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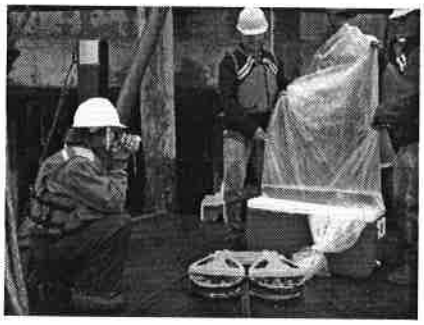
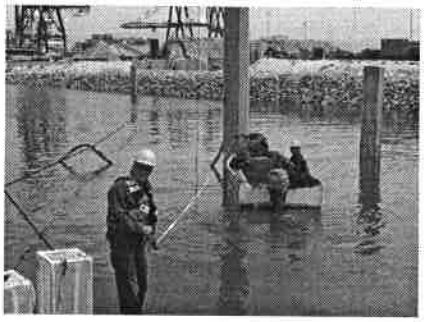
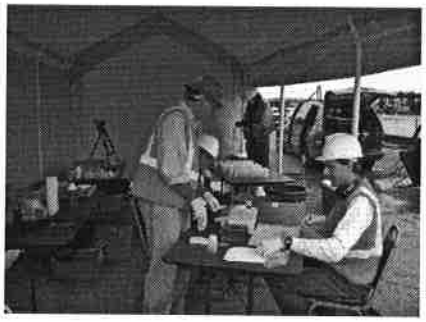
Strategic Environmental Consulting, Inc.

FINAL REPORT
Monitoring the Effects of Conventional Pile Driving on Three Species of Fish



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Executive Summary

An experiment testing the effects on fish of pile driving 2-foot diameter, jetted, concrete piles with a diesel hammer was conducted August 2, 3 and 4, 2004 at the construction site of Berth 22 in the Port of Oakland, California. Three local species of fish were used as test subjects; shiner perch, chinook salmon and northern anchovy. These three species represent three distinct types of swim bladder morphology and different anatomical relationships between the swim bladder and the inner ear.

Cages of fish were lowered approximately 25 feet deep, and held approximately 32 feet from the pile and exposed to pile driving pulses of underwater sound for approximately 3-4 minutes (>200 impulses). Immediately after they were brought up and carefully removed from the cage, their condition was observed and their behavior was recorded on video tape. Control batches of fish were also placed in a cage and lowered 25 feet deep and held at that depth for 10 minutes when there was no pile driving. After the treatment, the fish were sequentially anesthetized, and subjected to gross necropsy for external and internal indications of injury. Tissues samples were harvested and preserved in 10% neutral buffered formalin and sections were prepared routinely for histopathology. Tissue slides were stained with hematoxylin and eosin. Liver, swimbladder and kidney tissues from each fish were coded so that the exposure history was not known during sectioning or histopatholoic examination. Multiple sections through the heads of 19 northern anchovies (10 exposed and 9 controls) were examined for damage to the brain and inner ear.

The underwater sound pressure level, wave form and frequency were measured both in the cages and outside the cages during pile driving and during the controls. The piles were octagonal, steel reinforced concrete, 61 centimeters in diameter and up to 164 feet long with a center hole for injecting water at the tip during pile driving. The piles were driven by a Delmag D62-22® diesel pile driving hammer with a maximum rated energy of 223 kilojoules, resulting in exposures of the fish to average peak sound pressure levels of 185-189 dB re 1 Pa.

The results showed no significant difference in the behavior, near-term mortality rate, or tissue damage between the controls and the exposed fish. Statistical analysis comparing the few incidences of hemorrhaging indicated no statistically significant difference between controls and treatment groups. Statistical analysis of the histopathology evaluation of hemorrhaging in the brain and inner ear of anchovies indicated no statistically significant difference between treatment and control groups. The results indicate that pile driving with a diesel hammer on concrete piles does not result in injuries to adult northern anchovy, adult shiner perch or juvenile chinook salmon at a depth of approximately 25 feet, a distances as close as 32 feet from the pile where peak sound pressure levels are as high as 192 dB re 1μPa (SEL 166 dB re1μPa) for 3-4 minutes.

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Introduction

Background

Some types of pile driving are known to result in disturbance, injury and significant numbers of fish mortalities (Caltrans 2001, 2002, 2004, Shin 1995, Popper 2003, Longmuir et al. 2001). In response to these concerns, the regulatory community has developed a set of interim guidelines to protect fishery resources. The pile driving industry has been impacted by the requirement to provide mitigation whenever underwater noise from pile driving results in peak sound pressure levels over 180 dB re 1 μPa (decibel relative to one micro Pascal) (NOAA 2002). Mitigation can consist of either a bubble curtain or limits on the time of pile driving. Constructing, installing, operating and moving bubble curtains can increase the cost of a pile driving project (Fleming personal communications). If a bubble curtain is not used, then pile driving may be limited to a specific phase of a tide cycle a few hours a day, or to a seasonal construction window of a few months a year.

The pile driving industry has questioned the interim guidelines because of the absence of direct observation of adverse impacts to fish while using conventional, diesel hammers on concrete piles in the past. This report is a result of the efforts of a consortium, consisting of three pile driving contractors, a labor union and a project sponsor that collaborated in providing funding and technical support for the implementation of a study of the impact of conventional pile driving on three local species of fish.

Project Description

The Port of Oakland, California, located in central San Francisco Bay, is the United States' fourth busiest container port. See Figure 1. The Port is engaged in an extensive modernization effort including upgrading Berth 22, which was originally constructed in the 1920s and 1940s. The old piles supporting Berth 22 were removed and 590 new piles are being installed; 324 of these new piles are being placed below mean high water (MHW).

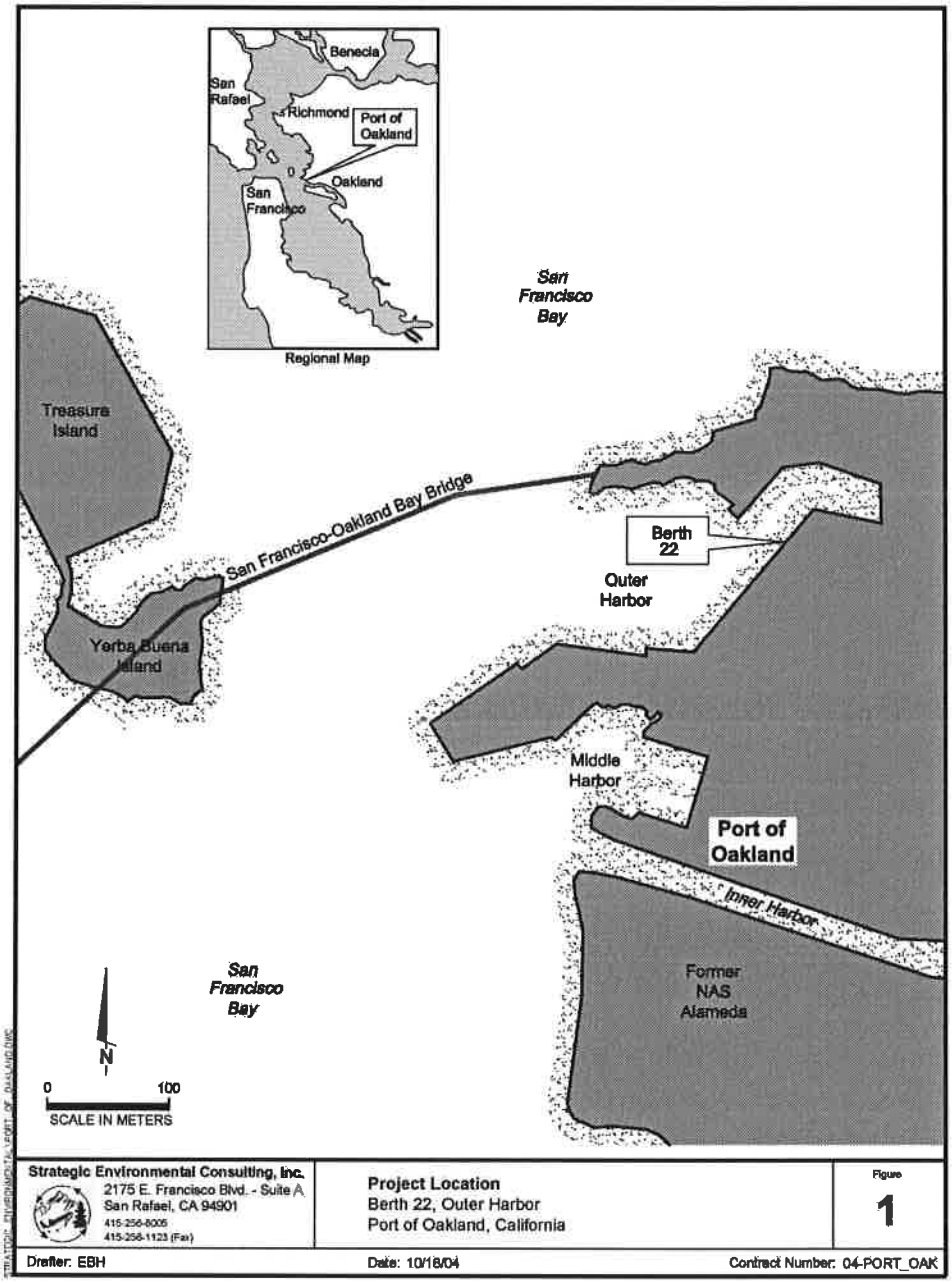


Figure 1. Project location in San Francisco Bay.

The Port of Oakland outer harbor opens into central San Francisco Bay, where water quality is dominated by conditions in the Pacific Ocean with influence from runoff from local

tributaries to San Francisco Bay, stormwater drains, and discharge from the Sacramento-San Joaquin Rivers. Salinity and temperature measurements at the site indicated there was no stratification by temperature or salinity at the time of the study.

The Oakland outer harbor and area adjacent to Berth 22 is hydroacoustically noisy being the locus of heavy industrial activity, construction, tug boat operations, and activities associated with loading and off loading large container vessels. The Berth 22 project area is located near the widening mouth of the Port of Oakland Outer Harbor which is approximately 225 meters wide opposite the Berth 22 project area. See Figure 2.

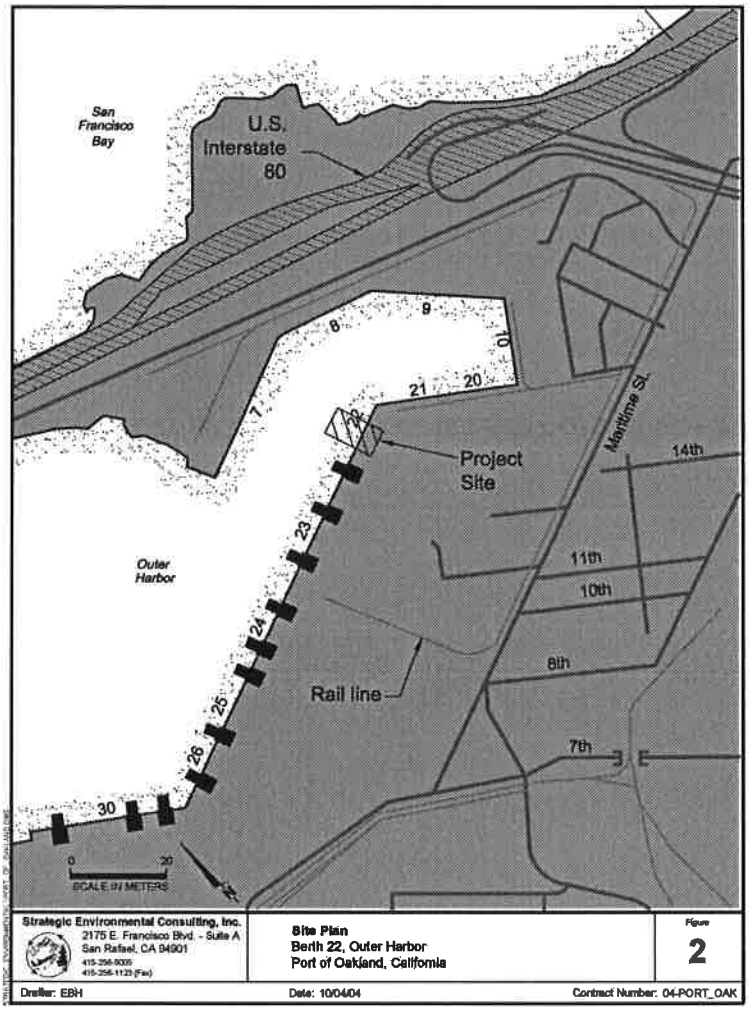


Figure 2. Site Plan.

Methods and Materials

Piles

The piles driven during this project were octagonal, steel reinforced concrete, 61 cm (2 ft) in diameter and up to 50 m (164 ft) long with a center hole for injecting water at the tip during pile driving. "Jetting" facilitates pile driving in a sandy substrate. Piles for supporting the new Berth 22 wharf were assigned rows with a unique alphanumeric identifier for each pile. See Figure 3. The "F" piles were entirely on shore and the "A" piles were in water approximately 13 m (42 feet) deep at mean lower low water (MLLW). The specific piles used in this study are listed in Table 1. The piles, pile arrangement, hammer and high pressure hose for jetting are shown in Figures 4, 5, and 7

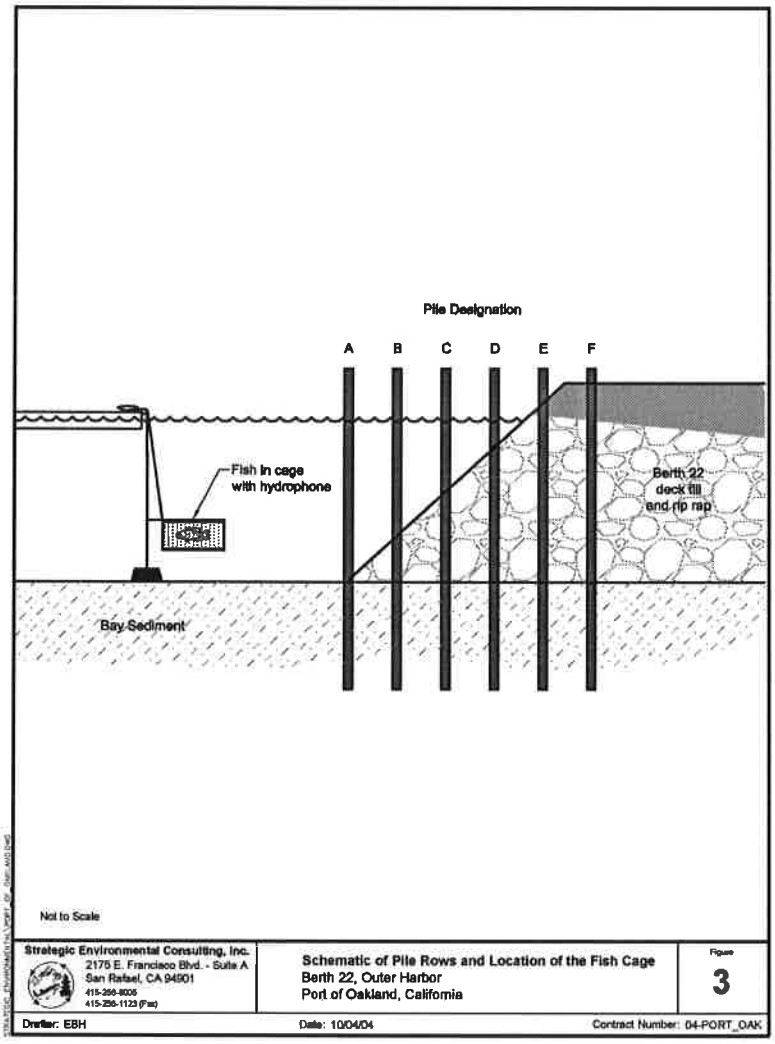


Figure 3. Schematic of the pile rows and location of the fish cage.

Table 1. Summary of pile, pile driving fuel setting, and length (William Partridge personal communication).

Date	Pile ID	Fuel Setting	Pile Length m
8/2/2004	277 B	2-3	40 m (130 ft)
8/3/2004	277 A	2-3	50 m (164 ft)
8/3/2004	284 B	2-3	40 m (130 ft)
8/4/2004	284 A	2-3	50 m (164 ft)

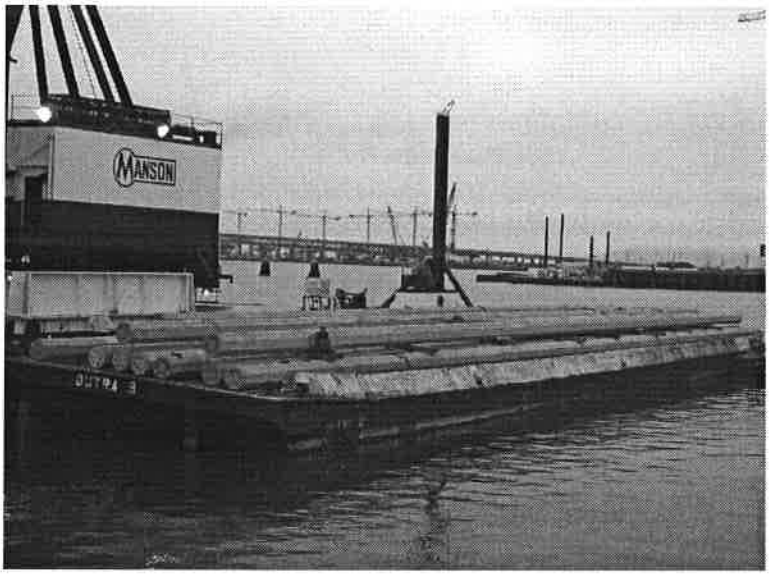


Figure 4. Concrete piles used in the study.

Hammer Energy

The piles were driven by a Delmag Model D62-22P® diesel pile driving hammer which has a ram weight of 60.97 KN, and a maximum rated energy of 223 kilojoules for the maximum fuel pump setting. The hammer was operated at a fuel pump setting of 2, increasing to a setting of 3 towards the end of the drive. Measurements of the hammer energy transferred to the pile on pile 277A, using a Pile Driving Analyzer (Pile Dynamics Inc. Model PAK) with two vertical accelerometers and two strain transducers attached to the pile near the top (Abe personal communications). The average energy delivered to the pile for the first 10 blows was 27.4 Kilojoules (20.2 kip-ft) or about 18% of the rated energy. Towards the end of the

drive after the fish had been removed from the water, energy transferred to the pile increased to 39.3 kilojoules (29.0 kip-ft) or approximately 27% of the rated energy for the reduced fuel pump setting. Pile driving with pile cushions significantly reduces the energy delivered to the pile (Abe and Thendean 1996).

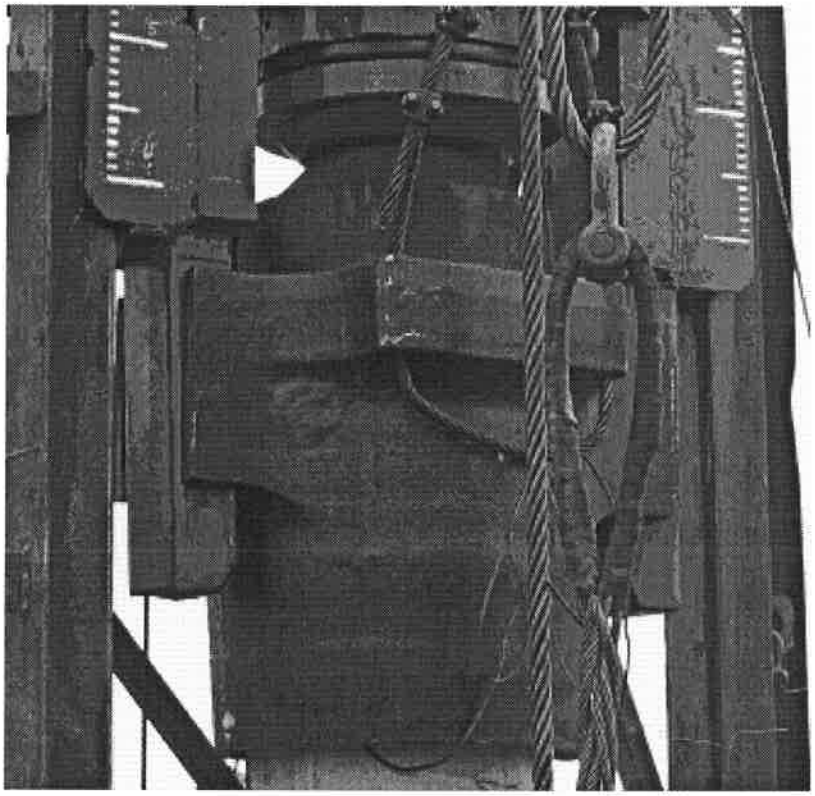


Figure 5. Helmet or hammer cushion seated on the pile is used to protect the hammer.

Helmet

The pile driving hammer assembly includes a "helmet" that fits over the top of the pile. See Figures 5 and 6. The helmet also contains a pile cushion which protects the pile top, and in this case consisted of 12 inches of plywood. The helmet or hammer cushion consists of alternating layers of aluminum and Micarta to protect the hammer ram and anvil. The hammer cushion used in this project consisted of three layers of aluminum approximately 1.25 cm (½ in) thick and three layers of micarta approximately 5 cm (2 in) thick.

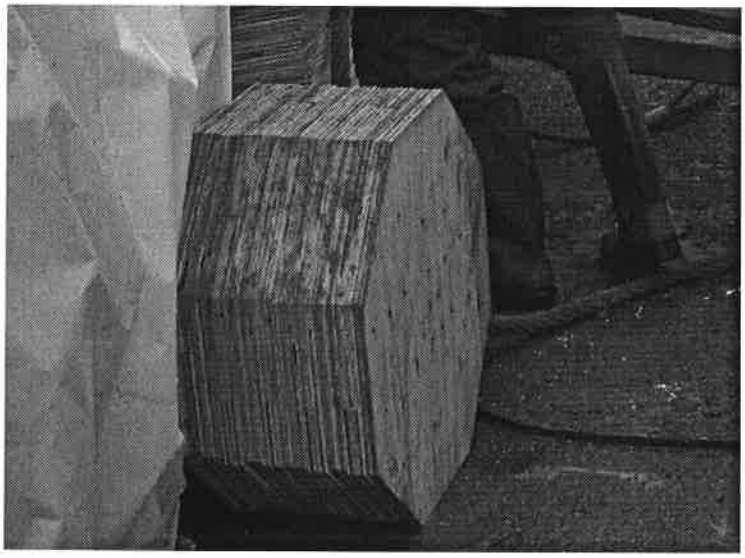


Figure 6. Uninstalled plywood cushion block 30.48 cm (12 in.) thick.

Figure 7. A pile being driven showing the hose used for "jetting".

Caged Fish Monitoring

Species

Fish with swim bladders can be broadly categorized into three different groups: hearing specialists, hearing non-specialists with a tube from the gas bladder to the gut (physostomous), and hearing non-specialists without a tube from the gas bladder to the gut (physoclistous). The three species selected for this study, chinook salmon *Oncorhynchus tshawytscha*, northern anchovy *Engraulis mordax* and shiner perch *Cymatogaster aggregata* represent these three main swimbladder-inner ear systems and generally represent the species commonly found in San Francisco Bay.

Salmon

Fall-run chinook salmon is an anadromous species, native to California. Chinook were selected for this study to represent all salmonids that use San Francisco Bay as a migratory corridor in moving to and from the spawning grounds in Bay tributaries and rearing in the Pacific Ocean. In addition to chinook salmon, steelhead (*Oncorhynchus mykiss*) also use San Francisco Bay as a migratory corridor. Salmonids are physostomous, having a connection between the swim bladder and the gastrointestinal tract. Through this connection, the gas bladder can be partially deflated. They are considered hearing generalists because they do not have a connection between the swim bladder and the inner ear. Consequently they are comparatively insensitive to underwater sound compared to hearing specialists (Stober 1969, Abbott 1973, Popper 1997). Though they are comparatively insensitive to most underwater sound, salmonids can detect very low frequency (10Hz) sound and show a strong avoidance response to a 10 Hz pulse up to several meters away (Knudsen 1997).

Juvenile Fall-run chinook salmon were obtained from the California Department of Fish and Game (CDFG) Nimbus hatchery on June 28, 2004, where they were being reared under freshwater conditions. They were transported to the fish holding facility at the Romberg Tiburon Center where they underwent smoltification. They were incrementally acclimated to salt water over a 48 hour period and kept in a tank with chilled, recirculated San Francisco Bay water until the time they were to be used in this study.

Perch

Shiner perch were selected because they are physoclistous, with a closed swim bladder, a characteristic of many species of fish that are recreationally and commercially important such as striped bass *Roccus saxatilis* and rockfish (Sebastes sp) (Moyle and Cech 2000). They are also relatively easy to keep alive in small enclosures compared to other wild species, and they are readily available through a local bait dealer. Shiner perch are native to San Francisco Bay and have been an important element in the California recreational fishery for many years (Karpov et al. 1995).

Shiner perch and similar species of surfperch may be one of the main groups of fish impacted by pile driving because they tend to aggregate around physical structures such as piers and

docks and many have been seen floating to the surface around other large pile driving operations in San Francisco Bay when there were no bubble curtains in operation (Caltrans 2002, 2004). There is no available audiogram for shiner perch. The European perch *Perca fluviatilis*, response to underwater sound has been described by Wolff (1967).

Anchovy

The northern anchovy has historically been the most abundant species found in San Francisco Bay (Goals Project 1999) and one of the main species impacted by pile driving as indicated by the number picked up by gulls around large pile driving operations when there was no bubble curtain in operation (Caltrans 2001, 2004). Anchovies are physostomous and also have a direct link between the swim bladder and the inner ear via two capillary tubes (O'Connell 1955). The tubes end in sacs directly adjacent to the inner ear termed auditory bullas. This arrangement is found in all clupeiform fishes, such as Pacific herring *Clupes harengus*, American shad *Alosa sapidissima*, and Pacific sardines *Sardinops sagax caeruleus* all of which are found in San Francisco Bay. The anchovy swim bladder is divided into an anterior and posterior chamber with a muscular septum in between that may regulate the pressure in the capillary tubes as the fish changes depth (O'Connell 1955). There is no audiogram available for the northern anchovy but it is undoubtedly a hearing specialist as are all clupeids, though its hearing ability is probably limited to frequencies less than 4 kHz (Mann et al. 2001).

Anchovies are notoriously difficult to use in confined studies. For example, a hearing study on the bay anchovy *Anchoa mitchilli* noted that it was only possible to keep them alive in a tank for 15 minutes (Mann et al. 2001).

Appendix A shows the results of an independent holding/transport study conducted in September 2004 with four batches of anchovies held in large plastic bags charged with oxygen and held in coolers (Igloo® 90 liter) without exposure to pile driving. For the first few hours after they were picked up from the bait dealer they swam around slowly. But after approximately 6 hours there was an increase in the rate of anchovy mortality and approximately 37% died by the end of 7 hours and approximately 77% died by the end of 8 hours.

Fish Holding Facilities

Prior to being used in the study, the perch and salmon were held in 1,800-liter (480-gallon) custom-made fiberglass round tanks at San Francisco State University's Bay field station, Romberg Tiburon Center for Environmental Studies (RTC). The RTC Bay water supply is drawn directly from an intake pipe 3 meters from the surface of the Bay. The daily salinity, turbidity and temperature régime in the tanks reflected the salinity and turbidity in central San Francisco Bay. Due to the high water temperature during July, the tank with the salmon was cooled to maintain a temperature of 11-12 ^{0}C and the exchange rate was reduced to about 4 water exchanges per day.

Fish Handling Procedures

Chinook were transported from the Nimbus fish hatchery in oxygen-filled bags placed in a large insulated cooler. A similar process was employed for transporting shiner perch from Loch Lomond Live Bait in San Rafael to RTC. Newly captured perch were anesthetized with

tricaine (MS222) and their head and gill chambers were quickly inspected for injuries and parasitic isopods. Injured fish were discarded, the isopods were removed and the fish were transported to the RTC holding facility in oxygenated plastic bags. The anchovies required for each day's field work were purchased on each of the days that they were to be used for the study from J&P Bait in San Francisco. The fish handling strategy emphasized pouring the fish from container to container in contrast to catching them with nets and placing them in the next container. Every possible effort was made to prevent the fish from pummeling each other and losing scales from beating their tails against the nets. Fish were placed in large plastic bags with water in the bottom and then poured out of the bags into the cage or tanks. The fish were transported in bags of water placed in 90-liter coolers with the lids down to minimize visual stimuli.

Cage and Deployment System

Three cages were constructed of 2.5-centimeter diameter PVC pipe with dimensions of 33 x 33 x 81.3 centimeters with 6.3-millimeter smooth nylon mesh netting sewn to fit snugly over the frame. The end of the net was elongated so that it could be tied with a slip knot so the fish could be poured into and out of the net cage. The PVC pipe had numerous 0.3-centimeter holes to allow air to escape from the frame when it was submerged. Two 61-centimeter long sections of steel rebar, 1-centimeter in diameter were inserted inside the bottom tubes of the frame to give the net frame weight and keep the bottom sections down when in the water. Each cage frame had a harness with a snap swivel. The snap swivel was used to attach the cage harness to a strong anchor line deployed off of the floating work platform. Each anchor line was attached to a concrete-filled bucket weighing 30 kilograms. The anchor line helped keep the cage at a constant depth even in very strong tidal currents.

A floating work platform was positioned 10 meters from the pile and three anchor lines were lowered to the bottom to hold the cages in position irrespective of the tidal currents. See Figure 9. Before pile driving started, a technician lowered one of the fish cages half way into the water, keeping the open end up; the bag of fish were lowered into the cage and upended pouring the fish into the cage water. The end of the cage net was tied off with a quick release slipknot, and the cage was lowered to the pre-determined depth of 8 meters and held in place by a tether line.

Figure 8. Measuring the distance from the pile to the cage.

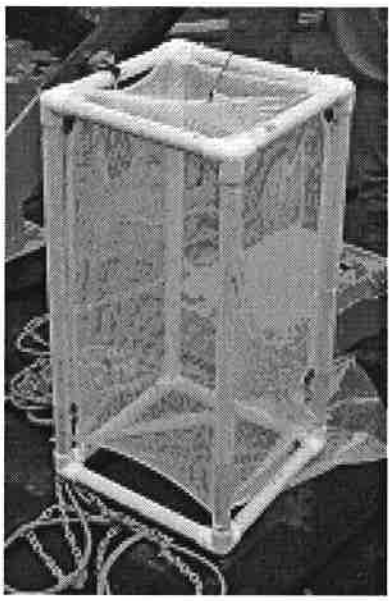


Figure 9. Cage with the hydrophone inserted through the mesh at the top end of the. cage

Figure 10. Retrieving the cage with the cage retrieval net.

The time was noted at the moment the fish were poured into the partially submerged cage. It typically took about a minute and half to get the cage tied up, turned around and dropped to depth. The time at depth was recorded and then the time at the surface during retrieval, was also recorded. The "fish pouring" method was used throughout the retrieval process. Retrieving the fish from the cages required the use of a large, specially-designed cage retrieval net that supported a large, perforated plastic bag. The cage retrieval net completely surrounded the cage. See Figure 10. The entire cage with the fish in the water was opened by loosening the slipknot and the fish swam into the large perforated plastic bag as the cage was lifted out of the water. Then the large perforated bag full of fish and water was upended into the water-filled transport bag in the transport cooler. The transport bag was charged with oxygen and the cooler lid was closed. Then the coolers were carefully transported to the field laboratory site for necropsy. The cooler was checked at least once every two hours to ensure that the plastic transport bag was not leaking and to verify that the fish were not showing signs of low dissolved oxygen stress. Fish exposure data was recorded on forms printed on water-resistant paper. The actual number of pile strikes was counted and recorded.

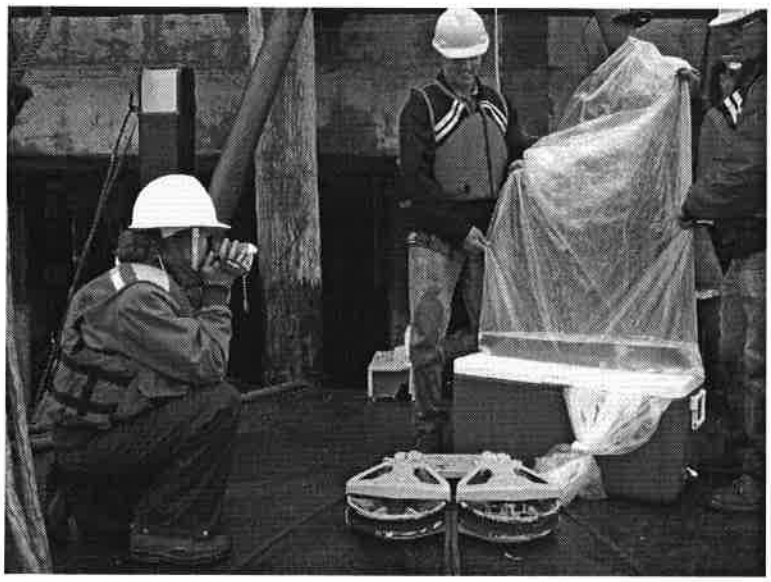


Figure 11. Video documentation of post exposure behavior.

Video Documentation of Behavior

Immediately after the fish were brought up and poured into the transport bag, their swimming behavior was digitally recorded for approximately one minute. See Figure 11. Later, the video tape was examined for indications of abnormal behavior. The treatment groups and

control groups were scored simply as the number of individual fish that exhibited abnormal behavior during that one minute time frame. Abnormal behavior consisted of a fish lying on its side, swimming upside down, rolling over, or erratic bursts of swimming. These types of abnormal swimming behavior had been noted in monitoring pile driving impacts on fish on the Benicia-Martinez Bridge and the Bay Bridge (Caltrans 2004).

Pile Driving Exposure

Pile driving started as soon as all the cages were at depth. The fish were exposed to the hydroacoustic impulse from continuous pile driving for at least 200 pile strikes, or approximately four minutes. The first group of fish was exposed to approximately 400 blows. The 200-blow exposure was subsequently selected because pile driving was typically not continuous after the first 200 blows due to the need to make adjustments to the pile alignment rigging as the length of the pile in the pile guide frame became shorter. The controls were placed in cages using the same procedures as the treatment groups and left at 8-m in depth for 10 minutes when there was no pile driving.

