/Location Assumed
	"	*Flumes*	3D9.1BF1276922	Railroad	6/18/01	14:00	15.9	31.2	5/18/01	9:53	H	
	"	"	"		*Subsequent Recycling Through Freshwater*				7/11/01	9:39	H	
	"	"	3D9.1BF113C19D	Railroad	6/18/01	14:00	15.9	13.2	6/5/01	9:55	H	
	"	"	"	Railroad	6/18/01	21:30	-	-	*Saltwater Recap*		H	
	"	"	3D9.1BF113CE28	Railroad	6/18/01	14:00	15.9	13.2	6/5/01	9:38	H	
	"	"	3D9.1BF113D0F4	Railroad	6/18/01	14:30	20.2	13.2	6/5/01	9:55	H	
	"	"	3D9.1BF113C7A3	Railroad	6/18/01	14:30	20.2	13.2	6/5/01	9:35	H	
	"	"	3D9.1BF113D08C	Railroad	6/18/01	21:30	-	13.5	6/5/01	9:56	H	
	"	"	3D9.1BF113BFD5	Railroad	6/18/01	21:30	-	13.5	6/5/01	9:57	H	
	"	"	3D9.1BF113D710	Railroad	6/18/01	21:30	-	13.5	6/5/01	9:43	H	Capture Date/Location Assumed
	"	"	3D9.1BF113B4D2	Railroad	6/18/01	21:30	-	13.5	6/5/01	9:37	H	
	"	"	3D9.1BF1137C5A	Railroad	6/18/01	21:30	-	13.5	6/5/01	9:45	H	
	"	"	"	Railroad	6/19/01	21:00	17.0	-	*Saltwater Recap*		H	
	"	"	3D9.1BF11376DD	Coke Machine	6/19/01	21:30	21.5	14.5	6/5/01	10:03	H	
	"	"	3D9.1BF113C5DF	Coke Machine	6/19/01	21:30	21.5	14.5	6/5/01	9:38	H	
	"	"	3D9.1BF11381E5	Railroad	6/19/01	22:30	-	14.5	6/5/01	10:11	H	

Table 3-5. Summary of Beach Seine Recapture Data Below Locks, Lake Washington GI 2001 PIT Tag Study

					Saltwater				Flumes			
Species	**Release Location**	**Release Date**	**Tag No.**	**Capture Location**	**Date Captured**	**Time Captured**	**Salinity (ppt)**	**Days in Saltwater**	**Date Detected**	**Time Detected**	**Hatchery/ Natural**	**Comments**
	"	"	3D9.1BF113CA30	Railroad	6/20/01	11:30	-	15.1	6/5/01	9:50	H	
	"	"	3D9.1BF113C328	Railroad	6/20/01	11:30	-	15.1	6/5/01	10:09	H	
	"	"	3D9.1BF113C179	Railroad	6/20/01	21:00	16.8	15.5	6/5/01	9:44	H	
	"	"	3D9.1BF113B40E	Middle Beach	6/22/01	1:00	-	16.6	6/5/01	9:36	H	
	Bear Cr	5/25/01	3D9.1BF10CAC75	Railroad	6/18/01	14:00	15.9	0.8	6/17/01	19:57	**N**	
	"	5/30/01	3D9.1BF1107FA4	Railroad	6/19/01	10:00	-	0.0	6/19/01	9:53	**N**	
	Lake Union	5/30/01	3D9.1BF11125A4	Statue of Liberty	6/18/01	10:30	22.9	2.9	6/15/01	12:27	H	
	"	5/30/01	3D9.1BF10D7AB1	Piling Beach	6/22/01	12:30	-	4.0	6/18/01	13:11	H	
	Montlake	6/5/01	3D9.1BF0FF3E85	Dolphin 8	6/18/01	10:00	27.8	-	*Not Detected*		H	
	"	6/12/01	3D9.1BF0E6123B	Railroad	6/21/01	23:30	-	-	*Not Detected*		**N**	
	UW Hatchery	5/21/01	3D9.1BF113901E	Statue of Liberty	6/6/01	13:45	-	6.1	5/31/01	12:02	H	Capture Date/Location Assumed
Coho	Bear Cr	5/9/01	3D9.1BF1133781	Groundswell	6/13/01	10:30	-	0.7	6/12/01	18:19	**N**	
	"	5/16/01	3D9.1BF1112F0C	Groundswell	6/20/01	22:30	20.5	8.3	6/12/01	14:39	**N**	
	Cedar R	5/18/01	3D9.1BF1114BCC	Railroad	6/19/01	10:45	-	0.03	6/19/01	10:02	**N**	
	"	5/17/01	3D9.1BF11144E0	Groundswell	6/20/01	14:00	-	6.4	6/14/01	4:22	**N**	
	Lake Union	5/22/01	3D9.1BF114E014	Railroad	6/18/01	23:30	-	-	*Not Detected*		H	Grew From 112 to 120 mm in 27d

released the week of May 21, 2001, and 82% for Montlake chinook released the weeks of June 4 and 11, 2001 (determined using program RELEASE; Burnham et al. 1987; model H2p; see output in Appendix C). In addition, the proportion using the flumes may not have been constant over the passage season.

This last point is suggested by the PIT tag data, where the tunnel reader detection rate computed for most release groups decreased over time (Figures 3-37, 3-38, and 3-39). This trend was strongest for chinook (Figure 3-37), which outmigrated the latest, and weakest for sockeye (Figure 3-39), which outmigrated the earliest during the passage season. Average weekly detection rates (after adjusting for detection efficiency) were on the order of 20%, 50%, and 70% for chinook released in Bear Creek, the Cedar River, and the Montlake Cut, respectively, in early May (Figure 3-40). By late June to early July, they were near zero. In contrast, the detection rate for chinook caught in Lake Union and released near the Fremont Cut was more steady, holding around 30% to 40%.

Coho salmon detection rates followed a similar but less prominent trend, probably because the majority had outmigrated before the chinook detection rates dropped substantially (Figure 3-41). However, naturally reared coho salmon caught in Lake Union showed a stronger declining trend than their chinook counterparts, whereas the hatchery fish in those samples were detected at a steadier rate. Sockeye salmon caught in the vicinity of the Montlake Cut also showed a declining trend, whereas sockeye caught in Lake Union were associated with a relatively level, albeit more variable, trend (Figure 3-42). Sample sizes for steelhead were generally too small to infer a trend (Figure 3-42).

Given the apparent temporal trend in detection rate and the small number of samples from which the proportion using the flumes could be estimated from (poorly, to boot), it was not possible to estimate absolute survivals of the release groups to the Locks, as indicated in Section 2.6.5. However, the PIT tag data indicated some interesting results regarding survival along different portions of the migration route. Comparisons of detection rates for chinook caught and released in the Montlake Cut and Lake Union indicated that survival was effectively 100% through that portion of the LWSC between the weeks of May 28 and June 18, 2001 (Table 3-6). These numbers are much higher than that estimated in 2000 (64%), but the latter, lower number may have been associated with mortality caused by a disease outbreak in the LWSC that year. Alternatively, the lower survival estimate for the week of June 25, 2001 is similar to the 2000 estimates, suggesting annual variation exists in the timing of when survival through the LWSC begins to decrease.

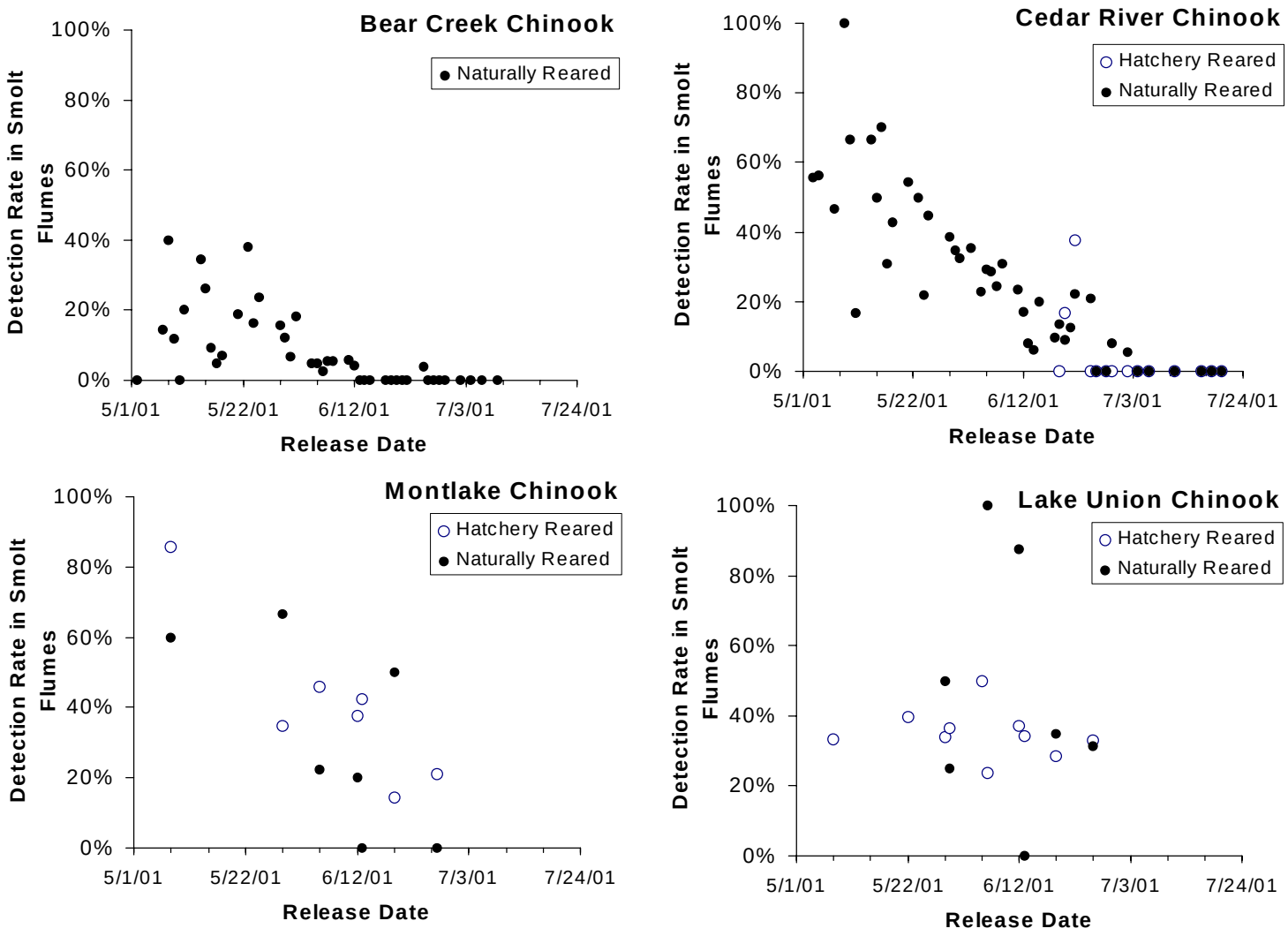


Figure 3-37. Daily variation of detection rate at the smolt flumes of PIT tagged juvenile chinook salmon, by release location, release date, and origin, 2001 Lake Washington GI study. Each data point was calculated by dividing the number released in a group into the number subsequently detected at the Locks, adjusted for detection efficiency.

