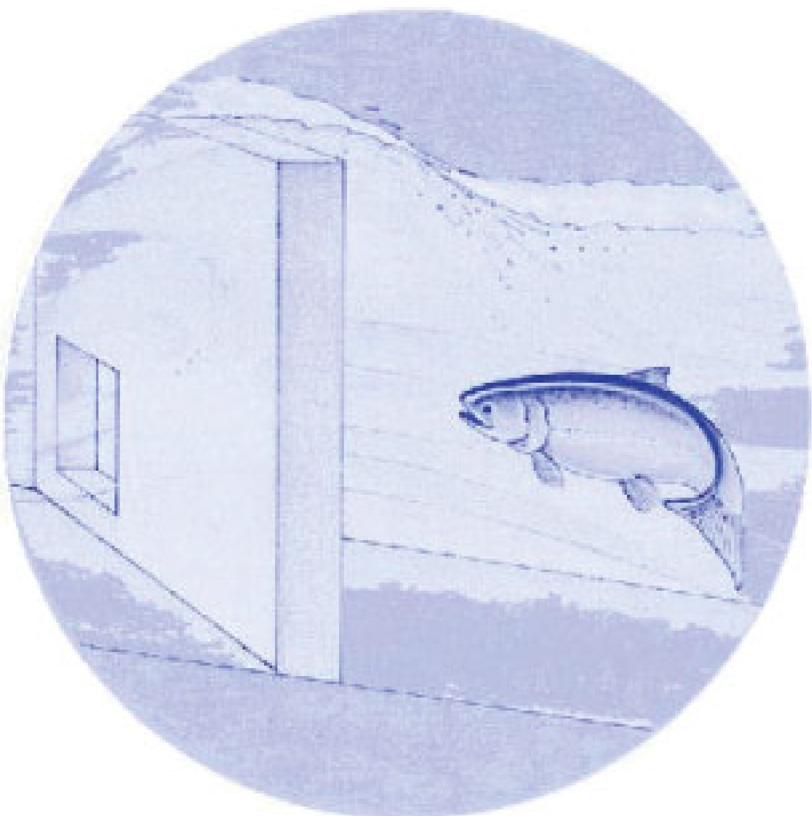
Chinook Salmon Adult Abundance Monitoring

Hydroacoustic Assessment of Chinook Salmon Escapement to the Secesh River, Idaho

Final Report
2002 - 2004



DOE/BP-00000652-17

January 2004

This Document should be cited as follows:

Johnson, R., C. McKinstry, R. Mueller, "Chinook Salmon Adult Abundance Monitoring; Hydroacoustic Assessment of Chinook Salmon Escapement to the Secesh River, Idaho", 2002-2004 Final Report, Project No. 199703000, 34 electronic pages, (BPA Report DOE/BP-00000652-17)

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This report was funded by the Bonneville Power Administration (BPA), U.S. Department of Energy, as part of BPA's program to protect, mitigate, and enhance fish and wildlife affected by the development and operation of hydroelectric facilities on the Columbia River and its tributaries. The views in this report are the author's and do not necessarily represent the views of BPA.

PNNL-14513

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

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PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
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UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RL01830

Printed in the United States of America

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Summary

Accurate determination of adult salmon spawner abundance is key to the assessment of recovery actions for wild Snake River spring/summer Chinook salmon (*Onchorynchus tshawytscha*), a species listed as "threatened" under the Endangered Species Act (ESA). As part of the Bonneville Power Administration Fish and Wildlife Program, the Nez Perce Tribe operates an experimental project in the South Fork of the Salmon River subbasin. The project has involved noninvasive monitoring of Chinook salmon escapement on the Secesh River between 1997 and 2000 and on Lake Creek since 1998. The overall goal of this project is to accurately estimate adult Chinook salmon spawning escapement numbers to the Secesh River and Lake Creek.

Using time-lapse underwater video technology in conjunction with their fish counting stations, Nez Perce researchers have successfully collected information on adult Chinook salmon spawner abundance, run timing, and fish-per-redd numbers on Lake Creek since 1998. However, the larger stream environment in the Secesh River prevented successful implementation of the underwater video technique to enumerate adult Chinook salmon abundance. High stream discharge and debris loads in the Secesh caused failure of the temporary fish counting station, preventing coverage of the early migrating portion of the spawning run. Accurate adult abundance information could not be obtained on the Secesh with the underwater video method.

Consequently, the Nez Perce Tribe now is evaluating advanced technologies and methodologies for measuring adult Chinook salmon abundance in the Secesh River. In 2003, the use of an acoustic camera for assessing spawner escapement was examined. Pacific Northwest National Laboratory, in a collaborative arrangement with the Nez Perce Tribe, provided the technical expertise to implement the acoustic camera component of the counting station on the Secesh River.

This report documents the first year of a proposed three-year study to determine the efficacy of using an acoustic camera to count adult migrant Chinook salmon as they make their way to the spawning grounds on the Secesh River and Lake Creek. A phased approach to applying the acoustic camera was proposed, starting with testing and evaluation in spring 2003, followed by a full implementation in 2004 and 2005. The goal of this effort is to better assess the early run components when water clarity and night visibility preclude the use of optical techniques.

A single acoustic camera was used to test the technology for enumerating adult salmon passage at the Secesh River. The acoustic camera was deployed on the Secesh at a site engineered with an artificial substrate to control the river bottom morphometry and the passage channel. The primary goal of the analysis for this first year of deployment was to validate counts of migrant salmon. The validation plan involved covering the area with optical video cameras so that both optical and acoustic camera images of the same viewing region could be acquired simultaneously. A secondary test was contrived after the fish passage was complete using a controlled setting at the Pacific Northwest National Laboratory in Richland, Washington, in which we tested the detectability as a function of turbidity levels.

Optical and acoustic camera multiplexed video recordings of adult Chinook salmon were made at the Secesh River fish counting station from August 20 through August 29, 2003. The acoustic camera

performed as well as or better than the optical camera at detecting adult Chinook salmon over the 10-day test period. However, the acoustic camera was not perfect; the data reflected adult Chinook salmon detections made by the optical camera that were missed by the acoustic camera. The conditions for counting using the optical camera were near ideal, with shallow clear water and good light penetration. The relative performance of the acoustic camera is expected to be even better than the optical camera in early spring when water clarity and light penetration are limited.

Results of the laboratory tests at the Pacific Northwest National Laboratory facility indicated that the detection rate for the acoustic camera system was essentially 100% across all levels of turbidity in the experiments.

Overall, the acoustic camera outperformed the optical camera at detecting fish, both in the laboratory tank and at the Secesh River fish counting station. However, the optical camera approach still offers some advantages over the acoustic camera under certain limited circumstances. The primary advantages are better species, gender and condition determination and better separation of debris from fish moving downstream. Using both systems in parallel will provide the most robust and accurate platform for counting fish in the field by exploiting the relative strengths of both systems through the season.

Key recommendations emerging from the study provide guidance toward developing a state-of-the-art counting system for assessing adult Chinook salmon escapement abundance:

- Continued field-testing is advised under high flow and turbidity conditions. Flow (measured in specific locations over and near the artificial substrate), river depth, and turbidity should be monitored continuously during testing. Because of the late arrival of the acoustic camera in 2003, several additional years of testing will be necessary to fully field-validate the system. The first year will be devoted to determining the parameters under which adequate validation data might be possible at the counting site. The second year would then be the true validation test year. This is largely because the window of opportunity to test is limited to the spring freshet period of high turbidity when the acoustic camera is most useful. If an accelerated validation process is desired, a more detailed laboratory study might be contrived next year after detailed flow and turbidity measurements are made during the spring freshet. Pacific Northwest National Laboratory has submitted a detailed plan for validating these tests and studies to the Nez Perce Tribe for inclusion in the latter's annual report to the Bonneville Power Administration on the overall project.