Hydroacoustic Monitoring

During fish exposure and during the control periods, sound measurements were made using G.R.A.S. CT10 hydrophones with PCB in-line charge amplifiers (Model 422E13) and PCB Multi Gain Signal Conditioners (Model 480M122). The signals were fed into Larson Davis Model 820 Integrating Sound Level Meters (SLM) Type 1 and Sony Model TCD-D100 Digital Audio Tape Recorders (DAT). The multi gain signal conditioner provided the ability to lower or raise the signal strength so that measurements could be made within the dynamic range of the instruments used to analyze the signals. The unweighted peak sound pressure level (SPL) and root-mean-square average sound pressure levels ($RMS_{impulse}$) were measured "live" using the SLM in the field. The $RMS_{impulse}$ values were measured live using the impulse exponential time weighting (35 msec rise time) function of the SLM. Subsequent analyses of the acoustic impulse based on the DAT recordings were conducted with a Larson Davis Model 3000 Real Time Analyzer (RTA) for narrow-band and waveform analyses.

The hydroacoustic measurement systems were calibrated prior to use in the field with a G.R.A.S. Type 42AA Pistonphone and hydrophone coupler. The pistonphone coupler system produces a continuous 145.3 dB re 1 µPa tone at 250Hz. The tone was then measured by the SLM and recorded onto 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 re 1 µPa of the calibration levels. The pistonphone output was certified at an independent facility. Underwater sound measurements were made in the cage with the fish, and with a reference hydrophone a few meters outside the cage. See Figure 12. In addition, measurements were made independently 100 meters southeast of the pile being driven.

Hydroacoustic Reporting

A variety of methods are used here to describe the characteristics of the underwater sound measured. See Appendix B. Figures B-1 through B-9 depict a trace of the wave form

showing the under pressure and over pressure as a function of time illustrates many features of a single pile driving hydroacoustic event. The peak pressure is the highest absolute value of the measured waveform. The RMS level is determined by analyzing the waveform and computing the average of the squared pressure over the time that comprised the portion of the wave form containing 90% of the sound energy (Richardson et al 1995). A third figure illustrates the frequency of the sound in 1/3 octave band widths up to 2500 Hz.

Necropsy Procedure

Gross Necropsies were performed at the Port of Oakland, on a pier overlooking the pile driving construction site. Fish were killed with an overdose of anesthesia (MS-222, Finquel®, approximately 300 mg/L) and by exsanguination during the necropsy. All the necropsy data is located in Appendix C. Time from the end of exposure to the beginning of the necropsy (post-exposure hold time) varied for each species:

1. Chinook salmon (29 to 181minutes)
2. Northern anchovy (14 to 99 minutes)
3. Shiner perch (61 to 225 minutes)

The anchovies were generally selected for necropsy before the other species because they were the most sensitive to handling and confinement stress.

Immediately after each fish was anesthetized, it was weighed, measured (standard length), and examined for external lesions. All were assigned a unique number in the order in which they were subjected to necropsy:

1. Chinook salmon (04POS-1 through 04POS-72)
2. Northern anchovy (04POA-1 through 04POA-65)
3. Shiner perch (04POP-1 through 04POP-67)

All lesions were recorded on a unique data sheet for each fish. Each fish was placed on its right side for necropsy. To minimize internal bleeding during the necropsy, the first cut on each fish was a full-thickness transverse section just caudal to the anus. Then the left operculum was removed, and the left lateral abdominal wall was cut from the pectoral girdle to the anus. The body wall was removed from the heart and liver by cutting the transverse septum to the midventral line. Finally, the left lateral body wall was removed by making a midventral cut from the pectoral girdle to the anus. Liver, kidney, and swimbladder were examined for hemorrhage and any other significant lesions. Organs were preserved in 10% neutral buffered formalin. The kidney and swimbladder were removed as part of a transverse body wedge that also included spinal cord, vertebrae, skeletal muscle, and skin. For northern anchovy only, the head was removed by making a transverse section at the level of the operculum; dorsal skin and bone were removed, and the remaining head tissue was preserved in 10% neutral buffered formalin.

Processing and Analyzing Organs for Histopathology

After the field part of the experiment was complete, preserved tissues were transported from the Port of Oakland to Central Histology Facility in Sacramento, California, arriving on August 5, 2004. Each fish was randomly assigned a unique number for processing and examination of all organs. Organs were trimmed to a thickness of less than 3 mm, any organs with bone were decalcified, and all tissues were processed routinely into paraffin, sectioned at 3 – 4 μm thickness, stained with hematoxylin and eosin, and coverslipped. For the northern anchovy, heads were processed from 19 fish for histopathology (04POA-2 through 04POA-20; 9 control fish and 10 hammer-exposed fish). The operculum, snout, and mandible were removed before processing to paraffin. The remaining tissues were processed routinely into paraffin and sectioned 3-4 μm thick at 200- μm intervals through the entire paraffin block. Each section was stained with hematoxylin and eosin, and coverslipped. The number of sections examined varied from 12 to 33 per head, depending on the size of the fish (some heads were as thick as 6 mm). All tissues were sectioned and examined in ascending numerical order based on the random number. In this way, neither the histotechnician nor the pathologist had knowledge of an organ's exposure history during sectioning, microscopic examination, and lesion scoring.

Slides were examined using a binocular light microscope, and changes in the tissues were entered directly into a computer spreadsheet (one row per fish). The most common changes were scored semiquantitatively on a scale from 0 (none), 1 (mild), 2 (moderate), or 3 (severe). Each lesion was classified and assigned a severity score based on standard criteria, and good examples of each lesion-score combination were clearly identified. See Appendix C, Table C-1. This type of analysis has been used in several peer-reviewed publications describing results from both laboratory- and field-based studies (Marty et al. 1998; Hedrick et al. 1999; Marty et al. 1999; Hedrick et al. 2000; Marty et al. 2003a; Marty et al. 2003b).

After all organs were examined and scores assigned (11-10-04), exposure codes for each fish were revealed and fish were sorted based on exposure history. For each lesion and type of exposure (hammer or control), summary statistics were calculated for basic comparisons (count, mean, and standard error).

Experimental Design

Each treatment group consisted of a cage of approximately 9 fish of the same species exposed to at least 200 pile strikes at a horizontal distance of approximately 10 meters (32 feet) and a depth of 8 meters (24 feet) below the water surface. There were four replicates of the pile driving treatment for each of the three species, and four control groups for each species. Procedures for control groups were identical to the procedures for the treatment groups with the exception that the control groups were submerged for a minimum of 10 minutes in the cage in the water when there was no pile driving. The sample size goal for each species was 72 fish. Because of mortality independent of the experimental protocol, only 65 northern anchovy and 67 shiner perch were available for necropsy and histopathology. A total of 204 fish were provided for necropsy and histopathology examination:

1. 72 Chinook salmon *Oncorhynchus mykiss* (35 exposed, 37 controls)

2. 65 northern anchovy *Engraulis mordax* (32 exposed, 33 controls)
3. 67 shiner perch *Cymatogaster aggregata* (36 exposed, 31 controls)

Variables to be analyzed were abnormal swimming behavior immediately after the fish were brought up, near-term mortality, hemorrhaging and a summary histopathology score.

The null hypothesis was: mean response$_{treatment}$ = mean response$_{control}$.

Two of the controls were submerged before the pile driving treatments and two were submerged after the pile driving treatments to minimize, or at least balance, the effects of holding time on the experiment. The formal design is a nested ANOVA discussed further in Appendix D.

Results

The fish were exposed to at least 200 pile driving impulses (201-400) with average peak sound pressure levels ranging from 185-189 dB re 1 μ Pa. See Figures 12-15 and B1-B9. The main data elements are summarized in Table 2 below. Peak sound pressure level is the highest absolute value of the measured wave form and can be a negative or positive pressure peak (Caltans 2004). The average peak is a calculated average of the peak values of a number of selected waves during a prerecorded interval selected for analysis. The highest peak in a series of impulses recorded was 194 dB re 1 μPa for pile 284 A. But the average peak is considered more representative of the exposure level for the treatment groups.

The measurement of the background noise levels was not a project objective because the instrumentation was tuned to capturing very loud noises. Background noise levels without a specific event or source were probably on the order of 155 dB re 1 μPa peak (Reyff personal communication). People moving around on the raft and heavy equipment created noticeable noise that contributed to the background noise level in the area. Figure 12 shows a background level of 133 dB re 1 μPa RMS at 3:17 when there was no pile driving.

Behavior and Near-Term Mortalities

The results from the review of the digital tapes are listed in Table 2. Visual examination of the behavior after exposure to pile driving and subsequent evaluation of the video recordings of their behavior indicated no abnormal swimming behavior in the perch and salmon. There were also no near-term mortalities in the perch and salmon treatment groups. There was no difference between the behavior of the perch, salmon and anchovies treatment groups and control groups. A total of five anchovies in two of the pile driving exposure groups exhibited abnormal swimming behavior and five anchovies in two of the control groups exhibited abnormal swimming behavior. There were two near-term mortalities in one of the anchovy treatment groups. The abnormal swimming behavior and near-term mortalities in the anchovies were apparently due to the prolonged pre-test holding time (See Appendix A). Dead and moribund anchovies were removed from the transport bags before exposure. In spite of the pile driving and industrial activity in the area, schools of small fish were observed on several occasions exhibiting the upward dart-and-turn feeding behavior typical Bay area pelagic fish. On at least one occasion they were observed to be directly under the

raft supporting the cages and thus they were as close to the pile as the caged fish. Attempts to catch and identify these small fish were unsuccessful.

Hydroacoustic Monitoring Results

Pile 277B, August 2, 2004

The first set of measurements and fish exposures to pile driving sounds were conducted on August 2, 2004 when Pile 277B was driven. Measurements were made at 10-m from the pile in one of the three cages containing fish. Measurements were also made at a reference position outside of the cage (at 10-m from the pile), an unattended position 100-m northeast of the pile, and an unattended position 100-m southwest of the pile. All hydrophones were positioned at a depth of about 8-m, where water depths were about 10-m to 13-m deep. The DAT recorder for the 10-m fish cage and reference position failed; and therefore, recordings at 10-m from the pile were not made. Continuous SLM measurements were successfully made at all positions. Ambient conditions were measured after pile driving when "control" fish were placed in the water near the pile. Results are shown in Figure 12.

At 10-m, sound pressure levels ranged from about 183 dB re 1 µPa peak (173 dB re 1 µPa RMS) at the beginning of the drive to 191 dB re 1 µPa Peak (178 dB re 1 µPa RMS) around the middle of the drive. Levels were fairly consistent for the last 5 minutes of the approximate 10-minute drive session. The RMS level was about 10 to 12 dB re 1 µPa lower than the peak sound pressure and the SEL was about 10 dB re 1 µPa lower than the RMS pressure level. Fish were exposed to average peak sound pressure levels of 188 dB re 1 µPa peak, 176 dB re 1 µPa RMS, and approximately 166 dB re 1 µPa SEL. At the distant positions, sound pressure levels were 15 to 20 dB re 1 µPa lower. There may have been some shielding between the 10-m and 100-m southwest positions due to the angular configuration of the dock. Levels 100-m northeast were about 5 dB re 1 µPa higher than those measured at 100-m to the southwest.

Pile 277A, August 3, 2004

Pile 277A was driven during the early afternoon of August 3, 2004. Measurements were made inside two of the fish cages, at a reference position outside the cage, and at the 100m southwest position from the dock. Fish were exposed to approximately 200 impulses (approximately 3 minutes of driving). Pile driving was suspended until all fish had been removed from the water. Underwater sound measurements continued at the reference positions (10-m from the pile) and at the 100-m distant position when pile driving resumed. Ambient conditions were measured in the morning when control fish were placed in the water near the dock prior to pile driving. Results are shown in Figure 13.

During the entire driving period, sound pressure levels at 10-m from the pile ranged from 182 dB re 1 µPa Peak (171 dB re 1 µPa RMS) to 190 dB Peak (176 dB re 1 µPa RMS). The SEL was about 165 dB re 1 µPa. During the period when fish were exposed (for the first 3 to 4 minutes of the nearly 30-minute drive), average sound pressure levels were 185 dB re 1 µPa Peak, 173 dB re 1 µPa RMS and 163 dB re 1 µPa B SEL. Sound pressure levels were highest near the middle and end of the drive. Average sound pressure levels at 100-m southwest were 167 dB re 1 µPa Peak, 156 dB re 1 µPa RMS and about 146 dB re 1 µPa

SEL. There may have been some shielding between the 10-m and the 100-m positions due to the angular configuration of the dock. Sound pressure levels were about 20 dB re 1 µPa lower at 100m southwest than at 10m from the pile.

Pile 284B, August 3, 2004

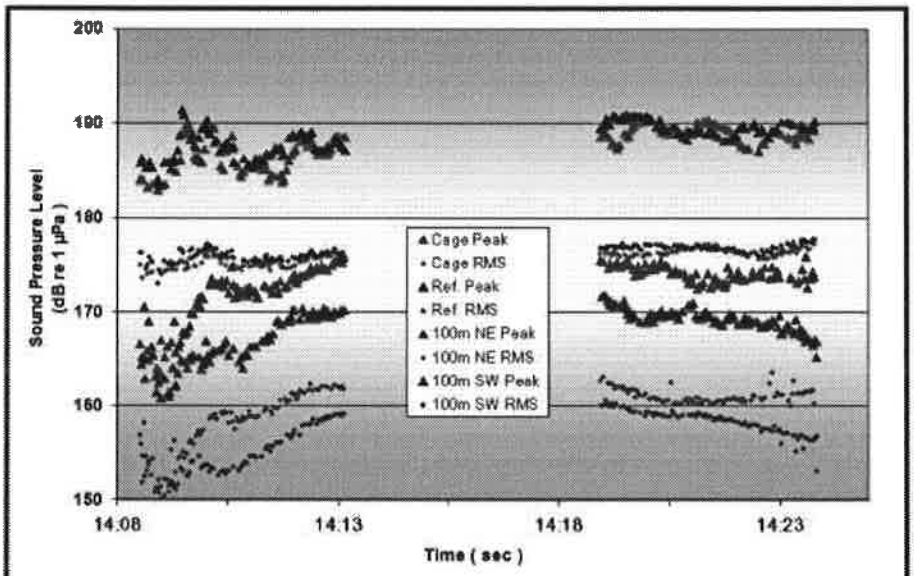
Pile 284B was driven late on the afternoon on August 3, 2004. Measurement distances were the same as for Pile 277A, which was driven earlier that day. This pile was installed further east than the other two piles that were driven previously. Results are shown in Figure 14.

During the entire driving period, sound pressure levels at 10-m from the pile ranged from 182 dB re 1 µPa Peak (171 dB re 1 µPa RMS) to 190 dB re 1 µPa Peak (178 dB re 1 µPa RMS). The SEL was about 164 dB re 1 µPa. During the period when fish were exposed (for the first 3 to 4 minutes of the nearly 30-minute drive), average sound pressure levels were 186 dB re 1 µPa Peak, 176 dB re 1 µPa RMS and about 164 dB SEL. Average sound pressure levels at 100-m southwest were 174 dB Peak, 163 dB re 1 µPa RMS and about 152 dB re 1 µPa SEL. Sound pressure levels were highest near the beginning and end of the drive. Sound pressure levels were about 12 dB re 1 µPa lower at 100m southwest than at 10m from the pile.

Pile 284A, August 4, 2004

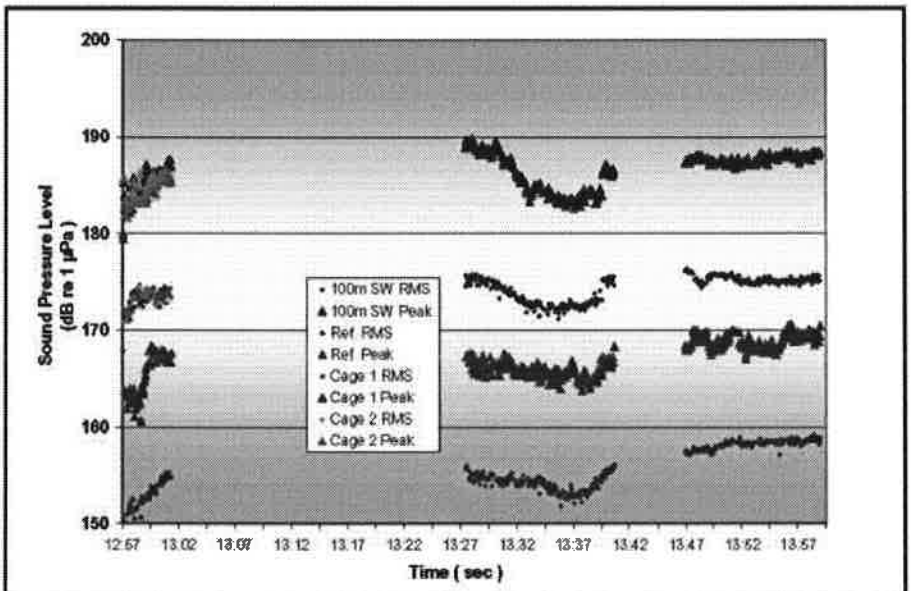
Pile 284A was driven during the morning of August 4, 2004. Measurement distances were similar to those made during the driving of Piles 277A and 284B. The 100m southwest position was further east, near the edge of the existing dock. Ambient conditions were measured in the morning when control fish were placed in the water near the dock prior to pile driving. Results are shown in Figure 15.

During the entire driving period, sound pressure levels at 10m from the pile ranged from 183 dB re 1 µPa Peak (170 dB re 1 µPa RMS) to 192 dB re 1 µPa Peak (177 dB re 1 µPa RMS). The SEL was about 166 dB re 1 µPa. During the period when fish were exposed (for the first 3 to 4 minutes of the nearly 25-minute drive), average sound pressure levels were 188 dB re 1 µPa Peak, 176 dB re 1 µPa RMS and about 167 d re 1 µPa B SEL. Average sound pressure levels at 100m southwest were 174 dB re 1 µPa Peak, 162 dB RMS and about 152 dB re 1 µPa SEL. Sound pressure levels were highest near the beginning and end of the drive. Sound pressure levels were about 14 dB re 1 µPa lower at 100m southwest than at 10m from the pile.



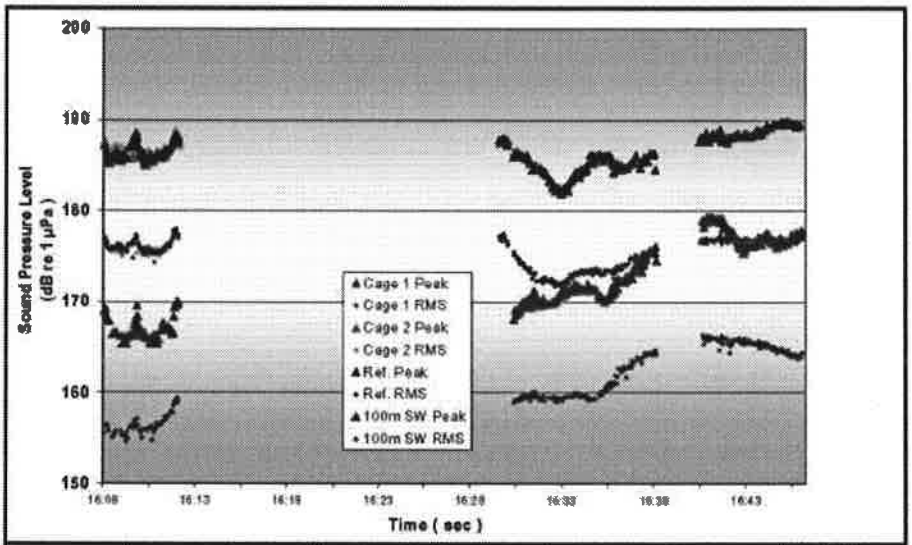
Time	Position	Peak		RMS		SEL
		Average	Range	Average	Range	Typical
Fish in water						
14:08 - 13 and 14:19 - 23	10m -Chinook	188	183 - 191	176	173 – 177	--
	10m Reference	188	183 - 191	176	173 – 178	--
	100m Southwest	168	161 - 172	157	151 – 161	--
	100m Northeast	173	161 – 177	160	150 – 167	--
Fish Control Measurements – ambient conditions						
15:17 - 22	Fish cage	--	--	133	124 - 145	--

Figure 12. Measured Sound Pressure Levels for Pile 277B (reported in dB re 1 µPa).



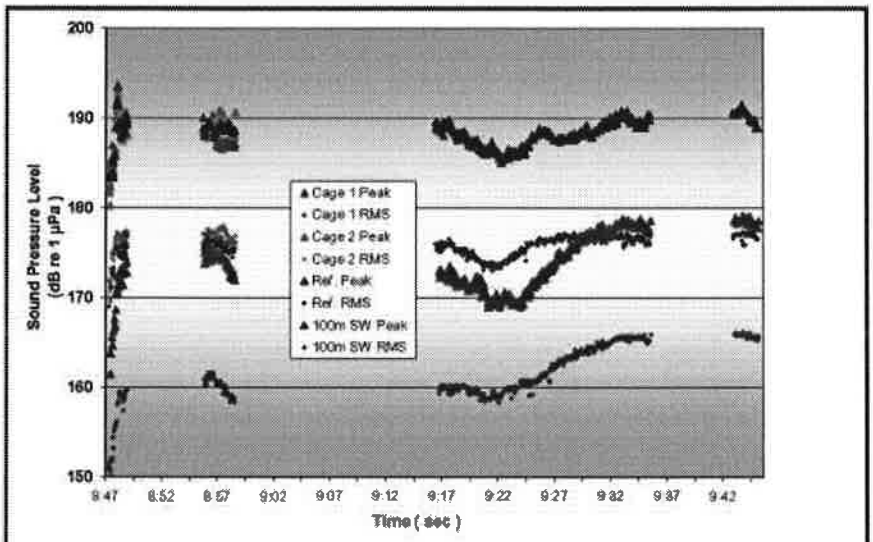
Time	Position	Peak		RMS		SEL
		Average	Range	Average	Range	Typical
Fish Control Measurements – ambient conditions						
10:33–39	Fish cage	--	--	132	123 - 144	--
Fish in Water						
12:57 to 13:02	10 m – Chinook	185	182 - 187	173	171 - 175	163
	10 m – Perch	185	182 - 187	173	171 - 175	163
	10 m – Reference	185	183 - 188	173	171 - 175	163
	100 m - Southwest	165	161 - 168	153	150 - 155	145
Fish out of Water						
13:29 - 47	10 m – Reference	187	183 - 190	174	171 - 176	165
	100 m - Southwest	167	164 - 171	156	152 - 159	146

Figure 13. Measured sound pressure levels for pile 277 A.



Time	Position	Peak		RMS		SEL
		Average	Range	Average	Range	Typical
Fish in Water						
16:08-12	10 m – Chinook	186	185 - 188	176	174 - 178	164
	10 m –Perch	187	185 - 189	176	175 - 178	165
	10 m – Reference	186	185 - 189	176	175 - 178	164
	100 m - Southwest	167	165 - 170	156	155 - 159	146
Fish out of Water						
16:30 - 40	10 m – Reference	186	182 - 190	175	171 – 178	164
	100 m - Southwest	174	168 - 179	163	159 – 166	152

Figure 14. Measured sound pressure levels for pile 284B.



Time	Position	Peak		RMS		SEL
		Average	Range	Average	Range	Typical
Fish in Water						
8:47 – 8:49 and 8:55 – 9:00	10 m – Chinook	188	183 – 194	176	172 – 178	168
	10 m – Anchovy	189	180 - 193	176	170 – 178	167
	10 m – Reference	188	183 - 192	175	169 – 177	166
	100 m - Southwest	172	161 - 176	159	150 – 162	150
Fish out of Water						
16:30 - 38 and 16:40 - 46	10 m – Reference	188	185 - 192	176	173 – 177	166
	100 m - Southwest	174	169 - 179	162	158 – 166	152

Figure 15. Measured sound pressure levels for pile 284 A.

Table 2. Summary of data collected 8/2/04-8/4/04.

Exposure Treatment

TG ID	SPECIES	DATE	PILE ID	No.	TIME	NO. IMP.	PSPL	BEHAV.	MORT.	COMMENTS
1A1T	Anchovy	8/2/2004	277B	9	6hr 10min	400	191	0	0	
2A2T	Anchovy	8/3/2004	277A	10	5hr 51min	201	190	4	0	4 not swimming after exposure
2A4T	Anchovy	8/3/2004	284B	4	9hr 1min	201	190	0	2	5 dead removed prior to exp.
3A1T	Anchovy	8/4/2004	284A	9	2hr 40min	201	192	1	0	1 not swimming post exp
1C1T	Chinook	8/2/2004	277B	9	6hr 55min	400	191	0	0	
2C2T	Chinook	8/3/2004	277A	9	6hr 47min	201	190	0	0	
2C4T	Chinook	8/3/2004	284B	9	9hr 53min	201	190	0	0	
3C1T	Chinook	8/4/2004	284A	9	2hr 36min	201	192	0	0	
1P1T	Perch	8/2/2004	277B	9	6hr 50min	400	191	0	0	
2P2T	Perch	8/3/2004	277A	9	6hr 43min	201	190	0	0	
2P4T	Perch	8/3/2004	284B	9	9hr 47min	201	190	0	0	
3P1T	Perch	8/4/2004	284A	9	2hr 32min	201	192	0	0	

Control Treatment

1A2C	Anchovy	8/2/2004	n/a	9	7hr 16min	n/a	n/a	0	0	
2A1C	Anchovy	8/3/2004	n/a	10	3hr 5min	n/a	n/a	0	0	
2A3C	Anchovy	*8/3/2004*	*n/a*	*10*	*8hr 10min*	*n/a*	*n/a*	4	0	40% mortality in controls
3A2C	Anchovy	8/4/2004	n/a	9	4hr 7min	n/a	n/a	1	0	1 not swimming post treatment
1C2C	Chinook	8/2/2004	n/a	9	8hr 35min	n/a	n/a	0	0	
2C1C	Chinook	8/3/2004	n/a	9	4hr 28min	n/a	n/a	0	0	
2C3C	Chinook	8/3/2004	n/a	9	8hr 55min	n/a	n/a	0	0	
3C2C	Chinook	8/4/2004	n/a	9	4hr 13min	n/a	n/a	0	0	
1P2C	Perch	8/2/2004	n/a	9	8hr 10min	n/a	n/a	0	0	
2P1C	Perch	8/3/2004	n/a	9	4hr 51min	n/a	n/a	0	0	
2P3C	Perch	8/3/2004	n/a	9	8hr 40min	n/a	n/a	0	0	
3P2C	Perch	8/4/2004	n/a	6	2hr 46min	n/a	n/a	0	0	4 crushed and removed prior to exp.

Explanation of abbreviations in Table 2

TGID = Treatment group identification code
Species = Northern anchovies, chinook salmon or surfperch
Date = Date of exposure
Pile ID = Pile identification by number and row
No. = Number of fish in the treatment group
Time = Holding time before being used in the experiment
No. IMP. = Number of pile blows
PSPL = Peak sound pressure level measured dB re 1 μ Pa.
Behav. = Number of fish that exhibited abnormal swimming behavior during one minute
Mort. = Number of near-term mortalities

Necropsy and Histology Results

All the results of the gross necropsy and histopathology examinations are included in Appendix C. All three fish species, particularly the shiner perch and northern anchovy, had a variety of mostly minor lesions and parasites as might be expected in wild fish. Therefore, these fish were probably representative of members of their species in San Francisco Bay that might be exposed to pile driving. Hemorrhage was the lesion thought most likely to be associated with exposure to pile driving, and several fish had hemorrhage. See Table 3. Of the 13 fish with hemorrhage, seven were hammer-exposed and six were control fish: evidence that hemorrhage was more likely a result of handling or a pre-existing condition than it was a result of exposure to concrete pile driving. Thirty-six percent of the northern anchovies had gross reddening (vascular congestion or hemorrhage) in the snout.

One chinook salmon had hemorrhage in the liver (04POS-22, a control fish) that was described grossly as "7, 1-mm-diameter red foci on the liver." Sections of normal livers had small numbers of erythrocytes (= red blood cells) within blood vessels (Figure C-2), but the affected liver had distended and ruptured capillaries (= sinusoids) filled by abundant erythrocytes (Figure C-2). No northern anchovy or shiner perch had hemorrhage in the liver.

Swimbladder hemorrhage occurred in one chinook salmon, one shiner perch, and eight northern anchovy. The normal swimbladder (Figure C-3) is surrounded by small numbers of blood vessels. Hemorrhage was limited to the outside of the swimbladder (Figure C-4); in every fish the swimbladder lumen had no hemorrhage.

Hemorrhage in the brain or inner ear occurred in two of the 19 northern anchovies examined, and both were control fish. Both affected fish died before the necropsy began, and neither fish had gross lesions more severe than mild focal skin reddening in one of the two affected fish. Sections of the normal brain had small to moderate numbers of erythrocytes in the blood vessels around the brain, and the lumen of the semicircular canals of the inner ear were free of erythrocytes (Figure C-5). In fish with hemorrhage, erythrocytes surrounded cranial nerves at the base of the brain and partly filled the semicircular canals (Figure C-6). Examination of head sections from 19 northern anchovy yielded no lesions significantly related to pile driving exposure; therefore, heads from the remaining 46 northern anchovy

were not sectioned or examined (they are archived in physiologic saline), and standard criteria for head lesions were not established.

One hammer-exposed chinook salmon had severe hemorrhage in the spinal cord (04POS-1). None of the northern anchovy or shiner perch had hemorrhage in the spinal cord. Sections of normal spinal cord had small to moderate numbers of erythrocytes in blood vessels, and the spinal cord was free of bacteria (Figure C-7). In the fish with hemorrhage in the spinal cord, relatively large numbers of erythrocytes were scattered throughout the spinal cord, outside of blood vessels (Figure C-8). Small numbers of small basophilic structures amongst the hemorrhage, probably bacterial rods, provide evidence that the hemorrhage was present for at least 24 hours before the fish was sampled. The gross finding of a 5×6 mm focus of reddening around the ribs is consistent with trauma as the cause of hemorrhage in the ribs and the spinal cord. Focal hemorrhage in the ribs is more consistent with trauma from blunt force than with barotrauma.

Table 3. Comparison of gross and microscopic observations of hemorrhage in Chinook salmon (04POS-), shiner perch (04POP-), and northern anchovy (04POA-). Note hemorrhage is found in both controls and treatment fish.

Sample Number	Exposure history	Organ	Observation	
			Gross	Microscopic
04POS-1	Hammer	spinal cord	5×6 mm focus of reddening on right ribs (near where spinal cord examined) (fish died before necropsy started)	severe spinal cord hemorrhage with small numbers of bacteria
04POS-22	Control	Liver	hemorrhage in liver; not in swimbladder	hemorrhage in liver (Fig. C-2) and swimbladder
04POP-55	Hammer	liver and swimbladder	hemorrhage in abdominal cavity scored as visceral cavity, liver, and swimbladder hemorrhage	only skeletal muscle hemorrhage on "blind examination," but mild hemorrhage on ventral margin of swimbladder noted after exposure history revealed
04POA-5	Hammer	swimbladder	hemorrhage in swimbladder and visceral cavity; mild reddening near anal fin;	moderate swimbladder hemorrhage
04POA-11	Hammer	swimbladder	Normal	mild swimbladder hemorrhage
04POA-16	Control	Head	Mild focal skin reddening, site not recorded (fish died before necropsy started)	moderate hemorrhage at base of brain and in inner ear (Fig. C-6)
04POA-	Control	Head	normal (fish died before	moderate hemorrhage at

18			necropsy started)	base of brain
04POA-20	Control	swimbladder	Mild focal skin reddening, site not recorded	mild swimbladder hemorrhage
04POA-32	Hammer	swimbladder	Mild focal skin reddening, site not recorded	mild swimbladder hemorrhage
04POA-37	Hammer	swimbladder	normal (fish died before necropsy started)	moderate swimbladder hemorrhage (Fig. C-4)
04POA-42	Control	swimbladder	Mild focal skin reddening, site not recorded	mild swimbladder hemorrhage
04POA-49	Hammer	swimbladder	Mild focal skin reddening, site not recorded	mild swimbladder hemorrhage
04POA-64	Control	swimbladder	Mild focal skin reddening on snout (fish died before necropsy started)	mild swimbladder hemorrhage

Statistical Analysis of Hemorrhaging

As explained in Appendix D, the standard errors associated with the treatment means in the tables of Appendix C were not part of the experimental design, which was that of a nested analysis of variance (ANOVA). Nevertheless, it can be seen from inspection of the mean total scores in Table 4 below (half of which do not differ in the first decimal place) that no obvious differences exist between hammer and control groups as tabulated in Appendices C and D. The variable named GROSS is the sum of the gross necropsy scores seen in Appendix C. The variable HISTO is the sum of the histopathology scores in Appendix C. The variable named HISTO in Table 4 is the same as LESION in Appendix D. The scores were summed in order to approximate normality, but also to simplify the analysis and avoid multiple testing of possibly correlated injuries. Summaries of the ANOVAs (Tables 5 and 6) indicate no significant effect of pile driving.

Table 4. Mean summary scores for gross necropsy (GROSS) and histological lesions (HISTO).

	Anchovy	Salmon	Perch
GROSS			
hammer	3.0	1.9	2.0
control	3.4	1.9	2.0
HISTO			
hammer	10.7	9.5	8.4
control	10.0	9.6	8.4

Table 5. Nested ANOVA results for the sum of nine gross necropsy scores.

Source	Sum-of-Squares	Df	Mean-Square	F-ratio	P
Anchovy					
HAMMER	1.454	1	1.454	1.704	0.240
CAGE(HAMMER)	5.117	6	0.853		
Salmon					
HAMMER	0.021	1	0.021	0.133	0.728
CAGE(HAMMER)	0.953	6	0.159		
Perch					
HAMMER	0.003	1	0.003	0.002	0.969
CAGE(HAMMER)	11.662	6	1.944		

Table 6. Nested ANOVA results for the sum of 23 histological lesion scores.

Source	Sum-of-Squares	Df	Mean-Square	F-ratio	P
Anchovy					
HAMMER	5.629	1	5.629	2.79	0.146
CAGE(HAMMER)	12.103	6	2.017		
Salmon					
HAMMER	0.051	1	0.051	0.006	0.939
CAGE(HAMMER)	47.633	6	7.939		
Perch					
HAMMER	0.191	1	0.191	0.175	0.691
CAGE(HAMMER)	6.573	6	1.095		

Samples of anchovy heads from the first pile and the first control were also sectioned and examined for lesions in or near the inner ear (Appendix C). The three hemorrhage and vascular congestion scores (IEH, BSH, BSC) were added together as summarized here in Table 7. The obvious design in this part of the experiment is that of a one-tailed *t*-test of the null hypothesis that the mean score of the control group is greater or equal to that of the exposed (hammer) group. Since the mean score of the control group is indeed (apparently by chance) greater than that of the exposed group, there is no chance of rejecting the null, and the test was not performed.