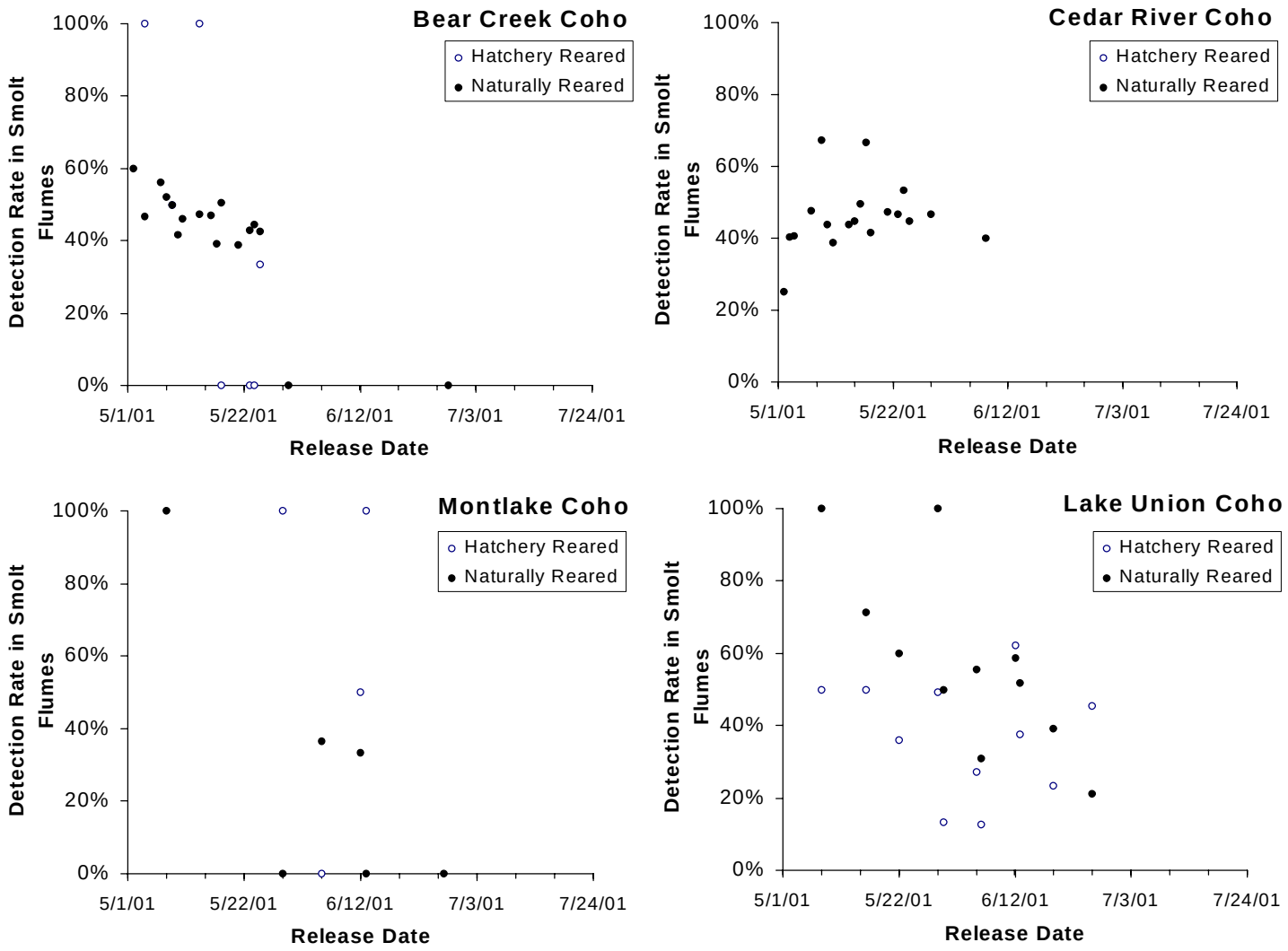


Figure 3-38. Daily variation of detection rate at the smolt flumes of PIT tagged juvenile coho salmon, by release location, release date, and origin, 2001 Lake Washington GI study. Each data point was calculated by dividing the number released in a group into the number subsequently detected at the Locks, adjusted for detection efficiency.

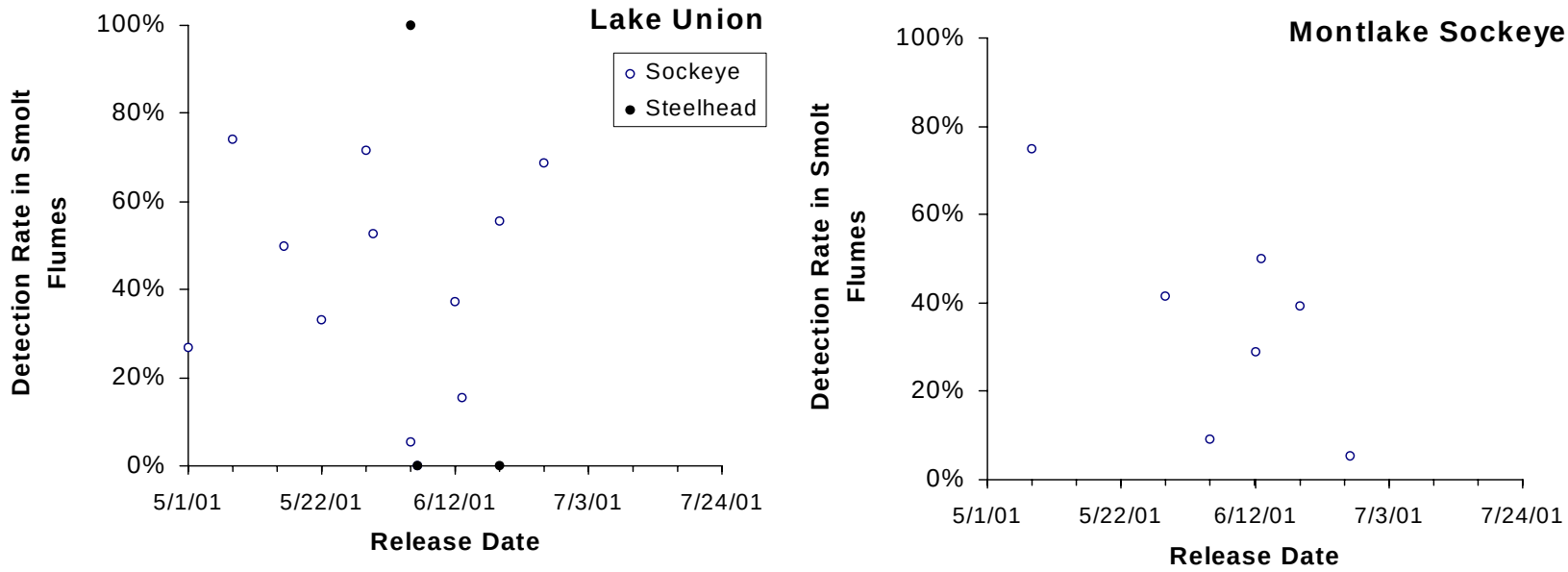


Figure 3-39. Daily variation of detection rate at the smolt flumes of PIT tagged juvenile sockeye salmon, by release location, release date, and origin, 2001 Lake Washington GI study. Each data point was calculated by dividing the number released in a group into the number subsequently detected at the Locks, adjusted for detection efficiency.

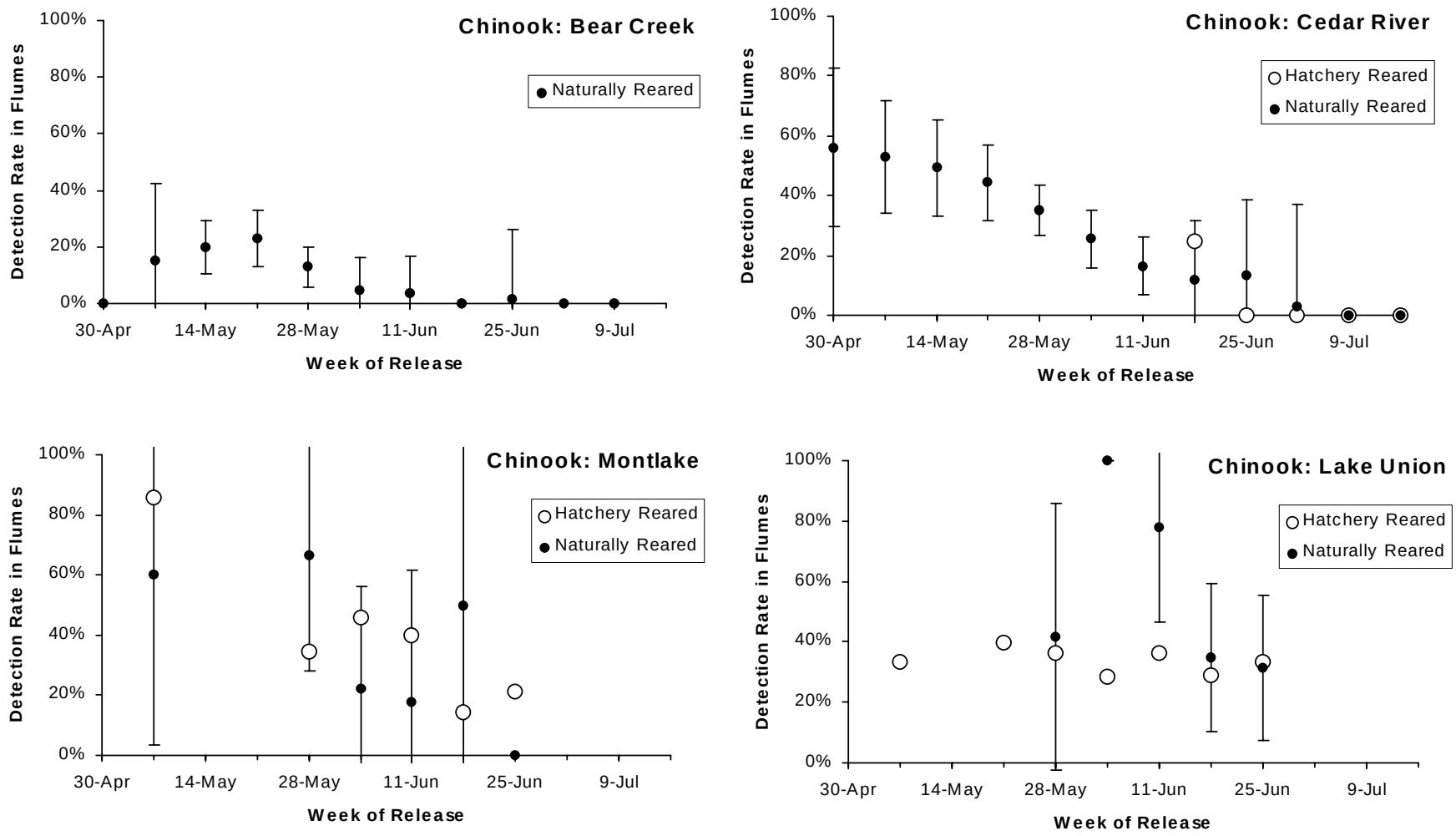


Figure 3-40. Weekly variation of detection rate at the smolt flumes of PIT tagged juvenile chinook salmon, by release location, week of release, and origin, 2001 Lake Washington GI study. The data in Figure 3-37 were grouped by week. 95% CI are presented based on the binomial approximation for a proportion.

