Acoustic Monitoring and In-situ Exposures of Juvenile Coho Salmon to Pile Driving Noise at the Port of Anchorage Marine Terminal Redevelopment Project Knik Arm, Anchorage, Alaska

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URS Corporation

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ACRONYMS

ADF&G	Alaska Department of Fish & Game
dB	decibels
dB re 1 μPa	decibels referenced to 1 microPascal (associated with maximum peak pressure measurements)
dB re 1 μPa**2-sec	decibels referenced to 1 microPascal at 2-second intervals (associated with accumulative SEL pressure measurements)
ICRC	Integrated Concepts & Research Corporation
kg	kilogram
km	kilometers
Leq[1-second]	equivalent continuous sound pressure level [dB] averaged over 1 second
m	meters
mg/L	milligrams/liter
mg/ml	milligrams/milliliters
MLLW	mean lower low water
mm	millimeter
MOA	Municipality of Anchorage
MTR	(Port of Anchorage) Marine Terminal Redevelopment (Project)
NMFS	(National Oceanic and Atmospheric Administration), National Marine Fisheries Service
NTU	nephelometric turbidity units
POA	Port of Anchorage (Administration)
Port	Port of Anchorage (facility)
re	referenced to
rms	root mean square
SLM	(Model 831 Integrating) Sound Level Meter
SEL	sound exposure level
SPL	sound pressure level
URS	URS Corporation
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
WDFW	Washington Department of Fish and Wildlife
μPA	microPascal
**2-sec	at 2-second intervals

ACOUSTIC MONITORING AND IN-SITU
EXPOSURES OF JUVENILE COHO SALMON
TO PILE DRIVING NOISE AT THE
PORT OF ANCHORAGE MARINE TERMINAL
REDEVELOPMENT PROJECT
KNIK ARM, ANCHORAGE, ALASKA

1.0 INTRODUCTION

The Port of Anchorage Administration (POA) and the United States Department of Transportation, Maritime Administration (Maritime Administration) are the owner and lead federal agency, respectively, for the Marine Terminal Redevelopment Project (MTR Project), Port of Anchorage, Alaska. Integrated Concepts & Research Corporation (ICRC) serves as the program manager for the MTR Project.

The URS Corporation (URS) was contracted by ICRC to conduct a live cage fish study at the Port of Anchorage facility (Port) during construction involving in-water sheet pile driving. URS subcontracted Pentec Environmental, the natural resources arm of Hart Crowser, Inc. and Illingworth and Rodkin, Inc. to assist with technical aspects of the study.

This report summarizes the implementation and results of the study conducted in June 2009 to determine the potential effects of sheet pile driving activities on outmigrating juvenile salmonids.

During this study, caged juvenile coho salmon were exposed to sheet pile driving noise and associated acoustic measurements were made; extended behavioral observations of exposed fish were followed by necropsies to look for any delayed or sublethal adverse effects. Section 1 of this report presents the background, description of the construction project, and purpose of the study. Section 2 presents field, laboratory, and analytical methodologies. Section 3 presents the major findings of the study. Section 4 provides a discussion of results and an assessment of risk of sheet pile driving to Knik Arm salmonids, and Section 5 presents the study conclusions.

1.1 Background

The MTR Project construction began in September 2007 and will continue through 2014. The MTR Project is designed to upgrade and expand the Port facilities by replacing aging and obsolete existing dock structures and provide additional berthing to accommodate modern shipping vessels. The MTR Project addresses existing and future capacity requirements to adequately support the economic growth of Alaska. The Port is located within the Municipality of Anchorage (MOA) on the Knik Arm of Upper Cook Inlet (Figures 1 and 2).

On August 10, 2007, U.S. Army Corps of Engineers (USACE) issued a Section 404/10 Permit to the POA, which authorizes discharge of dredged and fill material in waters of the U.S., including wetlands, necessary for the expansion of the Port of Anchorage within Knik Arm, Alaska (POA-2003-502). One condition of the USACE permit requires that the POA conduct an on-site study of pile driving effects on fish. The purpose of the study is to determine the potential effects of vibratory and impact hammer sheet-pile driving activities on salmonids at various distances and measured sound-pressure levels. A live cage fish study and hydroacoustic monitoring are required for this analysis.

The Alaska Department of Fish & Game's (ADF&G) Elmendorf Fish Hatchery annually releases juvenile Chinook (*Oncorhynchus tshawytscha*) and coho salmon (*O. kisutch*) into Knik Arm via Ship Creek, which lies adjacent to the Port of Anchorage. The USACE permit stipulates that pile driving must cease for a 7-day period after each release of juvenile salmonids from the Elmendorf Fish Hatchery. There are typically two releases each summer. Based upon the results of the fish study, the requirement for a 7-day pile-driving shutdown may be modified.

1.2 Sheet Pile Installation

The MTR Project includes construction of new steel bulkhead waterfront structures with fill material (soil/gravel) placed and compacted behind the face of the bulkhead.

The bulkhead structures are composed of conjoining steel sheet piles, forming a row of U-shaped cells with face sheets contacting the waterline and tail sheets installed perpendicular to the waterfront. The face of each completed cell is curved outward, creating a scalloped surface. Fill is carefully placed in the water prior to driving the pile to construct a platform for pile driving cranes. Over 1,000 face sheets and 3,000 tail sheets were scheduled for installation in 2009. Sheet piles are approximately 20 inches wide and up to 90 feet long. It was expected that vibratory hammers would be used approximately 75 percent of the time and impact pile drivers used the remaining 25 percent of the time to drive each pile to specified depth. To date, records show actual pile driving time to be significantly less than 50 percent of total work time (URS 2009).

Project construction includes both in-water and out-of-water activities. Pile driving takes place in both the submerged and tidally influenced zones. The submerged zone is defined as seaward of the fill at or below the elevation -6.4 feet mean lower low water (MLLW). The tidally influenced zone encompasses the area below +34.6 feet MLLW to the point where the high tide line intersects the fill slope. Only the in-water activities in either the submerged or tidally influenced zones have the potential to harm fish species due to underwater noise disturbance in the project area (URS 2009).

2.0 STUDY METHODS

The acoustic monitoring and live cage study was conducted between June 10 and June 22, 2009. The objectives of the study were to determine the physical and behavioral effects of pile driving on juvenile salmonids in Knik Arm. Preliminary work conducted during the 2008 construction season (Pentec 2008) identified and addressed logistical issues in preparation for actual testing with live fish in 2009. The following activities were conducted during the 2009 study:

- Construction of a functional wet lab at the Port;
- Construction, rigging, and testing of fish live cages with attached acoustic monitoring equipment;
- *In-situ* exposure of juvenile coho salmon to pile driving in Knik Arm;
- Measurement of noise exposures during the *in-situ* fish testing; and
- Monitoring for delayed behavioral and physical effects of pile driving noise on juvenile coho salmon by observation and necropsy, respectively.

2.1 Wet Lab and Test Fish

The study required access to, and holding of, several hundred juvenile salmon at a facility within easy transport range of the live cage test sites. It was necessary to construct a wet lab facility at the Port and to obtain and hold juvenile salmon from a local hatchery.

2.1.1 Laboratory Components

An onshore wet lab facility suitable for holding and conducting post-exposure observations of fish health and behavior was designed and set up in an unheated and covered parking garage on the deck level of the existing POA Offices Building. The garage sheltered the lab from the sun and wind and had a door opening to Port docks for ease of movement in and out of the lab during construction. It also had separate entrances for accessing the lab area without disturbing fish under observation. Floor drain holes provided access to the area under the dock for the intake and discharge of water directly from and to Knik Arm.

The wet lab constructed during the study had five major components (Figure 3):

- A water supply system with screened intake, hose, pump system, and discharge piping through the laboratory floor;
- Three settling tanks with baffles to allow suspended sediment to settle and particulate filters to remove additional sediment to further improve water clarity;
- Tanks for holding fish prior to exposures;
- Tanks for post-exposure observations of fish; and
- A visual screen system around post-exposure observation tanks so that fish could be observed without disturbance.

2.1.2 Water Quality Parameters

Seawater for the wet lab was supplied by a 110-volt submersible sump pump rated at 85 gallons per minute. The pump was mounted beneath the wet lab on one of the more seaward pilings under the dock at a depth of approximately –5 feet MLLW. The seawater from the pump was routed up through a floor drain into the lab and into the first settling tank. Two excess flow lines were also built into the system to bypass the settling tanks and direct flow back through the floor drain to prevent system overflow during high tide conditions (Figure 3).

To reduce ambient turbidity, seawater was discharged into the first of three large settling tanks (48 inches by 42 inches by 29 inches), each equipped with a 2 particulate filters mounted directly below the discharge pipe and a submerged baffle system (Photograph 1). Each settling tank had a bottom drain valve for removing settled solids and a surface drain line that led to the next settling tank. From the second settling tank, slightly clarified water discharged to a pre-exposure holding pool (5-foot diameter) and a fasting pool (4-foot diameter) where fish were held prior to live cage experiments (Photograph 2; Figure 3).

From the third settling tank, slightly less turbid seawater was discharged to short- and long-term observation tanks. For short-term tanks, water flowed into four small (4-foot diameter) wading pools, which were used for holding and observing juvenile salmonids for the first 2 hours after live cage exposures (Photograph 3). For long-term tanks, water flowed into 16 small (2-foot diameter) pools, which were used for holding and observing juvenile salmonids for 48 hours after live cage exposures (Photograph 4; Figure 3). All tanks drained directly back to Knik Arm.

Temperature, dissolved oxygen, and salinity in all of the tanks were periodically monitored and recorded while fish were in the facility to ensure that conditions did not cause additional stress. The collection of turbidity measurements occurred on either side of the each baffle filters in the settling tanks, as well as in holding and observation pools, to determine the system effectiveness in clarifying ambient Knik Arm seawater.

2.1.3 Test Species and Handling

The test species used in the study were juvenile coho salmon obtained from the ADF&G Elmendorf Fish Hatchery, located on Ship Creek approximately 2 miles from the Port (Fish Transport Permit No. 09A-0041). The juvenile coho were between 86 and 124 millimeters (mm) (Figure 4) and weighed approximately 8 to 16 grams. Approximately 100 fish were obtained on June 13, and an additional 300 fish were obtained on June 16. Fish were of adequate size and age to undergo the transfer from freshwater to the estuarine water supplying the lab (10.0 to 13.8 parts per thousand salinity). The initial batch of fish was held and observed for 3 days prior to testing to allow acclimation to ambient Knik Arm seawater; no mortalities were observed during this period. All fish were considered in good health upon visual examination; little to no evidence of fin abrasion, scale loss, or other indications of poor health or injury was observed.

Hatchery fish were fed daily with pellet food acquired from the hatchery. Test fish were placed in the fasting pool (no food provided) for at least 24 hours prior to exposure. All fish were transferred using small mesh aquarium dip nets to minimize stress and handling times.

2.2 In-situ Exposures and Acoustic Monitoring

The overall approach to this study was to place juvenile coho salmon in live cages suspended in Knik Arm to expose them to waterborne noise generated by the driving of sheet piles with a variety of pile drivers. Cages were instrumented to record sound pressures actually experienced by the fish. In total, 16 fish exposures were run from June 16 through June 19, as detailed in Table 1.

2.2.1 Live Cage and Hydrophone Deployment

The *in-situ* exposure of salmonids to pile driving noise was conducted by placing juvenile coho salmon into live cages equipped with hydrophones at various distances from the pile during actual periods of pile driving. The cages had an external metal frame to provide rigidity, to prevent collapse when subjected to high currents, and to allow attachment of acoustic instruments. Two hydrophones were incorporated as part of the test cage: one was attached to the metal support structure outside the back of the cage to minimize noise produced by cavitation in high currents, and another positioned inside the front third of the cage near the axial center. The inside hydrophone provided the primary sound level reading, which was compared to the outside hydrophone reading to evaluate changes to the acoustic environment caused by the cage. A third hydrophone was sometimes deployed independent of the cage off of the front of the vessel to measure the noise environment closer to pile driving. This hydrophone was moved to various depths in the water column to better describe the prevailing sound field and was also employed for taking noise measurements while the support vessel was drifting at the reference site.

To provide fish shelter from strong currents during the test period, the live cages had a solid cone-shaped shroud surrounding the front end (Photograph 5). They also had a zipper for easy access to the inside of the cage.

Live cages were deployed in two ways: 1) cages were suspended from a boom attached to the 26-foot *R/V Jakayte* adjacent to the pile driving operations (Photograph 6; Figure 2) anchored at a reference location in Knik Arm near the mouth of Chester Creek.

Cages deployed off of the *R/V Jakayte* were suspended approximately 1.5 meters (m) out from the side of the vessel by a horizontal boom (stiff arm) and approximately 1 to 2.5 m beneath the water surface. The cage maintained this depth during the test period by the use of lines through a pulley system and a 10-kilogram (kg) torpedo-shaped brass weight designed to pull downward in current.

The live cage deployed in the reference area was suspended approximately 1 m beneath the surface by a buoy anchored on the bottom. The area off of Chester Creek provided a suitable reference site because it was approximately 4 kilometers (km) from pile driving activity, but otherwise had physical and environmental characteristics similar to those at the Port. These characteristics include similar tidal extremes and currents, water quality parameters (temperature, turbidity, salinity, and dissolved oxygen), and proximity to a stream mouth.

Test fish used in the *in-situ* exposures were shuttled from the wet lab facility to the *R/V Jakayte* at the North Float dock in a bucket of ambient seawater. On board, fish were held in a cooler of aerated ambient seawater until ready for deployment.

For live cage deployments, approximately 10 fish were quickly netted and transferred from the cooler to the live cage. The test cage and fish were then gently lowered into Knik Arm and deployed into position to be exposed to the actual pile driving noise. During the course of the exposure, the following parameters were recorded:

- Deployment time;
- Retrieval time;
- Number of pile driver strikes (for impact hammers); and
- Distance to pile.

After the test exposure, the cage was lifted from the water on end and the fish netted from the reservoir in the cone of the live cage and placed in a separate labeled bucket. Fish were then brought back to the lab and placed in a short-term observation tank.

For the reference deployments, fish were transferred to the off-site reference live cage in the same manner at the beginning of the field day, and remained deployed until the end of *in-situ* exposures for that day. After the exposures for the day were completed, reference fish were retrieved, transferred to the lab, and placed into a short-term observation tank. Hence, reference fish were exposed to the same handling as test fish, and to prolonged exposures to Knik Arm conditions, absent nearby pile driving noise.

2.2.2 Test Design

The test design and summary of *in-situ* exposures is presented in Table 1. Live cage tests exposed juvenile coho salmon to pile driving operations using a small and large impact pile driver, and a vibratory pile driver. Fish in the test cages were exposed to the driving of sheet piles. The effect of driving large diameter, hollow steel pipe piles was not tested during the study, since very few hollow steel pipe piles were being driven during the 2009 construction season and none were being driven at the time of this study.

As specified in the test design, both static and dynamic tests were conducted during vibratory and impact pile driving. During the static tests, the live cage was attached to the support vessel and held in a fixed position in relation to the driven pile. For dynamic tests, the support vessel and live cage drifted past an active pile driving operation to simulate exposures and evaluate vulnerability of migrating fish passively carried through the immediate areas of pile driving; field data and observations suggest that, because of the strong currents, a juvenile salmonid may have only limited ability to react to noise by swimming away from the noise source. Studies at Port MacKenzie indicated that juvenile salmon are carried passively along at least some artificial shorelines in Knik Arm (Pentec 2005a, b).

2.2.3 Acoustic Measurements

Acoustic measurements were made using a Reson TC 4033 with PCB in-line charge amplifiers (Model 422E13) and PCB Multi-Gain Signal Conditioners (Model 480M122). The signals were fed into a Larson Davis Model 820, or Model 831, Integrating Sound Level Meters (SLM) and Marantz Model PMD 660 Solid State Recorders. The hydrophones were connected to both a Larson Davis Model 820 Integrating SLM (Type 1) and a Marantz Model PMD 660 through a PCB multi-gain signal conditioner. The multi-gain signal conditioner provides the ability to increase the signal strength (i.e., add gain) so that measurements are made within the dynamic range of the instruments used to analyze the signals. The peak sound pressure and sound exposure levels (SEL) were measured “live” using the SLMs. The Larson Davis Model 820 SLM has the ability to measure the unweighted peak sound pressure.

Data were collected from hydrophones in two ways: (1) measurement of peak and SEL sound levels for each second; and (2) digital audio recording of the sounds for subsequent analysis. Following each day of measurements, digital data captured by the SLMs were downloaded to computer systems. These data were converted and stored in raw ASCII format. The SLMs were primarily used to provide accurate live readings. These readings were observed and recorded in field notebooks periodically. Digital audio tape recordings were analyzed for selected pile driving events. The sound pressures measured from the tapes were compared to the “live” measurements to avoid any data processing errors. At the same time, the technician listened to the signals to ensure that high quality tape recordings were made (no noise interference) and that the source was pile driving noise.

The measurement systems were calibrated prior to use in the field with a G.R.A.S. Type 42AA Pistonphone and hydrophone coupler. The pistonphone, when used with the hydrophone coupler, produces a continuous 136.4-decibel (dB) referenced to (re) 1 microPascal (µPa) tone for the Reson TC4033 hydrophone at 250 hertz. The SLMs are calibrated to this tone prior to use in the field. The tone is then measured by the SLM and is recorded on to the beginning of the digital audiotapes that were used in the field. The system calibration status was checked at the end of the measurement event by both measuring the calibration tone and recording the post-measurement tone on tape. Tape analysis included the measurement of the calibration tone at the beginning and end of tape recording events. All systems were found to be within 0.5 dB of the calibration levels. The pistonphone output was certified at an independent facility.

