San Francisco – Oakland Bay Bridge
East Span Seismic Safety Project

FISHERIES AND HYDROACOUSTIC MONITORING PROGRAM COMPLIANCE REPORT

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FISHERIES AND HYDROACOUSTIC MONITORING PROGRAM COMPLIANCE REPORT

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EXECUTIVE SUMMARY

This report summarizes the work accomplished under the terms of the Fisheries and Hydroacoustic Monitoring Program (FHMP) Work Plan that was developed and implemented in compliance with the terms and conditions of the National Marine Fisheries Service's (NMFS) Biological Opinion and the California Department of Fish and Game's (CDFG) 2081 Incidental Take Permit for construction of the new San Francisco-Oakland Bay Bridge East Span (Caltrans 2002a).

This report summarizes hydroacoustic monitoring conducted for pile-driving within dewatered cofferdams (temporary water-tight enclosures built in the water and pumped dry to expose the bay bottom so that construction of piers can be undertaken), pile-driving with use of a bubble curtain system (this pile-driving is not confined by a cofferdam), and caged fish. Hydroacoustic data are primarily reported as the peak sound pressure level (SPL) for the measurements taken during the caged fish studies. Both peak SPL and Root Mean Square (RMS) SPL are presented for the hydroacoustic characterizations. Caged fish monitoring was conducted at various depths, distances, and durations of exposure for shiner surfperch and steelhead. Monitoring was also conducted for two bubble curtain on/off studies.

Hydroacoustic monitoring was conducted for pile-driving within dewatered cofferdams at Piers E16E and E10E. Monitoring at Pier E16E revealed that peak SPLs were approximately 15-20 dB higher at 95 meters (312 feet) west than at 25 meters (82 feet) west of the pile. The acoustic field around the cofferdam for Pier E10E indicated that the SPLs were 15-20 dB higher southeast of the piles than in the other cardinal directions, with a focal point approximately 100-150 meters (328-492 feet) south-southeast of the piles. The reasons for this are unclear, but it may be related to the composition of the bay bottom substrates.

Numerous measurements were made around Piers E3E-E6E. Piles at these locations are surrounded by a bubble curtain, which is used to attenuate the SPLs. The tidal currents affected bubble curtain performance by approximately 10 dB depending on the direction of flow. Sound pressures generally increased as the pile was driven deeper and as the pile-driving operator adjusted the pile-driving energy to push the pile about 2.5 centimeters (1 inch) deeper on each blow. Sound pressures tended to drop off faster towards the east because of the shallowness of the water. There may have been some channeling of the pile-driving sound field due to the depth of the water along the north-south deep water shipping channel and rocky substrates in the deeper sediments. These variables made it very difficult to predict SPLs at any distance. However in general, the 180 dB peak isopleth was on the order of 500 meters (1,640 feet) from the pile, which is about what was expected.

The duration of the impulse varied considerably, depending on pile-driving conditions such as the distance from the pile and if a bubble curtain system or a cofferdam is used. Measurements around cofferdams indicated the peak-to-peak rise time was about 3 milliseconds. Most of the energy for these impulses was below 500 Hertz (Hz), with much of the energy at 100 to 300 Hz. The magnitude of these acoustical impulses was dependent on direction. Measurements around piles with a bubble curtain showed a peak-to-peak rise time on the order of 1 to 3 milliseconds. The pile impulses with a bubble curtain on were characterized by faster rise times that translated into higher frequency sound energy content. Typically, the peak-to-peak rise time for unattenuated impulses was about 1 to 2 milliseconds, and the duration, where 90% of the energy occurs, ranged from very short periods of 50 milliseconds to over 80 milliseconds. Much of the sound energy was contained over the frequency range below 800 Hz.

Hydroacoustic measurements were made within the fish cage on each monitoring trip. The hydroacoustic monitoring team placed hydrophones directly in the fish cage; reference hydrophones were placed directly on the pile-driving barge, at different distances from the pile and near the caged fish.

Caged fish monitoring was conducted at Piers E3E-E6E in November and December of 2003 and January of 2004. Two species of fish with different types of swim bladders were exposed to pile-driving for various periods of time, water depths, and distances away from the pile. Over 2,000 shiner surfperch (*Cymatogaster aggregata*) and steelhead (*Oncorhynchus mykiss*) were used in eight monitoring trips. The numbers of fish used varied somewhat from trip to trip, but 94 treatment groups, with approximately 30 fish per treatment group, were used in various aspects of the program.

Treatment groups of fish were exposed to pile-driving at distances from 23 to 314 meters (75 to 1,030 feet), with durations of exposure from one to twenty minutes, and depths from 2 to 10 meters (7 to 33 feet) deep. Three types of controls were used to help differentiate between the effects of exposure to pile-driving pulses and other potential causes of injury or mortality. Holding facility controls remained in their tanks at the Romberg Tiburon Center for Environmental Studies (RTC) and did not go through any of the phases of handling experienced by the fish exposed to pile-driving. Transport controls remained in their transport bags and coolers for the entire trip, and were never put in a cage. Cage controls were groups of fish that were put into the cage and lowered to depth for 5-10 minutes when there was no pile-driving.

After exposure to pile-driving, fish behavior was recorded with a digital video recorder, and the fish were taken to holding tanks at RTC where their survival was documented over the next 48 hours. At the end of the 48-hour post-exposure monitoring period, all the fish were sacrificed and preserved in a deep freezer. The fish were thawed, measured, and evaluated at a later date for signs of injury, disease and barotrauma. All the fish that died within 48 hours were called mortalities and given a macroscopic necropsy. In addition five fish from each treatment group were randomly selected for a brief macroscopic necropsy. The mortalities were typically due to handling stress, low dissolved oxygen in the transport bags, parasitic infections, bacterial infections and smoltification stress. Some treatment groups of fish that were known to have experienced unusual disease, handling problems or low dissolved oxygen stress were eliminated from the pool of fish used for statistical evaluation.