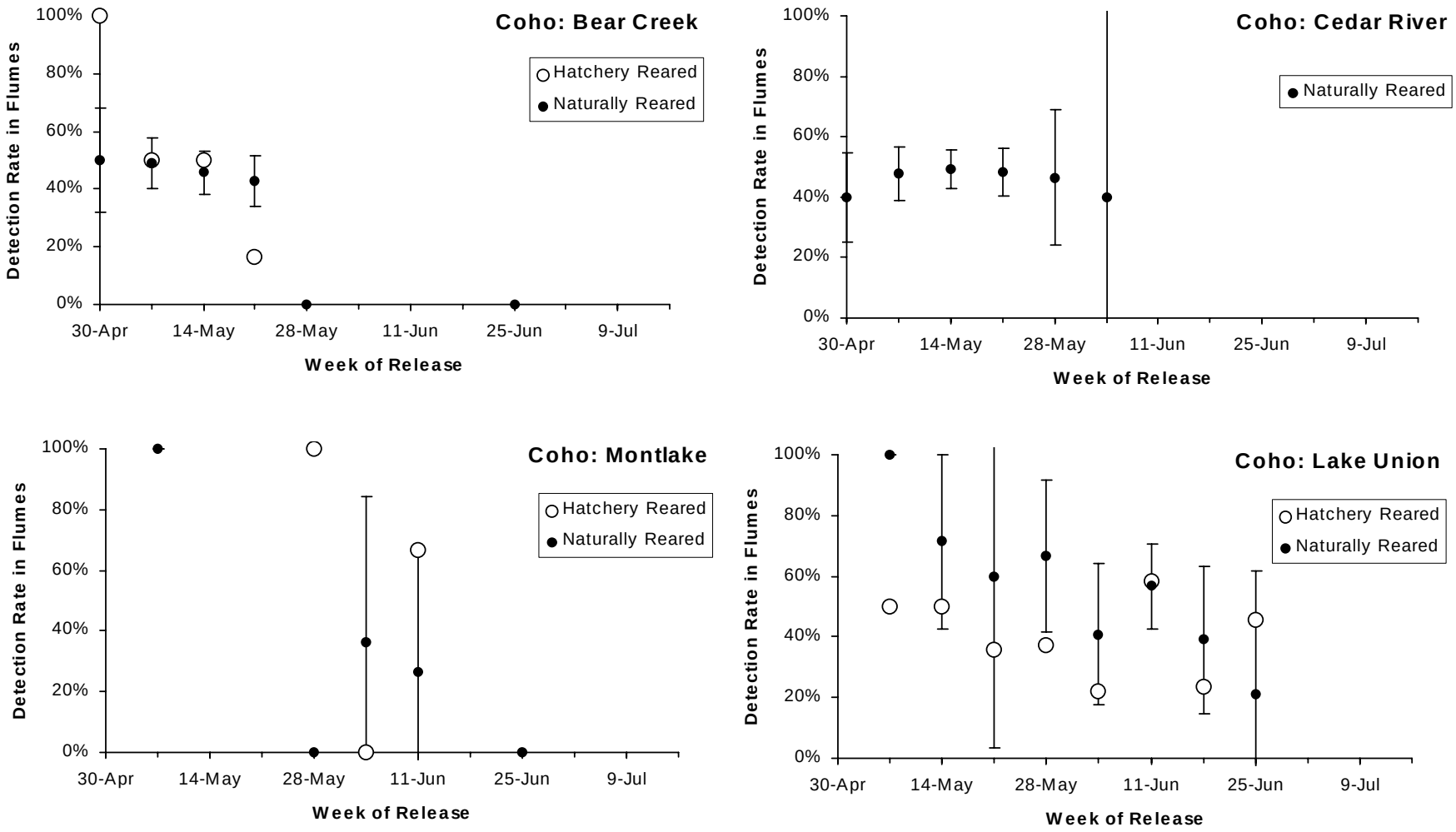
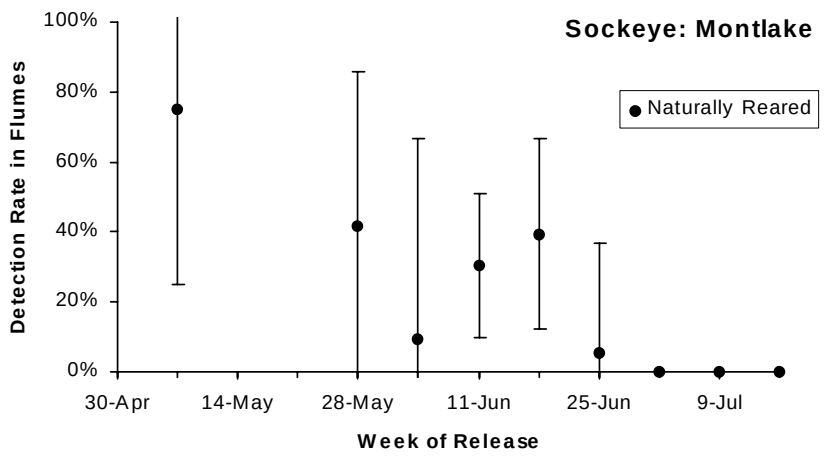
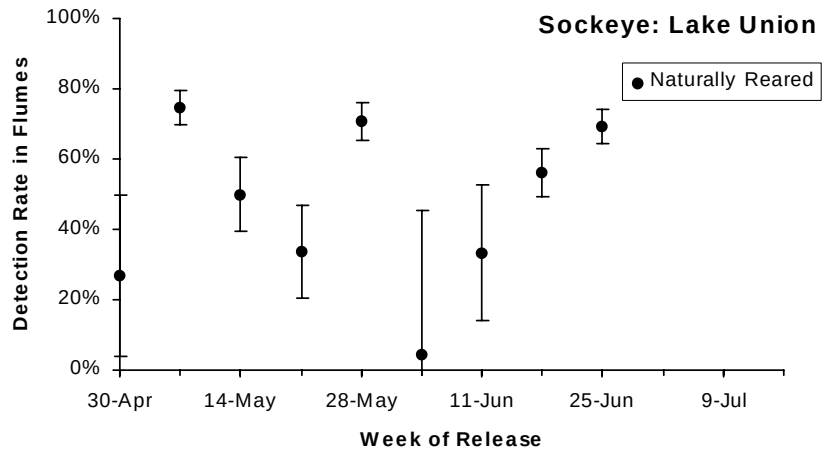


Figure 3-41. Weekly variation of detection rate at the smolt flumes of PIT tagged juvenile coho salmon, by release location, week of release, and origin, 2001 Lake Washington GI study. The data in Figure 3-38 were grouped by week. 95% CI are presented based on the binomial approximation for a proportion.





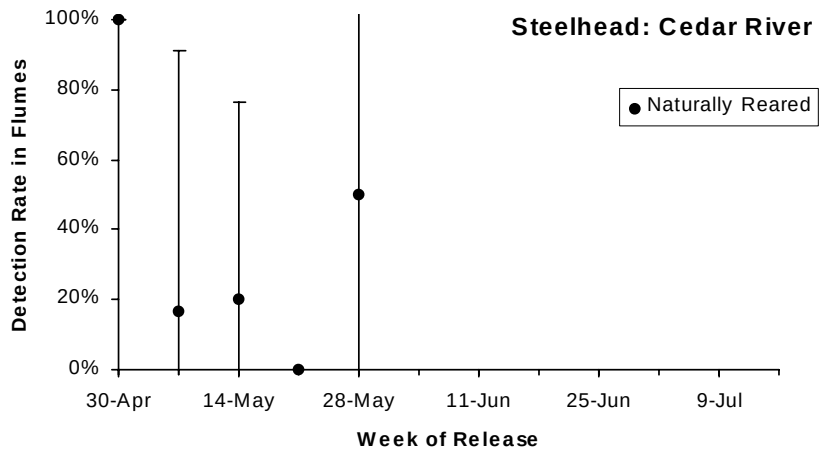


Figure 3-42. Weekly variation of detection rate at the smolt flumes of PIT tagged juvenile sockeye salmon, by release location, week of release, and origin, 2001 Lake Washington GI study. The data in Figure 3-39 were grouped by week. 95% CI are presented based on the binomial approximation for a proportion.

Table 3-6. Estimated survivals over different segments of the chinook salmon juvenile outmigration route in the Lake Washington system, 2001.

	Chinook Release Groups, By Week of Release					**Estimated Migration Route Increment Survivals**			
	Issaquah Hatchery	**Bear Creek**	**Cedar River**	**Montlake Cut**	**Lake Union**	**Issaquah Hatchery - Bear Creek**	**Bear Creek - Montlake Cut**	**Cedar River - Montlake Cut**	**Montlake - Fremont Cut**
Comparison 1	--	--	--	--	--	--	53%	100%	100%
Week of Release	--	5/14/01	5/21/01	5/28/01	6/4/01				
No. Released	--	357	142	110	23				
No. in Smolt Flumes	--	71	63	41	8				
Comparison 2	--	--	--	--	--	100%	54%	81%	100%
Week of Release	5/14/01	5/21/01	5/28/01	6/4/01	6/11/01				
No. Released	4676	320	374	236	160				
No. in Smolt Flumes	1762	74	131	102	62				
Comparison 3	--	--	--	--	--	--	34%	67%	100%
Week of Release	--	5/28/01	6/4/01	6/11/01	6/18/01				
No. Released	--	685	320	255	551				
No. in Smolt Flumes	--	89	82	98	162				
Comparison 4	--	--	--	--	--	--	27%	94%	53%
Week of Release	--	6/4/01	6/11/01	6/18/01	6/25/01				
No. Released	--	277	360	23	516				
No. in Smolt Flumes	--	13	59	4	170				

Comparison of detection rates for Issaquah Hatchery fish and chinook caught and released in Bear Creek indicated that survival of the hatchery chinook was also effectively 100% as they migrated to the mouth of Bear Creek.

In contrast, the two tributary chinook stocks appeared to experience a decrease in survival over time during the outmigration period (Table 3-6). Chinook from Bear Creek appeared to experience a steady survival rate as they migrated to the Montlake Cut, of around 53% to 54% during the latter half of May and first week of June. The survival estimates then began to decline each successive week. It is important to note that the magnitude of estimated survival for about the same time period as Comparisons 2 and 3 in Table 3-6 was similar to that determined in 2000 (43%).

Chinook from the Cedar River had a higher survival rate overall compared with chinook from Bear Creek, but exhibited a decreasing trend beginning around the end of May. However, for fish tagged during the second week in June, survival to the Montlake Cut increased again to above the 90% level (Table 3-6). The estimated survivals for the end of May and early June 2001 (81% and 67%) are also similar in magnitude to that determined for Cedar River chinook in 2000 (79%). Hence, the survival estimates for these portions of the migration route appear to be generally consistent between the two years of study.

Post-tagging mortality rates likely influenced the numbers above (see Section 3.1), but assuming they were of similar, small order of magnitude on average would result in the rates effectively canceling out in the calculation of route increment survivals, with a minor effect on the accuracy of the resulting estimate. This may be a reasonable assumption given that only in a few instances did tagging mortality exceed 1%.