- Real-time counting software should be developed to provide in situ migrant salmon counts and individual fish meristics throughout the migration period. Backup video and digital records should be maintained during the season for comparison with automated counts.

- Incorporation of mobile wireless telemetry into the system should be considered to provide near-real-time data flow from the counting site to the processing/analysis center. The real-time data flow will 1) provide quality assurance/quality control on the data collected in the field and 2) allow for timely processing of the data.

- A database system should be instituted to provide organized data management and metadata for audit and accountability. Acoustic imaging systems are capable of collecting large volumes of data from multiple sites. Therefore, data management becomes necessary to provide the degree of accountability that is necessary, particularly when dealing with ESA-listed species of salmon.

Acknowledgments

The authors gratefully acknowledge the vision and contribution of the Nez Perce Tribe in undertaking this research effort to aid in the restoration of the wild Chinook salmon runs to the Snake River drainage through the application of advanced technologies. We specifically thank Dave Faurot for his unending energy and enthusiasm for the project, many hours reviewing data tapes, and critical contributions to the report. We also thank the field crew—Mike Busby, Dan Felt, Mark Gutman, and Dan Kolodny—for their able efforts and diligence in establishing the first acoustic camera counting station in Idaho. And finally, thanks to Paul Kucera who provided many insightful and helpful comments on the report.

We also would like to thank the Pacific Northwest National Laboratory staff for their contributions to the project. Jake Tucker designed and supervised the construction and installation of the artificial substrate and helped with system deployment in the field. Tom Kiefer rebuilt the entire electronics package for recording data in a remarkable two days. Mary Ann Simmons and Dave Geist provided peer review of the manuscript. Technical editing was performed by Andrea Currie. Text formatting was done by Rose Urbina.

This project was funded by the Bonneville Power Administration under Contract DE-AC06-76RL01830. We thank our COTR, Debbie Dockerty, for her input on the report and her expert guidance and direction during project execution.

Abbreviations Used in This Report

APL	Applied Physics Laboratory
cfs	cubic feet per second
cm	centimeter(s)
dc	direct current
DIDSON	dual frequency identification sonar
ESA	Endangered Species Act
ft	foot (feet)
hr	hour(s)
in.	inch(es)
m	meter(s)
mm	millimeter(s)
min	minute(s)
NMFS	National Marine Fisheries Service
NTU	nephelometric turbidity unit(s)
PNNL	Pacific Northwest National Laboratory
sec	second(s)
V	volt(s)

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1.0 Introduction

This report documents the first year of a study to implement an acoustic imaging camera counting station to quantify adult salmon abundance in the Secesh River in central Idaho. The Nez Perce Tribe and the Pacific Northwest National Laboratory (PNNL) undertook the work as a collaborative effort in 2003.

1.1 Background

Accurate determination of adult salmon spawner abundance is important in managing Snake River Chinook salmon (*Onchorynchus tshawytscha*). This salmon species is listed as "threatened" under the Endangered Species Act (ESA). The National Marine Fisheries Service (NMFS) *Biological Opinion for the Operation of the Federal Columbia River Power System* (NMFS 2000) has called for accurate abundance information to help assess recovery actions for wild Snake River spring/summer Chinook salmon.

The need for accurate population status is detailed in many sources:

- More accurate counts of adult Chinook salmon returning to natal spawning grounds are necessary to evaluate recovery efforts based on threshold goals (NMFS 2000).

- The preservation of a species is intimately tied to accurate assessments of its population status (Reed and Blaustein 1997).

- Numbers of spawners on the spawning grounds is of fundamental importance to the future of the populations (Mundy 1999).

- Without abundance information, we cannot measure the effectiveness of conservation actions for a threatened species (Botkin et al. 2000).

- Counting fish through the process of validation monitoring is the only way that a link between cause (standards and guidelines) and effect (trend) can be confirmed quantitatively (Botkin et al. 2000).

- "Wy-Kan-Ush-Me-Wa-Kush-Wit (Spirit of the Salmon)" (Columbia River Inter-Tribal Fish Commission 1995) provides guidance to

> Establish and monitor escapement checkpoints at mainstem dams and in index subbasins. ….Methods to be used include video counting at hydropower dams and at key locations in tributaries…. The least intrusive method should be used to collect the necessary information…. Establish additional monitoring programs for each of the subbasin tributary systems to monitor adult escapement and resulting smolt production, and to evaluate (by measuring the number of adults returning) the ability of managers to meet goals set by the Columbia River Fish Management Plan.

The Nez Perce Tribe has operated an experimental, passive, noninvasive Chinook salmon escapement monitoring project in the South Fork of the Salmon River subbasin, on the Secesh River between 1997 and 2000, and on Lake Creek since 1998, utilizing time-lapse underwater video technology in conjunction with its fish counting stations. This project has yielded actual adult salmon spawner abundance information, run timing, and fish-per-redd numbers on Lake Creek since 1998 without directly handling the salmon (Faurot and Kucera 1999; Faurot et al. 2000; Faurot and Kucera 2001a, 2001b, 2002, 2003).

According to Faurot and Kucera (2003), the larger stream environment in the Secesh River prevented successful implementation of the underwater video technique to enumerate adult salmon abundance. High stream discharge and debris loads in the Secesh River caused failure of the temporary fish counting station and thus prevented coverage of the early migrating portion of the spawning run. Accurate adult abundance information could not be obtained on the Secesh River with the underwater video method, and other techniques needed to be implemented.

The Nez Perce Tribe now is evaluating and implementing advanced technologies and methodologies for measuring adult abundance in the Secesh River. In 2003, the use of an acoustic camera was examined as a technology for assessing spawner escapement by providing video-like images of passing fish regardless of water clarity or light levels.

The acoustic camera technology used was a dual frequency identification sonar (DIDSON) developed by the Applied Physics Laboratory (APL) at the University of Washington for the Space and Naval Warfare Systems Center harbor surveillance program (Belcher et al. 2001). It can detect objects out to 48 m and provide video-quality images to identify objects out to 9 m. The DIDSON acoustic camera is the second generation of imaging sonar from the APL with technology similar to the Limpet Mine Imaging Sonar (Belcher et al. 1999). It was designed to bridge the gap between 1) existing sonar that can detect acoustic targets at long ranges but cannot record the shape or size of targets and 2) optical systems that can videotape fish in clear water but are limited at low light levels or when turbidity is high. The acoustic camera has a high resolution and fast frame rate designed to allow it to substitute for optical systems in turbid or dark water. The images within 1 to 9 m of the device are so clear that users can see fish undulating as they swim and can differentiate the head from the tail.

The acoustic camera is a nonintrusive device, with low signal-to-noise ratios, and it is not as limited by turbidity or light and not as sensitive to entrained air as 6- to 10-degree beams used for hydroacoustic sampling. The clarity is possible because the field of view is composed of 96 different 0.33-degree beams operating at 1.8 MHz and 48 different 0.6-degree beams operating at 1 MHz. It can sample up to 12 frames per second and has a 29-degree field of view. The multiple beams allow image processing that produces a near-field image similar to that of a charge-coupled device black-and-white camera. Because it has a fan of many narrow adjacent beams in one dimension, it can be aimed into a two-dimensional corner and still image fish swimming there. The acoustic camera has been used successfully to document fish passage close to structures at hydroelectric projects in the mid and lower Columbia River basins (Moursund et al. 2002; Mueller et al. 2003) but has not undergone proof-of-principle testing in small streams.