The most commonly noted indications of barotrauma injury were a bright red coloration (erythemia) at the base of the pectoral fins, internal bleeding, hyperemia along the abdominal wall and damage to the kidney. The most severe barotrauma injuries occurred when the bubble curtain was off. Some internal injuries suggestive of barotrauma occurred when the bubble curtain was on. In surfperch, the most common indication of barotrauma injury was an abnormality in the appearance of the kidney, such as a change in the coloration or definition of the kidney compared to controls. The most common indication of barotrauma injury in steelhead was bright red coloration at the base of the pectoral fins and bright red coloration of the arteries running vertically down the internal abdominal cavity from the dorsal aorta.

A Student's t-test for comparison of means was used to evaluate and compare the percentage of mortalities between the control groups, and different types of exposures. There were no statistically significant differences between cage controls, fish species, fish size, treatment distances, and the durations of exposure. The operation of the bubble curtain precluded fish barotrauma mortalities at the distance, depths and durations of exposures used as treatments in this study.

Hydroacoustic measurements indicated that use of the bubble curtain resulted in reductions of 5 dB to almost 20 dB at positions of around 100 meters (328 feet) or closer, depending mostly on current conditions. At almost 500 meters (1,640 feet), the reductions measured during Pier E6E pile-driving were 0 to 2 dB.

The evaluation of compliance monitoring results determined that the FHMP met its study objectives with the exception of peak SPLs being 150 db or less at 4,400 meters (14,436 feet) and comparing fish mortality rates with the bubble curtain on to those with the bubble curtain off. Caltrans is currently in discussion with CDFG and NMFS regarding a possible third bubble curtain on/off study, which would be completed at Pier E3W or E4W, and would allow for completion of the bubble curtain compliance test. In addition, there has been a very limited amount of bird predation monitoring to date and no fish have been collected from the water for examination. This is due to the limited amount of bubble curtain on/off monitoring that has occurred. A report summarizing observations on moribund fish and gull predation will be presented at a later date after pile-driving has occurred at Pier E3W as well as during the next bubble curtain on/off study, if approved by the CDFG and NMFS.

A summary of the results of the compliance tests are as follows:

- **Peak SPLs at or less than 204 dB at 69 Meters (226 Feet):** The criterion was met and sound pressures greater than 204 dB were never recorded at distances greater than 69 meters (226 feet) from the pile.
- **Peak SPLs at or less than 180 dB at 440 Meters (1,444 Feet):** The criterion was generally met, but the regression of SPLs on distance using all the distance monitoring data showed SPLs exceeded the criteria by one dB; one data point was 10 dB over the criterion, while another was 11 dB below.
- **Peak SPLs at or less than 150 dB at 4,400 Meters (14,436 Feet):** The criterion was not met, possibly due to complicated underwater sound propagation in shallow water and flanking noise coming up from the bottom as the pile was pushed deeper into the rock. However, hydroacoustic data was not collected to verify this; the most distant measurements were 170 dB at 2,200 meters (7,218 feet) northwest of pile-driving activities. Additional measurements will be made during pile-driving for Pier E3W.

- **No Near-term Mortalities at Distances Greater Than 69 Meters (226 Feet):** There were no near-term barotrauma mortalities beyond 69 meters (226 feet).
- **No Delayed Mortalities at Distances Greater Than 440 Meters (1,444 feet):** Since there were no barotrauma delayed mortalities at distances greater than 30 meters (98 feet) from the pile, there was no monitoring conducted at distances greater than 440 meters.
- **No Near-term Mortalities at Peak SPLs Less Than 204 dB:** There were no near-term mortalities at sound pressure levels less than 204 dB.
- **No Delayed Mortalities at Peak SPLs Less Than 180 dB:** There was no monitoring at SPLs below 180 dB; it was concluded during the course of the monitoring program that since there were no barotrauma delayed mortalities at SPLs below 204 dB there would not be any at 180dB.
- **The bubble curtain reduces the mortality rate.** The amount of data collected was not enough to statistically be able to determine if there was a significant reduction in the rate of mortality when the bubble curtain was on compared to when it was off.

1.0 INTRODUCTION

In order to improve the seismic safety of the San Francisco-Oakland Bay Bridge (SFOBB), the State of California, Department of Transportation (Caltrans) is replacing the existing East Span with a new bridge immediately to the north. This is a multi-year effort that will involve a number of construction activities on land as well as in the Bay, including the driving of 259 large-diameter piles to support the Skyway and Self-Anchored Suspension components of the new bridge.

In the fall and winter of 2000, Caltrans conducted the Pile Demonstration Project (PIDP) to assess the use of large hammers to install large-diameter piles at the project site. This demonstration project gave Caltrans an opportunity to assess the sound pressure levels (SPLs) from driving large-diameter piles and test the operation and effectiveness of sound attenuation devices. During the PIDP, Caltrans tested two systems which use air bubbles with the goal of attenuating peak underwater SPLs due to pile-driving. One system deployed the air bubbles from a ring of perforated pipes surrounding the pile and the template system used for holding the pile in place; the second system supplied the air bubbles adjacent to and between two layers of fabric surrounding the pile. Results of environmental monitoring conducted during the PIDP indicated that both systems reduced fish mortalities, as compared to a pile driven without attenuation.

Following the PIDP, Caltrans held a workshop on pile-driving and bubble curtains in August 2001, and subsequently consulted with experts on bubble curtains and the effects of underwater sound on fish (Greene 2001, Hastings 2001). Based on these efforts to obtain information on the best available technology consistent with the engineering and construction requirements for the new bridge, Caltrans included a bubble curtain system in the specifications for the construction project. The air bubble curtain system chosen deploys air bubbles from rings of perforated pipes surrounding the pile and template system (used for holding the pile in place). This allows for the pile-driving operation to be completely enclosed by bubbles for the full depth of the water column and for a radial dimension of at least 2 meters (6.5 feet) as measured from the outside surface of the pile.

The use of the bubble curtain will attenuate the effects of sound pressure waves on fish during pile-driving that is not contained within dewatered cofferdams. One effect the bubble curtain will reduce is barotrauma injury and related mortality. Barotrauma is the pathology associated with drastic changes in pressure. Pile-driving barotrauma may result in a variety of internal, external injuries, behavioral changes, near-term mortality or delayed mortality (Popper 2003). Mortality may be instantaneous or occur several minutes or days after exposure (Hastings 2001).