Confidence intervals for survival estimates were generally large because of the small numbers of recaptures and the number of tagged fish released in each group (generally 1000 fish or less). A range of variances of the estimated survival of a release group to the Locks were determined by S. Smith of NMFS, assuming *a priori* (in the absence of data) that survival between the Locks and the beach seine sites equaled 0.95. The analyses were conducted for a range of release numbers (1,000 to 10,000 fish), survival magnitudes (0.5 to 0.9), and detection probabilities at the Locks (0.2 to 0.4) and beach seining (0.05 to 0.15). The resulting estimates are presented in Appendix D, and indicate the approximate range of precision that may be expected for the release and recapture numbers presented in Table 3-1, absent other sources of error.

4. DISCUSSION

The results of this study provided important insights supplementing and adding to those obtained in 2000 regarding mortality, migration, and passage characteristics of tagged fish in the Lake Washington and LWSC system. In whole, the data indicate that PIT tagging is a useful and important tool for evaluating outmigration characteristics and the effects of the Locks on juvenile salmon, which were primary study objectives. The results further permit evaluation of the relation between Locks operations and downstream passage by salmon smolts, identification of potential changes to operations that may reduce the effects or help conserve water in a benign manner, and identifying future studies that may be designed to obtain more complete information on smolt behavior in the system. These issues are discussed below.

Detection efficiency of the tunnel readers was improved significantly compared with the 2000 study. However, the 2001 study still suffered from the same problem regarding incomplete coverage of all the routes through the Locks, and the resulting data indicate that this may be an important deficiency in evaluating survival through the Locks facilities.

An interesting side observation regarding migration routes through the Lake Washington system is warranted here based on the PIT tagging data. There were no known releases of hatchery chinook in the Cedar River, yet several were captured and tagged at the screw trap beginning on June 19, 2001. It is highly possible that these were Issaquah Hatchery chinook that migrated along the eastern side of Lake Washington, and made a foray into the lower reaches of the Cedar River as they were searching for a passage route (the screw trap was located a short distance upstream of slack water). Assuming a median travel speed of approximately 2.6 km/day (Figure 3-22), and a migration distance of 88 km (determined using a similar technique for deriving Table 3-2), results in an estimated average travel time of 34 days from the hatchery to the Cedar River trap. Since the hatchery fish were released on May 15, this corresponds to an estimated median arrival date of June 18, which is one day before the time that hatchery chinook first starting showing up in the Cedar River samples. This is of the correct order of magnitude to conclude that the hatchery fish in the Cedar River trap most likely originated from the Issaquah Hatchery.

4.1 DOES PIT TAGGING MEET THE STUDY OBJECTIVES?

Based on the results of this and the preceding year studies, PIT tag technology appears to be a viable technique for assessing mortality over different portions of the migration route. This is an

important outcome, even if it is not possible to estimate absolute total mortality over the entire migration route. The results also provide important information regarding migration and passage characteristics, as well as evaluating the effects of the LWSC project on hatchery and naturally-produced chinook and other salmon species. And, although the precision of the survival estimates may be relatively low in this pilot study, similarity between the 2000 and 2001 results suggests that the estimated survivals for the different routes are of the correct order of magnitude. The resulting information thus appears to be extremely useful for evaluating factors influencing survival along different segments of the migration route.

The second study objective was also met. Specifically, PIT tagging was found to be viable for naturally-reared smolts in tributaries to Lake Washington and for smolts migrating through the LWSC. Continued tagging over the outmigration period allows evaluation of temporal variation in survival and migration characteristics.

With respect to the third main study objective, chinook salmon juveniles from the Issaquah Hatchery were observed to be similar to naturally-spawned tributary chinook in terms of migration and passage behavior, and possibly survival to the Locks. An exception was apparent for the calibration test fish, which were held and released under the least “normal” conditions of all the hatchery release groups. The UW Hatchery chinook did not appear to be a reasonable model of naturally reared fish because their outmigration behavior was radically different. However, in lieu of taking tagged hatchery fish to different release locations in Lake Washington Tributaries, and acclimatizing them prior to release, continued tagging of naturally reared fish remains recommended as the most direct means for addressing survival, migration, and passage characteristics.

The large tunnel readers were still operating below the desired minimum detection efficiency of 95%. Flume 4B was operating at an average efficiency of 89% and Flume 5B at 90%. These values are high enough that the adjusted detection numbers give assurance that the trends reported here are realistic. However, they are still sufficiently low that they add a level of uncertainty to total survival estimates. Further structural modifications may be needed.

One potential problem that was not resolved this year and that may have also influenced detection efficiency was "pulsing" of water through the flumes at higher lake levels, and development of standing waves. This was manifest by periodic overtopping of the flume sides near the tunnel reader throats, and a visual pulse in the outfall discharge rate. This pulsing occasionally resulted in the ejection of a fish stick out of the flume before it entered the tunnel

reader. Fish were not observed to have been similarly ejected, and may not have because they appeared to swim near the bottom of the flume as they were drawn into the throat, whereas the sticks were floating on the surface. However, pulsing and overtopping were associated with intense turbulence at the throat entrance, which may have contributed to lower detection efficiency by orienting some fish and fish sticks closer to perpendicular to the long axis of the flume, a sub-optimal orientation. Modification of the flume hydraulics appears necessary.

4.2 MEETING THE ASSUMPTIONS OF PIT TAG BASED SURVIVAL ESTIMATORS

The survival estimates presented in this report must be regarded cautiously. Differential detection rates can provide an indication of survival between two release locations, assuming similar detection probabilities. The validity of this assumption, however, depends on whether the two groups move downstream at about the same time, and are randomly mixed when they arrive at the Locks (Burnham et al. 1987; Iwamoto et al. 1994). The bias in survival estimates that results from not meeting the assumption increases with distance between the two release locations in a reach (Dauble et al. 1993).

In contrast with the 2000 study, the Issaquah Hatchery chinook appeared to have 100% survival as they passed through Lake Sammamish in 2001, as did chinook migrating between the Montlake Cut and the Fremont Cut. Bear Creek chinook appeared to have lower survival to the Montlake Cut than Cedar River chinook. Nevertheless, the segment-specific survival estimates were reasonably consistent for around the same time period in the both 2000 and 2001, suggesting indirectly that the assumption of similar detection probabilities is met once the proportion using the flumes is canceled out in the calculation.

The accuracy and precision of the survival estimates depend on several critical assumptions. Estimates of survival and proportion of tagged fish using the flumes are sensitive to the number of tagged fish recaptured in the beach seine samples. Sampling in 2000 indicated that sampling effort in the inner bay should be on the order of 105 seine samples at each beach site within the bay, with at least 7 daily seine sets needed in each site during the peak chinook outmigration period. This was not feasible in 2001, and additional sampling would be needed in order to increase recapture numbers of PIT tagged fish and minimize the uncertainty about survival estimates. This would also provide more data describing the time of transition between fresh- and saltwater.

It is also possible that the incomplete coverage of passage routes could have had a systematic effect on the survival estimates if different release groups had different mean patterns of migration through the Locks. For example, one group may have migrated predominantly along the south shore where they were more likely to pass through the flumes and be detected, whereas another may have been more likely to have migrated along the north shore and be under-represented in the PIT tag detection data. We don't know if this is the case or not, but the possibility highlights the importance of sampling the alternate routes for PIT tagged fish as well. Simultaneous releases on both sides of the LWSC using PIT tagged fish are recommended here to evaluate this issue further. The corresponding null hypothesis is that fish released on the north and south sides of the LWSC channel have similar detection rates in the flumes. Such improvements may also increase the accuracy and precision of future survival estimates by providing indirect information on the proportion using the flumes, which could not be addressed adequately in this study because so few tagged fish were captured below the Locks during the peak chinook outmigration period.

A final concern remains regarding release group sample size, which is a statistical, logistical, and financial issue in PIT tagging-based survival studies. The confidence interval estimates depicted in Appendix D indicate that large numbers of fish are required in each tagging release group. There is a break in the curves plotted in Appendix D in terms of the percent change in precision of the estimate with sample size, at about 2,500 to 3,000 fish per group. At higher sample sizes, the incremental reduction in the confidence interval is smaller and changes less rapidly with increasing numbers of tagged fish. At smaller sample sizes, the confidence interval increases at a much greater rate with decreasing numbers of fish tagged. Unfortunately, the two years of study to date indicate that a sample size of 2,500 tagged fish per release group, or per week, is not achievable in Bear Creek and the Cedar River. However, this does not invalidate the overall utility of the data.

4.2.1 Possible Influence of Water Quality on Passage at Locks

Incomplete PIT tag detection coverage at the Locks also has important implications regarding determination of the proportion using the smolt flumes. The data collected in 2001 indicate that the proportion changes with time. A review of available water quality data suggests that the change may be due to changes in water temperature, where surface water temperatures in the LWSC generally reach adverse levels sooner in the outmigration season than near-bottom temperatures. Hence the decrease in detection rates over time could reflect a shift in passage behavior where the outmigrants gradually seek deeper routes through the Locks. This would

most likely occur via the large lock, the sill elevation of which is 20 feet below that of the small lock on the lake side. Water quality data collected by the USACE in the LWSC support this hypothesis. Figure 4-1 shows that water temperatures in 2001 climbed continually during the passage season, and leveled out around the middle of July. In most locations, the near-bottom water temperature was approximately 1-2ºC cooler than the surface temperature. Because of this, it is not clear if the data from the Fremont bridge station reflect real conditions or equipment malfunction (Figure 4-1). Water temperatures below the Locks are also much cooler (Figure 4-2), and salt water wedges intruding upstream through the large and small locks would result in cooler, brackish water near the bottom that the smolts may be attracted to as the surface water warms in the LWSC. Water temperatures in the large lock approached 15ºC around the beginning of June, and 19ºC around the first week in July 2001 (Figure 4-2). These temperatures are of significance because they represent approximate limits to optimal juvenile salmon production and growth, respectively (ODEQ 1995; McCullough 1999). Temperature preference has been correlated with optimal growth temperature, and the general preference of juvenile salmonids appears to be for temperatures that are about 15ºC and lower (McCullough 1999). By comparison, detection rates of the tagged Bear Creek and Cedar River chinook and coho smolts began dropping substantially around the end of May, when surface temperatures approached 15ºC, and the rates approached zero around the beginning of July 2001 when temperatures approached 19ºC (Figure 3-40). This result suggests that use of the smolt flumes may have little benefit for smolt passage as the upper temperature threshold is approached.

4.3 INFLUENCE OF LOCK OPERATIONS ON PASSAGE AND ESTUARINE TRANSITION

There are several features of lock construction or operation that are suggested by the 2001 PIT tag data to influence downstream passage that are evaluated below. The data further indicate that there are seasonal and diurnal environmental and operational features that result in changes in passage behavior.

