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FINAL REPORT

Seattle Public Utilities

PIT Tagging of Juvenile Salmon Smolts in the Lake Washington Basin: Fifth and Sixth Year (2004-2005) Pilot Study Results

Lake Washington General Ecosystem Restoration General Investigation Study

U.S. Army Corps of Engineers, Seattle District
and
Seattle Public Utilities

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R2 Resource Consultants, Inc.

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Prepared for:

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Funding and resources provided by:

- U.S. Army Corps of Engineers
- Seattle Public Utilities
- King County
- King Conservation District
- Washington Department of Fish and Wildlife

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ABSTRACT

This study continued the evaluation of Passive Integrated Transponder (PIT) tag technology for monitoring smolt migration and survival characteristics as they pass through the Lake Washington and Lake Washington Ship Canal (LWSC) system, including the Hiram M. Chittenden Locks (Locks). This document presents results of the fifth and sixth consecutive years of study conducted as part of the Lake Washington General Investigation Study. Four smolt flumes and PIT tag detection devices (tunnel readers) were again installed over the spillway dam of the Locks to monitor outmigration during the spring of 2004 and 2005. Funding was limited in 2004, resulting in a reduced scope that year. Standard 12 mm tags were used in 2004, whereas newer "supertags" were used in 2005 resulting in improved detection efficiency. Primarily juvenile Chinook (both years) and coho salmon (2005 only) 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 in 2005. In addition, a small group of hatchery-reared Chinook were tagged, held, and released at the Issaquah Creek Hatchery in 2005.

Tunnel reader calibration tests were performed in 2005 using wooden sticks with tags to evaluate the detection efficiency of the tunnel readers, which was found to be higher on average than before because of the use of supertags. No calibration testing was conducted in 2004, but periodic monitoring of the readers by USACE staff indicated that the drifting problem was not as severe as in previous years. Similar issues as previous years included 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.

Flume passage rates were reduced in 2004 compared with other years because of early warming of surface water temperatures in the LWSC and Lake Washington and reduced water availability, resulting in use of fewer flumes and reduced passage rates at the flumes. Nevertheless, the data continued to provide valuable, detailed biological information for fifth and sixth consecutive years 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 information included seasonal and diurnal migration and passage timing, passage routes through the Locks, and further evidence of repeat cycling through the Locks and residualism, both of which may be related to water temperatures in the LWSC and Lake Washington. Water temperature in the LWSC and lunar phase appeared to interact in their influence on outmigration and passage characteristics, although temperature may have the stronger influence.

The information from these studies can be used for shaping spill timing and volume requirements at the Locks, and for evaluating causal mechanisms of decline. A synopsis is presented of salient results for all six study years, and study implications and improvements are suggested.

Results of adult PIT tag monitoring in the fish ladder in 2004 and 2005 are also provided in appendices. The adult detection data have provided information regarding both juvenile and adult migration and passage patterns and survival.

Implementation of PIT tagging is not assured for 2006 and in the future. The data have proven extremely useful for monitoring purposes and should continue to provide valuable insights into factors influencing salmon populations in the Lake Washington basin. Future activities will depend on a concerted funding commitment by stakeholders in the basin to continue PIT tagging as part of a longer term monitoring program.

ACKNOWLEDGEMENTS

This document reports the results of studies conducted jointly by Seattle Public Utilities, King County/Metro and the U.S. Army Corps of Engineers (USACE), Seattle District as part of the Lake Washington General Investigation (LWGI) Study. Project managers for the respective funding institutions are: Linda Smith, Project Manager, LWGI Section 1135 Study, and Chuck Ebel and Fred Goetz, PIT Tag Study Project Managers, USACE; Doug Houck, King County/Metro; and Melinda Jones, Jean White, Keith Kurko, Julie Hall, and Gail Arnold, Seattle Public Utilities. A large number of persons contributed significantly to study design and implementation in 2004 and 2005, including: Dave Seiler, WDFW, team leader for the multi-year study of smolt trapping in Lake Washington tributaries; Lindsey Fleischer, Clayton Kinsel, Pete Topping, and Kelly Kiyohara, WDFW, were responsible for tagging fish caught in the tributary screw traps and providing data for this analysis; Kyle Bouchard, Adrienne Fox, and Peter Johnson, BAE Systems/USACE Waterways Experiment Station, assisted with monitoring the tunnel reader and data logging equipment, and provided general support at the Locks; and John Post and Bill Livermore, USACE, were responsible for installation and implementation of smolt flume facilities and provided assistance in other aspects of the study. Bruce Bachen, Keith Kurko, and Julie Hall of Seattle Public Utilities provided helpful reviews.

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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 concurrent, related activities 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 for flood control (Hanson 1957). 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 it was constructed through to the present day.

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 listings under the federal Endangered Species Act (ESA) of Puget Sound Chinook salmon (*Oncorhynchus tshawytscha*; listed in 1999 as “threatened”; 64 FR 14308) and bull trout (*Salvelinus confluentus*; listed in 1999 as “threatened”; 64 FR 58910), and potential listing of coho salmon (*O. kisutch*). Sockeye salmon (*O. nerka*) is also an important species in the basin for water and fisheries management. 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 at the locks that minimize or eliminate adverse effects. In addition, it is important that migration behavior and survival be better understood in the Lake Washington basin to maximize effectiveness of restoration efforts and projects. This document details the results from fifth and sixth year studies of migration and passage behavior and survival using Passive

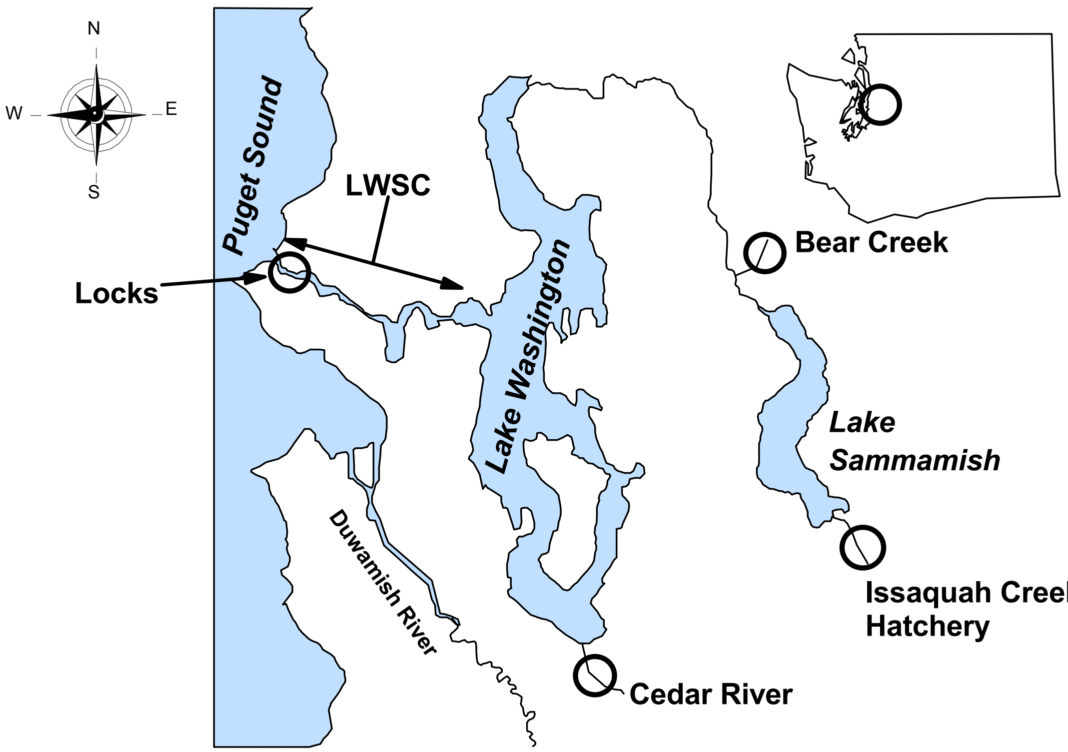


Figure 1-1. Locations of the Lake Washington Ship Canal (LWSC), Hiram M. Chittenden Locks, and PIT-tagged fish releases in the Lake Washington.

Integrated Transponder (PIT) tag technology (Prentice et al. 1990a,b,c). The work builds on four years of work conducted as part of the greater Lake Washington General Ecosystem Restoration General Investigation (LWGI) Study 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 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.

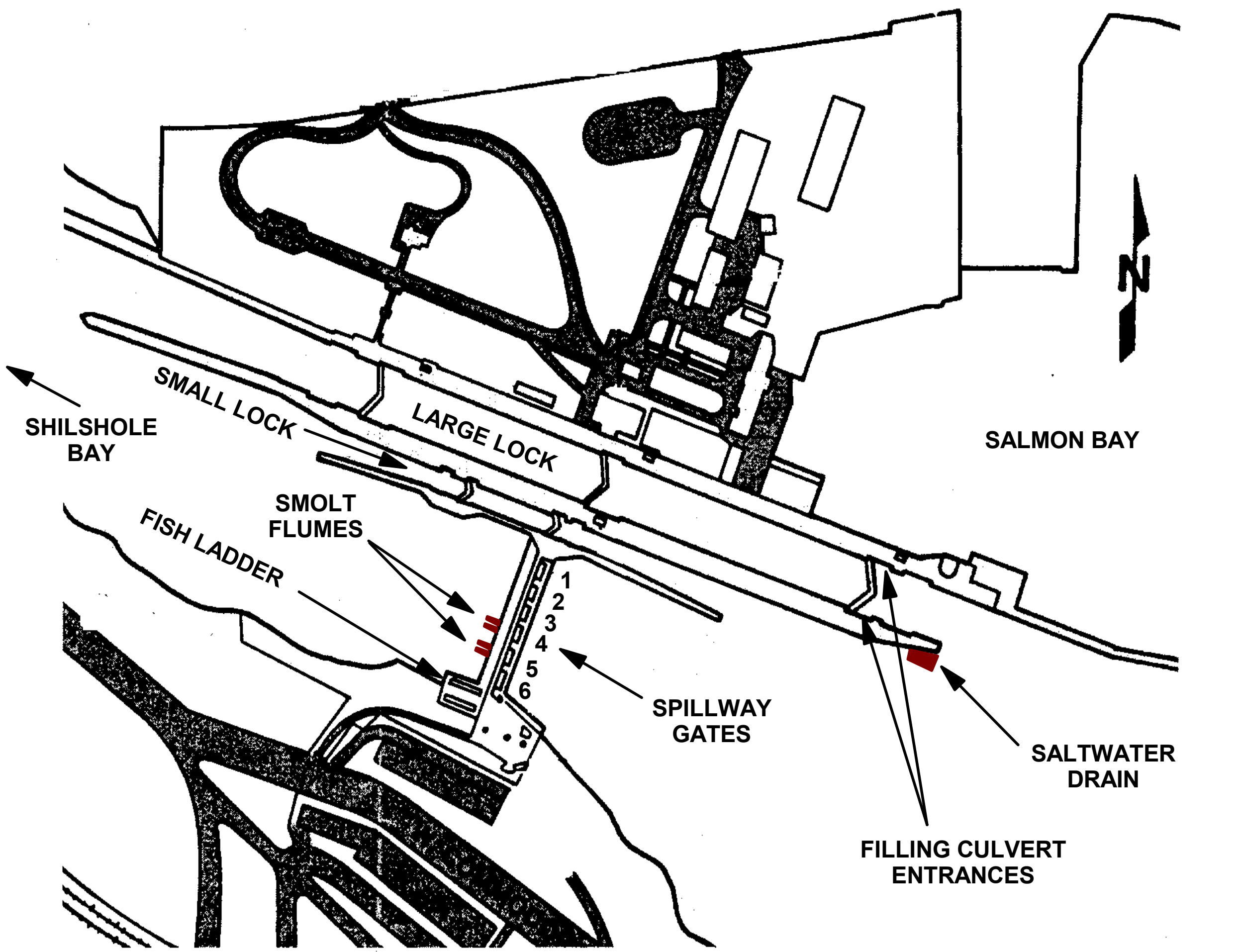


Figure 1-2. Plan view of the Hiram M. Chittenden Locks showing major structural features and location of smolt flumes and tunnel readers in spill bays 4 and 5.

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, particularly with respect to managing water quality of Lake Washington and Lake Union where 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 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, including through the fish ladder.

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 have been 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 operating 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 2004 and 2005 PIT tag studies are part of the greater LWGI study, which was initiated in May 1999. The LWGI study is a USACE project with the City of Seattle (Seattle Public Utilities) and King County as local sponsors. In addition, funding has been provided for tag detection in the fish ladder by a King Conservation District grant.

The purpose of the LWGI study is to develop a set of ecosystem restoration projects to provide benefits primarily to salmon in the Lake Washington basin. This includes evaluation of various projects that may contribute to restoration of ecological processes or functions within the Lake Washington basin, including projects that will improve passage of juvenile and adult salmon through the Locks. The LWGI study has included salmon studies at the Locks, in the Ship Canal, and in Lakes Washington and Sammamish and their tributaries since 2000. Activities have entailed studies that improve knowledge and understanding of the life history and ecology of native fish in the Lake Washington basin. Relevant projects have included making fish passage improvements at the Locks and in the LWSC, and implementing water conservation measures to provide additional water for fish passage through the Locks. PIT tagging studies help address data needs associated with better understanding of salmon migration in the greater Lake Washington basin and relative survival of out-migrating juvenile salmon, and have been conducted every year of the GI Study. In addition, PIT tag monitoring of juveniles has complemented post-flume construction monitoring performed as part of the Lake Washington Ship Canal Smolt Passage, Section 1135 Restoration Project (USACE 1999).

Results presented in this report address the following overall objectives for PIT tagging during years 5 and 6 of the LWGI Study:

- Continue documentation of the migration timing characteristics of naturally and hatchery reared salmon in the Lake Washington basin with a primary emphasis on Chinook salmon;
- Further focus the evaluation of mark and recapture of PIT-tagged fish as a means to evaluate factors influencing survival of outmigrating Chinook juveniles; and
- Evaluate hypotheses based on previous years' results with the 2004-2005 results.

In addressing the above objectives, the resulting data were intended for use in evaluating alternative operations and structural measures at the Locks and other restoration measures in the Lake Washington system.

2. METHODS

Tagging efforts were reduced in 2004 and 2005 compared with previous years, reflecting funding constraints. Primary goals of the 2004 and 2005 study were to further evaluate the feasibility of PIT tagging in the Lake Washington system and the influence on migration patterns of factors within and outside of the control of water management operations at the Locks. The overall study design involved tagging and release of natural and hatchery origin juvenile Chinook salmon at up to three locations in the watershed, and detecting them at the Locks. 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). Delayed tagging mortalities generally do not exceed 1% based on extensive experience in the Columbia River (Muir et al., 2001a,b; Dare 2003). 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.

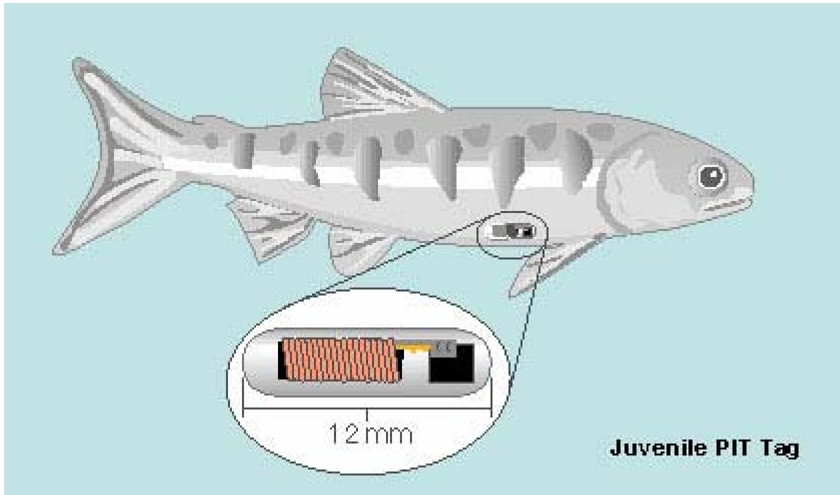


Figure 2-1. Schematic of a Passive Integrated Transponder (PIT) tag inside a juvenile salmonid.

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 flume hydraulics. This was a greater problem in the two large flumes (4B and 5B). At certain lake levels, supercritical flow 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 approximately 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.

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 during reader detection efficiency testing. 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 brand 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 J -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 number of the coil that detected the tag, and the time and date of detection. Coil identification numbers were reversed in order from previous years, however. In 2003 and earlier, coils 11 and 12 represented flume 4A, coils 21 and 22 flume 4B, coils 31 and 32 flume 5C, and coils 41 and 42 represented flume 5B. In 2004 and 2005, the order of coil numbers was reversed during flume installation, where coils 11 and 12 were for flume 5B, etc. Data were retrieved remotely from the computers on a weekly 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 and PIT tag funnel readers, 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.

It is not known the extent to which tunnel reader electronics may have drifted from maximum detection efficiency in 2004 as has occurred in previous years. Such phase shifts would have resulted in an undetermined reduction in detection efficiency in 2004, but did not appear to have affected efficiency substantially in 2005 when newer, improved “supertags” were used. Calibration testing results are presented in Chapter 3 for 2005, 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 three main study groups (see Section 3.1 for numbers tagged and released):

- An experimental group of Chinook salmon were tagged and later released at the Issaquah Hatchery in 2005 to provide another year of data for this stream, for identifying longer term trends;
- Naturally-spawned Chinook salmon (both years), coho salmon (2005 only), and an occasional steelhead (2005 only) offspring 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). L. Fleischer, Clayton Kinsel, and Pete Topping (WDFW) 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 a data collection station (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.

Letter reports from WDFW detailing 2004 and 2005 tagging activities and mortalities are presented in Appendix A.

Releases of PIT tagged fish were designed to address questions regarding 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 410 age 0+ Chinook salmon originating from the Issaquah Creek hatchery were tagged on location on April 27, 2005. Of these, one fish died during tagging. It is unknown if any died later during holding. 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.

The fish were relatively small (length generally between 55-75 mm) and thus difficult to tag. Water temperatures were relatively warm compared with previous years, on the order of 13 ºC - 14ºC. Feeding 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. Warmer water temperatures promoted rapid tag wound healing, and only fish that appeared to be in prime condition were tagged (L. Fleischer, WDFW, personal communication). The raceway was not checked after it had been drained, however, so the possibility exists that an unknown number of tags may have been shed. The number is likely to have been very small, if non-zero. A total of 409 tagged fish were thus assumed to have ultimately been released with other Chinook smolts on May 16, 2005 into Issaquah Creek.

2.3.2 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. Only Chinook juveniles were tagged in 2004. 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 5, 2004 and May 2, 2005. Tagging continued until June 18, 2004 and June 21, 2005 in Bear Creek, and until July 2, 2004 and July

12, 2005 in the Cedar River. Tagging dates encompassed the peak of the outmigration period for naturally-produced smolts. A total of 2,185 and 3,414 fish were tagged and released in the Cedar River in 2004 and 2005, respectively, and 1,512 and 2,631 fish respectively in Bear Creek. Most of the fish were Chinook and coho salmon, although eleven steelhead trout were tagged in the Cedar River in 2005. A primary goal of this portion of the study was to determine survival and migration characteristics of the main fraction of the Chinook and coho salmon smolt runs from 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. Tests were not conducted of post tagging mortality and tag shed rates; results from previous years indicated that such rates were likely to have been negligible (see WDFW tagging reports in Appendix A). Fish tagged in Bear Creek and the Cedar River were exclusively naturally reared. The tagged Chinook were likely all sub-yearlings, whereas it is likely that most of the coho and steelhead were yearlings.

2.4 CALIBRATION TESTING OF THE TUNNEL READERS

"Fish sticks" were used once in 2004 and three times in 2005 to monitor the detection efficiency of the tunnel readers. 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 (0º) to the long axis of the stick, and (2) where the tag was oriented 45º to the long axis. Previous year's results indicated the fish sticks provided a reasonable index of detection efficiency, and that averaging the results of the 0º and 45º stick tests approximated live fish results (DeVries et al. 2005). A less expensive alternative to using a boat below the Locks to retrieve test sticks was developed in which five sticks of a particular tag orientation were tied together approximately 2 feet apart on fishing line and released into the flumes from the spillway walkway using a surf-casting rod and reel. A test conducted in 2004 suggested that the five sticks had a similar probability of detection as five sticks dropped individually into the flumes and retrieved below with a boat. Each stick array was released into each flume for a total of twenty sticks per flume for each tag orientation. The associated error in determining detection efficiency of a given tag orientation was therefore 5%, with an overall detection efficiency error of 2.5%. The number of fish sticks 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. Standard, older tags were used in 2004, whereas the newer, improved supertags were used in 2005, consistent with the types of tags in use each year.

2.5 EVALUATION OF SMALL LOCK OPERATIONS ON DAILY VARIATION IN SMOLT PASSAGE THROUGH THE FLUMES

The PIT tag studies to date have consistently indicated that the majority of tagged smolts pass through the flumes during daylight hours. The frequency distributions of hourly passage rates were comparable to frequency distributions of small lock openings. It was hypothesized that the daily variation in passage rates might reflect the influence of velocity variation in the spillway forebay associated with small lock filling (DeVries et al. 2005). This hypothesis was tested opportunistically in 2005 on two occasions when there was sufficient water available, on June 2-3 and June 14-15. Each test involved alternating between a normal daily lock opening pattern, when the small lock was opened more frequently during the day than the night, and a uniform distribution where the frequency of lock openings was forced to be similar during both day and nighttime hours. For the uniform case, the tower master on duty was instructed to conduct false lockages at the same times with respect to a 12-hour cycle as occurred during the preceding daylight hours, with adjustments made to include real lockages. This protocol was selected as being the simplest and least likely to be confusing in its implementation. For example, if a lockage occurred at 2:03 pm, a false lockage was also conducted at 2:03 am unless a real lockage occurred shortly before. The null hypothesis was that diurnal passage rate distributions should not reflect the small lock opening frequency distribution, that is the 24-hour cumulative frequency distributions of flume passage should be similar for both the variable and uniform distributions of small lockages.

2.6 DETECTION STRATEGY

The 2004 and 2005 studies relied primarily on releasing fish at two to three locations in the watershed and detecting them at the Locks. As in previous years, not all of the passage routes through the Locks were monitored. 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.

2.7 DATA ANALYSES

Data analyses generally followed those in previous years, with the notable exception that survival to the Locks was not evaluated in 2004 and 2005 because of the limited number of release locations.

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. Information was not available regarding growth and length at time of passage at the Locks. 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 identify potential fish size dependent effects suggested by the data that might influence survival of each stock to the Locks. 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 (J 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 hatchery 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.

For the two small lock tests described in Section 2.5, the resulting hourly cumulative frequency distributions of flume passage and small lock openings were compared using Chi-Square tests. Rejection of the null hypothesis was interpreted to mean that small lock filling patterns were a strong control on daily variation in passage rates. Failure to reject the null hypothesis was interpreted to mean that other factors, including particularly diurnal vertical migrations based on hydroacoustic data (Johnson et al. 2004), were a stronger influence on daily variation in passage rates through the flumes.

Flume passage rates were also evaluated for their potential relation to small lock fillings over the course of the outmigration season. The same Fortran computer program used in previous years calculated the number of detections that occurred (i) while the small lock was filling and for five minutes thereafter ("fill" period), and (ii) until the time of the next fill sequence ("between-fill" period). Times 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. 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 counts were compared using a t-test 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.

3. RESULTS

The results of this study were strongly influenced by low flows into Lake Washington in 2004, comparable to 2003, which was also characterized by a dry spring. Inflows were lower overall in 2004 than in 2005 when water availability was greater (USGS gage data). In contrast to 2003, however, when there was no spill through spill bays 1-3, there were periods in 2004 and 2005 when additional spill was necessary to maintain target lake levels. Additional spill occurred on May 5, 26-31, and June 5 in 2004, and on May 4, 9-11, 15-16, 18-24, and June 1, 6, 13 in 2005. Most spill outside of the flumes occurred during nighttime or late afternoon hours, to increase chances of detecting tagged fish in the flumes during the day. Flumes were generally shut down at night in both years to conserve water, especially in 2004. These operating procedures were based on previous years' PIT tag study results showing that more than 95% of fish passage in the flumes occurred during daylight hours (DeVries et al. 2005).

Figures 3-1 and 3-2 show the approximate times that the flumes were open during the 2004 and 2005 studies, respectively, according to logs kept in the lock control tower, notes taken by flume observers in 2004, and PIT tag detection times. The flumes were never opened continuously over a more than 24 hour period during the 2004 study. There were few days in 2005 that all four flumes were open continuously, although Flume 5B was operated nearly continuously until early July 2005. The flume schedule in May-June 2004 was controlled by a study of flume passage and culvert entrainment in 2004 with different flume combinations each day (DeVries and Hendrix 2005). Flume passage was provided through July to varying extents. After July 25, 2004, only Flume 5C was opened during daylight hours to provide passage opportunities even though detection rates of PIT tagged fish had fallen to zero. Flumes 4A and 4B were opened during daylight hours throughout July 2005. There were also periods during the study when the flumes were closed for maintenance. Consequently, the flume coverage for PIT tags was neither continuous nor consistent.

The flumes operated long enough that the sockeye and coho salmon outmigrations were essentially complete and the numbers of tagged Chinook salmon passing through the flumes had decreased substantially to near zero, consistent with visual flume count data (DeVries and Hendrix 2005). 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 report.

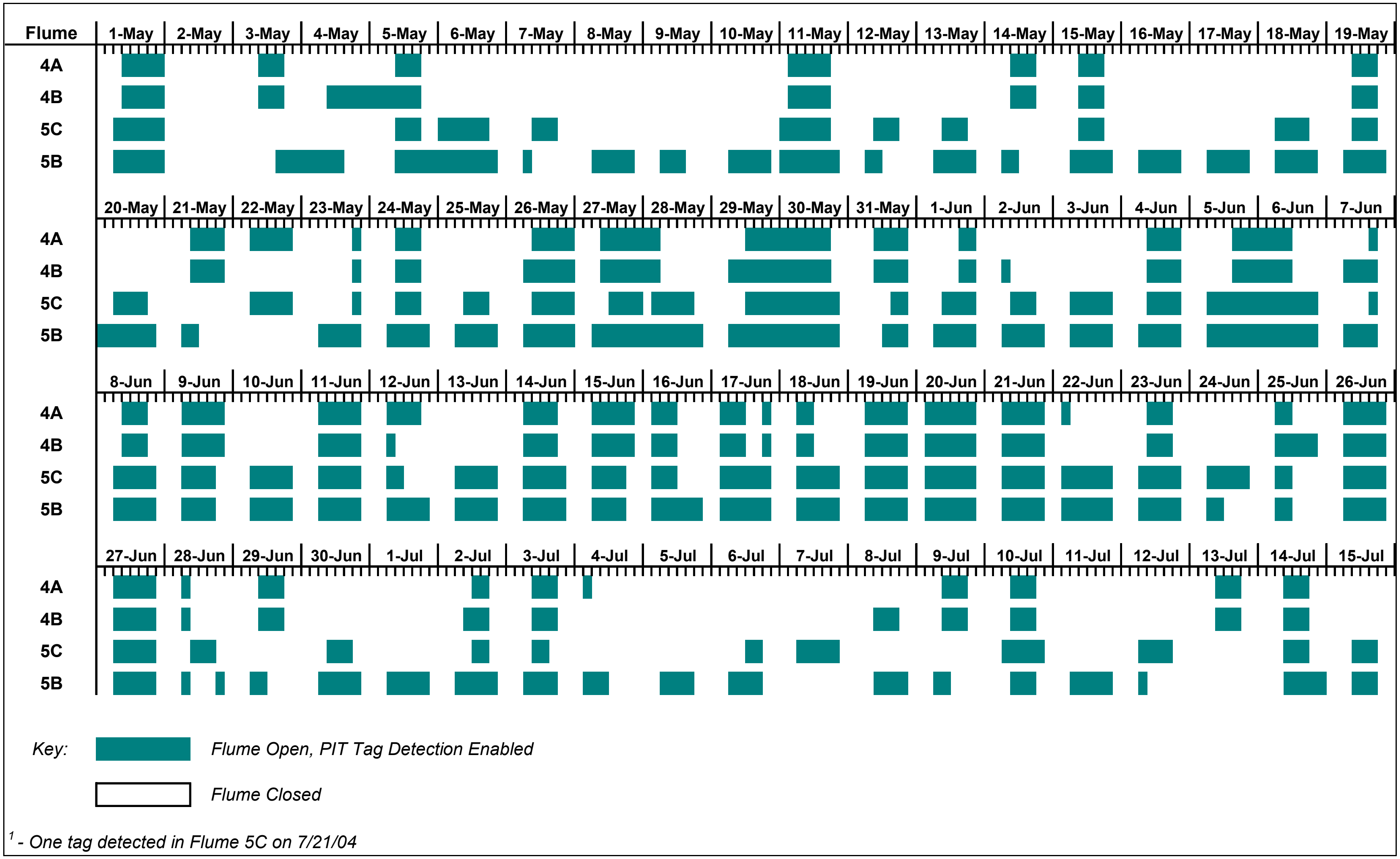


Figure 3-1. Times that the smolt flumes were open at the Locks during the 2004 PIT tag study until tunnel reader detections had essentially ceased (one fish detected in Flume 5C on 7/21/04).

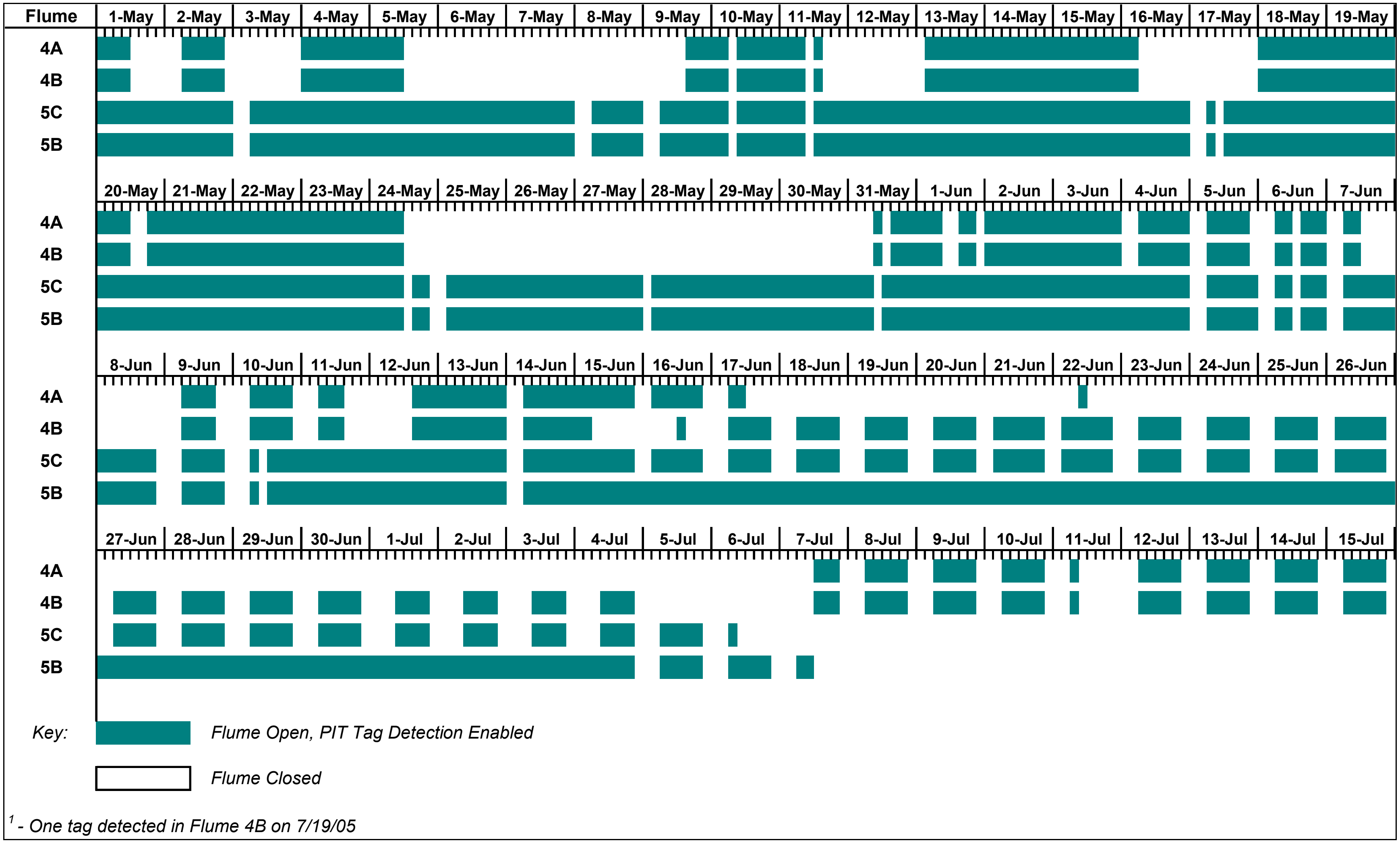


Figure 3-2. Times that the smolt flumes were open at the Locks during the 2005 PIT tag study until tunnel reader detections had essentially ceased (one fish detected in Flume 4B on 7/19/05).

This section focuses predominantly on results for 2004 and 2005, and in a few cases presents previous years' results for comparative purposes. The results are compared in greater depth with previous findings and hypotheses in Section 4.

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 3-3 through 3-5 depict the cumulative 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 thirteen tags detected in the tunnel readers that were not identified in the 2000, 2001, 2002, or 2003 tagging files, probably because they were not detected by the tagging station equipment, so the origin release date, and/or species of those fish could not be determined conclusively. Of these, two tags did not appear to come from the Lake Washington GI studies based on their tag numbers, but they were not listed in the PTAGIS database. Another two of these tags were likely fish tagged in 2002 or 2001 based on the tag number. Two more tags were detected that 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; those tags were edited into the tagging files accordingly. Two tags were also detected from a separate pilot study involving acoustic tags.

3.2 TUNNEL READER CALIBRATION TESTING

Although the tunnel readers were monitored only once on July 2, 2004 because of insufficient funding, the result indicated that the readers were operating satisfactorily. Detection efficiencies were 85%, 100%, and 95% for flumes 4B, 5C, and 5B, respectively. These levels were consistent with previous years' detection efficiency. Flume 4A was not tested, but it was regularly associated with efficiencies at or near 100% in previous years (DeVries et al. 2005). Detection efficiencies were higher in 2005 using the supertags and appeared to remain consistently high over the course of the outmigration season (Figure 3-6). 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). Detection efficiencies in 2005 averaged 98% in Flumes 4A and 5C, 95% in Flume 4B, and 90% in Flume 5B. These numbers were comparable to previous years. Detection efficiency did not appear to be as variable in Flume 5B in 2005 as in previous years. The mean detection efficiency estimates were used to estimate the total numbers of PIT-tagged fish passing through the flumes by dividing the number detected from each release group in a flume by that flume's detection efficiency.

Table 3-1. Summary of 2004 and 2005 PIT tag release and recapture numbers, Lake Washington GI Study.

Species (Year)	Origin	Issaquah Creek Hatchery	Bear Creek	Cedar River
		Total Numbers Tagged and Released:		
Chinook (2004)	Natural	--	1512	2185
	Hatchery	--	--	6
Chinook (2005)	Natural	--	1424	2075
	Hatchery	409	--	63
Coho (2005)	Natural	--	1207	1265
Steelhead (2005)	Natural	--	--	11
		Total Numbers Detected in Smolt Flumes:		
Chinook (2004)	Natural	--	221	325
	Hatchery	--	--	0
Chinook (2005)	Natural	--	320	521
	Hatchery	56	--	2
Coho (2005)	Natural	--	636	591
Steelhead (2005)	Natural	--	--	0
		Estimated Total Numbers Passing Through Smolt Flumes:		
Chinook (2004)	Natural	--	231	334
	Hatchery	--	--	0
Chinook (2005)	Natural	--	341	556
				2
	Hatchery	59	--	
Coho (2005)	Natural	--	675	
Steelhead (2005)	Natural	--	--	

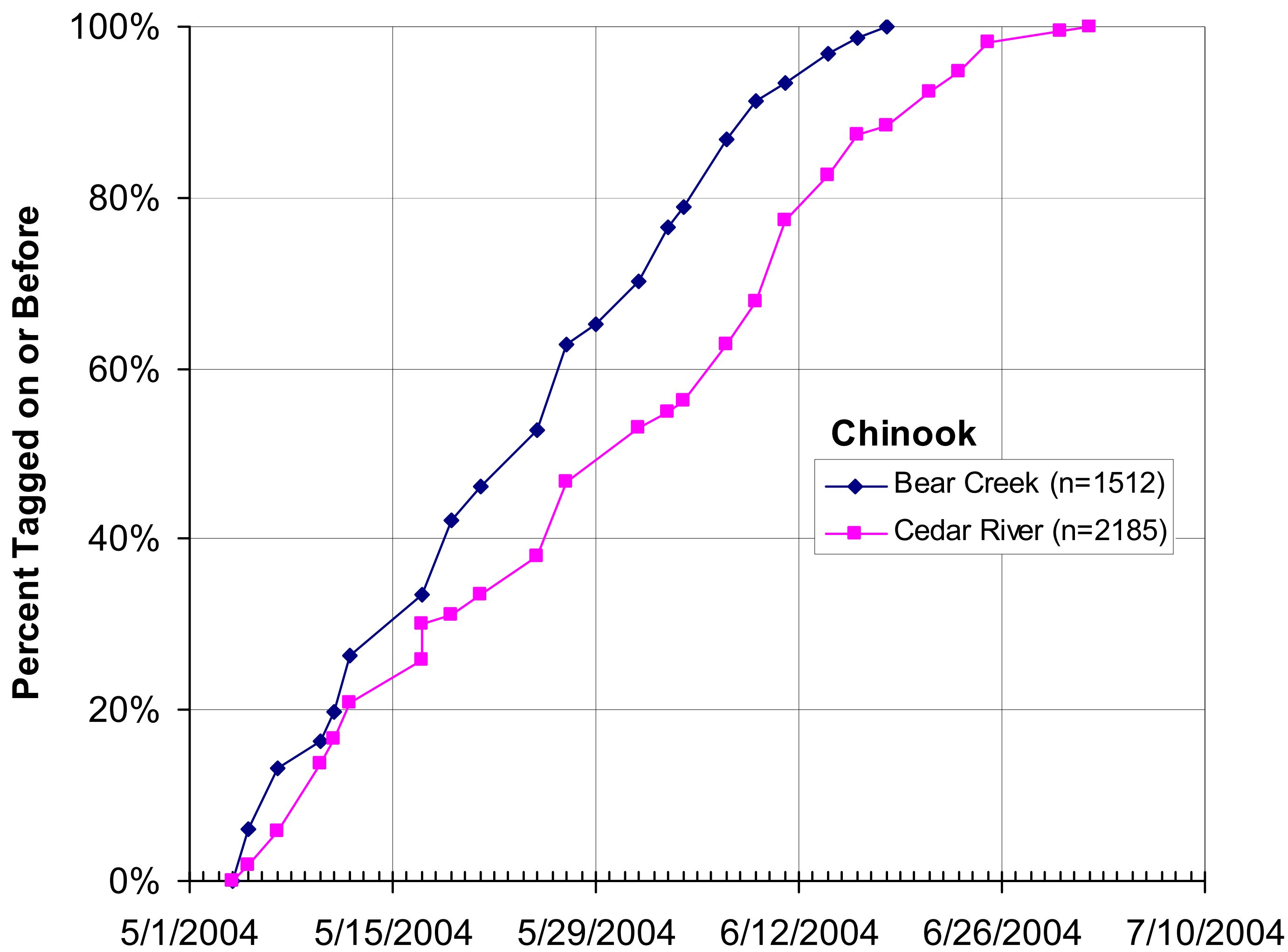


Figure 3-3. Cumulative frequency distributions of juvenile natural origin Chinook salmon PIT tagging numbers by date and location, 2004 Lake Washington PIT Tagging study.

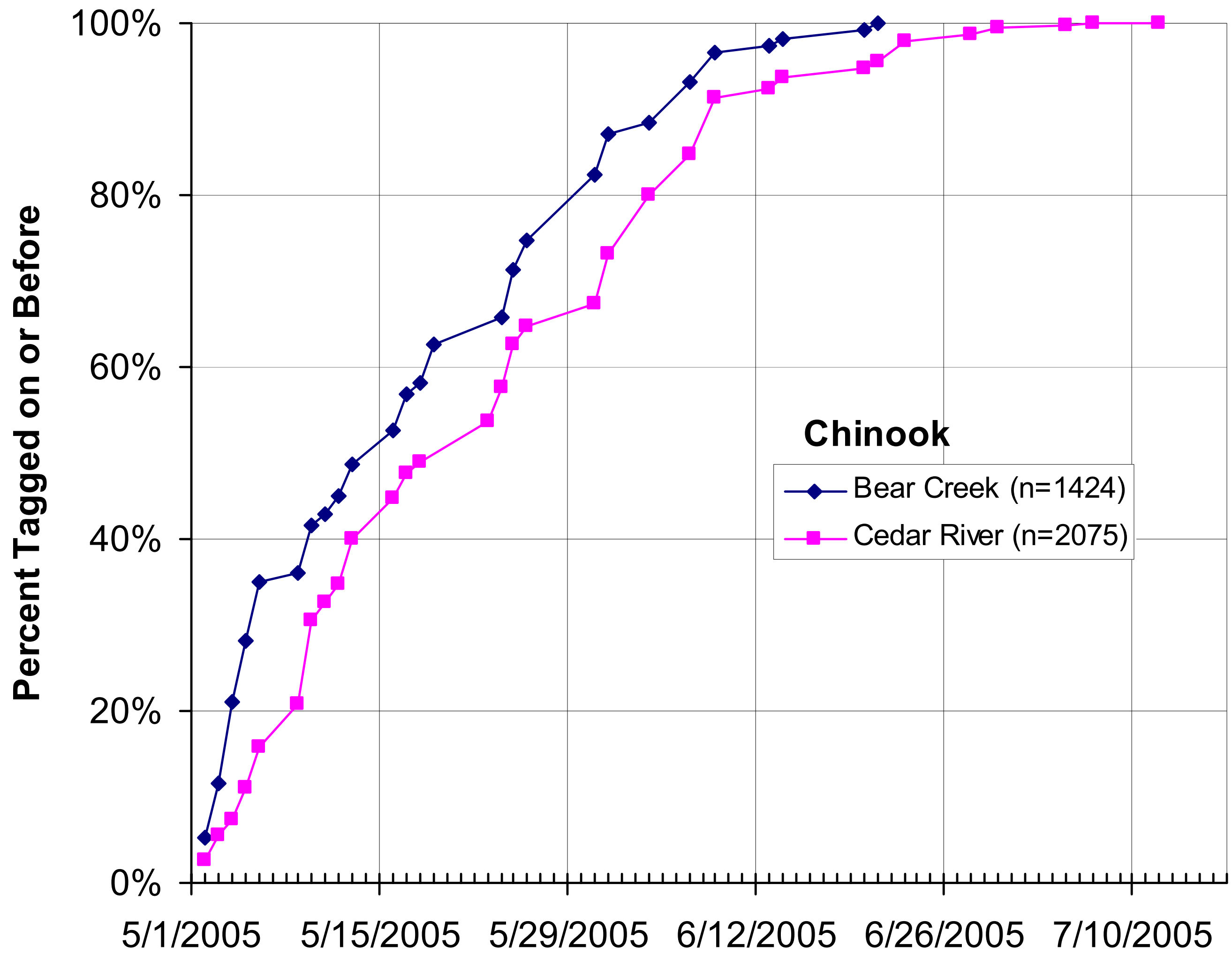


Figure 3-4. Cumulative frequency distributions of juvenile natural origin Chinook salmon PIT tagging numbers by date and location, 2005 Lake Washington PIT Tagging study.

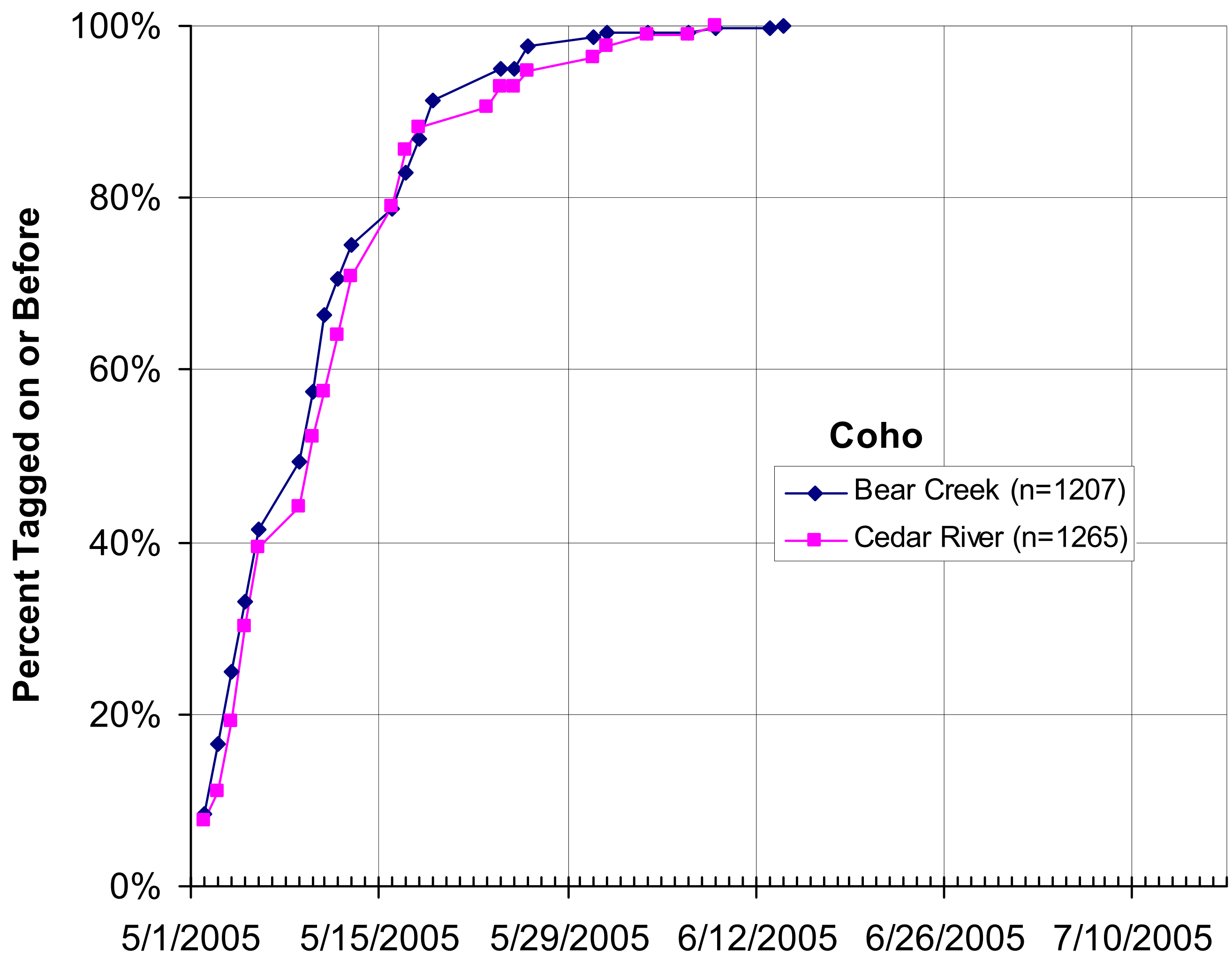


Figure 3-5. Cumulative frequency distributions of juvenile natural origin coho salmon PIT tagging numbers by date and location, 2005 Lake Washington PIT tagging study.