The Fisheries and Hydroacoustic Monitoring Program (FHMP) Work Plan (Caltrans 2002a) was prepared and submitted in compliance with the terms and conditions of the National Marine Fisheries Service's (NMFS) Biological Opinion and the California Department of Fish and Game's (CDFG) 2081 Incidental Take Permit. As specified by NMFS and CDFG, the Work Plan detailed Caltrans' committed approach to monitoring the performance of the bubble curtain in minimizing the level of incidental take of listed fish species.

The FHMP consists of:

- Making underwater sound measurements at various distances and depths from pile-driving operations;
- Making observations on predation by gulls and other birds;
- Examining injured fish collected from the water during pile-driving; and
- Conducting experiments using different species and sizes of fish in cages at different durations of exposure, distances and depths.

This report summarizes the results of FHMP field studies and analyses accomplished to date. It is considered an interim report because Caltrans is currently discussing with CDFG and NMFS the possibility of an additional bubble curtain on/off study, which would be conducted at either Pier E3W or Pier E4W. If the proposal is approved, Caltrans will be able to meet the third objective of the Work Plan and an Addendum would be submitted before the end of 2004.

1.1 PROJECT SETTING

1.1.1 The East Span Seismic Safety Project

The East Span Seismic Safety Project (East Span Project) replaces the existing East Span of the SFOBB with a new bridge that features a pre-cast segmental "skyway" and a Self-Anchored Suspension span near Yerba Buena Island (YBI) in central San Francisco Bay. See Figure 1-1.

Figure 1-1. Artist rendering of the new San Francisco-Oakland Bay Bridge East Span

The project has four primary components (see Figure 1-2)

- Geofill at the Oakland Touchdown
- Oakland Approach Structures
- Skyway
- Self-Anchored Suspension/Yerba Buena Island transition structure (SAS/YBI)

To facilitate an efficient and cost-effective building program, the SAS/YBI component has been separated into several construction contracts. In addition, Caltrans will pursue a separate contract to remove the existing bridge.

1.1.2 Central San Francisco Bay

The project area consists of the construction zone along the north side of the existing East Span. See Figures 1-3 and 1-4 for the project location and study area. The project area is bounded by YBI on the west, Oakland Inner Harbor to the south and the Oakland Touchdown to the east. To the north, San Francisco Bay stretches out for nearly 14 kilometers (9 miles) before it is bounded by the Richmond San Rafael Bridge.

1.1.3 The Fisheries and Hydroacoustic Monitoring Program Study Area

The FHMP study area was in the general location of active bridge construction with numerous tug boats, crew boats, and barges within the project area limits. Most of the study was conducted in a relatively shallow area adjacent to the deep-water shipping channel that passes under the east side of the existing Bay Bridge.

1.2 OBJECTIVES

1.2.1 Purpose of the Monitoring Program

The purpose of the FHMP is to assess the performance of the bubble curtain and the level of impact on fisheries. According to the NMFS's Biological Opinion (p. 8):

> "It is anticipated that the fisheries monitoring program will be similar to the PIDP including (1) observations on predation by gulls and other birds, (2) examination of injured fish collected from the water, (3) experiments using fish in cages at different distances. This fisheries program will be designed to document near-term fish mortalities and the likelihood of delayed mortality of differing sizes and species of fish that have swim bladders. In addition to biological monitoring, measurements of sound pressure and other parameters will be monitored. The specific monitoring plan will be developed by FHWA and Caltrans for review and approval by NMFS and California Department of Fish and Game (DFG). It is estimated that fisheries monitoring will cost approximately $500,000."