Sound generated by percussive pile driving has the potential to affect fish in several ways. The range of effects potentially includes alteration of behavior to physical injury or mortality, depending on the intensity and characteristics of the sound, the size and mass of the fish, and the fish’s anatomical characteristics (Yelverton et al. 1975—cited in Hastings and Popper 2005). Because little was known about the effects of underwater pile driving noise on fish, the California Department of Transportation (Caltrans) commissioned the preparation of several white papers to collect and evaluate literature, which could be used to establish interim criteria for the analysis of pile driving impacts to fish. Hastings and Popper (2005) reviewed the literature on the effects of sound on fishes, and identified data gaps and potential studies that would be needed to address areas of uncertainty relative to the measurement of sound and the response of fishes to sound. This paper concluded that interim criteria based on single-strike sound exposure level (SEL) to prevent physical injury were warranted. However, these suggested interim criteria did not address effects associated with repetitive sound events or pile strikes. Application of interim criteria led to the publication of two additional white papers, Popper et al. (2006) and Carlson et al. (2007), that identified a dual-criteria approach that was based on peak sound pressure and sound exposure level.

NOAA's National Marine Fisheries Service (NOAA Fisheries) recently described the application of new hydroacoustic criteria for assessing the effects of pile driving on fish (Stadler and Woodbury 2009). The new interim criteria uses two acoustic metrics – peak sound pressure level (SPL) and accumulated sound exposure level (SEL). These criteria are used during consultation with federal agencies to assess acoustic impacts to fish species administered by the agency. Currently, NOAA Fisheries considers the onset of physical injury would be expected if either the peak sound pressure exceeds 206 dB (re: 1 μPa) or the SEL, accumulated over all pile strikes generally occurring within a single day, exceeds 187 dB (re: 1 μPa2•sec) for fishes 2 grams or larger, or 183 dB for smaller fishes. These interim criteria were agreed upon by several federal and state transportation and resource agencies along the West Coast of the United States, through the Fisheries Hydroacoustic Working Group (FHWG 2008). That criterion is based on a single-strike peak sound pressure and an accumulation of sound energy represented by accumulated unweighted SEL over the course of pile driving in one day. The single strike SEL is important for describing acoustic exposures, because it is related to the sound energy received by a fish for each pile strike.

Acoustic data for impact pile driving were reported as peak sound pressures (in dB referenced to 1 micro pascal or 1 µPa), the sound exposure level per pile strike or SEL (in dB referenced to 1 µPa second^2) and the accumulated SEL for the entire test exposure period (also in dB referenced to 1 µPa second^2). Acoustic data for vibratory pile driving was reported the same as impact driving, except SEL data are reported for each second, which is the same as the one second energy averaged sound level (Leq[1-second]), which is referenced to 1 µPa.

2.3 Post-Exposure Observations

Following exposure to pile driving noise, the live cage was brought to the surface and fish were observed in the reservoir at the front of the cage for any mortalities before being placed into a bucket with aerated ambient seawater. Each batch of fish was then transported back to the wet lab for post-exposure observations. Upon arrival at the wet lab facility, fish from each test were carefully counted and transferred into the short-term observation pools (separate pool for each batch). The observer immediately left the pool area, retreating behind the observation screen to record fish behavior.

From behind the screen, behavior of fish in each batch was observed and recorded. Data collected included the following:

- Number of surviving fish;
- Swimming behavior;
- Position in tank (vertical and horizontal);
- General signs of distress; and
- Schooling behavior, if any.

Observations were repeated at 2 hours after the end of the exposure test; 5 minutes into the observation period a small disturbance noise (either placing a metal rod in the center of the pool and banging on the rod or three taps on the pool wall with a wooden pole) was introduced into the observation pool and the response behavior of fish recorded for the remaining 5 minutes.

Observations were repeated again at 4 hours after the end of the exposure test. After 5 minutes of observation, a small quantity of food pellets was added to the pool and feeding behavior recorded for the remaining 5 minutes (note that fish were not fed for 24 hours prior to the start of the exposures).

Following the feeding test, each batch of fish was netted out of the short-term observation pool and transferred to an individual long-term observation tank, where observations were made at 12-, 24-, and 48-hour intervals after exposure.

2.4 Necropsies

At the end of the 48-hour observation period, all fish in each batch were captured and euthanized. To euthanize the fish humanely and to reduce any chance of injury (external and/or internal), fish were placed in a solution of filtered seawater from the flow-through system and an anesthetic (MS-222; 99.5 percent tricaine methanesulfonate). This solution contained an adequate concentration of the anesthetic (approximately 1 milligram/milliliter [mg/ml]) to stop gill pumping within 10 minutes. Upon cessation of gill pumping in all fish from the group, fish were immediately transferred to a prelabeled bag and placed on ice until necropsies could be performed. All necropsies were performed within 12 hours of euthanization.

Necropsies were performed to examine for the presence/extent of lethal/sublethal effects on the internal organs of the exposed fish. Necropsies began with a detailed examination for external injuries, primarily in the form of subcutaneous bleeding. Internal examinations were performed under a dissecting scope focusing on three major areas: the body wall cavity, swim bladder, and kidney. Injury levels were determined and recorded according to a numerical scale based on Hubbs et al. (1960):

(1) No damage (fish survives);

(2) Light hemorrhaging (fish survives);

(3) Light hemorrhaging and some kidney damage (impaired escape response and possible increased vulnerability to predation);

(4) Swimbladder bursts and gross kidney damage (fish killed);

(5) Incomplete body wall break and gross internal damage (fish killed); and

(6) Complete rupture of body cavity and organ destruction (fish killed).

A minimum of five fish were examined from each batch unless internal injury was noted in any fish, in which case, all fish in the batch were necropsied. Photographs were taken of representative fish in each batch (Photographs 7 through 25).

3.0 RESULTS

The results of acoustic monitoring, live cage exposures, post-exposure observations and necropsies of juvenile coho salmon are detailed below and summarized in Tables 2 and 3.

3.1 Wet Lab Performance and Water Quality

One of the biggest challenges in constructing a useful wet lab for observing post-exposure juvenile salmonids in Knik Arm seawater is reducing the highly turbid ambient conditions to the point where the fish could be observed in the water column. During the 2008 trial study, a system of two settling tanks with baffles to reduce movement of the water and allow for settling of particulates was constructed, and turbidity measured at different points in the set up. There was a substantial decrease in turbidity seen between ambient Knik Arm water and the observation pools (Pentec 2008). Based on these findings, it was determined that the baffle system was partially effective at reducing turbidity, but it was hoped that clarity could be improved with the addition of a third tank and a filtration system. Particulate filters were added to the set up in 2009, but it was difficult to provide enough filtration to account for the increased flow needed to supply water to the entire lab system. With the entire lab running, a total of 13 observation tanks (relatively low flow) and 2 holding tanks (relatively high flow) required an order of magnitude higher flow compared to 2008 flow through the settling tanks. Therefore, for a given volume of water, settling time was reduced and thus water clarity was lower (turbidity higher) for the 2009 study than the 2008 trial study.

Turbidity in the post-exposure observation pools measured between 380 and 500 nephelometric turbidity units (NTU), compared with 94 and 170 in 2008 (Pentec 2008). Seawater collected directly from Knik Arm measured between 400 and 650 NTU. This represents at best, about a 50 percent reduction in turbidity after flowing through the three settling tanks. Water in the observation pools was not as clear as desired, but observations of fish behavior could be made when depths were kept to approximately 4 inches or less. The swimming activity of the fish continually resuspended particles that settled to the bottom of the observation pools, thus keeping turbidity high.

During the 2008 Trial Study, temperature and salinity measurements collected in the wet lab and in nearshore and offshore waters of Knik Arm showed the waters are well-mixed. Salinity measurements collected offshore of the north extension area, nearshore at Cairn Point north of the Port, and in the wet lab at the Port differed by no more than 1.0 parts per thousand, and temperatures differed by no more than 0.2 degrees Celsius. In the present study, temperature and salinity were measured daily in the wet lab as part of the water quality check. Temperatures ranged from 12.7 to 13.4 degrees Celsius, while the salinity ranged from 10 to 13.8 parts per thousand during the course of the study. Dissolved oxygen measurements collected in the post-exposure holding pools averaged 7.84 milligrams per liter (mg/L) (range from 5.45 to 9.49 mg/L), which is within the range of acceptable levels for maintaining juvenile salmonids (Carter 2005).

3.2 Acoustic Measurements

In all, there were 3 reference exposures and 13 exposures to pile driving noise: 2 during vibratory driving and 11 during impact driving. Of the impact driving exposures, 3 were while a small impact hammer (BSP SL-60) was driving piles, and the remaining 8 were while the larger J&M 115 was operating; although the smaller hammer was working simultaneously and within 50 m of the cages for several of these tests (Table 2).

Summary information on acoustic measurements for each exposure (worst case) include accumulated SEL, maximum SEL (per pile strike) or maximum SEL (per second), and maximum peak pressure (Table 2). Ranges of measurements at specific distances are discussed below.

3.2.1 Test Exposures

Maximum peak pressures observed during live cage deployments ranged from 177 to 195 dB re 1 μPa (Table 2). (All peak underwater sound levels are referenced to μPA for the remainder of this report). As expected, the large impact pile driver was responsible for the highest peak pressures (181 to 195 dB), with the small hammer and vibratory drivers creating lower but similar levels (177 to 189 dB). The accumulated SEL ranged from 174.8 to 190.6 dB re 1 μPA at 2-second intervals (**2-sec). (All accumulated SEL underwater sound levels are referenced to μPa**2-sec for the remainder of this report). Again, the very highest levels were found with the large impact pile driver, but generally similar SELs were observed with all three pile driver types. The distance to the live cage from the pile drivers ranged from 1.5 to 30 m during static tests and from 4 m to over 30 m from the pile driver during dynamic (drifting) tests. Individual batches of fish were exposed to a large but varying number of pile driver strikes ranging from a minimum of 354 strikes to a maximum of 2,781. The duration of exposures ranged from 13 to 36 minutes for the large impact pile driver and 20 to 47 minutes for the small driver. Exposure duration with the vibratory hammer ranged from 30 to 51 minutes (Table 2).

Acoustic measurements with the smaller hammer (BSP SL30) were collected on June 16 for 3 tests and involved a total of 10 pile driving events. Measurements were collected approximately 10 to 25 m from the pile driver. At 10 m from the pile driver, peak sound pressures were about 180 dB and SEL levels were 155 dB. At 20 to 25 m, peak sound pressure levels were 170 dB and SEL levels were 145 dB.

Acoustic measurements collected with the larger J&M 115 impact pile driver were collected on June 17 and 19 for 8 tests and a total of 24 different pile driving events. Pile driving events are discrete pile driving periods. Most of the tests occurred during multiple pile driving events. Typically, a pile driving event would last for a few minutes and the hammer would be moved to another nearby pile within a minute or two and pile driving would continue. Measurement positions from the pile driver ranged from less than 2 m to about 25 m. The highest levels measured per pile strike were 195 dB peak and 171 dB SEL at less than 5 m from the pile. At 10 m from the pile, sound levels were about 185 to 190 dB peak and 160 to 165 dB SEL (per pile strike). Measurements collected at 5 to 10 m from the face wall and pile driving were affected by near field sound radiation as sound was radiated out into the water from a large portion of the sheet wall, i.e., not just from the single pile, or pile pair, being driven. At 25 m, sound levels were about 170 dB peak and 150 dB SEL (per pile strike), but these measurements were not recorded directly perpendicular to the pile being driven.

Fish were exposed to vibratory pile installation noise during two separate tests conducted on June 18 when the APE 200-6 hammer was used. The range of distances to this activity varied from about less than 1 m to 9 m. However, the position relative to the pile installation varied from near perpendicular to the activity to parallel to the sheet wall. Most close proximity measurements (i.e., within 5 m) were made almost perpendicular to the wall. Sound levels approximately 9 m from the activity were generally 165 to 170 dB peak, with SELs (per second) of 150 to 160 dB. Sounds from vibratory installation varied by 5 to 10 dB through the drive. For instance, several driving events measured at approximately 9 m had peak pressures that ranged from 158 to 172 dB, while the SELs (per second) ranged from 147 to 161 dB.

Background noise levels in pile driving areas did not contribute measurably to overall accumulated SEL. Background noise levels, generally caused by transient construction noises, waves, and currents, ranged from 120 to >140 dB. When background noises were higher than 140 dB, it was often caused by another pile driver operating nearby. Also contributing to background noise levels were short duration increases caused by vessel maneuvering, which could produce levels between 125 to 135 dB. Background levels were often higher for the hydrophone outside of the cage relative to the primary hydrophone inside of the cage because of greater exposure to moving water. The in-cage hydrophone was somewhat protected from this effect.

Figures 5 through 17 present the sound charts that show the pile driving waveforms and the various acoustical descriptions associated with the signal for each of the test exposures. They illustrate peak pressure and SELs for both the primary hydrophone in the cage and the reference hydrophone attached outside of the cage on the frame. The accumulated SEL is also plotted.

3.2.2. Reference Exposures

In the three reference cage exposures offshore of Chester Creek, acoustic measurements were collected in the vicinity of the fish cage just after deployment in the morning and after cage retrieval during mid to late afternoon. Ambient background measurements within Knik Arm ranged from 111 to 140 dB (Table 2). The source of ambient noises included wave chop impacting the side of the vessel, breaking waves, and current turbulence against the cage and hydrophones. On most days, higher noise levels were observed after the afternoon cage retrieval because of higher wind and wave energies experienced later in the day. Weather tended to be milder during the morning deployments. Distant pile driving (both impact and vibratory) could be heard by the acoustician, but it could not be quantified because it was generally at or below background levels.

3.3 Fish Responses

Observations of post-exposure behavior (including mortality) began immediately after the completion of the first live cage exposures on June 16 and continued through June 22, 2009.

3.3.1 Mortality

No acute or delayed mortality of any juvenile coho salmon was seen as a result of exposure to in-water pile driving (Table 3). The only mortalities occurred before the study began, when two fish leapt out of the holding tank before the tank was covered with netting material. Of the 133 test fish, all survived the full 48-hour observation period after exposure to noise from vibratory or impact pile driving at distances ranging from less than 1 m to over 30 m. All 30 reference fish, caged offshore of Chester Creek approximately 4 km away from the study site, also survived for 48 hours post-exposure.

3.3.2 Behavioral Observations

After live cage exposures, short-term (2 to 4 hours) and long-term (24 to 48 hours) observations were conducted in the wet lab in different sets of holding tanks during the experimental period.

3.3.2.1 Short-term

Behavioral responses seen in juvenile coho salmon during the first 4 hours following exposure to pile driving noise were considered normal and consistent with handling stress from transportation and netting. Fish were first observed for mortalities in the live cage reservoir immediately after being removed from the water; no mortalities were found.

"Normal" behavior for the short-term laboratory observation periods was determined to be active swimming (fairly fast swimming, slightly agitated, constantly testing tank edges) during the first pool observation, with more relaxed swimming during each successive observation period. This is typical behavior for salmonids that have experienced being transported or netted. It takes several hours for juvenile salmonids to acclimate to a new environment and resume calm swimming behavior. All 16 batches of fish exhibited this pattern of behavior during the first observation immediately following return to the lab.

The second observation took place 2 hours after the batch was removed from the live cage. Because of this, there were varying times of acclimation to the short-term pool, but each batch had been acclimated for at least 1 hour prior to the second observation. The purpose of the second observation was to check for any delayed mortality and check for a startle response. The first startle action was initiated by placing a metal rod into the center of the pool and creating a loud noise by banging a wrench against the rod several times. This startle action was used for the first five batches of fish (including a reference batch); however, it did not elicit any type of startle or alarm response for any of the fish, regardless of treatment. A final attempt was made to elicit a startle response from the unexposed fish in the holding tank; the result was the same lack of response. Therefore, a new startle action was created by hitting the metal rod against the side wall of the pool three to five times. This evoked a typical “freeze” response: the fish limited their movement and sank to the bottom of the tank for varying amounts of time. Similar responses were observed after striking the metal rod against the side wall of the holding tank. Startle response was also observed in the remaining 11 batches of fish, including the reference batches, indicating that the pile driving noise had no adverse effect on the ability of the fish to respond normally to threatening stimuli.

The third laboratory observation was 4 hours after removal from the live cage. All 16 batches were much calmer with no visible signs of stress at the time of these observations. The purpose of this observational period beyond, checking for delayed mortality, was to determine if feeding behavior was altered by pile driving exposure. Each batch was observed for 5 minutes prior to introduction of food pellets supplied by the Elmendorf Fish Hatchery; these pellets are considered to be a preferred food for the hatchery-raised fish. There were variable levels of feeding activity, ranging from no feeding during the 5 minutes observed, to immediately striking the food pellets, which was not uncommon. Two batches were not observed feeding at all, three batches had minor delays in starting to feed, and the remaining 11 batches fed actively and immediately. The likely cause of the variable feeding activity seen between the groups was extremely high turbidity, contributing to low visibility and making it hard for the fish to find the food.