Table 7. Summed anchovy head lesion scores (n is sample size, sd is sample standard deviation).

Group	n	Mean	sd
control	9	1.7	1.7
hammer	10	0.7	0.7

These results indicate the degree of injury in fish, as measured by these necropsy and histological scores, was not significantly affected by exposure to pile driving under the conditions of the test.

Discussion

There were no differences in behavior and near-term mortalities between the treatment group and the controls of shiner perch and chinook salmon (See Table 2 where a comparison between groups with all zero mortalities does not warrant statistical analysis). Abnormal behavior and mortalities noted for the anchovies are consistent with a set of observations testing different holding methods where anchovies held longer than 6 hours in oxygenated bags start to exhibit abnormal swimming behavior and then die, with approximately 37% mortality after 7 hours and a total of approximately 77% mortality after 8 hours. See Appendix A.

Hydroacoustic monitoring with reference hydrophones outside the cages showed that the sound pressure levels, wave form and frequency characteristics are virtually identical inside and outside the cages.

The average peak sound pressure levels from driving concrete piles of 182-192 dB re 1 µPa at 10 meters were substantially less than the sound pressure levels resulting from driving 8-foot diameter steel pipe piles with a 1,700 KJ hydraulic hammer on the Bay Bridge replacement projects which were typically 209-211 dB re 1 µPa at 24 meters without a bubble curtain (Caltrans 2004).

The relationship between peak sound pressure level from pile driving and barotrauma is much better understood today than it was several years ago. Caged fish monitoring at the Bay Bridge resulted in much higher sound pressure levels and more indications of barotraumas (Caltrans 2004). Peak sound pressure levels as low as 192 dB re 1µPa never resulted in indications of vestibular injury, near term mortality or delayed mortality (Caltrans 2004). Results of caged fish monitoring on the Bay Bridge project indicated the lowest peak sound pressure level that clearly resulted in barotrauma injuries and mortalities for shiner perch exposed to pile driving without a bubble curtain in operation was 207 dB re 1µPa (Caltrans 2004). The lowest peak sound pressure level associated with barotrauma injuries and mortalities in steelhead with the bubble curtain not in operation was 208 dB re 1 µPa (Caltrans 2004).

These results indicate that conventional pile driving of concrete pile had no significant effect on fish health under the test conditions described. The peak sound pressure levels generated with a diesel hammer on a concrete pile do not appear to be high enough to result in near-term mortalities, internal hemorrhaging or vestibular injuries. Small differences in lesion scores were consistent with random separation of the fish into two groups. Longer exposure might have resulted in injuries, but it is highly unlikely that an unrestrained fish would stay in the area for extended periods due to passive transport by tidal currents. It is not known if fish would actively leave the area just because of a high level of acoustic intensity in their environment (Mueller et al. 1999, Keevin 1997). The presence of schools of small fish that were not injured and appeared to be feeding in the immediate area further suggests that the pile driving noises were not injurious. In contrast, schools of fish near Bay Bridge pile driving operations resulted in numerous near-term mortalities when the bubble curtain was not operating. No stunned fish were observed to float to the surface around Berth 22 during pile driving and there were no observations of gulls diving for moribund fish during any of the three day of pile driving tests.

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Appendix A Results of a study on holding anchovies in oxygenated bags

On September 14, 2004. A bucket of live anchovies were purchased from J & P Bait company in San Francisco, and small groups were placed in large plastic bags charged with oxygen and then the bags were placed in four 90 liter coolers. The coolers were transported to the Romberg Tiburon Center Green House, approximately 20 minutes away, and left undisturbed at that location except for observations made approximately every two hours. At two hour intervals the cooler lids were raised, the bags were recharged with oxygen, and the number of mortalities were counted. Then the cooler lid was closed and the fish were left undisturbed for another two hours when the lid was opened and the mortalities were counted again. Table Appendix A-1 summarizes the results of this study.

Table A1. Summary of observations on the rate of mortality of northern anchovies held in oxygenated bags in 90 liter transport coolers.

	Mortalities				Summary		
Time	c1	c2	C3	c4	Hour	mort. during interval	Cumulative % mort.
7:00	0	0	0	0	0	0	0
9:00	0	0	1	0	2	1	2.33
11:00	0	0	1	0	4	1	4.65
13:00	0	3	1	0	6	4	13.95
14:00	3	3	2	2	7	10	37..21
15:00	6	5	3	3	8	17	76.74
Total Mortalities	9	11	8	5		33	
Starting No.	12	10	10	11		43	

Appendix B Summary of Wave Form, Frequency and Energy

B-3

Berth 22 Pile Drive Signal Analysis - Pile #277A, Fish in Water - Cage Sensors 8/3/04-3

Figure a. Waveform

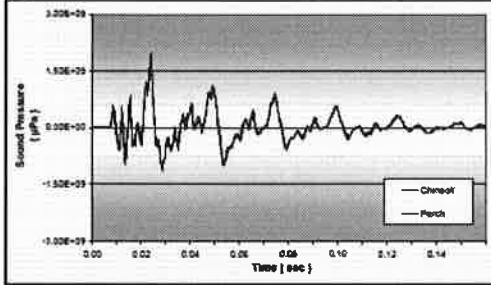


Figure b. Narrow Band Frequency Spectra

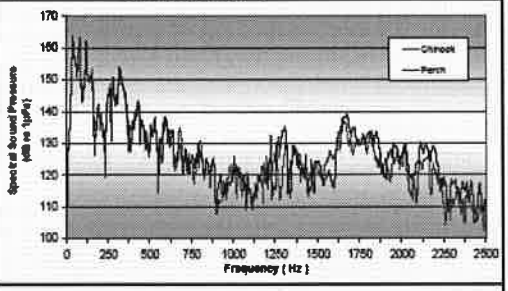


Figure c. Accumulation of Sound Energy

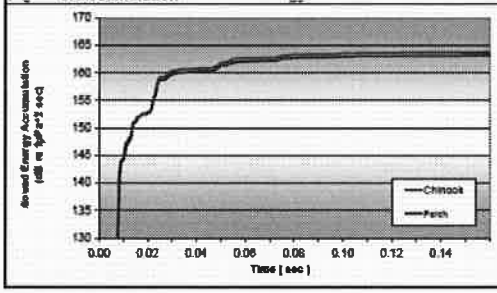


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meters - 13:01:00	Peak	RMS90%*	SEL
Chinook	186	174	164
Perch	185	173	163

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS$_{impulse}$**
Reported Average	185	173
Reported Maximum	187	175

*Impulse averaged over 90% of accumulated energy (5% to 95%)
**Standard 35 msec "impulse" RMS time window

**Standard 35 msec "impulse" RMS time window

B-2

Berth 22 Pile Drive Signal Analysis - Pile #277A, Fish in Water - Cage Sensors 8/3/04-2

Figure a. Waveform

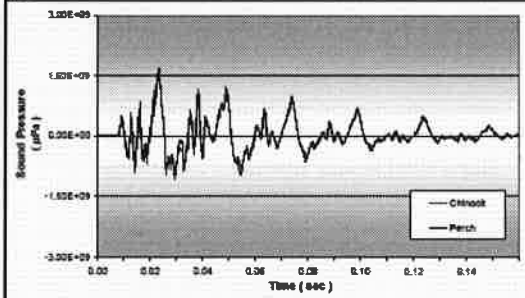


Figure b. Narrow Band Frequency Spectra

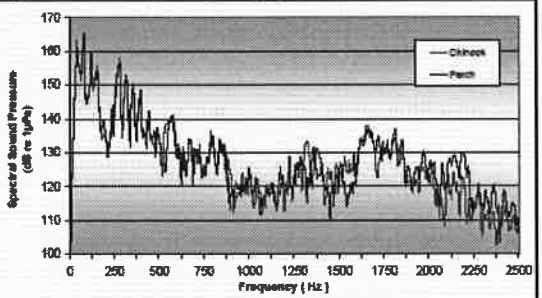


Figure c. Accumulation of Sound Energy

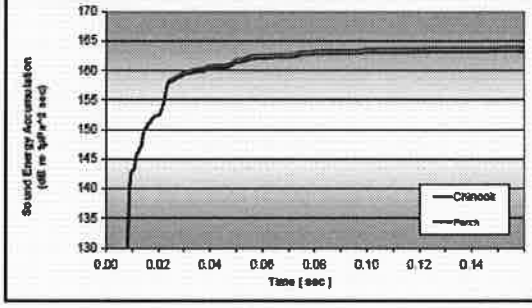


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meters - 13:00:00	Peak	RMS90%*	SEL
Chinook	185	174	164
Perch	184	174	163

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS$_{impulse}$**
Reported Average	185	173
Reported Maximum	187	175

*Impulse averaged over 90% of accumulated energy (5% to 95%)
**Standard 35 msec "impulse" RMS time window

B-4

Berth 22 Pile Drive Signal Analysis - Pile #284B, Fish in Water - Cage Sensors 8/3/04-1

Figure a. Waveform

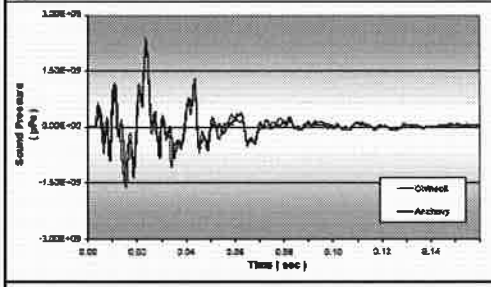


Figure b. Narrow Band Frequency Spectra

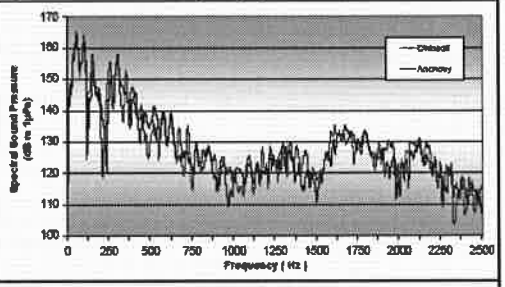


Figure c. Accumulation of Sound Energy

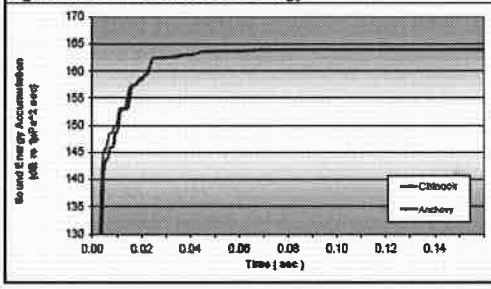


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meters - 16:09:00	Peak	RMS90%*	SEL
Chinook	188	177	164
Anchovy	186	176	164

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	$RMS_{impulse}$**
Reported Average	186	176
Reported Maximum	189	178

*Impulse averaged over 90% of accumulated energy (5% to 95%)
**Standard 35 msec "impulse" RMS time window

B-5

Berth 22 Pile Drive Signal Analysis - Pile #284B, Fish in Water - Cage Sensors 8/3/04-2

Figure a. Waveform

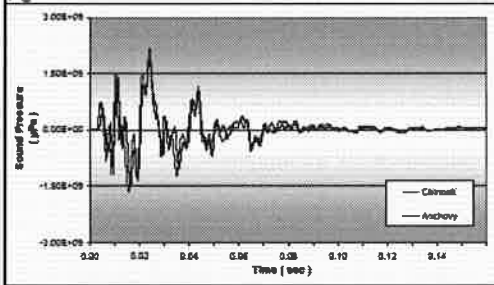


Figure b. Narrow Band Frequency Spectra

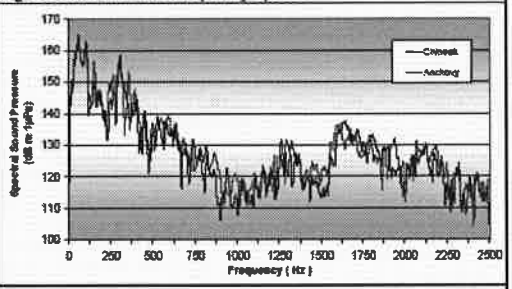


Figure c. Accumulation of Sound Energy

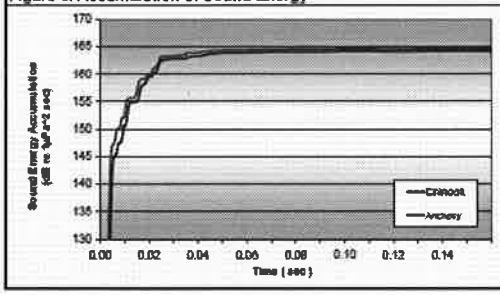


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meters - 16:10:00	Peak	RMS90%*	SEL
Chinook	187	178	165
Anchovy	186	177	164

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	$RMS_{impulse}$**
Reported Average	186	176
Reported Maximum	189	178

*Impulse averaged over 90% of accumulated energy (5% to 95%)
**Standard 35 msec "impulse" RMS time window

B-7

Berth 22 Pile Drive Signal Analysis - Pile #284A, Fish in Water - Cage Sensors 8/4/04-1

Figure a. Waveform

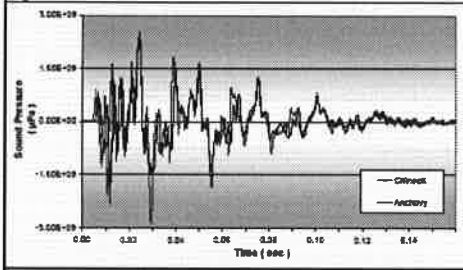


Figure b. Narrow Band Frequency Spectra

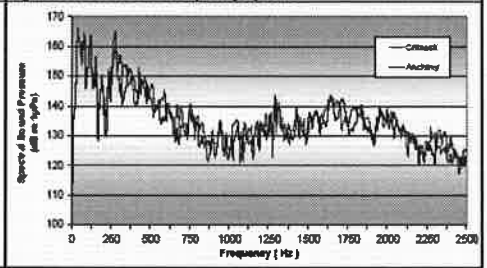


Figure c. Accumulation of Sound Energy

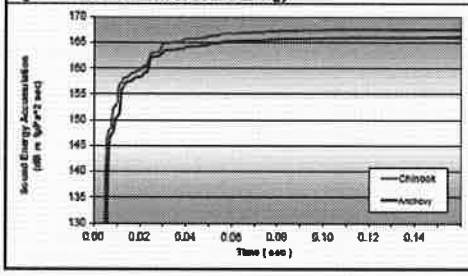


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meters - 08:56:00	Peak	RMS90%*	SEL
Chinook	189	178	168
Anchovy	188	177	166

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS90%**
Reported Average	188	175
Reported Maximum	192	177

*Impulse averaged over 90% of accumulated energy (5% to 95%)
**Standard 35 msec "impulse" RMS time window

B-8

Berth 22 Pile Drive Signal Analysis - Pile #284A, Fish in Water - Cage Sensors 8/4/04-2

Figure a. Waveform

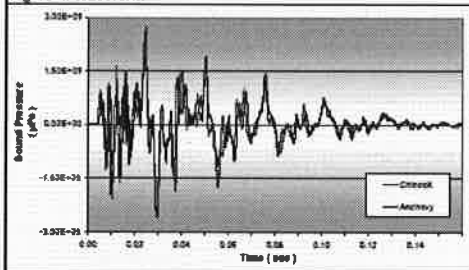


Figure b. Narrow Band Frequency Spectra

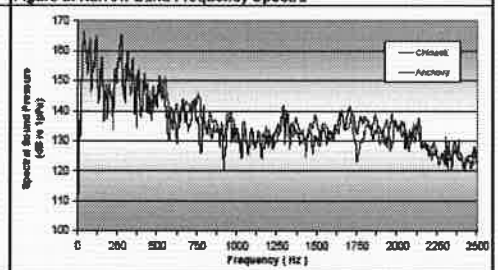


Figure c. Accumulation of Sound Energy

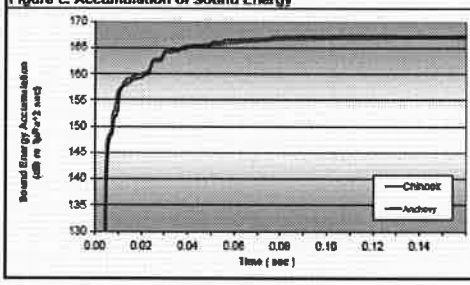


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meters - 08:57:00	Peak	RMS90%*	SEL
Chinook	188	177	167
Anchovy	189	178	167

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS90%**
Reported Average	188	175
Reported Maximum	192	177

*Impulse averaged over 90% of accumulated energy (5% to 95%)
**Standard 35 msec "impulse" RMS time window

B-9

Berth 22 Pile Drive Signal Analysis - Pile #284A, Fish in Water - Cage Sensors 8/4/04-3

Figure a. Waveform

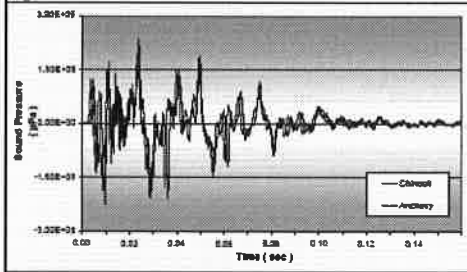


Figure b. Narrow Band Frequency Spectra

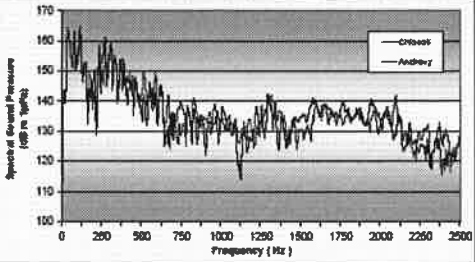


Figure c. Accumulation of Sound Energy

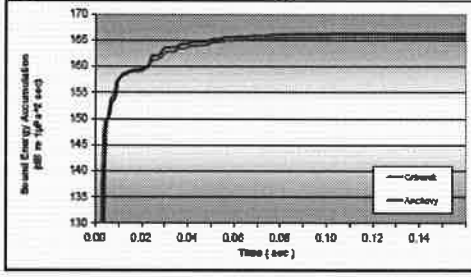


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meters - 08:58:00	Peak	RMS90%*	SEL
Chinook	185	177	166
Anchovy	187	177	166

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS$_{Impulse}$**
Reported Average	188	175
Reported Maximum	192	177

*Impulse averaged over 90% of accumulated energy (5% to 95%)
**Standard 35 msec "impulse" RMS time window

B-6

Berth 22 Pile Drive Signal Analysis - Pile #284B, Fish in Water - Cage Sensors 8/3/04-3

Figure a. Waveform

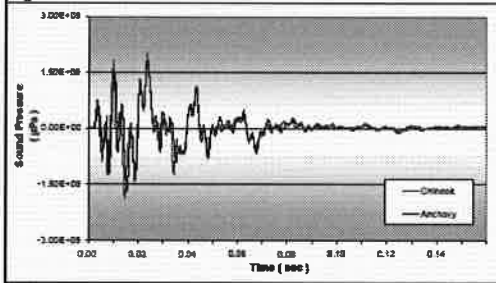


Figure b. Narrow Band Frequency Spectra

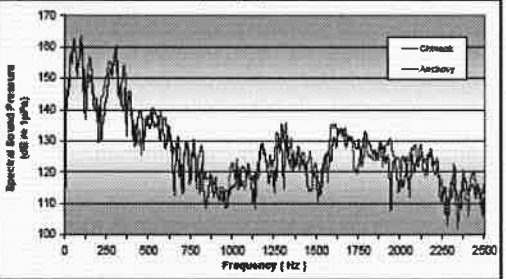


Figure c. Accumulation of Sound Energy

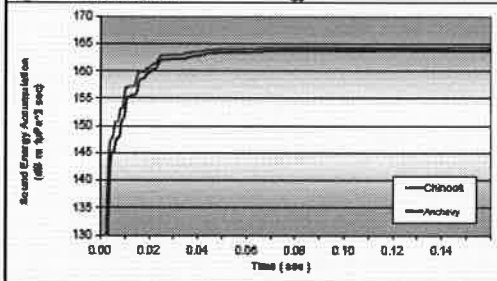


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

10 meters - 16:11:00	Peak	RMS90%*	SEL
Chinook	186	177	164
Anchovy	185	176	164

Typical Sound Pressure / Energy Levels Throughout Drive

	Peak	RMS$_{Impulse}$**
Reported Average	186	176
Reported Maximum	189	178

*Impulse averaged over 90% of accumulated energy (5% to 95%)
**Standard 35 msec "impulse" RMS time window

Appendix C. Necropsy and Histology Results

Table C-1. Summary of type specimens for liver scores used during histopathologic examination ("type specimens" are good examples of each lesion score). Abbreviations are explained on the next pages.

Liver (Summary of type specimens)				
Lesion Abbreviation	None score = 0	Mild score = 1	Moderate score = 2	Severe score = 3
Atly	04FPS2-6A	04FPS1-11A	04FPS1-9A	none
Art	None	04FPS1-11A	04FPS1-9A	none
GD	None	04FPS2-26A	04FPS1-71A	04FPS1-61A
HEM	04FPS1-61A	none	04FPS1-28A	none
LMA	04FPS1-61A	04FPS2-6A	04FPS1-A	04FPS2-13A
LIP	04FPS1-61A	04FPS1-27A	04FPS3-3A	04FPS1-25A
FPL	04FPS1-61A	04FPS1-12A	None	none
CPL	04FPS1-61A	04FPS1-64A	04FPS1-65A	none
PVL	04FPS1-61A	04FPS1-14A	None	none

Quality Control/Quality Assurance

1. Atly = Autolysis. Changes in membrane integrity begin immediately after death, and are often aided by leakage of bile onto cells.
   a. score = 0; no membrane changes, erythrocytes stained intensely.
   b. score = 1; loss of membrane integrity; hepatocytes had fragmented nuclei and pale basophilic cytoplasm; changes were probably due to autodigestion from leakage of bile.
   c. score = 2; cell adhesion has broken down is some areas; band of bile digestion >300 μm thick. Moderate autolysis is evidence that the fish was dead before the tissues were preserved.
   d. score = 3; none were severe.

2. Art = Artifact. Tissue changes that were not inherent in the tissue sampled. Sources of artifact included handling at necropsy, processing, sectioning, and staining. Artifact is

scored on the basis that it impedes interpretation of tissue morphology. Examples of artifact include splits, bubbles, or knife marks in tissues.

a. score = 0; sections had no tissue alterations that would impede analysis or photography of any part of the sections.
b. score = 1; tissue alterations were present, but some areas could still be photographed without artifact, and analysis for lesions was unaffected. This is the most common score for paraffin-embedded sections.
c. score = 2; tissue alteration prevented analysis for lesions in some areas and photography would be unacceptable anywhere.
d. score = 3; tissue alterations were too extensive for histopathologic analysis.

Physiological condition

1. GD = glycogen depletion. A lesion in hepatocytes; hepatocytes normally have abundant cytoplasmic glycogen stores characterized by a large volume of clear, irregular, poorly demarcated vacuoles (= glycogen vacuoles).
score = 0; hepatocytes had abundant glycogen vacuoles.
score = 1; glycogen vacuoles were smaller, but still larger than nuclei.
score = 2; glycogen vacuoles were smaller than or about equal to nuclear diameter.
score = 3; glycogen vacuoles were absent for most hepatocytes.

Lesions

1. HEM = hemorrhage. Erythrocytes outside of normal vascular channels were considered to be a result of hemorrhage.
score = 0; no hemorrhage.
score = 1; hemorrhage present, but total area affected < 500 μm in diameter.
score = 2; total area of hemorrhage > 500 μm in diameter but < 2 mm in diameter.
score = 3; total area of hemorrhage > 2 mm in diameter.

2. LMA = liver pigmented macrophage aggregates. Pigmented macrophage aggregates were usually pigmented yellow-brown, scattered in the hepatic parenchyma, and they occasionally contained leukocytes. Many LMA in shiner perch were pink (evidence of abundant protein). Contents of macrophage aggregates are variable, but often include lipofuscin (termed ceroid in some fish references), iron, and/or glycoproteins. Melanin-containing melanomacrophage centers are sometimes in salmonid livers; however, melanin-containing cells were NOT scored as part of LMA.
score = 0; no macrophage aggregates.
score = 1; sections had <7 MAs greater than 40 μm in diameter per 100× field.
score = 2; sections had 7 but <14 MAs greater than 40 μm in diameter per 100× field.
score = 3; sections had 14 MAs greater than 40 μm in diameter per 100× field.

3. LIP = lipidosis. A change/lesion in hepatocytes; excess lipid appears as clear, round, well-demarcated, cytoplasmic vacuoles (= lipid vacuoles). Pathologic change is more likely when the vacuoles are significantly larger than nuclei. When nearly all hepatocytes are uniformly affected and vacuoles are about the size of nuclei, the change may be normal form of energy storage (especially in northern anchovy).
score = 0; hepatocytes had no lipid vacuoles.
score = 1; < 33% of hepatocytes in the section had lipid vacuoles larger than nuclei, or <50% had lipid vacuoles that were smaller than nuclei.
score = 2; 34-66% of hepatocytes in the section had lipid vacuoles larger than nuclei, or 50-100% of hepatocytes had vacuoles that were rarely larger than nuclei.
score = 3; more than 66% of hepatocytes in the section had lipid vacuoles that were larger than nuclei.

4. FPL = focal/multifocal parenchymal leukocytes. Leukocyte aggregates were usually less than 500 µm in diameter and were composed mostly of lymphocytes.
score = 0; no focal parenchymal leukocytes.
score = 1; <1 focus of parenchymal leukocytes per 100× field.
score = 2; 1-2 foci of parenchymal leukocytes per 100× field.
score = 3; none were severe

5. CPL = cholangitis/pericholangial leukocytes (lymphocytes, plasma cells, and macrophages): a lesion of the bile ductules and the surrounding connective tissue (adventitia).
score = 0; <3 leukocytes in the region of every bile duct in the section.
score = 1; 3 - many leukocytes infiltrate or surround at least one bile duct in the section, but leukocytes do not extend into the surrounding parenchyma.
score = 2; leukocytes or plasma cells extend into the surrounding parenchyma.
score = 3; none were severe.

6. PVL = perivascular leukocytes (eosinophilic granular cells, lymphocytes, and plasma cells). A lesion of the connective tissue (adventitia) surrounding blood vessels. Leukocytes within the tunica intima and tunica media were NOT included in this category.
score = 0; <3 leukocytes in the adventitia of any vessel in the section.
score = 1; 3 - many leukocytes in the adventitia of at least one vessel in the section, but leukocytes do not extend into the surrounding parenchyma or the muscular tunics of the vessel.
score = 2; perivascular leukocytes extend into the surrounding parenchyma, and more than one vessel is involved.
score = 3; none were severe.

7. IHEM = gastrointestinal hemorrhage. For most fish, sections of stomach, intestine, and/or mesenteries were included with the liver and examined for hemorrhage. None of

these tissues had any evidence of hemorrhage; therefore, definitions of lesion scores were not established.

Figure 1. Normal Chinook salmon liver (04POS-39, control fish). Gallbladder (g), bile ductule (d), and blood vessel (v).

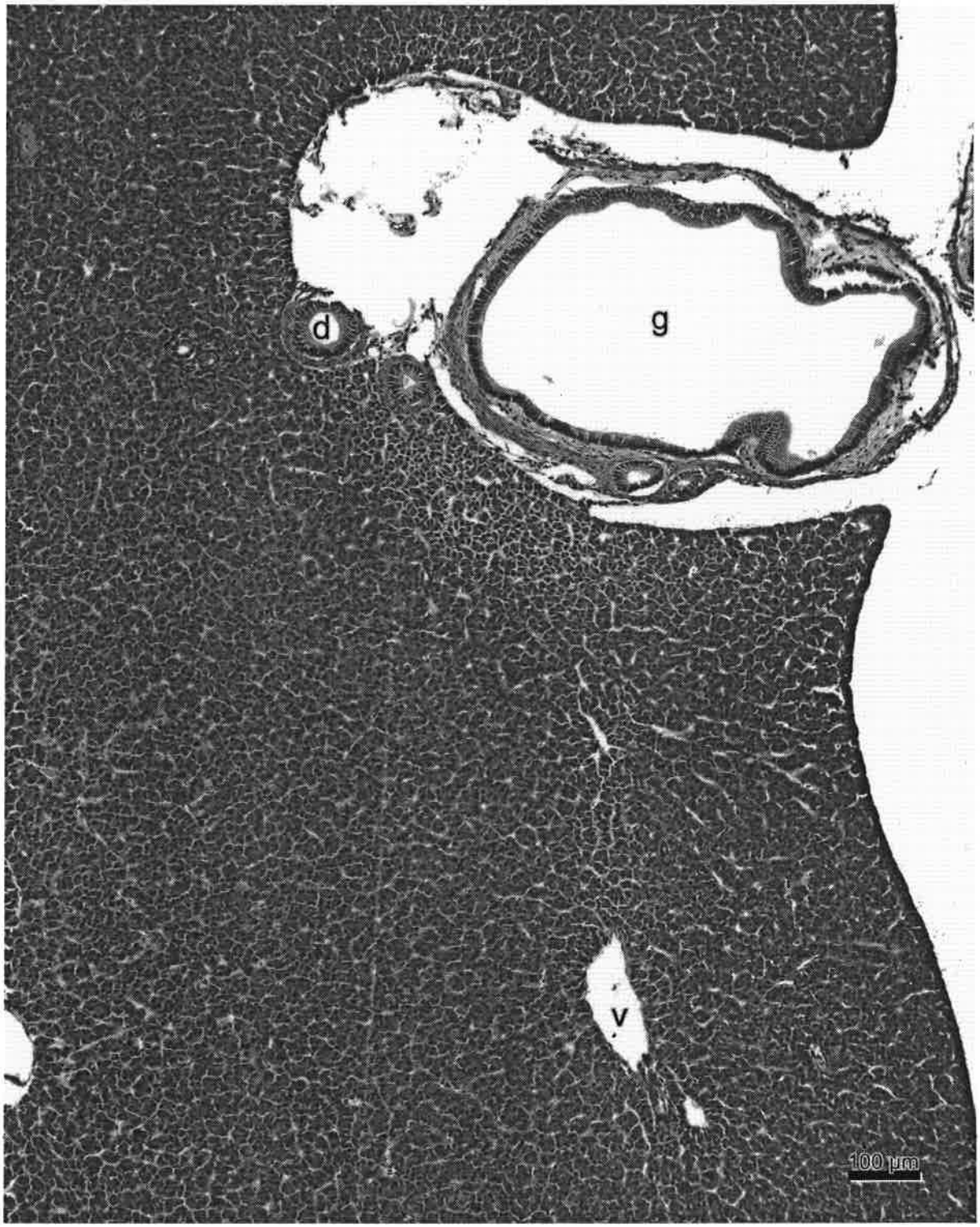


Figure 2. Hemorrhage (arrowheads) in Chinook salmon liver (04POS-22, control fish). Gallbladder (g), bile ductule (d), and blood vessel (v).

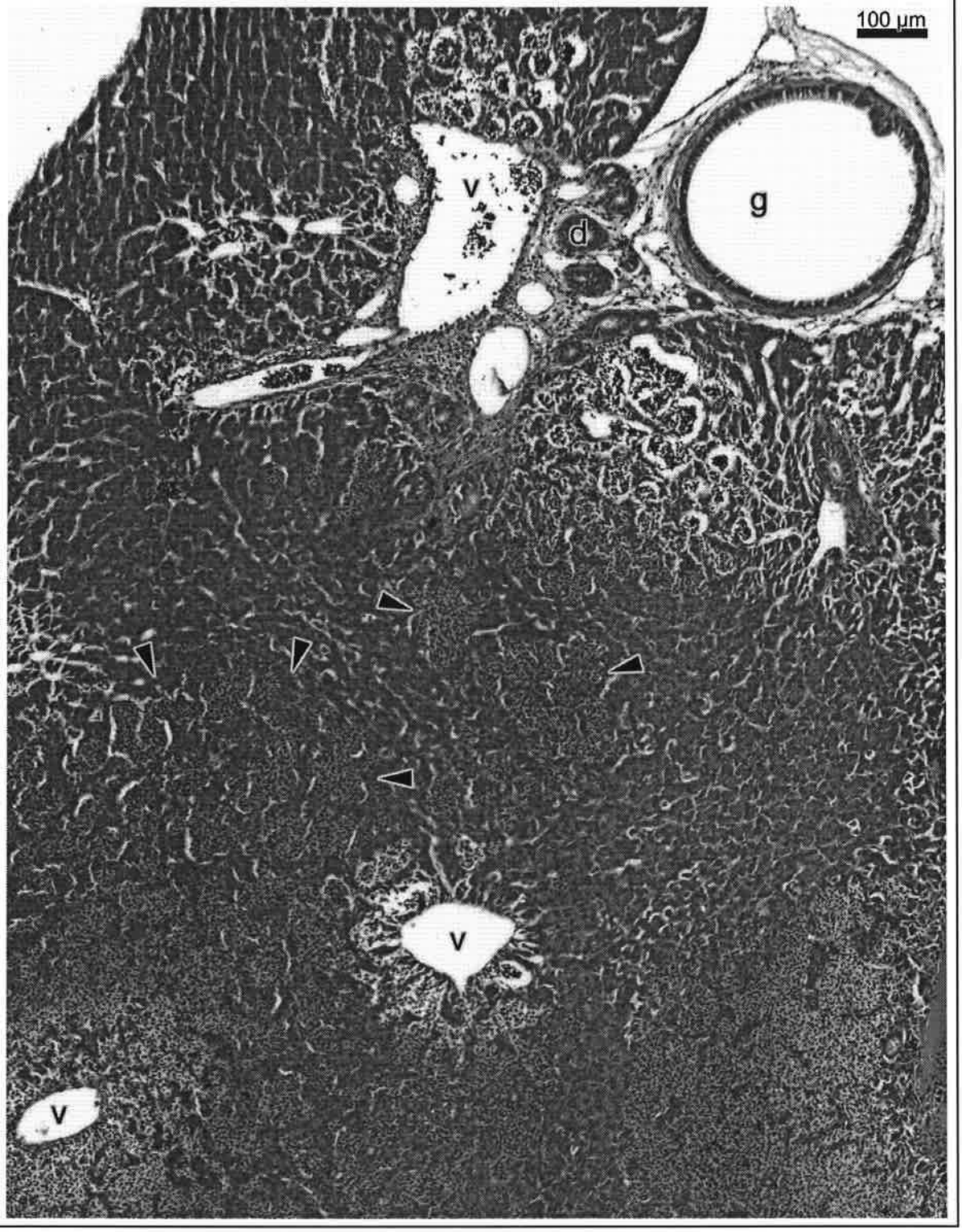


Figure 3. Normal northern anchovy swimbladder (04POA-48, hammer-exposed fish). Swimbladder (s) and kidney (k).