Pacific Northwest National Laboratory, in a collaborative arrangement with the Nez Perce Tribe, provided the technical expertise to implement the acoustic camera component of the counting station on the Secesh River with the goal of better assessing the early run components when water clarity and night visibility preclude the use of optical techniques.

1.2 Project Goal

The overall goal of this project is to accurately estimate spawning escapement numbers to the Secesh River and Lake Creek to meet the informational requirement for management to assess progress toward recovery goals for ESA-listed species of salmon. To accomplish this, the same multiyear objectives used for the underwater video research (Faurot and Kucera 1999) are being followed for the acoustic camera portion of the study, namely

1. Determine the first arrival of adult salmon to the counting site on the Secesh River.

2. Estimate the abundance of adult salmon spawners entering the Secesh River.

3. Determine the run timing of adult salmon spawning migration into the Secesh River on an annual basis.

4. Compare the accuracy of redd count methodology with the underwater optical camera and acoustic camera escapement estimation techniques.

The acoustic camera has potential to generate thorough escapement abundance data sets that provide a scientifically sound basis for salmon conservation and allow evaluation of recovery thresholds (NMFS 2000). The importance of providing quantitative adult escapement abundance information is well recognized within the scientific community (Foose et al. 1995; Botkin et al. 2000), and such information offers significant decision support for agency recovery planning efforts (NMFS 2000). Quantifying adult salmon spawner abundance will directly measure benefits of the Bonneville Power Administration Fish and Wildlife Program projects and effects of recovery alternatives.

Application of the acoustic camera to estimate the abundance of spawning salmon was proposed to be implemented in a phased approach starting with testing and evaluation in spring 2003, followed by a full implementation in 2004 and 2005. Pacific Northwest National Laboratory provided engineering and technical/scientific evaluation support to the Nez Perce Tribe in the first year.

1.3 Report Contents

Section 2 of this report documents the methods used for site setup and validation measurements. Descriptions of the study site at the Secesh River and the test facility at PNNL also are provided in Section 2. The validation results are presented in Section 3. Section 4 lists the study accomplishments and results and presents a number of recommendations based on the first year of deployment of the acoustic camera for counting adult salmon in a small stream. References are listed in Section 5.

2.0 Methods

A single acoustic camera was used to test the technology for enumerating adult salmon passage at the Secesh River. The acoustic camera was deployed on the Secesh River at a site engineered to control the river bottom morphometry and the passage channel. The primary goal of the analysis for this first year of deployment was to validate counts of migrant salmon. The validation plan was simple, given the late arrival of the acoustic camera and low clear water conditions—cover the area with optical video cameras so that both optical and acoustic camera images of the same viewing region could be acquired simultaneously. A secondary test was contrived after the fish passage was complete using a controlled setting at the PNNL facility in which we tested the detectability as a function of turbidity levels. The methods used are described in the following sections.

2.1 Study Site Descriptions

The field study was conducted on the Secesh River in central Idaho, and the laboratory study was conducted at the Pacific Northwest National Laboratory in Richland, Washington. The descriptions below detail the study sites.

2.1.1 Secesh River Study Site

The Secesh River is a tributary of the South Fork Salmon River in central Idaho (Figure 2.1). The Secesh River originates at the confluence of Summit and Lake Creeks; Marshall Lake (not shown on the map) is the source for Lake Creek. The Secesh River subwatershed encompasses approximately 68,797 hectares. Channel gradients range from less than 1% at the origin to more than 10% in canyon sections. Discharge readings have ranged from highs of several thousand cubic feet per second (cfs) recorded in May and June to lows of about 100 cfs in September.

The acoustic camera portion of the project is being performed on the Secesh River, at the Chinook Campground, R5E, T22N, Section 26 (latitude 45° 12’ 40”, longitude 115° 11’ 37”). The Chinook Campground is approximately 300 m from the proposed counting site on the Secesh River.

A major consideration for migrant salmon counting is site selection. The site we have chosen is on a long sweeping bend in the river, as illustrated in Figures 2.2 and 2.3. It has a gently sloping bottom from a gravel/sand bar on the inside of the bend to a cut-bank on the opposite side (Figure 2.4). Preparation of the site was to include removal of depressions with gravel bag fill and removal of large obstructions that would obscure the acoustic camera viewing area. Figure 2.5 shows a bottom contour cross-section plot measured in the general area of the deployment site. This illustrates the need for engineering the site slightly to achieve the desired fit to the artificial substrate. The rises and depressions represent areas where fish traveling near the substrate might pass undetected.

