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PIT Tagging of Juvenile Salmon Smolts in the Lake Washington Basin: Third Year (2002) Pilot Study Results

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

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PIT Tagging of Juvenile Salmon Smolts in the Lake Washington Basin: Third Year (2002) Pilot Study Results

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ABSTRACT

This third and final year pilot study under the Lake Washington GI continued the evaluation of the feasibility of using Passive Integrated Transponder (PIT) tag technology to monitor smolt migration and survival characteristics as they pass through the Lake Washington Ship Canal (LWSC) system, including the Hiram M. Chittenden Locks (Locks). Four smolt flumes and PIT tag detection devices (tunnel readers) were installed over the spillway dam of the Locks to monitor outmigration during the spring of 2002. Juvenile chinook and coho salmon were captured, tagged and released in the lower reaches of the Cedar River and Bear Creek. A few steelhead juveniles were also captured, tagged, and released. Hatchery-reared chinook were tagged, held, and released at the Issaquah Creek Hatchery and the University of Washington Hatchery. Calibration tests were performed using tagged hatchery chinook juveniles to evaluate the detection efficiency of the tunnel readers. Hatchery chinook were also used to evaluate shoreline affinity in the LWSC. Fewer problems were encountered this year as a result of learning from the first two years of study. The most significant problem that was not completely resolved involved structural features of the flumes reducing the detection efficiency of the tunnel readers, and the absence of complete coverage of PIT tagged fish passing the Locks through other routes. Nevertheless, the data provided valuable, detailed biological information for a third, consecutive year on migration and passage behavior of salmon smolts originating from different parts of the Lake Washington basin and transitioning to adult life in saltwater. The data included seasonal and diurnal migration and passage timing, passage routes through the Locks, and further evidence of repeat cycling through the Locks. Passage rates were compared with flume discharge with the goal of determining optimal water allocation to the flumes. The data were also used to evaluate survival for different portions of the migration route, although the precision of the estimates was poor because of variable detection rates at the Locks on both a daily and seasonal basis, and the small number of release locations. Hatchery chinook were found to not exhibit shoreline affinity in the LWSC and appeared to mix thoroughly. A small number of chinook, coho, and sockeye juveniles tagged in 2001 came through the Locks in 2002, as did one Issaquah Creek chinook tagged in 2000. Water temperature in the LWSC and lunar phase appeared to influence outmigration characteristics. This information can be used for shaping spill timing and volume requirements at the Locks, and for evaluating causal mechanisms of decline. Study implications and improvements are suggested.

ACKNOWLEDGEMENTS

This study was part of the Lake Washington General Investigation (LWGI) Study with funding provided by Seattle Public Utilities, King County Metro and the U.S. Army Corps of Engineers (USACE), Seattle District. Project managers for the respective funding institutions are: Linda Smith, Project Manager, LWGI Section 1135 Study, and Fred Goetz, PIT Tag Study Project Manager, USACE; Doug Houck, King County/Metro; and Keith Kurko and Gail Arnold, Seattle Public Utilities. A large number of persons contributed significantly to study design and implementation, including: Kurt Fresh, NOAA Fisheries (formerly at Washington Department of Fish and Wildlife, WDFW) and Chris Waldbillig, WDFW, transported hatchery test fish from the Issaquah Creek Hatchery to the King County/Metro Environmental Laboratory; Francis Sweeney, and Gary Yoshida provided holding facilities and took care of fish at the King County-Metro Environmental Laboratory; Dave Seiler, WDFW, team leader for the multi-year study of smolt trapping in Lake Washington tributaries; Scott McCutcheon of Biomark, Inc., and Jim Sadler, USACE provided assistance with tagging fish or troubleshooting PIT tag tagging and detection equipment; Lindsey Fleischer, WDFW, was responsible for tagging fish caught in the tributary screw traps; Kyle Bouchard and Peter Johnson, MevaTec/USACE Waterways Experiment Station, provided tunnel reader data on a daily basis and were on site to monitor the equipment, and provided general support at the Locks; and Chuck Ebel, John Post, Bill Livermore, and Jeff Dillon, USACE, responsible for structural design and implementation of smolt flume facilities and provided assistance in other aspects of the study.

1. INTRODUCTION

The Hiram M. Chittenden Locks (Locks; also known as the Ballard Locks) were constructed by the Seattle District, U.S. Army Corps of Engineers (USACE) as part of the Lake Washington Ship Canal (LWSC) project between 1911 and 1916 to provide for navigation between Lake Washington and Puget Sound (Figure 1-1). The LWSC is approximately 14 km (8.6 miles) long and lies entirely within the boundaries of the city of Seattle. The project was authorized by Public Law 61-264, River and Harbor Act of 25 June 1910, in the First Session of the 60th Congress in accordance with a plan set forth in House Document 953. The Montlake Cut, which extends between Lake Washington and Lake Union, was the final link in the route and was completed in 1917. Official dedication of the Locks project occurred on July 4, 1917. Other related activities that occurred around the same time included closure of the historic outflow of Lake Washington into the Black River in 1912 and concomitant rerouting of the Cedar River into the lake. Although the Locks have since undergone several structural modifications and improvements including construction of a saltwater intrusion barrier in 1966 and a new fish ladder in 1976, the entire LWSC project has effectively influenced anadromous fish passage and migration from the time they were constructed through to the present day.

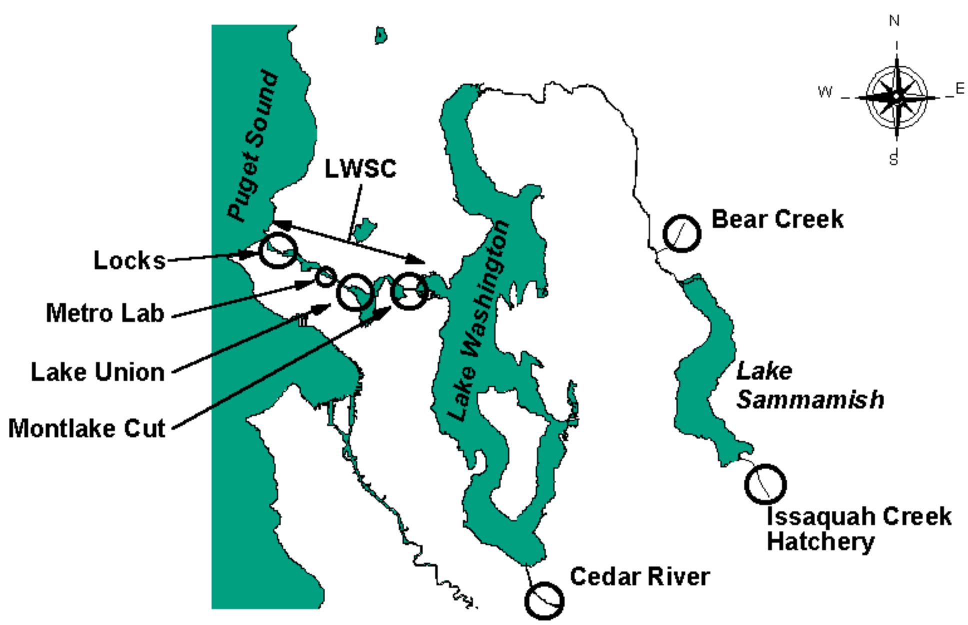


Figure 1-1. Locations of the Lake Washington Ship Canal (LWSC), Hiram M. Chittenden Locks, and PIT-tagged fish releases in the Lake Washington basin.

The Washington Department of Fish and Wildlife (WFDW) and Muckleshoot Indian Tribe (MIT) initiated field research in 1994, in cooperation with the Environmental Resources Section of the Seattle District, regarding the effects of operation of the Locks on the survival and general well-being of anadromous salmonids utilizing the Lake Washington watershed for various parts of their life-cycle. Issues raised in the studies have included successful downstream passage of juvenile and adult outmigrants, loss of estuarine habitat and the effects of a relatively sudden freshwater-saltwater transition, intrusion of saltwater into Lake Washington, and upstream passage of adult migrants. These and other concerns are particularly germane now in light of recent listings under the federal Endangered Species Act (ESA) of 1973 of Puget Sound chinook salmon (*Oncorhynchus tshawytscha*) and bull trout (*Salvelinus confluentus*), and potential listing of coho salmon (*O. kisutch*). It is important that the influence of the LWSC project on salmonid survival and health be fully understood so that appropriate measures can be developed and enacted that minimize or eliminate adverse effects. This document details the results from the second year of activities under a study that was designed to evaluate those effects using Passive Integrated Transponder (PIT) tag technology (Prentice et al. 1990a, b, c). The study is part of the greater Lake Washington General Ecosystem Restoration General Investigation (LWGI) Study being conducted by the Seattle District of the USACE.

1.1 PHYSICAL LAYOUT, FEATURES, AND OPERATION OF THE LOCKS

The Locks consist of a large and small lock on the north side, a fish ladder on the south side, and a 71.6 m (235') long concrete gravity spillway dam extending between the small lock and the ladder (Figure 1-2). There is also a saltwater return system that consists of a drain leading to below the spillway dam and a pipe that runs along the bottom of the LWSC to the fish ladder. The pipe discharge is distributed to a number of steps where it mixes with the freshwater entering the head of the ladder.

The large lock is 24.4 m (80') wide and can accommodate ships with drafts up to 9.1 m (30'). It consists of three operating gates that divide the lock into two chambers, two 4.3 m (14') high by 2.6 m (8.5') wide culverts that run longitudinally along each side of the lock and pass lake water into the lock to fill it, filling valves, and dewatering facilities. During normal operations, either one or both chambers are used depending on the size and number of ships passing through the facility. The valves can be used to vary the rate at which the lock is filled. A saltwater barrier is located at the upstream end of the lock and can be raised to reduce the volume of saltwater intruding into the LWSC when the upper gate is opened. Relatively strong density currents can

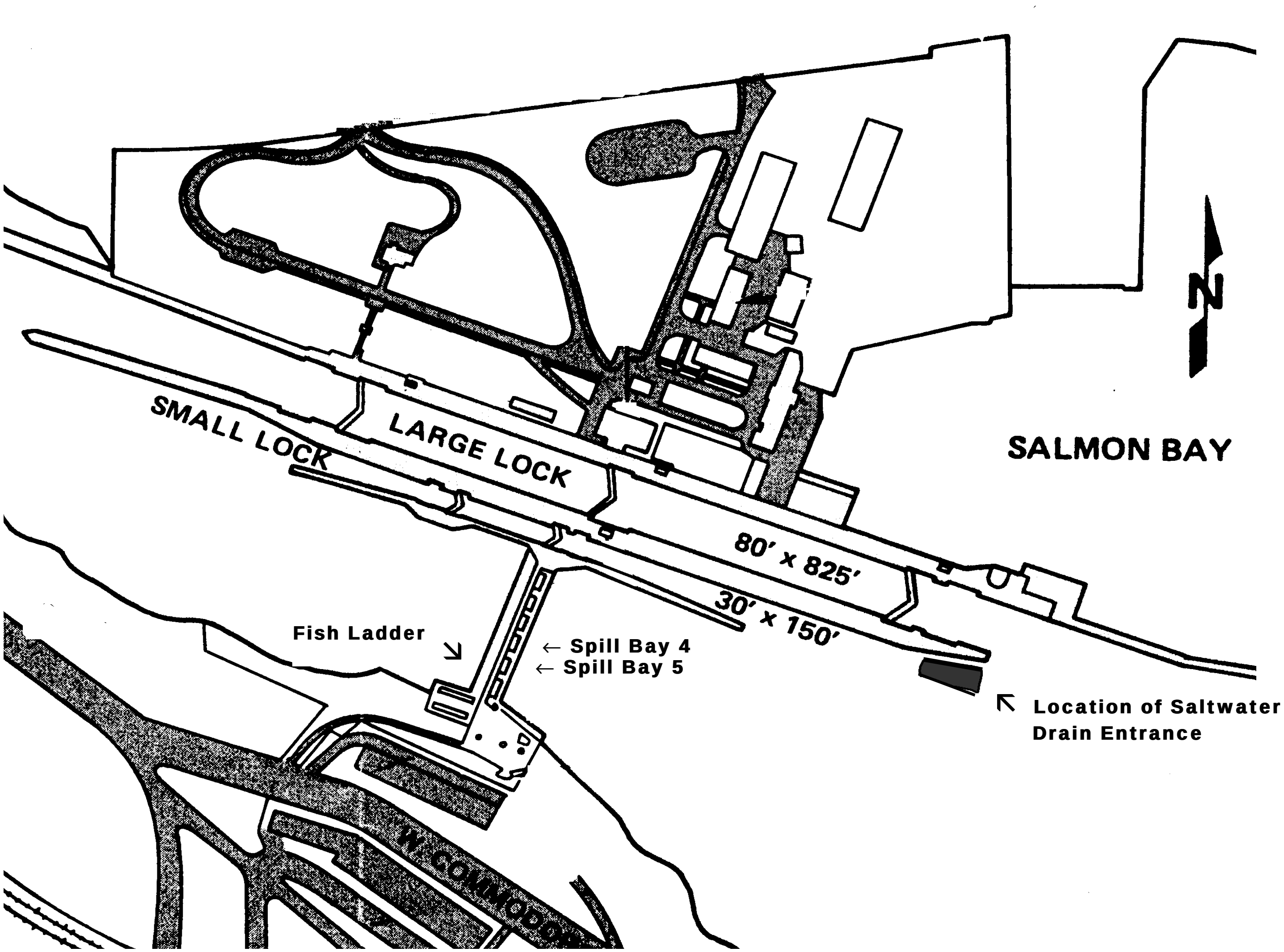


Figure 1-2. Plan view of the Hiram M. Chittenden Locks showing major structural features and location of tunnel readers in spill bays 4 and 5.

occur within the lock when the gate is opened, as surface freshwater enters the lock to replace the denser saltwater flowing out into the LWSC.

The small lock is 9.1 m (30') wide and can accommodate smaller boats with drafts up to 4.9 m (16'). It consists of two operating gates, two 1.8 m (6') high by 2.6 m (8.5') wide culverts that run longitudinally along each side of the lock and pass lake water into the lock to fill it, filling valves, and dewatering facilities. The valves can be used to vary the rate at which the lock is filled.

Saltwater intrusion is an important concern, particular with respect to managing water quality of Lake Washington and Lake Union, because of the concern that the resulting density stratification and water quality attributes of the lakes could transform their deeper areas into sterile, anaerobic waters. The Washington Department of Ecology has correspondingly set water quality standards, where the salinity in the LWSC at the University Bridge may not exceed 1 $^{o}/_{oo}$ (parts per thousand, ppt) at any point in the water column. The Locks are therefore managed to minimize intrusion as much as possible, which occurs with each lockage when a denser, more saline layer flows upstream under the less dense freshwater in the form of a density (or, gravity) current. The large lock is associated with approximately 25 times more saltwater intruding per lockage than the small lock, but the small lock is conversely used more frequently. A hinged barrier on the large lock bottom partly retards saltwater intrusion, but the main line of defense is the saltwater drain located immediately upstream. The saltwater drain has a discharge capacity of 300 cfs and returns water downstream.

The spillway dam consists of six bays that are numbered sequentially as numbers 1 through 6, from North to South. Each bay is 9.8 m (32') wide and controlled by a 3.8 m (12.5') radius tainter gate that is driven by an independent electric motor. The spillway has a design head of 2.3 m (7.4'), a crest elevation of 4.2 m (13.75'), an ogee shape, and is capable of discharging up to 515 m^3/s (18,200 cfs) at the maximum regulated Lake Washington elevation of 6.7 m (22'). Beginning in May 2000, four seasonal smolt passage flumes (smolt flumes) have been installed in bays 4 and 5 with the goal of passing downstream migrating juvenile salmonids by the Locks (the flumes will be installed in April in each following year). These flumes replaced a prototype 'smolt slide' that was installed initially in 1995 for the same purpose of passing smolts downstream of the Locks.

The Locks regulate the elevation of the water surface of Salmon Bay, Lake Union, and Lake Washington. Project authorization documents specify the normal operating levels to be between

6.1 m (20') and 6.7 m (22') above the USACE Project Datum. The Project Datum, established on 1 January 1919, is 2.08 m (6.82') below the National Geodetic Vertical Datum (NGVD) and 0.17 m (0.57') below the Seattle mean lower low water (MLLW) elevation. In constructing the LWSC project, the level of Lake Washington was lowered about 2.7 m (9') from its historic elevation. The storage between the 6.1 m and 6.7 m levels has been used historically to augment LWSC inflows for use in operating the Locks, the saltwater return system, and the fish ladder facility. More recently, the storage is also used to provide flows to the smolt flumes during the spring outmigration period.

There are four seasonal periods of operation: the winter holding period (low pool), the spring refill period, the summer conservation holding period (full pool), and the fall drawdown period. The lake elevation is maintained at the minimum level (6.1 m) during winter months to allow for maintenance on docks, walls, etc. by businesses and lakeside residents, minimize wave and erosion damage during winter storms, and provide storage space for high inflows during flood events. The spring refill period begins February 15 and continues until generally the first week in May when the lake reaches 6.66 m (21.85'), which is slightly less than the full pool level (6.7 m; levels can reach this depending on water availability). The spillway gates (and also now the flumes when appropriate) are operated to keep the lake elevation near its maximum authorized normal level of 6.7 m. The upper limit is dictated by physical design restrictions of the spillway gates and requirements of lake-associated infrastructure. Water demands of the Locks, the saltwater drain, the fish ladder, and the flumes result in the lake elevation gradually lowering, beginning in late June to late July depending on water availability. The Water Conservation Plan that is in effect at the Locks attempts to maintain lake levels at or above the 6.1 m level as much as possible (70% historic reliability level). It is not always possible, however, to maintain this elevation during abnormally low water years and when higher than usual saltwater intrusion associated with lock openings requires additional flushing.

1.2 CONTEXT AND PURPOSE OF THE PIT TAG STUDY

The PIT tag study is part of the greater LWGI study, which was initiated in July 1999. In addition to the USACE, co-sponsors of the LWGI study include the City of Seattle and King County. Other participants in the 2002 study include WDFW, the USACE Waterways Experiment Station (WES), and Biomark Inc. The Locks were previously the focus of four years of baseline studies between 1995 and 1998 that pertained to fish passage conditions and behavior of migratory juvenile chinook salmon and other migratory salmonid species. These studies have been a cooperative effort between several resource agencies, including the WDFW, MIT, WES and the USACE.

The purpose of the LWGI study is to evaluate various projects that may contribute to (i) restoration of ecological processes or functions within the Lake Washington basin, including improving fish passage at the Locks, and (ii) water conservation by the LWSC project to provide additional water for fish passage through the Locks. The LWGI study consists of environmental monitoring activities occurring over 2000, 2001, and 2002 that complement post-flume construction monitoring performed as part of the Lake Washington Ship Canal Smolt Passage, Section 1135 Restoration Project (USACE 1999). Monitoring activities are targeted at evaluating both juvenile and adult salmon passage at the Locks. Juvenile monitoring activities include: PIT tagging and detection at various locations including the Locks; beach seining in Lake Washington and in the saltwater environs of the Locks; studying food habits of juvenile chinook salmon in Lake Washington and of piscine predators below the Locks; monitoring of fish entrainment into the large lock culverts and subsequent injury and survival using split beam hydroacoustics and purse seine sampling; monitoring of entrainment into the saltwater drain using split-beam hydroacoustics, and monitoring of passage during spill over spillbay gate No. 2 using single beam hydroacoustics.

Monitoring objectives for the juvenile studies in the LWSC include:

- Developing smolt survival (mortality) estimates for each salmon species migrating through the LWSC and Locks;
- Identifying major limiting factors contributing to smolt mortality;
- Monitor fish passage through major outlets at the Locks (including studies under the LWSC Section 1135 Project) – four new smolt passage flumes, the large lock culvert intakes, the saltwater drain, and spillway gates; and
- Identifying and assessing possible structural and non-structural restoration measures that may improve smolt survival.

Results presented in this report address the following objectives common to all three years of the PIT tag study component of the LWGI study:

- Evaluating the efficacy of PIT tagging as a means for estimating survival of wild and hatchery fish as they migrate through different portions of the Lake Washington and LWSC system;

- Evaluating the efficacy of PIT tagging naturally-reared smolts in tributaries to Lake Washington and in the LWSC;
- Assessing whether hatchery-reared chinook salmon are a good model for evaluating the effects of the LWSC project on naturally-reared fish; and
- Evaluate smolt mortality for salmon species migrating through the LWSC and Locks, and evaluate migration pathways, passage structures, and the effects of water conservation.

In addition to survival estimates, measures that indicate the success of meeting these primary objectives include obtaining useful information on migration and passage behavior and survival estimates. The resulting data can be used in evaluations of alternative operations at the Locks and other restoration measures, and either directly or indirectly address the following specific restoration objectives of the LWSC Section 1135 project:

- Increasing smolt passage numbers over the spillway;
- Minimizing smolt entrainment into the large lock filling culverts;
- Minimizing smolt injury during passage through the large lock culverts;
- Evaluating the effects of the Locks on smolts during their estuarine phase; and
- Minimizing injury and mortality to chinook salmon in conformance with ESA listing of Puget Sound chinook.

2. METHODS

The methods used in this study reflect more than basic needs for evaluating the feasibility of PIT tagging in the Lake Washington system. This study was also designed to yield first-order estimates of survival over various portions of the migration route and details about migration characteristics related to factors within and outside of the control of water management operations at the Locks. The overall study design involved tagging and release of wild and hatchery juvenile chinook salmon at various locations in the watershed, and detecting them at the Locks and downstream. Study design and methods are described below.

2.1 PIT TAG TECHNOLOGY

PIT tags are small, unobtrusive electronic devices that are implanted in the abdominal cavity of fish. The tags used in this study were 134.2 kHz Destron-Fearing TX1400BE, 14 character tags. The tags do not appear to influence fish behavior or survival significantly when inserted properly (Prentice et al. 1990c). Tagging mortalities generally do not exceed 1%-2% based on experience in the Columbia River (S. Achord, NMFS, personal communication). The tags consist of an antenna coil of coated copper wire that is connected to an integrated circuit chip, all encased in a glass tube that is approximately 12 mm long and 2.1 mm in diameter (Figure 2-1). The device works on the principle of induction of current in a coil as it passes through an electromagnetic field. As the tag passes through the field created by a detection device, the current that is induced in the coil powers the chip, which subsequently transmits a unique tag identification number code through the coil. The tag signal is received by a coil loop of the detection device and is decoded. Each PIT tag in this study had 10 unique characters that distinguished it from approximately 34×10^9 other possible code combinations (Prentice et al. 1990a, b, c).

The distance at which a PIT tag may be detected is relatively short because of power generation and dissipation concerns in a water medium. Consequently, the fish must either be made to pass through the coil of a detection apparatus that is fixed in position at a structure where passage can be controlled, or the tagged fish must be captured in the field and held near a portable ('hand-held') detector. In this study, four fixed detectors ('tunnel readers') were custom fabricated and installed in spillway bays 4 and 5 at the Locks, and hand-held detectors were used in the field for detecting tagged fish that were caught during various seining operations.

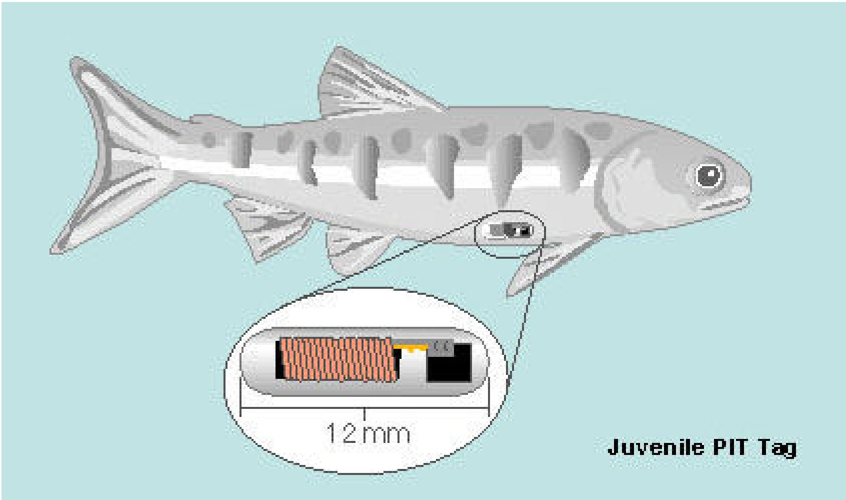


Figure 2-1. Schematic of a Passive Integrated Transponder (PIT) tag inside a juvenile salmonid.

2.2 INSTALLATION AND MONITORING OF TUNNEL READERS AT THE LOCKS

Spillway bays 4 and 5 were converted into smolt passage facilities by raising the radial gates and installing bulkheads with adjustable gates that controlled free surface water flow into four flumes, two located in each bay. Flumes were numbered according to spillway bay (4 or 5) and entrance size (A = 0.69 m (2.25') wide entrance; B = 1.8 m (6') wide entrance; C = 1.2 m (4') wide entrance). Flume number assignments were, from north to south, 4A, 4B, 5C, and 5B (or alternatively, numbers 1 through 4, respectively). Each flume was cantilevered out over the spillway face and led to a tunnel reader that was attached to its end (Figure 2-2). However, this configuration was associated with structural vibration problems in 2000 that led to reduced detection efficiencies. In response, the flumes were "stiffened" at the beginning of the 2001 study by using steel rods attached at one end to the flume and at the other end to the concrete spillway. Tension was applied to the rods by means of turn-buckles, which were adjusted until structural vibrations were minimized. Unfortunately, some residual vibrations remained that could not be corrected, and that were apparently associated with the open channel flow contraction and standing waves occurring in the flumes. This was a greater problem in the two large flumes (4B and 5B). At certain lake levels, standing waves appeared to move slowly through the readers, as manifest by pulses in the outfall water.

The sidewalls and floor of each flume were constructed of stainless steel screen so that some of the water entering the flume passed through the screens, thereby reducing the amount of water entering the tunnel reader. A larger flow rate was needed at the entrance of the flume than could be passed through the tunnel reader to ensure (i) large attraction flows and (ii) water velocities that significantly exceeded the swimming capacity of the tagged fish as they passed through the flume and reader. Entrance flows to each flume at normal operating capacity were 1.4, 3.7, 2.5, and 3.7 m^3/s (50, 130, 90, and 130 cfs) for Flumes 4A, 4B, 5C, and 5B, respectively. Outflows were 0.34, 0.42, 0.40, and 0.42 m^3/s (12, 15, 14, and 15 cfs), respectively. The difference between inflow and outflow is the amount that passed through the screen walls of the flumes, and was designed to facilitate visual monitoring or capture of smolts passing through the flumes.

A flow-related operational problem occurred irregularly when the lake level was relatively high, and involved periodic over-topping of the flumes. The amount of water spilling over was relatively small, and occurred in pulses that may have been associated with the transient standing waves. However, a fish stick would occasionally be ejected from the flume in this manner. Observation of the flumes and fish swimming behavior did not indicate fish were being ejected, suggesting that few if any fish bypassed the tunnel reader when the flume overtopped. Because the number of PIT tagged fish was small relative to the total number of fish passing the Locks, it is likely that if tagged fish were ejected, the number would have been negligible.

The tunnel readers used were Destron-Fearing 134.2 kHz PIT tag monitors. Each tunnel reader contained two independent sets of coil and electronic components that detected and recorded PIT tags separately as they passed through the reader (Figure 2-3). The tag numbers were stored on two computers (one main, one backup) located in the fish ladder maintenance room. The Windows™-based MINIMON computer program was used. This program automatically created a new file each day and stored a complete record of detections and self-testing logs for each coil. Relevant data included PIT tag numbers, identification of the coil that detected the tag, and the time and date of detection. The older DOS-based program, MULTIMON, was also used to download data stored in electronic buffers designed into the tunnel reader coil circuitry, to compare with the data stored by MINIMON in cases when computer problems occurred. Data were retrieved from the computers on almost a daily basis. The PIT tag information was extracted using a Fortran program written to filter out other information and pre-process the data prior to QA/QC checking and subsequent data analyses.

Figure 2-2. The smolt flumes, in position and operating at the Locks during spring 2000. Flumes are numbered, from left to right (and north to south), 4A, 4B, 5C, and 5B. View is from walkway next to fish ladder.

Figure 2-3. A PIT tag tunnel reader, prior to its installation at the Locks. Note the two reader coil units. Flow is from left to right through the pipe. The mounting bolts on the left end are for attaching the reader to the flume.

As in 2000 and 2001, tunnel reader electronics would go out of phase from time to time, but the exact time and duration could not be determined because testing was not performed on a daily basis. This phase shift would result in reduced detection efficiency. For example, the coils of the tunnel reader in Flume 5B appeared to have gone out of phase the week preceding June 26, 2002, at which time the electronics were re-tuned by J. Sadler to maximize potential detection efficiency; the electronics were checked periodically by J. Sadler. It is not known the extent to which these problems affected the total number of tag detections evaluated in this study. Calibration testing results are presented in Chapter 3, from which daily detection efficiencies were estimated.

2.3 TAGGING, HOLDING, AND RELEASE OF FISH

Juveniles of three salmonid species were tagged: chinook salmon, coho salmon, and steelhead trout. PIT tagging was conducted for five main study groups:

- Calibration groups of hatchery chinook salmon were tagged and held at the King County/Metro (Metro) Environmental Laboratory and University of Washington Hatchery for later release into the smolt slides. These fish were used to determine the detection efficiency of the tunnel readers installed at the Locks during the smolt outmigration season;
- An experimental group of chinook salmon were tagged and later released at the Issaquah Hatchery;
- Experimental groups of tagged Issaquah Hatchery chinook salmon were held at the Metro Laboratory and released near the north and south shores of the LWSC at different locations to evaluate shoreline affinity and proportion using the flumes;
- Naturally-spawned fish were caught by WDFW personnel, tagged, and released at two different locations in the Lake Washington watershed to evaluate passage characteristics of fish using the smolt flumes:
    - Bear Creek (at the WDFW juvenile outmigrant smolt screwtrap)
    - Cedar River (at the WDFW juvenile outmigrant smolt screwtrap)

All tagging was conducted using methods described by Prentice et al. (1990c). C.S. McCutcheon (Biomark Inc.), C. Ebel (USACE), and L. Fleischer (WDFW) tagged hatchery chinook salmon at the Issaquah Creek and University of Washington hatcheries and at the Metro Lab. L. Fleischer also tagged fish caught at the Bear Creek and Cedar River screwtraps.