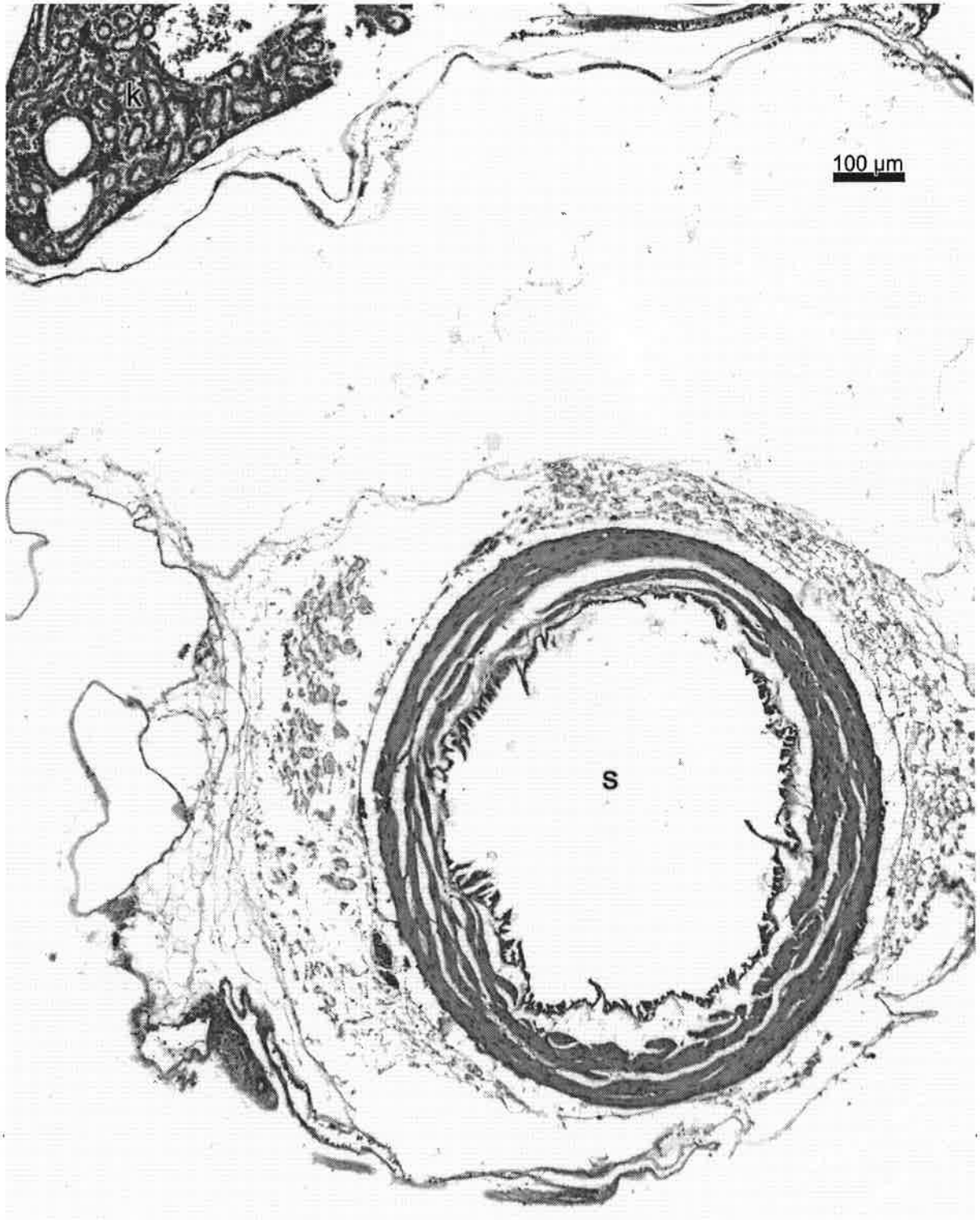


Figure 4. Hemorrhage (arrowheads) dorsal to swimbladder of a northern anchovy (04POA-37, control fish). Swimbladder (s), kidney (k), and skeletal muscle (m).

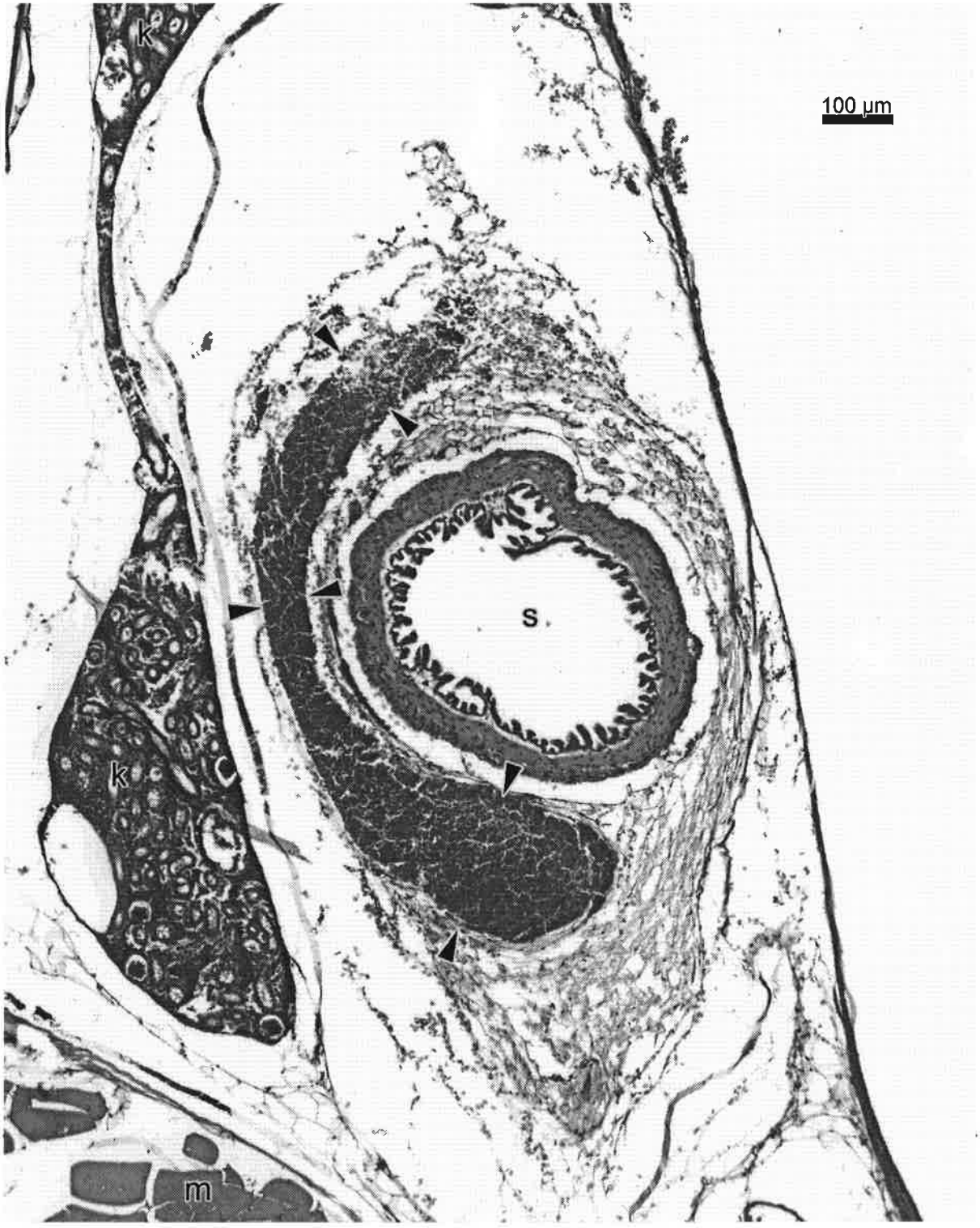
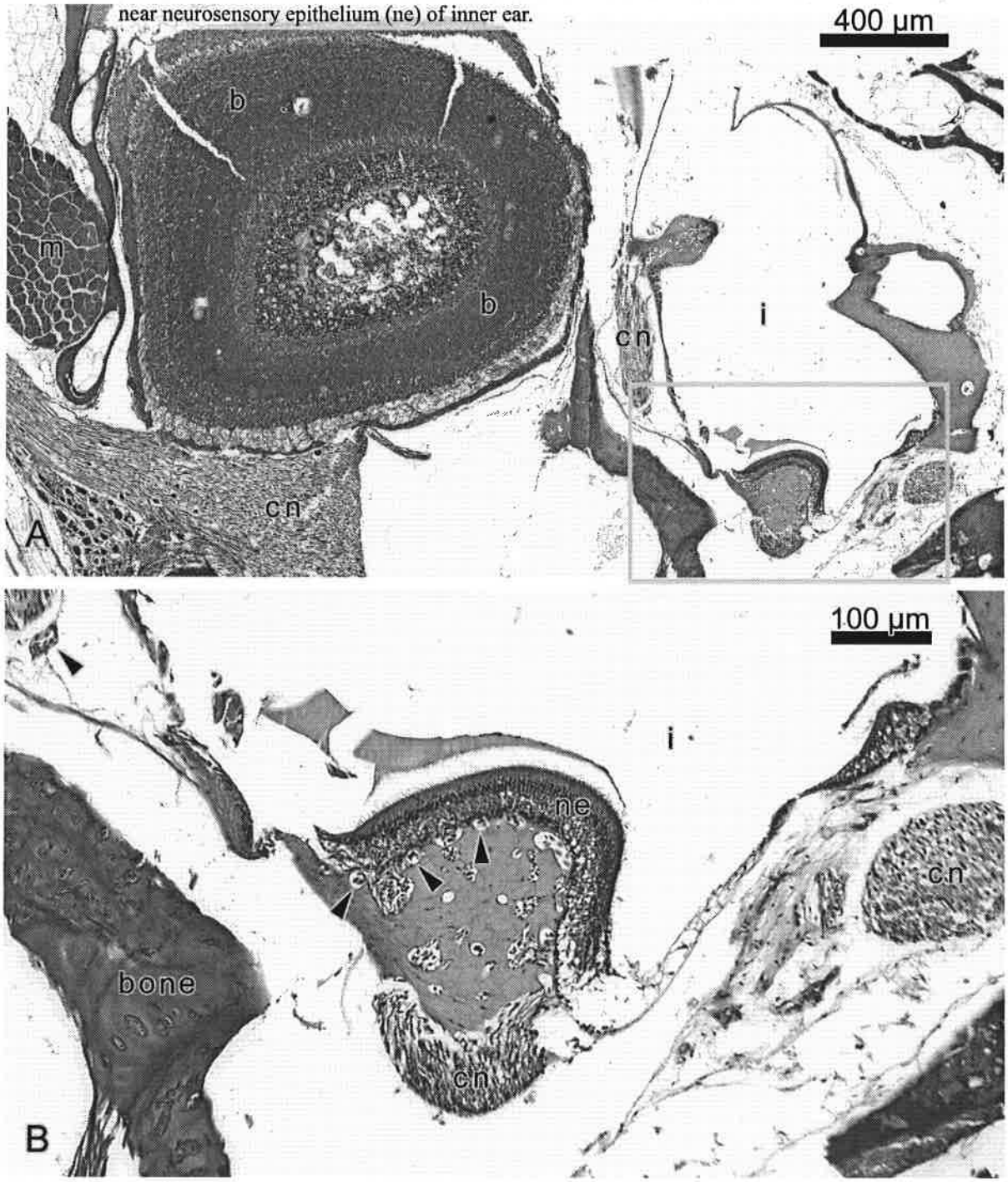


Figure 5. Section of brain (b) and surrounding inner ear (i), cranial nerves (cn), skeletal muscle (m), and bone of a northern anchovy (04POA-20, control fish). Yellow box in A outlines area shown at higher magnification in B. Note intact blood vessels (arrowheads), and lack of hemorrhage near neurosensory epithelium (ne) of inner ear.



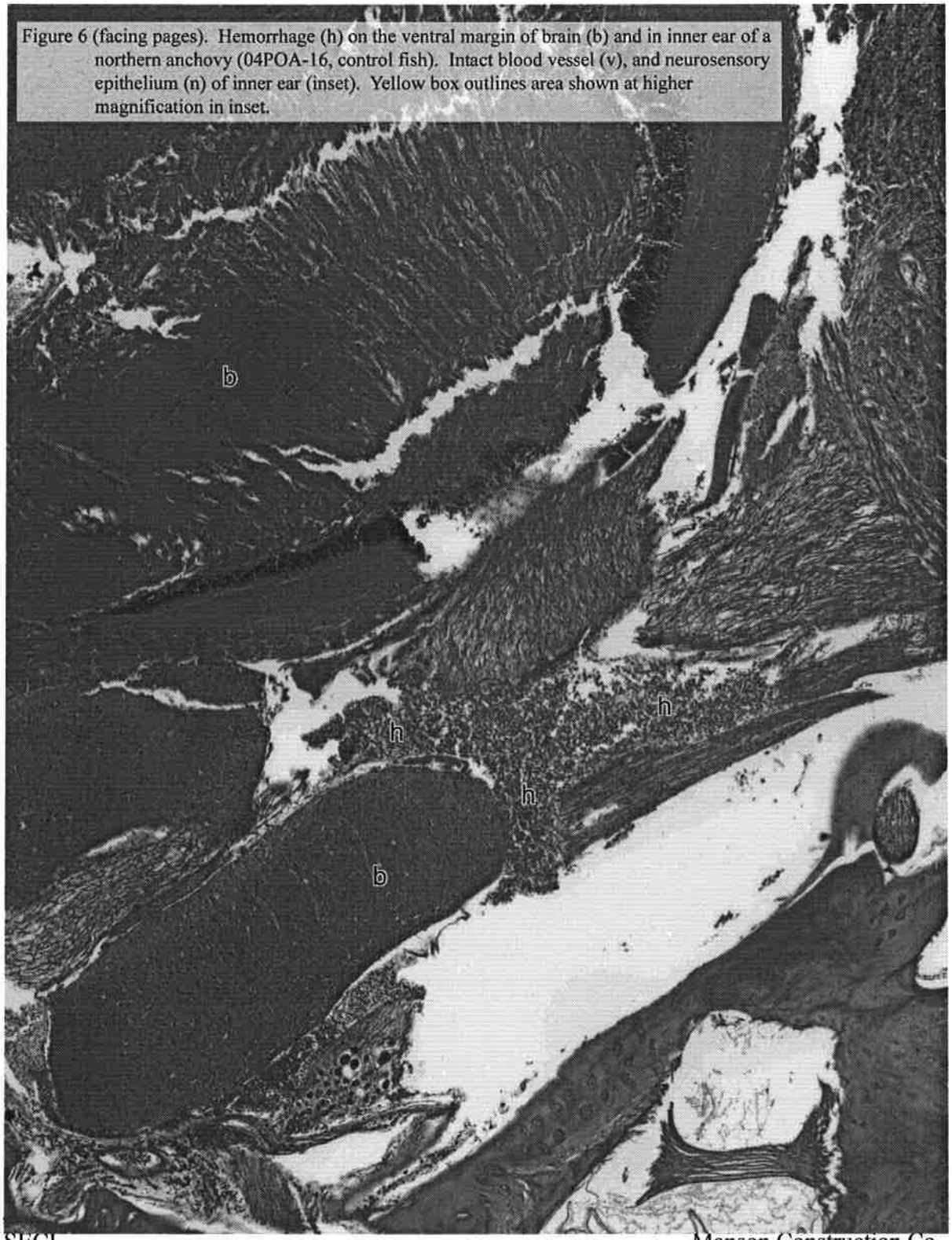


Figure 6 (facing pages). Hemorrhage (h) on the ventral margin of brain (b) and in inner ear of a northern anchovy (04POA-16, control fish). Intact blood vessel (v), and neurosensory epithelium (n) of inner ear (inset). Yellow box outlines area shown at higher magnification in inset.

Figure 6 continued

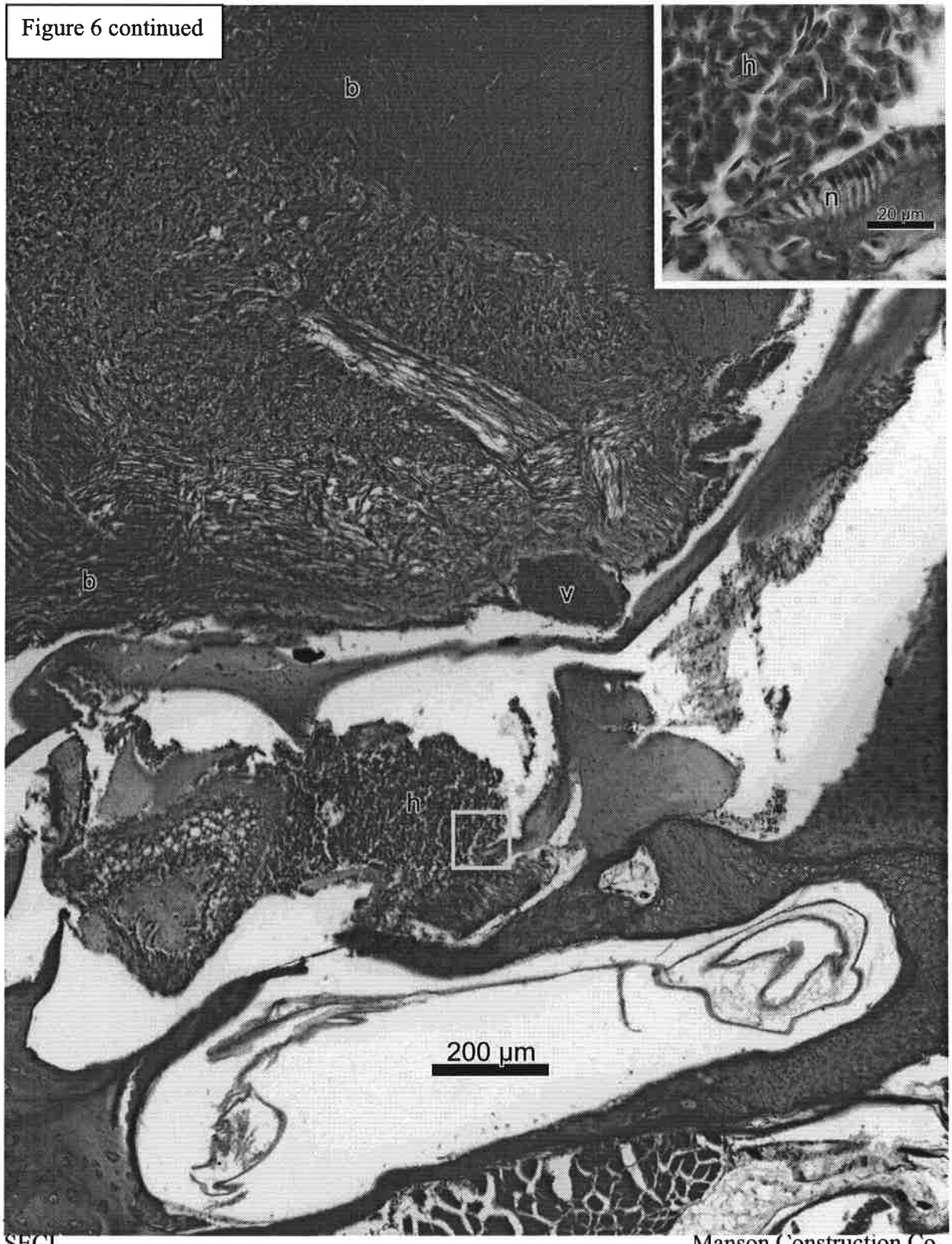


Figure 7. Section of spinal cord surrounded by skeletal muscle (m) and bone; Chinook salmon (04POS-15, control fish). Note intact blood vessel (arrowhead) and lack of hemorrhage.

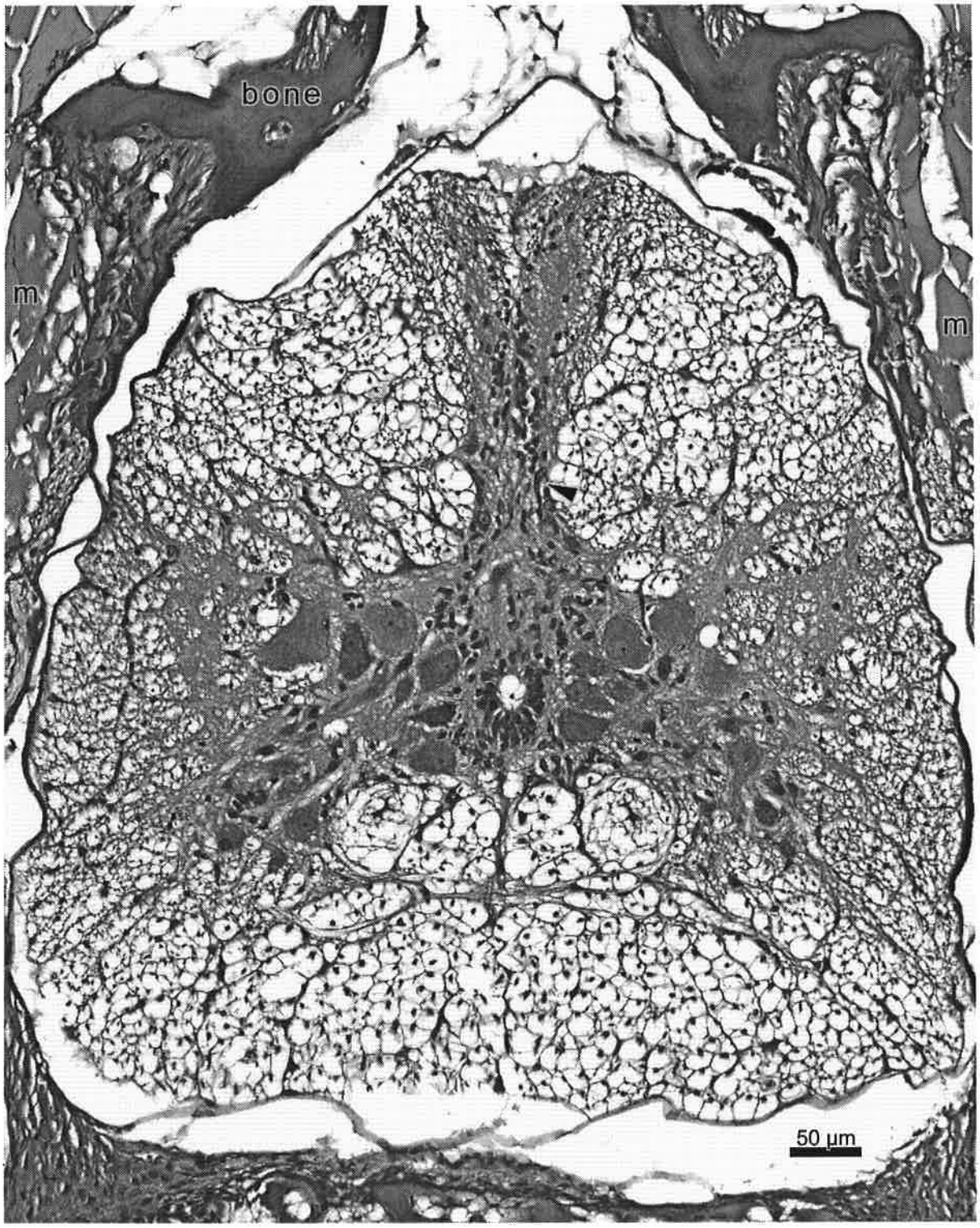
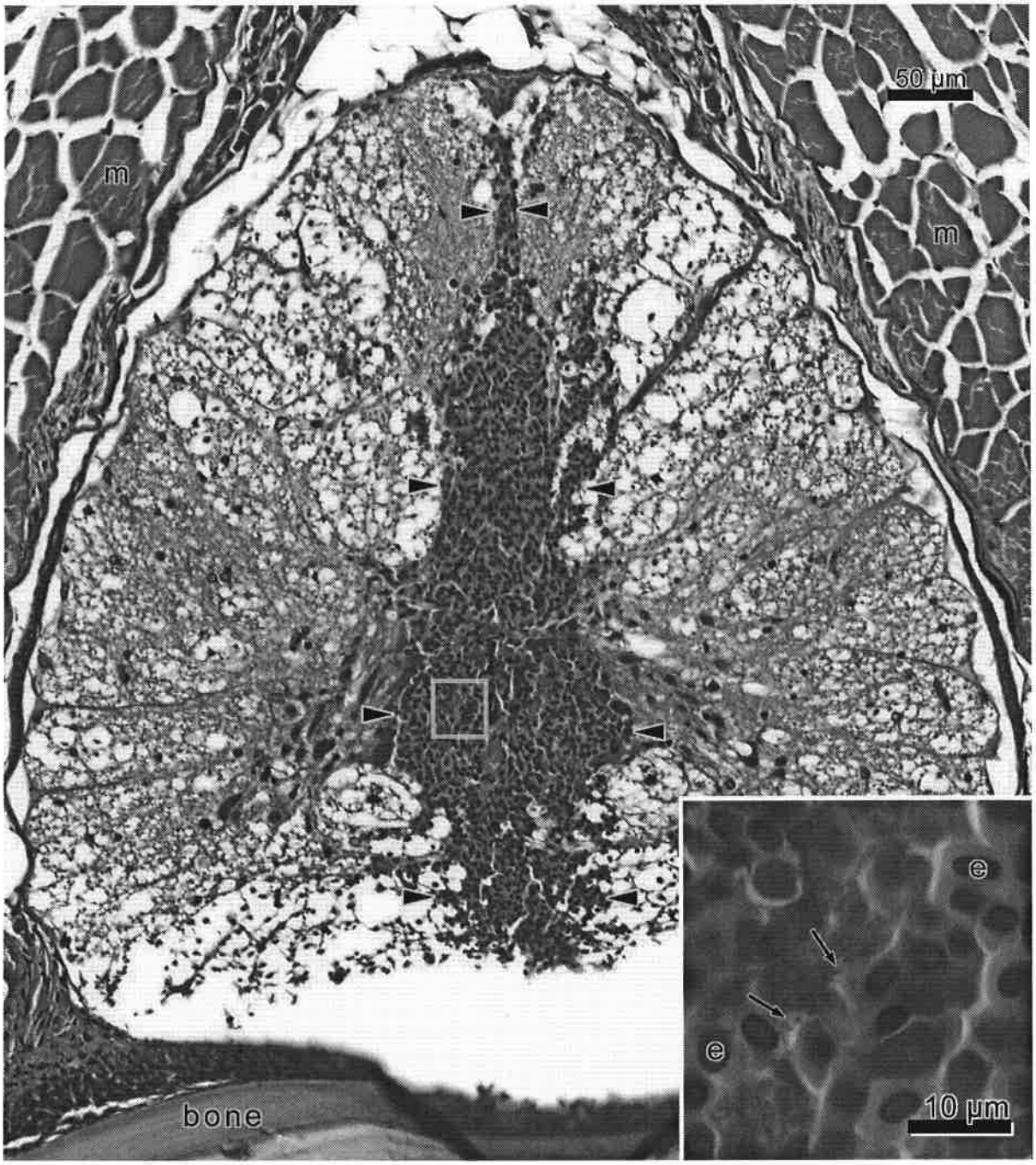


Figure 8. Hemorrhage (arrowheads) in Chinook salmon spinal cord (04POS-1, hammer-exposed fish). Skeletal muscle (m) surrounds the dorsal part of the spinal cord. Yellow box outlines area shown at higher magnification in inset. Inset - nucleated erythrocytes (e); small blue structures (arrows) might be bacteria.



Appendix C-1. Northern anchovy results, Port of Oakland study on the effects of concrete pile driving

Sample # = number assigned sequentially to each fish in the field
Slide # = number assigned by Gary D. Marty for histopathology (blind study)
Type of exposure = hammer or control
Code = exposure/species code assigned by Strategic Environmental, Inc.
Exposure end time = time when pile driving stopped
Hold = selection for necropsy; R = random, S = selected;
L = standard length (mm)
Gross Sex = M (male); F (female); U (unknown);
Path. = pathologist; GDM = Gary D. Marty
Wt. = total body weight (g)
Recorder = Andy Jahn (AEJ), Jody Zaitlin (JAZ), Marucia Britto (MB)
Necropsy start = time that necropsy started
Hold time = time from end of exposure to necropsy start

#	Sample #	Slide #		Sample date	Type of exposure	Code	Exposure end time	Hold	(mm) Length	(g) Weight	Path.	Recorder	Necropsy Start	Hold time (min.)
1	04POA-12	04FPS3-	10	08/02/04	control	MPOO1A1C	3:16 PM	R	120	15.3	GDM	JAZ	4:14 PM	58
2	04POA-13	04FPS3-	33	08/02/04	control	MPOO1A1C	3:16 PM	R	116	12.0	GDM	JAZ	4:20 PM	64
3	04POA-14	04FPS3-	46	08/02/04	control	MPOO1A1C	3:16 PM	R	124	18.4	GDM	JAZ	4:24 PM	68
4	04POA-15	04FPS3-	14	08/02/04	control	MPOO1A1C	3:16 PM	S	111	11.0	GDM	JAZ	4:33 PM	77
5	04POA-16	04FPS3-	35	08/02/04	control	MPOO1A1C	3:16 PM	S	104	9.8	GDM	JAZ	4:38 PM	82
6	04POA-17	04FPS3-	41	08/02/04	control	MPOO1A1C	3:16 PM	S	102	9.2	GDM	JAZ	4:41 PM	85
7	04POA-18	04FPS3-	5	08/02/04	control	MPOO1A1C	3:16 PM	S	95	7.3	GDM	JAZ	4:45 PM	89
8	04POA-19	04FPS3-	34	08/02/04	control	MPOO1A1C	3:16 PM	R	110	11.8	GDM	JAZ	4:50 PM	94

9	04POA-20	04FPS3-	26	08/02/04	control	MPOO1A1C	3:16 PM	R	108	11.0	GDM	JAZ	4:55 PM	99
10	04POA-21	04FPS3-	12	08/03/04	control	MPOO2A1C	10:18 AM	R	117	14.7	GDM	MB	10:32 AM	14
11	04POA-22	04FPS3-	50	08/03/04	control	MPOO2A1C	10:18 AM	S	100	7.6	GDM	MB	10:37 AM	19
12	04POA-23	04FPS3-	21	08/03/04	control	MPOO2A1C	10:18 AM	R	121	14.4	GDM	MB	10:40 AM	22
13	04POA-24	04FPS3-	39	08/03/04	control	MPOO2A1C	10:18 AM	R	96	6.7	GDM	MB	10:45 AM	27
14	04POA-25	04FPS3-	6	08/03/04	control	MPOO2A1C	10:18 AM	R	119	12.6	GDM	MB	10:50 AM	32
15	04POA-26	04FPS3-	32	08/03/04	control	MPOO2A1C	10:18 AM	S	121	16.2	GDM	MB	10:54 AM	36
16	04POA-27	04FPS3-	70	08/03/04	control	MPOO2A1C	10:18 AM	R	121	17.3	GDM	MB	11:00 AM	42
17	04POA-28	04FPS3-	1	08/03/04	control	MPOO2A1C	10:18 AM	R	116	15.9	GDM	MB	11:04 AM	46
18	04POA-29	04FPS3-	19	08/03/04	control	MPOO2A1C	10:18 AM	R	108	10.9	GDM	MB	11:07 AM	49
19	04POA-39	04FPS3-	17	08/03/04	control	MPOO2A3C	3:22 PM	S	117	13.0	GDM	MB	3:50 PM	28
20	04POA-40	04FPS3-	43	08/03/04	control	MPOO2A3C	3:22 PM	R	131	21.3	GDM	MB	3:54 PM	32
21	04POA-41	04FPS3-	8	08/03/04	control	MPOO2A3C	3:22 PM	R	115	10.5	GDM	MB	3:58 PM	36
22	04POA-42	04FPS3-	37	08/03/04	control	MPOO2A3C	3:22 PM	R	117	14.6	GDM	MB	4:01 PM	39
23	04POA-43	04FPS3-	47	08/03/04	control	MPOO2A3C	3:22 PM	R	116	15.4	GDM	MB	4:05 PM	43
24	04POA-44	04FPS3-	2	08/03/04	control	MPOO2A3C	3:22 PM	S	127	17.6	GDM	MB	4:08 PM	46
25	04POA-45	04FPS3-	61	08/03/04	control	MPOO2A3C	3:22 PM	S	107	10.1	GDM	MB	4:11 PM	49
26	04POA-46	04FPS3-	16	08/03/04	control	MPOO2A3C	3:22 PM	S	109	11.5	GDM	MB	4:14 PM	52
27	04POA-47	04FPS3-	56	08/03/04	control	MPOO2A3C	3:22 PM	S	113	14.0	GDM	MB	4:18 PM	56
28	04POA-60	04FPS3-	13	08/04/04	control	MPOO3AC	10:21 AM	S	114	11.1	GDM	MB	11:31 AM	70
29	04POA-61	04FPS3-	11	08/04/04	control	MPOO3AC	10:21 AM	S	115	11.5	GDM	MB	11:35 AM	74
30	04POA-62	04FPS3-	42	08/04/04	control	MPOO3AC	10:21 AM	S	115	12.0	GDM	MB	11:37 AM	76

