PNNL-14160

# Evaluation of the Effects of Extended Length Submerged Bar Screens on Migrating Juvenile Pacific Lamprey (*Lampetra tridentata*) at John Day Dam in 2002

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FINAL REPORT
March 2003

Prepared for
the U.S. Army Corps of Engineers
Portland District
Portland, Oregon
under Contract DE-AC06-76RL01830

Pacific Northwest
National Laboratory
Operated by Battelle for the
U.S. Department of Energy

## LEGAL NOTICE

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# Executive Summary

Pacific lamprey (*Lampetra tridentata*) is the largest and most abundant lamprey species in the Snake and Columbia River system. Because the Pacific Lamprey is a native anadromous species, the U.S. Army Corps of Engineers has an interest in facilitating its protection at federally operated hydroelectric projects. Pacific Northwest National Laboratory (PNNL) conducted a study in 2002 to ascertain the effects of the modified extended-length submerged bar screens (ESBS) on juvenile Pacific lamprey at John Day Dam. The project focused on three tasks. The first consisted of *in situ* video observations of lamprey encountering the modified ESBS within an operating turbine intake at John Day Dam. The second was to infer the effectiveness of the ESBS at guiding juvenile lamprey by conducting releases of lamprey implanted with passive integrated transponder (PIT) tags concurrent with fyke net testing. The final task was to test the assumption that PIT tagged juvenile lamprey behave normally in burst speed and sustained swim speed laboratory tests.

The ESBS was modified prior to 2002 from 3.175 mm to 1.75 mm bar spacing because previous studies showed that juvenile lamprey were becoming wedged in the bar screens. During 105 hours of video, 50 lamprey and 18 smolts were observed interacting with the modified ESBS in slot 7C. Many of these lamprey and smolt came into brief contact with the screen. A few observed fish became impinged on the screen face, but none were wedged in the 1.75 mm opening of the bar spacing. Spatially, the majority of lamprey were observed on the upper and lower 10 feet of the screen (86 %), while very few occurred on the middle 20 feet. Most smolts were observed on the lower half of the screen (79%). Directional movement of fish on the screen face corresponded with reported flow patterns.

The PIT tag detection rate at the juvenile fish facility was 99.6% for animals released into the juvenile bypass system downstream of the gatewell and 11.7% for those released in the gatewell. This difference may be due to a damaged vertical barrier screen, which had numerous holes in the screen face when inspected post-season. In fyke net tests, 99.3% of lamprey were committed to turbine passage. This suggested a high susceptibility to gap loss (with fish passing through the gap above the ESBS), as fish were released in a manner designed to ensure contact with the upper portion of the ESBS. In tests of swim performance, no significant difference was shown between tagged and untagged lamprey for sustained swim speed (ANOVA; $p = 0.12$); however, maximum burst speeds differed significantly (t-test; $p = 0.02$). There was no relationship between tagged lamprey size and burst swim speed ($r = 0.19$, $p=0.31$). Sustained swimming speed of tagged lamprey was significantly correlated with total length ($r = 0.43$, $p=0.02$).

The narrower bar screens of the modified ESBS were effective in preventing the permanent wedging of lamprey between the bar spacing. Therefore, if extended-length bar screens are installed in all units at John Day Dam, they should have the 1.75-mm bar clearance. For all new screen designs, the Corps should use this narrower 1.75-mm spacing whenever possible.

# Acknowledgments

We sincerely acknowledge the cooperation, assistance, and hard work of the following:

**U.S. Army Corps of Engineers staff**

Dan Feil and Mike Langeslay for project oversight; Bob Cordie and Miro Zyndol for their research coordination activities; Don Kumm and all the John Day Dam riggers for their outstanding support and suggestions at the dam; and Dick Leatherbury and Mike Colesar for administration and engineering support.

**Pacific States Marine Fisheries Commission staff**

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**NOAA Fisheries**

Dean Brege, Randy Absolon, and their crew generously retrieved our tagged lamprey from the fyke nets and shared early 2002 fyke net results.

**Oregon Department of Fish and Wildlife staff**

Rosanna Tudor provided the juvenile lamprey run timing data for McNary Dam. Benjamon Clemans provided the juvenile lamprey run timing data for Little Goose Dam.

**Battelle staff**

Scott Abernethy maintained the PNNL fish holding and laboratory facilities in Richland. Traci Degerman created all of the digital movies and conducted the Pitagis queries. Phil Butler, Heidi Kos, Bill Markham and Nathan Phillips worked odd hours in support of the field and lab work. Susan Thorsten managed and backed up the electronic data.

# Contents

# Figures

# Tables

# 1.0 Introduction

This report describes laboratory and field studies of juvenile Pacific lamprey passage at John Day Dam conducted by the Pacific Northwest National Laboratory (PNNL) for the U.S. Army Corps of Engineers - Portland District. This study is one of several research projects funded by the Corps that evaluated fish passage at John Day Dam in 2002. The District funded other parallel research on juvenile salmonids in 2002 including a radio telemetry study by the U.S. Geological Survey, Biological Resources Division (USGS BRD), a hydroacoustic study by PNNL, and a fyke net study of fish guidance efficiency by the National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NOAA Fisheries).

## 1.1 Background

Pacific lamprey (*Lampetra tridentata*) is the largest and most abundant lamprey species in the Snake and Columbia River system (Wydoski and Whitney 1979). It is parasitic as an adult in the ocean, it migrates into freshwater to spawn, and larvae develop in the gravel-mud substrate for several years before migrating downstream as young adults. The current distribution of Pacific lamprey extends to Chief Joseph and Hells Canyon dams, in the mainstem Columbia and Snake rivers, respectively. Principal spawning and rearing habitats occur in tributary streams (Kan 1975), with limited use of mainstem corridors except during adult and juvenile migration periods.

A widespread decline in numbers of Pacific lamprey has occurred since the 1960s, the period when most dam construction occurred in the lower Snake and Columbia Rivers. This decline has been attributed to several causes including habitat loss, water pollution, ocean conditions, and dam passage (Close et al. 1995). While studies have been initiated to investigate potential causes of population decline, the emphasis has been on abundance monitoring, adult migration, and habitat restoration (Jackson et al. 1996). There have been few studies that specifically address effects of dam operations on juvenile survival.

Operations at mainstem hydroelectric projects may impact juvenile lamprey during downstream passage. One concern is that juvenile lamprey have a higher potential for entrainment through turbines because they swim lower in the water column than anadromous salmonids (Long 1968). Another key concern is how juvenile lamprey respond to barrier screens placed at projects to bypass fish into collection facilities. For example, some investigators have reported large numbers of juvenile lamprey impinged between individual bars of fixed bar screens at The Dalles and McNary dams (Hatch and Parker 1998).

In the spring of 1999, modified screens were evaluated at John Day Dam in Unit 7 to document impacts to fry and lamprey. Juvenile salmonids that passed through the test unit gatewell that year incurred high mortality, on the order of 12% to 48% (Brege et al. 2001). Therefore, a prototype vertical barrier screen and an outlet flow control device were developed in 1999-2000 and deployed in 2001. Additionally, alternatives to the deeper gatewell orifices at John Day Dam are also being explored. Finally, based on previous lamprey research, the wedge wire bar spacing was reduced from 3.175 to 1.75 mm in 2002. This was expected to significantly decrease the permanent impingement or wedging potential of juvenile lamprey while not impairing the screen's effectiveness at guiding smolts.

## 1.2 Previous Studies

Laboratory studies were completed in 1999 to document diel swimming behavior, burst and sustained swim speed, and effects of velocity on impingement at bar screens. Tests were also conducted to evaluate the effects of shear on survival and injury (Moursund et al. 2000). These studies demonstrated that juvenile lamprey have a distinct activity period that is limited almost entirely to periods of darkness. Average burst speed for juvenile lamprey during forced swim trials was 2.3 ft/sec or 5.2 body lengths/sec. Juvenile lamprey became impinged on bar screens at velocities of 1.5 ft/sec during prolonged (12 hr) exposures in the swim chamber. These are slower speeds than the average velocities of 2.4 ft/sec found at the bypass screen face in turbine intakes (Weiland and Escher 2001). In addition, video cameras were used to document tail-first penetration behavior in our test screen system. This behavior resulted in juvenile lampreys being stuck between the bar plates, a response similar to that observed at John Day and McNary dams.

Laboratory and field studies were continued by PNNL during 2000-2001. These studies consisted of laboratory screen impingement versus water velocity tests using angled bar and mesh screens, effects of pressure, and lamprey response to white and strobe light (Moursund et al. 2001). Field tests were conducted at McNary Dam, unit 4B, using underwater video cameras and infrared light sources fastened to the ESBS brush bar during May and June of 2000 and June of 2001. In 2000, over 40 lamprey were documented during the video evaluation. In 2001, 15 juvenile lamprey were observed along with 57 smolts. The majority of lamprey were observed during the first few hours of darkness with interaction ranging from impingement on the screen face to becoming totally wedged between the bar screen slots.

In addition to the camera observations, PIT-tagged lamprey were released at McNary Dam in 2001. PIT tagging procedures were modified from a study conducted by Oregon State University (Schreck et al. 1999). Results from releases at McNary Dam showed that single-coil detection efficiency was 97%, which was comparable to the detection rate for juvenile salmon. Detection rates following releases of 700 lamprey in the collection channel, gatewell, and forebay were 66.9, 72.0, and 21.6% respectively.

## 1.3 Study Goals and Objectives

The goal of this study was to determine the effects of the John Day Dam juvenile bypass system, and specifically the modified ESBS, on the behavior and survival of juvenile Pacific lamprey. The objectives were as follows:

1. Make direct real-time observations within an operating turbine intake, of actively migrating juvenile Pacific lamprey and smolts at the modified ESBS. Determine whether or not juvenile lamprey and smolts were being impinged on the screen face or wedged into the openings between bars.

2. Infer the effectiveness of the screen at guiding juvenile lamprey by conducting PIT tag releases concurrent with fyke net testing. Determine the fate of tagged lamprey, whether guided or unguided, from releases made in the forebay.

3. Test swim performance of lamprey in the laboratory with and without PIT tags to assure that tagged individuals were able to swim with the same ability as untagged fish.

## 1.4 Study Site Description

John Day Dam, located at Columbia River mile 215.6, includes a navigation lock, a spillway with 20 bays (numbered from north to south), and a 1,975-ft-long powerhouse comprised of 16 turbines and 4 skeleton bays (numbered from south to north) (Figure 1.1 and 1.2). Each turbine unit is divided into three intakes, identified as A, B, and C, beginning from the north. Standard length submerged traveling screens (STS) were in all units at the time of this test, except for unit 7, which contained the modified ESBS. A juvenile fish facility is located on the Oregon shore.

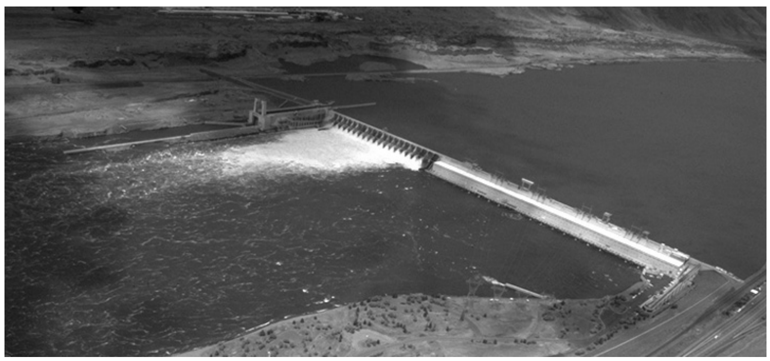

**Figure 1.1.** Aerial Photograph of John Day Dam. Flow is from right to left.


**Figure 1.2.** Location of John Day Dam in Relation to Other Mainstem Hydroelectric Facilities in the Columbia River Basin

## 1.5 Report Organization

This report has several sections. The study and explanation of the research are put into context in the introduction. Section 2, Methods, describes the techniques and equipment used for the in-turbine underwater video observations, PIT tag and release lamprey guidance tests, and PIT tag swim performance experiments, as well as the data processing and analysis. Statistical, graphical, and tabular representations of field and laboratory data are presented in the results section, Section 3. Explanations of the data from the results are provided in the discussion (Section 4). Section 5 consists of the conclusion and recommendations. Section 6 is References. Appendix A provides charts of historical run timings for Pacific lamprey at John Day and other Columbia and Snake River dams. Appendix B includes design specifications for camera and pulley mounts, cable braces, and wiring diagrams for lights and cameras.

# 2.0 Methods

Laboratory and field evaluations for 2002 focused on characterizing the behavior of juvenile lamprey and salmonid smolts that encountered the prototype ESBS and determining its effectiveness at routing juvenile lamprey away from the turbines. Behavior was characterized during the juvenile outmigration period via *in situ* observations of an operating turbine unit outfitted with ESBS. PIT tag releases within and immediately upstream of John Day Dam were used to determine ESBS guidance effectiveness for juvenile lamprey. Laboratory observations were conducted to evaluate swimming behavior in PIT tagged fish. Test animals were acquired from the fish bypass facility at John Day Dam in April, May, and June 2002.

## 2.1 In Turbine Optical Cameras

Optical underwater video cameras were used to document the behavior of juvenile lamprey and smolts interacting with the ESBS. Four cameras were secured to the brush bar mechanism of unit 7C. Three cameras were oriented facing the top of the screen and directed toward the screen face at a 31° angle down from vertical. A fourth camera was positioned facing north, along the length of the brush bar. Video/power cables were routed along the brush bar and run up the center of the screen face (Figure 2.1). Cable guides were also fastened to the flow vane to reduce cable friction. Two spring-tensioned cable reels with slip rings were used to take up the slack in the cable as the brush bar moved up and down the screen.

During the recording period, the brush bar was operated under manual control, allowing it to be stopped when fish were in view of the cameras. It was operated on the normal 20-min cycle and stopped only when fish were encountered. During non-recording periods, the brush was set to cycle automatically. The coverage, based on three 1-ft-wide strips for the field of view, encompassed 15% of the 20-ft-wide ESBS surface area. All recordings were made on 8-mm digital video format tapes.

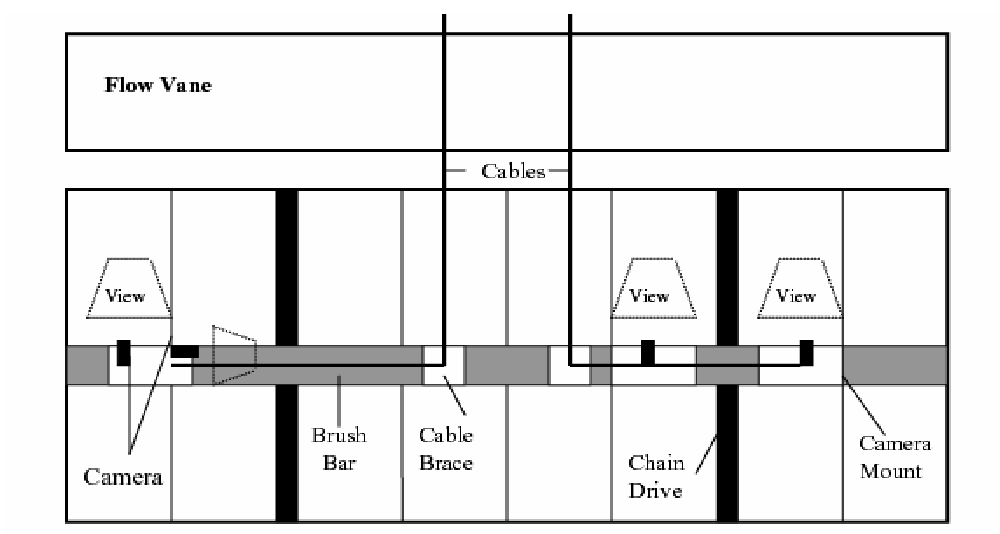


**Figure 2.1**. Diagram of the Optical Camera Deployments and their Associated Fields of View

Video recording took place between 2000 and 0200 h (six hours), May 22-28 and June 6-16, 2002. On May 22 and June 6 sampling did not begin until 2100 and 2130 respectively. The selected sampling time corresponded to peak diurnal activity as determined by previous laboratory tests (Moursund et al. 2000) and the majority of lamprey sightings in an average 24-hr period at McNary Dam (Moursund et al. 2001). This is also when the bulk of lampreys were collected at the juvenile bypass system (JBS). Faults with the cable system and power supplies disabled various cameras throughout the sampling periods (Table 2.1). The gap between May 28 and June 6 sampling was the result of cable failure on May 29. New cables were installed and redeployed with additional strain relief on June 6, at which time sampling resumed. A power supply issue (the result of an excessive voltage drop across the telemetry cable) was resolved by June 7. All video recordings were reviewed post-season for fish occurrences. Records were kept on the date, time, screen location, duration of appearance, and direction of movement for each fish observed.

**Table 2.1.** Record of Camera Operations. Camera A was located on north side facing up, Camera B was in center facing up, Camera C was on south side facing up, and camera D was facing down the length of the brush bar. O = Operational, X = Not operational, I = Intermittent operation.

| | Camera A | Camera B | Camera C | Camera D |
|---|---|---|---|---|
| May 22 | O | O | O | O |
| May 23 | O | O | X | I |
| May 24 | O | I | X | X |
| May 25 | O | I | X | X |
| May 26 | O | I | X | X |
| May 27 | O | I | X | X |
| May 28 | I | I | X | X |
| June 6 | X | I | X | X |
| June 7 | O | O | O | O |
| June 8 | O | O | I | I |
| June 9 | O | O | X | X |
| June 10 | O | O | O | O |
| June 11 | O | O | O | O |
| June 12 | O | O | O | O |
| June 13 | O | O | O | O |
| June 14 | O | O | O | O |
| June 15 | O | O | O | O |
| June 16 | O | O | O | O |

## 2.2 PIT Tag and Release

Juvenile lamprey were acquired from the John Day Dam smolt monitoring facility between early April and mid June. Fish that were released in the JBS prior to April 17 were tagged and allowed to recover in a tank of ambient river water at the smolt monitoring facility for six days prior to release. Lamprey released in the forebay or gatewell after June 18 were transported to the PNNL Aquatic Laboratory in aerated coolers and held in a 190-gal Living Stream™ tank in chilled (6° C) and UV filtered well water. The change in holding conditions was made in an effort to reduce fungal infection that had become prevalent within the population being held at the John Day smolt monitoring facility.