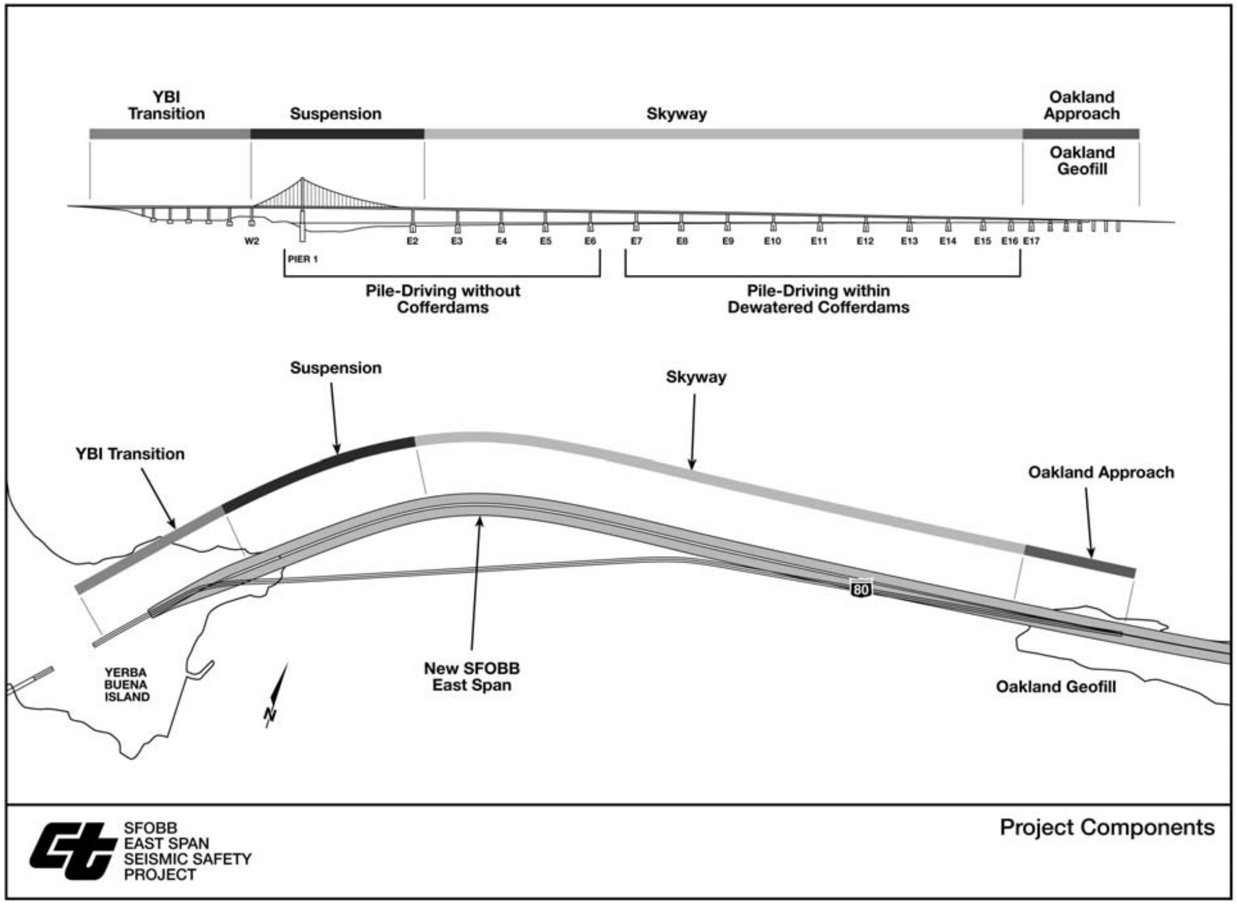


Figure 1-2. Project Components

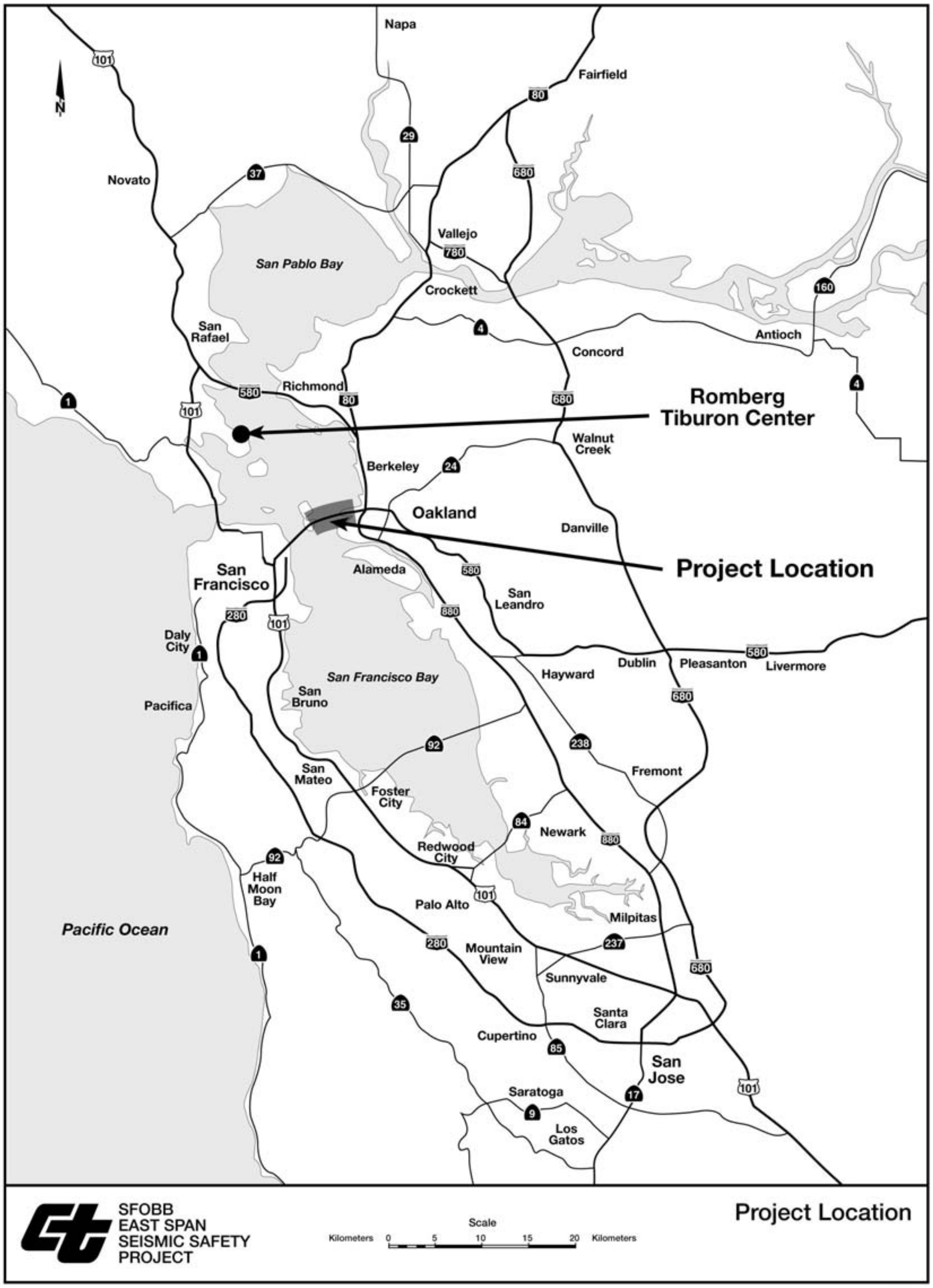


Figure 1-3. Project Location

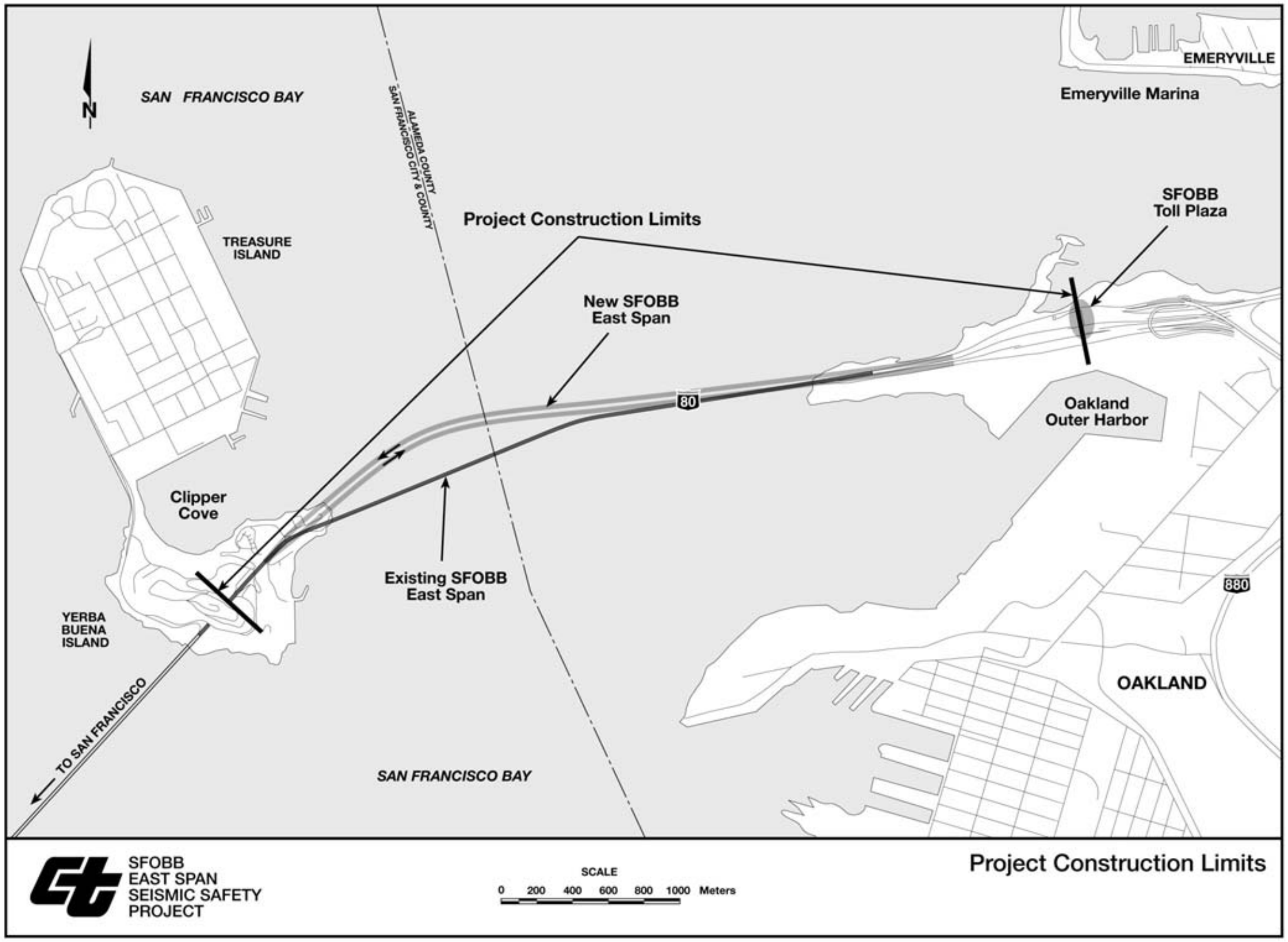


Figure 1-4. Project Construction Limits

1.2.2 Terms and Conditions from the NMFS's Biological Opinion and CDFG's 2081 Incidental Take Permit

The terms and conditions of the NMFS's Biological Opinion specifically related to the FHMP are addressed in Item 4 (p. 48):

> "4. Ensure a fisheries and hydroacoustic monitoring program is properly implemented.
>
> 4a. A fisheries and hydroacoustic monitoring plan will be developed that includes the following:
>
> (1) underwater sound measurements at various distances and depths from pile-driving operations;
>
> (2) evaluation of fish mortality and injury rates through the use of caged fish at various distances and depths from pile-driving operations; and
>
> (3) observations of bird predation and behavior.
>
> 4b. The draft fisheries and hydroacoustic monitoring plan will be provided to the NMFS for review and approval 90 days prior to initiation of pile-driving.
>
> 4c. Data from the monitoring program will be made available to NMFS on a real-time basis.
>
> 4d. An interim report will be provided to NMFS prior to December 31, 2002, and a final report will be provided by June 1, 2004.
>
> 4e. All salmonids killed and collected by this project must be transferred to the NMFS Southwest Fisheries Science Center Santa Cruz Laboratory Tissue Repository within thirty days of collection."

The terms and conditions of the CDFG's 2081 Incidental Take Permit are similar to those of the NMFS's Biological Opinion. The monitoring methods required for the FHMP are the same, but the reports required by CDFG include monthly compliance reports, quarterly compliance reports, annual status reports, and a final monitoring report no later than 45 days after completion of the project.