Tagging operations involved insertion into the abdominal cavity using a large bore syringe, and measuring the length of the fish on a custom digitizing pad. Data for individual fish were collected using one or two data collection stations (Biomark brand) equipped with Pacific States Marine Fisheries Commission (PSMFC) software (PITTAG2.EXE). The PIT tag number and fish length data were scanned into a PIT Tag Information System (PTAGIS) format file for submission to the PSMFC database maintained in Portland, Oregon (the files were edited for mortalities and tag loss before submission). After tagging, the needles on the syringes were disinfected in an ethyl alcohol bath for a minimum of 10 minutes before being reloaded and reused.

A letter report from L. Fleischer detailing 2002 tributary tagging activities and mortalities is presented in Appendix A.

Releases of PIT tagged fish were designed to address questions regarding (i) differential survival rates along portions of the migration route, and (ii) the nature and variation of outmigration characteristics in the Lake Washington watershed. Release locations are depicted in Figure 1-1.

2.3.1 Issaquah Hatchery Chinook

A total of 4041 age 0+ chinook salmon originating from the Issaquah Creek hatchery were tagged on location on April 22 and 23, 2002. Of these, 4024 fish were released with other chinook smolts on May 31, 2002 into Issaquah Creek. The tagged fish were held in the outdoor raceways with other non-tagged fish. Tagging was done during the same period that the fish were being fin-clipped by hatchery personnel. Fish were transported in buckets to two tagging stations, anaesthetized, tagged, and released into a separate cage placed within one of the raceways.

C. McCutcheon (Biomark) supervised tagging activities and was also a tagger. Tagging was performed by an individual for a few hours at a time, at which point another person would take over. The fish were relatively small (length generally between 55-75 mm) and thus difficult to tag. Water temperatures were relatively cold (on the order of 5 ºC), and only 9 fish died during tagging. In contrast with 2001, the overall tag shedding rate appeared to be low during the holding period, as only 9 tags were recovered from the holding cage using a powerful magnet; no tags were recovered from the raceway bottom. This probably reflects the fact that the 2001 fish had been fed prior to tagging, whereas feeding of the 2002 fish was stopped three days prior to tagging and was not resumed until three days after tagging. The fish therefore did not have full stomachs that would promote tag ejection prior to the tagging wound healing. In addition, only fish that appeared to be in prime condition were tagged (C. Ebel, USACE, personal communication). The raceway was not checked after it had been drained, however, so the possibility exists that an unknown, additional number of tags may have been shed.

2.3.2 Metro Laboratory Chinook

A group of 1787 chinook juveniles were transported from the Issaquah Creek Hatchery to the Metro Laboratory in early April 2002, and tagged on April 25, 2002. The fish were anaesthetized by Biomark and Corps personnel prior to tagging using MS-222, to reduce stress and injury during tagging. Water temperature was around 8ºC. Fish were removed using standard dip nets and groups of approximately 60 fish were placed in 19 liter (5 gallon) buckets and carried to the tagging tables. Small groups of approximately 20 fish were then dipped and anaesthetized prior to tagging. Fish smaller than 55 mm were not tagged. This resulted in a total of 18 fish being excluded from tagging due to size along with 2 fish that were excluded due to injury. There were no immediate tagging mortalities. The total mortality and shed tag rates over the approximately 6 week holding period were 1.3% and 2.0%, respectively (24 mortalities and 35 shed tags). Twenty-three tags were detected at the Locks but were not part of any formal release group. A remaining 45 tags were not accounted for after inventorying mortalities, shed tags, fish used in calibration and shoreline affinity testing, and tunnel reader detection data. These 68 tags may have been in fish that escaped through tank drains, or were shed and lost through the drain during tank cleanings.

The fish were divided among eight 0.9 m (3') diameter tanks set up inside in the bioassay lab of the building. Water used to hold all fish at the Metro Laboratory consisted of UV-treated lake water that was chilled when necessary to reach a target holding temperature of 10ºC (50ºF). Tanks were warmed to within a few degrees of ambient in the Ship Canal 24 hours prior to release to reduce the chance of increased stress or mortality due to temperature differences. The fish were designated for release as calibration test fish for evaluating the detection efficiency of the tunnel readers, and for use in the shoreline affinity tests. Gary Yoshida provided primary assistance and fish care at the Metro Laboratory.

2.3.3 University of Washington Hatchery Chinook

1,006 chinook salmon juveniles rearing at the UW hatchery were PIT tagged on April 26, 2002. These fish were held at the UW hatchery and transferred in sub-groups as space became free at the Metro Laboratory during calibration testing. Similar tagging procedures were used as at the Metro Laboratory. These fish were held in a large circulating tank located within the hatchery building. Temperature at time of tagging was around 9ºC. Only 10 fish died during tagging. However, the tank water was drawn from the LWSC but was not chilled. As a consequence, many fish died later from disease and stress over the 8 week holding period as ambient water temperatures in the LWSC increased. A total of 182 fish died or shed tags. 16 tags were detected at the Locks but were not part of any formal release group; these fish may have escaped from the Metro Laboratory tanks through the drains (one jumper was found on the ground; Gary Yoshida, King County/Metro, personal communication). A remaining 71 tags were not accounted for after inventorying mortalities, shed tags, fish used in calibration and shoreline affinity testing, and tunnel reader detection data.

2.3.4 Tributary Fish

Juvenile chinook and coho salmon and steelhead trout of natural origin were caught and tagged at WDFW downstream migrant screw traps (see, e.g., Thedinga et al. 1996 for a description of a screw trap) in two streams in the Lake Washington system. The sites were located in (i) lower Bear Creek, below the railroad trestle, downstream of Redmond Way, and (ii) in the lower Cedar River just upstream from the Logan Street Bridge (Figure 1-1). Tagging was initiated at both sites on May 1, 2002. Tagging continued until July 10 in Bear Creek, and July 12, 2002 in the Cedar River. Tagging dates encompassed the peak of the outmigration period for naturally-produced smolts. A total of 1859 fish were tagged and released in the Cedar River, and 4974 fish in Bear Creek. Most of the fish were chinook and coho salmon, although a few steelhead trout were also tagged. A primary goal of this portion of the study was to determine survival and migration characteristics of the main fraction of the run for each species in each stream.

Fish were collected overnight in the screw traps. On each day of tagging, fish trapped the night before were transferred using sanctuary dip nets to 5 gallon buckets and then to a small tub containing MS-222. A PIT tag was inserted into the anaesthetized fish, which were then returned into a recovery bucket. Fish were allowed to recover fully from the anesthetic before they were released back directly into the river below the screw trap, usually within an hour after tagging. In general, all or nearly all chinook, coho, and steelhead present in the trap that day were tagged, except for a few fish that were smaller than about 70 mm in length, which were too difficult to handle and for which the tag was large relative to the abdominal cavity size. Of fish held overnight to evaluate post tagging mortality and tag shed rates, no chinook died or lost tags, and only one coho in Bear Creek died (see report in Appendix A). Fish tagged in Bear Creek and the Cedar River were exclusively naturally reared fish. The tagged chinook were likely all sub-yearlings, whereas it is likely that most of the coho and steelhead were yearlings (Appendix A).

2.4 CALIBRATION TESTING OF THE TUNNEL READERS

The chinook salmon held at the Metro Laboratory and UW hatchery were designated primarily as calibration test fish. Calibration test fish were released in small groups on four separate occasions between May 3 and June 24, 2002 to evaluate the detection efficiency of the tunnel readers. Groups of 50 fish were released directly into the mouth of each flume through an angled PVC pipe. Visual observation during the 2000 study by D. Houck, King County using an underwater camera during one of the tests indicated that less than 1% of the fish on average may have escaped from the mouth of a flume during testing. There were no escapees detected in the tunnel readers subsequent to the tests in 2002, suggesting that all calibration test fish passed through the flumes during the tests.

"Fish sticks" were constructed to supplement the live fish, so that they could be used more frequently and reduce the study's dependence on fish being held at the Metro Laboratory. The sticks were constructed out of 30 cm lengths of 1.9 cm (sold as ¾") x 1.9 cm hemlock stock wood. A small hole was drilled and a PIT tag was inserted and sealed in. Two types of sticks were constructed: (1) where the tag was oriented parallel (0^{o}) to the long axis of the stick, and (2) where the tag was oriented 45° to the long axis. Ten sticks of each type were dropped sequentially into each flume, in such a manner that they entered the tunnel reader approximately parallel to the flow streamlines thereby mimicking the passage of PIT tagged fish. The sticks were painted with bright fluorescent colors to facilitate retrieval using a boat below the flumes. In early to mid-May, 10 sticks of each PIT tag orientation were thrown one by one into each flume, whereas 20 sticks of each orientation were used during the chinook passage period. Associated errors in determining detection efficiency of a given tag orientation were therefore 10% and 5% during each respective period; overall detection efficiency errors were 5% and 2.5%, respectively.

The number of test fish and fish sticks that were detected was determined from the file created by MINIMON. Detection efficiency was calculated as the ratio of number detected to number released in each flume, expressed as a percentage. Electronic marker notes were placed in the computer file immediately before each live fish group was released and the time noted in field books so that the detected tag codes and discrete flume tests could be distinguished accordingly. A FORTRAN program was written to extract the fish stick data and summarize those results.

The 10 cm I.D. PVC pipe used by Pfeifer (2002) to evaluate smolt counting effectiveness in the flume discharge was also used in tests to compare detection efficiencies between fish released into the flume mouth from a boat (the procedure used in 2000 and 2001) and fish released from the walkway. This was done to determine if the more time-efficient walkway-based method could be followed in subsequent years. Similar numbers of tagged fish were released from the boat and the walkway as part of the third calibration test, and the detection rates were compared.

2.5 EVALUATION OF SHORELINE AFFINITY AND PROPORTION USING SMOLT FLUMES

Groups of juvenile chinook salmon originating from the Issaquah Hatchery were released near the south and north shores at different locations within the LWSC to evaluate shoreline affinity and the proportion using the smolt flumes. The ad hoc experiment was designed to evaluate simultaneously, to first order, both the issue of shoreline affinity and proportion using the flumes (P_{SF}), while accepting a low level of statistical precision because of a limited number of tagged fish available for the test. In addition to indicating the approximate order of magnitude of the degree to which shoreline affinity is important and the approximate value of P_{SF}, the results were expected to indicate which issue should be addressed in greater depth in the future using greater sample sizes and a more rigorous sampling design. The design called for releasing replicate groups of fish near the north and south shore the same day at a number of locations in the LWSC. Locations included the eastern end of the Montlake Cut, the eastern and western ends of the Fremont Cut, and within approximately 300 m of the Locks (Figure 2-4).

The fish were tagged and held at the Metro Laboratory. The temperature of the holding water was gradually increased over a 24 hour period prior to release until it was approximately 1-2 degrees C below ambient. Fish were transferred from the holding tanks to ice chests, and the water in the chests equilibrated to ambient surface temperature in the LWSC during transport to the release locations.

The experiment was based on the assumption that survival to the Locks is high (>95%), particularly from the eastern end of the Fremont Cut, which seemed reasonable based on the first year's results. By ignoring the confounding effect of survival, only the proportion using the flumes and the degree to which mixing occurs as fish approach the Locks were treated as unknowns. These two unknown quantities can be evaluated to first order by releasing groups of fish on the north and south side of the LWSC at different distances from the Locks, and evaluating whether north-south mixing occurs. Letting N_{FSi} and N_{FNi} be the numbers from each

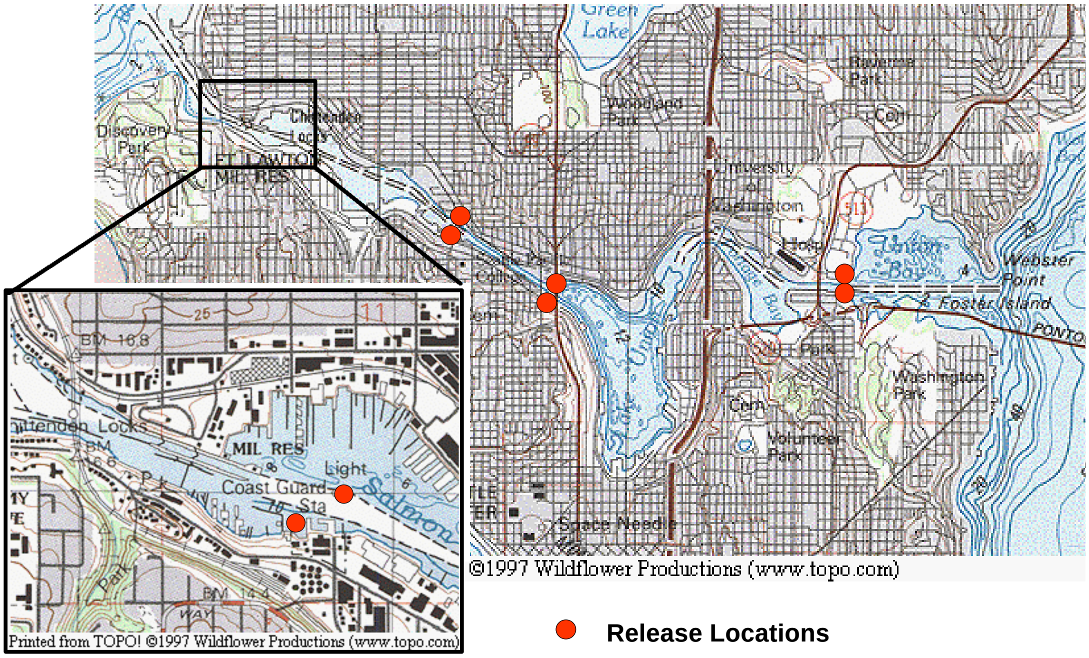


Figure 2-4. Locations where PIT tagged juvenile hatchery chinook salmon were released to evaluate shoreline affinity within the LWSC and the proportion using the smolt flumes at the Locks.

release group ***i*** detected in the flumes, corrected for detection efficiency, the null hypothesis that can be tested is that the average of the ratio (N_{FSi}:N_{FNi}) equals 1 (i.e., no shoreline affinity). The alternate hypothesis is that the average ratio is greater than 1.

The proportion using the flumes was evaluated by plotting the ratio against distance to the flumes, on the basis that a relatively consistent proportion using the flumes for a given side of the ship canal would be indicated by an asymptotic relationship in the plot. If there is shoreline affinity, then the asymptotic value would differ between the north and south release groups; if not, the two curves should converge. The selected release locations also facilitate a crude evaluation of whether mixing was more likely to occur in narrow than wide cross-sections of the LWSC.

Numbers of replicates and replicate sample sizes were constrained by the number of fish that could be held at the Metro Laboratory and the simultaneous need for tagged fish to perform tunnel reader calibration testing. The number of replicates and fish in each group was an important limitation to the statistical precision of the experiment, hence the exploratory nature of this experiment. A release group size of 100 fish was considered to be a pragmatic number based on holding capabilities at the Metro Laboratory, and was expected to result in a moderately precise detection rate based on the binomial approximation. The 2000 and 2001 study results indicated an expected detection rate between 20% and 50% depending on water temperature and date during the outmigration season (barring unforeseen disease, water quality problems, etc.). Approximately 1,500 fish were available, which allowed two replicate release groups of 100 fish at all locations except the Montlake Cut, where release groups of 150 fish were desired to account for potential mortality within Portage Bay and Lake Union. The two replicate releases at the other locations were performed on consecutive days to evaluate the potential for daily variation. Some group numbers were less than 100 fish on the final day of release, reflecting availability of remaining fish at the Metro Laboratory.

Release timing was based on the results of the 2000 and 2001 PIT tag studies, which indicated that the majority of chinook smolts passed through the Locks within a day or two after the moon was at apogee, which in 2002 occurred on June 4. It was assumed that releasing the fish around that time would be associated with directed migration of the test fish to the Locks, possibly as they followed other migrating fish. For example, test groups of hatchery chinook released in late May of 2000 near the eastern end of the Fremont Cut passed through the flumes around the same time as natural fish within a day or two after apogee that year. Consequently, test fish were released in front of the Locks and near the Fremont Cut on June 6 and 7, 2002. The Montlake Cut groups were released a week earlier on May 31, 2002 because previous data indicated that it took fish from that location about a week to pass through the Locks, thereby ensuring that all test groups passed through the Locks at approximately the same time.

2.6 DETECTION STRATEGY

The 2002 study involved detecting fish only at the Locks, but as in 2000 and 2001, not all of the passage routes through the Locks were monitored. The primary goal of the 2002 study was to further evaluate passage characteristics of fish tagged in the tributaries. Sampling was not conducted at different locations along the passage route, however. There were no detection facilities or sampling conducted in the small lock, the other spillway gates, the saltwater drain, or the fish ladder. An unknown proportion of tagged fish therefore passed downstream without being detected. This feature of the study influenced the accuracy and precision of survival estimates, but did not substantially influence evaluations of overall migration and passage characteristics.

2.7 DATA ANALYSES

2.7.1 Physical Characteristics of the Fish

Other than general body condition at time of tagging, the only physical characteristic of the tagged fish that was measured was total length at time of tagging, and whether the fish could be discerned to have been of hatchery origin. Almost all of the tagged fish were measured, with the exception of a small number whose lengths were inadvertently not recorded by the digitizing system. Hence, information was not available regarding growth and length at time of passage at the Locks. Instead, fish lengths at time of tagging were used primarily to compare potential size differences between the detected and undetected fish by means of frequency analysis using a Chi Square test of observed (=detected fish) and expected (=released fish) frequencies (Zar 1984). This was done for each group as a whole, irrespective of release date to see if there were any population-level differences in fish length arriving at the Locks compared with lengths at other points along the migration route.

The length data from the Cedar River and Bear Creek tagging operations were also used to compute average lengths of tagged fish at different times at each location. The results were plotted against tagging date to identify temporal trends, if any, that might potentially influence size-dependent survival to the Locks, or suggest partitioning of the length frequency data by tagging date.

2.7.2 Migration Behavior

The dates of PIT tag detections at the Locks were used to identify patterns and differences in migration timing, total travel time until passage through the flumes, and average migration rate among the different test groups. Average migration rate was computed by dividing travel distance by the number of days between release and detection at the Locks. Travel distances were determined using the "Topo" software package (™Wildflower productions) by tracing assumed migration routes five times on electronic topographic quad sheets and averaging the numbers calculated by the program. Routes in the LWSC were assumed to follow the mid-channel line on average. Routes through Lake Washington were assumed to follow the west shoreline from either the mouth of the Cedar River, or the mouth of the Sammamish River, where the path as traced ran within approximately 400 m (¼ mile) offshore (note, however, that some fish exiting the Sammamish River were determined during this study to have likely migrated along the eastern shore of Lake Washington; see Section 4.0). Traced routes through Lake Sammamish followed both west and east shorelines and an average was taken of the two.

2.7.3 Passage Behavior at the Locks

The dates and times of PIT tag detections at the Locks were used to identify patterns and differences in seasonal and daily passage timing among the different test groups at the Locks. Tag codes were also evaluated for recycling times through the Locks, based on repeated detections at the tunnel readers and/or in purse seine samples in the large lock.

To evaluate the influence of filling of the large and small locks on smolt passage through the flumes, detection times were compared with times at which various components of the Locks were operating. Fortran programs were written that counted the number of detections that occurred while (i) the small and large locks were filling and for five minutes thereafter ("fill" period), and (ii) until the time of the next fill sequence ("between-fill" period). Time of lock openings were determined from records maintained by the Lockmaster, and the time for each lock to fill was determined as a function of tide elevation and observations of fill times at different tide levels. In the case of the large lock, the fill time was also a function of whether one or both chambers were being filled and how fast the water was allowed to flow through the culverts (i.e., continuous, gradual, or intermediate fill patterns). A post-fill period of five minutes was selected arbitrarily (absent specific data), assuming that fish continued to swim about actively for a short period after the velocity field in the spillway dam forebay returned to approximately steady-state, non-fill conditions. The exact time for velocities to return to steady state has not been determined in recent measurements of velocity fields above the Locks, but appears to be less than 5 minutes based on available measurements (Johnson et al. 2001). Velocity transients associated with density currents when the upper gates are opened (Lingel 1997) were not considered.

The two sets of numbers generated by the programs were compared using t-tests to evaluate the hypothesis that transient changes in water currents in the vicinity of the Locks caused by lock filling operations were associated with increased passage through the flumes. The null hypothesis was that passage was not significantly different in pairwise comparisons of sequential observations of numbers of fish passing through the flumes during and between fills.

2.7.4 Survival Estimation

Survival could not be estimated to high accuracy or precision because (i) the proportion of tagged fish using the smolt flumes (P_{SF} ; compared with other routes through the Locks) could not be estimated to high accuracy or precision, (ii) of variable tunnel reader detection efficiencies

(Section 3.2), and (iii) seasonal variation in detection rates, possibly related to increasing water temperature in the LWSC, was likely reflected in a change in the proportion using the flumes (Section 3.6). Also, the 2002 study did not involve tagging and releasing fish at different locations along the outmigration route, so route segment survivals could not be estimated as was done in 2000 and 2001 (DeVries 2000, 2001).

Survivals were evaluated for each chinook release group for different hypothesized values of P_{SF} by comparing the number of fish released ($N_{group\ REL}$) with the number of fish detected at the smolt flumes ($N_{group\ SF}$), subject to the proportion using the flumes and the detection efficiency of the tunnel readers. The total number of PIT tagged fish from each release group passing through the four smolt flumes was estimated using an average detection efficiency for each flume *i* (E_{SFi}; determined during the calibration testing):

$$\hat{N}_{group_{SF}} = \sum_{i=1}^{4} \hat{N}_{group_{SF\,i}} = \sum_{i=1}^{4} \frac{N_{group_{SF\,i}}}{\overline{E}_{SF\,i}}$$

Let the fraction of tagged fish arriving at the Locks that pass downstream through the flumes equal P_{SF}. Assuming that this value influences all survival estimates the same, the relative differences in survival estimated for different portions of the outmigration routes should be approximately preserved. The survival of each group (S_{group}) is then estimated as:

$$\hat{S}_{group} = \frac{\hat{N}_{group_{SF}}}{\hat{P}_{SF}\ N_{group_{REL}}}$$

However, the proportion using the flumes could not be directly estimated in 2002, and thus overall survival could not be estimated for Bear Creek and Cedar River fish. However, survival could be estimated for a route segment between two release locations assuming that the detection probability of each group is the same at the Locks. This assumption is reasonable when the two groups pass through the flumes on roughly the same date. The appropriate release group(s) to include in the calculation was identified by comparing travel times from the different release locations, and going back in time accordingly. Survival between two points 1 (upstream) and 2 (downstream) were correspondingly estimated using:

$$\hat{S}_{1-2} = \frac{\hat{N}_{group1_{SF}} / \hat{N}_{group1_{Rel}}}{\hat{N}_{group2_{SF}} / \hat{N}_{group2_{Rel}}}$$

The variance of this estimate is a function of the variances of the ratios in the numerator (p_1) and denominator (p_2), per the Taylor Series approximation:

$$\hat{V}ar\left(\hat{S} = \frac{p_1}{p_2}\right) \approx \frac{\hat{V}ar(p_1)}{(p_2)^2} + \frac{(p_1)^2 \hat{V}ar(p_2)}{(p_2)^4}$$

The variance of each ratio p_1 and p_2 was estimated using the relationship between the F distribution and the binomial distribution (Zar 1984, equations 22.26 and 22.27). An example of approximate 95% confidence limits for a survival estimate of 0.75 and different release group sizes is given in Figure 2-5

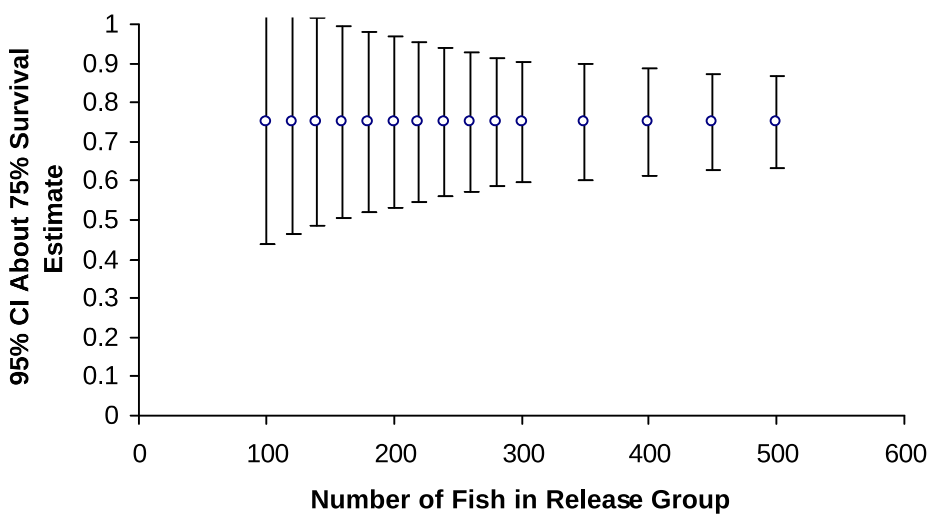


Figure 2-5. Approximate 95% confidence limits for an example migration route segment survival estimate of 0.75 and different PIT tag release group sizes, 2002 Lake Washington GI study.

3. RESULTS

The results of this study were less influenced by water conservation needs in 2002 than in 2000 and 2001 because of a wet spring. There was enough water available to run all four flumes nearly continuously through the third week of June, and intermittently through the first week of July. There was also considerable volumes of water spilled through Spillway 1 ending July 1, 2002, with spill occurring on 27 days in May and on 15 days in June 2002. Beginning the second week of July, the USACE began to shut down flumes one by one while keeping flumes open intermittently as long as possible. Flume passage was provided through the end of August 2002. Based on the results of the 2000 and 2001 studies, the flumes were shut down at night during the latter part of the outmigration season to conserve water without adversely affecting passage numbers (fish were most likely to pass during daylight hours). Flume 5B was selected as the final flume to keep open because the previous two year's results indicated that the larger flumes passed more fish. Figure 3-1 shows the times that the flumes were open during the study according to logs kept in the lock control tower and PIT tag detection times. The schedule during the three weeks beginning in the second half of June reflects the experimental design for tests conducted to determine relative fish guidance efficiency (RFGE), which compared the numbers using the flumes with the numbers entrained in the large lock culverts (Pfeifer 2003). During this period, selected flumes were closed between 0600 and 1800 hours (Figure 3-1). There were also short periods when the flumes were closed for maintenance. Consequently, the flume coverage for PIT tags was neither continuous nor consistent.

The primary computer crashed on three occasions: 6/10/02, 7/1/02, and around midday on 7/5/02 through the morning of 7/8/02. This was also a problem in 2001 and was thought to be related originally to the number of files in the data directory. Unauthorized computer use was a problem in 2000. The reason for these three events is unknown. Fortunately, the backup computer data were not affected, so no detection data were lost.

The flumes operated long enough that the numbers of tagged chinook passing through the flumes had decreased substantially to near zero, consistent with visual flume count data (P. Johnson and K. Bouchard, personal communication). Behavioral patterns evident in the data were therefore unlikely to have been influenced significantly by systematic error. These patterns relate to migration, passage, and the transition to saltwater, and provide significant insight into the basic biology of juvenile outmigrant salmonids in the Lake Washington system, as described in the remainder of this section.

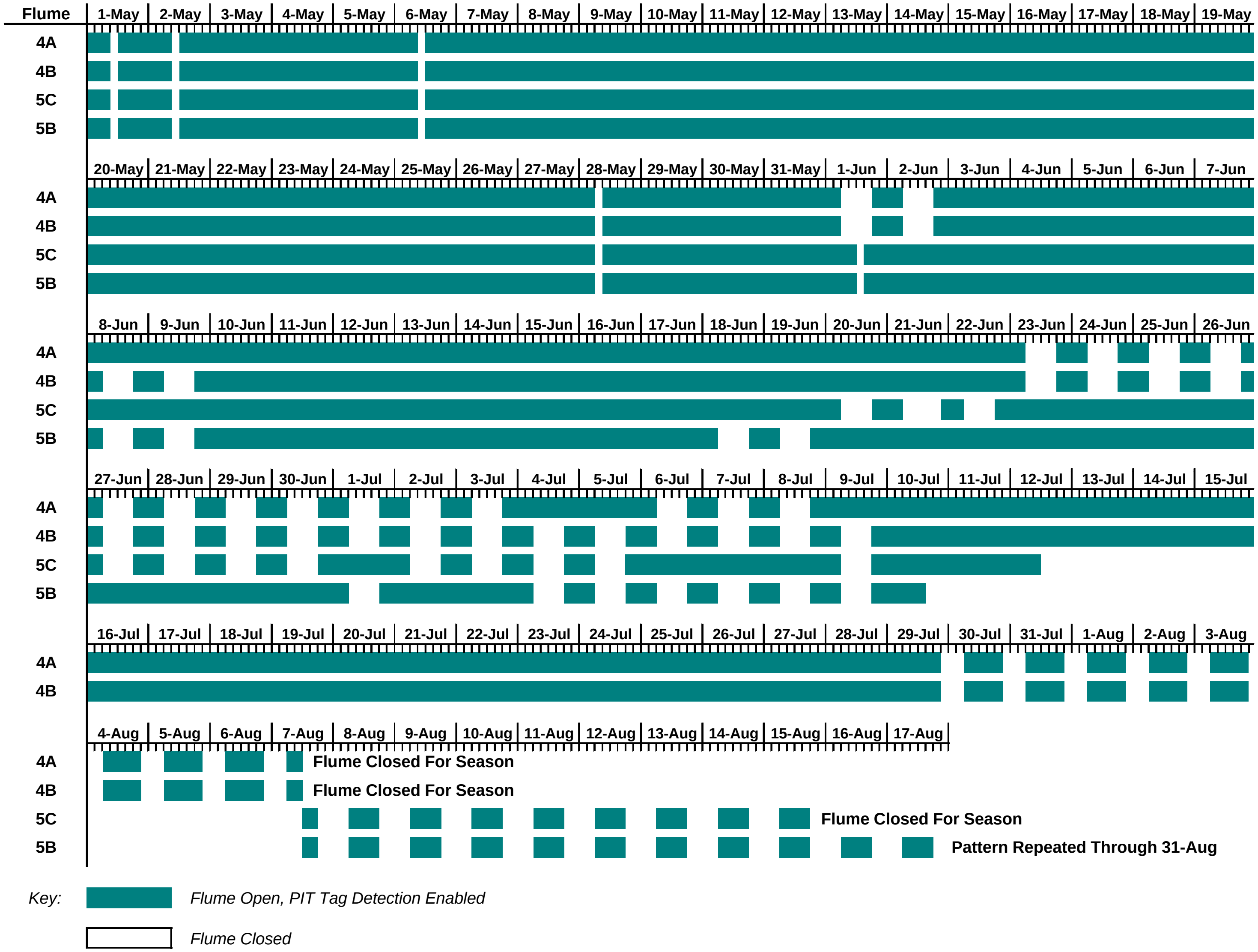


Figure 3-1. Times that the smolt flumes were open at the Locks during the 2002 PIT tag study after the first test fish were released.