This progressive susceptibility to infection has occurred when water temperatures exceeded 12° C in prior studies (Moursund et al. 2000).

### 2.2.1 PIT Tagging Procedure and Measurements

Lamprey were removed from the holding tank in lots of 15 to 20 and placed in an anesthetizing solution of MS-222 (250 mg/L, pH 7.0). When their activity level decreased each lamprey was measured for total length. Also, 851 lamprey were measured for width at three positions (Figure 2.2) and examined for visible abnormalities. These morphological measures were collected to explain the process and progression that lamprey experience after impingement and how it differs between 3.175 and 1.75 mm bar spacing. The positions of abnormalities or injuries were recorded in quadrants with reference to body position (Figure 2.3) and ventral and dorsal surfaces. Each abnormality was recorded as a bruise, scar, abrasion, or mark.

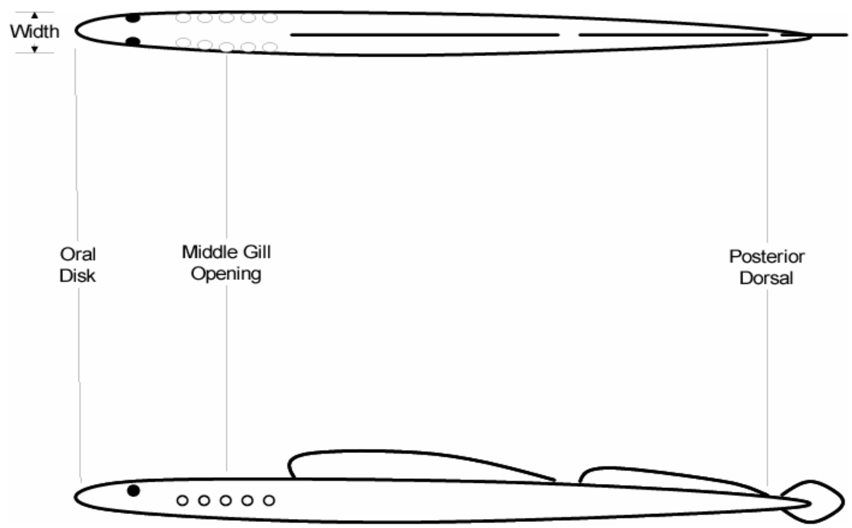


**Figure 2.2.** Width Measurement Points on Lamprey

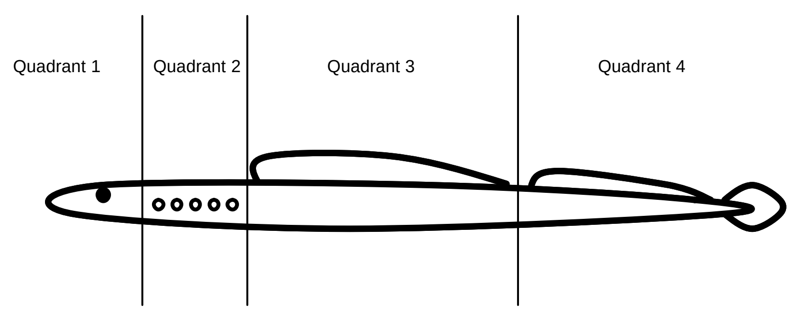


**Figure 2.3**. Quadrants for Recording Observations of Previously Existing Abnormalities

Each lamprey was then placed on a moist, artificially slime-coated, closed-cell foam pad with the right side gill openings facing up. A 22-gauge hypodermic needle was used to puncture a small hole about 5 mm posterior of the gill pores (Figure 2.4a). A tapered dissecting needle was then used to enlarge the opening slightly allowing insertion of the PIT tag injector needle (Figure 2.4b). A 12-gauge PIT tag injector needle was inserted, bevel side up, until the needle opening was under the skin (Figure 2.4c). The PIT tag injector was rotated, orienting the bevel side toward the lamprey body and the tag was injected into the body cavity. To minimize the potential for tag shedding, particularly through dam passage, the incision was closed with a single suture (Figure 2.4d).

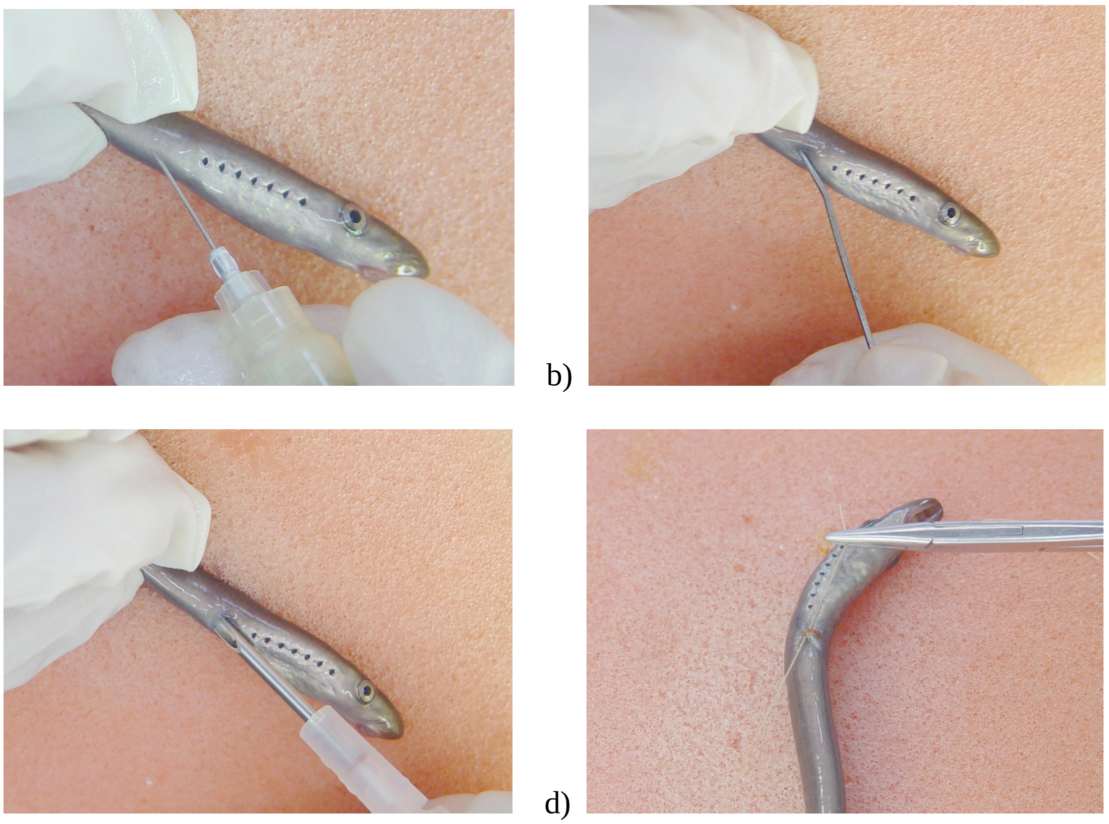


**Figure 2.4.** PIT Tag Implantation. a) hypodermic puncture; b) enlarge opening with tapered dissecting needle; c) tag inserted with PIT tag injector; d) a single suture to close the incision.

### 2.2.2 Release Procedures

Several tagged juvenile lamprey were released in the juvenile bypass system, as follows: 60 were released in the gatewell of unit 7C, 54 were released at the crestgate, 79 were released at the dewatering screens, 50 were released at the diversion fork, 33 at the fish and debris separator, and 36 just upstream of the primary detector coils (Figure 2.5). In addition, in concert with the NOAA Fisheries fyke net study, 628 were released immediately upstream of the turbine of unit 7B and 51 were released in the gatewell.

In order to conduct releases in the JBS and gatewell, lamprey were transported to the appropriate release site in an opaque container covered with a dark towel to shield them from facility lighting. They were removed from the transport container via dip net, scanned with a portable PIT tag reader, transferred to an opaque release canister, lowered to the water surface, and individually released directly into the flume sections and gatewell. Releases took place approximately 10 m above the crest gate, 400 m upstream of the primary dewatering structure, 200 m upstream of the switch gate, 5 m upstream of the fish and debris separator, and 2 m upstream of the primary detector coils. Releases in the gatewell occurred on the forebay side in the center. Each fish was released individually at intervals of 30 seconds or greater in order to reduce the potential for overlapping detections.

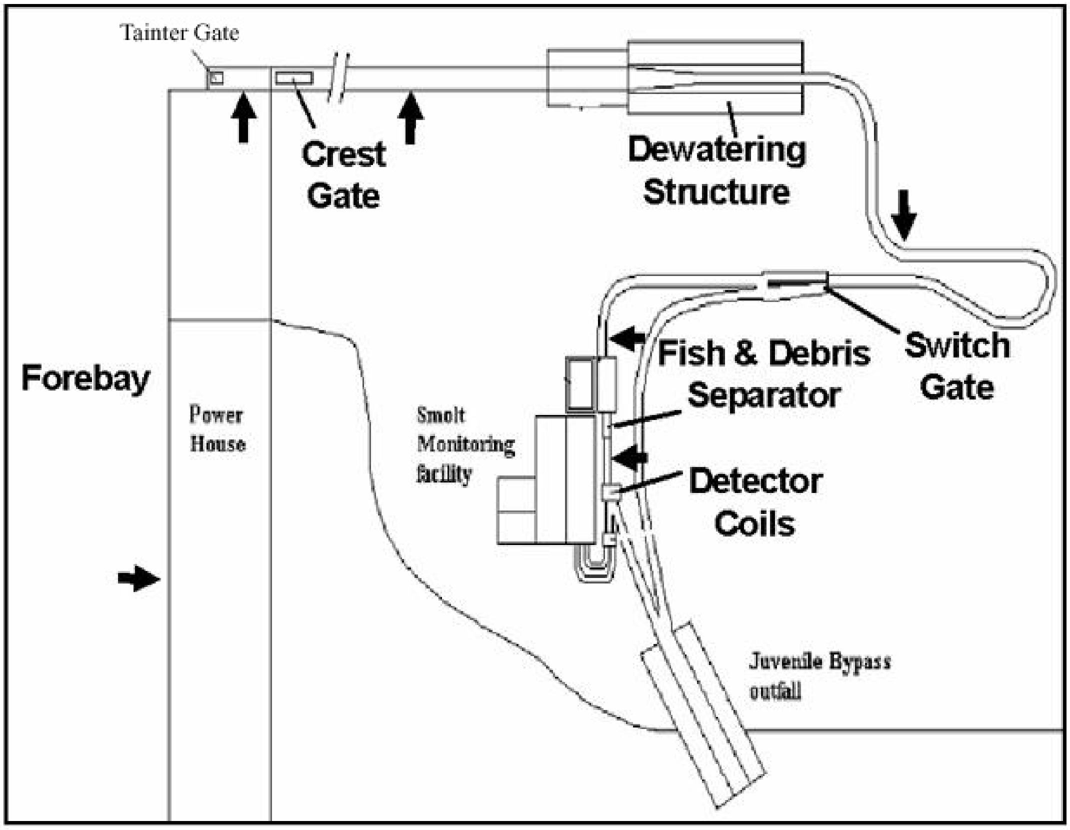


**Figure 2.5.** Overhead View of the John Day Dam Juvenile Fish Facility. Fish enter the system at the tainter gate and exit at the juvenile bypass outfall. Bold arrows indicate release locations.

Within the gatewell, lamprey were released by lowering a 6-gal pail into the gatewell slot. Upon reaching the water surface, the bucket was inverted using a nylon rope attached to its base, enabling the lamprey to swim out of their own volition. Releases into the JBS were accomplished in a similar fashion, or when possible lamprey were lowered by hand into the flume using the opaque release canister.

To address concerns regarding PIT-tagged lamprey taking up temporary residence in the primary detector coils, a group of lamprey (69) were released upstream of the primary detector coils on March 28, 2002. The primary focus of these releases was to examine the possibility of lamprey holding position within the primary detector coils, causing the separator gate to remain open for an extended period of time, which would result in excessive sort-by-code bycatch. Secondarily the releases acted as a control to determine the efficiency of PIT tag detection in lamprey released immediately upstream of the primary detectors. These fish were separated into two release groups: 36 were released upstream of the detector and 33 were released upstream of the fish and debris separator.

The remaining releases in the JBS were conducted on April 23, 2002. Totals of 50, 79, and 54 lamprey were released upstream of the switch gate, dewatering screens, and canter gate, respectively.

Forebay releases upstream from unit 7B were conducted in concert with the NOAA Fisheries fyke net study beginning on June 18 and extended through June 20, 2002. Two forebay releases were conducted at approximately 2000 and 2100 on each of the three nights, in groups of about 100; totaling 206, 212, and 210 fish on June 18, 19, and 20 respectively. The release mechanism was a 1/8-in. nylon mesh-lined aluminum canister (9 in. length × 6 in. diameter) with an upward swinging hinged door. A canister mount was attached to the top portion of the trash rake, which allowed a water-filled bucket to be temporarily positioned while lamprey were being loaded and lowered to the water surface. The bucket was suspended beneath the canister via a rope routed to a pulley on the forebay handrail of the trash rake crane. The bucket was lowered with the canister until it reached the surface water, at which point it was removed and the canister descended with the trash rake. The door was held closed with a detent ring pin to which a rope was attached. The same rope was attached to the door allowing it to be held open once the pin was removed, permitting the lamprey to swim out. The lamprey were released approximately 5, 10, and 15 ft below the top of the intake on June 18, 19, and 20 respectively. These release locations were chosen to ensure that lamprey would contact the face of the ESBS above the nadir of sweeping flows, thus allowing us to test the guidance efficiency of lamprey moving up the screen toward the gatewell. The turbine was operating at 130 MW on the first two nights and 155 MW on the last.

The above releases were conducted in concert with the NOAA Fisheries fyke net study. NOAA Fisheries followed the same protocol as the 1999 study conducted at John Day Dam (Brege et al. 2001). Lamprey committed to turbine passage were caught in the fyke net and their position and physical condition were recorded (Figure 2.6). Gatewell dip-net catches provided an estimate of the number of fish guided by the ESBS (Swan et al. 1979). Figure 2.7 shows the locations of the ESBS, the fyke nets, and the gatewell in John Day Dam unit 7B.

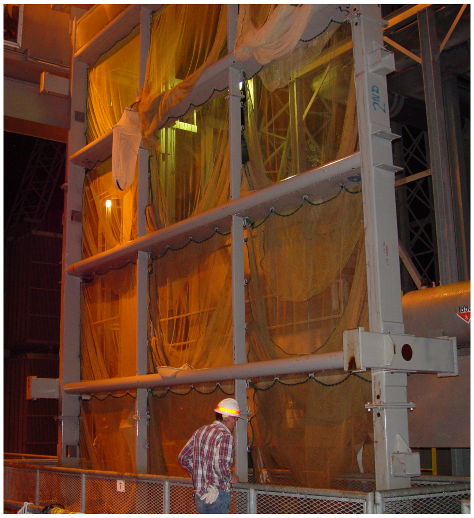

**Figure 2.6.** Fyke Net Frame Being Removed from the Gatewell Slot of Unit 7B

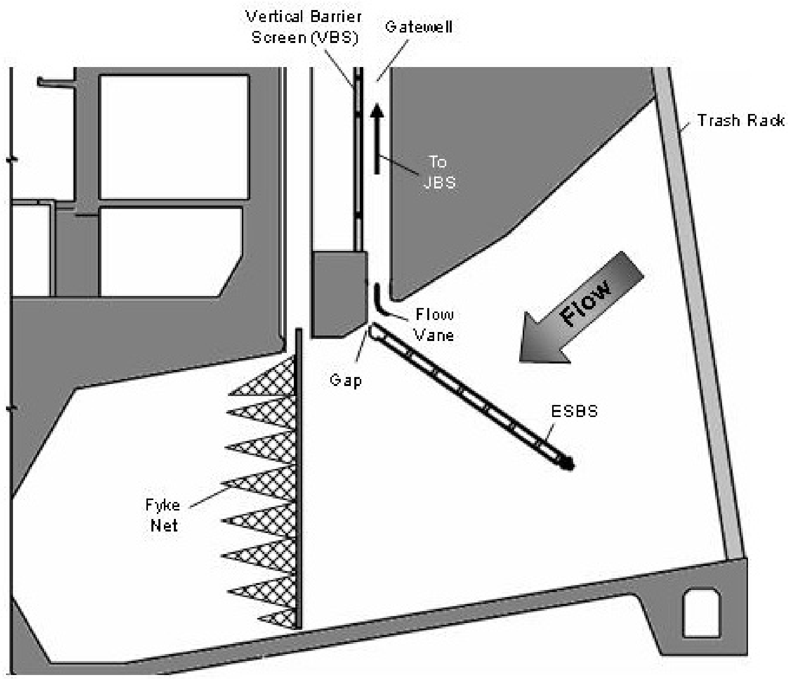


**Figure 2.7.** Locations of the ESBS, Fyke Nets, and Gatewell in John Day Dam Unit 7B

## 2.3 Swimming Performance of PIT Tagged Lamprey

PIT tagged lamprey were tested for swimming behavior using methods developed in 1999 (Moursund et al., 2000). These experiments were replicated in controlled environment tests at the PNNL Aquatic Laboratory. Sixty lamprey were tested for sustained and burst speed capabilities: 30 tagged and 30 control. Lamprey were collected from the John Day Dam smolt monitoring facility in mid June and transported to Richland on June 21, 2002, where they were acclimated and held in a 190-gal Living Stream™ tank in chilled (6° C) and ultraviolet filtered well water.