31	04POA-63	04FPS3-	40	08/04/04	control	MPOO3AC	10:21 AM	S	105	10.4	GDM	MB	11:40 AM	79
32	04POA-64	04FPS3-	28	08/04/04	control	MPOO3AC	10:21 AM	S	104	8.5	GDM	MB	11:45 AM	84
33	04POA-65	04FPS3-	63	08/04/04	control	MPOO3AC	10:21 AM	S	113	12.5	GDM	MB	11:50 AM	89
34	04POA-1	04FPS3-	51	08/02/04	hammer	MPOO1A1T	2:30 PM	R	110	10.9	GDM	AEJ	3:15 PM	45
35	04POA-2	04FPS3-	44	08/02/04	hammer	MPOO1A1T	2:30 PM	R	116	14.9	GDM	AEJ	3:22 PM	52
36	04POA-3	04FPS3-	20	08/02/04	hammer	MPOO1A1T	2:30 PM	R	100	9.0	GDM	AEJ	3:27 PM	57
37	04POA-4	04FPS3-	57	08/02/04	hammer	MPOO1A1T	2:30 PM	R	95	7.7	GDM	AEJ	3:31 PM	61
38	04POA-5	04FPS3-	25	08/02/04	hammer	MPOO1A1T	2:30 PM	R	121	16.6	GDM	AEJ	3:37 PM	67
39	04POA-6	04FPS3-	15	08/02/04	hammer	MPOO1A1T	2:30 PM	R	115	13.5	GDM	AEJ	3:43 PM	73
40	04POA-7	04FPS3-	59	08/02/04	hammer	MPOO1A1T	2:30 PM	R	110	11.2	GDM	AEJ	3:47 PM	77
41	04POA-8	04FPS3-	24	08/02/04	hammer	MPOO1A1T	2:30 PM	R	93	5.9	GDM	AEJ	3:52 PM	82
42	04POA-9	04FPS3-	58	08/02/04	hammer	MPOO1A1T	2:30 PM	R	93	5.8	GDM	AEJ	3:58 PM	88
43	04POA-10	04FPS3-	9	08/02/04	hammer	MPOO1A1T	2:30 PM	R	100	8.6	GDM	AEJ	4:01 PM	91
44	04POA-11	04FPS3-	45	08/02/04	hammer	MPOO1A1T	2:30 PM	R	111	11.5	GDM	JAZ	4:05 PM	95
45	04POA-30	04FPS3-	64	08/03/04	hammer	MPOO2A2	1:15 PM	S	107	9.3	GDM	AEJ	1:43 PM	28
46	04POA-31	04FPS3-	30	08/03/04	hammer	MPOO2A2	1:15 PM	S	121	15.2	GDM	MB	1:46 PM	31
47	04POA-32	04FPS3-	29	08/03/04	hammer	MPOO2A2	1:15 PM	R	124	16.8	GDM	MB	1:50 PM	35
48	04POA-33	04FPS3-	36	08/03/04	hammer	MPOO2A2	1:15 PM	R	120	17.0	GDM	MB	1:55 PM	40
49	04POA-34	04FPS3-	53	08/03/04	hammer	MPOO2A2	1:15 PM	R	118	15.1	GDM	MB	2:00 PM	45
50	04POA-35	04FPS3-	3	08/03/04	hammer	MPOO2A2	1:15 PM	R	125	19.4	GDM	MB	2:04 PM	49
51	04POA-36	04FPS3-	72	08/03/04	hammer	MPOO2A2	1:15 PM	R	113	11.2	GDM	MB	2:07 PM	52
52	04POA-37	04FPS3-	18	08/03/04	hammer	MPOO2A2	1:15 PM	S	119	15.3	GDM	MB	2:10 PM	55
53	04POA-38	04FPS3-	52	08/03/04	hammer	MPOO2A2	1:15 PM	S	105	9.6	GDM	MB	2:14 PM	59
54	04POA-48	04FPS3-	23	08/03/04	hammer	MPOO2A4T	4:25 PM	S	116	13.5	GDM	MB	5:30 PM	65
55	04POA-49	04FPS3-	38	08/03/04	hammer	MPOO2A4T	4:25 PM	R	131	18.9	GDM	MB	5:33 PM	68
56	04POA-50	04FPS3-	62	08/03/04	hammer	MPOO2A4T	4:25 PM	R	120	14.4	GDM	MB	5:45 PM	80

57	04POA-51	04FPS3-	69	08/03/04	hammer	MPOO2A4T	4:25 PM	R	117	13.9	GDM	MB	5:50 PM	85
58	04POA-52	04FPS3-	71	08/04/04	hammer	MPOO3AT	9:12 AM	S	92	5.9	GDM	MB	9:34 AM	22
59	04POA-53	04FPS3-	4	08/04/04	hammer	MPOO3AT	9:12 AM	R	117	12.7	GDM	MB	9:41 AM	29
60	04POA-54	04FPS3-	49	08/04/04	hammer	MPOO3AT	9:12 AM	R	122	17.7	GDM	MB	9:45 AM	33
61	04POA-55	04FPS3-	31	08/04/04	hammer	MPOO3AT	9:12 AM	S	102	8.2	GDM	MB	9:49 AM	37
62	04POA-56	04FPS3-	66	08/04/04	hammer	MPOO3AT	9:12 AM	R	108	11.4	GDM	MB	9:52 AM	40
63	04POA-57	04FPS3-	54	08/04/04	hammer	MPOO3AT	9:12 AM	R	115	13.1	GDM	MB	9:56 AM	44
64	04POA-58	04FPS3-	48	08/04/04	hammer	MPOO3AT	9:12 AM	R	105	8.6	GDM	MB	10:00 AM	48
65	04POA-59	04FPS3-	22	08/04/04	hammer	MPOO3AT	9:12 AM	R	116	11.7	GDM	MB	10:05 AM	53
66	04POA-66	04FPS3-	60	no fish										
67	04POA-67	04FPS3-	67	no fish										
68	04POA-68	04FPS3-	7	no fish										
69	04POA-69	04FPS3-	55	no fish										
70	04POA-70	04FPS3-	68	no fish										
71	04POA-71	04FPS3-	27	no fish										
72	04POA-72	04FPS3-	65	no fish										

ctl.	n	control	n	33	33	33
	mean		**mean**	**112.9**	**12.6**	**56.2**
	SE		SE	1.5	0.6	4.2
ham.	n	hammer	n	32	32	32
	mean		**mean**	**111.8**	**12.3**	**55.8**
	SE		SE	1.8	0.7	3.6

External/Gross Lesion Scores; scored as none (0), mild (1), moderate (2), severe (3), or no data (ND):

CFF = caudal fin fraying
CFR = caudal fin reddening
OFF = other fin fraying
FBR = fin base reddening
FSR = focal skin reddening
VCH = visceral cavity hemorrhage
LH = liver hemorrhage
SBH = swimbladder hemorrhage
KH = kidney hemorrhage

		External/Gross Lesion Scores									Gross	
#	Sample #	CFF	CFR	OFF	FBR	FSR	VCH	LH	SBH	KH	Sex	Gross Comments
1	04POA-12	2	1	2	0	1	0	0	0	0	F	
2	04POA-13	1	0	1	0	0	0	0	0	0	F	
3	04POA-14	1	0	2	0	2	0	0	0	0	F	
4	04POA-15	2	0	0	0	0	0	0	0	0	U	fish was selected because it was dead;
5	04POA-16	2	0	1	0	1	0	0	0	0	U	fish was selected because it was dead;
6	04POA-17	1	0	1	0	1	0	0	0	0	F	fish was selected because it was dead;
7	04POA-18	1	0	1	0	0	0	0	0	0	U	fish was selected because it was dead;
8	04POA-19	1	0	1	0	1	0	0	0	0	F	
9	04POA-20	2	0	1	0	1	0	0	0	0	M	
10	04POA-21	3	1	1	0	1	0	0	0	0	M	FSR on snout

11	04POA-22	1	0	1	0	1	0	0	0	0	F	fish was selected because it was dead;
12	04POA-23	1	0	1	0	1	0	0	0	0	M	FSR on snout
13	04POA-24	2	0	1	0	1	0	0	0	0	M	
14	04POA-25	1	0	1	0	0	0	0	0	0	F	
15	04POA-26	1	0	0	1	1	0	0	0	0	F	FSR on snout; fish selected because it was swimming poorly
16	04POA-27	1	0	1	0	1	0	0	0	0	F	
17	04POA-28	1	0	1	1	1	0	0	0	0	M	FSR on snout and body
18	04POA-29	1	0	1	0	0	0	0	0	0	F	
19	04POA-39	1	0	1	0	1	0	0	0	0	M	FSR on snout; fish was selected because it was dead;
20	04POA-40	1	0	1	0	1	0	0	0	0	F	FSR on snout; lying on side on bottom of tank;
21	04POA-41	1	0	1	0	1	0	0	0	0	M	
22	04POA-42	1	1	2	1	1	0	0	0	0	M	
23	04POA-43	0	0	1	0	1	0	0	0	0	F	
24	04POA-44	1	0	1	1	2	0	0	0	0	M	FSR on snout and body; fish was selected because it was dead;
25	04POA-45	0	0	1	0	1	0	0	0	0	F	fish was selected because it was dead;
26	04POA-46	1	0	0	0	0	0	0	0	0	F	fish was selected because it was dead;
27	04POA-47	1	0	1	0	1	0	0	0	0	M	fish was selected because it was dead;
28	04POA-60	2	0	1	1	1	0	0	0	0	F	fish was selected because it was dead;
29	04POA-61	1	0	1	0	1	0	0	0	0	M	fish was selected because it was lying on its side, but still alive;
30	04POA-62	2	1	2	0	1	0	0	0	0	M	fish was selected because it was the only live fish
31	04POA-63	1	0	1	0	1	0	0	0	0	F	fish was selected because it was dead;
32	04POA-64	1	0	1	0	1	0	0	0	0	F	fish was selected because it was dead; FSR on snout
33	04POA-65	1	0	1	0	1	0	0	0	0	M	fish was selected because it was dead;
34	04POA-1	2	0	1	0	1	0	0	0	0	F	
35	04POA-2	1	0	1	0	1	0	0	0	0	F	
36	04POA-3	0	0	1	0	1	0	0	0	0	F	FSR on snout
37	04POA-4	0	0	0	0	1	0	0	0	0	F	FSR near right eye

38	04POA-5	1	0	1	0	1	1	0	1	0	F	FSR near anal fin; tan (pale) liver
39	04POA-6	2	0	1	1	1	0	0	0	0	M	FSR near anal fin;
40	04POA-7	0	0	1	0	1	0	0	0	0	M	
41	04POA-8	0	0	0	0	1	0	0	0	0	F	
42	04POA-9	1	0	1	0	0	0	0	0	0	F	
43	04POA-10	1	0	2	0	1	0	0	0	0	U	FSR on rt. snout
44	04POA-11	1	0	1	0	0	0	0	0	0	F	
45	04POA-30	1	0	1	0	0	0	0	0	0	F	fish was selected because it was dead;
46	04POA-31	1	0	1	0	1	0	0	0	0	U	fish was selected because it was dead;
47	04POA-32	1	0	1	0	1	0	0	0	0	M	
48	04POA-33	1	0	1	0	1	0	0	0	0	F	
49	04POA-34	1	0	1	0	2	0	0	0	0	F	
50	04POA-35	1	1	1	0	1	0	0	0	0	F	FSR on snout
51	04POA-36	1	0	1	0	0	0	0	0	0	F	
52	04POA-37	1	0	1	0	0	0	0	0	0	F	fish was selected because it was dead;
53	04POA-38	1	0	1	0	0	0	0	0	0	M	fish was selected because it was dead;
54	04POA-48	1	0	1	0	1	0	0	0	0	U	fish was selected because it was dead;
55	04POA-49	1	0	1	0	1	0	0	0	0	F	PHOTO of normal viscera
56	04POA-50	2	0	2	0	2	0	0	0	0	M	FSR on snout and body
57	04POA-51	1	0	1	0	1	0	0	0	0	F	PHOTO of normal swimbladder
58	04POA-52	1	0	1	0	1	0	0	0	0	M	fish was selected because it was dead;
59	04POA-53	1	0	1	1	1	0	0	0	0	F	FSR on snout; PHOTO of whole external fish;
60	04POA-54	1	0	1	0	1	0	0	0	0	M	
61	04POA-55	1	0	1	0	1	0	0	0	0	M	selected because fish was swimming poorly;
62	04POA-56	1	0	1	0	1	0	0	0	0	F	
63	04POA-57	1	0	1	0	1	0	0	0	0	M	
64	04POA-58	1	0	1	0	1	0	0	0	0	F	FSR on snout
65	04POA-59	1	0	1	0	1	0	0	0	0	F	
66	04POA-66											

67	04POA-67
68	04POA-68
69	04POA-69
70	04POA-70
71	04POA-71
72	04POA-72

ctl.	n	33	33	33	33	33	33	33	33	33
	mean	**1.2**	**0.1**	**1.0**	**0.2**	**0.9**	**0.0**	**0.0**	**0.0**	**0.0**
	SE	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
ham.	n	32	32	32	32	32	32	32	32	32
	mean	**1.0**	**0.0**	**1.0**	**0.1**	**0.9**	**0.0**	**0.0**	**0.0**	**0.0**
	SE	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0

LIVER -

Atly = autolysis
Art = artifact
GD = glycogen depletion
HEM = hemorrhage
LMA = macrophage aggregates
LIP = lipidosis
FPL = focal/multifocal parenchymal leukocytes
CPL = cholangitis/pericholangial leukocytes
PVL = perivascular lymphocytes/leukocytes
IHEM = intestinal hemorrhage

		Liver									Intestine	
#	Sample #	LAtly	LArt	LGD	LHEM	LMA	LLIP	LFPL	LCPL	LPVL	IHEM	Liver Comments
1	04POA-12	1	1	3	0	1	0	0	0	0	0	
2	04POA-13	1	1	3	0	0	1	0	0	0	0	
3	04POA-14	0	1	3	0	1	3	0	0	0	0	
4	04POA-15	1	1	2	0	0	1	0	0	0	0	
5	04POA-16	1	1	3	0	0	1	0	0	0	0	
6	04POA-17	1	1	2	0	0	1	0	0	0	0	
7	04POA-18	1	2	3	0	0	0	0	0	0	0	
8	04POA-19	1	1	3	0	1	0	0	0	0	0	

9	04POA-20	0	2	3	0	0	0	0	0	0	0	
10	04POA-21	1	1	3	0	1	1	0	0	0	0	
11	04POA-22	1	1	3	0	0	0	0	0	0	0	
12	04POA-23	1	1	3	0	0	0	0	0	0	0	2 sections of a 180-µm-wide parasite expand a blood vessel;
13	04POA-24	1	1	3	0	0	0	0	0	0	0	
14	04POA-25	1	1	3	0	3	0	0	0	0	0	
15	04POA-26	1	1	3	0	1	0	0	0	0	0	
16	04POA-27	1	1	3	0	0	1	0	0	0	0	
17	04POA-28	1	1	3	0	2	0	0	0	0	0	
18	04POA-29	1	1	3	0	1	0	0	0	0	0	
19	04POA-39	1	1	3	0	1	1	0	0	0	0	
20	04POA-40	1	1	2	0	1	0	0	0	0	0	
21	04POA-41	1	1	3	0	1	0	0	0	0	0	
22	04POA-42	0	1	3	0	1	0	0	0	0	0	
23	04POA-43	1	1	2	0	0	1	0	0	0	0	
24	04POA-44	1	1	3	0	1	1	0	0	0	0	
25	04POA-45	1	1	3	0	0	1	0	0	0	0	
26	04POA-46	1	1	3	0	2	1	0	0	0	0	
27	04POA-47	1	1	2	0	0	1	1	0	0	0	1 section of a 180-µm-wide parasite expands a blood vessel;
28	04POA-60	1	1	3	0	0	0	0	0	0	0	
29	04POA-61	1	1	3	0	0	0	0	0	0	0	
30	04POA-62	1	1	3	0	0	0	0	0	0	0	
31	04POA-63	1	1	2	0	1	0	0	0	0	0	
32	04POA-64	0	1	3	0	1	0	0	0	0	0	one piece has a 200-µm-diam LMA; nearby vessels are surrounded by hyaline collagen deposits up to 15 µm thick;
33	04POA-65	1	1	3	0	1	2	0	0	0	0	
34	04POA-1	1	1	3	0	1	0	0	0	0	0	
35	04POA-2	1	1	3	0	1	0	0	0	0	0	

36	04POA-3	1	1	3	0	0	0	0	0	0	0	
37	04POA-4	1	1	3	0	1	0	1	0	0	0	
38	04POA-5	1	1	3	0	1	3	0	0	0	0	
39	04POA-6	1	1	3	0	1	0	0	0	0	0	
40	04POA-7	0	1	3	0	0	0	0	0	0	0	
41	04POA-8	1	1	3	0	0	0	0	0	0	0	
42	04POA-9	0	1	3	0	0	0	0	0	0	0	
43	04POA-10	1	2	3	0	0	0	0	0	0	0	200x120 µm parasite (larval nematode?) is partly surrounded by granulomatous infl. and eosinophilic granular cells;
44	04POA-11	1	1	3	0	1	0	0	0	0	0	
45	04POA-30	1	1	3	0	0	0	0	0	0	0	
46	04POA-31	1	1	3	0	1	0	0	0	0	0	
47	04POA-32	0	1	3	0	1	2	0	0	0	0	
48	04POA-33	1	1	2	0	0	1	0	0	0	0	
49	04POA-34	1	1	3	0	0	0	0	0	0	0	
50	04POA-35	1	1	3	0	2	2	0	0	0	0	
51	04POA-36	1	1	3	0	1	0	0	0	0	0	
52	04POA-37	1	1	3	0	0	2	0	0	0	0	
53	04POA-38	1	1	3	0	1	1	1	0	0	0	
54	04POA-48	1	1	2	0	0	1	0	0	0	0	
55	04POA-49	1	1	3	0	0	0	0	0	0	0	
56	04POA-50	1	1	2	0	0	2	0	0	0	0	
57	04POA-51	0	1	3	0	0	0	0	0	0	0	
58	04POA-52	0	1	3	0	0	0	0	0	0	0	
59	04POA-53	1	1	3	0	1	0	0	0	0	0	
60	04POA-54	1	1	3	0	1	0	1	0	0	0	
61	04POA-55	1	1	3	0	0	0	0	0	0	0	
62	04POA-56	1	1	3	0	1	0	0	0	0	0	thrombocyte-rich mural thrombi in heart (moderate);
63	04POA-57	1	1	3	0	1	0	1	0	0	0	
64	04POA-58	1	1	3	0	1	0	0	0	0	0	

65	04POA-59	1	1	3	0	1	0	0	0	0	0
66	04POA-66	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
67	04POA-67	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
68	04POA-68	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
69	04POA-69	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
70	04POA-70	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
71	04POA-71	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
72	04POA-72	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
ctl.	n	33	33	33	33	33	33	33	33	33	33
	mean	**0.9**	**1.1**	**2.8**	**0.0**	**0.6**	**0.5**	**0.0**	**0.0**	**0.0**	**0.0**
	SE	0.1	0.0	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0
ham.	n	32	32	32	32	32	32	32	32	32	32
	mean	**0.8**	**1.0**	**2.9**	**0.0**	**0.6**	**0.4**	**0.1**	**0.0**	**0.0**	**0.0**
	SE	0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0

KIDNEY

HEM = hemorrhage

HPC = hematopoietic cells (relative area)

IRT = immature renal tubules

KMA = pigmented macrophage aggregates
TEP = tubular epithelial protein (intracytoplasmic)

CON = congestion

TEV = tubular epithelial vacuolation

TDI = tubular dilation (of lumen)

SBH = swimbladder hemorrhage

SMH = skeletal muscle/skin hemorrhage

MIC = microsporidian parasite (skeletal muscle)

SCH = spinal cord hemorrhage

Sex = male (M), female (F), or gonad not present in section (NP)

#	Sample #	Atly	Art	Hem	Hpc	Irt	Kma	Tep	Con	Tev	Tdi	Sbh	Smh	Mic	Sch	Sex	Kidney/Body Wedge Comments
1	04POA-12	0	1	0	0	0	0	0	1	0	0	0	0	0	0	F	
2	04POA-13	0	1	0	0	0	1	0	1	0	0	0	0	1	0	F	
3	04POA-14	0	1	0	1	0	1	0	1	0	0	0	0	1	0	F	
4	04POA-15	0	1	0	0	0	0	0	2	0	0	0	0	0	0	NP	cartilage cylinder with epithelial-line internal space ventral to kidney;
5	04POA-16	0	1	0	1	0	1	0	2	0	0	NP	0	0	0	NP	cartilage cylinder with epithelial-line internal space ventral to kidney;
6	04POA-17	1	1	0	0	0	0	0	2	0	0	0	0	1	0	NP	
7	04POA-18	0	1	0	0	0	1	0	2	0	0	0	0	0	0	NP	
8	04POA-19	0	1	0	0	0	0	0	1	0	0	0	0	1	0	F	microsporidian spores and sporoblasts in renal tubule;

9	04POA-20	0	1	0	0	0	1	0	1	0	0	1	0	1	0	NP	
10	04POA-21	0	1	0	1	0	1	0	2	0	0	0	0	1	0	NP	
11	04POA-22	0	1	0	1	0	1	0	1	0	0	0	0	0	0	NP	
12	04POA-23	0	1	0	1	0	1	0	1	0	0	0	0	1	0	NP	
13	04POA-24	0	1	0	0	0	0	0	1	0	0	0	0	0	0	NP	
14	04POA-25	0	1	0	0	0	2	0	1	0	0	0	0	0	0	NP	kidney contains a small thyroid follicle;
15	04POA-26	0	1	0	1	0	1	0	2	0	0	0	0	1	0	M	
16	04POA-27	0	1	0	0	0	1	0	1	0	0	0	0	0	0	NP	
17	04POA-28	0	1	0	0	0	1	0	1	0	0	0	0	0	0	NP	
18	04POA-29	0	1	0	0	0	1	0	1	0	0	0	0	0	0	F	
19	04POA-39	0	1	0	0	0	1	0	1	0	0	0	0	1	0	NP	
20	04POA-40	0	1	0	1	0	1	0	1	0	0	NP	0	1	0	F	
21	04POA-41	0	1	0	1	0	0	0	1	0	0	0	0	1	0	NP	
22	04POA-42	0	1	0	1	0	0	0	2	0	0	1	0	1	0	M	
23	04POA-43	0	1	0	1	0	1	0	1	0	0	NP	0	1	0	NP	
24	04POA-44	0	1	0	0	1	1	0	1	0	0	0	0	0	0	M	
25	04POA-45	0	1	0	0	0	1	0	1	0	0	0	0	0	0	NP	
26	04POA-46	0	1	0	0	0	1	0	1	0	0	0	0	0	0	F	
27	04POA-47	0	1	0	0	0	1	0	1	0	0	0	0	0	0	NP	
28	04POA-60	0	1	0	0	0	0	0	1	0	0	0	0	1	0	F	
29	04POA-61	0	1	0	0	0	1	0	1	0	0	0	0	1	0	M	4 granulomas in the hypodermis, each <300 µm in diameter;
30	04POA-62	0	1	0	1	0	1	0	1	0	0	0	0	1	0	M	
31	04POA-63	0	1	0	0	0	1	0	1	0	0	0	0	0	0	NP	encysted parasite in sk. muscle (500 µm diam.);
32	04POA-64	0	1	0	1	0	1	0	1	0	0	1	0	1	0	NP	skeletal myonecrosis, regionally diffuse, acute, moderate;
33	04POA-65	1	1	0	0	0	0	0	1	0	0	0	0	1	0	NP	
34	04POA-1	0	1	0	1	0	1	0	1	0	0	NP	0	1	0	F	encysted parasite in sk. muscle (300 µm diam.);

35	04POA-2	0	1	0	1	0	1	0	0	0	0	0	0	1	0	F	
36	04POA-3	0	1	0	1	0	1	0	1	0	0	0	0	1	0	F	
37	04POA-4	0	1	0	1	0	1	0	1	0	0	0	0	1	0	F	encysted parasite in sk. muscle (500 µm diam.);
38	04POA-5	0	1	0	0	0	0	0	1	0	0	2	0	1	0	NP	
39	04POA-6	0	1	0	1	0	0	0	1	0	0	0	0	1	0	NP	
40	04POA-7	0	1	0	1	1	1	0	2	0	0	NP	0	1	0	NP	
41	04POA-8	0	1	0	0	0	0	0	1	0	0	0	0	1	0	NP	
42	04POA-9	0	1	0	0	1	1	0	1	0	0	0	0	0	0	NP	
43	04POA-10	0	1	0	0	0	1	0	1	0	0	0	0	1	0	NP	
44	04POA-11	0	1	0	1	0	1	0	1	0	0	1	0	1	0	NP	
45	04POA-30	0	1	0	0	0	1	0	1	0	0	0	0	1	0	NP	
46	04POA-31	0	1	0	0	0	1	0	1	0	0	0	0	1	0	NP	
47	04POA-32	0	1	0	1	0	1	0	1	0	0	1	0	1	0	NP	
48	04POA-33	0	1	0	1	0	1	0	1	0	0	0	0	2	0	F	3 thyroid follicles in kidney;
49	04POA-34	0	1	0	1	0	1	0	1	0	0	0	0	1	0	F	
50	04POA-35	0	1	0	0	0	2	0	1	0	0	0	0	0	0	F	
51	04POA-36	0	1	0	1	0	1	0	1	0	0	0	0	1	0	F	
52	04POA-37	0	1	0	0	0	1	0	2	0	0	2	0	1	0	NP	
53	04POA-38	0	1	0	1	0	1	0	1	0	0	0	0	1	0	F	
54	04POA-48	0	1	0	0	0	1	0	1	0	0	0	0	1	0	NP	
55	04POA-49	0	1	0	1	0	1	0	0	0	0	1	0	1	0	F	myxosporean (Kudoa sp.?) in sk. muscle fibers;
56	04POA-50	0	1	0	0	0	1	0	1	0	0	0	0	1	0	M	
57	04POA-51	0	1	0	1	0	1	0	2	0	0	0	0	1	0	F	
58	04POA-52	0	1	0	0	0	1	0	1	0	0	0	0	1	0	NP	
59	04POA-53	0	1	0	0	1	1	0	1	0	0	0	0	1	0	F	encysted parasite in sk. muscle (400 µm diam.);
60	04POA-54	0	1	0	1	0	1	0	1	0	0	0	0	1	0	NP	
61	04POA-55	0	1	0	3	0	1	0	1	0	0	0	0	1	0	M	

62	04POA-56	0	1	0	1	0	1	0	1	0	0	0	0	1	0	F
63	04POA-57	0	1	0	0	0	1	0	1	0	0	0	0	1	0	NP
64	04POA-58	0	1	0	0	0	0	0	1	0	0	0	0	1	0	F
65	04POA-59	0	1	0	0	0	1	0	1	0	0	NP	0	1	0	NP
66	04POA-66	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
67	04POA-67	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
68	04POA-68	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
69	04POA-69	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
70	04POA-70	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
71	04POA-71	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
72	04POA-72	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP	NP
ctl.	n	33	33	33	33	33	33	33	33	33	33	30	33	33	33	
	mean	**0.1**	**1.0**	**0.0**	**0.4**	**0.0**	**0.8**	**0.0**	**1.2**	**0.0**	**0.0**	**0.1**	**0.0**	**0.5**	**0.0**	
	SE	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.1	0.0	0.1	0.0	
ham.	n	32	32	32	32	32	32	32	32	32	32	29	32	32	32	
	mean	**0.0**	**1.0**	**0.0**	**0.6**	**0.1**	**0.9**	**0.0**	**1.0**	**0.0**	**0.0**	**0.2**	**0.0**	**1.0**	**0.0**	
	SE	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.1	0.0	0.1	0.0	

Appendix C-3. Northern anchovy results (head), Port of Oakland study on the effects of concrete pile driving

Sample # = number assigned sequentially to each fish in the field
Slide # = number assigned by Gary D. Marty for histopathology (blind study)
Type of exposure = hammer or control
Code = exposure/species code assigned by Strategic Environmental, Inc.
Head scores: scored as none (0), mild (1), moderate (2), severe (3), or no data (blank or ND):
#scts = number of step sections head that were examined (each ~200 µm apart)
Atly = autolysis
Art = artifact
Art sct = section # in which artifact was scored
Pituitary Sct. #s = sections that contained the pituitary gland
IEH = inner ear hemorrhage
BSH = brain-spinal cord hemorrhage
BSC = brain-spinal cord vascular congestion (i.e., filled blood vessels)
BSC sct. = section # in which BSC was scored

							HEAD									
#	Sample #	Slide #		Sample date	Type of exposure	Code	Head #scts	plane of sections	Atly	Art	Art sct	Pituitary sct. #s	IEH	BSH	BSC	BSC sct.
1	04POA-12	04FPS3-	10	08/02/04	control	MPOO1A1C	24	sagittal	2	1	10	11-13	0	0	1	12
2	04POA-13	04FPS3-	33	08/02/04	control	MPOO1A1C	24	sagittal	2	2	8	12-14	0	0	1	8
3	04POA-	04FPS3-	46	08/02/04	control	MPOO1A1C	21	sagittal	1	2	2	8-10	0	0	2	16

	14															
4	04POA-15	04FPS3-	14	08/02/04	control	MPOO1A1C	21	sagittal	2	2	5	4-7	0	0	1	6
5	04POA-16	04FPS3-	35	08/02/04	control	MPOO1A1C	15	sagittal	1	2	1	4-6	2	2	2	10
6	04POA-17	04FPS3-	41	08/02/04	control	MPOO1A1C	25	sagittal	2	1	4	14-19	0	0	1	7
7	04POA-18	04FPS3-	5	08/02/04	control	MPOO1A1C	19	sagittal	2	2	7	6-8	0	2	0	NA
8	04POA-19	04FPS3-	34	08/02/04	control	MPOO1A1C	23	sagittal	1	2	4	3-6	0	0	1	10
9	04POA-20	04FPS3-	26	08/02/04	control	MPOO1A1C	24	sagittal	2	2	3	12-14	0	0	0	NA
35	04POA-2	04FPS3-	44	08/02/04	hammer	MPOO1A1T	27	sagittal	1	2	1	23-26	0	0	1	1&16
36	04POA-3	04FPS3-	20	08/02/04	hammer	MPOO1A1T	33	coronal	1	2	11	21-22	0	0	1	13
37	04POA-4	04FPS3-	57	08/02/04	hammer	MPOO1A1T	18	sagittal	1	2	1	3-5	0	0	2	11
38	04POA-5	04FPS3-	25	08/02/04	hammer	MPOO1A1T	30	sagittal	2	2	12	10-14	0	0	0	NA
39	04POA-6	04FPS3-	15	08/02/04	hammer	MPOO1A1T	24	sagittal	2	2	13	9-12	0	0	1	10
40	04POA-7	04FPS3-	59	08/02/04	hammer	MPOO1A1T	24	sagittal	1	1	5	7-10	0	0	1	19
41	04POA-8	04FPS3-	24	08/02/04	hammer	MPOO1A1T	21	oblique-sagittal	1	1	4	1-2	0	0	0	NA
42	04POA-9	04FPS3-	58	08/02/04	hammer	MPOO1A1T	12	sagittal	1	2	1	4-6	0	0	0	NA
43	04POA-10	04FPS3-	9	08/02/04	hammer	MPOO1A1T	27	sagittal	1	1	13	13-15	0	0	0	NA

44	04POA-11	04FPS3-	45	08/02/04	hammer	MPOO1A1T	27	sagittal	1	2	7	7-8	0	0	1	2
					control	n			9	9			9		9	
						mean			**1.7**	**1.8**			**0.2**	**0**	**1.0**	
						SE			0.2	0.1			0.2	0	0.2	
					hammer	n			10	10			10		10	
						mean			**1.2**	**1.7**			**0.0**	**0**	**0.7**	
						SE			0.1	0.2			0.0	0	0.2	

#	Sample #	Comments
1	04POA-12	
2	04POA-13	
3	04POA-14	
4	04POA-15	
5	04POA-16	scts. 1 and 2 have hemorrhage covering neurosensory epithelium; hemorrhage in scts. 4, 5, & 9 covers base of brain; sct. 7 has an irregular strand of microsporidians that is 600 µm long and about 100 µm in diameter; sct. 12 has hem in branchial cavity;
6	04POA-17	hemorrhage dorsal to spinal cord in scts 20-23 is considered artifact associated with removing the top of the skull for better fixation;
7	04POA-18	sct 2 has hemorrhage ventral to brain
8	04POA-19	sct. 2 has an irregular strand of microsporidians that is 2 mm long and about 100 µm in diameter;
9	04POA-20	sct. 4 PHOTO of intact neurosensory epithelium; sct. 5 has a 400-µm-diameter microsporidian xenoma in the loose connective tissues anterior and ventral to the brain; sct. 8 has two microsporidian xenomas, each about 150 x 60 µm,in the skeletal muscle near the optic nerve; sct 9-12, encysted cestode in skeletal muscle dorsal to spinal cord;
35	04POA-2	this head was trimmed midsagittally and then sectioned in two pieces from medial to lateral; scts 7-12 contains an encysted cestode in the skeletal muscle dorsal to the spinal cord;

36	04POA-3	sct 17 good for photo of the largest of the 3 semicircular canals; microsporidian xenoma in skeletal muscle is 120 x 60 µm;
37	04POA-4	
38	04POA-5	sct. 21 has 2 foci of microsporidian xenomas, each about 150 x 100 µm;
39	04POA-6	Section 7 has a 250 x 100 µm microsporidian xenoma posterior to the choroid plexus and a 150 x 150 µm focus near the optic nerve;
40	04POA-7	
41	04POA-8	sct. 9 has intact vessels around brain and spinal cord
42	04POA-9	scts 1-10 contain an encysted cestode in the skeletal muscle dorsal to the spinal cord (sct 3 contains the scolex);
43	04POA-10	
44	04POA-11	

Appendix C-4. Shiner perch results, Port of Oakland study on the effects of concrete pile driving

Sample # = number assigned sequentially to each fish in the field
Slide # = number assigned by Gary D. Marty for histopathology (blind study)
Type of exposure = hammer or control
Code = exposure/species code assigned by Strategic Environmental, Inc.
Exposure end time = time when pile driving stopped
Hold = selection for necropsy; R = random, S = selected;
L = standard length (mm)
Wt. = total body weight (g)
Path. = pathologist; GDM = Gary D. Marty
Recorder = Andy Jahn (AEJ), Jody Zaitlin (JAZ), Marucia Britto (MB)
Necropsy start = time that necropsy started
Hold time = time from end of exposure to necrospy start