3.1 PIT TAG DATA SUMMARIES

Table 3-1 summarizes numbers of fish and the locations at which they were tagged and released. The estimated numbers passing through the flumes reflect corrections based on average detection efficiencies determined for each flume in the calibration tests. Figures 3-2 and 3-3 depict the numbers and dates of tagging for each chinook and coho group and release location. The numbers and dates of release of each species at each location, and the corresponding numbers detected in each flume are also presented in tabular form in Appendix B.

There were 7 tags detected in the tunnel readers that were not identified in the 2000, 2001, and 2002 tagging files, probably because they were not detected by the tagging station equipment, so the origin of those fish could not be determined. This number was smaller than occurred in 2000 and 2001. Another 14 tags were detected and were not in the tagging files, but their origin was deduced because the identification number of the bags they came in was noted during tagging.

Table 3-1. Summary of 2002 PIT tag release and tunnel reader re-detection numbers, Lake Washington GI Study.

Species	Origin	Issaquah Creek Hatchery	Bear Creek	Cedar River
		Total Numbers Tagged and Released:		
Chinook	Natural	--	2309	814
	Hatchery	4024	--	--
Coho	Natural	--	2661	1038
Steelhead	Natural	--	4	7
		Total Numbers Detected in Smolt Flumes:		
Chinook	Natural	--	676	164
	Hatchery	1411	--	--
Coho	Natural	--	1611	578
Steelhead	Natural	--	0	1
		Estimated Total Numbers Passing Through Smolt Flumes:		
Chinook	Natural	--	735	170
	Hatchery	1569	--	--
Coho	Natural	--	1718	613
Steelhead	Natural	--	0	1

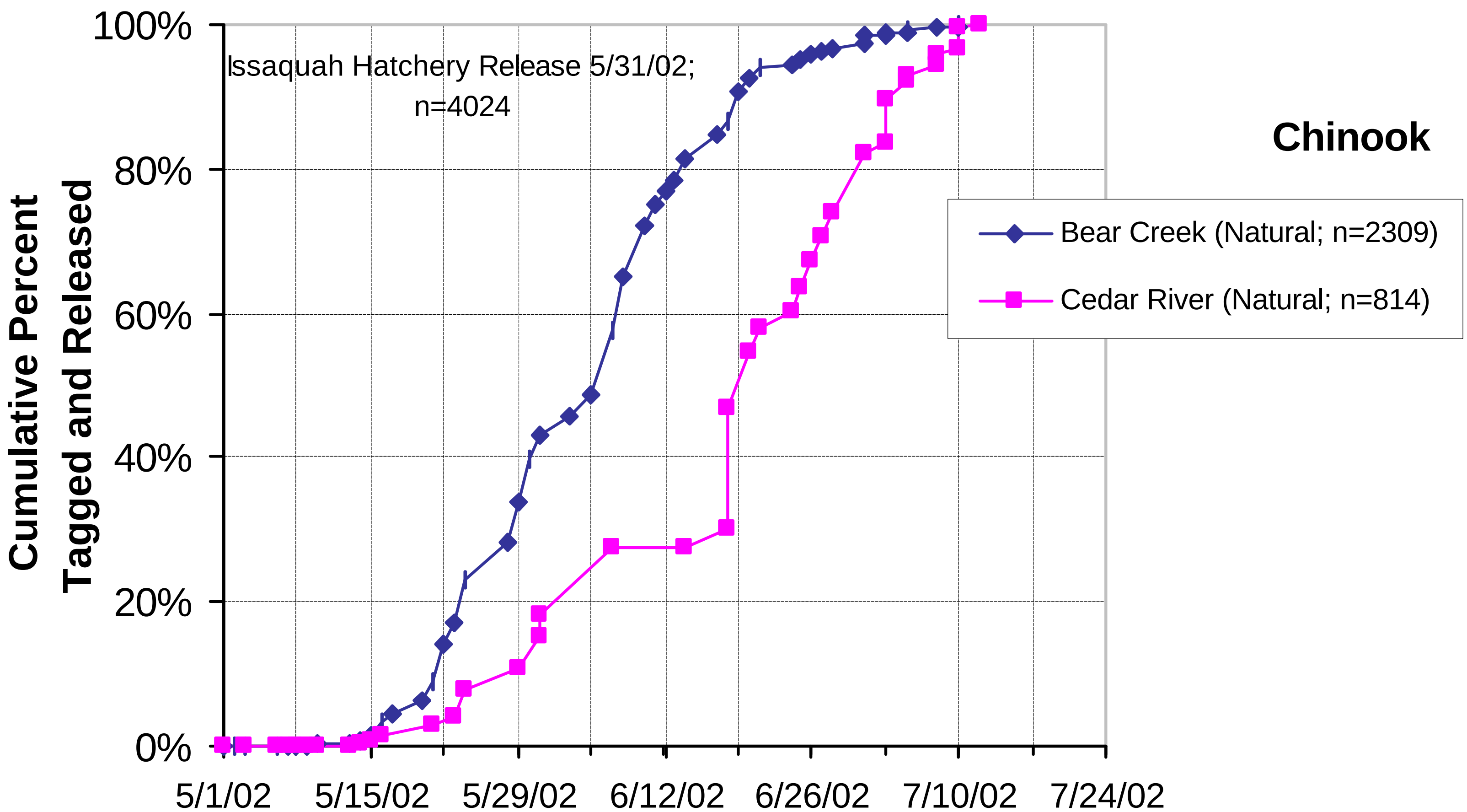


Figure 3-2. Cumulative frequency distributions of juvenile chinook salmon PIT tagging numbers by date and location, 2002 Lake Washington GI study.

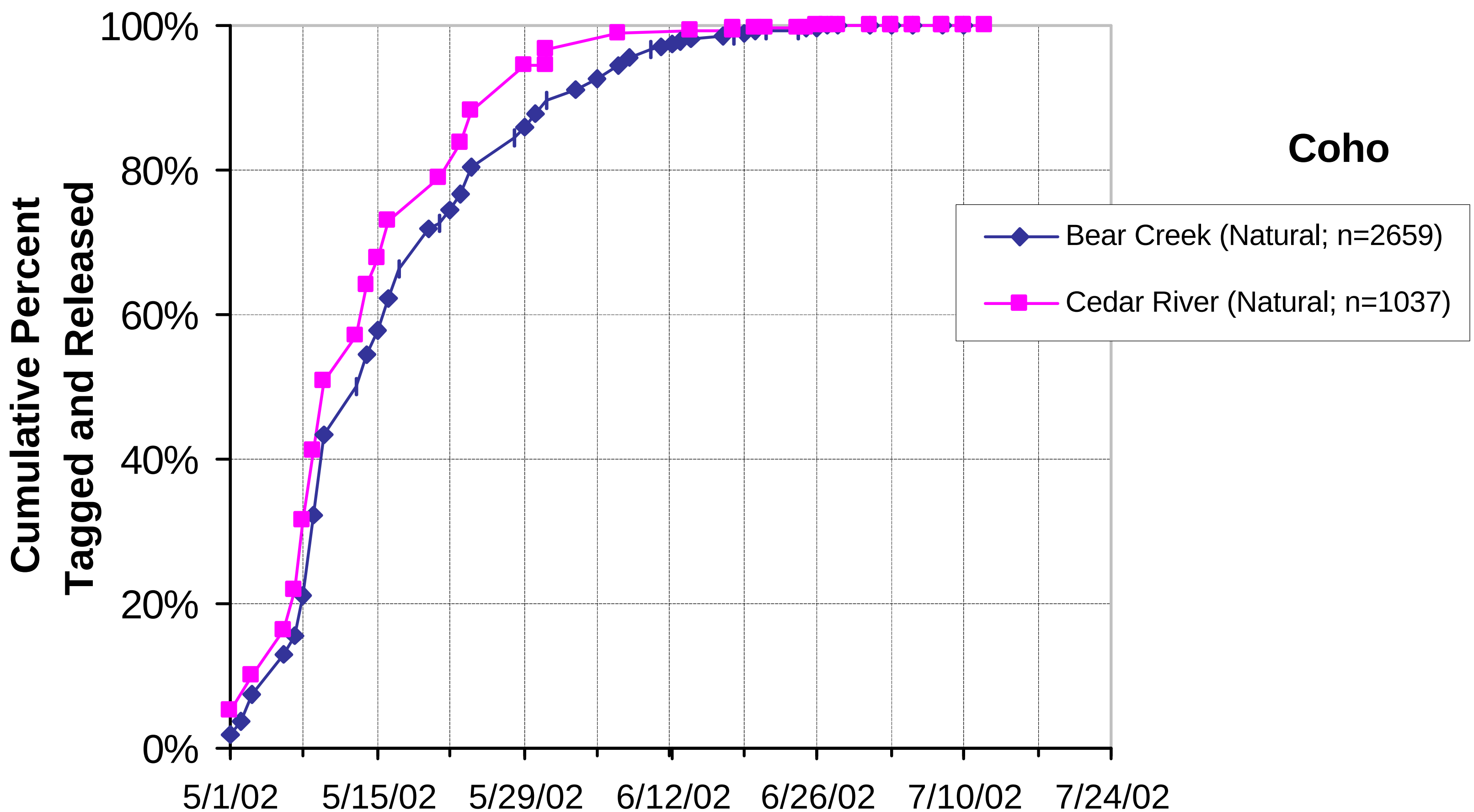


Figure 3-3. Cumulative frequency distributions of juvenile coho salmon PIT tagging numbers by date and location, 2002 Lake Washington GI study.

3.2 CALIBRATION TESTING AND FLUME/TUNNEL READER OPERATION PROBLEMS

Detection efficiency was generally similar to levels experienced in 2001, which were higher than in 2000. This was a result of structural modifications in 2001 that were developed to reduce vibration of the cantilevered flume assembly. The Locks are the only known installation of PIT tag readers where they are not rigidly supported. The vibration occurred at a frequency that interfered with tag detection (DeVries 2001). The modifications improved detection efficiency to recommended levels in the small and mid-sized flumes (4A, 5C), but not in the two large flumes (4B, 5B). In addition to decreased effectiveness, variation in detection efficiency increased with flume size (Figure 3-4). Guidelines for the Columbia River require a minimum detection efficiency of 95% with four coils operating, and most systems there operate in the 98-100 percent efficiency range (D. Park, Biomark, personal communication). Beginning in May after study fish were released, detection efficiencies based on calibration test fish averaged 99% and 94% in Flumes 4A and 5C, respectively, and 89% in Flume 4B.

Detection efficiency was considerably more variable in Flume 5B. The primary reason appeared to be that the flume's dewatering plates were adjusted on June 20, 2002 and were not reset to their original configuration until July 2, 2002 (K. Bouchard, MevaTec, personal communication). This period is indicated by the arrows in Figure 3-4. The coils in the Flume 5B tunnel reader were not adjusted to compensate for the new plate configuration, and detection efficiency was reduced during this period. Before this period, the efficiency of test fish detection averaged 92% in Flume 5B. However, calibration test fish detection efficiency was greater than fish stick detection efficiency during a test conducted on June 26, 2002, so it is possible that there was a difference in detection efficiencies between floating fish sticks and tagged fish swimming closer to the flume bottom. The fish stick tests may have underestimated detection efficiency of live fish during this period.

The calibration tests also indicated that the fish sticks with tags oriented parallel to the flow in the flumes were detected with slightly greater efficiency on average than were live tagged fish (Figure 3-5). In contrast, the fish sticks with tags oriented at 45^o were detected at a similar or slightly lower rate as the tagged fish. Visual observation of fish passing through the flumes indicated that they swim vigorously facing upstream, and thus their bodies are not always oriented optimally for detection. The average of the 0^o and 45^o results was generally similar to that using live fish (Figure 3-5). Consequently, the results for test fish (when used), 0^o sticks, and 45^o sticks were averaged on each test date, and daily detection efficiencies were interpolated for each flume using the computed averages. The July 9, 2002 test result for Flume 5B was assumed to apply back to July 2, 2002, corresponding to the adjustment of the dewatering plates that day. The daily detection efficiency estimates were used to adjust the total numbers of PIT-tagged fish passing through the flumes, as described in Section 2.6.5.

The values circled in Figure 3-4 for Flume 4A were not used in the efficiency calculations as they were uncharacteristically low for this flume, which usually detects essentially 100 percent of all tags. It is suspected here that the technician conducting the test may have experienced problems with passers-by taking a "souvenir" or throwing a stick over the side while the technician was not looking (this happened several times in 2002).

Detection efficiencies were similar for fish released one by one from the walkway using the PVC pipe and fish released directly into the flume mouth from a boat. Detection efficiencies were generally lower for fish flushed through the pipe together in small groups. The walkway release approach was less time consuming than when using a boat, particularly with respect to transporting the fish from the Metro Laboratory to the Locks. In addition, there was no chance for escape of fish released from the walkway.

3.3 FISH LENGTH CHARACTERISTICS

Fish lengths were determined primarily at the time of tagging and should not be used to infer size at time of passage at the Locks. Figures 3-6 through 3-11 depict the range and frequency distributions of lengths of the fish that were tagged in each group, and compares the distributions with those of the fish that were detected at the Locks. The figures also depict the change in mean length of fish at the LWSC and tributary locations where tagging continued over the course of the passage season. In general, there was limited evidence of a consistent effect of fish size on detection rate at the Locks, indicating that tagged fish generally had an equal probability of passing through the flumes. In all cases, the two distributions were not significantly different and overlapped at the 5% significance level (Chi-Square test of expected frequencies; Locks = observed, tagging = expected).

Mean lengths of juvenile chinook captured in Bear Creek and the Cedar River appeared to exhibit different patterns. As in 2001, mean lengths increased in Bear Creek until around June 4, 2002 (Figure 3-7). Lengths then remained similar until around June 24, 2002, after which they increased again. Partitioning the length data into two groups divided by June 4, 2002 (only three fish were detected from groups tagged after June 24, 2002) indicated different temporal patterns existed. Overall, Bear Creek chinook detected at the Locks were not significantly different in size from all fish released (Figure 3-7). The same was true for fish tagged and released before June 4, 2002. In contrast, Bear Creek chinook detected at the Locks after June 4, 2002, were proportionally larger than fish from the total sample released (Figure 3-8; critical á <0.001, 22 classes, ignoring distribution tail outliers). This pattern was also observed

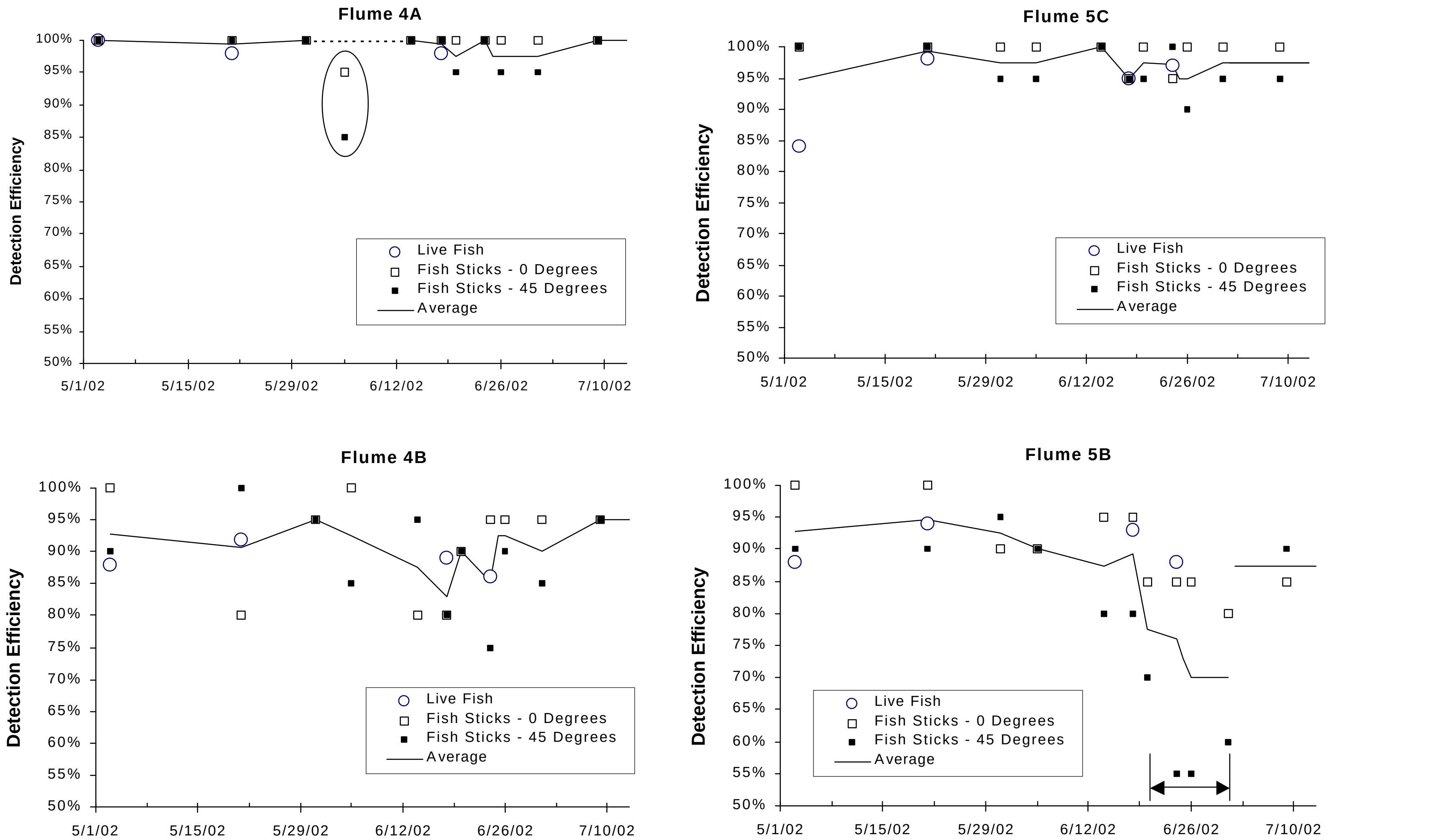


Figure 3-4. Results of calibration tests of tunnel detector efficiency at the Locks using PIT tagged fish and fish sticks released directly into each flume, 2002 Lake Washington GI study. The period that dewatering plates were adjusted in Flume 5B is indicated by the double arrow. Circled data points for Flume 4A are suspect.

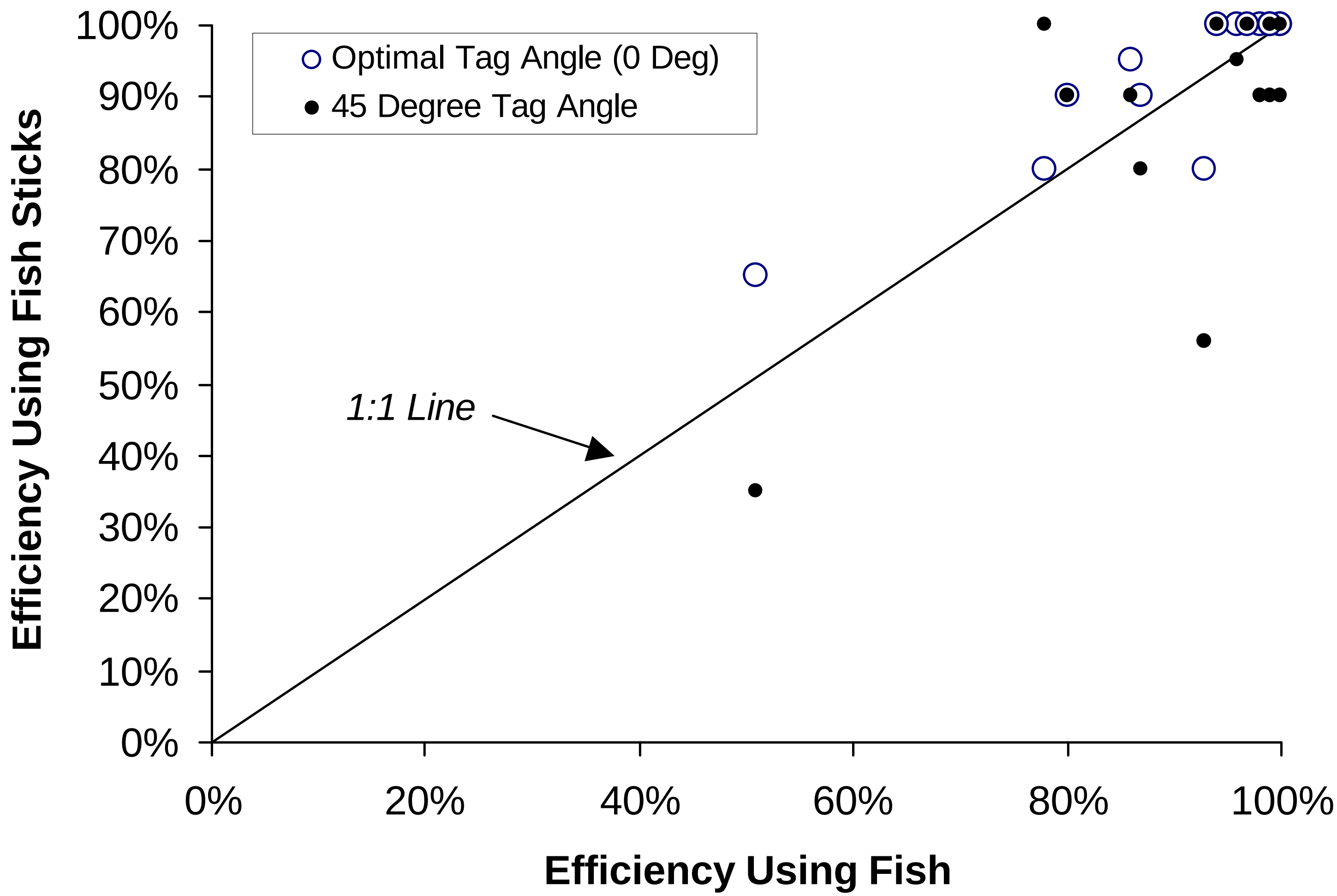


Figure 3-5. Comparisons of tunnel detector efficiencies at the Locks determined using live fish and fish sticks, 2002 Lake Washington GI study.

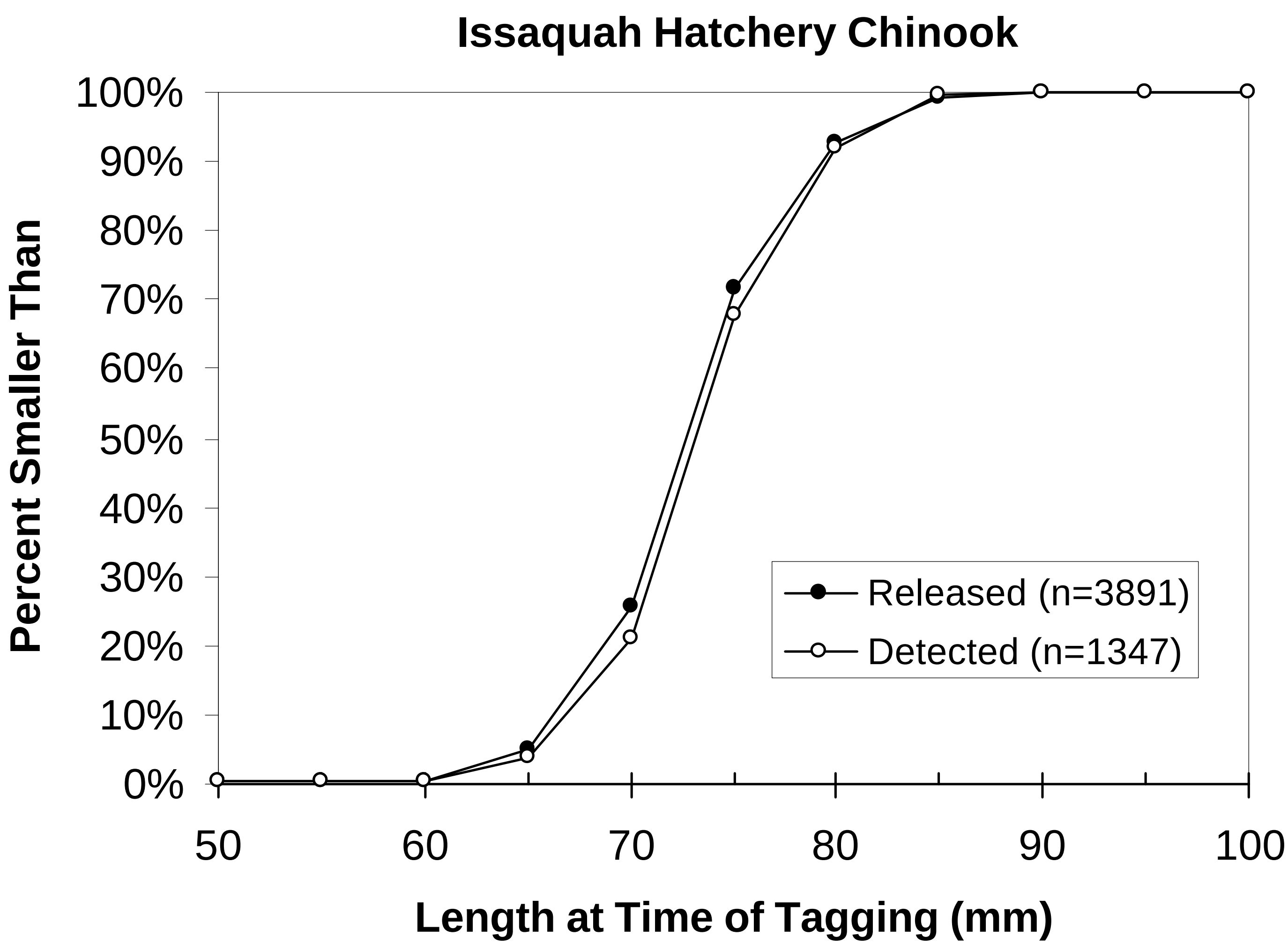
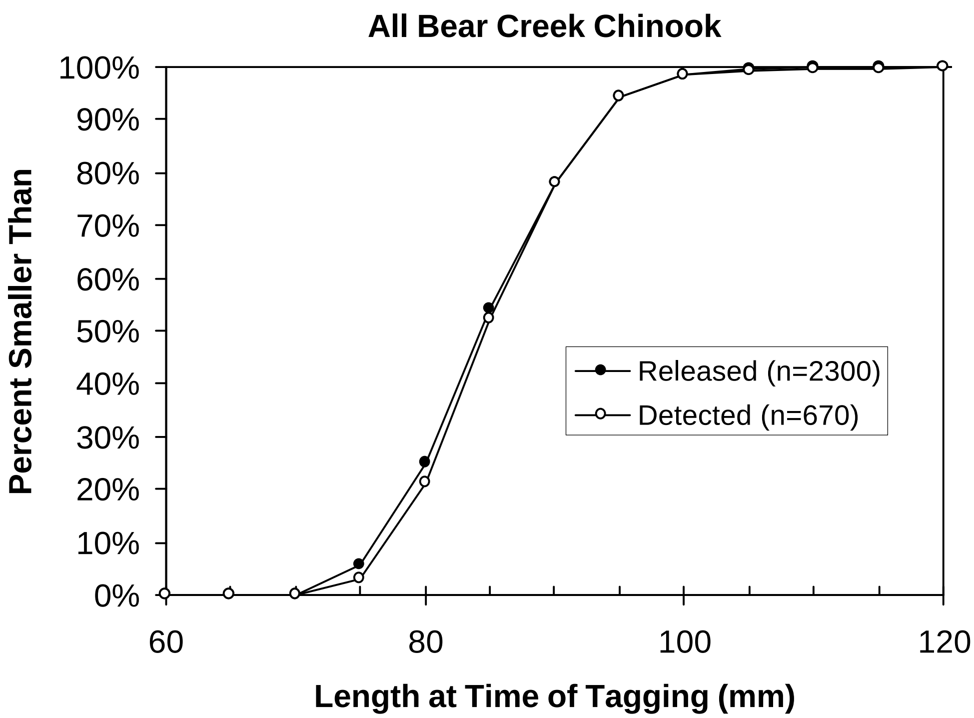


Figure 3-6. Cumulative frequency distributions of lengths of tagged and detected chinook salmon released at the Issaquah Hatchery, 2002 Lake Washington GI study.



