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# **PIT Tagging of Juvenile Salmon Smolts in the Lake Washington Basin: Year 2000 Pilot Study Results**

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

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*Final Report Prepared For*

U.S. Army Corps of Engineers, Seattle District

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## ABSTRACT

This first year pilot study evaluated the feasibility of using Passive Integrated Transponder (PIT) tag technology to monitor smolt migration and survival characteristics as they pass through the Lake Washington Ship Canal (LWSC) system, including the Hiram M. Chittenden Locks (Locks). Four smolt flumes and PIT tag detection devices (tunnel readers) were installed over the spillway dam of the Locks to monitor outmigration during the spring of 2000. Hatchery chinook salmon juveniles were tagged and released at two locations in the LWSC, and naturally-reared chinook juveniles captured in screw traps were tagged and released in the lower reaches of the Cedar River, Bear Creek, and Issaquah Creek. Hatchery-reared chinook were also trapped, tagged, and released in Issaquah Creek. Chinook, sockeye, and coho salmon juveniles were also captured, tagged, and released in Lake Union. Calibration tests were performed using tagged hatchery chinook juveniles to evaluate the detection efficiency of the tunnel readers. Samples of fish captured by purse seining in the large lock and by beach seining in saltwater areas below the Locks were interrogated using hand-held detectors for PIT tagged fish. Problems were encountered, including a disease outbreak in the LWSC that influenced survival of hatchery fish used in the study, structural features of the flume supports reducing the detection efficiency of the tunnel readers, and the absence of complete coverage of PIT tagged fish passing the Locks through other routes. Nevertheless, the data provided valuable, detailed biological information on migration, passage, and estuarine behavior of salmon smolts originating from different parts of the Lake Washington basin and transitioning to adult life in saltwater. The data included seasonal and diurnal migration and passage timing, passage routes through the Locks, and time to transition to saltwater. The data also provided approximate survival estimates for different portions of the migration route, although the precision of the estimates was extremely poor because of variable detection rates at the Locks, low detection rates below the Locks, and uncertainty introduced by the disease problem. This information can be used for shaping spill timing and volume requirements at the Locks, and for evaluating causal mechanisms of decline. Study implications and improvements are suggested.

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Reviewers of the draft report include: Fred Goetz, Brian Footen, Dave Seiler, Steve Achord, Steve Smith, Brad Eppard, Doug Houck, Peter Johnson, Eric Warner, and Chuck Ebel. Their comments helped improve the final report.

## 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 60<sup>th</sup> Congress in accordance with a plan set forth in House Document 953. The Montlake Cut, which extends between Lake Washington and Lake Union, was the final link in the route and was completed in 1917. Official dedication of the Locks project occurred on July 4, 1917. Other related activities that occurred around the same time included closure of the historic outflow of Lake Washington into the Black River in 1912 and concomitant rerouting of the Cedar River into the lake. Although the Locks have since undergone several structural modifications and improvements including construction of a saltwater intrusion barrier in 1966 and a new fish ladder in 1976, the entire LWSC project has effectively influenced anadromous fish passage and migration from the time they were constructed through to the present day.

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

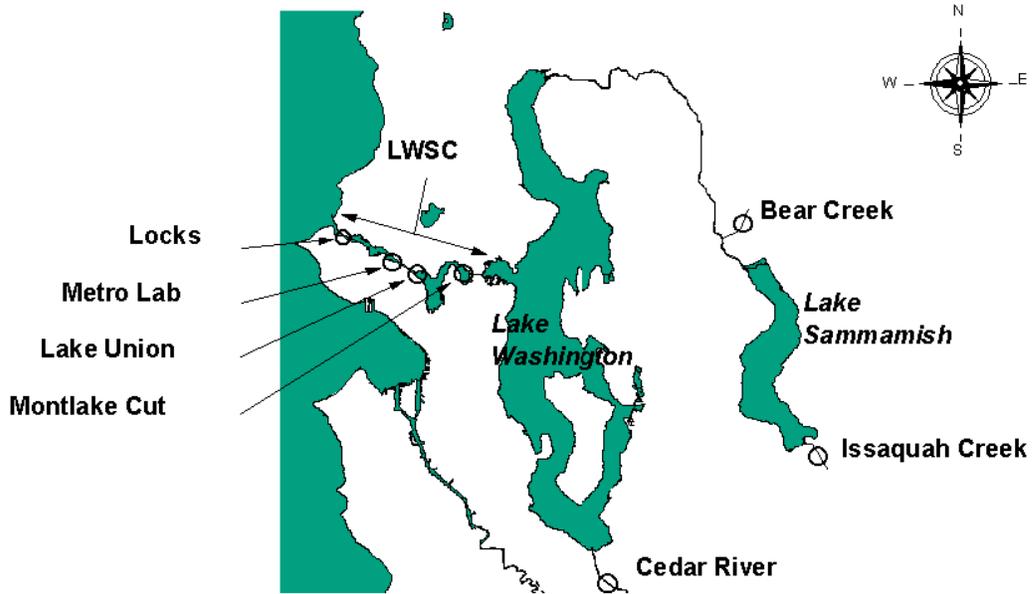


Figure 1-1. Locations of the Lake Washington Ship Canal (LWSC), Hiram M. Chittenden Locks, and PIT-tagged fish releases in the Seattle area, Washington.

## 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 unwatering 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.

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

Saltwater intrusion is an important concern, particular with respect to managing water quality of Lake Washington and Lake Union, because of the concern that the resulting density stratification and water quality attributes of the lakes could transform their deeper areas into sterile, anaerobic waters. The Washington Department of Ecology has correspondingly set water quality standards, where the salinity in the LWSC at the University Bridge may not exceed 1 ‰ (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

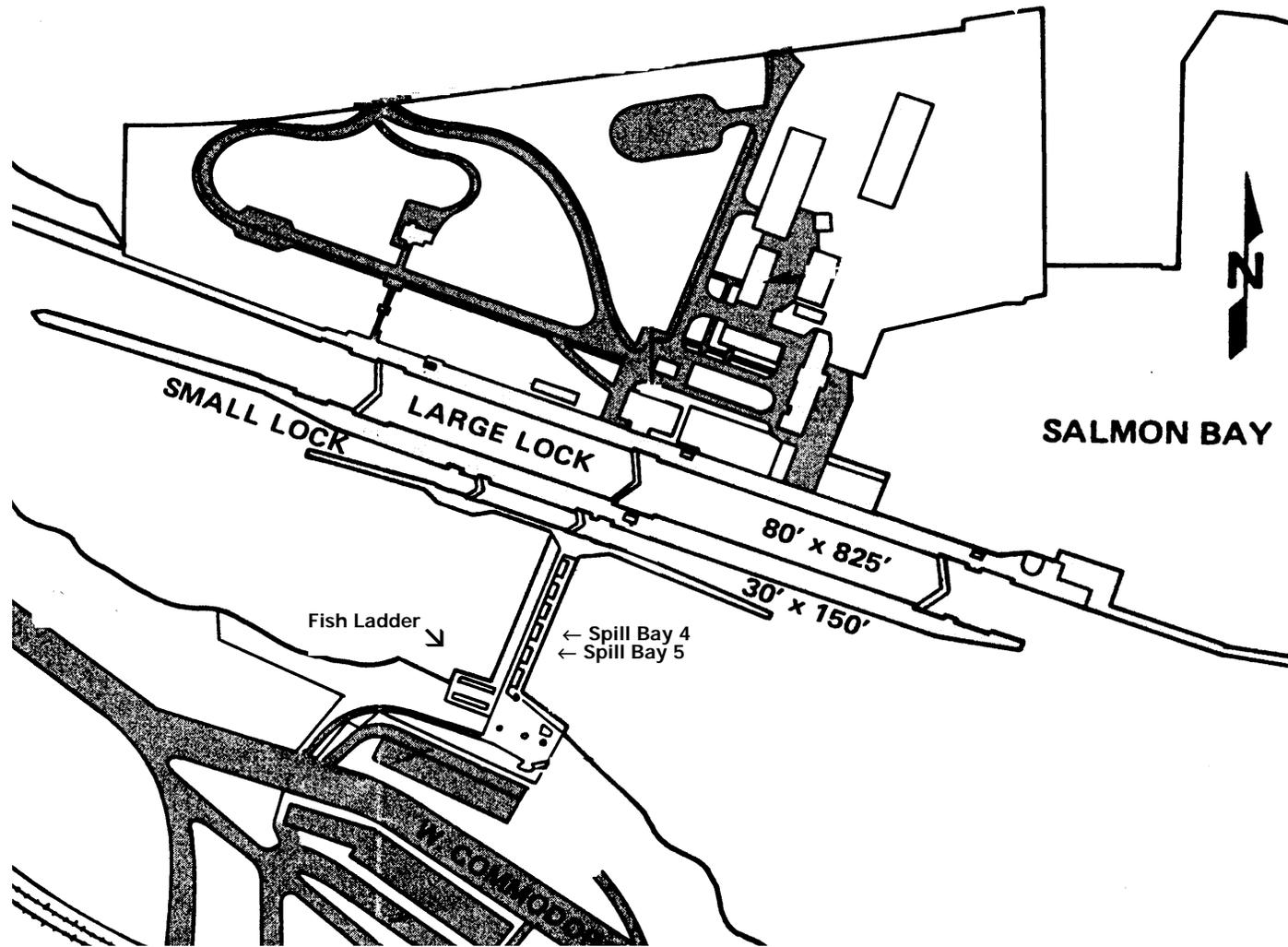


Figure 1-2. Plan view of the Hiram M. Chittenden Locks showing major structural features and location of tunnel readers in spill bays 4 and 5.

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 8.5 m<sup>3</sup>/s (300 cfs) and returns water downstream.

The spillway dam consist 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<sup>3</sup>/s (18,200 cfs) at the maximum regulated Lake Washington elevation of 6.7 m (22'). Beginning in May 2000, four seasonal smolt passage flumes (smolt flumes) have been installed in bays 4 and 5 with the goal of passing downstream migrating juvenile salmonids by the locks (the flumes will be installed in April in each following year). These flumes replaced a prototype 'smolt slide' that was installed initially in 1995 for the same purpose of passing smolts downstream of the Locks.

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

There are four seasonal periods of operation: the winter holding period (low pool), the spring refill period, the summer conservation holding period (full pool), and the fall drawdown period. The lake elevation is maintained at the minimum level (6.1 m) during winter months to allow for maintenance on docks, walls, etc. by businesses and lakeside residents, minimize wave and erosion damage during winter storms, and provide storage space for high inflows during flood events. The spring refill period begins February 15 and continues until generally the first week in May when the lake reaches 6.66 m (21.85'), which is slightly less than the full pool level (6.7 m; levels can reach this depending on water availability). The spillway gates (and also now the flumes when appropriate) are operated to keep the lake elevation near its maximum authorized normal level of 6.7 m. The upper limit is dictated by physical design restrictions of the spillway

gates and requirements of lake-associated infrastructure. Water demands of the locks, the saltwater drain, the fish ladder, and the flumes result in the lake elevation gradually lowering, beginning in late June to late July depending on water availability. The Water Conservation Plan that is in effect at the Locks attempts to maintain lake levels at or above the 6.1 m level as much as possible (70% historic reliability level). It is not always possible, however, to maintain this elevation during abnormally low water years and when higher than usual saltwater intrusion associated with lock openings requires additional flushing.

## **1.2 CONTEXT AND PURPOSE OF THE PIT TAG STUDY**

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

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

- Developing smolt survival (mortality) estimates for each salmon species migrating through the LWSC and Locks;
- Identifying major limiting factors contributing to smolt mortality; and
- Identifying and assessing possible structural and non-structural restoration measures that may improve smolt survival.

Objectives for monitoring during year 1 (2000) of the LWGI Study were:

- Evaluate the efficacy of PIT-tagging as a means to estimate mortality for wild and hatchery fish;
- Monitor fish passage through major outlets at the Locks (including studies under the LWSC Section 1135 Project) – four new smolt passage flumes, the large lock culvert intakes, the saltwater drain, and spillway gates; and
- Begin development of smolt mortality estimates for each salmon species migrating through the Locks via major pathways (i.e., the fish ladder, smolt passage flumes, two navigation locks, and the saltwater drain intake) and using the mortality estimates to evaluate each of the pathways or passage structures and the effects of water conservation.

Results are presented in this report that address the following objectives specific to the first year PIT tag assessment component of the LWGI study:

- Evaluating the efficacy of PIT tagging as a means for estimating survival of hatchery fish as they migrate through different portions of the Lake Washington and LWSC system;
- Evaluating the efficacy of PIT tagging naturally-reared smolts in tributaries to Lake Washington and in the LWSC; and
- Assessing whether hatchery-reared chinook salmon are a good model for evaluating the effects of the LWSC project on naturally-reared fish.

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

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

## 2. METHODS

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

### 2.1 PIT TAG TECHNOLOGY

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

The distance at which a PIT tag may be detected is relatively short, however, 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.

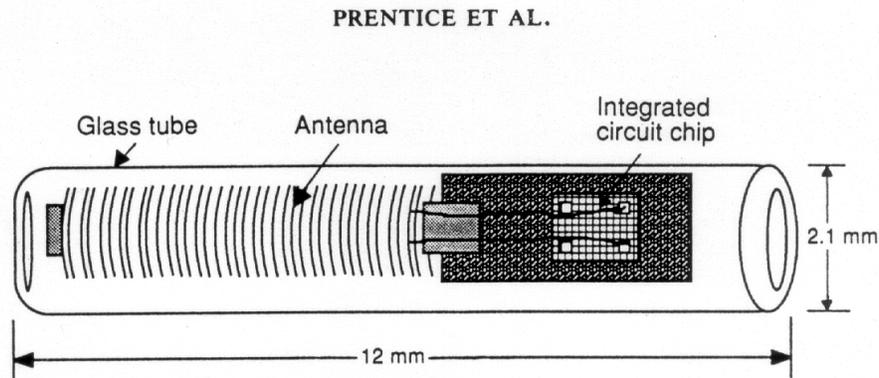


Figure 2-1. Schematic of a Passive Integrated Transponder (PIT) tag (from Prentice et al. 1990a).

## 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). The side walls 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<sup>3</sup>/s (50, 130, 90, and 130 cfs) for flumes 4A, 4B, 5C, and 5B, respectively. Outflows were 0.34, 0.42, 0.40, and 0.42 m<sup>3</sup>/s (12, 15, 14, and 15 cfs), respectively. The difference between inflow and outflow is the amount that passed through the screen walls of the flumes, and was designed to facilitate visual monitoring or capture of smolts passing through the flumes.



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



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

The tunnel readers used were Destron-Fearing 134.2 kHz PIT tag monitors. Each tunnel reader contained two independent sets of coil and electronic components that detected and recorded PIT tags separately as they passed through the reader (Figure 2-3). The tag numbers were stored on a computer located in the fish ladder maintenance room. The MULTIMON computer program was used. This program automatically created a new file each day and stored a complete record of detections and self-testing logs for each coil. Relevant data included PIT tag numbers, identification of the coil that detected the tag, and the time and date of detection. MULTIMON also allowed diagnostic communication with each coil, including downloading of data stored in electronic buffers designed into the coil circuitry, to compare with the data stored by MULTIMON. Data were retrieved from MULTIMON at least once a week and the PIT tag information extracted using a Fortran program that was written to filter out other information and pre-process the data prior to QA/QC checking and subsequent data analyses.

### **2.3 TAGGING, HOLDING, AND RELEASE OF FISH**

PIT tagging was conducted for three main study groups:

- Calibration groups were tagged and released into the smolt slides. This was done to determine the detection efficiency of the tunnel readers installed at the Locks;
- Experimental groups were tagged and release above the locks to evaluate passage characteristics of hatchery fish using the new smolt slides; and
- Predominantly naturally-reared fish groups were caught, tagged, and released at different locations in the Lake Washington watershed to evaluate passage characteristics of naturally-spawned fish using the new smolt slides. Hatchery fish were also caught, tagged, and released at some locations.

Specifically, tagging was conducted at six locations (Figure 1-1):

- At the University of Washington (UW) fish hatchery located near the west end of the Montlake Cut;
- At the King County/Metro (Metro) Environmental Laboratory;
- In Lake Union, offshore from Gasworks Park;
- At the WDFW juvenile outmigrant smolt traps located in the Cedar River, Bear Creek, and Issaquah Creek.

All tagging was conducted by experienced biologists using methods described by Prentice et al. (1990c). C.S. McCutcheon, B.A. Turley, and D. Park of Biomark Inc. were responsible for tagging all but the Lake Union fish, which were tagged by S. Achord of NMFS (letter reports from each are presented in Appendix A). Tagging operations involved insertion into the abdominal cavity using a large bore syringe, and measuring the length of the fish on a custom digitizing pad. Data for individual fish were collected using one or two data collection stations (Biomark brand) equipped with Pacific States Marine Fisheries Commission (PSMFC) software (PITTAG2.EXE). The PIT tag number and fish length data were scanned into a PIT Tag Information System (PTAGIS) format file for submission to the PSMFC database maintained in Portland, Oregon (the files were edited for mortalities and tag loss before submission). After tagging, the needles on the syringes were disinfected in an ethyl alcohol bath for a minimum of 10 minutes before being reloaded and reused. Twenty-four-hour post-tagging mortalities were noted for the fish held at the UW hatchery, metro, and selected groups of the fish captured in Lake Union.

Releases of PIT tagged fish were designed to address questions regarding (i) differential survival rates along portions of the migration route, and (ii) the nature and variation of outmigration characteristics in the Lake Washington watershed. Release locations are depicted in Figure 1-1. 24-hour post-release mortality was not determined for any of the release groups.

### **2.3.1 UW and Metro Laboratory Fish**

Approximately 10,000 age 0+ chinook salmon originating from the Issaquah Creek hatchery were held at the UW hatchery as eight groups in four 4.9 m long by 0.9 m wide by 0.9 m deep (16' x 3' x 3') raceways, of which two were divided into two compartments. The raceways received a continuous supply of untreated lake water. An additional 1200 fish originating from the Issaquah Creek hatchery were held at the Metro Laboratory and divided among eight 0.9 m (3') diameter tanks set up inside in the bioassay lab of the building and a 4.9 m x 0.9 m x 0.9 m raceway set up outside of the bioassay lab. The Metro Laboratory raceway was divided into 8 separate compartments. Water used to hold all fish at the Metro Laboratory consisted of untreated lake water that was chilled when necessary to reach a target holding temperature of 10E C (50E F). All fish were transported from the Issaquah Creek hatchery in mid-April. The fish held at the UW hatchery were designated for release into the LWSC at either the Montlake Cut or the Fremont Cut. The fish held at the Metro Laboratory were designated for release as calibration test fish for evaluating the detection efficiency of the tunnel readers. The fish were provided and managed by K. Fresh of WDFW, who also oversaw design, construction, and

maintenance of all fish holding facilities, care of the fish, and transportation and release of the fish at the respective release locations. King County personnel provided assistance at the Metro Laboratory.

Tagging was conducted on April 18 and 19, 2000 for the UW fish, and on April 20, 2000 for the Metro Laboratory fish. Fish at the UW were removed from their holding tanks using dip nets. Groups of approximately 50 fish were caught using standard dip nets and carried between 30 and 100 feet from the tanks to the tagging tables by WDFW personnel. The fish were anesthetized by WDFW personnel prior to tagging using MS-222, to reduce stress and injury during tagging. Fish at the Metro Lab were also removed using standard dip nets and groups of approximately 60 fish were placed in 19 liter (5 gallon) buckets and carried to the tagging tables by WDFW personnel. Small groups of approximately 20 fish were then dipped and anesthetized prior to tagging. Fish sizes ranged from 45-mm to 85-mm in all groups. Fish smaller than 55-mm were removed from the study and were not tagged. Limited mortality (0.1-1.1%; mean = 0.7%) occurred in either group within several days after tagging, and tag retention rates were high (> 99%).

Based on visual observations of reaction and recovery rate from the anesthetic, short-term tag losses, and mortality rates, variation in fish handling between the UW hatchery and Metro Laboratory may have been associated with greater stress during tagging at the UW tagging site (Biomark observations). The method used at the Metro Lab minimized the time the fish were in the dip nets. The use of other methods such as sanctuary dip-nets, fish augers, or other methods of water to water transfer may have better results in future tagging.

The fish held at the UW hatchery were released on three occasions, on May 26, May 28, and June 1, 2000. On each release date, fish were released as two distinct groups into the LWSC. One group was released near the hatchery, approximately 100 meters west of the Montlake Bridge, and the other was released in front of the Metro Laboratory. Differential detection rates of the two groups can provide an indication of survival between the two release locations, assuming similar detection probabilities. The validity of this assumption, however, depends on whether the two groups move downstream at about the same time, and are randomly mixed when they arrive at the Locks (Burnham et al. 1987; Iwamoto et al. 1994). The bias in survival estimates that results from not meeting the assumption increases with distance between the two release locations in a reach (Dauble et al. 1993).

### 2.3.2 Tributary Fish

Sub-yearling chinook salmon were caught and tagged at three WDFW screw traps (see, e.g., Thedinga et al. 1996 for a description of a screwtrap). The sites were located in (i) lower Bear Creek, below the railroad trestle, downstream of Redmond Way, (ii) in the lower Cedar River just upstream from the Logan Street Bridge; and (iii) in Issaquah Creek just downstream of the SE 56<sup>th</sup> Street Bridge (Figure 1-1). Tagging occurred between May 23 and June 7, 2000, during the peak of the outmigration period for naturally-produced smolts. A primary goal of the releases was to determine survival and migration characteristics of the main portion of the run in each stream.

Fish were collected overnight in the screw traps. On each day of tagging, fish trapped the night before were transferred using sanctuary dip nets to 5 gallon buckets and then to a small tub containing MS-222. A PIT tag was inserted into the anesthetized 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. All or nearly all chinook present in the trap that day were tagged, except for a few fish that were smaller than about 60 mm in length, which were too difficult to handle and for which the tag was large relative to the abdominal cavity size. Figures 2-4 through 2-6 depict the days that tagging occurred in each tributary relative to the run timing. A total of 1149 fish were tagged at the three sites, out of which 273 fish were tagged and released in the Cedar River, 348 in Issaquah Creek, and 528 in Bear Creek. Fish tagged in Bear Creek and the Cedar River were exclusively naturally reared fish, whereas 122 of the 348 tagged in Issaquah Creek were confirmed to be hatchery-released fish.

### 2.3.3 Lake Union Fish

In Lake Union, juvenile chinook, sockeye (*O. nerka*), and coho salmon were captured offshore of Gasworks Park by D. Seiler and other WDFW personnel using a purse seine. Tagging was performed by NMFS personnel (see letter report in Appendix A). The goal was to evaluate whether the three species could be captured and PIT tagged successfully in the LWSC, and determine what proportion of those fish could be detected at the Locks. Capture and tagging occurred during the period of May 17 through May 25, 2000. Sockeye were caught and tagged on May 17, 18, 23, and 24. The first two groups were held and released on May 19, the third group was released on the same day of capture, and the fourth group was held and released on May 25. Coho and chinook were caught and tagged on May 23 and 24. The first group of both

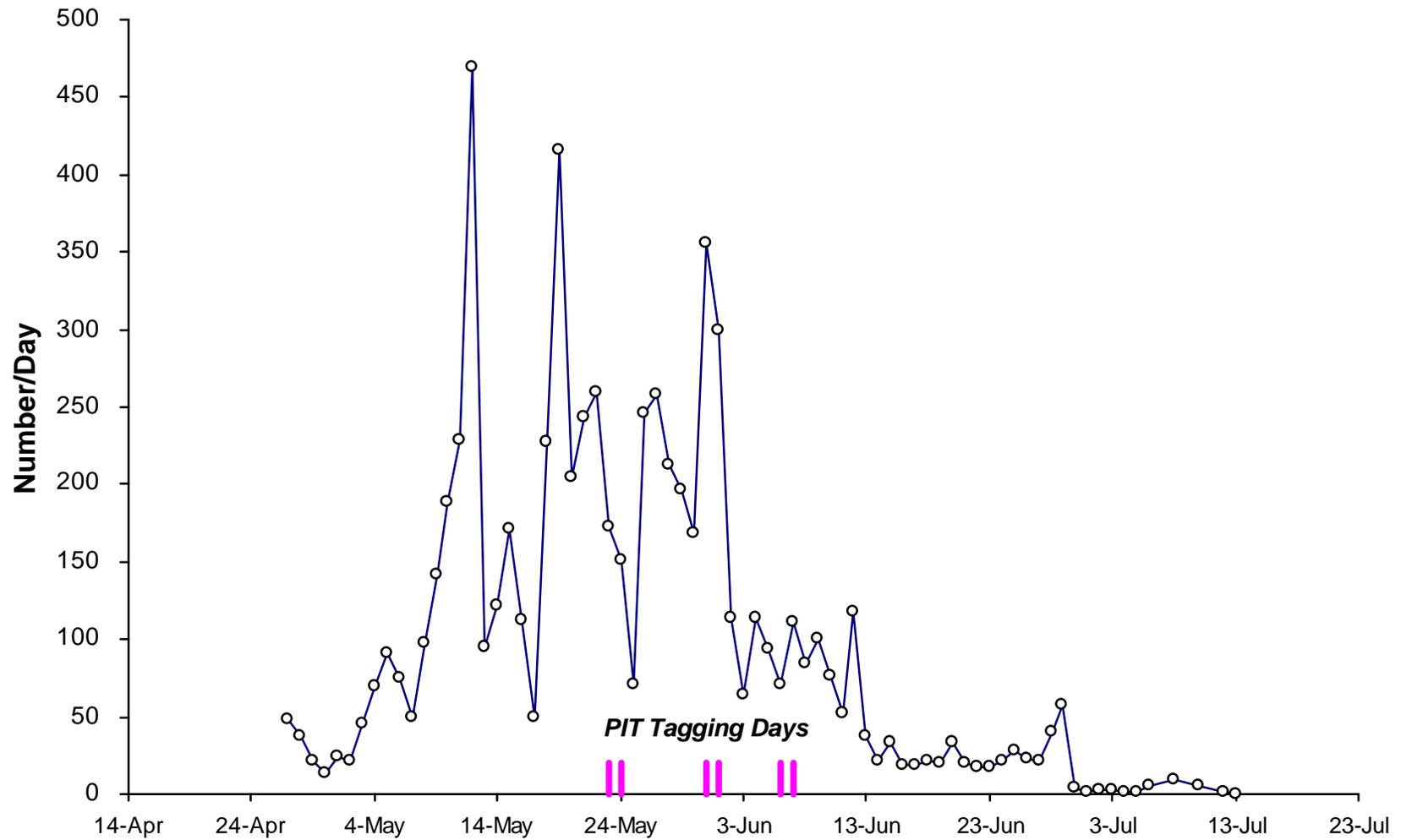


Figure 2-4. Daily catches of young-of-year chinook salmon in the WDFW screw trap in Bear Creek. Days when fish were PIT-tagged are indicated by the vertical bars. Preliminary catch data from WDFW (subject to change).