The similarity in numbers using both gates when all four flumes are operational suggests that there may not be a nearshore route preference of outmigrants. This possibility was raised in the 2000 study, but it was also suggested at that time that the results might reflect instead attraction flow near the gate entrances (DeVries 2001). In addition to the similar proportions detected in each gate while all four flumes were operational (reported above), a calculation of numbers of smolts per unit volume of water passed through each flume in 2001 also supports this hypothesis. Figure 4-3 depicts the daily passage rates per unit discharge of each species in each flume and tagging location for the study period. Flume 5C generally passed the most chinook and sockeye

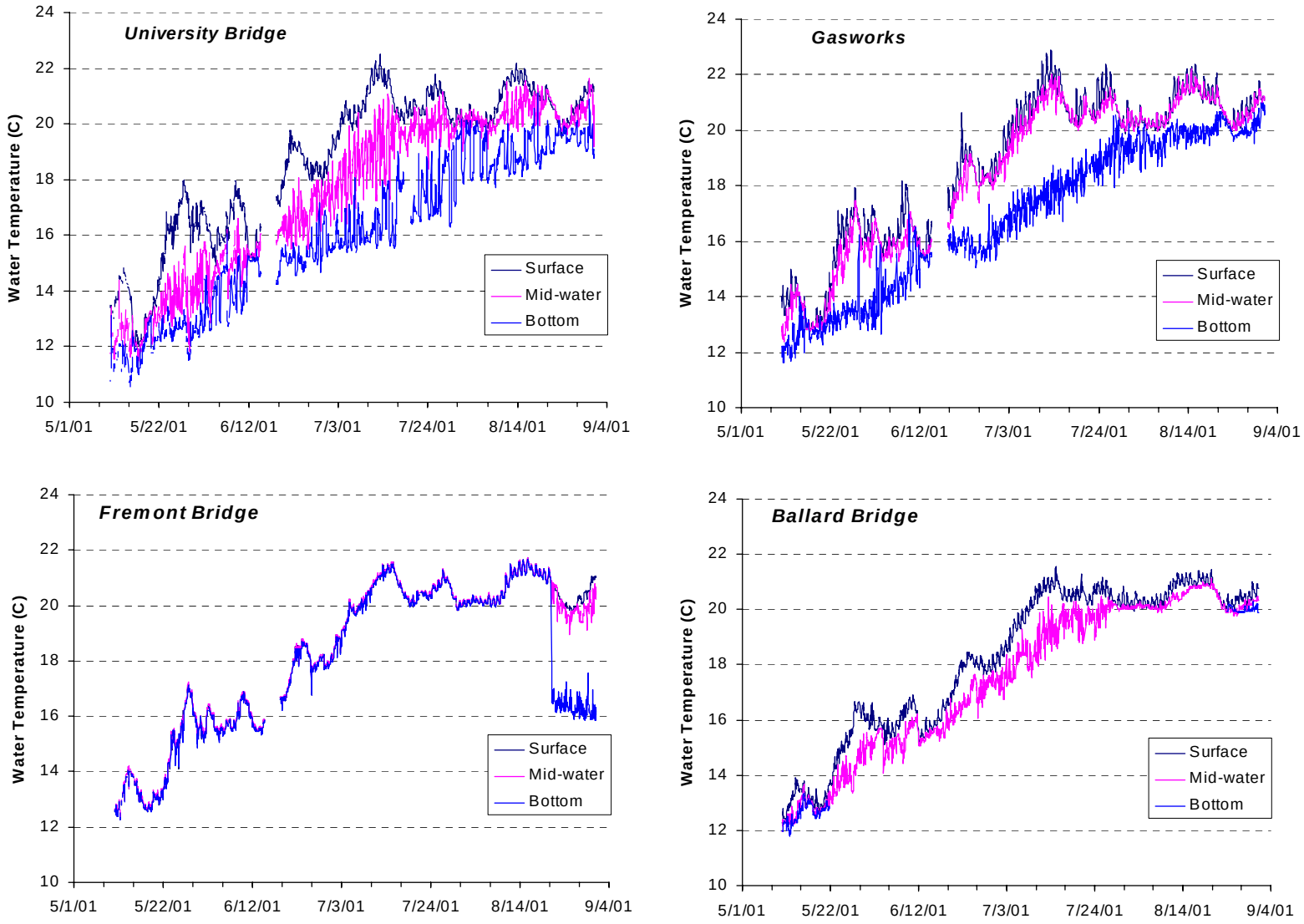


Figure 4-1. Temporal variation in water temperatures measured in the LWSC during the 2001 Lake Washington GI study.

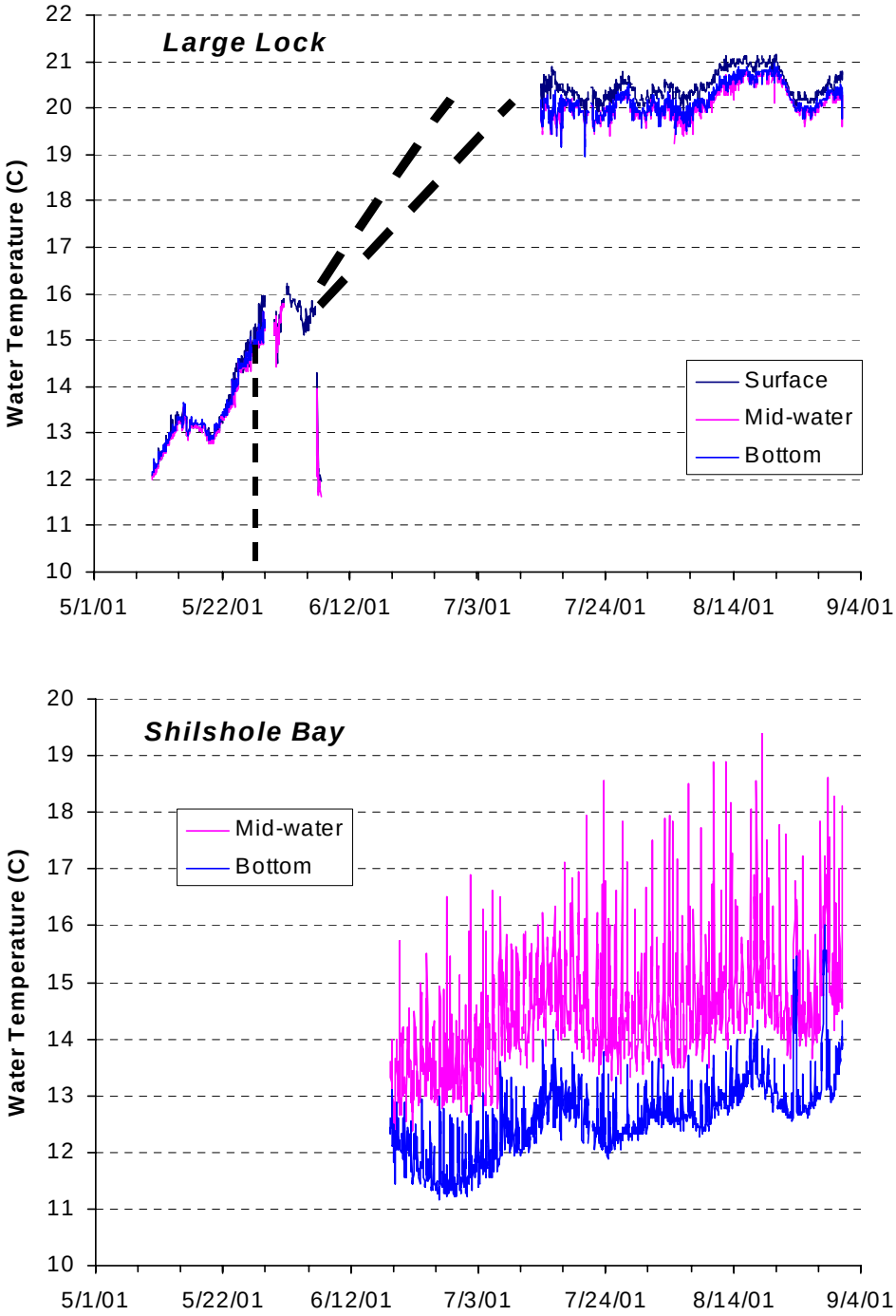


Figure 4-2. Temporal variation in water temperatures measured in the large lock (top) and immediately below the Locks (bottom) during the 2001 Lake Washington GI study. The thick, diagonal dashed lines indicate the likely range of temperatures during a data gap, based on the measurements depicted in Figure 4-1. The vertical dashed line indicates the approximate date when surface water temperatures exceeded the upper preferred temperature for juvenile salmon (15ºC; ODEQ 1995; McCullough 1999).

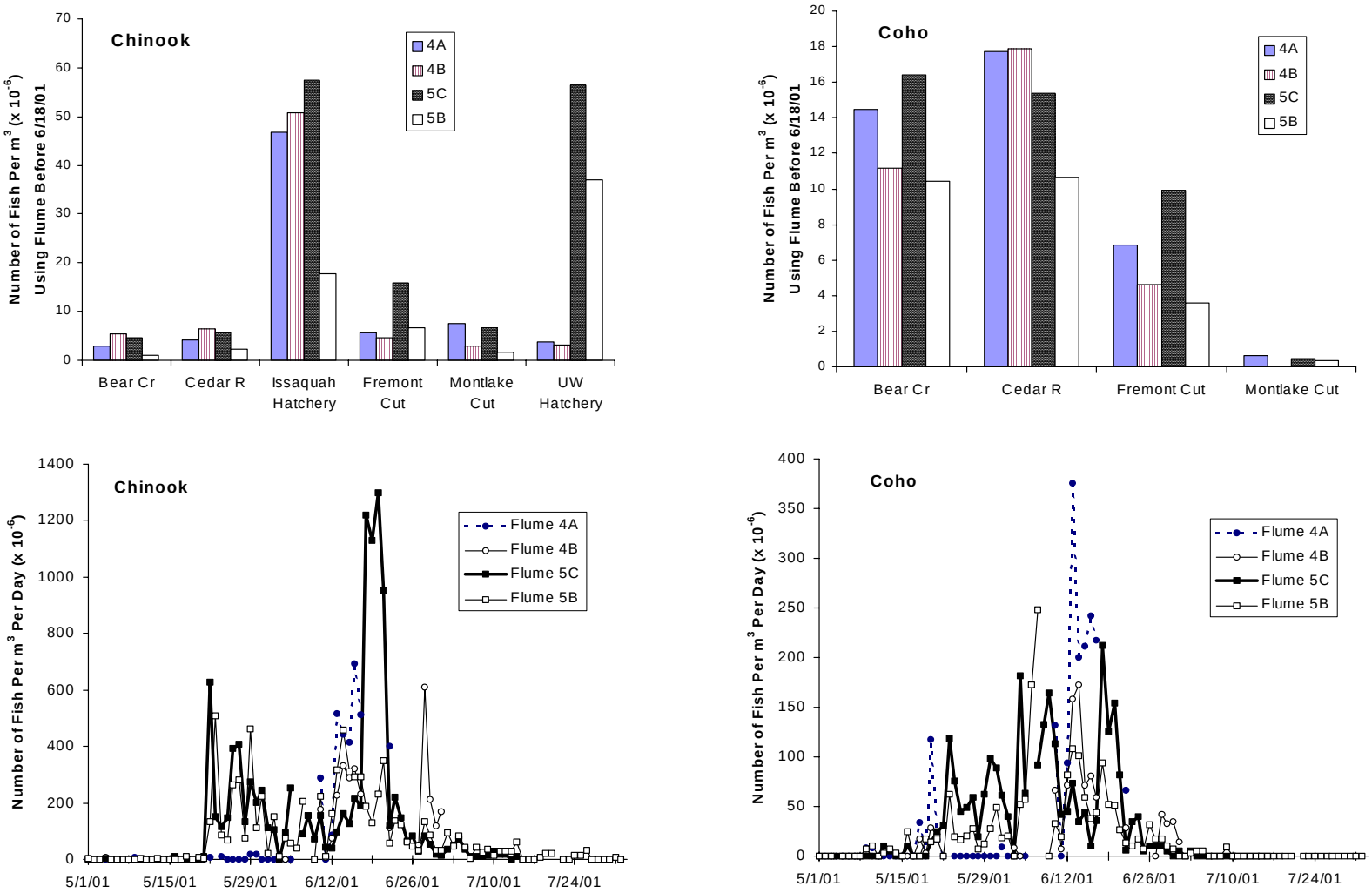
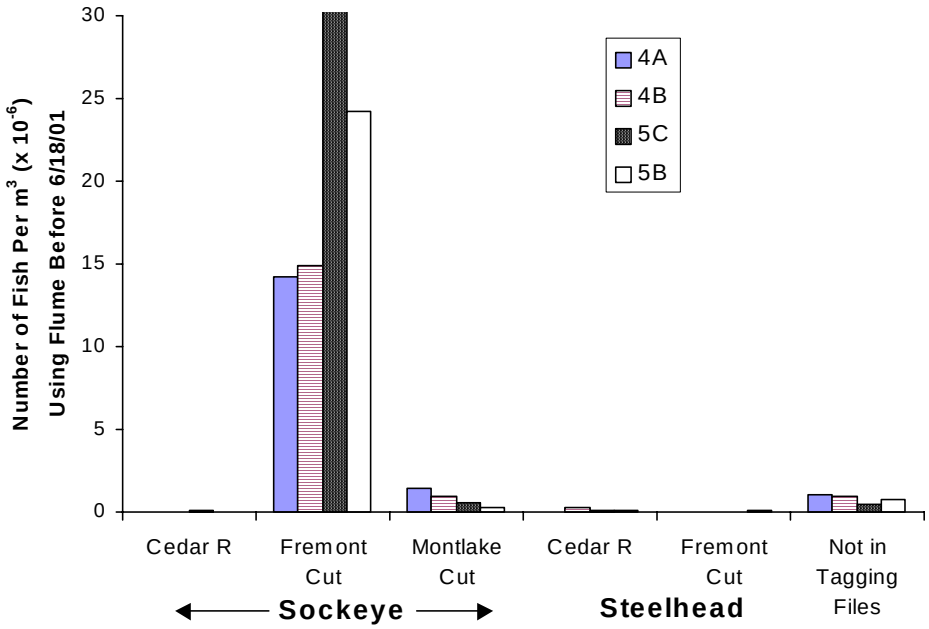