Overall, the responses observed during the short-term periods were consistent with the stress of being handled several times over the course of an hour or two. Behavior appeared to normalize for all 16 batches over a 4-

hour period, which is a reasonable window to expect juvenile salmonid acclimation to a new environment.

3.3.2.2 Long-term

The main purpose of the long-term observation periods was to document any delayed mortality as a result of the exposures. In addition to checking for mortalities, the fish were also checked for any gross abnormal behavior. There was no delayed mortality of any of the 163 fish that were put into the long-term tanks and no abnormal behavior was observed in these fish. Fish appeared calm, which is consistent with acclimation times observed in the short-term pools. Also, because the long-term tanks had taller sides that did not require a cover of netting material (Photograph 4), the fish were not disturbed by removal of the cover prior to observation.

3.3.3 Necropsies

In total, 97 of the 163 test fish were necropsied (60 percent) to determine whether any sublethal injuries could be identified and attributed to exposure to pile driver noise (Table 3). The vast majority of the fish examined exhibited no external or internal injuries consistent with barotrauma (e.g., Photographs 7 through 25). A small number of fish examined (3.9 percent of exposed fish; 10.5 percent of reference fish) displayed a minor amount of reddening or light hemorrhaging of the internal wall of the body cavity (in tissue surrounding the ribcage). This anomalous reddening, when present, was similar in both exposed and reference fish (Photographs 11, 14, and 15 for exposed fish; Photographs 12 and 13 for reference fish) and did not appear to be associated with injury to the kidney and, in each case, swim bladders were intact. The low frequency and minimal apparent severity of these anomalies, the presence of a higher percentage of similar anomalies in reference fish, and the apparent lack of dose dependency (i.e., there was no trend of increased injury with increased noise levels), make it unlikely that these effects resulted from noise exposure. These minor abnormalities may have resulted from handling in the hatchery transfer, during field transfers to and from the live cages, or from the time interval between euthanasia and necropsy.

4.0 DISCUSSION

This study exposed juvenile coho salmon to the sound pressures generated by the impact and vibratory pile driving of sheet piles. Very few investigations have been conducted with sheet piles. A few researchers have conducted acoustic monitoring but without experimental fish exposures, or conducted observational studies of the migratory responses of fish in proximity to sheet pile driving operations. In previous work, acoustic monitoring has found that sheet pile driving with an impact hammer results in waterborne noises that are consistently lower than the impact driving of round hollow steel piles. No behavioral anomalies have been observed. The present study has provided further scientific evidence that sheet pile driving does indeed result in comparatively lower waterborne noise levels than measured with pipe piles, and further shows that *in-situ* exposures to sheet pile driving under the circumstances measured do not cause injuries to juvenile salmonids.

However, the impact pile driving of large round steel piles (24-inch and greater diameter) have been found to result in disturbance, injury and significant numbers of fish mortalities (Caltrans 2002 and 2004; Shin 1995; Longmuir and Lively 2001; Popper 2003). In response to these concerns, the regulatory community has developed a set of conservative interim guidelines to protect fishery resources whenever underwater noise from pile driving results in peak sound pressure levels over 180 dB.

The remainder of this discussion presents a review of the findings of other pile driving studies, and using the body of current literature and our findings, presents an evaluation of the the potential risk that the MTR Project represents to outmigrating juvenile salmonids. The objective of the discussion is to assess whether current interim guidelines are applicable to sheet pile driving at the MTR Project and whether juvenile salmon are at risk from pile driving noise following release from the ADF&G Elmendorf fish hatchery.

4.1 Other Industry Studies

Impact driving of hollow steel pipe piles has been shown to create peak underwater sound pressure levels in excess of 200 dB (Pentec 2006; Blackwell and Greene 2002; Blackwell 2005). These sound pressure levels have been shown in other studies to cause injuries to fish in the vicinity, with possible behavior-altering sound levels emanating for hundreds of meters (Turnpenny and Nedwell 1994; review by Hastings and Popper 2005). One of the first times these effects were documented was during the construction of the Benicia-Martinez Bridge in San Francisco Bay during which the mortality of several species of fish were observed in the vicinity of the bridge after the impact pile driving of very large diameter steel piles (8 feet diameter piles). A substantial increase in the feeding behavior of gulls and other seabirds was also observed in the vicinity of pile driving, suggesting the presence of dead or stunned fish. Acoustic monitoring showed peak sound pressure levels between 227 and 214 dB at distances between 5 m and 20 m from piles (Reyff 2008).

Feist et al. (1996) investigated the effects of impact driving of concrete piles on juvenile pink (*Onchorynchus gorbuscha*) and chum salmon (*O. keta*) behavior and distribution in Everett Harbor, Washington. The authors reported that there may be changes in general behavior and school size, and that fish appeared to be driven toward the acoustically isolated side of the site during impact pile driving. However, the abundance of fish schools did not change significantly with or without pile driving, and schools were often observed around the barge-mounted pile driving rigs. No impacts on feeding were reported. The study concluded that any effects of impact driving of concrete piles on juvenile salmonid fitness would be very difficult to measure quantitatively. Such direct visual observations of fish behavior are precluded in Knik Arm by high turbidity levels.

Grette (1985) investigated the impacts of steel sheet pile driving on adult salmonid runs (Chinook (*O. tschawytscha*), coho, and sockeye (*O. nerka*) through the Hiram H. Chittenden Locks in Seattle, Washington. The study found that daily patterns of migration through the locks were similar during periods of pile driving, and during periods when no pile driving occurred. The study concluded that pile driving did not influence the number of salmon ascending the fish ladder within the locks.

Recent experience in Puget Sound Washington and elsewhere, however, has documented more severe effects from the use of an impact hammer to drive large diameter, hollow steel piles. Effects are believed to be exacerbated if piles are driven in hard substrates (i.e., gravel, cobble) when compared with effects of pile driving into softer sands or mud. Similar to observations in California, impact driving of 24-inch diameter steel piles in late 2002 at a ferry terminal in Puget Sound resulted in mortality of a number of sea perch (Embiotocidae), and similar size or larger piles driven by impact hammer at the Port of Seattle resulted in mortality of Pacific herring (*Clupea pallasi*; Erstad, P., Washington Department of Fish and Wildlife, [WDFW], personal communications). However, impact driving of 24-inch diameter steel pipe piles at the Mukilteo Ferry dock, and 12-inch diameter steel pipe piles at a nearby port facility in early 2003, did not result in documented fish kills (Pentec 2003).

Caltrans (2004) investigated the effects of pile driving on two species of fish: shiner perch (*Cymatogaster aggregata*) and steelhead trout (*Oncorhynchus mykiss*) during the driving of large steel pipe piles. This study found indications of baratrauma in both species, but statistical analyses found no statistically significant differences between cage controls, fish species, fish size, treatment distances, and the durations of exposure. For shiner perch, the most common indication of barotrauma was an abnormality in the appearance of the kidney; for steelhead the most common indication was bright red coloration at the base of the pectoral fins and of the arteries running along the abdominal wall. Shiner perch exposed to sound pressures of 204 dB or greater appeared to exhibit injuries, but steelhead did not. Data from one treatment group indicated that steelhead were not as susceptible to injury from pile driving, which could possibly be attributed to the ability of salmonids to partially empty their swimbladders.

Strategic Environmental Consulting, Inc. (SECI 2004) simultaneously investigated the effects of pile driving on three fish species: anchovy (*Engraulis mordax*), Chinook salmon, and shiner perch, and found that behavior and near-term mortalities were not significantly different between the treatment group and the controls for all three species, given exposure to sound pressure levels in excess of 185 dB peak. They concluded that peak exposure as high as 189 dB over a 4-minute period of driving did not result in vestibular injury, acute mortality, or delayed mortality.

In a recent (2007) field study in Puget Sound, Ruggerone et al. (2008) exposed juvenile coho salmon in live cages to over 1,600 strikes with an impact hammer of fourteen, 20-inch diameter hollow steel pipe piles. Live cages were placed from 1.8 to 6.7 m from the pile being driven. Measured sound pressures experienced were up to 208 dB peak, and 194 dB root mean square $_{\text{(rms).}}$ SEL reached 179 dB and cumulative SEL was approximately 207 dB over the 4.3-hour exposure period. No mortality and no visible sublethal effects were observed in fish held up to 19 days after the exposure. Necropsies found no gross external or internal injuries associated with pile driving. Exposed fish fed normally and only a minor startle response was seen in some fish upon initiation of driving a given pile.

One major difference between previous work and this study was the inability to observe behavior during *in-situ* exposures, due to low visibility in the turbid Knik Arm water. Studies by Feist et al. (1996), Grette (1985), and Ruggerone et al. (2008) investigating effects of pile driving on fish species observed only minor behavioral responses such as change in schooling behavior or a minor startle response upon initiation of pile driving. Responses were observed *in-situ* and no further behavioral changes or abnormalities were seen during post-exposure observation. As a result, these studies concluded that there were no lasting effects on behavior of fish as a result of pile driving. Findings from this study are consistent with other pile driving studies examining the effect of noise on juvenile salmonids.

4.2 Interim Criteria and Study Findings

On June 12, 2008, the Fisheries Hydroacoustic Working Group, composed of several state and federal agencies, including National Marine Fisheries Services (NMFS), the Federal Highways Administration, and three state highway agencies signed a memorandum agreeing to interim criteria for use during all pile driving projects. These criteria have been identified as a peak sound pressure level of 206 dB and an accumulated SEL of 187 dB for all fish 2 grams or larger. For fish less than 2 grams, the criterion for accumulated SEL is 183 dB (FHWG 2008). The findings of this study were compared to these interim criteria to assess the potential effects of pile driving at the MTR Project on outmigrating juvenile salmonids.

Sound levels generated by the majority of our test exposures were generally below thresholds known or believed to subject fish to harm. In these tests, maximum peak pressure was typically less than 190 dB. Two tests (7 and 15) reached maximum peak pressures greater than 190 dB but the peak criterion of 206 dB was not approached (Table 3).

All test fish were greater than the 2 grams threshold, ranging from 8 to 16 grams. Upon release from the hatchery, it is expected that juvenile coho would be at least 15 grams or larger (Ransom, L. Hatchery Manager, Elmendorf Fish Hatchery, personal communication, June 12, 2009). Four of the 13 noise exposures in our tests (31 percent) resulted in an accumulated SEL of less than the 183 dB criterion for fish less than 2 grams. Three of the tests produced an accumulated SEL above the criterion for fish less than 2 grams but below the criterion for larger fish. Six tests produced an accumulated SEL above the conservative criterion for larger fish (Table 3).

Test 13 best simulated a “reasonable-case” fish exposure scenario; the fish in the live cage drifted in the current past the impact driving of the sheet piles. In this exposure, the cage passed within 4 m of the pile driving. This test resulted in a maximum peak pressure of 189 dB and an accumulated SEL of 179 dB, both well below the dual interim criteria.

Test 15 simulated a worse-case exposure scenario, in which fish were held quite close to pile driving activities for an extended period. The greatest accumulated SEL (190.6 dB) was reached in Test 15 where the test cage was held near the sheet pile wall, about 4-5 m from the large impact hammer, driving a pile that was at refusal, for over 30 minutes and 1,458 strikes (Table 2). This exposure is unrealistic for Knik Arm outmigrating salmon, but was conducted in an attempt to create exposures that would cause measurable injury of the test fish. No mortality or internal abnormalities were observed with this test batch even though the accumulated SEL criterion was exceeded. The peak sound pressure criterion was not exceeded during this test.

Overall, despite our attempts to expose fish to maximum potential noise, this study of sheet pile driving measured only relatively low levels of sound energy compared with exposures to pipe pile driving reported in the literature to cause adverse effects on fish. Correspondingly, no immediate or delayed mortality and no evidence of barotraumatic injury associated with sheet pile driving was found. These results were consistent even as the test fish experienced progressively increased cumulative exposures.

At the request of the fish study team, the contractor deviated from normal practices to accommodate the team's request to extend periods of impact pile driving on piles that were essentially at refusal. This was the case during Test 15 when the sheet pile was struck over 1,400 times, and in Test 16 when the pile was struck over 700 times by the large pile driver. In both tests, the test cage was held as close as possible to the piles being driven. Peak sound pressure levels were still below peak criterion during both of these tests. This translated into situations where noise exposure from pile driving activity would far exceed any realistic noise exposure of unconstrained fish to construction noise associated with the MTR Project.

The relatively low underwater sound pressures measured in this study are consistent with the few documented examples of acoustic monitoring at sheet pile operations. At Port of Oakland Berth 23, acoustic measurements were collected at various distances from five sheet piles driven by an impact hammer. Peak sound pressure levels ranged from 188 to 209 dB, at distances between 5 and 40 m from the sheet face. Accumulative SELs ranged from 162 to 179.6 dB over 12 to 15 minutes of pile driving (Illingworth and Rodkin 2007). Out of 10 measurements, only one exceeded the peak interim criterion of 206 dB. None of the SEL measurements exceeded either of the accumulative criteria. At Port of Oakland Berth 30, acoustic measurements were collected from five sheet piles driven by a vibratory hammer. All peak (166 to 185 dB) and accumulative (155 to 162 dB) SEL sound pressures measured were below the interim criteria (Illingworth and Rodkin 2007). Thus, both of these tests of sheet pile driving show that generated noise is typically well below the interim criteria established based on impact driving results.

4.3 Assessment of Risk to Knik Arm Salmonids

The findings from this study demonstrate that sheet pile driving with the impact and vibratory hammer pile drivers used for the MTR Project pose a very low risk to outmigrating juvenile coho salmon released from nearby hatcheries in Knik Arm. Tests exposed these salmonids to pile driving conditions and exposure durations that would be considered worse-case scenarios. Survival during these tests was 100 percent with no evidence of injury associated with barotrauma and no behavioral abnormalities resulting from exposure to pile driving. The few internal abnormalities observed during necropsies occurred at a higher frequency in reference deployments and were likely the result of handling stress either at the hatchery or during the study.

Unlike most of the test scenarios conducted, the strong currents prevalent within Knik Arm (maximum currents greater than 7 knots) would limit exposure to excessive noise levels associated with pile driving. Generally, under these current regimes, juvenile salmon would move passively with the currents as they move out of the more turbulent portions of inner Knik Arm or seek out shallow low-gradient nearshore flats. Such low-gradient flats are not present in the MTR pile driving area. During periods of slack tide, when currents are lowest, there is a potential for juvenile salmon to occupy areas near pile driving operations for extended periods, but during most tide cycles this would occur for less than 1 hour during high and low tide. To protect beluga whales, which tend to move out of inner portions of Knik Arm during these periods, both the USACE Permit and the NMFS Letter of Authorization prohibit pile driving for 2 hours on either side of low slack tide. Hence, juveniles would be vulnerable to extended periods of pile driving sound pressures only during the daytime high slack tide. As reported, however, even extended periods of exposure to pile driving sound pressures yielded no visible internal or external injuries to juvenile salmon.

This study exposed hatchery raised juvenile coho salmon to pile driving operations, but annual releases of juvenile Chinook salmon also take place in Knik Arm in late-May or early-June, potentially exposing these fish also to sound pressures generated by pile driving. Chinook are released at a smaller size than coho, generally with a target release weight of 12.0 grams (coho are released at a target size of approximately 17 to 20 grams). Because of the cool winter in 2008/2009, juvenile Chinook growth rates in the hatchery were much lower and fish were released at a much smaller size, a mean weight of 7.6 grams (Ransom, L., Hatchery Manager, Elmendorf Fish Hatchery, personal communication, August 26, 2009). Though smaller than coho, these fish are substantially larger than the 2-gram threshold for the accumulated SEL criterion. The vulnerability of juvenile Chinook salmon was not investigated during this study, but it is expected that conclusions based on the testing of coho juveniles would apply to Chinook as well.

In addition to the release of juvenile hatchery coho and Chinook salmon into Knik Arm, outmigration of wild juveniles of all five salmonid species occurs during the spring and summer (Figure 18; Pentec 2005a, b). Length-frequency data collected by Pentec (2005a, b) show a young-of-the-year cohort for pink and chum salmon, mostly between 21 and 50 mm. A small number of young-of-the-year coho in the same size range were also observed early in the spring. Many of these fish would be smaller than 2 grams and may be more susceptible to pile driving sound pressures. However, it is probable that these fish would be swept past any specific area of pile driving in Knik Arm more quickly than larger outmigrants due to their reduced swimming ability. This was evident in tow netting studies conducted in the Arm and off of the Port MacKenzie Pier (Pentec 2005b). In this study, a tow net was hung from the Port MacKenzie Pier and fished passively at varying tidal cycles, as well as actively towed within offshore portions of the Arm. Smaller chum and pink salmon were more abundant in offshore sampling, while larger coho were more abundant in the nearshore. Higher catch rates of chum and pink salmon were also found in the passively fished tow net hung from the pier during higher flow velocities. These findings suggest that small fish are more likely entrained in the strong central Arm currents and carried more or less passively out of Knik Arm with the net southerly water flow These fish would likely have a lower exposure to pile driving noise as they were swept past the MTR site.

In general, the lack of any evidence of barotraumatic injury in juvenile salmonids during this study is likely attributed to the relatively low sound pressures found during the driving of sheet piles at the MTR Project site. This is consistent with studies that have collected acoustic data during sheet pile driving operations at other sites (Illingworth and Rodkin 2007). All of the studies, including this one, show a very low incidence of exceeding sound pressure levels that have been shown to cause barotrauma in fish. Collectively, these data and investigations provide a degree of scientific support to indicate that the Interim Criteria adopted by the Fisheries Hydroacoustic Working Group are not applicable to the impact pile driving of sheet piles.