#	Sample #	Slide #	Sample date	Type of exposure	Code	Exposure end time	Hold	(mm) Length	(g) Weight	Path.	Recorder	Necropsy Start	Hold time (min.)
1	04POP-10	04FPS2- 49	08/02/04	control	MPOO1P1C	3:26 PM	R	82	11.8	GDM	JAZ	6:51 PM	205
2	04POP-11	04FPS2- 45	08/02/04	control	MPOO1P1C	3:26 PM	R	84	13.3	GDM	JAZ	6:54 PM	208
3	04POP-12	04FPS2- 47	08/02/04	control	MPOO1P1C	3:26 PM	R	95	16.8	GDM	JAZ	6:57 PM	211
4	04POP-13	04FPS2- 54	08/02/04	control	MPOO1P1C	3:26 PM	R	90	16.0	GDM	JAZ	7:00 PM	214
5	04POP-14	04FPS2- 68	08/02/04	control	MPOO1P1C	3:26 PM	R	88	16.4	GDM	JAZ	7:03 PM	217
6	04POP-15	04FPS2- 57	08/02/04	control	MPOO1P1C	3:26 PM	R	94	17.5	GDM	JAZ	7:06 PM	220
7	04POP-16	04FPS2- 60	08/02/04	control	MPOO1P1C	3:26 PM	R	98	18.7	GDM	JAZ	7:09 PM	223
8	04POP-17	04FPS2- 12	08/02/04	control	MPOO1P1C	3:26 PM	R	93	18.0	GDM	JAZ	7:11 PM	225
9	04POP-18	04FPS2- 58	08/03/04	control	MPOOP3C	11:04 AM	R	94	17.7	GDM	MB	12:05 PM	61
10	04POP-19	04FPS2- 33	08/03/04	control	MPOOP3C	11:04 AM	R	102	23.7	GDM	MB	12:09 PM	65

11	04POP-20	04FPS2-	39	08/03/04	control	MPOOP3C	11:04 AM	R	91	16.6	GDM	MB	12:16 PM	72
12	04POP-21	04FPS2-	11	08/03/04	control	MPOOP3C	11:04 AM	R	108	28.9	GDM	MB	12:20 PM	76
13	04POP-22	04FPS2-	16	08/03/04	control	MPOOP3C	11:04 AM	R	87	15.2	GDM	MB	12:25 PM	81
14	04POP-23	04FPS2-	19	08/03/04	control	MPOOP3C	11:04 AM	R	87	12.7	GDM	MB	12:29 PM	85
15	04POP-24	04FPS2-	70	08/03/04	control	MPOOP3C	11:04 AM	R	85	13.8	GDM	MB	12:31 PM	87
16	04POP-25	04FPS2-	44	08/03/04	control	MPOOP3C	11:04 AM	R	65	6.3	GDM	MB	12:35 PM	91
17	04POP-35	04FPS2-	52	08/03/04	control	MPOO2P1C	2:50 PM	R	93	18.7	GDM	MB	4:31 PM	101
18	04POP-36	04FPS2-	13	08/03/04	control	MPOO2P1C	2:50 PM	R	90	15.6	GDM	MB	4:34 PM	104
19	04POP-37	04FPS2-	26	08/03/04	control	MPOO2P1C	2:50 PM	R	80	11.4	GDM	MB	4:39 PM	109
20	04POP-38	04FPS2-	55	08/03/04	control	MPOO2P1C	2:50 PM	R	90	15.0	GDM	MB	4:41 PM	111
21	04POP-39	04FPS2-	21	08/03/04	control	MPOO2P1C	2:50 PM	R	93	18.1	GDM	MB	4:44 PM	114
22	04POP-40	04FPS2-	5	08/03/04	control	MPOO2P1C	2:50 PM	R	78	6.0	GDM	MB	4:47 PM	117
23	04POP-41	04FPS2-	48	08/03/04	control	MPOO2P1C	2:50 PM	R	80	12.0	GDM	MB	4:50 PM	120
24	04POP-42	04FPS2-	40	08/03/04	control	MPOO2P1C	2:50 PM	R	86	11.4	GDM	MB	4:55 PM	125
25	04POP-43	04FPS2-	14	08/03/04	control	MPOO2P1C	2:50 PM	R	88	14.4	GDM	MB	4:58 PM	128
26	04POP-62	04FPS2-	4	08/04/04	control	MPOO3P2C	10:46 AM	S	104	23.7	GDM	MB	12:27 PM	101
27	04POP-63	04FPS2-	32	08/04/04	control	MPOO3P2C	10:46 AM	R	88	14.7	GDM	MB	12:31 PM	105
28	04POP-64	04FPS2-	61	08/04/04	control	MPOO3P2C	10:46 AM	R	92	16.2	GDM	MB	12:34 PM	108
29	04POP-65	04FPS2-	25	08/04/04	control	MPOO3P2C	10:46 AM	R	90	15.1	GDM	MB	12:37 PM	111
30	04POP-66	04FPS2-	8	08/04/04	control	MPOO3P2C	10:46 AM	R	89	13.6	GDM	MB	12:39 PM	113
31	04POP-67	04FPS2-	71	08/04/04	control	MPOO3P2C	10:46 AM	R	83	13.2	GDM	MB	12:43 PM	117
32	04POP-1	04FPS2-	56	08/02/04	hammer	MPOO1P1T	2:30 PM	R	82	13.1	GDM	JAZ	5:27 PM	177
33	04POP-2	04FPS2-	69	08/02/04	hammer	MPOO1P1T	2:30 PM	R	87	13.6	GDM	JAZ	5:31 PM	181
34	04POP-3	04FPS2-	3	08/02/04	hammer	MPOO1P1T	2:30 PM	R	83	12.0	GDM	JAZ	5:34 PM	184

35	04POP-4	04FPS2-	17	08/02/04	hammer	MPOO1P1T	2:30 PM	R	89	11.3	GDM	JAZ	5:38 PM	188
36	04POP-5	04FPS2-	18	08/02/04	hammer	MPOO1P1T	2:30 PM	R	91	15.3	GDM	JAZ	5:40 PM	190
37	04POP-6	04FPS2-	53	08/02/04	hammer	MPOO1P1T	2:30 PM	R	99	15.5	GDM	JAZ	5:45 PM	195
38	04POP-7	04FPS2-	15	08/02/04	hammer	MPOO1P1T	2:30 PM	R	93	17.1	GDM	JAZ	5:47 PM	197
39	04POP-8	04FPS2-	10	08/02/04	hammer	MPOO1P1T	2:30 PM	R	84	12.6	GDM	JAZ	5:50 PM	200
40	04POP-9	04FPS2-	62	08/02/04	hammer	MPOO1P1T	2:30 PM	R	90	16.3	GDM	JAZ	5:53 PM	203
41	04POP-26	04FPS2-	20	08/03/04	hammer	MPOO2P2T	1:06 PM	R	80	12.2	GDM	MB	2:21 PM	75
42	04POP-27	04FPS2-	67	08/03/04	hammer	MPOO2P2T	1:06 PM	R	85	12.8	GDM	MB	2:24 PM	78
43	04POP-28	04FPS2-	43	08/03/04	hammer	MPOO2P2T	1:06 PM	R	91	15.4	GDM	MB	2:27 PM	81
44	04POP-29	04FPS2-	2	08/03/04	hammer	MPOO2P2T	1:06 PM	R	82	12.7	GDM	MB	2:30 PM	84
45	04POP-30	04FPS2-	29	08/03/04	hammer	MPOO2P2T	1:06 PM	R	80	11.2	GDM	MB	2:34 PM	88
46	04POP-31	04FPS2-	72	08/03/04	hammer	MPOO2P2T	1:06 PM	R	88	15.3	GDM	MB	2:36 PM	90
47	04POP-32	04FPS2-	7	08/03/04	hammer	MPOO2P2T	1:06 PM	R	86	15.7	GDM	MB	2:40 PM	94
48	04POP-33	04FPS2-	23	08/03/04	hammer	MPOO2P2T	1:06 PM	R	87	14.3	GDM	MB	2:44 PM	98
49	04POP-34	04FPS2-	65	08/03/04	hammer	MPOO2P2T	1:06 PM	R	88	13.5	GDM	MB	2:47 PM	101
50	04POP-44	04FPS2-	36	08/03/04	hammer	MPOO2P4T	4:15 PM	R	90	16.5	GDM	MB	6:34 PM	139
51	04POP-45	04FPS2-	6	08/03/04	hammer	MPOO2P4T	4:15 PM	R	100	21.6	GDM	MB	6:37 PM	142
52	04POP-46	04FPS2-	1	08/03/04	hammer	MPOO2P4T	4:15 PM	R	75	10.7	GDM	MB	6:40 PM	145
53	04POP-47	04FPS2-	31	08/03/04	hammer	MPOO2P4T	4:15 PM	R	95	18.3	GDM	MB	6:44 PM	149
54	04POP-48	04FPS2-	46	08/03/04	hammer	MPOO2P4T	4:15 PM	R	74	8.8	GDM	MB	6:46 PM	151
55	04POP-49	04FPS2-	63	08/03/04	hammer	MPOO2P4T	4:15 PM	R	90	15.5	GDM	MB	6:50 PM	155
56	04POP-50	04FPS2-	30	08/03/04	hammer	MPOO2P4T	4:15 PM	R	91	16.5	GDM	MB	6:54 PM	159
57	04POP-51	04FPS2-	42	08/03/04	hammer	MPOO2P4T	4:15 PM	R	97	20.5	GDM	MB	7:00 PM	165
58	04POP-52	04FPS2-	64	08/03/04	hammer	MPOO2P4T	4:15 PM	R	84	14.4	GDM	MB	7:04 PM	169
59	04POP-53	04FPS2-	22	08/04/04	hammer	MPOO3P1T	9:04 AM	R	94	16.7	GDM	MB	10:50 AM	106
60	04POP-54	04FPS2-	34	08/04/04	hammer	MPOO3P1T	9:04 AM	R	94	18.5	GDM	MB	10:53 AM	109
61	04POP-55	04FPS2-	41	08/04/04	hammer	MPOO3P1T	9:04 AM	R	108	32.1	GDM	MB	10:57 AM	113

62	04POP-56	04FPS2-	24	08/04/04	hammer	MPOO3P1T	9:04 AM	R	93	18.1	GDM	MB	11:08 AM	124
63	04POP-57	04FPS2-	35	08/04/04	hammer	MPOO3P1T	9:04 AM	R	86	13.7	GDM	MB	11:11 AM	127
64	04POP-58	04FPS2-	50	08/04/04	hammer	MPOO3P1T	9:04 AM	R	87	15.4	GDM	MB	11:15 AM	131
65	04POP-59	04FPS2-	38	08/04/04	hammer	MPOO3P1T	9:04 AM	R	93	17.3	GDM	MB	11:17 AM	133
66	04POP-60	04FPS2-	9	08/04/04	hammer	MPOO3P1T	9:04 AM	R	93	17.8	GDM	MB	11:20 AM	136
67	04POP-61	04FPS2-	27	08/04/04	hammer	MPOO3P1T	9:04 AM	R	78	10.4	GDM	MB	11:25 AM	141
68	04POP-68	04FPS2-	51	no fish										
69	04POP-69	04FPS2-	28	no fish										
70	04POP-70	04FPS2-	66	no fish										
71	04POP-71	04FPS2-	37	no fish										
72	04POP-72	04FPS2-	59	no fish										
ctl.	n				control	n			31	31				31
	mean					**mean**			**89.3**	**15.6**				**129.8**
	SE					SE			1.5	0.8				9.7
ham.	n				hammer	n			36	36				36
	mean					**mean**			**88.5**	**15.4**				**138.8**
	SE					SE			1.2	0.7				6.6

External/Gross Lesion Scores; scored as none (0), mild (1), moderate (2), severe (3), or no data (ND):

CFF = caudal fin fraying
CFR = caudal fin reddening
OFF = other fin fraying
FBR = fin base reddening
FSR = focal skin reddening
VCH = visceral cavity hemorrhage
LH = liver hemorrhage
SBH = swimbladder hemorrhage
KH = kidney hemorrhage

Gross Sex = M (male); F (female); U (unknown);

		External/Gross Lesion Scores									Gross	
#	Sample #	CFF	CFR	OFF	FBR	FSR	VCH	LH	SBH	KH	Sex	Gross Comments
1	04POP-10	1	0	1	0	0	0	0	0	0	M	
2	04POP-11	1	0	0	0	0	0	0	0	0	M	
3	04POP-12	2	0	1	1	0	0	0	0	0	F	
4	04POP-13	0	0	1	0	0	0	0	0	0	F	
5	04POP-14	1	0	1	0	0	0	0	0	0	M	
6	04POP-15	1	0	1	0	0	0	0	0	0	F	
7	04POP-16	1	0	0	0	0	0	0	0	0	F	
8	04POP-17	1	0	0	0	0	0	0	0	0	M	
9	04POP-18	1	0	1	0	0	0	0	0	0	M	
10	04POP-19	2	0	1	0	1	0	0	0	0	M	PHOTO #1 of normal fish (viscera)
11	04POP-20	1	0	0	0	0	0	0	0	0	M	

12	04POP-21	2	0	1	0	0	0	0	0	0	M	
13	04POP-22	1	0	0	0	0	0	0	0	0	M	
14	04POP-23	1	0	1	0	0	0	0	0	0	F	
15	04POP-24	1	0	1	0	0	0	0	0	0	M	
16	04POP-25	1	0	1	1	0	0	0	0	0	M	
17	04POP-35	1	0	1	0	0	0	0	0	0	M	
18	04POP-36	2	0	1	0	0	0	0	0	0	M	
19	04POP-37	1	0	1	0	0	0	0	0	0	F	
20	04POP-38	1	0	0	0	0	0	0	0	0	M	
21	04POP-39	2	0	0	1	0	0	0	0	0	F	
22	04POP-40	1	0	1	0	0	0	0	0	0	M	
23	04POP-41	1	0	0	0	0	0	0	0	0	M	
24	04POP-42	1	0	0	0	0	0	0	0	0	F	
25	04POP-43	1	0	0	0	0	0	0	0	0	M	
26	04POP-62	1	0	0	0	0	0	0	0	0	M	selected because it was dead (stuck in fold of bag)
27	04POP-63	2	0	0	1	0	0	0	0	0	F	
28	04POP-64	1	0	1	0	0	0	0	0	0	M	
29	04POP-65	1	0	1	1	0	0	0	0	0	F	
30	04POP-66	1	0	1	0	0	0	0	0	0	M	
31	04POP-67	1	0	1	0	0	0	0	0	0	M	
32	04POP-1	1	0	1	0	0	0	0	0	0	M	
33	04POP-2	1	0	1	0	0	0	0	0	0	F	
34	04POP-3	2	0	1	0	0	0	0	0	0	M	
35	04POP-4	1	0	0	0	0	0	0	0	0	M	
36	04POP-5	1	0	1	0	0	0	0	0	0	F	

37	04POP-6	1	0	1	0	0	0	0	0	0	M	
38	04POP-7	1	0	1	0	0	0	0	0	0	M	
39	04POP-8	2	0	1	0	0	0	0	0	0	M	
40	04POP-9	2	0	0	0	0	0	0	0	0	M	
41	04POP-26	1	0	1	0	0	0	0	0	0	M	
42	04POP-27	1	0	0	0	0	0	0	0	0	F	
43	04POP-28	1	0	1	0	0	0	0	0	0	F	
44	04POP-29	1	0	0	0	0	0	0	0	0	M	
45	04POP-30	1	0	1	0	0	0	0	0	0	M	
46	04POP-31	1	0	0	0	0	0	0	0	0	M	
47	04POP-32	1	0	0	0	0	0	0	0	0	M	
48	04POP-33	1	0	1	0	0	0	0	0	0	M	
49	04POP-34	1	0	0	0	0	0	0	0	0	M	
50	04POP-44	2	0	1	0	0	0	0	0	0	M	
51	04POP-45	2	0	0	0	0	0	0	0	0	M	
52	04POP-46	0	0	1	0	0	0	0	0	0	M	
53	04POP-47	1	0	1	0	0	0	0	0	0	F	
54	04POP-48	1	0	0	0	0	0	0	0	0	F	
55	04POP-49	1	0	1	0	0	0	0	0	0	M	
56	04POP-50	1	0	0	0	0	0	0	0	0	M	
57	04POP-51	1	0	0	0	0	0	0	0	0	M	PHOTO #5 of normal fish (whole)
58	04POP-52	1	0	0	0	0	0	0	0	0	M	
59	04POP-53	1	0	1	0	0	0	0	0	0	M	
60	04POP-54	1	0	1	0	0	0	0	0	0	M	
61	04POP-55	1	0	1	1	1	1	1	1	0	M	abdominal cavity contains 2 mL of red fluid (PHOTO #8)
62	04POP-56	2	0	0	0	0	0	0	0	0	M	

63	04POP-57	1	0	1	0	1	0	0	0	0	M
64	04POP-58	1	0	1	0	0	0	0	0	0	M
65	04POP-59	1	1	1	0	0	0	0	0	0	M
66	04POP-60	1	0	1	0	0	0	0	0	0	F
67	04POP-61	1	0	1	0	0	0	0	0	0	F
68	04POP-68										
69	04POP-69										
70	04POP-70										
71	04POP-71										
72	04POP-72										
ctl.	n	31	31	31	31	31	31	31	31	31	
	mean	**1.2**	**0.0**	**0.6**	**0.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	
	SE	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	
ham.	n	36	36	36	36	36	36	36	36	36	
	mean	**1.1**	**0.0**	**0.6**	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	
	SE	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	

LIVER -

Atly = autolysis

Art = artifact

GD = glycogen depletion

HEM = hemorrhage

LMA = macrophage aggregates

LIP = lipidosis

FPL = focal/multifocal parenchymal leukocytes

CPL = cholangitis/pericholangial leukocytes

PVL = perivascular lymphocytes/leukocytes

IHEM = intestinal hemmorhage

		Liver									Intestine	
#	Sample #	LAtly	LArt	GD	HEM	LMA	LIP	FPL	CPL	PVL	IHEM	Liver Comments
1	04POP-10	0	1	2	0	0	0	0	0	0	0	
2	04POP-11	0	1	2	0	0	0	0	0	0	0	
3	04POP-12	0	1	1	0	0	0	0	0	0	NP	
4	04POP-13	0	1	2	0	0	0	0	0	0	0	
5	04POP-14	0	1	2	0	0	0	0	0	0	0	

6	04POP-15	0	1	1	0	0	0	0	0	0	0
7	04POP-16	1	1	3	0	0	0	0	0	0	0
8	04POP-17	0	1	3	0	0	0	0	0	0	NP
9	04POP-18	0	1	3	0	0	0	1	0	1	0
10	04POP-19	0	1	3	0	1	0	0	0	0	0
11	04POP-20	0	1	3	0	1	0	1	0	0	0
12	04POP-21	0	1	3	0	0	0	1	0	0	NP
13	04POP-22	0	1	3	0	0	0	0	0	0	NP
14	04POP-23	0	1	3	0	0	0	0	0	0	0
15	04POP-24	0	1	2	0	0	0	0	0	0	NP
16	04POP-25	0	1	3	0	0	0	0	0	0	0
17	04POP-35	0	1	2	0	0	0	0	0	0	NP
18	04POP-36	0	1	3	0	3	0	0	0	0	NP
19	04POP-37	0	1	1	0	0	0	0	0	0	NP
20	04POP-38	0	1	3	0	0	0	0	0	0	0
21	04POP-39	0	1	3	0	0	0	0	0	0	NP
22	04POP-40	0	1	3	0	0	0	0	0	0	0
23	04POP-41	0	1	3	0	0	0	0	0	0	NP
24	04POP-42	0	1	3	0	0	0	0	0	0	NP
25	04POP-43	0	1	3	0	0	0	0	0	0	NP
26	04POP-62	0	1	3	0	0	2	0	0	0	0
27	04POP-63	0	1	3	0	0	0	0	0	0	NP
28	04POP-64	0	1	2	0	0	0	0	0	0	0

29	04POP-65	0	1	2	0	0	0	0	0	0	NP
30	04POP-66	0	1	3	0	1	0	0	1	0	NP
31	04POP-67	1	1	2	0	0	0	0	0	0	0
32	04POP-1	0	1	1	0	0	0	0	0	0	0
33	04POP-2	1	1	2	0	0	0	0	0	0	0
34	04POP-3	0	1	3	0	0	0	0	0	0	0
35	04POP-4	0	1	3	0	0	0	0	0	0	NP
36	04POP-5	0	1	3	0	0	0	0	1	0	0
37	04POP-6	0	1	3	0	0	0	0	0	0	NP
38	04POP-7	1	1	3	0	1	0	0	0	0	NP
39	04POP-8	0	1	2	0	0	0	0	0	0	NP
40	04POP-9	0	1	1	0	0	0	0	0	0	NP
41	04POP-26	0	1	3	0	0	0	0	0	0	0
42	04POP-27	0	1	2	0	0	0	0	0	0	0
43	04POP-28	0	1	2	0	1	0	0	0	0	0
44	04POP-29	0	1	2	0	0	0	0	0	0	0
45	04POP-30	0	1	2	0	0	0	0	0	0	0
46	04POP-31	0	1	2	0	0	0	0	0	0	0
47	04POP-32	0	1	3	0	0	0	0	0	0	NP
48	04POP-33	0	1	3	0	0	0	0	0	0	0
49	04POP-34	0	1	3	0	0	0	0	0	0	0
50	04POP-44	0	1	3	0	0	0	0	0	0	0
51	04POP-45	0	1	3	0	1	0	0	0	0	NP
52	04POP-46	0	1	2	0	0	0	0	0	0	0
53	04POP-47	0	1	3	0	0	0	0	0	0	NP
54	04POP-48	0	1	3	0	0	0	0	0	0	NP
55	04POP-49	0	1	3	0	0	0	0	0	0	0

dead cestode encysted on margin of liver 600 µm in diameter;

56	04POP-50	0	1	3	0	0	0	0	0	0	NP
57	04POP-51	0	1	3	0	0	0	0	0	0	NP
58	04POP-52	1	1	3	0	1	0	0	0	0	NP
59	04POP-53	0	1	3	0	0	0	0	1	0	NP
60	04POP-54	0	1	3	0	0	0	0	0	0	NP
61	04POP-55	0	1	3	0	0	0	0	0	0	NP
62	04POP-56	0	1	3	0	0	0	0	1	0	NP
63	04POP-57	0	1	3	0	1	0	0	0	0	NP
64	04POP-58	0	1	3	0	0	0	0	0	0	NP
65	04POP-59	0	1	3	0	0	0	0	0	0	0
66	04POP-60	0	1	3	0	1	0	0	0	0	NP
67	04POP-61	0	1	3	0	0	0	0	0	0	0
68	04POP-68										
69	04POP-69										
70	04POP-70										
71	04POP-71										
72	04POP-72										
ctl.	n	31	31	31	31	31	31	31	31	31	16
	mean	**0.1**	**1.0**	**2.5**	**0.0**	**0.2**	**0.1**	**0.1**	**0.0**	**0.0**	**0.0**
	SE	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0
ham.	n	36	36	36	36	36	36	36	36	36	17
	mean	**0.1**	**1.0**	**2.7**	**0.0**	**0.2**	**0.0**	**0.0**	**0.1**	**0.0**	**0.0**
	SE	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0

KIDNEY

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HEM = hemorrhage

HPC = hematopoietic cells (relative area)

IRT = immature renal tubules

KMA = pigmented macrophage aggregates

TEP = tubular epithelial protein (intracytoplasmic)

CON = congestion

TEV = tubular epithelial vacuolation

TDI = tubular dilation (of lumen)

SBH = swimbladder hemorrhage

SMH = skeletal muscle/skin hemorrhage

SCH = spinal cord hemorrhage

		Kidney/Body Wedge Lesions												
#	Sample #	Atly	Art	Hem	Hpc	Irt	Kma	Tep	Con	Tev	Tdi	Sbh	Smh	Sch	Kidney/Body Wedge Comments
1	04POP-10	0	1	0	1	0	1	1	1	0	0	0	0	0	
2	04POP-11	0	1	0	1	0	1	0	1	1	0	0	0	0	
3	04POP-12	0	1	0	1	0	1	0	1	0	0	0	0	0	
4	04POP-13	0	1	0	0	0	1	0	1	0	0	0	0	0	focus of granulomatous inflammation dorsal to kidney 300 x 200 µm;
5	04POP-14	0	1	0	0	1	0	1	1	1	0	0	0	0	
6	04POP-15	0	1	0	0	0	0	1	1	0	0	0	0	0	slide includes a section of testis; focus of granulomatous inflammation ventral to vertebra and near ganglion is 200 µm in diam.
7	04POP-16	0	1	0	1	0	0	0	1	0	0	0	0	0	dermal granuloma (dead parasite?) is about

														80x120 µm;
8	04POP-17	0	1	0	0	0	0	0	1	0	0	0	0	0	a roughly L-shaped mass of foreign material (probably of parasitic origin), 1 x 0.4 mm, is surrounded by a narrow band of fibrous tissue;
9	04POP-18	0	1	0	2	0	3	0	0	0	0	0	0	0	200-µm-diam. cyst of unknown etiology in kidney;slide includes liver
10	04POP-19	0	1	0	2	0	2	0	0	0	0	0	0	0	
11	04POP-20	0	2	0	3	0	3	0	0	0	0	0	0	0	focus of granulomatous inflammation in dorsal connective tissue surrounds a 300-µm-long section of a blood vessel;
12	04POP-21	0	1	0	1	0	3	0	0	1	0	0	0	0	
13	04POP-22	0	1	0	0	0	1	0	1	0	0	0	0	0	
14	04POP-23	0	1	0	0	1	1	0	1	0	0	0	0	0	
15	04POP-24	0	1	0	0	0	1	0	1	1	0	0	0	0	foci of encysted multinucleate organisms (nematode larvae?) in skin are each about 50 µm in diameter; slide includes liver
16	04POP-25	0	1	0	0	0	0	0	2	1	0	0	0	0	
17	04POP-35	0	1	0	0	0	1	0	1	0	0	0	0	0	
18	04POP-36	0	1	0	2	0	2	0	0	0	0	0	0	0	skin contains multiple foci of encysted multinucleate organisms that are about 50 µm in diameter;
19	04POP-37	0	2	0	1	0	0	0	1	0	0	0	0	0	
20	04POP-38	0	1	0	1	0	1	0	2	0	0	0	0	0	slide includes a section of testis;
21	04POP-39	0	1	0	1	0	0	0	1	0	0	0	0	0	
22	04POP-40	0	1	0	0	1	0	1	1	0	0	0	0	0	
23	04POP-41	0	1	0	0	0	1	0	2	1	0	0	0	0	
24	04POP-42	0	2	0	1	0	1	0	0	0	0	0	0	0	
25	04POP-43	0	1	0	1	0	1	0	2	1	0	0	0	0	
26	04POP-62	0	1	0	1	0	2	0	2	0	0	0	0	0	
27	04POP-63	0	1	0	1	0	1	0	1	0	0	0	0	0	200-µm-diameter cyst of unknown etiology in kidney;slide includes a section of liver
28	04POP-64	0	1	0	0	0	0	0	2	0	0	0	0	0	

29	04POP-65	0	1	0	1	0	1	0	1	0	0	0	0	0	free RBCs between kidney and body wall is considered to be an artifact of sampling;
30	04POP-66	0	1	0	2	0	1	0	1	0	0	0	0	0	
31	04POP-67	0	1	0	1	0	1	0	1	1	0	0	0	0	
32	04POP-1	0	1	0	0	0	0	1	1	0	0	0	0	0	focus of granulomatous inflammation dorsal to epaxial skeletal muscle is 200 µm in diameter;
33	04POP-2	0	2	0	1	0	0	0	1	0	0	0	0	0	cestode encysted in skeletal muscle (300 µm in diameter);
34	04POP-3	0	1	0	1	0	1	1	2	0	0	0	0	0	
35	04POP-4	0	1	0	0	0	0	1	1	0	0	0	0	0	
36	04POP-5	0	1	0	0	0	1	1	1	0	2	0	0	0	
37	04POP-6	0	1	0	0	0	1	1	1	0	0	0	0	0	
38	04POP-7	0	1	0	0	1	2	1	1	0	0	0	0	0	
39	04POP-8	0	1	0	1	0	2	0	1	0	0	0	0	0	
40	04POP-9	0	1	0	2	0	1	2	1	0	0	0	0	0	
41	04POP-26	0	2	0	1	0	0	0	0	0	0	0	0	0	
42	04POP-27	0	1	0	2	0	1	0	1	0	0	0	0	0	hypodermal granuloma (larval nematodes?) is about 350x120 µm;
43	04POP-28	0	1	0	1	0	1	0	1	0	0	0	0	0	focus of acute skeletal muscle necrosis (250 µm in diameter)
44	04POP-29	0	1	0	1	0	2	0	1	0	0	0	0	0	
45	04POP-30	1	1	0	0	0	0	0	1	0	0	0	0	0	
46	04POP-31	0	1	0	2	0	1	0	1	0	0	0	0	0	
47	04POP-32	0	1	0	1	0	1	0	0	0	0	0	0	0	
48	04POP-33	0	1	0	0	0	0	0	1	0	0	0	0	0	section includes prominent rete mirabile;
49	04POP-34	0	1	0	0	0	1	0	1	0	0	0	0	0	
50	04POP-44	1	1	0	2	0	1	0	1	0	0	0	0	0	
51	04POP-45	0	1	0	1	0	2	0	1	1	0	0	0	0	
52	04POP-46	0	1	0	1	0	0	0	1	0	0	0	0	0	
53	04POP-47	0	1	0	0	0	1	0	0	0	0	0	0	0	400-µm-diameter foreign body granuloma (dead parasite?) on dorsal dermis; 150 x 100 µm granuloma near ventral rib;

54	04POP-48	1	1	0	1	0	1	0	0	0	0	0	0	0	
55	04POP-49	0	1	0	1	0	3	0	1	0	0	0	0	0	
56	04POP-50	0	2	0	0	0	0	0	1	0	0	0	0	0	
57	04POP-51	0	1	0	1	0	1	0	1	0	0	0	0	0	2-mm-long focus of granulomatous inflammation and larval nematodes in dorsal hypodermis (unilateral)
58	04POP-52	0	1	0	0	0	1	0	2	2	0	0	0	0	trematode metacercaria encysted in dorsal muscle (250x200 µm);
59	04POP-53	0	1	0	0	1	1	0	1	0	0	0	0	0	
60	04POP-54	0	1	0	0	0	1	1	1	0	0	0	0	0	
61	04POP-55	0	1	0	3	0	3	0	0	0	0	0	1	0	skin contains multiple foci of encysted multinucleate organisms (larval nematodes?) that are each about 50 µm in diameter;
62	04POP-56	0	1	0	1	0	1	0	2	0	0	0	0	0	
63	04POP-57	0	1	0	1	0	3	0	1	0	0	0	0	0	multiple foci of granulomatous inflammation in a spinal nerve; slide includes a section of testis;
64	04POP-58	0	1	0	1	0	0	0	1	0	0	0	0	0	trematode metacercaria encysted in muscle (250x350 µm);
65	04POP-59	0	1	0	0	0	0	0	2	0	0	0	0	0	
66	04POP-60	0	1	0	0	0	0	1	0	0	0	0	0	0	
67	04POP-61	0	1	0	1	0	0	1	1	1	0	0	0	0	
68	04POP-68														
69	04POP-69														
70	04POP-70														
71	04POP-71														
72	04POP-72														
ctl.	n	31	31	31	31	31	31	31	31	31	31	31	31	31	
	mean	**0.0**	**1.1**	**0.0**	**0.8**	**0.1**	**1.0**	**0.1**	**1.0**	**0.3**	**0.0**	**0.0**	**0.0**	**0.0**	
	SE	0.0	0.1	0.0	0.1	0.1	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	
ham.	n	36	36	36	36	36	36	36	36	36	36	36	36	36	

mean	**0.1**	**1.1**	**0.0**	**0.8**	**0.1**	**0.9**	**0.3**	**0.9**	**0.1**	**0.1**	**0.0**	**0.0**	**0.0**
SE	0.0	0.0	0.0	0.1	0.0	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0

Appendix C-5. Chinook salmon results, Port of Oakland study on the effects of concrete pile driving

Sample # = number assigned sequentially to each fish in the field
Slide # = number assigned by Gary D. Marty for histopathology (blind study)
Type of exposure = hammer or control
Code = exposure/species code assigned by Strategic Environmental, Inc.
Exposure end time = time when pile driving stopped
Hold = selection for necropsy; R = random, S = selected;

L = standard length (mm)
Wt. = total body weight (g)

Path. = pathologist; GDM = Gary D. Marty

Recorder = Andy Jahn (AEJ), Jody Zaitlin (JAZ), Marucia Britto (MB)

Necropsy start = time that necropsy started
Hold time = time from end of exposure to necropsy start

#	Sample #	Slide #	Sample date	Type of exposure	Code	Exposure end time	Hold	(mm) Length	(g) Weight	Path.	Recorder	Necropsy Start	Hold time (min.)
1	04POS-9	04FPS1- 32	08/02/04	control	MPOO1C1C	3:45 PM	R	92	10.0	GDM	JAZ	6:27 PM	162
2	04POS-10	04FPS1- 36	08/02/04	control	MPOO1C1C	3:45 PM	R	75	5.8	GDM	JAZ	6:29 PM	164
3	04POS-11	04FPS1- 41	08/02/04	control	MPOO1C1C	3:45 PM	R	96	10.7	GDM	JAZ	6:32 PM	167
4	04POS-12	04FPS1- 38	08/02/04	control	MPOO1C1C	3:45 PM	R	99	8.1	GDM	JAZ	6:34 PM	169
5	04POS-13	04FPS1- 23	08/02/04	control	MPOO1C1C	3:45 PM	R	89	8.9	GDM	JAZ	6:36 PM	171
6	04POS-14	04FPS1- 30	08/02/04	control	MPOO1C1C	3:45 PM	R	91	9.2	GDM	JAZ	6:39 PM	174
7	04POS-15	04FPS1- 67	08/02/04	control	MPOO1C1C	3:45 PM	R	84	7.4	GDM	JAZ	6:41 PM	176