1.2.3 Work Plan Objectives

The three objectives outlined in the Work Plan are:

1. Determine if SPLs with the bubble curtain on met the following NMFS and CDFG noise criteria:

   a) Peak SPLs at or less than 204 decibels (dB) at 69 meters (226 feet) from pile-driving activities;

   b) Peak SPLs at or less than 180 dB at 440 meters (1,444 feet) from pile-driving activities; and

   c) Peak SPLs at or less than 150 dB at 4,400 meters (14,436 feet) from pile-driving activities.

2. Determine if estimated fish mortality rates with the bubble curtain on met the following NMFS and CDFG criteria:
    a) Near-term mortality zone bounded by 69 meters (226 feet) or less from pile-driving activities;
    b) Delayed mortality zone bounded by 440 meters (1,444 feet) or less from pile-driving activities;
    c) Near-term mortality zone bounded by SPLs at or less than 204 dB; and
    d) Delayed mortality zone bounded by SPLs at or less than 180 dB.

3. Compare fish mortality rates with the bubble curtain on to those with the bubble curtain off.

1.2.4 Compliance Tests

The tests summarized in Table 1.2-1 will be used to determine compliance with the NMFS and CDFG requirements.

1.3 TERMINOLOGY

This report uses specialized terminology related to underwater sound and technical aspects of the monitoring program. A comprehensive listing of definitions and acronyms is included in Section 6.5.

Unless specified otherwise, sound pressure is defined as peak sound pressure level (SPL max) in decibels (dB) referenced to one micro Pascal (1 μ Pa). The second most common descriptor is in terms of the Root Mean Square (RMS). A full discussion of the metrics used in this report is found in Section 2.