5.0 SUMMARY AND CONCLUSIONS

During this study, field operations successfully exposed juvenile coho salmon held in live cages to pile driving noise and conducted post-exposure observations of exposed and reference fish in a controlled wet-lab setting. Juvenile coho salmon were exposed to the driving of sheet piles by two types of impact pile drivers and by a vibratory driver. The following summary/ conclusions were reached:

- Juvenile coho salmon used for the study were collected from the ADF&G Elmendorf Fish Hatchery. Fish were healthy, ranging from 86 to 124 mm, and generally ranging from 10 to 16 grams per fish. The fish readily acclimated to ambient Knik Arm estuarine water with no mortalities prior to field trials.

- A total of 13 tests exposed juvenile salmon to pile driving sound pressures; three day-long reference exposures were situated approximately 4 km from pile driving operations.

- No short-term or long-term mortalities of juvenile hatchery coho salmon were observed in exposed or reference fish.

- Sound pressures measured during acoustic monitoring were relatively low, ranging from 177 to 195 dB peak. Accumulative SEL sound pressures ranged from 179.2 to 190.6 dB.

- No measured peak pressures exceeded the Interim Criterion of 206 dB. Six the 13 tests slightly exceeded the accumulated SEL criterion of 187 dB for fish over 2 grams.

- During post-exposure observations, no short- or long-term behavioral abnormalities were observed in fish exposed to pile driving sound pressures or in the reference fish.

- Post-exposure necropsies found slight body wall hemorrhaging in 3 fish exposed to pile driving noise (3.9 percent) and 2 reference fish (10.5 percent). No dose-dependent relationships were observed in the exposed fish with abnormalities. There was no evidence that these abnormalities were caused by barotrauma; they likely resulted from normal handling during the live cage experiments.

- Data from this study and other acoustic monitoring and pile driving studies strongly indicate that sheet pile driving during the MTR Project poses little risk to outmigrating juvenile salmon.

- The wet lab constructed at the Port facility was generally successful at holding and observing pre- and post-exposure fish through the duration of the live cage study. A decrease in turbidity was achieved with the system of settling tanks, settling baffles, and particulate filters; however turbidity was still higher than optimal. Post-exposure observations were conducted for feeding behavior, startle response, and surface dwelling behavior, all of which indicated no negative effects from pile driving.

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TABLES

Table 1 – Juvenile Salmon Live Cage Exposure Scenarios and Test Variables

		Pile Driver			
Date	Test No.	Type	Model	Test Type	Mean Distance from Pile Driver (meters)
6/16/09	1	--	--	Reference	4 km
	2	Small Impact	BSP SL30	Static	23
	3	Small Impact	BSP SL30	Static	25
	4	Small Impact	BSP SL30	Static	12
6/17/09	5	--	--	Reference	4 km
	6	Large Impact	J & M 115	Static	33
	7	Large Impact	J & M 115	Static	10
	8	Large Impact	J & M 115	Static	8
	9	Large Impact	J & M 115	Static	8
6/18/09	10	Vibratory	APE 200-6	Static	7
	11	Vibratory	APE 200-6	Static	1.5
6/19/08	12	--	--	Reference	4 km
	13	Large Impact	J & M 115	Dynamic	Drift from 4m to >25m from pile
	14	Large Impact	J & M 115	Dynamic	Drift from 6m to >30m from pile
	15	Large Impact	J & M 115	Static	5
	16	Large Impact	J & M 115	Static	4

Table 2 - Acoustic Measurements of Pile Driver Noise

		Pile Driver			Exposure				Acoustic Conditions		
Test No.	**Test Conditions**	**Type**	**Model**	**Strikes**	**Date**	**Start**	**Stop**	**Time (h:m)**	**Acc. SEL**	**Max SEL$_{[strike]}$**	**Max Peak**
1	Reference	n/a	n/a	n/a	16-Jun	11:00	15:50	4:50	116-140		
2	Drifting 20 to 25 m from wall	Impact	BSP SL30	861	16-Jun	12:05	12:25	20 min	174.8	153	177
3	Drifting 19 to 30 m from wall	Impact	BSP SL30	697	16-Jun	12:29	12:49	21 min	177.9	155	178
4	Drifting 9 to 28 m from wall; majority of time 10 to 14 m	Impact	BSP SL30	2781	16-Jun	14:47	15:34	47 min	186.9	163	189
5	Reference	n/a	n/a	n/a	17-Jun	11:48	16:08	4:20	123-140		
6	Drifting 23 to 43 m from wall; majority of time about 25 m from large hammer; small hammer active about 50+ from cage	Impact	J&M 115 (BSP SL30 in distance)	406	17-Jun	14:00	14:19	19 min	181.1	154	182
7	Drifting 3 to 20 m from wall; majority of time about 10 m from large hammer; small hammer active about 15 to 20 m from cage (between two hammers)	Impact	J&M 115 (BSP SL30 in distance)	809	17-Jun	14:31	14:51	20 min	188.2	166	193
8	Drifting 3 to 50 m from wall; majority of time about 6 to 10 m from large hammer; small hammer active about 10 to 20 m distant	Impact	J&M 115 (BSP SL30 in distance)	509	17-Jun	14:54	15:07	13 min	184.0	163	189
9	Drifting 3 to 50 m from wall; majority of time about 6 to 10 m from large hammer; small hammer active about 10 to 20 m distant	Impact	J&M 115 (BSP SL30 in distance)	485	17-Jun	15:25	15:42	17 min	184.3	163	188
10	Vessel moored to pile So. of corner of south work area; 4.5 to 9 m from cage	Vibratory	APE 200-6	n/a	18-Jun	16:24	16:54	30 min	187.6	171	184
11	Vessel moored to pile So. of corner of south work area; 0.6 to 2.5 m from cage	Vibratory	APE 200-6	n/a	18-Jun	17:21	18:12	51 min	187.1	166	181
12	Reference	n/a	n/a	n/a	19-Jun	0825	16:00	7:23	111-139		
13	Drift along wall; closest point to pile is 4 m; ends of drift approximately 25+ m from pile	Impact	J&M 115	354	19-Jun	8:40	8:55	15 min	179.2	163	189
14	Drifting started at 6 m, moved to >30 m, ended 5 to 6 m from pile	Impact	J&M 115	861	19-Jun	9:00	9:28	29 min	188.5	163	189
15	Drifting start then held on to wall; cage 3 to 8 m from pile; mostly 4 to 5 m from pile	Impact	J&M 115	1458	19-Jun	14:13	14:49	36 min	190.6	165	195
16	Drifting start then held on to wall; cage 3 to 8 m from pile; mostly about 4 m from pile	Impact	J&M 115	708	19-Jun	15:05	15:26	21 min	187.1	166	181

Notes:
All reference tests at same mooring approximately 4 km from Port.
All acoustic conditions reported as follows:

- Accumulated SEL in dB re 1µPa**2-sec
- Maximum Sound Exposure Level per strike or second (SEL$_{[strike]}$)in dB re 1 µPa
- Maximum peak pressure in dB re 1 µPa

"Drifting" - outboard motors were used, as needed, to maintain position.

Table 3 - Exposed Fish Test Results

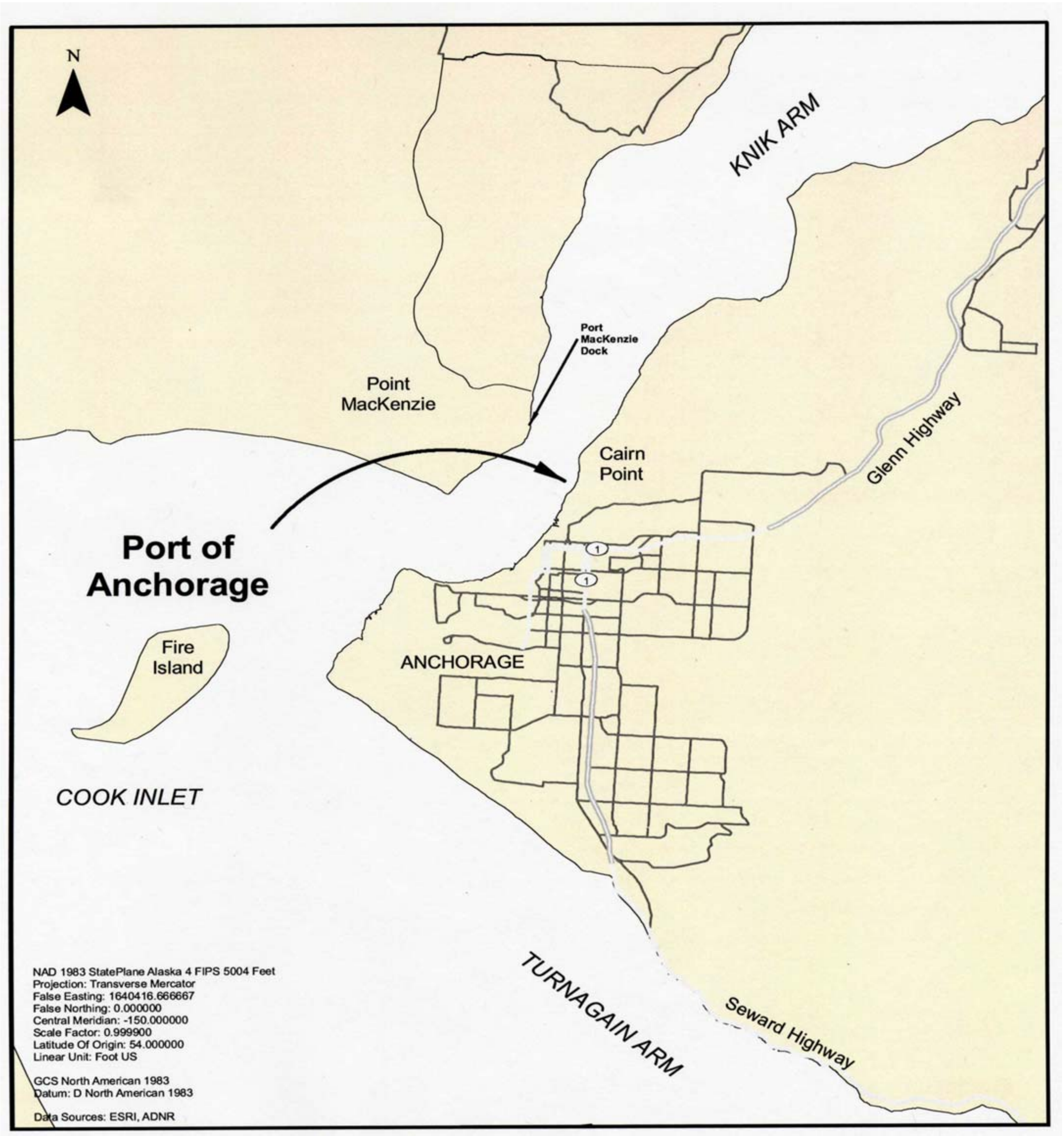
		Acoustic Conditions			Test Fish				
Test No.	**Pile Driver Type**	**Acc. SEL**	**Max SEL$_{[strike]}$**	**Max Peak**	**No. of Fish in Test Batch**	**Mortality**	**Behavior**	**Necropsy Results**	**Number of Fish Necropsied**
1	Reference	--	--	--	10	0	Normal	No abnormalities	5
2	Impact	174.8	153	177	10	0	Normal	No abnormalities	5
3	Impact	177.9	155	178	10	0	Normal	No abnormalities	6
4	Impact	186.9	163	189	10	0	Normal	1 fish with slight body wall hemorrhaging	10
5	Reference	--	--	--	10	0	Normal	2 fish with slight body wall hemorrhaging	9
6	Impact	181.1	154	182	10	0	Normal	2 fish with slight body wall hemorrhaging	10
7	Impact	188.2	166	193	12	0	Normal	No abnormalities	5
8	Impact	184.0	163	189	8	0	Normal	No abnormalities	5
9	Impact	184.3	163	188	10	0	Normal	No abnormalities	5
10	Vibratory	187.6	171	184	13	0	Normal	No abnormalities	6
11	Vibratory	187.1	166	181	10	0	Normal	No abnormalities	5
12	Reference	--	--	--	10	0	Normal	No abnormalities	5
13	Impact	179.2	163	189	10	0	Normal	No abnormalities	5
14	Impact	188.5	163	189	10	0	Normal	No abnormalities	5
15	Impact	190.6	165	195	10	0	Normal	No abnormalities	6
16	Impact	187.1	166	181	10	0	Normal	No abnormalities	5
					163	**0**			**97**
								Percent Necropsied:	**60%**
								Total Percent Anomalies:	**5.2%**
								- Reference Fish:	**10.5%**
								- Exposed Fish:	**3.9%**

Notes: Acc. SEL = Accumulated Sound Exposure Level in dB re 1µPa**2-sec

SEL[strike] = Maximum Sound Exposure Level per strike or second in dB re 1 µPa

Max Peak = Peak sound pressure in dB re 1 µPa

FIGURES



Port of Anchorage Fish Study
Anchorage, Alaska

Port of Anchorage Marine Terminal Redevelopment Project - Vicinity Map

12684-03 9/09

PENTEC ENVIRONMENTAL

Figure

1

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Note: Background from Microsoft Streets and Trips, 2007.

Miles
0 0.375 0.75 1.5

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Live Cage Fish Study Project Area
Anchorage, Alaska

Study Area

12684-03

9/09

PENTEC ENVIRONMENTAL

Figure
2

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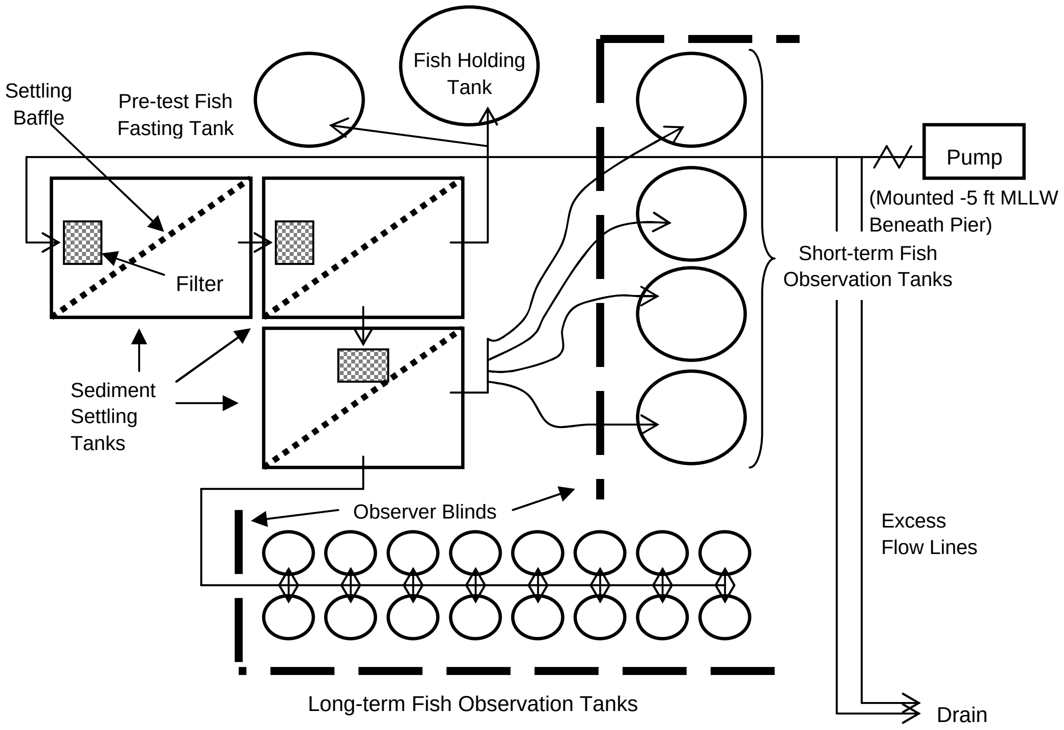