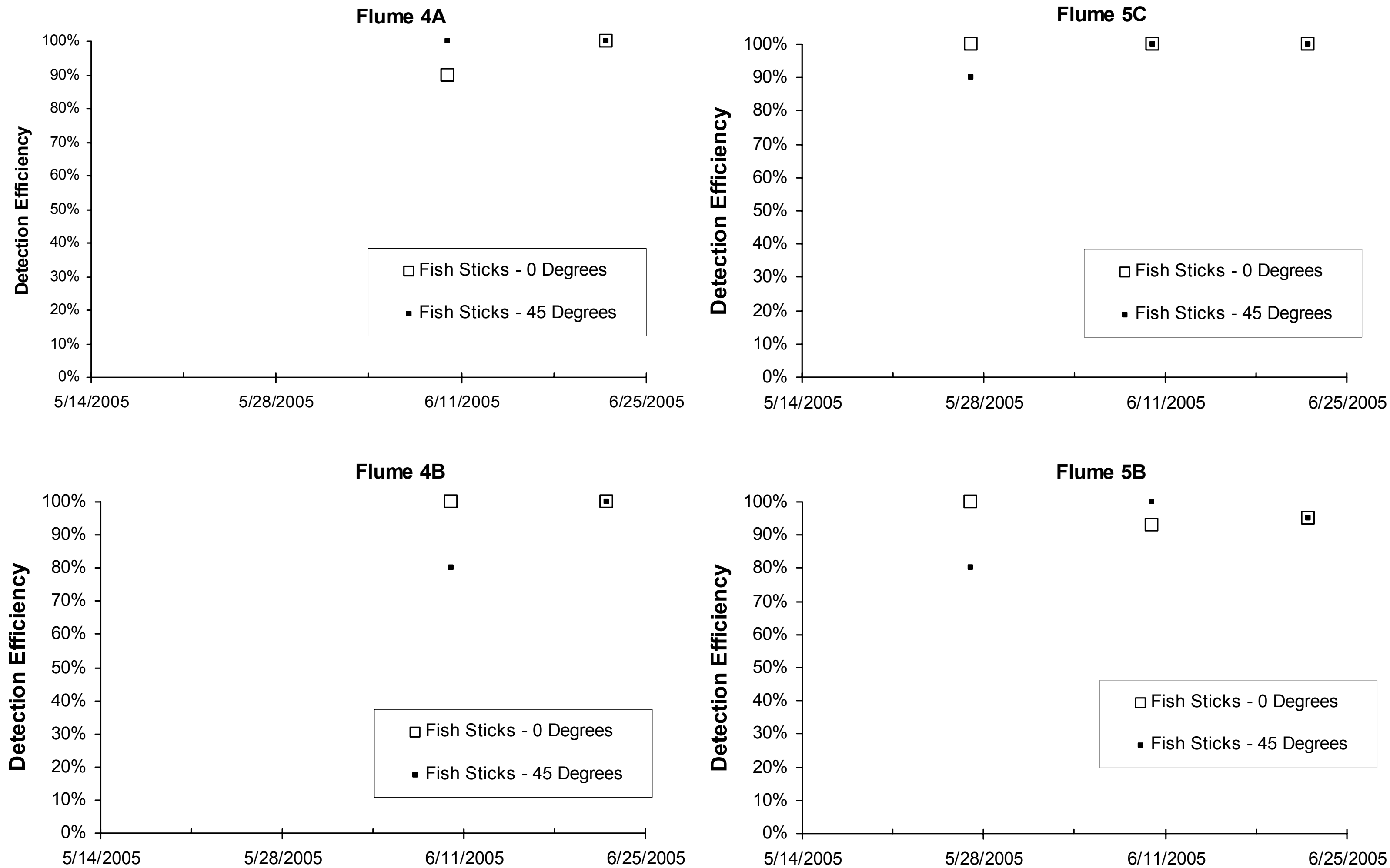


Figure 3-6. Results of calibration tests of tunnel detector efficiency at the Locks using fish sticks released directly into each flume, 2005 PIT tag study.

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 3-7 through 3-13 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 tributary locations where tagging continued over the passage season.

In general, there was limited evidence of a consistent effect of fish size overall on detection rate at the Locks, indicating that tagged Chinook and coho smolts of all sizes 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).

The patterns in which mean lengths changed over the outmigration season were markedly different in 2004 and 2005 in Bear Creek than in previous years (Figures 3-8 and 3-9). Mean lengths stayed approximately the same over the May-June tagging period in 2004 and 2005. Changes were more evident in earlier years, especially in May, when there was also a break in trend lines evident in some years that suggested two populations. Temperature logger data collected by King County indicate that water temperatures were warmer in May of 2004 and 2005 than in 2003, which may have affected bioenergetics and accelerated growth earlier (Greg Volkhardt, WDFW, personal communication December 2005; also see Section 4.2).

Mean lengths of juvenile Chinook captured in the Cedar River appeared to exhibit relatively steady growth patterns in 2004 and 2005 that were generally consistent with previous years (Figures 3-10 and 3-11). An interesting phenomenon was observed both years in the Cedar River, where the variability in lengths was greater after apogee than before (apogee occurred June 17, 2004 and June 11, 2005).

As in previous years, mean lengths of coho salmon smolts remained relatively constant compared with Chinook smolts over the 2005 outmigration season in both Bear Creek and the Cedar River (Figures 3-12 and 3-13). There were no significant differences in size distributions of released and detected coho overall (Chi-square test, critical $\alpha > 0.05$).

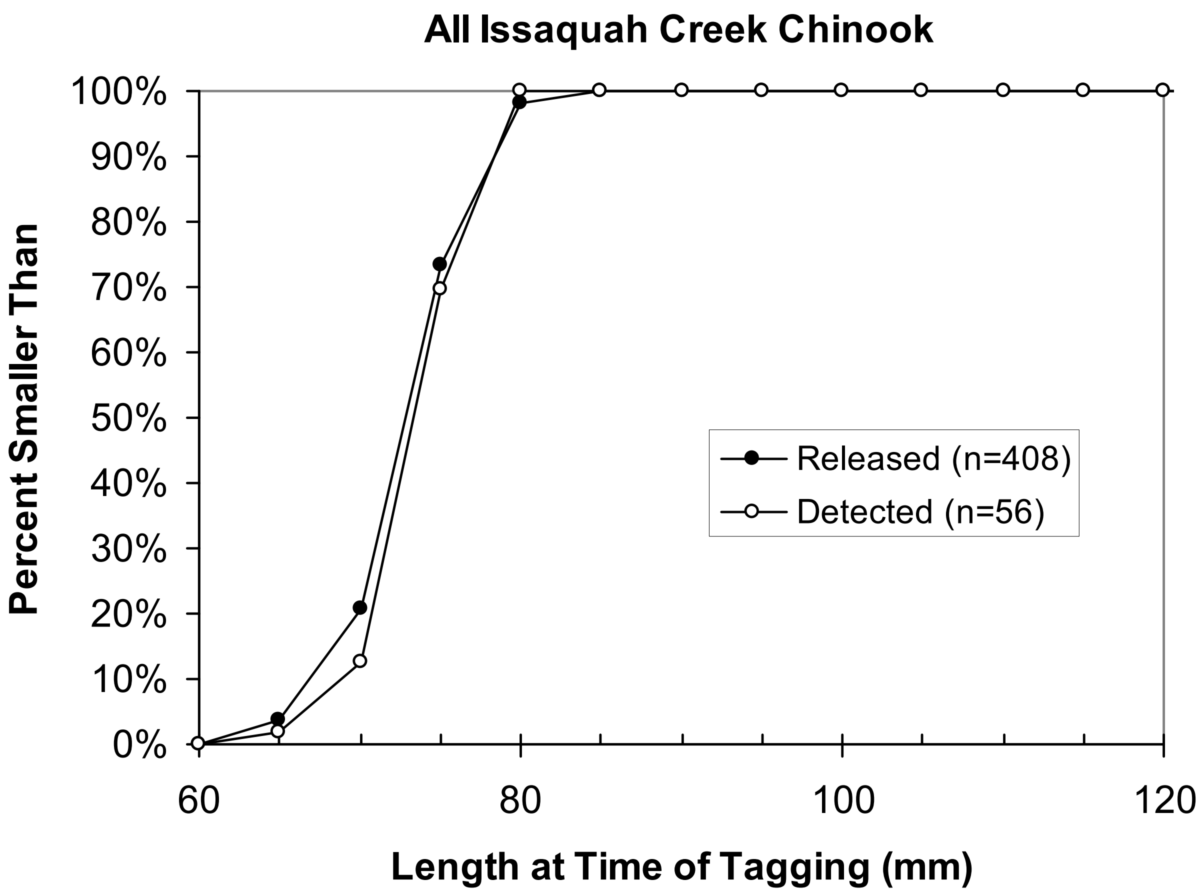


Figure 3-7. Cumulative frequency distributions of lengths of tagged and detected Chinook salmon released at the Issaquah Hatchery, 2005 PIT tagging study. Hatchery fish were not tagged in 2004.

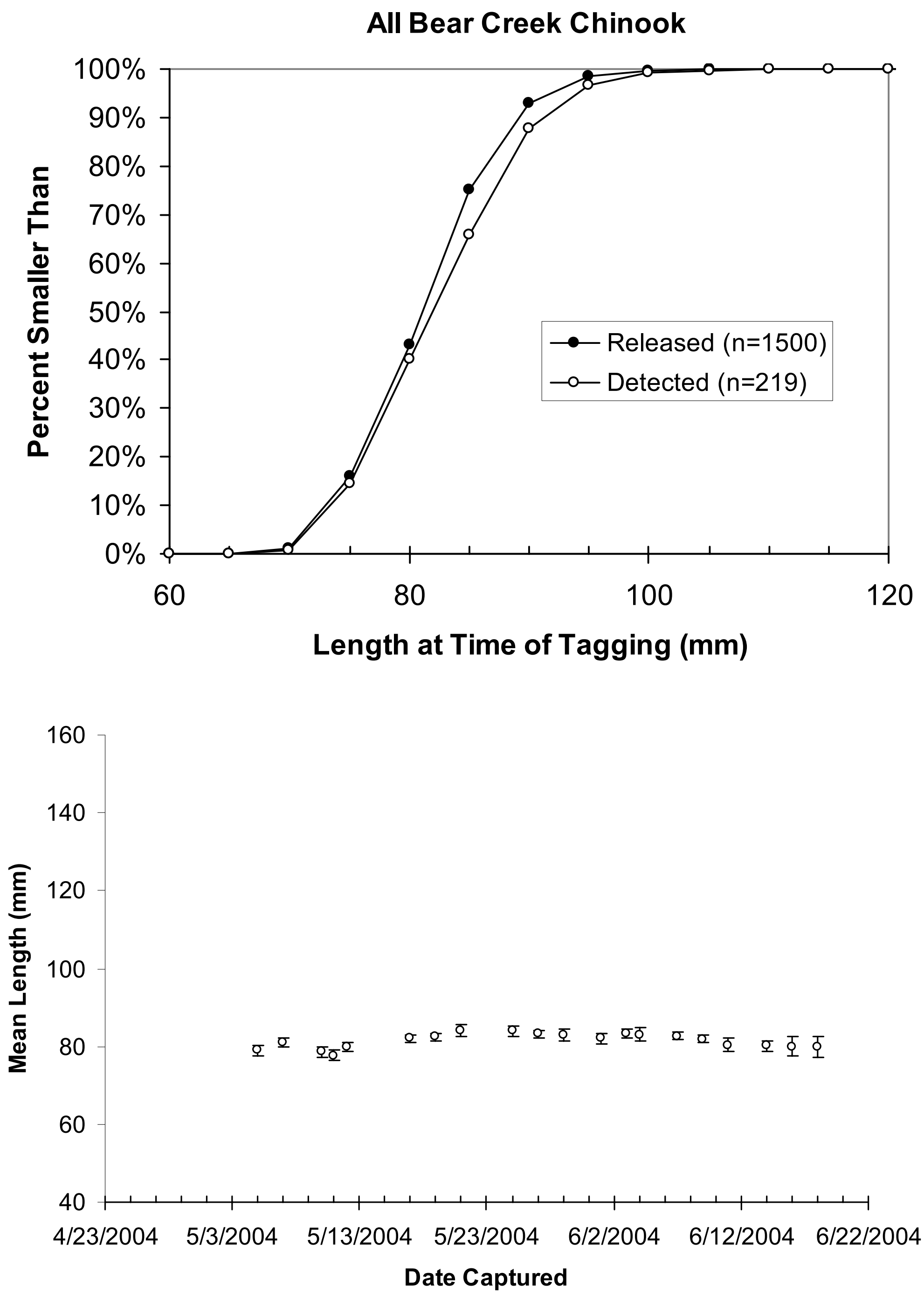
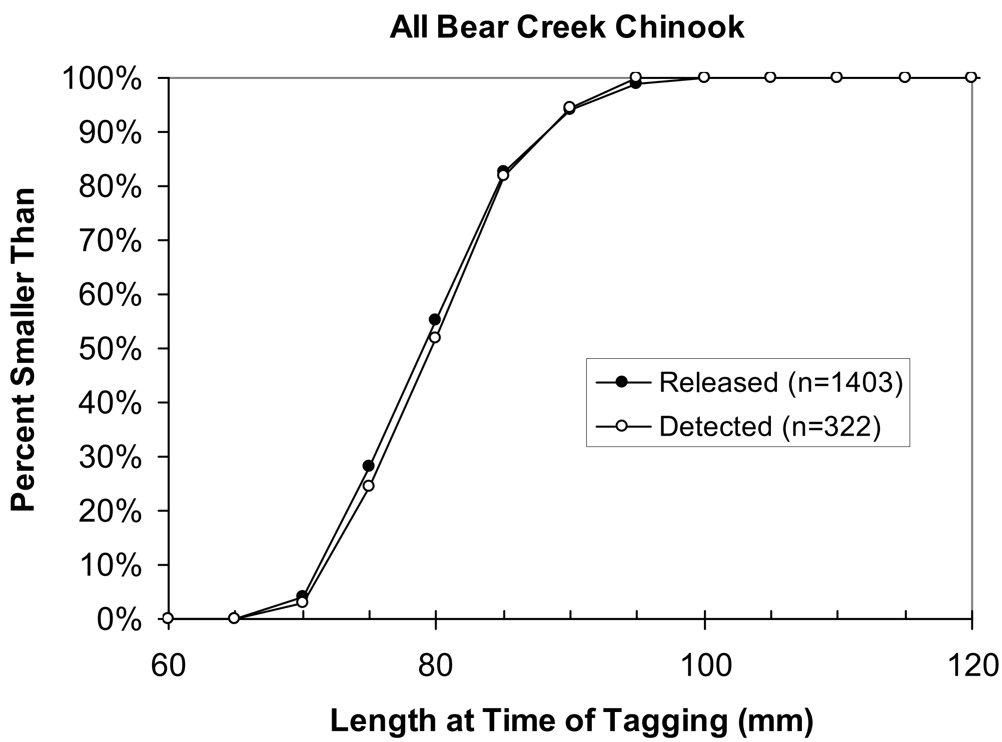


Figure 3-8. Cumulative frequency distributions of lengths of tagged and detected Chinook salmon caught in Bear Creek (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2004 Lake Washington PIT tag study.



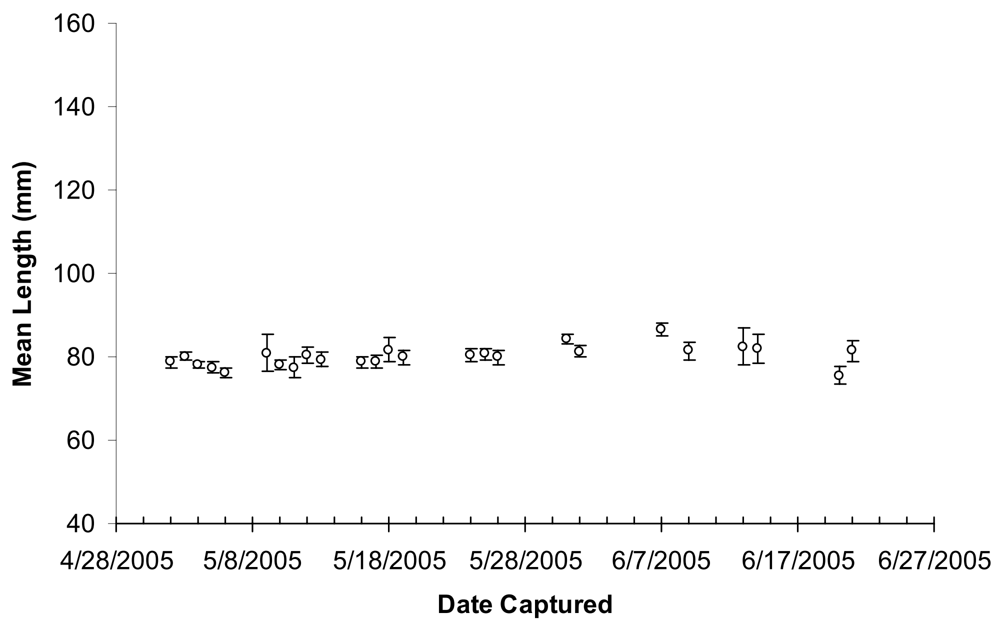
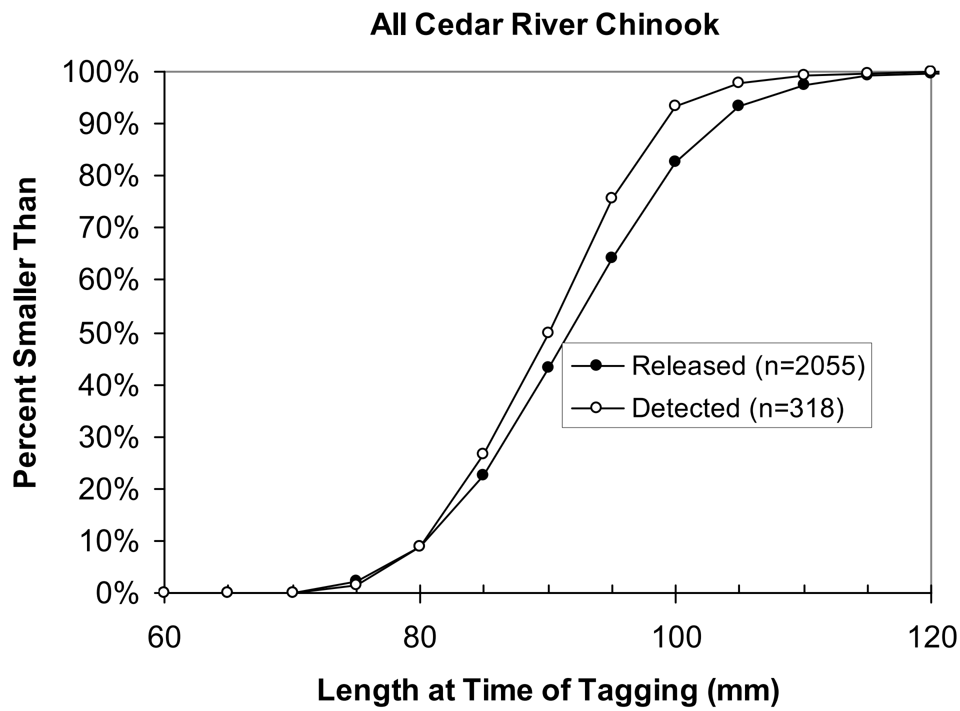


Figure 3-9. Cumulative frequency distributions of lengths of tagged and detected Chinook salmon caught in Bear Creek (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2005 Lake Washington PIT tag study.



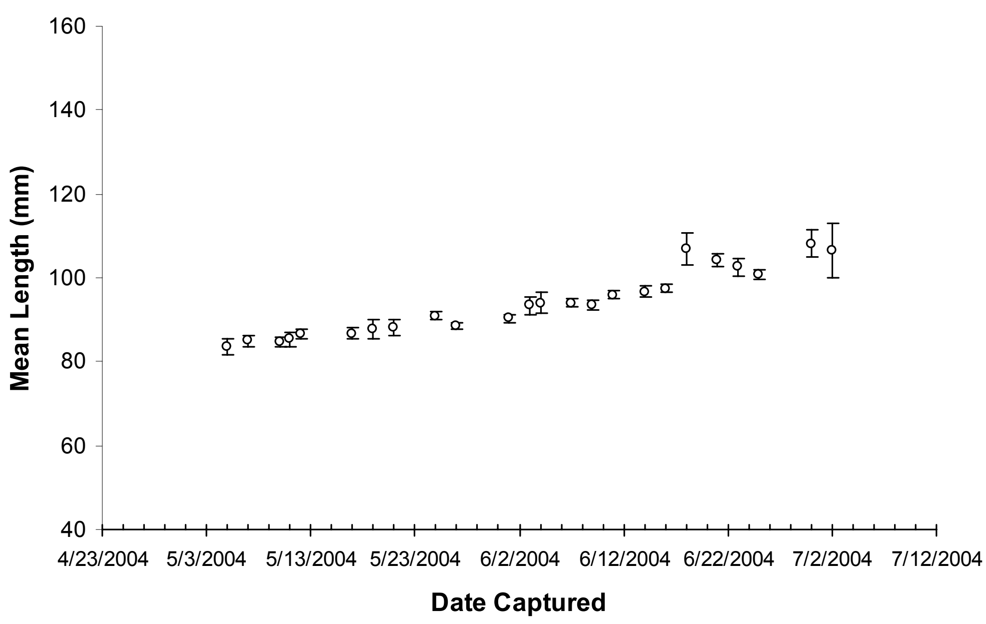
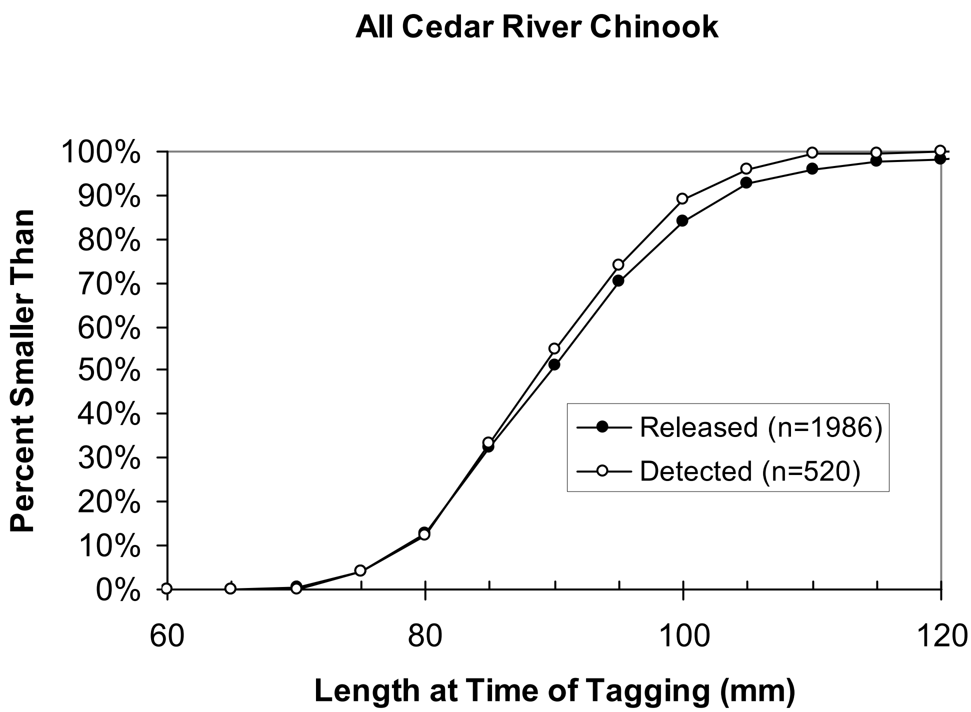


Figure 3-10. Cumulative frequency distributions of lengths of tagged and detected Chinook salmon caught in the Cedar River (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2004 Lake Washington PIT tag study.



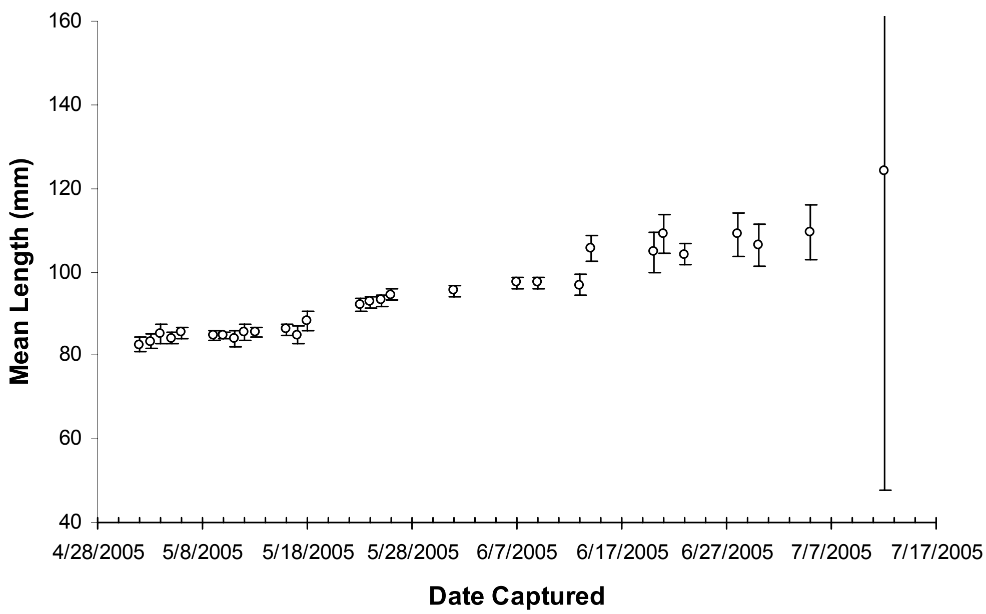


Figure 3-11. Cumulative frequency distributions of lengths of tagged and detected Chinook salmon caught in the Cedar River (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2005 Lake Washington PIT tag.

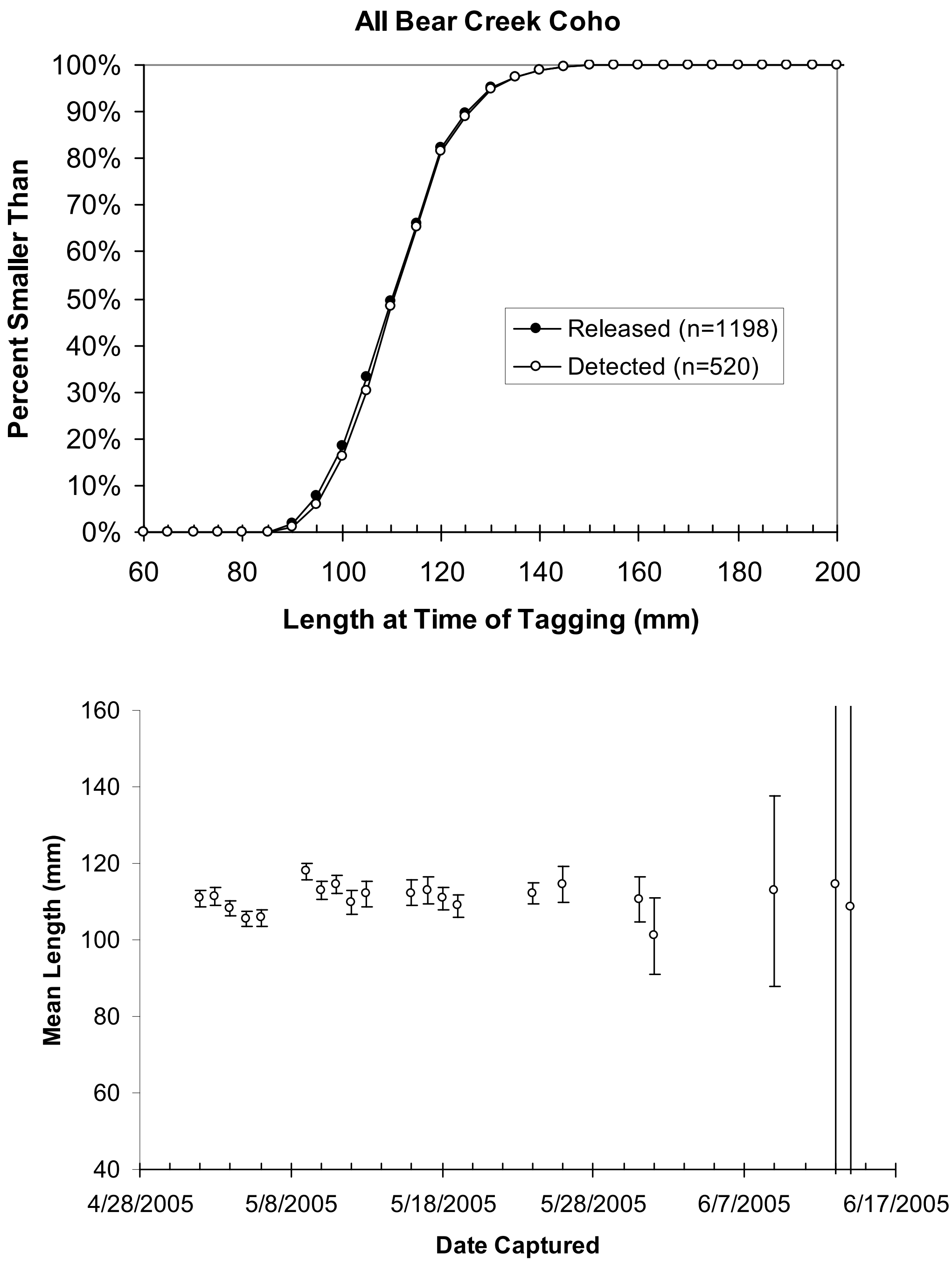
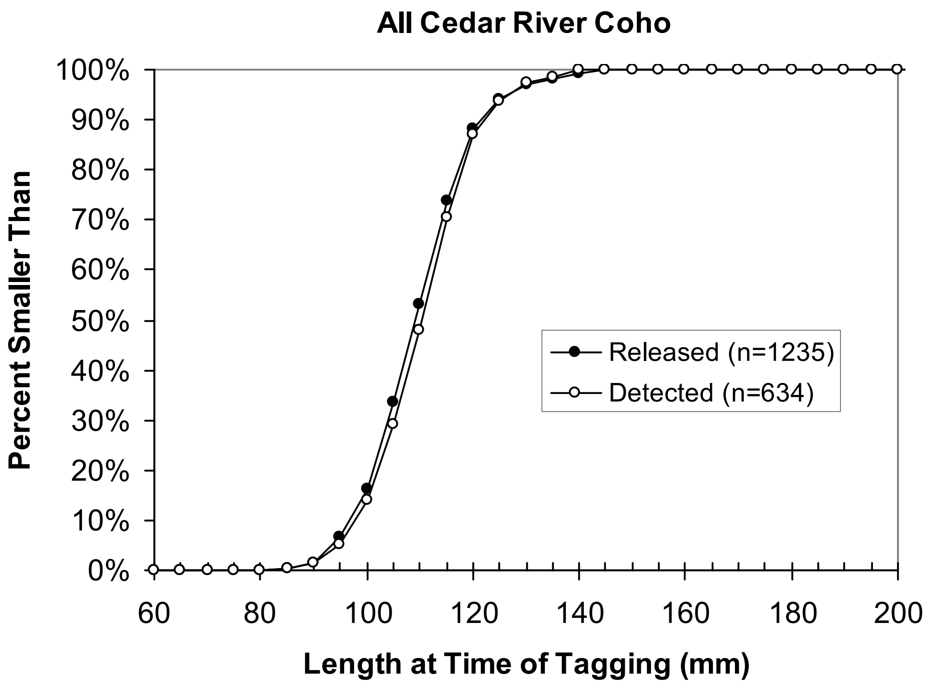


Figure 3-12. Cumulative frequency distributions of lengths of tagged and detected coho salmon caught in Bear Creek (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2005 Lake Washington PIT tag study.



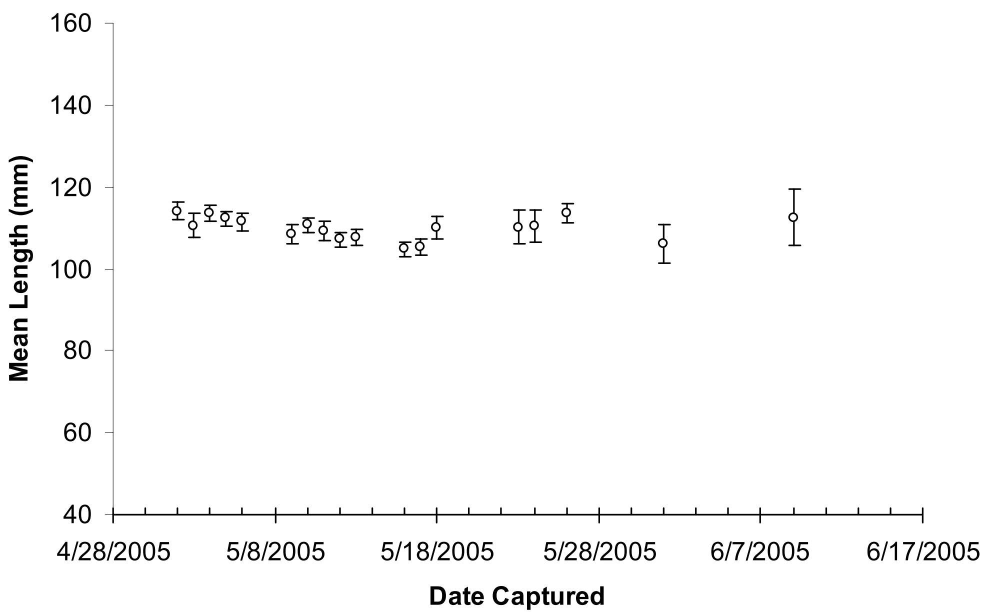


Figure 3-13. Cumulative frequency distributions of lengths of tagged and detected coho salmon caught in the Cedar River (top), and temporal variation in the mean length and 95% CI of the different release groups (bottom), 2005 Lake Washington PIT tag study.

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, and residualism in Lake Washington.

3.4.1 Migration Timing

As in previous years, coho salmon generally outmigrated first followed by Chinook salmon in 2005 (Figure 3-14). Similar to previous years, Cedar River Chinook in 2004 and 2005, and coho smolts in 2005, passed slightly later in the season overall than Bear Creek fish (Figures 3-15 and 3-16). The Issaquah Hatchery Chinook passed through the Locks later than the Bear Creek and Cedar River Chinook in 2005 (Figure 3-15).

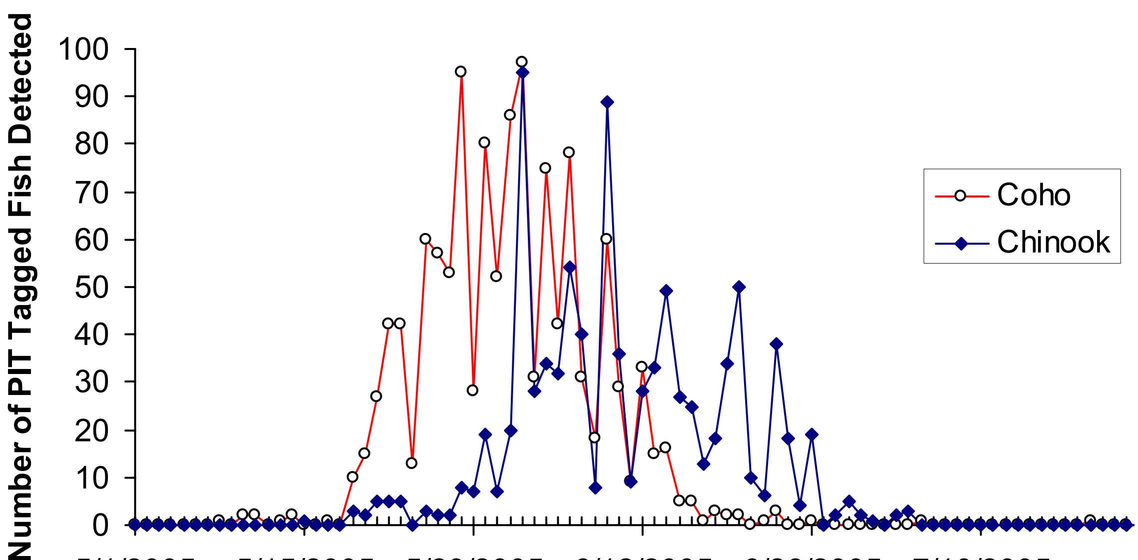


Figure 3-14. Seasonal frequencies of detections at the Locks of Coho and Chinook salmon PIT tagged at Issaquah Hatchery, Bear Creek, and Cedar River, 2005 Lake Washington PIT tag study.

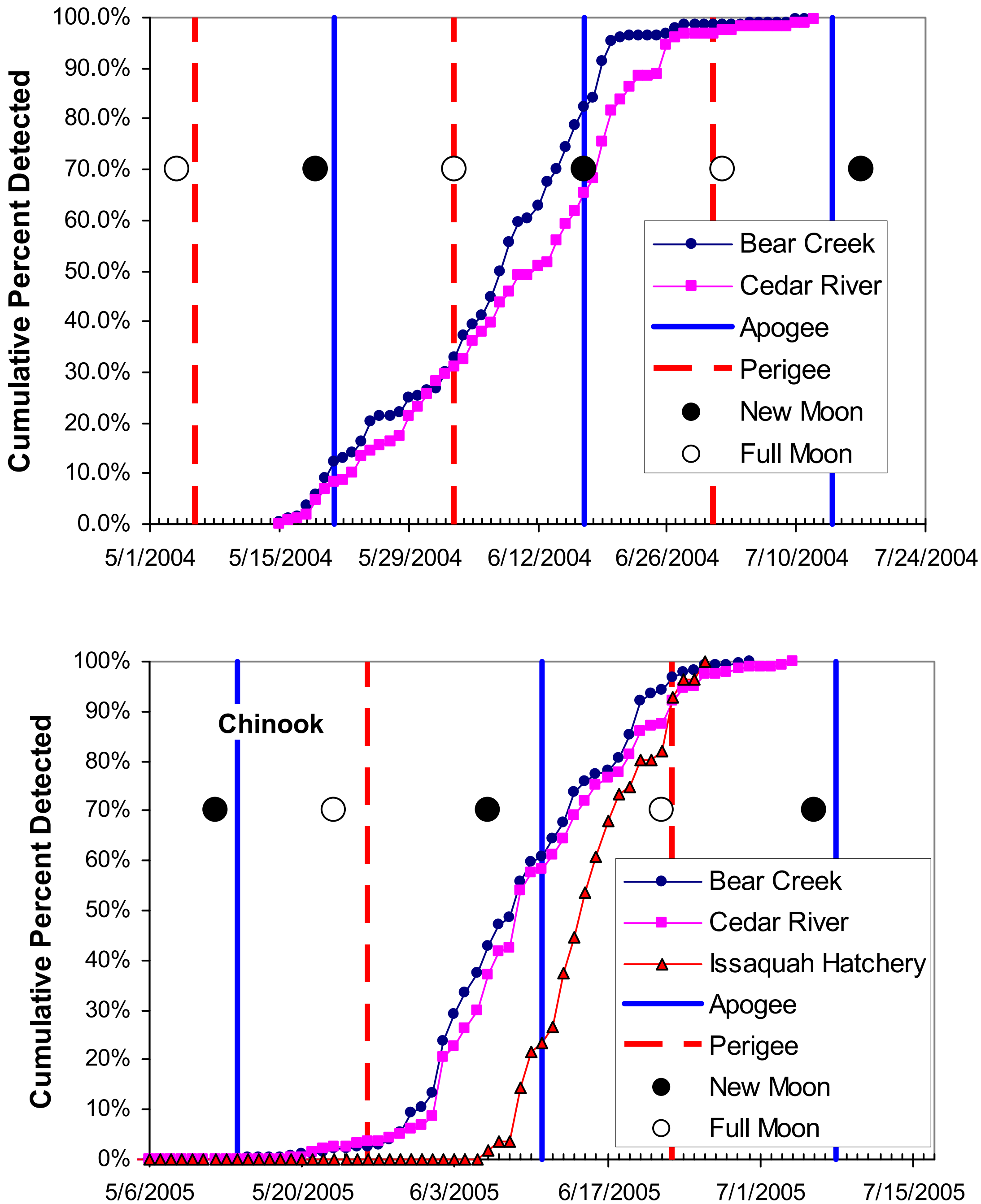


Figure 3-15. Cumulative frequency distributions of the numbers of PIT tagged juvenile Chinook salmon that were detected, as they passed the smolt flumes at the Locks, by date and release location, 2004 (top) and 2005 (bottom) Lake Washington PIT tag studies. The dates when the moon was at apogee (farthest from Earth and perigee (closest to Earth) are indicated by the vertical lines.

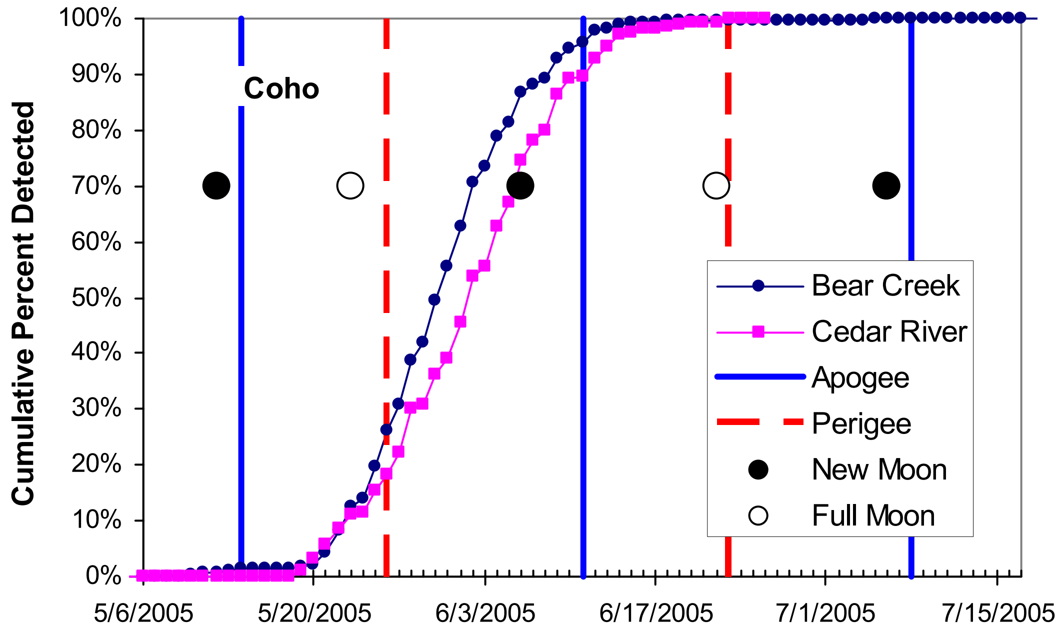


Figure 3-16. Cumulative frequency distributions of the numbers of PIT tagged juvenile coho salmon that were detected, as they passed the smolt flumes at the Locks, by date and release location, 2005 Lake Washington PIT tag study. The dates when the moon was at apogee (farthest from Earth) and perigee (closest to Earth) are indicated by the vertical lines.

A comparison of the passage timing data with lunar data indicated Chinook smolt passage timing was less strongly related to the date of apogee than has been observed in previous years (Figure 3-15; DeVries et al. 2004). Apogee occurred on May 21 and June 17, 2004, and June 11, 2005. Passage timing was earlier in 2004 than in 2000 when apogee occurred around the same date. Issaquah Hatchery Chinook from 2001 and 2005 exhibited similar passage timing, whereas Bear Creek and Cedar River Chinook passed the locks several weeks earlier in 2004 and 2005 than they did when apogee occurred around the same dates in 2000 and 2001, respectively (Figure 3-17). Coho salmon smolts similarly passed earlier in 2005 than in 2001 (Figure 3-18).

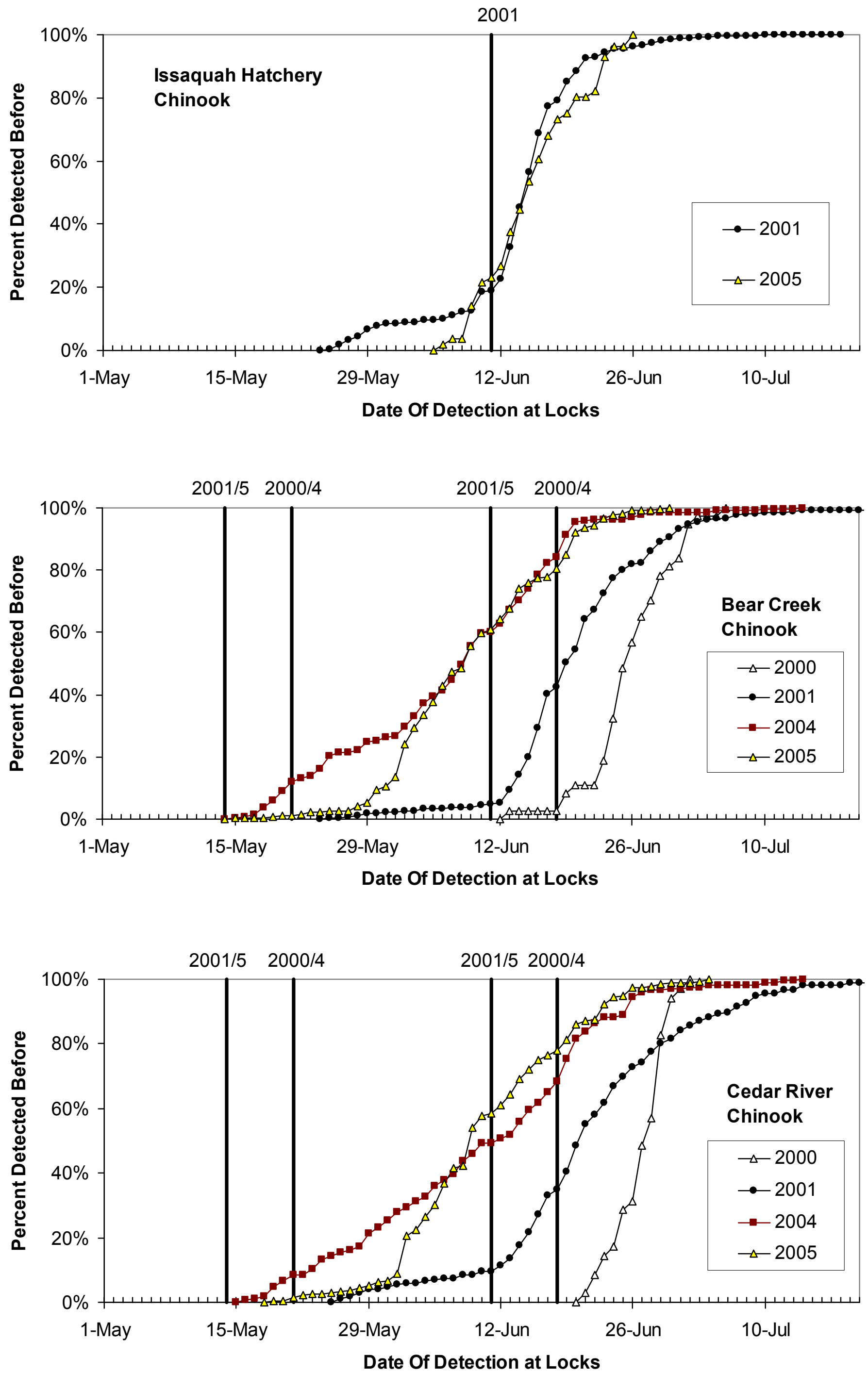


Figure 3-17. Comparison of passage timing of Chinook salmon smolts originating from the Issaquah Hatchery, Bear Creek, and the Cedar River in 2004 and 2005 with previous years when lunar apogee occurred around the same dates. The vertical line denotes the occurrence of apogee for each pair of years.