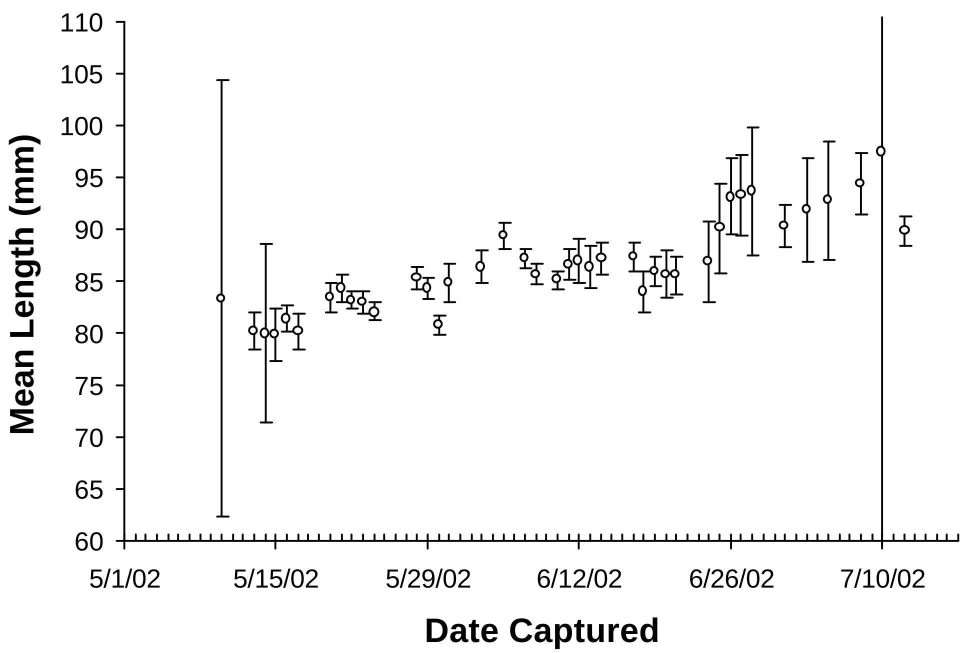
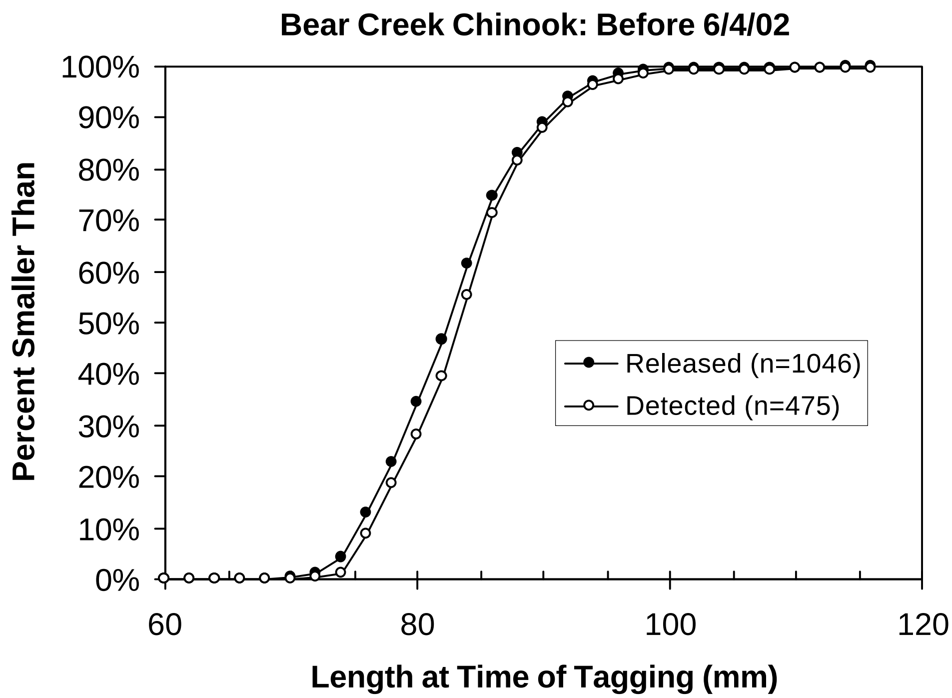


Figure 3-7. Cumulative frequency distributions of lengths of tagged and detected chinook salmon caught in Bear Creek (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2002 Lake Washington GI study.



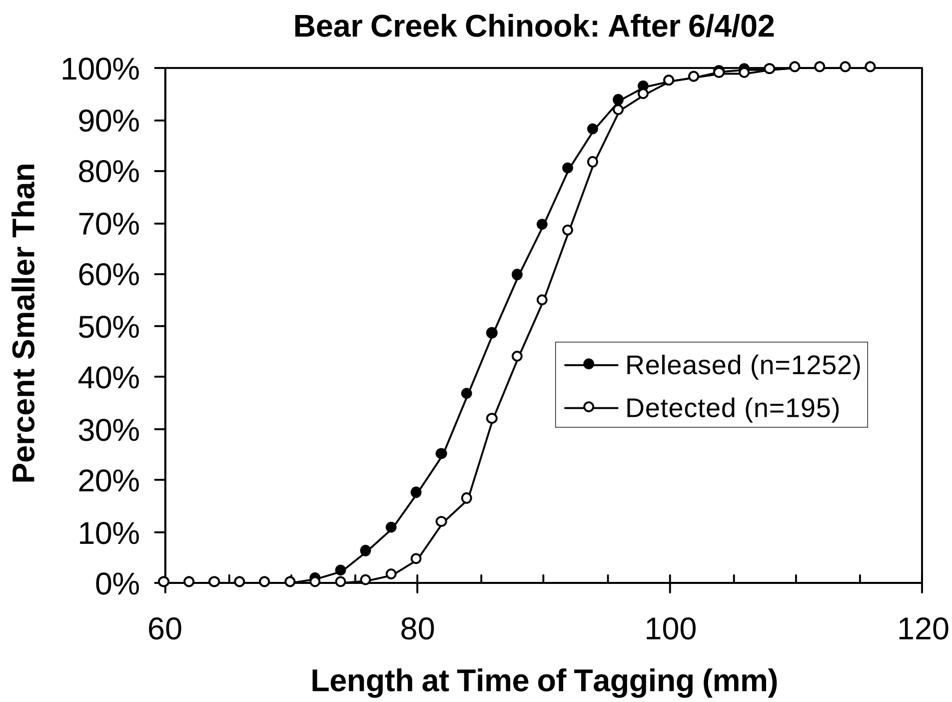


Figure 3-8. Cumulative frequency distributions of lengths of tagged and detected chinook salmon caught in Bear Creek before 5/27/01 (top) and between 5/27/01 and 6/12/01 (bottom), 2002 Lake Washington GI study.

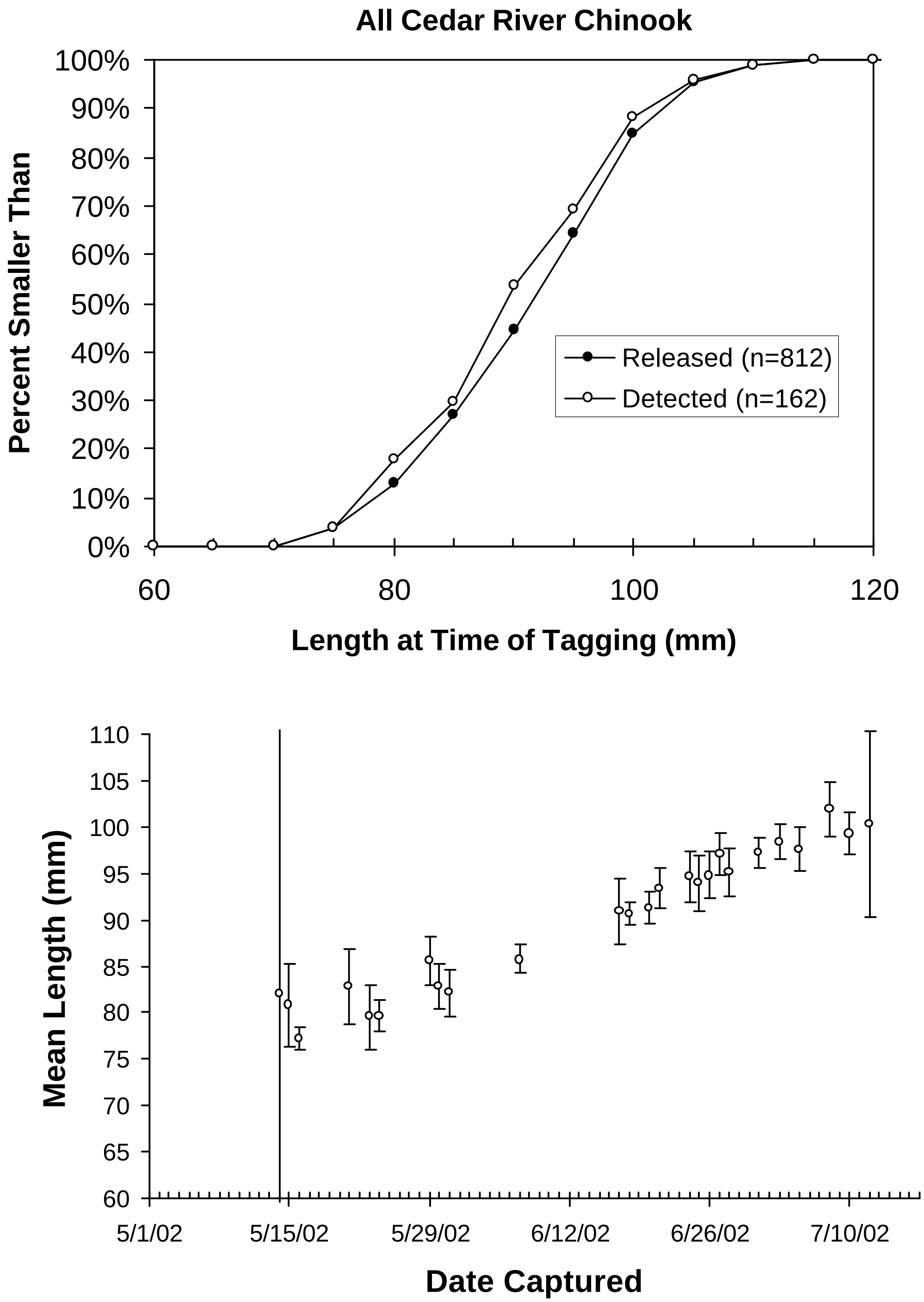
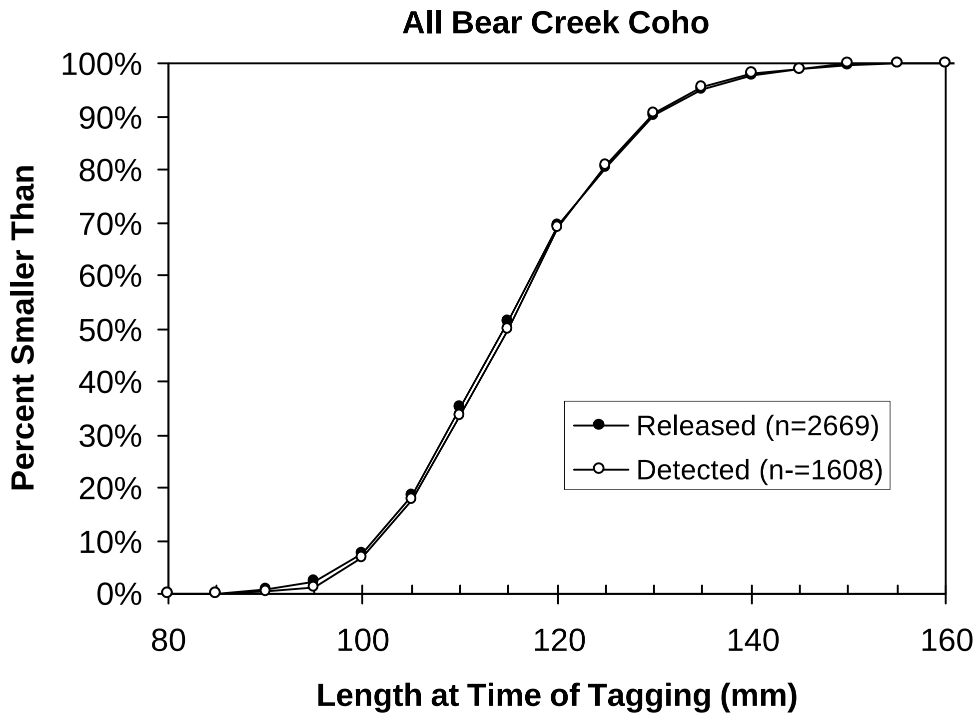


Figure 3-9. Cumulative frequency distributions of lengths of tagged and detected chinook salmon caught in the Cedar River (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2002 Lake Washington GI study.



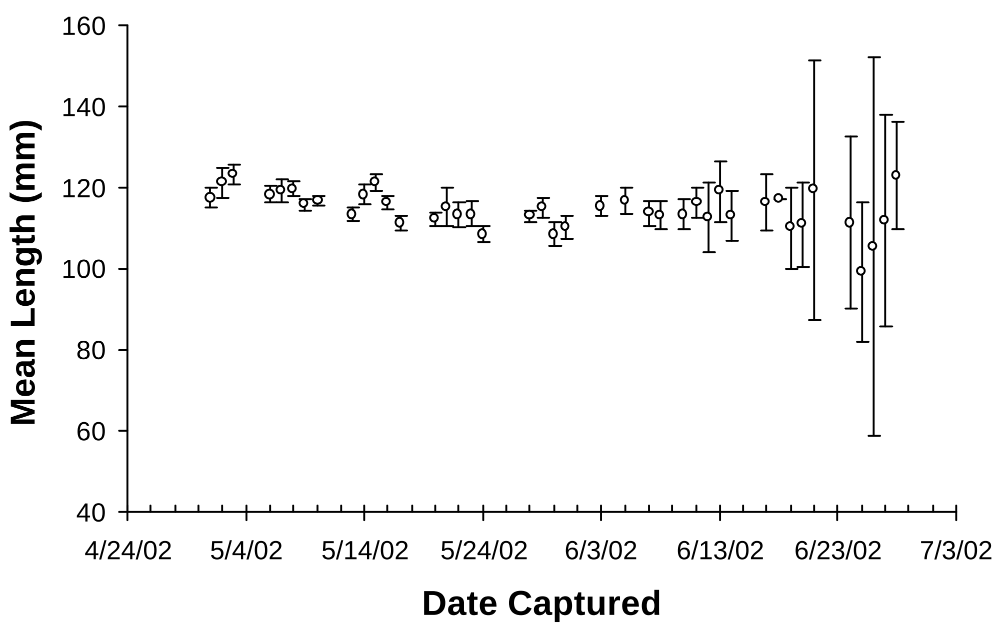


Figure 3-10. Cumulative frequency distributions of lengths of tagged and detected coho salmon caught in Bear Creek (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2002 Lake Washington GI study.

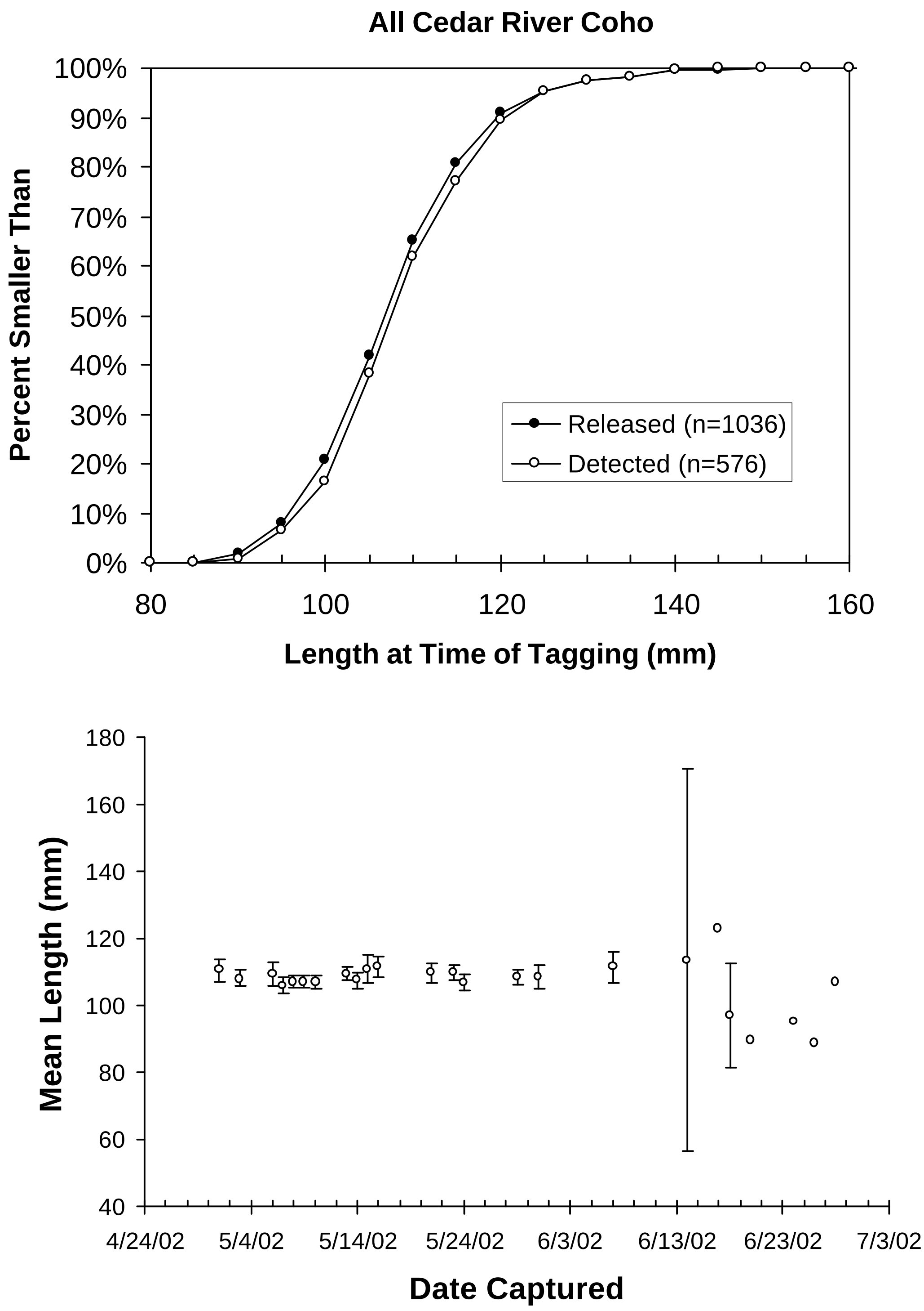


Figure 3-11. Cumulative frequency distributions of lengths of tagged and detected coho salmon caught in the Cedar River (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2002 Lake Washington GI study.

in 2000 and 2001. Cedar River chinook lengths gradually increased over the outmigration season (Figure 3-9). There were no significant differences in size distributions of released and detected fish, even when the data were partitioned into the two periods suggested by the Bear Creek data in Figure 3-7.

Mean lengths of coho salmon remained relatively constant over the outmigration season in both Bear Creek and the Cedar River (Figures 3-10 and 3-11). There were no significant differences in size distributions of released and detected coho (Chi-square test, á = <0.05; Figures 3-10 and 3-11).

3.4 MIGRATION BEHAVIOR

The PIT tag data provided valuable information on arrival date and travel rate to the Locks from the different release locations. It is possible that the majority of the chinook run had passed through the Locks before the flumes were shut down, because the cumulative distributions of passage timing for each release group had pronounced asymptotes at their upper ends (Figure 3-12). However, as will be discussed later, this may be in part an artifact of changes in passage behavior at the Locks, where later-arriving fish may have used the flumes less and chosen alternate routes (e.g., through the two locks).

3.4.1 Migration Timing

As in 2000, coho salmon generally outmigrated first followed by chinook salmon (Figure 3-12). The Issaquah Hatchery and Bear Creek chinook passed through the Locks at about the same time. In contrast to 2001, Cedar River chinook passed later in the season. Conversely, coho salmon juveniles from Bear Creek and the Cedar River passed closer to the same time, although Cedar River fish were again slightly later than Bear Creek fish (Figure 3-12).

A comparison of the passage timing data with lunar data indicated passage timing was consistent with patterns observed in 2000 and 2001, suggesting further that a strong connection existed between moon location relative to the earth and passage timing of chinook and coho salmon. This connection appeared to be stronger than for moon phase, which is reasonable considering that light intensity at the Locks at night is strongly influenced by illumination and cloud cover. Specifically, passage through the Locks increased markedly for all three species within a day or two of the moon being at apogee (i.e., when it is farthest from the earth; Figure 3-12). Apogee occurred on May 7 and June 4, 2002. Passage was nearly complete by the time of the next

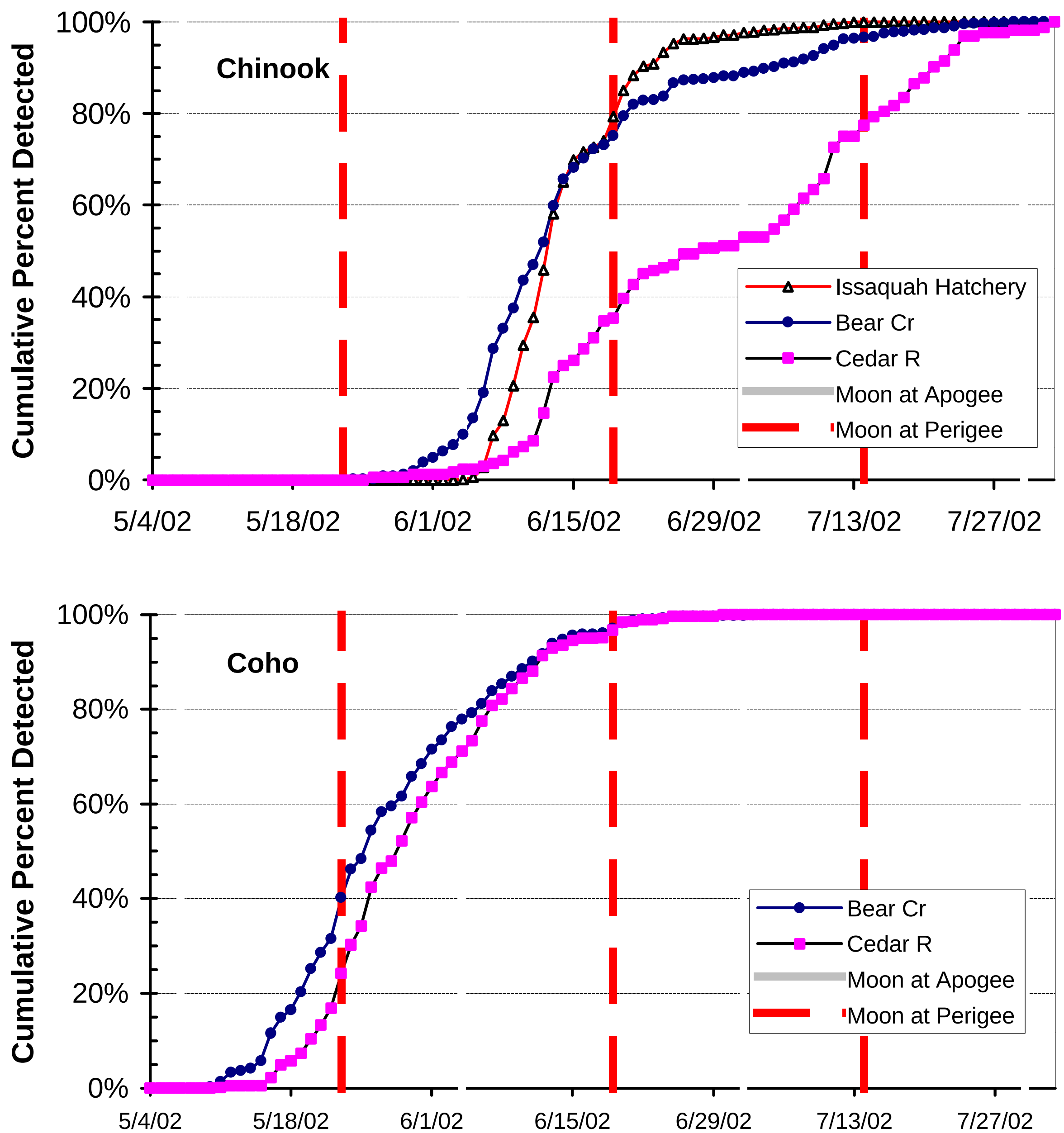


Figure 3-12. Cumulative frequency distributions of the numbers of PIT tagged juvenile chinook and coho salmon that were detected, as they passed the smolt flumes at the Locks, by date and release location, 2002 Lake Washington GI study. The dates when the moon was at apogee and perigee are indicated by the vertical lines.

apogee (July 2, 2002). A gravitational influence on passage timing is therefore suggested by the tunnel reader detection data. It is unknown if the fish detect this influence directly, if the behavior is in response to variation in saltwater intrusion, or if the influence is manifest through small-magnitude tidal phenomena in Lake Washington and the LWSC.

3.4.2 Migration Rate

Average migration rates varied between the Issaquah and UW hatchery, Lake Union, Montlake, and tributary release groups. Table 3-2 lists the estimated minimum travel distances between the different release locations and the Locks, excluding possible detours. Chinook salmon juveniles exhibited migration rates that differed markedly from rates observed in 2000 and 2001 (cf. DeVries 2001, 2002). In contrast to previous years, the number of days between release and detection did not reflect the distance traveled in 2002, with fish released farther away taking a shorter time to reach and pass the Locks (Figure 3-13). A similar pattern was observed for coho salmon. Both chinook and coho salmon juveniles appeared to generally compensate for longer outmigration distances by traveling more rapidly on average (Figure 3-13). Migration rates were generally faster than in 2001 when both species migrated at roughly half the rate observed in 2002 (Figure 3-13). These and the other average migration rates reported here are all subject to uncertainty regarding the length of time spent in the vicinity of the Locks before passing through the flumes. For example, if tagged fish spend more than a few days near the Locks, their actual migration rate to the Locks would be faster than the rates estimated here.

Table 3-2. Minimum travel distances between release locations of PIT tagged fish and the Locks (see Section 2.6.2 for details on how distances were determined).

Release Location	Distance to Locks (km)
West of Fremont Bridge (Metro Laboratory)	3.1
East of Fremont Bridge	4.4
East of Montlake Cut	10
Cedar River	39
Bear Creek	56
Issaquah Creek	76

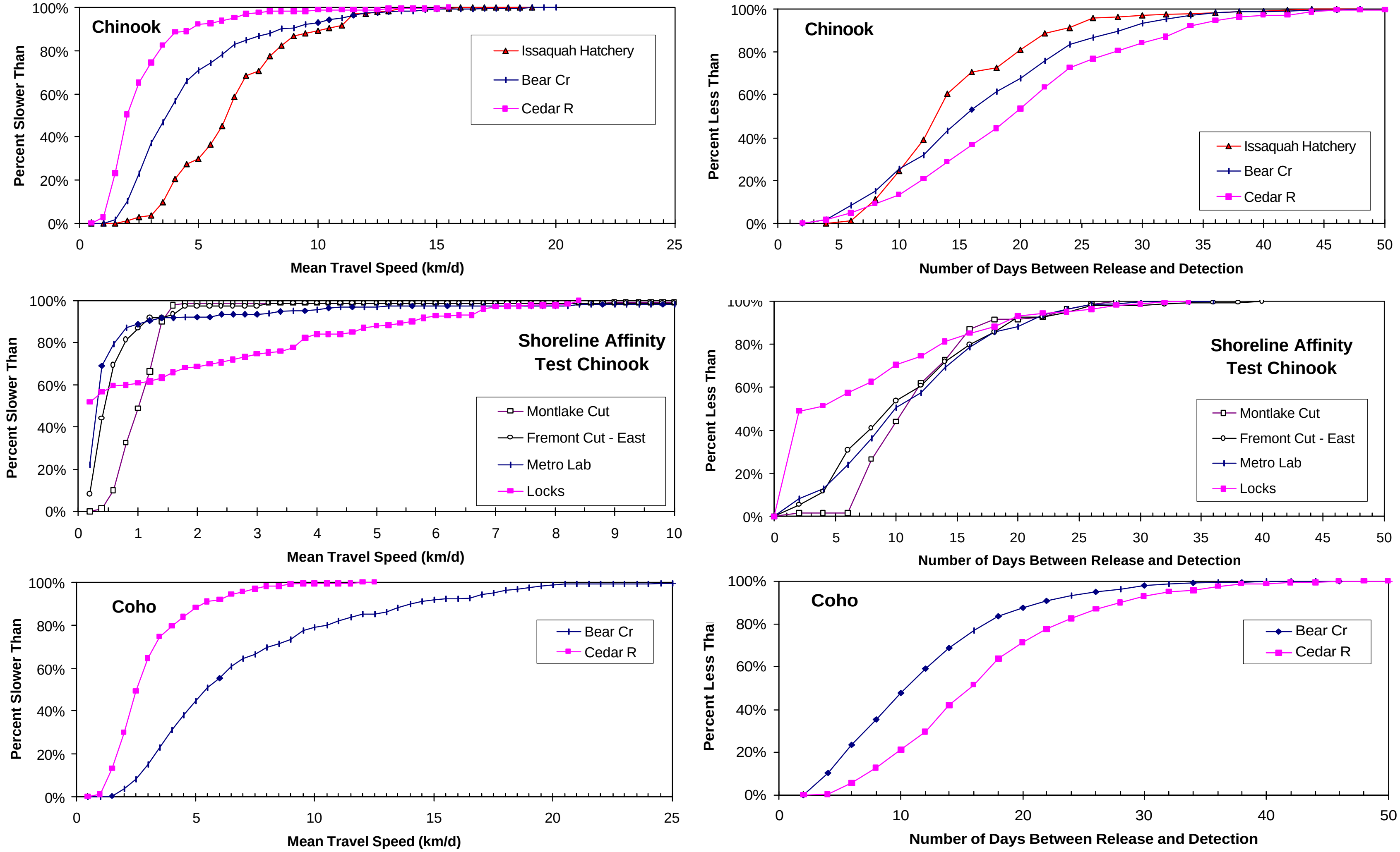


Figure 3-13. Cumulative frequency distributions of average travel speed (left) and time (right) of PIT tagged juvenile chinook (top and middle) and coho salmon (bottom) detected in the smolt flumes at the Locks, by release location, 2002 Lake Washington GI study.

Figure 3-14 indicates that migration rates of individual chinook and coho salmon juveniles exhibit an increasing trend with time over the course of the outmigration season. These results are similar to results seen in 2001 and suggest further that juvenile salmon in the Lake Washington system speed up their migration slightly as the end of the passage season approaches.

The cumulative frequency distributions of numbers of juvenile salmon tagged and detected at the flumes can also be used to describe travel times for the different release groups (Figure 3-15). In general, the distributions indicate that chinook salmon originating in Bear Creek and the Cedar River took approximately 2 weeks on average to reach and pass the smolt flumes.

Freshwater recaptures at the screwtraps were greater in number in 2002 than in the previous two years (Table 3-3). All but one chinook were recaptured in Bear Creek, and no chinook were recaptured more than one day after tagging. Coho salmon exhibited a tendency to remain in the vicinity of the trap for longer.

3.4.3 Shoreline Affinity in the LWSC

The number of replicates was too small to test for significant differences. Nonetheless, the tunnel reader detection data were consistent with the hypothesis that there is no shoreline affinity. The ratio of south:north detections did not appear to be substantially different from 1.0 for all groups except the fish released approximately 300 m from the Locks, of which a higher proportion of fish released on the south side was detected in the flumes than of fish released on the north side (Figure 3-16). These results suggest that smolts disperse and mix fully as they migrate through the LWSC before they reach the Locks.