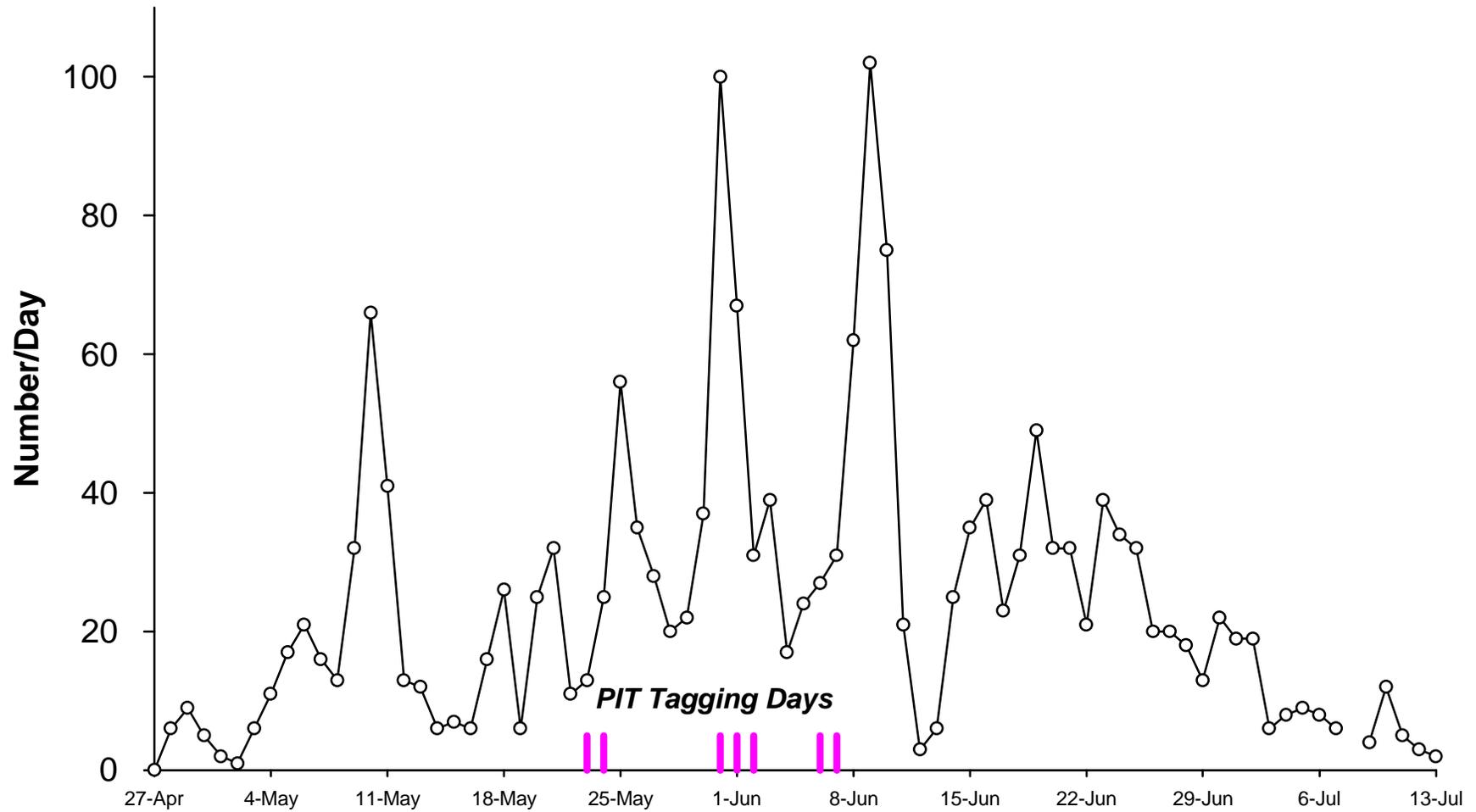


Figure 2-5. Daily catches of young-of-year chinook salmon in the WDFW screw trap in Cedar River. Days when fish were PIT-tagged are indicated by the vertical bars. Preliminary catch data from WDFW (subject to change).

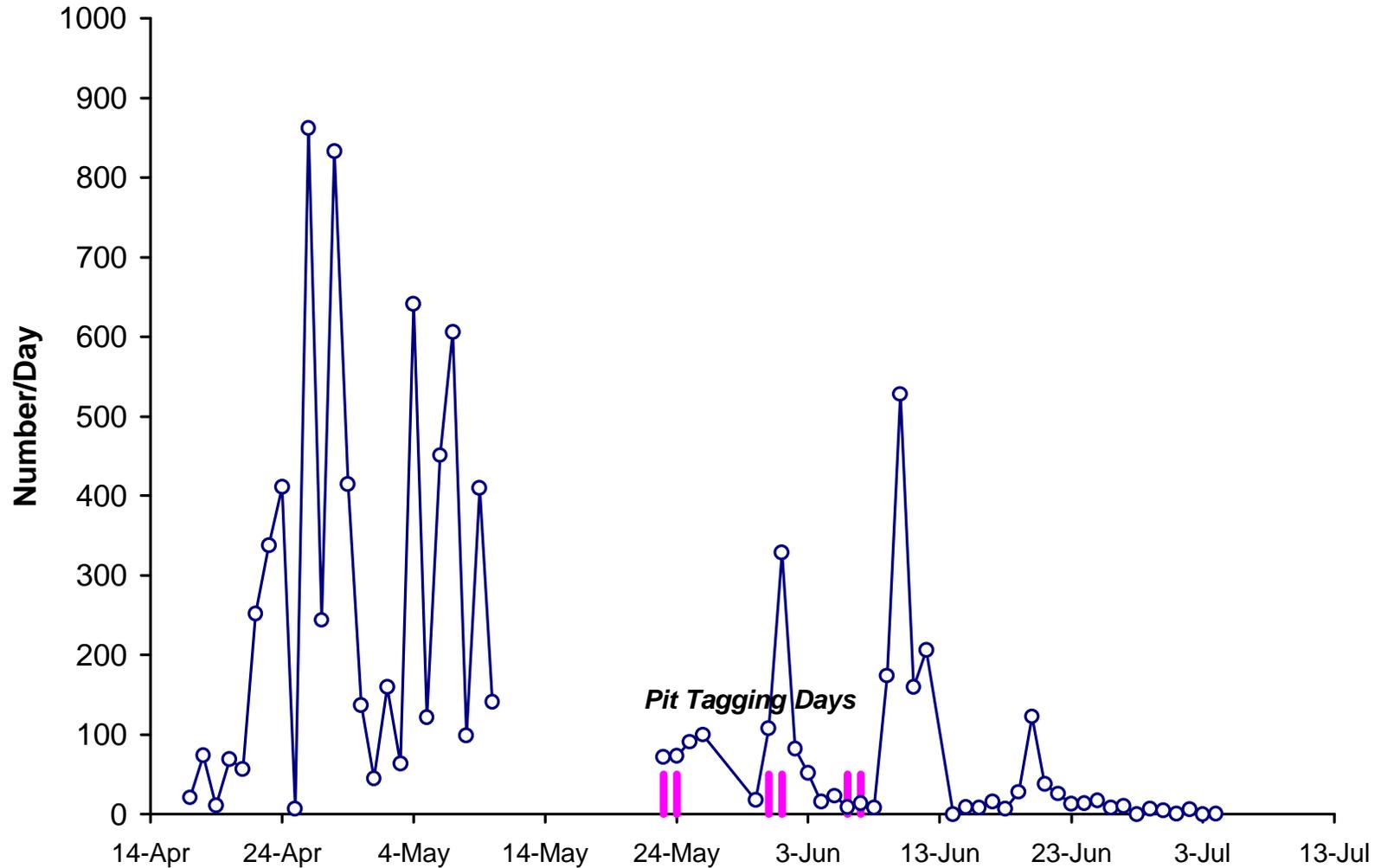


Figure 2-6. Daily catches of young-of-year chinook salmon in the WDFW screw trap in Issaquah Creek. Days when fish were PIT-tagged are indicated by the vertical bars. The trap was out of the water between May 11 and May 22, 2000 to avoid large catches of fish released from the Issaquah Creek Hatchery. Preliminary data from WDFW (subject to change).

species was released the same day of capture, while the second was held and released a day later on May 25.

The captured fish were transported in 114 liter (30 gallon) transfer containers to a NMFS marking barge for PIT tagging that same day. On arrival to the marking barge, fish were transferred to one of two large, oxygenated holding tanks that were continuously supplied with fresh lake water. Fish were transferred from the fish holding tank to another using sanctuary dip nets and anesthetized using MS-222. Fish were PIT tagged one by one and scanned into the PIT tag file. PIT tags were sterilized in alcohol prior to use. Fish length was digitized and comments recorded when appropriate regarding condition of fish or tagging operation details. The tagged fish were then put in the other large fish holding tank on the barge to recover, or in a large live cage that sat in the lake water beside the barge when the fish were held for 24 hours or longer.

After tagging was completed, fish were allowed to recover in the fresh water tank for a minimum of a half hour. All mortalities were scanned and the tags were removed from the tagging files. One mortality was inadvertently missed and not recovered. Fish that were held in the live cages for overnight or longer were dipped from the live cages, anesthetized, and scanned for a PIT tag to confirm it was still in place. These fish were put in a tank on the barge and allowed to recover, then released as described above. Study objectives were to tag approximately 1500 fish total. In all, 511 chinook, 505 sockeye, and 444 coho salmon were released with PIT tags. The three groups of sockeye held between one and two days experienced an average 24 hour post-tagging mortality equal to approximately 3% (a total of 9 fish out of 516 died between tagging and release). None of the tagged coho, and only 1 out of 512 chinook, died between tagging and release.

The marking barge was moved to the release site after tagging. Mortalities were removed, and the remaining fish were subsequently released mid-channel through a 10 cm (4") flexible hose, approximately 100 meters east of the Fremont Bridge to increase their probability of survival from predation (there appear to be relatively few predators in the Fremont Cut; K. Fresh, pers. comm.).

The origin of the fish was not determined, but likely included a large proportion of 1999 brood year chinook and coho that had been released from the University of Washington hatchery on May 22 (these two species were tagged only on May 23 and 25; sockeye were tagged on these days and on May 19 as well).

## 2.4 CALIBRATION TESTING OF THE TUNNEL READERS

Approximately 700 of the 1200 chinook salmon held at the Metro Laboratory were designated as calibration test fish. Calibration test fish were released in small groups on eight separate occasions between May 19 and June 13, 2000 to evaluate the detection efficiency of the tunnel readers. Twelve groups of 55 fish were tagged originally and held separately, but because of unexpected and uncontrollable disease problems that occurred in the LWSC during the study (discussed in Section 3), the number of fish available for calibration tests varied. Calibration testing was halted after June 13, 2000 because the remaining fish held at the UW hatchery and Metro Laboratory were released in lieu of losing them all to disease in the holding facilities.

Groups of between 30 and 55 fish were released directly into the mouth of each flume, either by hand or through an angled PVC pipe. Visual observation by D. Houck, King County using an underwater camera during one of the tests indicated that less than 1% of the fish on average may have escaped from the mouth of a flume during testing (D. Houck, personal communication). Escapees were confirmed directly by the tunnel readers for only the third test, in which four out of the 155 test fish, (2.6%) used were detected passing through the flumes within five hours after the test had concluded. This test appears to have been compromised, however, by the presence of a plywood board partially blocking the entrance to one of the flumes (4B; 55 test fish were fed into the flume; the escaped fish were from this group). The board was not discovered until after the test was completed, and was removed at that time. Hence, the 2.5% escapee rate associated with this test is likely to have been much higher than would be expected under normal calibration testing conditions.

The number of test fish that were detected was determined from the file created by MULTIMON. Detection efficiency was calculated as the ratio of number detected to number released in each flume. Electronic marker notes were placed in the file immediately before each group was released and the time noted in field books so that the detected tag codes and discrete flume tests could be distinguished accordingly.

## 2.5 DETECTION STRATEGY

The study was designed to detect fish at and below the Locks from primarily a feasibility perspective. Hence, not all of the passage routes through the Locks were monitored, and it is possible that a large proportion of tagged fish passed downstream without being detected. This feature of the study influenced the accuracy of survival estimates, but did not substantially influence evaluations of migration characteristics.

The tunnel readers were the primary means for detecting PIT tagged fish released above the Locks and were operated 24 hours a day. Hand held readers were also used to scan for tagged fish in purse seine samples collected in the large lock. All fish caught in the purse seine were released below the chamber, with the center gate kept closed to prevent their re-entrance during subsequent sampling. However, sampling effort was inconsistent over the study period because goals of the purse seining were associated primarily with evaluating entrainment into the filling culverts, and the size of the catches was frequently large. As a consequence, sampling for PIT tagged fish was a secondary objective and scanning was intermittent.

There were no detection facilities or sampling conducted in the small lock, the saltwater drain, or the fish ladder.

PIT tags were scanned for regularly in beach seine samples collected two days a week, twice a month, by B. Footen of the MIT. Sampling effort was relatively consistent throughout the study period. Sampling was conducted at a large number of locations in the inner bay and in Puget Sound proper (Figure 2-7). Fish were held in large tubs and checked for tags by waving the antenna of the hand-held detector through the water among the fish, or by pouring the fish from one bucket into another through the loop of the antenna (it was not determined which method worked best).

Sampling was also conducted periodically for PIT tags in the Sammamish Canal during the spring and early summer of 2000 (E. Jeanes, R2, personal communication), and on one of the days that beach seining was being conducted by WDFW in the north half of Lake Washington, on 15 June, 2000. No tagged fish were detected in either case, indicating that greater sampling effort and release numbers would be needed if detection of tagged fish at different locations of Lake Washington is a future goal.

## **2.6 DATA ANALYSES**

### **2.6.1 Physical Characteristics of the Fish**

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. Fish with PIT tags that were detected in beach seine samples were not measured for length in order to reduce the time of handling and potential for shock. For similar reasons, only a subset of fish detected in the purse seine

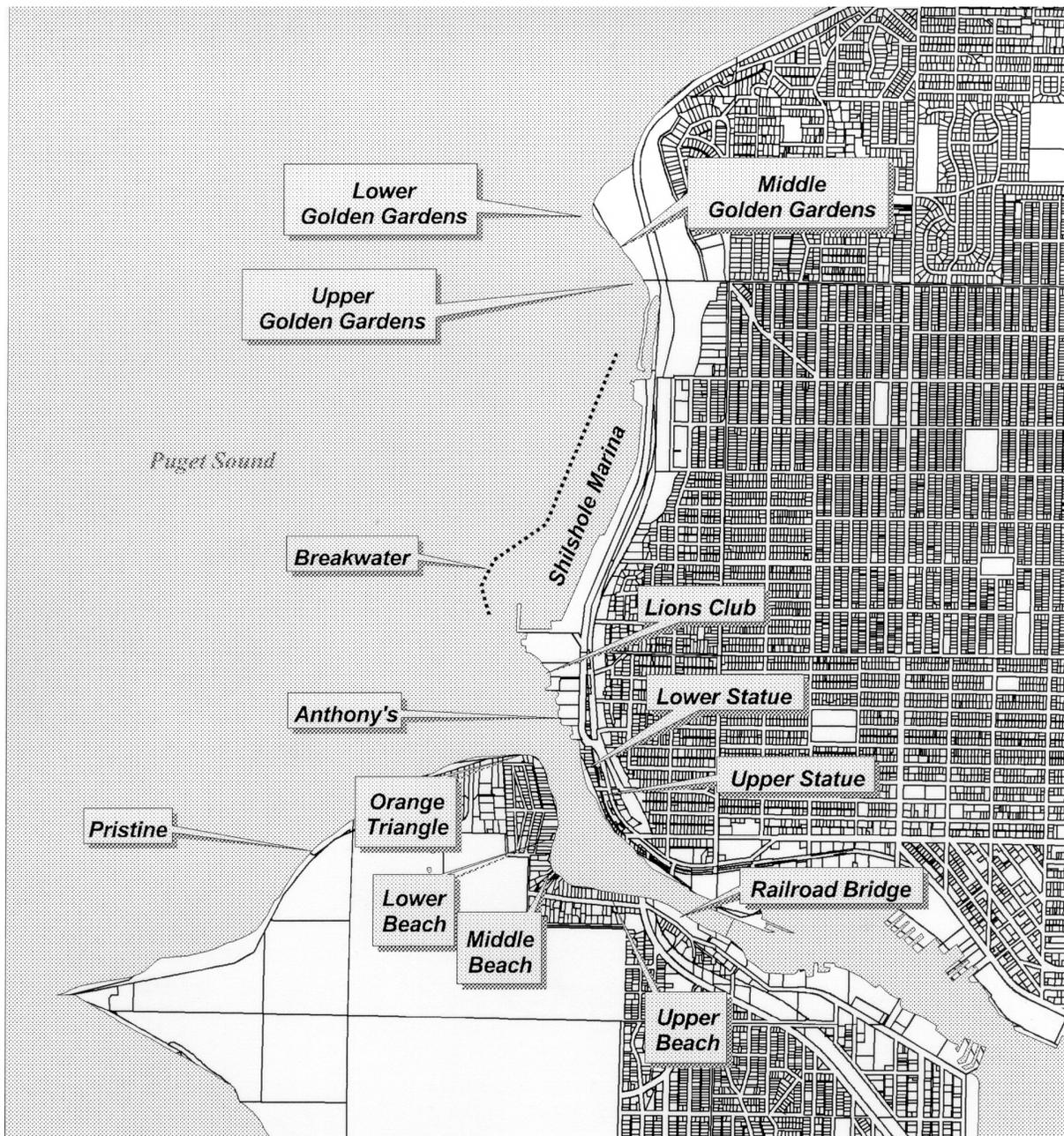


Figure 2-7. Location of beach seining sites sampled by the Muckleshoot Indian Tribe in the inner (top) and outer (bottom) bay areas below the Locks (map from B. Footen, MIT).

sampling in the large lock were measured. Hence, information was not available regarding growth and length at time of passage at the locks. Instead, fish lengths at time of tagging were used 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).

### **2.6.2 Migration Behavior**

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

### **2.6.3 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, as well as preferential passage routes through the Locks. Tag codes were also evaluated for recycling times through the locks, based on repeated detections at the tunnel readers and/or in purse seine samples in the large lock.

To evaluate the influence of filling of the large and small locks on smolt passage through the flumes, detection times were compared with times at which various components of the Locks were operating. Fortran programs were written that counted the number of detections that occurred while (i) the small and large locks were filling and for five minutes thereafter ("fill" period), and (ii) until the time of the next fill sequence ("between-fill" period). Time of lock openings were determined from records maintained by the Lockmaster, and the time for each lock to fill was determined as a function of tide elevation and observations of fill times at different tide levels. In the case of the large lock, the fill time was also a function of whether one

or both chambers were being filled and how fast the water was allowed to flow through the culverts (i.e., continuous, gradual, or intermediate fill patterns). A post-fill period of five minutes was selected arbitrarily (absent specific data), assuming that fish continued to swim about actively for a short period after the velocity field in the spillway dam forebay returned to approximately steady-state, non-fill conditions. The exact time for velocities to return to steady state has not been determined in recent measurements of velocity fields above the Locks, but appears to be less than 5 minutes based on available data (Johnson et al. 2001). Velocity transients associated with density currents when the upper gates open (Lingel 1997) were not considered.

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

#### **2.6.4 Estuarine Behavior**

The dates and times that PIT tagged fish were detected in beach seine samples were compared with detection time and date at the Locks, or with release dates if not detected at the Locks. The intervening times were computed and evaluated with respect to location of release above and capture below the Locks, and salinity characteristics below the Locks. The maximum possible time for transition to saltwater (salinity > 20 ppt) was computed.

#### **2.6.5 Survival Estimation**

Survival could not be estimated to high accuracy or precision because (i) a disease that originated in the LWSC resulted in an unknown post-release loss rate of tagged test fish released in the Montlake cut and at the Metro Laboratory (described in Section 3.0), (ii) low numbers of recaptures below the locks (see Section 3.1), (iii) a control group of PIT tagged fish was not released below the locks to estimate beach seine capture efficiency, (iv) the proportion of tagged fish using the smolt flumes compared with other routes through the Locks was unknown, and (v) problems with tunnel reader detection efficiencies (see Section 3.2). However, it was still possible to use the detection numbers to estimate roughly the relative differences in survival along the migration route, and the order of magnitude of survival possible for a given proportion using the flumes while passing the Locks.

Survivals were estimated for each release group by comparing the number of fish released ( $N_{group\ REL}$ ) with the number of fish detected at the smolt flumes ( $N_{group\ SF}$ ), subject to the proportion using the flumes and the detection efficiency of the tunnel readers. In general, the following steps and assumptions were made to estimate survival over the different portions of the migration route depicted in Figure 2-8.

The total number of PIT tagged fish from each release group passing through the four smolt flumes was estimated using an average detection efficiency for each flume  $i$  ( $E_{SF\ i}$ ; determined during the calibration testing):

$$\hat{N}_{group\ SF} = \sum_{i=1}^4 \hat{N}_{group\ SF\ i} = \sum_{i=1}^4 \frac{N_{group\ SF\ i}}{\bar{E}_{SF\ i}}$$

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

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

This is equivalent to the maximum likelihood estimator of Burnham et al. (1987; p.114). The proportion passing through the flumes (after correcting for tunnel reader efficiency), which is analogous to the probability of detection at the locks, was estimated using the following equation (Burnham et al. 1987; p.114):

$$\hat{P}_{SF} = \frac{m_{t23}}{m_{t13} + m_{t23}}$$

where:

- $m_{t13}$  = Number of PIT tagged fish caught in beach seine samples below the Locks
- $m_{t23}$  = Number of PIT tagged fish in beach seine samples detected in flumes

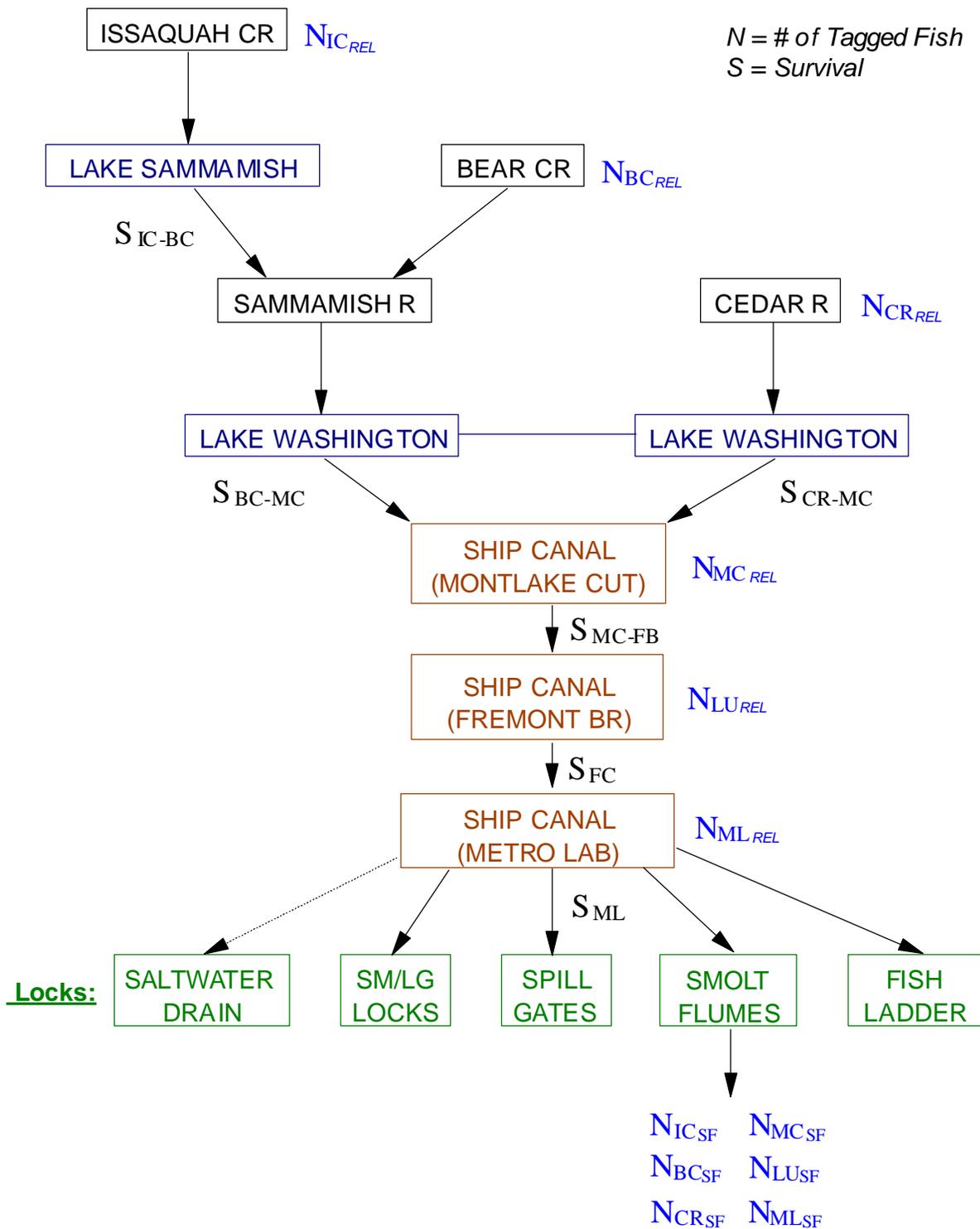


Figure 2-8. Schematic of migration routes in the Lake Washington and LWSC system, and associated survivals along segments of the route. Notation is described in the text.

The variance estimate for the survival estimate is (Burnham et al. 1987; p 115):

$$\hat{Var}(\hat{S}_{group}) = (\hat{S}_{group})^2 \left[ \frac{1}{m_{t12} + m_{t13}} - \frac{1}{N_{groupREL}} + (1 - \hat{P}_{SF})^2 \mathbf{x} \right]$$

$$\mathbf{x} = \frac{1}{m_{t23}} - \frac{1}{m_{t12}} + \left[ \left( 1 - \frac{m_{t23}}{m_{t12}} \right)^2 \left( \frac{m_{t12}}{m_{t13} (m_{t12} + m_{t13})} \right) \right]$$

where:

$m_{t12}$  = Number of PIT tagged fish passing through flumes (assumed unharmed).

The variance estimate for the proportion using the flumes is (Burnham et al. 1987; p 115):

$$\hat{Var}(\hat{P}_{SF}) = (\hat{P}_{SF} (1 - \hat{P}_{SF}))^2 \left[ \frac{1}{m_{t23}} + \frac{1}{m_{t13}} \right]$$

These estimates do not include other sources of uncertainty. One source is error in the detection efficiency estimate. Another is that the chinook held at the UW hatchery and released at the Montlake Cut and Metro Laboratory locations were subject to disease that likely continued to affect them after they were released. The appropriate corrected survival estimates absent the effects of disease for these fish was:

$$\hat{S}_{group} = \frac{\hat{N}_{groupSF}}{\hat{P}_{SF} \hat{S}_{DISEASE} N_{groupREL}}$$

The variance of the disease-survival term could not be estimated, and hence its contribution to the variance of overall survival estimates could not be determined. The other PIT tag releases were unlikely to have been significantly affected by the disease, however. The Lake Union (LU) fish were tagged, released, and passed through the Locks generally before the disease was

noticed in the LWSC, whereas the tributary fish appeared to have arrived in the LWSC after the disease had run its course there among the resident fish.

Survivals along different increments of the route were estimated working in the upstream direction as follows:

- In the Fremont Cut (FC) between the Fremont Bridge (FB) and Metro Laboratory (ML):

$$\hat{S}_{FC} = \frac{\hat{S}_{group=LU}}{\hat{S}_{group=ML}}$$

- From the Montlake Cut (MC) to the Fremont Bridge:

$$\hat{S}_{MC-FB} = \frac{\hat{S}_{group=MC}}{\hat{S}_{group=LU}}$$

- From Cedar River (CR) trap to the Montlake Cut:

$$\hat{S}_{CR-MC} = \frac{\hat{S}_{group=CR}}{\hat{S}_{group=MC}}$$

- From Bear Creek (BC) trap to the Montlake Cut:

$$\hat{S}_{BC-MC} = \frac{\hat{S}_{group=BC}}{\hat{S}_{group=MC}}$$

- From Issaquah Creek (IC) trap to mouth of Bear Creek (assuming negligible mortality between the Bear Creek trap and mouth):

$$\hat{S}_{IC-BC} = \frac{\hat{S}_{group=IC}}{\hat{S}_{group=BC}}$$

The variance of these route-increment-survival estimates can be estimated by the first order approximation:

$$\hat{Var}\left(\hat{S} = \frac{S_1}{S_2}\right) \approx \frac{\hat{Var}(\hat{S}_1)}{(\hat{S}_2)^2} + \frac{(\hat{S}_1)^2 \hat{Var}(\hat{S}_2)}{(\hat{S}_2)^4}$$

For comparative purposes, Ricker's method for small numbers of recaptures was adapted to analysis of the PIT tag data by substituting space for time (Equation 5.3 in Ricker 1975):

$$\hat{S} = \frac{R_{12} \hat{N}_{groupSF}}{N_{groupREL} (R_{22} + 1)}$$

where:

$R_{12}$  = Number of released fish caught in second sampling =  $m_{t13}$

$R_{22}$  = Number of flume detections caught in second sampling =  $m_{t23}$

### 3. RESULTS

In addition to disease (for which the exact pathogen remains unresolved) and relatively low detection efficiency (see below), the results of this study were influenced by water conservation needs. By the end of June, the volume of water available in the lake for operating the flumes, locks, fish ladder, and saltwater drain was critically low. The decision was made by the USACE to shut down all but one flume, and keep it running as long as possible until water was no longer available to operate the flumes. It was decided that the flow would be switched periodically between flumes until then. Figure 3-1 shows the times that the flumes were open during the study, according to logs kept in the lock control tower. In summary, Flumes 4B, 5C, and 5B were open for most of the study period, but there were short periods when they were closed for maintenance, and thus the coverage for PIT tags was not continuous nor consistent. Dates and times that individual flumes and/or tunnel detectors were shut off for maintenance or other reasons are also depicted.