### 2.3.1 Burst Speed

It was possible to test 30 fish per day; therefore tests were conducted over a two day period. The first day consisted of untagged fish, while the second day was used to test tagged fish. A holding trough was used to test maximum burst speed. A plastic grid was placed on the bottom with markings at 10-cm intervals and a camera was suspended over the trough to record lamprey movement. Individual lamprey were selected haphazardly from a holding pen, placed into the trough, and allowed to acclimate for 5 min. Once the fish was in view of the camera, it was induced to swim by squirting water through a pipette. The fish was then allowed to rest for 3 minutes before being stimulated again. This process was repeated a total of five times per fish and was conducted on 60 lamprey. Video was collected at a 1/30-s frame interval. The maximum speed attained was the fastest run as measured within a 10-frame (1/3-s) interval. A maximum burst speed was attained for all 60 individuals and a t-test (one tailed, $\alpha=0.5$) was used to determine whether there was a significant difference in burst speed between tagged and untagged lamprey. Because tagged and untagged lamprey were tested on different days, it is not possible to determine whether differences are the result of tagging or the test day.

### 2.3.2 Sustained Swim Speed

A second set of experiments was designed to measure sustained swim speed. This required that we deal with the general unwillingness of juvenile lamprey to swim. A 40 cm diameter × 115 cm length mesh tube was constructed from 1/8-in. nylon mesh and placed inside a 2,200 L Brett-type respirometer. The tube was sealed at both ends, had a small entry port at the upstream end, and a downstream end that was electrified with wire woven into the mesh. This design succeeded in accomplishing three things necessary to conduct the experiment. First, juvenile lamprey were forced to continuously swim because they could not attach to the mesh screen. Second, the electrification prevented them from resting at the back of the tube. Third, fish could be observed through the translucent mesh. A control panel was used to regulate the voltage and current of the electrified portion to 5V and 0.6A DC. Water velocity was increased at 0.5 ft/s intervals every 5 min until the lamprey became fatigued. It was possible to test 20 fish per day; therefore tests were conducted over a period of three days. On the first, second and third days 20 untagged, 10 untagged followed by 10 tagged, and 20 tagged fish were tested respectively. Fish were selected haphazardly from a holding pen. Main-effects ANOVA was used to evaluate the significance of Tag and Day effects. The tag by day interaction term was dropped because that term was not significant in tests performed with Generalized Linear Model (GLZ, Statistica Software).

# 3.0 Results

## 3.1 Study Conditions

The environmental and dam operational characteristics during the 2002 study are described in this section. These data set the stage and context for the results that follow.

### 3.1.1 River Discharge and Temperature

River discharge during the study period averaged 274 kcfs, which was 87% of the 10-yr average. The minimum discharge was 171 kcfs on May 12. The maximum discharge was 384 kcfs on June 6. Spring had lower flows (77% of the 10-yr average) than summer (101% of the 10-yr average). Spill averaged 86 kcfs (108% of the 10-yr average) with a low of 38 kcfs on May 2 and a high of 196 kcfs on June 5. Spill was slightly below average during the spring and slightly above average during the summer. River temperature increased steadily over the study period, averaging 19.1°C, with the low and high at the beginning and end of the study period, respectively (Figure 3.1).

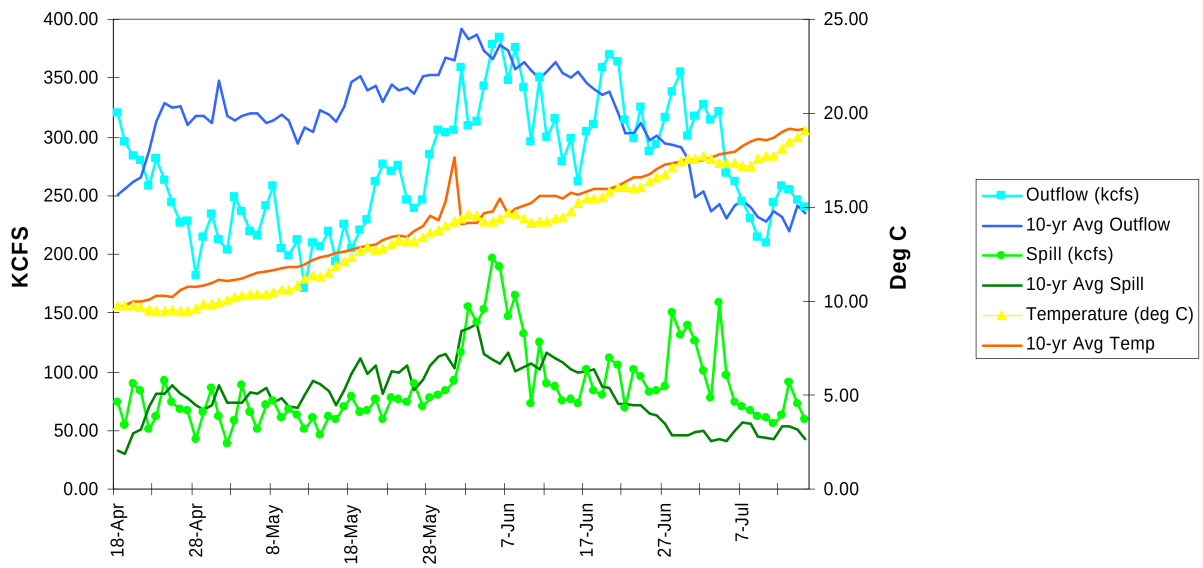


**Figure 3.1.** Daily River Discharge and Temperature for 2002 (lines with markers) and the 10-yr Average (lines only). Data from DART (2002).

### 3.1.2 Species Composition and Run Timing

Based on data from the Smolt Monitoring Program, the estimated number of juvenile lamprey passing John Day Dam during 2002 was very high (273,178) compared to the 1998 to 2001 average of 135,230 (Figure 3.2). Compared to the 1998 to 2002 average, the spring run timing was normal, while the summer run was slightly late. Detailed historical data are presented in Appendix A.

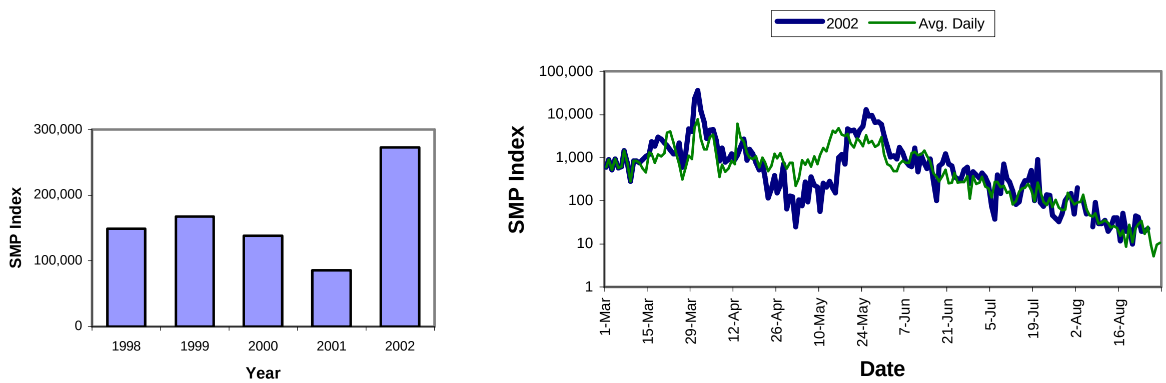


**Figure 3.2.** Historical Run Size for Juvenile Pacific Lamprey from 1998 to 2002, through Oct. 29 (left). Run timing for juvenile Pacific lamprey in 2002 compared to the 1998-2002 daily average at John Day Dam (right). Data are from the Smolt Monitoring Program.

Species composition and run timing data for juvenile salmonids are presented below. The division of spring and summer for the analyses in this report were based on the transition of dominance of the run from yearling chinook to subyearling chinook on June 6. During spring, 55% of downstream migrants were yearling chinook, 24% were sockeye, and 13% were steelhead as indicated by smolt monitoring data from the sampling site at John Day Dam. The remainder of the run consisted of coho and subyearling chinook smolts. During summer, 91% of downstream migrants were subyearling chinook (Figure 3.3).

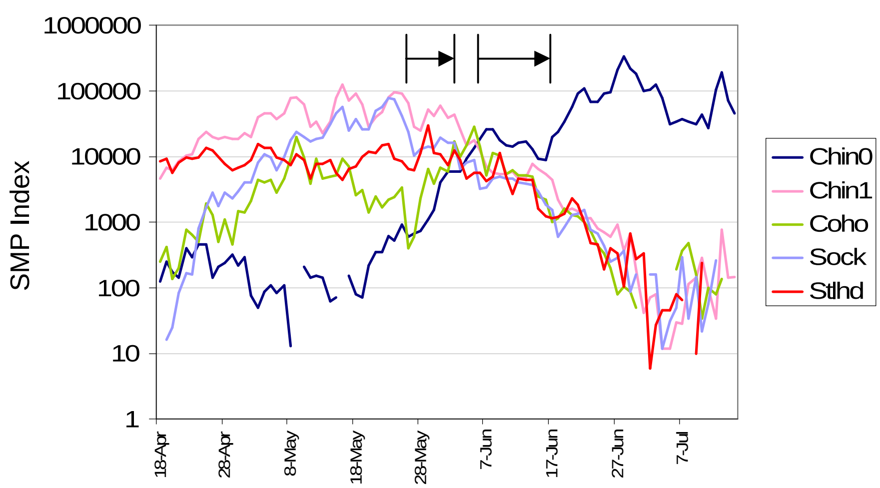


**Figure 3.3.** Species Composition Data from the John Day Dam Smolt Monitoring Facility. Data from DART (2002). Arrows indicate optical video sampling periods.

The spring *in situ* observation data collection occurred after the spring lamprey run but during the first half of the summer peak. The spring sampling period also coincided with the last half of the yearling chinook and sockeye runs. The summer data was collected during the transition of the chinook salmon run from yearling to sub-yearling and following the summer lamprey run. The species composition for the spring sampling period was 0.5% sub-yearling chinook, 53.1% yearling chinook, 1.6% coho, 36.0% sockeye, and 8.8% steelhead. The species composition for the summer sampling period was 43.4% sub-yearling chinook, 17.1% yearling chinook, 17.5% coho, 10.0% sockeye, and 12.0% steelhead.

### 3.1.3 Dam Operations

Hourly dam operations show the range of operations at the dam. Both powerhouse and spillway discharge changed with spill treatment related to a comparison of 12 versus 24-hour spill. Forebay elevation was nearly constant (Figure 3.4).


**Figure 3.4.** Hourly Dam Operations

## 3.2 Optical Camera Observations

This section describes *in situ* video camera observations on the screen face. Abundance, temporal and spatial distribution, and behavior are described.

### 3.2.1 Abundance

During 105 hours of video recording 50 lamprey, 18 smolts, 2 unidentified fish, and 1,715 unidentified fry were observed. Typical lamprey behavior in close proximity to the screen could be characterized as an apparently uncontrolled ascent or descent along the screen face with which the majority (78%) made periodic contact. Smolt were frequently observed making contact with the screen face (44%), usually with their tails, while actively swimming away from the screen. The unidentified fry were always observed in contact with the screen and were identified by their body wrapping over a single bar. Lengths of the unidentified fry were estimated to be approximately 2 mm.

### 3.2.2 Temporal Distribution

The majority of lamprey were observed between 2000 h and 2200 h, while salmonid observations were evenly dispersed throughout the sampling period (Figure 3.5). Unidentified fry observations were most abundant between 2300 h and 0100 h. During the recording period, there was a slight increase in the number of lamprey observed from spring to summer, while salmonid numbers remained relatively constant. Unidentified fry displayed a sharp decline in numbers from spring to summer (Figure 3.6).

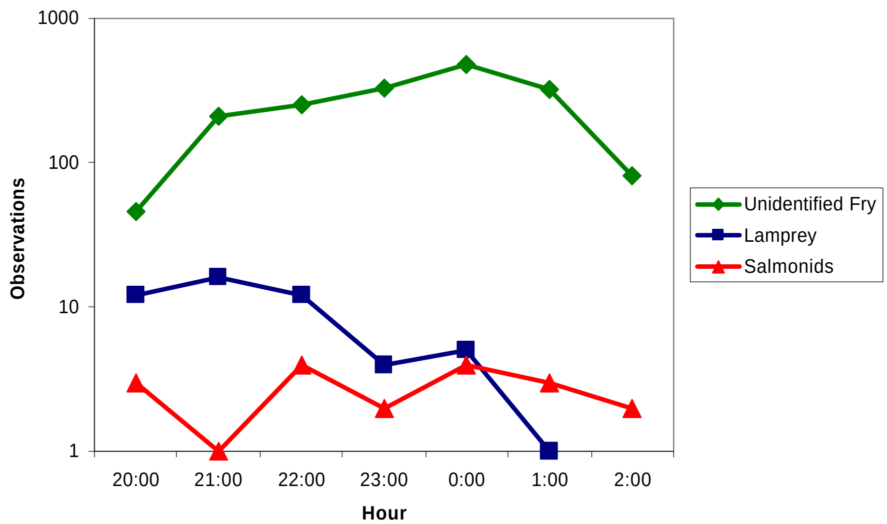


**Figure 3.5.** Total Number of Lamprey and Smolt Observed over the Sampling Period (hour 2000 represents the time from 2000 to 2059) from May 22-28 and June 6-16.

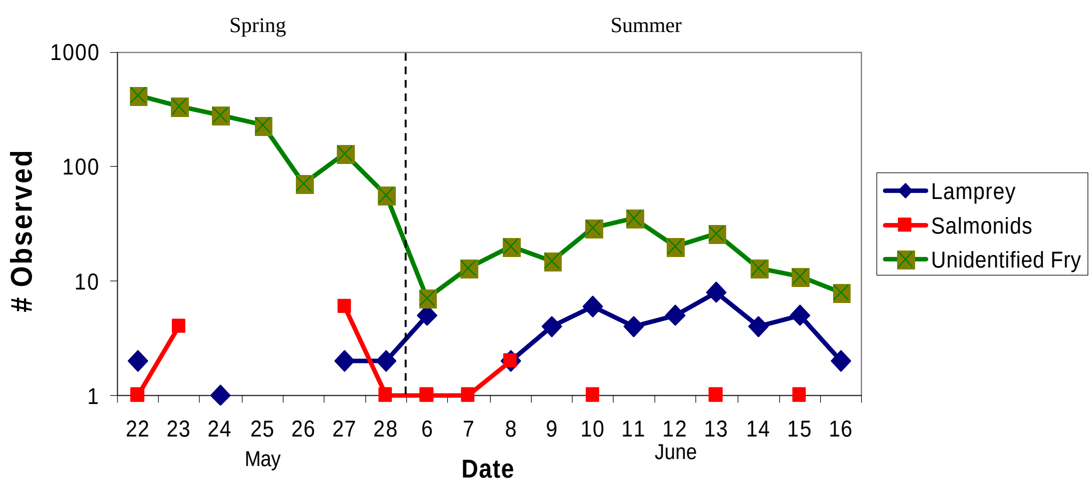


**Figure 3.6.** Total Number of Lamprey and Salmonids Observed over the Sampling Period (observations after 2359 h are included in the following day).

### 3.2.3 Spatial Distribution

Of the three up-looking cameras, most fish were observed with the center camera and fewest were observed with the south camera. The vertical distribution of observations showed the majority of lamprey occurred in the upper and lower 10 ft of the screen, while very few were observed in the middle 20 ft (Figure 3.7). The salmonids display a similar trend, although they are distributed more evenly across the entire screen. The unidentified fry were observed almost entirely on the lower half of the screen.

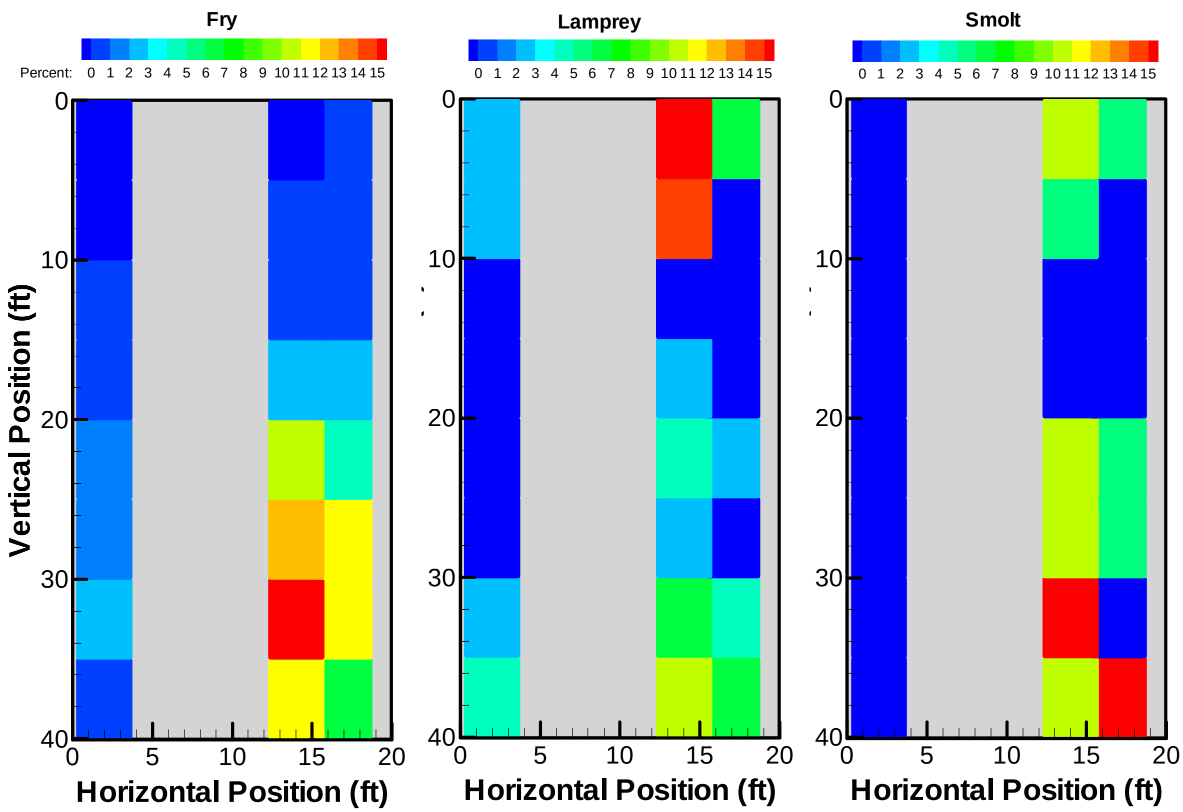


**Figure 3.7.** Spatial Distribution of Lamprey, Smolts, and Unidentified Fry Observed with the Brush Bar Mounted Video Cameras. The top of the screen is represented by 0 on the Y-axis; the south end of the screen is indicated by 0 on the X-axis. The gray areas were not sampled.