3.4.4 Residualism in the Lake Washington System

The 2002 study confirmed the hypothesis suggested by length frequency data collected in the 2000 and 2001 studies that some outmigrants may remain in Lake Washington or Lake Union as yearlings before entering saltwater. One natural chinook detected in 2002 was tagged in Issaquah Creek in 2000 (Table 3-4). A relatively large number of chinook, coho, and sockeye were detected in 2002 that had been tagged in 2001. Seven tags were detected that were registered to Bill Muir, NMFS, and were not in the 2002 tagging files. These tags most likely originated from tagging done by Steve Achord, NMFS, in the LWSC in 2001. Comparisons of the fish length and tagging date data in Table 3-4 with length frequency distributions in 2000 and 2001 indicated that the residualized fish were from the smaller half of the size distribution of all

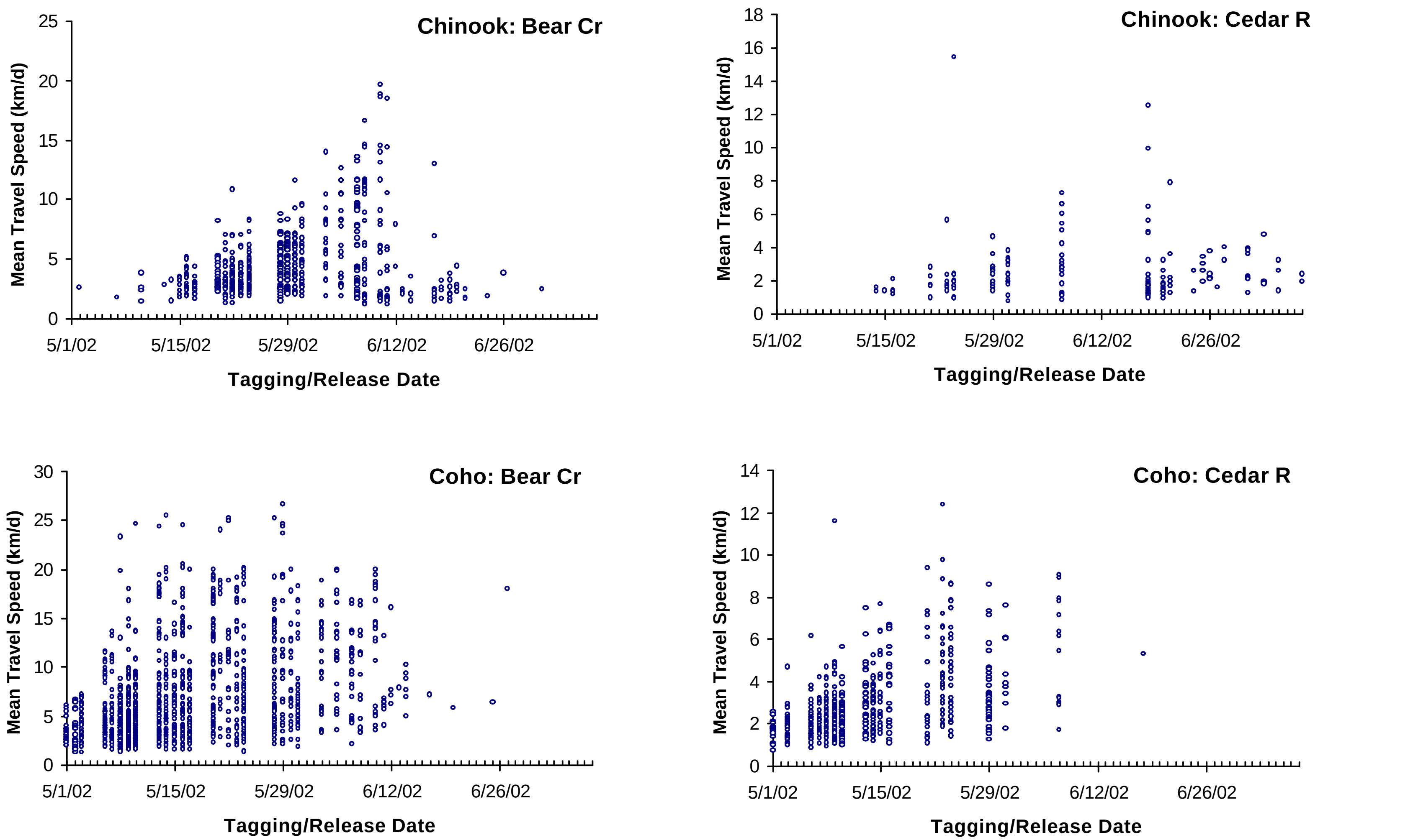


Figure 3-14. Scatterplot of mean travel speed of individual PIT tagged juvenile chinook and coho salmon that were detected as they passed the smolt flumes at the Locks, plotted by release date and location, 2002 Lake Washington GI study.

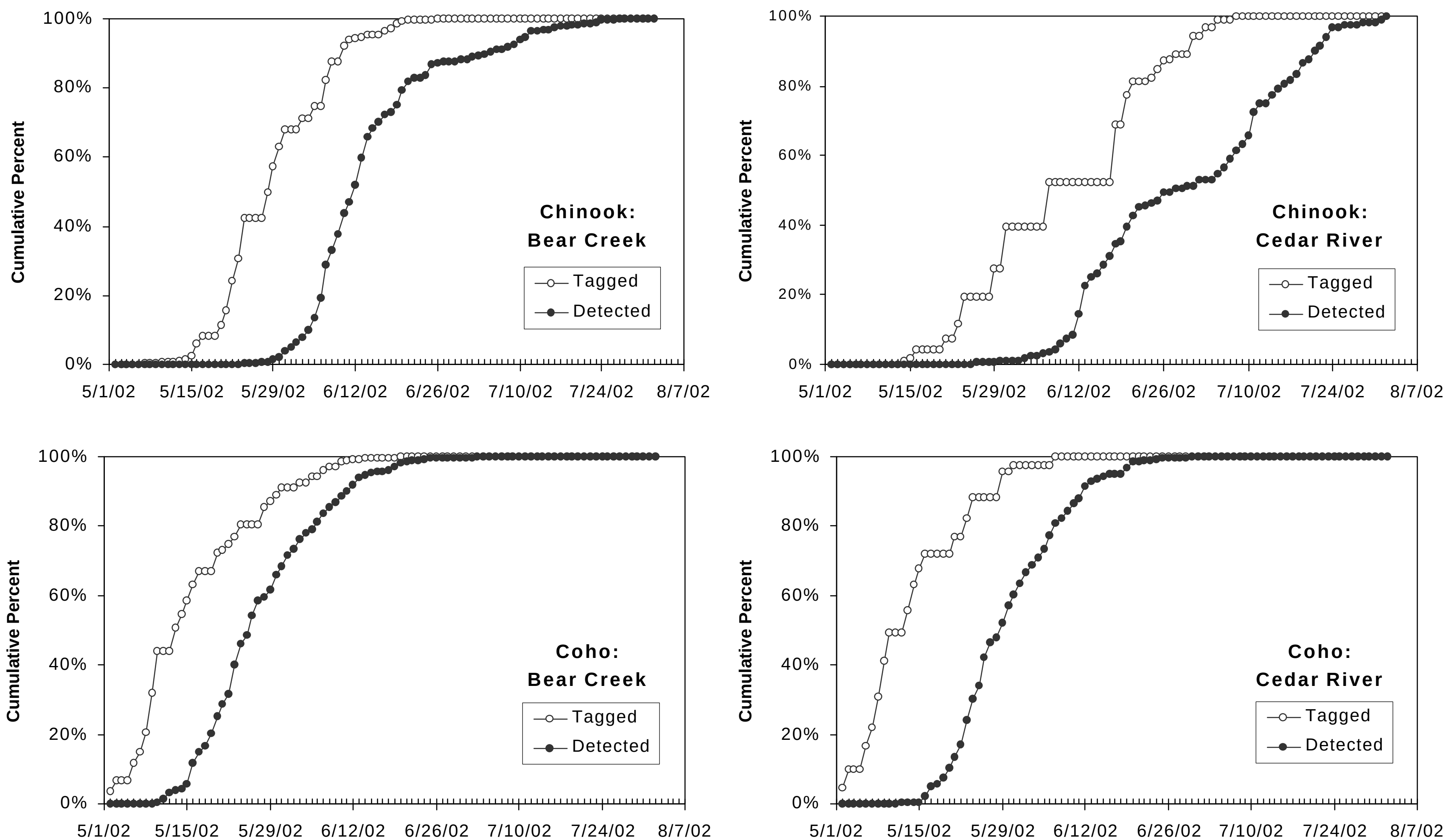


Figure 3-15. Cumulative frequency distributions of the numbers of PIT tagged juvenile chinook and coho salmon that were tagged and detected as they passed the smolt flumes at the Locks, by date and release location, 2002 Lake Washington GI study. The horizontal difference between the two curves in each plot reflects the average time taken by all fish from a release location to travel to the Locks and pass through the smolt flumes.

Table 3-3. Fish[1] recaptured in screw traps in 2002 in the Lake Washington GI study.

		Length (mm)		Date of			
Species	**Location**	**Tagging**	**Recapture**	**Tagging**	**Recapture**	**Interval (Days)**	**Detection Date at Locks**
Chinook	Bear Cr	79	80	5/20/02	5/21/02	1	6/11/02
	Bear Cr	78	78	5/22/02	5/23/02	1	6/20/02
	Bear Cr	79	78	5/22/02	5/23/02	1	Not Detected
	Bear Cr	79	81	5/30/02	5/31/02	1	Not Detected
	Bear Cr	74	73	5/30/02	5/31/02	1	Not Detected
	Bear Cr	92	92	5/30/02	5/31/02	1	Not Detected
	Bear Cr	94	88	6/7/02	6/8/02	1	Not Detected
	Bear Cr	93	93	6/7/02	6/8/02	1	Not Detected
	Bear Cr	93	92	6/7/02	6/8/02	1	Not Detected
	Bear Cr	89	88	6/17/02	6/18/02	1	Not Detected
	Bear Cr	74	75	6/17/02	6/18/02	1	Not Detected
	Bear Cr	83	83	6/24/02	6/25/02	1	Not Detected
	Bear Cr	84	84	6/17/02	6/18/02	1	Not Detected
	Cedar R	75	75	5/30/02	5/31/02	1	Not Detected
Coho	Bear Cr	128	127	5/6/02	5/7/02	1	5/17/02
	Bear Cr	126	125	5/6/02	5/8/02	2	5/22/02
	Bear Cr	110	111	5/7/02	5/8/02	1	6/5/02
	Bear Cr	116	112	5/7/02	5/8/02	1	5/30/02
	Bear Cr	112	113	5/8/02	5/9/02	1	Not Detected
	Bear Cr	135	135	5/16/02	5/17/02	1	Not Detected
	Bear Cr	119	119	5/23/02	5/24/02	1	6/1/02
	Bear Cr	121	124	5/28/02	5/31/02	3	6/4/02
	Bear Cr	111	110	5/31/02	6/3/02	3	6/6/02
	Bear Cr	129	137	5/31/02	6/7/02	7	6/20/02
	Bear Cr	106	108	6/3/02	6/5/02	2	Not Detected
	Bear Cr	115	117	6/3/02	6/11/02	8	Not Detected
	Bear Cr	96	101	6/7/02	6/10/02	3	Not Detected
	Bear Cr	107	105	6/8/02	6/11/02	3	6/25/02
	Bear Cr	113	113	6/13/02	6/14/02	1	Not Detected

[1] - All had adipose fins intact.

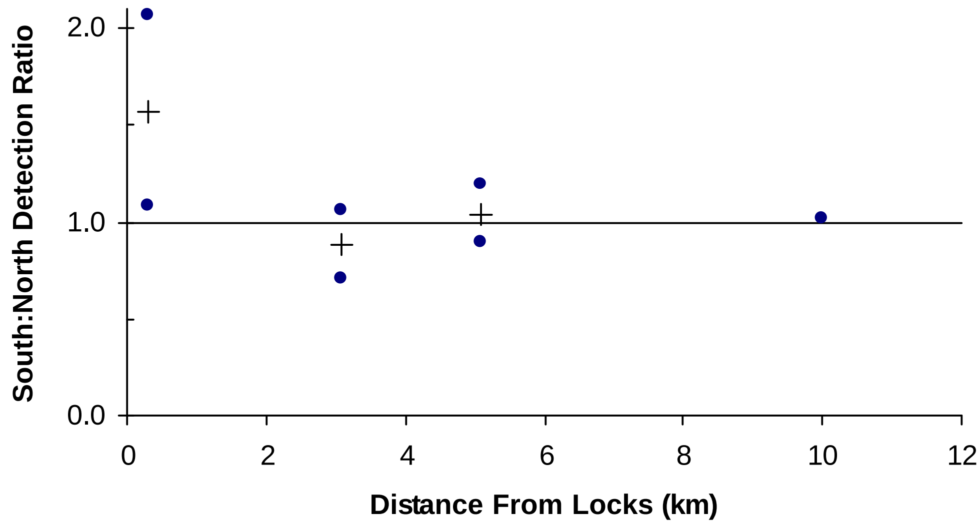


Figure 3-16. Ratio of numbers of fish released in late May-early June along the south shore to numbers of fish released at the same time along the north shore and detected in the smolt flumes, 2002 Lake Washington GI Study. Numbers have been adjusted to account for flume detection efficiencies. Average values are depicted by the '+' symbol.

tagged fish, and that they were from groups tagged later in the outmigration season. This is discussed further in Section 4.2.

3.5 PASSAGE BEHAVIOR AT LOCKS

The PIT tag data also provided valuable information on the daily timing and routes of downstream passage at the Locks.

3.5.1 Diurnal Variation in Passage Timing

As in 2000 and 2001, a behavioral pattern that was common to all release groups was the predominance of passage during daylight hours (Figure 3-17). Passage rates increased markedly beginning around 5:00 am. Moreover, there were generally two pronounced peak passage times: between approximately 6:00 am and 9:00 am, and between 5:00 pm and 8:00 pm. The second peak occurred much later in the day than in 2001, when it occurred between 11:00 am and 2:00 pm. The passage timing distributions reflected differences and similarities between stocks observed in the migration rate data (Figure 3-18; cf. Figure 3-13). Issaquah Hatchery and Bear Creek chinook juveniles exhibited similar hourly passage timing distributions, as did Bear

Table 3-4. Fish detected at the Locks in 2002 but tagged in 2001 or 2000.

	Tagging			Flume Detection		
Species	**Length (mm)**	**Location**	**Date**	**Date**	**Time**	**Interval (Days)**
Chinook [1]	87	Issaquah Cr Trap	6/7/00	6/3/02	14:10	726
	76	Bear Creek	5/15/01	5/17/02	11:33	367
	80	Bear Creek	6/5/01	5/5/02	15:00	334
	82	Bear Creek	6/12/01	5/7/02	14:28	329
	71	Bear Creek	6/21/01	5/12/02	10:57	325
	85	Cedar River	6/11/01	5/25/02	18:12	348
Coho [1]	108	Bear Creek	5/4/01	5/16/02	11:58	377
	124	Cedar River	5/23/01	6/12/02	12:44	385
Sockeye [1]	107	Cedar River	7/4/01	5/11/02	14:25	311
	100	Lake Union	6/19/01	5/16/02	15:20	331
	102	Lake Union	6/19/01	5/16/02	10:54	331
	105	Lake Union	6/26/01	5/28/02	18:18	336
	98	Lake Union	6/26/01	5/12/02	5:51	320
	100	Lake Union	6/26/01	6/8/02	5:08	347
	104	Lake Union	6/26/01	5/11/02	15:25	319
	108	Lake Union	6/26/01	5/20/02	18:10	328
	95	Lake Union	6/26/01	5/11/02	6:10	319
	102	Lake Union	6/26/01	5/16/02	15:58	324
	95	Lake Union	6/26/01	5/11/02	16:52	319
	89	Montlake Cut	6/19/01	5/22/02	19:56:11	337
	87	Montlake Cut	6/19/01	5/23/02	7:08:03	338
Unknown	Unknown	Unknown	2001	6/10/02	0:22:57	na
	Unknown	Unknown	2001	6/7/02	10:32:08	na
	Unknown	Unknown	2001	6/1/02	13:23:05	na
	Unknown	Unknown	2001	6/15/02	19:03:06	na
	Unknown	Unknown	2001	5/20/02	6:22:00	na
	Unknown	Unknown	2001	5/24/02	5:05:21	na
	Unknown	Unknown	2001	6/8/02	18:09:09	na

[1] - All had adipose fins intact.

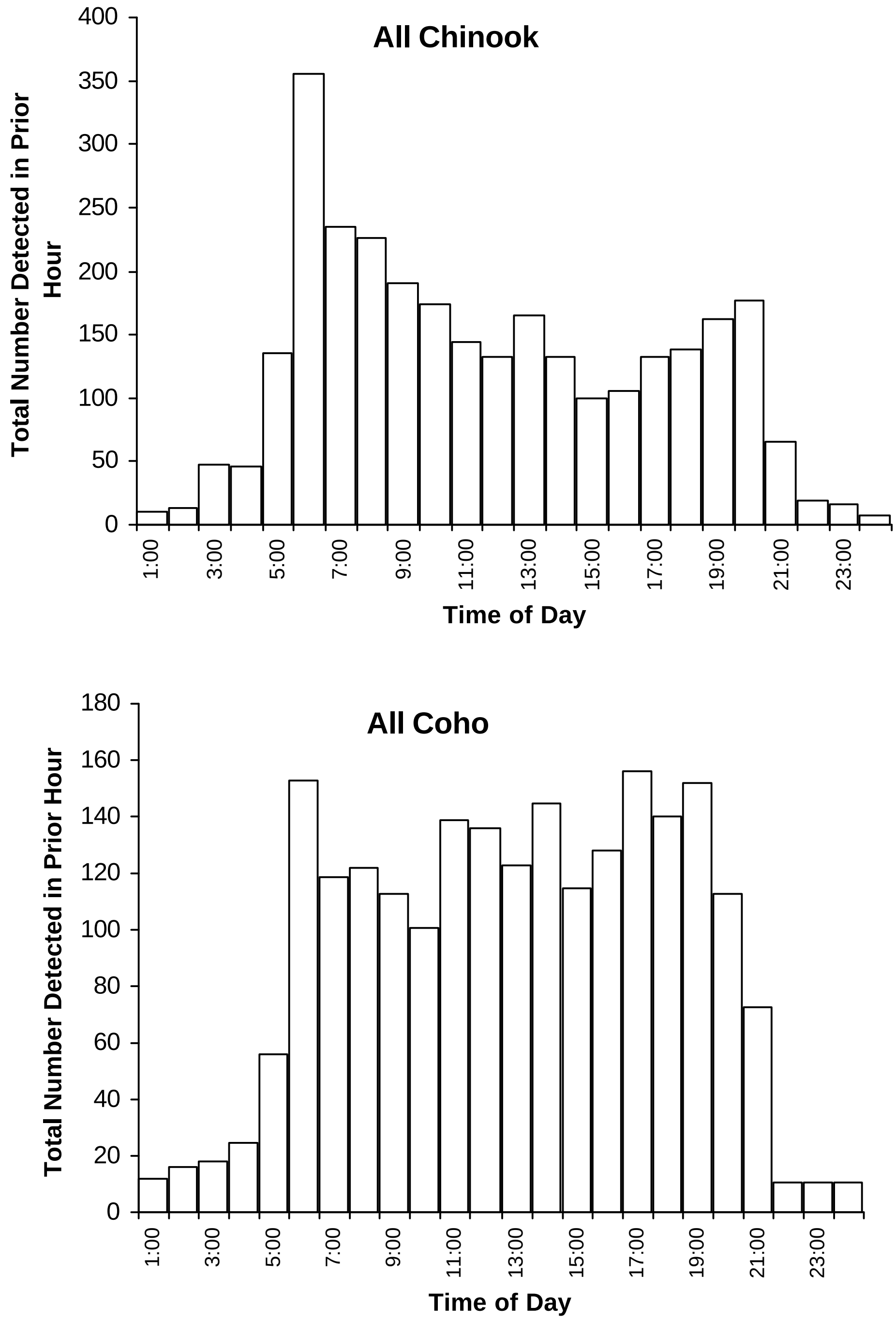


Figure 3-17. Diurnal variation in time of passage through the smolt flumes at the Locks by PIT tagged juvenile chinook and coho salmon, 2002 Lake Washington GI study. All release groups for each salmon species are represented.

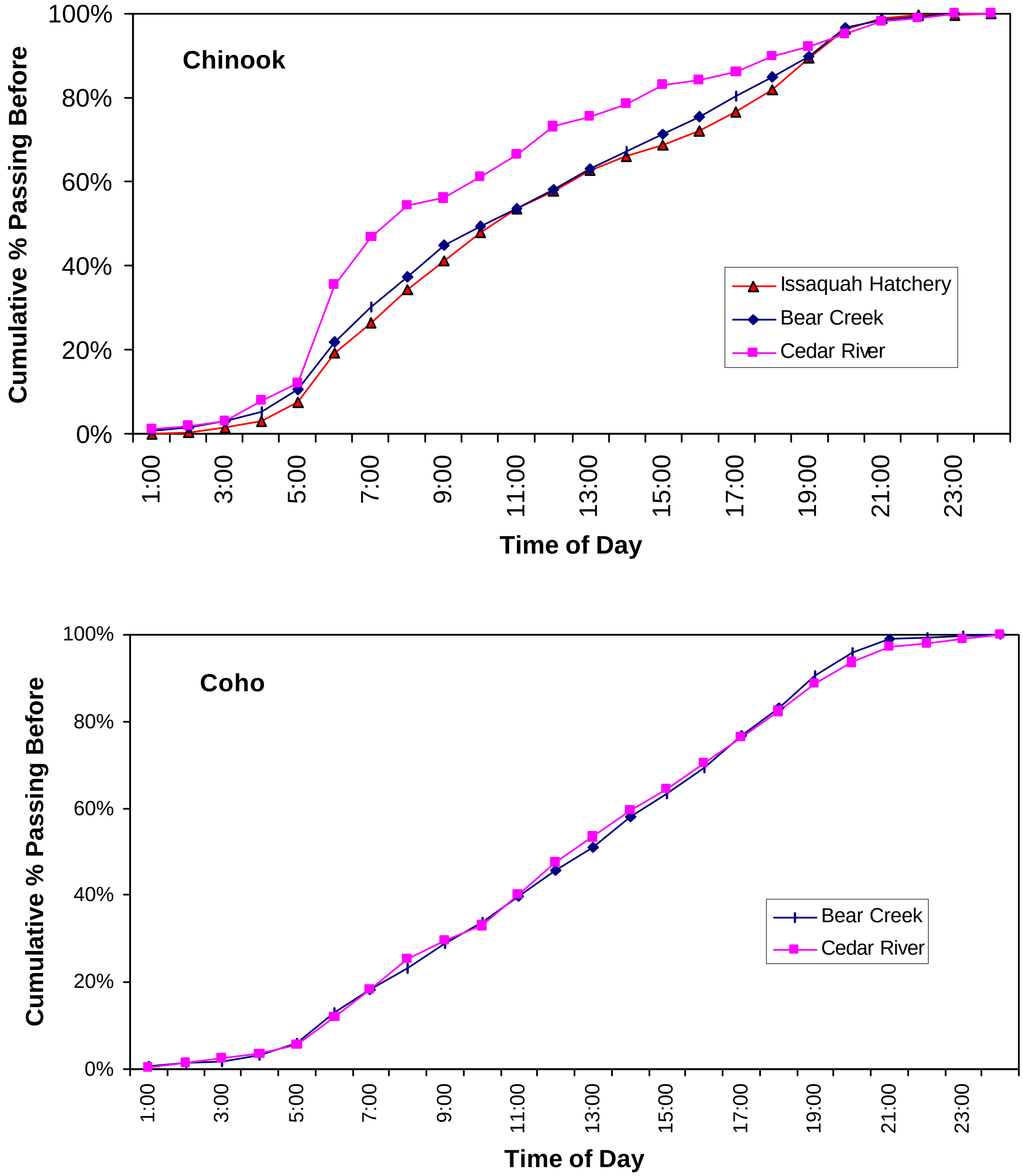


Figure 3-18. Cumulative frequency distributions of the diurnal variation in time of passage through the smolt flumes at the Locks by PIT tagged juvenile chinook and coho salmon, by release location, 2002 Lake Washington GI study.

Creek and Cedar River coho juveniles. Cedar River chinook juveniles, which took longer to migrate to the Locks, tended to pass earlier in the day than Issaquah Hatchery and Bear Creek chinook (Figure 3-18). These results generally stand in contrast to data collected for the Columbia River system, where passage at hydropower facilities has been noted to occur predominantly during nighttime hours (e.g., Brege et al. 1996).

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 5 to through June 17, 2002; see Figure 3-1). In 2002, 61%, and 47% of detected chinook and coho, respectively, passed through gate 5 when all four flumes were operational. A similar result was noted in 2001.

Figure 3-19 depicts the possible passage routes through the Locks. As in 2000 and 2001, the PIT tag data confirmed once more that recycling occurred through the Locks, where 65 PIT tagged chinook and 10 coho salmon were detected twice by the tunnel readers (Figure 3-20). They therefore had to have migrated back upstream through either the large or small lock. Recycling time patterns appeared to be similar to patterns observed in the 2000 and 2001 studies. Calibration test chinook exhibited a stronger tendency for recycling than fish originating from the other groups. The few coho detected more than once generally exhibited shorter recycling times than the chinook. The behavior of the calibration test chinook may have reflected their being held in chilled water and subsequent release directly into the flumes. As in the 2000 and 2001 studies, the intervening time between first and second detection shortened as the outmigration season progressed for all release groups represented in Figure 3-20.

There were 14 chinook and 1 coho that recycled more than twice (Figure 3-21). The calibration test chinook exhibited the strongest recycling behavior of all the groups. One recycled seven times. The trend for reduced recycling time was stronger in 2002 than 2001, however, when this behavior was exhibited exclusively by UW hatchery fish. In 2002, the repeat recyclers included a later arriving chinook from Bear Creek.

The shoreline affinity test results depicted in Figure 3-22 indicate the hatchery chinook juveniles that were released mixed fully within the LWSC. The previous two year's data and results in Section 3.6 suggest that it is reasonable to assume survival to the locks from the three release locations near the Fremont Cut and Montlake Cut was nearly 100%. Given these observations, the shoreline affinity test releases in the LWSC suggest that an average of approximately 44% of

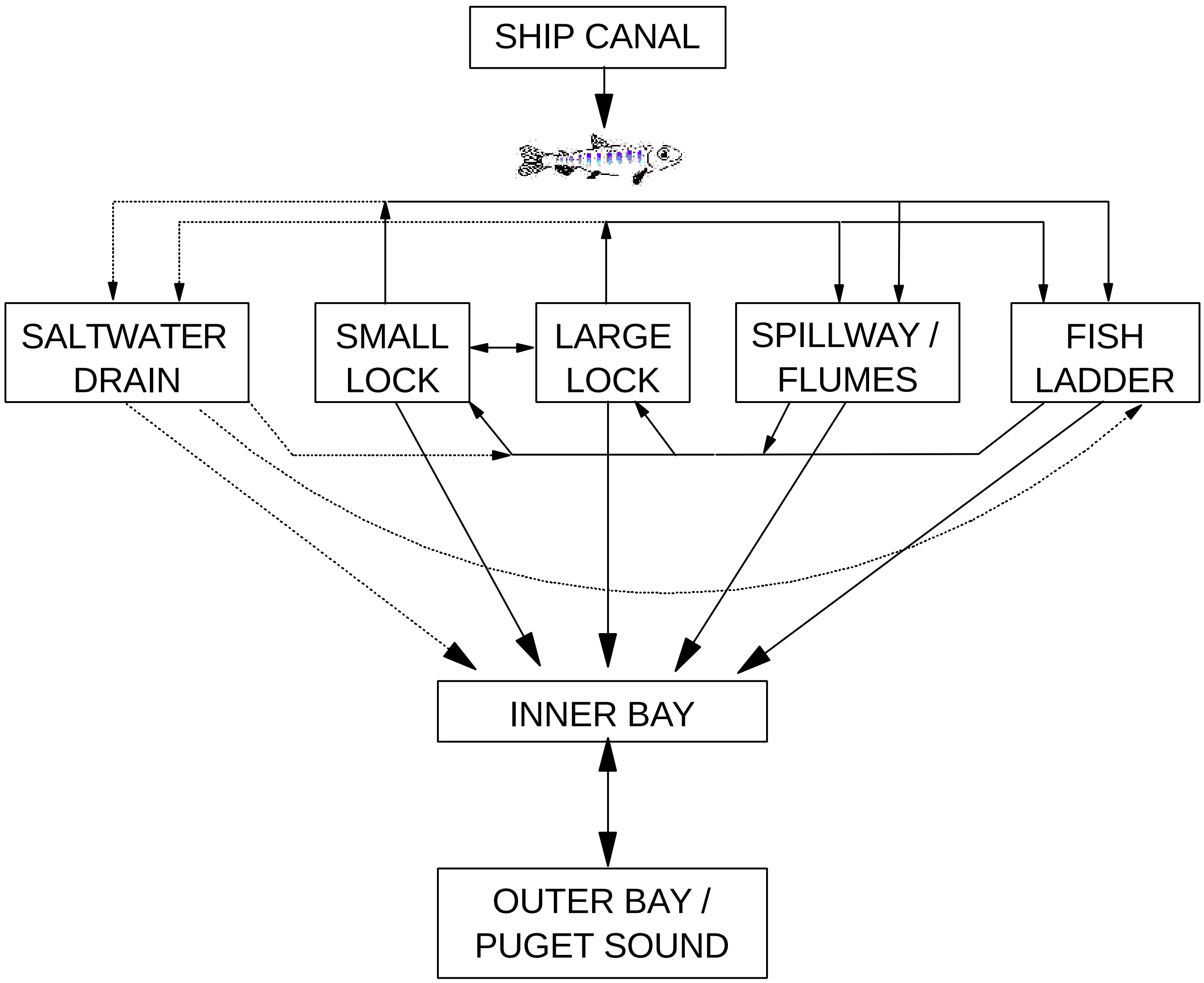


Figure 3-19. Possible migration routes of juvenile salmon through the Hiram M. Chittenden Locks to the saltwater beaches located below. The routes are indicated for fish after they have first encountered the Locks and have entered one of the five structural facilities indicated. For example, a fish entering 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.