Despite these problems, there were enough PIT tag detections at the Locks and downstream, and the flumes appeared to have operated for long enough that the chinook run appeared to be nearing its end by the time the flumes had shut down and numbers passing the locks had decreased substantially. This was also suggested by the visual flume count data (Johnson et al. 2001). 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. A substantial portion of this section reports on these behavioral features. Rough estimates of survival are also presented, although it must be emphasized that they are likely to be highly imprecise for reasons explained later.

#### 3.1 PIT TAG DATA SUMMARIES

Table 3-1 summarizes numbers of fish and the locations and dates at which they were tagged, released, and detected. Note that the numbers of fish held at the UW hatchery and released at the Metro Laboratory are not the same fish as those held at the Metro Laboratory, which were used primarily for calibration testing. The numbers in the table therefore do not include fish that were destined for calibration testing. All references to releases at the Metro Laboratory are of fish held at the UW hatchery, unless noted explicitly otherwise.



Table 3-1. Summary of PIT tagging and detection numbers for test fish -- 2000 Pilot study (excludes tunnel reader calibration test fish).

Tagging Date	Chinook Held at UW Hatchery						Lake Union Fish			Tributary Chinook				Remaining UW Fish <sup>2</sup>	Totals
	Test 1		Test 2		Test 3		Chinook	Coho	Sockeye	Bear Cr	Cedar R	Issaquah Cr			
	Metro Lab <sup>1</sup>	Montlake	Metro Lab	Montlake	Metro Lab	Montlake						Natural	Natural		
<b>NUMBERS TAGGED</b>															
4/17, 4/18	1086	1078	1100	1107	2137	1107								495	8110
5/17								38							38
5/18								62							62
5/23							499	417	312	105	6	39	20		1398
5/24							13	27	104	60	19	29	41		293
5/31										101	49	20	71		241
6/1										76	112	30	75		293
6/2											26				26
6/6										96	30	3	6		135
6/7										87	31	1	13		132
<b>Totals</b>	<b>1086</b>	<b>1078</b>	<b>1100</b>	<b>1107</b>	<b>2137</b>	<b>1107</b>	<b>512</b>	<b>444</b>	<b>516</b>	<b>525</b>	<b>273</b>	<b>122</b>	<b>226</b>	<b>495</b>	<b>10728</b>
<b>NUMBERS RELEASED</b>															
5/19									95						95
5/23							498	417	309	105	6	39	20		1394
5/24										60	19	29	41		149
5/25							13	27	103						143
5/26	1021	970													1991
5/28			1039	1055											2094
5/31										101	49	20	71		241
6/1					1655	985				76	112	30	75		2933
6/2											26				26
6/6										96	30	3	6		135
6/7										87	31	1	13		132
6/10														206	206
<b>Totals</b>	<b>1021</b>	<b>970</b>	<b>1039</b>	<b>1055</b>	<b>1655</b>	<b>985</b>	<b>511</b>	<b>444</b>	<b>507</b>	<b>525</b>	<b>273</b>	<b>122</b>	<b>226</b>	<b>206</b>	<b>9539</b>

Table 3-1. Summary of PIT tagging and detection numbers for test fish -- 2000 Pilot study (excludes tunnel reader calibration test fish).

Flume	Chinook Held at UW Hatchery						Lake Union Fish			Tributary Chinook				Remaining UW Fish <sup>2</sup>	Totals
	Test 1		Test 2		Test 3		Chinook	Coho	Sockeye	Bear Cr	Cedar R	Issaquah Cr			
	Metro Lab <sup>1</sup>	Montlake	Metro Lab	Montlake	Metro Lab	Montlake				Natural	Natural	Hatchery	Natural		
<b>TOTAL NUMBER DETECTED AT TUNNEL READERS</b>															
<b>4A</b>	1	0	0	0	0	0	0	1	1	0	0	0	0	0	3
<b>4B</b>	42	18	39	23	54	20	34	19	32	8	3	0	0	2	294
<b>5C</b>	44	29	52	35	85	41	30	13	16	8	12	1	0	2	368
<b>5B</b>	76	36	101	54	117	51	62	27	81	21	20	0	1	3	650
<b>Totals</b>	<b>163</b>	<b>83</b>	<b>192</b>	<b>112</b>	<b>256</b>	<b>112</b>	<b>126</b>	<b>60</b>	<b>130</b>	<b>37</b>	<b>35</b>	<b>1</b>	<b>1</b>	<b>7</b>	<b>1315</b>
<b>Percent of No. Released</b>	<b>16%</b>	<b>9%</b>	<b>18%</b>	<b>11%</b>	<b>15%</b>	<b>11%</b>	<b>25%</b>	<b>14%</b>	<b>26%</b>	<b>71%</b>	<b>13%</b>	<b>0.8%</b>	<b>0.4%</b>	<b>3%</b>	
<b>TOTAL NUMBER DETECTED IN LARGE LOCK SEINING</b>															
	1	0	1	0	4	1	2	1	0	0	0	0	0	1	11
<b>TOTAL NUMBER DETECTED IN BEACH SEINING</b>															
	1	0	2	1	1	0	3	1	0	0	0	0	0	5	14

<sup>1</sup> - 19 fish from this group were used in calibration tests and are not included in the numbers presented in this column

<sup>2</sup> - 495 fish from this group were used in calibration tests; there were also 7 mystery tags detected at flumes that were not in tagging file records.

Immediate tagging mortalities and losses were negligible (0.1% to 1.5% at the UW hatchery, mean = 0.7%); losses were associated primarily with disease problems in the raceways while fish were being held until the planned release date. There were seven tags identified by the tunnel readers, one tag in the large lock, and five tags recorded in field notes during beach seining that were not identified in the original tagging files, and that either represent a code identification error on the part of the tunnel reader or note taker, or were inadvertently not recorded during tagging activities. This is because some of the hand-held readers were not set in store mode; this problem will be rectified in 2001.

### **3.2 CALIBRATION TESTING AND FLUME/TUNNEL READER OPERATION PROBLEMS**

There were several problems in the study that need to be corrected or re-evaluated in future studies. Most significant was the poor detection efficiency of the tunnel readers. Figure 3-2 depicts the results of the calibration tests, in which it can be seen that detection efficiency was highly variable, and ranged generally between 50% and 90% for the three flumes nearest the fish ladder, and less than 25% for the small, northernmost flume (4A). 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).

Flume 4A was turned off twice during the study because of poorly- or non-performing coils in the tunnel reader that were influenced by low signal-to-noise ratios. The first time the tunnel reader and flume was turned off was because one of its two coils would not work correctly. Once that coil was replaced, the flume was opened for a few days until a subsequent calibration test indicated that the reader was still suffering from low efficiency, at which point it was decided to close the flume for the duration of the 2000 study. There was too great a risk of missing a large number of PIT tags, and the other tunnel readers were operating more effectively.

It was determined during the study in consultations between the USACE and J. Sadler of Biomark that the flumes were vibrating at a frequency that likely was interfering with the ability of the readers to detect PIT tags. The vibration was a consequence of cantilevering the flume and tunnel reader out over the face of the spillway dam. This is the only installation of PIT tag readers where they are not rigidly supported (D. Park, Biomark, personal communication); in all other applications, including approximately 200 installations on the Columbia River, the tunnel readers are bolted directly down to concrete which eliminates the possibility of vibration. In contrast, the cantilevered support assembly constructed at the Locks allowed high frequency

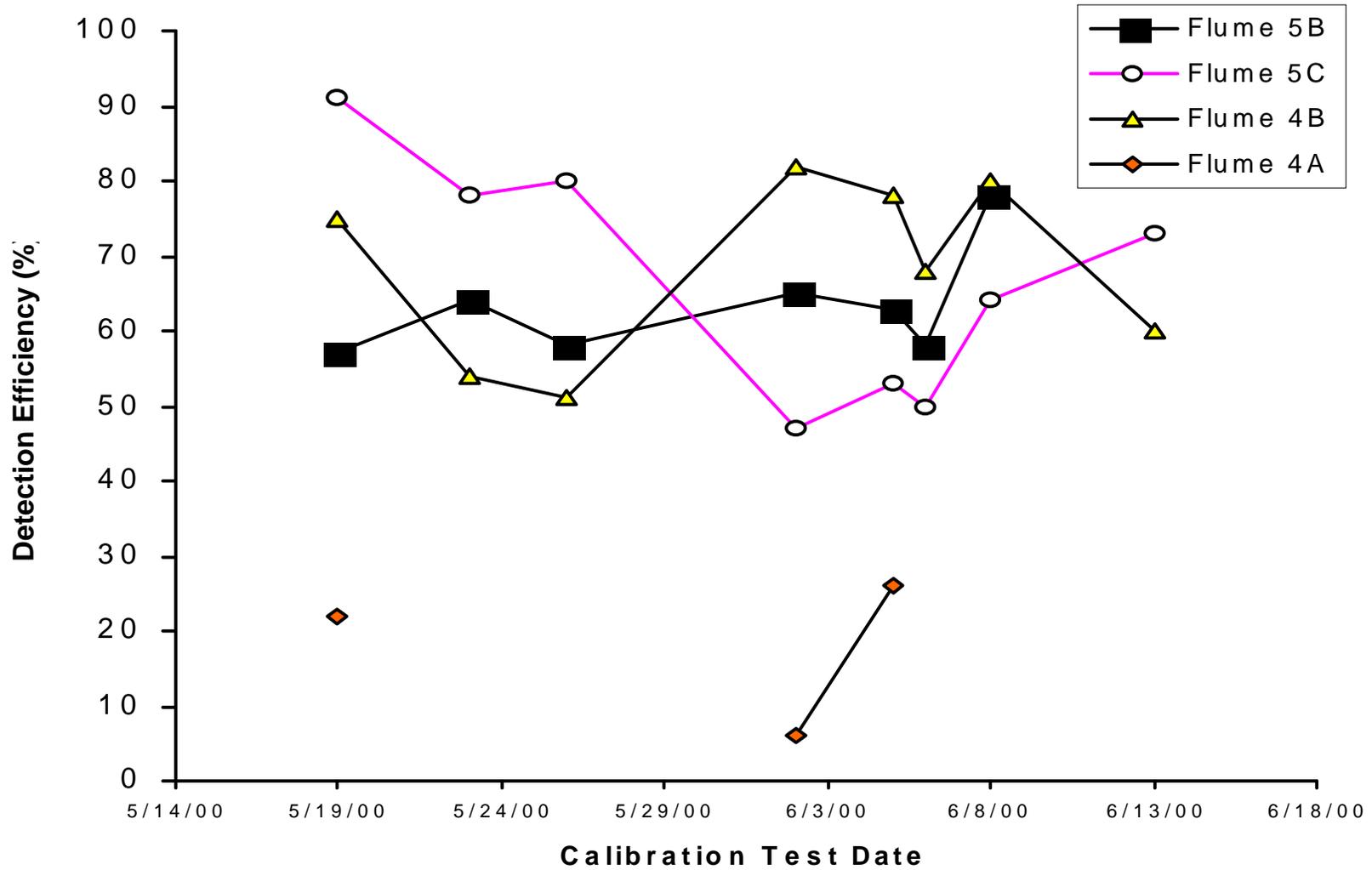


Figure 3-2. Results of calibration tests of tunnel detector efficiency using PIT-tagged fish released directly into the mouth of each flume. Flume 4A was shut down for most of the study.

vibrations to develop in the system. In an effort to reduce the vibrations, large concrete 'Ecology' blocks were placed on the cantilevered support platforms. This measure reduced, but did not sufficiently correct the vibration problem, which continued throughout the study. Subsequent tests by the Navy using accelerometers determined that the vibration frequency was such that the PIT tag frequencies could be canceled out. As a result, the tunnel readers were detecting PIT tags at a low rate of efficiency. This problem is to be addressed next year by making appropriate structural modifications to the flume support assembly.

There were several other incidental operation-related problems that resulted in breaks in the monitoring period as indicated in Figure 3-1. At around 9:00 pm on May 22, the data collection mode of the MULTIMON program had been turned off by an unidentified Locks employee who had accessed the computer in the fish ladder maintenance room for unknown reasons. This was discovered the next day in the course of conducting the second calibration test, and the program was restarted in data collection mode. A warning sign was placed on the keyboard, and there were no further occurrences. The buffer of each coil was downloaded and compared to the records maintained by MULTIMON to evaluate whether any PIT tagged fish had been missed during that period, and it was confirmed that no tagged fish had passed during the seventeen hour period that the program was not recording. However, comparison of the buffer files with the calibration test data indicated a potential hardware problem in which the first tag recorded in the buffer after restarting the program was not recorded by MULTIMON. This occurred for five of the six coils in operation at that time (Flume 4A was closed). Although the effect on the study was not significant given the one-time occurrence, it is noted here as an issue to be aware of in other PIT tag applications.

In a separate incident, the electronics of the tunnel reader attached to flume 5B had not been turned back on by Locks staff after they had completed maintenance activities at the end of the work day on Friday, June 9. The problem was discovered on the morning of June 13 during the eighth and final calibration test, and was corrected immediately after the test by turning the electronics back on inside the tunnel reader's main control panel. The reader had therefore not been recording tagged fish while the flume remained open for over three days, and an unknown number of PIT-tagged fish passed through the flume during that period. Fortunately, a review of the data (see section 3.4) suggested that passage rates were very low during that period. The number of PIT tags missed should therefore not have had a significant effect on the outcome of the analyses presented in this report. Regardless, the eighth calibration test for that flume was a complete loss that day.

Despite these problems, the calibration test results provided an estimate of the average detection efficiency of each tunnel reader. The expected total numbers of PIT-tagged fish passing through the flumes were extrapolated by dividing the numbers in Table 3-1 by the average detection efficiencies for each flume, using the data depicted in Figure 3-2. The resulting estimates are summarized in Table 3-2 for each release group.

### 3.3 FISH LENGTH CHARACTERISTICS

Fish lengths were determined only at the time of tagging, and with the possible exception of the Lake Union fish, should not be used to infer size at time of passage at the Locks. Figures 3-3, 3-4, and 3-5 depict the range and distributions of lengths of fish that were tagged in each group, and compares the distributions with those of the fish that were detected at the Locks. In general, the chinook salmon detected at the Locks were slightly larger in size when compared to the tagging group as a whole, and there were no significant differences in the length distributions of the two test groups released at the UW hatchery and Metro at the 5% significance level (Chi-Square test of expected frequencies; Locks = observed, tagging = expected). Bear Creek chinook detected at the Locks were proportionally larger than the total sample released ( $p=0.033$ , 17 classes), although the result may not be meaningful because the small sample size detected at the Locks ( $n=27$ ) had a large influence on the calculation of the Chi Square statistic. Similarly, the sample size of detections from Issaquah Creek ( $n=2$ ) was too small to test for meaningful differences. Of the Lake Union fish, only the length frequency distribution for coho salmon detected at the Locks was significantly larger in size compared to that of the tagging group ( $p=0.004$ ; 24 classes). In contrast, proportionally fewer of the larger tagged sockeye salmon were detected at the Locks, but the size distributions of the groups were not significantly different at the 5% level. Therefore, with the possible exception of coho salmon, the potential for effects of fish size on migration, passage, or survival statistics derived from the PIT tag detections at the Locks does not appear to have been significant.

The chinook salmon that were caught, tagged, and released in Lake Union were significantly larger on average (mean = 115 mm, standard deviation = 9 mm) than the test fish held at the UW hatchery (mean = 74 mm, standard deviation = 5 mm) or the tributary fish (Bear Creek: mean = 82 mm, standard deviation = 9 mm; Cedar River: mean = 90 mm, standard deviation = 9 mm) (two-tailed t-test;  $p=0.05$ ). Given the dates of capture (May 23 and 25), it is likely that many if not most of the chinook and coho tagged in Lake Union originated from UW hatchery stock released on May 22 (origin was not noted for the Lake Union fish, but more than half of the fish tagged were recalled to have had hatchery markings; S. Achord, personal communication). Because a small number of what appeared to be yearlings were caught in the large lock purse

Table 3-2. Estimated total number of PIT tagged fish passing through flumes.

Flume	Average Detection Efficiency	Chinook Held at UW Hatchery						Tributary Chinook						
		Released 5/26/00		Released 5/28/00		Released 6/1/00		Lake Union Fish			Bear Cr	Cedar R	Issaquah Cr	
		Metro Lab	Montlake	Metro Lab	Montlake	Metro Lab	Montlake	Chinook	Coho	Sockeye	Natural	Natural	Hatchery	Natural
4A	18%	5	0	0	0	0	0	0	5	5	0	0	0	0
4B	69%	60	26	56	33	78	28	49	27	46	11	4	0	0
5C	67%	65	43	77	52	126	61	44	19	23	11	17	1	0
5B	63%	120	57	160	85	185	80	98	42	128	33	31	0	1
ALL		250	126	293	170	389	169	191	93	202	55	52	1	1
<b>Number Released</b>		<b>1040</b>	<b>970</b>	<b>1039</b>	<b>1055</b>	<b>1655</b>	<b>985</b>	<b>511</b>	<b>464</b>	<b>507</b>	<b>525</b>	<b>273</b>	<b>122</b>	<b>226</b>
<b>Percent Passing</b>		<b>24%</b>	<b>13%</b>	<b>28%</b>	<b>16%</b>	<b>24%</b>	<b>17%</b>	<b>37%</b>	<b>20%</b>	<b>40%</b>	<b>10%</b>	<b>19%</b>	<b>0.8%</b>	<b>0.4%</b>

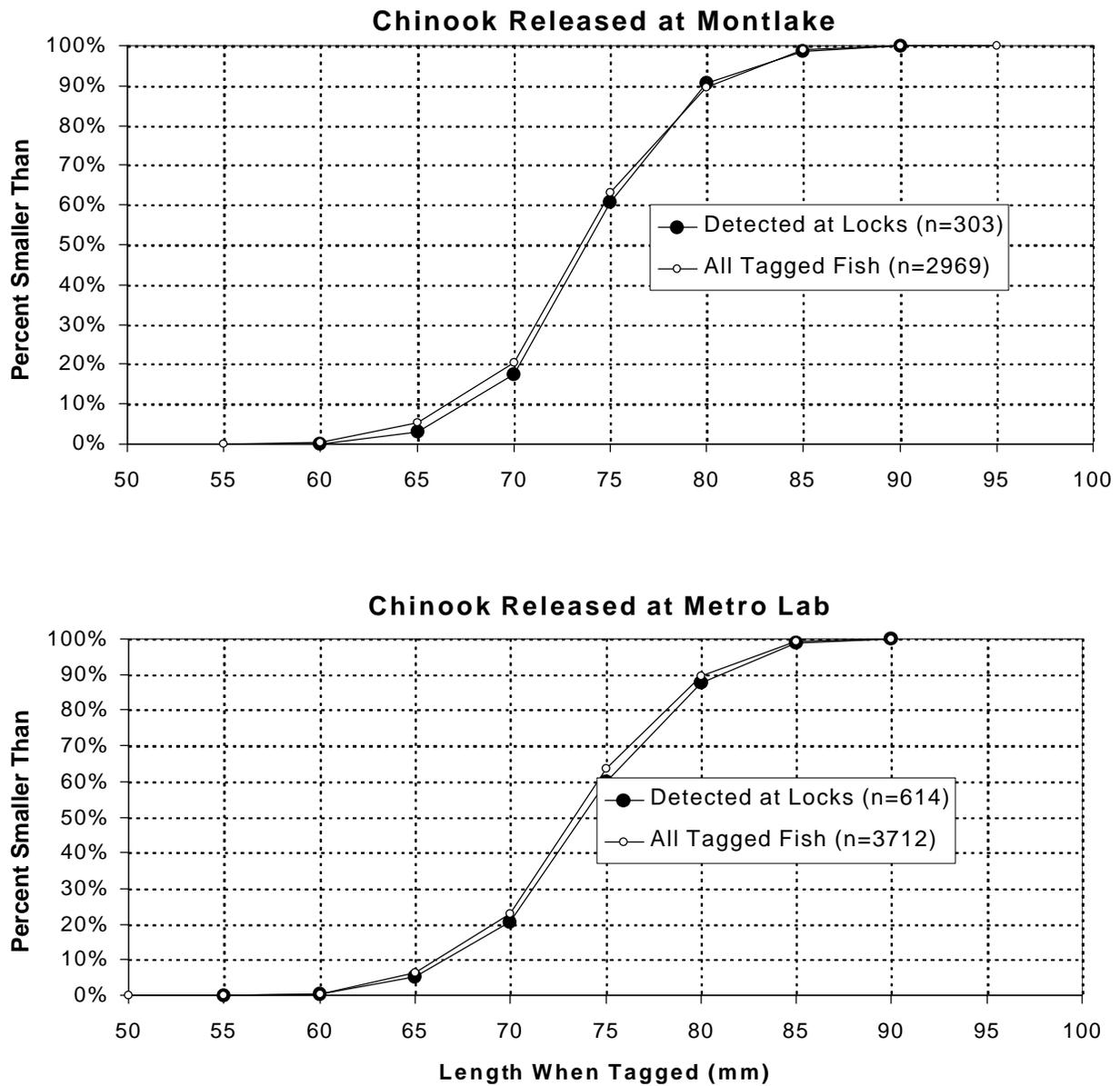


Figure 3-3. Cumulative frequency distributions of lengths of tagged and detected chinook salmon released at Montlake (top) and the Metro Laboratory (bottom).

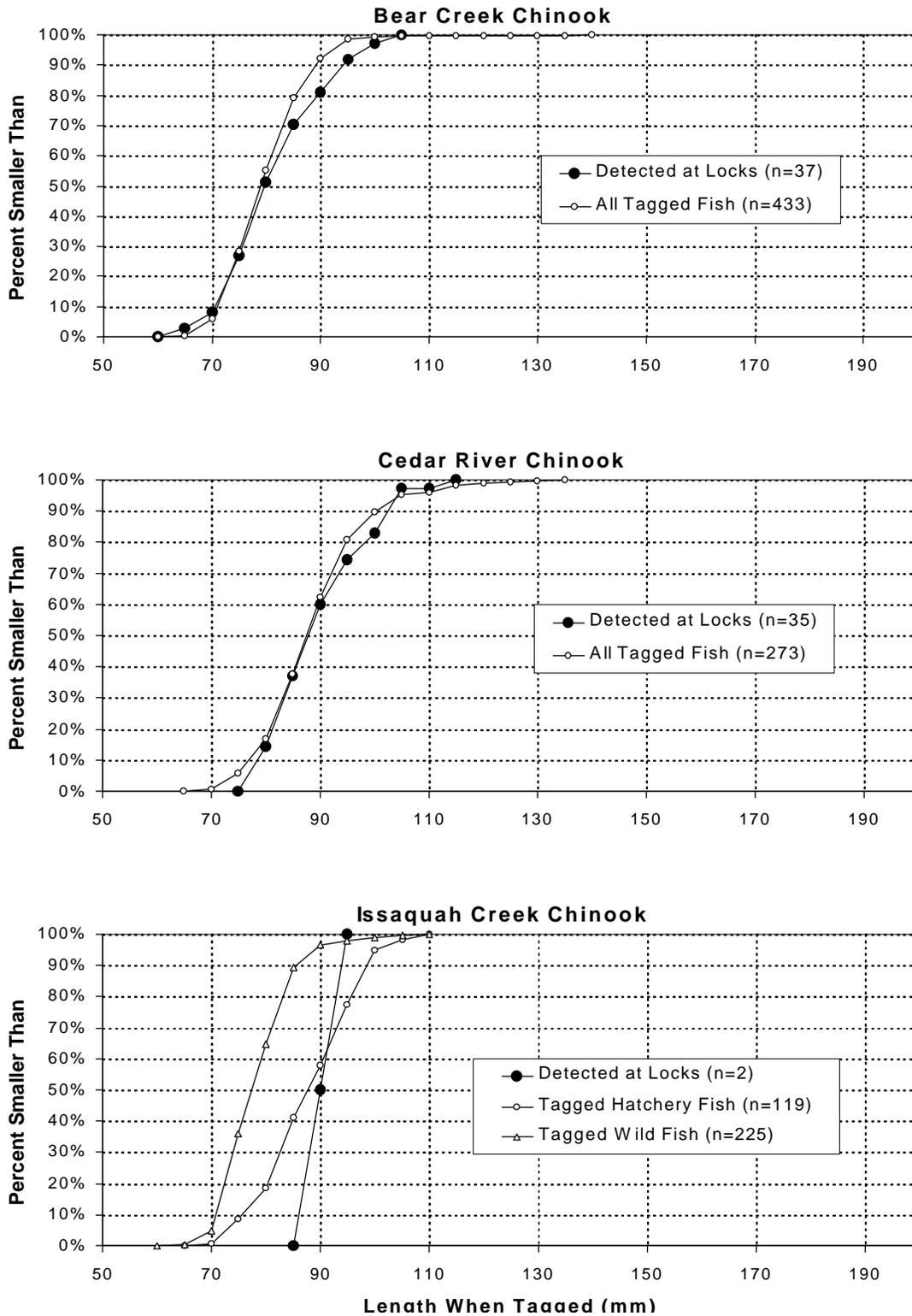


Figure 3-4. Cumulative frequency distributions of lengths of tagged and detected chinook salmon released in Bear Creek (top), the Cedar River (middle), and Issaquah Creek (bottom).