Port of Anchorage Fish Study
Anchorage, Alaska

Wet Lab Configuration

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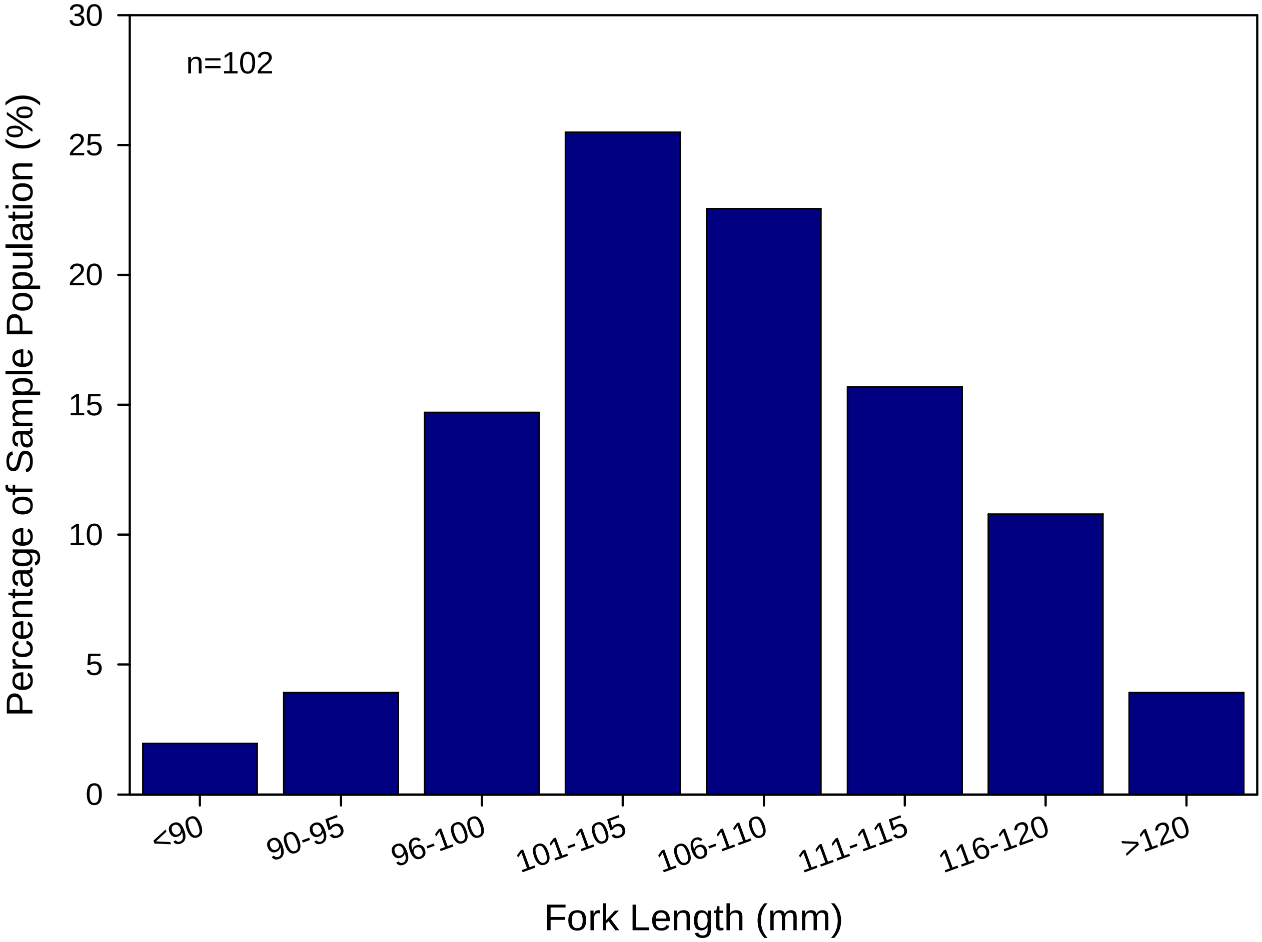
Figure

3



Port of Anchorage Fish Study
Anchorage, Alaska

Size Distribution of Coho Salmon used in the Live Cage Studies

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Figure

4

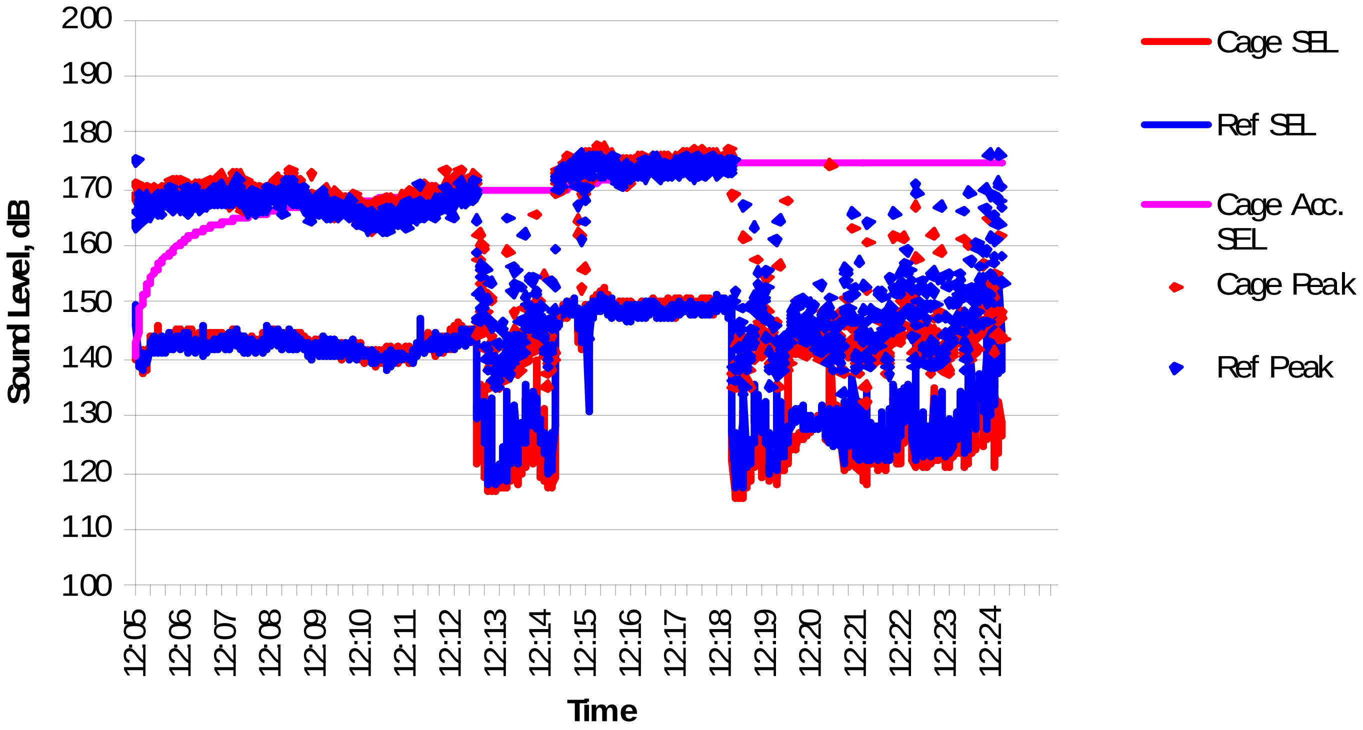

Figure 5. Sound charts for Batch 2.

Port of Anchorage Fish Study
Anchorage, Alaska

Sound Charts for Batch 2

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Figure
5

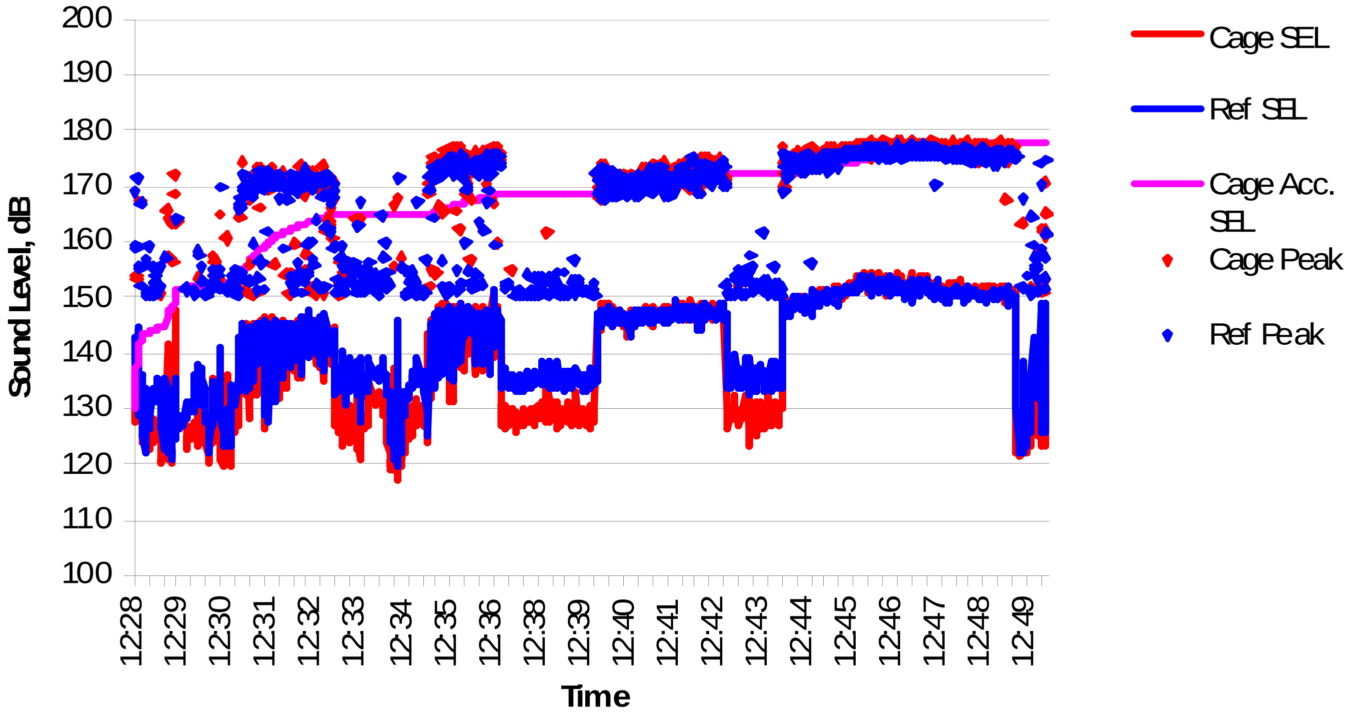

Figure 6. Sound chart for Batch 3.

Port of Anchorage Fish Study
Anchorage, Alaska

Sound Charts for Batch 3

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Figure

6

00684\03\Draft Report Anchorage Expansion Site8-31-2009\Figures\Figure 6

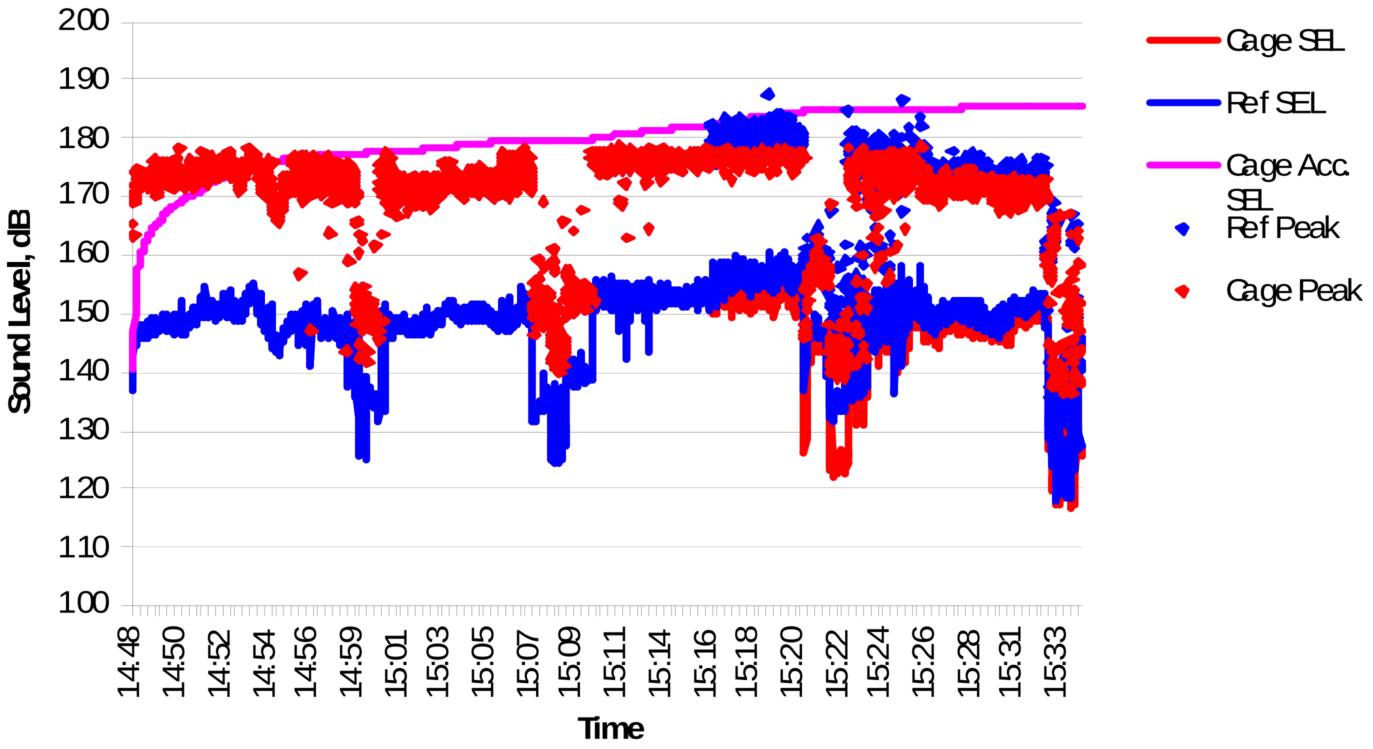

Figure 7. Sound chart for Batch 4.

Port of Anchorage Fish Study
Anchorage, Alaska

Sound Charts for Batch 4

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PENTEC ENVIRONMENTAL

Figure
7

00684\03\Draft Report Anchorage Expansion Site8-31-2009\Figures\Figure 7

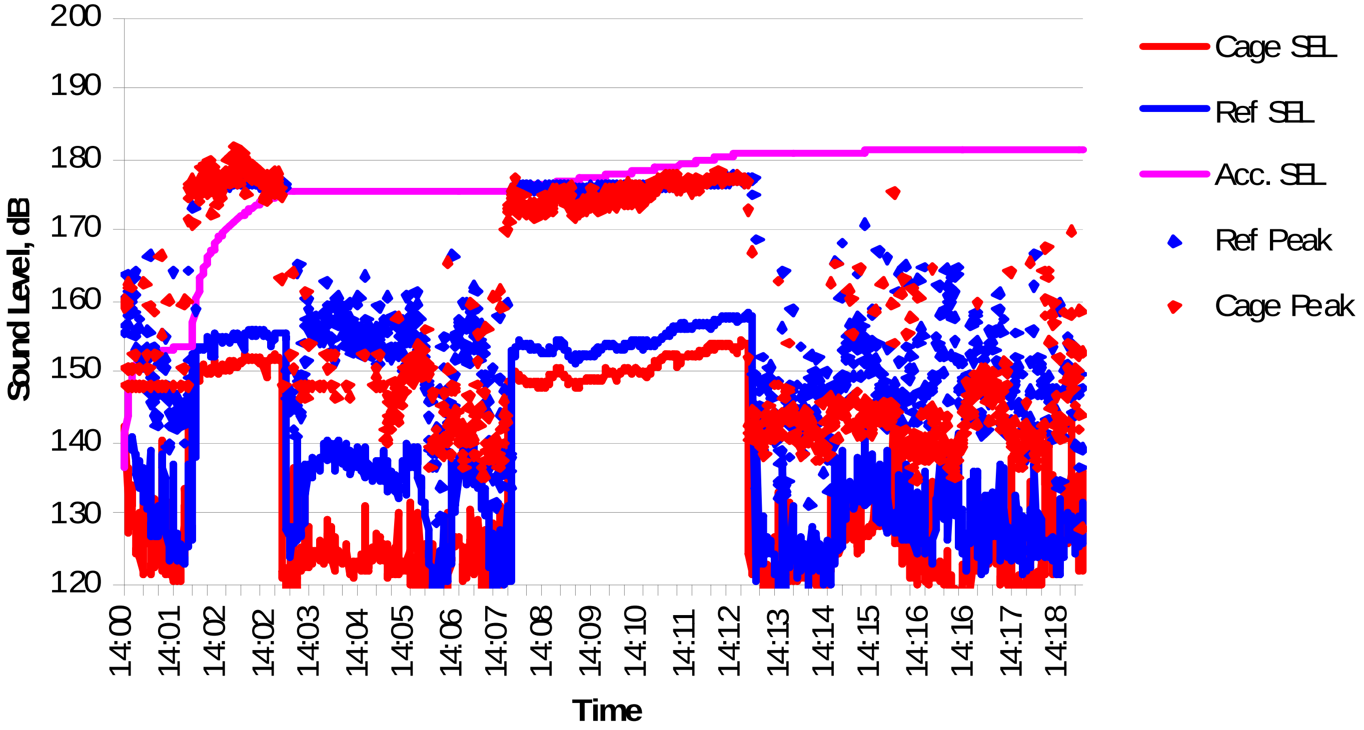

Figure 8. Sound chart for Batch 6.