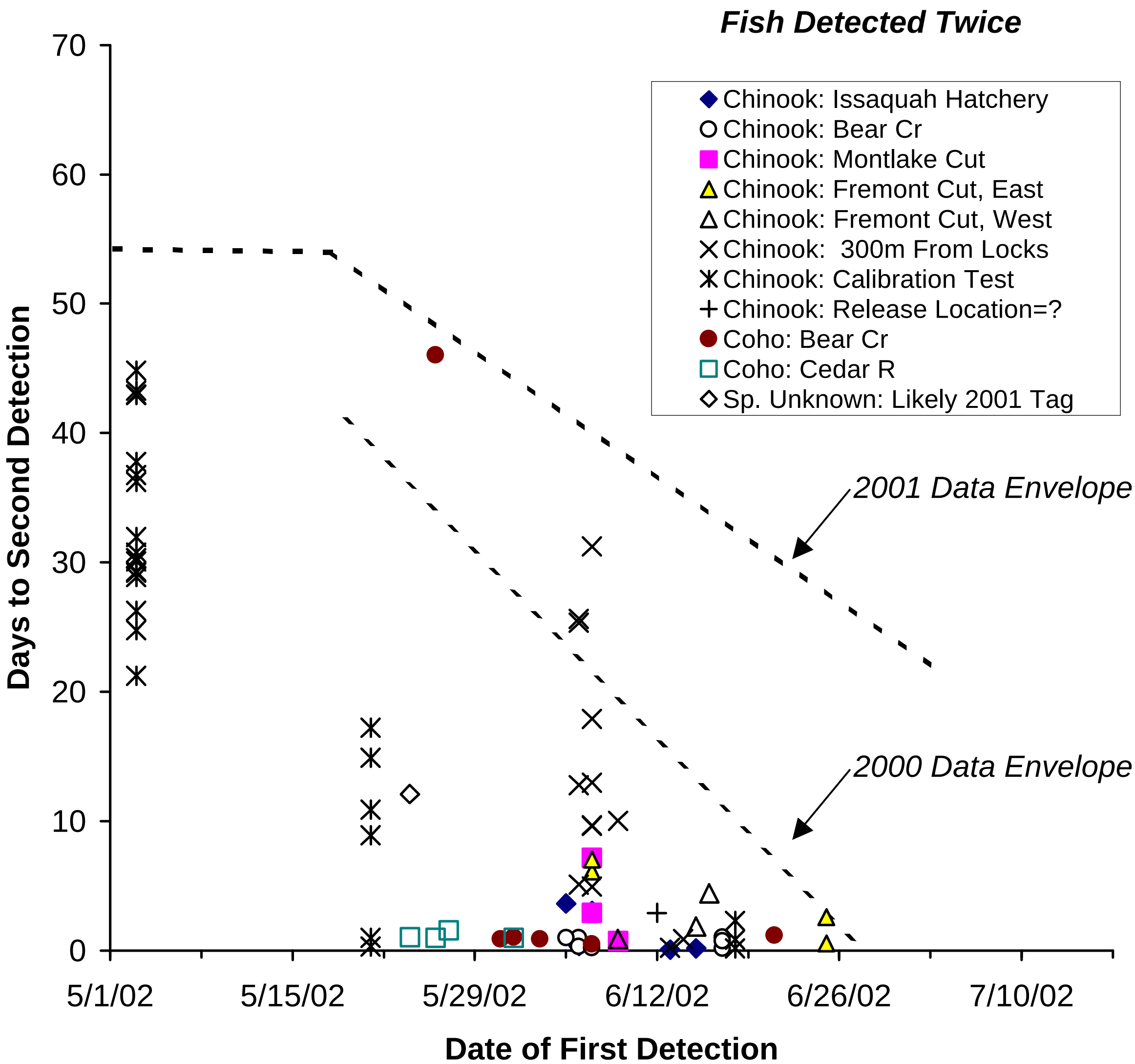


Figure 3-20. Recycling times of PIT tagged juvenile chinook and coho salmon passing downstream twice through the smolt flumes at the Locks, 2002 Lake Washington GI study. The upper data envelope from the 2000 and 2001 studies are indicated by the diagonal dashed line.

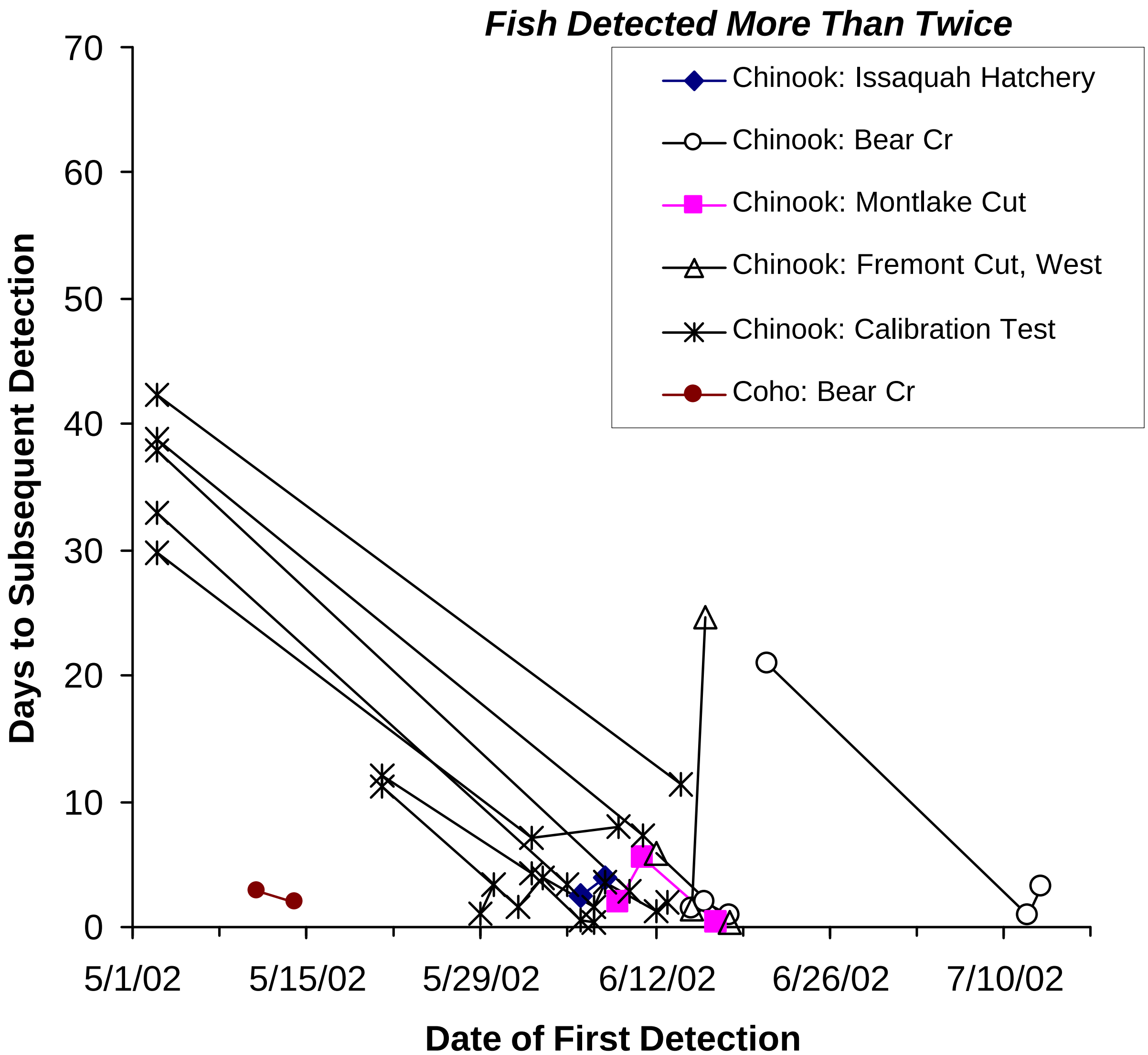


Figure 3-21. Recycling times of PIT tagged juvenile chinook and coho salmon passing downstream more than two times through the smolt flumes at the Locks, 2002 Lake Washington GI study.

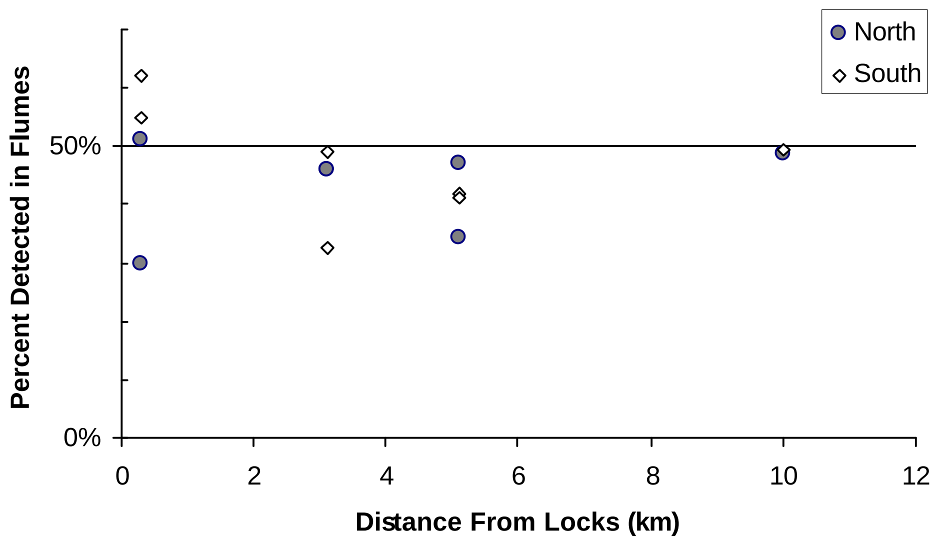


Figure 3-22. Proportion of fish released in late May-early June along the south and north shore that passed through the smolt flumes, 2002 Lake Washington GI Study. Numbers have been adjusted to account for flume detection efficiencies.

fish surviving the migration through the LWSC in early June 2002 used the smolt flumes, and the remainder used the alternate routes depicted in Figure 3-19 (Figure 3-22). This number excludes the fish released within 300 m of the Locks.

In summary, the PIT tag data indicate that a strong seasonal influence on outmigration existed in the LWSC, and that some chinook and coho juveniles lingered in the upstream and downstream vicinity of the Locks before making a final transition to saltwater during May and June 2002. There was no relation of recycling time between detections in the flumes to release group or size of fish at time of tagging. In addition, there does not appear to be shoreline affinity in the LWSC, at least in the case of hatchery chinook salmon.

3.5.3 Influence of Lock Operations on Passage Through Flumes

Figures 3-23 and 3-24 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

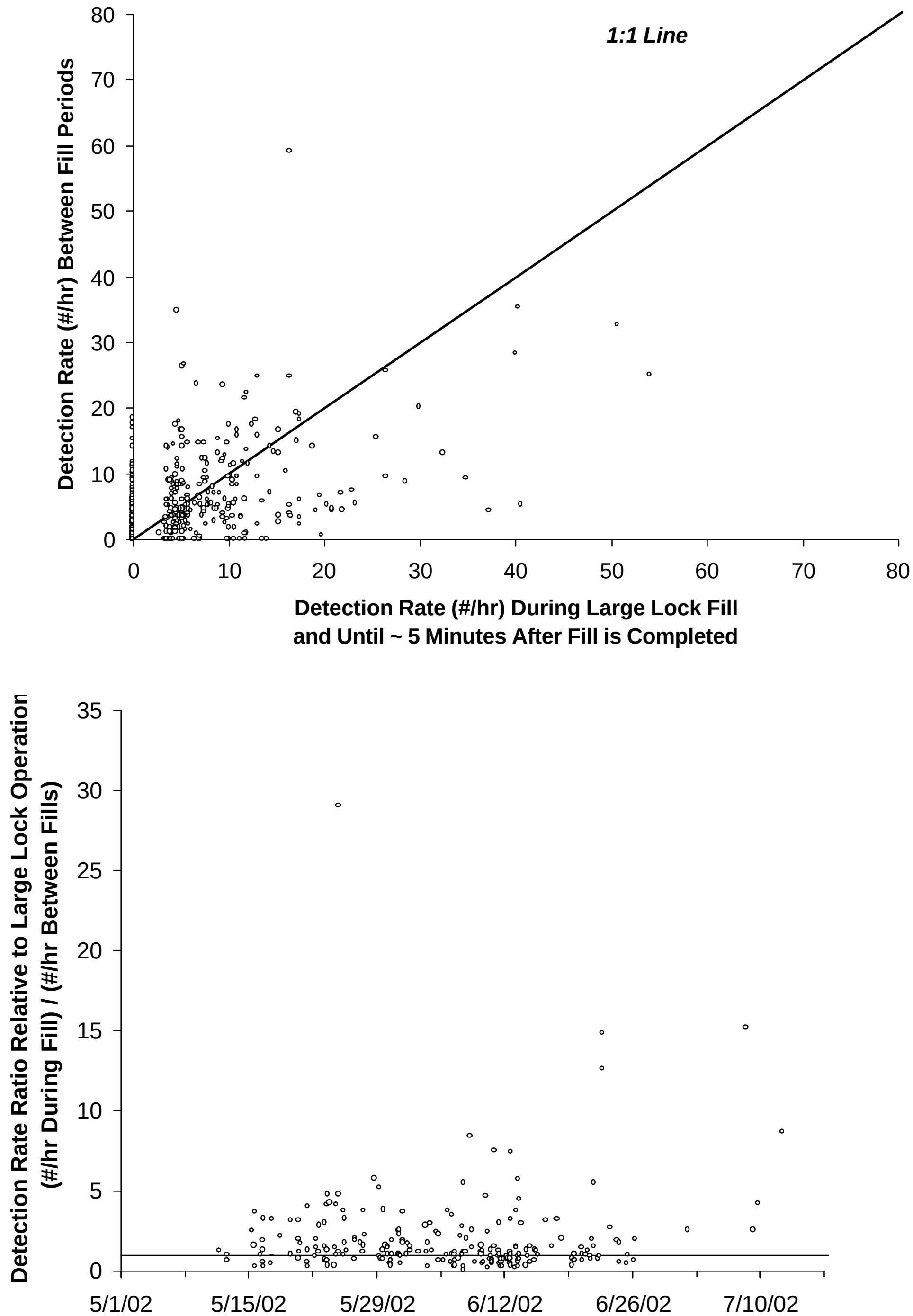


Figure 3-23. Comparison of passage rates of PIT tagged juvenile salmon (all species) through the smolt flumes at the Locks during filling of the large lock and until the next fill, 2002 Lake Washington GI study. The bottom plot shows the ratio of the two passage rates over time. The line of equality is indicated by the solid diagonal (top) and horizontal (bottom) line.

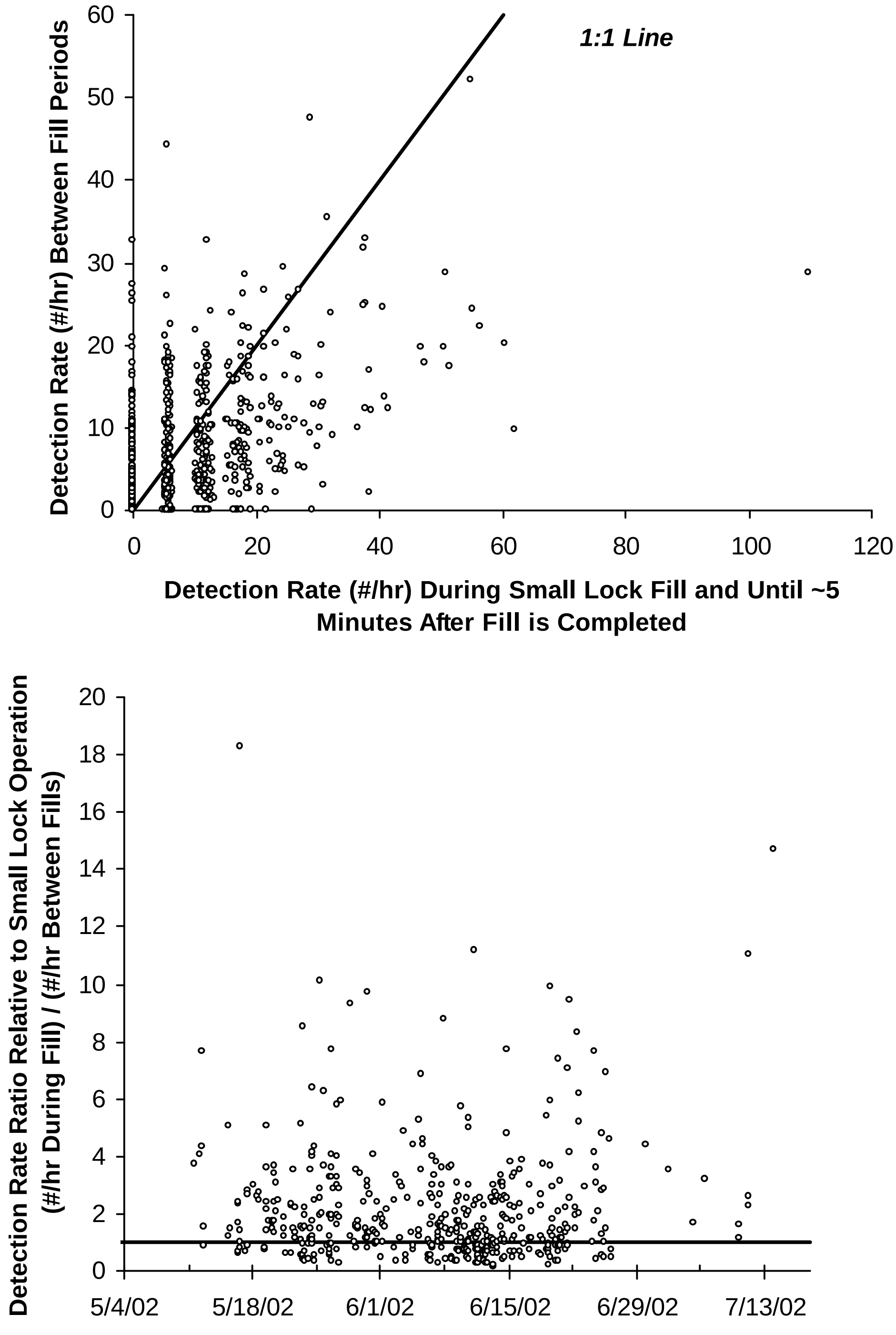


Figure 3-24. Comparison of passage rates of PIT tagged juvenile salmon (all species) through the smolt flumes at the Locks during filling of the small lock and until the next fill, 2002 Lake Washington GI study. The bottom plot shows the ratio of the two passage rates over time. The line of equality is indicated by the solid diagonal (top) and horizontal (bottom) line.

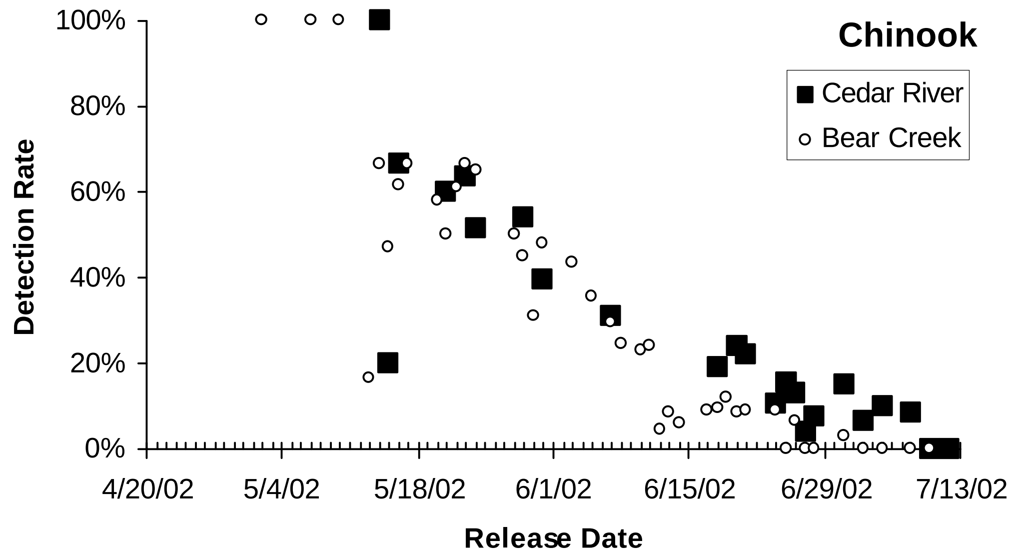
culverts (Johnson et al. 2001) as the majority of PIT tag detections occurred during daylight hours. To evaluate this statistically, the data in the figures were filtered and cases identified where fish were detected during consecutive fill and between-fill periods. A ratio was calculated of the passage 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 both 2001 and 2002, the numbers detected per unit time during fill were approximately twice the number between fills on average for each lock. In other words, mean passage rates through the flumes were double while the locks were filling than when they were not filling.

3.6 DETECTION RATE AND SURVIVAL ESTIMATES

The PIT tag data were used to evaluate temporal variation in detection rates at the smolt flumes and 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 nor precisely over the passage season. The 2001 PIT tag data indicated that the proportion using the flumes dropped off during the course of the season. This phenomenon was observed again in 2002 and was consistent for both the Bear Creek and Cedar River chinook and coho juveniles (Figure 3-25). Cedar River chinook appeared to have a slightly higher detection rate in late June and early July 2002, which could suggest a slightly higher survival rate for that group during that period. Sample sizes for steelhead were too small to infer trends.

The fall-off in detection rate was more pronounced and gradual for chinook than for coho salmon early in the 2002 passage season (Figures 3-25 and 3-26). Average weekly detection rates (after adjusting for detection efficiency) were on the order of 50% to 60% for chinook released in Bear Creek and the Cedar River in early May and declined to near zero by the end of June 2002 (Figure 3-26). In contrast, the detection rates for coho salmon held relatively steady at around 60% to 80% until the first week in June, and then dropped off rapidly to zero within the next two weeks (Figure 3-26).

Given the apparent temporal trend in proportion using the flumes suggested by the 2001 and 2002 data, it was not possible to estimate absolute survivals of the release groups to the Locks because the proportion itself was estimated only once (44% in early June, based on the shoreline affinity test). Nevertheless, the PIT tag data did indicate that survival within the LWSC was high in 2002, similar to 2001, based on comparing detection rates of different release groups passing



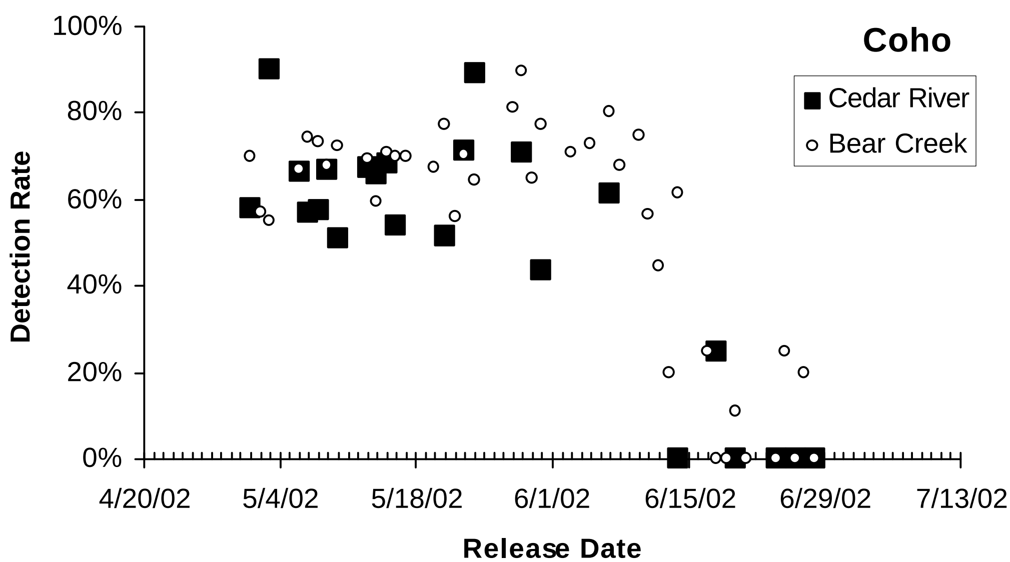


Figure 3-25. Daily variation of detection rate at the smolt flumes of PIT tagged juvenile chinook and coho salmon originating in Bear Creek and the Cedar River by release date, 2002 Lake Washington GI study. Each data point was calculated by dividing the number released in a group into the number subsequently detected at the Locks, adjusted for detection efficiency.

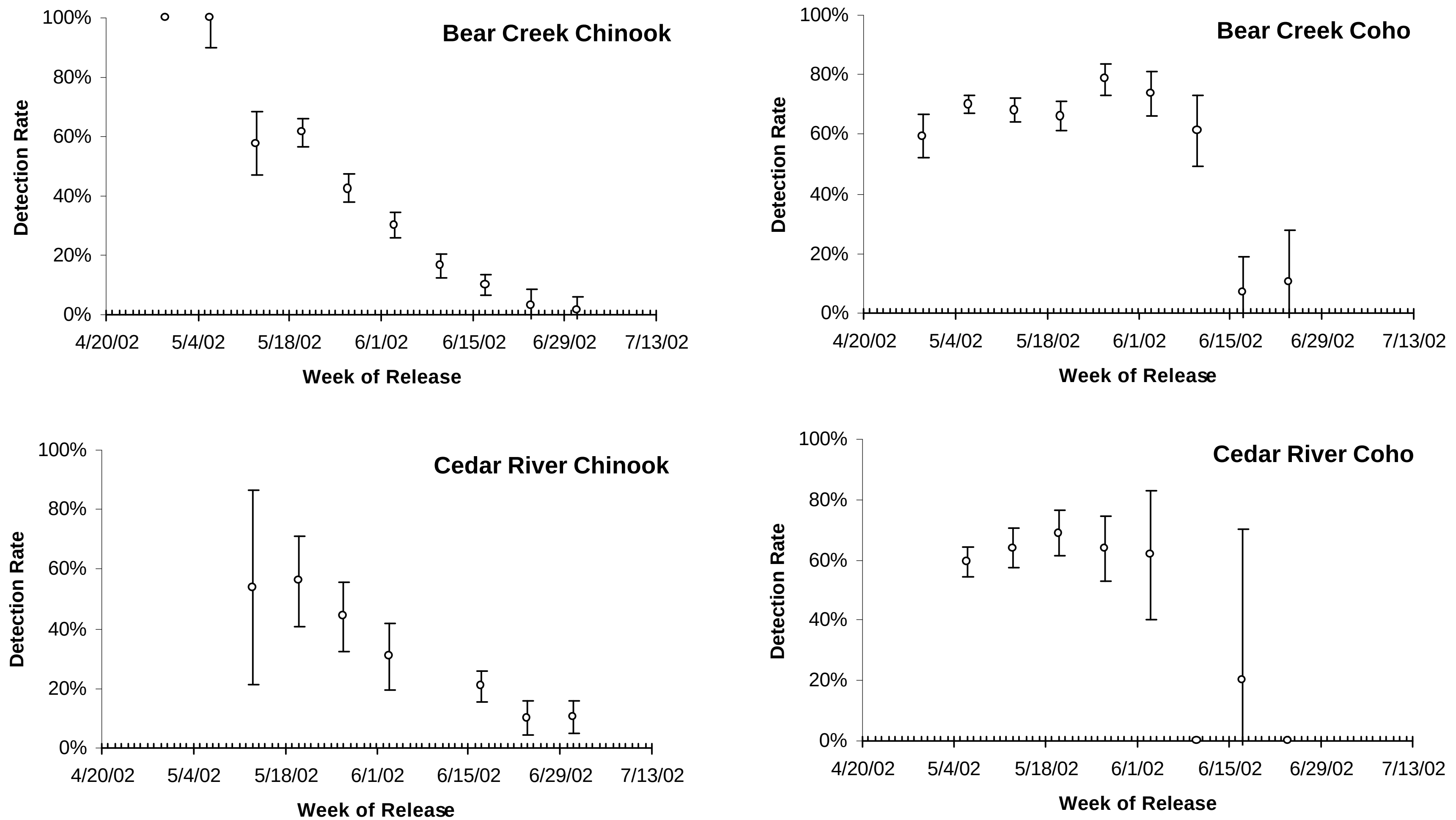


Figure 3-26. Weekly variation of detection rate at the smolt flumes of PIT tagged juvenile chinook and coho salmon originating in Bear Creek and the Cedar River by release date, 2002 Lake Washington GI study. The data in Figure 3-25 were grouped by week. 95% CI are presented based on the binomial approximation for a proportion

through the smolt flumes around the same week (Table 3-5). In addition, survival of the respective groups appeared to be relatively high between the three tributary release locations and the Montlake Cut, on the order of 80% to 90% (the precision of these estimates is low, however, with a 95% confidence interval ranging between roughly 60% and 100%; Zar 1984). Table 3-5 also suggests survival of the Issaquah Hatchery fish to Bear Creek was approximately 95%. Confidence intervals for these survival estimates were large, on the order of the ranges depicted in Figure 2-5. These estimates should not be used in population modeling unless the associated error is also propagated through, and it is recognized that they probably do not represent survival over the entire outmigration season.

Delayed post-tagging mortality rates could have influenced the numbers above (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 there was only one tagging mortality (a coho) and no shed tags in the case of the tributary fish (see Appendix A), and mortality and tag shed rates of the Issaquah Hatchery fish were less than 1% prior to release. All fish used in the shoreline affinity study appeared healthy at the time of their release.

Table 3-5. Route Segment Survival Estimates For Chinook, 2002 PIT Tag Study.

		Survival Estimate To:		
Release Location	**% Using Flumes [1]**	**Montlake Cut**	**Fremont Cut**	**Metro Lab**
Issaquah Hatchery (released 5/31/02)	39.0%	80%	94%	90%
Bear Creek (released week of 5/28/02)	41.3%	84%	100%	95%
Cedar River (released week of 5/28/02)	42.9%	87%	100%	99%
Montlake Cut (released 5/31)	49.0%		100%	100%
Fremont Cut (released 6/6-7/02)	41.4%			95%
Metro Laboratory (released 6/6-7/02)	43.4%			

[1] *- Numbers adjusted for detection efficiency; Assumes similar probability of using flumes*

4. DISCUSSION

The results of this study provided important insights supporting, supplementing, and adding to those obtained in 2000 and 2001 regarding mortality, migration, and passage characteristics of tagged fish in the Lake Washington and LWSC system. In whole, the data continue to 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 comparable to efficiencies determined in 2001, with the exception of Flume 5B which had a reduced efficiency when the dewatering plate was adjusted. This indicates that the plates should not be adjusted without implementing appropriate tunnel reader recalibration measures in future studies. The 2002 study still suffered from the same problems as in 2000 and 2001 regarding structural and hydraulic effects on detection efficiencies and incomplete coverage of all the routes through the Locks. The data again indicate that these may be important precision-related limitations on evaluations of survival through the Locks facilities.