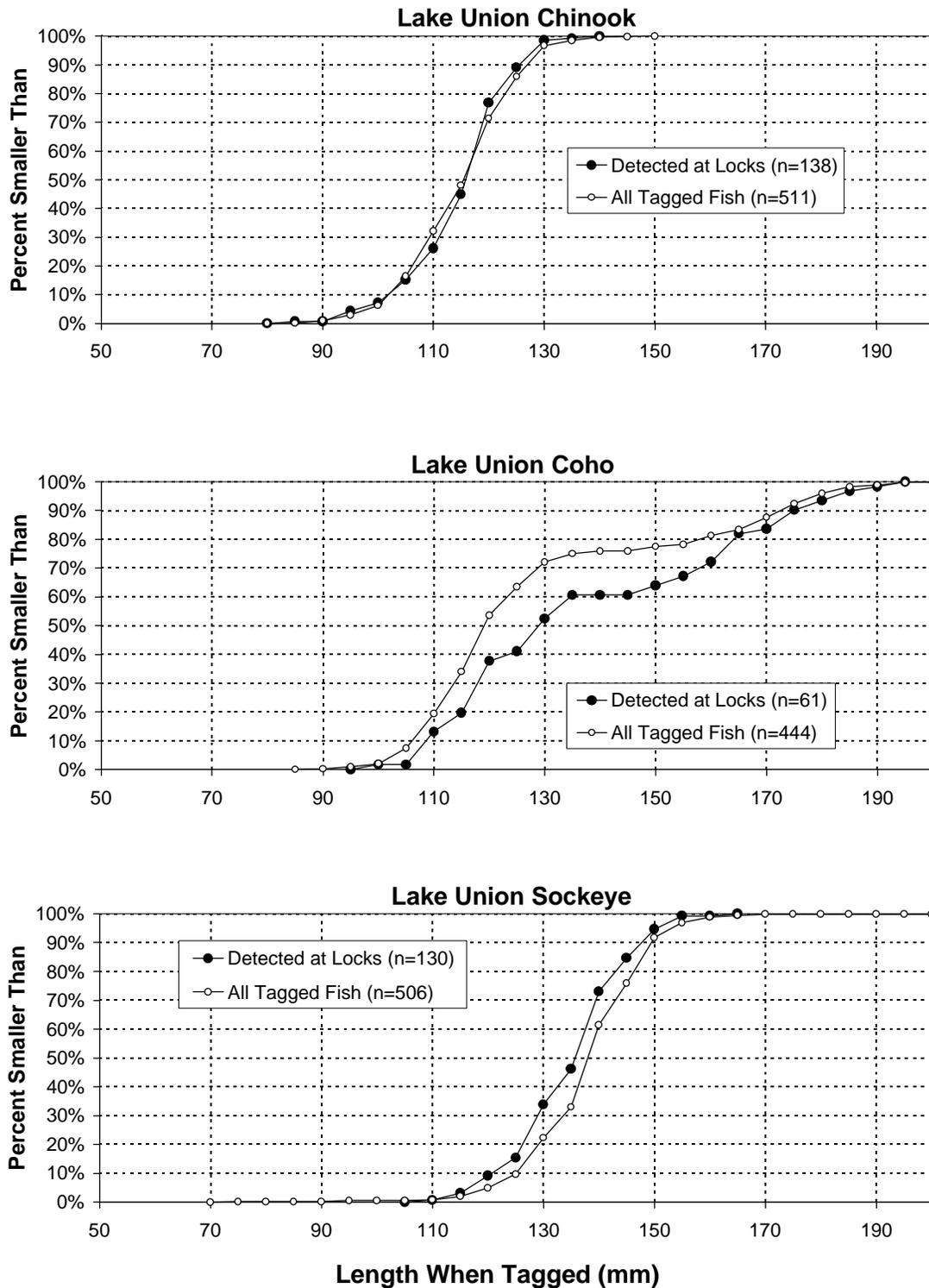


Figure 3-5. Cumulative frequency distributions of lengths of tagged and detected chinook (top), coho (middle), and sockeye (bottom) salmon released in Lake Union near the Fremont Bridge.

seines, including before the UW hatchery's releases (data in Goetz et al., in preparation), it is possible that a few of these fish could have been yearlings given the size range. However, scales were not taken to evaluate this possibility.

### **3.4 MIGRATION BEHAVIOR**

The PIT tag data provided information on arrival date and travel rate to the Locks from the different release locations. The probability appears to be high that the majority of the chinook run had passed through the Locks before the flumes were shut down, because the cumulative distributions of passage timing for each release group had clear inflection points and pronounced asymptotes at their upper ends (Figures 3-6 through 3-8). If the fish were still passing in large numbers relative to the total run size at the time that flumes were shut down, the distributions would have exhibited a steep climb to the 100% level without tailing off as they do in the figures. A similar trend was indicated in the beach seining data (Footen 2000). Because of this, it is likely that the data presented here are representative of the behavior of the majority of the PIT tagged fish that were released and passed the Locks. It is therefore assumed implicitly in this report that the later migrating fish in the tributaries (Figures 2-4, 2-5, and 2-6) speed up en route to the Locks as they get closer to the end of June; this assumption remains to be tested formally.

#### **3.4.1 Migration Timing**

The young-of-year chinook salmon released in the Montlake Cut and at the Metro Laboratory exhibited similar migration behavior. The majority of fish from both release locations passed through the flumes around the same time during the last two weeks in June 2000, irrespective of release date (approximately 90% of the UW releases and 75% of the Metro releases; Figure 3-6). This is seen more clearly in Figure 3-7, in which the distributions of travel time for the three test groups between release and detection were offset at intervals similar to the time between the three release dates. Tagged fish from both release locations passed through the flumes in relatively small numbers until about June 20, at which time numbers increased significantly (Figure 3-6). Proportionally more of the fish released at the Metro Laboratory passed prior to June 20 than fish released in the Montlake Cut, however (Figure 3-7).

Of the fish caught, tagged, and released in Lake Union, sockeye salmon appeared to be outmigrating most actively. More than 90% of the tagged fish had passed through the Locks within 4 days of their release at the east end of the Fremont Cut, by May 27 (Figures 3-6 and 3-8). The coho salmon were also in the midst of their outmigration during the second half of May,

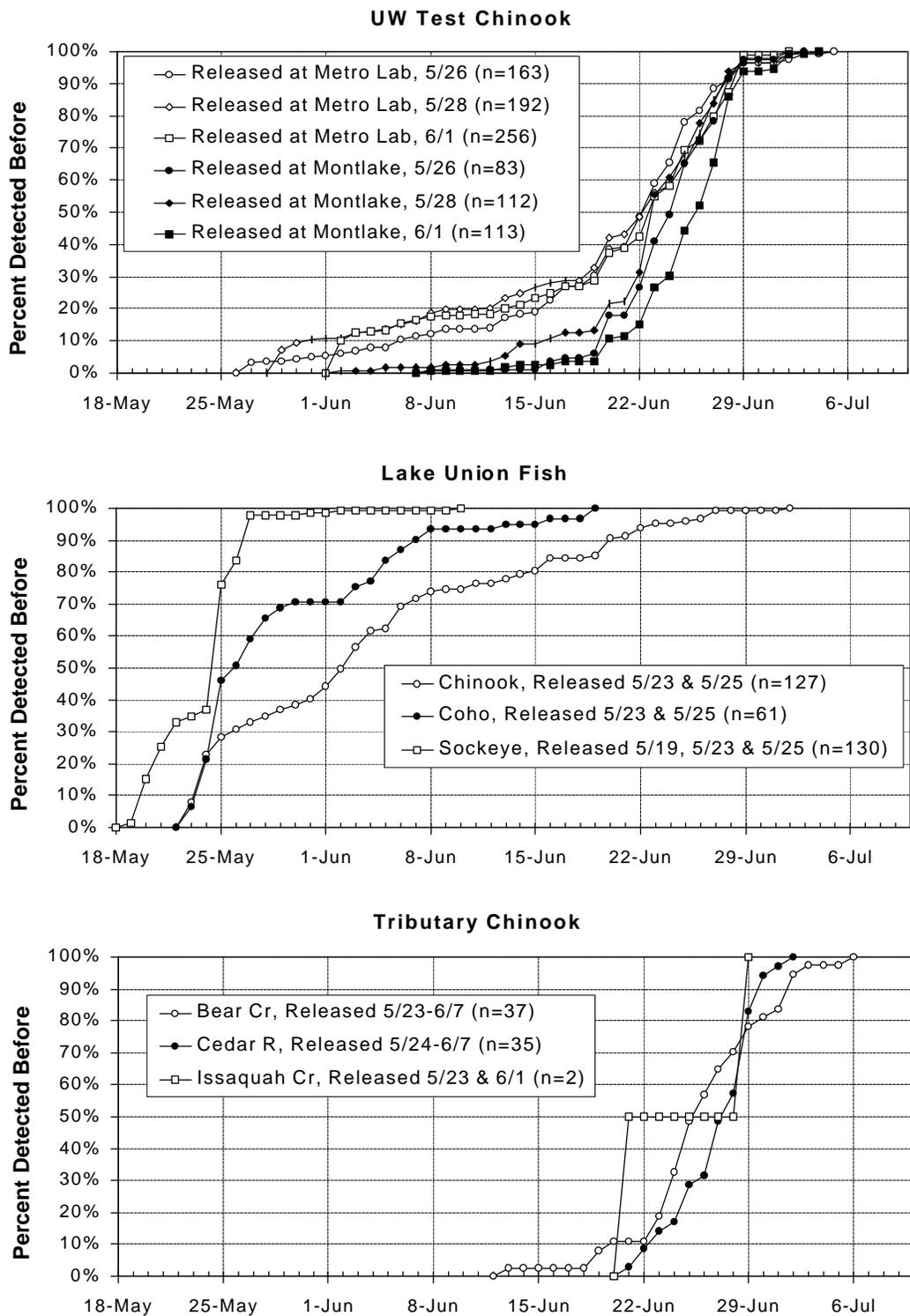


Figure 3-6. Cumulative frequency distributions of dates in the year 2000 at which PIT-tagged juveniles arriving at the Locks were detected passing through the smolt flumes.

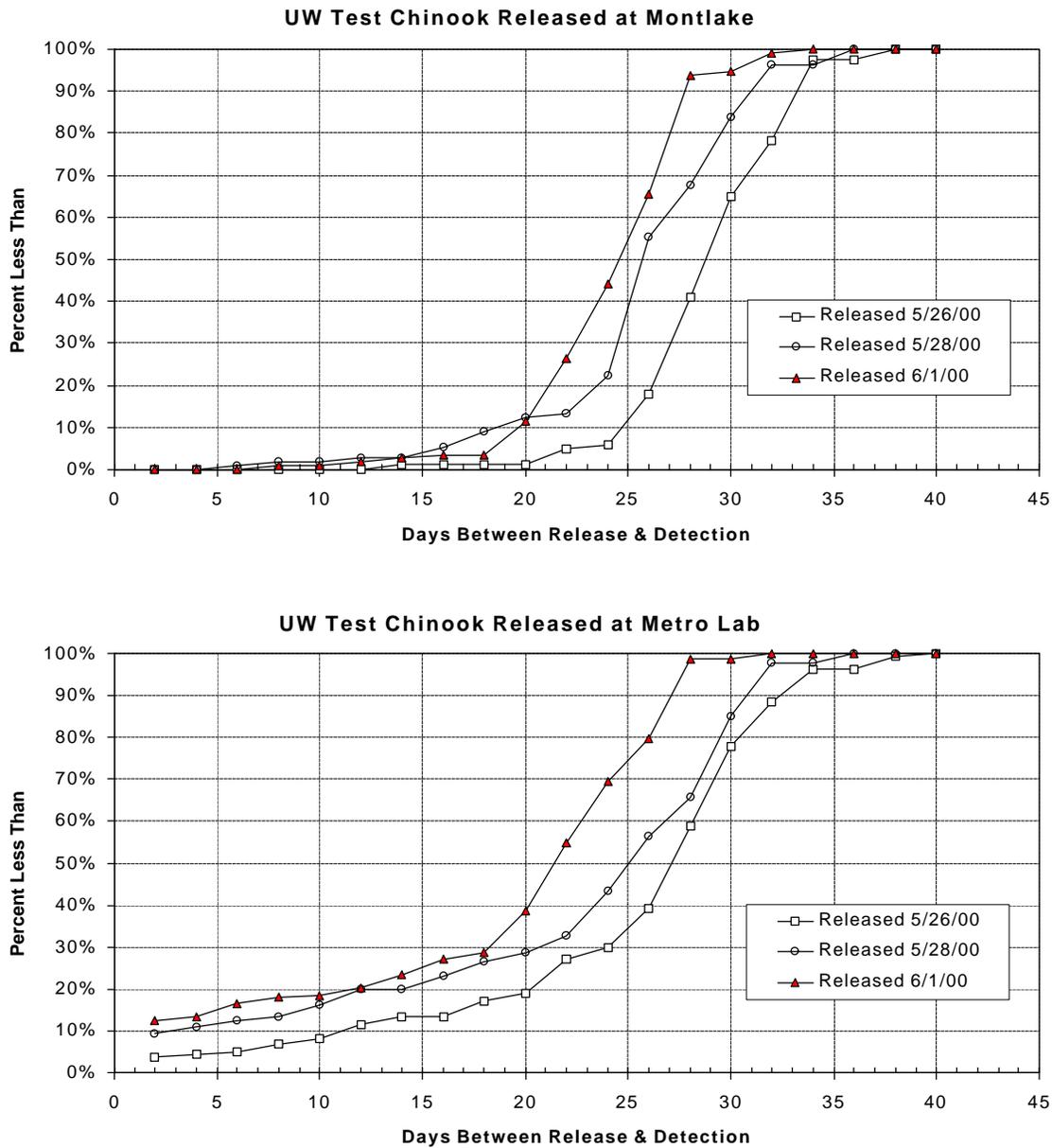


Figure 3-7. Cumulative frequency distributions of travel time for the three test groups of PIT tagged juvenile chinook salmon released in the Montlake Cut (top) and at the Metro Laboratory (bottom), and detected in the smolt flumes at the Locks during the year 2000 study.

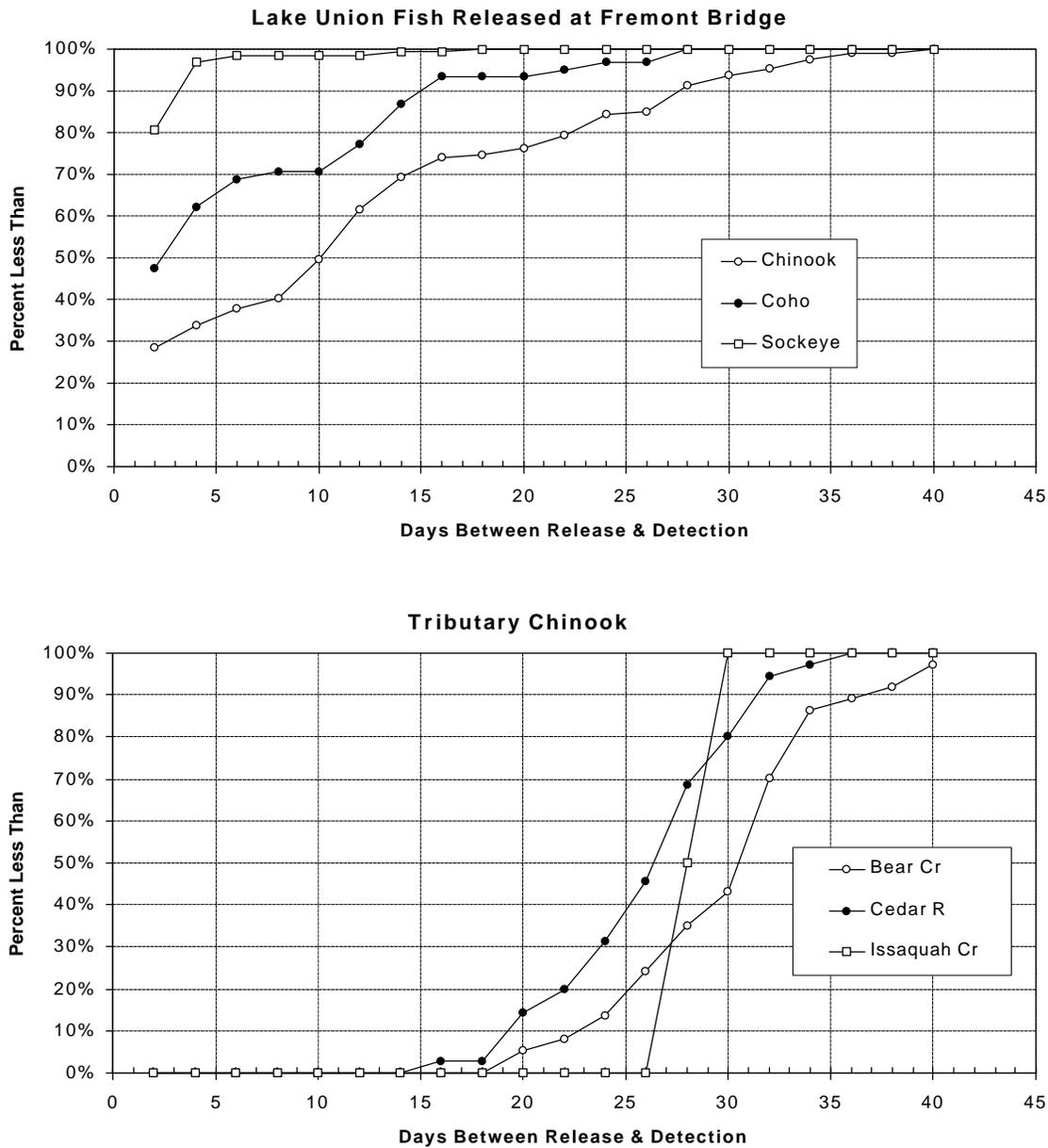


Figure 3-8. Cumulative frequency distributions of travel time for the PIT tagged juvenile salmon released in Lake Union (top) and major tributaries in the Lake Washington system (bottom), and detected in the smolt flumes at the Locks during the year 2000 study.

although they took longer than the sockeye to pass through the Locks, where 40% of the tagged coho took longer than 4 days. More than 90% of the coho had passed by the end of the first week of June (Figures 3-6 and 3-8).

Chinook salmon caught and tagged in Lake Union took longer to complete their outmigration than the coho and sockeye, and their passage date distributions overlapped with those of the tributary chinook (Figures 3-6 and 3-8). The origin of the fish was unknown, but likely included a large fraction that were raised at the UW hatchery. It is possible given the lengths of chinook that were caught relative to tributary fish that a few may have been yearlings, but because origin was not noted in the tagging files, this remains unconfirmed. There was a slight inverse relation between size of the chinook and time interval between release and detection at the locks (slope significantly different from zero;  $p=0.001$ ) but the correlation was poor ( $r^2=0.08$ ).

The chinook juveniles caught in the tributary screw traps exhibited similar passage timing distributions (Figure 3-6). Travel times took between 20 and 35 days for most fish (Figure 3-8). Only two Issaquah Creek fish were detected at the Locks, of which one was of confirmed hatchery origin. Given that the tributary fish were tagged and released during the middle or later portion of the main runs (Figures 2-4 through 2-6), the detection results for these streams should be largely representative of their respective outmigration patterns. However, smolts were still being caught in the traps at the time that the flumes were shut down, and the fate and migration characteristics of those late-migrating fish cannot be deduced from this year's data.

### 3.4.2 Migration Rate

Average migration rates varied between the UW test, Lake Union, and tributary release groups. Table 3-3 lists the estimated minimum travel distances between the different release locations and the Locks, excluding possible detours. More than 90% of the UW test chinook released in the Montlake Cut, and 80% of the fish released at the Metro Laboratory moved at an average speed of 0.5 km/day or slower between release and detection (Figure 3-9). These and the other average migration rates reported 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 they spend more than a few days near the locks, their actual migration rate to the Locks would be faster than the rates estimated here.

Lake Union fish had the most variable average migration rates, where approximately 80% of tagged sockeye, and 50% of coho, moved 1.6 km/day on average or faster (Figure 3-10). Although chinook captured and tagged in Lake Union moved more slowly, they generally

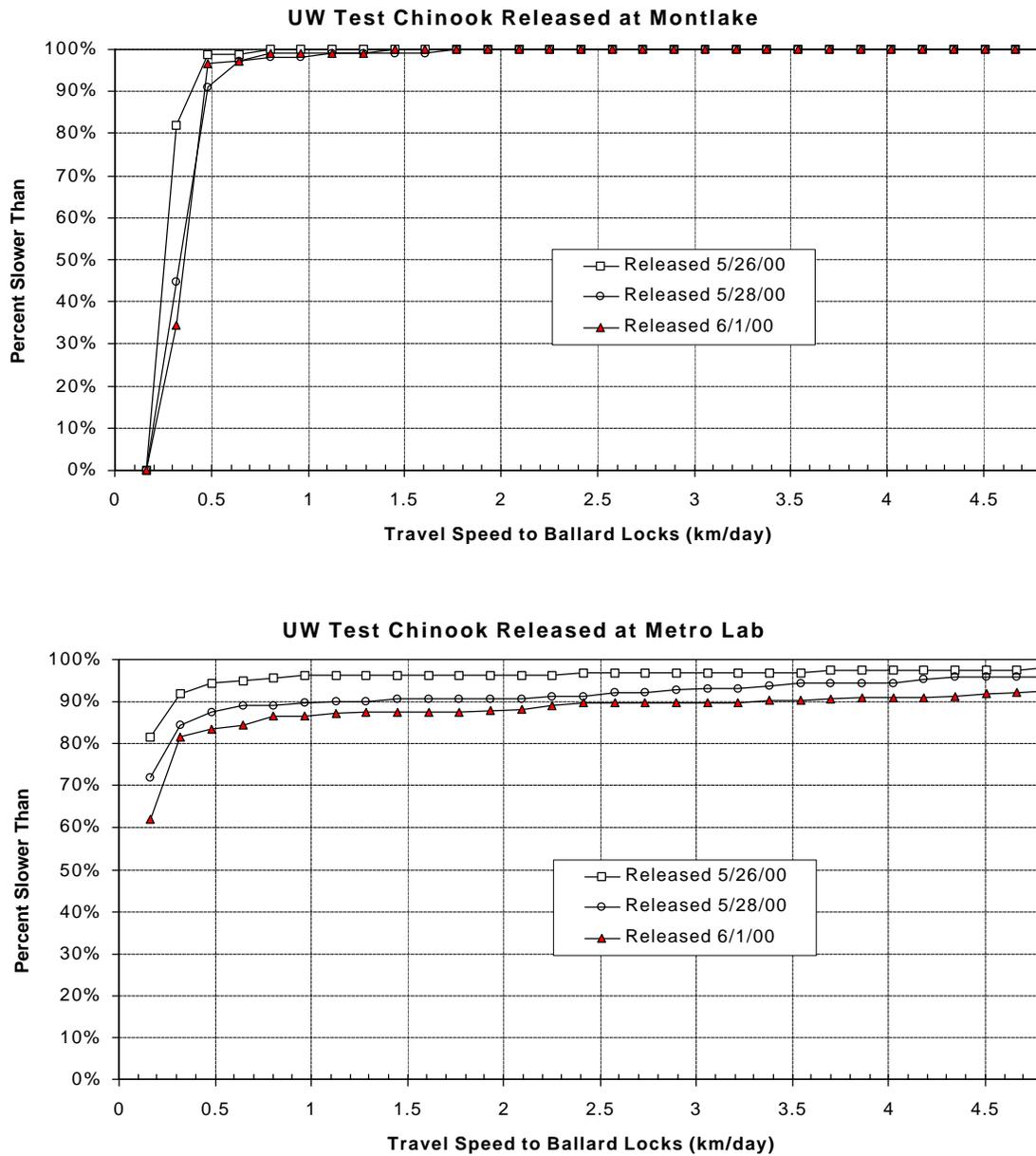


Figure 3-9. Cumulative frequency distributions of average travel speed to the Locks of the PIT tagged juvenile chinook salmon released in the Montlake Cut (top) and at the Metro Laboratory (bottom) during the year 2000 study.

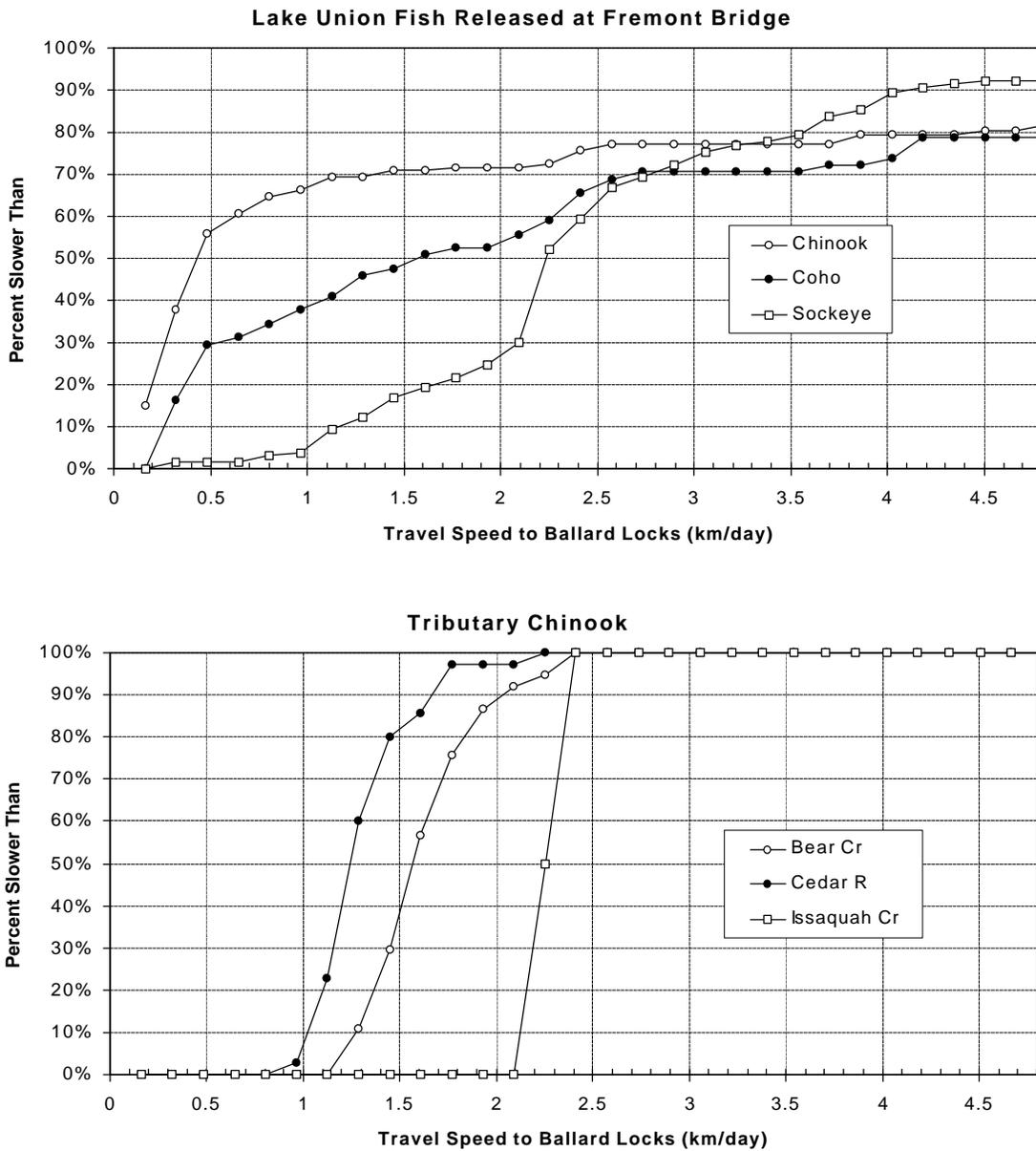


Figure 3-10. Cumulative frequency distributions of average travel speed to the Locks of PIT tagged juvenile salmon released at the Fremont Bridge (top) and in major tributaries of the Lake Washington system (bottom) during the year 2000 study.

migrated faster than the UW test fish: approximately 56% moved 0.5 km/day or slower. However, there were members of each of the three species that moved faster than 4.8 km/day (Figure 3-10).

Tributary fish moved at average speeds that reflected the distance that needed to be traversed. Issaquah Creek chinook appeared to migrate faster than Bear Creek chinook, which migrated faster than Cedar River fish (Figure 3-10). All stocks were found to migrate at rates ranging between 0.8 and 2.5 km/day on average.