Table 1.2-1. Summary of SPLs and distances from the Work Plan based on NMFS Biological Opinion and CDFG 2081 Incidental Take Permit.

No.	FACTOR	METHODOLOGY	TEST CRITERIA
1	The sound pressure level does not exceed 204 dB at 69 meters (226 feet).	Hydroacoustic monitoring	True or false
2	The sound pressure level does not exceed 180 dB at 440 meters (1,444 feet).	Hydroacoustic monitoring	True or false
3	The sound pressure level does not exceed 150 dB at 4,400 meters (14,436 feet).	Hydroacoustic monitoring and extrapolation from hydroacoustic measurements because area is so large	True or false
4	There are no near-term mortalities beyond 69 meters (226 feet).	Caged fish monitoring between 70 and 440 meters (230 and 1,444 feet) from the pile	None of the fish used in the caged fish experiments in the delayed mortality zone die within 1 hour due to barotraumas.
5	There are no delayed mortalities beyond 440 meters (1,444 feet).	Caged fish monitoring at 500 meters (1,640 feet)	None of the fish used in the caged fish experiments beyond the delayed mortality zone die within 48 hours due to barotraumas.
6	There are no near-term mortalities at sound pressure levels less than 204 dB.	Caged fish monitoring between 70 and 440 meters (230 and 1,444 feet) from the pile where the sound pressure level is less than 204 dB	None of the fish used in the caged fish experiments where the sound pressure level is less than 204 dB die within 1 hour due to barotraumas.
7	There are no delayed mortalities at sound pressure levels less than 180 dB.	Caged fish monitoring outside 440 meters (1,444 feet) where the sound pressure level is less than 180 dB	None of the fish used in the caged fish experiments where the sound pressure level is less than 180 dB die within 48 hours due to barotraumas.
8	The bubble curtain reduces the mortality rate.	Caged fish monitoring in the near-term mortality zone with the bubble curtain on and off	A t-test to determine if there is a significant reduction in the rate of mortality when the bubble curtain is on compared to when it is off.

2.0 METHODS AND MATERIALS

The FHMP was designed as a monitoring program with many discrete elements in order to capture as much information as possible on the underwater sound effects of pile-driving. The following section describes and discusses the methods and materials used in implementing the FHMP.

2.1 OVERVIEW OF THE FHMP WORK PLAN

The FHMP Work Plan was designed to monitor in-Bay pile-driving under four different conditions:

- Pile-driving within dewatered cofferdams at Piers E16E and E10E;
- Pile-driving without dewatered cofferdams and utilizing a bubble curtain system for Piers E3E – E6E;
- Pile-driving associated with the Self-Anchored Suspension (SAS), which will also utilize a bubble curtain system; and
- Bubble curtain on and off studies.

The dewatered cofferdams were expected to provide a considerable degree of sound attenuation. Therefore, hydroacoustic measurements only with no biological monitoring were made at the dewatered cofferdams.

Biological monitoring included:

- Caged fish studies with a hydrophone in the cage during pile-driving with use of a bubble curtain system;
- Bubble curtain on and off studies; and
- Predation by piscivorous birds.

Due to dramatically different field conditions than had been anticipated during the formation of the Work Plan, a number of the study elements deviated somewhat from the proposed methods. The following sections discuss the proposed methods along with deviations.

2.1.1 Hydroacoustic Monitoring

Pier E16E is in very shallow water (-3 meters [9.8 feet] mean sea level [MSL]), so only limited hydroacoustic monitoring would be performed. This initial monitoring would provide data early in the construction process to assess the effectiveness of the cofferdams. Pier E10E is in slightly deeper water and was the first of three locations where hydroacoustic monitoring was to be conducted to characterize the hydroacoustic field surrounding pile-driving operations. The second set of acoustic field characterization measurements would be around Pier E6E, the eastern most pier proposed to be constructed without a cofferdam. The third set of hydroacoustic field characterization measurements would be made during pile-driving for the SAS. Piers E3, E4, E5, and E6 of the Skyway, as well as the piers for the SAS are not surrounded by cofferdams; therefore, a bubble curtain system will surround each pile driven to attenuate the SPLs.

2.1.2 Caged Fish Monitoring

Caged fish monitoring was designed to utilize shiner surfperch and steelhead with a cage holding 30 fish. The initial work for the caged fish monitoring would consist of a duration study and a bubble curtain on/off control study. This would be followed by caged fish studies at varies distances and depths.

The caged fish element of the Work Plan specified 17 monitoring trips with six groups of fish on each trip. The first four monitoring trips would establish an optimum duration of exposure for all the subsequent monitoring. The next four trips would be conducted in the near-term mortality zone followed by four trips in the delayed mortality zone, and the last four trips would be beyond the delayed mortality zone.

2.1.3 Bubble Curtain On/Off Monitoring

Bubble curtain on/off monitoring would be conducted to directly compare the effects during pile-driving with the bubble curtain on and with the bubble curtain off on fish. Only steelhead would be used in this study. The intent was to have the fish at a distance that corresponded to sound pressures between 215 dB and 220 dB.

2.1.4 Bird Predation Monitoring

Monitoring of piscivorous birds would be part of the basis for evaluating the effectiveness of the bubble curtain system and consequently it was only to be used during the bubble curtain on/off study and during pile-driving for the SAS, which would be in deep water where the bubble coverage of the piles might be affected by strong tidal currents.

2.1.5 Examination of Injured Fish Collected from the Water

Fish would be collected from the water close to the pile-driving support barges using long-handled dip nets. Fish salvage would be conducted only during the bubble curtain on/off study and during pile-driving for the SAS.

The fish collected would be examined for indications of the extent and nature of their injuries. Fish removed from the water would be placed in holding tanks on the research vessel and observed for at least 20 minutes. These fish would be evaluated using two criteria:

- Degree of external observable injury
- Degree of internal anatomical injury

Injured fish collected from the water that show signs of recovering would be held in a well-aerated tank on board the research vessel, and later transferred to the holding facility and observed for 48 hours before they undergo necropsy.