Figure 4-3. Number of PIT tagged salmon passing through each flume normalized to unit discharge, by release location before June 18, 2001 while all four flumes were generally operational (top; see Figure 3-1 for periods of operation), and over the outmigration period (bottom), 2001 Lake Washington GI study.



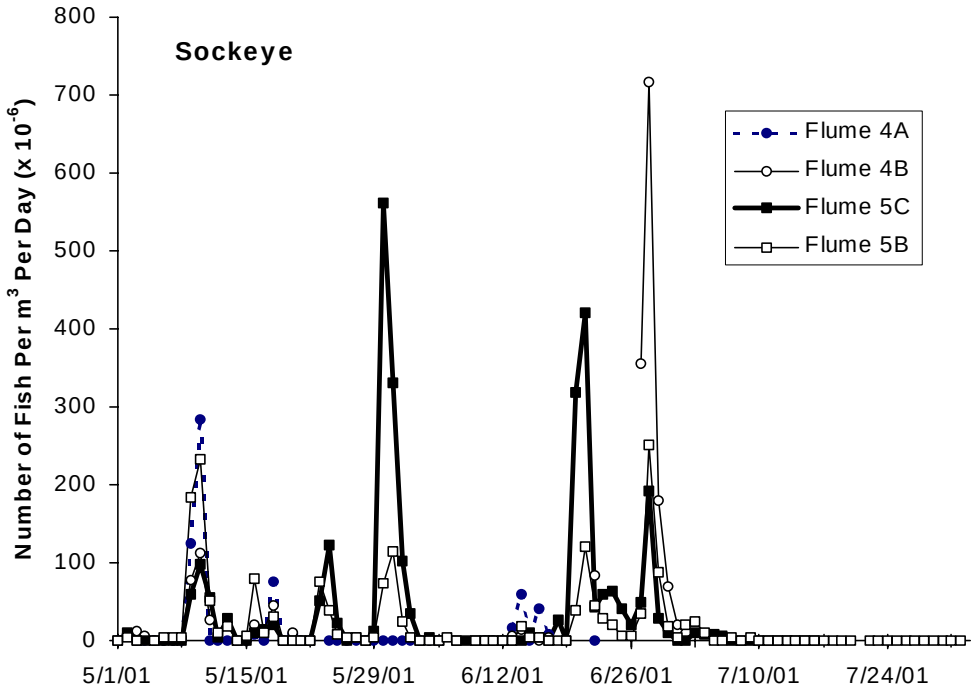


Figure 4-3 cont Number of PIT tagged salmon passing through each flume normalized to unit discharge, by release location before June 18, 2001 while all four flumes were generally operational (top; see Figure 3-1 for periods of operation), and over the outmigration period (bottom), 2001 Lake Washington GI study.

per unit discharge, but this appears to be associated with simultaneous operation of Flume 5B. Results were mixed for coho. Of special note, the UW hatchery chinook appeared to show a strong preference for gate 5 (Figure 4-3). This may have been because Flume 4B was shut down for most of the time that this group passed the Locks, and Flume 4A presented relatively little attraction flow. Hence, while the smaller flumes appear to pass proportionally more fish per unit discharge than the large flumes, their success may be dependent on the total attraction flow rate through the gate. Because the flow fields in the two spill gates appear to be relatively independent of one another, the total flow entering a gate appears to be an important influence on successful use of the smolt flumes. This is consistent with other data suggesting increased passage rates with increased spill through gate 2 (BioSonics, Inc. 2001).

4.3.1 Influence on Juveniles Located Below the Locks

As in 2000, the tunnel detector and large lock purse seining data from 2001 indicate that some fish recycled through the Locks. It is unknown whether this was because (i) fish were entrained during lock openings and became disoriented, (ii) some fish that passed through the flumes were not completely smolt-ready and thus actively avoided more saline water by swimming upstream through the Locks in the less saline lens, or (iii) fish were swimming about in pseudo-random movements that were directed on average in the upstream direction.

The influence of entrainment into the large lock is difficult to evaluate because of the physics involved. As the lower gate is opened, a saline wedge intrudes near the bottom into the large lock chamber, resulting in downstream displacement of a surface lens of the relatively well-mixed, but less saline water initially present in the lock chamber (Lingel 1997). If juvenile salmonids are entrained physically from downstream, they would thus have to be present primarily within the deeper, more saline water that moves upstream. Fish present nearer the surface would tend to be moved in the downstream direction because of the density currents (Lingel 1997). Alternatively, if juveniles were seeking fresher water, they would initially have to swim upstream against the surface discharge of less saline water. Once inside the chamber, the same process is repeated when the upper gate is opened. Hence, if fish are indeed entrained in the upstream direction to above the Locks, they would have to be consistently within the deeper parts of the water column. Underwater video data and visual observations suggest that salmonid smolts are surface oriented in the vicinity of the Locks structures, while acoustic data show that surface-oriented aggregations, when entrained through filling culverts into the large lock chamber, resume their surface orientation within minutes (J. Dawson, BioSonics Inc., personal communication). These observations are consistent with the findings of Schreck et al.

(2000), who determined that fish in the Columbia River estuary held within the upper 4 m of the water column, in fresher water as they made the transition to saltwater. This type of smolt behavior may reduce the likelihood of physical entrainment in the upstream direction during gate opening operations. In addition, Johnson et al. (2001) determined that fish near the entrance to the large lock filling culvert entrance were distributed in two distinct groups, one near the bottom and one near the surface. Although species in each group were not determined, the composition likely reflects vertical salinity differences with downstream migrant smolts remaining in the upper freshwater layer when the upper gates are opened.

Smolts that may be entrained upstream in the saltwater wedge and re-exposed to lake water may be able to similarly withstand the transition (particularly chum and coho salmon; Clarke and Hirano 1995), but the physiological costs and resulting stress levels have not been determined in the case of the Locks. This would need to be addressed, for example, if it were determined that saltwater-acclimated smolts were entrained upstream in the deeper, more saline layer.

The trend depicted in Figure 3-33 of shorter recycling interval as the spring outmigration season progresses suggests that an avoidance of more saline water may be plausible in the case of some fish. These fish would have to either initially swim upstream in the surface layer outflow when the gates are opened, or have a non-random tendency to swim upstream into the lock chamber when the density currents have subsided, prior to closing of the gate. We do not know the answer to this presently.

Water quality profile data collected below the Locks by C. Simenstad and W. Couch of the University of Washington in 1999, and by D. Houck of King County/Metro in 2000 and 2001 indicate that there is a low-salinity lens in roughly the upper 1 to 3 meters of the water surface that is less than 20 ppt in concentration. This lens sometimes extends out to the railroad bridge and beyond depending on discharge at the Locks and tide. Table 3-5 suggests that a rapid osmotic transition had occurred in many of the juveniles captured in the beach seine samples in the inner bay area, where salinities nearer the surface are on the order of 15-20 ppt during the spring outflow months. Juvenile and fry chinook salmon are capable of sudden transitions from freshwater to water with salinities as high as 16 to 20 ppt without apparent adverse survival effects (Macdonald et al. 1988; Healey 1991; Clarke and Hirano 1995; Kreeger 1995). However, tolerance of even 30 ppt has been noted to not be an adequate criterion for identifying smolts (Clarke and Hirano 1995), and thus it is possible that the relatively quick transition may still be stressful (Macdonald et al. 1988). The possibility also exists for increased delayed mortality in saltwater after the transition, associated with scale loss when water temperatures in the LWSC

increase to stressful levels during the outmigration season (Clarke and Shelbourne 1985). Blood chemistry sampling of PIT tagged fish passing through the flumes and caught in the beach seine samples would provide more direct evidence of physiological stress and smolt readiness. In any case, the PIT tag data suggest that the downstream migrants spend relatively little time in the lower salinity lens below the Locks before making the transition to higher salinity water. They may thus spend relatively little time in an 'estuarine' setting with salinities below 10 ppt, unless they first spend some time in the saltwater wedge above the Locks. Available hydroacoustic data indicate that some smolts are distributed within this more saline zone above the Locks (Johnson et al. 2001; P. Johnson, pers. comm.). It is thus possible that a subset of the total outmigrant population acclimatizes to high salinity water before passing the Locks.

What also remains unknown is whether fish that make the transition are more susceptible to avian or other forms of predation during that short period while they are confined to the relatively small freshwater area below the Locks. Macdonald et al. (1988) noted this to be a problem for fish that were released directly in water with salinity greater than 11 ppt, suggesting a similar problem may exist for juveniles passing the Locks. This is the subject of work conducted by the MIT (Footen 2000).