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

Release Location	Distance to Locks (km)
Metro Laboratory	3.1
East of Fremont Bridge	5.1
Montlake Cut	10
Cedar River	39
Bear Creek	56
Issaquah Creek	76

### 3.5 PASSAGE BEHAVIOR AT LOCKS

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

#### 3.5.1 Diurnal Variation in Passage Timing

A behavioral pattern that was common to nearly all release groups was the predominance of passage during daylight hours (Figure 3-11). Tagged coho salmon showed the least pronounced pattern, in which numbers per hour were nearly uniform across all hours. The pattern was most striking for tagged sockeye, of which none passed during nighttime hours. Lake Union and tributary chinook passed predominantly during dawn and daylight hours, but there were a small number that passed through the flumes during the night. Highest passage rates for these groups generally occurred between 5:00 am and 10:00 am. The UW test chinook showed a similar pattern irrespective of release location, with two pronounced peak passage times: between approximately 7:00 am and 9:00 am, and between 11:00 am and 2:00 pm. Proportionally fewer chinook released in the Montlake Cut passed through during nighttime hours than chinook released at the Metro Laboratory (Figure 3-11). The pattern became more pronounced during the

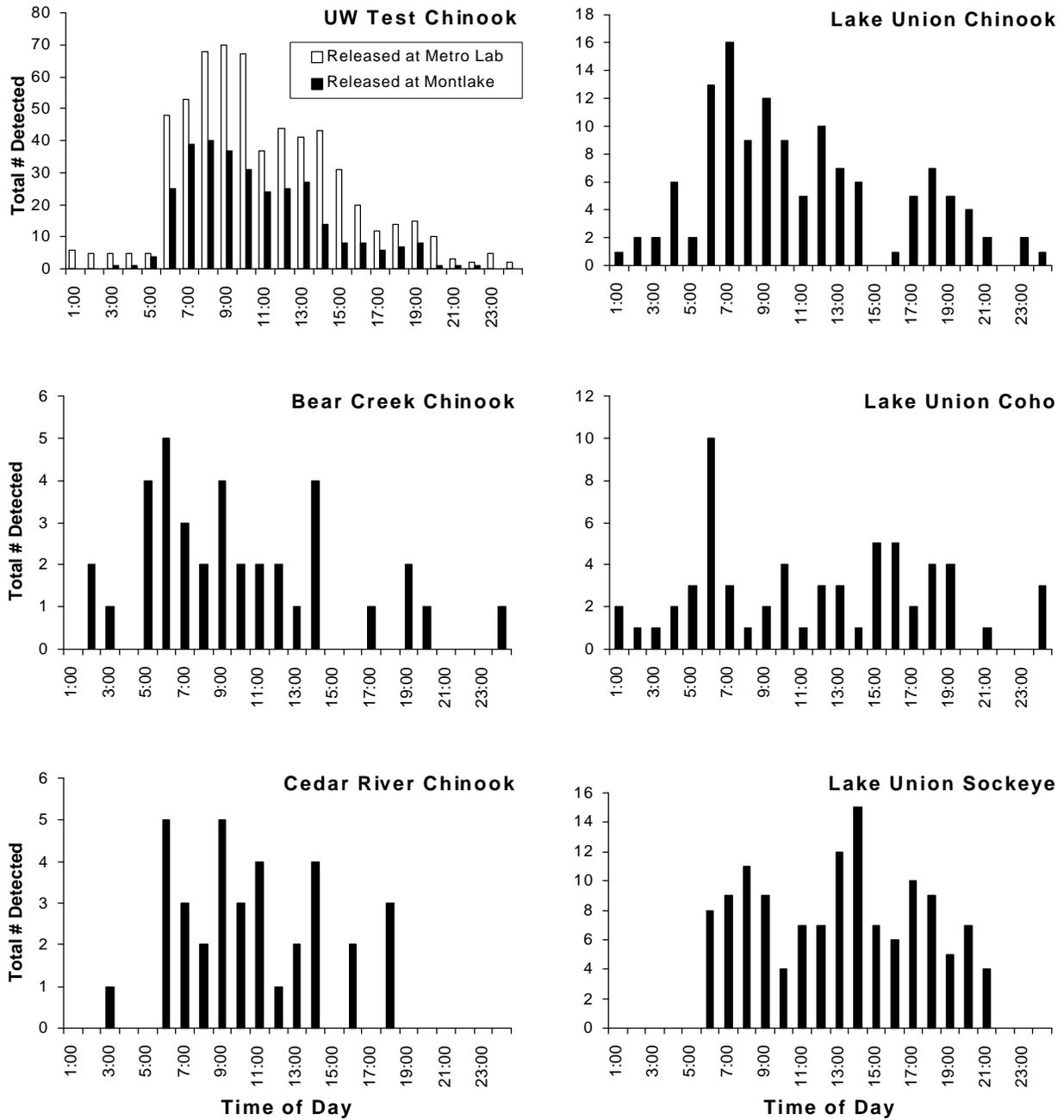


Figure 3-11. Diurnal variation in time of passage by PIT tagged juvenile salmon through the smolt flumes installed at the Locks during the year 2000 study.

latter two weeks of June than before that time period (Figure 3-12). Similar results were noted in acoustic monitoring of the entrance to spillway bay 2 (Biosonics 2001). These results stand in stark contrast to data collected for the Columbia River system, where passage at hydropower facilities was noted to occur predominantly during nighttime hours (e.g., Brege et al. 1996).

### 3.5.2 Routes Through the Locks

Of the PIT tagged fish that passed through the smolt flumes, the majority passed through the two flumes closest to the fish ladder. On most days when Flumes 4B, 5C, and 5B were operating, more than 70% of tagged chinook passed through the flumes in bay 5 (Figure 3-13). Figure 3-14 and 3-15 show similar trends for sockeye and coho, respectively. Flumes 4B and 5B had approximately the same entrance flow rates, yet 5B was usually associated with greater numbers of PIT tagged fish. A similar trend was noted in visual counts of all fish exiting the tunnel readers (Johnson et al. 2001).

Figure 3-16 depicts the possible passage routes through the Locks. The PIT tag data confirm that recycling does occur through the locks as indicated in the figure. For example, 30 PIT tagged fish were detected twice by the tunnel readers (Figure 3-17). They therefore had to have migrated back upstream through either the large or small lock. The intervening time between first and second detection varied relatively uniformly up to more than 40 days early on during the outmigration season, but shortened as the season progressed. During the last two weeks in June 2000, recycling times were 3 days or less. The solid diagonal line in Figure 3-17 indicates the maximum possible detection period before the flumes were shut down, but fish had recycled within ten days of that time such that the limits to the data do not appear to have been influenced by changes in flume operation. The data in Figure 3-17 therefore indicate that a strong seasonal influence on outmigration existed in the LWSC, and that chinook juveniles lingered in the upstream and downstream vicinity of the Locks before most actively making the transition to saltwater during the last two weeks of June 2000. There was no relation between recycling time and release group or size of fish at time of tagging.

The purse seine data provided direct evidence of recycling specifically through the large lock. Three tagged fish were detected in samples collected there approximately two weeks after they had been detected passing through the tunnel readers (Table 3-4). The other tagged fish that were detected in the samples could have passed through the flumes undetected and were recycling, or were passing downstream through the lock for the first (or subsequent) time.

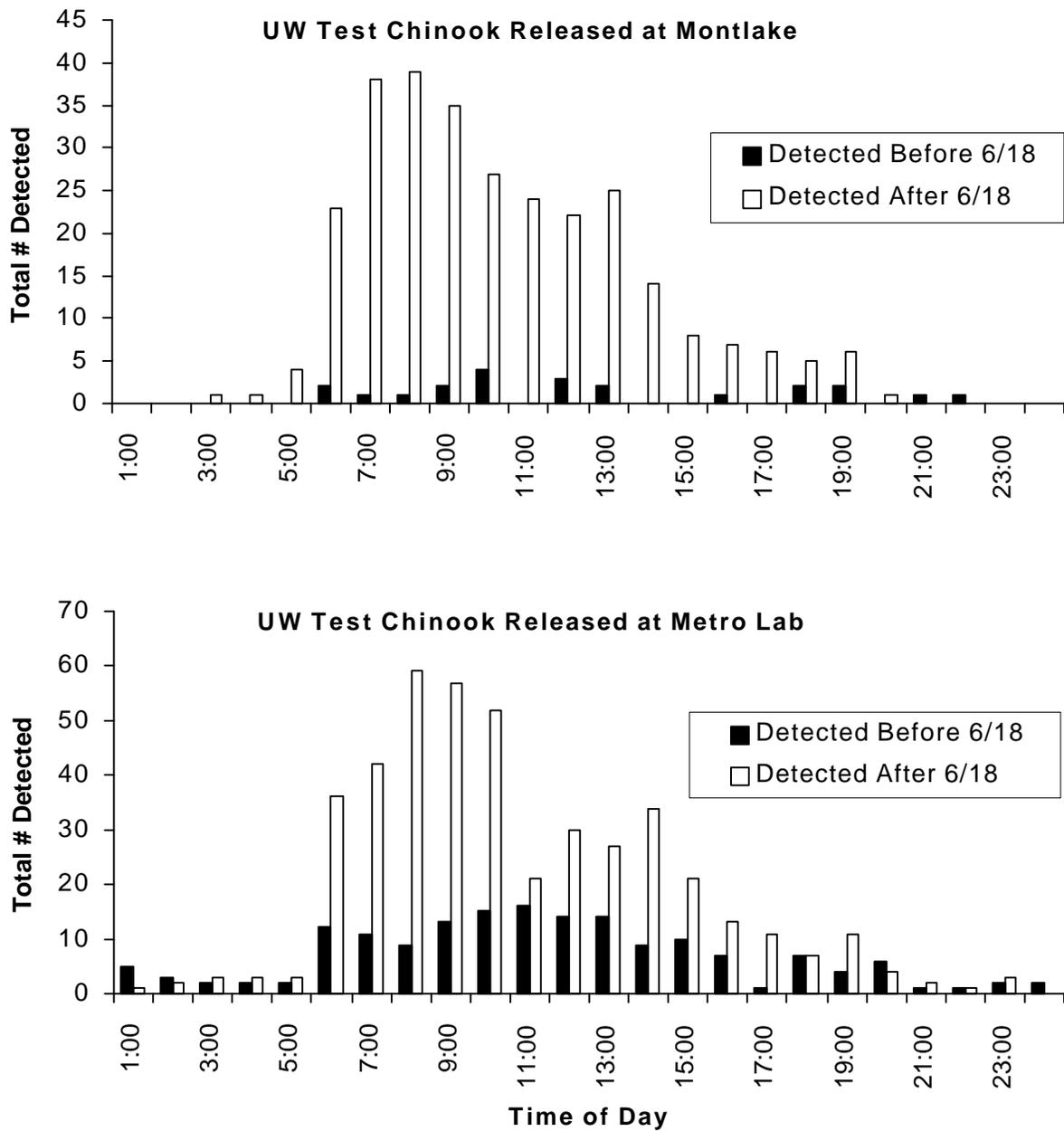


Figure 3-12. Diurnal variation in time of passage by PIT tagged juvenile chinook salmon through the smolt flumes installed at the Locks during the year 2000 study. The data have been segregated according to whether they were detected before or after June 18 (no fish were detected on June 18).

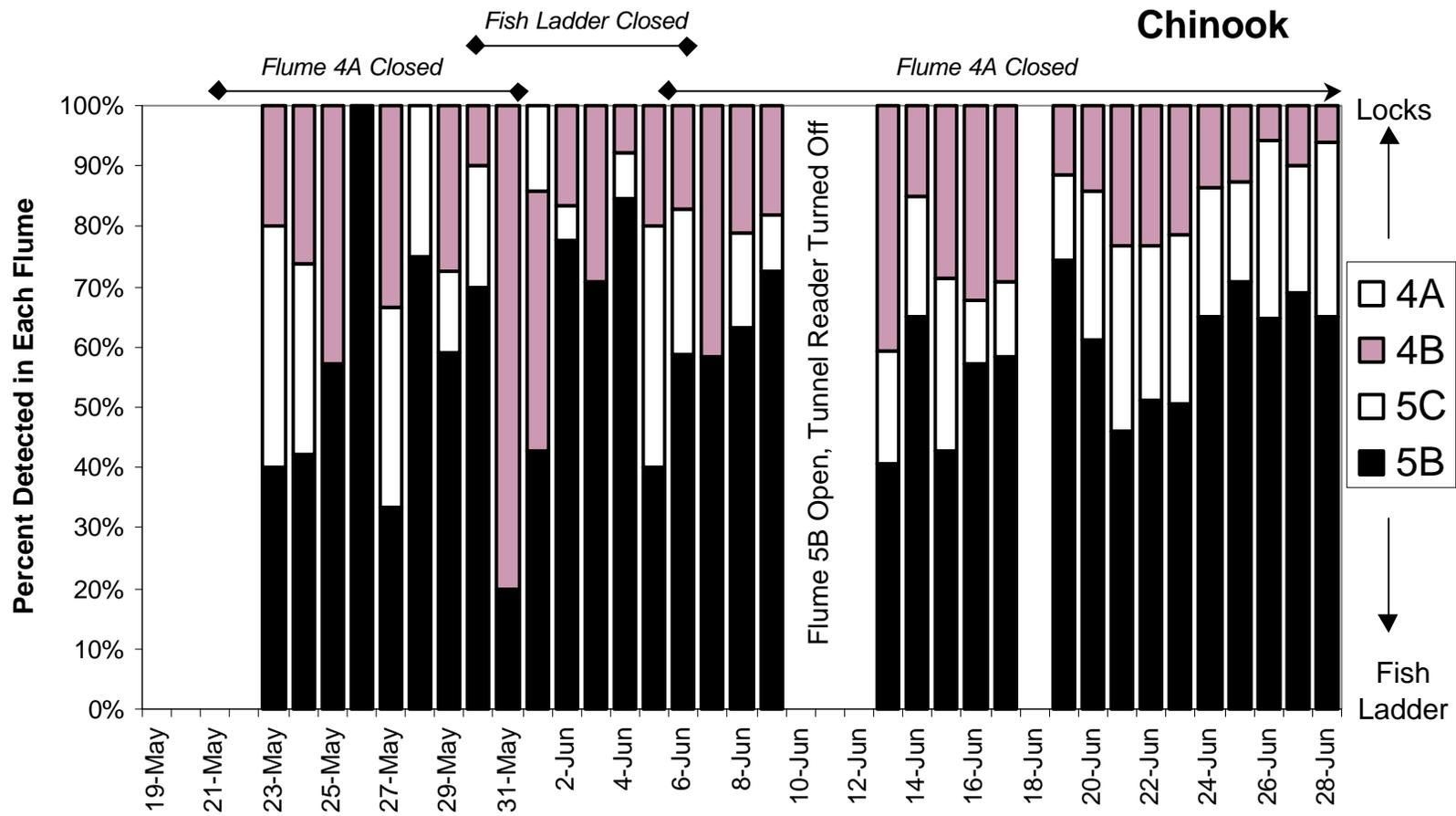


Figure 3-13. Proportion of total number of PIT-tagged juvenile chinook salmon detected each day in each smolt flume installed at the Locks during the year 2000 study.

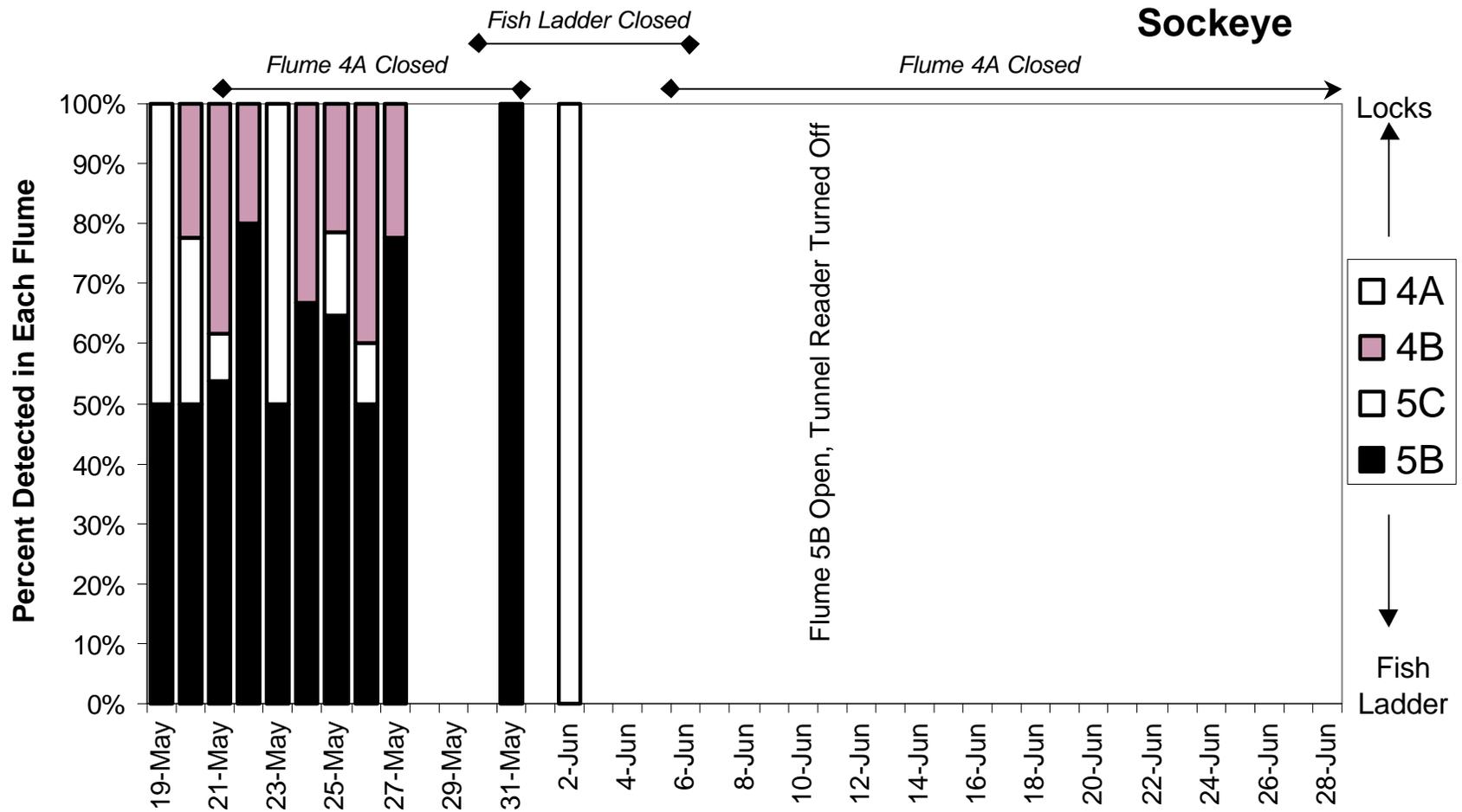


Figure 3-14. Proportion of total number of PIT-tagged juvenile sockeye salmon detected each day in each smolt flume installed at the Locks during the year 2000 study. One hundred percent detection by a single flume indicates that only one fish was detected that day.

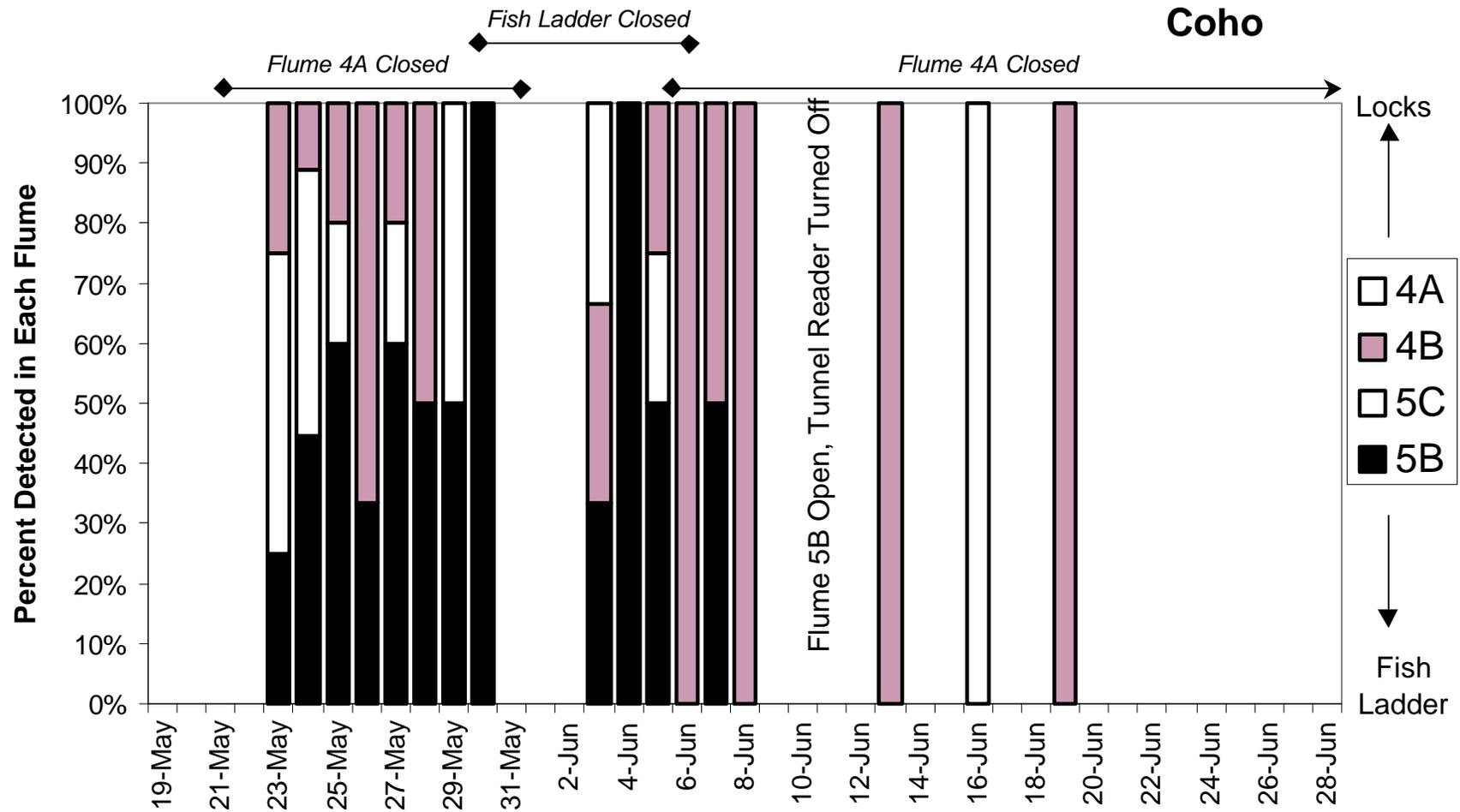


Figure 3-15. Proportion of total number of PIT-tagged juvenile coho salmon detected each day in each smolt flume installed at the Locks during the year 2000 study. One hundred percent detection by a single flume indicates that only one fish was detected that day.

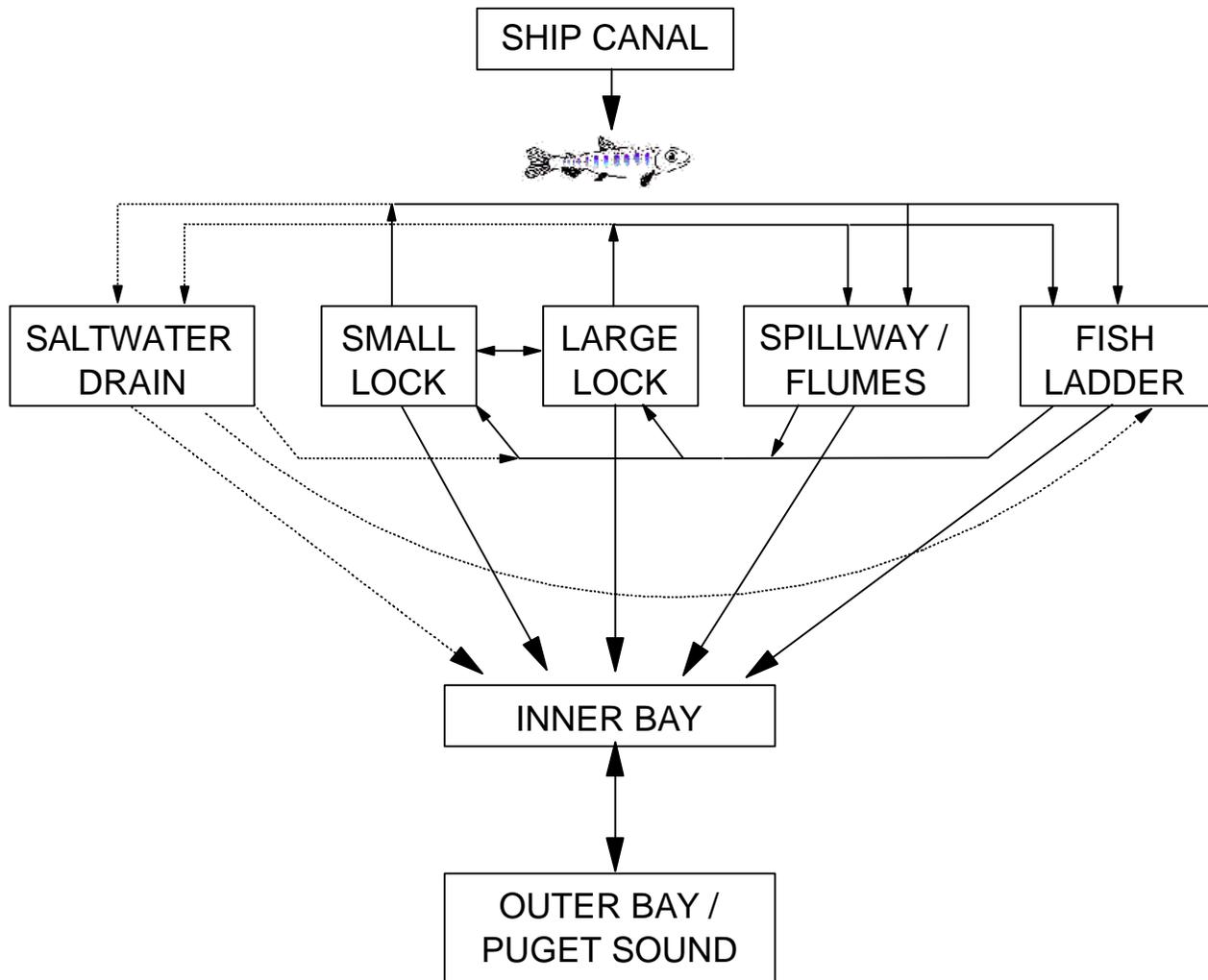


Figure 3-16. Possible migration routes of juvenile salmon through the Hiram M. Chittenden Locks to the saltwater beaches located below. The routes are indicated for fish after they have first encountered the locks and have entered one of the five structural facilities indicated. For example, a fish entering the smolt flumes may subsequently move back upstream through either the small or large lock, and return downstream through any of the five routes. Alternatively, the fish may migrate directly to saltwater. The route through the saltwater drain is thought to be of lesser importance to smolt passage than the other four routes and is thus indicated by the dashed lines.