Port of Anchorage Fish Study
Anchorage, Alaska

Sound Charts for Batch 6

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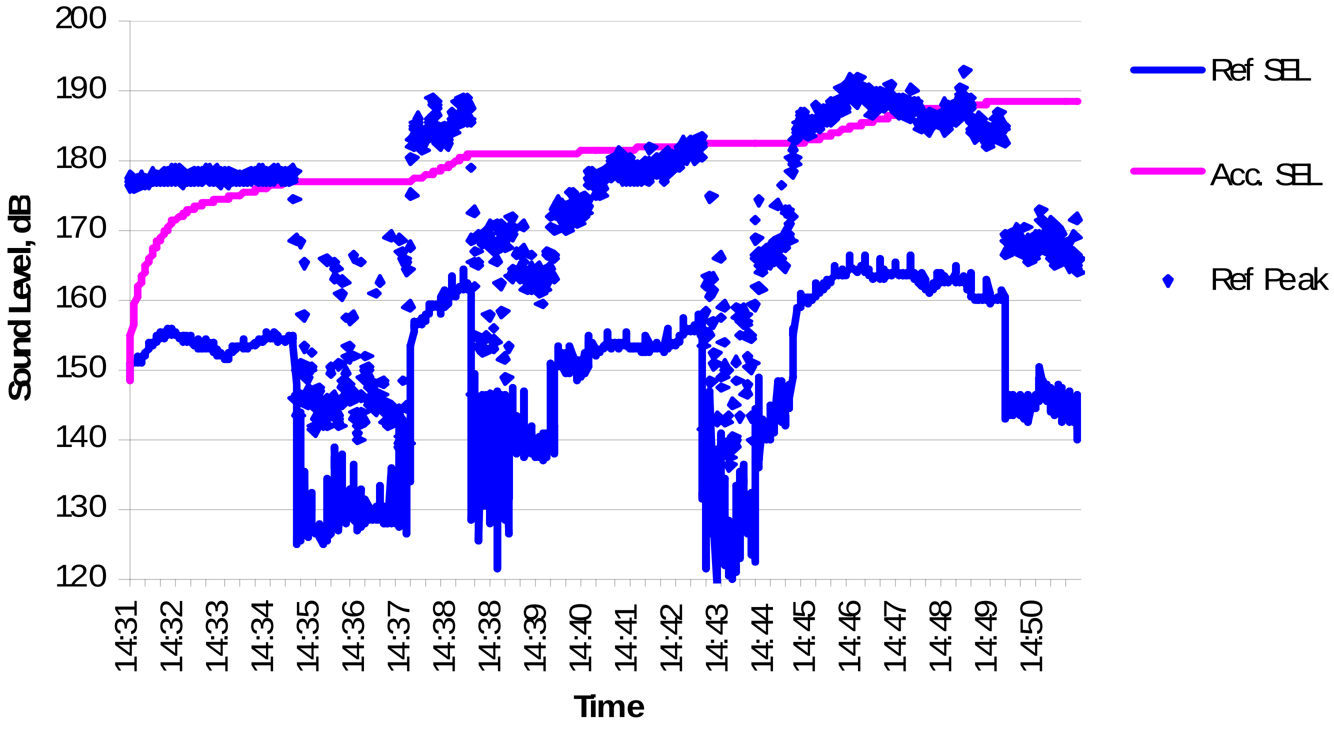
PENTEC ENVIRONMENTAL

Figure

8



Port of Anchorage Fish Study
Anchorage, Alaska

Sound Charts for Batch 7

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Figure

9

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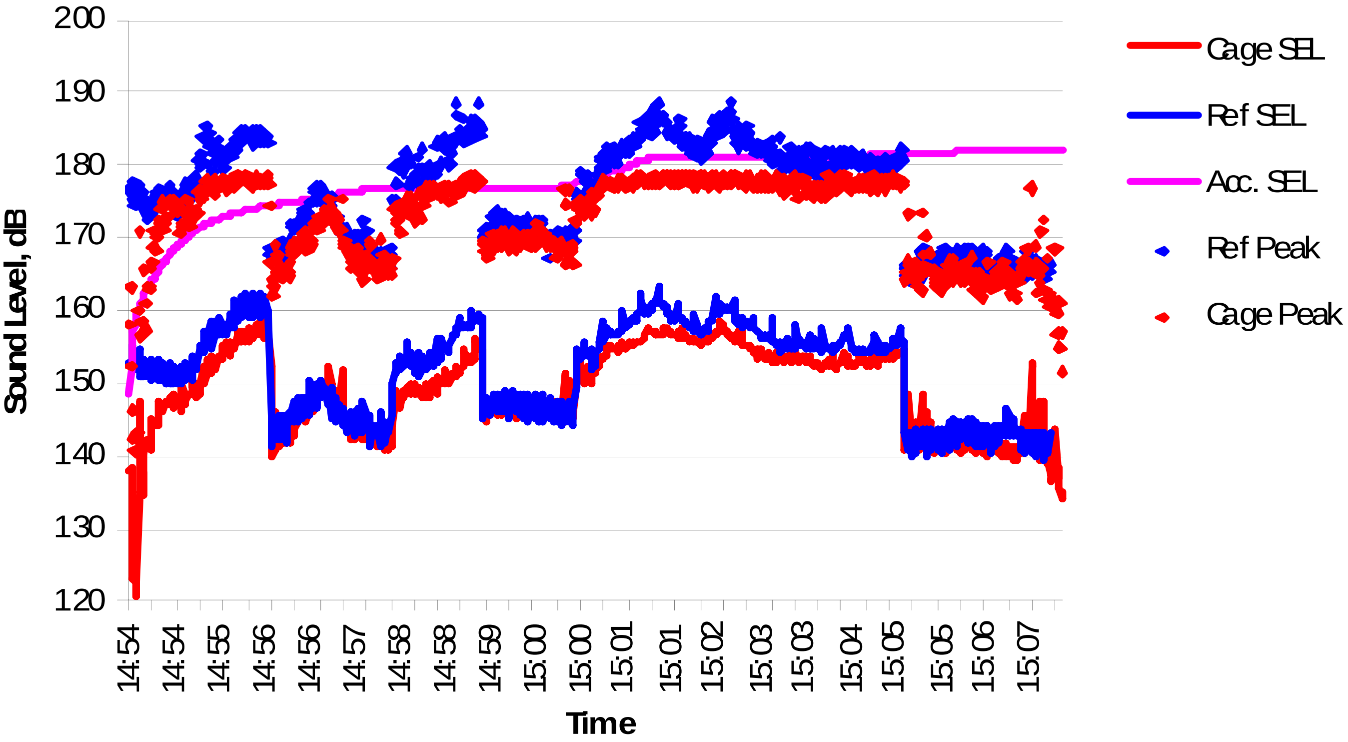

Port of Anchorage Fish Study
Anchorage, Alaska

Sound Charts for Batch 8

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Figure

10

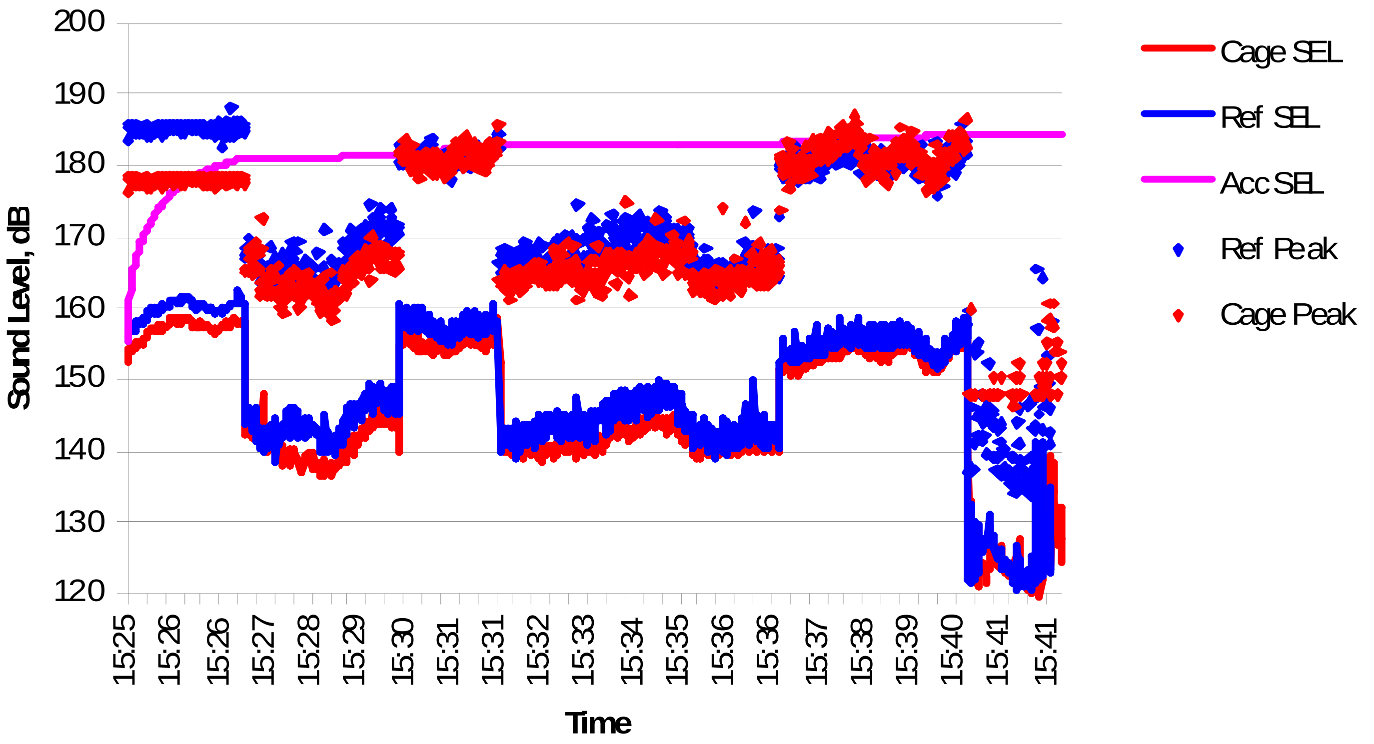

Figure 11. Sound chart for Batch 9.

Port of Anchorage Fish Study
Anchorage, Alaska

Sound Charts for Batch 9

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PENTEC ENVIRONMENTAL

Figure

11

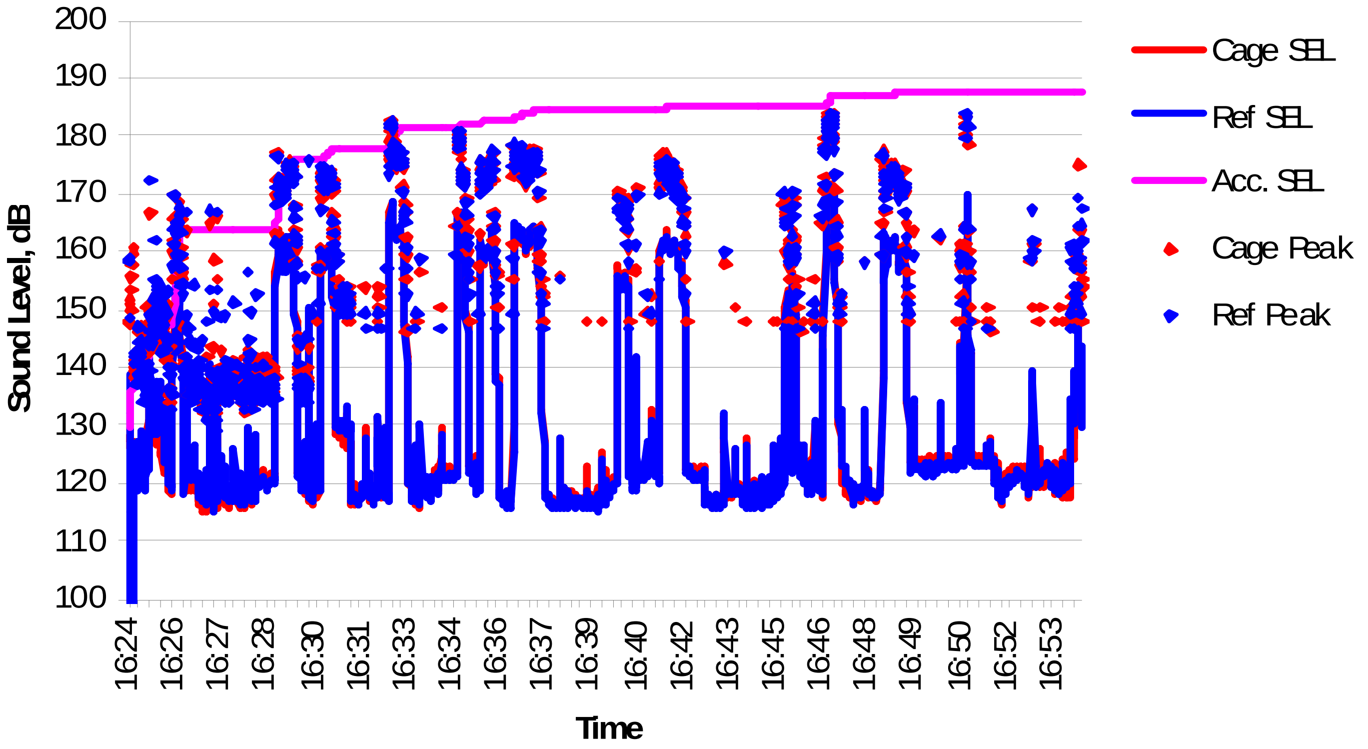

Figure 12. Sound chart for Batch 10.

Port of Anchorage Fish Study
Anchorage, Alaska

Sound Charts for Batch 10

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Figure
12

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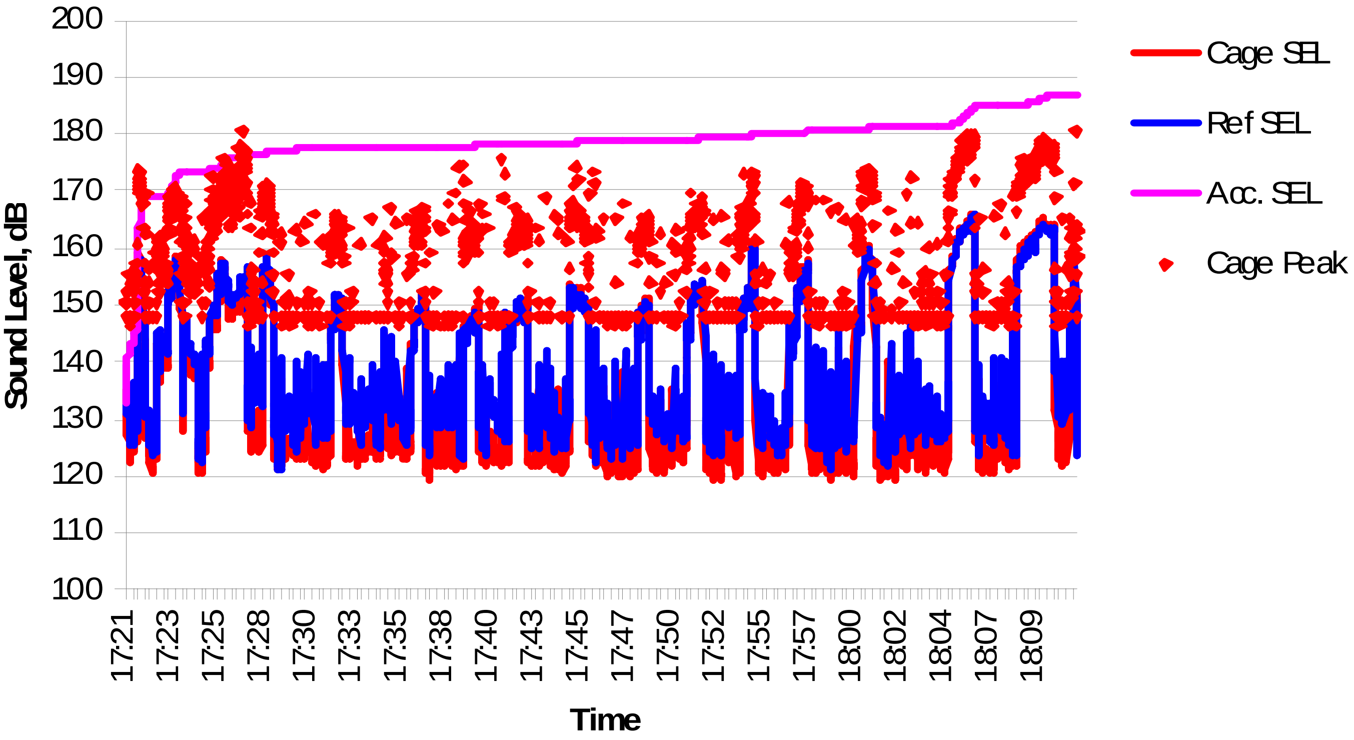


Figure 13. Sound chart for Batch 11.