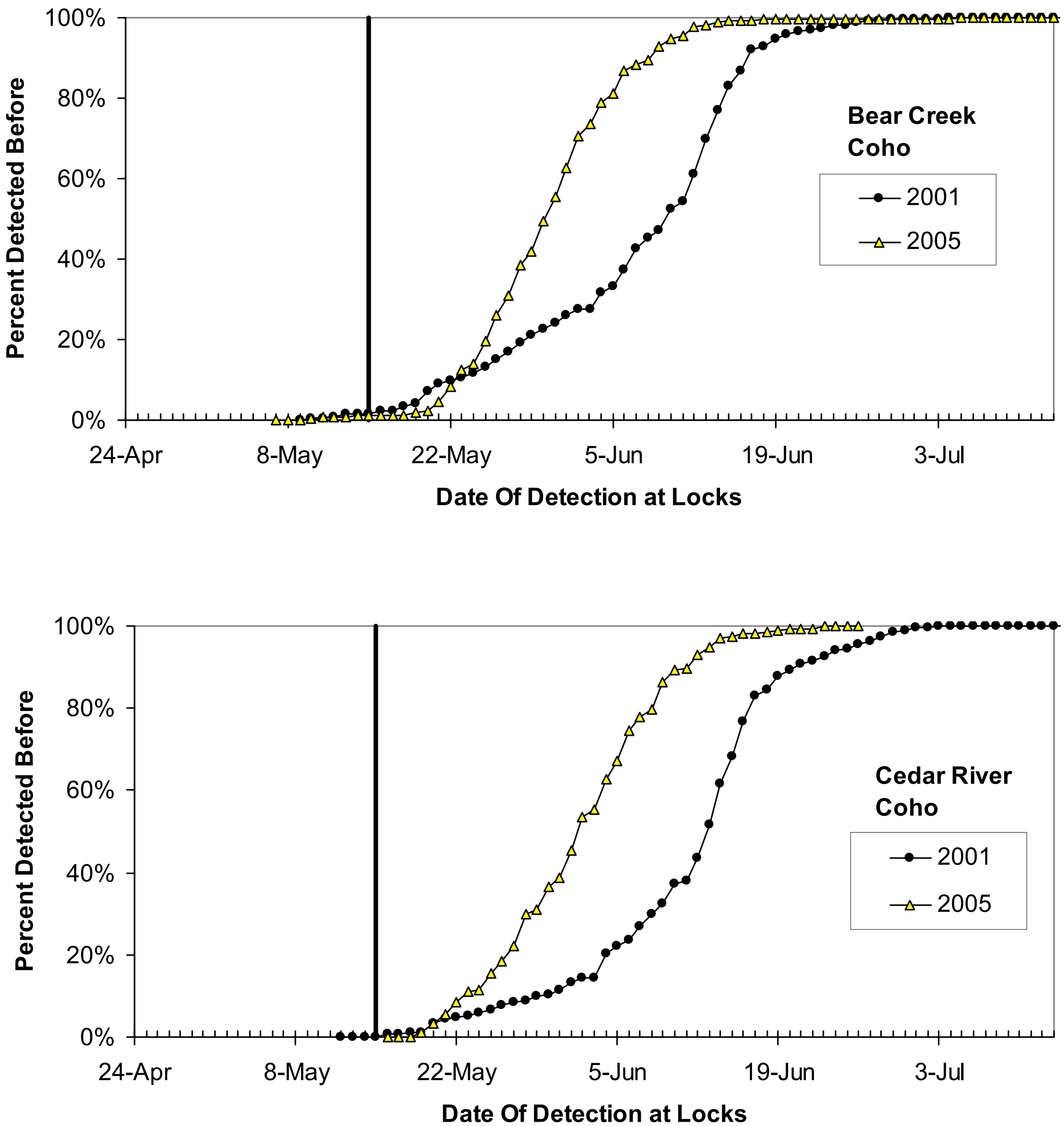


Figure 3-18. Comparison of passage timing of coho salmon smolts originating from Bear Creek and the Cedar River in 2005 with 2001 when lunar apogee occurred around the same date. The vertical line denotes the occurrence of apogee for each pair of years.

3.4.2 Migration Rate

Average migration rates varied between the Issaquah 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, where the Cedar River site is closest to the Locks and the Issaquah Hatchery is farthest. Migration rates appeared to be proportional to travel distance in 2004 and 2005. Chinook smolts from Bear Creek took longer but migrated faster on average than Cedar River Chinook in both years (Figure 3-19). Issaquah Hatchery Chinook similarly took longer but migrated faster on average than the other sites. In the case of coho smolts, however, Bear Creek fish took less time to reach the Locks in 2005 (Figure 3-20). The 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.

Figures 3-21 and 3-22 indicate that migration rates of individual Chinook and coho salmon juveniles exhibited an increasing trend with time over the course of the outmigration season in 2005, but this did not appear to be the case for Chinook in 2004 when migration rates were more variable and did not exhibit as strong a temporal trend. The 2005 results are similar to previous years' and suggest further that juvenile salmon in the Lake Washington system speed up their migration as the end of the passage season approaches. The strength of the relationship appeared to be comparable for Chinook and coho salmon in 2005.

Table 3-2. Approximate minimum travel distances between release locations of PIT tagged fish and the Locks (see Section 2.7.2 for details on how distances were determined).

Release Location	Distance to Locks (km)
Cedar River	39
Bear Creek	56
Issaquah Creek	76

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 (Figures 3-23 and 3-24). In general, the distributions indicate that Chinook salmon originating in Bear Creek and the Cedar River took approximately 2 weeks and 3 weeks on average to reach and pass the smolt flumes in 2004 and 2005, respectively. Coho salmon took approximately 3 weeks in 2005.

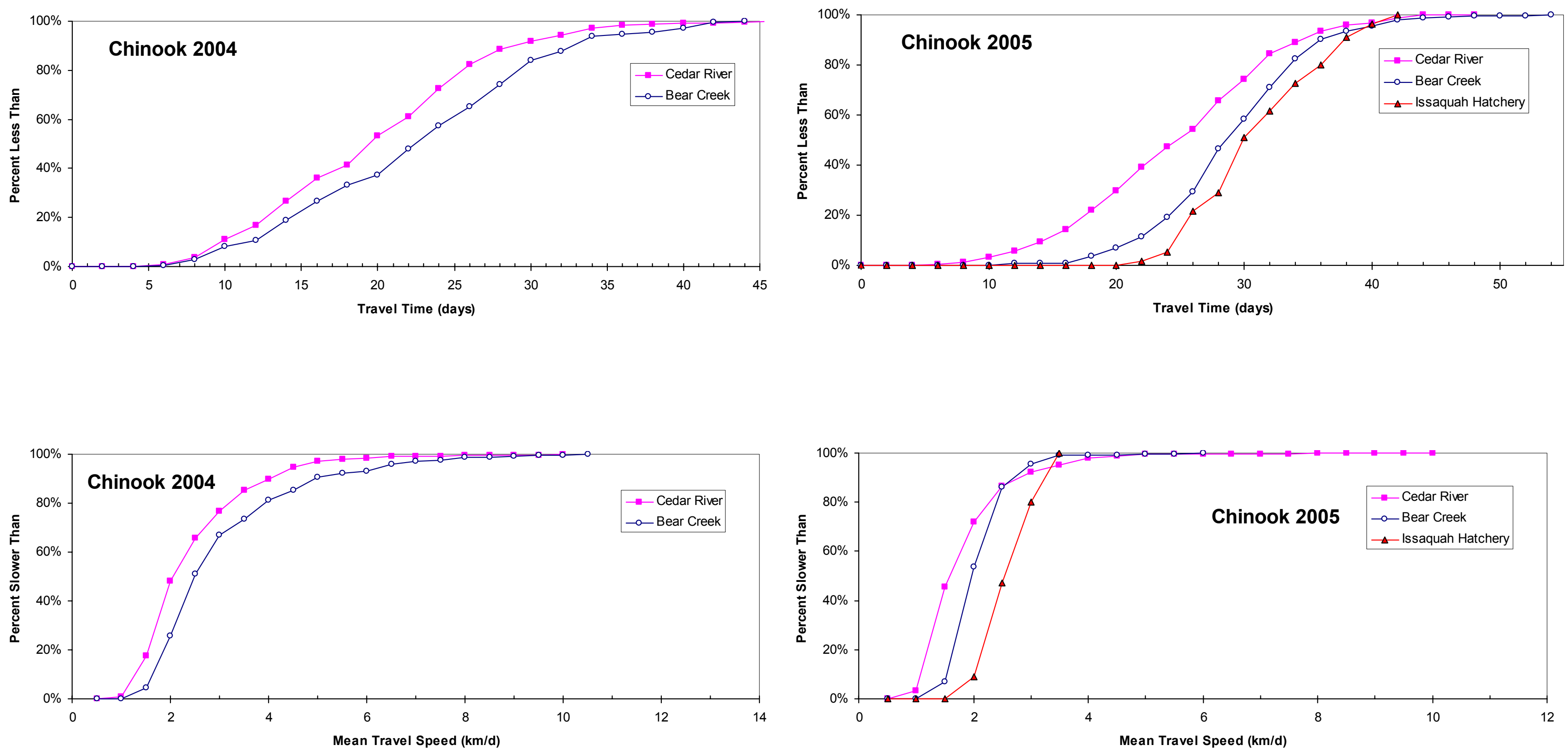
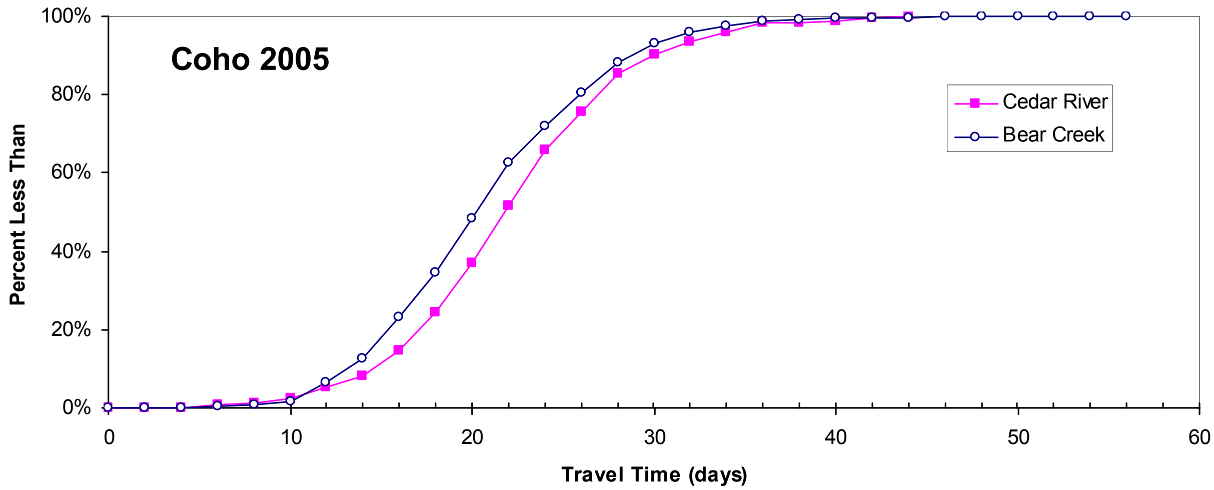


Figure 3-19. Cumulative frequency distributions of average travel time (top) and speed (bottom) of PIT tagged juvenile Chinook detected in the smolt flumes at the Locks in 2004 (left) and 2005 (right), by release location, 2004 and 2005 Lake Washington PIT tag studies.



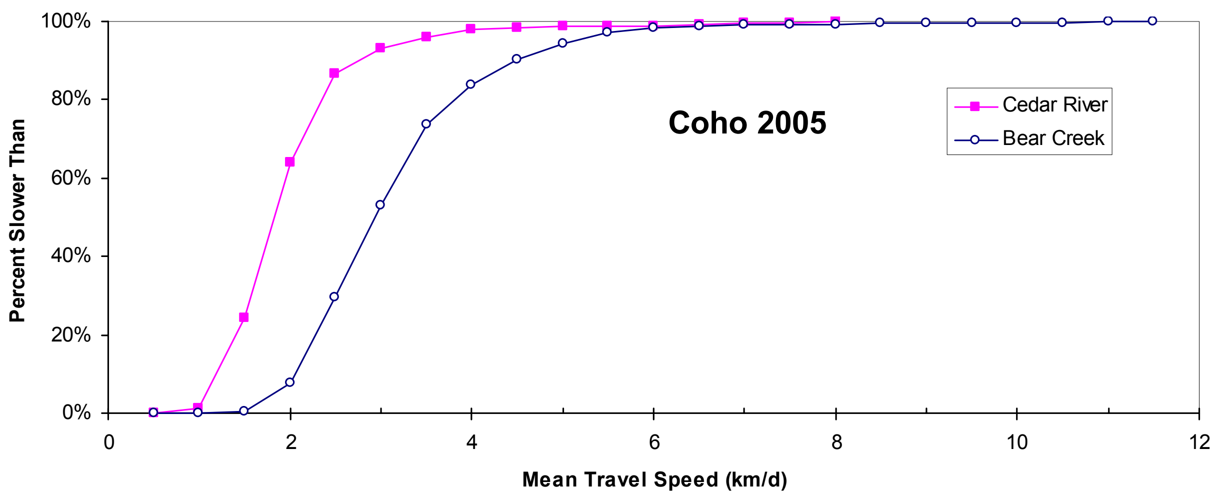


Figure 3-20. Cumulative frequency distributions of average travel time (top) and speed (bottom) of PIT tagged juvenile coho salmon detected in the smolt flumes at the Locks, by release location, 2005 Lake Washington PIT tag study.

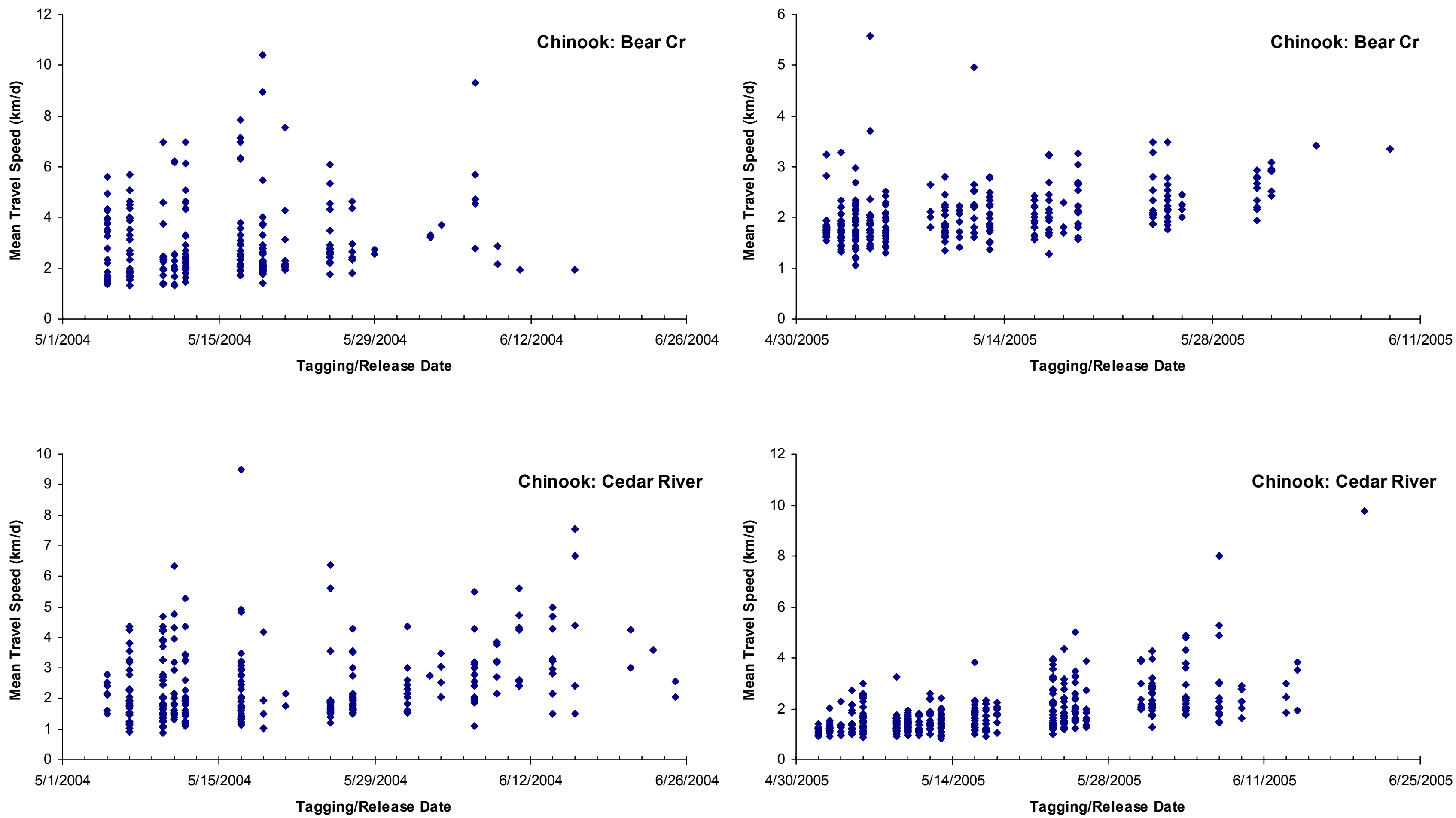
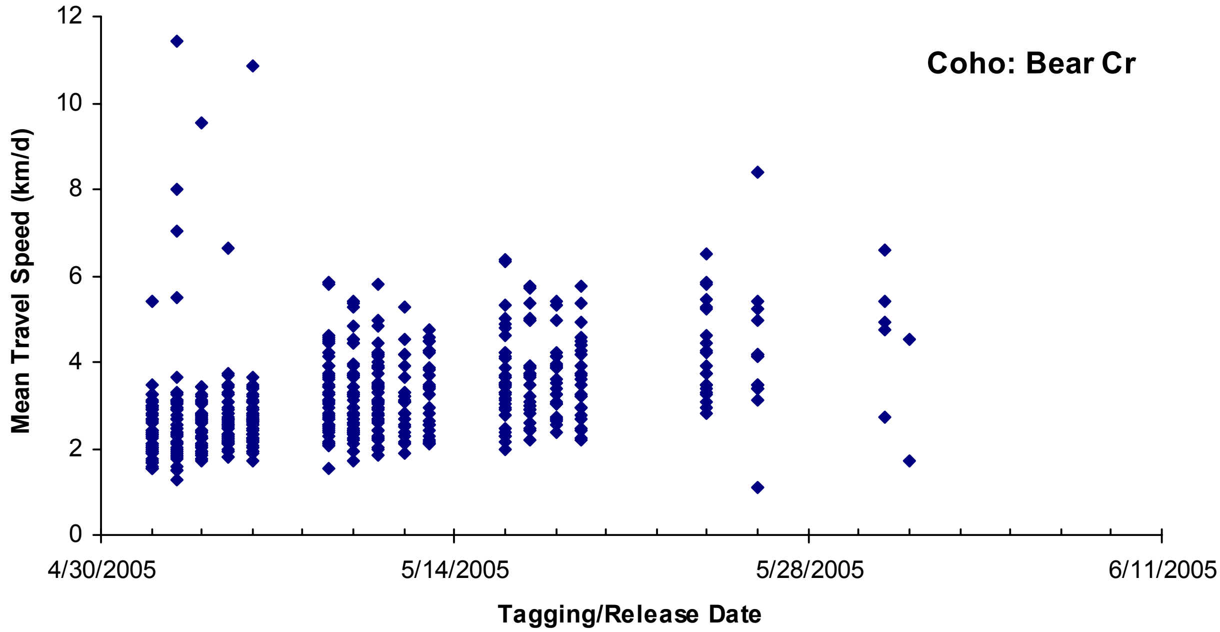


Figure 3-21. Scatterplot of mean travel speed of individual PIT tagged juvenile Chinook salmon that were detected as they passed the smolt flumes at the Locks, plotted by release date and location, 2004 (left) and 2005 (right) Lake Washington PIT tag studies.



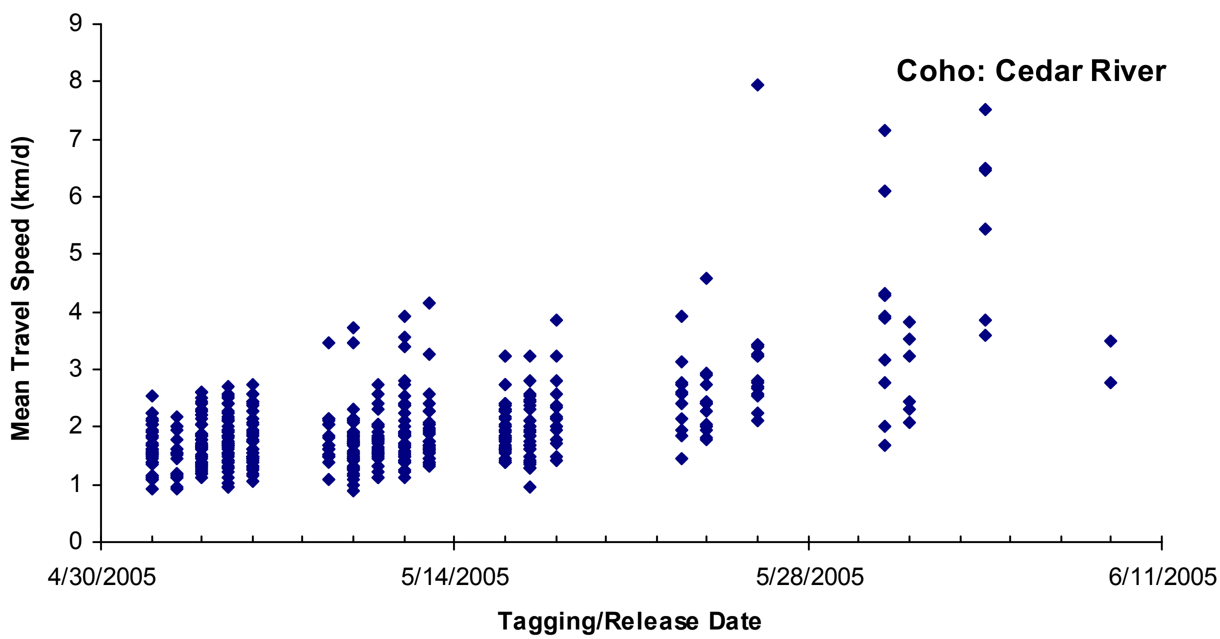


Figure 3-22. Scatterplot of mean travel speed of individual PIT tagged juvenile coho salmon that were detected as they passed the smolt flumes at the Locks, plotted by release date and location, 2005 Lake Washington PIT tag study.

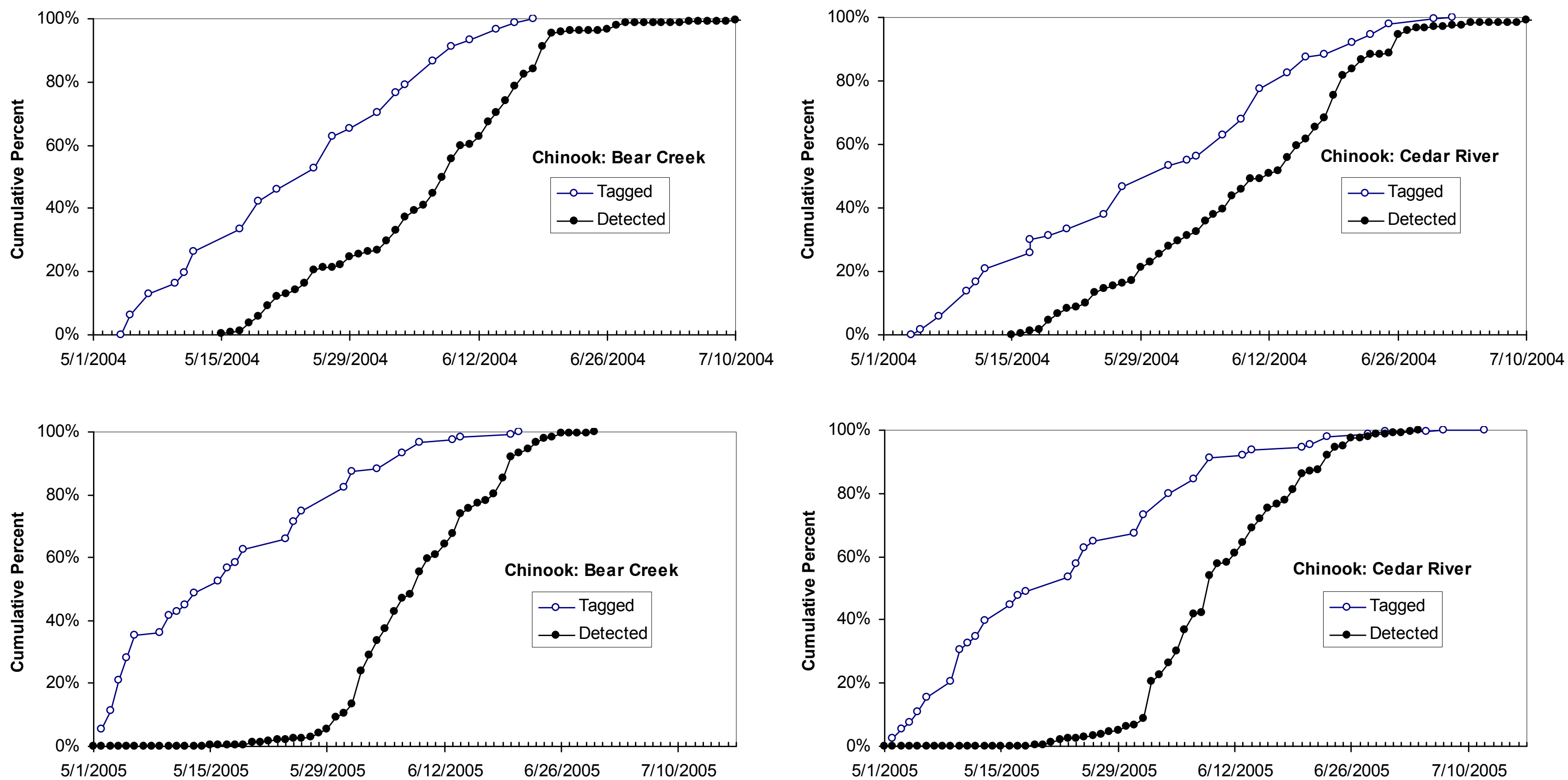
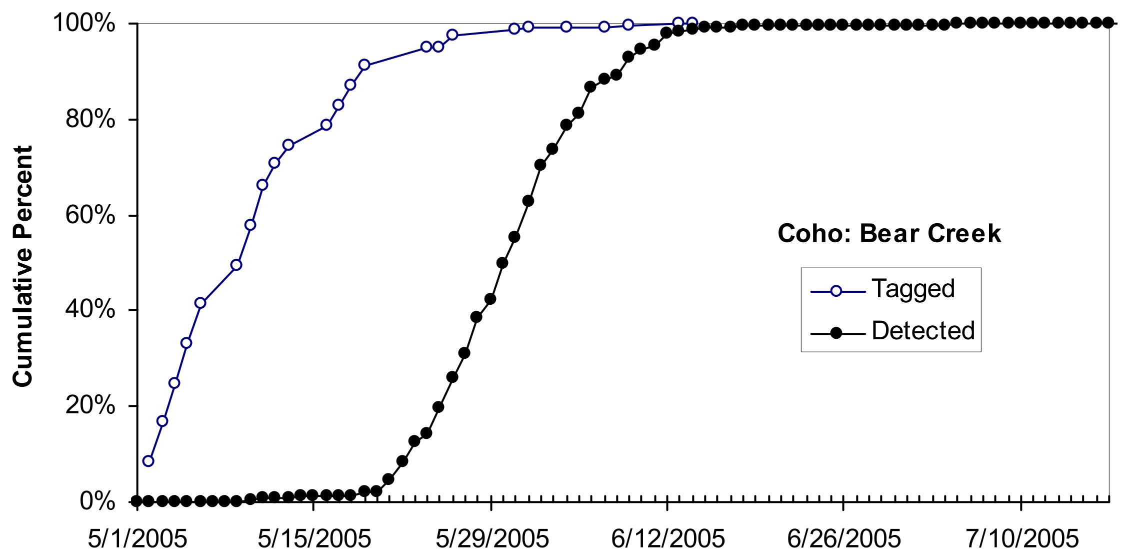


Figure 3-23. Cumulative frequency distributions of the numbers of PIT tagged juvenile Chinook salmon that were tagged and detected as they passed the smolt flumes at the Locks, by date and release location, 2004 (top) and 2005 (bottom) Lake Washington PIT tag studies. The horizontal difference between 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.



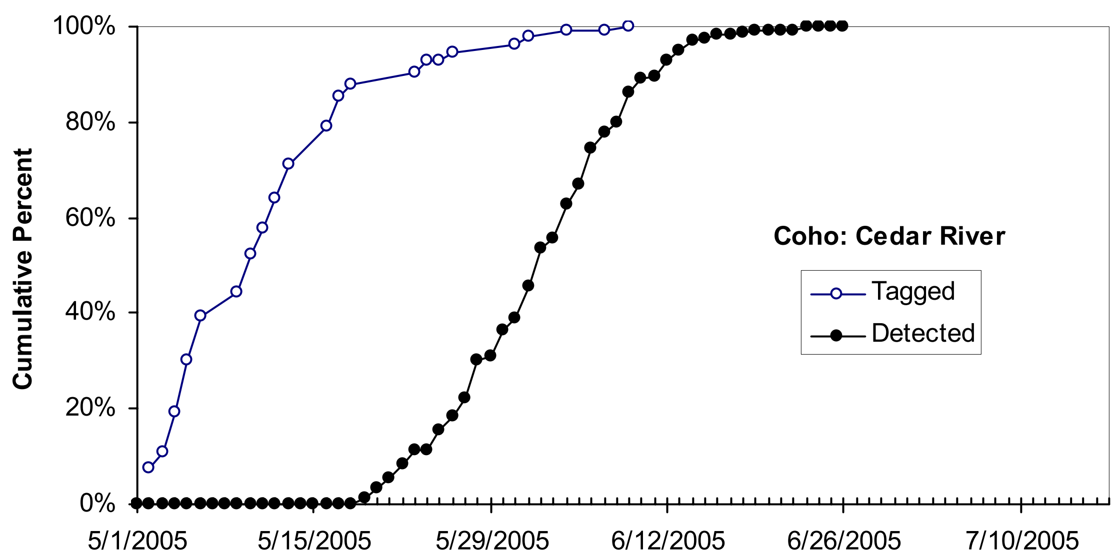


Figure 3-24. Cumulative frequency distributions of the numbers of PIT tagged juvenile coho salmon that were tagged and detected as they passed the smolt flumes at the Locks, by date and release location, 2005 Lake Washington PIT tag study. The horizontal difference between the two curves in each plot reflects the average time taken by all fish from a release location to travel to the Locks and pass through the smolt flumes.

Freshwater recaptures at the screwtraps were much smaller in number in 2004 and 2005 than in 2003 (Table 3-3). More fish were recaptured in Bear Creek, although the proportion of all recaptures was not as large as in 2003 when relatively fewer fish were recaptured in the Cedar River. Few fish were recaptured more than one day after tagging.

Table 3-3. Fish[1] recaptured in screw traps in 2004 and 2005.

Species	Location	Length (mm) Tagging	Recapture	Date of Tagging	Recapture	Interval (Days)	Detection Date at Locks
Chinook	Bear Cr	78	nm	5/10/04	5/11/04	1	Not Detected
"	"	88	nm	5/19/04	5/21/04	2	6/3/04
"	"	79	nm	6/7/04	6/9/04	2	Not Detected
"	"	87	nm	6/7/04	6/9/04	2	Not Detected
"	"	82	nm	5/4/05	5/5/04	1	Not Detected
"	Cedar R	79	nm	5/5/04	5/7/04	2	Not Detected
"	"	78	nm	5/10/04	5/11/04	1	Not Detected
"	"	88	nm	5/10/04	5/11/04	1	Not Detected
"	"	89	nm	5/10/04	5/11/04	1	Not Detected
"	"	nm	nm	5/3/04 [2]	5/4/05	1	Not Detected
"	"	nm	nm	5/3/04 [2]	5/4/05	1	6/3/05
Coho	Bear Cr	118	nm	5/2/05	5/3/05	1	Not Detected
"	"	102	nm	5/3/05	5/4/05	1	Not Detected
"	"	95	nm	5/4/05	5/5/05	1	Not Detected
"	"	102	nm	5/9/05	5/10/05	1	Not Detected
"	"	111	nm	5/9/05	5/10/05	1	Not Detected
"	"	128	nm	5/9/05	5/10/05	1	Not Detected
"	"	136	nm	5/9/05	5/10/05	1	Not Detected
"	"	123	nm	5/11/05	5/12/05	1	Not Detected
"	Cedar R	103	nm	5/6/05	5/11/05	5	Not Detected
"	"	95	nm	5/17/05	5/18/05	1	Not Detected
"	"	98	101	6/1/05	6/4/05	3	Not Detected

[1] - All had adipose fins intact.
[2] – Not detected at time of tagging; date based on tag bag number record kept by WDFW.

3.4.3 Tags From Other Studies, and Mystery Tags

An independent study is being conducted by the University of Washington and the NMFS' Northwest Fisheries Science Center in the Cedar River watershed (George Pess, NMFS, personal communication). Thirteen coho juveniles from that study were detected in the flumes in 2005.

Of these, eleven had been tagged in Rock Creek (above Landsburg) in March 2005, and the other two were tagged the previous late summer/early fall of 2004.

As in previous years, six fish of unknown origin were detected each year in 2004 and 2005. The tags were not in the master tag file received from the supplier and were not registered in the PTAGIS database. The tag numbers in 2004 were: 3D9.1BF1BF4E32, 3D9.1BF1DE0562, 3D9.1BF1C6FF42, 3D9.1BF16F851E, 3D9.1BF1D0BC4D, and 3D9.1BF1D119A0. The 2005 tag numbers were: 3D9.1BF18D6EC8, 3D9.1BF18D4B67, 3D9.1BF18D23E0, 3D9.1BF18C0A03, 3D9.1BF18BAC95, and 3D9.1BF18B95CC.

3.4.4 Residualism in the Lake Washington System

As in previous years, Chinook and coho salmon were detected in 2004 and 2005 that had been tagged in 2003 and 2004, respectively (Table 3-4). Most were Chinook that had been tagged later in the season in the preceding year and were detected early the next year relative to the main outmigration run. Comparisons of the fish length and tagging date data in Table 3-4 with length frequency distributions in 2003 and 2004 did not indicate any consistent trend in residualism as a function of fish size: two of the residualized Chinook were smaller than the 20th percentile of the size distribution and three were larger than the 80% percentile.

Table 3-4. Fish detected at the Locks in 2004 and 2005 but tagged and released in earlier years.

Species	Tagging Length (mm)	Release		Flume Detection		Interval (Days)
		Location	Date	Date	Time	
Chinook	92	Bear Creek	6/30/03	4/30/04	6:31:17	305
"	95	"	7/2/03	5/18/04	11:27:30	321
"	76	"	6/16/04	5/23/05	9:01:18	341
"	78	Cedar River	6/17/03	5/13/04	18:26:05	331
"	103	"	6/21/04	5/19/05	14:26:14	332
" [1]	86	Marymoor	6/3/03	5/23/04	5:26:50	355
" [1]	78	Kenmore	5/30/03	6/19/04	13:04:20	386
Coho	97	Cedar River	5/9/03	5/11/04	17:45:32	368

1 – Issaquah Hatchery fish hauled and released on site; all other fish were of natural origin.

3.5 PASSAGE BEHAVIOR AT LOCKS

The PIT tag data again provided valuable information on the daily timing and routes of downstream passage at the Locks, as well as insights into possible influences of lock operations on passage behavior.

3.5.1 Diurnal Variation in Passage Timing

Diurnal passage timing distributions could not be evaluated because of changes in flume operations in 2004 and 2005. The flumes were usually shut off at night to conserve water both years, reflecting the results of previous years (Figures 3-1, 3-2; DeVries et al. 2005). Chinook smolt passage timing distributions in 2004 were sharply peaked and strongly skewed with greatest passage occurring soon after the flumes were opened in the morning (Figure 3-25). In 2005, Chinook passage timing distributions were less sharply peaked (Figure 3-26), which likely reflected more frequent opening of flumes at night during periods of high spill. There was not as strong a secondary peak later in the day as in previous years, however. Coho salmon passage timing distributions were essentially uniform while the flumes were open in 2005 (Figure 3-27). Both species in Bear Creek and the Cedar River exhibited similar timing distributions overall within 2004 and 2005 (Figure 3-20).

3.5.2 Routes Through the Locks

Figure 3-28 depicts the possible passage routes through the Locks. As in previous years, the PIT tag data indicated that recycling occurred through the Locks in 2004 and 2005. The total number observed recycling was reduced compared with previous years, however, because calibration test fish were not used in 2004 and 2005 to evaluate tunnel reader detection efficiency. Those fish, which originated from the Issaquah Hatchery and were kept at the Metro Laboratory until release, exhibited a stronger tendency to recycle than fish tagged and released at the traps and elsewhere (DeVries et al. 2005). In any case, the number of natural origin fish recycling was comparable to previous years, with one Chinook recycling in 2004, and one Chinook and four coho recycling in 2005 (Table 3-5). Recycling timing patterns appeared to be shorter overall than in the previous four years, with five of six passing through a second time in less than 24 hours after first passage. Of fish originating from Bear Creek, Cedar River, and Issaquah Hatchery, approximately 0.18% and 0.11% of all Chinook detections corresponded to recyclers in 2004 and 2005, respectively, and 0.33% of coho detections recycled in 2005. Recycling rates in 2001, 2002, and 2003 were 0.39%, 0.71%, and 0.07% respectively, for Chinook, and 0.70%, 0.50%, and 0.06% respectively, for coho.

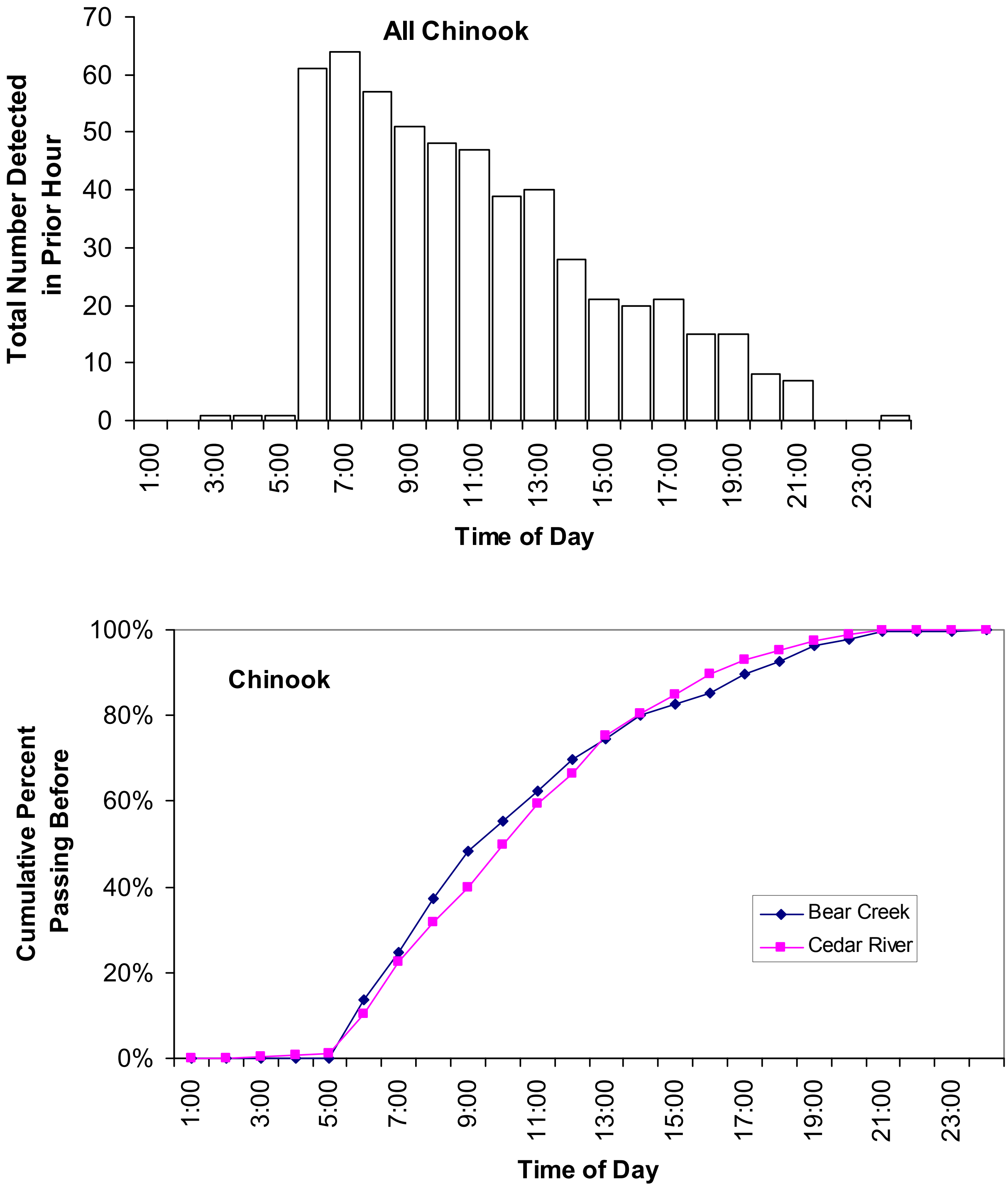


Figure 3-25. Diurnal variation in time of passage through the smolt flumes at the Locks by PIT tagged juvenile Chinook salmon (top), and cumulative frequency distributions by release location, 2004 Lake Washington PIT tag study.

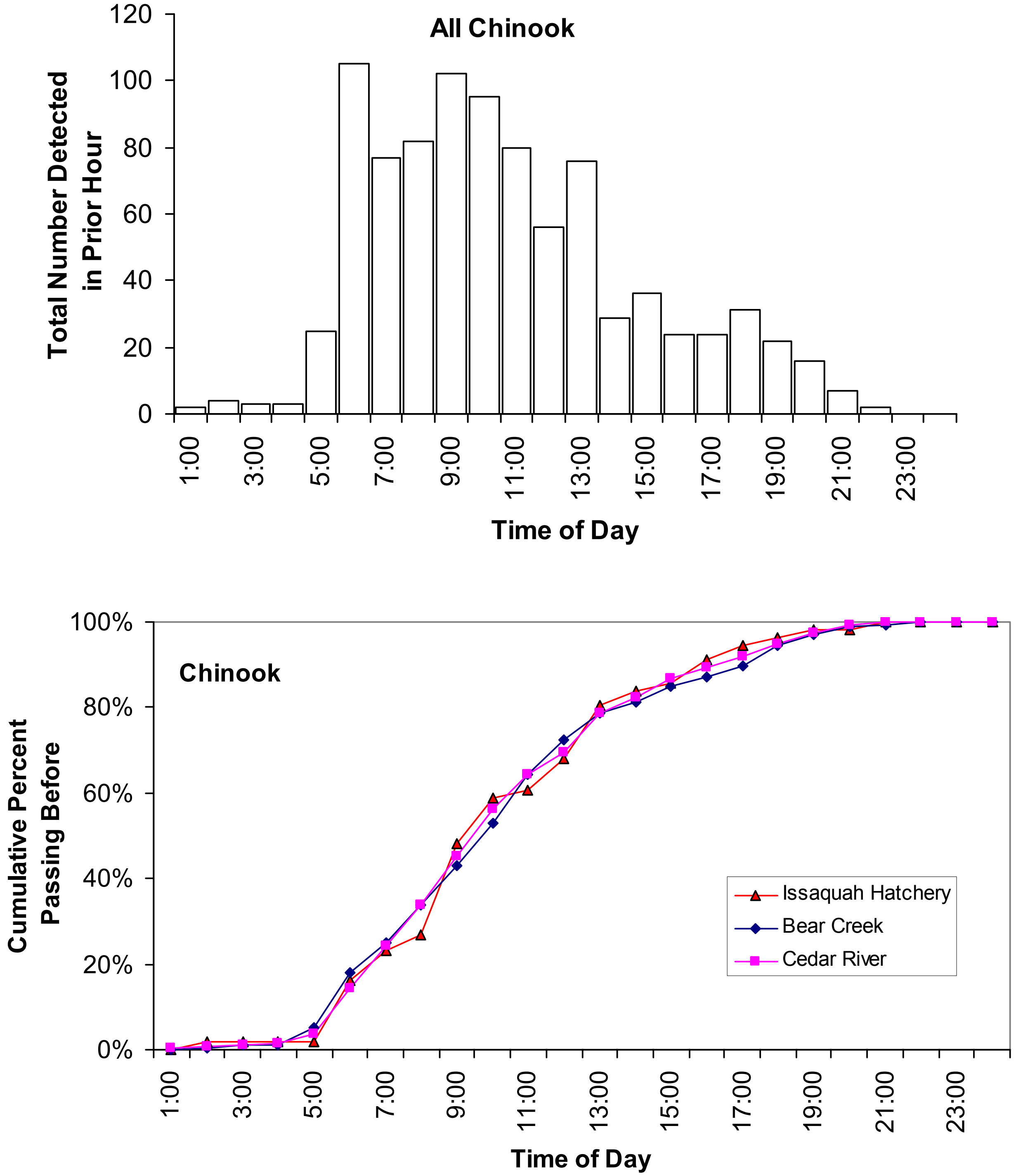
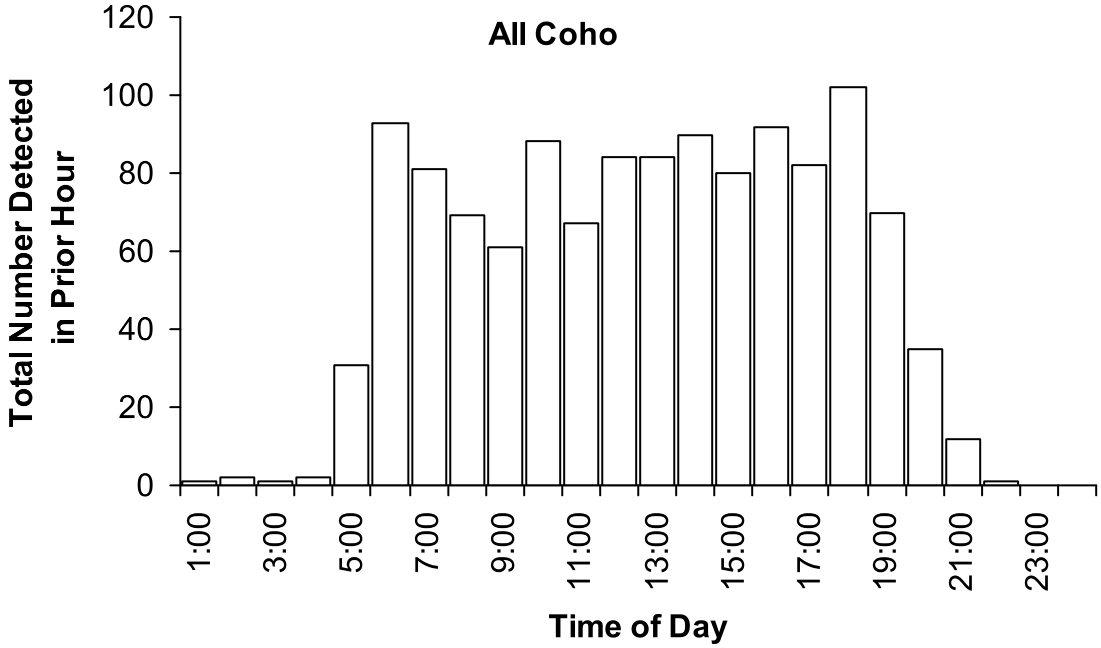


Figure 3-26. Diurnal variation in time of passage through the smolt flumes at the Locks by PIT tagged juvenile Chinook salmon (top), and cumulative frequency distributions by release location, 2005 Lake Washington PIT tag study.