### 3.2.4 Direction of Movement

A total of 67 lamprey and salmonids were observed on the face of the ESBS with the optical video cameras. It was possible to ascertain a net directional movement for 55 of these fish (Figure 3.8). Above the nadir of sweeping flows (about 2 m up from the lower screen tip) 61% of the fish were moving up the screen, 24% were moving side to side (75% moving from south to north), and 15% were moving down. At the nadir 29% were moving up the screen, 57% were moving side to side (75% north to south), and 14% were moving down. Below the nadir, none were moving up the screen, 50% were moving side to side (63% moving north to south), and 50% were moving down. Of fish with no net discernible direction of movement, 6 of 8 lamprey and 3 of 4 smolts were above the nadir.

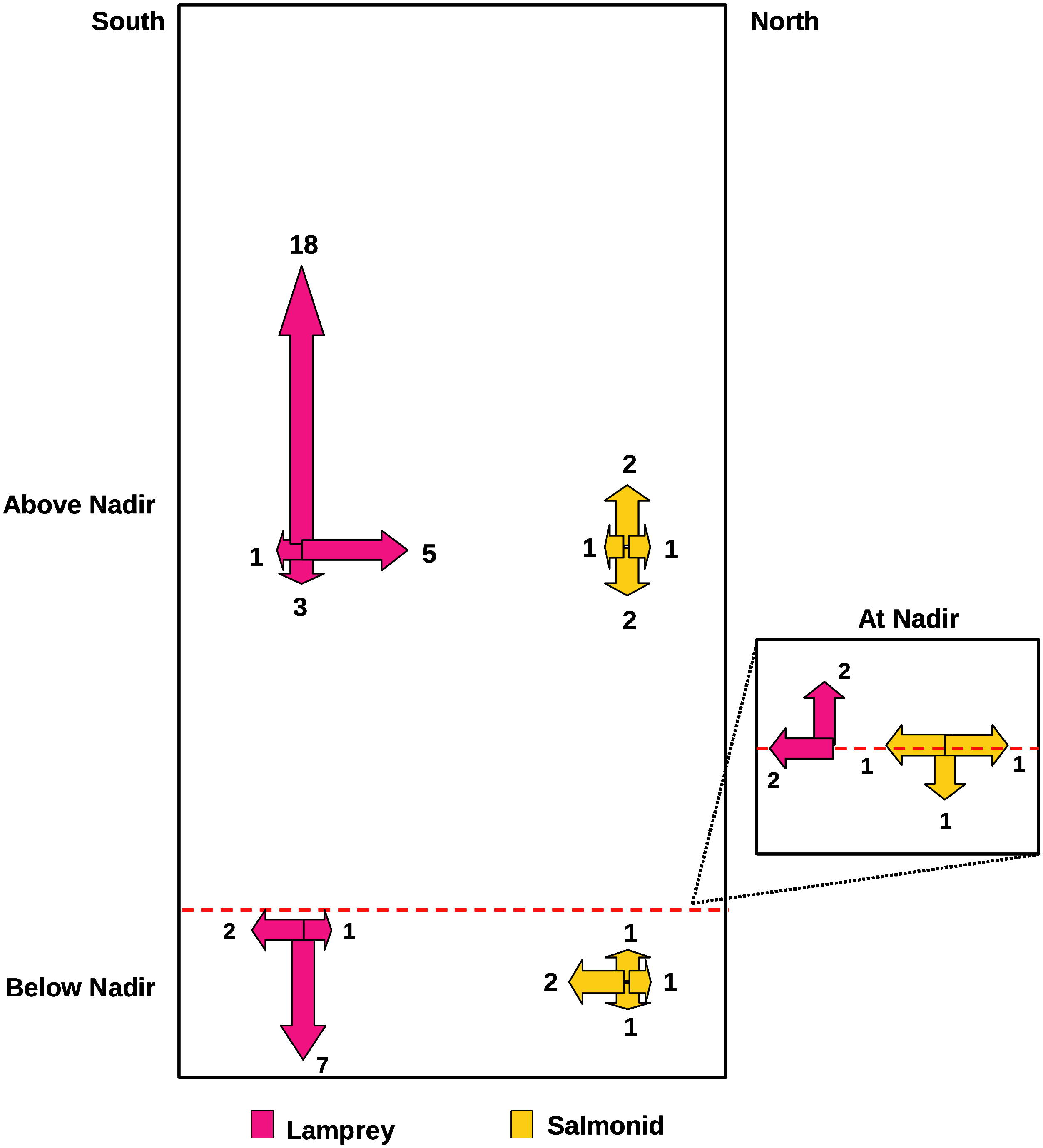


**Figure 3.8.** Directional Movement of 55 Lamprey and Smolt Observed by the Optical Cameras. The dotted line is the nadir of sweeping flows. Above this line, flows move toward the gatewell. Below this line, flows move downward toward the tip of the screen.

## 3.3 PIT Tag Releases

The juvenile bypass system and forebay release results are described in this section.

### 3.3.1 Morphology

Juvenile lamprey ranged from 112 to 186 mm in total length; the mean length was 137 mm for the test population. Posterior dorsal width measurements ranged from 0.7 to 2.1 mm with a mean of 1.1 mm. Middle gill width measurements ranged from 3.8 to 9.7 mm with a mean of 5.7 mm. Oral disk width measurements ranged from 3.5 to 9.8 mm with a mean of 5.6 mm (Figure 3.9).

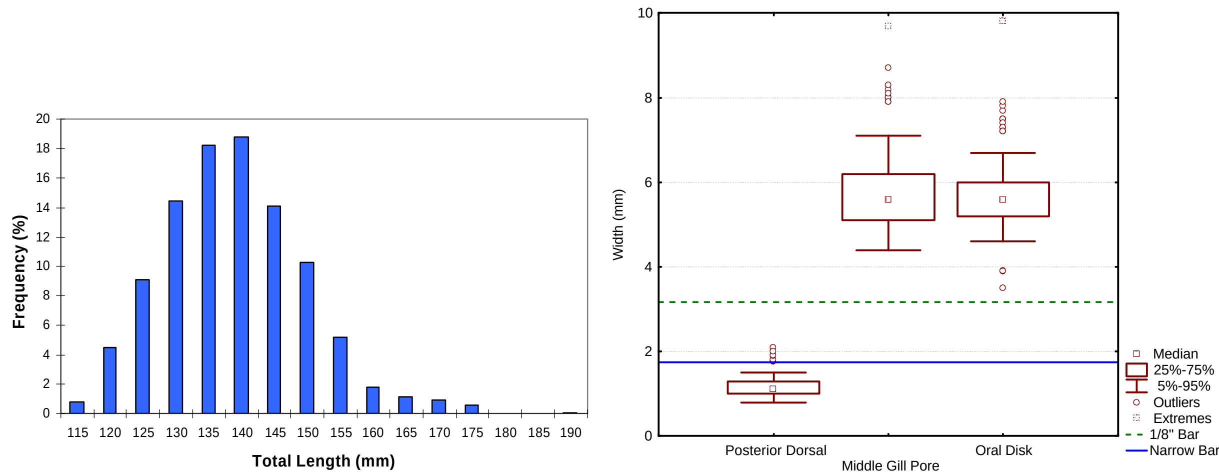


**Figure 3.9.** Total Length Frequencies of Tested Juvenile Lamprey; n = 1265 (left). Distribution of width measurements including markers indicating 3.175 and 1.75 mm bar spacing (right).

### 3.3.2 Juvenile Bypass System Releases

Detection rates downstream from the powerhouse were at or near 100% (Table 3.1). The gatewell release detections, however, were very low. The forebay releases described in the next section also suffered from poor accountability of lamprey fate in the gatewell.

**Table 3.1.** Number, Location, and Detection Rate of PIT Tagged Lamprey Released in the Juvenile Bypass System of John Day Dam

| Location | Date | Time | # Released | Detection (%) |
|---|---|---|---|---|
| Gatewell | 20 June | 20:34 | 35 | 0 |
| Gatewell | 25-June | 20:51 | 25 | 28 |
| Crest Gate | 23-April | 23:44 | 54 | 100 |
| Dewatering Structure | 23-April | 22:06 | 79 | 100 |
| Switch Gate | 23-April | 20:44 | 50 | 100 |
| Fish and Debris Separator | 28-March | 20:58 | 33 | 100 |
| Primary Detection Coils | 28-March | 20:06 | 36 | 97 |

### 3.3.3 Forebay Releases

Of the 628 lamprey released in the forebay of unit 7B during the NOAA Fisheries fyke net study, 47.6% were accounted for through the combination of fyke and dip net sampling and PIT tag detection in the JBS; 52.4% of the lamprey released were unaccounted for. Among those recaptured or detected in the JBS 98.0% were recaptured in the fyke nets, while 1.3% were re-captured in the dip net and 0.7% were accounted for via detection at the primary detector coils. Even in a dip net efficiency test in which 51 lamprey were released into the gatewell immediately prior to dip netting, only 29.4% were recovered; 11 (21.6%) via the dip net and 4 (7.9%) from the fyke net (Figure 3.10).

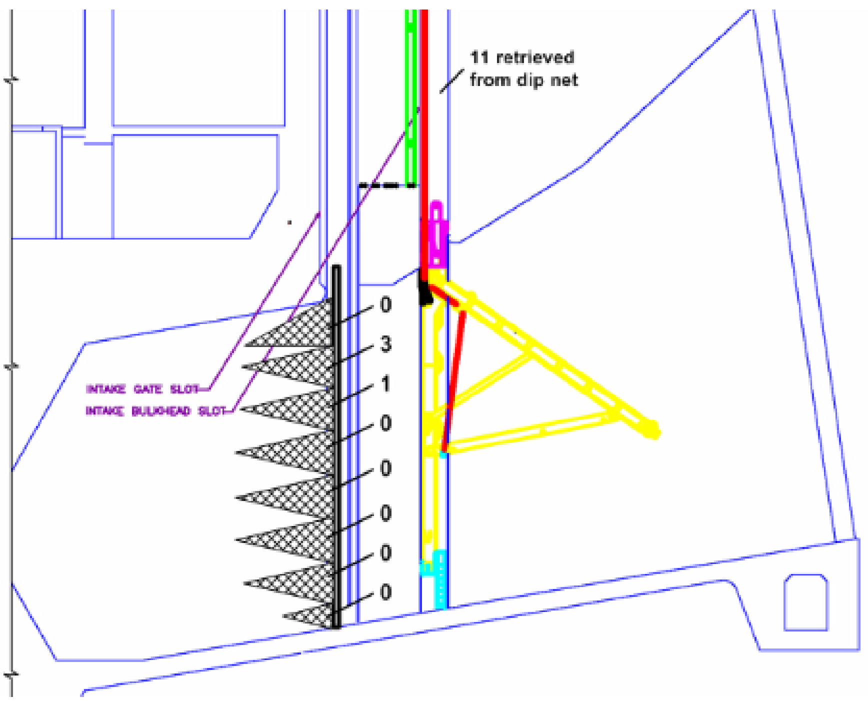


**Figure 3.10.** Distribution of Lamprey Released in Dip Net Efficiency Test; n = 51.

The majority (> 77%) of tagged lamprey collected in the fyke nets from unit 7B were recovered from the second and third nets from the top, regardless of release depth. Conversely, greater than 78% of the run of the river lamprey recovered from the fyke nets were in the second, third and fourth nets from the bottom. Run of the river salmon smolt recovered from the fyke nets during the three-day portion of the study occurred mostly in the second through sixth nets from the top, with the peak approximately in the fifth net (Figure 3.11). Horizontal distribution in the fyke nets illustrates the majority of the released lamprey being recaptured in the center then north fyke nets, while the fewest were recaptured in the south fyke nets (43, 41, and 16% respectively) (Table 3.2). Run of the river lamprey are distributed more evenly, with the most occurring in the north nets, and slightly fewer occurring in the central and south nets (36, 31, and 32% respectively) (Table 3.3). Smolts were captured in the highest numbers in the center fyke nets, with slightly fewer occurring in the north nets, and the fewest occurring in the south nets (38, 35, and 26% respectively) (Table 3.4).

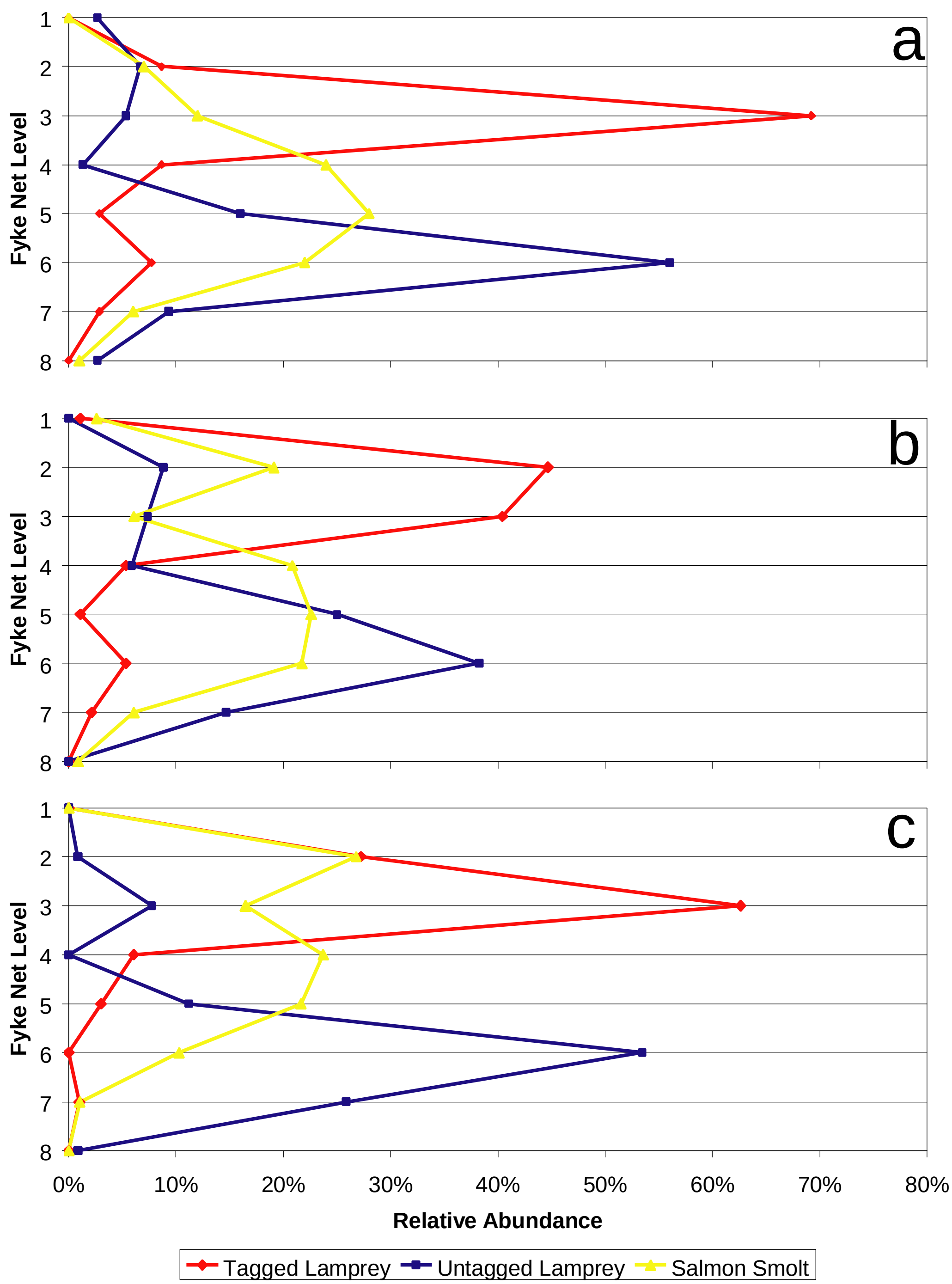


**Figure 3.11.** Vertical Distribution of PIT-Tagged Lamprey Released in the Forebay at 5 ft (panel a), 10 ft (panel b), or 15 ft (panel c) Below the Intake Ceiling Depth, Run of the River Untagged Lamprey, and Run of the River Untagged Salmonid Smolts as They Were Recovered from the Fyke Nets. These smolt data only represent the catch over the same time period as the lamprey releases. Data provided by NOAA Fisheries.