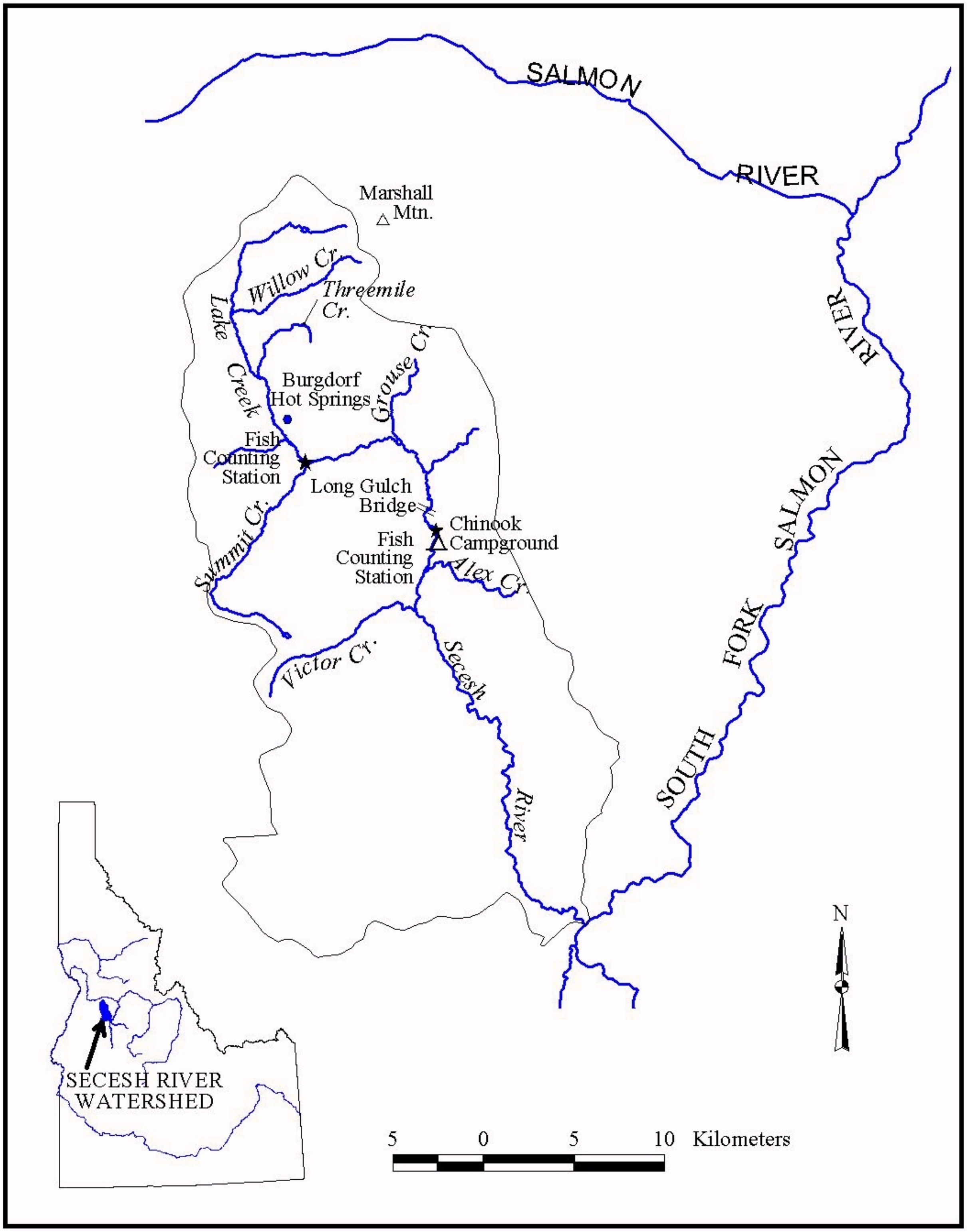

Figure 2.1. Secesh River Drainage and Locations of the Fish Counting Stations. The Secesh River acoustic camera test site is adjacent to the Chinook Campground.

Figure 2.2. Secesh River near Chinook Campground in Idaho. The test site ultimately selected is to the right of this photograph.

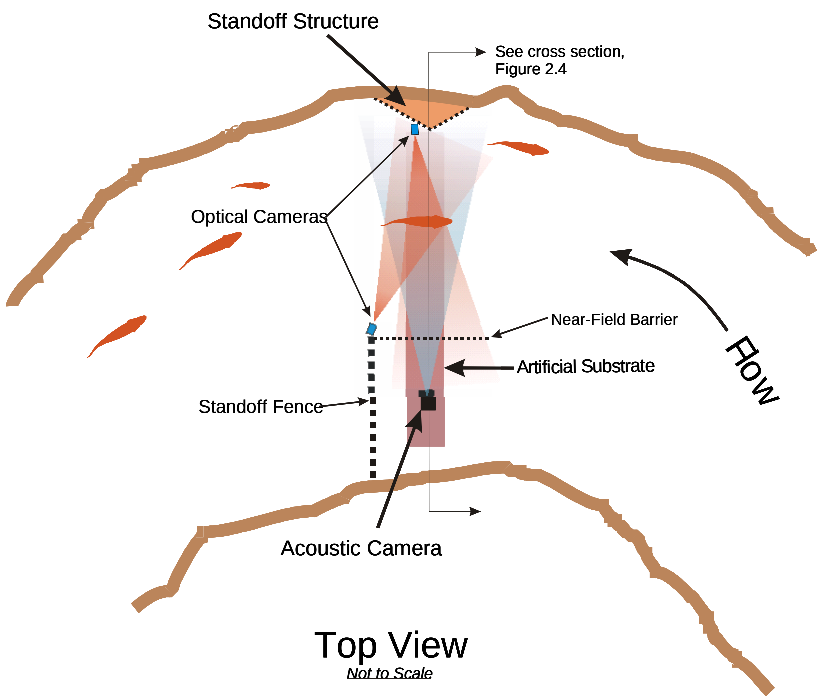

Figure 2.3. Plan View, Test Site on the Secesh River, Idaho

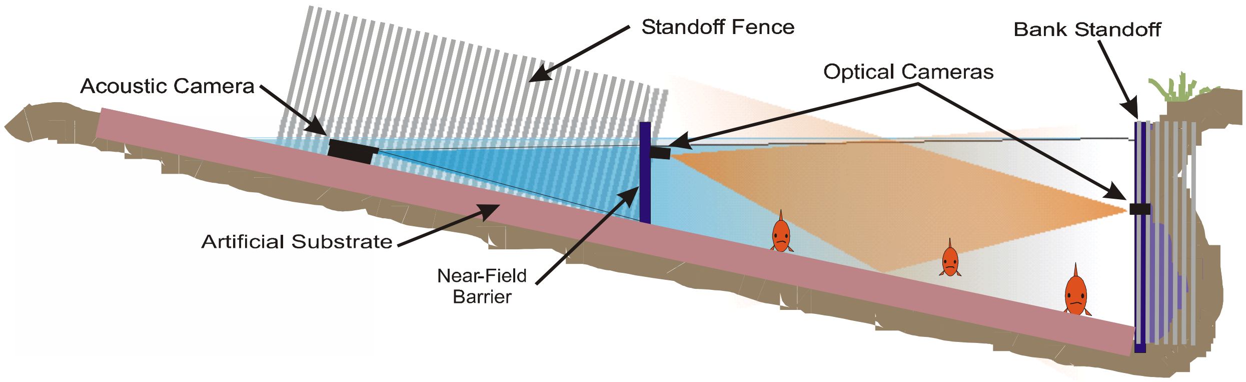

Figure 2.4. Cross Section of the Secesh River, Idaho, near the Chinook Campground

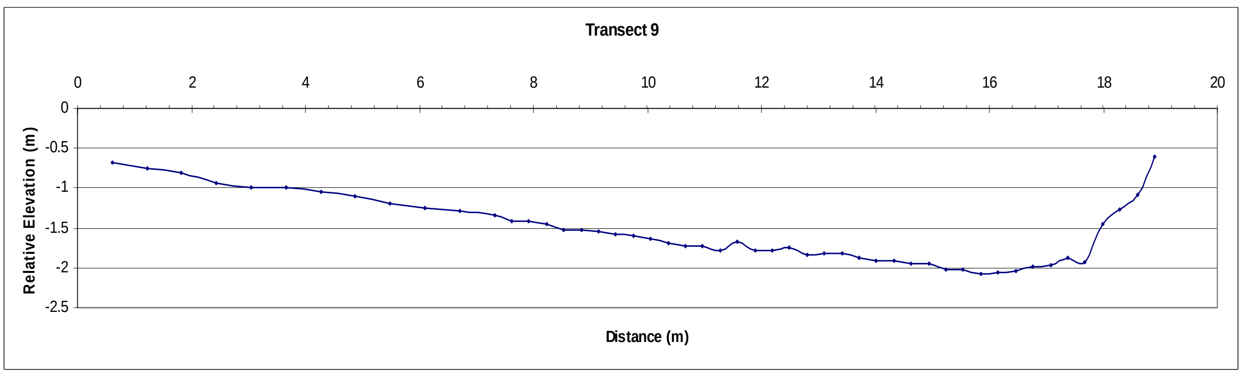

Figure 2.5. Measured Bottom Profile near the Site of the Artificial Substrate Deployment

2.1.2 Laboratory Validation Test Site

The laboratory validation tests were conducted at the fish facility on the PNNL campus in Richland, Washington. The facility has a ready source of test fish and large in-ground circular tanks as well as test flumes, large oval tanks, and a fish-rearing facility.

2.2 Site Engineering and Structural Design

Key elements to the successful application of an acoustic camera counting site are site selection and site engineering to optimize the effectiveness of the camera to detect and count migrant adult salmon. At the test site, this was accomplished by engineering the river cross section to optimize the acoustic beam coverage and thus increase the probability of detection as salmon move upstream past the location. Pacific Northwest National Laboratory functioned as an engineering consultant for this development; construction was largely the responsibility of the Nez Perce Tribe.