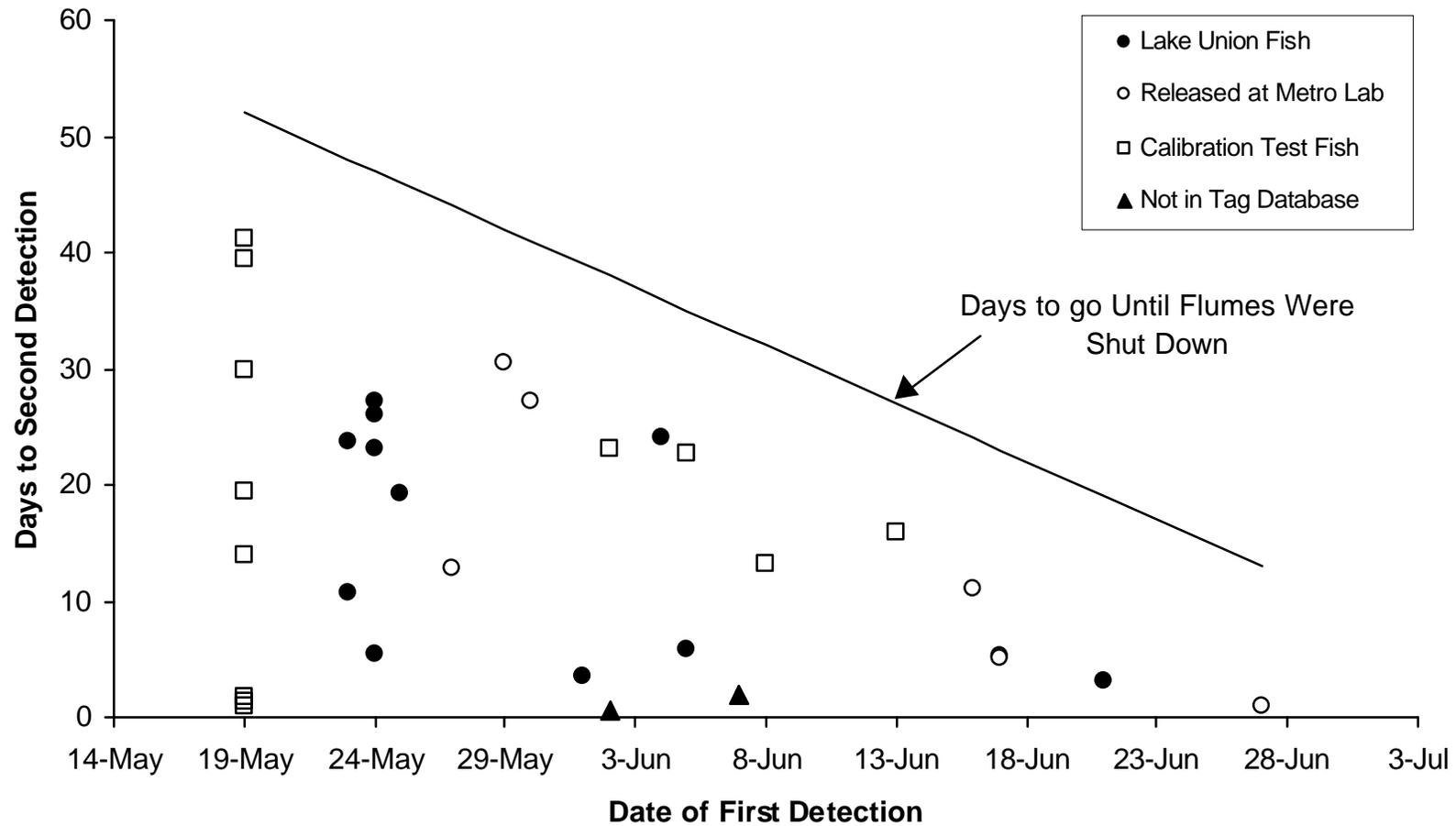


Figure 3-17. Recycling times of PIT tagged juvenile chinook salmon passing downstream through the smolt flumes installed at the Locks during the year 2000 study.

Table 3-4. Release-recapture data For PIT tagged fish caught in purse seine samples in the large lock during the year 2000 study.

Tag Number	Species	Release Location	Release Date	Release Time	Recapture Date	At Tagging	At Recapture	Comment
3D9.1BF0E14079	Chinook	Calib. Test 1	05/19/00	10:31	05/31/00	67	na	Recycling Through Lock
3D9.1BF0DDEBD0	Chinook	Lake Union	05/23/00	13:50	05/31/00	117	na	
3D9.1BF0F973A7	Chinook	Lake Union	05/23/00	13:50	05/31/00	112	na	
3D9.1BF0F7EFBL	na	na	na	na	05/31/00	na	na	Not in Tagging Files
3D9.1BF101E23D	Coho	Lake Union	05/23/00	13:50	06/06/00	109	133	
3D9.1BF0DDAD95	Chinook	Metro	05/26/00	21:30	06/07/00	69	126	
3D9.1BF0E15A75	Chinook	Metro	06/01/00	21:30	06/13/00	79	na	
3D9.1BF0E14DF0	Chinook	Metro	05/28/00	21:30	06/15/00	74	114	
3D9.1BF0DCEF63	Chinook	UW	06/01/00	21:30	06/20/00	72	na	
3D9.1BF0E3B4D6	Chinook	Metro	06/01/00	21:30	06/20/00	78	na	
3D9.1BF0E43FD8	Chinook	Calib. Test 5	6/5/00	16:25	06/20/00	67	na	Recycling Through Lock
3D9.1BF0E50762	Chinook	Calib. Test 7	6/8/00	9:31	06/20/00	74	na	Recycling Through Lock
3D9.1BF0DD93EB	Chinook	Metro	06/01/00	21:30	06/22/00	73	134	
3D9.1BF0E45FA3	Chinook	Metro	06/01/00	21:30	06/22/00	74	128	

### 3.5.3 Influence of Lock Operations on Passage Through Flumes

Figures 3-18 and 3-19 indicate that there was a tendency for PIT tagged fish to pass through the flumes at a higher rate during the fill period than during the between-fill period. To evaluate this statistically, the data in the figures were filtered and cases identified where fish were detected during consecutive fill and between-fill periods. A ratio was calculated of the passage rate during fill to the passage rate during the subsequent between-fill period. Two-tailed t-tests of the ratio indicated that it was significantly greater than 1.0 on average ( $p < 0.05$ ). In other words, the mean passage rates through the flumes was significantly greater during the fill period than afterwards for both the small and the large locks.

### 3.6 ESTUARINE BEHAVIOR

Beach sampling was conducted at the railroad bridge and downstream where salinity appears to be usually equal to or greater than 20 ppt. Captures of PIT tagged fish in the beach seine samples thus provide temporal and spatial information regarding the transition to saltwater. Table 3-5 summarizes the tagging and capture histories of PIT tagged fish caught in beach seine samples that were collected below the Locks. There was a large fraction of the PIT tagged fish that was caught in the inner bay within a few days of detection in the smolt flumes (Figure 3-20).

### 3.7 SURVIVAL ESTIMATES

The PIT tag data were used to estimate relative differences in survival over discrete segments of the outmigration route in the LWSC and the Lake Washington system, but the results were subject to unexplained uncertainty stemming from disease of the UW test fish and additional variation introduced by the tunnel reader detection efficiency problems. Estimates for other parts of the route were also influenced because they were contingent on estimating the survival of the Montlake Cut and Metro Laboratory release groups accurately. The uncertainty in the survival estimates for the UW test fish, generated by the disease outbreak and by the incomplete coverage of PIT tagged fish at the Locks resulted in increased uncertainty in the survival calculations.

Even without the effects of disease and detection efficiency, the confidence intervals for the survival estimates were generally large because of the small numbers of recaptures and the number of tagged fish released in each group (generally 1000 fish or less). A range of variances of the estimated survival of a release group to the Locks were determined by S. Smith of NMFS, assuming *a priori* (in the absence of data) that survival between the Locks and the beach seine sites equaled 0.95. The analyses were conducted for a range of release numbers (1,000 to 10,000

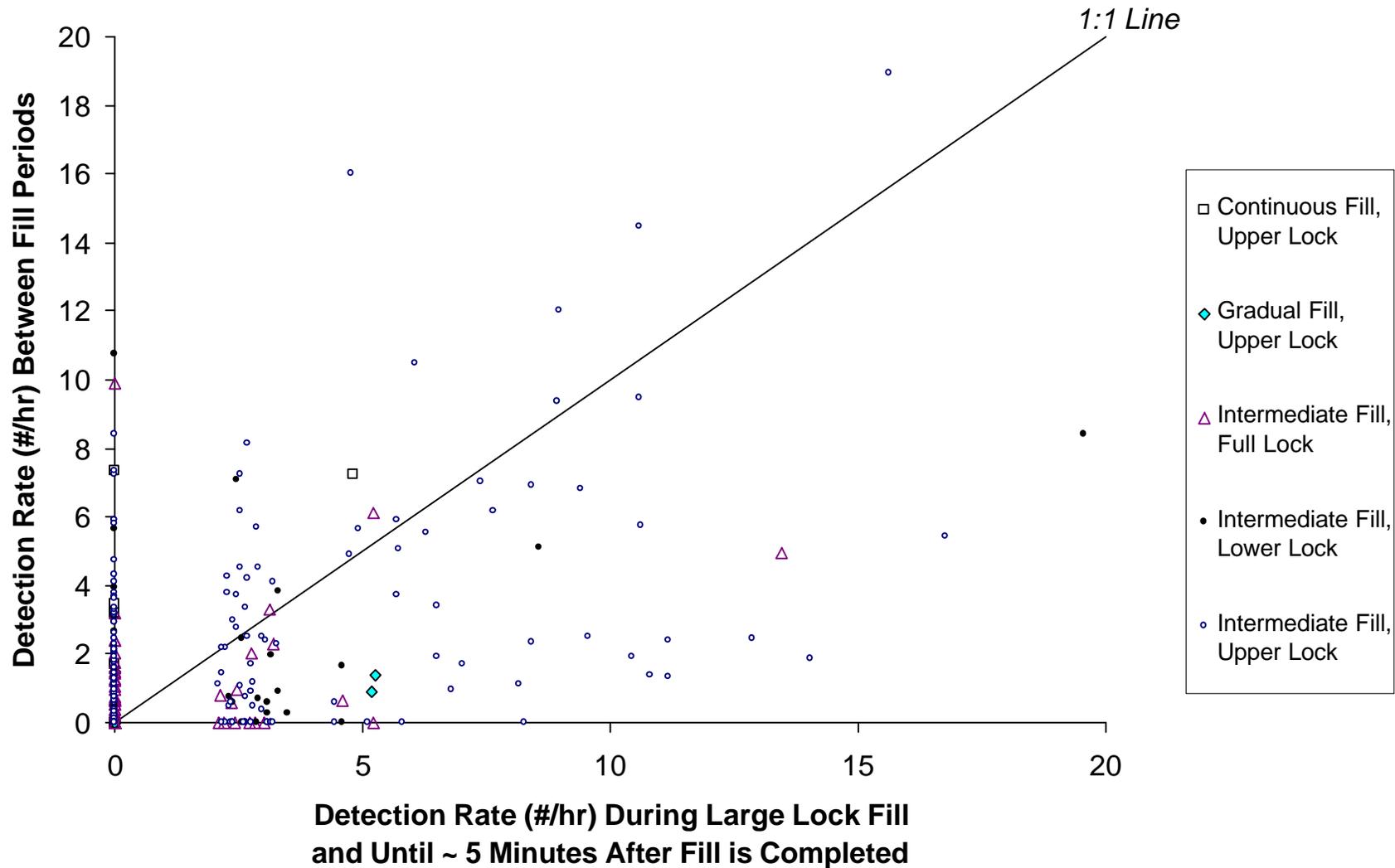


Figure 3-18. Comparison of passage rates of PIT tagged fish (all species) through the smolt flumes during large lock fill operations and in-between fills.

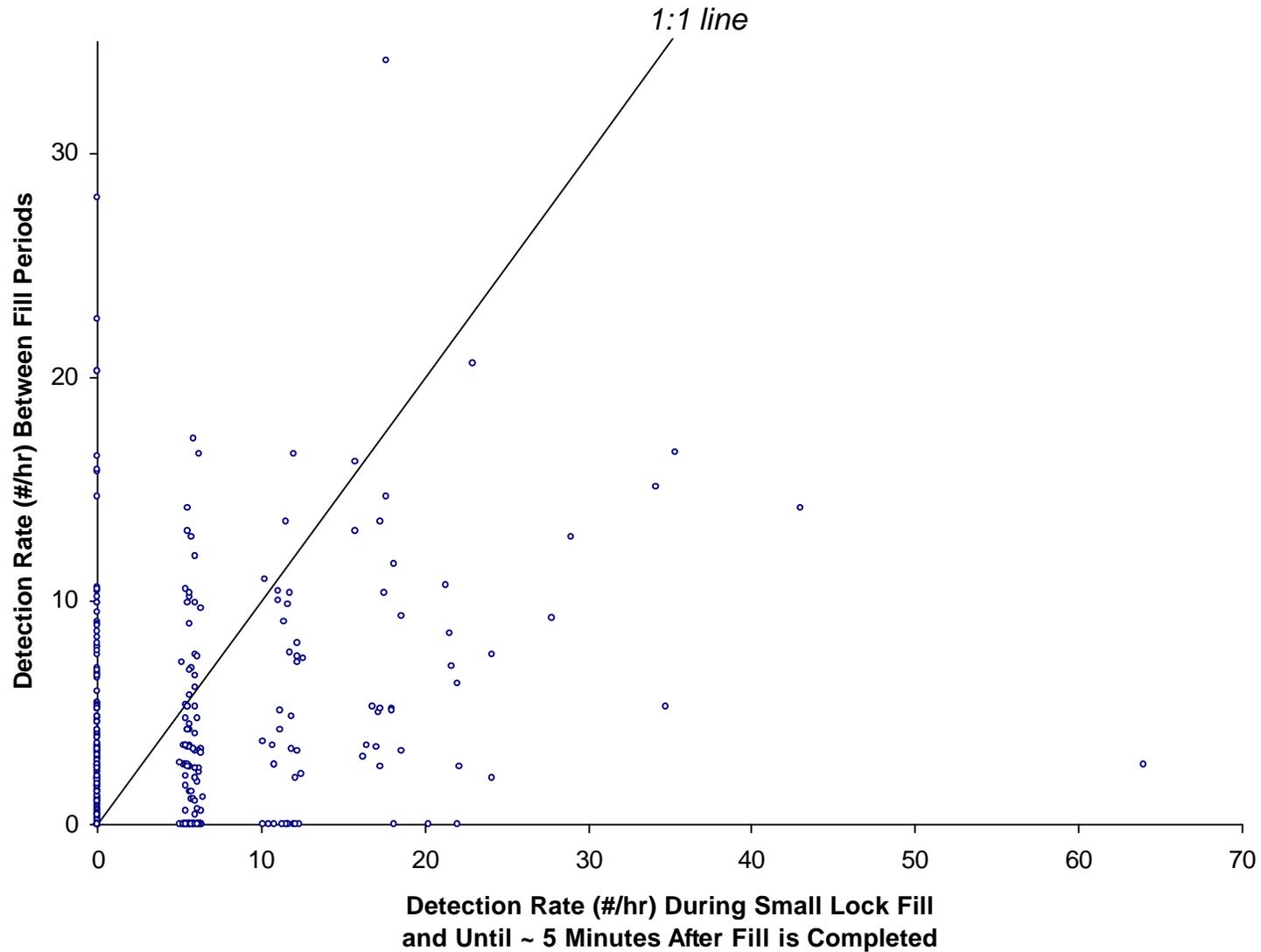


Figure 3-19. Comparison of passage rates of PIT tagged fish (all species) through the smolt flumes during small lock fill operations and in-between fills.

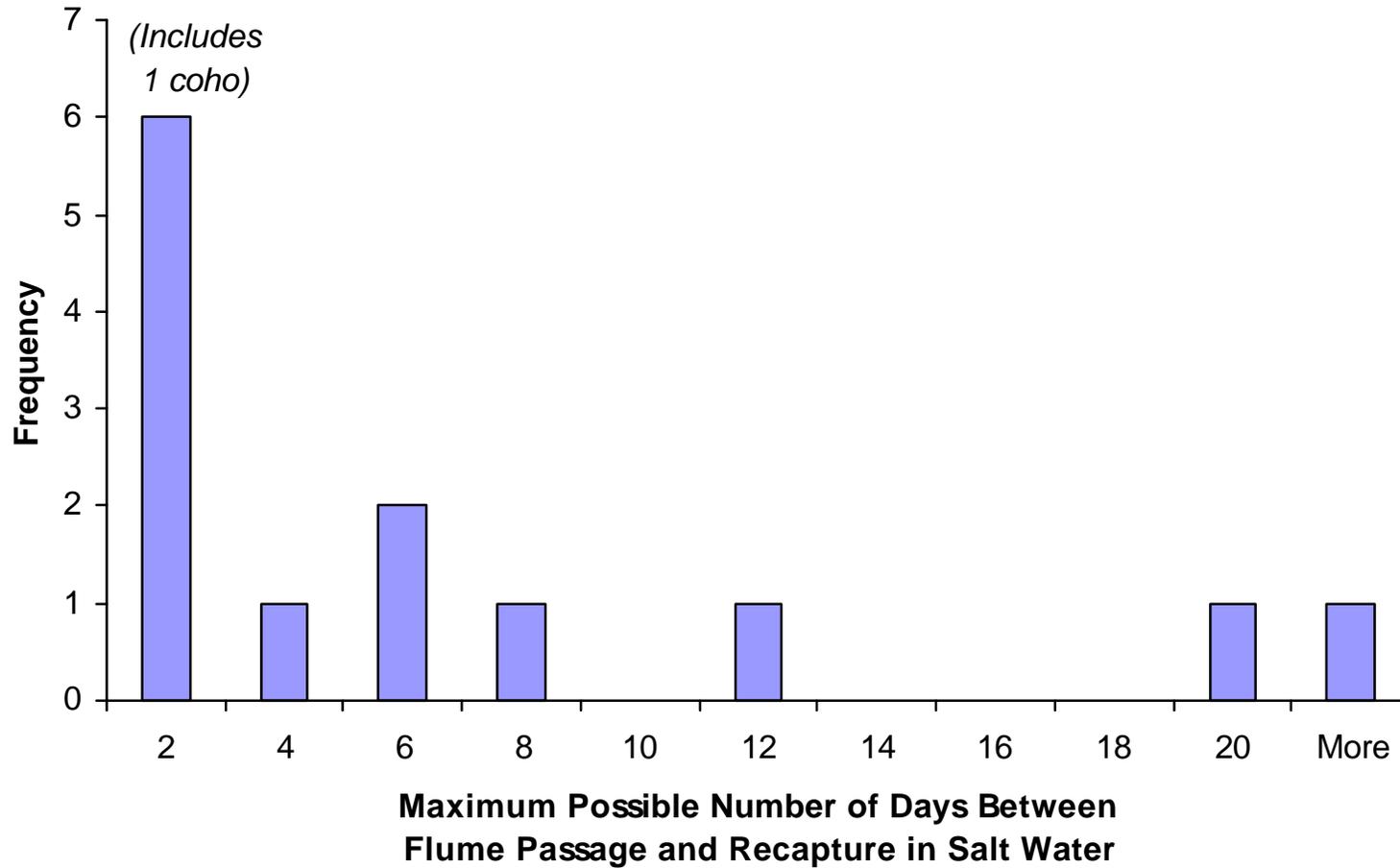


Figure 3-20. Capture frequencies with respect to the number of days between recapture in saltwater of PIT tagged juvenile chinook and coho salmon and their prior detection in the smolt flumes installed at the Locks during the year 2000 study. Data from Table 3-5.

Table 3-5. Release-recapture data For PIT tagged fish caught in beach seine samples below the Locks during the year 2000 study.

Tag Number <sup>1</sup>	Species	Release Location	Release Date	Release Time	Recapture Date	Recapture Location	Length At Tagging (mm)	Comment
3D9.1BF0DD1F94	Chinook	Calib. Test 1	5/19/00	~ 9:40	5/23/00	RRBR 30	74	Not detected during test
3D9.1BF0E15EDB	Chinook	Metro	5/28/00	21:30	5/31/00	UPBC 55	74	Not Detected by Tunnel Readers
3D9.1BF0DD203B	Chinook	Metro	6/1/00	21:30	6/22/00	UPBC 75	82	Not Detected by Tunnel Readers
3D9.1BF0DD34B5	Chinook	UW	5/28/00	21:30	6/22/00	UPST 73	81	Detected by Tunnel Reader 6/20/00 11:45
3D9.1BF0E1614A	Chinook	Calib. Test 7	6/8/00	9:27	6/19/00	BS9	73	Detected during test
3D9.1BF0DC9453	Chinook	Calib. Test 4	6/2/00	10:16	6/22/00	RRBR 70	78	Detected during test
3D9.1BF0E28DDC	Chinook	Calib. Test 1	5/19/00	10:21	5/25/00	ORTR 37	66	Detected during test
3D9.1BF0DD964D	Chinook	Metro	5/28/00	21:30	6/22/00	UPST 73	71	Detected by Tunnel Reader 6/21/00 13:22
3D9.1BF0E13E28	Chinook	Calib. Test 8	6/13/00	9:23	6/19/00	BS9	85	Detected during test
3D9.1BF0DD40D6	Chinook	Metro	5/26/00	21:30	6/21/00	LICL 42	71	Detected by Tunnel Reader 6/20/00 7:57
3D9.1BF0DC62DC	Chinook	Calib. Test 8	6/13/00	~9:30	6/20/00	ORTR 63	76	Not detected during test; flume down
3D9.1BF0DC87F9	Chinook	Calib. Test 1	5/19/00	10:04	6/20/00	MIBC 68	77	Detected during test
3D9.1BF0EF6716	Chinook	Lake Union	5/23/00	13:50	5/25/00	RRBR 38	106	Detected by Tunnel Reader 5/23/00 19:26
3D9.1BF0FAC35D	Chinook	Lake Union	5/23/00	13:50	5/31/00	LOBC 49	109	Not Detected by Tunnel Readers
3D9.1BF0F77D3B	Coho	Lake Union	5/23/00	13:50	5/31/00	MIBC 51	121	Detected by Tunnel Reader 5/29/00 9:30
3D9.1BF0F68405	Chinook	Lake Union	5/23/00	13:50	5/25/00	RRBR 38	148	Not Detected by Tunnel Readers

<sup>1</sup> - plus five tags not in tagging records – may have been missed during tagging, or are possible transcription errors in field notes

fish), survival magnitudes (0.5 to 0.9), and detection probabilities at the locks (0.2 to 0.4) and beach seining (0.05 to 0.15). The resulting estimates are presented in Appendix B, and indicate the approximate range of precision that may be expected for the release and recapture numbers presented in Table 3-1, absent other sources of error.

It was possible to determine survival from disease for the test chinook over the part of the study period while they were being held at the UW hatchery and Metro Laboratory, by dividing the number of surviving fish into the original number tagged (Figure 3-21). The fish being held at the Metro Laboratory died off more rapidly than the fish held at the UW hatchery, but were used primarily for calibration test purposes and were thus not used to estimate survival. Data were not collected that might indicate post-release survival of the UW fish, which had to be assumed for this analysis.

It is plausible that mortality rates dropped after release because the fish were no longer being held in close quarters, reducing the chance of infection, and the indigenous fish disease mortality rate appeared to be tailing off in the LWSC. The post-release survival from disease of the fish held at the UW hatchery and released in the Montlake Cut or at the Metro Laboratory may therefore have tailed off to an asymptotic value. One group ("U3A") was held at the UW hatchery longer than the six test release groups for use in calibration testing (to supplement losses of fish held at the Metro Laboratory). The group remnants were released into the LWSC on 10 June, 2000. Their disease mortality rate during the holding period could not be determined accurately because fish were dying while some of the group members were being withdrawn periodically for calibration tests (495 fish from this group were used in the tests), and records were not kept of daily mortalities after June 1. Hence, the actual disease survival rate lay between the two values indicated in Figure 3-21, depending on whether all of the fish that died are ascribed to the June 10 release group (the lower datum in the figure), or whether the mortalities are partitioned according to the ratio of calibration test fish to June 10 release numbers (upper datum). Assuming the other groups experienced a post-tagging, asymptotic survival rate similar to that experienced by the U3A group, and comparing that group's possible survival rates to those of the other groups depicted in Figure 3-21, suggests that the post-release survival rate may have been within the approximate range of 40% to 80%.

This range was evaluated using the survival equations described in Section 2.6.5. Assuming a post-release disease survival rate of 0.68 resulted in an estimated 100% survival between the Fremont Bridge and the Metro Laboratory, whereas a value of 0.41 resulted in 100% survival between the Montlake Cut and the Fremont Bridge. Using Ricker's (1975) estimator, the two

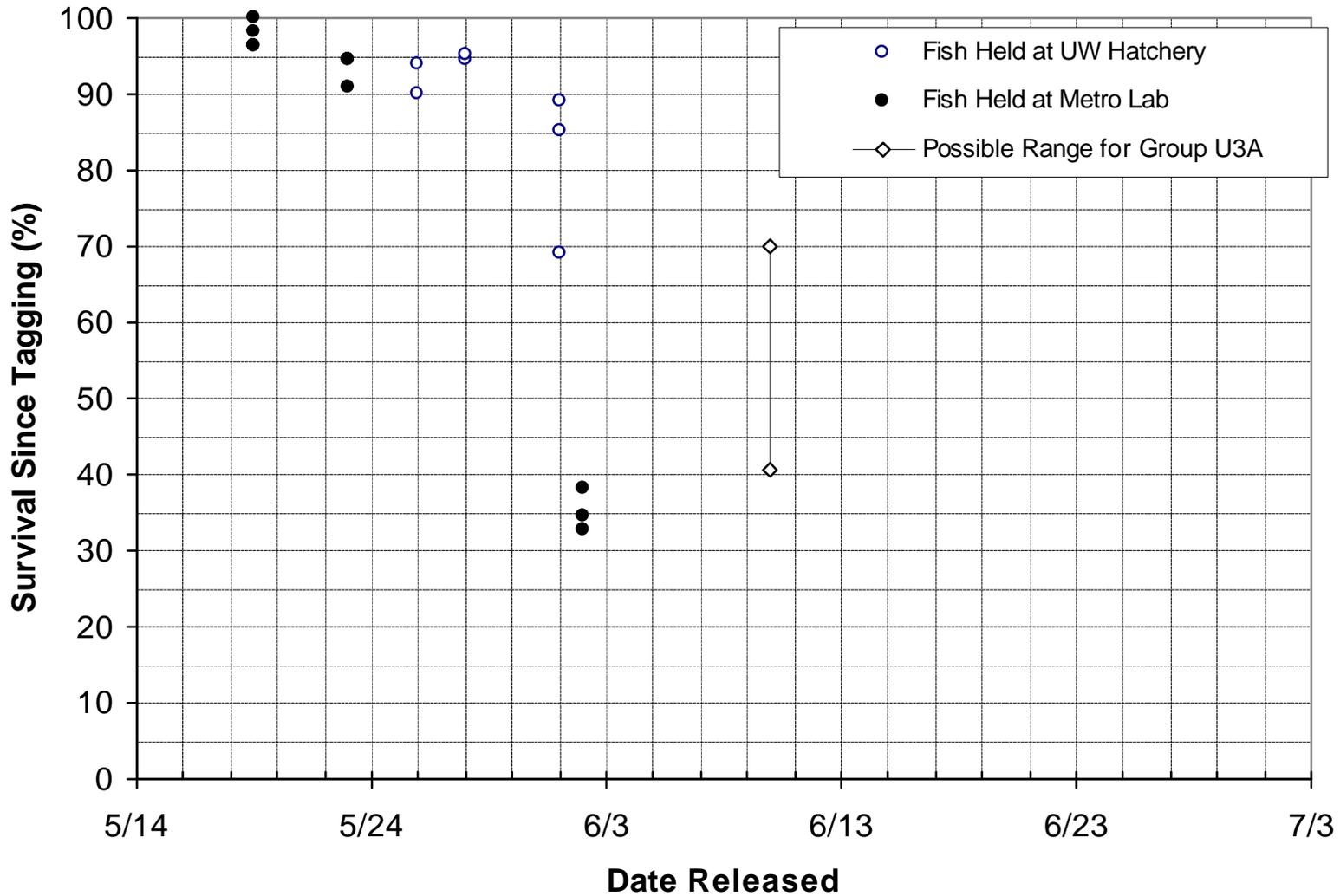


Figure 3-21. Survival at time of release from the LWSC disease of the different groups of PIT tagged juvenile chinook salmon that were held at the University of Washington hatchery and Metro Laboratory during the year 2000 study. See text for explanation of group U3A data.

corresponding disease survival rates were determined through iteration to be 0.60 and 0.14, respectively. It is likely that survival was close to 100% over the short distance between the Fremont Cut and the Metro Laboratory, given the general absence of piscine predator habitat. These outcomes suggest that the disease survival rate should be on the order of 0.60 to 0.68. Absent better information, a mean value of 0.64 was assumed in the estimation of survivals of the UW test fish as they migrated through the LWSC.