2.1.6 Deviations from the Work Plan

Adjustments in the implementation of the details of the Work Plan were necessary for a variety of reasons including changes in the construction schedule, pile-driving efficiency, better understanding of the hydroacoustic field produced by pile-driving, and biological variables. As information was gained and team efficiency improved with experience, adjustments were made to limit the caged fish studies to only what was needed to establish compliance. A letter was sent to the resource agencies in November 2003 explaining the need to make changes to the Work Plan. Some of the major deviations are discussed below. Other minor deviations will be discussed in the appropriate sections.

2.1.6.1 Construction Delay

Monitoring on Pier E6E could not start until the end of November 2003. This was just before the opening of the commercial herring season. When coordinating with CDFG and NMFS, these agencies reiterated that they would not approve the bubble curtain on/off study during the season when migratory salmon were in the Bay and pre-spawning herring aggregations were starting to form in the deep-water channels of the Bay (i.e., December 1 – May 31). Consequently, the bubble curtain on/off study was conducted during the first caged fish monitoring trip (November 21, 2003), and there was no opportunity to establish an optimum duration of exposure. See Section 2.1.6.3 for more details. The delay also affected the size of the steelhead used since they continued to grow for an extra five months. Instead of conducting the monitoring in the mild summer weather, monitoring took place in the winter.

2.1.6.2 Pile-driving Operations

Instead of driving one pile a day as originally envisioned, the contractor refined procedures so that up to three piles could be driven in one day. Instead of taking a minimum of one hour, pile-driving events typically took 30-40 minutes. In actual practice, the contractor would drive two piles part way down on one day using the small hammer (500kJ). Then a day or so later, the center pile and the other two that had been started earlier would be driven to their final tip elevation with the large hammer (1,700 kJ). The revised pile-driving schedule changed the implementation of the caged fish monitoring program in many ways including reducing the number of monitoring trips from a total of 17 to 8.

2.1.6.3 Bubble Curtain On/Off Studies

Because of numerous difficulties in implementing the first bubble curtain on/off study, CDFG and NMFS was contacted about the possibility of conducting a second study. Due to agency concerns related to the fact that Caltrans wanted to conducted the study during the timeframe when salmon and herring are in the Bay, CDFG and NMFS only approved a limited bubble curtain on/off study. The January 2004 study was limited to ten unattenuated pile strikes at Pier E3E and resulted in data that conflicted with the November 2003 on/off study. Caltrans is currently in discussion with CDFG and NMFS regarding a possible third bubble curtain on/off study, which would be completed at Pier E3W or E4W.

2.1.6.4 Hammer Energy and Sound Pressure Levels

The pile-driving energy was not constant and the peak SPLs were less than anticipated. It was observed that the SPLs produced with the small (500 kJ) hammer was often as large as that produced by the large (1,700 kJ) hammer. As a result, some of the caged fish monitoring was conducted when the small hammer was used.

2.1.6.5 Bird Predation Monitoring/Examination of Fish Collected from the Water

There has been a very limited amount of bird predation monitoring to date and no fish have been collected from the water for examination. This is due to the limited amount of bubble curtain on/off monitoring that has occurred. A report summarizing observations on moribund fish and gull predation will be presented at a later date after pile-driving has occurred at Pier E3W as well as during the next bubble curtain on/off study, if approved by CDFG and NMFS.

2.2 HYDROACOUSTIC METHODS AND MATERIALS

The following sections describe the methods and materials used in monitoring underwater sounds produced by pile-driving.

2.2.1 Monitoring Equipment and Calibration

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). At close-in positions where relatively high sound pressures were anticipated, PCB Type ICP Pressure Transducers were used to acquire the acoustic signals. The transducers were connected to both a Larson Davis Model 820 Integrating SLM (Type 1) and a Sony Model TCD-D100 DAT through a PCB multi-gain signal conditioner. Pressure transducers were used instead of a hydrophone system when peak pressure signals from the unattenuated piles were predicted to possibly exceed the hydrophone system limitations of 212 to 214 dB re 1 micro Pascal (μPa). The multi-gain signal conditioner provides the ability to increase the signal strength (i.e., add gain) so that measurements are made within the dynamic range of the instruments used to analyze the signals.

The peak pressures and root-mean square average SPLs ($RMS_{impulse}$ levels) were measured either “live”, using the SLM, or subsequently from DAT recordings 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 millisecond rise time) function of the Larson Davis Model 820 SLM. Additional subsequent analyses of the acoustical impulses were performed using a Larson Davis Model 2900 Real Time Analyzer. The real time analyzer provides narrow-band frequency and waveform analyses.

The measurement systems were calibrated prior to use in the field with a G.R.A.S. Type 42AA pistonphone and hydrophone coupler. A pistonphone is an acoustical calibrator used to generate a precise sound pressure for the calibration of instrumentation microphones. The pistonphone, when used with the hydrophone coupler, produces a continuous 145.3 dB (re 1 μPa) tone at 250 Hertz (Hz). The SLMs are calibrated to this tone prior to use in the field. The tone measured by the SLM is recorded at the beginning of the digital audiotapes that were used in the field. The system calibration status was checked at the end of the measurement event by both measuring the calibration tone and recording the post-measurement tone on tape. Tape analysis included the measurement of the calibration tone at the beginning and end of tape recording events. All systems were found to be within 0.5 dB of the calibration levels. The pistonphone output was certified at an independent facility.

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), measurement conditions (e.g., currents, sea conditions, etc.), 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.

2.2.2 Underwater Sound Descriptors

A graphed sound pressure pulse as a function of time is referred to as the waveform. NMFS has requested that Caltrans provide them with the peak pressure and the RMS or average pressure over the pulse duration. 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 (Greene, personal communication). 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 has been identified with various measurements. The total sound energy has been described as the “total energy flux” (E_T) (Finnerran et. al. 2002). The “total energy flux” is similar to the un-weighted sound exposure level (SEL), a common unit of sound energy used in airborne acoustics to describe short-duration events. The units are dB re 1μPa^2-sec. In this report, peak pressures and RMS sound pressure levels are expressed in decibels re 1 μPa. 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.