Three site preparation tasks were recommended:

1. Level the native substrate and remove obstructions.

2. Construct a standoff structure on the bank opposite the acoustic camera to prevent fish from swimming too close to the cut-bank side of the channel.

3. Construct a guide fence to prevent fish from tracking too close to the acoustic camera.

Tribal personnel conducted river cross-section measurements during low water in 2002 (Figure 2.5, for example), which identified the furthest upstream location most suitable for deployment and requiring minimal modification. The deployment site was ultimately moved further upstream when an alternative site was discovered at the head of the large bend in the river.

A standoff structure was constructed using galvanized steel pickets on the bank opposite the acoustic camera. This structure functioned to keep fish away from the cut-bank side of the channel.

Pacific Northwest National Laboratory designed an artificial substrate of milled aluminum trusses covered by aluminum sheeting to be deployed on the leveled native substrate (Figure 2.6). Three of six planned sections were fabricated for the initial tests because the water level was low. The remaining three sections were fabricated after the fish run was completed in 2003. Four sections were deployed ultimately by the Nez Perce Tribe but will likely need to be redone to allow for leveling the underlying substrate with gravel-filled sandbags. Additional site preparations will need to be completed in future project years to ensure that the site and equipment function properly. The natural river substrate will need to be leveled using gravel-filled sandbags so that the artificial substrate will be straight and parallel to the bottom. The flanges on the leading and trailing edges of the substrate are to be covered with gravel-filled sandbags to aid in holding the substrate in place. Additionally, anchors placed upstream with aircraft cable attachment to the substrate sections and pins driven into the substrate on the upstream flange will further secure the substrate sections during high-water events.

During the initial tests of the acoustic camera, a carriage was designed to carry and protect the camera. The carriage could be moved manually along the artificial substrate crest to track the water level as it drops or rises during the season. Caps along the crest of the artificial substrate could be removed to position the acoustic camera at the desired depth (usually 10 to 15 cm below the surface and aimed slightly down toward the substrate with the top of the beam approximately parallel to the surface).

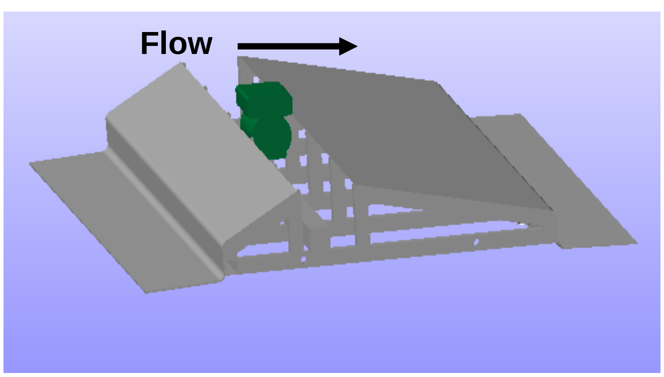

Figure 2.6. Substrate Section with Acoustic Camera in Slot (left); As-Built Substrate Section (right)

Nez Perce tribal personnel installed the standoff structure and a diversion fence and temporarily secured three sections of the substrate to the river bottom (Figure 2.7). Because this test was done late in the season while the water was low and clear, we noted that the majority of the migrant Chinook salmon were traveling in the deep water. It did not appear that a barrier was necessary to prevent fish from passing too close to the acoustic camera, so a temporary barrier was constructed of fine-mesh monofilament gill net and held in place by steel pickets. This appeared to function adequately except for the tendency to accumulate debris. Tribal personnel ultimately replaced the monofilament with steel wire mesh. This appeared to work well in the field, but we noted that similar wire mesh used in the laboratory resulted in considerable attenuation of the acoustic signal and should not be used in the field in future deployments. Flat panels of acoustically transparent material are available commercially and should replace the wire mesh.

The surface components of the system were packaged in an environmental case under a tarpaulin-covered tripod (Figure 2.8). The entire system, including video cameras, was powered by banks of 6-V dc batteries linked in series to provide 24 V dc to the system. The batteries were, in turn, charged by multiple solar panels. The solar panels were not adequate to provide charging capacity, so supplementary generator power was used periodically to fully charge the batteries.

2.3 Field Test of Acoustic Camera Technology

Once the site was engineered and the site set up, the next step was to test the acoustic camera. The deployment was conducted with an acoustic camera (Figure 2.9) with specifications as listed in Table 2.1.

Figure 2.7. Secesh River Counting Station. The direction of flow is from right to left. (Note: artificial substrate should be installed with the steep side toward the right or upstream.)

Figure 2.8. Surface Components of the Acoustic Camera and Optical Camera System

Figure 2.9. Acoustic Camera Used at the Secesh River, Idaho, in 2003

The acoustic camera operates in two modes—detection and identification. In the detection mode, the acoustic camera serves primarily as a target detection system similar to other multibeam acoustic devices, with minimal structure detail apparent in the images. In the identification mode, however, the images provide a relatively high degree of detail similar to those of a normal camera, such that the anterior and posterior extremes of the fish are recognizable and tail beat can be discerned easily (Figure 2.10). The latter operational mode was used in the Secesh River.

Table 2.1. Specifications for the Standard Acoustic Camera

Specification	Detection Mode	Identification Mode
Operating frequency	1.0 MHz	1.8 MHz
Beam width (two-way)	0.4º H by 12º V	0.3º H by 12º V
Number of beams	48	96
Source level (average)	202 dB re 1 µPa at 1 m	206 dB re 1 µPa at 1 m
Range settings window start window length	 0.75 m to 23.25 m in 0.75-m intervals 4.5 m, 9 m, 18 m, 36 m	 0.38 m to 11.63 m in 0.38-m steps 1.13 m, 2.25 m, 4.5 m, 9 m
Range bin size relative to window length	8 mm, 17 mm, 35 mm, 70 mm	2.2 mm 4.4 mm, 9 mm, 18 mm
Pulse length relative to window length	8 µs, 16 µs, 32 µs, 64 µs	4 µs, 8 µs, 16 µs, 32 µs
Specification	**Both Modes**	
Maximum frame rate (window length dependent)	4-21 frames/s	
Field-of-view	29º	
Remote focus	1 m to max range	
Power consumption	30 w typical	
Weight in air (dc option)	7.0 kg (15.4 lb)	
Weight in water (dc option)	0.61 kg neg. (1.33 lb)	
Dimensions	30.7 cm by 20.6 cm by 17.1 cm	
Source: Belcher et al. (2001).		

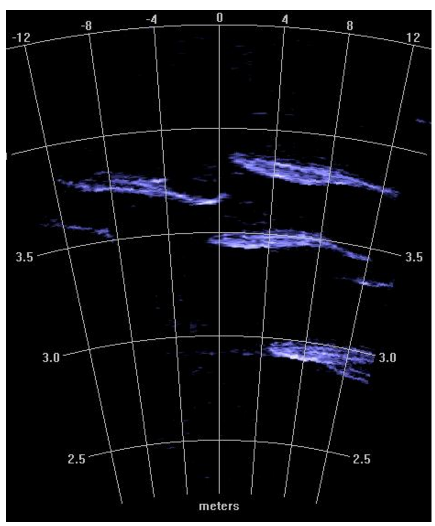

Figure 2.10. Detailed Images of Adult Salmon Captured by Acoustic Camera in Identification Mode

Initial detectability tests were conducted using a standard target (a 4-in. hollow copper sphere) to map the detection zone. The standard target was placed on the end of pole and swept through the volume viewed by the acoustic camera to allow for adjustment of the structures and acoustic camera. The final orientation provided coverage from the artificial substrate to the surface and from 1.5 m from the acoustic camera to the standoff structure on the opposite bank of the river. This orientation was deemed satisfactory for the initial validation tests.