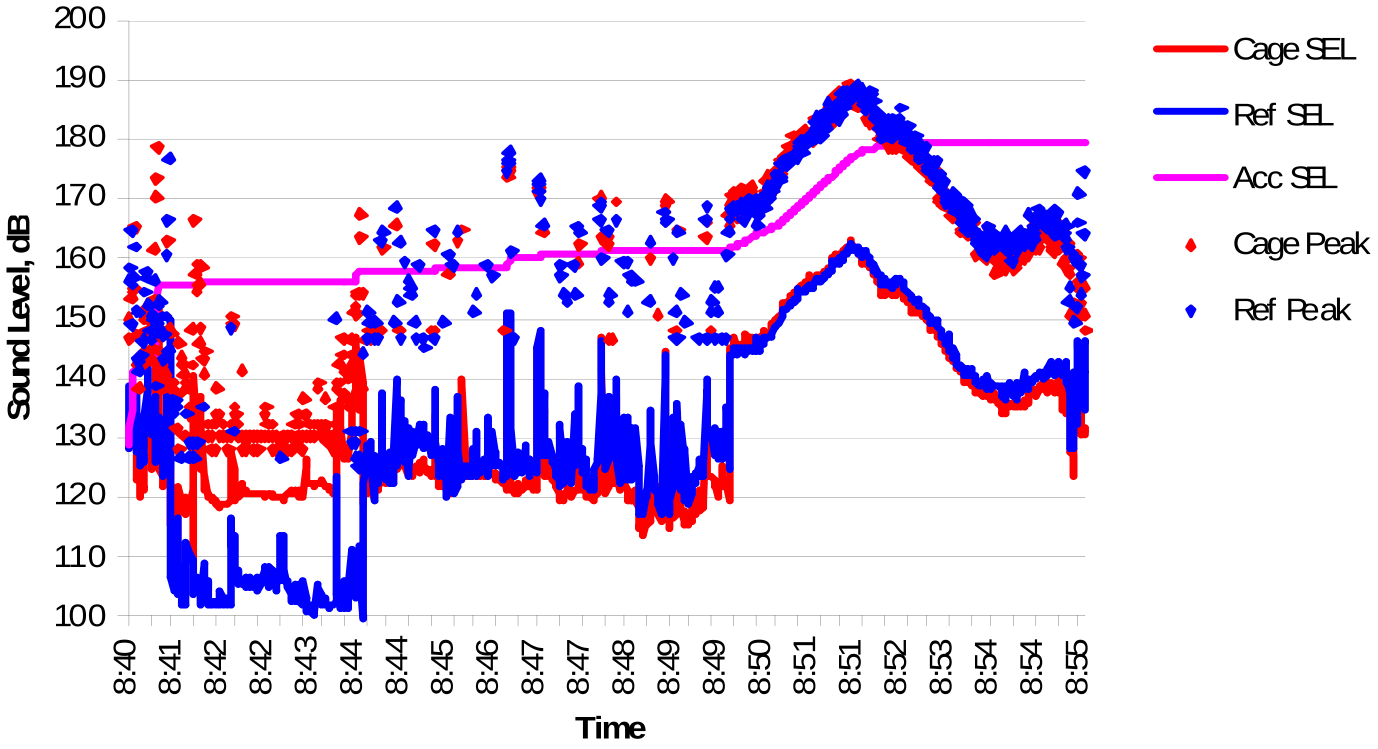
Port of Anchorage Fish Study
Anchorage, Alaska

Sound Charts for Batch 11

12684-03 9/09

PENTEC ENVIRONMENTAL

Figure
13



Port of Anchorage Fish Study
Anchorage, Alaska

Sound Charts for Batch 13

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PENTEC ENVIRONMENTAL

Figure

14

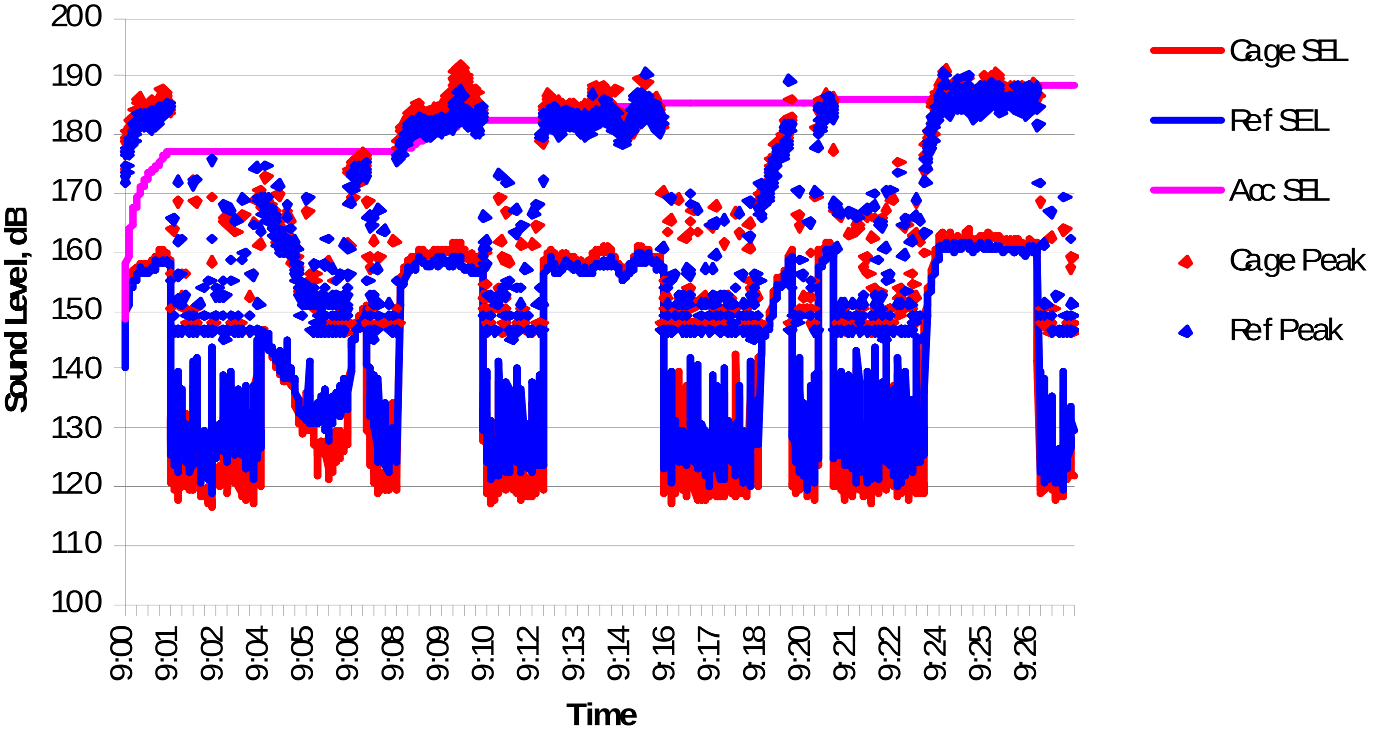


Figure 15. Sound chart for Batch 14.

Port of Anchorage Fish Study
Anchorage, Alaska

Sound Charts for Batch 14

12684-03 9/09

PENTEC ENVIRONMENTAL

Figure

15

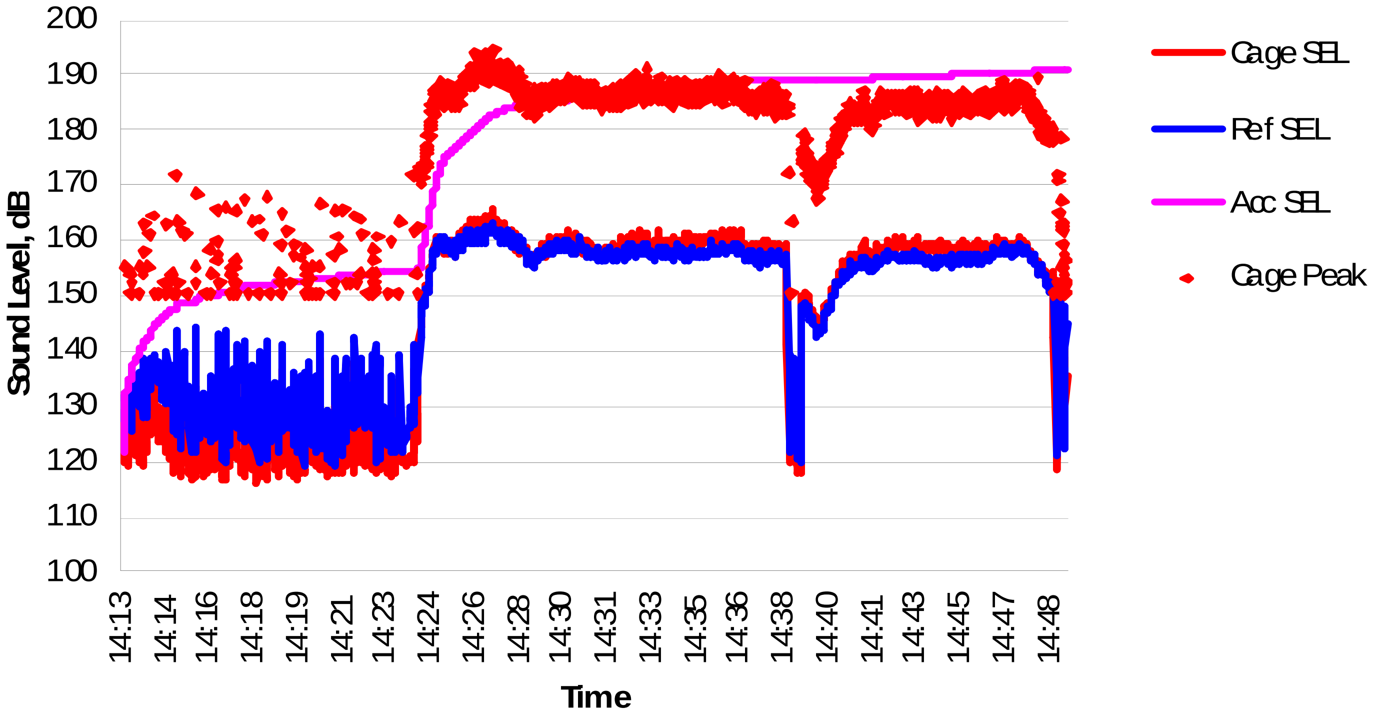


Figure 16. Sound chart for Batch 15.

Port of Anchorage Fish Study
Anchorage, Alaska

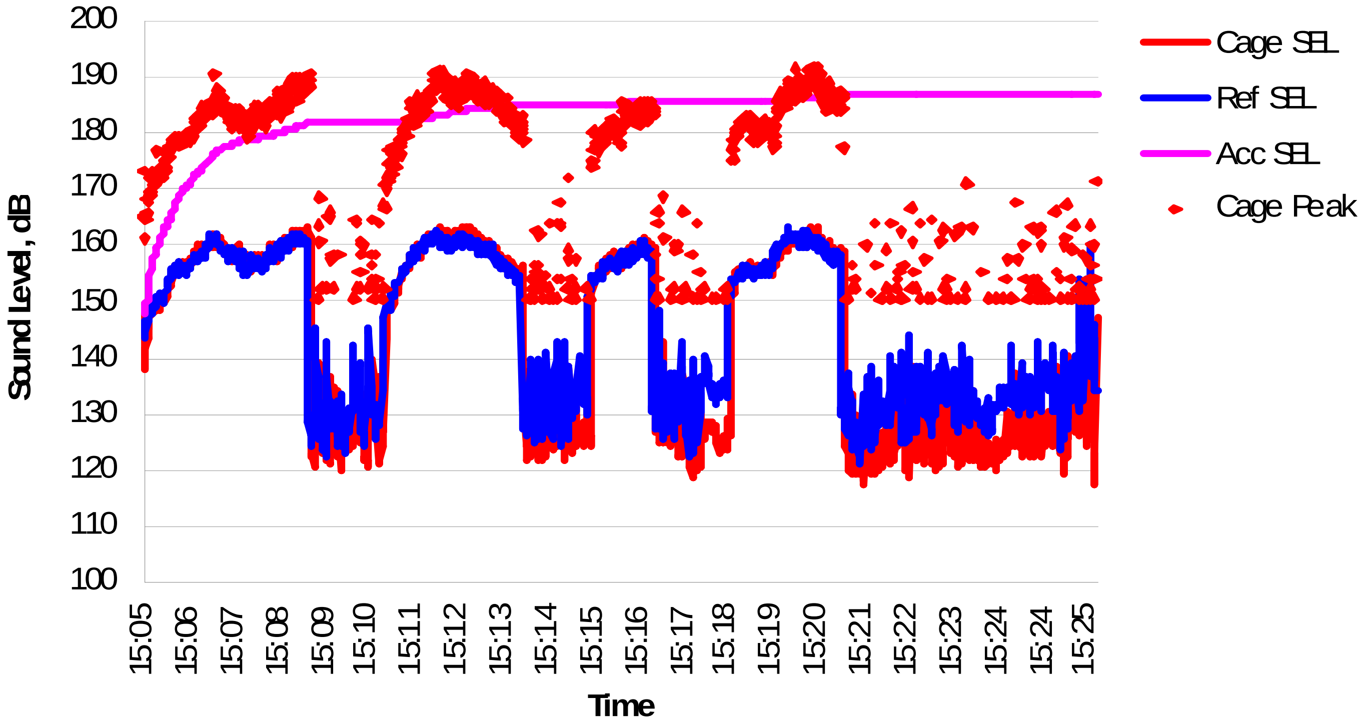
Sound Charts for Batch 15

12684-03 9/09

PENTEC ENVIRONMENTAL

Figure

16



Port of Anchorage Fish Study
Anchorage, Alaska

Sound Charts for Batch 16

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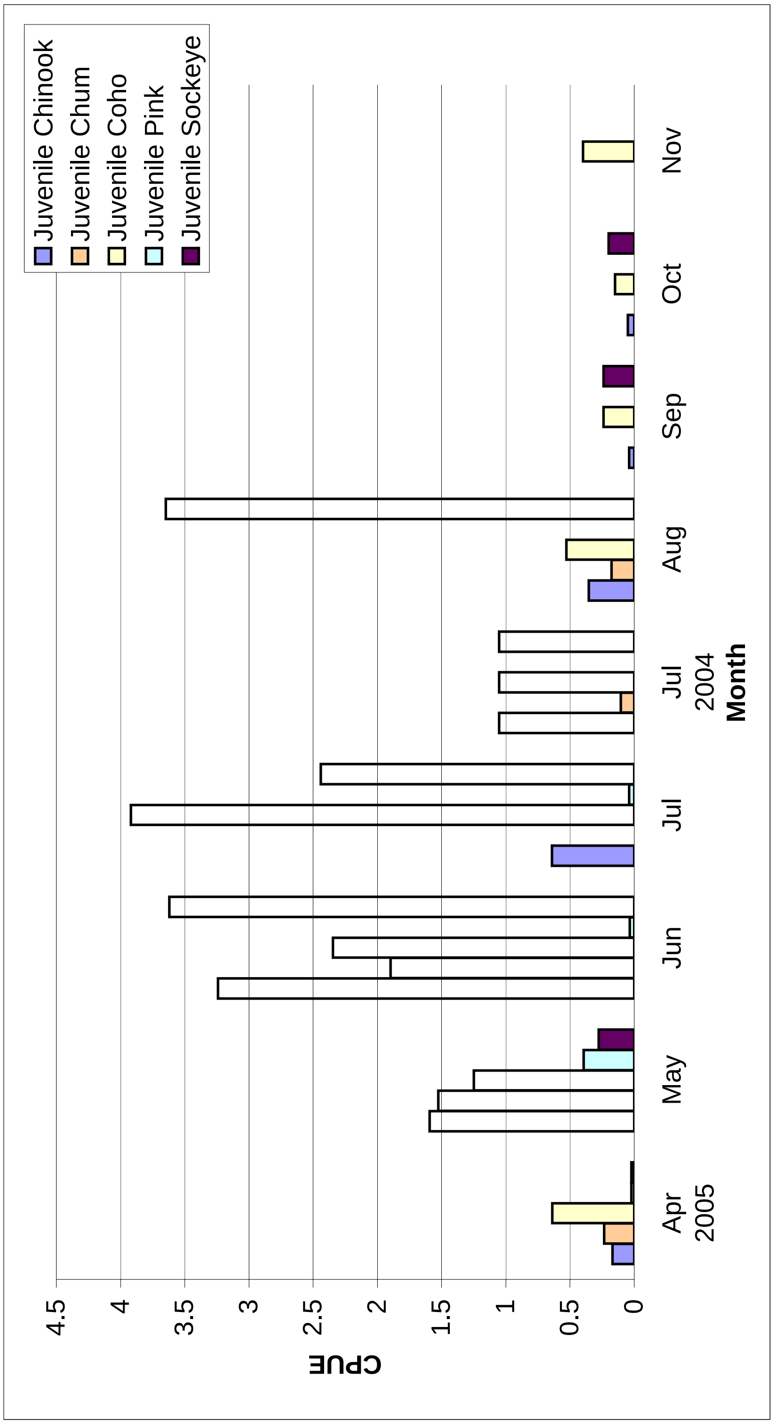
PENTEC ENVIRONMENTAL

Figure

17



Port of Anchorage Fish Study
Anchorage, Alaska

Juvenile Salmonid Catch per Unit Effort (CPUE) over Time; 120-Foot Beach Seine

12684-03

PENTEC ENVIRONMENTAL

Figure

18

PHOTOGRAPHS

Photograph 1 - Wet lab with series of three setting tanks.

Photograph 2 - Fish holding and fasting tanks prior to exposure.

Photograph 3 - Short-term observation tanks.

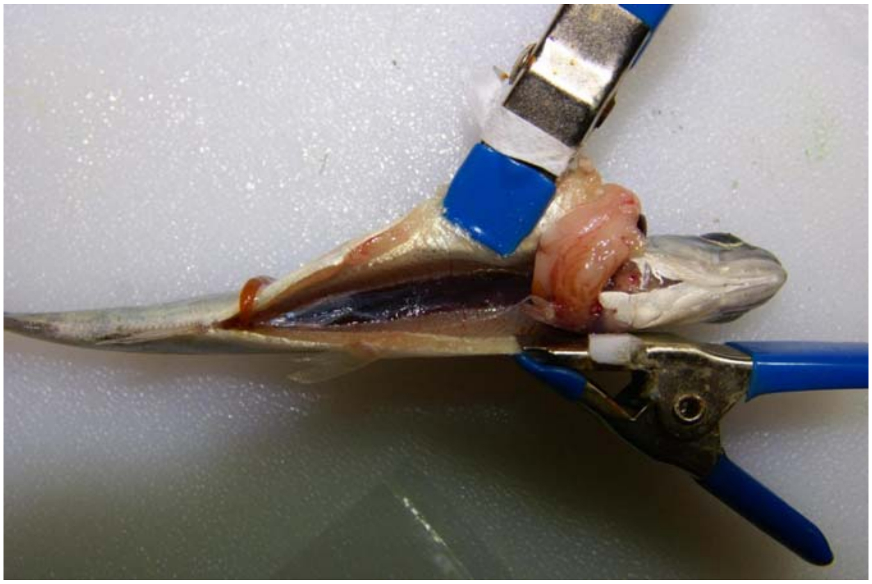
Photograph 4 - Long-term observation tanks.