**Table 3.2.** Total Numbers of PIT Tagged Lamprey Released in Forebay and Caught in Fyke Net over Three Days

| | North | Middle | South | Total |
|---|---|---|---|---|
| Level 1 | 0 | 1 | 0 | 1 |
| Level 2 | 13 | 27 | 38 | 79 |
| Level 3 | 29 | 84 | 59 | 172 |
| Level 4 | 2 | 2 | 16 | 20 |
| Level 5 | 2 | 3 | 2 | 7 |
| Level 6 | 3 | 8 | 2 | 13 |
| Level 7 | 0 | 2 | 4 | 6 |
| Level 8 | 0 | 0 | 0 | 0 |
| Total | 51 | 128 | 122 | 297 |

**Table 3.3.** Total Numbers Run of the River Lamprey Caught in Fyke Net over Three Days

| | North | Middle | South | Total |
|---|---|---|---|---|
| Level 1 | 0 | 2 | 0 | 2 |
| Level 2 | 3 | 4 | 5 | 12 |
| Level 3 | 12 | 3 | 3 | 18 |
| Level 4 | 2 | 1 | 2 | 5 |
| Level 5 | 15 | 8 | 19 | 42 |
| Level 6 | 47 | 46 | 37 | 130 |
| Level 7 | 14 | 17 | 18 | 49 |
| Level 8 | 1 | 1 | 0 | 2 |
| Total | 94 | 82 | 84 | 260 |

**Table 3.4**. Total Numbers of Run of the River Smolt Caught in Fyke Net over Three Days

| | North | Middle | South | Total |
|---|---|---|---|---|
| Level 1 | 1 | 0 | 2 | 3 |
| Level 2 | 22 | 27 | 6 | 55 |
| Level 3 | 18 | 9 | 8 | 35 |
| Level 4 | 22 | 22 | 27 | 71 |
| Level 5 | 24 | 33 | 18 | 75 |
| Level 6 | 20 | 26 | 11 | 57 |
| Level 7 | 3 | 3 | 8 | 14 |
| Level 8 | 1 | 0 | 1 | 2 |
| Total | 111 | 120 | 81 | 312 |

## 3.4 Swim Performance of Tagged Fish

This section compares the swim performance of PIT tagged versus untagged lamprey.

### 3.4.1 Measurements of Laboratory Fish

Juvenile lamprey from the PIT tagged group ranged from 128 to 171 mm in total length; the mean length was 145 mm. Total lengths of the untagged group ranged from 126 to 173 mm with a mean of 148 mm (Figure 3.12).

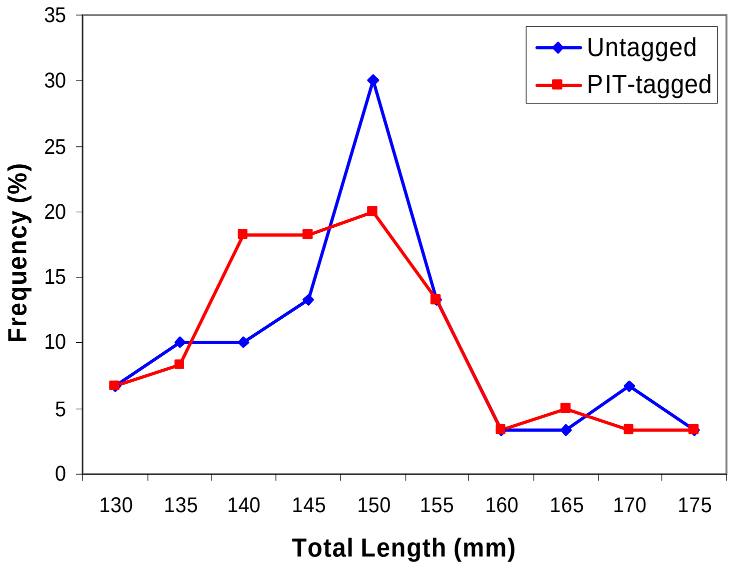


**Figure 3.12.** Frequency Distribution of Total Lengths of Experimental PIT Tagged (n = 30) and Untagged (n = 30) Juvenile Lamprey

### 3.4.2 Burst Swim Speed

Maximum burst speed for PIT tagged juvenile Pacific lamprey ranged from 0.9 to 3.5 ft/s with a mean of 2.5 ft/s. Untagged lamprey had burst speeds ranging from 2.0 to 3.6 ft/s with a mean of 2.7 ft/s (Figure 3.13). This equates to a specific swim speed (normalized to body length) of approximately 5.3 L/s for PIT tagged lamprey and 5.6 L/s for the untagged lamprey. Maximum burst speeds were significantly different between groups ($p = 0.02$).

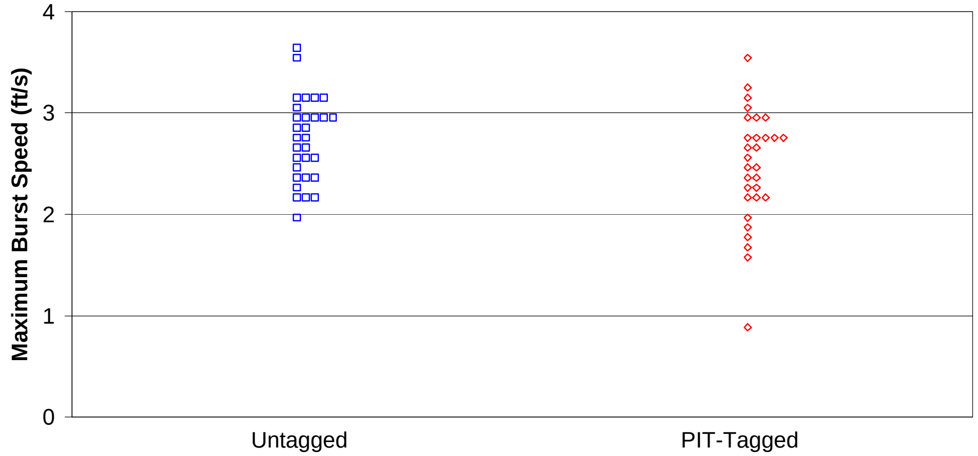


**Figure 3.13.** Distribution of Burst Speed Values for Individual PIT Tagged and Untagged Lamprey. Average Maximum Burst Speed Value was 2.5 ft/s (n=30) for PIT Tagged Lamprey and 2.7 ft/s for Untagged Lamprey (n=30)

### 3.4.3 Sustained Swim Speed

Sustained swim speed ranged from 0.5 to 2.0 ft/s for tagged and untagged lamprey with a mean of 1.22 ft/s for PIT tagged and 1.38 ft/s for untagged fish (Figure 3.14). PIT tagged and untagged lamprey show no significant difference in sustained speed in ANOVA tests (p = 0.12).

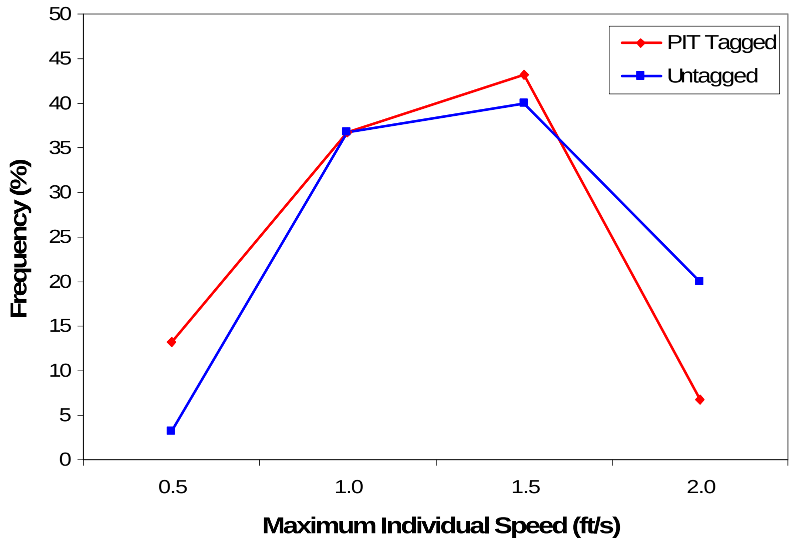


**Figure 3.14.** Distribution of Sustained Speed Values for Individual PIT Tagged and Untagged Lamprey. Mean maximum sustained speed value was 1.22 ft/s (n=30) for PIT tagged lamprey and 1.38 ft/s for untagged lamprey (n=30).

### 3.4.4 Size vs. Speed

Correlation analyses were performed for lamprey size in relation to burst speed and sustained speed in PIT tagged fish. Maximum burst speed was not significantly correlated with individual fish total length ($r = 0.19$, $p=0.31$) (Figure 3.15). Sustained swimming speed was significantly correlated with total length ($r = 0.43$, $p=0.02$) (Figure 3.16). Lengths were not available for untagged lamprey because individuals were not followed through the testing protocol.

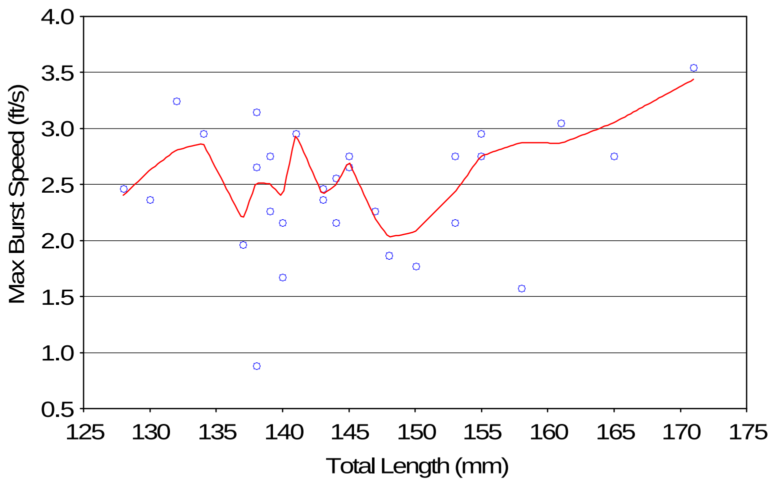


**Figure 3.15.** Maximum Burst Speed Versus Total Length for Individual PIT Tagged Lamprey. A LOESS fit is shown.

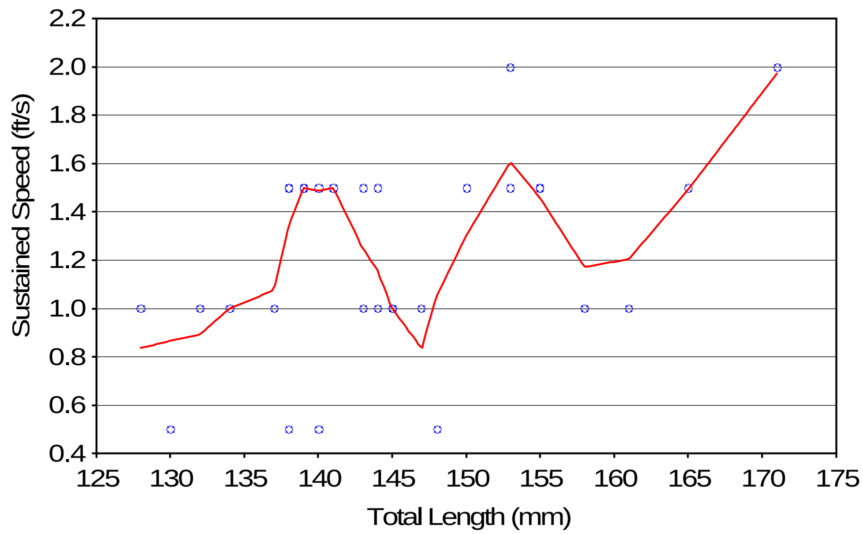


**Figure 3.16.** Sustained Speed Versus Total Length for Individual PIT Tagged Lamprey. A LOESS fit is shown.

# 4.0 Discussion

Laboratory and field trials characterized the behavior of juvenile lamprey encountering the prototype ESBS. Behavior on the screen itself was characterized during the juvenile outmigration period via *in situ* observations on the modified ESBS inside an operating turbine unit. PIT tag releases within and immediately upstream of John Day Dam were used to determine ESBS guidance effectiveness for juvenile lamprey. Laboratory observations were conducted to evaluate swimming behavior in PIT tagged fish. The overall effectiveness of the new screen at routing juvenile lamprey away from the turbines is discussed in this section.

## 4.1 *In Situ* Screen Observations

As in previous studies (Moursund et al. 2001 and 2002), we were able to use video cameras mounted on the brush bar of the ESBS to document the behavior of migrating juvenile lamprey and salmonid smolts passing near or coming in contact with the screen. Although only a small number of lamprey and smolt were observed, useful information about screen interactions can be drawn from the data collected.

None of the lamprey observed were apparently capable of swimming against the flows encountered on the screen, as was evident by the number coming in contact with the screen face. This is consistent with previous studies, in which juvenile lamprey have not exhibited an effective avoidance response to barriers in the field (Moursund et al. 2001 and Moursund et al. 2002) or in the laboratory (Moursund et al. 2000) under flows likely to be encountered near the screen. None of the fish observed were wedged between the 1.75 mm bar spacing; however, impingement on the screen face was observed for one lamprey and one smolt.

The directional movement of fishes observed on the screen face was similar to flow patterns (Weiland and Escher 2001). Net directional movement above the nadir of sweeping flow velocities, toward the gatewell area, indicated that the upward sweeping velocities in this region dictated lamprey movement. Conversely, all of the lamprey observed below the nadir were moving downward on the screen. These trends of directional movement did not have the same effect on smolts, which apparently had a greater degree of control over their movements under these hydraulic conditions.

The spatial and temporal distribution of fish observed on the screen face had a high degree of distinction between species. A large number of lamprey were observed near the top of the screen, the majority of which were in contact with the screen face as they traveled up the ESBS. Smolts were more evenly distributed along the screen face, with slight concentrations occurring in the upper and lower 10 feet. This is likely due to a combination of fish behavior and the sampling technique on the screen. Presumably all the juvenile lamprey are sliding up the screen face, whereas not all salmonids contact the screen or necessarily come close enough to the screen face for detection. Therefore, more lamprey detections were made near the top of the screen where the greater amount of downstream screen area created a higher detection rate.

The unidentified fry were highly abundant in the spring, but not in the summer. They were found almost exclusively on the lower half of the screen face. This is likely a reflection of their small body size combined with the increasing sweeping velocities higher on the screen and the resulting effect of clearing a planktonic animal off the upper portion of the screen face. Based on the size of the fish and the time of year they were abundant, we suspect that these were walleye fry (*Stizostedion vitreum vitreum*) (Brege 1981); however, because no specimens were captured, a positive identification was not possible.

## 4.2 PIT Tag Releases

Detection efficiency for juvenile lamprey released immediately upstream of the primary detector coils was similar to the 99.75% detection rate for smolts by Rowan and Carter (2000). Furthermore, near perfect detection efficiency for lamprey released downstream of the gatewell indicate that no passage problems for juvenile lamprey exist with the fish and debris separator, diversion fork, dewatering screens, or switch gate. However, the low percentage of lamprey detected at the primary detector following gatewell releases indicates that guidance may not be efficient from the gatewell into the remaining JBS. This could be the result of a low propensity for orifice passage due to their disposition to swim down toward the substrate and/or away from light. Another possibility is that damage over the season to the vertical barrier screen (VBS) resulting in numerous holes may have provided a route by which the lamprey could have vacated the gatewell, thus committing themselves to turbine entrainment. The holes in the VBS may also explain the low number of lamprey recovered from the dip net efficiency test performed in the gatewell of Unit 7B.

A high percentage (52%) of lamprey were unaccounted for following the forebay releases, considering the study goal of recapturing all or nearly all of the releases in either the fyke net, gatewell, or sort-by-code tank. A number of scenarios are possible. It is possible, for instance, that lamprey took up temporary residence in the gatewell, avoided dip net collection, and passed through the turbine once the fyke net was removed. The dip net basket was not designed to capture lamprey and their propensity to dive combined with their small body size may explain a poor lamprey catch efficiency. Another scenario is that the lamprey escaped the fyke nets themselves. Also designed to capture salmonids, the fyke nets have a mesh size of 6.35 mm with cod end mesh of 3.175 mm. The lamprey, which had a mean maximum body width of 5.7 mm, may have escaped the nets through the openings in the mesh.

Assuming that the catch efficiency of the fyke net is uniform across the intake, we can make inferences regarding turbine-committed lamprey. The vast majority of lamprey accounted for from the forebay releases were captured in the third fyke net row from the top. In contrast, the majority of the run-of-the-river lamprey were captured in the sixth fyke nets from the top indicating passage below the ESBS. Considering this, as well as camera observations illustrating that the majority of observed lamprey in contact with the ESBS were near the top, it appears that these lamprey passed through the gap between the top of the ESBS and the flow vane (Figure 4.1). The lamprey results, particularly the lack of lamprey in the first row of fyke nets that must have passed through the gap, challenge the assumption that the first row of fyke net catch represents gap loss. Both run-of-the-river lamprey and smolts showed a bimodal distribution with fish in rows 2 and 3. Closer investigation of the possible loss and fate of fish that pass through the gap may be warranted.