Next, two optical cameras were installed that viewed the entire area where fish could pass over the substrate (see Figure 2.3). The purpose of the optical cameras was to provide comparative counts for validation of the acoustic camera. One camera was mounted on the standoff structure looking across the channel toward the acoustic camera. A second camera was attached to the diversion structure downstream of the acoustic camera aimed toward the standoff structure. The video signals from the two optical cameras and the acoustic camera were multiplexed onto a single videotape for synchronized viewing and analysis.

Initial attempts to operate the system uncovered problems with the configuration and wiring in the surface component package. The entire system was subsequently transported to PNNL in Richland and rebuilt to operating order. Once the system was returned to the Secesh River, data collection was initiated.

2.4 Laboratory Test of Acoustic Camera Technology

Both acoustic and optical camera systems were evaluated ad hoc under artificially induced turbidity and partially controlled ambient lighting. The trials were conducted at the PNNL fish facility in a circular concrete tank 6.1 m (20 ft) in diameter containing well water at a depth of 0.7 m (2.3 ft) (Figure 3.11). Water temperature in the circular tank was held to 51°F. Approximately 40 brood-stock rainbow trout ranging in size from 30 to 50 cm (12 to 20 in.) were used in the study. The fish were segregated to the outer portion of the pond using a plastic mesh screen to ensure complete coverage of the counting area by both camera systems. System performance was evaluated under two different lighting conditions and under turbidity conditions (measured in nephelometric turbidity units, NTU) starting at high levels (>8.0 NTU) and falling to approximately 1 NTU over a 4- to 5-hour period.

Figure 2.11. Circular Concrete Tank (6.1 m [20 ft] in diameter by 0.7 m [2.3 ft] deep) Used for Laboratory Validation Tests at the Pacific Northwest National Laboratory Fish Facility

The acoustic camera was attached to a standpipe at the center of the pond on an adjustable aluminum bracket. The optical video camera used for the test was a DeepSea Power & Light, Inc., Model 1050 (Table 2.2). It was mounted on top of the acoustic camera just above the lens element (Figure 2.12). Lenses were aimed so that the field of view for each camera system completely overlapped in the counting area. The distance from the acoustic and optical camera lenses to the outer concrete tank wall was approximately 2.4 m (8 ft).

A second optical video camera (Inuktun Firefleye) was placed in the tank inside the screen fish barrier. This camera was fastened to a cinder block and positioned at approximately 18 cm (7 in.) from a white panel with a 0.8-cm (5/16-in.)-diameter circular hole near the top portion of the panel. Pixel intensity measurements from video image analysis of the black circular hole were used as a calibration standard of turbidity that could be measured on a continuous time scale, independent of turbidity meas-ures based on water samples. Water samples were taken approximately every 5 minutes through each

Table 2.2. Specifications for the Optical Video Camera (DeepSea Power & Light, Inc., Model 1050)

Feature	Specification
Image sensor	~8.5 mm (1/3 in.)
Field of view	77 degrees (H) x 59 degrees (V)
Number of pixels	537 (H) x 595 (V)
Resolution	400 + TV lines
Scene illumination	0.05 lux
Lens	2.8 mm

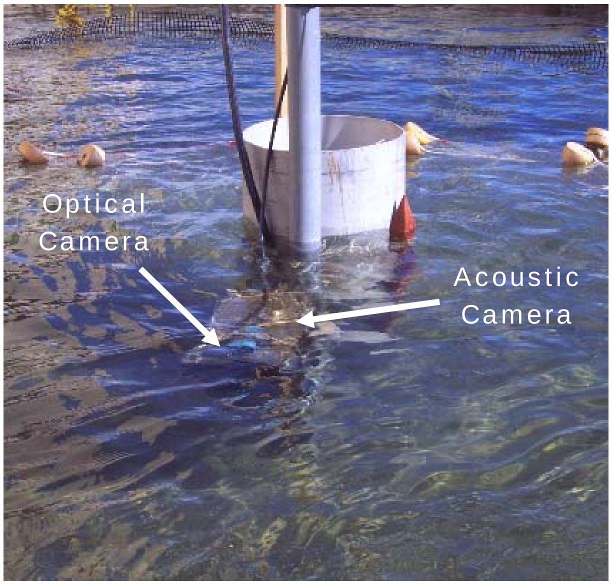

Figure 2.12. Acoustic Camera and Optical Camera Positioned at the Center of the Laboratory Test Pond

experimental trial with turbidity measured in nephelometric turbidity units using a Hach Turbidimeter. Video streams from all three cameras (acoustic, optical, and calibration standard) were multiplexed onto a single VHS tape, recorded in 6-hour time-lapse mode. The calibration standard data were collected in the event that inadequate numbers of direct readings were obtained. Because sufficient numbers of readings were obtained from the direct measurements, the calibration standard data were not used.

Four separate trials were conducted over two consecutive days. In the first trial, the tank was covered with a dark-colored tarpaulin to exclude ambient light, but the fish counting area was illuminated with four red underwater light-emitting diode light arrays to simulate night conditions. Only one trial with the tank covered was completed due to high winds that caused difficulty maintaining the integrity of the cover. The next three trials were conducted with the tank uncovered under ambient daylight conditions. In each trial, turbidity was introduced in the form of fine sediment or mud near the inflow jet. Mixing was allowed to occur over a period of approximately 5 minutes before turbidity samples were collected and measured. Fish counting samples were collected by Nez Perce personnel with expertise in video counting by review of the VHS tape on approximate 5-minute time intervals for each trial. This allowed suspended particles to either settle or be flushed out of the tank through the outflow, causing turbidity levels to drop monotonically over time. Fish detections were tabulated independently for both camera systems (acoustic and optical) at each sampling.

2.5 Processing and Analysis of Acoustic Camera Test Data

Most of the data processing and analysis were conducted by Nez Perce tribal personnel, both in-season and post-season. Pacific Northwest National Laboratory provided technical and scientific guidance to the processing and analysis phase of the project.

2.5.1 Field Data Processing and Analysis

Multiplexed optical and acoustic camera recordings were collected from the Secesh River fish counting station over a 10-day period in August 2003. Again, Nez Perce personnel with expertise in video counting reviewed the multiplexed VHS tapes with fish detections tabulated independently for both the acoustic and optical cameras. The data were supplied to PNNL for further analysis.

2.5.2 Laboratory Experimental Setup and Design

The Nez Perce Tribe reviewed the tapes to determine fish detections for both systems. Counts of fish in the counting region were made from separate review of the two camera systems corresponding to the timing of turbidity samples taken through each trial. Sections of the multiplexed tapes were reviewed over a 15-second time interval, with counts of individual fish logged. To control for potential observer bias, sections of tapes were reviewed and detection counts logged separately and independently between the two camera systems. The resulting data set was sent to PNNL for further analysis.

3.0 Results and Discussion

Video recordings made with the acoustic camera were compared to those made with the optical camera both in the field at the Secesh River counting site and in the laboratory. This section outlines the results of those comparisons.