4.3.2 Influence on Juveniles Located Above the Locks

Another behavioral influence of large and small lock operations is suggested by the PIT tag data regarding the movement of juveniles located above the Locks. As in 2000, the PIT tag data for 2001 suggest that filling operations of the small and large locks may influence passage timing through the flumes through transient changes in velocity patterns that occur in the forebay area. Responses by smolts to temporal and spatial changes in velocity have been noted elsewhere (e.g., in the Stanislaus River by Cramer and Demko 1993; in the Columbia River by Johnson et al. 2000). Juveniles may be induced to swim more actively in the forebay in response to unsteady flows when local currents increase temporarily while the large or small locks are filling. Increased swimming activity may increase the probability that outmigrants encounter the smolt flume entrances, with increased probability of passage.

4.3.3 Suggested Changes in Operations

Only two changes to flume operations are suggested by the data presently. Because nearly all of the PIT tagged fish passed through during daylight hours in both 2000 and 2001, the flumes could be shut off at night to conserve water so that they can be open to passage for a longer

period during the smolt migration season, possibly through the end of July. The PIT tag data suggest that more than 90% of the tagged fish passed through the flumes between daybreak and dusk in May and June. A similar trend was noted in 2000, through both the flumes (DeVries 2001) and spill gate #2 (BioSonics, Inc. 2001). The reason for this is unknown, but may be related to the frequency that the small and large locks are filled. Figures 3-35 and 3-36 suggest that a passage response exists with respect to lock filling. Figure 4-4 indicates that the frequency distributions for small lock filling times and smolt flume passage times are relatively similar (cf. Figure 3-29). The greater proportion of passage during the morning hours compared with the afternoon could reflect fish that arrive overnight and are waiting for passage cues. The large lock appears to have had a smaller influence than the small lock as its fill time distribution is more uniform (Figure 4-4). Since small and large lock fill times reflect use patterns that are unlikely to change, shutting the flumes down at night would help address water conservation needs for improving smolt passage at the Locks, a significant problem identified by USACE (1998).

A potential, adverse side effect that may need to be investigated, however, is related to the reduction in freshwater discharge and the corresponding effect on the spatial extent of the low salinity lens below the Locks during the night. Preliminary salinity data collected by King County in the spillway tailrace area indicate that the freshwater lens there may be reduced considerably in surface area and depth when the flumes are not operating, depending on tide. This could make the smolts more susceptible to piscine or avian predation if it is determined that they remain in the immediate vicinity of the tailrace area within the freshwater lens for an extended period (which seems unlikely based on the salt water recapture data), and are thus concentrated within a smaller area while they are making the transition to saltwater. This depends, of course, on whether significant predation occurs at night (night lighting in the area could conceivably facilitate this). In addition, avian predation has generally been observed immediately below the Locks during low tide, which is the time with the greatest freshwater lens (D. Houck, pers. comm.). It is not clear if this is thus an issue and is raised here strictly as a hypothesis. At this time, there is insufficient evidence to suggest the need for night spill in this context.

The second change suggested by the 2001 data is that the flumes could potentially be shut down for the season when surface water temperatures in the LWSC in the vicinity of the Locks reach 19ºC. The route of passage appears to shift to deeper alternatives, with few fish using the flumes after that temperature threshold is reached.

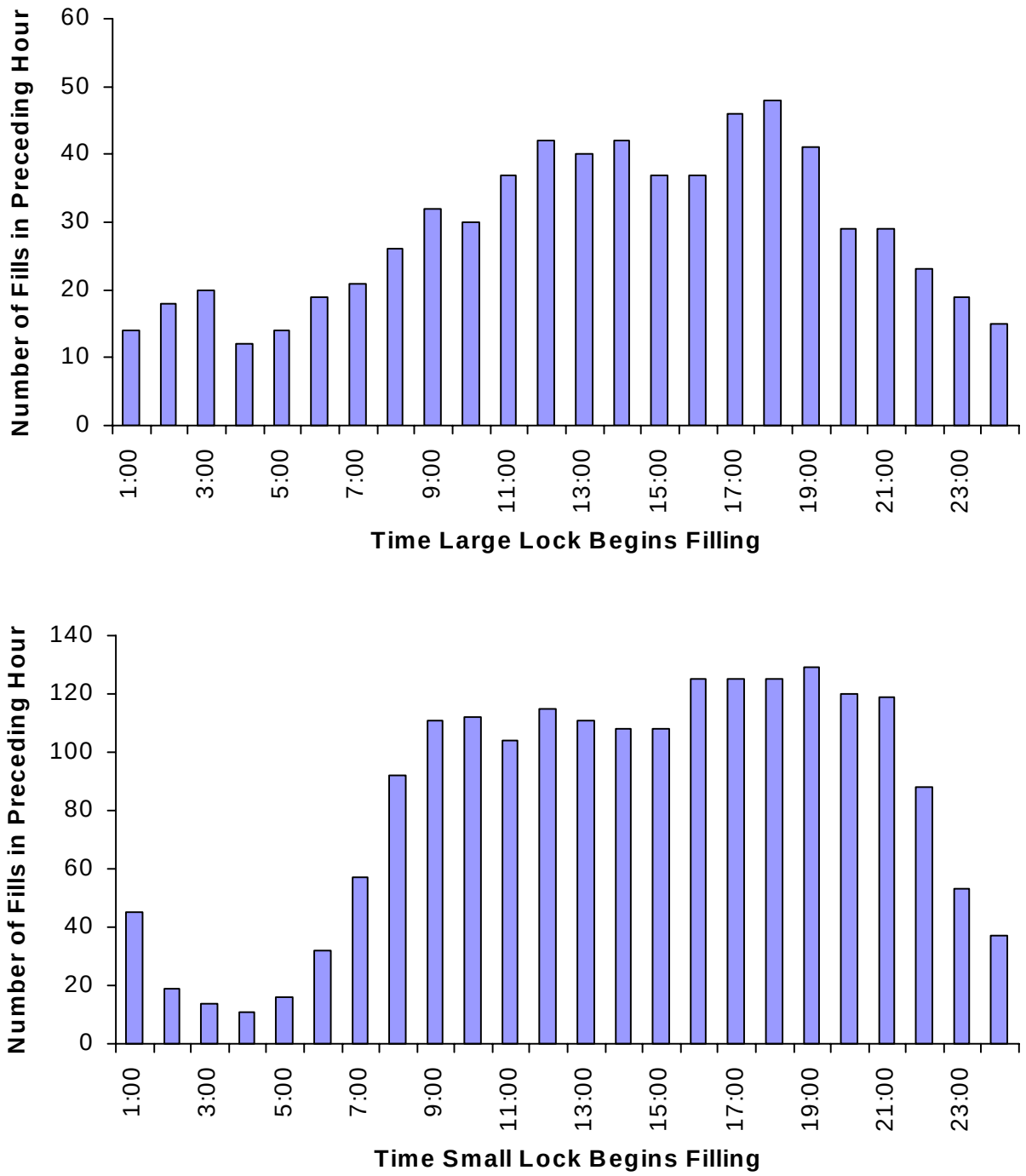


Figure 4-4. Diurnal variation in times at which the large (top) and small (bottom) Locks began to fill during the PIT tag study period of May 1 through July 14, 2001 Lake Washington GI study.

Other than possibly increasing attraction flows to the entrance of the smolt flumes (which could also increase the area of the mixing zone in the spillway tailrace), no changes to lock operations were suggested by the PIT tag data at this time. However, because there appears to be an influence of lock filling operations on smolt passage through the flumes, a possible future investigation would involve assessing systems that guide smolts to the flumes when the Locks are filling through their culvert intakes, and the effects of attraction flows. Recent work on the Columbia River system should provide an indication of whether appropriate structural measures would be technically feasible. The investigation should at the same time determine and compare the proportions of fish entering the large and small locks when the gates are opened to the numbers passing through the smolt flumes to determine whether guidance measures in particular would be expected to improve flume passage numbers measurably and economically.

4.4 FUTURE STUDY RECOMMENDATIONS

The following possible changes to study design are suggested on the basis of the data collected this year, and accompanying justifications are given:

- The vibration problem associated with the tunnel readers needs to be corrected additionally for the large flumes (4B and 5B). Detection efficiencies improved markedly over those experienced in 2000 as a result of the structural modifications applied in 2001, but it is important to continue working toward increasing the detection efficiency to above 95% as much as possible to reduce this source of variation to a negligible level. One possibility is to experiment with hydraulics within the flumes to reduce pulsing and smooth out the water surface within the tunnel readers and the flume flow lines.

- Calibration testing should continue with both tagged fish and the "fish sticks." Although the sticks perform well, it was determined during the 2001 study that the 0° sticks may slightly over-estimate detection efficiency for live fish. The 45° sticks appear to be more realistic, but may also slightly underestimate efficiency. Additional data are needed to further refine the calibration relation between the respective detection efficiencies.

- Fish should be tagged again in similar numbers at the Issaquah Hatchery and released from there directly into the stream to evaluate the high survival through Lake Sammamish suggested by the 2001 data. Tagging should also be performed at the Bear Creek and Cedar River screw traps between early May and early July to duplicate the results of this year's study regarding temporal variation in the proportion using the smolt flumes.

- If possible, purse seining and PIT tagging should be continued in Lake Union and in the vicinity of the Montlake Cut, to evaluate survival increments over different segments of the migration route. In contrast to 2000 when there were disease problems, the 2001 data suggest negligible mortality occurred in the LWSC. Further study would be useful for evaluating factors of decline in the LWSC.

- Beach seining for PIT tagged fish should focus on the inner bay and railroad bridge area, and not in the outer bay area, and be conducted more frequently to increase the catch numbers of PIT tagged fish. This is a critical component of the study, particularly with respect to estimating the proportion of fish using the flumes compared with other routes. In order to increase sampling effort and capture rate in the inner bay/railroad bridge area, purse seining should also be evaluated for feasibility and effectiveness. However, there is a risk that an insufficient number of recoveries will be made to determine the proportion using the flumes to a desired level of precision, and that more intensive sampling during the peak outmigration period may result in harming too many ESA-listed juvenile chinook salmon. A possible resolution to this problem would be to use an open-ended tow net fitted with a submersible PIT tag detector, where fish would be concentrated and pass through the detector with much lower potential for adverse effects. The feasibility of this would depend on the general absence of obstructions and “snags,” and the robustness of the detector in the saltwater environment.