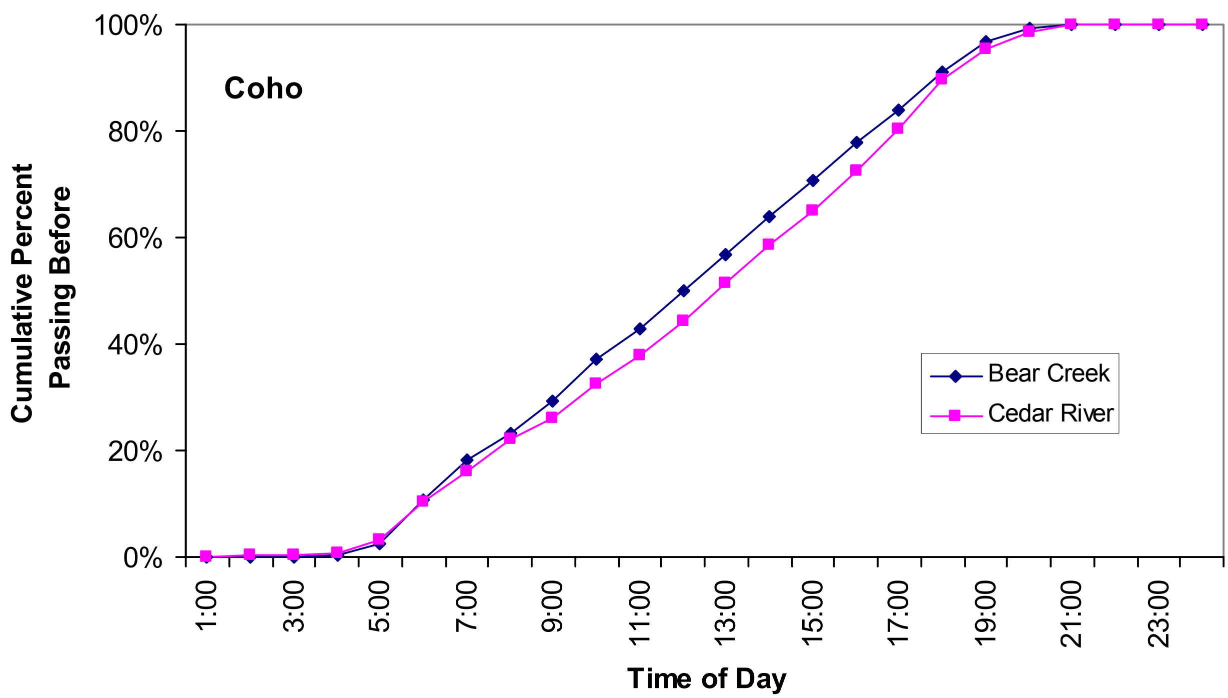


Figure 3-27. Diurnal variation in time of passage through the smolt flumes at the Locks by PIT tagged juvenile coho salmon (top), and cumulative frequency distributions by release location, 2005 Lake Washington PIT tag study.

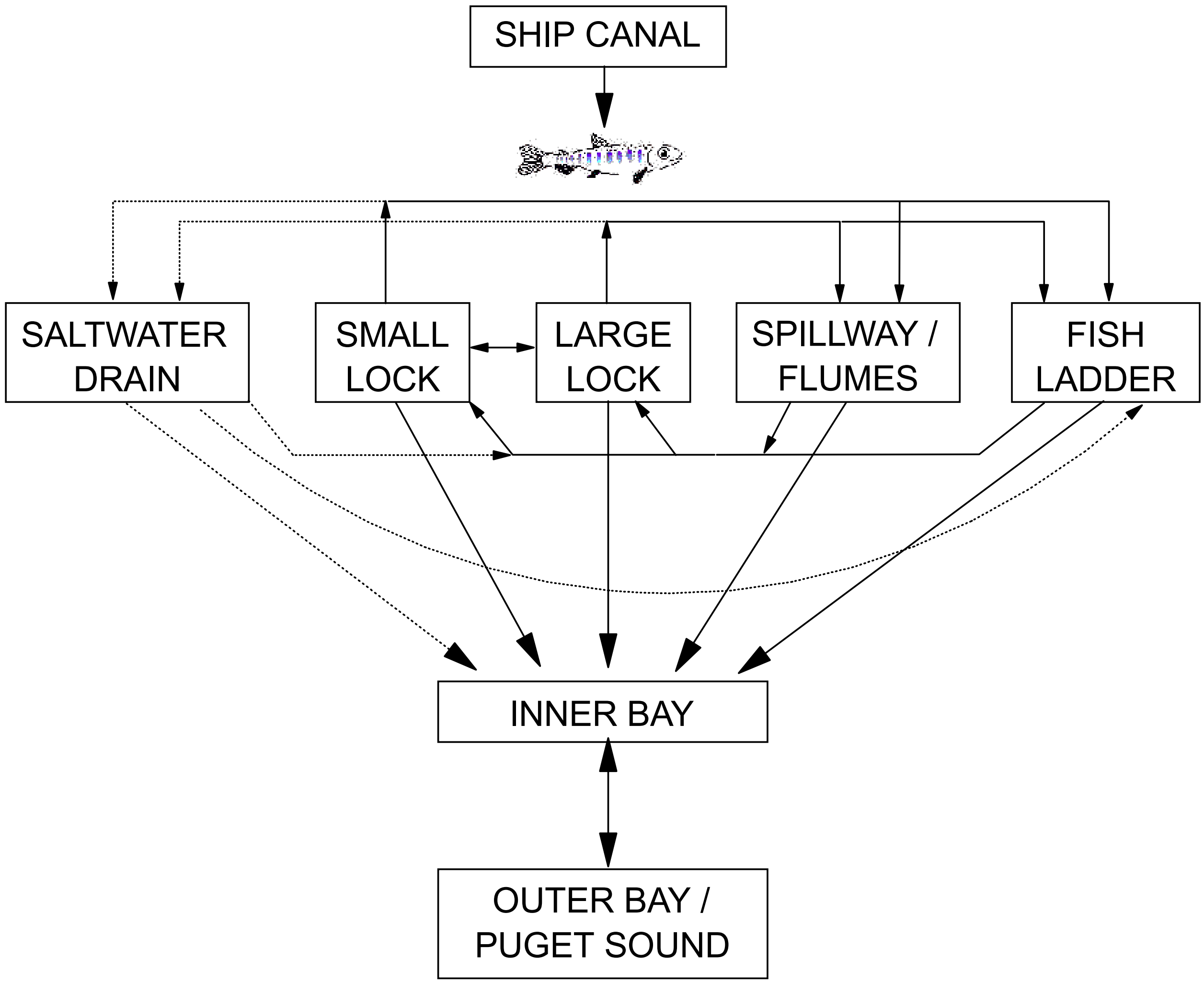
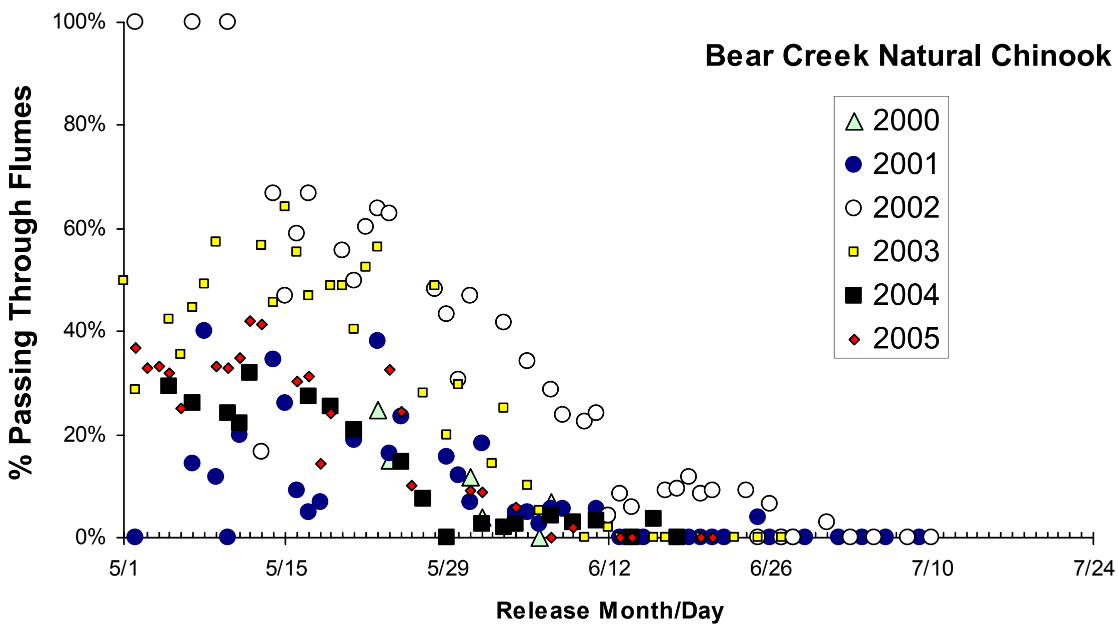


Figure 3-28. Possible migration routes of juvenile salmon through the Hiram M. Chittenden Locks to the Puget Sound. The routes are indicated for fish after they have first encountered the Locks and have entered one of the five structural facilities indicated. For example, a fish entering the smolt flumes 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.

Table 3-5. Fish that passed through the flumes more than once in 2004, 2005. All were of natural origin.

Study Year	Species	Tagging	First Detection			Days to Next Detection
		Length (mm)	Location	Date	Time	
2004	Chinook	88	Cedar River	6/16/2004	6:02:44	0.01
2005	Chinook	80	Bear Creek	6/3/2005	12:09:12	0.14
	Coho	102	Cedar River	6/3/2005	5:03:52	0.16
	Coho	105	Bear Creek	6/9/2005	13:32:23	40.2
	Coho	121	Bear Creek	6/10/2005	12:18:43	0.88
	Coho	113	Bear Creek	6/11/2005	12:48:40	0.86

The PIT tag data were used to evaluate seasonal variation in detection rates at the smolt flumes. The detection rate (number detected at Locks/number released on a given date) appears to reflect the proportion using the flumes overall (DeVries et al. 2005). Detection rates were not adversely influenced by the variation in tunnel reader detection efficiency in 2004 and 2005 and this required minor adjustment compared with previous years. Previous years' PIT tag data indicated that the proportion using the flumes dropped off during the course of the season. This phenomenon was observed again in 2004 and 2005 and was consistent for Bear Creek and Cedar River Chinook, and Bear Creek coho salmon juveniles. Detection rates in 2004 and 2005 were generally lower than in other years except 2000, which may reflect reduced flume operations and warmer water temperatures in 2004 and 2005 (Figures 3-29, 3-30). Detection rates were steadier for coho than for Chinook and dropped more rapidly in 2005. Average weekly detection rates (after adjusting for detection efficiency) for Chinook released in Bear Creek and the Cedar River in May 2004 and 2005 were on the order of 30%, down from around 40% to 60% in 2003 and previous years (Figures 3-31, 3-32). Detection rates declined to near zero for groups released around the third week of June in each year. The 2004 and 2005 results were generally consistent with the apparent seasonal trend in proportion using the flumes suggested by previous years' data.



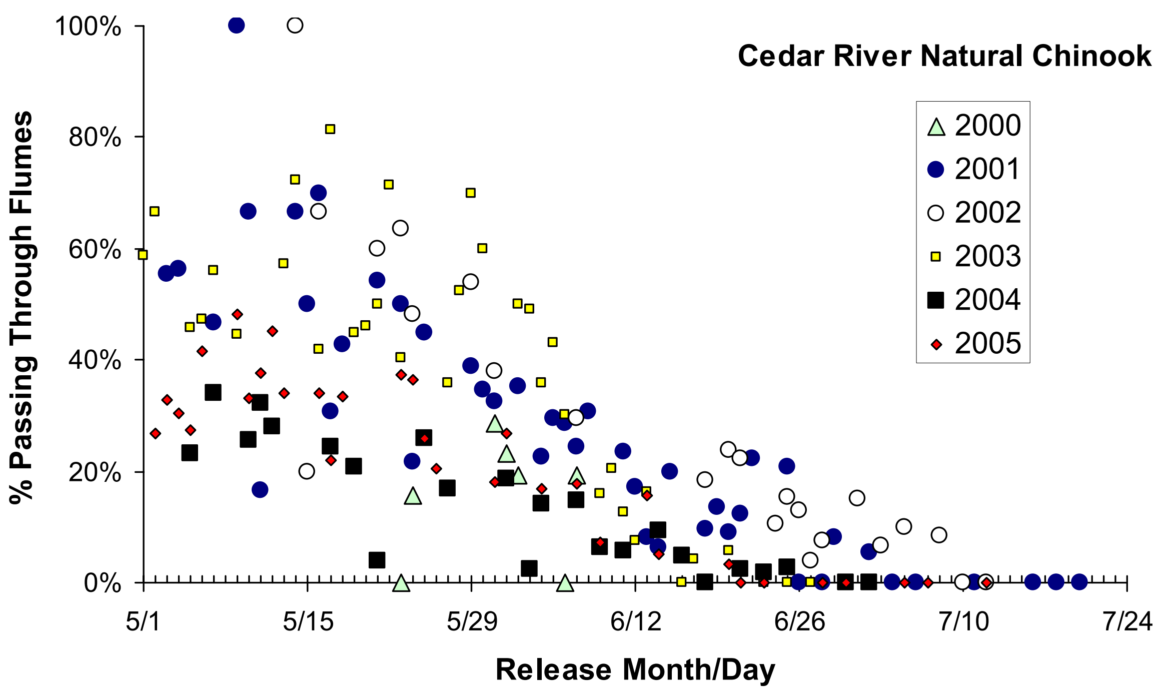
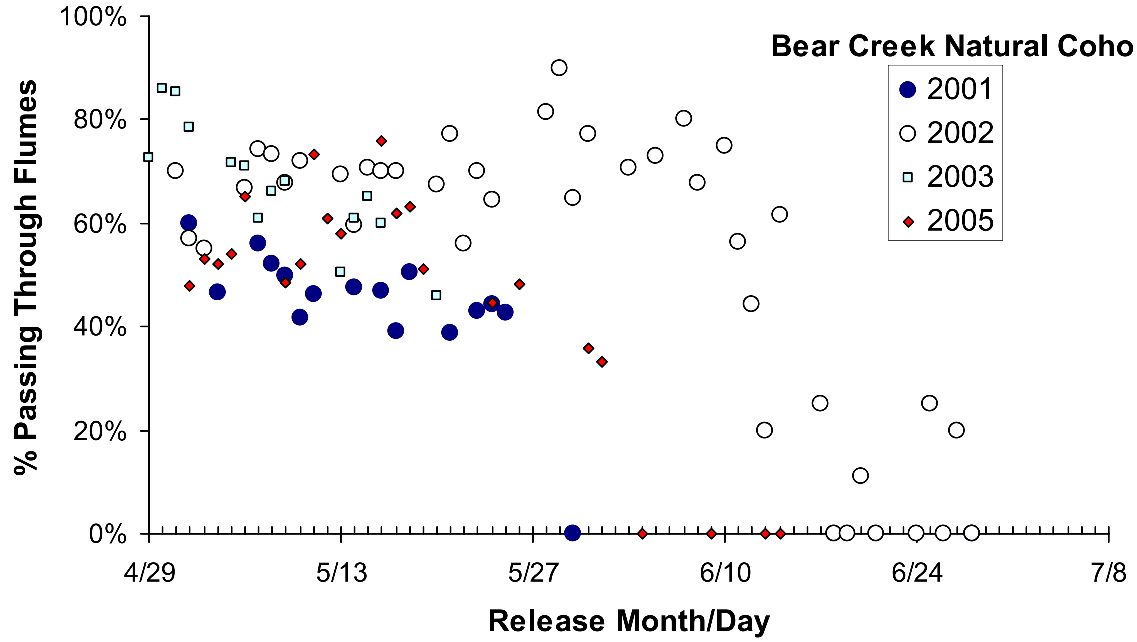


Figure 3-29. Daily variation of detection rate at the smolt flumes of PIT tagged juvenile Chinook salmon originating in Bear Creek and the Cedar River by release date, 2000-2005 Lake Washington PIT tag studies. Each data point was calculated by dividing the number released in a group into the number subsequently detected at the Locks, adjusted for detection efficiency.



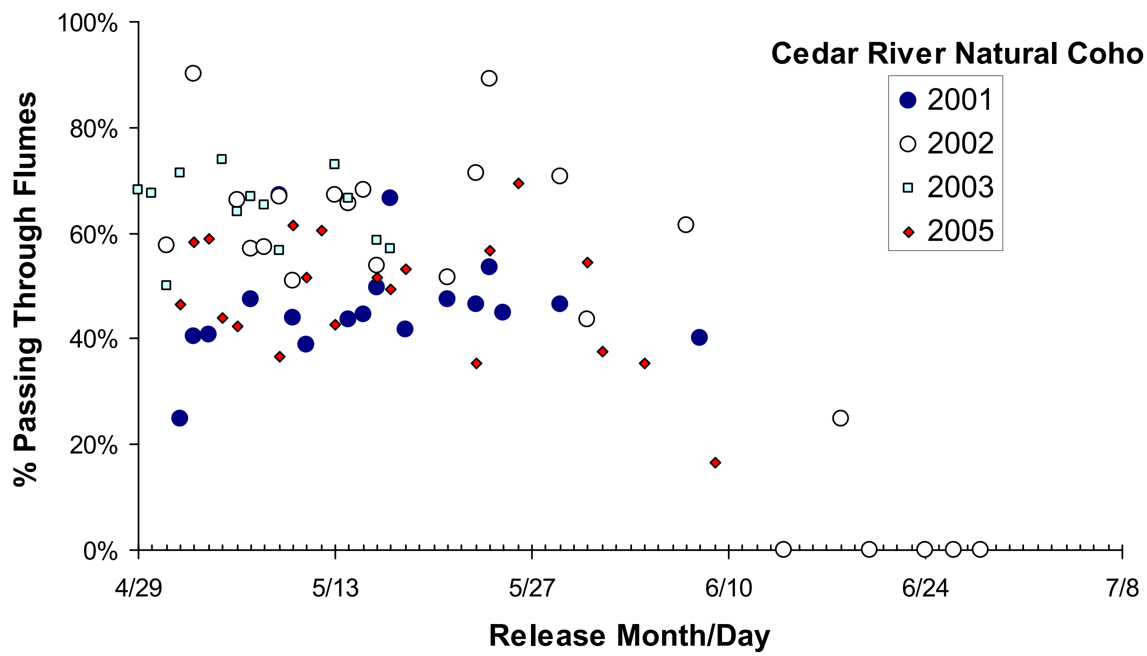


Figure 3-30. Daily variation of detection rate at the smolt flumes of PIT tagged juvenile coho salmon originating in Bear Creek and the Cedar River by release date, 2000-2005 Lake Washington PIT tag studies. Each data point was calculated by dividing the number released in a group into the number subsequently detected at the Locks, adjusted for detection efficiency.

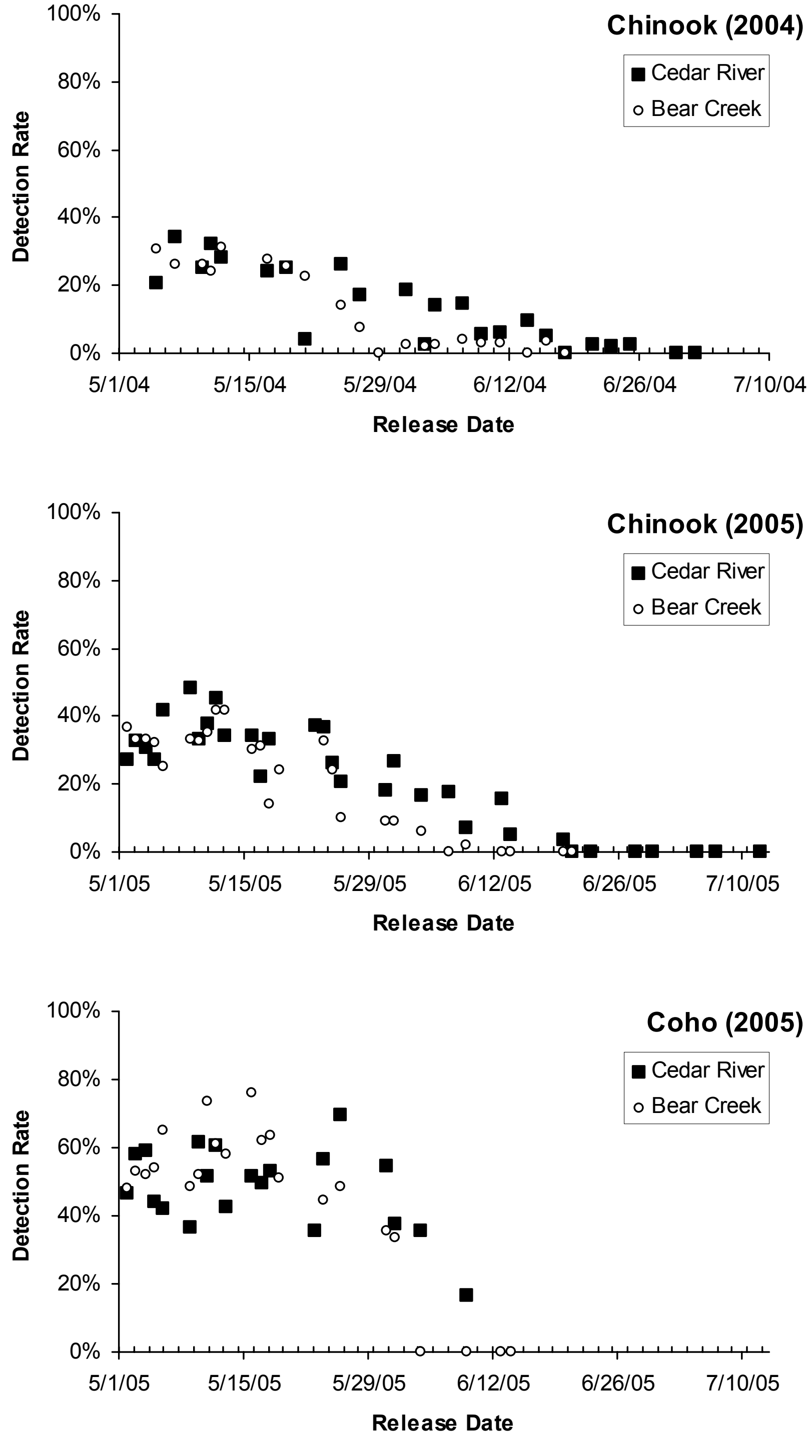


Figure 3-31. Comparison of daily detection rates at the smolt flumes of PIT tagged juvenile Chinook and coho salmon originating in Bear Creek and the Cedar River by release location, 2004 and 2005 Lake Washington PIT tag studies.

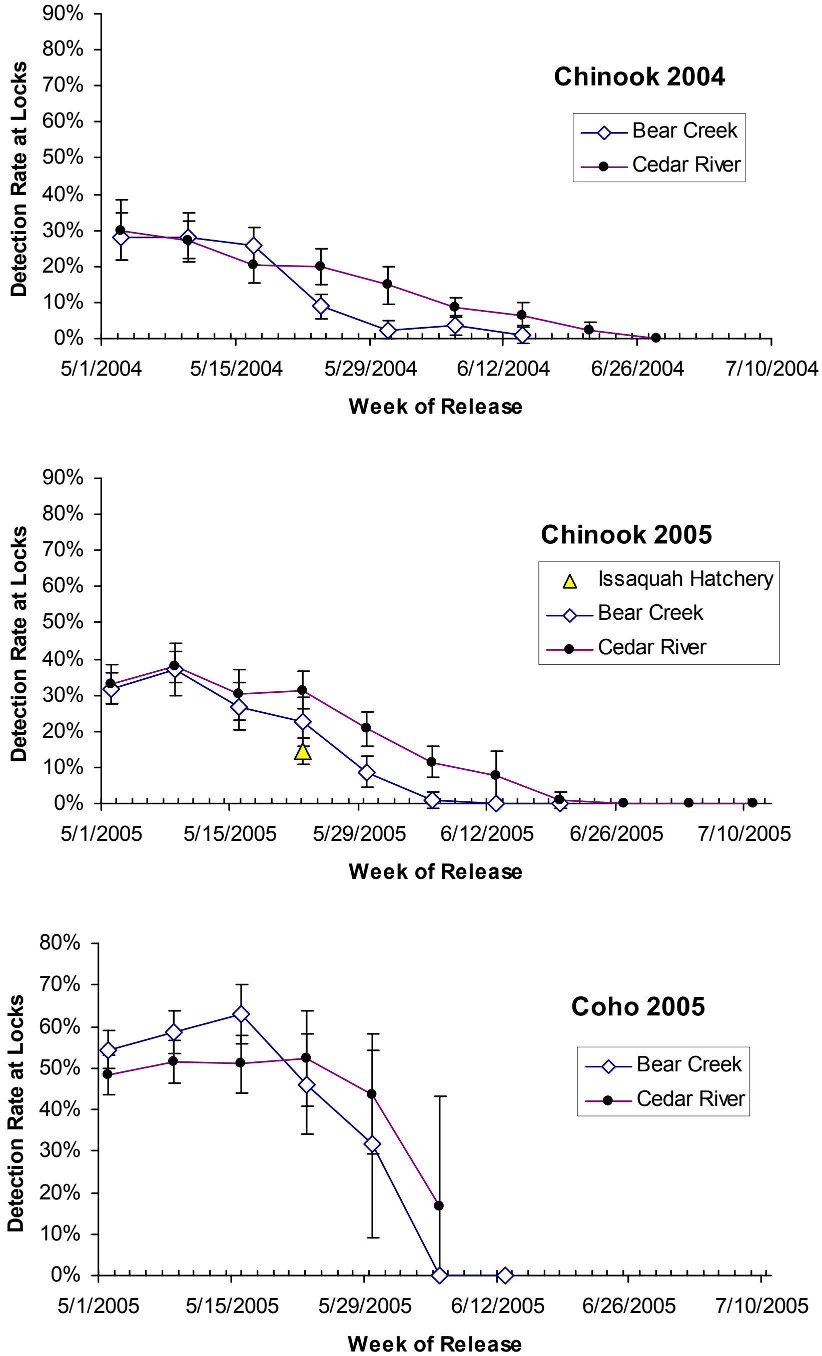


Figure 3-32. Weekly variation of detection rate at the smolt flumes of PIT tagged juvenile Chinook and coho salmon originating in Bear Creek and the Cedar River by release date, 2004 and 2005 Lake Washington PIT tag studies. The data in Figure 3-25 were grouped by week. Ninety-five percent CI are presented based on the binomial approximation for a proportion.

3.5.3 Influence of Lock Operations on Passage Through Flumes

Previous years' results have suggested that passage rates through the flumes are correlated with small lock filling operations. Figures 3-33 and 3-34 similarly indicate that there was a tendency for PIT tagged fish to pass through the flumes at a higher rate during the small lock fill period than during the between-fill period in 2004 and 2005. 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. Results were similar to previous years, where two-tailed t-tests of the ratio indicated that it was significantly greater than 1.0 on average in both 2004 and 2005 ($p<0.05$). The numbers detected per unit time during fill in 2004 and 2005 were approximately 2.5 and 3.1 times, respectively, the number between fills on average. In other words, mean passage rates through the flumes were roughly double to triple while the small lock was filling than when they were not filling in 2004 and 2005. In previous years they were roughly double, suggesting a stronger relation may exist in years with a warmer spring.

The two night-time small lock filling tests performed in 2005 did not indicate a change in diurnal timing distributions in fish passage relative to small lock filling (Figures 3-35, 3-36). The increased number of lockages overnight between June 2 and 3, and between June 14 and 15, resulted in a more uniform distribution during the morning hours of June 3 and June 15, respectively. However, there was not a comparable increase in PIT tag detections those mornings relative to other days before and after. This result suggests that smolt passage responses to small lock operations, as suggested by evaluating passage rates during and between fills, are likely to be restricted to daylight hours only.

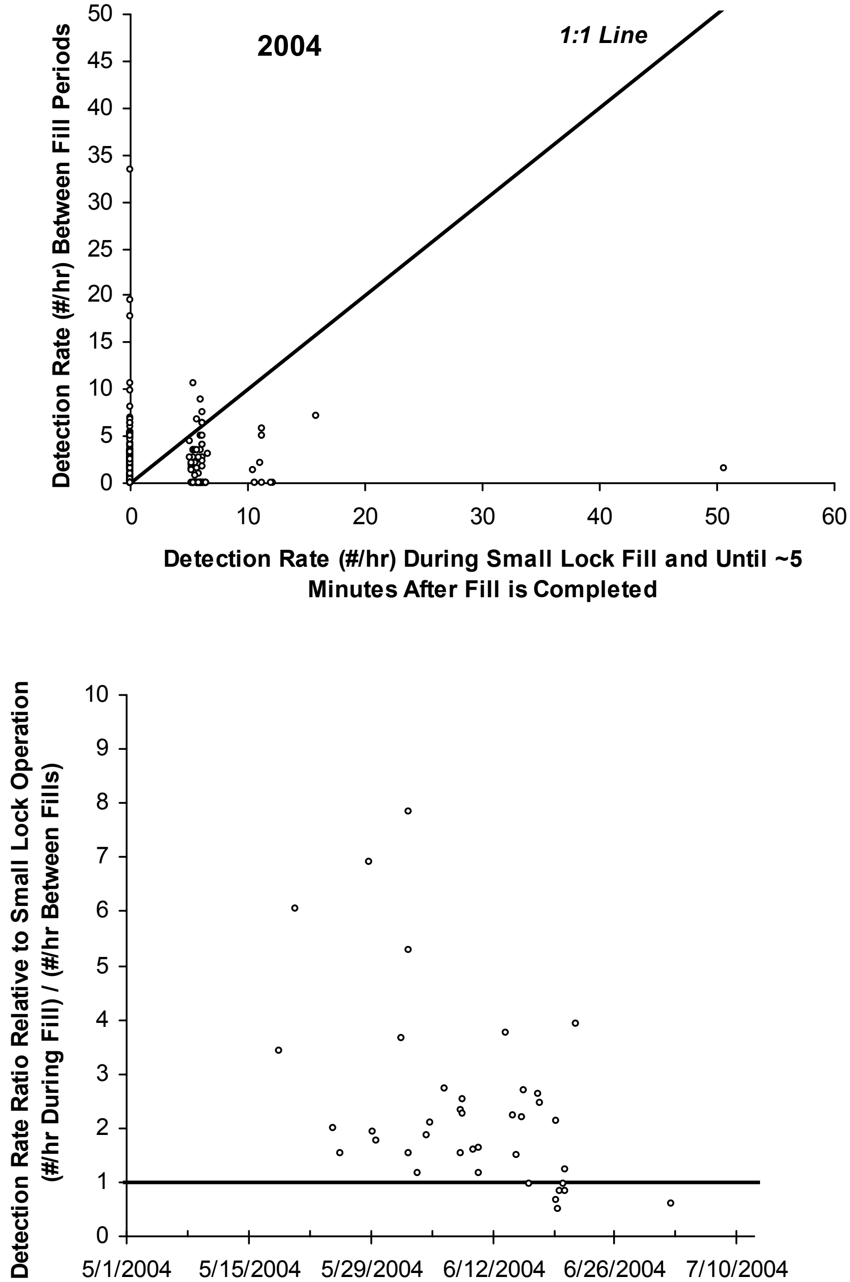


Figure 3-33. Comparison of passage rates of PIT tagged juvenile salmon (all species) through the smolt flumes at the Locks during filling of the small lock and until the next fill, 2004 Lake Washington PIT tag study. The bottom plot shows the ratio of the two passage rates over time. The line of equality is indicated by the solid diagonal (top) and horizontal (bottom) line.

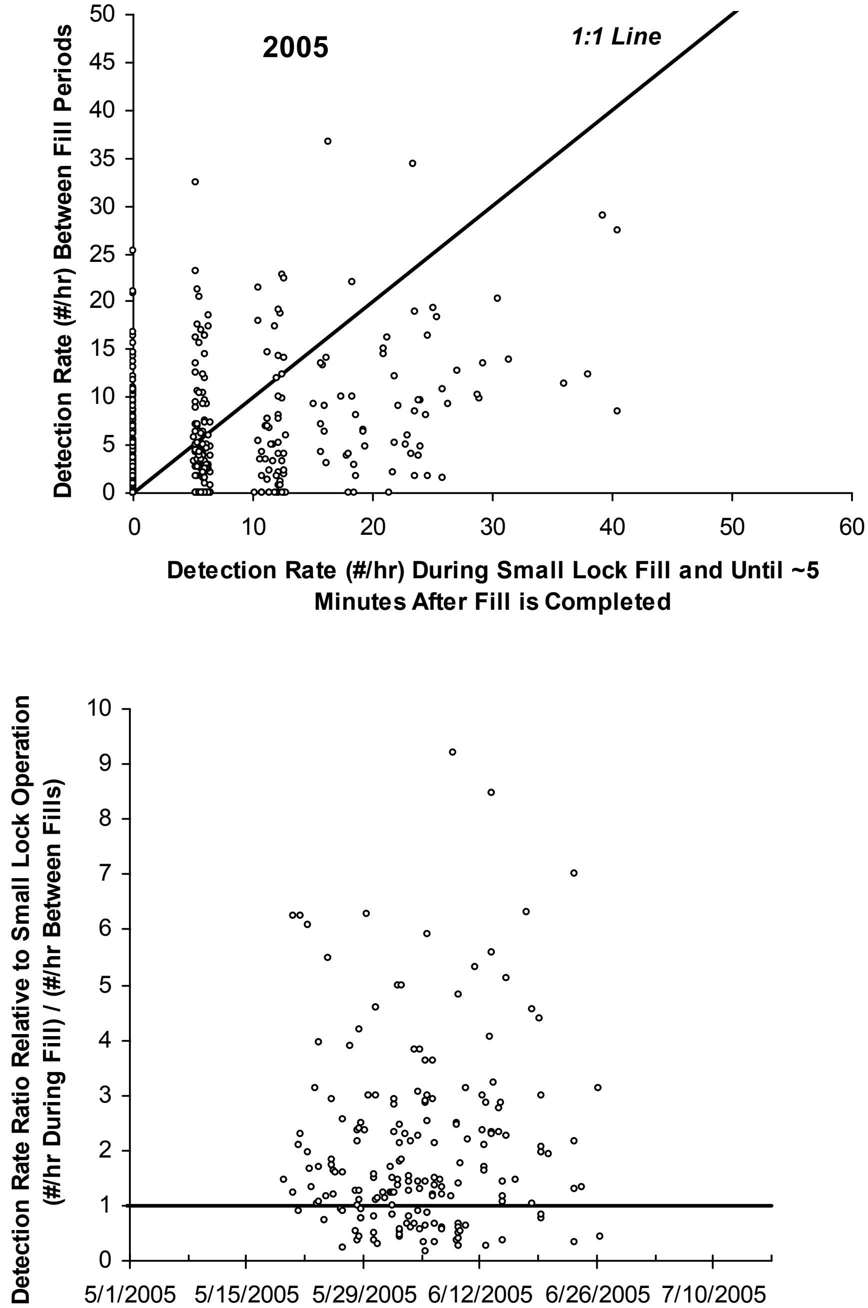


Figure 3-34. Comparison of passage rates of PIT tagged juvenile salmon (all species) through the smolt flumes at the Locks during filling of the small lock and until the next fill, 2005 Lake Washington PIT tag study. The bottom plot shows the ratio of the two passage rates over time. The line of equality is indicated by the solid diagonal (top) and horizontal (bottom) line.

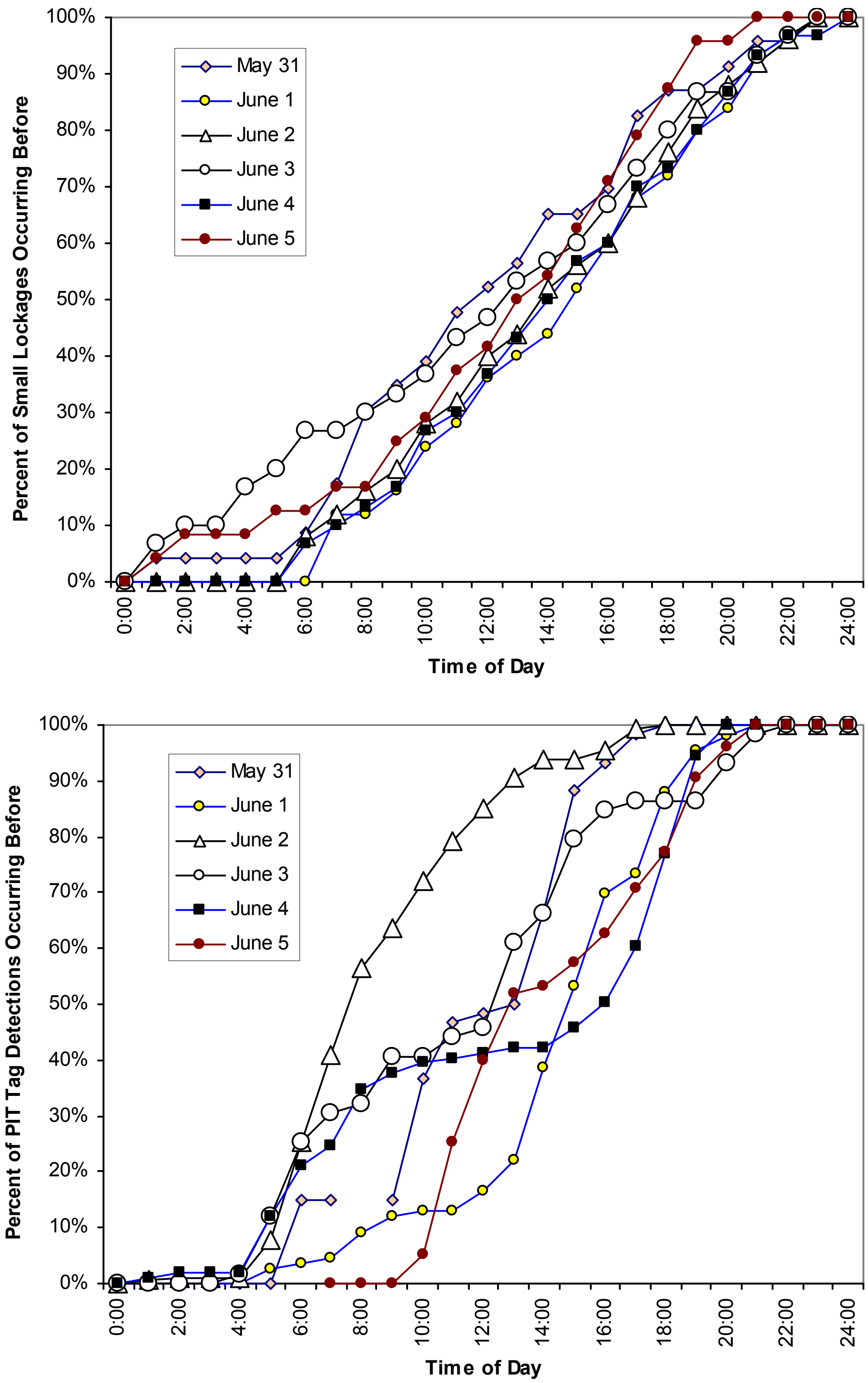
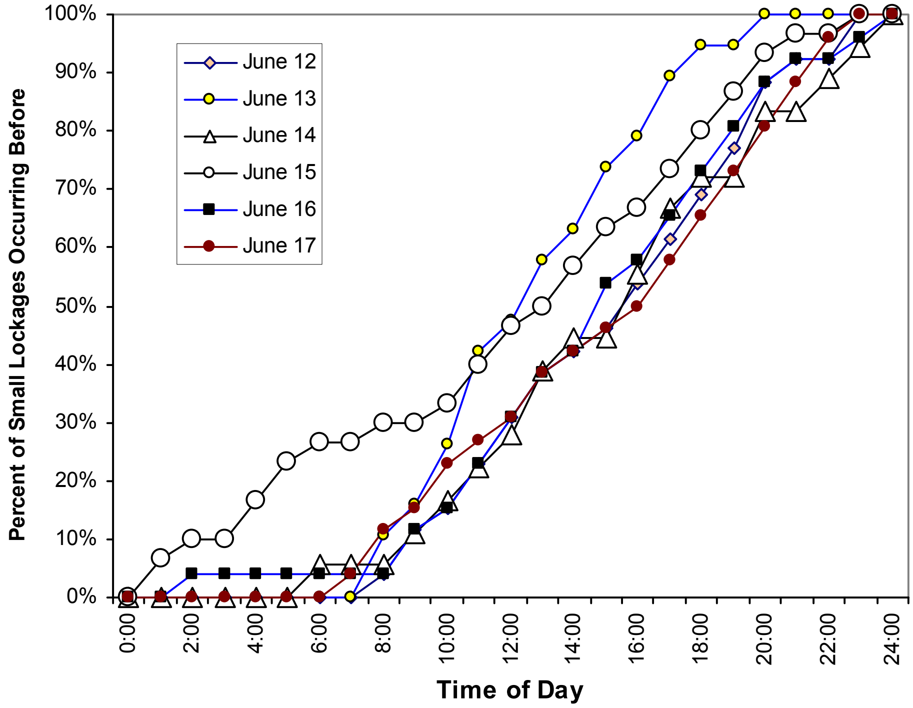


Figure 3-35. Cumulative frequency distributions of times of small lock openings (top) and PIT tag detections (bottom) around the time of the first small lock night-time opening test conducted the night of June 2-3, 2005. Each line represents the 24-hour period for that day.



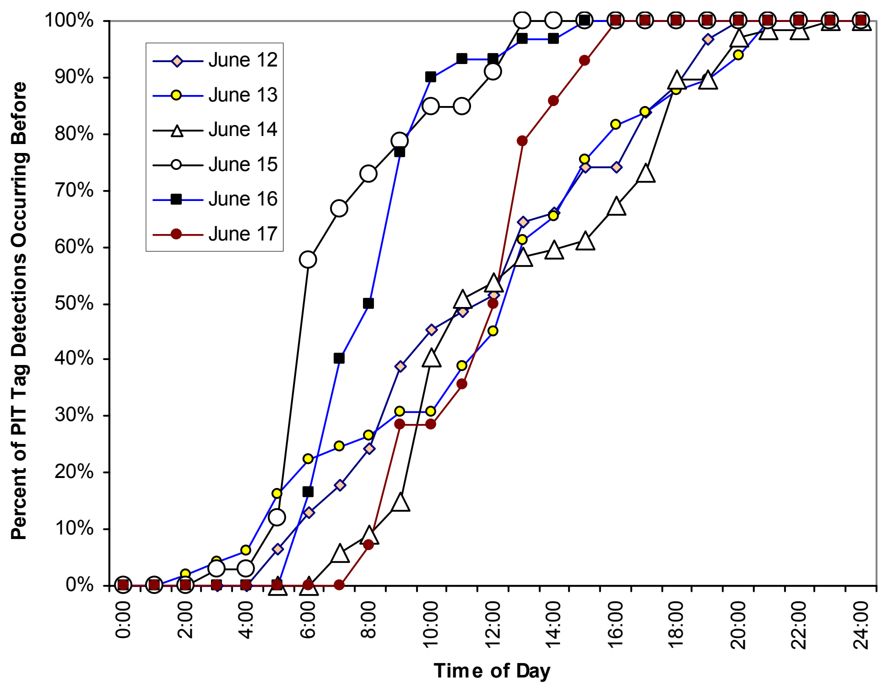


Figure 3-36. Cumulative frequency distributions of times of small lock openings (top) and PIT tag detections (bottom) around the time of the second small lock night-time opening test conducted the night of June 14-15, 2005. Each line represents the 24-hour period for that day.

4. DISCUSSION OF 2004-2005 RESULTS AND COMPARISON WITH SYNOPSIS OF 2000-2003 FINDINGS

The results of the 2004 and 2005 studies generally provided data corroborating insights obtained in previous years' PIT tagging studies as described in DeVries et al. (2005) regarding mortality, migration, and passage characteristics of tagged fish in the Lake Washington and LWSC system. This section was written to complement a more comprehensive review presented with relevant citations in DeVries et al. (2005). 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 permit further 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. Selected results are also compared with findings from previous years to refine or further support hypothesized trends in migration behavior, survival, environmental conditions, and Locks operations.

Tagging efforts in 2004 and 2005 will also be useful in future years for interpreting adult return data as PIT tagged fish are detected in the fish ladder. There have been two years of returns monitored to date, with results presented in Appendices C and D that demonstrate the importance of continued PIT tagging in the basin towards salmon management. A separate study was also undertaken in August 2005 in which groups of adult Chinook and sockeye salmon were tagged below the Locks by the USACE and WDFW to evaluate the proportion using the ladder and recycling characteristics. The results from that study, which also involved inserting acoustic tags, are forthcoming pending compilation and evaluation of out-of-basin detection data (F. Goetz, USACE, personal communication).

Detection efficiencies of the tunnel readers in 2004 and 2005 were generally as good as or better than efficiencies in previous years, especially in 2005 when exclusively "super tags" were used. The large tunnel readers were still operating below the desired minimum detection efficiency of 95%. Based on fish stick tests, Flumes 4B and 5B operated with minimum apparent efficiencies of 90% and better, values that were high enough, however, that the results reported for Chinook and coho salmon juveniles PIT tagged in 2004 and 2005 are likely representative of non-tagged fish.

4.1 COMPARISON BETWEEN HATCHERY AND NATURAL ORIGIN FISH

One important goal of the PIT tagging studies as part of the LWGI was to evaluate the use of hatchery Chinook juveniles for migration survival studies in lieu of natural origin fish. Data collected up through 2003 had indicated that the behavior of Issaquah Hatchery fish was reasonably similar to that of natural origin fish (DeVries et al. 2005). The 2005 study results continue to suggest that Chinook salmon juveniles released from the Issaquah Hatchery may exhibit migration and passage behavior sufficiently similar to that of naturally-spawned Chinook originating from Bear Creek and the Cedar River that they could potentially be used in subsequent migration studies (hatchery fish were not tagged in 2004). For example, Chinook tagged and released at the Issaquah Hatchery generally took several days longer than Bear Creek fish to migrate to and pass the Locks in 2001, 2004, 2005, but not in 2002 and 2003. Passage timing has been generally similar for all three stocks, although there has been greater similarity between Issaquah Hatchery and Bear Creek Chinook than either stock with Cedar River Chinook. In any case, the PIT tagging studies to date collectively indicate that hatchery fish should be tagged and released under as natural a situation as possible (see DeVries et al. 2005 for discussion of effects of water temperature and use of hatchery fish for tunnel reader calibration testing, however).

Greatest differences between hatchery and natural origin fish include the observation that the average migration rate of Chinook released from the Issaquah Hatchery has been generally faster than in the case of Bear Creek fish in all years, with greatest relative differences in cumulative migration rate distributions for the two release locations occurring in 2002 and 2003 (on order of ~1.5-2 km/d) compared with 2001 and 2005 (on order of ~0.5 km/d). The differences observed in migration rates could reflect effects of the release location being above Lake Sammamish and release date. Chinook were released from the hatchery around the end of the second week of May in 2001 and 2005, near the third week in 2003, and at the end of May in 2002.