3.1 Secesh River Validation Test Results

Optical and acoustic camera multiplexed video recordings were made of adult Chinook salmon at the Secesh River fish counting station over a 10-day period from August 20 through August 29, 2003. All counts were taken during daylight hours over these dates (Table 3.1). These recordings were reviewed, and adult Chinook salmon detections from the two sources were tabulated independently. Figure 3.1 shows the relative daily detection performance of the two types of imaging systems.

In Figure 3.1, it is clear that the acoustic camera performed as well as or better than the optical camera at detecting adult Chinook salmon over the 10-day test period. However, the acoustic camera was not perfect; acoustic camera detection percentages (red bars) less than 100% reflect adult Chinook salmon detections made by the optical camera that were missed by the acoustic camera. The conditions for counting using the optical camera were near ideal, with shallow clear water and good light penetration. The relative performance of the acoustic camera is expected to be even better than the optical camera in early spring when water clarity and light penetration are limited.

3.2 Laboratory Validation Test Results

Because no counts independent of the two camera systems were available, the maximum count on each 15-second interval between the optical and acoustic camera systems was taken as the total number of fish available for counting in that time interval. In all but one case, the count made from the acoustic camera system was equal to the maximum (i.e., total) count. Thus, the detection rate for the acoustic

Table 3.1. Daily Total Adult Chinook Salmon Detections with Start and End Times

Date	Total Adult Chinook Salmon Detections	Start Time	End Time
8/20/2003	90	14:24	20:59
8/21/2003	115	7:02	20:50
8/22/2003	104	7:03	23:06
8/23/2003	56	6:30	19:51
8/24/2003	83	7:01	18:45
8/25/2003	68	6:41	20:52
8/26/2003	73	6:50	19:59
8/27/2003	12	7:20	18:22
8/28/2003	11	7:20	17:09
8/29/2003	13	7:01	19:21

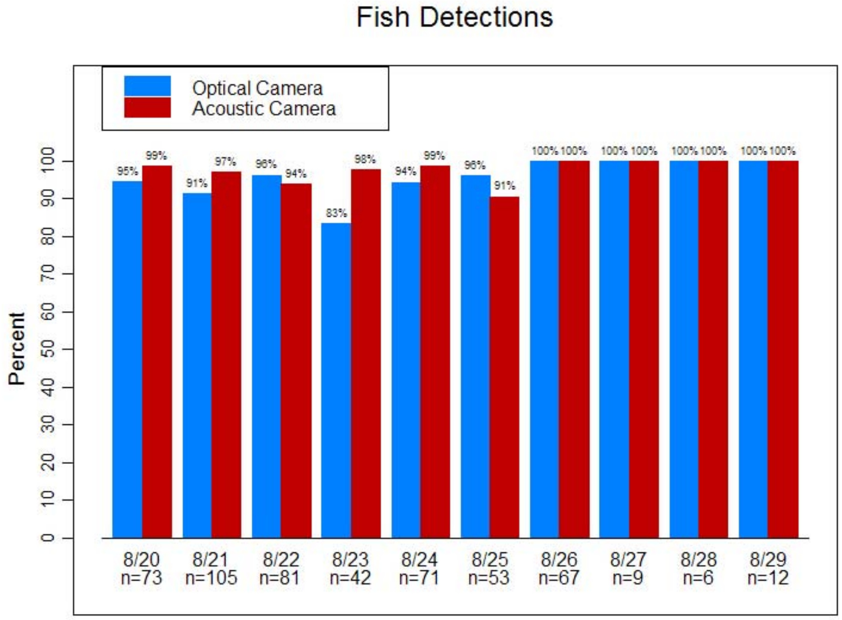

Figure 3.1. **Comparison of Percentage Adult Chinook Salmon Detections by Acoustic and Optical Cameras, August 20 through August 29, 2003, Secesh River Adult Chinook Salmon Counting Station**

camera system was essentially 100% across all levels of turbidity in these experiments. In contrast, all fish detections from optical camera review occurred at turbidity values of 3.0 NTU or less. Consequently, establishing a relationship between the probability of detection from the optical camera analysis and turbidity level (NTU) is the focus of this analysis (Figure 3.2).

To facilitate modeling detection probabilities by turbidity units, analysis was limited to 47 of 75 total samples with at least one fish detection by either system. In Figure 3.2, the probability of detection for the optical camera system is plotted on the vertical axis, with turbidity values measured from the four tank experiments on the horizontal axis. The points P_i recorded on time interval *i*, plotted in Figure 3.2, are defined as

$$P_i = 1 - \frac{d_i - v_i}{T_i}$$

where d_i = count from acoustic camera on time interval *i*
v_i = count from optical camera on time interval *i*
T_i = $\max(v_i, d_i)$.

These point pairs (NTU_i, P_i) were fit in separate models using locally weighted regression (loess) to data from the one tank-covered and three tank-uncovered experiments. The two interpolated turbidity values represent turbidity levels corresponding to a 95% probability of detection under these experimental conditions.

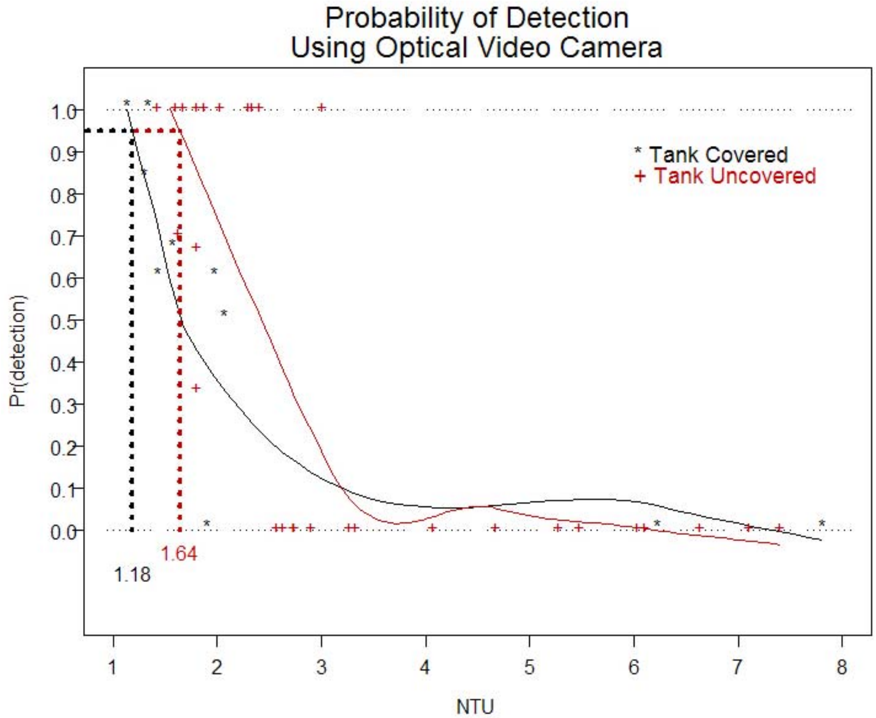

Figure 3.2. Loess Models Fit to Data from Circular Tank Experiments

The interpolated turbidity values (1.18 and 1.64 NTU) shown in Figure 3.2 could be used as a rough guideline for determining the relative performance of an optical camera for fish detections. The estimated turbidity value of 1.18 NTU made when the tank was covered is an upper bound on turbidity for the optical system during night counting conditions, while the turbidity value of 1.64 NTU estimated when the tank was uncovered is an upper bound for daylight counting. However, these values would need to be recalibrated for each field counting station. These results suggest that turbidity-induced interference on optical camera detections is more critical during hours of darkness or limited light than during daylight hours.