- If beach seining is continued below the Locks, control groups of PIT tagged fish should be released at the downstream base of the spillway dam, per study designs discussed by Burnham et al. (1987). This would result in better estimates of the proportion of fish using the flumes (P_{SF}) and survival. These groups are required because beach seine capture efficiency is also unknown and needs to be estimated in order to estimate the other parameters. However, substantially increased capture effort would be required below the Locks than occurred in 2000, to increase the recapture sample size. Figure 4-5 depicts the estimated sample size of PIT tag recaptures below the docks associated with a range of precision about the estimate of P_{SF}. The numbers and curve trend in the figure are generally representative for a range of release group sizes, survival to the Locks, and proportion using the flumes. Although the capture efficiency is unknown, the required sampling effort can be determined indirectly using the graph by noting that no more than 2 fish from a weekly release group (e.g., Bear Creek, Lake Union; not including calibration fish) were caught during the June 18-19 and 21-22 "blitz" sampling in 2001. Based on the typical range of weekly release numbers during the peak chinook outmigration (~100-500/week/location), about 40 PIT tagged fish would need to be caught from a given weekly release to know with about 95% confidence that the proportion using the flumes is X% $\forall$ 15% (absolute value). This corresponds to increasing the sampling effort up to 20-fold to get 40 tagged fish from a given weekly

release group. This estimate differs from the effort increase suggested in the first year's report (DeVries 2001), which was based in part on lumping the entire passage season together. In addition, sampling would need to account for the apparent seasonal change in proportion using the flumes in order to evaluate survivals.

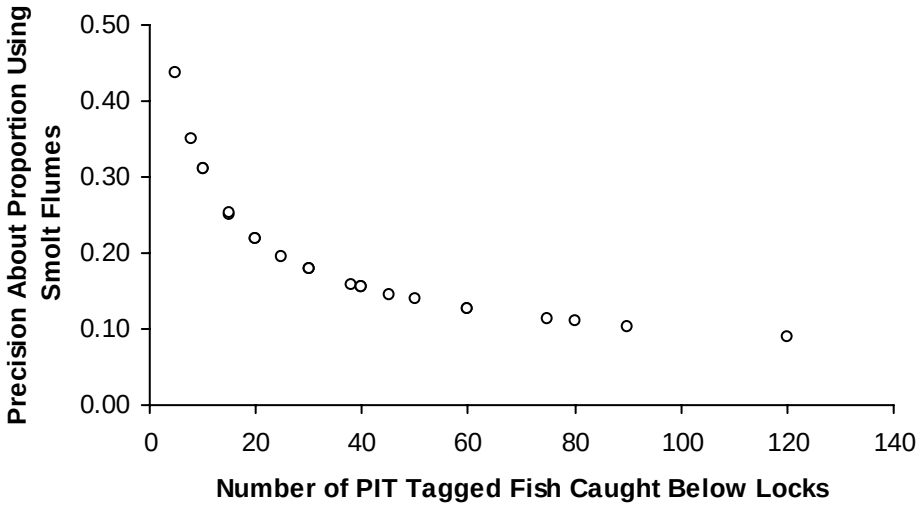


Figure 4-5. Variation in the approximate precision about the estimated proportion using the smolt flumes at the Locks, with numbers of PIT tagged fish recaptured by beach seining in Shilshole Bay.

- Purse seining could be conducted in the large lock and small lock to determine the proportion of PIT tagged fish passing through each, as well as provide better information on recycling patterns through the Locks. Because less water is used to fill the small lock than the large lock, it is possible that relatively less effort could be expended in the former. However, the data would only re-confirm that recycling takes place, which appears to be determined more thoroughly based on the tunnel reader detections. Much greater sampling effort would likely be needed if the data from the two locks were to be used to determine the proportion of tagged fish using that route.

- Sampling could also be conducted periodically in the fish ladder for PIT tagged fish. It is possible to construct a downstream migrant trap from which juveniles can be removed and scanned for PIT tags, although such a trap is time consuming to operate (D. Seiler, pers. comm.) and may interfere with upstream adult migration (E. Warner, pers. comm.). Planned construction of a PIT tag detector for returning adults would also be useful for monitoring smolts in subsequent years.

- Further tagging of UW hatchery chinook is not recommended because their migration and passage behaviors are so different from the other study groups.

- Fish should be held at the Metro Laboratory in 2002 for two purposes: (1) calibration testing, and (2) for release in the LWSC to evaluate shoreline affinity and effects on the proportion using the smolt flumes. Equal number groups should be released on the north and south shores, at different locations in the LWSC. It would be preferable to do this during the third week in June when the peak chinook outmigration is occurring. However, it will be necessary to hold the fish at the Lab at temperatures that are equal to or near the temperatures in the LWSC so that the fish are not thermally stressed upon release. Therefore, the fish should be held as long as possible, and released well before temperatures reach 19ºC (e.g., at 17ºC, which is the midpoint between the two thresholds evaluated here), and before disease or stress become a significant problem (but as close to the middle of June as possible).

- The blood of subsamples of PIT tagged fish passing through the flumes and caught in the beach seining should be tested for stress and signs of osmotic change or smolt readiness. This information is important for evaluating the effects of the Locks with respect to the relatively sudden transition to saltwater. Both smolt readiness (e.g., gill ATP-ase, sodium levels) and stress (e.g., plasma cortisol) measures would be required to determine if the fish caught in the beach seine samples were experiencing stress from rapid transition to saltwater because they were not completely ready to do.

5. REFERENCES

BioSonics, Inc. 2001. Acoustic and video measurements of fish passage at the Hiram M. Chittenden Locks: A year 2000 focus on the salt water drain and spill bay #2. Report prepared for USACE Seattle District. Seattle WA. March.

Brege, D.A., R.F. Absolon, and R.J. Graves. 1996. Seasonal and diel passage of juvenile salmonids at John Day Dam on the Columbia River. N. Am. J. Fish. Manag. 14: 659-665.

Burnham, K.P., D.R. Anderson, G.C. White, C. Brownie, and K.H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. Am. Fish. Soc. Mono. 5. Bethesda, MD.

Clarke, W.C., and J.E. Shelbourne. 1985. Growth and development of seawater adaptability by juvenile fall chinook salmon (*Oncorhynchus tshawytscha*) in relation to temperature. Aquaculture 45: 21-31.

Clarke, W.C., and T. Hirano. 1995. Osmoregulation. Pages 319-377 *in* Groot, C., L. Margolis, and W.C. Clarke, editors. Physiological ecology of Pacific salmon. UBC Press, Vancouver, B.C.

Cramer, S. P., and D. Demko. 1993. Effects of pulse flows on juvenile chinook migration in the Stanislaus River. Final Report to Tri-Dam, Pinecrest, CA.

Dauble, D.D., J. Skalski, A. Hoffman, and A.E. Giorgi. 1993. Evaluation and application of statistical methods for estimating smolt survival. Bonneville Power Administration, Contract No. DE-AI79-90BP62611, Project No. 86-118.

DeVries, P. 2001. PIT tagging of juvenile salmon smolts in the Lake Washington basin: Year 2000 pilot study results. Report prepared for USACE Seattle District. R2 Resource Consultants, Inc. Redmond, WA. April.

Footen, B. 2000. Preliminary results of an investigation into the impacts of piscivorous predation on juvenile chinook (*Oncorhynchus tshawytscha*) and other salmonids in Salmon and Shilshole Bays, King Co. WA. Draft report, Muckleshoot Indian Tribe. Auburn WA.

Goetz, F.A., D. Seiler, and P.N. Johnson. *In Preparation*. Summary of juvenile fish passage investigations at the Hiram M. Chittenden Locks: 1996-2000. Report to the Lake Washington Ecological Studies Group, Seattle, WA.

Healey, M.C. 1991. Life history of chinook salmon (*Oncorhynchus tshawytscha*). Pages 313-393 *in* Groot, C., and L. Margolis, editors. Pacific salmon life histories. UBC Press, Univ. Brit. Col. Vancouver Canada.

Iwamoto, R.N., and seven others. 1994. Survival estimates for the passage of juvenile chinook salmon through Snake River dams and reservoirs. Bonneville Power Administration, Contract No. DE-AI79-93BP10891, Project No. 93-29.

Jeanes, E.D., and P.J. Hilgert. 2002. Juvenile salmonid use of created stream habitats. Sammamish River, Washington. Report prepared for U.S. Army Corp of Engineers, Seattle District. R2 Resource Consultants, Inc. February.

Johnson, G.,J. Hedgepeth, A. Giorgi, and J. Skalski. 2000. Evaluation of smolt movements using an active fish tracking sonar at the sluiceway surface bypass, the Dalles Dam, 2000. Presented at Portland and Walla Walla Districts' Anadromous Fish Evaluation Program Annual Research Review, Nov. 13-16. Portland OR.

Johnson, P.N., F.A Goetz, M.E. Hanks, and G.R. Ploskey. 2001. Fish passage investigations at the Hiram M. Chittenden Locks, Seattle, WA in 2000. Draft Tech. Report prepared for USACE Seattle District. Waterways Experiment Station. March.

Kreeger, K.Y. 1995. Differences in the onset of salinity tolerance between juvenile chinook salmon from two coastal Oregon river systems. Can. J. Fish. Aquat. Sci. 52: 623-630.

Lingel, S.L. 1997. Scaling effects on the mixing processes of lock-exchange gravity currents. Ph.D. dissertation, Univ. of Washington, Seattle.

Macdonald, J.S., C.D. Levings, C.D. McAllister, U.H.M. Fagerlund, and J.R. McBride. 1988. A field experiment to test the importance of estuaries for chinook salmon (*Oncorhynchus tshawytscha*) survival: Short-term results. Can. J. Fish. Aquat. Sci. 45: 1366-1377.

McCullough, D.A. 1999. A review and synthesis of effects of alterations to the water temperature regime on freshwater life stages of salmonids, with special reference to chinook salmon. EPA Region 10, Water Resources Assessment, EPA 910-R-99-010.

Oregon Department of Environmental Quality (ODEQ). 1995. 1992-1994 water quality standards review. Portland, OR.

Prentice, E.F., T.A. Flagg, and C.S. McCutcheon. 1990a. Feasibility of using implantible passive integrated transponder (PIT) tags in salmonids. Pages 317-322 *in* Parker, N.C., and five others, editors. Fish marking techniques. Am. Fish. Soc. Spec. Symp. 7. Bethesda, MD.

Prentice, E.F., T.A. Flagg, C.S. McCutcheon, and D.F. Brastow. 1990b. PIT-tag monitoring systems for hydroelectric dams and fish hatcheries. Pages 323-334 *in* Parker, N.C., and five others, editors. Fish marking techniques. Am. Fish. Soc. Spec. Symp. 7. Bethesda, MD.

Prentice, E.F., T.A. Flagg, C.S. McCutcheon, D.F. Brastow, and D.C. Cross. 1990c. Equipment, methods, and an automated data-entry station for PIT-tagging. Pages 335-340 *in* Parker, N.C., and five others, editors. Fish marking techniques. Am. Fish. Soc. Spec. Symp. 7. Bethesda, MD.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Bd. Can. No. 191. Ottawa.

Thedinga, J.F., M.L. Murphy, S.W. Johnson, J.M. Lorenz, and K.V. Koski. 1996. Determination of salmonid smolt yield with rotary-screw traps in the Situk River, Alaska, to predict effects of glacial flooding. N. Am. J. Fish. Manag. 14: 837-851.

U.S. Army Corps of Engineers (USACE). 1998. Lake Washington Section 216 water conservation/basin restoration study: Preliminary 905(b) analysis. Seattle, WA. June.

U.S. Army Corps of Engineers (USACE). 1999. Lake Washington Ship Canal Smolt Passage Section 1135 Restoration Project, Seattle, Washington: Ecosystem restoration report/Environmental Assessment and technical appendices. Final Report. August.

Zar, J.H. 1984. Biostatistical analysis. 2nd Ed. Prentice-Hall Inc., Englewood Cliffs, N.J.