Passage timing behavior in 2005 was different compared with previous years. Issaquah Hatchery Chinook exhibited a stronger relation between passage timing at the Locks and date of apogee in 2005 than Bear Creek and Cedar River fish (Figure 3-15). Natural origin Chinook passage timing distributions did not exhibit as strong a relation to the date of apogee in 2004 and 2005 as was seen in previous years (DeVries et al. 2004). One possible explanation is that water temperatures were warmer earlier in 2004 and 2005 in Bear Creek than in other years (see Sections 3.3 and 4.2). It is possible that the lunar influence on Issaquah Hatchery Chinook passage timing may not have been as strongly moderated by elevated water temperatures as may be the case suggested for natural origin fish by the 2004 and 2005 data. This is discussed again in Section 4.4.4.

4.2 POSSIBLE INFLUENCE OF WATER TEMPERATURE ON SURVIVAL AND PASSAGE

The proportion of tagged fish using the flumes appeared to have been slightly lower for most release groups in 2004 and 2005 than in 2002 and 2003 (Figure 3-29; Table 4-1). Detection rates decreased in each year as water temperatures increased (Figures 4-1, 4-2), consistent with previous years (DeVries et al. 2005). In addition, Chinook smolt detection rates were slightly higher in 2005, which had cooler near surface water temperatures than in 2004. As described below, decreasing detection rates may reflect effects of elevated water temperatures on survival to the locks and/or on migration and passage behavior. These phenomena in turn lead to hypotheses regarding trends in species abundance.

4.2.1 Survival and Predation

Survival of outmigrants to the locks may be adversely affected by elevated temperatures because of effects on predation rates. The overall rate at which juvenile Chinook, coho, and sockeye salmon are consumed will depend on when predator-prey habitats overlap spatially and vertically in the water column, abundance of prey relative to predators, and when water temperatures are near optimal levels for predator feeding rates (Tabor et al. 1993; Petersen and Ward 1999). Primary predators in the LWSC appear to be smallmouth (*Micropterus dolomieui*) and largemouth (*M. salmoides*) bass, and northern pikeminnow (*Ptychocheilus oregonensis*; Tabor et al. 2004). Studies in other Washington rivers indicate that smallmouth bass eat primarily subyearling Chinook, whereas northern pikeminnow also eat larger lifestages (Poe et al. 1991; Fritts and Pearsons 2004). Juvenile salmon consumption rates in the Columbia River have been found to be highest when water temperatures were highest (Vigg et al. 1991). Available information indicates the following influences of temperature on predation rates:

- Smallmouth bass prefer temperatures above about 20-21ºC and begin to feed more substantially when temperatures exceed 10ºC (Wydoski and Whitney 2003). They feed more actively at temperatures above 15ºC (Carlander 1977, cited in Naughton et al. 2004), and most actively around 20ºC (Wydoski and Whitney 2003). Moyle (2002) noted that preferred and optimal temperatures for growth and feeding are higher when food is abundant, and suggested that this species may seek out cooler water in part if that is where prey is found. Naughton et al. (2004) noted roughly five times higher predation rates on juvenile salmonids by smallmouth bass in the Columbia River in one year when temperature was around 20.6ºC compared with the previous year when temperature was around 16.7ºC, although the increase may have also partly reflected increased prey abundance.

Table 4-1. Summary of Releases and Detections of PIT tagged Chinook and coho salmon smolts[1] for major release locations, 2000-2005 Lake Washington GI PIT Tag Studies

			Issaquah Creek		Bear Creek		Cedar River	
Quantity	**Species**	**Year**	**Natural**	**Hatchery**	**Natural**	**Hatchery**	**Natural**	**Hatchery**
Number Released	Chinook	2000	226	122	525	--	273	--
		2001	--	4676	2132	--	1550	67
		2002	--	4024	2309	--	814	--
		2003	--	992	2305	--	1726	6
		2004	--	--	1512	--	2185	6
		2005	--	409	1424	--	2075	63
	Coho	2001	--	--	1011	12	1235	--
		2002	--	--	2661	--	1038	--
		2003	--	--	2044	--	1027	--
		2005	--	--	1207	--	1265	--
Fraction in Flumes[2]	Chinook	2000	0.004	0.008	0.1	--	0.19	--
		2001	--	0.38	0.13	--	0.29	0.06
		2002	--	0.39	0.32	--	0.21	--
		2003	--	0.28	0.35	--	0.3	0.17
		2004	--	--	0.15	--	0.15	0
		2005	--	0.14	0.24	--	0.27	0.03
	Coho	2001	--	--	0.47	0	0.49	--
		2002	--	--	0.65	--	0.59	--
		2003	--	--	0.72	--	0.66	--
		2005	--	--	0.56	--	0.50	--

[1] *- Insufficient data for sockeye salmon or steelhead trout*

[2] *- Adjusted for detection efficiency*

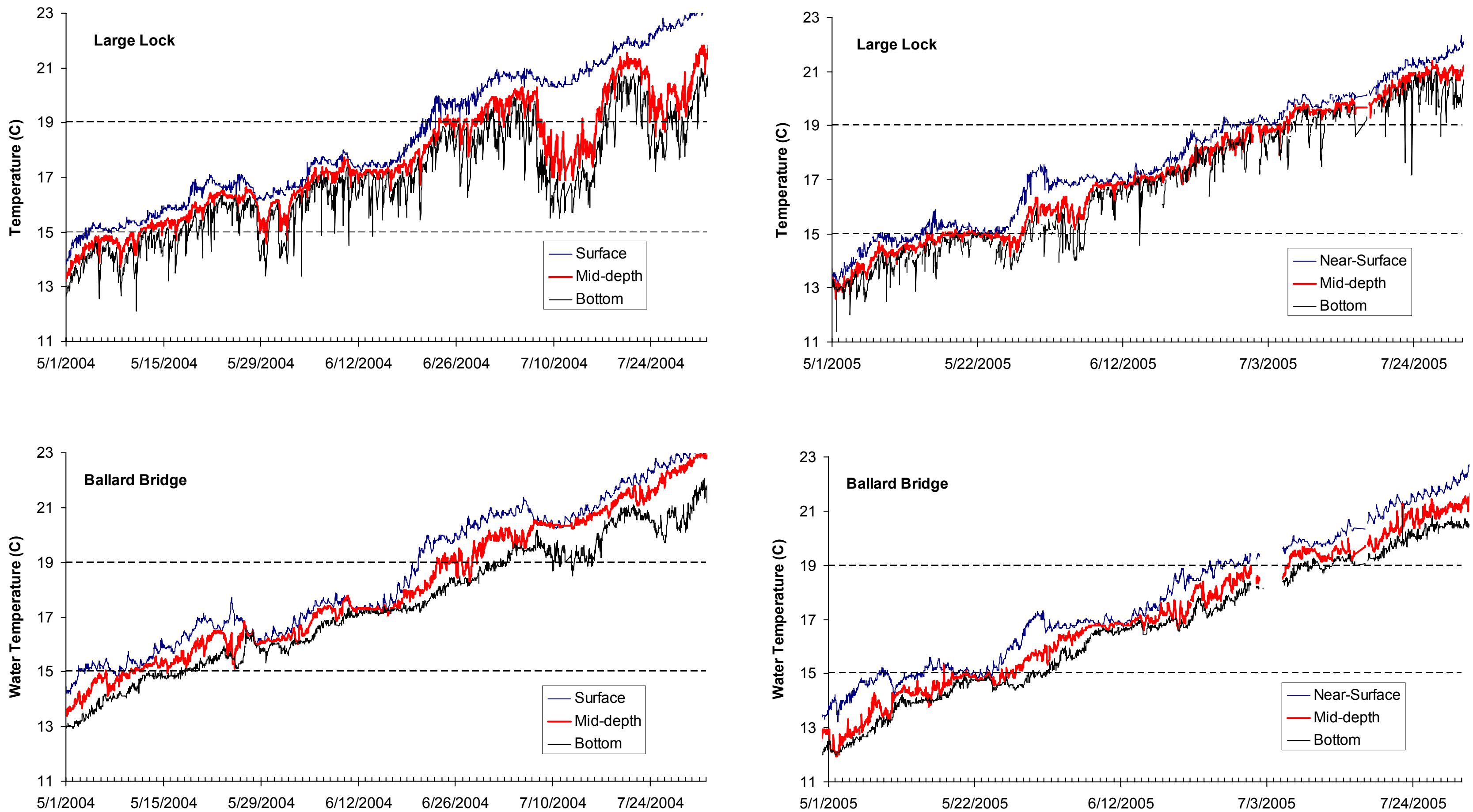


Figure 4-1. Temporal variation in water temperatures measured in the LWSC during the 2004 (left) and 2005 (right) Lake Washington PIT tag studies. The horizontal lines indicate approximate threshold criteria for optimal juvenile salmon growth (15°C) and avoidance and feeding inhibition (19°C).

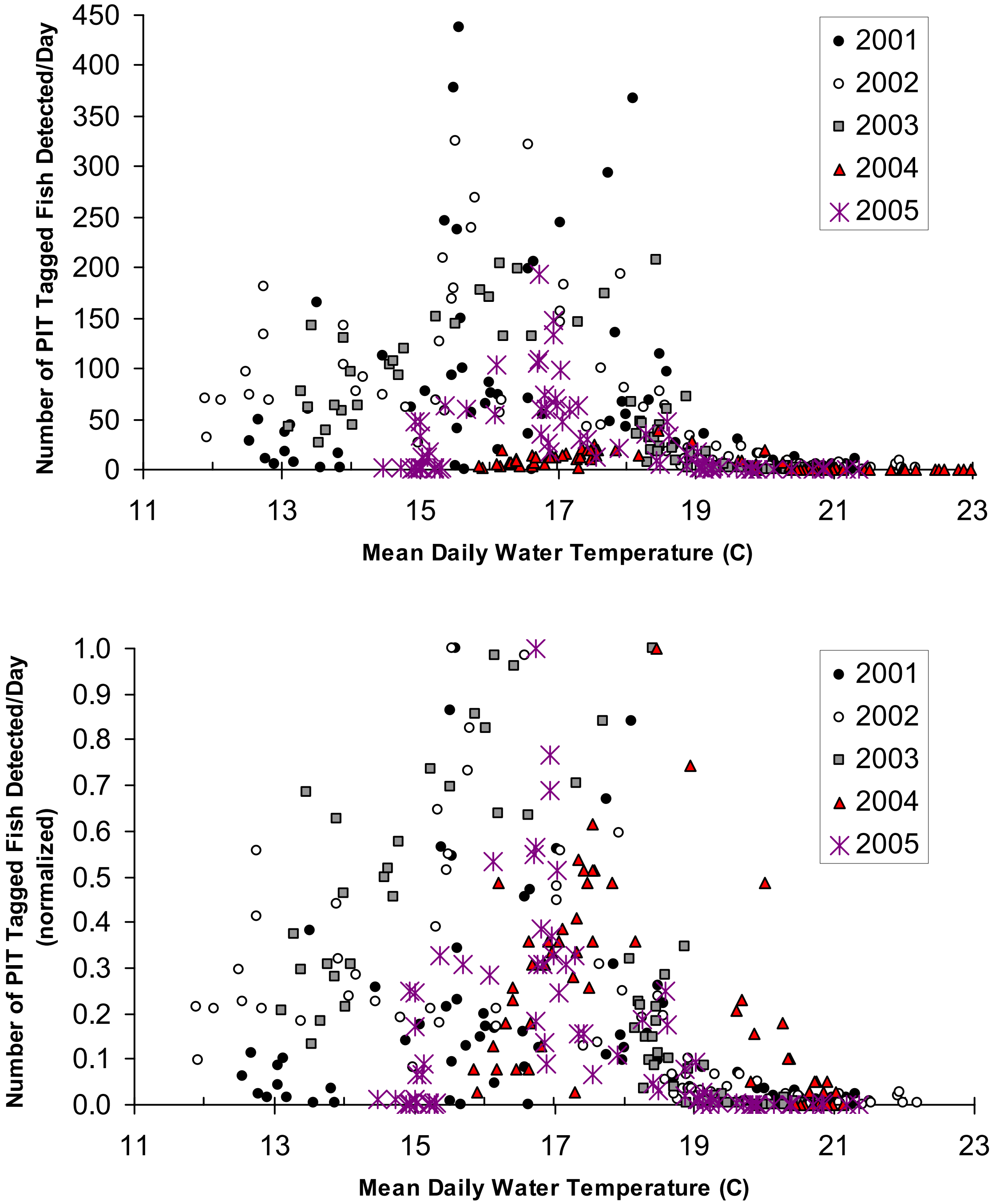


Figure 4-2. Variation in daily detection numbers in the smolt flumes with mean daily surface water temperature in the LWSC 2001-2005. Each data point represents the total number of PIT tagged fish detected over 24 hours, and the corresponding temperature for that day. Top graph: absolute detection numbers; bottom graph: numbers normalized with respect to the maximum daily number for the year.

- Largemouth bass exhibit temperature ranges for preference and growth similar to that of smallmouth bass (Wydoski and Whitney 2003; Moyle 2002).
- Northern pikeminnow in the Columbia River have been determined to feed more effectively at temperatures above about 15ºC, with optimal temperatures ranging between 20.1 and 22.7ºC (Petersen and Ward 1999), or around 21.5ºC (Vigg and Burley 1991). Consumption and growth rates drop rapidly with temperatures below about 15ºC (Petersen and Ward 1999). They have been noted to have been collected in Lake Washington in areas with highest temperatures ranging between 20-23ºC (Wydoski and Whitney 2003).

Since 2000, near-surface water temperatures in the LWSC have generally reached 15ºC between around the beginning of May (e.g., 2004) and the beginning of June (e.g., 2002). Temperatures have generally consistently exceeded 20ºC between around the third week in June (2004) and the middle of July (2002). Timing of temperature increases may limit the overall effect of predation mortality on outmigrating smolts in the LWSC because temperatures do not favor higher predation rates until later in the outmigration season. Smolts may also seek cooler water than bass later in the outmigration season. Releases of coho and Chinook smolts from the University of Washington hatchery may provide a major source of salmonid prey to bass and pikeminnow earlier in the migration season (Tabor et al. 2004), where smolts from elsewhere in the basin may benefit by being targeted less. Nonetheless, the reduced detection rates at the Locks later in the outmigration season could reflect in part the effect of temperature on predation rate.

4.2.2 Migration and Passage Depth

Surface water temperatures in the LWSC reach adverse levels sooner in the outmigration season than near-bottom temperatures. One hypothesis is that the decrease in detection rates over time could reflect a shift in passage behavior where the outmigrants gradually seek deeper routes through the LWSC and Locks. This hypothesis has not been fully tested using hydroacoustic data, but it will be evaluated more directly using microacoustic tags in 2006 and 2007 (Roger Tabor, USFWS personal communication). Passage later in the season could occur via the large lock and its filling culverts, with a sill elevation 20 feet below that of the small lock on the lake side and approximately 36 feet below the flume entrances. In most locations, the mid-column water temperature was approximately 1-2ºC cooler than the surface temperature. Water temperatures below the Locks were also much cooler. 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. Near-surface water temperatures reached 15ºC around the beginning of May, and 19ºC after the third week of June in 2004, earlier than in 2003 (Figure 4-1; DeVries et al. 2005). In 2005, temperatures reached 15ºC and 19ºC around the middle of May and end of June, respectively. These temperatures are of significance because they respectively approximate the limit to optimal juvenile salmon growth, and the approximate onset of feeding inhibition and avoidance during migration (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 the third week in May in both 2004 and 2005 (Figure 3-29). By the average time those fish had reached the Locks, surface temperatures had reached approximately 17ºC (Figure 4-1). Detection rates approached zero for groups released around the third week in June in 2004 and 2005. By the average time those fish had reached the entrance of the Locks (slightly over two weeks), surface temperatures had reached 19-20ºC. In 2001, 2002, and 2003, 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 near surface mean daily temperature exceeded approximately 19-20ºC (Figure 4-2). This generally occurred around the beginning of July (Figure 4-3). Diurnal variation in LWSC surface temperature is generally less than 0.5ºC, so similar results are seen for daily minimum and maximum temperatures.

Elevated water temperatures in the LWSC have the potential to affect a substantial number of Chinook smolts in this manner. A comparison of the median travel times of Chinook smolts tagged in 2004 and 2005 (~21 and ~25 days, respectively; Figure 3-19) with the dates near-surface water temperatures reached 19ºC at the Ballard Bridge (Figure 4-1) suggest that smolts leaving each stream after about June 1 of each year were more likely to experience adverse near-surface water temperatures in the LWSC than not. This would amount to approximately 6% and 11% of Bear Creek Chinook smolts, and 20% and 28% of Cedar River smolts in 2004 and 2005, respectively (data from Seiler et al. 2005, Volkhardt et al. 2006).

The low overall proportion using the flumes in 2004 compared with other years may reflect both a smaller number of flumes operating for shorter periods and relatively early warming of surface water in the LWSC, Lake Washington, and tributaries (Figures 4-3 and 4-4). Given the decrease observed in detection rates each year with increasing water temperatures, it is possible that a greater proportion would have been detected in the flumes if the spring of 2004 and 2005 had been cooler and wetter, and surface water temperatures had been closer to average or lower values prior to the end of the Chinook salmon smolt outmigration period.

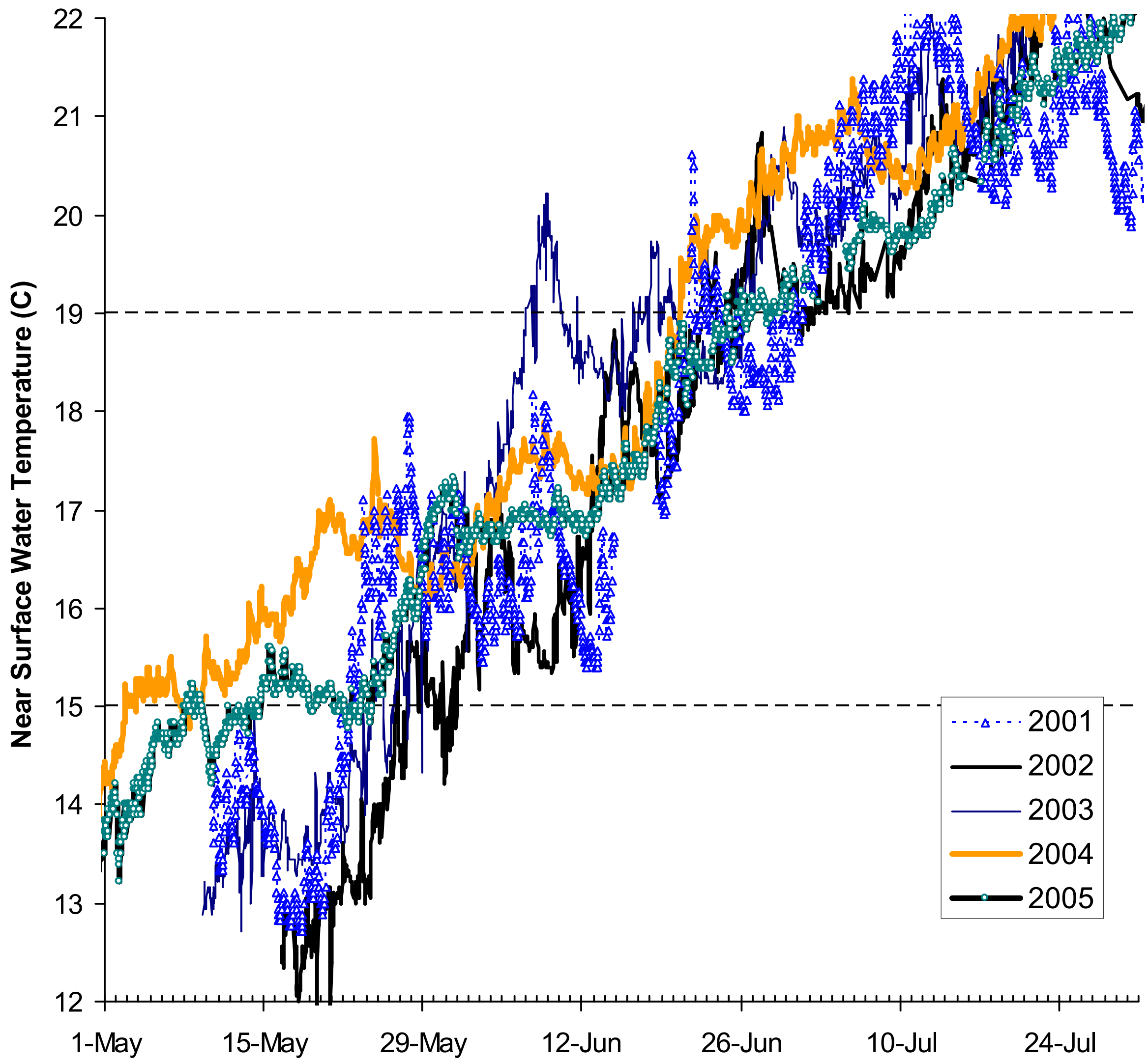


Figure 4-3. Between-year variation in near-surface water temperatures in the LWSC, 2001-2005 (USACE data).

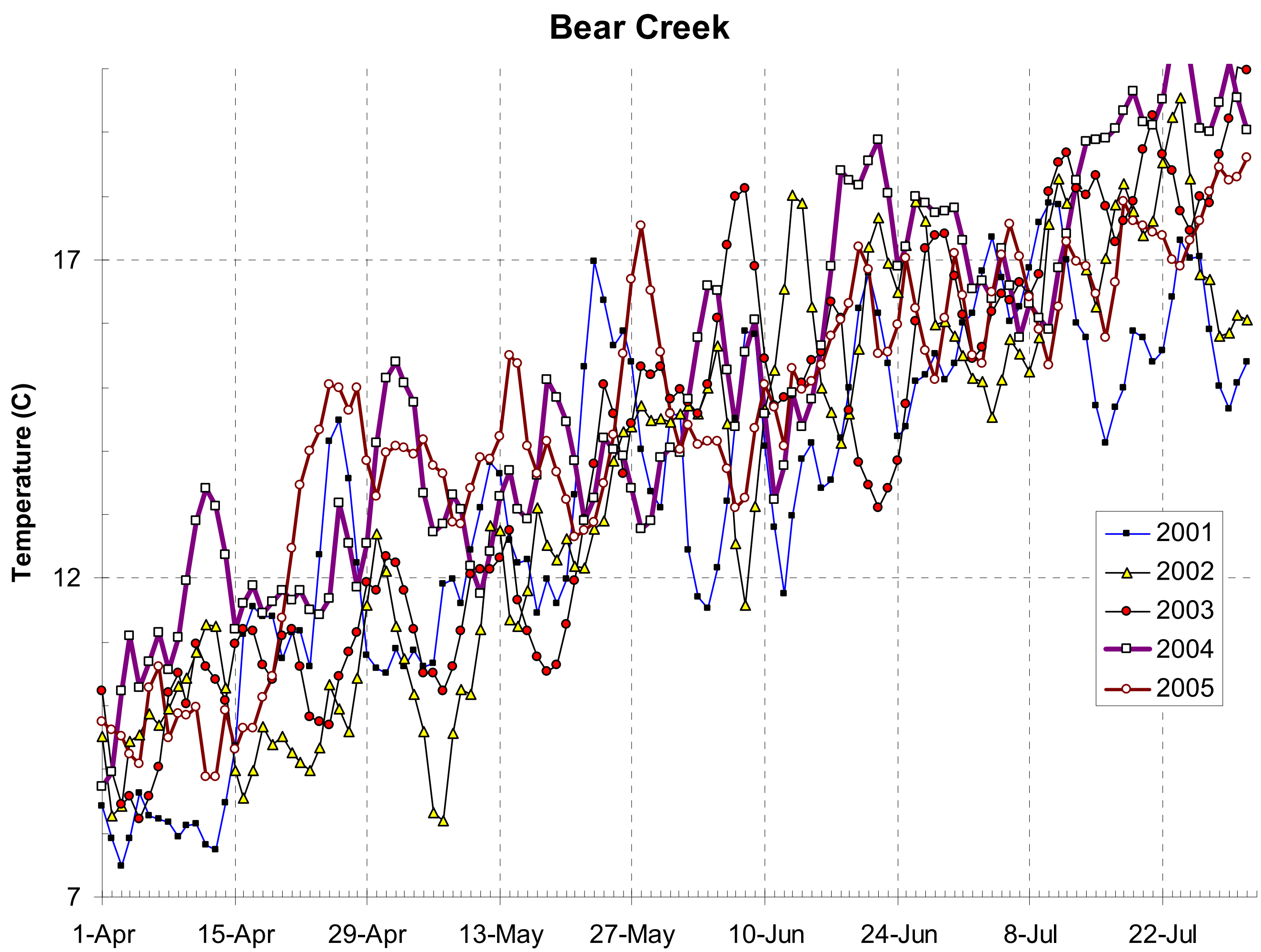


Figure 4-4. Between-year variation in daily mean water temperatures in lower Bear Creek, 2001-2005 (King County data).

A temperature-proportion hypothesis must be tempered, however, by the observation that spill patterns through the other gates without flumes may also influence the proportion detected in the flumes if the spill occurs during the passage season. A plausible hypothesis is that the proportion using the flumes is inversely related to the amount of spill through other gates, other factors being equal, because spill through the other gates presents an alternate passage route (see also Section 4.3.1.2). Review of the 2003, 2004 and 2005 data suggests that Chinook smolt detection rates were higher in 2003 than in 2004 and 2005 for groups released in May and the first week of June (Figure 3-29). Assuming a roughly 2-week median travel time to the locks, this corresponds roughly to detections between the middle of May and the middle of June. There was no spill during that same mid-May to mid-June period in 2003, limited spill through other gates in 2004 (on 7 days between May 26 and June 5), and more spill in 2005 (12 days between May 15 and June 13). Water temperatures during that period were first lower, then eventually higher in 2003 than in 2004 and 2005 (Figure 4-3). If only water temperature influenced detection rates, one might expect higher and then lower detection rates in 2003 than in 2004 and 2005 over that period, but this was not the case. Detection rates were consistently higher in 2003 for groups released in May than in 2004 and 2005 (Figure 3-29), suggesting that differences in spill may have influenced the number passing through the flumes. Conversely, spill occurred most extensively in 2002 when water temperatures were coolest overall, yet detection rates for Chinook released in May of 2002 were comparable to the 2003 detection rates when there was no spill. There is thus a possible balance between spill and temperature, but the relationship is difficult to elucidate. More focused studies would be needed to determine the interaction between surface water temperature and spill on passage rates through the flumes.

The 2004 detection and temperature data provide additional insight into fine-tuning operations for water management purposes. Given the warmer spring in 2004 (Figure 4-3), the higher detection rates at around 20ºC in 2004 than 2005 and previous years (Figure 4-2) suggest a hypothesis where acclimation to warmer water temperatures may have occurred in 2004 (cf. McCullough 1999). Acclimation could have allowed proportionally more outmigrant Chinook to migrate closer to the surface than in other years, and thus more fish would have been able to pass through the flumes. This hypothesis has implications to water management, where a threshold temperature has been suggested by previous years' data for determining when to shut down the flumes for the summer to conserve water (DeVries et al. 2005). Detection rates have generally dropped off precipitously when surface water temperatures reached 19-20ºC, except in 2004, when the apparent threshold was around 20-21ºC (lower graph in Figure 4-2). This finding suggests that a higher threshold temperature may be applicable in years when water temperatures in April and May are with well above average compared with other years (e.g., in Bear Creek in 2004; Figure 4-4).

These results suggest that use of the smolt flumes may have little benefit for smolt passage as some upper temperature threshold is approached in surface waters of the LWSC, and could be closed until the next spring for purposes of saving water for the saltwater drain, lockages, and the fish ladder instead. What level that threshold temperature should be remains to be determined, and will likely balance water availability, water use, water quality, and fish passage objectives. The highest mean daily temperatures in 2004 and 2005 at which flume passage of PIT tagged Chinook occurred were approximately 21.0°C (2 fish/day) and 20.8°C (1 fish/day), respectively. Previous years showed flume passage, albeit in small numbers (1-9 fish/day), at mean daily surface water temperatures as high as 21.3°C in 2001, 22.0°C in 2002, and 20.5°C in 2003 (Figure 4-2).

4.2.3 Residualism in Lake Washington

Nearly all fish tagged in 2004 and 2005 were detected at the Locks that same year, although a small number of Chinook and one coho were again detected passing through the Locks one year later (Table 3-4), and therefore must have residualized in the Lake Washington system. This behavior is thought to reflect the influence of rising water temperatures during the spring outmigration (DeVries et al. 2005). Of Chinook tagged and released in 2003 and 2004, respectively 0.45% and 0.29% of Bear Creek, and 0.31% and 0.22% of Cedar River fish were detected the next year. These two years were generally associated with warm water temperatures in the LWSC during the Chinook outmigration season (Figure 4-3). In comparison, no natural origin Chinook from the 2002 study, when water temperatures were cooler and flows higher, were detected in 2003 or 2004. In addition, the consistently higher residualization rates suggested for Bear Creek may reflect the influence of warmer water temperatures in the Sammamish River, which is thought to induce later migrating Chinook smolts to move into cooler water tributaries where they remain the rest of the summer (DeVries et al. 2005).

Other evidence from the 2004 and 2005 studies includes the facts that (i) most of the natural origin fish in Table 3-4 were Chinook, which generally outmigrate later than coho, and (ii) all of the natural origin Chinook in Table 3-4 were released later in the outmigration season, and would thus have been more susceptible to the effects of elevated water temperature. These fish also came out relatively early the next spring, consistent with general yearling outmigration patterns in the system (DeVries et al. 2005). There is relatively little thermal stratification in late spring in the Fremont Cut, Montlake Cut, and Sammamish River, whereas bottom temperatures are cooler than surface temperatures in other locations in the LWSC and in lakes Washington and

Sammamish. Hence, it is possible that the two constrictions posed by the LWSC and Sammamish River present thermal barriers to outmigrants in late spring and early summer.

In the case of the Montlake and Fremont Cut entrances, it is hypothesized that thermal barriers may develop during the outmigration when near surface water temperatures rise above general smolt preference (~15°C) and tolerance (~ 19°C) limits (ODEQ 1995; McCullough 1999). The critical temperature at which a thermal barrier becomes significant has not been established directly, but appears to be somewhere within this range. Water temperature data collected at the 10 m depth in Lake Union (King County station A522), which approximates the bottom elevation of the Montlake and Fremont cuts (USACE Water Control Manual), indicate this temperature was reached in middle to late August in most years since 2000. The date at which the 15°C threshold is reached at the 10 m depth in Lake Union appears more variable, and ranged between the beginning of June in 2004 to the beginning of July in 2002. In Lake Washington, the 15°C threshold was reached at the 10 m depth in early to mid June (King County station 890). The range of dates at which 10 m depth water temperatures exceeded 15°C corresponds roughly to the range of tagging group release dates for which PIT tag detection rates began to decline. The thermal bottlenecks or barriers potentially posed by the Montlake and Fremont cuts are important in the sense that they may cause residualization in Lake Washington until the following spring. An extended year of lake residency would be expected to increase predation mortality rates in particular.

The effect of temperature on smolting may also be partially responsible for the observed residualization phenomenon. McCullough (1999) noted that an accelerated temperature regime could result in either earlier emigration or reduced success in smolting. Earlier emigration (e.g., associated with accelerated growth) is unlikely to explain the seasonal trend seen in the declining PIT tag detection rates of later migrating fish at the Locks, or the phenomenon of residualization. If there is a physiological effect, therefore, it is more likely to be manifest through effects to the smolting process. Temperatures in the range of 15°C-20°C have been found to adversely affect smolting of salmon, whereas temperatures greater than about 13°C have been associated with reduced smolting success of steelhead (McCullough 1999). These temperatures are within the range that may be associated with avoidance as described above, making it difficult to discern the relative importance of the two mechanisms based on the PIT tag data alone. However, Simenstad et al. (2003) continued to collect natural origin Chinook and coho salmon juveniles below the Locks in August 2001 after detection rates had declined to zero. DeVries and Hendrix (2005) argued that this result and other data on entrainment rates in the large lock filling culvert were consistent with a behavioral effect on migration depth, which in turn would influence residualization in the manner described above.

4.2.4 Possible Implications for Anadromous Salmonid Species Composition in the Lake Washington Basin

The data indicate that water temperatures in Lake Washington and the LWSC generally warm over the outmigration season. There is also evidence that temperatures in the system have been warming over the long term (e.g., Winder and Schindler 2004). Larger bodied sockeye, coho, and Chinook yearlings outmigrate and pass the Locks earlier in the spring than smaller, young of year sockeye and Chinook. Sockeye and coho yearlings appear to have the largest saltwater survivals and run sizes returning to the LWB based on the limited amount of adult PIT tag detection data available to date (Appendices C and D). As described above and in DeVries et al. (2005), detection rates, and thus potentially survival to the Locks, decline as water temperatures increase over the outmigration season to levels that are above various preference, tolerance, and saltwater adaptability criteria.

In addition, because predation risk increases with water temperature, survival to the Locks may decrease as water temperatures increase over the spring outmigration period. This interaction could potentially affect later migrating species and cohorts more adversely than earlier migrating ones. Greatest impacts of predation as related to water temperature would therefore be expected for later migrating Chinook and young of year sockeye smolts, and fewest impacts would be expected for larger bodied, earlier migrating sockeye and coho smolts.

It is thus reasonable to hypothesize that sockeye and coho salmon smolts may have an adaptive advantage over Chinook salmon smolts based on interactions between body size, outmigration timing, and water temperature patterns. The greater proclivity of steelhead to exhibit reverse smoltification at elevated temperatures (Wedemeyer et al. 1980) also leads to a hypothesis that gradual long term warming of the system could help explain the decline seen in this species' population. Additional study appears warranted to evaluate these hypotheses.

4.3 INFLUENCE OF LOCK OPERATIONS ON PASSAGE AND ESTUARINE TRANSITION

The 2004 and 2005 PIT tag data further corroborate findings from previous years that suggest there are several features of lock construction or operation that may also 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 Above the Locks

4.3.1.1 Influence of Lock Fillings

The preceding PIT tag studies indicated that operation of the small lock may have a stronger influence on passage rates in the flumes than the large lock (DeVries et al. 2005). The mechanism is hypothesized to be that lock filling operations influence flume passage rates through transient changes in velocity patterns occurring in the forebay area. Juveniles may be induced to swim more actively in the forebay area in response to unsteady flows when local currents increase temporarily while the small lock is filling. Increased swimming activity may increase the probability that outmigrants encounter the smolt flume entrances, with increased probability of passage. In corroboration, passage rates during fills of either lock were more than twice passage rates between successive fills in 2004 and 2005, consistent with previous years' results. The differences were significant at the 95% confidence level in both years.

The diurnal variation in passage rates seen in previous years could not be evaluated in 2004 and 2005 because flume operations were modified for water conservation purposes where the flumes were shut off at night. This reflected findings that the majority of smolts passed through the flumes during daylight hours. As described in Section 2.7.3, it was hypothesized based on results similar to those depicted in Figures 3-33 and 3-34, and similarity to small lock filling frequency distributions (Figure 4-5), that the diurnal variation reflected small lock operating frequency. However, the two small lock filling tests conducted in June of 2005 indicated this was not necessarily the case, since the diurnal passage pattern was retained even when the small lock was opened at a roughly uniform frequency over a 24 hour period (Figures 3-35, 3-36). An alternate explanation suggested by hydroacoustic data (Johnson et al. 2004) that smolts in the LWSC sound to deeper water at night, and are thus effectively unavailable to pass through the flumes, appears more plausible at this time.

4.3.1.2 Influence of Flume Flow Rate

A direct relationship between flume flow and passage numbers has been suggested by previous years' results to occur before water temperature affects passage behavior (DeVries et al. 2005). The relation of passage rate with flume flow was addressed for the 2004 data by DeVries and Hendrix (2005) and is thus not repeated in detail here. That work systematically evaluated the

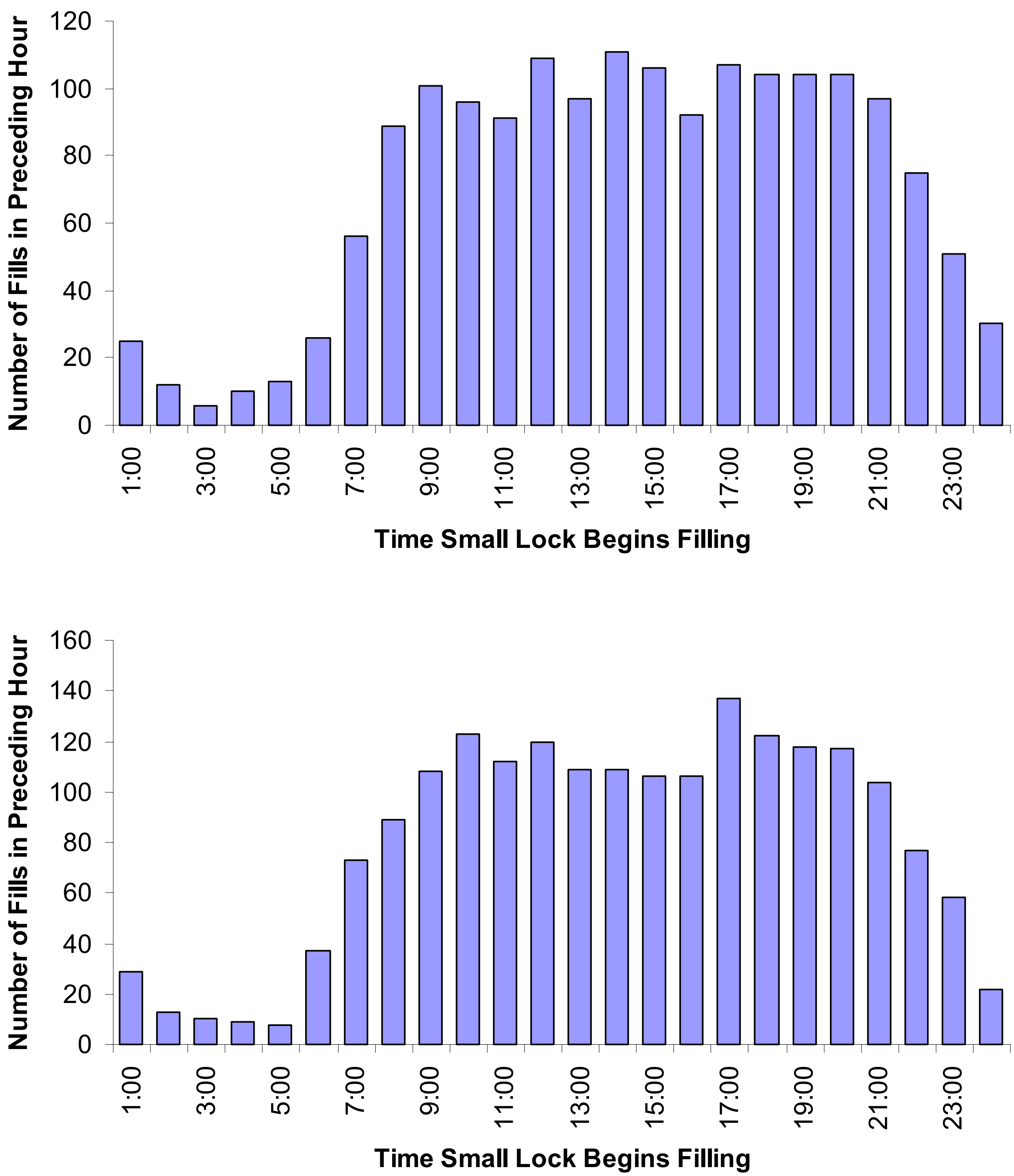


Figure 4-5. Diurnal variation in times at which the small lock began to fill during the 2004 (top) and 2005 (bottom) Lake Washington PIT tag study periods ending July 15, 2004 and 2005.

relation between flume flow and entrainment rates in the large lock filling culvert, relying on PIT tagging, observer count, and hydroacoustic data. A key finding of that analysis with respect to Locks operations and involving the PIT tag data was that maximum flume passage numbers appeared to increase with total flume flow rate. There was no apparent flume flow rate above which passage numbers decreased asymptotically. There was also some evidence that the flume flow-passage rate relation may have been stronger within a week or two after apogee occurred (DeVries and Hendrix 2005). The collective results suggest that additional flumes could be opened or substituted (e.g., both large flumes instead of one large and the medium-sized flume) as needed and feasible to maximize flume passage rates until water temperatures begin to affect migration depth as hypothesized and detection rates decline.

The 2005 flume data could not be used extensively to compare passage rates between flumes given the generally heavy reliance on flumes 5B and 5C, and more regular flume schedule over most of the outmigration season (Figure 3-2). However, there were fifteen days total when all four flumes were effectively open simultaneously during daylight hours (May 4, 10, 13, 14, 15, 18, 19, 21, 22, 23; June 2, 3, 10, 13, 14). Cumulative passage rates for each flume over those fifteen days are depicted in Figure 4-6. The flumes in gate 5 combined were associated with higher detection rates per unit cfs than the flumes in gate 4; similarly, flume 5B had a higher detection rate than the similarly sized flume 4B. The reverse has also occurred, for example, in 2001 (DeVries et al. 2005). The results depicted in Figure 4-6 could reflect the fact that spill occurred in gates 1, 2, and/or 3 on most of those same days evaluated in 2005. It is possible that fish swimming from the north side of the LWSC and that might otherwise have passed through flumes 4A or 4B were diverted instead through one of the three northern gates, thereby reducing the flume passage rate in gate 4.

4.3.2 Influence of Locks on Juveniles Located Below the Locks

As in previous years, the tunnel detector data from 2004 and 2005 indicate that some Chinook and coho salmon smolts recycled through the Locks (Table 3-5). As discussed in DeVries et al. (2005), it is unknown whether this was because (i) fish were entrained during lock openings and became disoriented, (ii) some fish that passed through the flumes were not completely smolt-ready and thus actively avoided more saline water by swimming upstream through the Locks in the less saline lens, or (iii) fish were swimming about in pseudo-random movements that were directed on average in the upstream direction. The most notable difference in 2004 and 2005 from previous years, however, is that most (5 of 6) occurrences of recycling occurred within 24 hours. All six cases listed in Table 3-6 occurred when near-surface water temperatures were around 17ºC, which is above the approximate thermal preference level of 15ºC discussed in

Section 4.2. It is possible that the short recycling time reflected a response to elevated temperatures in the LWSC compared with downstream of the Locks.

4.3.3 Suggested Changes in Operations

Two changes to flume operations were suggested by data collected through 2003 (DeVries et al. 2005):

- Shutting off the flumes at night; and
- Shutting off the flumes when some temperature threshold is reached in the LWSC.

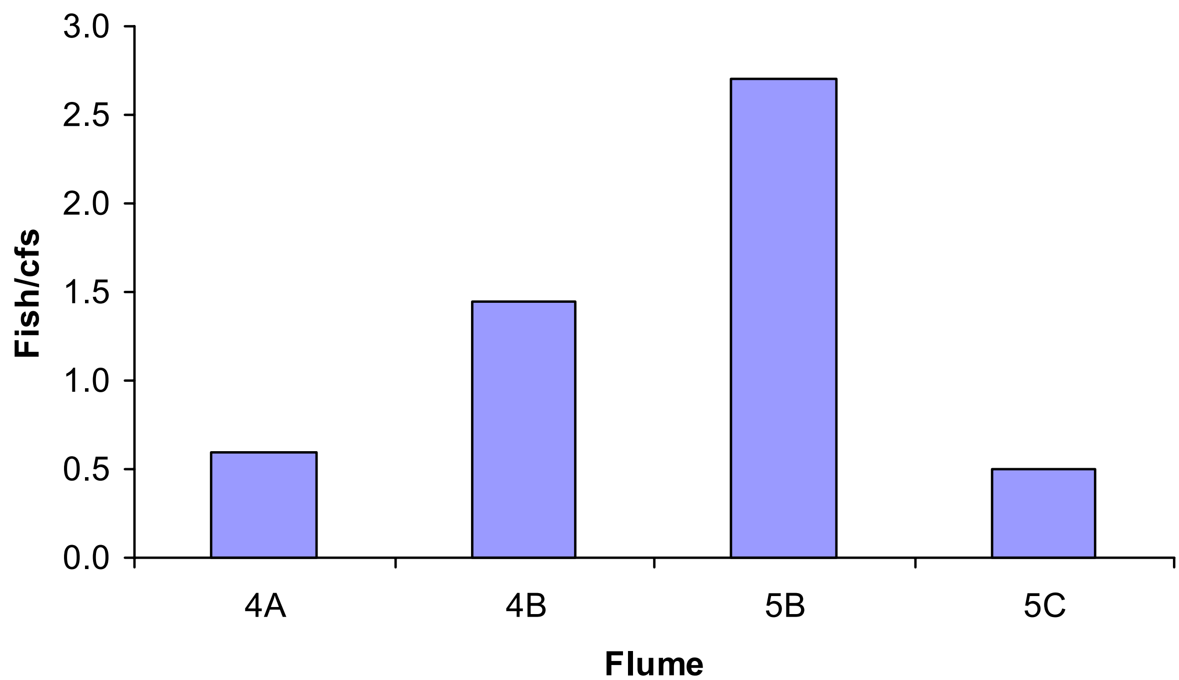


Figure 4-6. Number of all PIT tagged Chinook and coho salmon passing through each flume on 15 days total, normalized to unit discharge during the 2005 Lake Washington PIT tag study.

The 2005 small lock experiments suggest that the first option is reasonable from a salmon passage perspective because smolts appear to sound at night and thus only respond significantly to flume flows during daylight hours. Shutting the flumes down at night helps address water conservation needs for improving smolt passage at the Locks, a significant problem identified by USACE (1998), by allowing storage of water in the lake system to keep the flumes open for longer in the outmigration season.

The second change suggested by the collective studies is that the flumes could potentially be shut down for the season when surface water temperatures in the LWSC in the vicinity of the Locks reach 19ºC, 20ºC, or 21ºC (DeVries et al. 2005; DeVries and Hendrix 2005). The route of passage is hypothesized to shift to deeper alternatives, with few fish using the flumes after that temperature threshold is reached. As described earlier, the 2004 data suggest that the threshold could potentially be higher in years when water temperatures are warmer in April and May than normal if smolts do indeed acclimate to some extent. This effect needs to be studied in greater depth if management decisions are to be made accordingly.