3.3 Validation Test Conclusion

The acoustic camera outperformed the optical camera at detecting fish, both in the laboratory tank and at the Secesh River fish counting station. However, the optical camera approach still offers some advantages over the acoustic camera under certain limited circumstances. The primary advantages are better species, gender and condition determination and better separation of debris from fish moving downstream. Using both systems in parallel will provide the most robust and accurate platform for counting fish in the field by exploiting the relative strengths of both systems through the season. This was an initial attempt at validation constrained by the late arrival of the acoustic camera system. A comprehensive validation plan will be sent to the Nez Perce Tribe for inclusion in their annual report to BPA. The plan will detail analysis models for validating acoustic camera counts using underwater video and statistical replication techniques.

4.0 Summary and Recommendations

The following summary is for the first year of a proposed three-year study to determine the efficacy of using an acoustic camera to count adult migrant Chinook salmon as they make their way to the spawning grounds on the Secesh River and Lake Creek. The recommendations are provided as guidance toward developing a state-of-the-art counting system for assessing adult salmon escapement abundance.

4.1 Summary of Accomplishments and Results

This was the first deployment of an acoustic camera for counting adult migrant salmon in the Pacific Northwest. Late delivery of the acoustic camera resulted in a limited timeframe during which to accomplish all that was planned for the first year. This will undoubtedly delay the final counting station operation until at least two additional years of validation testing are completed. Despite the slow start, much was accomplished that will better prepare the Nez Perce Tribe to meet the challenges of the next two years. For example, the initial packaging of the system by an external vendor was faulty and non-functional. Pacific Northwest National Laboratory corrected the system electronics and made it functional. Difficulty removing and replacing the caps to the substrate were addressed and should not pose a problem next year. We better understand the data-handling requirements, which should result in improved data-handling capability. Additional accomplishments and results of the validation tests are summarized below.

- Pacific Northwest National Laboratory provided engineering, statistical, and scientific support to the Nez Perce Tribe for the initial tests of the acoustic camera counting system.

- An artificial substrate designed by PNNL provided the clean bottom necessary for near-faultless adult salmon detection at the Chinook Campground counting site on the Secesh River.

- The acoustic camera provided excellent coverage from surface to bottom and throughout the range of the channel crossing when tested with a copper sphere standard target.

- The acoustic camera performance matched or exceeded that of the optical cameras during 10 days of field testing under lower stream discharge conditions.

- The acoustic camera performance was superior to that of the optical camera under controlled laboratory conditions with varying light conditions and turbidity.

- Maximum turbidity under which optical cameras performed optimally in our laboratory experiments was determined to be 1.18 NTU for the low light condition with artificial lighting and 1.64 NTU for the daylight condition. This provides guidance for field validation tests in 2004 and 2005.

4.2 Recommendations

During this first year of deployment of the acoustic camera technology on the Secesh River, a good deal was learned about the site, the logistics, and the needs for the future. The list of recommendations that follows has come from this first year experience at the Secesh River counting site. Every site is unique in its challenges for providing accurate estimates of adult Chinook salmon escapement abundance. Thus, if this technology is applied elsewhere, users should assume that at most sites, at least three years of deployment effort will be necessary to become familiar with the dynamics of the site and address site-specific challenges. The recommendations should help with that process, both at the Secesh River site and at future deployment sites.

- The substrate at the counting site should be engineered with gravel-filled sandbags so that the ridge of the artificial substrate is straight and parallel to the sloping natural substrate.

- Proper anchoring and cabling should be installed to hold the substrate in place during high flow conditions. It is recommended that secure anchors be placed upstream of each panel of the substrate and connected with stainless steel aircraft cable bridles. The gravel bag apron should then be laid on the cables to further secure them.

- The artificial substrate aprons composed of gravel-filled sandbags should be extended to 2 m upstream and downstream of the artificial substrate to minimize hydraulic undercutting during high flow conditions.

- An automated river-level tracking device should be installed to keep the acoustic camera at a constant depth over the season when water levels are changing.

- The aluminum artificial substrate used in 2003 was a prototype. The final installation after initial testing is completed should be constructed of heavy steel and placed in the river by helicopter. The first three or four panels would need to be of this construction to prevent movement over multiple years of deployment. Shallow panels on the inside of the bend in the river could remain lightweight and movable. Adequate anchoring will need to be installed to last over multiple years and high-water events. Periodic maintenance of the structure will need to be budgeted for the future.

- Continued field testing is advised under high flow and turbidity conditions. Flow (measured in specific locations over and near the artificial substrate), river depth, and turbidity should be monitored continuously during testing. Because of the late arrival of the acoustic camera in 2003, several additional years of testing will be necessary to fully field-validate the system. The first year will be devoted to determining the parameters under which adequate validation data might be possible at the counting site. The second year would then be the true validation test year. This is largely because the window of opportunity to test is limited to the spring freshet period of high turbidity when the acoustic camera is most useful. If an accelerated validation process is desired, a more detailed laboratory study might be contrived next year after detailed flow and turbidity measurements are made during the spring freshet.

- The surface equipment (all of which is environmentally sensitive) should be placed in a protected housing large enough to permit two workers to work comfortably with the equipment during all weather conditions. A preferred shelter would be a mobile office, but a large wall tent might also work. The power supply for this equipment should be an electrically isolated generator with sufficient capacity to power the system plus two additional computers and necessary lighting (a single 60-watt light bulb). We recommend that a qualified electrician be consulted on the power requirements of future deployments. The preferred location for the work area is the Chinook Campground (electrical, video, and telemetry cables from the acoustic and video cameras can be extended to the campground).

- Optical cameras should be placed along the ridge of the artificial substrate pointing toward the cut-bank side of the channel and angled upward such that the fields of view overlap, with successive cameras visible during the highest turbidity events (i.e., the turbidity will determine the spacing of the cameras). As many as 8 to 10 cameras may be needed to cover the cross section of the river if all four panels of the artificial substrate are submerged. Alternatively, a smaller portion of the river cross section may be subsampled intensely.

- Additional tests should be conducted to ensure that the acoustic camera captures all regions of the water column. The hollow copper sphere used in 2003 can be used for this test, but it should be attached to an angled rod to prevent the rod from interfering with detection of the sphere. During spring high water, it will be necessary to deploy the standard from an overhead trolley because wading will likely not be possible. In this case, the sphere would be tethered to a heavy weight and then transected at various depths.

- The acoustic camera lens should be both protected and maintained during the data collection period. A standard target should be deployed in the field of view to evaluate the performance of the acoustic camera. For example, an increasingly out-of-focus standard target would indicate the need to clean the lens of the acoustic camera.

- An acoustically transparent material should be deployed 1 to 2 m in front of the acoustic camera to preclude fish from passing too close to the acoustic camera.

- Real-time counting software should be developed to provide in situ migrant salmon counts and individual fish meristics throughout the migration period. Backup video and digital records should be maintained during the season for comparison with automated counts.

- Incorporation of mobile wireless telemetry into the system should be considered to provide near-real-time data flow from the counting site to the processing/analysis center. This 1) provides quality assurance/quality control on the data collected in the field and 2) allows for timely processing of the data.

- A database system should be instituted to provide organized data management and metadata for audit and accountability. Acoustic imaging systems are capable of collecting large volumes of data from multiple sites. Therefore, data management becomes necessary to provide the degree of accountability that is necessary, particularly when dealing with ESA-listed species of salmon.

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