8	04POS-16	04FPS1-	6	08/02/04	control	MPOO1C1C	3:45 PM	R	75	5.9	GDM	JAZ	6:42 PM	177
9	04POS-17	04FPS1-	53	08/02/04	control	MPOO1C1C	3:45 PM	R	87	8.2	GDM	JAZ	6:46 PM	181
10	04POS-18	04FPS1-	72	08/03/04	control	MPOO2C1C	10:43 AM	R	83	6.5	GDM	MB	11:12 AM	29
11	04POS-19	04FPS1-	35	08/03/04	control	MPOO2C1C	10:43 AM	R	110	16.7	GDM	MB	11:15 AM	32
12	04POS-20	04FPS1-	13	08/03/04	control	MPOO2C1C	10:43 AM	R	88	7.9	GDM	MB	11:17 AM	34
13	04POS-21	04FPS1-	18	08/03/04	control	MPOO2C1C	10:43 AM	R	80	6.1	GDM	MB	11:20 AM	37
14	04POS-22	04FPS1-	28	08/03/04	control	MPOO2C1C	10:43 AM	R	79	7.0	GDM	MB	11:22 AM	39
15	04POS-23	04FPS1-	21	08/03/04	control	MPOO2C1C	10:43 AM	R	79	7.6	GDM	MB	11:30 AM	47
16	04POS-24	04FPS1-	57	08/03/04	control	MPOO2C1C	10:43 AM	R	97	11.7	GDM	MB	11:35 AM	52
17	04POS-25	04FPS1-	31	08/03/04	control	MPOO2C1C	10:43 AM	R	83	7.2	GDM	MB	11:36 AM	53
18	04POS-26	04FPS1-	2	08/03/04	control	MPOO2C1C	10:43 AM	R	90	8.3	GDM	MB	11:39 AM	56
19	04POS-36	04FPS1-	65	08/03/04	control	MPOO2C4C	3:05 PM	R	85	7.7	GDM	MB	5:02 PM	117
20	04POS-37	04FPS1-	16	08/03/04	control	MPOO2C4C	3:05 PM	R	101	12.4	GDM	MB	5:06 PM	121
21	04POS-38	04FPS1-	44	08/03/04	control	MPOO2C4C	3:05 PM	R	67	4.2	GDM	MB	5:09 PM	124
22	04POS-39	04FPS1-	61	08/03/04	control	MPOO2C4C	3:05 PM	R	94	9.8	GDM	MB	5:11 PM	126
23	04POS-40	04FPS1-	5	08/03/04	control	MPOO2C4C	3:05 PM	R	76	5.4	GDM	MB	5:14 PM	129
24	04POS-41	04FPS1-	8	08/03/04	control	MPOO2C4C	3:05 PM	R	90	8.3	GDM	MB	5:16 PM	131
25	04POS-42	04FPS1-	12	08/03/04	control	MPOO2C4C	3:05 PM	R	90	8.8	GDM	MB	5:20 PM	135
26	04POS-43	04FPS1-	22	08/03/04	control	MPOO2C4C	3:05 PM	R	108	16.0	GDM	MB	5:23 PM	138
27	04POS-62	04FPS1-	24	08/04/04	control	MPOO3C1C	10:27 AM	R	104	13.6	GDM	MB	11:58 AM	91
28	04POS-63	04FPS1-	59	08/04/04	control	MPOO3C1C	10:27 AM	R	84	6.9	GDM	MB	12:00 PM	93
29	04POS-64	04FPS1-	40	08/04/04	control	MPOO3C1C	10:27 AM	R	95	11.0	GDM	MB	12:04 PM	97
30	04POS-65	04FPS1-	15	08/04/04	control	MPOO3C1C	10:27 AM	R	86	7.7	GDM	MB	12:06 PM	99
31	04POS-66	04FPS1-	49	08/04/04	control	MPOO3C1C	10:27 AM	R	90	8.2	GDM	MB	12:09 PM	102
32	04POS-67	04FPS1-	34	08/04/04	control	MPOO3C1C	10:27 AM	R	73	4.9	GDM	MB	12:12 PM	105
33	04POS-68	04FPS1-	46	08/04/04	control	MPOO3C1C	10:27 AM	R	95	10.3	GDM	MB	12:14 PM	107
34	04POS-69	04FPS1-	70	08/04/04	control	MPOO3C1C	10:27 AM	R	85	7.6	GDM	MB	12:16 PM	109

35	04POS-70	04FPS1-	52	08/04/04	control	MPOO3C1C	10:27 AM	R	82	6.4	GDM	MB	12:18 PM	111
36	04POS-71	04FPS1-	58	08/04/04	control	MPOO3C1C	10:27 AM	R	89	8.3	GDM	MB	12:21 PM	114
37	04POS-72	04FPS1-	69	08/04/04	control	MPOO3C1C	10:27 AM	R	93	9.8	GDM	MB	12:25 PM	118
38	04POS-1	04FPS1-	9	08/02/04	hammer	MPOO1C1T	2:30 PM	S	80	6.3	GDM	AEJ	5:00 PM	150
39	04POS-2	04FPS1-	14	08/02/04	hammer	MPOO1C1T	2:30 PM	R	90	9.3	GDM	JAZ	5:03 PM	153
40	04POS-3	04FPS1-	50	08/02/04	hammer	MPOO1C1T	2:30 PM	R	92	9.9	GDM	JAZ	5:08 PM	158
41	04POS-4	04FPS1-	64	08/02/04	hammer	MPOO1C1T	2:30 PM	R	90	9.5	GDM	JAZ	5:11 PM	161
42	04POS-5	04FPS1-	54	08/02/04	hammer	MPOO1C1T	2:30 PM	R	88	7.9	GDM	JAZ	5:13 PM	163
43	04POS-6	04FPS1-	39	08/02/04	hammer	MPOO1C1T	2:30 PM	R	87	5.5	GDM	JAZ	5:17 PM	167
44	04POS-7	04FPS1-	4	08/02/04	hammer	MPOO1C1T	2:30 PM	R	89	9.0	GDM	JAZ	5:20 PM	170
45	04POS-8	04FPS1-	71	08/02/04	hammer	MPOO1C1T	2:30 PM	R	88	8.6	GDM	JAZ	5:23 PM	173
46	04POS-27	04FPS1-	66	08/03/04	hammer	MPOO2C2T	1:12 PM	R	90	8.8	GDM	MB	2:50 PM	98
47	04POS-28	04FPS1-	42	08/03/04	hammer	MPOO2C2T	1:12 PM	R	89	8.7	GDM	MB	2:55 PM	103
48	04POS-29	04FPS1-	17	08/03/04	hammer	MPOO2C2T	1:12 PM	R	86	8.0	GDM	MB	3:00 PM	108
49	04POS-30	04FPS1-	55	08/03/04	hammer	MPOO2C2T	1:12 PM	R	85	7.1	GDM	MB	3:02 PM	110
50	04POS-31	04FPS1-	56	08/03/04	hammer	MPOO2C2T	1:12 PM	R	91	10.0	GDM	MB	3:04 PM	112
51	04POS-32	04FPS1-	19	08/03/04	hammer	MPOO2C2T	1:12 PM	R	90	8.8	GDM	MB	3:06 PM	114
52	04POS-33	04FPS1-	27	08/03/04	hammer	MPOO2C2T	1:12 PM	R	95	10.9	GDM	MB	3:09 PM	117
53	04POS-34	04FPS1-	11	08/03/04	hammer	MPOO2C2T	1:12 PM	R	83	7.0	GDM	MB	3:12 PM	120
54	04POS-35	04FPS1-	45	08/03/04	hammer	MPOO2C2T	1:12 PM	R	76	4.7	GDM	MB	3:15 PM	123
55	04POS-44	04FPS1-	26	08/03/04	hammer	MPOO2C3T	4:20 PM	R	85	7.2	GDM	MB	6:04 PM	104
56	04POS-45	04FPS1-	25	08/03/04	hammer	MPOO2C3T	4:20 PM	R	93	9.3	GDM	MB	6:05 PM	105
57	04POS-46	04FPS1-	37	08/03/04	hammer	MPOO2C3T	4:20 PM	R	84	6.8	GDM	MB	6:07 PM	107
58	04POS-47	04FPS1-	68	08/03/04	hammer	MPOO2C3T	4:20 PM	R	95	10.2	GDM	MB	6:09 PM	109
59	04POS-48	04FPS1-	48	08/03/04	hammer	MPOO2C3T	4:20 PM	R	69	3.6	GDM	MB	6:12 PM	112
60	04POS-49	04FPS1-	20	08/03/04	hammer	MPOO2C3T	4:20 PM	R	85	6.9	GDM	MB	6:15 PM	115
61	04POS-50	04FPS1-	63	08/03/04	hammer	MPOO2C3T	4:20 PM	R	83	7.4	GDM	MB	6:17 PM	117
62	04POS-51	04FPS1-	33	08/03/04	hammer	MPOO2C3T	4:20 PM	R	91	8.9	GDM	MB	6:20 PM	120

63	04POS-52	04FPS1-	29	08/03/04	hammer	MPOO2C3T	4:20 PM	R	78	5.4	GDM	MB	6:22 PM	122
64	04POS-53	04FPS1-	47	08/04/04	hammer	MPOO3C2T	9:06 AM	R	92	8.3	GDM	MB	10:15 AM	69
65	04POS-54	04FPS1-	51	08/04/04	hammer	MPOO3C2T	9:06 AM	R	76	5.4	GDM	MB	10:19 AM	73
66	04POS-55	04FPS1-	7	08/04/04	hammer	MPOO3C2T	9:06 AM	R	79	6.1	GDM	MB	10:22 AM	76
67	04POS-56	04FPS1-	62	08/04/04	hammer	MPOO3C2T	9:06 AM	R	87	7.8	GDM	MB	10:25 AM	79
68	04POS-57	04FPS1-	3	08/04/04	hammer	MPOO3C2T	9:06 AM	R	85	7.0	GDM	MB	10:27 AM	81
69	04POS-58	04FPS1-	60	08/04/04	hammer	MPOO3C2T	9:06 AM	R	82	6.4	GDM	MB	10:30 AM	84
70	04POS-59	04FPS1-	43	08/04/04	hammer	MPOO3C2T	9:06 AM	R	83	6.6	GDM	MB	10:32 AM	86
71	04POS-60	04FPS1-	1	08/04/04	hammer	MPOO3C2T	9:06 AM	R	87	7.6	GDM	MB	10:35 AM	89
72	04POS-61	04FPS1-	10	08/04/04	hammer	MPOO3C2T	9:06 AM	R	85	7.6	GDM	MB	10:37 AM	91
ctl.	n				control	n			37	37				37
	mean					**mean**			**88.2**	**8.7**				**110.5**
	SE					SE			1.6	0.5				7.8
ham.	n				hammer	n			35	35				35
	mean					**mean**			**85.9**	**7.7**				**115.4**
	SE					SE			1.0	0.3				5.0

External/Gross Lesion Scores; scored as none (0), mild (1), moderate (2), severe (3), or no data (ND):

CFF = caudal fin fraying
CFR = caudal fin reddening
OFF = other fin fraying
FBR = fin base reddening
FSR = focal skin reddening
VCH = visceral cavity hemorrhage
LH = liver hemorrhage
SBH = swimbladder hemorrhage
KH = kidney hemorrhage

Gross Sex = M (male); F (female); U (unknown);

#	Sample #	External/Gross Lesion Scores									Gross Sex	Gross Comments
		CFF	CFR	OFF	FBR	FSR	VCH	LH	SBH	KH		
1	04POS-9	1	0	1	0	0	0	0	0	0	U	
2	04POS-10	1	0	0	0	0	0	0	0	0	U	
3	04POS-11	1	0	1	0	0	0	0	0	0	U	
4	04POS-12	1	0	1	0	0	0	0	0	0	U	
5	04POS-13	1	0	1	0	0	0	0	0	0	U	
6	04POS-14	1	0	1	0	0	0	0	0	0	U	
7	04POS-15	1	0	1	0	0	0	0	0	0	U	
8	04POS-16	1	0	1	0	0	0	0	0	0	U	
9	04POS-17	1	0	1	0	0	0	0	0	0	U	
10	04POS-18	1	0	1	0	0	0	0	0	0	U	
11	04POS-19	1	0	1	0	0	0	0	0	0	U	
12	04POS-20	1	0	1	0	0	0	0	0	0	U	fish was dropped on the ground after it was anesthetized;
13	04POS-21	1	0	1	0	0	0	0	0	0	U	

14	04POS-22	1	0	0	0	1	0	0	0	0	U	PHOTO #24 - 7 1-mm-diameter red foci on the liver
15	04POS-23	1	0	1	0	0	0	0	0	0	U	
16	04POS-24	1	0	1	0	0	0	0	0	0	U	
17	04POS-25	1	0	1	0	0	0	0	0	0	U	
18	04POS-26	2	0	1	0	0	0	0	0	0	U	liver is on the right side of the fish (normal is on the left side);
19	04POS-36	1	0	0	0	0	0	0	0	0	U	gills are pale;
20	04POS-37	1	0	1	0	0	0	0	0	0	U	
21	04POS-38	1	0	1	0	0	0	0	0	0	U	
22	04POS-39	1	0	0	0	0	0	0	0	0	U	
23	04POS-40	1	0	1	0	0	0	0	0	0	U	
24	04POS-41	1	0	1	0	0	0	0	0	0	U	
25	04POS-42	1	0	1	0	0	0	0	0	0	U	
26	04POS-43	1	0	1	0	0	0	0	0	0	U	
27	04POS-62	1	0	1	0	0	0	0	0	0	U	
28	04POS-63	1	0	1	0	0	0	0	0	0	U	fish was dropped after weighing
29	04POS-64	1	0	1	0	0	0	0	0	0	U	
30	04POS-65	1	0	1	0	0	0	0	0	0	U	
31	04POS-66	1	0	1	0	0	0	0	0	0	U	
32	04POS-67	0	0	1	0	0	0	0	0	0	U	
33	04POS-68	1	0	1	0	0	0	0	0	0	U	
34	04POS-69	1	0	1	0	0	0	0	0	0	U	
35	04POS-70	1	0	1	0	0	0	0	0	0	U	
36	04POS-71	0	0	1	0	0	0	0	0	0	U	
37	04POS-72	1	0	1	0	0	0	0	0	0	U	
38	04POS-1	1	0	0	0	0	0	0	0	0	M	internal focus of reddening, 5x6mm, around right ribs; pale gills; selected because it was dead;
39	04POS-2	1	0	1	0	0	0	0	0	0	F	

40	04POS-3	1	0	1	0	0	0	0	0	0	M	
41	04POS-4	1	0	1	0	0	0	0	0	0	M	
42	04POS-5	1	0	1	0	0	0	0	0	0	U	
43	04POS-6	1	0	1	0	0	0	0	0	0	U	
44	04POS-7	1	0	1	0	0	0	0	0	0	U	
45	04POS-8	1	0	1	0	0	0	0	0	0	U	
46	04POS-27	1	0	0	0	0	0	0	0	0	U	fish was dropped on the ground before it was anesthetized;
47	04POS-28	1	0	0	0	0	0	0	0	0	U	
48	04POS-29	1	0	1	0	0	0	0	0	0	U	
49	04POS-30	1	0	1	0	0	0	0	0	0	U	
50	04POS-31	1	0	1	0	0	0	0	0	0	U	
51	04POS-32	1	0	1	0	0	0	0	0	0	U	
52	04POS-33	1	0	1	0	0	0	0	0	0	U	
53	04POS-34	1	0	1	0	0	0	0	0	0	U	
54	04POS-35	1	0	1	0	0	0	0	0	0	U	
55	04POS-44	1	0	1	0	0	0	0	0	0	U	
56	04POS-45	1	0	0	0	0	0	0	0	0	U	
57	04POS-46	1	0	1	0	0	0	0	0	0	U	
58	04POS-47	1	1	1	0	0	0	0	0	0	U	
59	04POS-48	1	0	1	0	0	0	0	0	0	U	
60	04POS-49	1	0	1	0	0	0	0	0	0	U	
61	04POS-50	1	0	1	0	0	0	0	0	0	U	
62	04POS-51	1	0	1	0	0	0	0	0	0	U	
63	04POS-52	1	0	1	0	0	0	0	0	0	U	
64	04POS-53	1	0	1	0	0	0	0	0	0	U	PHOTO #7 - normal exterior
65	04POS-54	0	0	1	0	1	0	0	0	0	U	
66	04POS-55	1	0	0	0	0	0	0	0	0	U	
67	04POS-56	0	0	1	0	0	0	0	0	0	U	
68	04POS-57	1	0	1	0	0	0	0	0	0	U	

69	04POS-58	1	0	1	0	0	0	0	0	0	U
70	04POS-59	1	0	1	0	0	0	0	0	0	U
71	04POS-60	1	0	1	0	0	0	0	0	0	U
72	04POS-61	1	0	1	0	0	0	0	0	0	U
ctl.	n	37	37	37	37	37	37	37	37	37	
	mean	**1.0**	**0.0**	**0.9**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	
	SE	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	
ham.	n	35	35	35	35	35	35	35	35	35	
	mean	**0.9**	**0.0**	**0.9**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	
	SE	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	

LIVER -

Atly = autolysis
Art = artifact
GD = glycogen depletion
HEM = hemorrhage
LMA = macrophage aggregates
LIP = lipidosis
FPL = focal/multifocal parenchymal leukocytes
CPL = cholangitis/pericholangial leukocytes
PVL = perivascular lymphocytes/leukocytes
IHEM = intestinal hemmorhage

#	Sample #	Liver									Intestine	Liver Comments
		LAtly	LArt	GD	HEM	LMA	LIP	FPL	CPL	PVL	IHEM	
1	04POS-9	1	1	3	0	0	0	0	0	0	0	
2	04POS-10	1	1	3	0	0	0	0	0	0	0	
3	04POS-11	1	1	3	0	0	0	1	0	0	0	
4	04POS-12	1	1	3	0	0	0	0	0	0	0	
5	04POS-13	1	1	3	0	0	0	0	0	0	0	
6	04POS-14	1	1	3	0	0	0	0	0	0	0	
7	04POS-15	1	1	3	0	0	0	0	0	0	0	
8	04POS-16	1	1	3	0	0	0	0	0	0	0	
9	04POS-17	1	1	3	0	0	0	0	0	0	0	
10	04POS-18	1	1	3	0	0	0	0	0	0	0	
11	04POS-19	1	1	3	0	0	0	0	0	0	0	
12	04POS-20	1	1	3	0	0	0	0	0	0	0	

13	04POS-21	1	1	3	0	0	0	0	0	0	0	
14	04POS-22	1	1	3	2	0	0	0	0	0	0	
15	04POS-23	1	1	3	0	0	0	0	0	0	0	
16	04POS-24	1	1	3	0	0	0	0	0	0	0	
17	04POS-25	1	1	3	0	0	0	0	0	0	0	
18	04POS-26	1	1	3	0	0	0	0	0	0	0	
19	04POS-36	1	1	3	0	0	0	0	2	1	0	most of the sinusoids contain moderate numbers of leukocytes, which seem to be related to CPL;
20	04POS-37	1	1	3	0	0	0	0	0	0	0	
21	04POS-38	1	1	3	0	0	0	0	0	0	0	
22	04POS-39	1	1	3	0	0	0	0	0	0	0	
23	04POS-40	1	1	3	0	0	0	0	0	0	0	
24	04POS-41	1	1	3	0	0	0	0	0	0	0	
25	04POS-42	1	1	3	0	0	0	1	0	0	0	
26	04POS-43	1	1	3	0	0	0	0	0	0	0	
27	04POS-62	1	1	3	0	0	0	0	0	0	0	
28	04POS-63	1	1	3	0	0	0	0	0	0	0	
29	04POS-64	1	1	3	0	0	0	1	0	0	0	
30	04POS-65	1	1	3	0	0	0	0	0	1	0	
31	04POS-66	1	1	3	0	0	0	0	0	0	0	
32	04POS-67	1	1	3	0	0	0	0	0	0	0	
33	04POS-68	1	1	3	0	0	0	0	0	0	0	
34	04POS-69	1	1	3	0	0	0	0	0	0	0	
35	04POS-70	1	1	3	0	0	0	0	0	0	0	
36	04POS-71	1	1	3	0	0	0	0	0	0	0	
37	04POS-72	1	1	3	0	0	0	0	0	0	0	
38	04POS-1	2	2	3	0	0	0	0	0	0	0	probably a dead fish;

39	04POS-2	1	1	3	0	0	0	0	0	1	0
40	04POS-3	1	1	3	0	0	0	0	0	0	0
41	04POS-4	1	1	3	0	0	0	1	1	0	0
42	04POS-5	1	1	3	0	0	0	0	0	0	0
43	04POS-6	1	1	3	0	0	0	0	0	0	0
44	04POS-7	1	1	3	0	0	0	0	0	0	0
45	04POS-8	1	1	2	0	0	0	0	0	0	0
46	04POS-27	1	1	3	0	0	0	0	0	0	0
47	04POS-28	1	1	3	0	0	0	1	0	0	0
48	04POS-29	1	1	3	0	0	0	0	0	0	0
49	04POS-30	1	1	3	0	0	0	0	0	0	0
50	04POS-31	1	1	3	0	0	0	0	0	0	0
51	04POS-32	1	1	3	0	0	0	0	0	0	0
52	04POS-33	1	1	2	0	0	1	0	0	0	0
53	04POS-34	1	1	3	0	0	0	0	0	0	0
54	04POS-35	1	1	2	0	0	0	0	0	0	0
55	04POS-44	1	1	3	0	0	0	0	0	0	0
56	04POS-45	1	1	3	0	0	0	0	0	0	0
57	04POS-46	1	1	3	0	0	0	1	0	0	0
58	04POS-47	1	1	3	0	0	0	0	0	0	0
59	04POS-48	1	1	3	0	0	0	0	0	0	0
60	04POS-49	1	1	3	0	0	0	0	0	0	0
61	04POS-50	1	1	3	0	0	0	0	0	0	0
62	04POS-51	1	1	3	0	0	0	0	0	0	0
63	04POS-52	1	1	3	0	0	0	0	0	1	0
64	04POS-53	1	1	3	0	0	0	0	0	0	0
65	04POS-54	1	1	3	0	0	0	0	0	0	0
66	04POS-55	1	1	3	0	0	0	0	0	0	0
67	04POS-56	1	1	3	0	0	0	0	0	0	0

68	04POS-57	1	1	3	0	0	0	0	0	0	0
69	04POS-58	1	1	3	0	0	0	0	0	0	0
70	04POS-59	1	1	3	0	0	0	0	0	0	0
71	04POS-60	1	1	3	0	0	0	0	0	0	0
72	04POS-61	1	1	3	0	0	0	0	0	0	0
ctl.	n	37	37	37	37	37	37	37	37	37	37
	mean	**1.0**	**1.0**	**3.0**	**0.1**	**0.0**	**0.0**	**0.1**	**0.1**	**0.1**	**0.0**
	SE	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0
ham.	n	35	35	35	35	35	35	35	35	35	35
	mean	**1.0**	**1.0**	**2.9**	**0.0**	**0.0**	**0.0**	**0.1**	**0.0**	**0.1**	**0.0**
	SE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

KIDNEY
HEM = hemorrhage
HPC = hematopoietic cells (relative area)
IRT = immature renal tubules
KMA = pigmented macrophage aggregates
TEP = tubular epithelial protein (intracytoplasmic)
CON = congestion
TEV = tubular epithelial vacuolation
TDI = tubular dilation (of lumen)
SBH = swimbladder hemorrhage
SMH = skeletal muscle/skin hemorrhage
SCH = spinal cord hemorrhage
Sex = male (M), female (F), or gonad not present in section (NP)

#	Sample #	Kidney/Body Wedge Lesions													Kidney/Body Wedge Comments
		Atly	Art	Hem	Hpc	Irt	Kma	Tep	Con	Tev	Tdi	Sbh	Smh	Sch	Sex	
1	04POS-9	0	1	0	1	1	0	0	1	0	0	0	0	0	M	
2	04POS-10	0	1	0	1	2	0	0	1	0	0	0	0	0	F	
3	04POS-11	0	1	0	1	1	0	0	1	0	0	0	0	0	F	
4	04POS-12	0	1	0	1	1	0	0	1	0	0	0	0	0	M	
5	04POS-13	0	1	0	1	1	0	0	1	0	0	0	0	0	F	
6	04POS-14	0	1	0	1	1	0	0	1	0	0	0	0	0	F	
7	04POS-15	0	1	0	1	1	0	0	1	0	0	0	0	0	F	
8	04POS-16	0	1	0	1	1	0	0	1	0	0	0	0	0	M	
9	04POS-17	0	1	0	1	1	0	0	0	0	0	0	0	0	M	
10	04POS-18	0	1	0	1	1	0	0	1	0	0	0	0	0	NP	
11	04POS-19	0	1	0	1	1	0	0	1	0	0	0	0	0	M	
12	04POS-20	0	1	0	1	1	0	0	1	0	0	0	0	0	F	
13	04POS-21	0	1	0	1	1	0	0	1	0	0	0	0	0	F	
14	04POS-22	0	1	0	1	1	0	0	0	0	0	1	0	0	NP	
15	04POS-23	0	1	0	1	2	0	0	1	0	0	0	0	0	F	
16	04POS-24	0	1	0	1	2	0	0	2	0	0	0	0	0	M	
17	04POS-25	0	1	0	1	1	0	0	1	0	0	0	0	0	M	
18	04POS-26	0	2	0	1	3	0	0	1	0	0	0	0	0	M	
19	04POS-36	0	1	0	2	1	0	0	0	0	0	0	0	0	NP	skeletal muscle necrosis, multifocal, acute, mild; IRT includes Tetracapsuloides bryosalmonae (the cause of Proliferative Kidney Disease)
20	04POS-37	0	1	0	1	2	0	0	1	0	0	0	0	0	F	
21	04POS-38	0	1	0	1	1	0	0	1	0	0	0	0	0	F	
22	04POS-39	0	1	0	1	1	0	0	0	0	0	0	0	0	M	
23	04POS-40	0	1	0	1	1	0	0	1	0	0	0	0	0	M	
24	04POS-41	0	2	0	1	2	0	0	1	0	0	0	0	0	F	
25	04POS-42	0	1	0	1	1	0	0	2	0	0	0	0	0	M	
26	04POS-43	0	1	0	1	2	0	0	1	0	0	0	0	0	F	
27	04POS-62	0	1	0	1	1	0	0	1	0	0	0	0	0	M	

28	04POS-63	0	1	0	1	1	0	0	1	0	0	0	0	0	M
29	04POS-64	0	1	0	1	1	0	0	1	0	0	0	0	0	M
30	04POS-65	0	2	0	1	1	0	0	1	0	0	0	0	0	M
31	04POS-66	0	1	0	1	1	0	0	1	0	0	0	0	0	M
32	04POS-67	0	1	0	1	2	0	0	1	0	0	0	0	0	M
33	04POS-68	0	1	0	1	1	0	0	1	0	0	0	0	0	F
34	04POS-69	0	1	0	1	2	0	0	1	0	0	0	0	0	M
35	04POS-70	0	1	0	1	2	0	0	1	0	0	0	0	0	F
36	04POS-71	0	1	0	1	1	0	0	1	0	0	0	0	0	NP
37	04POS-72	0	2	0	1	1	0	0	1	0	0	0	0	0	F
38	04POS-1	0	1	0	1	1	0	0	1	0	0	0	0	3	F
39	04POS-2	0	1	0	1	1	0	0	0	0	0	0	0	0	M
40	04POS-3	0	1	0	1	1	0	0	1	0	0	0	0	0	M
41	04POS-4	0	1	0	1	3	0	0	1	0	0	0	0	0	M
42	04POS-5	0	1	0	1	1	0	0	0	0	0	0	0	0	F
43	04POS-6	0	1	0	1	1	0	0	1	0	0	0	0	0	F
44	04POS-7	0	1	0	1	1	0	0	1	0	0	0	0	0	F
45	04POS-8	0	2	0	1	1	0	0	1	0	0	0	0	0	M
46	04POS-27	0	1	0	1	2	0	0	1	0	0	0	0	0	M
47	04POS-28	0	1	0	1	1	0	0	1	0	0	0	0	0	F
48	04POS-29	0	1	0	1	2	0	0	1	0	0	0	0	0	NP
49	04POS-30	0	1	0	1	1	0	0	1	0	0	0	0	0	M
50	04POS-31	0	1	0	1	1	0	0	1	0	0	0	0	0	F
51	04POS-32	0	1	0	1	1	0	0	1	0	0	0	0	0	F
52	04POS-33	0	1	0	1	2	0	0	1	0	0	0	0	0	M
53	04POS-34	0	1	0	1	1	0	0	1	0	0	0	0	0	M
54	04POS-35	0	1	0	1	1	0	0	1	0	0	0	0	0	M
55	04POS-44	0	1	0	1	2	0	0	0	0	0	0	0	0	M
56	04POS-45	0	1	0	1	2	0	0	1	0	0	0	0	0	F
57	04POS-46	0	1	0	1	2	0	0	1	0	0	0	0	0	F
58	04POS-47	0	1	0	1	2	0	0	1	0	0	0	0	0	M
59	04POS-48	0	1	0	1	0	0	0	1	0	0	0	0	0	F
60	04POS-49	0	1	0	1	1	0	0	1	0	0	0	0	0	F

61	04POS-50	0	1	0	1	2	0	0	1	0	0	0	0	0	F
62	04POS-51	0	1	0	1	1	0	0	1	0	0	0	0	0	F
63	04POS-52	0	1	0	1	1	0	0	1	0	0	0	0	0	NP
64	04POS-53	0	1	0	1	2	0	0	1	0	0	0	0	0	M
65	04POS-54	0	1	0	1	1	0	0	0	0	0	0	0	0	M
66	04POS-55	0	2	0	1	1	0	0	1	0	0	0	0	0	M
67	04POS-56	0	1	0	1	1	0	0	1	0	0	0	0	0	NP
68	04POS-57	0	1	0	1	1	0	0	1	0	0	0	0	0	NP
69	04POS-58	0	1	0	1	1	0	0	1	0	0	0	0	0	F
70	04POS-59	0	1	0	1	2	0	0	1	0	0	0	0	0	NP
71	04POS-60	0	2	0	1	1	0	0	1	0	0	0	0	0	NP
72	04POS-61	0	1	0	1	1	0	0	1	0	0	0	0	0	F
ctl.	n	37	37	37	37	37	37	37	37	37	37	37	37	37	
	mean	**0.0**	**1.1**	**0.0**	**1.0**	**1.3**	**0.0**	**0.0**	**0.9**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	
	SE	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	
ham.	n	35	35	35	35	35	35	35	35	35	35	35	35	35	
	mean	**0.0**	**1.1**	**0.0**	**1.0**	**1.3**	**0.0**	**0.0**	**0.9**	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**	
	SE	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	

Quality Control/Quality Assurance

1. Atly = Autolysis. Changes in membrane integrity begin immediately after death.
   score = 0; no membrane changes, erythrocytes stained intensely.
   score = 1; none were mild
   score = 2; none were moderate
   score = 3; none were severe

2. Art = Artifact. Tissue changes that were not inherent in the tissue sampled. Sources of artifact included handling at necropsy, processing, sectioning, and staining. Artifact is scored on the basis that it impedes interpretation of tissue morphology. Examples of artifact include splits, bubbles, folds, or knife marks.
   score = 0; at least one section had no tissue alterations that would impede analysis or photography.
   score = 1; tissue alterations were present, but most areas could still be photographed without artifact, and analysis for lesions was unaffected.
   score = 2; tissue alteration prevented analysis for lesions in some areas and photography would be unacceptable anywhere.
   score = 3; tissue alterations were too extensive for histopathologic analysis.

Lesions

1. KHEM = hemorrhage in the kidney. Erythrocytes outside of normal vascular channels were considered to be a result of hemorrhage. Because fish kidneys have two blood supplies and abundant vascular sinuses, hemorrhage in fish kidneys is difficult to differentiate from vascular congestion.
   score = 0; no hemorrhage.
   score = 1; hemorrhage present, but total area affected < 500 µm in diameter.
   score = 2; total area of hemorrhage > 500 µm in diameter but < 2 mm in diameter.
   score = 3; total area of hemorrhage > 2 mm in diameter.

2. HPC = hematopoietic cells (relative area/volume). Hematopoiesis is a normal function of the renal interstitium, but the number of hematopoietic cells can be decreased or increased.
   score = 0; area of hematopoietic cells <1/2× area of tubules.
   score = 1; area of hematopoietic cells >1/2× area of tubules but < 1× area of tubules.
   score = 2; area of hematopoietic cells >1× area of tubules but < 1.5× area of tubules.
   score = 3; increased amounts of hematopoiesis, with bands of hematopoietic cells sometimes greater than 100 µm thick.

3. IRT = immature renal tubules. Immature renal tubules are small foci of basophilic epithelial cells. Each focus is usually 30-50 µm in diameter; sometimes, these foci do not contain a lumen. Immature tubular epithelial cells have a high nucleus:cytoplasm ratio (<1:2), cytoplasm is basophilic, and nuclei have vesiculated chromatin with prominent nucleoli. Growing fish normally have a few immature tubules, but numbers of immature tubules can also increase following tubular necrosis; therefore, comparison with control values is needed to determine significance. Lack of immature tubules might be expected in fish that are not growing or no longer have the capability to regenerate damaged tubules.
score = 0; no immature tubules in the cross section.
score = 1; ≤5 foci of immature epithelial cells per cross section.
score = 2; >5 but ≤10 foci of immature epithelial cells per cross section.
score = 3; >10 foci of immature epithelial cells per cross section.

4. KMA = kidney pigmented macrophage aggregates. Pigmented macrophage aggregates, found in the renal interstitium, were usually pigmented yellow-brown to green-brown. Some KMA were pink (evidence of abundant protein). Contents of macrophage aggregates are variable, but often include lipofuscin (termed ceroid in some fish references), iron, and/or glycoproteins. Melanin-containing melanomacrophage centers are disseminated throughout the kidney in salmonids and to a lesser extent in anchovies; however, melanin-containing cells were NOT scored as part of KMA.
score = 0; no MAs in sections examined.
score = 1; the sections had <6 MA per 100× field that were >40 µm in diameter.
score = 2; the sections had ≥6 but <15 MA per 100× field that were >40 µm in diameter.
score = 3; the sections had ≥15 MA per 100× field that were >40 µm in diameter.

5. TEP = renal tubular epithelial protein droplets. The cytoplasm of renal tubular epithelium contained protein droplets that were homogeneous, eosinophilic, and varied from 3 to 12 µm in diameter. Nuclei of affected cells were NOT undergoing degeneration.
score = 0; no renal tubular epithelial cells contained cytoplasmic protein droplets.
score = 1; fewer that 10% of renal tubular epithelial cells contained protein droplets.
score = 2; more than 10% of renal tubular epithelial cells contained protein droplets.
score = 3; none were severe.

6. CON = renal blood vessel/interstitial congestion.
score = 0; vessels were not congested, and total vascular sectional area was <5% of kidney sectional area.
score = 1; at least 2 vessels were full of erythrocytes; total vascular sectional area was >5% but <10% of kidney sectional area.
score = 2; total vascular sectional area was >10% but <25% of kidney sectional area.

score = 3; total vascular sectional area was >25% of kidney sectional area.

7. TEV = renal tubular epithelial vacuolation. The epithelium or renal tubules was considered vacuolated if it contained clear vacuoles with a cross-sectional area greater than that of the nucleus. In some cases, vacuoles may be a result of normal glycogen storage.
score = 0; tubular epithelium was not vacuolated.
score = 1; < 20% of proximal tubular epithelial cells were vacuolated.
score = 2; > 20% of proximal tubular epithelial cells were vacuolated.
score = 3; none were severe.