Photograph 5 - Live exposure cage with inner and outer hydrophones.

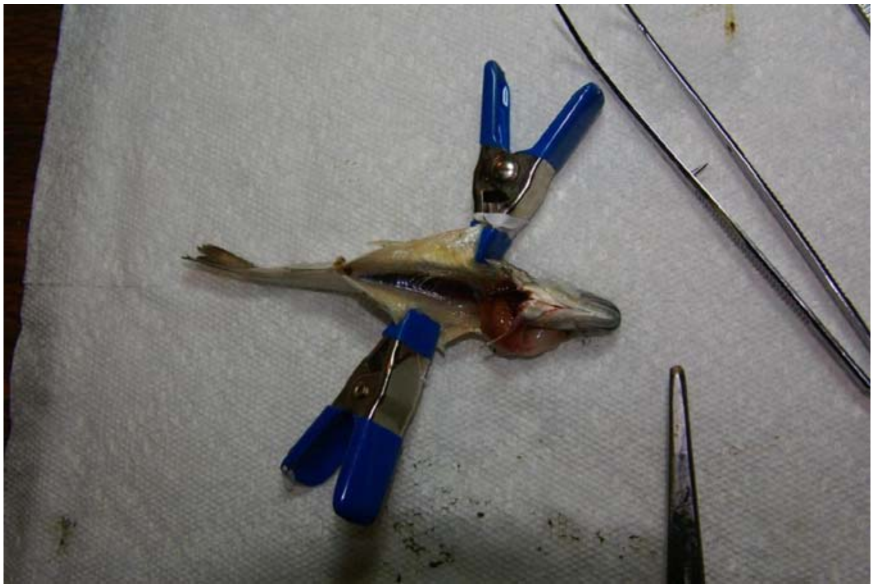
Photograph 6 - Live cage deployment set up on the *R/V Jakayte*.

Photograph 7 - Lab Control reference fish – no visible signs of internal trauma.

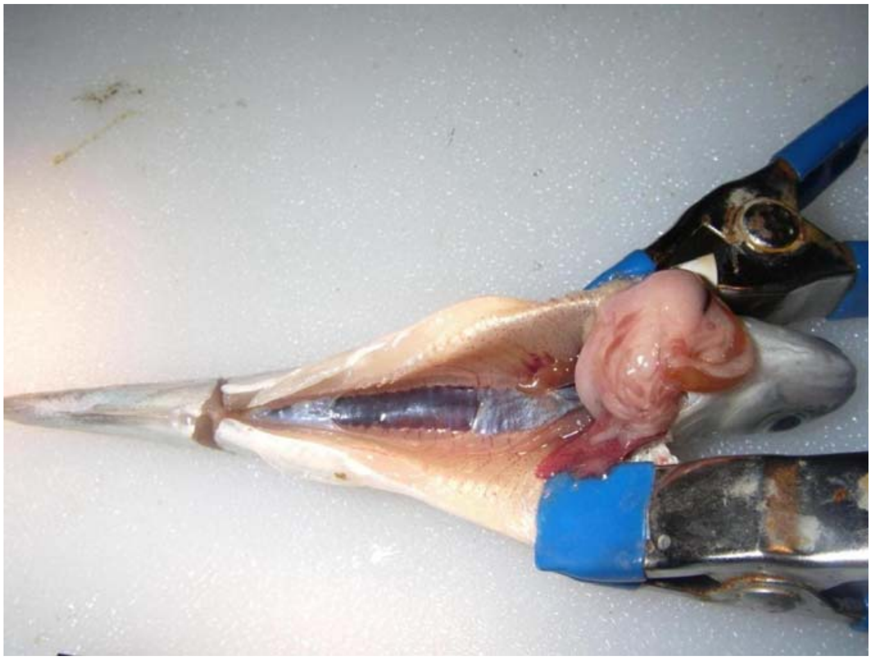
Photograph 8 - Batch 1 reference fish - no visible signs of internal trauma.



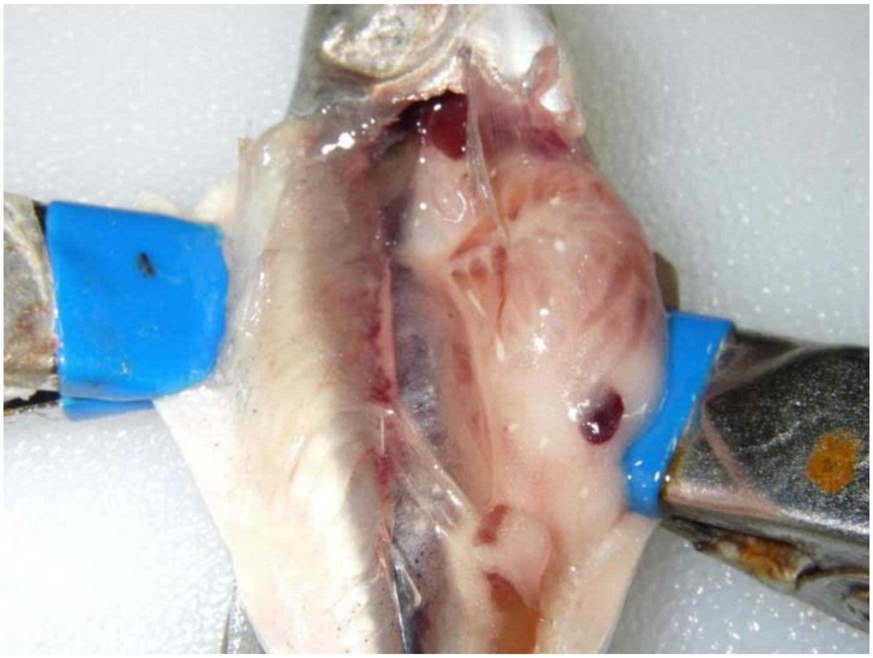
Photograph 9 - Batch 2 test fish - no visible signs of internal trauma.



Photograph 10 - Batch 3 test fish - no visible signs of internal trauma.



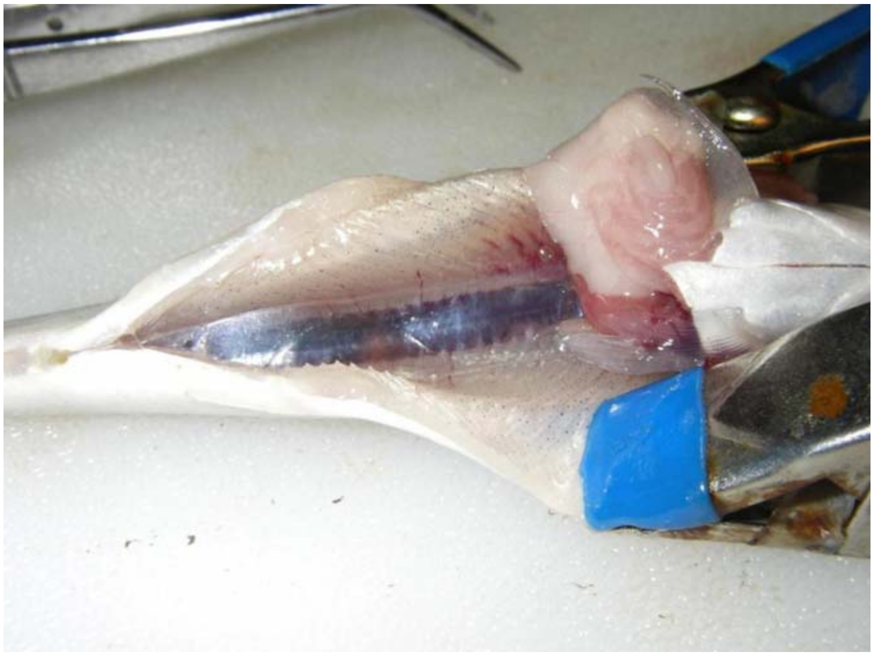
Photograph 11 - Batch 4 test fish with light internal hemorrhaging (Level 1) in the body wall near the heart.



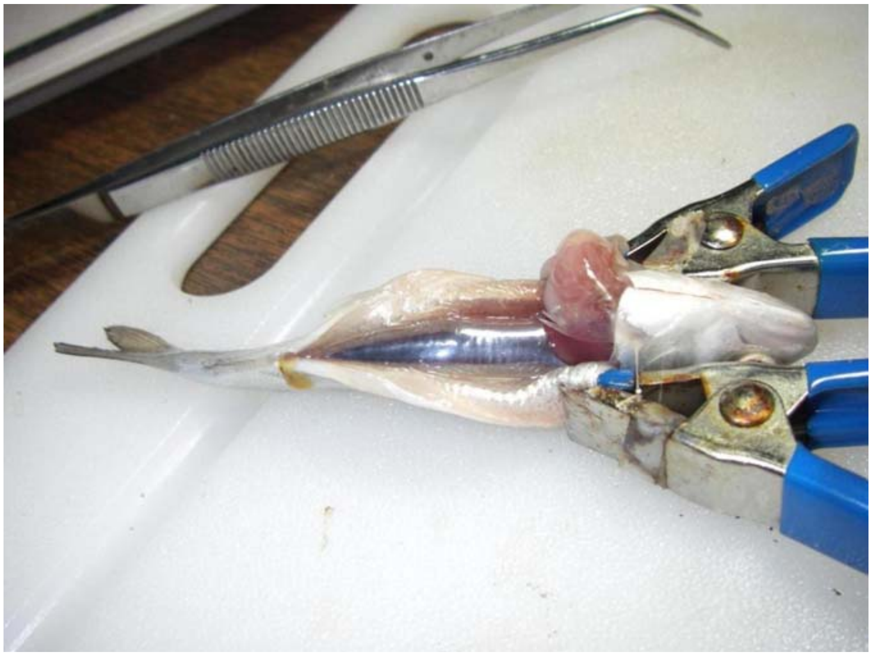
Photograph 12 - Batch 5 reference fish with light internal hemorrhaging at the base of the kidney.

Photograph 13 - Batch 5 reference fish with light internal hemorrhaging at the base of the kidney.

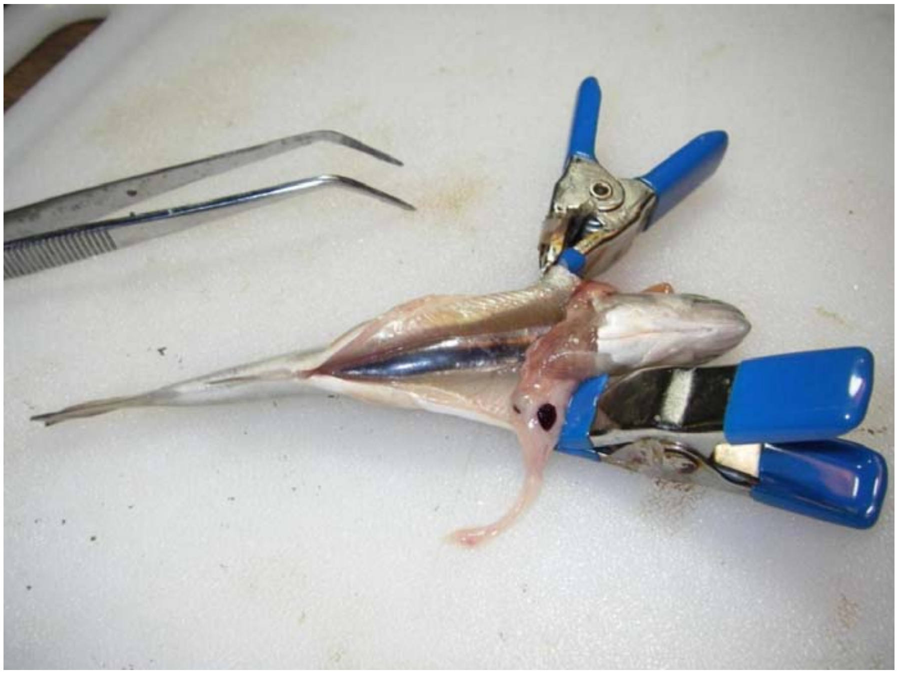
Photograph 14 - Batch 6 test fish with light internal hemorrhaging on dorsal portion of body wall.



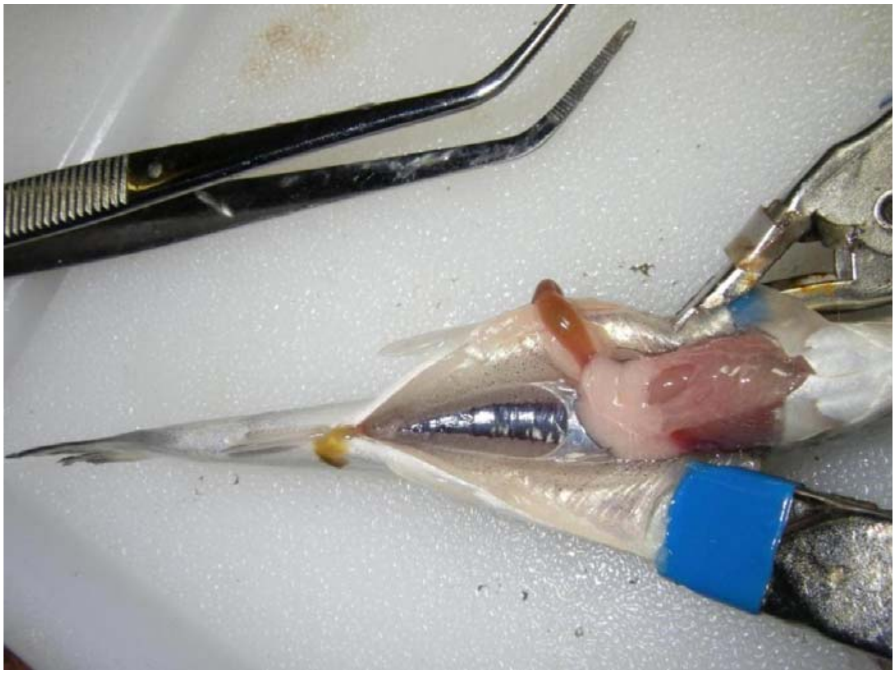
Photograph 15 - Batch 6 test fish with light internal hemorrhaging on the dorsal anterior of body wall.



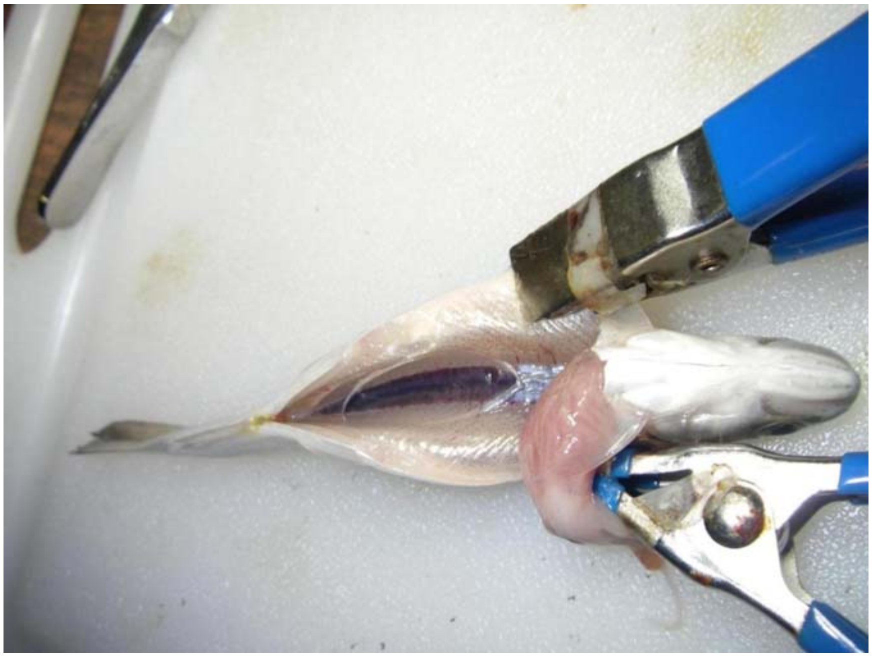
Photograph 16 - Batch 7 test fish - no visible signs of internal trauma.



Photograph 17 - Batch 8 test fish - no visible signs of internal trauma.



Photograph 18 - Batch 9 test fish - no visible signs of internal trauma.



Photograph 19 - Batch 10 test fish - no visible signs of internal trauma.

Photograph 20 - Batch 11 test fish - no visible signs of internal trauma.


Photograph 21 - Batch 12 reference fish - no visible signs of internal trauma.


Photograph 22 - Batch 13 test fish - no visible signs of internal trauma.

Photograph 23 - Batch 14 test fish - no visible signs of internal trauma.

Photograph 24 - Batch 15 test fish - no visible signs of internal trauma.

Photograph 25 - Batch 16 test fish - no visible signs of internal trauma.