There was greater spill through gates without instrumented smolt flumes in 2002 than in 2000 or 2001. Hence, it is possible that a greater proportion of tagged smolts passed through the non-instrumented spill gates than in preceding years, and that those fish might have used the flumes instead if there had not been as much spill. Decisions based on comparing 2002 with preceding year detection rates should therefore be made accordingly with this in mind.

As in 2001, hatchery chinook began showing up in Cedar River trap catches in June. The first such fish was caught on June 21, 2002, which is later than would have been expected based on the migration rate results (DeVries 2002). It is unknown what proportion migrate along the eastern shore of Lake Washington, so the migration rate data should be considered accordingly.

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 to a moderate degree of precision, thereby essentially meeting the first study objective (Section 1.2). This is an important outcome, even when 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 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 in 2002 to be similar to naturally-spawned chinook from Bear Creek in terms of migration and passage behavior, and possibly survival to the Locks. An exception was apparent for the calibration test fish, which exhibited the strongest recycling behavior at the Locks of all groups, but these fish were held and released under the least “normal” conditions of all the hatchery release groups. In lieu of taking tagged hatchery fish to different release locations in Lake Washington tributaries and acclimatizing them prior to release (a difficult endeavor), 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 92% before, and in the 70%-80% range while, the dewatering plates were in an adjusted position. These values are still high enough, however, that the adjusted detection numbers give assurance that the trends reported here are realistic. However, they are sufficiently low that they add a level of uncertainty to total survival estimates that is not encountered in other tunnel reader installations. Further structural modifications may be needed.

A separate problem that occurred in both 2001 and 2002 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 geometry appears necessary to result in a smoother hydraulic transition leading into the tunnel readers.

4.2 MEETING THE ASSUMPTIONS OF PIT TAG BASED SURVIVAL ESTIMATORS

The survival estimates presented in this report must be regarded cautiously. Estimator precision was relatively low because of the limited sample sizes and numbers of replicates involved. Use of the survival estimates in production models such as EDT is not recommended because they are essentially single point values in time with relatively large confidence intervals. That is not to say that the survival estimates are not useful – they are. Information such as migration route segment survival is useful for guiding future management decisions related to identifying where restoration and recovery efforts should be focused, even if the absolute magnitude of the survival estimate of any given segment is itself in question.

Indeed, the results suggest that differential detection rates can be used to provide an indication of survival between two release locations, assuming similar detection probabilities. The validity of this assumption 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). Bias related to distance between two locations (Dauble 1993) appears to be addressable by considering migration rates of two groups passing through around the same date and back-calculating the appropriate release dates to compare. The shoreline affinity test suggests that there is complete mixing within the LWSC. This result is supported anecdotally by the observation that smolts seem to leap from the water surface everywhere in Salmon Bay upstream of the Locks. Hence, meeting the assumption of complete mixing in the LWSC appears to be generally feasible, and the segment survival estimates should be indicative of overall survival trends.

On the basis of that conclusion, the 2002 segment survival trends and estimated magnitudes were generally similar to 2001 results. The Issaquah Hatchery chinook appeared to have experienced relatively high survival as they passed through Lake Sammamish in 2002, as did chinook migrating between the Montlake Cut and the Fremont Cut. Bear Creek chinook appeared to have a slightly lower survival to the Montlake Cut than Cedar River chinook, but both survivals appeared to be relatively high. The 2002 Bear Creek survival estimate appeared to be higher than that estimated for the same period in 2001.

The concern remains regarding release group sample size, which continues to be a statistical, logistical, and financial issue in PIT tagging-based survival studies. The confidence interval estimates depicted in Figure 2-5 indicate that release group sizes larger than about 300 fish should not result in substantial improvements in precision of route segment survival estimates using the equations presented in Section 2.7.4. While Burnham et al.'s (1987) maximum likelihood estimator used in the 2001 study may be superior from a bias perspective, the present approach appears to generate segment survival estimates of comparable precision that could at least be useful for identifying relative differences in survival along different segments of the outmigration route. Burnham et al.’s (1987) estimator is superior for evaluating overall survival, however, because the error in the individual route segment survival estimates is compounded when they are multiplied.

The shoreline affinity test results suggest that releases along the north and south shore in the vicinity of the Metro Laboratory may permit determining the proportion of fish using the smolt flumes. If this is true, then such releases made periodically during the outmigration season could be used to estimate the proportion using the smolt flumes as it changes over time, and thus also obtain estimates of survival over the outmigration/passage season. Future release strategies should be designed accordingly.

4.2.1 Possible Influence of Water Quality on Passage at Locks

The data collected in 2001 and 2002 indicate that the proportion of smolts using the flumes changes with time. A review of available water quality data for both years 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 in 2002 again support this hypothesis. Figure 4-1 shows that water temperatures in 2002 climbed continually during the passage season, and leveled out toward the end of July. This was later than in 2001 and reflects the cooler, wetter spring that occurred in 2002. In most locations, the near-bottom water temperature was approximately 1-2ºC cooler than the surface temperature. Water temperatures below the Locks are also much cooler, 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 and second weeks of July 2002 (Figure 4-1). 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 tagged Bear Creek and Cedar River chinook salmon began dropping for groups released around mid-May, when surface temperatures were around 12-13ºC, and the rates approached zero for groups released around the beginning of July 2002 when surface temperatures approached 19ºC (Figure 3-25). In both 2001 and 2002, total daily detection rates and numbers began to drop off as surface water temperatures in the LWSC exceeded 15ºC and leveled off at very low numbers when the mean daily temperature exceeded approximately 19-20ºC (Figure 4-2). Diurnal variation in lake surface temperature is generally less than 0.5ºC, so similar results are seen for daily minimum and maximum temperatures. This phenomenon may also explain the residualism observed in 2002. For example, the sockeye smolts that residualized between 2001 and 2002 were all tagged later in the 2001 outmigration season in the LWSC when water temperature warmed.

There was a greater contrast between the chinook and coho detection rates than seen in 2001. Detection rates of tagged Bear Creek and Cedar River coho smolts stayed relatively steady in 2002 for groups released up to the end of the first week in June, when surface temperatures approached 16-17ºC, and then dropped rapidly for groups released up to the end of June 2002, when temperatures approached 19ºC (Figure 3-25).

These results suggest that use of the smolt flumes may have little benefit for smolt passage as the upper temperature threshold is approached in surface waters of the LWSC, and that coho smolts may have a slightly higher behavioral temperature tolerance than chinook in the LWSC.

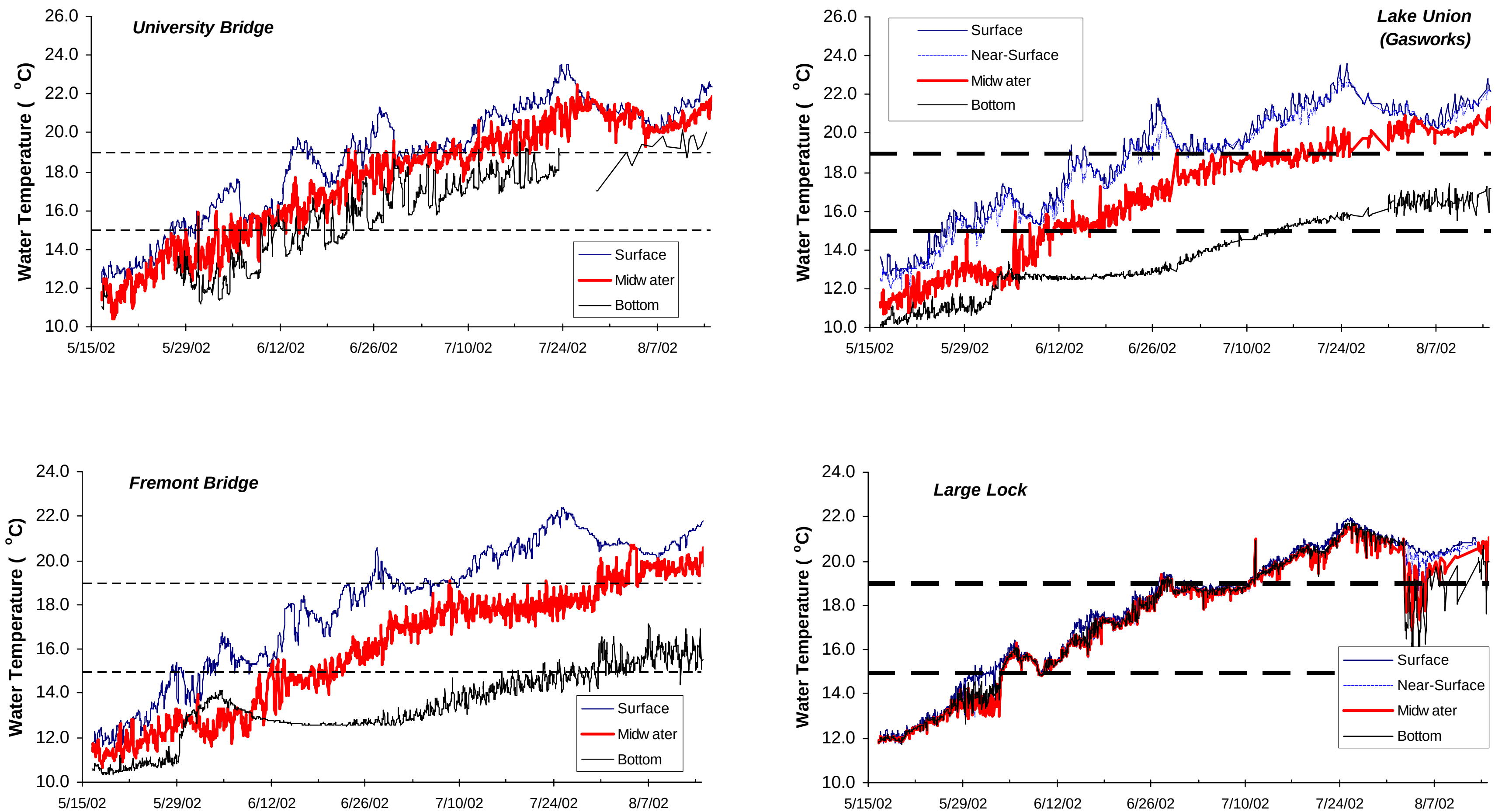


Figure 4-1. Temporal variation in water temperatures measured in the LWSC during the 2002 Lake Washington GI study.

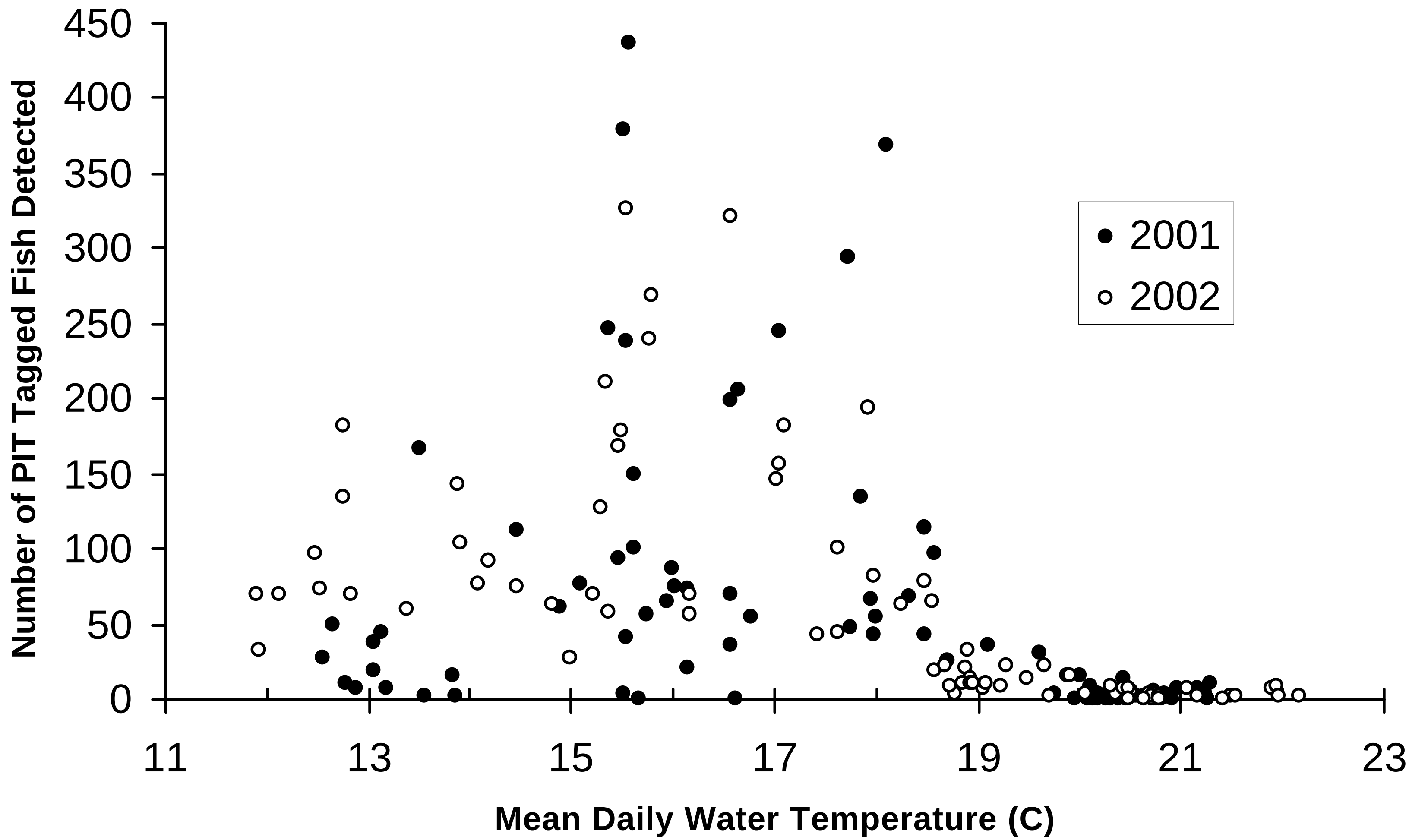


Figure 4-2. Variation in daily detection numbers in the smolt flumes with mean daily surface water temperature in the LWSC, 2001 and 2002.

4.3 INFLUENCE OF LOCK OPERATIONS ON PASSAGE AND ESTUARINE TRANSITION

The 2002 PIT tag data suggest that there are several features of lock construction or operation that may influence downstream passage and the transition to saltwater. These include seasonal and diurnal environmental and operational features that may result in changes in passage behavior, and are evaluated below.

4.3.1 Influence on Juveniles Located Below the Locks

As in 2000 and 2001, the tunnel detector data from 2002 indicate that some fish recycled through the Locks (Figures 3-20 and 3-21). 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. This phenomenon and its implications are discussed in DeVries (2001) and are not repeated here because the 2002 data simply reaffirm patterns observed in preceding years. The most notable difference from the 2000 and 2001 results was that natural origin chinook and coho were also noted to recycle more than twice in 2002 (Figure 3-21). Previously, only hatchery origin fish had exhibited this behavior.

4.3.2 Influence on Juveniles Located Above the Locks

A 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 and 2001, the PIT tag data for 2002 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.

The flow fields in the two spill gates appear to be relatively independent of one another, so the total flow entering a gate may also be an important influence on juvenile behavior in the forebay vicinity and subsequent passage through the smolt flumes. This is consistent with other data suggesting increased passage rates with increased spill through Gate 2 (BioSonics, Inc. 2001). Figure 4-3 depicts the daily detection rates per unit discharge of each species in each flume and tagging location over the passage season, and the total number of detections prior to June 18, 2002, while all four flumes were open. There were notable differences in the detection numbers using each gate and flume in 2001 and 2002. The number of detected chinook passing through Gate 5 in 2002 were larger per unit volume of water than in Gate 4 when all four flumes were operational (Figure 4-3), whereas the numbers were closer in 2001. Proportionally more coho passed through Gate 4 than in Gate 5 in 2002. Also, more chinook passed through flume 5B per unit volume of water overall than through the other flumes, whereas more passed through flume 5C in 2001.

A hypothesis was proposed in the 2001 data report that similar numbers in each gate might reflect a lack of shoreline affinity by outmigrants (DeVries 2002). Although the 2002 numbers depicted in Figure 4-2 do not lead to the same hypothesis, the shoreline affinity test fish do provide additional evidence when those numbers are also expressed per unit volume of water passing through the flumes. The north and south shore release groups exhibited similar tendencies for more fish to pass through Gate 5 than Gate 4 after normalizing for flow rate (Figure 4-4). This result suggests that attraction flow may be more important because Gate 5 passes 40 cfs more than Gate 4, or 55% of the total flow, when all four flumes are open.

The results of the 2002 study provide additional information regarding individual flume effectiveness. A subset of the flumes were open at various times during the study (Figure 3-1), from which differential detection rates between flumes can be used to infer usage patterns and possible operational modifications. For example, Gate 4 was closed during the day on June 1 and 2, 2002. During that time, proportionally more coho used Gate 5 than on preceding and succeeding days (Figure 4-3), while the total numbers detected remained about the same (Figure 4-5). A similar pattern occurred for both species on June 24-26, 2002 (Figure 3-1; Figure 4-3). On June 8 and 9, 2002, the two larger flumes 4B and 5B were closed during the day (Figure 3-1). On this occasion, proportionally more chinook and coho used the intermediate sized flume (5C) than on preceding and succeeding days (Figure 4-3), yet the total numbers detected again remained about the same (Figure 4-5). In contrast, use of the smallest flume (4A) did not change appreciably (Figure 4-3). These results suggest two interrelated features of flume operation that indicate the influence of attraction flow:

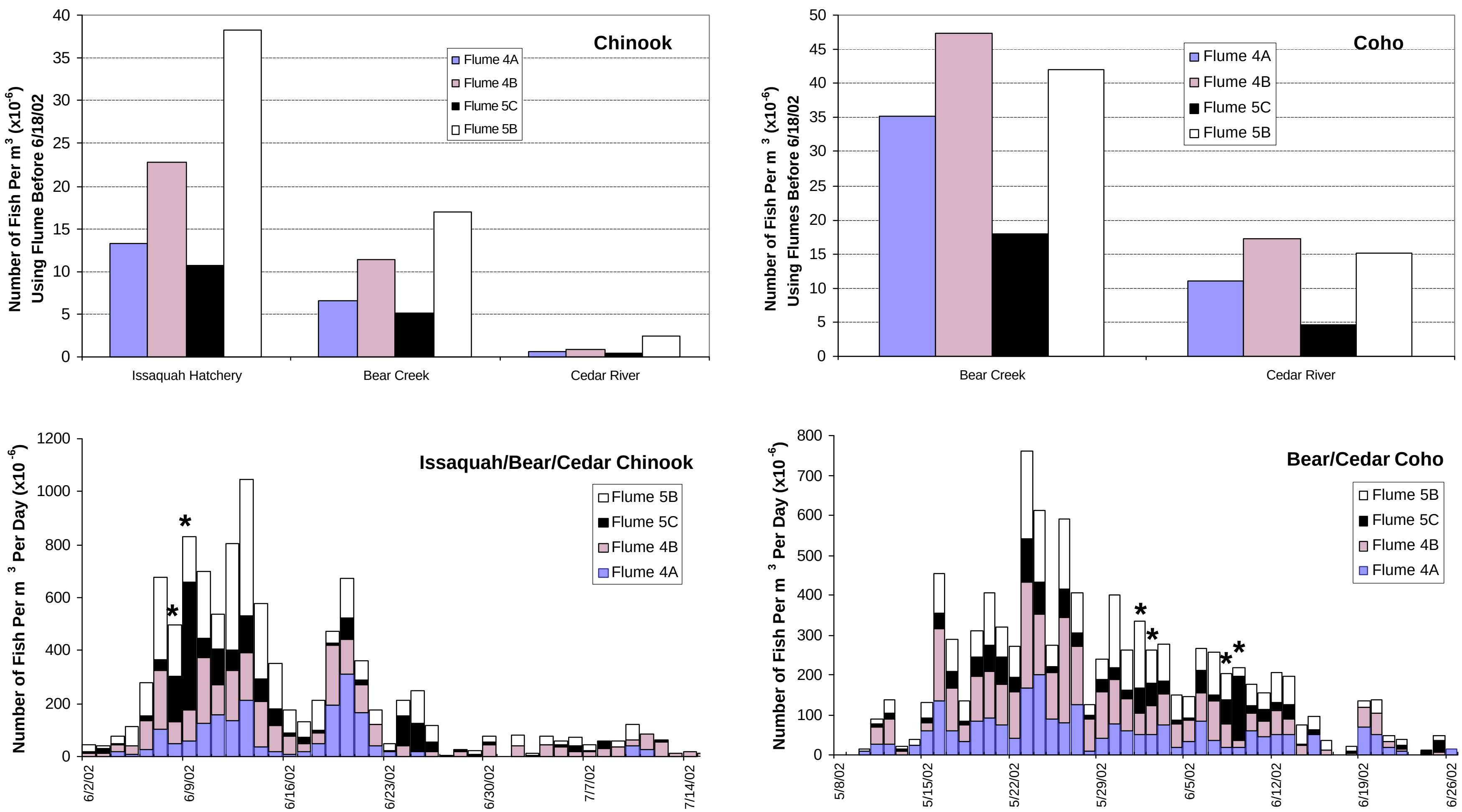


Figure 4-3. Number of PIT tagged salmon passing through each flume normalized to unit discharge, by release location before June 18, 2002 while all four flumes were generally operational (top; see Figure 3-1 for periods of operation), and over the outmigration period (bottom), 2002 Lake Washington GI study. Asterisks indicate dates before June 18 when not all flumes were open.

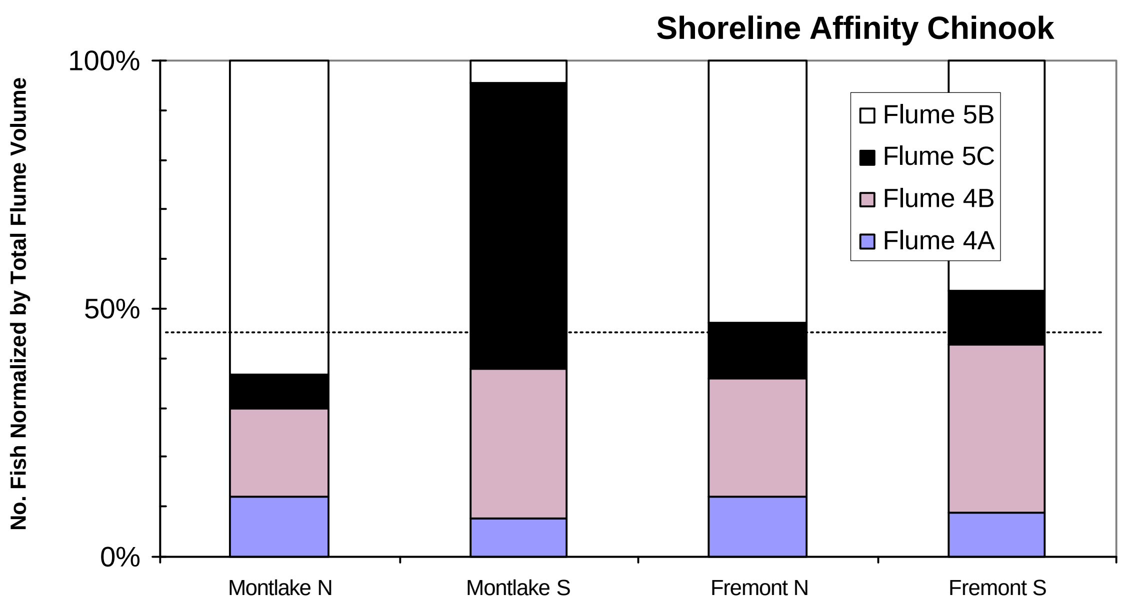


Figure 4-4. Number of PIT tagged chinook salmon from the shoreline affinity test passing through each flume before June 18, 2002 while all four flumes were generally operational (normalized to total flume discharge; see Figure 3-1 for periods of operation), 2002 Lake Washington GI study.

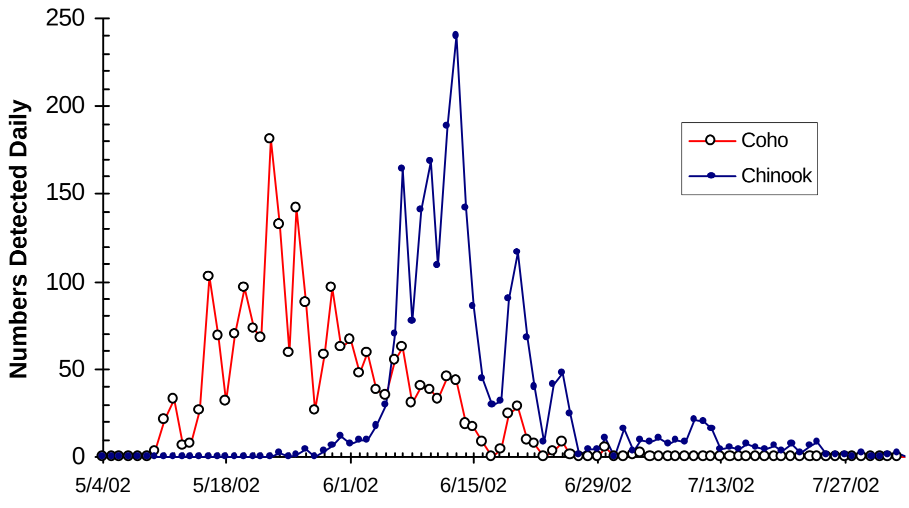


Figure 4-5. Total daily detection numbers in the smolt flumes of coho and chinook from Bear Creek, Cedar River, and Issaquah Hatchery, 2002 Lake Washington GI Study.

1. A compensation effect: When one gate (or the large flume in a gate) is closed, outmigrating smolts seek alternate routes and the passage rates in the remaining open flumes increase correspondingly.
2. A minimum attraction flow rate below which passage rates fall off significantly: Flume 4A does not appear to pass enough water by itself to attract additional smolts when flume 4B is closed. This result was also noted in 2001 for hatchery chinook released from the University of Washington (DeVries 2002).

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 all three years, 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 spill gate #2 in 2000 (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 3-23 and 3-24 suggest that a passage response exists with respect to lock filling. Figure 4-6 indicates that the frequency distributions for lock filling times and smolt flume passage times are relatively similar (cf. Figure 3-17). 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 larger influence than it did in 2001, when its fill time distribution was more uniform (DeVries 2002). This phenomenon could be tested in subsequent years by specifying a daytime opening pattern on alternating nights (i.e., uniform lock opening distribution over 24 hours vs. normal operations) and comparing diurnal passage rate variation on successive dates. 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).

The second change suggested by both the 2001 and 2002 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 20ºC. The route of passage appears to shift to deeper alternatives, with few fish using the flumes after that temperature threshold is reached.

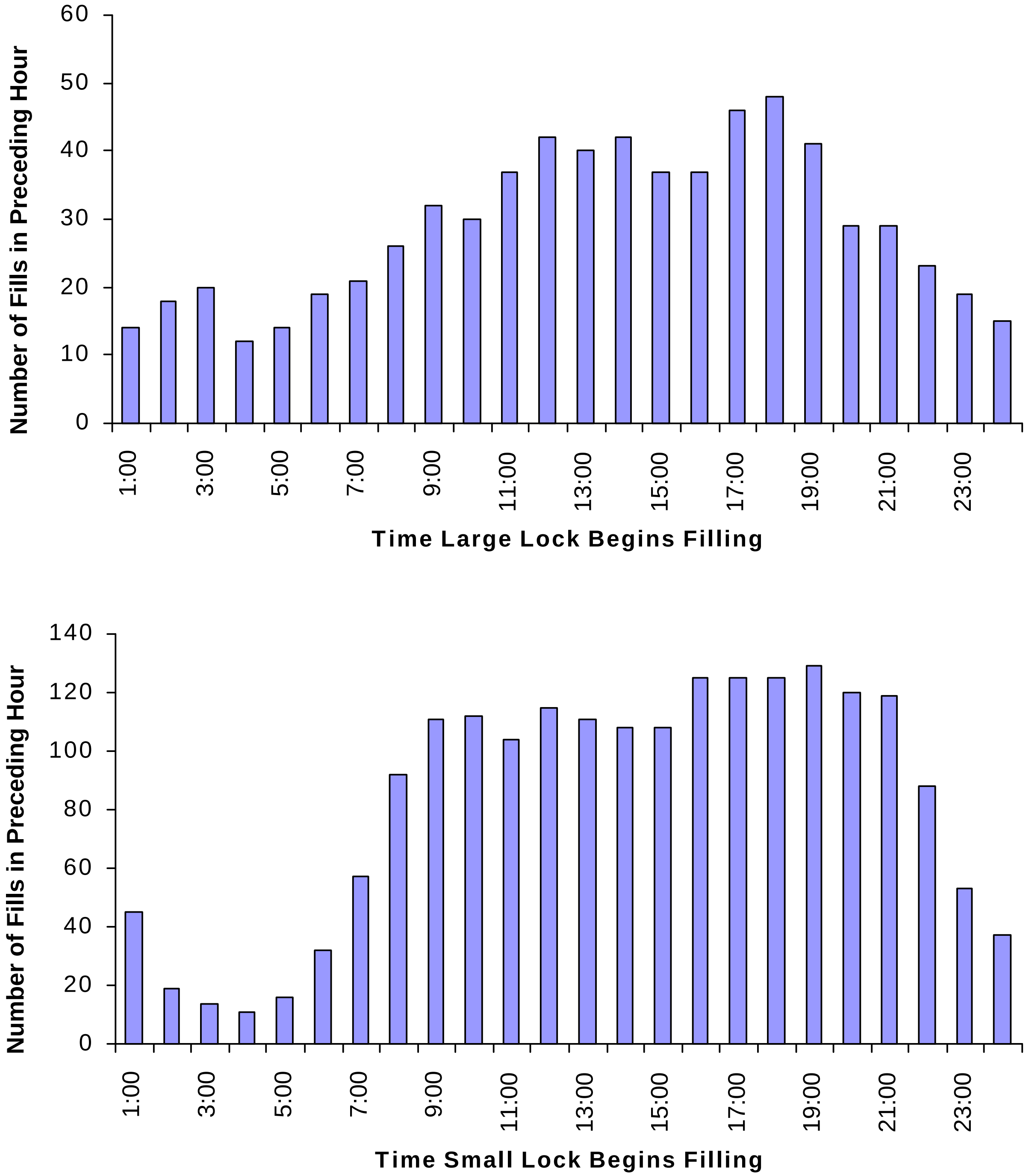


Figure 4-6. Diurnal variation in times at which the large (top) and small (bottom) Locks began to fill during the PIT tag study period of May 1 through July 31, 2002 Lake Washington GI study.