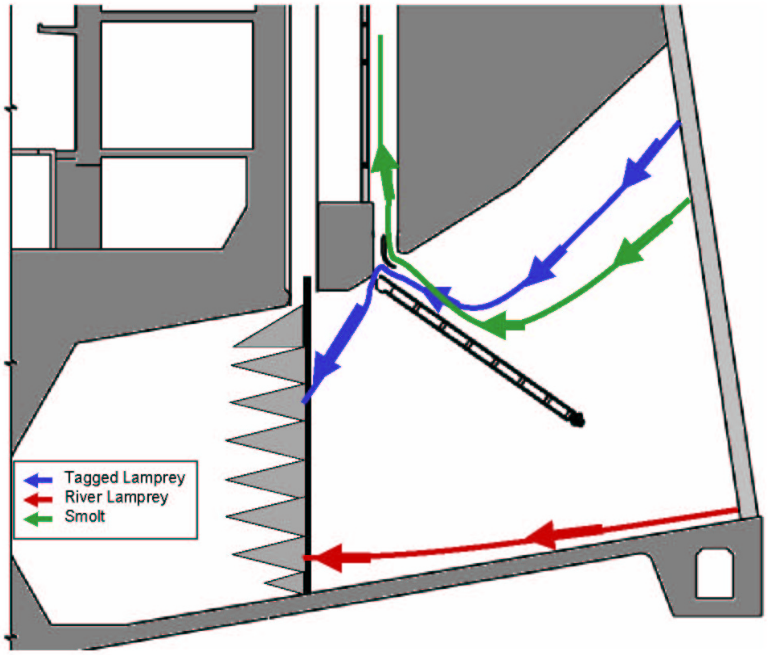


**Figure 4.1.** Hypothesized Pathway for the Majority of the PIT Tagged Lamprey, Run-of-the-River Lamprey, and Salmonid Smolts

It is important to note that there is evidence that turbine passage may not be as detrimental for lamprey as it is for other, particularly larger, fish. Laboratory studies conducted by Moursund et al. (2000 and 2001) demonstrated that lamprey do not exhibit the negative effects associated with shear or pressure changes coinciding with dam passage. However, cumulative effects, including any effects of strike, have not been tested.

The similarities in burst and sustained speeds of tagged relative to untagged lamprey indicate that tagged individuals are generally able to swim with the same ability as untagged. However, the statistical differences in maximum burst speed demonstrate that performance between the two groups can differ. Overall these laboratory tests showed that the swim performance of PIT tagged juvenile lamprey were similar to untagged lamprey over the time periods relevant to the field releases. Differences that were found are not likely to have any biological influence on the outcome of this study, nor would it alter the conclusions. In future studies, the potential for a tagging effect should be considered, with appropriate tests to evaluate its magnitude relative to study objectives.

# 5.0 Conclusions and Recommendations

Our video observations have illustrated that lamprey *in situ* behave in a manner similar to that observed in previous laboratory studies. Juvenile lamprey are poor swimmers and cannot swim faster than the water velocities found at the screen face. As a result they experience an almost instantaneous impingement on the screen, however, most are able to continue to move along the screen face. The narrower 1.75-mm bar spacing on the modified ESBS prevented lamprey from becoming wedged between the bar spacing.

Passage through the juvenile bypass system was extremely efficient, with the exception of the transition from the gatewell to the remaining juvenile bypass. In the transition from the forebay to the gatewell, however, a large number of lamprey were unaccounted for. Fyke net distributions of lamprey in the fyke nets suggest that the principal route taken was to be swept through the gap following contact with the screen face.

In conclusion, if extended-length bar screens are installed in all units at John Day Dam, they should have the 1.75-mm bar clearance. For all new screen designs, the Corps should use this narrower 1.75-mm spacing whenever possible. We recommend that future evaluation of the ESBS include observations of the gap via optical and/or acoustic cameras. Direct observations of the gap would demonstrate the frequency of gap loss. In addition, we recommend that the gatewell area receive additional examination regarding lamprey passage once the cause of damage to the VBS has been resolved.

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# Appendix A

## Historical Run Timing of Juvenile Pacific Lamprey

# Appendix A

# Historical Run Timing of Juvenile Pacific Lamprey

The following figures represent collection estimates of run timing for juvenile Pacific lamprey at several dams on the Columbia and Snake rivers based on daily average sample rate; the same sampling procedures are followed at each of the dams listed.