Figure 3-22 depicts the resulting survival estimates from release to the Locks as a function of the proportion of PIT tagged fish assumed to use the smolt flumes, in which the estimate of survival decreases as the assumed proportion of fish using the flumes increases based on the numbers detected by the tunnel readers. The estimates indicate the range of relative differences along different segments of the migration route. Before factoring in the uncertainty caused by disease and detection efficiency variation, the estimated variances for the chinook released at the Montlake Cut and Metro Lab were 0.05 and 0.19, respectively. Estimated variance for the Lake Union chinook survival to the Locks was 0.75, which is extremely high. Comparing these numbers to the magnitude of the survival estimates indicates that the uncertainty about the survival estimates was large in this study, on the order of  $\sqrt{50\%}$  of the estimate or more, even before including the effect of other error sources.

The proportion of tagged juvenile chinook using the flumes was estimated to range between 0.25 and 0.50, depending on the release group (Montlake:  $P_{SF} = 0.50$  {variance = 0.13;  $m_{t13}=m_{t23}=1$ }; Lake Union:  $P_{SF} = 0.25$  {variance = 0.04;  $m_{t13}=4$ ;  $m_{t23}=2$ }; Metro Laboratory:  $P_{SF} = 0.33$  {variance = 0.05;  $m_{t13}=3$ ;  $m_{t23}=1$ }; estimates for other groups were impossible because none were caught in the beach seine samples).

Survival estimates were lowest for the Issaquah Creek release group because only two tagged fish were detected at the Locks. This is indicative of either poor survival of juvenile chinook through Lake Sammamish, or that the main body of tagged Issaquah Creek fish had not yet arrived at the Locks by the time the flumes were shut down. Similarity in Locks arrival timing between the Issaquah Creek, Bear Creek, and Cedar River chinook suggests that the first possibility, low survival between Issaquah and Bear Creek, may be the more likely reason. The corresponding estimate of survival over that segment of the migration route was 0.055, or 5.5%. The precision of this estimate is likely to be very low given the small sample size of detections at the Locks, but the order of magnitude of the estimate nevertheless suggests a relatively low survival rate as chinook juveniles passed into and through Lake Sammamish compared with other portions of the migration route.

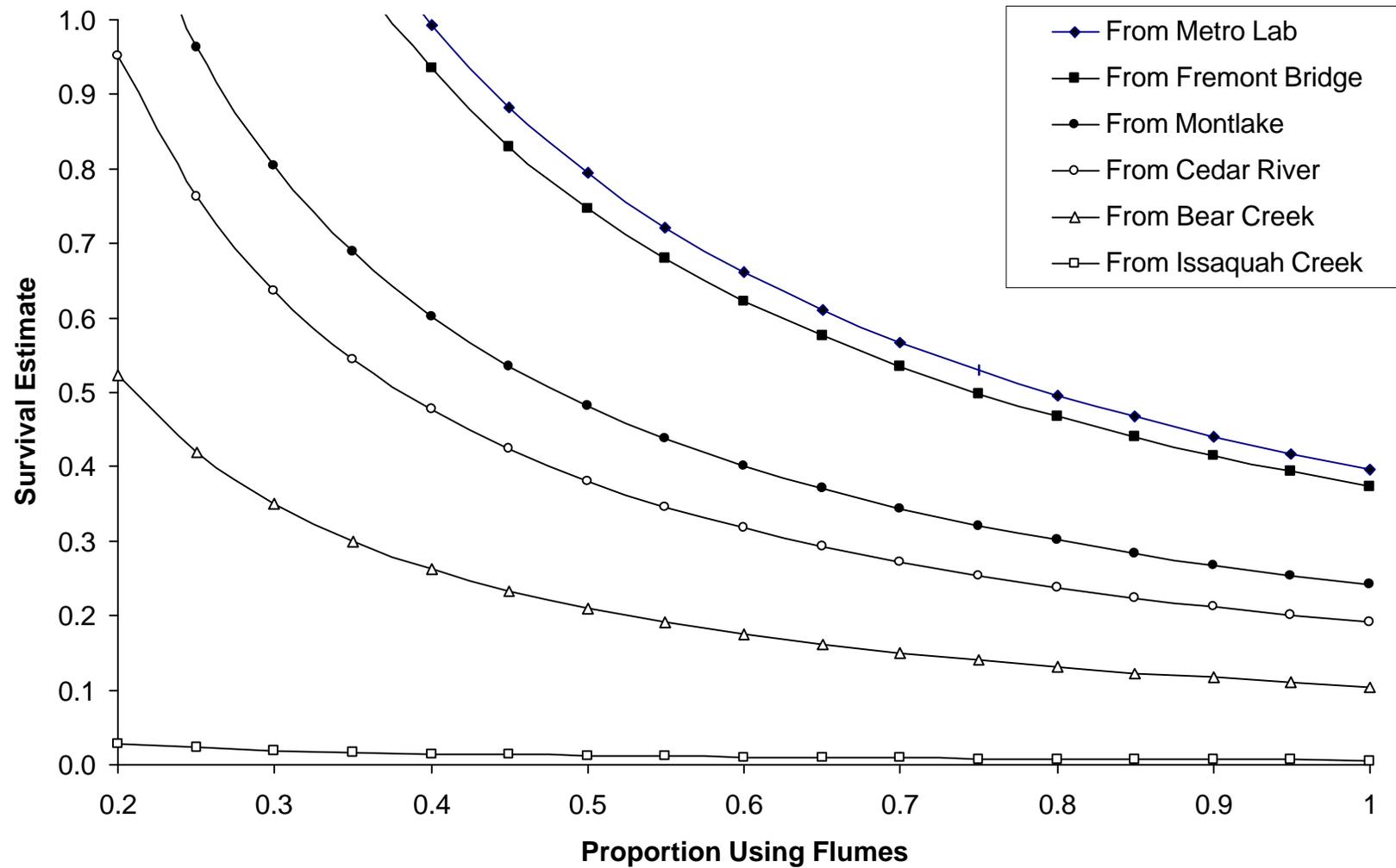


Figure 3-22. Variation of survival estimates for the different chinook salmon PIT tag release groups as a function of the proportion assumed to use the flumes as they passed through the Locks. All groups were assumed to pass in the same proportion, and the Montlake and Metro releases have been adjusted for an estimated post-release disease survival rate of 0.64.

The proportion using the flumes cancels out in the survival calculations for chinook migrating over the other route segments above the Metro Laboratory. Hence, a single value was determined for these segment survivals as follows, and is reflected in the vertical spacing of survival curves in Figure 3-22:

- Bear Creek to Montlake: 0.43
- Cedar River to Montlake: 0.79
- Montlake to Fremont Bridge: 0.64
- Fremont Bridge to Metro Lab: 0.94

The variances of these values are unacceptably large (on the order of the incremental survival estimate itself!) because of the small number of recaptures in the beach seining, without considering the influence of disease and detection efficiency problems.

## 4. DISCUSSION

The results of this study provided important insights into mortality, migration, and passage characteristics of tagged fish in the Lake Washington and LWSC system that permit evaluation of the efficacy of PIT tagging, a primary study objective. The results further permit evaluation of the relation between Locks operations and downstream passage by salmon smolts, and identification of potential changes to operations that may reduce the effects or help conserve water in a benign manner. These issues are discussed below.

The disease that occurred in the LWSC during the experiment had a substantial influence on the study results, particularly the survival estimates. It is likely that more tagged fish released in the Montlake Cut and at the Metro Laboratory would have been detected had the disease not occurred. It is also possible that some of the tagged tributary fish may have succumbed as they passed through the LWSC, although the timing of the disease and of the release and detection dates suggests that the effect on detection probability at the Locks was minor for those groups. As stated earlier, it is also unlikely that any of the Lake Union groups experienced significant disease problems because the majority were detected at the Locks before the most virulent phase of the disease occurred.

Problems with the detection efficiency of the tunnel readers and incomplete coverage of all the routes through the Locks were also significant issues in this study. Fortunately, detection efficiency appeared to vary randomly about a mean value for each tunnel reader. This is important because it suggests that results based on the detections do not suffer from what could otherwise be a critical methodological bias, and the more significant issue would then be precision rather than accuracy.

### 4.1 DOES PIT TAGGING MEET THE STUDY OBJECTIVES?

Based on the results of this first year's study, PIT tag technology appears to be a viable technique for assessing mortality, migration, and passage characteristics, as well as evaluating the effects of the LWSC project on hatchery and naturally-produced chinook and other salmon species. Ignoring problems specific to the year 2000 study such as disease (which does not occur annually to the extent experienced), and incomplete coverage of all passage routes through the Locks, it is possible to generate initial survival estimates for different segments of the migration route, thereby meeting the first study objective identified in Section 1.2 regarding the efficacy of PIT tagging. However, the precision of the survival estimates was extremely low in this pilot

study, particularly because of low recapture numbers in the beach seining and other reasons discussed in the next section. For improved survival estimation, several changes are indicated by the pilot study results, including (i) modifying the holding facilities for tagged hatchery fish to include additional protection from potential disease problems, (ii) correction of tunnel reader detection efficiency magnitude and variability variation in subsequent years, (iii) more intensive sampling for tagged fish below the locks within the inner bay, and (iv) increased numbers of fish in individual release groups. Such improvements will increase the accuracy and precision of future survival estimates.

The second study objective was also met. Specifically, PIT tagging was found to be viable for naturally-reared smolts in tributaries to Lake Washington and for smolts migrating through the LWSC. Highest detection rates occurred for fish tagged in Lake Union and released near the Fremont Bridge. Of the tributary chinook, a relatively large fraction of the fish tagged in Bear Creek and the Cedar River were detected at the Locks despite detection efficiency problems (Tables 3-1 and 3-2), and continued tagging in those tributaries appears warranted. However, the statistical power of the study was low because of the relatively small number of fish tagged in each stream. Changes in study design are suggested below that address this issue. Results were very poor for Issaquah Creek where only two fish were detected out of 348 tagged. This small detection rate resulted in extremely low confidence in survival estimates for fish originating from that stream. Changes to the present study design would be required if it is desired to continue tagging this stock. These changes are also identified below.

With respect to the third main study objective, hatchery chinook were observed to be similar to naturally-spawned tributary chinook in terms of arrival timing of the majority of fish, and of diurnal passage behavior at the Locks. However, their behavior was substantially different from that of the Lake Union chinook, which were significantly larger in size and may have originated from the UW hatchery among other sources. It is unknown whether any of the Lake Union chinook that were tagged were naturally reared. The effects of the Locks on the small fraction of late-migrating tributary fish could not be determined in this study. Johnson et al. (2001) determined passage behavior in their total flume counts that was similar to that of the hatchery fish with respect to proportion using the flumes nearer the fish ladder. Similarities also existed regarding distribution of passage numbers during daylight hours. Hence, hatchery-reared chinook salmon may be a reasonable model for evaluating the behavioral effects of the LWSC project on some naturally-reared fish, but possibly not all. As described in the next section, the use of hatchery fish may not be as useful for determining survival characteristics as opposed to behavioral characteristics. Continued tagging of naturally-reared fish in Lake Union and

elsewhere in the drainage therefore appears warranted, to address survival and passage of fish that may have alternate life history strategies in the Lake Washington system that are not represented by hatchery test fish.

#### **4.2 MEETING THE ASSUMPTIONS OF PIT TAG BASED SURVIVAL ESTIMATORS**

The survival estimates presented in this report must be regarded cautiously. They are offered primarily to demonstrate the feasibility of using PIT tags for estimating survivals along different portions of the migration route, and the degree of uncertainty that may be expected in future studies conducted under similar conditions. The estimates suggest that there is extremely low survival of Issaquah Creek fish as they pass through Lake Sammamish. Bear Creek chinook appear to have lower survival to the Montlake Cut than Cedar River chinook, possibly because the former also have to migrate through the Sammamish Canal. The data also suggest that chinook juveniles exhibit relatively low survival as they migrate between the Montlake Cut and the Fremont Cut. Data collected in the next two years of study will indicate if these trends are reasonable or not, assuming disease and operational problems are averted.

The accuracy and precision of the survival estimates depend on several critical assumptions. One implicit assumption is that all major sources of variation have been accounted for. The primary violations of this assumption occurred through the non-quantified contribution to mortality by the LWSC disease, and the large variation in detection efficiencies of the tunnel readers. The disease continued to plague the UW and Metro fish after mortalities of other indigenous fish in the LWSC were noted anecdotally to drop off, probably because they were held in high densities. Transmission to formerly healthy fish appeared to continue through the day of release, with probable delayed but non-quantified effects. The survival estimates calculated for 2000 may therefore be both biased and imprecise, with variance inflated by the uncertainty in the disease survival and detection efficiency estimates. Both of these sources of variation must be eliminated or rendered negligible in future studies.

Estimates of survival and proportion of tagged fish using the flumes are sensitive to the number of tagged fish recaptured in the beach seine samples. Sampling in 2000 involved sampling over a large area, including in Puget Sound, four times a month. The small number of PIT tagged fish recaptured (21) indicates that more intensive and repeated sampling effort is needed in the inner bay during the chinook outmigration period. Out of these 21 fish, 12 were known to have passed through the tunnel readers, which corresponds to roughly 1 % of the total number of fish detected by the readers (see Table 3-1). Such a low detection probability in the beach seining is associated with a large 95% confidence interval about the survival estimate. For example,

assuming for the combined study groups that the survival estimate is 0.6, the estimated 95% confidence interval for this low a beach seining detection probability is on the order of approximately  $\nabla 0.2$  and  $\nabla 0.35$  when the probability of detection at the Locks ranges between 0.4 and 0.2, respectively (can be estimated approximately by extrapolating the data depicted in Appendix B in log-log space to a beach seine detection probability of 0.01). When detection probability in the beach seining is increased to 0.15, the precision ranges between approximately  $\nabla 0.05$  and  $\nabla 0.08$ , which is a clear improvement over the present estimates. To increase the detection probability to the maximum depicted in Appendix B (i.e., 0.15), roughly a 15-fold increase in sampling effort may be required in the inner bay. Given that PIT tagged fish were caught on 7 sample dates (Table 3-5), to achieve such an increase in sampling effort would require a total of 105 seine samples at each beach site within the bay. Assuming that the majority of chinook smolts pass through the locks in the last two weeks of June, and that the inner bay can be sampled every weekday during a three week period (i.e., also assuming that tide and other sampling logistics are not a problem), at least 7 seine sets would be needed per site per day to meet this criterion. This may not be feasible, but the calculations nonetheless point to the need to increase sampling effort in the inner bay as much as possible in order to increase recapture numbers of PIT tagged fish and minimize the uncertainty about survival estimates. This would also provide more data describing the time of transition between fresh- and saltwater.

It is also possible that the incomplete coverage of passage routes could have had a systematic effect on the survival estimates if different release groups had different mean patterns of migration through the Locks. For example, one group may have migrated predominantly along the south shore where they were more likely to pass through the flumes and be detected, whereas another may have been more likely to have migrated along the north shore and be under-represented in the PIT tag detection data. We don't know if this is the case or not, but the possibility highlights the importance of sampling the alternate routes for PIT tagged fish as well.

Another important, explicit assumption that may not have been met consistently is that the different release groups traveled together through the LWSC and Locks at about the same time, and experienced similar mortality rates over shared migration reaches. This means effectively that the different groups should be mixed together in space and time in the reaches in which they co-occur. Figure 3-6 suggests that approximately 50% and more (depending on the release date) of the fish released in the Montlake Cut spent more time in the LWSC before passing through the Locks than did a comparable proportion of the fish released at the Metro Laboratory. The three groups released at the Metro Laboratory all came through in about the same proportions and the same time (Figure 3-6), suggesting similar behavior of fish occurs downstream of the Fremont

Cut. Their proximity to the Locks (about 3 km) and slower speed compared to the Lake Union fish suggest that they spent some time 'milling about' in the LWSC below the Fremont Cut before passing through the flumes. After about June 22, all six UW test groups appeared to be more evenly mixed as they passed through the flumes. The tributary fish appeared to be well-mixed in the LWSC, based on the similarity of arrival timing seen in Figure 3-6.

The cumulative distribution for Lake Union chinook salmon arrival date depicted in Figure 3-6 is closer to a uniform distribution than is the case for all other release groups, suggesting that the result represents either (i) a mixture of arrival date distributions of fish originating from a number of different sources, or (ii) if the fish were practically all from the regular UW hatchery release groups, they were at varying states of smolt readiness. Without a record of fish origin in the tagging files and monitoring of smolt readiness, this issue remains unresolved.

These results suggest that the chinook from the different release groups were not all as well-mixed as desired until about the last week in June, when all PIT tagged chinook groups appeared to migrate through in large numbers. The passage distributions similarly appeared to tail off at about the same time, before the flumes were shut off completely, suggesting that the end of the main run had occurred and that remaining tributary fish arriving after July 10 (see Figures 2-4 through 2-6) were not present in large numbers (that is not to discount the ecological importance of these fish, however). This pattern was also seen in the beach seining catch-per-unit-effort data (Footen 2000), suggesting similarly that the chinook run was petering out. It is unknown whether the Locks substantially delay or impede passage of chinook arriving later in July. A small number of juvenile chinook were captured in the large lock chamber during sampling for adults in August 2000 (E. Warner, MIT, personal communication). Late arriving fish should still have been able to pass the locks after the flumes were shut off, through the alternate routes depicted in Figure 3-16. They would thus be susceptible to capture in the beach seining, assuming no significant increases in mortality between the Locks and the inner beaches. Alternatively, it is possible that late arriving fish were more likely to pass through the lock culverts and become injured and die, or may end up residualizing in the LWSC and Lake Washington. These alternative outcomes would reduce their probability of capture in the beach seining.

The arrival timing results also suggest that survival estimates are partially influenced by release location of the hatchery chinook. Survival estimates would obviously be more representative of the effects of the LWSC and Locks on natural outmigrants if the study focused more on catching, tagging, and releasing fish at different locations of the LWSC, than on tagging, transporting, and

releasing large numbers of hatchery fish at different locations. This is recommended, if only to reduce the probability of a potential future disease outbreak influencing the results significantly. A potential problem with this recommendation, however, is that large numbers of tributary fish may be logistically unavailable for tagging.

Another important concern is release group sample size, which is a statistical, logistical, and financial issue in PIT tagging-based survival studies. The confidence interval estimates depicted in Appendix B indicate that large numbers of fish are required in each tagging release group. There is a break in the curves plotted in Appendix B in terms of the percent change in precision of the estimate with sample size, at about 2,500 to 3,000 fish per group. At higher sample sizes, the incremental reduction in the confidence interval is smaller and changes less rapidly with increasing numbers of tagged fish. At smaller sample sizes, the confidence interval increases at a much greater rate with decreasing numbers of fish tagged. A sample size of 2,500 tagged fish per release group is therefore recommended as an optimal value in order to maximize the number of potential release groups for a fixed number of PIT tags. Release groups smaller than about 2,500 fish therefore may be better utilized for evaluating behavioral attributes if high levels of precision in the survival estimates are desired. The optimum sample size may not always be possible, however, because smaller sample sizes may be dictated by fish availability, study objectives, and logistic or financial constraints. It suffices to state that the precision of the survival estimates will simply be lower in those cases, and does not invalidate the utility of the data.

#### **4.3 INFLUENCE OF LOCK OPERATIONS ON PASSAGE AND ESTUARINE TRANSITION**

There are several features of lock construction or operation that are suggested by the PIT tag data to influence downstream passage that are evaluated below. The data indicate that between 13% and 40% of fish tagged and released in the LWSC passed the Locks through the smolt flumes. The remainder included fish that died in the LWSC and fish that passed downstream through other routes. Better estimates of survival to the Locks would allow estimation of the remaining proportion that use routes through the Locks other than the flumes.

The greater number of fish passing through the flumes located closest to the fish ladder in spillway bay 5 at first suggests a possible nearshore route preference may be exhibited by smolts migrating downstream through the LWSC. However, the fish ladder does not appear to be an important downstream migration route. A trap constructed in 1994 in the ladder caught juveniles (D. Seiler, personal communication), but the numbers seen using the ladder by fish watchers has

been noted to be small relative to the numbers using the flumes and locks (B. Footen, personal communication). It is thus possible that the higher passage numbers through the flumes in spillway bay 5 may reflect more the influence of entrance velocity fields, because the total flow rate through this gate was greater than the flow rate through spillway bay 4. A greater entrance flow may have attracted more smolts. This potential influence of attraction flow could be evaluated in future work.

#### **4.3.1 Influence on Juveniles Located Below the Locks**

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

The influence of entrainment into the large lock is difficult to evaluate because of the physics involved. As the lower gate is opened, a saline wedge intrudes near the bottom into the large lock chamber, resulting in downstream displacement of a surface lens of the relatively well-mixed, but less saline water initially present in the lock chamber (Lingel 1997). If juvenile salmonids are entrained physically from downstream, they would thus have to be present primarily within the deeper, more saline water that moves upstream. Fish present nearer the surface would tend to be moved in the downstream direction because of the density currents (Lingel 1997). Alternatively, if juveniles were seeking fresher water, they would initially have to swim upstream against the surface discharge of less saline water. Once inside the chamber, the same process is repeated when the upper gate is opened. Hence, if fish are indeed entrained in the upstream direction to above the locks, they would have to be consistently within the deeper parts of the water column. Underwater video data and visual observations suggest that salmonid smolts are surface oriented in the vicinity of the locks structures, while acoustic data show that surface-oriented aggregations, when entrained through filling culverts into the large lock chamber, resume their surface orientation within minutes (J. Dawson, Biosonics Inc., personal communication). These observations are consistent with the findings of Schreck and Stahl (2000), who determined that fish in the Columbia River estuary held within the upper 4 m of the water column, in fresher water as they made the transition to saltwater. This type of smolt behavior may reduce the likelihood of physical entrainment in the upstream direction during gate opening operations. In addition, Johnson et al. (2001) determined that fish near the entrance to

the large lock filling culvert entrance were distributed in two distinct groups, one near the bottom and one near the surface. Although species in each group were not determined, the composition likely reflects vertical salinity differences with downstream migrant smolts remaining in the upper freshwater layer when the upper gates are opened.

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

The trend depicted in Figure 3-19 of shorter recycling interval as the spring outmigration season progresses suggests that an avoidance of more saline water may be plausible in the case of some fish. These fish would have to either initially swim upstream in the surface layer outflow when the gates are opened, or have a quasi-random tendency to swim upstream into the lock chamber when the density currents have subsided, prior to closing of the gate. We do not know the answer to this presently.

Water quality profile data collected below the Locks by C. Simenstad and W. Couch of the University of Washington in 1999, and by D. Houck of King County/Metro in 2000 indicate that there is a low-salinity lens in roughly the upper 1 to 3 meters of the water surface that is less than 20 ppt in concentration (Figure 4-1). This lens sometimes extends out to the railroad bridge and beyond depending on discharge at the Locks and tide. Table 3-5 and Figure 3-20 suggest that a rapid osmotic transition had occurred in a large fraction of the juveniles captured in the beach seine samples in the inner bay area, where salinities nearer the surface are on the order of 20 ppt during the spring outflow months. Juvenile and fry chinook salmon are capable of sudden transitions from freshwater to water with salinities as high as 16 to 20 ppt without apparent adverse survival effects (Macdonald et al. 1988; Healey 1991; Clarke and Hirano 1995; Kreeger 1995). However, tolerance of even 30 ppt has been noted to not be an adequate criterion for identifying smolts (Clarke and Hirano 1995), and thus it is possible that the relatively quick transition may still be stressful (Macdonald et al. 1988). The possibility also exists for increased delayed mortality in saltwater after the transition, associated with scale loss when water temperatures in the LWSC increase to stressful levels during the outmigration season (Clarke and Shelbourne 1985). Blood chemistry sampling of PIT tagged fish passing through the flumes and caught in the beach seine samples would provide more direct evidence of physiological stress and smolt readiness. In any case, the PIT tag data suggest that the downstream migrants

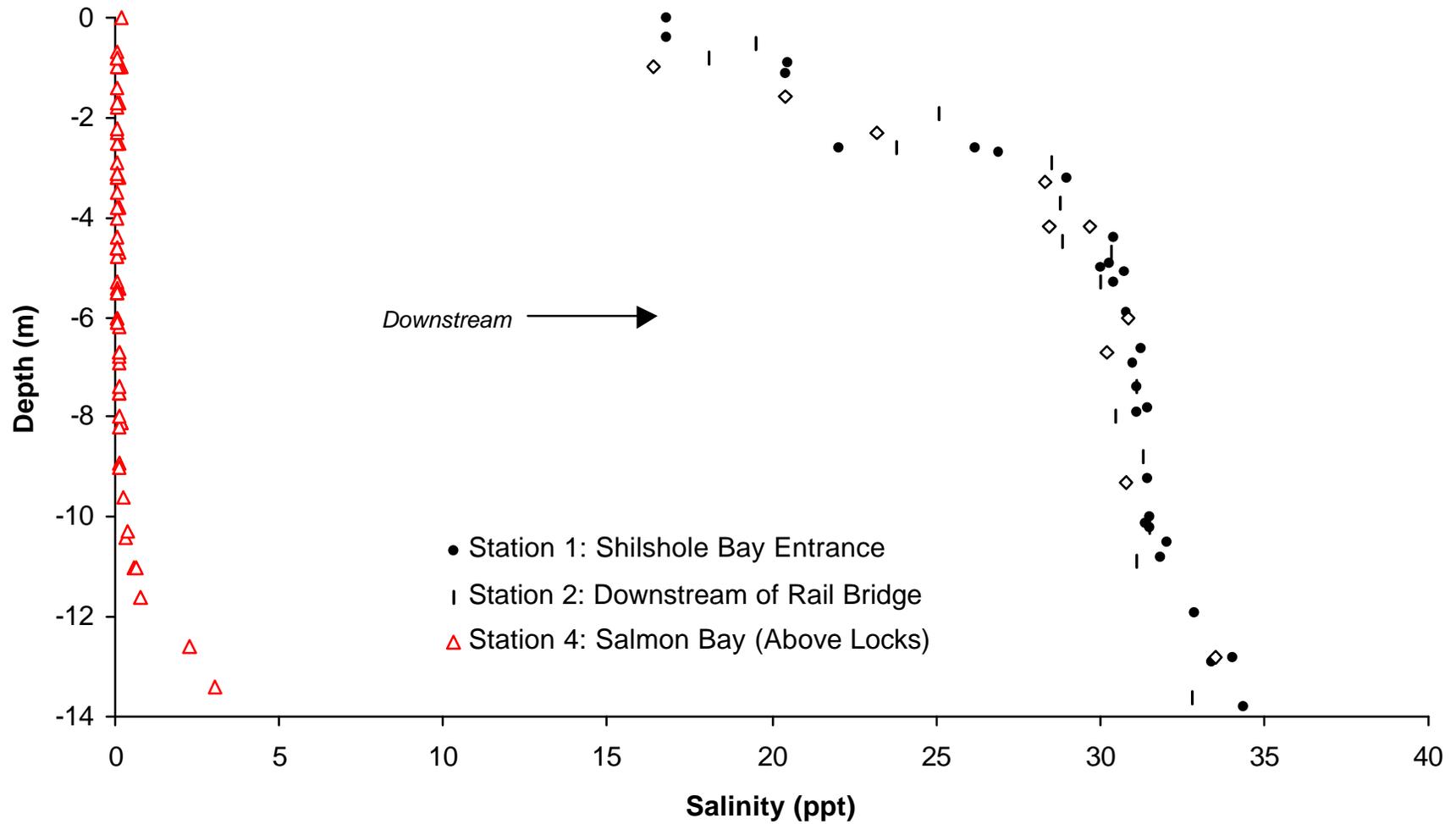


Figure 4-1. Salinity profile measurements made in the vicinity of the Locks on June 27, 1999 (data from C. Simenstad, University of Washington).

spend relatively little time in the lower salinity lens below the locks before making the transition to higher salinity water. They thus appear to spend relatively little time in an 'estuarine' setting with salinities below 10 ppt.