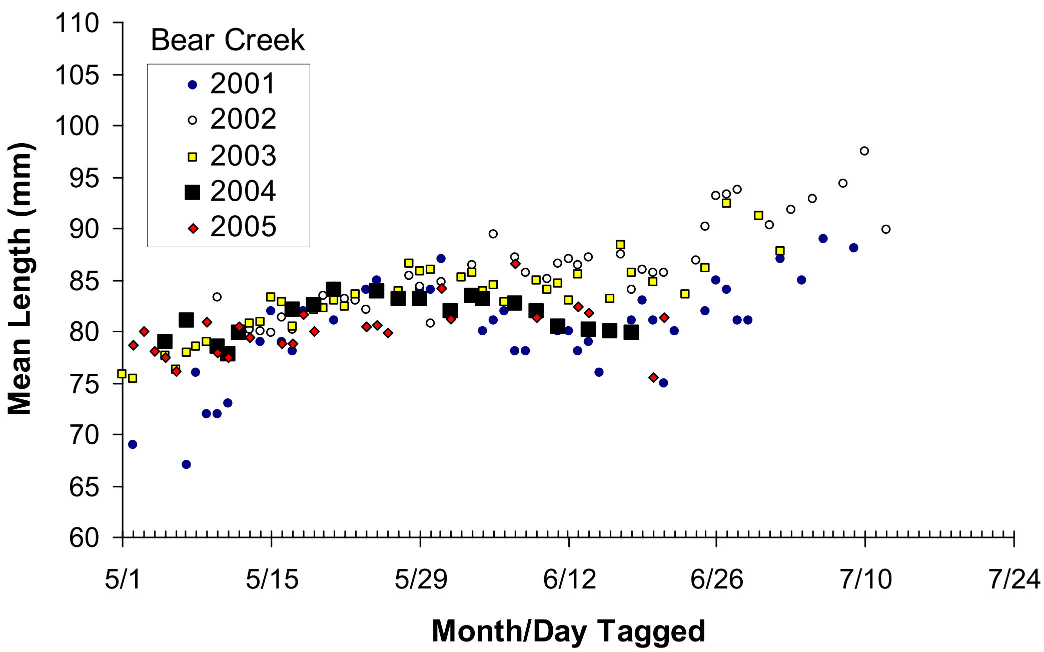
4.4 SYNOPSIS OF OTHER BEHAVIORAL CHARACTERISTICS

4.4.1 Size-Dependent Influences

Lengths of natural origin Chinook generally increased in the smolt trap catches as the 2004 and 2005 migration seasons progressed in the Cedar River (Figures 3-10, 3-11), but not Bear Creek (Figures 3-8, 3-9). Compared with previous years, mean lengths in the Cedar River during May were greater in 2004 and 2005 than in 2001-2003 (Figure 4-7). Lengths in Bear Creek were more similar over all years, with the exception that length increases were not apparent during the 2004 and 2005 studies. These trends may reflect warmer early spring water temperatures in both stream systems in 2004 and 2005 (Figure 4-4), which would tend to accelerate growth. The moderating effect of cool groundwater, especially in the Cottage Lake Creek sub-basin, could have resulted in the subsequent reduced rate of increase in mean lengths seen in the Bear Creek Chinook tagged in May, consistent with previous years' data. The Chinook length data for the Bear Creek trap may reflect a set of distinct stocks within the basin. Conversely, mean lengths of Chinook in the Cedar River generally increased steadily over the outmigration season, reflecting a more homogeneous stock (Figure 4-7).

4.4.2 Lunar Phase and Passage Timing

As noted in Section 3.4, the relation between lunar phase and the initiation of the main passage period for Chinook was not as strong in 2004 and 2005 as in previous years when passage at the



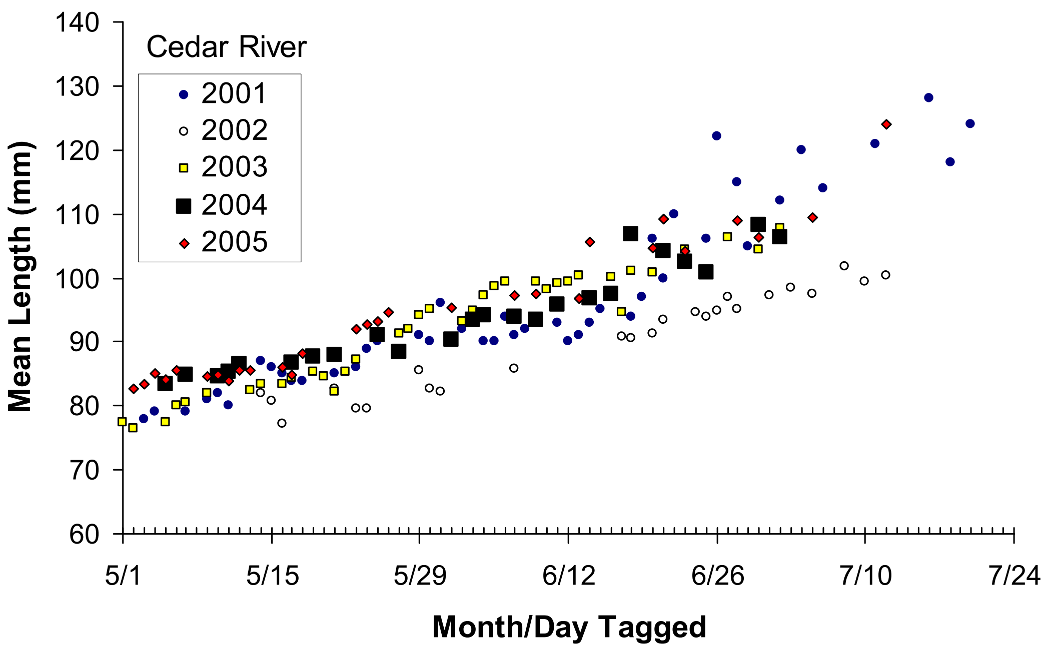


Figure 4-7. Temporal variation in mean lengths of Chinook caught, PIT tagged, and released in Bear Creek and the Cedar River, 2001-2005 Lake Washington GI studies.

Locks became substantial within a few days of the date that the moon was at apogee (farthest from the earth; DeVries et al. 2004). Chinook passage timing was earlier in 2004 than in 2000 when apogee occurred around the same dates (Figure 3-17). This suggested that the apparent connection between moon location relative to the earth and passage timing of Chinook salmon may have been influenced by other environmental factors. In particular, water temperatures in Bear Creek were generally warmer earlier in the outmigration season in 2004 and 2005 than in previous years (Figure 4-4). This observation leads to a hypothesis that water temperature may have a subtle influence on passage and migration behavior, where water temperature overrides hypothesized lunar gravitation cues on passage timing at the Locks in years with early warming. This is not inconsistent with the observation that larger bodied smolts may exhibit a weaker response than smaller fish (DeVries et al. 2004; DeVries et al. 2005), if growth rates were faster in 2004 and 2005 in response to earlier elevated temperatures.

4.4.3 Travel Times to the Locks

It was seen in DeVries et al. (2005) that migration rates for each species varied between stocks and years, where travel time did not consistently reflect travel distance, water temperatures, or location. Travel time distributions in 2004 and 2005 were generally intermediate to other years, but no clear pattern was evident (Figures 4-8, 4-9). For example, Chinook tagged in the Cedar River in 2004 and 2002 took about the same time to reach and pass the Locks, even though water temperatures were generally cooler in 2002 and warmer in 2004 (Figure 4-8). A different trend was seen in Bear Creek, where the relative positions of the travel time distributions did not reflect consistently the relative differences in water temperatures seen in 2002, 2003, 2004, and 2005. Tributary instream flows were highest of the four years in 2002, whereas flows in 2003 were lowest on record in some streams (e.g., Issaquah Creek; USGS data), and June surface water temperatures in the LWSC were generally coolest in 2002 and warmest in 2003 (Figure 4-3). Nonetheless, Bear Creek Chinook from both years exhibited similar travel time distributions. In addition, the travel time distributions for 2001 and 2005, when apogee occurred around the same date, were comparable for all three main release locations (Figure 4-8), suggesting a lunar gravitation influence on migration rate similar to that seen for passage at the Locks (DeVries et al. 2004). Regression slopes of travel speeds vs. Julian day for Bear Creek and Cedar River Chinook and coho were generally significantly different from zero ($p < 0.05$; exceptions were Bear Creek Chinook in 2004, Cedar River Chinook in 2002, and Bear Creek coho in 2001), but there were no consistent trends evident in regression lines across years, species, and stocks. The variation seen in travel times and migration rates over the six years of study thus appear to reflect a complicated interaction between many environmental cues and other factors including water temperature, flow, lunar phase, and release location.

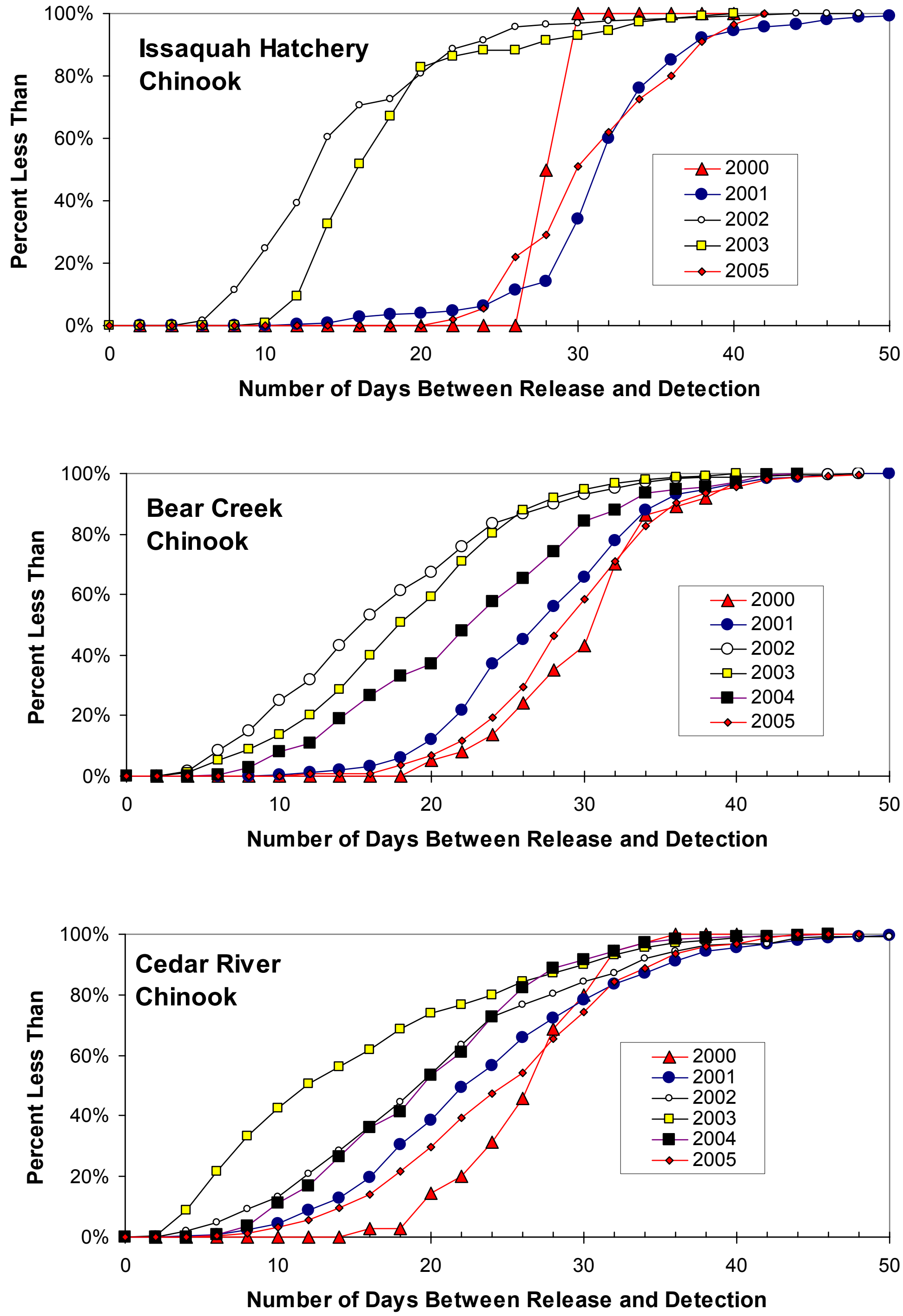
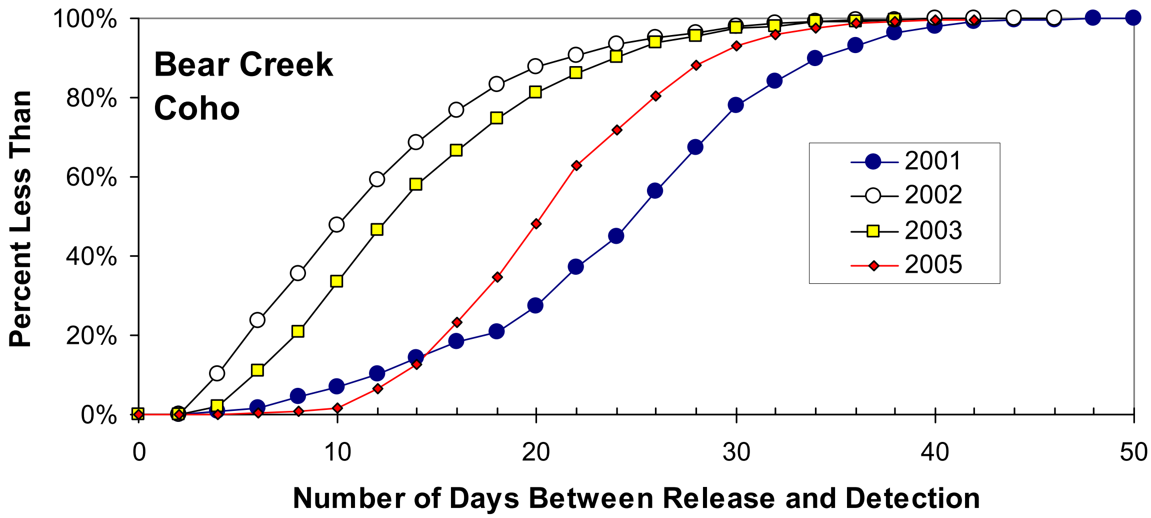


Figure 4-8. Between-year variation in travel time of tributary and hatchery Chinook salmon as they migrate through the Lake Washington system to the Locks, Lake Washington GI Study.



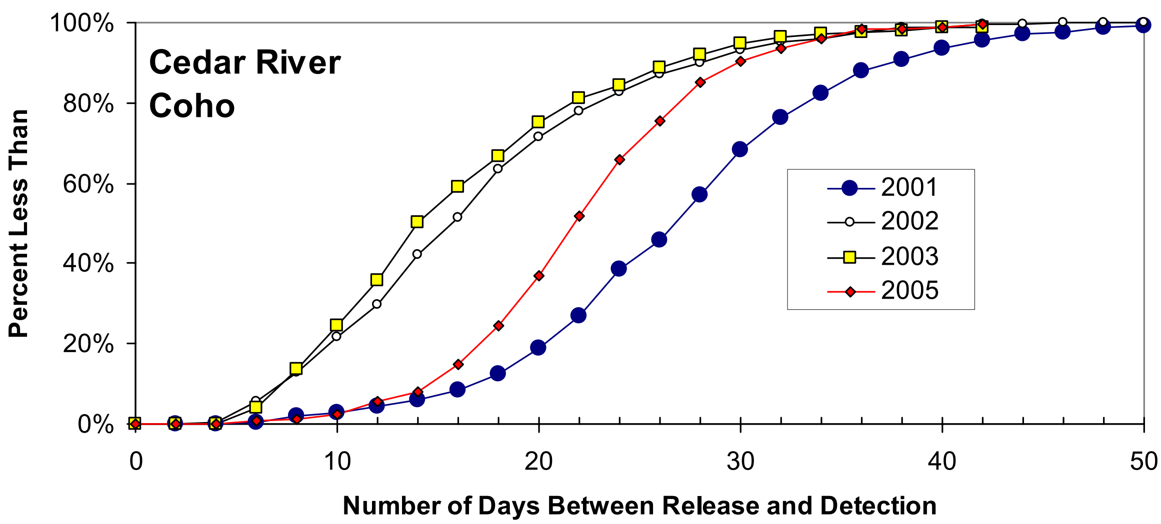


Figure 4-9. Between-year variation in travel time of tributary coho salmon as they migrate through the Lake Washington system to the Locks, Lake Washington GI Study.

4.4.4 Shoreline Affinity Behavior

The 2005 data provide further corroboration of the hypothesis that outmigrant Chinook exhibit an affinity to lake shorelines. As in previous years, hatchery Chinook began showing up in Cedar River trap catches in 2004 and 2005 several weeks after their release. In 2004, the first was caught on June 1, 21 days after release into Issaquah Creek (Seiler et al. 2005). In 2005, the first was caught on June 14, 29 days after release into Issaquah Creek. According to the median travel speed for Issaquah Hatchery Chinook PIT tagged in 2005 (~2.6 km/day) and approximate distance including following the eastern shoreline of Lake Washington (~88 km), fish would be expected on average to arrive at the trap location 34 days after release, on or about June 19, 2005. The catches of hatchery Chinook smolts in the Cedar River trap in 2005 were thus consistent with a shoreline affinity hypothesis, corresponding to fish that turned left instead of right at the mouth of the Sammamish River.

4.5 SUMMARY

The following primary observations or hypotheses were made based on the 2000-2005 PIT tag study results presented here and in DeVries et al. (2005). They represent a concise recap of the best available information to date. The original summary in DeVries et al. (2005) is repeated below. Modifications and additions based on the additional 2004 and 2005 results are presented in italics. The observations below do not represent all findings based on the PIT tag data but may be the most noteworthy and provide guidance for focusing future questions. Specific, supporting details and other observations may be found in the series of PIT tagging reports produced under the Lake Washington GI.

4.5.1 Survival Estimation

- Survival of Chinook smolts appears to be high (probably close to 100%) in the LWSC during most of the outmigration season, but may decrease when water temperatures exceed somewhere above about 15-19ºC.
- Survival estimates in most cases have been of low precision (most 95% confidence intervals spanned more than one quarter of the estimate in magnitude, and many were as big as the estimate itself), and have been complicated by warming water temperatures later in the season.
- PIT tag survival estimates were influenced, at minimum, by proportion using flumes, travel time distributions, residualism, and various sources of natural mortality.

- There is subtle but inconclusive evidence of a potential effect of fish size on detection rate at the Locks later in the outmigration season, where larger Chinook smolts may have a slightly greater probability of passing through the flumes than smaller smolts; however, differences in length frequency distributions of all fish tagged vs. all fish detected were not significantly different in a consistent manner for all Chinook stocks.

4.5.2 Migration Behavior in Freshwater

- Average migration rates vary spatially, seasonally, and annually. Travel times to the Locks generally, but not consistently, reflect travel distance and vary within (annually) and between (spatially) stocks.
- *Migration rates do not consistently reflect the influence of any one environmental variable. Water temperature, stream flow, lunar phase, and release location may all interact in their effect on distributions of travel time to the Locks.*
- Average Chinook smolt migration rates tend to increase as the outmigration season progresses; coho rates are steadier.
- Chinook smolts appear to move along lake shorelines while outmigrating.
- Chinook smolts may mix cross-channel in the LWSC in the Montlake Cut, Fremont Cut, and Locks forebay area.
- Sockeye smolts spend least time in the LWSC (in general, most within one week), Chinook smolts the most (most within three to four weeks); coho are intermediate (most within two weeks).
- Sockeye salmon smolts passing the Locks represent two age classes (young of year and yearlings).
- Yearlings of all three salmon species and University of Washington young of year Chinook generally pass through the Locks earlier than young of year Chinook and sockeye smolts; the distinction may reflect fish size.
- Chinook and coho salmon smolts have also been found to residualize in the system, with rates ranging between 0.09% and *0.45%. Residualization of Chinook smolts appears to be greater in years with warmer temperatures during the outmigration season, and may be greater for Bear Creek than Cedar River Chinook. It is possible a larger fraction residualizes where these percentages inherently reflect mortality rates for juveniles remaining an extra year or two in the system.*

- Smolts may have a higher probability of residualizing in Lake Washington as the outmigration season progresses and surface water temperatures warm. The Montlake Cut *and Sammamish River* may pose thermal barriers later in the season. *Residualized fish tend to be later migrants, and are among the first to pass the Locks the following year(s).*
- *The effects of temperature seen for PIT tagged salmon migration behavior suggests that long term, earlier warming of Lake Washington and the LWSC might be partially linked to increasing residualization of steelhead, and decreases in adult returns.*

4.5.3 Passage at the Locks and Lock Operations

- The proportion of fish using the flumes relative to other routes through the Locks is initially approximately steady, can be on the order of 40%-80% when all four flumes are open, and then decreases over time. *In years with warmer water temperatures, the proportion using the flumes can initially be on the order of 20%-40%, although this may also reflect reduced water availability and number of flumes being open.* The seasonal decrease appears to reflect warming surface water temperatures in the LWSC, decreasing flume flow rate, and a hypothesized vertical shift by outmigrants to deeper, cooler water. *However, the PIT tag data cannot be used to discern the relative importance of temperature effects on migration depth (avoidance) vs. growth rate and smoltification (residualization).*
- Late in the outmigration season, Chinook smolts would be more likely to pass through the deeper, large lock.
- Relatively few smolts pass through the flumes during the night; the greatest passage rates generally occur near dawn, which may reflect an accumulation of smolts arriving overnight.
- Passage rates through the flumes increase during small and large lock fillings compared with between-fill periods.
- Diurnal patterns in passage rates through the flumes *may reflect daily vertical migrations in the water column, not frequency of small lock operations. Smolts may move to deeper water during night-time hours where they would not be available to pass through the flumes. Hence, there appears to be a biological basis for shutting off the flumes at night to conserve water that can then be used to extend the overall period the flumes are operational as well as provide water for other beneficial uses such as the saltwater drain*.

- The number of PIT tagged smolts passing through the flumes increases with total flow rate through the flumes, on average, when water temperature is not influencing passage behavior.
- The small flume (4A) generally passes small numbers of smolts when operated alone in Gate 4.
- Passage rates may increase in a flume (other than the small flume) when its companion flume in the gate is shut off (i.e., a compensatory passage rate effect may exist).
- Water savings can most likely be achieved by (i) turning off the flumes at night, and (ii) shutting down the flumes when surface water temperatures regularly exceed some (to be determined) threshold value between 19-21°C, when flume passage rates become minor *(e.g., less than 5 PIT tagged fish/day). The magnitude of the threshold temperature may be a degree or so higher in years with warmer early spring water temperatures than in other years, reflecting possible earlier acclimation to some extent by Chinook smolts.*
- Some Chinook and coho smolts recycle upstream through the large or small lock with observed rates ranging between 0.06% and 0.70% for fish originating in tributaries; no sockeye smolts have been observed to recycle. The time between repeat passage decreases as the outmigration season progresses*, and may be shorter overall in years with warmer spring water temperatures*.
- Chinook released into the LWSC from the University of Washington Hatchery and the Issaquah Hatchery exhibited the strongest recycling behavior.
- *Passage timing of Issaquah Hatchery Chinook appears to be fairly similar to that of Bear Creek Chinook. Cedar River Chinook passage timing may differ from the other two stocks' behavior, however.*
- Passage/estuarine entry of young of year Chinook and sockeye smolts appears to be initiated in response to lunar apogee or quarter moon. *This phenomenon may be moderated by warmer water temperatures occurring early in the spring.*

4.5.4 Estuarine Transition

- Smolts may spend little time (e.g., less than an hour) in the freshwater lens immediately below the locks.
- Sockeye smolts appear to spend least time in the inner bay, Chinook smolts the most; coho may be intermediate.

- Hatchery Chinook may reside longer in the inner bay below the Locks than natural origin Chinook, possibly reflecting an abundant food supply from the LWSC.

4.6 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 (Italics are again used to denote modifications based on the 2004 and 2005 results):

- Structural vibration and surging problems continue to result in decreased detection efficiency in the large flumes (4B and 5B), albeit to a lesser extent in 2004 and 2005. 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. *The use of supertags appears to compensate for this problem somewhat where detection efficiency in the two large flumes is increased substantially.*
- Calibration testing should continue with both tagged fish and the "fish sticks" to further evaluate stick performance relative to using live fish because results to date indicate large variability remains when using fish sticks, but use of live fish is more expensive. Stick tests should be done frequently to identify the potential need for retuning of selected tunnel reader coils. Additional tests would be useful comparing a prototype approach *applied by the author in 2005* involving a string of sticks introduced to the flumes and recovered at the outlet using rod and reel and a long gaff. If effective, the method would eliminate the need for a boat to recover sticks downstream, thereby reducing effort and cost of calibration testing.
- Limited calibration test results in 2002 and 2003 indicate that live, tagged, hatchery 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. Recycling of large numbers of calibration test fish in 2003 indicate that the method may not result in significant harm to the specimens. 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 four years of data that more than one PIT tagged fish arriving from upstream passes through a flume at any moment in time and precludes detection of another tag).

- Future tag purchases should be of the newer "supertag" type only, given their greater detection rates at the flumes than of standard tags.
- Fish should be held at the Metro Laboratory primarily for calibration testing and releases at that location. Holding capacity could be increased in the future (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 experienced in previous years as water temperatures warm in the LWSC.
- Future tagging of fish at the Issaquah Hatchery is recommended only if fish can be released in smaller groups over the course of the migration season to better evaluate survival, migration, and passage characteristics of fish originating in Issaquah Creek. The one-time release at the hatchery each year in 2001-2003 and 2005 has proven useful, but it is unlikely extensive, additional, useful information can be derived from future such releases beyond identifying long term trends.
- Efforts in 2003 indicated that transporting hatchery fish from Issaquah Hatchery to different release locations in Lake Washington tributaries and tagging them onsite prior to release was a difficult endeavor as water temperatures warmed (see report in Appendix A), so continued tagging of fish at the location of capture remains recommended as the most direct means for addressing survival, migration, and passage characteristics. Ideally, PIT tagging should occur at a number of locations along the migration route to evaluate differential survival at different locations, but only when Lake Washington and LWSC water temperatures are forecasted to be average or cooler in the month of June. Future studies should be set up with the contingency that if the spring water temperatures are predicted to be high, that the study be postponed until the following year(s) when water temperature are more conducive to post-tagging survival in June. 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, and 2003 when there were likely water temperature-related post-tagging mortality 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.
- Beach seining below the Locks to recapture PIT tagged fish is not recommended at this time for purposes of estimating proportions using the flumes. Significant mortality and injury could be expected.
- Sampling could conceivably 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.

- Recently installed adult PIT tag readers in the fish ladder will make it possible in future years to scan for PIT tagged smolts, to determine the proportion of fish using that route. *See Appendices C and D for the 2004 and 2005 data reports. Continued, long term monitoring involving juvenile PIT tagging would provide valuable data based on adult returns*.

- If tagging is performed in the LWSC, each day's collection of tagged fish should be divided in two and each group released near the north and south shorelines, to continue evaluating shoreline affinity and proportion using the smolt flumes. Alternatively, hatchery Chinook could be held at the Metro Laboratory and released at that location at a minimum. Doing this over the passage season would facilitate an 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 lock operations on passage rates should *continue to be* investigated by alternating between a normal daily lock opening pattern, when each lock is 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. *This additional testing is needed to further evaluate the hypothesis that daily vertical migrations of smolts in the forebay are the cause of diurnal passage behavior in the flumes*.

- 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 beach seine samples were experiencing stress from rapid transition to saltwater because they were not completely ready to do.

- Other studies that would be informative and potentially lead to specific recovery-related actions include:

  - Determining proportion of fish migrating left or right upon exiting the Sammamish and Cedar rivers. This could be accomplished by standard capture-recapture techniques.
  - Evaluation of the hypothesis that migration depth changes in both Lake Washington and the LWSC with increasing water temperature over the course of the migration season. This would help identify more conclusively the relations between water temperature, habitat use during the outmigration, residualization, survival, and passage routes. In addition the results could be evaluated in the context of predator depth and feeding intensity to determine if there is habitat segregation and when predation effects are greater. Migration depth of natural Chinook could conceivably be addressed either by using smaller microacoustic tags than are currently available, or by experimental designs involving diving surveys. *Research is currently underway using microacoustic tags that may shed light on this (R. Tabor, USFWS, and K. Kurko, Seattle Public Utilities, personal communication)*.

- A small number of tagged fish were detected at the Locks each year that were not in the tagging files. Most appeared to have been missed during scanning at time of tagging. It was possible to resolve where and when they were tagged in most cases by noting tag packaging identification numbers during tagging, and identifying the bag that a tag originated from. However, there were also a small number of tags with numbers not part of the study sequence. Some were identifiable in the PTAGIS database and appeared to have been leftover tags from the Columbia River and were assumed to have been used inadvertently by NMFS in this study during 2000 or 2001. Others were not in the database and were not part of the tag sequence from the GI study; they were considered "mystery" tags, and may have been from another study. These occurrences are mentioned mainly to alert researchers using PIT tags of the possibility for missed tags in any study, and to recommend that they register their tags with the PTAGIS database in Portland, Oregon.

- *As long as funding is available to run the Bear Creek and Cedar River screw traps, they could continue to be used to tag fish if tags are made available (G. Volkhardt, WDFW, personal communication). However, future funding is uncertain, especially for Bear Creek. Future funding is also uncertain for connecting, calibrating, and maintaining the tunnel readers in the smolt flumes. A commitment would need to be made by the WRIA 8 (Lake Washington basin) water and fisheries management community to continue supporting PIT tagging efforts. Benefits include an improved understanding of the various results and conclusions reported here, which will lead to improved water management, Locks operations, and provide an improved understanding of the magnitude and ramifications of environmental factors including the water temperature problem in particular.*

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APPENDIX A

2004 and 2005 WDFW PIT Tagging Activity Summary Reports

Lake Washington Watershed PIT Tagging, 2004

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Methods

Downstream migrants captured at the Cedar River and Bear Creek rotary screw traps were PIT tagged from late April through early July 2004. The tagging station was set up daily on the banks at both locations: on the cement wall at Cedar River just upstream of the Logan Street Bridge and on the railroad trestle at Bear Creek just downstream of the Redmond Way Bridge. Healthy Chinook smolts 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. Tags were 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 tagged. Fish were held for recovery observation before being released.

Results

Tagging of Chinook smolts began on May 5 at both sites and continued through June 18 at Bear Creek and July 2 at the Cedar River. Tagging occurred Mondays, Wednesdays, and Fridays during the morning hours. Fish were held in live wells from the previous morning to increase the number of fish tagged.

At the Cedar River we tagged 2,191 Chinook smolts: six hatchery and 2,185 wild (Table 1). We tagged a total of 1,512 Chinook throughout the season at Bear Creek (Table 1). Mortality and tag loss is estimated to be less than 1% based on testing in 2001 and 2002.

Table 1. Smolts PIT tagged at Cedar River and Bear Creek screw traps, 2004.

Date Tagged	Cedar River Wild	Cedar River Ad-Marked	Bear Creek
05/05/04	39		92
05/07/04	90		107
05/10/04	168		50
05/11/04	65		50
05/12/04	96		100
05/17/04	200		109
05/19/04	24		130
05/21/04	50		61
05/25/04	100		99
05/27/04	190		150
06/01/04	139		74
06/03/04	41		96
06/04/04	28		37
06/07/04	142		118
06/09/04	112		69
06/11/04	205		32
06/14/04	116		50
06/16/04	104		29
06/18/04	24		20
06/21/04	83		0
06/23/04	53		0
06/25/04	74		0
06/30/04	29	4	0
07/02/04	13	2	0
Total	2,185	6	1,512

Lake Washington Watershed PIT Tagging, 2005

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October 2005

Methods

Downstream migrants captured at the Cedar River and Bear Creek rotary screw traps were PIT tagged from early May through mid July 2005. The tagging station was set up daily on the banks at both locations: on the cement wall at Cedar River just upstream of the Logan Street Bridge and on the railroad trestle at Bear Creek just downstream of the Redmond Way Bridge. Healthy Chinook smolts in excess of 70 mm were tagged. Smolts with visible physical injuries such as descaling greater than 20%, parasites, or 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. Tags were 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, or wounds resulting from our handling were recorded for each fish tagged. Fish were held for less than one hour for recovery observation before being released.

Results

Tagging of Chinook smolts began on May 2 at both sites and continued through June 21 at Bear Creek and July 12 at the Cedar River. Early in the season when fish were abundant tagging occurred almost every morning. Later in the season as migration slowed, tagging occurred two to three times a week. Fish were held in live wells from the previous morning to increase the number of fish tagged.

At the Cedar River we tagged 2,140 Chinook smolts: 63 hatchery and 2,077 naturally produced (Table 1). In addition, 1,277 naturally produced coho smolts and 11 naturally produced steelhead smolts were also tagged. A total of 1,424 naturally produced Chinook and 1,214 naturally produced coho were tagged at Bear Creek throughout the season (Table 1). Mortality and tag loss is estimated to be less than 1% based on results of holding groups of tagged smolts for 24 hours in 2001 and 2002.

Table 2. Chinook migrants PIT tagged at Cedar River and Bear Creek screw traps, 2005.

Date Tagged	Cedar River				Bear Creek	
	Wild Chinook	Ad-Marked Chinook	Wild Coho	Steelhead	Wild Chinook	Wild Coho
05/02/2005	52		114		76	100
05/03/2005	64		43		88	100
05/04/2005	37		102		136	100
05/05/2005	77		143		99	100
05/06/2005	97		116		100	100
05/09/2005	104		60		12	95
05/10/2005	203		101	6	79	103
05/11/2005	45		68		20	106
05/12/2005	42		81	1	31	51
05/13/2005	109		89	2	53	50
05/16/2005	100		101		53	50
05/17/2005	59		83		61	50
05/18/2005	27		32		21	50
05/19/2005					62	51
05/23/2005	99		31			
05/24/2005	85		30		46	47
05/25/2005	100			1	78	
05/26/2005	44		24	1	49	31
05/31/2005	55		22		109	14
06/01/2005	120		16		68	6
06/04/2005	143		17		17	2
06/07/2005	96				68	
06/09/2005	139		12		51	4
06/13/2005	19				11	2
06/14/2005	29	29			10	2
06/20/2005	21	8			15	
06/21/2005	18	9			11	
06/23/2005	49	9				
06/28/2005	17	1				
06/30/2005	16	5				
07/05/2005	3					
07/07/2005	7	1				
07/12/2005	1	1				
Total	2,077	63	1,285	11	1,424	1,214

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APPENDIX B

2004 and 2005 PIT Tagging
Release and Detection Summary Tables

Table B-1. Summary of tagging numbers, 2004 PIT tag study.

Release Location	Date	Time	Numbers Released: Chinook Hatchery	Chinook Natural	Coho Hatchery	Coho Natural	Sockeye Natural	Steelhead Natural	TAGGING FILE
Bear Creek	5/5/04	10:04	0	92	0	0	0	0	CSM04126.BR
	5/7/04	10:52	0	107	0	0	0	0	CSM04128.BR
	5/10/04	10:23	0	50	0	0	0	0	CSM04131.BR
	5/11/04	7:30	0	50	0	0	0	0	CSM04132.BR
	5/12/04	9:56	0	100	0	0	0	0	CSM04133.BR
	5/17/04	11:22	0	109	0	0	0	0	CSM04138.BR
	5/19/04	9:02	0	130	0	0	0	0	CSM04140.BR
	5/21/04	9:20	0	61	0	0	0	0	CSM04142.BR
	5/25/04	7:33	0	99	0	0	0	0	CSM04146.BR
	5/27/04	10:37	0	150	0	0	0	0	CSM04148.BR
	5/29/04	10:07	0	39	0	0	0	0	CSM04150.BR
	6/1/04	6:44	0	74	0	0	0	0	CSM04153.BR
	6/3/04	9:28	0	96	0	0	0	0	CSM04155.BR
	6/4/04	7:29	0	37	0	0	0	0	CSM04156.BR
	6/7/04	9:24	0	118	0	0	0	0	CSM04159.BR
	6/9/04	6:56	0	69	0	0	0	0	CSM04161.BR
	6/11/04	6:58	0	32	0	0	0	0	CSM04163.BR
	6/14/04	7:55	0	50	0	0	0	0	CSM04166.BR
	6/16/04	7:13	0	29	0	0	0	0	CSM04168.BR
	6/18/04	7:04	0	20	0	0	0	0	CSM04170.BR
Cedar River	5/5/04	7:16	0	39	0	0	0	0	CSM04126.CDR
	5/7/04	7:31	0	90	0	0	0	0	CSM04128.CDR
	5/10/04	8:04	0	168	0	0	0	0	CSM04131.CDR
	5/11/04	10:03	0	65	0	0	0	0	CSM04132.CDR
	5/12/04	7:25	0	96	0	0	0	0	CSM04133.CDR
	5/17/04	8:37	0	109	0	0	0	0	CSM04138.CD2
	5/17/04	8:02	0	91	0	0	0	0	CSM04138.CDR
	5/19/04	7:15	0	24	0	0	0	0	CSM04140.CDR
	5/21/04	7:09	0	50	0	0	0	0	CSM04142.CDR
	5/25/04	9:49	0	100	0	0	0	0	CSM04146.CDR
	5/27/04	7:19	0	190	0	0	0	0	CSM04148.CDR
	6/1/04	8:25	0	139	0	0	0	0	CSM04153.CDR
	6/3/04	7:21	0	41	0	0	0	0	CSM04155.CDR
	6/4/04	9:08	0	28	0	0	0	0	CSM04156.CDR
	6/7/04	7:08	0	142	0	0	0	0	CSM04159.CDR
	6/9/04	8:24	0	112	0	0	0	0	CSM04161.CDR
	6/11/04	8:19	0	205	0	0	0	0	CSM04163.CDR

Table B-1. Summary of tagging numbers, 2004 PIT tag study.

Release Location	Date	Time	Numbers Released: Chinook Hatchery	Chinook Natural	Coho Hatchery	Coho Natural	Sockeye Natural	Steelhead Natural	TAGGING FILE
Cedar River	6/14/04	9:31	0	116	0	0	0	0	CSM04166.CDR
	6/16/04	8:47	0	104	0	0	0	0	CSM04168.CDR
	6/18/04	8:45	0	24	0	0	0	0	CSM04170.CDR
	6/21/04	7:17	0	83	0	0	0	0	CSM04173.CDR
	6/23/04	7:20	0	53	0	0	0	0	CSM04175.CDR
	6/25/04	7:43	0	74	0	0	0	0	CSM04177.CDR
	6/30/04	7:27	2	29	0	0	0	0	CSM04182.CDR
	7/2/04	6:52	4	13	0	0	0	0	CSM04184.CDR

Table B-2. Summary of tagging numbers, 2005 PIT tag study.

Release Location	Date	Time	Numbers Released: Chinook Hatchery	Chinook Natural	Coho Hatchery	Coho Natural	Sockeye Natural	Steelhead Natural	TAGGING FILE
Issaquah Hatchery	5/16/05	10:00	409	0	0	0	0	0	L_F05117.ISS
Bear Creek	5/2/05	10:04	0	76	0	100	0	0	L_F05122.BR
	5/3/05	10:52	0	88	0	100	0	0	L_F05123.BR
	5/4/05	10:23	0	136	0	100	0	0	L_F05124.BR
	5/5/05	7:30	0	100	0	100	0	0	L_F05125.BR
	5/6/05	9:56	0	100	0	100	0	0	L_F05126.BR
	5/9/05	11:22	0	12	0	95	0	0	L_F05129.BR
	5/10/05	9:02	0	79	0	100	0	0	L_F05130.BR
	5/11/05	9:20	0	20	0	105	0	0	L_F05131.BR
	5/12/05	7:33	0	31	0	51	0	0	L_F05132.BR
	5/13/05	10:37	0	53	0	50	0	0	L_F05133.BR
	5/16/05	10:07	0	53	0	50	0	0	L_F05136.BR
	5/17/05	6:44	0	61	0	50	0	0	L_F05137.BR
	5/18/05	9:28	0	21	0	49	0	0	L_F05138.BR
	5/19/05	7:29	0	62	0	51	0	0	L_F05139.BR
	5/24/05	9:24	0	46	0	47	0	0	L_F05144.BR
	5/25/05	6:56	0	78	0	0	0	0	L_F05145.BR
	5/26/05	6:58	0	49	0	29	0	0	L_F05146.BR
	5/31/05	7:55	0	109	0	14	0	0	L_F05151.BR
	6/1/05	7:13	0	68	0	6	0	0	L_F05152.BR
	6/4/05	7:04	0	17	0	2	0	0	L_F05155.BR
	6/7/05	11:44	0	67	0	0	0	0	L_F05158.BR
	6/9/05	11:02	0	51	0	4	0	0	L_F05160.BR
	6/13/05	10:40	0	11	0	2	0	0	L_F05164.BR
	6/14/05	7:13	0	10	0	2	0	0	L_F05165.BR
	6/20/05	9:38	0	15	0	0	0	0	L_F05171.BR
	6/21/05	9:05	0	11	0	0	0	0	L_F05172.BR
Cedar River	5/2/05	7:44	0	52	0	97	0	0	L_F05122.CDR
	5/3/05	7:30	0	64	0	43	0	0	L_F05123.CDR
	5/4/05	12:34	0	36	0	102	0	0	L_F05124.CDR
	5/5/05	7:24	0	77	0	141	0	0	L_F05125.CDR
	5/6/05	9:33	0	96	0	116	0	0	L_F05126.CDR
	5/9/05	7:46	0	104	0	60	0	0	L_F05129.CDR
	5/10/05	7:21	0	203	0	101	0	6	L_F05130.CDR
	5/11/05	8:02	0	45	0	68	0	0	L_F05131.CDR
	5/12/05	7:27	0	42	0	81	0	1	L_F05132.CDR
	5/13/05	9:31	0	109	0	89	0	2	L_F05133.CDR

Table B-2. Summary of tagging numbers, 2005 PIT tag study.

			Numbers Released						
Release			Chinook		Coho		Sockeye	Steelhead	
Location	Date	Time	Hatchery	Natural	Hatchery	Natural	Natural	Natural	TAGGING FILE
Cedar River	5/16/05	7:34	0	100	0	101	0	0	L_F05136.CDR
	5/17/05	7:41	0	59	0	83	0	0	L_F05137.CDR
	5/18/05	10:14	0	27	0	32	0	0	L_F05138.CDR
	5/23/05	7:44	0	99	0	31	0	0	L_F05143.CDR
	5/24/05	8:25	0	85	0	30	0	0	L_F05144.CDR
	5/25/05	11:40	0	100	0	0	0	1	L_F05145.CDR
	5/26/05	7:52	0	44	0	23	0	1	L_F05146.CDR
	5/31/05	7:36	0	55	0	22	0	0	L_F05151.CDR
	6/1/05	8:44	0	120	0	16	0	0	L_F05152.CDR
	6/4/05	8:43	0	143	0	17	0	0	L_F05155.CDR
	6/7/05	7:52	0	96	0	0	0	0	L_F05158.CDR
	6/9/05	7:44	0	139	0	12	0	0	L_F05160.CDR
	6/13/05	8:19	0	19	0	0	0	0	L_F05164.CDR
	6/14/05	8:30	29	29	0	0	0	0	L_F05165.CDR
	6/20/05	8:08	8	21	0	0	0	0	L_F05171.CDR
	6/21/05	7:30	9	18	0	0	1	0	L_F05172.CDR
	6/23/05	8:13	9	49	0	0	0	0	L_F05174.CDR
	6/28/05	7:24	1	17	0	0	0	0	L_F05179.CDR
	6/30/05	8:28	5	16	0	0	0	0	L_F05181.CDR
	7/5/05	8:18	0	3	0	0	0	0	L_F05186.CDR
	7/7/05	7:19	1	7	0	0	0	0	L_F05188.CDR
	7/12/05	10:05	1	1	0	0	0	0	L_F05193.CDR

Table B-3. Summary of Chinook salmon recapture numbers, 2004 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
CSM04126.BR	Bear Creek	5/5/04	0	0	0	0	12	9	3	2
CSM04128.BR		5/7/04	0	0	0	0	18	3	6	0
CSM04131.BR		5/10/04	0	0	0	0	6	4	2	0
CSM04132.BR		5/11/04	0	0	0	0	6	3	2	0
CSM04133.BR		5/12/04	0	0	0	0	13	8	9	0
CSM04138.BR		5/17/04	0	0	0	0	14	7	6	2
CSM04140.BR		5/19/04	0	0	0	0	19	7	4	2
CSM04142.BR		5/21/04	0	0	0	0	7	5	1	0
CSM04146.BR		5/25/04	0	0	0	0	10	5	1	0
CSM04148.BR		5/27/04	0	0	0	0	8	1	1	1
CSM04150.BR		5/29/04	0	0	0	0	2	0	0	0
CSM04153.BR		6/1/04	0	0	0	0	0	0	0	0
CSM04155.BR		6/3/04	0	0	0	0	0	0	1	1
CSM04156.BR		6/4/04	0	0	0	0	1	0	0	0
CSM04159.BR		6/7/04	0	0	0	0	3	0	1	1
CSM04161.BR		6/9/04	0	0	0	0	2	0	0	0
CSM04163.BR		6/11/04	0	0	0	0	0	1	0	0
CSM04166.BR		6/14/04	0	0	0	0	0	0	0	0
CSM04168.BR		6/16/04	0	0	0	0	1	0	0	0
CSM04170.BR		6/18/04	0	0	0	0	0	0	0	0
CSM04126.CDR	Cedar River	5/5/04	0	0	0	0	3	2	3	0
CSM04128.CDR		5/7/04	0	0	0	0	18	5	6	1
CSM04131.CDR		5/10/04	0	0	0	0	19	6	14	2
CSM04132.CDR		5/11/04	0	0	0	0	12	5	3	0
CSM04133.CDR		5/12/04	0	0	0	0	14	6	4	2
CSM04138.CDR		5/17/04	0	0	0	0	14	2	2	1
CSM04138.CD2		5/17/04	0	0	0	0	13	6	8	1
CSM04140.CDR		5/19/04	0	0	0	0	2	3	0	0
CSM04142.CDR		5/21/04	0	0	0	0	1	1	0	0
CSM04146.CDR		5/25/04	0	0	0	0	14	6	4	1
CSM04148.CDR		5/27/04	0	0	0	0	19	5	5	2
CSM04153.CDR		6/1/04	0	0	0	0	18	3	3	1
CSM04155.CDR		6/3/04	0	0	0	0	0	1	0	0
CSM04156.CDR		6/4/04	0	0	0	0	4	0	0	0
CSM04159.CDR		6/7/04	0	0	0	0	18	2	1	0
CSM04161.CDR		6/9/04	0	0	0	0	2	0	3	1
CSM04163.CDR		6/11/04	0	0	0	0	9	1	2	0

Table B-3. Summary of Chinook salmon recapture numbers, 2004 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
CSM04166.CDR	Cedar River	6/14/04	0	0	0	0	9	2	0	0
CSM04168.CDR		6/16/04	0	0	0	0	1	1	2	1
CSM04170.CDR		6/18/04	0	0	0	0	0	0	0	0
CSM04173.CDR		6/21/04	0	0	0	0	1	1	0	0
CSM04175.CDR		6/23/04	0	0	0	0	0	1	0	0
CSM04177.CDR		6/25/04	0	0	0	0	2	0	0	0
CSM04182.CDR		6/30/04	0	0	0	0	0	0	0	0
CSM04184.CDR		7/2/04	0	0	0	0	0	0	0	0

Table B-4. Summary of Chinook salmon recapture numbers, 2005 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
L_F05117.ISS	Issaquah Hatchery	5/16/05	1	23	13	19	0	0	0	0
L_F05122.BR	Bear Creek	5/2/05	0	0	0	0	1	8	2	15
L_F05123.BR		5/3/05	0	0	0	0	4	0	6	17
L_F05124.BR		5/4/05	0	0	0	0	1	14	13	14
L_F05125.BR		5/5/05	0	0	0	0	2	8	3	17
L_F05126.BR		5/6/05	0	0	0	0	1	5	6	12
L_F05129.BR		5/9/05	0	0	0	0	0	0	1	3
L_F05130.BR		5/10/05	0	0	0	0	1	4	4	15
L_F05131.BR		5/11/05	0	0	0	0	0	2	2	3
L_F05132.BR		5/12/05	0	0	0	0	0	4	2	7
L_F05133.BR		5/13/05	0	0	0	0	0	5	3	13
L_F05136.BR		5/16/05	0	0	0	0	0	4	3	8
L_F05137.BR		5/17/05	0	0	0	0	0	6	1	11
L_F05138.BR		5/18/05	0	0	0	0	0	0	2	1
L_F05139.BR		5/19/05	0	0	0	0	1	5	3	5
L_F05144.BR		5/24/05	0	0	0	0	0	5	3	6
L_F05145.BR		5/25/05	0	0	0	0	0	7	1	10
L_F05146.BR		5/26/05	0	0	0	0	0	4	1	0
L_F05151.BR		5/31/05	0	0	0	0	0	3	1	5
L_F05152.BR		6/1/05	0	0	0	0	0	3	1	2
L_F05155.BR		6/4/05	0	0	0	0	0	1	0	0
L_F05158.BR		6/7/05	0	0	0	0	0	0	0	0
L_F05160.BR		6/9/05	0	0	0	0	0	1	0	0
L_F05164.BR		6/13/05	0	0	0	0	0	0	0	0
L_F05165.BR		6/14/05	0	0	0	0	0	0	0	0
L_F05171.BR		6/20/05	0	0	0	0	0	0	0	0
L_F05172.BR		6/21/05	0	0	0	0	0	0	0	0
L_F05122.CDR	Cedar River	5/2/05	0	0	0	0	2	0	2	9
L_F05123.CDR		5/3/05	0	0	0	0	0	8	3	9
L_F05124.CDR		5/4/05	0	0	0	0	0	5	0	5
L_F05125.CDR		5/5/05	0	0	0	0	0	7	1	12
L_F05126.CDR		5/6/05	0	0	0	0	2	4	8	23
L_F05129.CDR		5/9/05	0	0	0	0	2	10	6	28
L_F05130.CDR		5/10/05	0	0	0	0	2	17	11	32
L_F05131.CDR		5/11/05	0	0	0	0	0	5	5	6
L_F05132.CDR		5/12/05	0	0	0	0	0	5	5	8
L_F05133.CDR		5/13/05	0	0	0	0	2	13	8	12