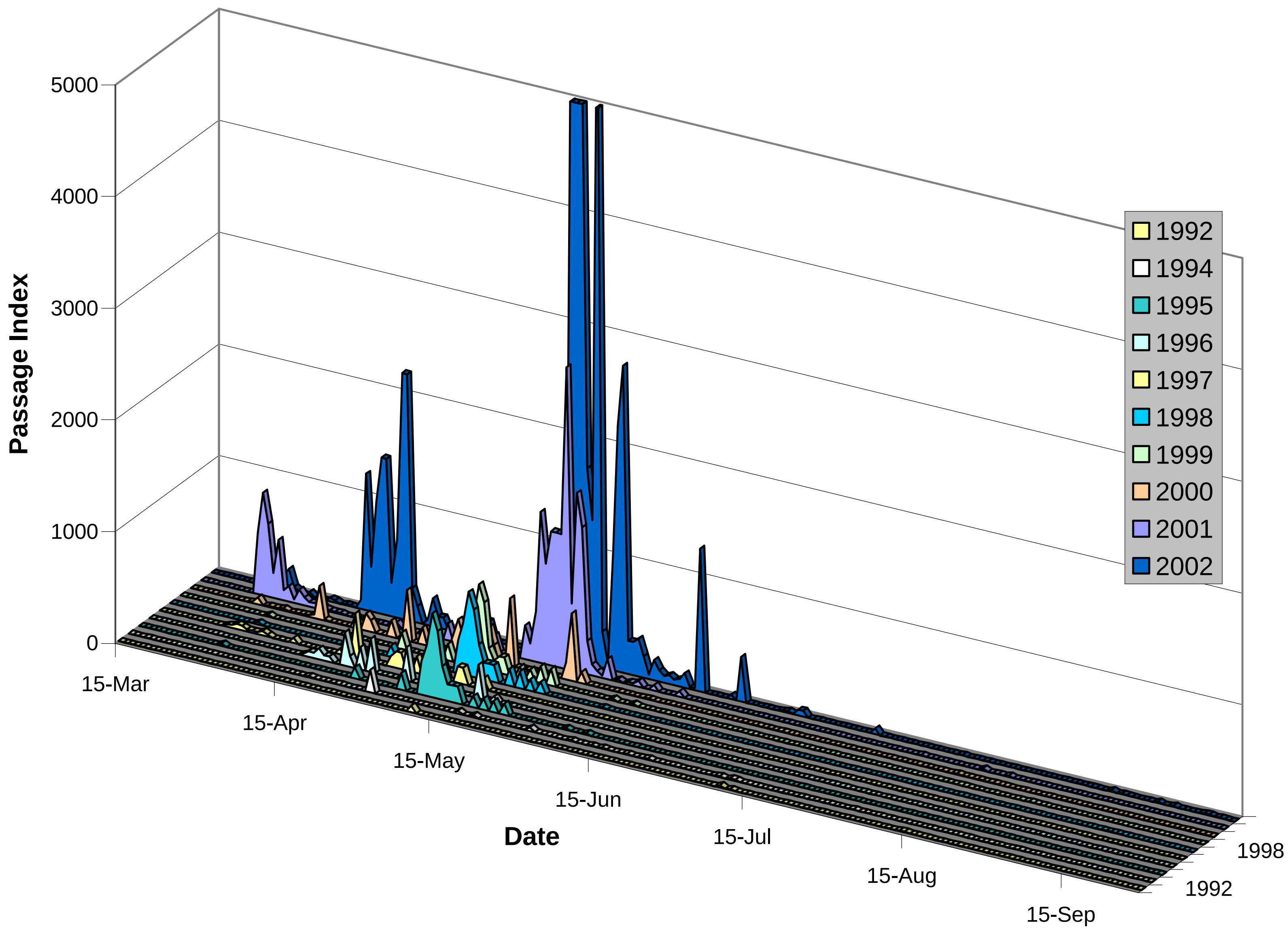



**Figure A.1** Historical Run Timing of Juvenile Lamprey at Lower Granite Dam

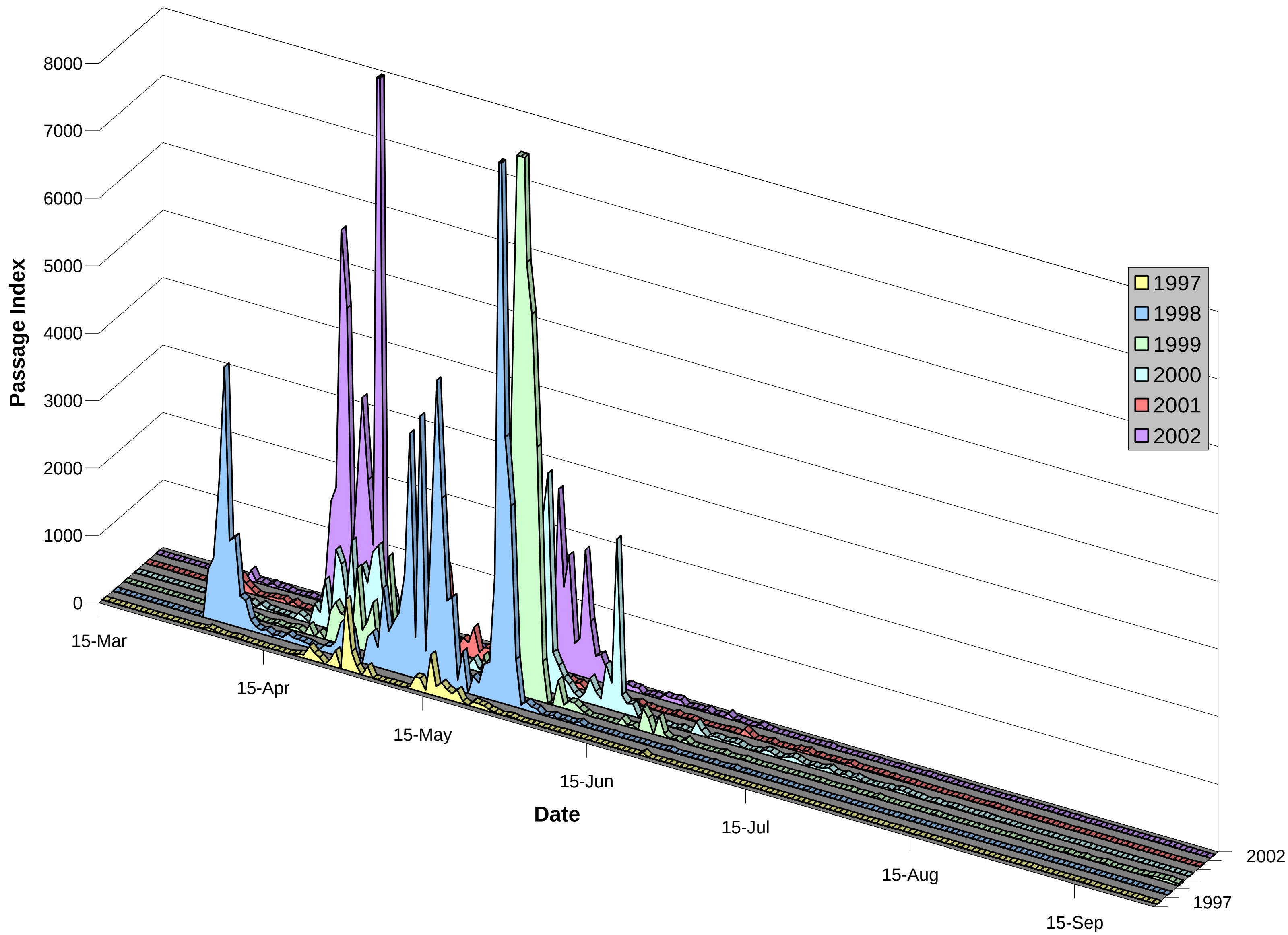



**Figure A.2.** Historical Run Timing of Juvenile Lamprey at Little Goose Dam

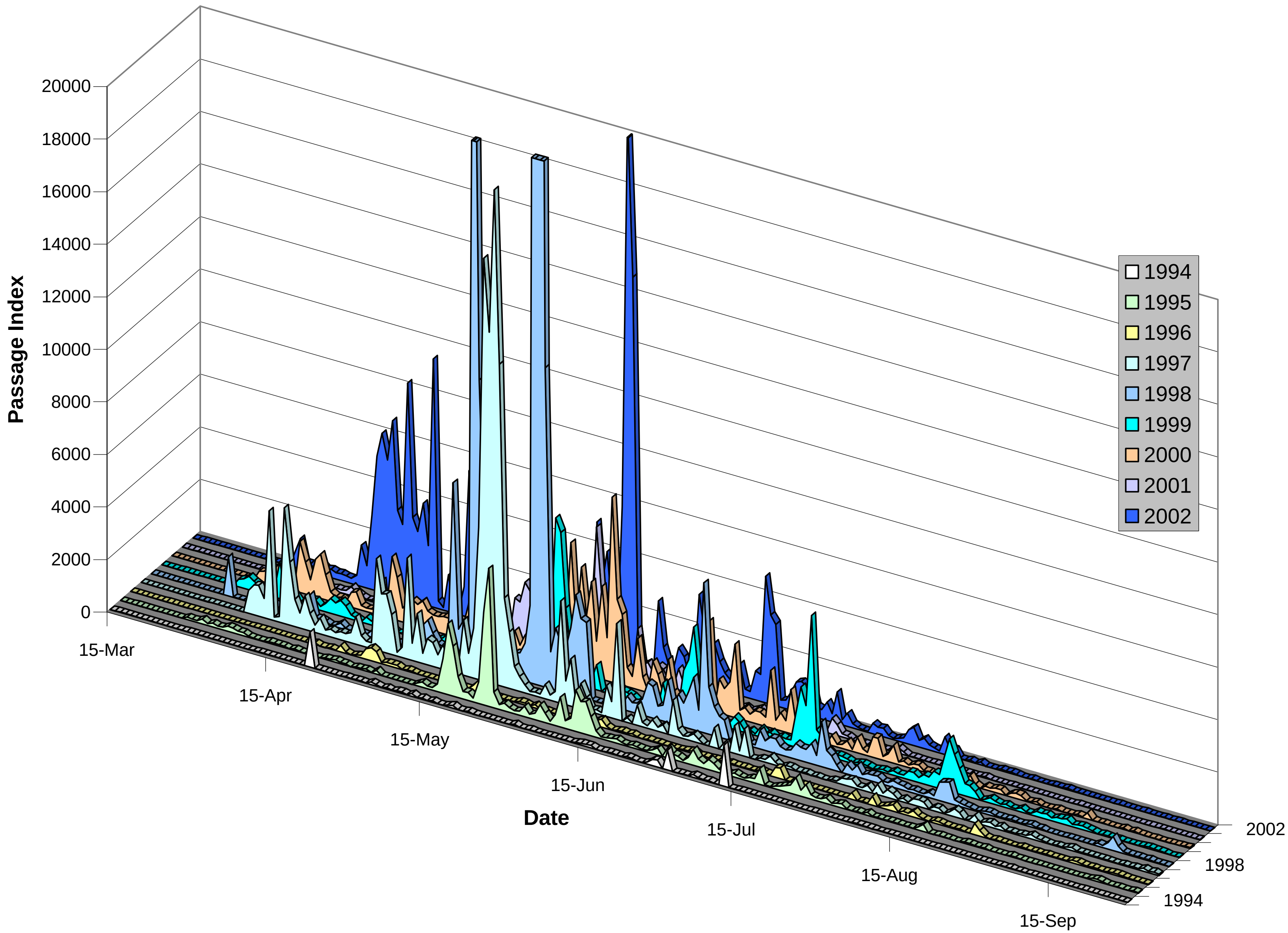



**Figure A.3.** Historical Run Timing of Juvenile Llamprey at McNary Dam

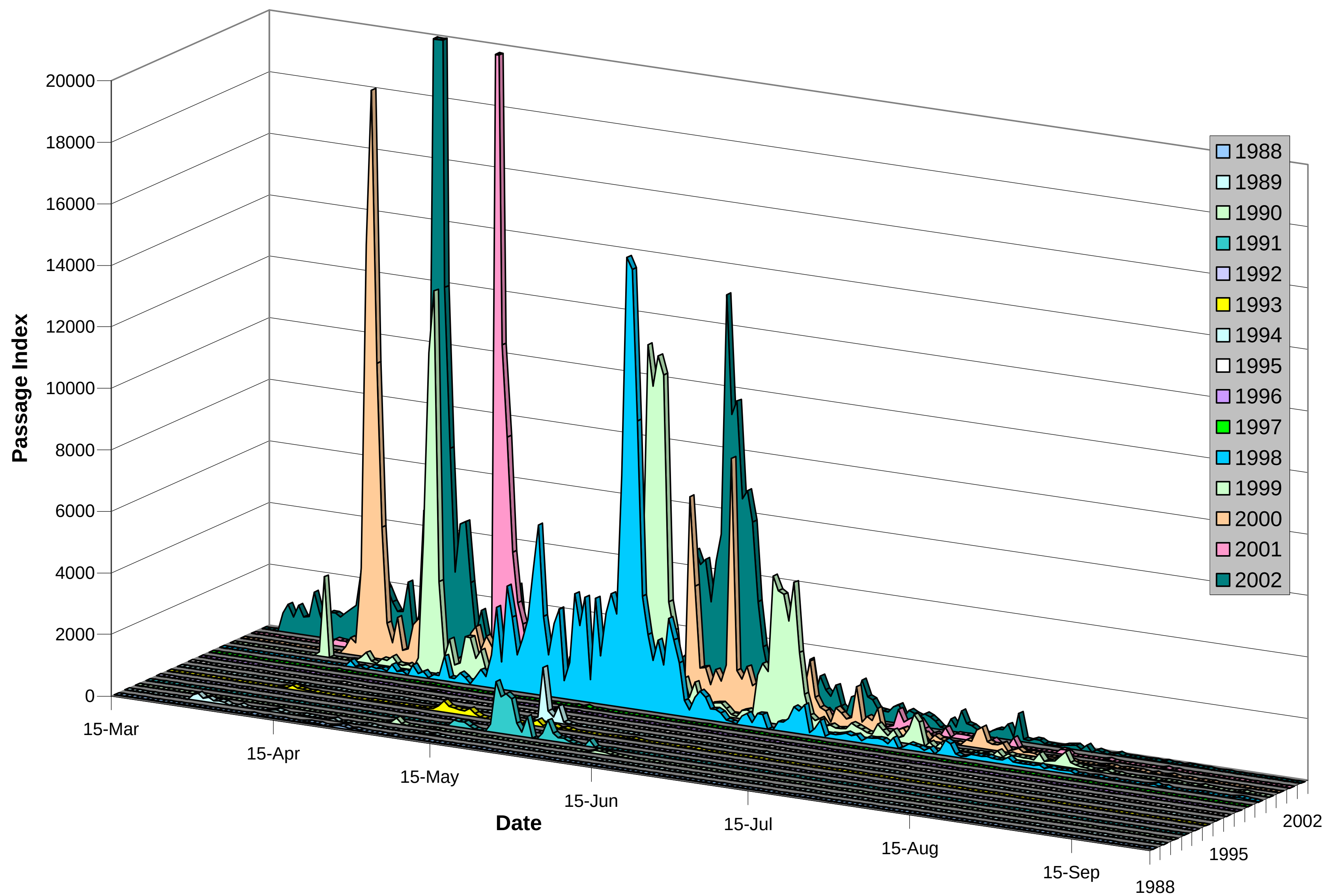



**Figure A.4.** Historical Run Timing of Juvenile Lamprey at John Day Dam

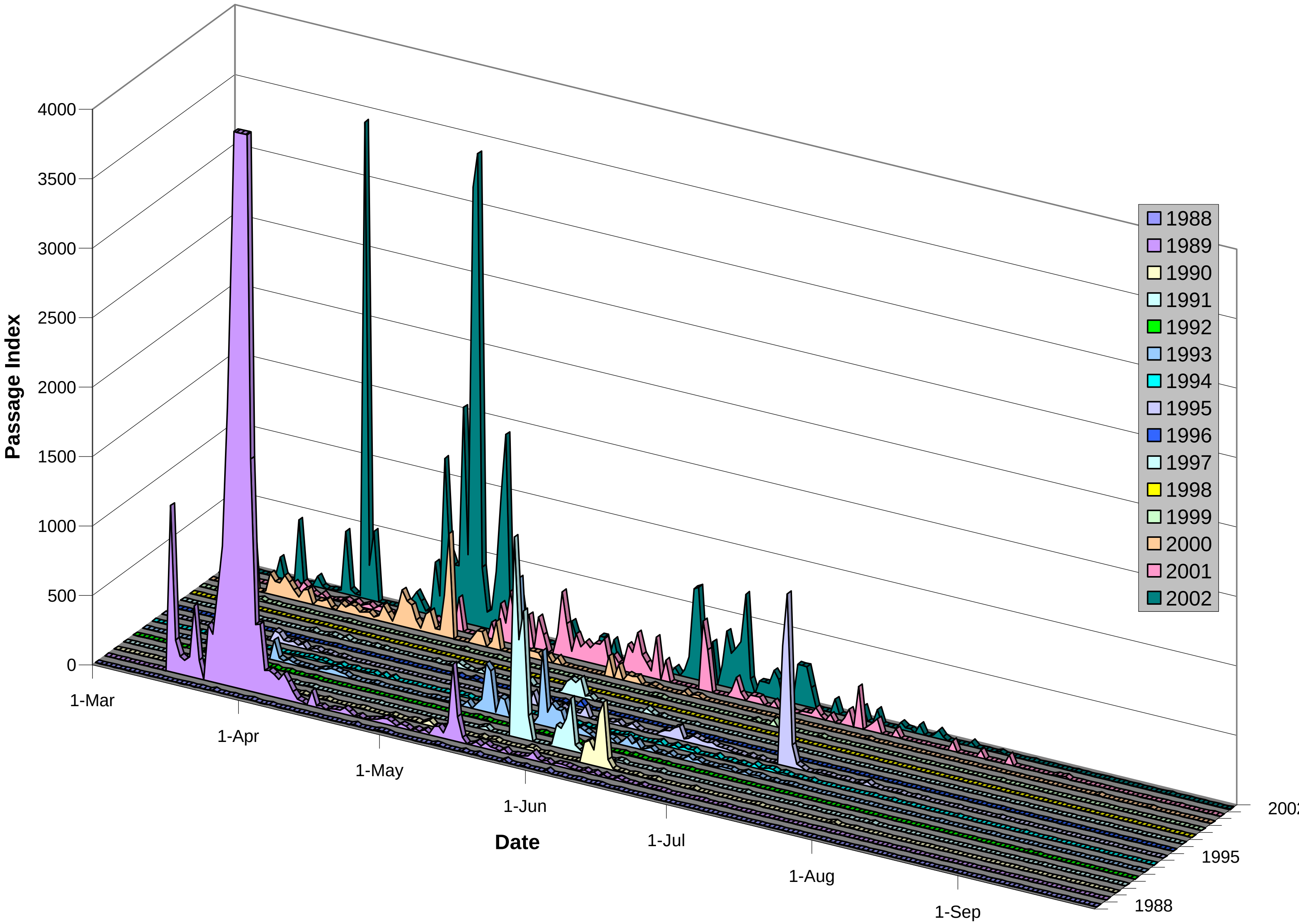



**Figure A.5.** Historical Run Timing of Juvenile Lamprey at Bonneville Dam

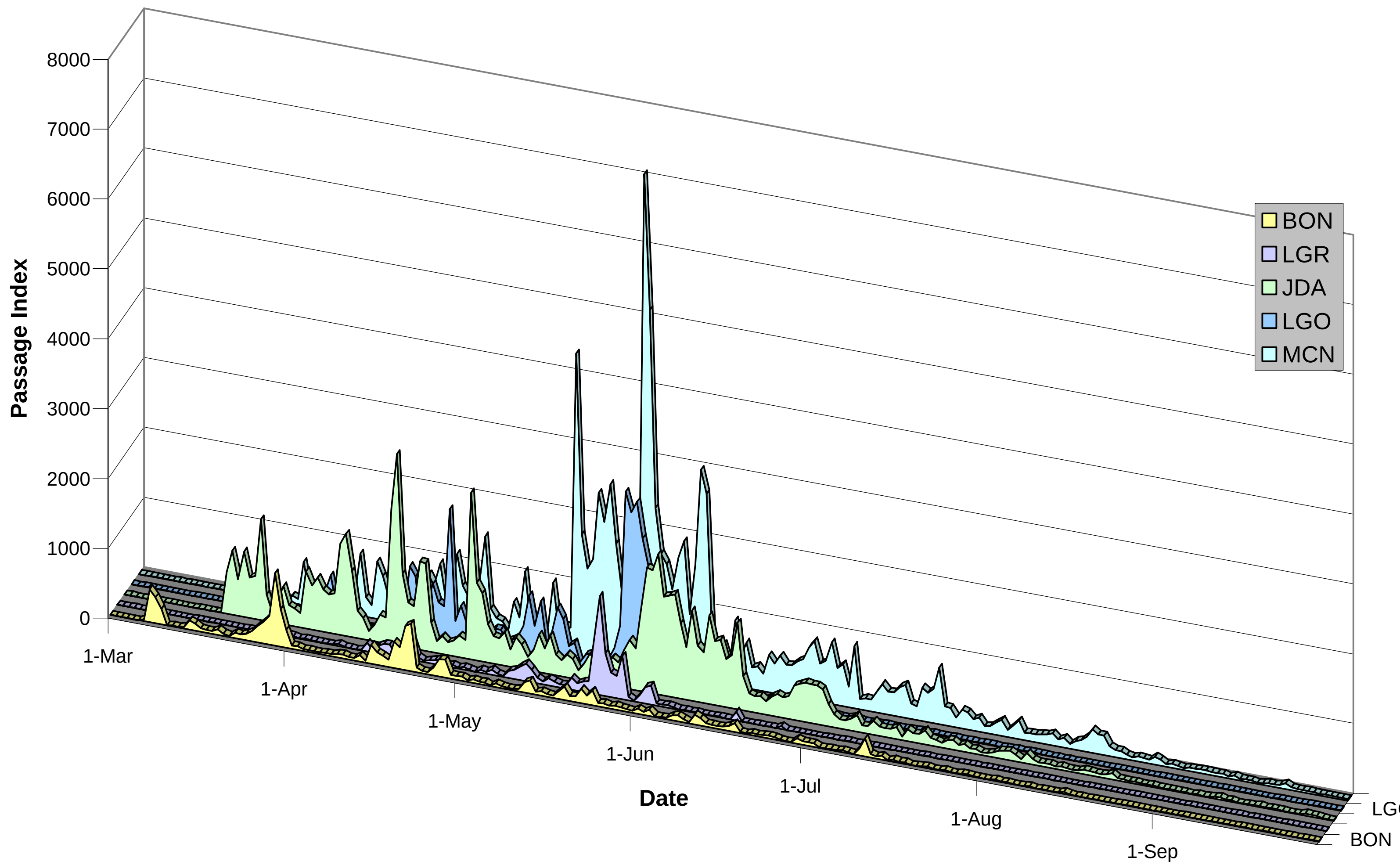



**Figure A.6.** Historical Run Timing of Five Dams on the Lower Columbia and Snake Rivers

# Appendix B

# Design Specifications

# Appendix B

# Design Specifications

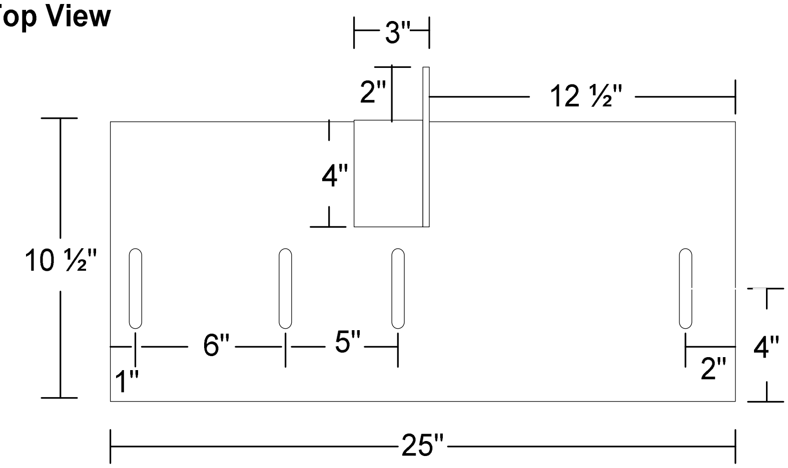
The design specifications and materials for the non-welded brush bar camera mounts, cable braces, and pulley mounts used to make *in situ* observations of Pacific lamprey on the surface of the ESBS at the John Day Dam are illustrated in the following figures. In addition, wiring diagrams illustrating the setup of lights and cameras are included.

Project = Uplooking Camera Mounts

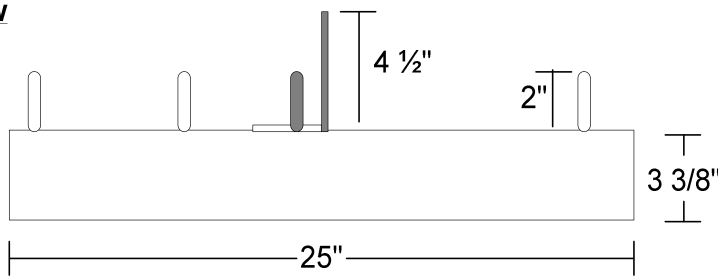
Material = ¼" Aluminum

Quantity = 2

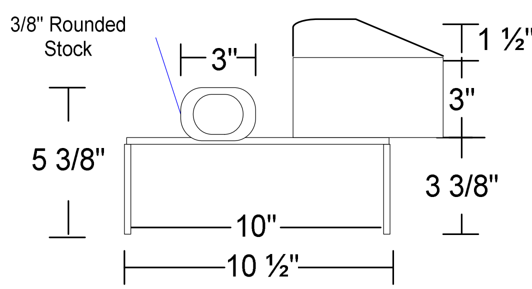
**Top View**




**Side View**




**End View**



Project = Sidelooking Camera Mounts

Material = ¼" Aluminum

Quantity = 1

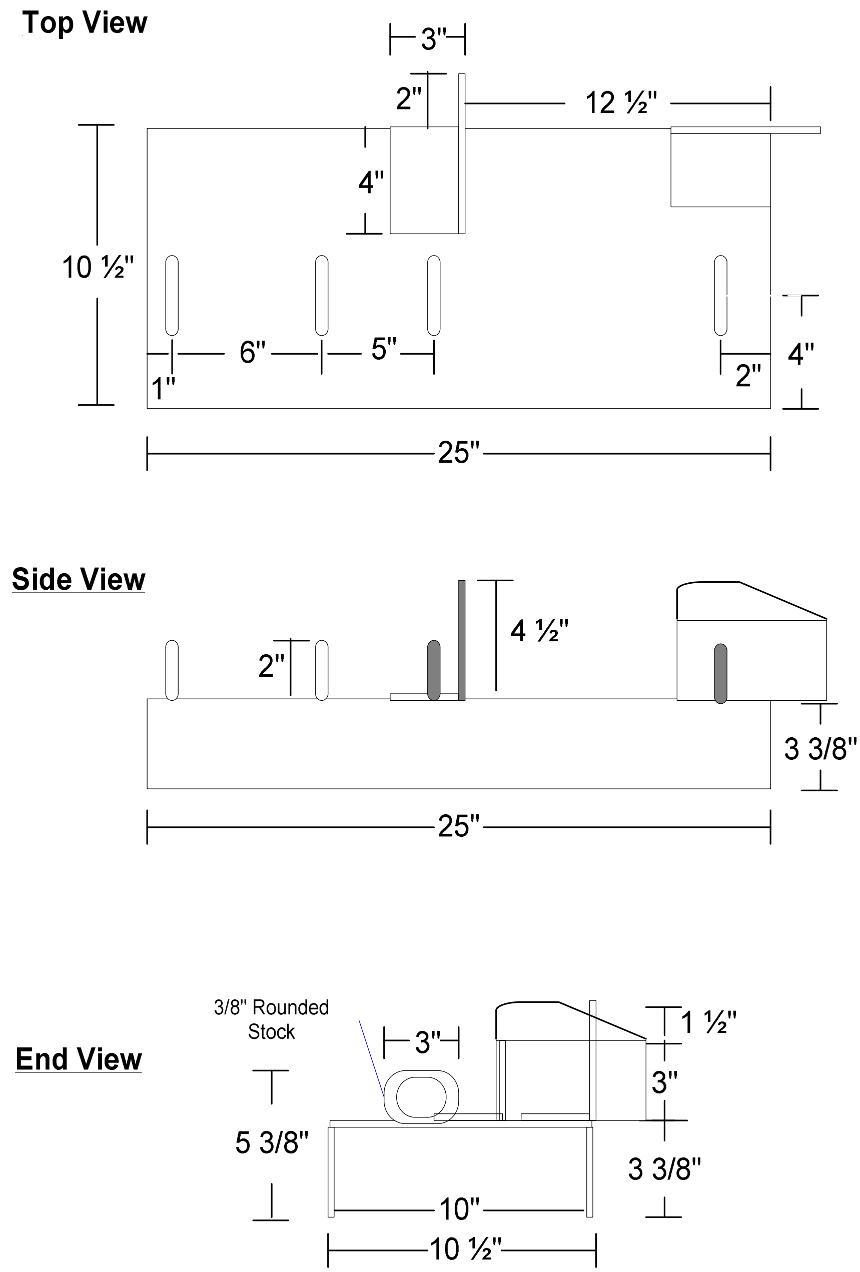



**Figure B.2.** Design Specifications of Non-Welded Brush Bar Mount for a Combination Side Looking and Up Looking Camera Mount