Other than possibly increasing attraction flows to the entrance of the smolt flumes (which could also increase the area of the freshwater-saltwater 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 the last three years, and accompanying justifications are given:

- The structural vibration and surging problems continue to result in decreased detection efficiency in the large flumes (4B and 5B), albeit to a lesser extent than in 2000. 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" to further evaluate stick performance relative to using live fish. Stick tests should be done frequently to identify the potential need for retuning of selected tunnel reader coils.

- Calibration testing should also be performed immediately after any manipulation of the flume dewatering screens. Such manipulation resulted in unsatisfactory detection rates in Flume 5B in 2002.

- Limited calibration test results indicate that live fish can be introduced into each flume from the spillway walkway by flushing them through a large diameter PVC pipe using buckets of water, rather than through the more time consuming hand-feeding into the face of the flume from the bow of a boat. Ideally, fish should be flushed individually and in groups to simulate a range of observed passage patterns. However, considering tag cost and holding facility limitations, at minimum the fish should be flushed down the pipe one at a time to maximize detection probability (it is unlikely based on the three years of data that more than one PIT tagged fish passes through a flume at any moment in time).

- In the near future, fish should be held at the Metro Laboratory for calibration testing only, in consideration of presently available holding capacity (holding capacity could increase in the future once construction is at the Laboratory is finished; F. Sweeney, King County/Metro, personal communication). Other objectives should rely on other sources of fish.

- Holding of chinook at the UW hatchery is not recommended for future PIT tag studies because of stress and disease problems as water temperatures warm in the LWSC.

- 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 and 2002 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.

- Ideally, PIT tagging should occur at a number of locations along the migration route to evaluate differential survival at different locations. Such information would be valuable for identifying measures at specific locations intended to increase overall survival. At minimum, purse seining could be continued in Lake Union and in the vicinity of the Montlake Cut to evaluate survival in the LWSC. In contrast to 2000 when there were disease problems, the 2001 and 2002 data suggest minor mortality occurred in the LWSC. Further study would be useful for evaluating factors of decline, particularly upstream of the LWSC.

- See DeVries (2002) if beach seining is desired below the Locks to recapture PIT tagged fish.

- Sampling 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 mostly re-confirm that recycling takes place, which appears to be determined more thoroughly based on the tunnel reader detections. Considerable 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, personal communication) and may interfere with upstream adult migration (E. Warner, personal communication). Planned construction of a PIT tag detector for returning adults would also be useful for monitoring for residualized smolts in subsequent years.

- Releases of tagging groups in the LWSC should be alternated between the north and south shorelines, to continue evaluating shoreline affinity and proportion using the smolt flumes. This should be done at all general locations sampled (e.g., at Montlake Cut and near the Fremont Bridge). Maintaining an alternating release pattern over the passage season would facilitate and evaluation of seasonal changes in the proportion using the smolt flumes, and thus an improved appreciation of the temporal variation in survival or residualization of outmigrants in the Lake Washington system.

- The influence of small and large lock operations on passage rates should be investigated by alternating between a normal daily lock opening pattern, when both locks are opened more frequently during the day than the night, and a uniform distribution where the frequency of lock openings is similar during both day and nighttime hours. Diurnal passage rate distributions should reflect the respective lock opening patterns tested if there is a relation between lock opening frequency and passage rate.

- The blood of subsamples of PIT tagged fish passing through the flumes could 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.

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APPENDIX A

2002 PIT Tagging Activity
Summary Report of L. Fleischer (WDFW)

Lake Washington Watershed PIT Tagging, 2002

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February 2003

Methods

Downstream migrants captured at the Cedar River and Bear Creek screw traps were PIT tagged from May to July 2002. The tagging station was set up on the banks at both locations, on the cement wall at Cedar River just above the Logan Street Bridge and on the railroad trestle at Bear Creek just below Redmond Way Bridge. Chinook and coho salmon and steelhead trout were tagged at both traps. Healthy fish in excess of 70 mm were tagged. Smolts with physical injuries, descaling greater than 20%, parasites, and predator marks, were not tagged. Fish were anesthetized in a solution of one gram of MS-222 per five gallons of water in preparation for tagging. The tag was inserted by syringe into the abdomen approximately halfway between the pectoral and pelvic fins. Size (fork length) and other physical data, such as scale loss, bleeding, and wounds, were recorded for each fish. Fish were held for recovery observation before being released. To estimate mortality and tag retention rates, groups of tagged fish were held for 24 hours. Fish were placed in a five-gallon bucket with a lid, and tied off to the trap to hang in the water. Small perforations in the bucket and lid allowed current to flow through the container, but were small enough to retain any tags. The next day fish condition was assessed and the container was examined for lost tags.

Results

Cedar River

Tagging began on May 1 and continued through July 12. Tagging occurred in the morning hours Monday through Friday. Throughout July, tagging occurred every other day due to low numbers of fish. Fish were held in live wells from the previous morning to increase the number of fish tagged. In total, we tagged 1,861 smolts (816 chinook, 1.038 coho and 7 steelhead) (Table 1).

Over the season, 136 chinook and 156 coho were held to assess mortality and tag loss. No fish died and no tags were lost (Table 2). Although those measured rates may underestimate actual rates, we believe mortality and tag loss were both very low.

One tagged chinook was recaptured at the Cedar River on May 31 (Table 3).

Bear Creek

Tagging began on May 1 and continued through July 10. Tagging occurred in the morning hours Monday through Friday. During July, tagging occurred every other day due to low numbers of fish. Fish were held over from the previous morning in order to increase the number of fish tagged. In total, 4,972 fish were tagged (Table 1). The number of age 0+ chinook tagged was 2,309, and 2,657 age 1+ coho were tagged. Four steelhead smolts were also tagged. An additional two fish were tagged; one that was tagged on May 21 or 22, and one tagged on May 30. These two fish were not entered into the database, but were detected going through the Ballard Locks. Their species is unknown.

Over the season, we held 134 chinook and 179 coho to assess mortality and tag loss (Table 2). No chinook died, but one coho mortality occurred on June 28. This fish was thin and partially descaled prior to tagging. The estimated mortality rate for chinook smolts was 0%, while coho was estimated at 0.6%. Due to the low sample size, we believe these mortality rates may underestimate the actual rates. While the mortality rate was not zero, because only one mortality was observed, it does indicate that the rate was low. On May 9, one coho smolt mortality occurred immediately after being tagged, which represents an instant mortality rate of 0.04% for coho tagged. All tags were retained resulting in an estimation of no tag loss.

There were a total of 29 recaptured pit tagged fish at Bear Creek: 15 chinook and 14 coho (Table 3). The recaptured coho were caught between May 3 and June 14, and the recaptured chinook were caught between May 21 and June 25.

APPENDIX B

2002 PIT Tagging Data
Release and Detection Summary Tables

Table B-1. Summary of tagging numbers, 2002 PIT tag study.

Release			Numbers Released						
			Chinook		Coho		Sockeye	Steelhead	
Location	**Date**	**Time**	**Hatchery**	**Natural**	**Hatchery**	**Natural**	**Natural**	**Natural**	**TAGGING FILE**
Bear Creek	5/1/02	11:00	0	0	0	50	0	1	Csm02121.fb1
	5/2/02	10:00	0	1	0	48	0	0	Csm02122.fb1
	5/3/02	10:00	0	0	0	98	0	0	Csm02123.fb1
	5/6/02	10:00	0	0	0	145	0	0	Csm02126.fb1
	5/7/02	10:30	0	1	0	74	0	0	Csm02127.fb1
	5/8/02	10:00	0	0	0	146	0	0	Csm02128.fb1
	5/9/02	11:00	0	0	0	298	0	1	Csm02129.fb1
	5/10/02	10:30	0	4	0	296	0	0	Csm02130.fb1
	5/13/02	10:30	0	6	0	179	0	0	Csm02133.fb1
	5/14/02	11:00	0	3	0	109	0	0	Csm02134.fb1
	5/15/02	10:30	0	17	0	96	0	0	Csm02135.fb1
	5/16/02	12:00	0	44	0	120	0	0	Csm02136.fb1
	5/17/02	10:30	0	27	0	103	0	0	Csm02137.fb1
	5/20/02	10:30	0	45	0	144	0	0	Csm02140.fb1
	5/21/02	10:30	0	62	0	22	0	0	Csm02141.fb1
	5/22/02	10:30	0	113	0	50	0	0	Csm02142.fb1
	5/23/02	10:30	0	72	0	57	0	0	Csm02143.fb1
	5/24/02	11:00	0	140	0	101	0	0	CSM02144.FB1
	5/28/02	10:30	0	118	0	107	0	0	CSM02148.FB1
	5/29/02	10:30	0	125	0	39	0	2	CSM02149.FB1
	5/30/02	10:00	0	141	0	51	0	0	CSM02150.FB1
	5/31/02	10:30	0	79	0	53	0	0	CSM02151.FB1
	6/3/02	9:00	0	55	0	41	0	0	CSM02154.FB1
	6/5/02	9:30	0	73	0	37	0	0	Csm02156.fb1
	6/7/02	10:30	0	207	0	45	0	0	Csm02158.fb1
	6/8/02	9:30	0	169	0	28	0	0	Csm02159.fb1
	6/10/02	10:00	0	164	0	32	0	0	Csm02161.fb1
	6/11/02	9:30	0	66	0	16	0	0	Csm02162.fb1
	6/12/02	8:15	0	46	0	9	0	0	Csm02163.fb1

Table B-1. Summary of tagging numbers, 2002 PIT tag study.

Release			Numbers Released						
			Chinook		**Coho**		**Sockeye**	**Steelhead**	
Location	**Date**	**Time**	**Hatchery**	**Natural**	**Hatchery**	**Natural**	**Natural**	**Natural**	**TAGGING FILE**
Bear Creek	6/13/02	8:30	0	36	0	5	0	0	Csm02164.fb1
(cont.)	6/14/02	8:45	0	67	0	13	0	0	Csm02165.fb1
	6/17/02	10:00	0	76	0	4	0	0	Csm02168.fb1
	6/18/02	9:30	0	42	0	2	0	0	Csm02169.fb1
	6/19/02	8:00	0	93	0	8	0	0	Csm02170.fb1
	6/20/02	9:00	0	47	0	9	0	0	Csm02171.fb1
	6/21/02	9:00	0	33	0	5	0	0	Csm02172.fb1
	6/24/02	10:00	0	11	0	3	0	0	Csm02175.fb1
	6/25/02	8:00	0	15	0	4	0	0	Csm02176.fb1
	6/26/02	9:00	0	15	0	3	0	0	CSM02177.FB1
	6/27/02	8:30	0	14	0	5	0	0	CSM02178.FB1
	6/28/02	8:00	0	9	0	4	0	0	CSM02179.FB1
	7/1/02	9:00	0	11	0	0	0	0	CSM02182.FB1
	7/1/02	9:00	0	24	0	0	0	0	CSM02182.FB2
	7/3/02	9:00	0	2	0	0	0	0	CSM02184.FB1
	7/3/02	9:00	0	10	0	0	0	0	CSM02184.FB2
	7/5/02	9:00	0	4	0	0	0	0	CSM02186.FB1
	7/5/02	9:00	0	5	0	0	0	0	CSM02186.FB2
	7/8/02	8:30	0	9	0	0	0	0	CSM02189.FB1
	7/10/02	8:30	0	2	0	0	0	0	CSM02191.FB1
	7/10/02	8:30	0	6	0	0	0	0	CSM02191.FB2
Cedar River	5/1/02	7:30	0	0	0	52	0	1	Csm02121.fc1
	5/3/02	7:30	0	0	0	50	0	0	Csm02123.fc1
	5/6/02	8:00	0	0	0	68	0	2	Csm02126.fc1
	5/7/02	8:00	0	0	0	56	0	0	Csm02127.fc1
	5/8/02	7:30	0	0	0	100	0	0	Csm02128.fc1
	5/9/02	8:30	0	0	0	100	0	1	Csm02129.fc1
	5/10/02	8:00	0	0	0	100	0	0	Csm02130.fc1
	5/13/02	7:30	0	0	0	64	0	0	Csm02133.fc1
	5/14/02	8:00	0	2	0	73	0	1	Csm02134.fc1

Table B-1. Summary of tagging numbers, 2002 PIT tag study.

Release			Numbers Released						
			Chinook		Coho		Sockeye	Steelhead	
Location	**Date**	**Time**	**Hatchery**	**Natural**	**Hatchery**	**Natural**	**Natural**	**Natural**	**TAGGING FILE**
Cedar River	5/15/02	8:00	0	5	0	41	0	1	Csm02135.fc1
(cont.)	5/16/02	8:30	0	6	0	52	0	0	Csm02136.fc1
	5/21/02	7:30	0	10	0	62	0	0	Csm02141.fc1
	5/23/02	7:30	0	11	0	49	0	1	Csm02143.fc1
	5/24/02	7:30	0	29	0	46	0	0	CSM02144.FC1
	5/29/02	7:30	0	26	0	65	0	0	CSM02149.FC1
	5/31/02	6:30	0	34	0	0	0	0	CSM02150.FC1
	5/31/02	7:30	0	24	0	23	0	0	CSM02151.FC1
	6/7/02	7:30	0	78	0	26	0	0	Csm02158.fc1
	6/14/02	6:30	0	0	0	2	0	0	Csm02165.fc1
	6/18/02	7:00	0	20	0	1	0	0	Csm02168.fc1
	6/18/02	7:30	0	137	0	3	0	0	Csm02169.fc1
	6/20/02	7:30	0	63	0	1	0	0	Csm02171.fc1
	6/21/02	7:00	0	27	0	0	0	0	Csm02172.fc1
	6/24/02	8:00	0	19	0	1	0	0	Csm02175.fc1
	6/25/02	7:00	0	26	0	0	0	0	Csm02176.fc1
	6/26/02	8:00	0	31	0	1	0	0	CSM02177.FC1
	6/27/02	7:30	0	26	0	0	0	0	CSM02178.FC1
	6/28/02	7:00	0	27	0	1	0	0	CSM02179.FC1
	7/1/02	7:30	0	67	0	0	0	0	CSM02182.FC1
	7/3/02	7:30	0	12	0	0	0	0	CSM02184.FC1
	7/3/02	7:30	0	48	0	0	0	0	CSM02184.FC2
	7/5/02	7:00	0	21	0	0	0	0	CSM02186.FC1
	7/5/02	7:00	0	9	0	0	0	0	CSM02186.FC2
	7/8/02	7:00	0	12	0	0	0	0	CSM02189.FC1
	7/8/02	7:00	0	12	0	0	0	0	CSM02189.FC2
	7/10/02	7:00	0	5	0	0	0	0	CSM02191.FC1
	7/10/02	7:00	0	24	0	0	0	0	CSM02191.FC2
	7/12/02	7:00	0	3	0	0	0	0	CSM02193.FC1

Table B-2. Summary of chinook salmon recapture numbers, 2002 PIT tag study.

	Release		Number of Fish Detected at Locks in Each Flume							
			Hatchery Produced				Naturally Produced			
Tagging File	**Location**	**Date**	**4A**	**4B**	**5C**	**5B**	**4A**	**4B**	**5C**	**5B**
Csm02121.fb1	Bear Creek	05/01/02	0	0	0	0	0	0	0	0
Csm02122.fb1		05/02/02	0	0	0	0	1	0	0	0
Csm02123.fb1		05/03/02	0	0	0	0	0	0	0	0
Csm02126.fb1		05/06/02	0	0	0	0	0	0	0	0
Csm02127.fb1		05/07/02	0	0	0	0	0	1	0	0
Csm02128.fb1		05/08/02	0	0	0	0	0	0	0	0
Csm02129.fb1		05/09/02	0	0	0	0	0	0	0	0
Csm02130.fb1		05/10/02	0	0	0	0	0	3	1	0
Csm02133.fb1		05/13/02	0	0	0	0	0	1	0	0
Csm02134.fb1		05/14/02	0	0	0	0	0	0	0	2
Csm02135.fb1		05/15/02	0	0	0	0	0	1	0	6
Csm02136.fb1		05/16/02	0	0	0	0	2	2	5	15
Csm02137.fb1		05/17/02	0	0	0	0	0	6	3	7
Csm02140.fb1		05/20/02	0	0	0	0	3	7	4	9
Csm02141.fb1		05/21/02	0	0	0	0	1	11	4	12
Csm02142.fb1		05/22/02	0	0	0	0	4	25	8	25
Csm02143.fb1		05/23/02	0	0	0	0	4	11	4	23
CSM02144.FB1		05/24/02	0	0	0	0	6	24	14	37
CSM02148.FB1		05/28/02	0	0	0	0	7	15	8	23
CSM02149.FB1		05/29/02	0	0	0	0	5	16	10	19
CSM02150.FB1		05/30/02	0	0	0	0	4	12	8	16
CSM02151.FB1		05/31/02	0	0	0	0	6	6	8	14
CSM02154.FB1		06/03/02	0	0	0	0	3	6	3	9
Csm02156.fb1		06/05/02	0	0	0	0	1	4	5	13
Csm02158.fb1		06/07/02	0	0	0	0	4	21	7	22
Csm02159.fb1		06/08/02	0	0	0	0	0	13	3	20
Csm02161.fb1		06/10/02	0	0	0	0	6	17	6	6
Csm02162.fb1		06/11/02	0	0	0	0	0	7	1	6
Csm02163.fb1		06/12/02	0	0	0	0	0	1	0	1
Csm02164.fb1		06/13/02	0	0	0	0	0	2	1	0
Csm02165.fb1		06/14/02	0	0	0	0	1	3	0	0
Csm02168.fb1		06/17/02	0	0	0	0	1	4	0	2
Csm02169.fb1		06/18/02	0	0	0	0	0	2	0	2
Csm02170.fb1		06/19/02	0	0	0	0	0	7	1	2
Csm02171.fb1		06/20/02	0	0	0	0	0	4	0	0

Table B-2. Summary of chinook salmon recapture numbers, 2002 PIT tag study.

			Number of Fish Detected at Locks in Each Flume							
	Release		Hatchery Produced				Naturally Produced			
Tagging File	**Location**	**Date**	**4A**	**4B**	**5C**	**5B**	**4A**	**4B**	**5C**	**5B**
Csm02172.fb1	Bear Creek	06/21/02	0	0	0	0	0	3	0	0
Csm02175.fb1	(cont.)	06/24/02	0	0	0	0	0	1	0	0
Csm02176.fb1		06/25/02	0	0	0	0	0	0	0	0
CSM02177.FB1		06/26/02	0	0	0	0	0	1	0	0
CSM02178.FB1		06/27/02	0	0	0	0	0	0	0	0
CSM02179.FB1		06/28/02	0	0	0	0	0	0	0	0
CSM02182.FB1		07/01/02	0	0	0	0	0	1	0	0
CSM02184.FB1		07/03/02	0	0	0	0	0	0	0	0
CSM02186.FB1		07/05/02	0	0	0	0	0	0	0	0
CSM02189.FB1		07/08/02	0	0	0	0	0	0	0	0
CSM02191.FB1		07/10/02	0	0	0	0	0	0	0	0
Csm02121.fc1	Cedar River	05/01/02	0	0	0	0	0	0	0	0
Csm02123.fc1		05/03/02	0	0	0	0	0	0	0	0
Csm02126.fc1		05/06/02	0	0	0	0	0	0	0	0
Csm02127.fc1		05/07/02	0	0	0	0	0	0	0	0
Csm02128.fc1		05/08/02	0	0	0	0	0	0	0	0
Csm02129.fc1		05/09/02	0	0	0	0	0	0	0	0
Csm02130.fc1		05/10/02	0	0	0	0	0	0	0	0
Csm02133.fc1		05/13/02	0	0	0	0	0	0	0	0
Csm02134.fc1		05/14/02	0	0	0	0	1	1	0	0
Csm02135.fc1		05/15/02	0	0	0	0	0	0	1	0
Csm02136.fc1		05/16/02	0	0	0	0	0	2	0	2
Csm02141.fc1		05/21/02	0	0	0	0	0	1	0	4
Csm02143.fc1		05/23/02	0	0	0	0	0	3	2	2
CSM02144.FC1		05/24/02	0	0	0	0	1	1	2	9
CSM02149.FC1		05/29/02	0	0	0	0	2	5	2	4
CSM02150.FC1		05/31/02	0	0	0	0	2	6	0	4
CSM02151.FC1		05/31/02	0	0	0	0	2	1	1	4
Csm02158.fc1		06/07/02	0	0	0	0	3	8	0	10
Csm02165.fc1		06/14/02	0	0	0	0	0	0	0	0
Csm02168.fc1		06/18/02	0	0	0	0	1	1	0	2
Csm02169.fc1		06/18/02	0	0	0	0	1	16	3	3
Csm02171.fc1		06/20/02	0	0	0	0	1	12	0	1
Csm02172.fc1		06/21/02	0	0	0	0	1	3	0	2
Csm02175.fc1		06/24/02	0	0	0	0	0	2	0	0

Table B-2. Summary of chinook salmon recapture numbers, 2002 PIT tag study.

			Number of Fish Detected at Locks in Each Flume							
	Release		Hatchery Produced				Naturally Produced			
Tagging File	**Location**	**Date**	**4A**	**4B**	**5C**	**5B**	**4A**	**4B**	**5C**	**5B**
Csm02176.fc1	Cedar River	06/25/02	0	0	0	0	0	1	1	2
CSM02177.FC1	(cont.)	06/26/02	0	0	0	0	0	3	0	1
CSM02178.FC1		06/27/02	0	0	0	0	0	1	0	0
CSM02179.FC1		06/28/02	0	0	0	0	0	2	0	0
CSM02182.FC1		07/01/02	0	0	0	0	0	9	0	0
CSM02184.FC1		07/03/02	0	0	0	0	0	4	0	0
CSM02186.FC1		07/05/02	0	0	0	0	0	3	0	0
CSM02189.FC1		07/08/02	0	0	0	0	0	2	0	0
CSM02191.FC1		07/10/02	0	0	0	0	0	0	0	0
CSM02193.FC1		07/12/02	0	0	0	0	0	0	0	0
CSM02112.I01	Issaquah Hatchery	5/31/02	88	265	163	367	0	0	0	0
CSM02112.I02		5/31/02	58	178	71	219	0	0	0	0

Table B-3. Summary of coho salmon recapture numbers, 2002 PIT tag study.

			Number of Fish Detected at Locks in Each Flume							
	Released		Hatchery Produced				Naturally Produced			
Tagging File	**Location**	**Date**	**4A**	**4B**	**5C**	**5B**	**4A**	**4B**	**5C**	**5B**
Csm02121.fb1	Bear Creek	05/01/02	0	0	0	0	6	12	2	12
Csm02122.fb1		05/02/02	0	0	0	0	5	12	2	7
Csm02123.fb1		05/03/02	0	0	0	0	8	16	4	20
Csm02126.fb1		05/06/02	0	0	0	0	7	47	11	22
Csm02127.fb1		05/07/02	0	0	0	0	8	21	4	17
Csm02128.fb1		05/08/02	0	0	0	0	14	37	9	36
Csm02129.fb1		05/09/02	0	0	0	0	22	64	25	70
Csm02130.fb1		05/10/02	0	0	0	0	19	72	27	73
Csm02133.fb1		05/13/02	0	0	0	0	19	40	15	38
Csm02134.fb1		05/14/02	0	0	0	0	9	20	10	20
Csm02135.fb1		05/15/02	0	0	0	0	10	31	5	16
Csm02136.fb1		05/16/02	0	0	0	0	8	28	9	30
Csm02137.fb1		05/17/02	0	0	0	0	6	26	10	22
Csm02140.fb1		05/20/02	0	0	0	0	11	40	9	27
Csm02141.fb1		05/21/02	0	0	0	0	1	8	1	5
Csm02142.fb1		05/22/02	0	0	0	0	5	13	1	7
Csm02143.fb1		05/23/02	0	0	0	0	3	19	5	9
CSM02144.FB1		05/24/02	0	0	0	0	1	22	9	26
CSM02148.FB1		05/28/02	0	0	0	0	5	22	22	29
CSM02149.FB1		05/29/02	0	0	0	0	4	11	3	13
CSM02150.FB1		05/30/02	0	0	0	0	5	7	3	14
CSM02151.FB1		05/31/02	0	0	0	0	3	13	6	15
CSM02154.FB1		06/03/02	0	0	0	0	4	10	4	8
Csm02156.fb1		06/05/02	0	0	0	0	2	4	8	11
Csm02158.fb1		06/07/02	0	0	0	0	5	12	0	15
Csm02159.fb1		06/08/02	0	0	0	0	3	2	4	8
Csm02161.fb1		06/10/02	0	0	0	0	3	7	1	10
Csm02162.fb1		06/11/02	0	0	0	0	2	5	1	1
Csm02163.fb1		06/12/02	0	0	0	0	1	2	0	1
Csm02164.fb1		06/13/02	0	0	0	0	0	1	0	0
Csm02165.fb1		06/14/02	0	0	0	0	0	2	1	4
Csm02168.fb1		06/17/02	0	0	0	0	0	1	0	0
Csm02169.fb1		06/18/02	0	0	0	0	0	0	0	0
Csm02170.fb1		06/19/02	0	0	0	0	0	0	0	0
Csm02171.fb1		06/20/02	0	0	0	0	0	1	0	0

Table B-3. Summary of coho salmon recapture numbers, 2002 PIT tag study.

			Number of Fish Detected at Locks in Each Flume							
	Released		Hatchery Produced				Naturally Produced			
Tagging File	**Location**	**Date**	**4A**	**4B**	**5C**	**5B**	**4A**	**4B**	**5C**	**5B**
Csm02172.fb1	Bear Creek	06/21/02	0	0	0	0	0	0	0	0
Csm02175.fb1	(cont.)	06/24/02	0	0	0	0	0	0	0	0
Csm02176.fb1		06/25/02	0	0	0	0	0	0	0	1
CSM02177.FB1		06/26/02	0	0	0	0	0	0	0	0
CSM02178.FB1		06/27/02	0	0	0	0	0	0	0	1
CSM02179.FB1		06/28/02	0	0	0	0	0	0	0	0
CSM02182.FB1		07/01/02	0	0	0	0	0	0	0	0
CSM02184.FB1		07/03/02	0	0	0	0	0	0	0	0
CSM02186.FB1		07/05/02	0	0	0	0	0	0	0	0
CSM02189.FB1		07/08/02	0	0	0	0	0	0	0	0
CSM02191.FB1		07/10/02	0	0	0	0	0	0	0	0
Csm02121.fc1	Cedar River	05/01/02	0	0	0	0	2	11	3	11
Csm02123.fc1		05/03/02	0	0	0	0	3	14	2	12
Csm02126.fc1		05/06/02	0	0	0	0	3	19	2	16
Csm02127.fc1		05/07/02	0	0	0	0	5	11	2	11
Csm02128.fc1		05/08/02	0	0	0	0	2	20	10	20
Csm02129.fc1		05/09/02	0	0	0	0	11	28	8	14
Csm02130.fc1		05/10/02	0	0	0	0	6	24	5	12
Csm02133.fc1		05/13/02	0	0	0	0	3	13	4	18
Csm02134.fc1		05/14/02	0	0	0	0	7	14	2	20
Csm02135.fc1		05/15/02	0	0	0	0	1	10	2	12
Csm02136.fc1		05/16/02	0	0	0	0	2	10	1	12
Csm02141.fc1		05/21/02	0	0	0	0	3	13	3	10
Csm02143.fc1		05/23/02	0	0	0	0	3	13	2	13
CSM02144.FC1		05/24/02	0	0	0	0	6	6	5	19
CSM02149.FC1		05/29/02	0	0	0	0	4	15	8	15
CSM02150.FC1		05/31/02	0	0	0	0	0	0	0	0
CSM02151.FC1		05/31/02	0	0	0	0	3	3	2	2
Csm02158.fc1		06/07/02	0	0	0	0	2	7	2	3
Csm02165.fc1		06/14/02	0	0	0	0	0	0	0	0
Csm02168.fc1		06/18/02	0	0	0	0	0	0	1	0
Csm02169.fc1		06/18/02	0	0	0	0	0	0	0	0
Csm02171.fc1		06/20/02	0	0	0	0	0	0	0	0
Csm02172.fc1		06/21/02	0	0	0	0	0	0	0	0
Csm02175.fc1		06/24/02	0	0	0	0	0	0	0	0

Table B-3. Summary of coho salmon recapture numbers, 2002 PIT tag study.

			Number of Fish Detected at Locks in Each Flume							
	Released		Hatchery Produced				Naturally Produced			
Tagging File	**Location**	**Date**	**4A**	**4B**	**5C**	**5B**	**4A**	**4B**	**5C**	**5B**
Csm02176.fc1	Cedar River	06/25/02	0	0	0	0	0	0	0	0
CSM02177.FC1	(cont.)	06/26/02	0	0	0	0	0	0	0	0
CSM02178.FC1		06/27/02	0	0	0	0	0	0	0	0
CSM02179.FC1		06/28/02	0	0	0	0	0	0	0	0
CSM02182.FC1		07/01/02	0	0	0	0	0	0	0	0
CSM02184.FC1		07/03/02	0	0	0	0	0	0	0	0
CSM02186.FC1		07/05/02	0	0	0	0	0	0	0	0
CSM02189.FC1		07/08/02	0	0	0	0	0	0	0	0
CSM02191.FC1		07/10/02	0	0	0	0	0	0	0	0
CSM02193.FC1		07/12/02	0	0	0	0	0	0	0	0