Table B-4. Summary of Chinook salmon recapture numbers, 2005 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**
L_F05136.CDR	Cedar River	5/16/05	0	0	0	0	0	13	4	14
L_F05137.CDR		5/17/05	0	0	0	0	1	6	3	3
L_F05138.CDR		5/18/05	0	0	0	0	1	2	0	5
L_F05143.CDR		5/23/05	0	0	0	0	0	14	5	15
L_F05144.CDR		5/24/05	0	0	0	0	2	7	8	13
L_F05145.CDR		5/25/05	0	0	0	0	1	7	4	13
L_F05146.CDR		5/26/05	0	0	0	0	0	4	2	3
L_F05151.CDR		5/31/05	0	0	0	0	0	6	0	4
L_F05152.CDR		6/1/05	0	0	0	0	0	13	10	7
L_F05155.CDR		6/4/05	0	0	0	0	0	9	6	8
L_F05158.CDR		6/7/05	0	0	0	0	0	6	8	3
L_F05160.CDR		6/9/05	0	0	0	0	0	2	1	6
L_F05164.CDR		6/13/05	0	0	0	0	0	0	3	0
L_F05165.CDR		6/14/05	0	1	0	0	0	0	0	2
L_F05171.CDR		6/20/05	0	0	1	0	0	0	0	0
L_F05172.CDR		6/21/05	0	0	0	0	0	0	0	0
L_F05174.CDR		6/23/05	0	0	0	0	0	0	0	0
L_F05179.CDR		6/28/05	0	0	0	0	0	0	0	0
L_F05181.CDR		6/30/05	0	0	0	0	0	0	0	0
L_F05186.CDR		7/5/05	0	0	0	0	0	0	0	0
L_F05188.CDR		7/7/05	0	0	0	0	0	0	0	0
L_F05193.CDR		7/12/05	0	0	0	0	0	0	0	0

Table B-5. Summary of coho salmon recapture numbers, 2005 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**
L_F05122.BR	Bear Creek	5/2/05	0	0	0	0	0	11	9	24
L_F05123.BR		5/3/05	0	0	0	0	2	13	14	22
L_F05124.BR		5/4/05	0	0	0	0	0	12	13	23
L_F05125.BR		5/5/05	0	0	0	0	1	5	18	27
L_F05126.BR		5/6/05	0	0	0	0	1	7	23	31
L_F05129.BR		5/9/05	0	0	0	0	0	9	9	25
L_F05130.BR		5/10/05	0	0	0	0	3	10	15	21
L_F05131.BR		5/11/05	0	0	0	0	2	6	25	40
L_F05132.BR		5/12/05	0	0	0	0	1	5	5	18
L_F05133.BR		5/13/05	0	0	0	0	0	0	0	0
L_F05136.BR		5/16/05	0	0	0	0	3	7	9	17
L_F05137.BR		5/17/05	0	0	0	0	1	6	2	20
L_F05138.BR		5/18/05	0	0	0	0	0	1	4	23
L_F05139.BR		5/19/05	0	0	0	0	1	6	7	11
L_F05144.BR		5/24/05	0	0	0	0	2	4	2	13
L_F05145.BR		5/25/05	0	0	0	0	0	0	0	0
L_F05146.BR		5/26/05	0	0	0	0	0	3	4	7
L_F05151.BR		5/31/05	0	0	0	0	1	1	1	2
L_F05152.BR		6/1/05	0	0	0	0	0	0	2	0
L_F05155.BR		6/4/05	0	0	0	0	0	0	0	0
L_F05158.BR		6/7/05	0	0	0	0	0	0	0	0
L_F05160.BR		6/9/05	0	0	0	0	0	0	0	0
L_F05164.BR		6/13/05	0	0	0	0	0	0	0	0
L_F05165.BR		6/14/05	0	0	0	0	0	0	0	0
L_F05171.BR		6/20/05	0	0	0	0	0	0	0	0
L_F05172.BR		6/21/05	0	0	0	0	0	0	0	0
L_F05122.CDR	Cedar River	5/2/05	0	0	0	0	1	5	13	23
L_F05123.CDR		5/3/05	0	0	0	0	1	4	4	14
L_F05124.CDR		5/4/05	0	0	0	0	0	10	19	28
L_F05125.CDR		5/5/05	0	0	0	0	1	12	16	29
L_F05126.CDR		5/6/05	0	0	0	0	0	6	10	30
L_F05129.CDR		5/9/05	0	0	0	0	1	2	7	11
L_F05130.CDR		5/10/05	0	0	0	0	2	13	17	26
L_F05131.CDR		5/11/05	0	0	0	0	3	8	7	15
L_F05132.CDR		5/12/05	0	0	0	0	0	8	12	26
L_F05133.CDR		5/13/05	0	0	0	0	4	8	9	15
L_F05136.CDR		5/16/05	0	0	0	0	3	9	9	28
L_F05137.CDR		5/17/05	0	0	0	0	4	11	12	12
L_F05138.CDR		5/18/05	0	0	0	0	1	3	3	9
L_F05143.CDR		5/23/05	0	0	0	0	0	5	2	4

Table B-5. Summary of coho salmon recapture numbers, 2005 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**
L_F05144.CDR	Cedar River	5/24/05	0	0	0	0	0	4	3	9
L_F05145.CDR		5/25/05	0	0	0	0	0	0	0	0
L_F05146.CDR		5/26/05	0	0	0	0	3	1	2	9
L_F05151.CDR		5/31/05	0	0	0	0	2	1	2	6
L_F05152.CDR		6/1/05	0	0	0	0	0	2	1	3
L_F05155.CDR		6/4/05	0	0	0	0	1	1	0	4
L_F05158.CDR		6/7/05	0	0	0	0	0	0	0	0
L_F05160.CDR		6/9/05	0	0	0	0	0	1	0	1
L_F05164.CDR		6/13/05	0	0	0	0	0	0	0	0
L_F05165.CDR		6/14/05	0	0	0	0	0	0	0	0
L_F05171.CDR		6/20/05	0	0	0	0	0	0	0	0
L_F05172.CDR		6/21/05	0	0	0	0	0	0	0	0
L_F05174.CDR		6/23/05	0	0	0	0	0	0	0	0
L_F05179.CDR		6/28/05	0	0	0	0	0	0	0	0
L_F05181.CDR		6/30/05	0	0	0	0	0	0	0	0
L_F05186.CDR		7/5/05	0	0	0	0	0	0	0	0
L_F05188.CDR		7/7/05	0	0	0	0	0	0	0	0
L_F05193.CDR		7/12/05	0	0	0	0	0	0	0	0

APPENDIX C

2004 Adult PIT Tag Reader Data Report

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Technical Memorandum

Date: December 6, 2004 Project Number: 1482.01/MM103

To: Chuck Ebel, Linda Smith, Fred Goetz (USACE, Seattle District)

cc: Melinda Jones, Bruce Bachen, Keith Kurko, Julie Hall, Gail Arnold Coburn (SPU);

David Seiler (WDFW)

Mike Mahovlich (MIT)

R2 File

From: Paul DeVries

Subject: Adult PIT Tag Reader Detection Summary as of December 5, 2004

This technical memorandum supersedes an earlier memorandum dated November 8, 2004. It further summarizes detection and release characteristics of PIT tagged fish passing through the Hiram M. Chittenden Locks fish ladder between June 8 and December 5, 2004, provides additional clarifying details, notes trends in the data, and suggests research questions stemming from the data. Funding for the reader purchase, installation, and this analysis was provided by the City of Seattle, King Conservation District, Washington Department of Fish and Wildlife (WDFW), and the U.S. Army Corps of Engineers (USACE). Only three new detections occurred in November since the previous update, but these fish were coho salmon that had passed through the ladder previously.

Four sets of antennae and adult readers were installed in the fish ladder in early June 2004. The readers were connected to the same data collection computers as the tunnel readers installed in the four smolt flumes in gates 4 and 5 of the Locks spillway. Two of the four antennae surrounded the orifice and weir of the first step (“upper,” #1), located at the downstream end of the fish viewing chamber and the remaining two surrounded the orifice and weir of the fourth step (“lower,” #4) downstream. The numbering system used in recording data is as follows: coil 01 is the overflow and coil 02 the orifice on the upper step; coil 03 is the overflow and coil 04 the orifice on the lower step. Fish moving upstream or downstream through the ladder could therefore not avoid passing through a monitored location, and generally had the potential to be detected twice.

Thirty (30) adult sockeye salmon (*Oncorhynchus nerka*) were tagged and released in the fish ladder to test the detection efficiency of the adult readers. Eight (8) were tagged with disk tags and PIT tags on July 21, 2004; twenty-two (22) more were tagged with PIT tags only and released on July 22, 2004. Water temperature in the ladder was 20.7 degrees C on July 22, 2004. The fish were released from the walkway at the western end of the ladder, in the switchback section (approximately a 10 feet drop; Lindsey Fleischer, WDFW, personal communication). The fish appeared to recover sufficiently, and each test fish could either migrate upstream or downstream through the ladder, where downstream migrants would not have been detected by the antennae.

Table 1 summarizes detection characteristics of the thirty test fish. Four of the eight fish released with disk and PIT tags on July 21, 2004 were detected in the ladder upstream of their release point. Of these, only two were detected on the same day of tagging. Three fish appeared to have recycled, where they passed upstream through the ladder more than once, implying they passed downstream through the large or small lock. Nineteen of the twenty-two fish tagged only with PIT tags and released on the next day were detected in the ladder, suggesting that the disk tagged fish were less likely to continue migrating up through the ladder than fish that were only PIT tagged. Of the nineteen fish migrating upstream through the ladder, fifteen were detected on the same day of tagging. Four of the nineteen test sockeye (21%) also recycled, one of them passing upstream through the ladder a total of three times. Recycling times varied, but were nearly two months in the case of one of the test fish (Table 1). All but one of the twenty-two "PIT tag only" test sockeye detected were detected at both steps (Table 1). In that case, the one fish was detected by the lower weir and may not have passed upstream; it may have attempted an upstream leap and then turned around and swam back downstream. Overall detection efficiency of the adult readers was therefore at or around 100 percent for the test fish, assuming the non-detected fish swam downstream through the ladder after release.

Table 2 summarizes the detection and tagging history of each detected PIT tagged fish other than the test sockeye. Most or all of these fish had been tagged as part of the Lake Washington GI Study (see below). All three salmon species tagged previously were detected, with each exhibiting certain characteristics, as described below:

- Four of twenty-two returning PIT tagged sockeye salmon adults (18%) passed twice through the fish ladder, with intervening recycling times ranging between 1, 1, 6, and 54 days. All sockeye adults detected in the ladder were tagged in 2001. Five fish were detected at the upstream weir or orifice only; it is not clear if these fish either:

escaped detection in the downstream weir or orifice; or, entered the fish ladder from the upstream end, passed near the antennae, and then turned around again.

- Two Chinook salmon (*O. tshawytscha*) smolts from this year's PIT tagging in the Cedar River were detected moving downstream in the fish ladder relatively late in the outmigration season. Returning fish from 2001, 2002, and 2003 were detected. Most fish passed upstream through the orifices. Only one (7%) of the fifteen returning adults passed twice through the fish ladder, with a recycling time of 7 days.
- All of the fifty-two returning coho salmon (*O. kisutch*) had been tagged in 2003. More (63%) had been tagged in Bear Creek. Seventeen (33%) fish passed more than once through the fish ladder, with recycling times ranging between 1-36 days. Of these, three coho adults passed three times through the ladder, and one passed five times.
- Two mystery tags were detected. The origin of these fish is currently unknown; one was reportedly shipped to Biomark in early 2000 (Anthony Carson, Biomark, personal communication) and may have been used in the Lake Washington GI study that year; the other was shipped to the USACE by Biomark in the fall of 2000 (Anthony Carson, Biomark, personal communication) and may have been used in 2001.

The need for a study of recycling characteristics (e.g., percentage of run, timing, causes) is indicated by the data in order to better assess run size estimates. The last date of passage for each recycling fish is depicted below with symbols representing individual fish. Recycling may be related to water temperature, although the most recent data indicate some adult coho still recycle when temperatures fall below Department of Ecology's recommended upper limit for adult migration between 16-17°C (Hicks 2002). Most recycling occurred when temperatures exceeded this criterion. Hence, it is possible that recycling behavior at the Locks is related to water temperature in the Lake Washington Ship Canal, although temperature is likely not the only reason.

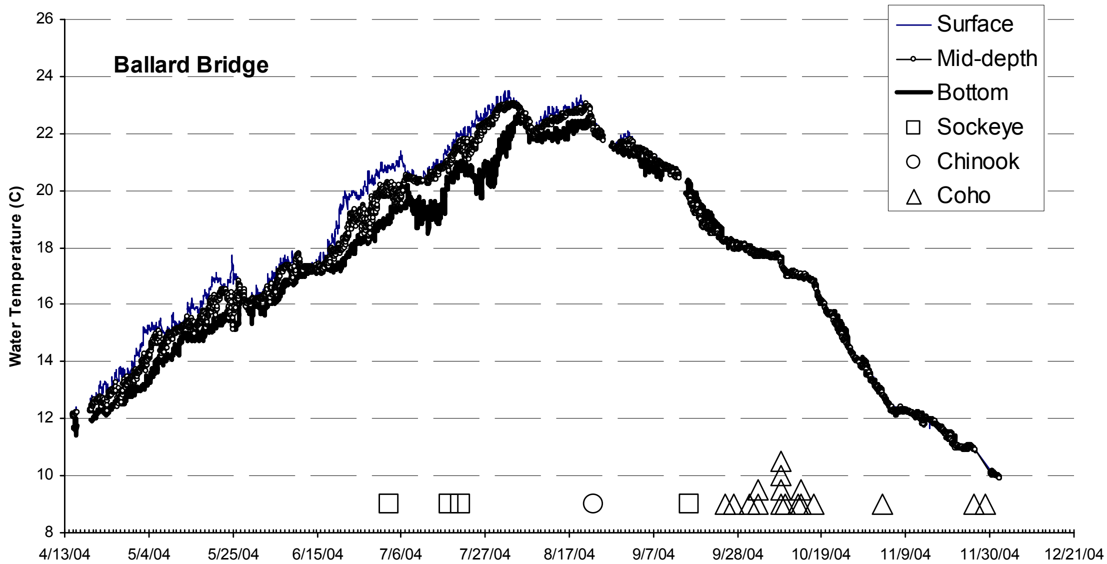

Table 3 summarizes the detection numbers for each species' release group, in terms of both adults and juveniles. The size of a release group is defined as the number of juveniles tagged and released on a given day at a given location. The following observations are drawn from Table 3:

- Roughly half the sockeye adults detected in the ladder were also detected as smolts in the flumes, suggesting the proportion of fish using the flumes as smolts was also on the order of 50%, which is comparable to the detection rate for those release groups as determined in the juvenile PIT tagging analyses (e.g., compare Table 3 numbers with Figure 3-42 of the 2001 data report).
- Of the later migrating Chinook smolts from the Cedar River, 1 of 4 returning adults (25%) were detected in the flumes, which is also comparable to the detection rate for those release groups as determined in the juvenile PIT tagging analyses (e.g., compare Table 3 numbers with Figures 3-40 or 4-1 of the 2001 or 2003 data reports).
- Roughly 67% of the coho salmon adults were also detected in the flumes, which is comparable to the overall detection rate for the same groups in 2003 (e.g., compare Table 3 numbers with Figure 3-25 of the 2003 data report).
- The overall comparability of smolt flume detection rates in the adult returns with the results of the juvenile studies suggests that the juvenile detection rates at the Locks reflect the proportion using the flumes, at least before the juvenile detection rates fall

off substantially with increasing water temperature. If that suggestion is true, then one possible inference is that juvenile outmigrant survival in Lake Washington and the Lake Washington Ship Canal (LWSC) is relatively high for those groups with returning adult detections, especially compared with survival once below the Locks. Analyses of later migrating groups with no adult detections may also be revealing, but data and additional analyses based on the entire adult run are needed.

- Smolt-to-adult ratios (SARs) appear to be at least on the order of 1% and higher depending on the proportion of the adult run using the fish ladder. The Muckleshoot Indian Tribe has approximately 10 years of data that can be used to estimate this proportion (Mike Mahovlich, personal communication), and subsequently estimate SARs for each release group using the adult PIT tag detection data. The estimates may need to be adjusted to reflect recycling in the ladder, however. Nonetheless, the resulting SAR estimates could then be compared with water temperatures and other factors during the outmigration season to determine temporal effects on smolt migration through Lake Washington and the LWSC and subsequent returns.

Three of the Issaquah Hatchery Chinook detected in the ladder (see Table 2) have been recovered at the hatchery to date (Lindsey Fleischer, WDFW, personal communication):

- 3D9.1BF1132A14, 72 cm FL, Female (detected at hatchery 9/28/04)
- 3D9.1BF144708A, 55.5 cm FL, Male (detected at hatchery 9/28/04)
- 3D9.1BF1129CDD ~60 cm FL, Male (detected at hatchery 10/12/04)

Two more Issaquah Hatchery Chinook that arrived at the Hatchery were not detected in the fish ladder:

- 3D9.1BF1132114, 80 cm FL, Female: Released on 05/15/01; detected as a smolt in Flume 5C at 08:06 am on 6/24/01; detected at hatchery 10/05/04
- 3D9.1BF11379D8 ~75 cm FL, Female: Released on 5/15/01; detected in Flume 4B at 5:37 am on 6/13/01; detected at hatchery 10/12/04

WDFW personnel have found two Chinook adults in Cottage Creek that were tagged in May 2002 (Lindsey Fleischer, personal communication), but were not detected in the fish ladder:

- 3D9.1BF141C7AA: Released in Bear Creek on 05/22/02; detected as a smolt in Flume 5B on 6/7/02

- 3D9.1BF141B8D9: Released in Bear Creek on 5/29/02; detected as a smolt in Flume 5B on 6/8/02

SPU personnel also found a Chinook adult male at RM 15 in the Cedar River (Karl Burton, personal communication):

- 3D9.1BF1119CF5: Released in the Cedar River on 5/29/01; not detected in Flumes as a smolt

Table 1. Summary of Test PIT Tagged Sockeye Adult Releases and Detections.

Tag Number	Release Date	Detection			Inferred Direction of Movement
		Date	Time	Location	
Tagged With Disk and PIT Tags:					
3D9.1BF10D2052	7/21/04	7/21/04	18:18:39	Lower Orifice	Upstream
		7/21/04	18:49:36	Upper Weir	Upstream
		8/5/04	5:55:22	Lower Weir	Upstream
		8/5/04	6:22:05	Upper Weir	Upstream
3D9.1BF10D8B80	7/21/04	7/21/04	20:28:14	Lower Weir	Upstream
		7/21/04	20:35:48	Upper Weir	Upstream
		9/15/04	12:10:18	Lower Orifice	Upstream
		9/15/04	12:37:05	Upper Orifice	Upstream
3D9.1BF1118E13	7/21/04	7/22/04	5:33:05	Lower Weir	Upstream
		7/22/04	6:34:52	Upper Weir	Upstream Attempt
		7/22/04	7:51:09	Upper Weir	Upstream Attempt
		7/22/04	21:19:53	Upper Orifice	Upstream Attempt
		7/22/04	22:11:46	Upper Orifice	Upstream Attempt
		7/22/04	22:22:27	Lower Weir	Downstream
3D9.1BF112789F	7/21/04	7/22/04	7:09:07	Lower Orifice	Upstream
		7/22/04	14:04:48	Upper Weir	Upstream Attempt
		7/22/04	18:56:45	Upper Weir	Upstream Attempt
		7/22/04	21:42:04	Upper Orifice	Upstream Attempt
		7/23/04	0:10:21	Upper Orifice	Upstream
3D9.1BF10CE45B	7/21/04	Not detected			
3D9.1BF10CE4E4	7/21/04	Not detected			
3D9.1BF1419C12	7/21/04	Not detected			
3D9.1BF144624F	7/21/04	Not detected			
Tagged With PIT Tags Only:					
3D9.1BF0DD0917	7/22/04	7/22/04	10:14:07	Lower Orifice	Upstream
		7/22/04	10:31:37	Upper Orifice	Upstream
3D9.1BF10CDBFA	7/22/04	7/22/04	14:05:04	Lower Orifice	Upstream
		7/22/04	14:44:36	Upper Orifice	Upstream
		8/12/04	19:47:01	Lower Weir	Upstream
		8/12/04	20:01:30	Upper Orifice	Upstream
3D9.1BF10D2AC2	7/22/04	8/12/04	20:55:50	Lower Weir	Upstream
		8/12/04	21:08:22	Upper Weir	Upstream
3D9.1BF10D8404	7/22/04	7/22/04	9:36:31	Lower Weir	Upstream
		7/22/04	10:26:16	Upper Orifice	Upstream
3D9.1BF10D87C2	7/22/04	7/22/04	21:21:10	Lower Weir	Upstream
		7/22/04	21:27:09	Upper Weir	Upstream
		9/5/04	7:30:20	Lower Orifice	Upstream
		9/5/04	7:38:06	Upper Orifice	Upstream

Table 1. Summary of Test PIT Tagged Sockeye Adult Releases and Detections.

Tag Number	Release Date	Detection			Inferred Direction of Movement
		Date	Time	Location	
3D9.1BF111344D	7/22/04	8/9/04	13:40:11	Lower Orifice	Upstream
		8/9/04	13:42:27	Upper Orifice	Upstream
		8/12/04	15:29:28	Lower Orifice	Upstream
		8/12/04	15:31:15	Upper Orifice	Upstream
		8/22/04	13:58:28	Lower Orifice	Upstream
		8/22/04	14:13:42	Upper Orifice	Upstream
3D9.1BF1113DE0	7/22/04	7/22/04	9:46:53	Lower Orifice	Upstream
		7/22/04	11:45:16	Upper Orifice	Upstream
3D9.1BF1114D34	7/22/04	7/22/04	9:33:03	Lower Weir	Upstream Attempt
		7/22/04	9:33:11	Lower Orifice	Upstream
		7/22/04	9:49:59	Upper Weir	Upstream
3D9.1BF1119A78	7/22/04	7/22/04	11:38:35	Lower Weir	Upstream
		7/22/04	12:30:13	Upper Orifice	Upstream
3D9.1BF1119BE3	7/22/04	7/22/04	12:23:09	Lower Weir	Upstream
		7/22/04	13:35:47	Upper Weir	Upstream
3D9.1BF11D72D7	7/22/04	7/22/04	10:02:16	Lower Orifice	Upstream
		7/22/04	10:42:09	Upper Orifice	Upstream
3D9.1BF144A252	7/22/04	7/22/04	9:51:04	Lower Orifice	Upstream
		7/22/04	10:25:00	Upper Orifice	Upstream
3D9.1BF1453DC1	7/22/04	8/22/04	11:32:13	Lower Weir	Upstream
		8/22/04	12:15:12	Upper Weir	Upstream
3D9.1BF14AAE49	7/22/04	7/22/04	11:02:37	Lower Orifice	Upstream
		7/22/04	11:34:42	Upper Orifice	Upstream
3D9.1BF150A5DF	7/22/04	7/22/04	9:40:38	Lower Orifice	Upstream
		7/22/04	11:02:30	Upper Orifice	Upstream
3D9.1BF1578024	7/22/04	7/22/04	9:44:24	Lower Orifice	Upstream
		7/22/04	10:38:30	Upper Orifice	Upstream
		7/31/04	7:08:20	Lower Orifice	Upstream
		7/31/04	7:35:57	Upper Weir	Upstream
3D9.1BF15C68BA	7/22/04	7/22/04	9:01:19	Lower Weir	Upstream
		7/22/04	9:18:52	Upper Orifice	Upstream
3D9.1BF15F297F	7/22/04	7/25/04	10:55:46	Lower Weir	Upstream
		7/25/04	11:14:02	Upper Weir	Upstream
3D9.1BF1903C21	7/22/04	7/22/04	9:27:58	Lower Weir	Upstream Attempt?
3D9.1BF10C94DC	7/22/04	Not detected			
3D9.1BF10CFD24	7/22/04	Not detected			
3D9.1BF17E63E1	7/22/04	Not detected			

Table 2. Tagging and Detection Information Available for Each PIT Tag Detected in the Hiram M. Chittenden Locks Fish Ladder Between June 8 and November 3, 2004.

				Smolt Life Stage							Adult Life Stage			
				Tagging/Release				Detection in Flumes			Detection in Ladder			Inferred Direction of Movement
Tag Number	Species	Origin	Tagging File	Date	Location	Length (mm)	Water Temp (C)	Date	Time	Flume	Date	Time	Location	
3D9.1BF10C9ED5	Sockeye	W	S_A01128.gs1	5/8/01	Lake Union	125	12	--	--	--	6/28/04	20:42:29	Lower Orifice	Upstream
											6/28/04	20:43:40	Upper Orifice	Upstream
3D9.1BF10D0A18	Sockeye	W	S_A01149.gs1	5/29/01	Lake Union	146	17.5	5/31/01	9:11:38	5C	6/23/04	7:11:08	Upper Orifice	?
3D9.1BF10D1996	Sockeye	W	S_A01128.gs1	5/8/01	Lake Union	137	12	--	--	--	6/22/04	17:08:46	Upper Weir	?
3D9.1BF10D1AF4	Sockeye	W	S_A01128.gs1	5/8/01	Lake Union	121	12	5/10/01	14:27:31	5C	6/27/04	6:40:00	Lower Orifice	Upstream
											6/27/04	6:44:41	Upper Orifice	Upstream
3D9.1BF10D20E1	Sockeye	W	S_A01149.gs1	5/29/01	Lake Union	136	17.5	5/31/01	15:44:51	5C	7/18/04	17:41:27	Lower Orifice	Upstream
											7/18/04	17:42:03	Upper Orifice	Upstream
3D9.1BF10D554B	Sockeye	W	S_A01177.gs1	6/26/01	Lake Union	105	18	--	--	--	7/13/04	11:44:26	Lower Orifice	Upstream
											7/13/04	11:46:11	Upper Orifice	Upstream
3D9.1BF10D743D	Sockeye	W	S_A01149.gs1	5/29/01	Lake Union	142	17.5	5/31/01	5:28:36	5B	6/23/04	21:18:09	Upper Weir	Upstream Attempt
											6/23/04	22:57:03	Upper Orifice	Upstream Attempt
											6/23/04	23:03:59	Upper Weir	Upstream
3D9.1BF10D96D7	Sockeye	W	S_A01142.gs1	5/22/01	Lake Union	144	14	5/24/01	9:38:40	5C	7/2/04	5:37:52	Lower Orifice	Upstream
											7/2/04	5:38:32	Upper Orifice	Upstream
											7/3/04	7:04:39	Lower Orifice	Upstream
											7/3/04	7:06:21	Upper Orifice	Upstream
3D9.1BF11079C4	Sockeye	W	S_A01149.gs1	5/29/01	Lake Union	149	17.5	5/30/01	14:58:32	5C	6/8/04	18:13:11	Upper Orifice	?
3D9.1BF111327F	Sockeye	W	S_A01150.gs1	5/30/01	Lake Union	144	16.5	--	--	--	6/25/04	10:44:20	Lower Orifice	Upstream
											6/25/04	10:58:39	Upper Orifice	Upstream
3D9.1BF11136B7	Sockeye	W	S_A01149.gs1	5/29/01	Lake Union	144	17.5	--	--	--	7/3/04	19:10:37	Lower Orifice	Upstream
											7/3/04	19:11:04	Upper Orifice	Upstream

Table 2. Tagging and Detection Information Available for Each PIT Tag Detected in the Hiram M. Chittenden Locks Fish Ladder Between June 8 and November 3, 2004.

				Smolt Life Stage							Adult Life Stage			
				Tagging/Release				Detection in Flumes			Detection in Ladder			Inferred Direction of Movement
Tag Number	Species	Origin	Tagging File	Date	Location	Length (mm)	Water Temp (C)	Date	Time	Flume	Date	Time	Location	
3D9.1BF1113C0B	Sockeye	W	S_A01149.gs1	5/29/01	Lake Union	147	17.5	5/30/01	16:52:24	5C	7/17/04	7:44:55	Lower Orifice	Upstream
											7/17/04	7:54:56	Upper Orifice	Upstream
											7/18/04	8:40:03	Lower Orifice	Upstream
											7/18/04	8:50:36	Upper Orifice	Upstream
3D9.1BF1114074	Sockeye	W	S_A01149.gs1	5/29/01	Lake Union	147	17.5	5/30/01	18:52:11	5C	6/30/04	20:19:41	Lower Orifice	Upstream
											6/30/04	20:19:51	Upper Orifice	Upstream
3D9.1BF111464A	Sockeye	W	S_A01149.gs1	5/29/01	Lake Union	140	17.5	--	--	--	7/25/04	16:49:14	Lower Orifice	Upstream
											7/25/04	18:10:46	Upper Weir	Upstream Attempt
											7/25/04	22:17:43	Upper Orifice	Upstream
3D9.1BF111472D	Sockeye	W	S_A01128.gs1	5/8/01	Lake Union	128	12	--	--	--	7/5/04	17:47:06	Lower Weir	Upstream
											7/5/04	18:00:46	Upper Weir	Upstream
3D9.1BF1114CFE	Sockeye	W	S_A01149.gs1	5/29/01	Lake Union	141	17.5	5/30/01	16:35:34	5C	7/24/04	9:04:25	Lower Weir	Upstream
											7/24/04	9:38:10	Upper Orifice	Upstream
											9/16/04	16:19:02	Lower Weir	Upstream
											9/16/04	16:32:33	Upper Orifice	Upstream
3D9.1BF1114FF7	Sockeye	W	S_A01149.gs1	5/29/01	Lake Union	146	17.5	5/31/01	11:00:56	5C	7/7/04	7:10:47	Lower Weir	Upstream
											7/7/04	7:26:58	Upper Weir	Upstream
3D9.1BF111572F	Sockeye	W	S_A01128.gs1	5/8/01	Lake Union	138	12	--	--	--	6/19/04	17:38:20	Upper Orifice	?
3D9.1BF1118F76	Sockeye	W	S_A01135.gs1	5/16/01	Lake Union	127	12	5/18/01	13:26:41	5B	6/18/04	6:17:08	Upper Weir	?
3D9.1BF11198F4	Sockeye	W	S_A01128.gs1	5/8/01	Lake Union	125	12	5/10/01	15:01:15	4A	6/26/04	11:55:32	Lower Orifice	Upstream
											6/26/04	12:30:49	Upper Orifice	Upstream
3D9.1BF11199B2	Sockeye	W	S_A01149.gs1	5/29/01	Lake Union	144	17.5	--	--	--	7/8/04	20:33:21	Lower Weir	Upstream
											7/8/04	20:33:53	Upper Weir	Upstream

Table 2. Tagging and Detection Information Available for Each PIT Tag Detected in the Hiram M. Chittenden Locks Fish Ladder Between June 8 and November 3, 2004.

				Smolt Life Stage							Adult Life Stage			
				Tagging/Release				Detection in Flumes			Detection in Ladder			Inferred Direction of Movement
Tag Number	Species	Origin	Tagging File	Date	Location	Length (mm)	Water Temp (C)	Date	Time	Flume	Date	Time	Location	
3D9.1BF111A89A	Sockeye	W	S_A01128.gs1	5/8/01	Lake Union	137	12	5/9/01	14:28:10	4A	7/15/04	21:27:39	Lower Orifice	Upstream
											7/15/04	21:43:45	Upper Orifice	Upstream
											7/21/04	19:50:20	Lower Orifice	Upstream
											7/21/04	20:08:59	Upper Orifice	Upstream
3D9.1BF109C153	Chinook	W	CSM04175.cdr	6/23/04	Cedar River	120	14.4	*Not Analyzed (2004 Smolt)*			7/4/04	4:10:42	Upper Weir	Downstream
											7/4/04	4:11:32	Lower Orifice	Downstream
3D9.1BF10D0A8A	Chinook	W	Csm01163.fc1	6/12/01	Cedar River	94	10	6/26/01	4:35:24	5B	8/21/04	18:23:47	Lower Orifice	Upstream
											8/21/04	18:24:37	Upper Orifice	Upstream
3D9.1BF10D6CD6	Chinook	W	Csm01156.fc1	6/5/01	Cedar River	83	8	--	--	--	8/28/04	17:55:54	Lower Orifice	Upstream
											8/28/04	18:01:45	Upper Orifice	Upstream
3D9.1BF1115105	Chinook	W	Csm01151.fc1	5/31/01	Cedar River	85	10	--	--	--	9/5/04	19:11:09	Lower Orifice	Upstream
											9/5/04	19:11:27	Upper Orifice	Upstream
3D9.1BF1129CDD	Chinook	H	CSM02112.I01	4/22/02; 5/31/2002	Issaquah Hatchery	70	5	--	--	--	8/8/04	14:42:01	Lower Orifice	Upstream
											8/8/04	14:51:41	Upper Orifice	Upstream
3D9.1BF113098B	Chinook	H	CSM01102.UW2	4/12/2001; 5/21/2001	UW Hatchery	84	6	--	--	--	8/23/04	18:21:18	Lower Orifice	Upstream
											8/23/04	18:21:47	Upper Weir	Upstream Attempt
											8/23/04	19:36:52	Upper Orifice	Upstream Attempt
											8/23/04	19:41:00	Lower Orifice	Downstream
3D9.1BF1130D34	Chinook	H	CSM01102.UW1	4/12/2001; 5/21/2001	UW Hatchery	79	6	5/22/01	15:34:09	5C	10/3/04	8:33:47	Lower Orifice	Upstream
											10/3/04	8:37:56	Upper Orifice	Upstream

Table 2. Tagging and Detection Information Available for Each PIT Tag Detected in the Hiram M. Chittenden Locks Fish Ladder Between June 8 and November 3, 2004.

				Smolt Life Stage							Adult Life Stage			
				Tagging/Release				Detection in Flumes			Detection in Ladder			Inferred Direction of Movement
Tag Number	Species	Origin	Tagging File	Date	Location	Length (mm)	Water Temp (C)	Date	Time	Flume	Date	Time	Location	
3D9.1BF1132A14	Chinook	H	CSM02112.I02	4/22/02; 5/31/2002	Issaquah Hatchery	74	5	7/6/02	5:40:35	4B	8/22/04	16:46:27	Lower Weir	Upstream Attempt
3D9.1BF113479D	Chinook	H	S_A01099.I01	4/9/2001; 5/15/2001	Issaquah Hatchery	58	5	6/20/01	10:55:48	5B	9/3/04	19:31:14	Lower Weir	Upstream
											9/3/04	19:51:18	Upper Orifice	Upstream
3D9.1BF11359D8	Chinook	H	CSM01099.I01	4/9/2001; 5/15/2001	Issaquah Hatchery	62	5	6/15/01	13:58:48	5B	8/26/04	13:38:47	Lower Orifice	Upstream
											8/26/04	13:49:10	Upper Orifice	Upstream
3D9.1BF1135FE3	Chinook	H	CSM01099.I01	4/9/2001; 5/15/2001	Issaquah Hatchery	66	5	--	--	--	8/19/04	16:58:21	Lower Orifice	Upstream
											8/19/04	16:59:23	Upper Orifice	Upstream
3D9.1BF113D0B6	Chinook	H	S_A01099.I01	4/9/2001; 5/15/2001	Issaquah Hatchery	74	5	6/10/01	8:18:41	5B	8/11/04	16:47:53	Lower Orifice	Upstream
											8/11/04	16:48:34	Upper Orifice	Upstream
3D9.1BF144708A	Chinook	H	csm03105.I01	4/15/2003; 5/19/2003	Issaquah Hatchery	68	9.5	6/19/03	14:20:18	4B	7/18/04	6:34:01	Lower Orifice	Upstream
											7/18/04	6:49:08	Upper Orifice	Upstream
3D9.1BF14A6577	Chinook	W	CSM03150.FC1	5/30/03	Cedar River	98	13	--	--	--	8/16/04	15:03:22	Lower Orifice	Upstream
											8/16/04	15:03:47	Upper Orifice	Upstream
											8/23/04	14:37:53	Lower Orifice	Upstream
											8/23/04	14:38:22	Upper Orifice	Upstream
3D9.1BF1D20AA7	Chinook	W	CSM04146.CDR	5/27/04	Cedar River	84	12.7	*Not Analyzed (2004*			6/22/04	3:03:03	Upper Weir	Downstream

Table 2. Tagging and Detection Information Available for Each PIT Tag Detected in the Hiram M. Chittenden Locks Fish Ladder Between June 8 and November 3, 2004.

				Smolt Life Stage							Adult Life Stage			
				Tagging/Release				Detection in Flumes			Detection in Ladder			Inferred Direction of Movement
Tag Number	Species	Origin	Tagging File	Date	Location	Length (mm)	Water Temp (C)	Date	Time	Flume	Date	Time	Location	
									Smolt)					
3D9.1BF113655C	Chinook	H	CSM01102.UW2	5/21/01	UW Hatchery	90	6	5/26-28/01	--	5C	9/18/04	16:07:01	Lower Orifice	Upstream
											9/18/04	16:07:18	Upper Orifice	Upstream
3D9.1BF113D739	Chinook	H	CSM01102.UW1	5/21/01	UW Hatchery	80	6	--	--	--	9/16/04	7:53:03	Lower Orifice	Upstream
											9/16/04	7:53:17	Upper Orifice	Upstream
3D9.1BF141AC20	Coho	W	CSM03119.FB1	4/29/03	Bear Creek	142	10	5/19/03	5:52:44	5C	9/15/04	15:39:18	Lower Weir	Upstream Attempt
											9/15/04	15:59:02	Lower Orifice	Upstream
											9/15/04	16:16:41	Upper Orifice	Upstream
3D9.1BF1449CA1	Coho	W	CSM03122.FC1	5/2/03	Cedar River	141	10	5/11/03	6:30:39	5B	10/5/04	16:09:02	Lower Orifice	Upstream
											10/5/04	16:09:46	Upper Orifice	Upstream
3D9.1BF144A165	Coho	W	CSM03122.FC1	5/2/03	Cedar River	135	10	5/19/03	15:16:39	5B	10/19/04	16:01:10	Lower Weir	Upstream
											10/19/04	16:01:33	Upper Orifice	Upstream
3D9.1BF144A47E	Coho	W	CSM03121.FC1	5/1/03	Cedar River	123	10	--	--	--	10/10/04	16:13:19	Lower Orifice	Upstream
											10/10/04	16:21:33	Upper Orifice	Upstream
											10/17/04	10:58:10	Lower Orifice	Upstream
											10/17/04	11:03:21	Upper Orifice	Upstream
3D9.1BF144A6B6	Coho	W	CSM03121.FC1	5/1/03	Cedar River	117	10	5/29/03	14:02:32	5C	9/23/04	18:39:25	Lower Orifice	Upstream
											9/23/04	18:49:46	Upper Orifice	Upstream
3D9.1BF14523E7	Coho	W	CSM03121.FC1	5/1/03	Cedar River	103	10	--	--	--	10/26/04	14:52:17	Lower Orifice	Upstream
											10/26/04	15:12:32	Upper Orifice	Upstream
3D9.1BF15715BD	Coho	W	CSM03119.FB1	4/29/03	Bear Creek	115	10	--	--	--	9/24/04	11:23:58	Lower Orifice	Upstream
											9/24/04	11:46:23	Upper Weir	Upstream

Table 2. Tagging and Detection Information Available for Each PIT Tag Detected in the Hiram M. Chittenden Locks Fish Ladder Between June 8 and November 3, 2004.

				Smolt Life Stage							Adult Life Stage			
				Tagging/Release				Detection in Flumes			Detection in Ladder			Inferred Direction of Movement
Tag Number	Species	Origin	Tagging File	Date	Location	Length (mm)	Water Temp (C)	Date	Time	Flume	Date	Time	Location	
3D9.1BF1571F13	Coho	W	CSM03120.FB1	4/30/03	Bear Creek	119	10	5/13/03	16:09:25	5C	10/19/04	8:49:26	Lower Orifice	Upstream
											10/19/04	8:55:43	Upper Orifice	Upstream
3D9.1BF157339B	Coho	W	CSM03120.FB1	4/30/03	Bear Creek	119	10	5/14/03	7:06:01	5B	9/25/04	10:50:50	Lower Orifice	Upstream
											9/25/04	11:00:43	Upper Orifice	Upstream
											10/1/04	14:50:07	Lower Orifice	Upstream
											10/1/04	14:58:09	Upper Orifice	Upstream
3D9.1BF1577D29	Coho	W	CSM03120.FB1	4/30/03	Bear Creek	126	10	5/10/03	17:33:28	5C	10/19/04	9:00:53	Lower Orifice	Upstream
											10/19/04	9:02:40	Upper Orifice	Upstream
3D9.1BF1577E5E	Coho	W	CSM03120.FC1	4/30/03	Cedar River	94	10	--	--	--	9/25/04	7:50:18	Lower Orifice	Upstream
											9/25/04	7:55:27	Upper Orifice	Upstream
3D9.1BF1577FF3	Coho	W	CSM03120.FB1	4/30/03	Bear Creek	124	10	5/7/03	10:41:38	4B	10/8/04	17:59:16	Lower Orifice	Upstream
											10/8/04	18:13:23	Upper Orifice	Upstream
3D9.1BF157833B	Coho	W	CSM03121.FB1	5/1/03	Bear Creek	105	10	5/10/03	18:26:52	5B	9/20/04	12:10:11	Lower Orifice	Upstream
											9/20/04	12:20:49	Upper Orifice	Upstream
3D9.1BF157834C	Coho	W	CSM03120.FB1	4/30/03	Bear Creek	140	10	5/10/03	13:36:30	5B	9/26/04	12:16:55	Lower Weir	Upstream
											9/26/04	12:24:37	Upper Weir	Upstream
3D9.1BF157C94C	Coho	W	CSM03121.FB1	5/1/03	Bear Creek	146	10	5/19/03	3:45:34	5B	9/24/04	10:40:35	Lower Orifice	Upstream
											9/24/04	11:02:59	Upper Orifice	Upstream
3D9.1BF157CFB4	Coho	W	CSM03119.FB1	4/29/03	Bear Creek	132	10	--	--	--	9/17/04	13:21:22	Lower Weir	Upstream
											9/17/04	13:30:13	Upper Orifice	Upstream
3D9.1BF157D2B1	Coho	W	CSM03119.FB1	4/29/03	Bear Creek	128	10	5/8/03	8:53:11	4B	9/24/04	17:33:38	Lower Orifice	Upstream
											9/24/04	17:34:49	Upper Orifice	Upstream
											10/3/04	8:06:00	Lower Weir	Upstream
											10/3/04	8:06:52	Upper Orifice	Upstream

Table 2. Tagging and Detection Information Available for Each PIT Tag Detected in the Hiram M. Chittenden Locks Fish Ladder Between June 8 and November 3, 2004.

				Smolt Life Stage							Adult Life Stage			
				Tagging/Release				Detection in Flumes			Detection in Ladder			Inferred Direction of Movement
Tag Number	Species	Origin	Tagging File	Date	Location	Length (mm)	Water Temp (C)	Date	Time	Flume	Date	Time	Location	
3D9.1BF157D7B5	Coho	W	CSM03119.FC1	4/29/03	Cedar River	115	10	5/25/03	18:55:45	5C	11/1/04	12:17:02	Lower Orifice	Upstream
											11/1/04	12:30:00	Upper Weir	Upstream
											11/3/04	13:52:41	Lower Orifice	Upstream
											11/3/04	13:53:47	Upper Orifice	Upstream
3D9.1BF157D96F	Coho	W	CSM03120.FC1	4/30/03	Cedar River	107	10	6/17/03	6:34:01	5C	10/31/04	5:37:45	Lower Orifice	Upstream
											10/31/04	5:49:33	Upper Orifice	Upstream
3D9.1BF15AE239	Coho	W	CSM03125.FC1	5/5/03	Cedar River	112	9	5/18/03	12:48:14	5B	10/28/04	14:53:26	Lower Orifice	Upstream
											10/28/04	15:00:17	Upper Orifice	Upstream
											11/29/04	13:20:15	Lower Orifice	Upstream
											11/29/04	13:20:33	Upper Orifice	Upstream
3D9.1BF17D9A75	Coho	W	CSM03134.FB1	5/14/03	Bear Creek	105	12	5/26/03	19:07:32	5B	9/26/04	14:50:50	Lower Weir	Upstream
											9/26/04	14:51:46	Upper Orifice	Upstream
3D9.1BF17D9B40	Coho	W	CSM03134.FC1	5/15/03	Cedar River	116	11	--	--	--	9/29/04	18:24:30	Lower Weir	Upstream
											9/29/04	18:24:51	Upper Weir	Upstream
											10/9/04	12:39:18	Lower Orifice	Upstream
											10/9/04	12:43:56	Upper Orifice	Upstream
3D9.1BF17DA50E	Coho	W	CSM03134.FB1	5/14/03	Bear Creek	117	12	--	--	--	9/20/04	13:49:48	Lower Weir	Upstream
											9/20/04	13:59:48	Upper Weir	Upstream
											10/13/04	16:45:46	Lower Weir	Upstream
											10/13/04	16:46:04	Upper Orifice	Upstream
3D9.1BF17DA775	Coho	W	CSM03126.FC1	5/6/03	Cedar River	113	9	5/31/03	6:10:54	5C	10/23/04	10:55:36	Lower Orifice	Upstream
											10/23/04	11:01:30	Upper Orifice	Upstream
3D9.1BF17DB2D9	Coho	W	CSM03125.FC1	5/5/03	Cedar River	115	9	5/15/03	5:27:35	5B	10/4/04	15:54:18	Lower Orifice	Upstream
											10/4/04	15:55:29	Upper Orifice	Upstream

Table 2. Tagging and Detection Information Available for Each PIT Tag Detected in the Hiram M. Chittenden Locks Fish Ladder Between June 8 and November 3, 2004.