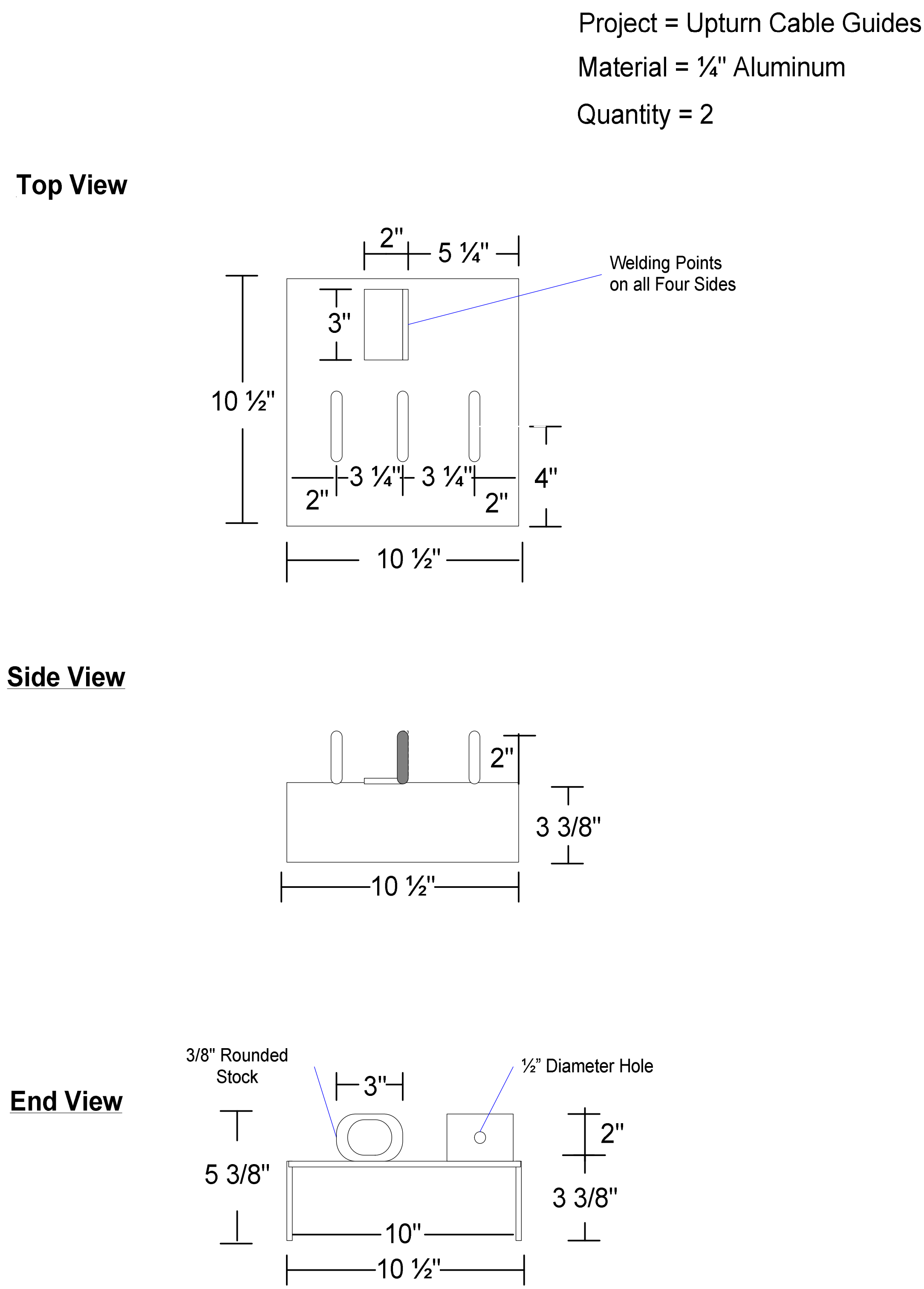



**Figure B.3.** Design Specifications of Non-Welded Brush Bar Mounts for Vertical Cable Braces

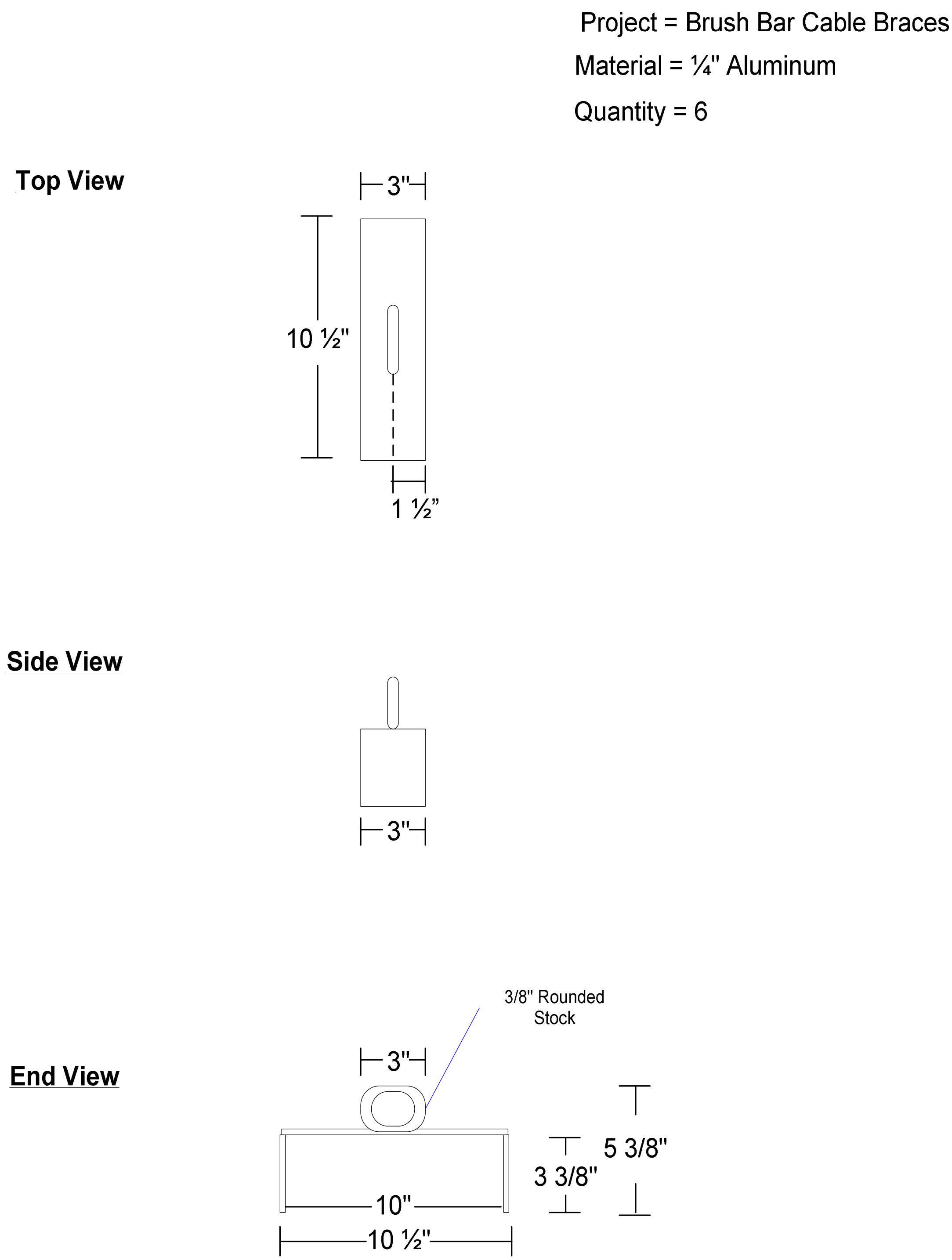
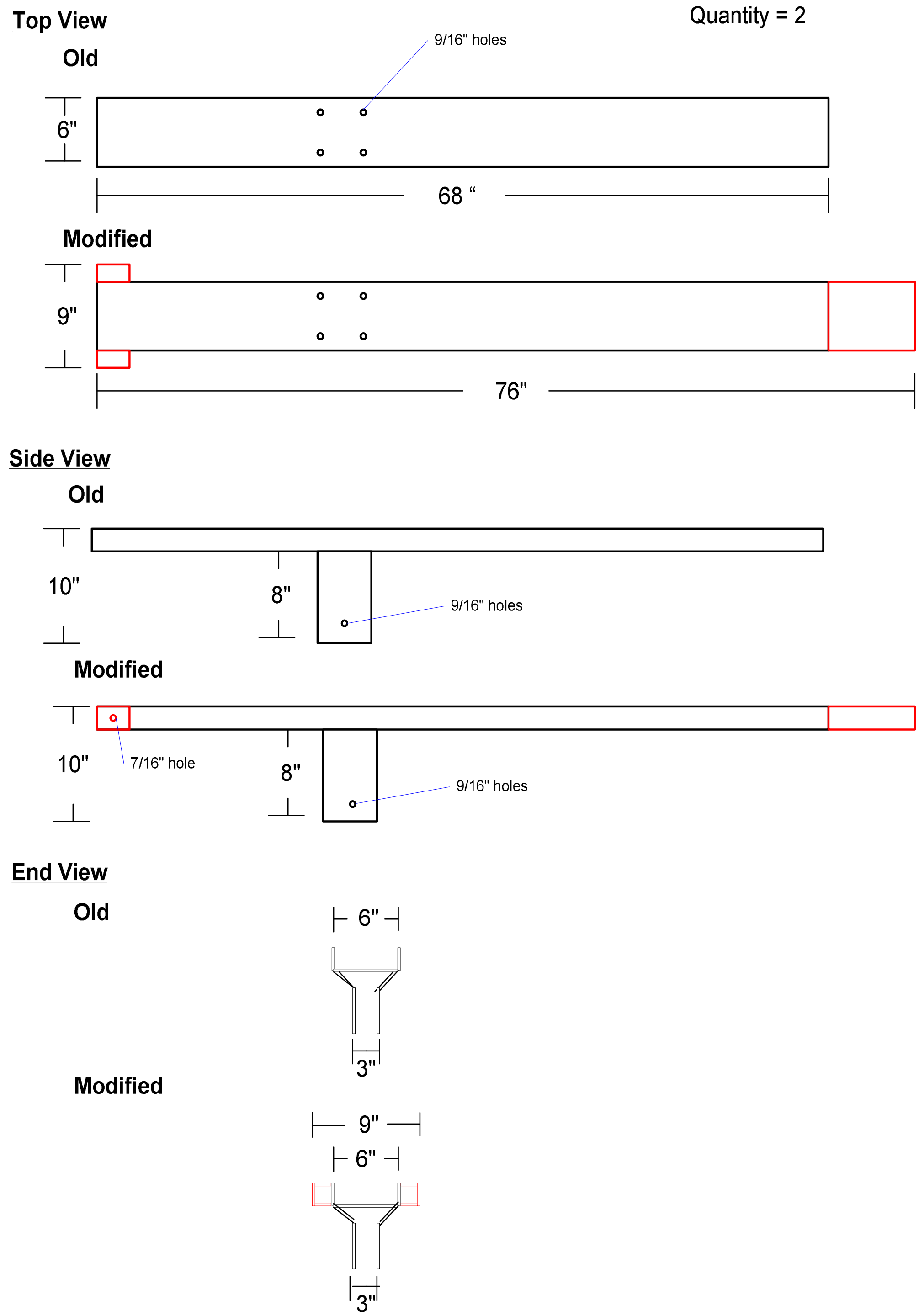
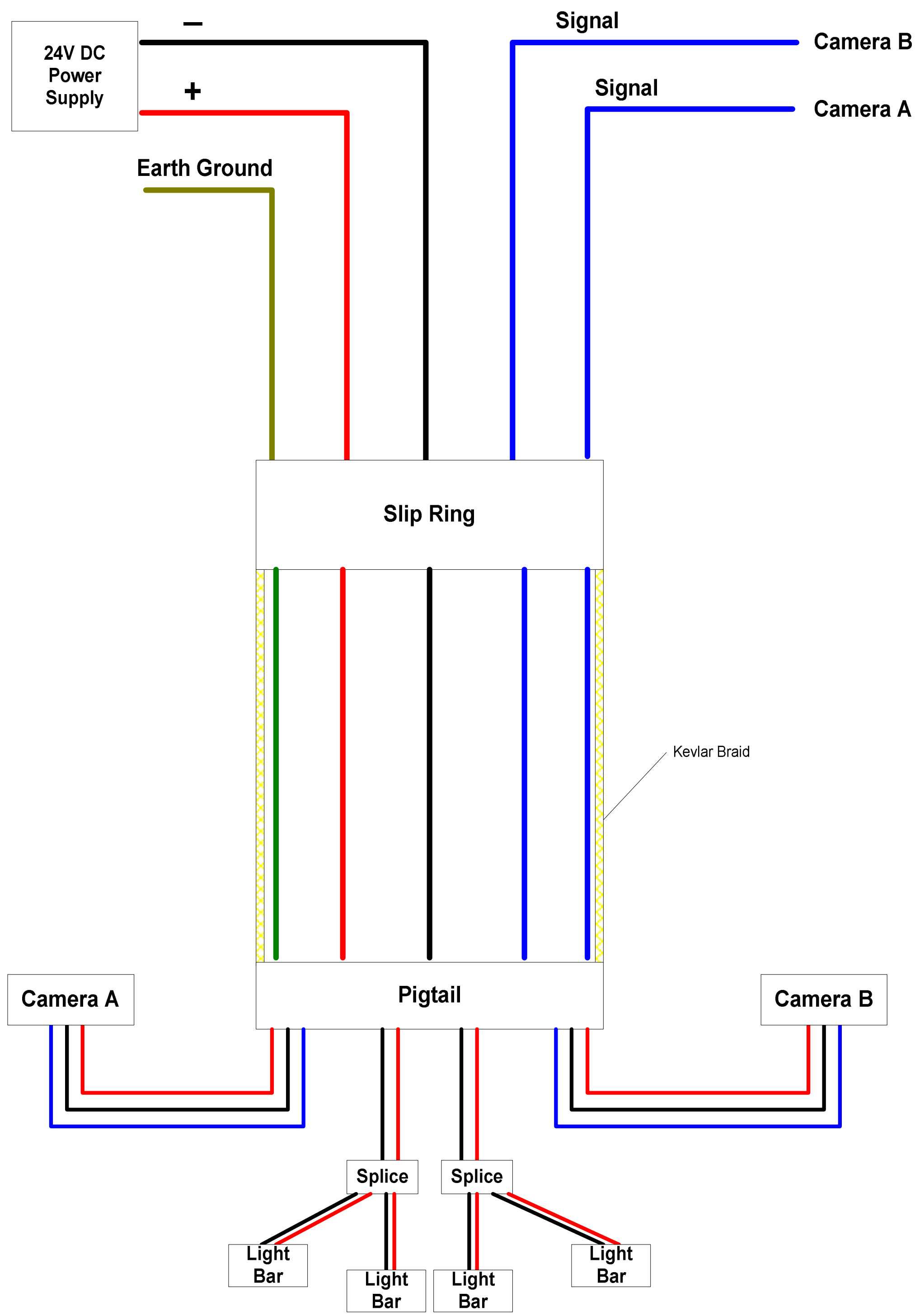
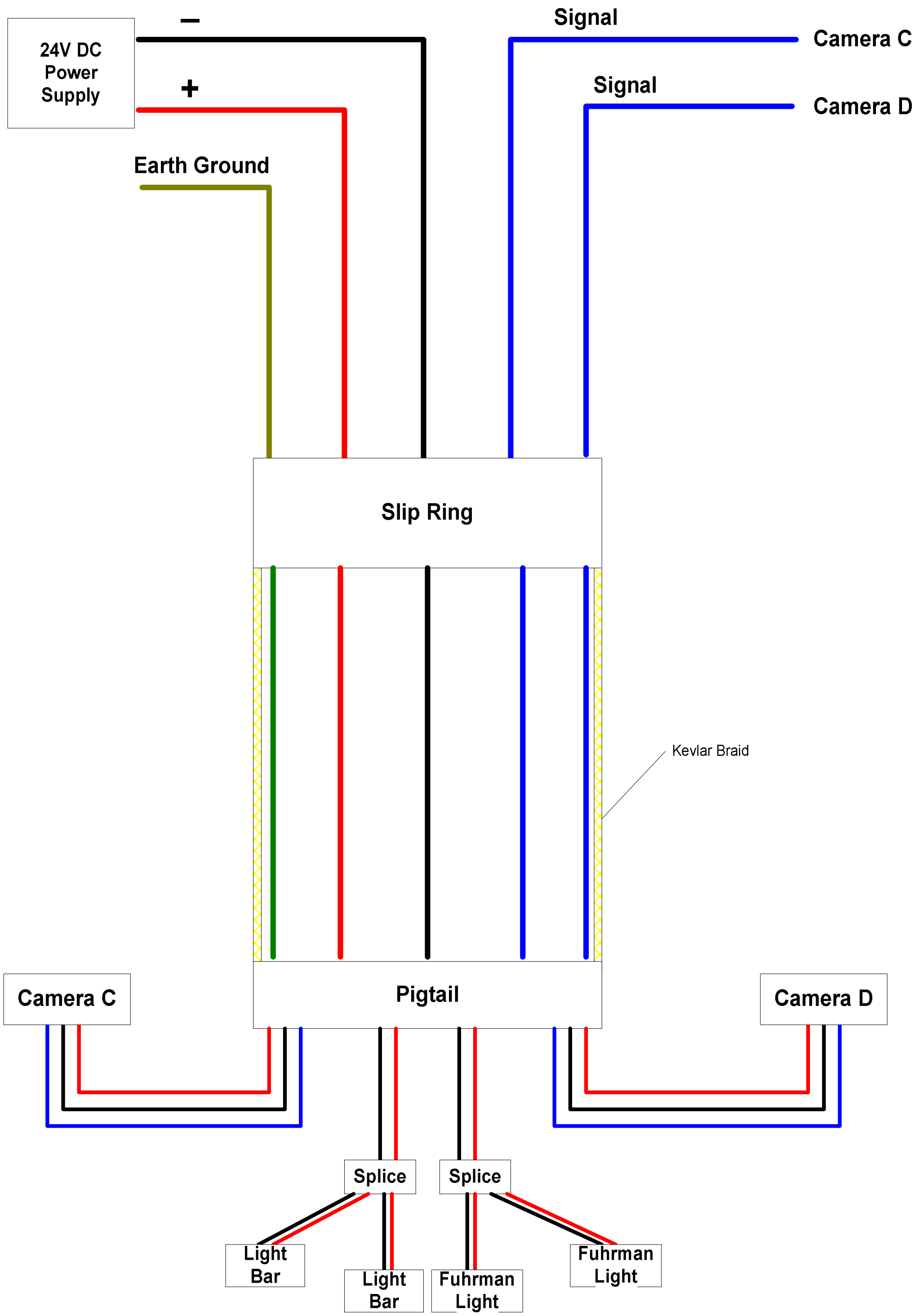



**Figure B.4.** Design Specifications of Non-Welded Brush Bar Mounts for Horizontal Cable Braces

Project = Modified Pulley Mounts
Material = ¼" Aluminum
Quantity = 2




24V DC
Power
Supply
–
+
Earth Ground
Signal
Camera B
Signal
Camera A
Slip Ring
Kevlar Braid
Pigtail
Camera A
Camera B
Splice
Splice
Light
Bar
Light
Bar
Light
Bar
Light
Bar


24V DC
Power
Supply
–
+
Earth Ground
Signal
Camera C
Signal
Camera D
Slip Ring
Kevlar Braid
Pigtail
Camera C
Camera D
Splice
Splice
Light
Bar
Light
Bar
Fuhrman
Light
Fuhrman
Light