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

#### **4.3.2 Influence on Juveniles Located Above the Locks**

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

#### **4.3.3 Suggested Changes in Operations**

Only one substantial change to flume operations is suggested by the data presently. Because nearly all of the PIT tagged fish passed through during daylight hours, the flumes could be shut off at night to conserve water so that they can be open to passage for a longer period during the smolt migration season, possibly through the end of July. The PIT tag data suggest that more than 90% of the tagged fish passed through the flumes between daybreak and dusk in May and June. This modification would help address water conservation needs for improving smolt passage at the Locks, a significant problem identified by USACE (1998).

A potential, adverse side effect that would need to be investigated, however, is related to the reduction in freshwater discharge and the corresponding effect on the spatial extent of the low

salinity lens below the locks during the night. Preliminary salinity data collected by King County in the spillway tailrace area indicate that the fresher water lens there may be reduced considerably in surface area and depth when the flumes are not operating, depending on tide. This could make the smolts more susceptible to piscine or avian predation if it is determined that they are concentrated within a smaller area while they are making the transition to saltwater.

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

#### **4.4 FUTURE STUDY RECOMMENDATIONS**

The following changes to study design are suggested on the basis of the data collected this year, and accompanying justifications are given. Several of the changes were identified by the collaborative working group during a meeting that occurred at the Locks on November 20, 2000. The possible changes include:

- The vibration problem associated with the tunnel readers needs to be corrected. The variation observed in detection efficiencies is too great presently and the average efficiency too low for the number of tagged fish that can be released practically as part of the LWGI study. It is important that the sample size of detected fish be increased as much as possible to yield greater confidence in survival estimates. The U.S. Navy, in collaboration with J. Sadler, tested the vibration frequencies using an accelerometer. The results of those tests indicate that structural modifications are possible, and these will be undertaken prior to year 2001 monitoring activities.
- Calibration testing should continue, but it should be possible to use both tagged fish and "fish sticks," which are brightly colored pieces of wood to which a PIT tag is attached, oriented either 45E or 90E to the tunnel detector field. The fish sticks are recovered by

boat below the locks after the test is completed. Using fish sticks saves tagged fish for other purposes, and it should be possible to develop a calibration relation between the respective detection efficiencies. Equal numbers of sticks (Biomark recommends  $n=25$ ) should be used for each orientation.

- Fish could be tagged at the Issaquah Creek Hatchery and released from there directly into the stream if survival through Lake Sammamish is of interest. Because of the low numbers of detections at the Locks during this year's study, a larger sample size (e.g., 5,000 fish) is recommended. Otherwise, the resulting precision could be similar in magnitude to the survival estimate.
- Purse seining and PIT tagging should be continued in Lake Union, to evaluate passage, survival, and migration characteristics of fish that may not be represented by the tributary sampling or by releases of tagged hatchery fish.
- Beach seining for PIT tagged fish should focus on the inner bay and railroad bridge area, and be conducted more frequently to increase the catch numbers of PIT tagged fish. This is a critical component of the study, particularly with respect to estimating the proportion of fish using the flumes compared with other routes. In order to increase sampling effort and capture rate in the inner bay/railroad bridge area, purse seining should also be evaluated for feasibility and effectiveness.
- Control groups of PIT tagged fish should be released at the downstream base of the spillway dam, per study designs discussed by Burnham et al. (1987). This would result in better estimates of the proportion of fish using the flumes and survival. These groups are required because beach seine capture efficiency is also unknown and needs to be estimated in order to estimate the other parameters. However, substantially increased capture effort would be required below the Locks than occurred in 2000, to increase the recapture sample size. Ideally, similar numbers of control group fish would be released as were released upstream, although smaller numbers can be released with an associated lower precision about the estimates.
- Purse seining should be conducted again in the large lock, but also in the small lock to determine 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.
- Sampling should also be conducted periodically in the fish ladder for PIT tagged fish. It is possible to construct a downstream migrant trap from which juveniles can be removed and scanned for PIT tags, although such a trap is time consuming to operate (D. Seiler,

personal communicator) and may interfere with upstream adult migration (E. Warner, personal communication). Planned construction of a PIT tag detector for returning adults would also be useful for monitoring smolts in subsequent years.

- It may not be necessary to hold release test groups (other than calibration test fish) at the UW hatchery or at the Metro Laboratory if greater effort can be directed at catching and tagging fish passing through the LWSC. The Lake Union tagging results indicate that this is a feasible method, and may be more representative of natural fish migration patterns and survival. Tagging could occur periodically over the season, depending on the availability of the NMFS' tagging barge. Sampling could also be conducted in Union Bay of Lake Washington to provide fish for tagging, and for catching PIT-tagged tributary fish which would provide data regarding their travel times as they migrate through the lake.
- The blood of subsamples of PIT tagged fish passing through the flumes and caught in the beach seining should be tested for stress and signs of osmotic change or smolt readiness. This information is important for evaluating the effects of the Locks with respect to the relatively sudden transition to saltwater. Both smolt readiness (e.g., gill ATP-ase, sodium levels) and stress (e.g., plasma cortisol) measures would be required to determine if the fish caught in the beach seine samples were experiencing stress from rapid transition to saltwater because they were not completely ready to do.

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# **APPENDIX A**

## **Letter Reports from D. Park (Biomark) and S. Achord (NMFS)**

**Report on PIT Tagging Activities at  
University of Washington Hatchery,  
King County Metro Laboratory,  
And Lake Sammamish Screw Trap Sites.**

**Produced for U.S. Army Corps of Engineers,  
Seattle District**

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**July 11, 2000**

## Introduction

In 2000, Biomark Inc. was responsible for tagging approximately 11,000 fish for the Lake Washington General Investigation Study. This study involved several agencies. The marking portion of the project was designed as a pilot study to determine the efficiency of the Destron-Fearing 134.2 kHz Passive-Integrated-Transponder (PIT) tag monitors, recently installed at Ballard Locks on Lake Washington; and study the feasibility of using PIT tags to determine the timing and survival through Ballard Locks from various parts of the Lake Washington Watershed.

During this project, Biomark worked closely with the Washington Department of Fish and Wildlife (WDFW), Kurt L. Fresh as project leader at University of Washington Hatchery and King County Metro Lab, Dave Siler at the three screw trap collection sites, and Paul DeVries of R2 Consultants.

## Methods and Material

WDFW was responsible for obtaining all the fish used in the experiments; designing, constructing, and maintaining all fish holding facilities; transporting all the fish to the tagging locations; and transporting and releasing the fish at the proper release location.

Paul Devries was responsible for managing the data, producing the project report, and providing recommendations for next years evaluation.

Biomark was responsible for PIT tagging juvenile salmon provided by the WDFW and turning the tagging files over to Paul Devries. All tagging was conducted by experienced biologists using methods described by Prentice et al. (1990.) The tags used were 12-mm 134.2 kHz Destron-Fearing (TX1400BE). Data for individual fish were collected using two Biomark Data Collection Station equipped with PSMFC software (PITTAG2.EXE).

The tagging was divided into three study phases:

1. **Calibration groups** were tagged and released into the smolt slides. This was done to determine the efficiency of the monitors installed at Ballard Locks.
2. **Experimental groups** were tagged and release above the locks to determine the passage rate of fish using the new smolt slides.
3. And, **wild fish groups** were caught, tagged, and released into tributaries of Lake Washington.

- **Calibration study methods**

WDFW collected and transported approximately 700 chinook salmon in Mid-April from the Washington State Issaquah Creek Fish Hatchery to the King County Metro Lab for Calibration Study fish. These fish were held in divided raceways for approximately one week. Tagging for this project was conducted on April 20, 2000.

Fish at the Metro Lab were removed from the raceway using standard dip nets. Groups of approximately 60 fish were placed in 5 gallon buckets and carried to the tagging tables by WDFW personnel. Small groups of approximately 20 fish were then dipped and anesthetized as needed by the tagging personal provided by Biomark.

Fish sizes ranged from 45-mm to 85-mm. Fish smaller than 55-mm were removed from the study prior to tagging.

Twelve groups of 55 fish were tagged and held separately. Groups 1 - 8 were placed into circular tanks located inside the Metro Lab. Groups 9 - 12 were held in a divided above ground raceway outside the Metro Lab (Table 1).

Groups 1-8 were released during the first day of testing while groups 8-12 were held and released at a later date. Details of the releases will be discussed in a separate report.

- **Experimental study group methods**

WDFW collected and transported approximately 10,000 chinook salmon in Mid-April from the Washington State Issaquah Creek Fish Hatchery to the University of Washington Fish Hatchery. An additional 1200 fish were transported and held at the King County Metro Lab.

The fish taken to the University of Washington (UW) were held in large circular tanks for approximately one week while the fish taken to the Metro Lab were held for one week in an above ground raceway. Tagging for the Experimental Study fish was conducted on April 18 and 19, 2000 at the UW while the fish at the Metro Lab were tagged on April 20, 2000. Eight groups of between 1027 and 1110 fish were tagged at the UW. While 1107 fish were tagged in the single group tagged at the Metro Lab (Table 1).

Fish at the UW were removed from the circular tanks using standard dip nets. Groups of approximately 50 fish were dipped and carried between 30 and 100 feet from the circular tanks

to the tagging tables in standard dip nets by WDFW personnel. These fish were then pre-anesthetized by WDFW personnel.

Fish at the Metro Lab were removed from the raceway using standard dip nets. Groups of approximately 60 fish were placed in 5 gallon buckets and carried to the tagging tables by WDFW personnel. Small groups of approximately 20 fish were then dipped and anesthetized as needed by the tagging personal provided by Biomark.

Fish sizes ranged from 45-mm to 85-mm. Fish smaller than 55-mm were removed from the study prior to tagging.

The 9 groups of fish were released into the ship canal at various locations on separate dates. Details of these releases will be discussed in a separate report.

- **Wild fish study group methods**

Wild and hatchery sub-yearling Chinook salmon at three Washington Department of Fish and Wildlife screw trap sites near Lake Sammamish were tagged in this portion of the study. A total of 1149 fish were tagged at the three collection sites (Cedar River, Issaquah Creek, Big Bear Creek). 273 fish were tagged at the Cedar River trap, 348 at Issaquah Creek, and 528 at Big Bear Creek. Tagging took place between May 23 and June 8, 2000.

Experienced taggers from Biomark Inc. conducted all of tagging with assistance on data collection and moving fish from fisheries technicians working for WDFW. Fish were collected over night via screw traps. On the day of tagging the fish were transported on shore via 5 gallon bucket and then dip netted into a preanesthetic of H<sub>2</sub>O and MS-222. A PIT tag was inserted into the fish and then returned into a recovery bucket. Fish were allowed to fully recover from the anesthetic and were released back into the river below the screw trap.

## **Discussion**

- **Fish handling**

Fish were handled differently between the WDFW and Metro Lab. Fish were observed to be more stressed at the UW tagging site. Observations included: reacting much quicker to the same concentration of anesthetic (MS-222), recovering much slower from anesthetic, having a higher shed tag rate, and having a higher mortality rate. (Tag shed and mortality will be discussed in a separate report.)

We recommend using fish handling methods during collection that will reduce the time the fish is out of the water in a dip net. The method used at the Metro Lab minimized the time the fish were in standard dip nets and appeared to be an acceptable method. However, the use of other methods such as sanctuary dip-nets, fish augers, and other methods of water to water transfer have been demonstrated to be very passive methods by other researchers.

**Summary Report on Pilot Study Year of PIT-tagging  
of Juvenile Salmonids in the Ship Canal above  
the Hiram M. Chittenden Locks, Seattle, Washington**

This summary report covers the PIT tagging and releases of juvenile salmonids that were collected by purse-seining on the east side of Gas Works Park in Lake Union. Purse-seining operations were conducted by WDF and fish tagging and releases were conducted by NMFS.

**Methods**

A gas operated water pump, manifold, hoses, and associated 30 gallon transfer containers were supplied by NMFS for use during transport of salmonids to the marking barge after purse-seining. Procedures used to purse-seine and handle fish on the purse seine vessel will be reported by WDF.

On arrival of the fish to the marking barge the fish were transferred to one of two large fish holding tanks that were supplied with fresh water via the barge water pump. In addition, oxygen was supplied in the live tanks as well as all fish handling and tagging containers to reduce the stress of handling and tagging. Fish were dipped from the fish holding tank with sanctuary dip nets. A measured amount of MS-222 solution (by bottle dispenser) was added to the sanctuary dip net. This brought the concentration to about 40 to 50 ppm. Procedures for making and applying the MS-222 solution--200 g of powdered MS-222 to 1 gallon of water, 1 ml of this solution to 1 liter of water or about 5 to 10 ml for a typical pan of water and fish (1.5 to 2 gallons). This may be altered depending upon the strength of the batch of MS-222 used.

Fish were then sorted to be PIT-tagged, species to be tagged later were quickly sorted to a 30 gallon holding container supplied by running water and oxygen. Fish were then PIT tagged, scanned into the PIT tag file, length digitized, and comments made if needed. They were then put in the other large fish holding tank on the barge or a large live cage in the water beside the barge. These live cages by the barge were used when holding fish for 24 hours or longer. Each species were tagged in separate PIT tagging files. After tagging, the needles on the syringes were disinfected in an ethyl alcohol bath for a minimum of 10 minutes before re-loaded and used again. All PIT tags were also disinfected with ethyl alcohol before used.

After tagging, fish were allowed to recover in the fresh water tank for a minimum of 0.5 hours. We then moved the marking barge to the release site, examined the tank for mortalities which were removed and subsequently released the fish via a 4 inch flexible hose in mid-channel about 100 yards above the Fremont Bridge. All mortalities were scanned and the tags were removed (dotted out) from the tagging files. One mortality was inadvertently missed and not recovered. Fish that were held in the live cages for over night or longer were dipped from the live cages, anesthetized, and scanned for a PIT tag. These fish were put in a tank on the barge and allowed to recover, then released as described above.

## Results

The following tagging and release results will cover each species separately.

### Sockeye

<u>Tag date</u>	<u>Number tagged</u>	<u>Number mortality</u>	<u>Held?</u>	<u>Release date</u>	<u>Release time</u>	<u>Number released</u>
5/17/00	38	3	yes	5/19/00	08:30	35
5/18/00	62	2	yes	5/19/00	08:30	60
5/23/00	311	3	no	5/23/00	13:50	308
5/24/00	103	1	yes	5/25/00	07:50	102
Total	514	9	---	-----	-----	505

### Coho

<u>Tag date</u>	<u>Number tagged</u>	<u>Number mortality</u>	<u>Held?</u>	<u>Release date</u>	<u>Release time</u>	<u>Number released</u>
5/23/00	417	0	no	5/23/00	13:50	417
5/24/00	27	0	yes	5/25/00	07:50	27
Totals	444	0	---	-----	-----	444

### Chinook

<u>Tag date</u>	<u>Number tagged</u>	<u>Number mortality</u>	<u>Held?</u>	<u>Release date</u>	<u>Release time</u>	<u>Number released</u>
5/23/00	499	1	no	5/23/00	13:50	498
5/24/00	13	0	yes	5/25/00	07:50	13
Totals	512	1	---	-----	-----	511

In addition to the above tagged and released fish, 17 Coho, 38 chinook, and approximately 362 sockeye were sorted out and not tagged.

All fish brought to the marking barge by WDF were alive. Two sockeye lost their tags during holding (2/203) for 1.0% tag loss. Due to circumstances with purse-seining we only held 13 chinook and 27 coho over night. However, observations on the Coho and Chinook after tagging indicated no reason to believe any major differences from the results observed for sockeye after holding.

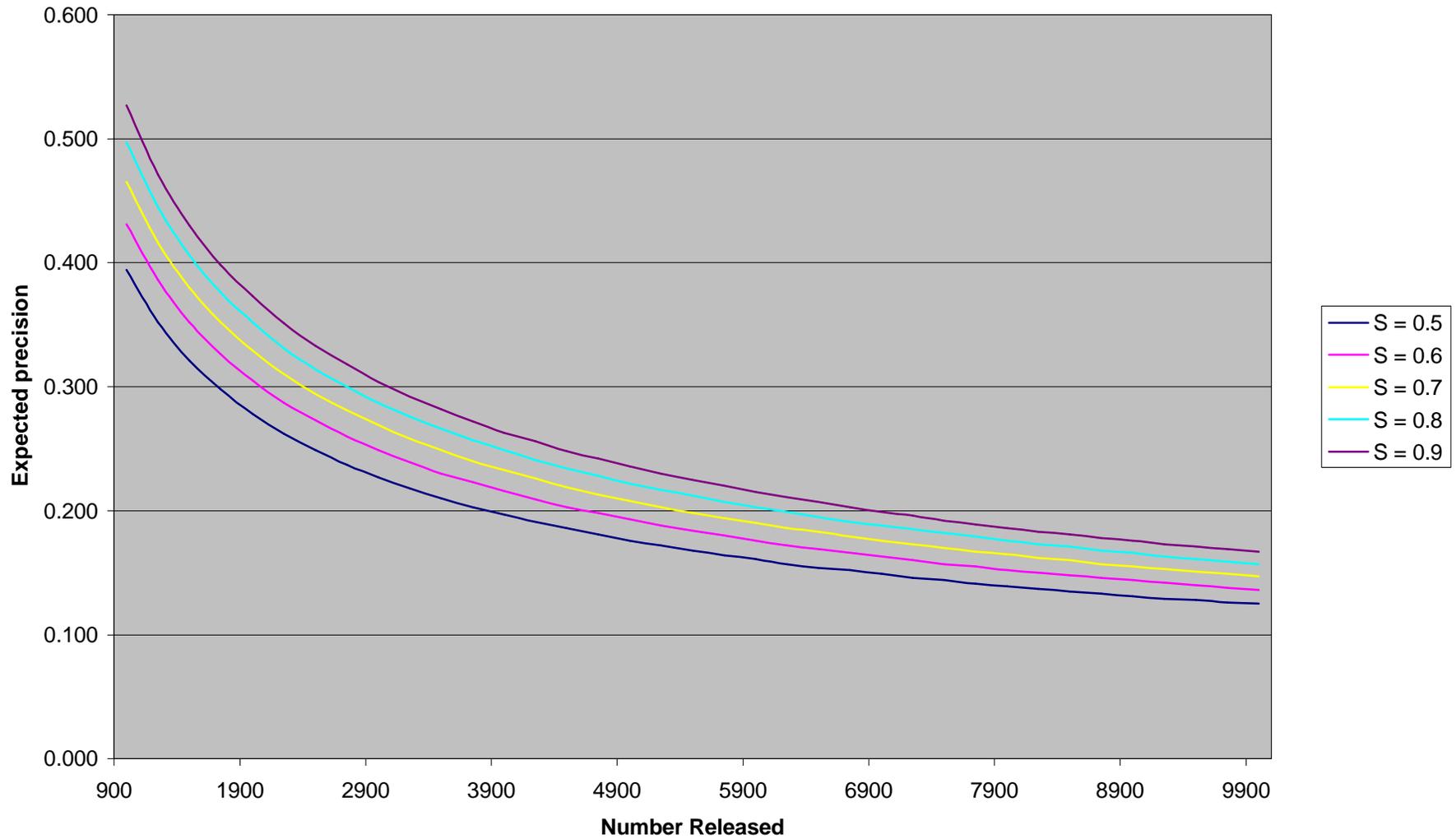
This pilot study demonstrated that these salmon smolts can be collected and tagged with very low collection and tagging mortality, with handling procedures outlined above. However, a

very important point is that we had luck on our side with water temperatures. By far the majority of the fish were collected and tagged at a constant 14 degrees C. Water temperatures only fluctuated 2 degrees C during the study. All these factors contributed to the very low 0.7% (10/1470) overall mortality and 2.5% (6/243) delayed mortality.

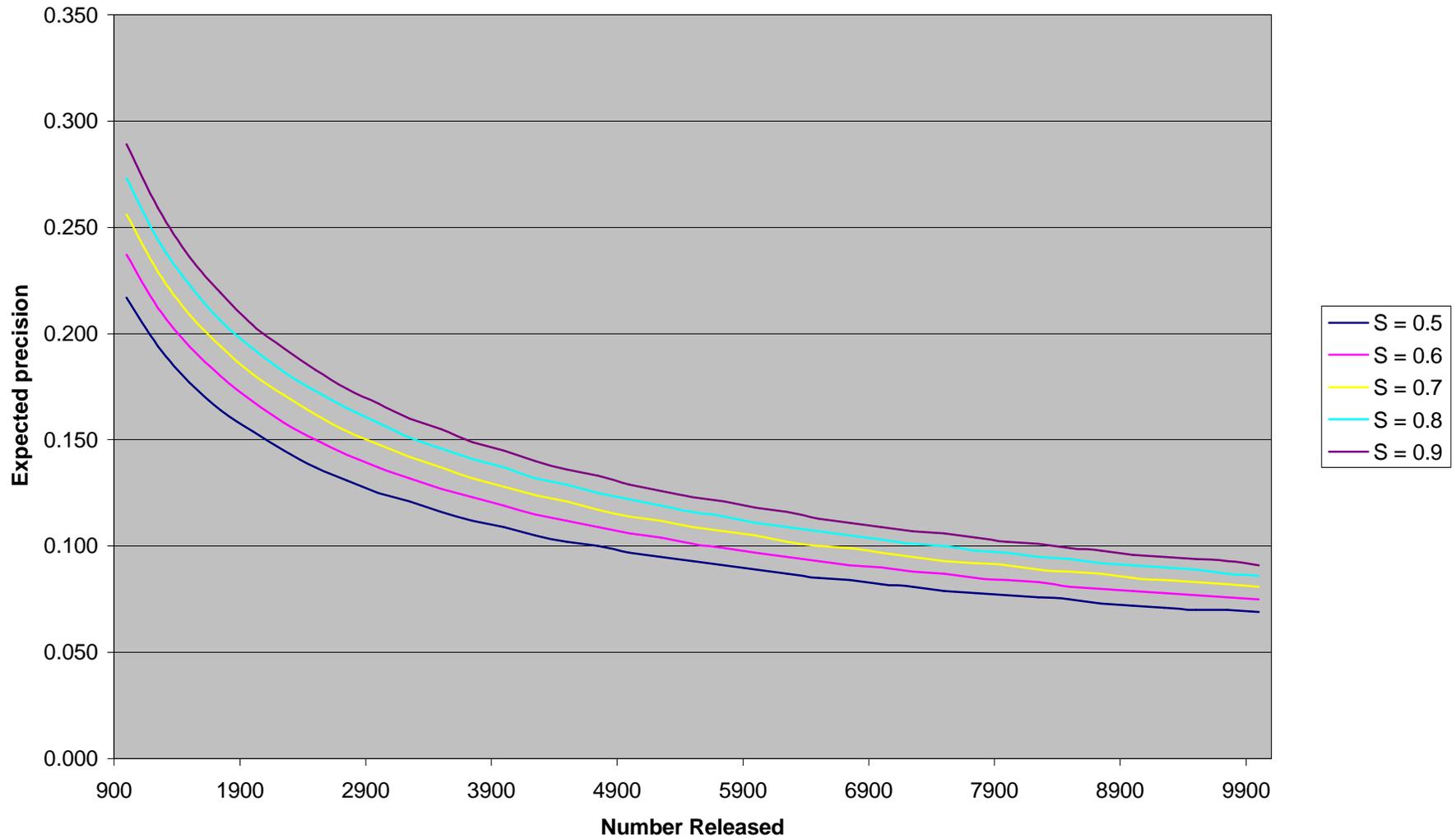
## **APPENDIX B**

**Expected Half-Width 95% Confidence Intervals for Survival Estimates  
for a Range of Release Numbers, Survival Estimates (S),  
Detection Probabilities at the Locks (P1),  
and Detection Probabilities in Sampling Below the Locks (P2),  
Assuming Survival to Capture Below the Locks Equals 95%**

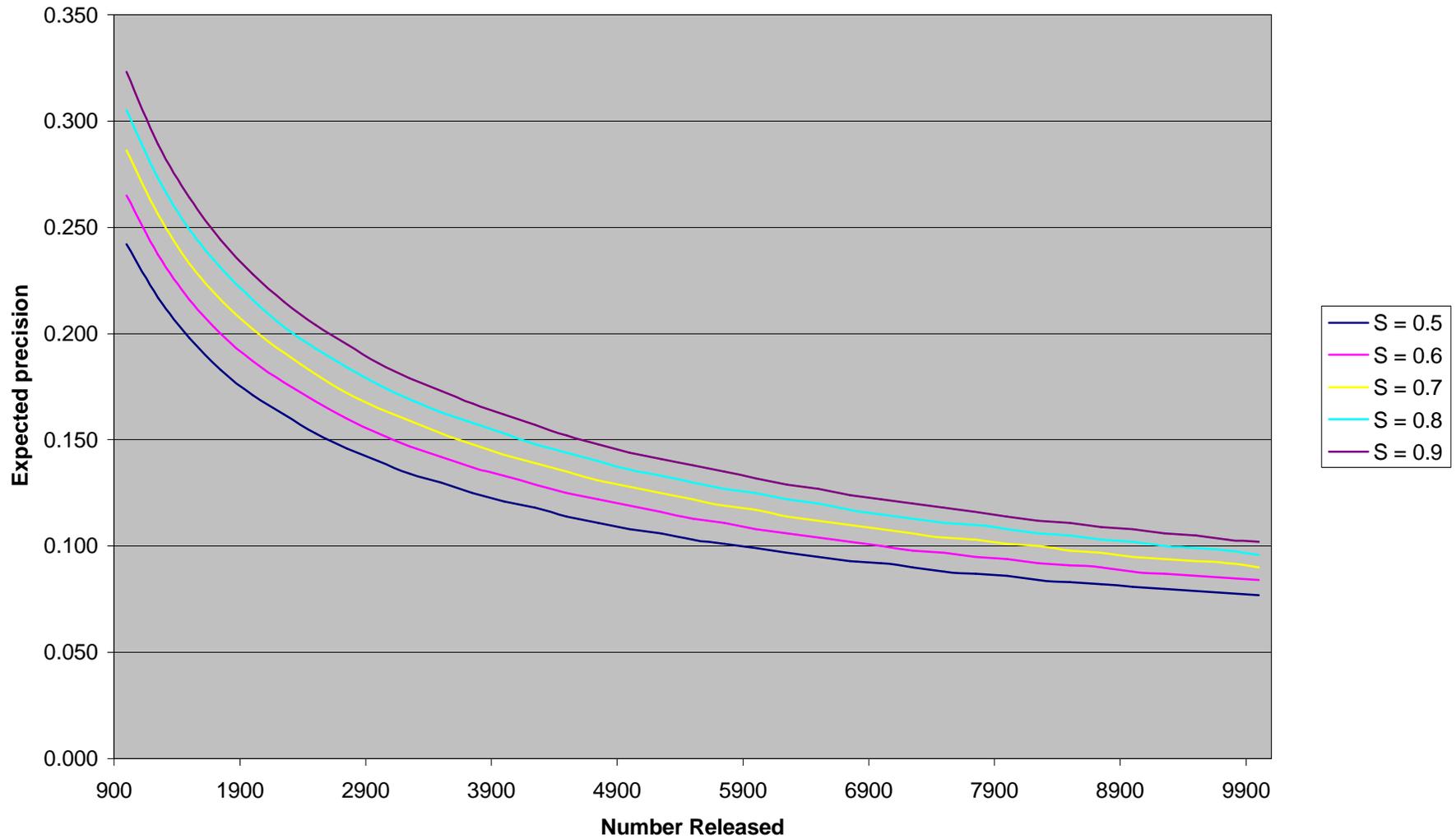
Expected half-width 95% CI  
P1 = 0.20 P2 = 0.05



Expected half-width 95% CI  
P1 = 0.20 P2 = 0.15



Expected half-width 95% CI  
P1 = 0.40 P2 = 0.05



Expected half-width 95% CI  
P1 = 0.40 P2 = 0.15