				Smolt Life Stage							Adult Life Stage			
				Tagging/Release				Detection in Flumes			Detection in Ladder			Inferred Direction of Movement
Tag Number	Species	Origin	Tagging File	Date	Location	Length (mm)	Water Temp (C)	Date	Time	Flume	Date	Time	Location	
3D9.1BF17DEB99	Coho	W	CSM03133.FB1	5/13/03	Bear Creek	130	12	--	--	--	9/8/04	16:54:18	Lower Orifice	Upstream
											9/8/04	16:54:42	Upper Orifice	Upstream
											9/26/04	7:56:07	Lower Orifice	Upstream
											9/26/04	7:56:49	Upper Orifice	Upstream
											10/9/04	12:54:49	Lower Orifice	Upstream
											10/9/04	12:57:11	Upper Orifice	Upstream
3D9.1BF17E0632	Coho	W	CSM03126.FB1	5/6/03	Bear Creek	105	10	5/14/03	10:19:49	5C	9/28/04	17:15:20	Lower Weir	Upstream
											9/28/04	17:16:35	Upper Orifice	Upstream
3D9.1BF17E1B0C	Coho	W	CSM03133.FB1	5/13/03	Bear Creek	120	12	5/26/03	19:54:38	5C	9/24/04	9:53:05	Lower Orifice	Upstream
											9/24/04	10:00:13	Upper Orifice	Upstream
3D9.1BF17E2063	Coho	W	CSM03125.FB1	5/5/03	Bear Creek	111	10	5/19/03	15:45:29	5C	9/25/04	19:03:37	Lower Orifice	Upstream Attempt
											9/25/04	19:11:09	Lower Orifice	Upstream
											9/25/04	19:11:59	Upper Orifice	Upstream
											10/1/04	15:07:51	Lower Orifice	Upstream
											10/1/04	15:13:43	Upper Orifice	Upstream
											10/3/04	16:48:11	Lower Orifice	Upstream
											10/3/04	16:54:10	Upper Orifice	Upstream
											10/4/04	17:06:18	Lower Orifice	Upstream
											10/4/04	17:10:12	Upper Orifice	Upstream
											10/14/04	9:27:01	Lower Orifice	Upstream
											10/14/04	9:31:44	Upper Orifice	Upstream
3D9.1BF17E273C	Coho	W	CSM03122.FB1	5/2/03	Bear Creek	127	10	--	--	--	9/25/04	11:15:03	Lower Orifice	Upstream
											9/25/04	11:28:02	Upper Weir	Upstream
3D9.1BF17E3D94	Coho	W	CSM03122.FC1	5/2/03	Cedar River	140	10	5/19/03	8:30:20	5C	10/6/04	19:09:39	Lower Orifice	Upstream
											10/6/04	19:21:02	Upper Orifice	Upstream

Table 2. Tagging and Detection Information Available for Each PIT Tag Detected in the Hiram M. Chittenden Locks Fish Ladder Between June 8 and November 3, 2004.

				Smolt Life Stage							Adult Life Stage			
				Tagging/Release				Detection in Flumes			Detection in Ladder			Inferred Direction of Movement
Tag Number	Species	Origin	Tagging File	Date	Location	Length (mm)	Water Temp (C)	Date	Time	Flume	Date	Time	Location	
											10/8/04	13:12:06	Lower Orifice	Upstream
											10/8/04	13:16:00	Upper Orifice	Upstream
											10/9/04	10:43:20	Lower Orifice	Upstream
											10/9/04	10:52:16	Upper Weir	Upstream
3D9.1BF17E56F7	Coho	W	CSM03129.FB1	5/9/03	Bear Creek	99	10	--	--	--	9/25/04	10:39:18	Lower Orifice	Upstream
											9/25/04	10:48:36	Upper Orifice	Upstream
3D9.1BF17E5716	Coho	W	CSM03127.FC1	5/7/03	Cedar River	147	9	--	--	--	9/24/04	13:03:27	Lower Weir	Upstream
											9/24/04	13:14:36	Upper Weir	Upstream
3D9.1BF17E5AB5	Coho	W	CSM03134.FB1	5/14/03	Bear Creek	107	12	5/31/03	13:15:37	4B	9/19/04	9:04:13	Lower Weir	Upstream
											9/19/04	9:16:43	Upper Orifice	Upstream
											9/25/04	12:05:55	Lower Orifice	Upstream
											9/25/04	12:12:46	Upper Orifice	Upstream
3D9.1BF17E5D68	Coho	W	CSM03122.FB1	5/2/03	Bear Creek	*not measured*	10	--	--	--	9/22/04	9:56:52	Lower Orifice	Upstream
											9/22/04	10:05:21	Upper Orifice	Upstream
3D9.1BF17E5DC8	Coho	W	CSM03122.FB1	5/2/03	Bear Creek	129	10	--	--	--	9/29/04	8:57:01	Lower Orifice	Upstream
											9/29/04	9:12:37	Upper Orifice	Upstream
											10/3/04	11:56:54	Lower Orifice	Upstream
											10/3/04	12:00:51	Upper Orifice	Upstream
3D9.1BF17E6900	Coho	W	CSM03134.FB1	5/14/03	Bear Creek	128	12	--	--	--	9/20/04	13:02:47	Lower Orifice	Upstream
											9/20/04	13:10:55	Upper Orifice	Upstream
3D9.1BF17E6A54	Coho	W	CSM03134.FB1	5/14/03	Bear Creek	113	12	5/24/03	11:52:13	5C	9/17/04	8:38:46	Lower Orifice	Upstream
											9/17/04	8:39:51	Upper Orifice	Upstream
											10/10/04	11:48:28	Lower Orifice	Upstream
											10/10/04	12:01:00	Upper Orifice	Upstream
3D9.1BF17E6E5A	Coho	W	CSM03134.FB1	5/14/03	Bear Creek	130	12	--	--	--	9/27/04	11:37:35	Lower Orifice	Upstream

Table 2. Tagging and Detection Information Available for Each PIT Tag Detected in the Hiram M. Chittenden Locks Fish Ladder Between June 8 and November 3, 2004.

				Smolt Life Stage							Adult Life Stage			
				Tagging/Release				Detection in Flumes			Detection in Ladder			Inferred Direction of Movement
Tag Number	Species	Origin	Tagging File	Date	Location	Length (mm)	Water Temp (C)	Date	Time	Flume	Date	Time	Location	
											9/27/04	11:45:57	Upper Orifice	Upstream
3D9.1BF17E7547	Coho	W	CSM03127.FB1	5/7/03	Bear Creek	105	11	5/19/03	10:11:36	5B	10/9/04	18:36:54	Lower Orifice	Upstream
											10/9/04	18:42:31	Upper Orifice	Upstream
3D9.1BF17E9D3F	Coho	W	CSM03136.FC1	5/16/03	Cedar River	125	9	5/20/03	9:14:00	5C	10/9/04	12:27:31	Lower Orifice	Upstream
											10/9/04	12:29:43	Upper Orifice	Upstream
3D9.1BF17EF004	Coho	W	CSM03129.FB1	5/9/03	Bear Creek	128	10	5/28/03	16:41:20	5C	9/23/04	10:59:57	Lower Orifice	Upstream
											9/23/04	11:05:23	Upper Orifice	Upstream
3D9.1BF1850424	Coho	W	CSM03126.FC1	5/6/03	Cedar River	118	9	--	--	--	10/14/04	15:37:29	Lower Orifice	Upstream
											10/14/04	15:45:43	Upper Orifice	Upstream
3D9.1BF185684C	Coho	W	CSM03136.FB1	5/16/03	Bear Creek	130	10	6/1/03	5:12:51	4B	9/18/04	17:04:14	Lower Orifice	Upstream
											9/18/04	17:08:54	Upper Orifice	Upstream
3D9.1BF185746E	Coho	W	CSM03136.FB1	5/16/03	Bear Creek	127	10	6/21/03	11:00:39	4B	9/16/04	9:53:28	Lower Weir	Upstream
											9/16/04	9:55:20	Upper Weir	Upstream
3D9.1BF185855D	Coho	W	CSM03126.FB1	5/6/03	Bear Creek	110	10	6/1/03	17:40:13	4B	9/25/04	19:01:11	Lower Orifice	Upstream
											9/25/04	19:09:56	Upper Orifice	Upstream
											10/9/04	12:50:15	Lower Weir	Upstream
											10/9/04	12:57:37	Upper Weir	Upstream
3D9.1BF18589E4	Coho	W	CSM03122.FB1	5/2/03	Bear Creek	135	10	--	--	--	9/23/04	10:20:38	Lower Orifice	Upstream
											9/23/04	10:26:48	Upper Orifice	Upstream
3D9.1BF1858DF3	Coho	W	CSM03122.FC1	5/2/03	Cedar River	120	10	5/23/03	9:18:05	5B	10/20/04	14:52:38	Lower Orifice	Upstream
											10/20/04	15:01:44	Upper Orifice	Upstream
											11/26/04	12:20:46	Lower Orifice	Upstream
											11/26/04	12:38:54	Upper Orifice	Upstream
3D9.1BF1859216	Coho	W	CSM03134.FB1	5/14/03	Bear Creek	100	12	5/29/03	7:11:47	5B	9/26/04	17:22:44	Lower Weir	Upstream Attempt
											9/26/04	17:30:58	Lower Orifice	Upstream

Table 2. Tagging and Detection Information Available for Each PIT Tag Detected in the Hiram M. Chittenden Locks Fish Ladder Between June 8 and November 3, 2004.

				Smolt Life Stage							Adult Life Stage			
				Tagging/Release				Detection in Flumes			Detection in Ladder			Inferred Direction of Movement
Tag Number	Species	Origin	Tagging File	Date	Location	Length (mm)	Water Temp (C)	Date	Time	Flume	Date	Time	Location	
											9/26/04	17:41:17	Upper Weir	Upstream
3D9.1BF185953E	Coho	W	CSM03140.FB1	5/20/03	Bear Creek	126	11.5	5/24/03	9:08:52	5C	9/24/04	13:34:04	Lower Weir	Upstream
											9/24/04	13:46:25	Upper Weir	Upstream
											9/27/04	9:36:56	Lower Weir	Upstream
											9/27/04	9:42:30	Upper Weir	Upstream
3D9.1BF185995F	Coho	W	CSM03127.FC1	5/7/03	Cedar River	146	9	5/19/03	8:30:28	5C	10/10/04	7:53:25	Lower Orifice	Upstream
											10/10/04	8:00:39	Upper Orifice	Upstream
3D9.1BF1859B90	Coho	W	CSM03129.FC1	5/9/03	Cedar River	110	10	6/5/03	14:36:54	4B	9/24/04	14:07:29	Lower Weir	Upstream
											9/24/04	14:08:08	Upper Weir	Upstream
											9/26/04	9:16:33	Lower Weir	Upstream
											9/26/04	9:17:07	Upper Weir	Upstream
											10/14/04	7:47:40	Lower Weir	Upstream
											10/14/04	7:48:12	Upper Weir	Upstream
3D9.1BF0E4FCFD	*Not in Lake Washington GI 2000-2003 tagging files, PTAGIS database, or Biomark vendor files*							--	--	--	8/14/04	16:05:40	Lower Orifice	Upstream
											8/14/04	16:25:02	Upper Orifice	Upstream
3D9.1BF1114493	*Not in Lake Washington GI 2000-2003 tagging files; Shipped to Corps in 2000*							--	--	--	7/6/04	7:31:21	Lower Weir	Upstream
											7/6/04	7:59:10	Upper Weir	Upstream

Table 3. Summary of Adult PIT Tag Detection Data in Fish Ladder, and Release Characteristics (as of November 3, 2004)

		Release		Number of Smolts		Number of Adults Detected		
Species	Origin	Location	Date	Released	Detected in Flumes	In Ladder	And As Smolts in Flumes	Percent Detected in Ladder
Sockeye	Natural	Lake Union	5/8/01	435	298	7	3	1.6%
			5/16/01	174	80	1	1	0.6%
			5/22/01	154	48	1	1	0.6%
			5/29/01	366	251	11	8	3.0%
			5/30/01	36	19	1	0	2.8%
			6/26/01	519	324	1	0	0.2%
Chinook	Natural	Cedar River	5/31/01	145	45	1	0	0.7%
			6/5/01	68	19	1	0	1.5%
			6/12/01	204	32	1	1	0.5%
			5/30/03	35	17	1 [2]	0	2.9%
			2004	*Not Determined Yet*		2 [3]	0	na
	Hatchery	Issaquah Hatchery	5/15/01	4676	1630	4	3	0.1%
			5/31/02	4024	1411	2	1	0.05%
			5/19/03	992	236	1 [2]	1	0.1%
		UW Hatchery	5/21/01	2015	996	4	2	0.2%
Coho	Natural	Bear Creek	4/29/03	347	211	4	2	1.2%
			4/30/03	240	172	5	5	2.1%
			5/1/03	157	112	2	2	1.3%
			5/2/03	250	164	4	0	1.6%
			5/5/03	205	126	1	1	0.5%
			5/6/03	100	60	2	2	2.0%

Table 3. Summary of Adult PIT Tag Detection Data in Fish Ladder, and Release Characteristics (as of November 3, 2004)

		Release		Number of Smolts		Number of Adults Detected		
Species	Origin	Location	Date	Released	Detected in Flumes	In Ladder	And As Smolts in Flumes	Percent Detected in Ladder
			5/7/03	100	51	1	1	1.0%
			5/9/03	100	60	2	1	2.0%
			5/13/03	95	41	2	1	2.1%
			5/14/03	100	53	7	4	7.0%
			5/16/03	100	53	2	2	2.0%
			5/20/03	50	21	1	1	2.0%
		Cedar River	4/29/03	50	29	1	1	2.0%
			4/30/03	102	57	2	1	2.0%
			5/1/03	62	25	3	1	4.8%
			5/2/03	84	51	4	4	4.8%
			5/5/03	61	38	2	2	3.3%
			5/6/03	150	83	2	1	1.3%
			5/7/03	94	53	2	1	2.1%
			5/9/03	99	47	1	1	1.0%
			5/15/03	45	25	1	0	2.2%
			5/16/03	155	78	1	1	0.6%
Unknown [4]	Unknown	Unknown	Unknown	Unknown	Unknown	2	0	na

[1] - *not adjusted for detection efficiency of tunnel readers*

[2] - *Jack?*

[3] - *2004 Outmigrants*

[4] - *Not in Lake Washington Tagging Files, PTAGIS database, or Biomark vendor records*

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APPENDIX D

2005 Adult PIT Tag Reader Data Report

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Technical Memorandum

Date: November 8, 2005 Project Number: 1430.01/MM104

To: Jean White, Bruce Bachen, Keith Kurko, Julie Hall, Gail Arnold Coburn (SPU);
Chuck Ebel, Linda Smith, Fred Goetz (USACE, Seattle District)

cc: David Seiler (WDFW)
Mike Mahovlich (MIT)
R2 File

From: Paul DeVries, Noble Hendrix

Subject: Adult PIT Tag Reader Detection Summary as of November 7, 2005,
Hiram M. Chittenden Locks Fish Ladder

This technical memorandum summarizes detection and release characteristics of PIT tagged fish passing through the Hiram M. Chittenden Locks fish ladder as of November 7, 2005. The 2005 data are also analyzed with the 2004 ladder detection data, and trends are noted in the data. Research questions are suggested based on the analysis. Funding for the PIT tag reader purchase, installation, and this analysis was provided by the City of Seattle, King Conservation District, Washington Department of Fish and Wildlife (WDFW), and the U.S. Army Corps of Engineers (USACE).

Four sets of antennae and PIT tag readers were installed in the fish ladder in early June 2004. The readers were connected to the same data collection computers as the tunnel readers installed in the four smolt flumes in gates 4 and 5 of the Locks spillway. Two of the four antennae surround the orifice and weir of the first step (“upper,” #1), located at the downstream end of the fish viewing chamber, and the remaining two surround the orifice and weir of the fourth step (“lower,” #4) downstream. The upstream coils monitor the same portals through which fish are counted by observers in the fish viewing room. The numbering system used in recording data is as follows: coil 01 is the overflow weir and coil 02 the orifice on the upper step; coil 03 is the overflow weir and coil 04 the orifice on the lower step. Fish moving upstream or downstream through the ladder could therefore not avoid passing through a monitored location. Fish had the potential to be detected twice, which would have indicated the direction of movement and whether passage was likely to have been successful.

This memorandum focuses on returning adult salmon that were PIT tagged as part of the Lake Washington General Investigation (LWGI) juvenile salmon outmigration studies. A pilot experiment was also conducted by the USACE, WDFW, and R2 Resource Consultants in August 2005 where adult Chinook (*Oncorhynchus tshawytscha*) and sockeye salmon (*O. nerka*) were caught in the large lock, PIT tagged, and released near the railroad bridge pilings at Commodore Park. All of the Chinook were tagged with archival temperature tags, and some Chinook were implanted with acoustic tags. The results of that study will be summarized in a separate report once additional retrieval and tracking data have been analyzed, although selected results are also presented here.

Table 1 summarizes the detection and tagging history of each fish returning through the fish ladder that had been tagged as part of the LWGI juvenile outmigration studies. Sampling in 2004 indicated that the detection efficiency was 100 percent, which influenced interpretation of passage movements. For example, if a fish was detected only at the lower step and not at the upper step, it was inferred that the fish was not successful at passing. All salient information is nonetheless provided in Table 1 so that the reader can make his or her own interpretation if desired.

The following characteristics were noted in the detection data:

No coho salmon juveniles were PIT tagged in 2004, and no adults were thus detected returning in 2005. However, three coho that had been tagged in the spring of 2005 returned in the fall and were detected moving upstream in the ladder, presumably as jacks.

No sockeye salmon were detected in 2005. Based on fish size at time of PIT tagging, predominantly yearling outmigrants (likely 21 out of 22) tagged in the Ship Canal in 2001 were detected returning in 2004 (DeVries et al. 2003, 2004). Only one probable young of year fish from 2001 (tag number 3D9.1BF10D554B, FL=105 mm on 6/26/01) was detected as a returning adult in 2004. Because a similar number of young of year and yearling sockeye passed through the flumes in 2001 (DeVries et al. 2002), it is hypothesized that the absence of returning tagged sockeye adults this year may reflect poorer survival of young of year sockeye in saltwater.

Returning Chinook from 2001, 2002, 2003, and 2004 were detected in 2005, representing a wide range of age classes.

As in 2004, most Chinook passed upstream through the orifices as opposed to the weirs.

Two of sixteen (12.5%) returning Chinook adults passed twice through the fish ladder, and another one (6.3%) passed through three times, with recycling times ranging between 6-14 days. In addition, three out of thirty-six (8.3%) Chinook adults from the pilot experiment recycled twice, with recycling times ranging between 2-20 days. These data can be used to estimate correction factors that account for recycling-induced bias in fish ladder counts. This subject will be discussed in greater detail in the forthcoming report of the pilot experiment results.

The last date of passage for each recycling fish is depicted below with a water temperature time series for the Lake Washington Ship Canal (open circles are returning fish tagged as juveniles, dark circles are adults used in the pilot experiment). Recycling occurred when water temperature exceeded Department of Ecology's recommended upper limit for adult migration (between 16°-17°C; Hicks 2002), although other factors may also be related to this behavior.

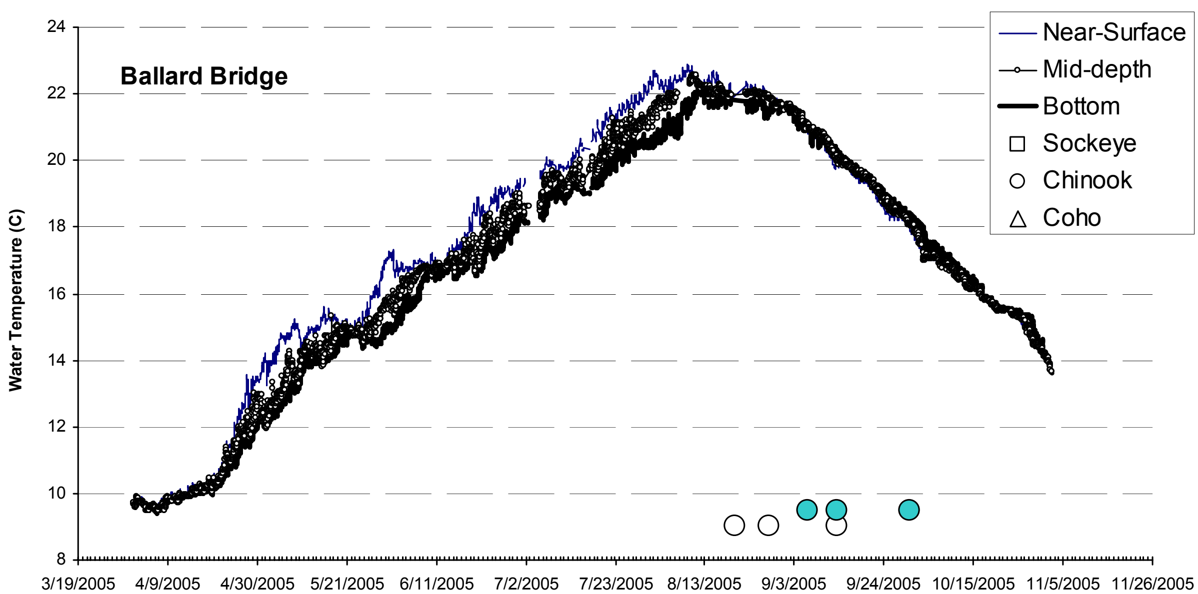
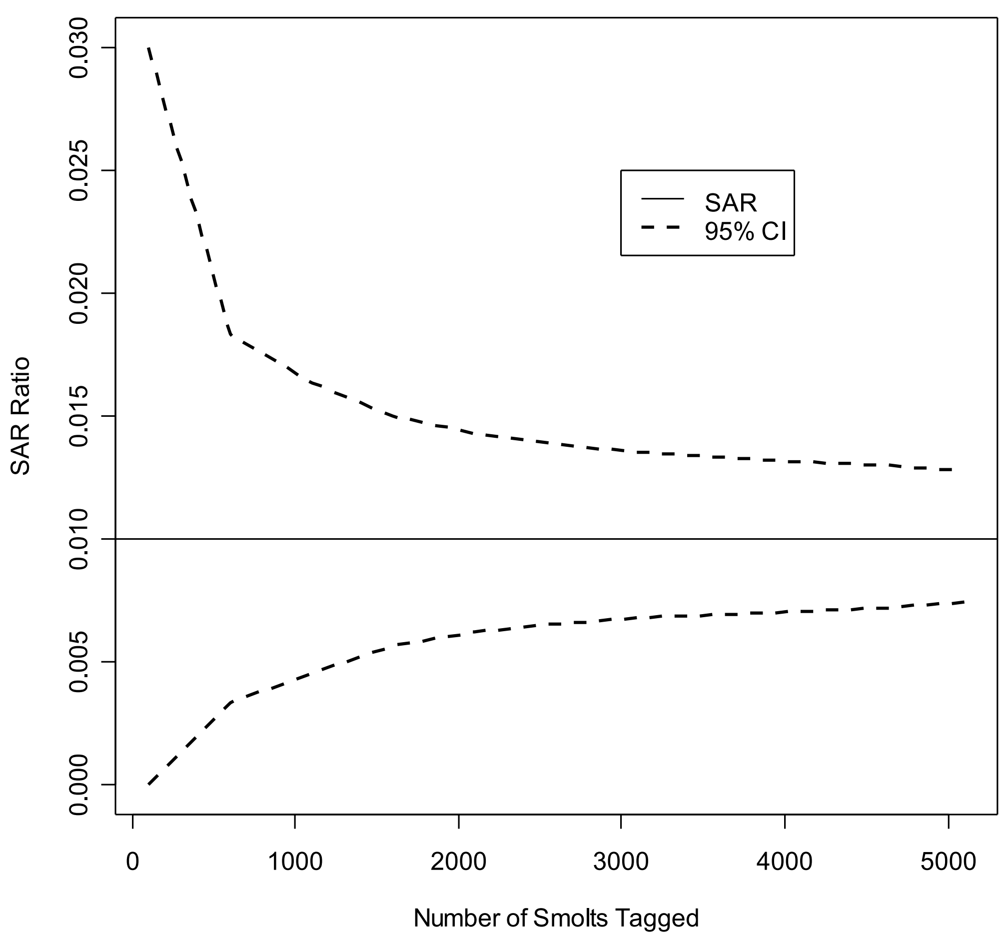


Table 2 summarizes the age structure of returning fish for the two years of monitoring in the fish ladder. The detection numbers are small, which will influence the ultimate precision of smolt-to-adult return (SAR) ratio estimates. Given that four age classes have been detected to return in the ladder, continued monitoring will be necessary for several years in order to estimate SARs. The number of years required for a run reconstruction is dependent upon the number of ages at which adults are returning. Because four ages have been detected in the adult returns, at least four years of ladder detection data are required for a single estimate of the SAR ratio. The single estimate of SAR is an estimate from a distribution, however, where the spread of the distribution depends upon the number of tagged smolts. The figure below is an example of how the 95% confidence interval (95% CI) changes as a function of the number of smolts tagged. The 95% CI decreases as tagging rate increases, although the marginal benefit of increasing sample size decreases as the sample sizes become larger. The assumed SAR in the example is 0.01, which was derived from Table 2 assuming that if 1500 smolts are tagged on average, if approximately one-third of returning adults pass through the ladder, and if approximately 5 adults were counted in the ladder, then 15 tagged adults total were assumed to have passed the Locks. Therefore the SAR ratio was assumed to be 15/1500 = 0.01, and should be treated as an example only.



We note that the above figure assumes that the SAR ratio is known, but in reality only a single estimate of SAR could be calculated from 4 years of data. Additional years would be required for more estimates of the SAR ratio. In order to estimate the variance of the average SAR, at least 3 samples would be needed (i.e., 6 years of monitoring for tag returns). The resulting SAR estimates could then be compared with water temperatures and other factors during the outmigration season to evaluate temporal effects on smolt migration through Lake Washington and the LWSC and subsequent returns.

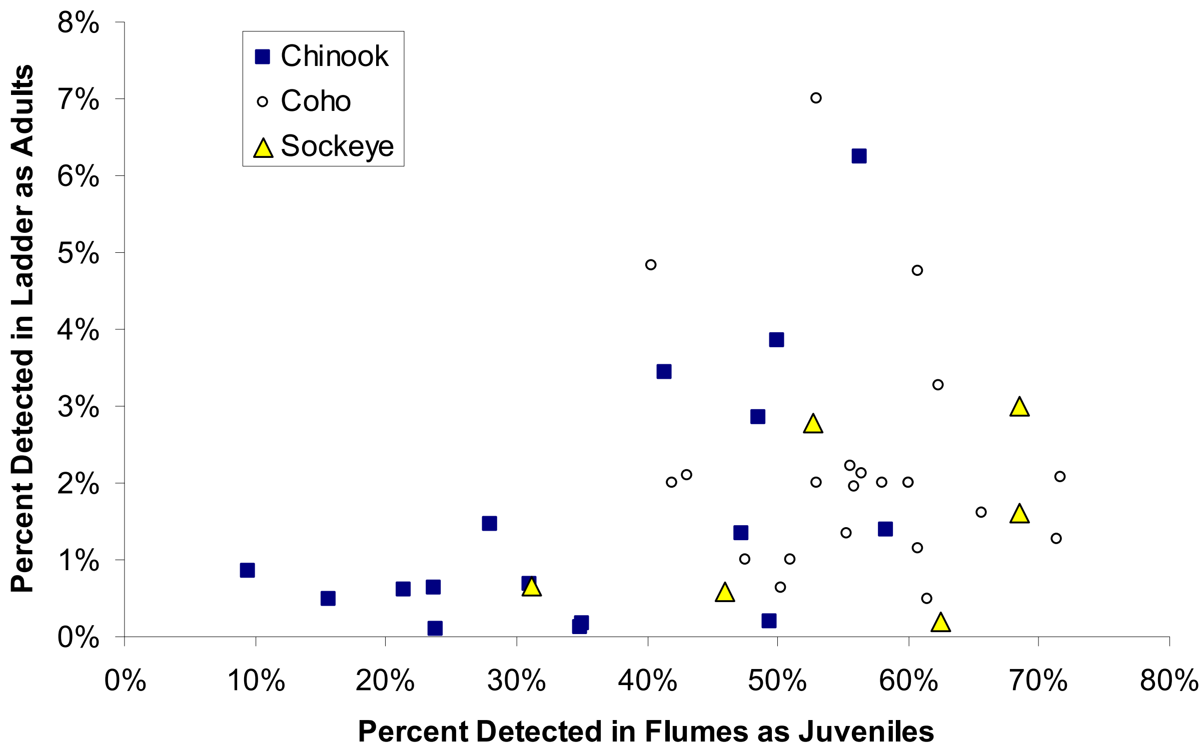
Table 3 summarizes the proportion of adults detected in the fish ladder that migrated through the flumes as juveniles. Such information can be used to evaluate the overall proportion using the flumes as smolts. Table 4 is an update of Table 2 from the 2004 data memorandum (DeVries 2004), and summarizes the detection numbers for each species' release group in terms of adults and juveniles. The size of a release group is defined as the number of juveniles tagged and released on a given day at a given location.

The following observations are drawn from Tables 3 and 4:

The majority of values for the proportion of an outmigration year class using the flumes in Table 3 are 50% and higher based on the adult return data. The average from summing over all data is 63%, which is generally similar to proportions estimated for the May to early June period using the juvenile outmigration detection data, suggesting that outmigrant survival is high in freshwater during that period.

However, the return rates of adults in Table 4 appear to be too low at present for assessing seasonal declines in the proportion using the flumes to a reasonable level of precision. The numbers in Table 4 can be used in power analyses to identify suitable sample sizes of juvenile release groups for determining flume use proportions based on adult return data. For example, PIT tag release groups in May would need to be composed of at least 5000 juveniles to yield an estimated 60% using the flumes with a 95% confidence interval of +/- 20%, assuming survival of tagged juveniles to the Locks is 100%, the SAR rate equals 1%, and 50% of adults use the fish ladder.

Proportionally fewer adults appear to return for release groups from which proportionally fewer fish were detected in the flumes. This can be seen graphically in the figure below, where each data point represents percentages from a release group in Table 4:



The patterns depicted in the above figure suggest that release groups exhibiting a proportion using the flumes less than about 40% also have a lower probability of returning as adults than groups with a higher percentage detected in the flumes. The results of a logistic regression (Table 5) indicate that there is a significantly lower (P =0.026) adult return rate for Chinook release groups that have fewer than 40% detected in the flumes. For Chinook, this translates to natural origin juveniles released in Bear Creek and the Cedar River around May 31 and later (see Table 4 for dates) having a lower probability of returning as adults than juvenile Chinook released earlier. Possible reasons include differential lake survival and reduced saltwater fitness of later migrating smolts, possibly in response to increased water temperature (Tabor et al. 2004; DeVries et al. 2005).

Lower commensurate juvenile detection and adult return rates also occurred in the case of Issaquah Hatchery Chinook smolts, which were released in middle to late May (Table 4), compared with natural origin fish. The reason for this may be related to additional mortality and the potential influence of water temperature on residualization in Lake Sammamish (DeVries et al. 2005).

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Tabor, R.A., M.T. Celedonia, F. Mejia, R.M. Piaskowski, D.L. Low, B. Footen, and L. Park. 2004. Predation of juvenile Chinook salmon by predatory fishes in three areas of the Lake Washington basin. U.S. Fish and Wildlife Service, Lacey WA. February.

Table 1. Tagging and detection information available for each PIT Tag detected in the Hiram M. Chittenden Locks fish ladder between May 1 and October 31, 2005. (Tag numbers are ordered alphanumerically.)

			Smolt Life Stage							Adult Life Stage			
			Tagging/Release				Detection in Flumes			Detection in Ladder			
Tag Number	Species	Origin	Date	Location	Length (mm)	Water Temp (C)	Date	Time	Flume	Date	Time	Location	Inferred Direction of Movement
3D9.1BF1123A1E	Chinook	W	5/30/2003	Bear Cr	80	14	--	--	--	8/19/2005	19:57:57	Lower Orifice	Upstream
										8/19/2005	20:01:08	Upper Orifice	Upstream
3D9.1BF1132028	Chinook	H	5/15/2001	Issaquah Hatchery	64	5	--	--	--	8/14/2005	13:44:12	Lower Orifice	Upstream
										8/14/2005	13:56:43	Upper Orifice	Upstream
3D9.1BF1136AA5	Chinook	H	5/31/2002	Issaquah Hatchery	78	5	6/6/2002	17:54:58	4B	7/6/2005	17:03:47	Lower Orifice	Upstream
										7/6/2005	17:12:42	Upper Orifice	Upstream
3D9.1BF1136D80	Chinook	H	5/31/2002	Issaquah Hatchery	78	5	--	--	--	9/7/2005	15:10:57	Lower Weir	Upstream
										9/7/2005	15:31:16	Upper Orifice	Upstream
3D9.1BF1137975	Chinook	H	5/31/2002	Issaquah Hatchery	70	5	6/20/2002	6:15:19	4B	8/19/2005	15:15:21	Lower Weir	Upstream
										8/19/2005	15:52:28	Upper Weir	Upstream
										8/28/2005	10:56:59	Lower Orifice	Upstream
										8/28/2005	11:04:42	Upper Orifice	Upstream

Table 1. Tagging and detection information available for each PIT Tag detected in the Hiram M. Chittenden Locks fish ladder between May 1 and October 31, 2005. (Tag numbers are ordered alphanumerically.)

			Smolt Life Stage							Adult Life Stage			
			Tagging/Release				Detection in Flumes			Detection in Ladder			
Tag Number	Species	Origin	Date	Location	Length (mm)	Water Temp (C)	Date	Time	Flume	Date	Time	Location	Inferred Direction of Movement
3D9.1BF113963B	Chinook	H	5/31/2002	Issaquah Hatchery	68	5	--	--	--	8/20/2005	17:10:00	Lower Orifice	Upstream
										8/20/2005	17:10:28	Upper Orifice	Upstream
3D9.1BF113B42A	Chinook	W	5/4/2001	Cedar R	83	8	--	--	--	9/5/2005	8:00:13	Lower Orifice	Upstream
										9/5/2005	8:26:00	Upper Orifice	Upstream
3D9.1BF11440F2	Chinook	H	5/15/2001	Issaquah Hatchery	60	5	6/14/2001	10:10:04	4A	8/12/2005	11:39:56	Lower Weir	Upstream
										8/12/2005	11:41:26	Upper Weir	Upstream
3D9.1BF11471B5	Chinook	H	5/31/2002	Issaquah Hatchery	--	5	--	--	--	8/13/2005	19:48:39	Lower Weir	Upstream Attempt
										8/13/2005	19:49:00	Lower Orifice	Upstream
										8/13/2005	20:35:31	Upper Weir	Upstream
3D9.1BF141BC53	Chinook	W	5/29/2002	Cedar R	87	11	6/12/2002	5:07:13	4B	8/25/2005	8:06:01	Upper Orifice	Downstream, Aborted?
3D9.1BF141D557	Chinook	W	5/23/2002	Bear Cr	84	12	--	--	--	8/30/2005	15:17:31	Lower Weir	Upstream
										8/30/2005	15:18:45	Upper Orifice	Upstream

Table 1. Tagging and detection information available for each PIT Tag detected in the Hiram M. Chittenden Locks fish ladder between May 1 and October 31, 2005. (Tag numbers are ordered alphanumerically.)

			Smolt Life Stage							Adult Life Stage			
			Tagging/Release				Detection in Flumes			Detection in Ladder			
Tag Number	Species	Origin	Date	Location	Length (mm)	Water Temp (C)	Date	Time	Flume	Date	Time	Location	Inferred Direction of Movement
3D9.1BF1429113	Chinook	W	5/24/2002	Cedar R	94	10	5/26/2002	20:04:31	5B	8/19/2005	16:57:18	Lower Orifice	Upstream
										8/19/2005	16:57:33	Upper Orifice	Upstream
3D9.1BF15780F0	Chinook	W	6/10/2002	Bear Cr	85	13	--	--	--	8/23/2005	19:36:39	Lower Orifice	Upstream
										8/23/2005	19:37:00	Upper Orifice	Upstream
3D9.1BF157DF93	Chinook	H	5/12/2003	Flumes (Cal Test)	55	--	5/12/2003	11:33:41	5C	8/17/2005	10:25:25	Lower Orifice	Upstream
										8/17/2005	10:36:19	Upper Orifice	Upstream
3D9.1BF173A73E	Chinook	W	6/14/2004	Cedar R	82	12	7/10/2004	10:48:35	4A	9/15/2005	5:09:02	Lower Orifice	Upstream
										9/15/2005	5:27:45	Upper Orifice	Upstream
3D9.1BF17E7F2F	Chinook	W	5/13/2003	Bear Cr	80	12	6/3/2003	7:25:05	4B	8/6/2005	8:24:07	Lower Orifice	Upstream
										8/6/2005	8:25:35	Upper Orifice	Upstream
										8/20/2005	17:12:49	Lower Orifice	Upstream
										8/20/2005	17:17:54	Upper Weir	Upstream

Table 1. Tagging and detection information available for each PIT Tag detected in the Hiram M. Chittenden Locks fish ladder between May 1 and October 31, 2005. (Tag numbers are ordered alphanumerically.)

			Smolt Life Stage							Adult Life Stage			
			Tagging/Release				Detection in Flumes			Detection in Ladder			
Tag Number	Species	Origin	Date	Location	Length (mm)	Water Temp (C)	Date	Time	Flume	Date	Time	Location	Inferred Direction of Movement
3D9.1BF17E97D4	Chinook	H	5/6/2003	Marymoor	83	12	--	--	--	8/29/2005	14:36:58	Lower Weir	Upstream
										8/29/2005	14:37:10	Upper Weir	Upstream
										9/7/2005	8:36:50	Lower Weir	Upstream
										9/7/2005	8:37:03	Upper Weir	Upstream
										9/13/2005	12:54:55	Lower Orifice	Upstream
										9/13/2005	12:55:38	Upper Orifice	Upstream
3D9.1BF1FF54FB	Coho	W	5/13/2005	Cedar R	117	12	6/5/2005	17:58:36	4B	10/7/2005	16:18:51	Lower Weir	Upstream
										10/7/2005	16:34:32	Upper Weir	Upstream
3D9.1BF207D6F0	Coho	W	5/11/2005	Cedar R	134	12	6/3/2005	7:01:33	4B	9/24/2005	17:48:41	Lower Weir	Upstream Attempt
										9/24/2005	17:54:33	Lower Orifice	Upstream
										9/24/2005	18:01:44	Upper Orifice	Upstream

Table 1. Tagging and detection information available for each PIT Tag detected in the Hiram M. Chittenden Locks fish ladder between May 1 and October 31, 2005. (Tag numbers are ordered alphanumerically.)

			Smolt Life Stage							Adult Life Stage			
			Tagging/Release				Detection in Flumes			Detection in Ladder			
Tag Number	Species	Origin	Date	Location	Length (mm)	Water Temp (C)	Date	Time	Flume	Date	Time	Location	Inferred Direction of Movement
3D9.1BF20823CA	Coho	W	5/5/2005	Cedar R	129	12	--	--	--	10/24/2005	14:48:15	Lower Weir	Upstream Attempt
										10/24/2005	14:57:22	Lower Orifice	Upstream
										10/24/2005	15:01:40	Upper Orifice	Upstream

Table 2. Summary of smolt-to-adult return data, 2004-2005 ladder data combined.

				In Year J		Number of Returning Adults Detected in Ladder					Percent of Adults Also Detected as Smolts in Flumes			
Site	Species	Migratory Year J	Origin	Number of Smolts Released	Fraction Detected in Flumes [1]	Year J	Year J+1	Year J+2	Year J+3	Year J+4	Year J+1	Year J+2	Year J+3	Year J+4
Bear Cr	Chinook	2000	W	525	0.070	na	na	na	na	0	na	na	na	0
Bear Cr	Chinook	2001	W	2132	0.127	na	na	na	0	0	na	na	0	0
Bear Cr	Chinook	2002	W	2309	0.318	na	na	0	2	na	na	0	0	na
Bear Cr	Chinook	2003	W	2305	0.354	na	0	2	na	na	0	0.500	na	na
Bear Cr	Chinook	2004	W	1537	0.148	0	0	na	na	na	0	na	na	na
Bear Cr	Coho	2002	W	2661	0.646	na	na	0	0	na	na	0	0	na
Bear Cr	Coho	2003	W	2044	0.720	na	33	0	na	na	0.667	0	na	na
Bear Cr	Coho	2004	W	0	na	na	0	na	na	na	0	na	na	na
Bear Cr	Coho	2005	W	1207	0.559	0	na	na	na	na	na	na	na	na
Cedar R	Chinook	2000	W	273	0.128	na	na	na	na	0	na	na	na	0
Cedar R	Chinook	2001	W	1550	0.288	na	na	na	3	1	na	na	0.333	0
Cedar R	Chinook	2002	W	814	0.209	na	na	0	2	na	na	0	1.000	na
Cedar R	Chinook	2003	W	1726	0.303	na	1	0	na	na	0	0	na	na
Cedar R	Chinook	2004	W	2192	0.154	0	1	na	na	na	1.000	na	na	na
Cedar R	Coho	2002	W	1038	0.591	na	na	0	0	na	na	0	0	na
Cedar R	Coho	2003	W	1027	0.664	na	19	0	na	na	0.684	0	na	na
Cedar R	Coho	2004	W	0	na	na	0	na	na	na	0	na	na	na
Cedar R	Coho	2005	W	1265	0.496	3	na	na	na	na	na	na	na	na
Issaquah	Chinook	2000	H	122	0.008	na	na	na	na	0	na	na	na	0
Issaquah	Chinook	2001	H	4676	0.377	na	na	na	4	2	na	na	0.750	0.500
Issaquah	Chinook	2002	H	4024	0.390	na	na	2	5	na	na	0.500	0.400	na
Issaquah	Chinook	2003	H	992	0.278	na	1	0	na	na	1.000	0	na	na
Issaquah	Chinook	2004	H	0	0.000	0	0	na	na	na	0	na	na	na

Table 2. Summary of smolt-to-adult return data, 2004-2005 ladder data combined.

Site	Species	Migratory Year J	Origin	In Year J: Number of Smolts Released	In Year J: Fraction Detected in Flumes [1]	Number of Returning Adults Detected in Ladder: Year J	Year J+1	Year J+2	Year J+3	Year J+4	Percent of Adults Also Detected as Smolts in Flumes: Year J+1	Year J+2	Year J+3	Year J+4
Marymoor	Chinook	2003	H	1154	0.333	na	0	1	na	na	0	0	na	na
Lake Union	Sockeye	2001	U	2219	0.613	na	na	na	22	0	na	na	0.591	0

[1] - *Adjusted for detection efficiency*

Table 3. Proportions of returning PIT-tagged salmon adults detected in the flumes as juveniles, 2004-2005 ladder data combined.

			Juvenile Flume Use		
Species	**Release Location**	**Migratory Year**	**Number Detected**	**Number Not Detected**	**% Using Flumes**
Chinook	Issaquah Hatchery	2000	0	0	na
		2001	4	2	67%
		2002	3	4	43%
		2003	1	0	100%
		2004	0	0	na
	UW Hatchery	2001	2	2	50%
	Bear Creek	2000	0	0	na
		2001	0	0	na
		2002	0	2	0%
		2003	1	1	50%
		2004	0	0	na
	Cedar River	2000	0	0	na
		2001	1	3	25%
		2002	2	0	100%
		2003	0	0	na
		2004	1	0	100%
Coho	Bear Creek	2003	22	11	67%
		2005	0	0	na
	Cedar River	2003	13	6	68%
		2005	2	1	67%
Sockeye	Lake Union	2001	13	9	59%
		Total:	**65**	**41**	**63%**

Table 4. Summary of adult PIT Tag detection data in fish ladder in 2004-2005, and release characteristics (as of October 31, 2005).

		Release		Number of Smolts		Number of Adults Detected		Percent of Smolts Detected in Flumes [1]	Percent of Smolts Detected in Ladder
Species	Origin	Location	Date	Released	Detected in Flumes [1]	In Ladder	And As Smolts in Flumes		
Sockeye	Natural	Lake Union	5/8/2001	435	298	7	3	69%	1.61%
			5/16/2001	174	80	1	1	46%	0.57%
			5/22/2001	154	48	1	1	31%	0.65%
			5/29/2001	366	251	11	8	69%	3.01%
			5/30/2001	36	19	1	0	53%	2.78%
			6/26/2001	519	324	1	0	62%	0.19%
Chinook	Natural	Bear Creek	5/23/2002	72	42	1	0	58%	1.39%
			6/10/2002	164	35	1	0	21%	0.61%
			5/13/2003	74	35	1	1	47%	1.35%
			5/30/2003	156	37	1	0	24%	0.64%
		Cedar River	5/4/2001	16	9	1	0	56%	6.25%
			5/31/2001	145	45	1	0	31%	0.69%
			6/5/2001	68	19	1	0	28%	1.47%
			6/12/2001	204	32	1	1	16%	0.49%
			5/24/2002	29	12	1	1	41%	3.45%
			5/29/2002	26	13	1	1	50%	3.85%
			5/30/2003	35	17	1 [2]	0	49%	2.86%
			6/14/2004	116	11	1 [2]	1	9%	0.86%

Table 4. Summary of adult PIT Tag detection data in fish ladder in 2004-2005, and release characteristics (as of October 31, 2005).

		Release		Number of Smolts		Number of Adults Detected		Percent of Smolts Detected in Flumes [1]	Percent of Smolts Detected in Ladder
Species	Origin	Location	Date	Released	Detected in Flumes [1]	In Ladder	And As Smolts in Flumes		
Chinook	Hatchery	Issaquah Hatchery	5/15/2001	4676	1630	6	4	35%	0.13%
			5/31/2002	4024	1411	7	3	35%	0.17%
			5/19/2003	992	236	1 [2]	1	24%	0.10%
		UW Hatchery	5/21/2001	2015	996	4	2	49%	0.20%
Coho	Natural	Bear Creek	4/29/2003	347	211	4	2	61%	1.15%
			4/30/2003	240	172	5	5	72%	2.08%
			5/1/2003	157	112	2	2	71%	1.27%
			5/2/2003	250	164	4	0	66%	1.60%
			5/5/2003	205	126	1	1	61%	0.49%
			5/6/2003	100	60	2	2	60%	2.00%
			5/7/2003	100	51	1	1	51%	1.00%
			5/9/2003	100	60	2	1	60%	2.00%
			5/13/2003	95	41	2	1	43%	2.11%
			5/14/2003	100	53	7	4	53%	7.00%
			5/16/2003	100	53	2	2	53%	2.00%
			5/20/2003	50	21	1	1	42%	2.00%

Table 4. Summary of adult PIT Tag detection data in fish ladder in 2004-2005, and release characteristics (as of October 31, 2005).

		Release		Number of Smolts		Number of Adults Detected		Percent of Smolts Detected in Flumes [1]	Percent of Smolts Detected in Ladder
Species	Origin	Location	Date	Released	Detected in Flumes [1]	In Ladder	And As Smolts in Flumes		
Coho	Natural	Cedar River	4/29/2003	50	29	1	1	58%	2.00%
			4/30/2003	102	57	2	1	56%	1.96%
			5/1/2003	62	25	3	1	40%	4.84%
			5/2/2003	84	51	4	4	61%	4.76%
			5/5/2003	61	38	2	2	62%	3.28%
			5/6/2003	150	83	2	1	55%	1.33%
			5/7/2003	94	53	2	1	56%	2.13%
			5/9/2003	99	47	1	1	47%	1.01%
			5/15/2003	45	25	1	0	56%	2.22%
			5/16/2003	155	78	1	1	50%	0.65%

[1] *- not adjusted for detection efficiency of tunnel readers*

[2] *– Jack?*

Table 5. Analysis of Deviance table for proportion of adults returning through the fish ladder at the Hiram M. Chittenden Locks Fish Ladder. The location of juvenile release and the proportion using flumes (a factor with two levels-less than 40% versus greater than 40%).[1] An interaction of location and flume was also included in the model. Terms were added sequentially (first to last). The test statistic is compared to a Chi Square distribution to determine the level of significance

	Df	Deviance	Residual Df	Residual Dev	P(>|Chi|)
NULL	15	29.2783			
Location	3	22.4622	12	6.8161	0.0001
Flume	1	4.9466	11	1.8695	0.0261
LocationXFlume	1	0.4744	10	1.3951	0.4910

[1] The null hypothesis being tested was that the percent of adults returning was the same across all levels of flume detections. To test this hypothesis, Chinook return groups were analyzed at two levels. An arbitrary value was chosen at 40% detected in flumes as juveniles; therefore, Chinook groups that had less than 40% migrate through the flumes was one level and Chinook with more than 40% detected in the flumes was the second level.

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