8. TDI = tubular dilation (of lumen). A lesion of the renal tubules. A tubule was considered dilated when luminal diameter was more than 2× the thickness of the tubular epithelium.
score = 0; tubules were not dilated.
score = 1; <50% of the tubules were dilated.
score = 2; >50% of the tubules were dilated.
score = 3; at least one tubule dilated >500 µm in diameter.

9. SBH = swimbladder hemorrhage. Erythrocytes outside of normal vascular channels were considered to be a result of hemorrhage. Hemorrhage resulting from trauma was difficult to differentiate from hemorrhage resulting from the necropsy because fish were subjected to necropsy while their heart continued to beat; therefore, comparison with control values is needed to determine significance.
score = 0; no hemorrhage.
score = 1; hemorrhage present, but total area affected < 500 µm in diameter.
score = 2; total area of hemorrhage > 500 µm in diameter but < 2 mm in diameter.
score = 3; total area of hemorrhage > 2 mm in diameter.

10. SMH = skeletal muscle/skin hemorrhage. Erythrocytes outside of normal vascular channels were considered to be a result of hemorrhage.
score = 0; no hemorrhage.
score = 1; hemorrhage present, but total area affected < 500 µm in diameter.
score = 2; total area of hemorrhage > 500 µm in diameter but < 2 mm in diameter.
score = 3; total area of hemorrhage > 2 mm in diameter.

11. MIC = skeletal muscle microsporidian parasites. These parasites occurred and were scored only in northern anchovy. Microsporidians (sporoblasts and spores) filled individual skeletal muscle fibers.
score = 0; no microsporidians in skeletal muscle fibers.
score = 1; microsporidians in 1-15 skeletal muscle fibers per body wedge.
score = 2; microsporidians in 16-30 skeletal muscle fibers per body wedge.

score = 3; microsporidians in >30 skeletal muscle fibers per body wedge.

12. SCH = spinal cord hemorrhage. Erythrocytes outside of normal vascular channels were considered to be a result of hemorrhage.
score = 0; no hemorrhage.
score = 1; hemorrhage present, but total area affected < 100 µm in diameter.
score = 2; total area of hemorrhage > 100 µm in diameter but < 200 µm in diameter.
score = 3; total area of hemorrhage > 200 µm in diameter.

Appendix D. Statistical Analysis of Histological Lesions

A. Jahn, Ph D. Port of Oakland

Purpose and Objective

The purpose of the study was to test whether normal driving of 24-inch concrete piles in San Francisco Bay sediments is harmful to fish at a distance of 10 m (or greater) from the pile. During the planning phase, it was anticipated that driving piles in deep water would give a worst-case (greatest sound level) scenario, such that generalizing from these results to more near-shore pile driving would be conservative. The objective of this appendix is to describe the experiment in formal terms and to analyze a key result, histological lesions.

Experimental Design

The basic design of the experiment was that of two-factor analysis of variance (ANOVA) with pile driving being the main factor, and individual piles as a second factor nested within the pile driving 'treatment.' The pile driving condition is referred to elsewhere in this report as 'hammer on' vs. 'hammer off,' and so this variable will be called HAMMER, a categorical variable coded as on/off (1/0) or hammer/control. The experimental units were batches of fish exposed in cages to one or the other condition of HAMMER. For each fish species, replicate cages of fish were subjected to pile driving events (HAMMER=on) or control exposures (HAMMER=off). Control batches were not subjected to in-water pile driving sound but were treated in every other respect as similarly as possible to the exposed (HAMMER=on) batches. Logistically, it was only possible to expose a single batch of fish (per species) to an individual pile, and in any case, we wanted the results to be representative of some range of conditions, so several piles were used (Table D-1). The four piles thus "sampled" represent a range of conditions that was hoped to generally represent the driving of 24-inch concrete piles in relatively deep water, as described in the main text. In part to emphasize that the experimental unit was the batch of fish per species exposed together in a cage, the pile variable will be called CAGE, also a categorical variable in the ANOVA.

Table D-1. Main characteristics of the exposure scheme. Peak range and RMS are sound level metrics reported as dB re. 1 μ Pa (see Appendix E).

							number of fish		
Cage	Date	Exposure end time	pile #	pile length (m)	peak range (dB)	Average RMS (dB)	anchovy	perch	salmon
1	8/2/04	14:30	277B	40	183 - 191	176	11	9	8
2	8/3/04	13:15	277A	50	182 - 187	173	9	9	9
3	8/3/04	16:25	284B	40	185 - 188	176	4	9	9
4	8/4/04	09:12	284A	50	183 - 194	176	8	9	9
5	8/2/04	15:16	control	-	-	-	9	8	9
6	8/3/04	10:18	control	-	-	-	9	8	9
7	8/3/04	15:22	control	-	-	-	9	9	8
8	8/4/04	10:21	control	-	-	-	6	6	11

The design is hierarchical, with the random factor CAGE nested within the fixed factor HAMMER. A thorough and quite readable discussion of such a design can be found in Underwood (1997).

Data Reduction and Analysis

Dr. Marty scored nine gross necropsy conditions and some 23 histological lesions from liver, kidney, intestine, and various other tissues for each fish. In Appendix C, the data are presented essentially as two treatment groups (hammer/control) with a mean and overall (naïve) standard error for each treatment, i.e., ignoring the grouping into cages. In that useful summary, treatment means are seen generally to differ by a small amount compared to their standard errors, even though the tabulated standard errors are about half as large as they should be (if calculated for each cage of fish). For the formal analysis presented here, scores for 23 histological lesions were summed to form a single response variable, called LESION. This variable was less skewed than the original variables and, though not normal, at least approached symmetry (Figure D-1). The mean LESION score is given for each species in each cage in Table D-2.

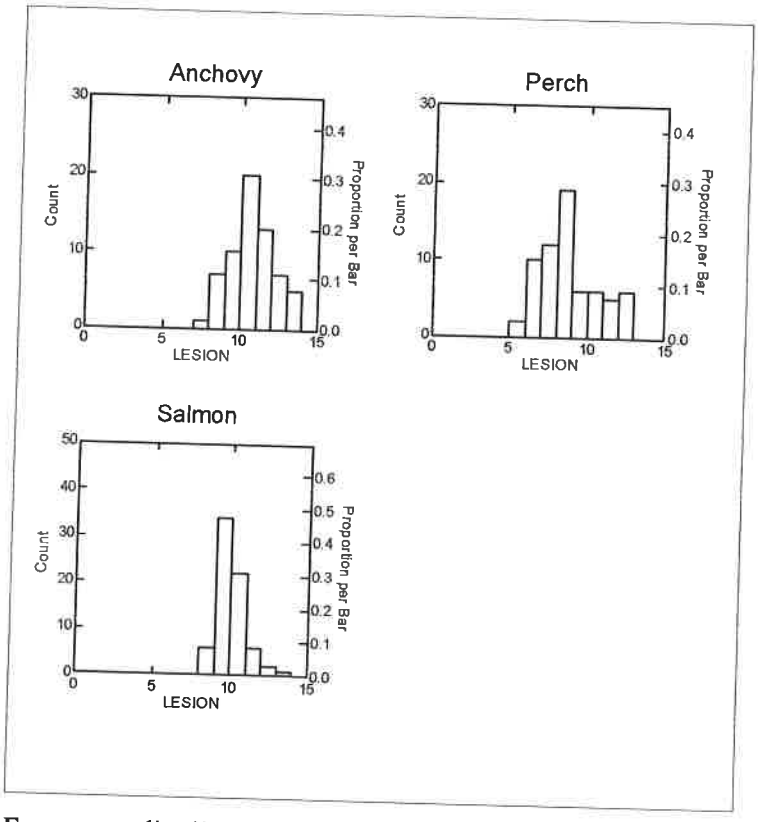

Figure D-1. Frequency distribution plots of the summed variable LESION for each of the three species.

Table D-2. Cage means and treatment means of total histological lesion scores.

	Average total histological lesion score		
Cage #	anchovy	perch	salmon
1	10.5	8.7	10.0
2	11.6	7.2	9.3
3	9.8	8.7	9.6
4	10.5	8.9	9.3
5	9.9	6.9	9.1
6	10.1	9.6	9.9
7	10.2	8.3	10.0
8	9.7	8.8	9.6
hammer	10.7	8.4	9.5
control	10.0	8.4	9.6

A view of the data that corresponds better to the actual ANOVA is given in Figure D-2. We are testing the null hypothesis that there is no treatment effect on LESION over and above the background of variability seen in cages of fish. The analysis was done using the Systat program package (versions 9 and 11). The general linear model of the ANOVA is (in Systat notation):

LESION = CONSTANT + HAMMER +CAGE(HAMMER)

where LESION, HAMMER and CAGE are as defined above, CONSTANT is the mean response, and the parentheses indicate that CAGE effects are nested within the main factor HAMMER. As explained by Underwood (1997), the logic of the experiment (desire to generalize to other, comparable pile driving) dictates that CAGE (corresponding to piles) is a random variable, and thus the sum of squares for CAGE(HAMMER) is the proper denominator for the F ratio in our hypothesis test[1].

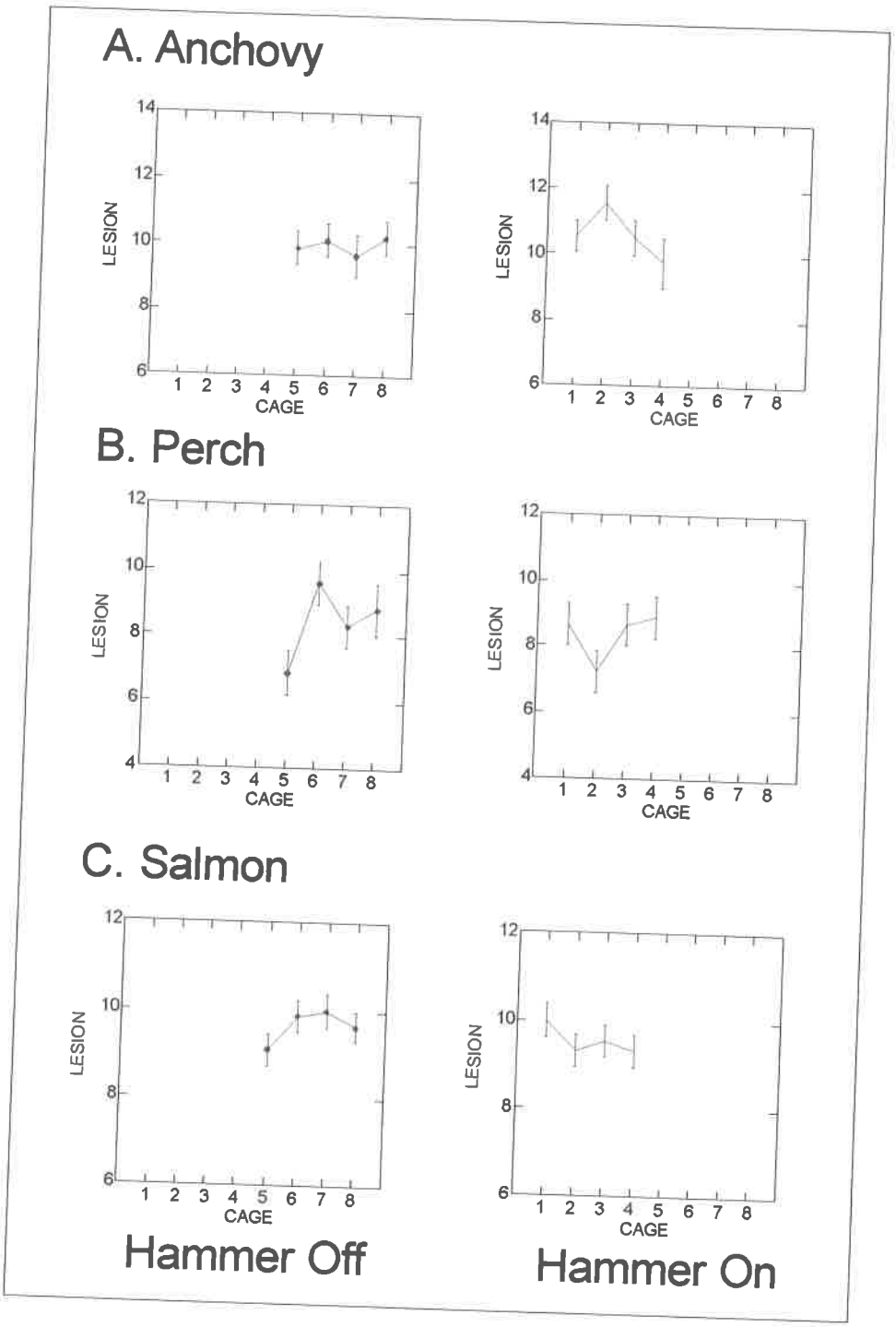

Figure D-2. Means and standard errors of the sum of histological lesion scores (LESION) for three fish species by cage number (X axis) and pile driving treatment. See Table D-1.

Statistical Results and Discussion

The ANOVA results are given in Table D-3. The small number of degrees of freedom in the denominator of the F ratio is due to the small number of experimental units (2 treatments **x** (# replicates -1) = 6). As expected from examination of Table D-2 and the data and statistics presented in Appendix C, the pile driving effect was not significant for any species. That is, as mentioned above, the tabulated standard errors in Appendix C are smaller than they would be if computed for each cage of fish, and so the too-powerful t-tests suggested by these 'naïve' standard errors and sample sizes would more likely have shown differences (i.e., treatment mean lesion scores differing by more than roughly 3.4 standard errors) than the less powerful (but more logical) ANOVAs that were actually performed.

Table D-3. Results of the nested ANOVA on LESION.

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Anchovy					
HAMMER	5.629	1	5.629	2.79	0.146
CAGE(HAMMER)	12.103	6	2.017		
Perch					
HAMMER	0.051	1	0.051	0.006	0.939
CAGE(HAMMER)	47.633	6	7.939		
Salmon					
HAMMER	0.191	1	0.191	0.175	0.691
CAGE(HAMMER)	6.573	6	1.095		

Although a greater number of replicate exposures (cages/piles) would obviously have increased the power of the experiment (as well as the cost), it is apparent that the lack of significant results is due at least as much to the absence of a measurable effect as to any shortage of effort. As seen in Figure D-2, there was broad overlap in the mean response between the two treatments for all three species, even though the three highest cage means for anchovy were for the hammer-on condition (accounting for the relatively high mean square in Table D-3). Remembering that LESION is the sum of 23 individual scores, the between-treatment difference of 0.7 for anchovy (Table D-2) translates to an average scoring difference of about 0.03, where 0 = no lesion, 1 = mild lesion, and so forth (Appendix C). We are apparently seeing what we should expect to see in fish that have been handled as they were to set up this experiment. To reliably detect a treatment effect as subtle as a small fraction of a unit in Dr. Marty's scoring system, it seems that better-controlled conditions, likely in a laboratory setting, would be necessary. Conversely, exposing fish to greater sound levels in the field, either through greater driving energies or closer placement to the piles (or both), would at some point likely produce significant effects, even with the same approach as used here. However, that was not our purpose. Our purpose, as stated above, was simply to test for evidence that

the normal driving of 24-inch concrete piles in San Francisco Bay sediments is harmful to fish at a distance of 10 m (or greater) from the pile. No such evidence was found. In conclusion, the degree of injury in fish, as measured by unbiased scoring of histological slides, was not significantly affected by exposure to pile driving under the conditions of the test in Oakland Outer Harbor in August 2004, even though peak sound levels ranged above 180 dB (an *ad-hoc* regulatory criterion) in all trials.

References and End Note

Sokal, R. R. and F. J Rohlf. 1981. Biometry. 2nd edition. Freeman, NY. 859 p.

Underwood, A. J. 1997. Experiments in Ecology. Cambridge University Press. 504 p.

Winer, B. J., D. R. Brown, and K. M. Michels. Statistical Principles in Experimental Design. 3rd edition. McGraw-Hill. 1057 p.

[1] Some authors (e.g. Winer et al. 1991) suggest first testing the significance of the intermediate-level sum of squares (in the present case, CAGE(HAMMER)) against the residual error and, if it is not significant, combining these sums of squares and degrees of freedom for a more robust estimate of error and, with more degrees of freedom, a more powerful F test. Sokal and Rohlf (1981), while acknowledging a controversy among statisticians, pass along advice from a particular source in the primary literature on when to pool and when not to pool error terms, general to all ANOVA. I did not pool for the fundamental reason that the driving of various piles in different places with different sediment stratigraphy, etc., really does produce sound energies that differ in some respects (differences that were further confounded here with different fish holding times), and failing to reject the null hypothesis that these differences did not matter to the fish is not the same thing as proving it. A second, though less profound, rationale is that the extra step makes no difference in the conclusions reached for the cases considered here, as shown below for the anchovy data. For the record, CAGE(HAMMER) had $p \cong 0.5$ for anchovy and salmon, $p=0.06$ for perch.

Anchovy data (response variable LESION) analyzed two ways

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
1					
HAMMER	5.629	1	5.629	2.791	0.146
CAGE(HAMMER)	12.103	6	2.017	0.843	0.542
Error	136.366	57	2.392		
2					
HAMMER	5.629	1	5.629	2.389	0.127
C(H) + Error	148.469	63	2.357		

Appendix E: Port of Oakland Berth 22 Underwater Sound Measurement Data for Pile Driving Activity, August 2-4, 2004

August 18, 2004
Revised January 19, 2005

* * *

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Executive Summary

Underwater sound pressure levels were measured during the driving of octagonal concrete piles as part of the Berth 22 construction project at the Port of Oakland. Peak sound pressure levels measured at 10 meters from the pile typically ranged from 185 to 188 dB re 1 µPa. The associated root-mean-square sound pressure levels were typically 173 to 176 dB re 1 µPa and the sound energy levels were about 163 to 167 dB re 1 µPa. Levels measured at 100m from the pile were 12 to 20 dB re 1 µPa lower. Underwater sound pressure levels were measured inside cages containing fish that were exposed to pile driving at 10 meters from the pile. This report contains results of measured underwater sound pressure levels and results of data analysis from the recordings of these sounds.

Job No: 04-115

Introduction

Upwards of one thousand concrete piles are driven in the San Francisco Bay and Sacramento-San Joaquin River Delta each year. These piles are used in the construction of dock supports for many ports throughout the Bay Area, local marinas, break waters, and ferry terminals. In an effort to understand the effects of the noise generated during the driving of these piles on sensitive receptors, namely three local species of swim bladder fish, an industry-sponsored study was conducted during the construction of Berth 22 in the Port of Oakland from August 2 through August 4, 2004. A 224 kilo joule (165,000 foot pound) diesel hammer was used to drive 61-centimeter (24 inch) diameter octagonal concrete piles into consolidated bay sands. Caged test fish were suspended in the water at a distance of 10 meters from the pile to expose the fish to pulses of underwater sounds produced by pile driving. As part of the study, underwater sound measurements were made. The underwater sound measurements were conducted during the driving of four piles, and are used to quantify the level of noise exposure to the test fish.

All measurements were made during unattenuated pile driving conditions. Water depth exceeded 10 meters in the proximity of the piles being driven. Underwater sound measurements were conducted: inside the cages containing test fish (positioned 10 m from the pile), outside of the fish cages, and at a distance of 100 m from the pile. All underwater measurements were made at a depth of 8 m. The underwater sound measurement data presented in this report are used to evaluate the noise exposure to the test fish as well as provide information on sound pressures at a distance of 100 m from the pile being driven.

Diesel hammers and reinforced concrete piles are considered "conventional" by the Bay Area pile driving industry. These types of piles and the hammers used to install them are distinctly different from the steel shell piles and very large hydraulic hammers used in large bridge construction projects.

Project Description

Construction Equipment

The construction project involved the driving of 61-centimeter diameter octagonal concrete piles to support new dock facilities for Berth 22 at the Port of Oakland. The piles are driven approximately 15 to 30 meters into the substrate at the edge of the ship channel. The channel edge has comparatively steep banks and the water depth is approximately 13 m. Figure 1 shows a picture of the pile driving activity during underwater sound measurements.

Pile driving was conducted using a model D62-22 Delmag diesel pile hammer. The hammer operates as a large piston (13,000 lbs) in a diesel combustion engine generating up to 224 kilo joules (165,000 foot lbs) of energy on each blow. There are several features that protect the pile and equipment, most notably the cushion block, which consists of laminated plywood that is about 1/3rd. of a meter thick and separates the "pill" of the pile hammer and the pile. This "softens the blow" from the hammer to the pile, as the hammer does not directly strike the concrete pile.

Figure 1. Driving Pile 284A.

Fish Cage Measurements

Three species of fish (anchovy, perch, and salmon) were exposed to the underwater sounds at 10m from pile driving. Underwater sound measurements were made both inside and outside of the fish cages to measure the level of sound exposure. Underwater sound measurements were also made at 100m from the pile. This report presents the underwater sound data collected during this study.

Methodology

Measurement Positions

Measurements were made during the driving of "A" or "B" row (or outer) piles. These piles are driven in the deepest waters, about 10- to 13-meter deep water. In general, fish were exposed to the first 200 pile strikes.[1]. The fish were placed in cages that were lowered 8 meters below the water surface. A hydrophone was attached to at least one of the three cages (see Figure 2). Another hydrophone was placed outside the cage at a

[1]. Fish were exposed to over 400 pile strikes during the first test on August 2; however, the remainder of the tests were terminated when there were 200 strikes in order to standardize exposure.

similar depth and distance. A third hydrophone was placed in the water at 100m to the southwest (at the Maersk Dock). This sensor was also placed at a depth of 8m.

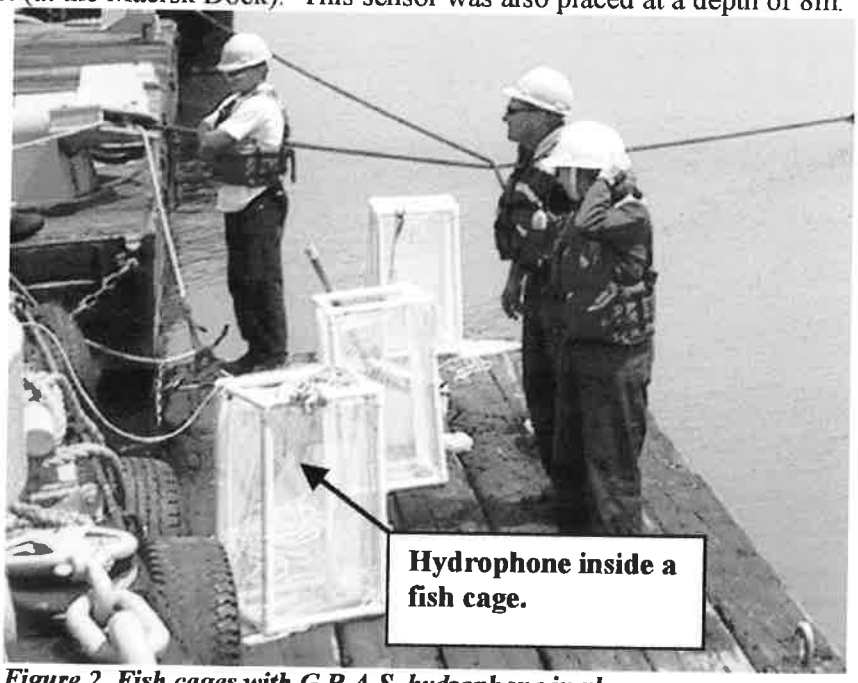

Figure 2. Fish cages with G.R.A.S. hydrophone in place.

Measurement Equipment

Measurements were made using G.R.A.S. CT10 hydrophones with PCB in-line charge amplifiers (Model 422E13) and PCB Multi Gain Signal Conditioners (Model 480M122). The signals were fed into Larson Davis Model 820 Integrating Sound Level Meters (Type 1) and Sony Model TCD-D100 Digital Audio Tape Recorders (DAT). The multi gain signal conditioner provides the ability to lower or raise the signal strength so that measurements are made within the dynamic range of the instruments used to analyze the signals.

The peak pressure and root-mean square average sound pressure levels ($RMS_{impulse}$ levels) were measured "live" using the SLM. The Larson Davis Model 820 SLM has the ability to measure the unweighted peak sound pressure. RMS levels were measured with the SLM using the standard "impulse exponential-time-weighting" (35 msec rise time) function of the Larson Davis Model 820 SLM. Additional subsequent analyses of the acoustical impulses were performed using a Larson Davis Model 3000 Real Time Analyzer. The real time analyzer provides narrow-band frequency and waveform analyses.

Underwater Sound Descriptors

When a pile driving hammer strikes a pile a pulse is created which propagates through the pile and radiates sound into the water and the ground substrate as well as the air. Sound pressure pulse as a function of time is referred to as the waveform. The peak pressure is the highest absolute value of the measured waveform, and can be a negative or

positive pressure peak. The RMS level is determined by analyzing the waveform and computing the average of the squared pressures over the time that comprise that portion of the waveform containing 90 percent of the sound energy.[2] This RMS term is described as $RMS_{90\%}$ in this report. This can be approximated for pile driving by measuring the signal with a precision sound level meter set to the "impulse" RMS setting ($RMS_{impulse}$). Another measure of the pressure waveform that can be used to describe the pulse is the sound energy itself. The total sound energy in the pulse is called various things. In a recent article it is described as the "total energy flux".[3] The "total energy flux" can be equivalent to the un-weighted sound exposure level (SEL), a common unit of sound energy used in airborne acoustics to describe short-duration events. The unit is dB re $1\mu Pa^2$-sec.

In this report, peak pressures and RMS sound pressure levels are expressed in decibels re 1 μPa; however, in other literature they can take other forms such as a Pascal or pounds per square inch. The total sound energy in an impulse accumulates over the duration of the impulse. How rapidly the energy accumulates may be significant in assessing the potential effects of impulses on fish.

Researchers have indicated that high peak pressure along with the rate of change (i.e., rise time) are important considerations in assessing potential biological impacts (i.e., injury or mortality).[4] Descriptors such as the peak pressure, $RMS_{90\%}$, and SEL or "total energy flux" are useful descriptors in describing the magnitude of these impulses. These descriptors do not adequately account for the effect of rise time for pile driving impulses. The peak pressure only refers to the magnitude of maximum pressure fluctuation, which may be only one factor causing damage. The RMS averaged over 90% of the impulse includes averaging over a relatively long period of the impulse where the pressure fluctuation is much lower. For instance, about 50% of the energy from a typical pile driving impulse accumulates in less than a quarter of the time that 90% of the energy accumulates. The SEL is generally normalized to one second and, therefore, is not as useful for discerning differences in impulses where the majority of the energy occurs within $1/10^{th}$ of a second. However, SEL is useful to researchers in assessing impacts to animals. The pressure waveforms show the individual characteristics of these strikes; however, it is difficult to identify any meaningful differences in the impulses. Studying the waveforms can provide an indication of rise time; however, rise time differences are not clearly apparent due to the numerous rapid fluctuations that are characteristic to this type of impulse. A plot showing the accumulated sound energy over the duration of the impulse (or at least the portion where much of the energy accumulates) appears to be the best available tool to illustrate the differences in source strength and rise time.

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[2] Richardson, Greene, Malone & Thomson, *Marine Mammals and Noise,* Academic Press, 1995 and Greene, personal communication.

[3] Finerran, et. al., *Temporary Shift in Masked Hearing Thresholds in Odontocetes after Exposure to Single Underwater Impulses from a Seismic Watergun,* Journal of the Acoustical Society of America, June 2002.

[4] Wardle, et.al. *Effects of Seismic Air Guns on Marine Fish.* Continental Shelf Research 21 (2001) 1005-1027. Pergamon. June 21, 2000.

Underwater Sound Measurement Data Management

Data were collected from hydrophones in two ways: (1) measurement of peak and $RMS_{impulse}$ sound pressures for each second; and (2) digital audio recording of the sounds for subsequent signal 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 recorded in field notebooks from time to time. 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 the source was pile driving noise.

Quality Control

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 145.3 dB re 1 µPa tone at 250Hz. 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 re 1 µPa of the calibration levels. The pistonphone output was certified at an independent facility.

All field notes were recorded in water-resistant field notebooks. Such notebook entries include calibration notes, measurement positions (i.e., distance from source, depth of sensor), system gain settings, and the equipment used to make each measurement. Notebook entries were copied after each measurement day and filed for safekeeping. Digital audiotapes were labeled and stored for subsequent analysis.

Data Presentation

This section presents measured sound pressure levels. Representative pile driving sound recordings were analyzed and are also presented in this section. Peak and $RMS_{impulse}$ levels reported in these sections were measured directly from SLMs used in the field. The $RMS_{90\%}$ and SEL were calculated based on signal analysis of representative pile driving strikes. Examinations of the analyzed pile strikes found that the $RMS_{impulse}$ closely approximated the $RMS_{90\%}$ level; therefore, the $RMS_{impulse}$ was used to describe the RMS measure of the pile driving pulses.

Pile 277B, August 2, 2004

The first set of measurements and fish exposures to pile driving sounds were conducted on August 2, 2004 when Pile 277B was driven. Measurements were made at 10m from the pile in one of the three cages containing fish. Measurements were also made at a reference position outside of the cage (at 10m from the pile), an unattended position 100m northeast of the pile, and an unattended position 100m southwest of the pile (at the Maersk Dock). All hydrophones were positioned at a depth of about 8m, where water depths were about 10m to 13m deep. The DAT recorder for the 10m fish cage and reference position failed; and therefore, recordings at 10m from the pile were not made. Continuous SLM measurements were successfully made at all positions. Ambient conditions were measured after pile driving when "control" fish were placed in the water near the pile. Results are shown in Table E-1.

At 10m, sound pressure levels ranged from about 183 dB re 1 µPa peak (173 dB re 1 µPa RMS) at the beginning of the drive to 191 dB re 1 µPa, Peak (178 dB re 1 µPa RMS) around the middle of the drive. Levels were fairly consistent for the last 5 minutes of the approximate 10-minute drive. The RMS level was about 10 to 12 dB re 1 µPa lower than the peak sound pressure and the SEL was about 10 dB re 1 µPa lower than the RMS pressure level. Fish were exposed to average peak sound pressure levels of 188 dB re 1 µPa peak, 176 dB re 1 µPa RMS, and approximately 166 dB SEL. At the distant positions, sound pressure levels were 15 to 20 dB re 1 µPa lower. There may have been some shielding between the 10m and 100m southwest positions. Levels 100m northeast were about 5 dB re 1 µPa higher than those measured at 100m to the southwest.

Pile 277A, August 3, 2004

Pile 277A was driven during the early afternoon of August 3, 2004. Measurements were made inside two of the fish cages, at a reference position outside the cage, and at the 100m southwest position from the Maersk dock. Fish were exposed to approximately 200 impulses (approximately 3 minutes of driving). Pile driving was suspended until all fish had been removed from the water. Underwater sound measurements continued at the reference positions (10m from the pile) and at the 100m distant position when pile driving resumed. Ambient conditions were measured in the morning when control fish were placed in the water near the Maersk Dock prior to pile driving. Results are shown in Table E-2.

During the entire driving period, sound pressure levels at 10m from the pile ranged from 182 dB re 1 µPa Peak (171 dB re 1 µPa RMS) to 190 dB re 1 µPa Peak (176 dB re 1 µPa RMS). The SEL was about 165 dB re 1 µPa. During the period when fish were exposed (for the first 3 to 4 minutes of the nearly 30-minute drive), average sound pressure levels were 185 re 1 µPa dB Peak, 173 dB re 1 µPa RMS and 163 dB re 1 µPa SEL. Sound pressure levels were highest near the middle and end of the drive. Average sound pressure levels at 100m southwest were 167 dB re 1 µPa Peak, 156 dB re 1 µPa RMS and about 146 dB re 1 µPa SEL. There may have been some shielding between the 10m and

the 100m positions. Sound pressure levels were about 20 dB re 1 µPa lower at 100m southwest than at 10m from the pile.

Pile 284B, August 3, 2004

Pile 284B was driven late on the afternoon on August 3, 2004. Measurement distances were the same as for Pile 277A, which was driven earlier that day. This pile was installed further east than the other two piles that were driven previously. Results are shown in Table E- 3.

During the entire driving period, sound pressure levels at 10m from the pile ranged from 182 dB re 1 µPa Peak (171 dB re 1 µPa RMS) to 190 re 1 µPa dB re 1 µPa Peak (178 dB re 1 µPa RMS). The SEL was about 164 dB. During the period when fish were exposed (for the first 3 to 4 minutes of the nearly 30-minute drive), average sound pressure levels were 186 dB re 1 µPa Peak, 176 dB re 1 µPa RMS and about 164 dB re 1 µPa SEL. Average sound pressure levels at 100m southwest were 174 dB re 1 µPa Peak, 163 dB re 1 µPa RMS and about 152 dB re 1 µPa SEL. Sound pressure levels were highest near the beginning and end of the drive. Sound pressure levels were about 12 dB re 1 µPa lower at 100m southwest than at 10m from the pile.

Pile 284A, August 4, 2004

Pile 284A was driven during the morning of August 4, 2004. Measurement distances were similar to those made during the driving of Piles 277A and 284B. The 100m southwest position was further east, near the edge of the existing Maersk dock. Ambient conditions were measured in the morning when control fish were placed in the water near the Maersk Dock prior to pile driving. Results are shown in Table E-4.

During the entire driving period, sound pressure levels at 10m from the pile ranged from 183 dB re 1 µPa Peak (170 dB re 1 µPa RMS) to 192 dB re 1 µPa Peak (177 dB re 1 µPa RMS). The SEL was about 166 dB re 1 µPa. During the period when fish were exposed (for the first 3 to 4 minutes of the nearly 25-minute drive), average sound pressure levels were 188 dB re 1 µPa Peak, 176 dB re 1 µPa RMS and about 167 dB re 1 µPa SEL. Average sound pressure levels at 100m southwest were 174 dB re 1 µPa Peak, 162 dB re 1 µPa RMS and about 152 dB re 1 µPa SEL. Sound pressure levels were highest near the beginning and end of the drive. Sound pressure levels were about 14 d re 1 µPa B lower at 100m southwest than at 10m from the pile.

Acoustic Signal Analysis

Representative impulses from fish cage tests were analyzed to illustrate waveforms, provide narrow band frequency spectra (i.e., 6 Hz resolution), and plots of accumulated sound energy. The analysis was also used to calculate acoustical descriptors such as the RMS over 90% of the energy and the total sound energy or SEL of the impulse event.