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.

Impulses were analyzed to illustrate waveforms, provide narrow band frequency (i.e., 6 Hz resolution) spectra, 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 unweighted SEL or the total sound energy (E_T). The peak pressure and RMS impulse level ($RMS_{impulse}$) are conveniently measured with a Larson Davis Model 820 Precision SLM. This type of instrument allows for efficient measurement of these acoustical descriptors over relatively long periods of time or numerous pile strike impulses. The $RMS_{impulse}$ that is commonly reported in this document is the SPL averaged over the loudest 35-millisecond period during an impulse. This descriptor has been used to approximate the RMS where 90 percent of the energy in an impulse occurs ($RMS_{90\%}$). Data analysis from the PIDP found that the $RMS_{impulse}$ conservatively estimated the $RMS_{90\%}$ by about 1 dB (Caltrans 2001a). The attenuated strikes measured for this study using the production piles have a different relationship. The $RMS_{impulse}$ is about 2 to 3 dB higher than the $RMS_{90\%}$ (with a range of 1 to 5 dB). The larger differential occurs because the averaging time is longer (between 5% and 95%) accumulated sound energy for the attenuated pulse. The total energy, E_T or SEL, was calculated from selected impulses for each fish cage exposure. E_T was typically 11 to 12 dB below the $RMS_{90\%}$ or about 14 to 15 dB below the $RMS_{impulse}$. The SEL was measured from signal analysis of selected DAT recordings. A relationship between RMS_{90}, $RMS_{impulse}$ and SEL was established from this signal analysis process.

2.2.3 Underwater Sound Measurement Positions

2.2.3.1 Hydroacoustic Characterization

For Pier E16E, there were four measurement positions that ranged from 25 to 95 meters (82 to 312 feet) from the pile-driving. Measurements were made at only one depth, about 1 to 2 meters (3 to 7 feet) above the bottom since the water was shallow (i.e., less than 4 meters [13 feet]). For the two other Piers (E10E and E6E), there were at least seven measurement positions on the water, at distances of about 50 to over 500 meters (164 to over 1,640 feet) from the pile-driving. Measurements were made at two different depths. Measurement depths were about 2 meters (7 feet) below the water surface and 2 meters (7 feet) above the bottom. At least two of the measurement positions were fixed, at distances of about 50 and 100 meters (164 and 328 feet). In general, measurements were made at the required distances of about 50 meters (164 feet), 100 meters (328 feet), and 500 meters (1,640 feet) in at least two different directions (e.g., north, south, east, or west of the pile). Additional spot measurements were made to supplement the data sets. Measurements were also made at approximately 1,000 meters (3,280 feet) in one direction. Supplemental measurements were made at positions in close proximity to the pile-driving at Piers E5E and E3E.

2.2.3.2 Caged Fish Monitoring Method

During caged fish studies, sound pressures were measured where fish were exposed to pile-driving sounds, using two hydrophone systems: one inside the cage and the other outside the cage at a depth of 2 meters (6.5 feet) from the bottom. A third hydrophone measurement system was usually placed on the barge at about 50 meters (164 feet) from the pile. The ability to position this system depended on construction activities.

2.2.4 Underwater Sound Measurement Data Management

Following each day of measurements, digital data captured by the SLMs were downloaded to computer systems. These data were converted and stored in raw text format. The SLMs were primarily used to provide accurate live readings. These readings were recorded in field notebooks from time to time. The SLMs have a memory capacity of about two hours, so they were not used as primary data acquisition systems. The digital audiotapes had a capacity to record up to four hours per tape. There also was the ability to change tapes in the field to acquire data on days where more than four hours of measurements were necessary. The digital audio tape recordings were then analyzed using SLMs. 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 the pile-driving sounds. Relatively strong currents caused tension on the sensor line creating noise that is referred to as "strumming". Strumming did affect some measurements made at distant positions where the signals were weaker. These noise-affected data were excluded from any data reporting.

2.2.5 Hydroacoustic Compliance Tests

Measurements from many monitoring trips were pooled and plotted by distance from the pile for pile-driving with the bubble curtain on to arrive at a best-fit interpolation of peak SPL for distance.

2.3 CAGED FISH METHODS AND MATERIALS

2.3.1 Fish

Fish with gas bladders can be broadly categorized into three different groups: hearing specialists, hearing non-specialists with a tube from the gas bladder to the gut, and hearing non-specialists without a tube from the gas bladder to the gut. One type of hearing specialists includes the taxon Ostariophysi, which have a series of bones linking the gas bladder and the inner ear. Most Ostariophysi are fresh-water species such as carp and catfish. No Ostariophysi are found in central San Francisco Bay, although some are found in the Sacramento-San Joaquin River Delta. Hearing specialists include herring and some types of cod. Hearing non-specialists with a tube from the gas bladder to the gut include salmonids, and hearing non-specialists without a tube from the gas bladder to the gut include perch-like fishes.

The main criteria for selecting a particular species were ease of acquisition and handling and the characteristics of the gas bladder and acoustico-lateralis systems. Six different species of fish were considered for their suitability for a caged fish monitoring program including juvenile Chinook salmon (*Oncorhynchus tshawytscha*), white sturgeon (*Acipenser transmontanus*), northern anchovy (*Engraulis mordax*), Pacific herring (*Clupea pallasi*), shiner surfperch (C*ymatogaster aggregata)* and rainbow/steelhead trout (*Oncorhynchus mykiss)*. The species selected were steelhead and shiner surfperch due primarily to their swimbladder configuration, ease of handling and availability.

2.3.1.1 Steelhead

Steelhead trout or more simply steelhead can be anadromous or freshwater residents. Resident forms are commonly referred to as rainbow trout. The anadromous form is referred to as steelhead. Steelhead was considered an ideal species with which to conduct the monitoring experiments because they are hearing non-specialist, physostomous fish (i.e., have a tube running from the gas bladder to the gut).

For this study, juvenile steelhead test subjects were obtained from the CDFG hatchery at Nimbus, California where they were being reared under freshwater conditions. Fish were transported to a fish holding facility at RTC where they underwent smoltification. Smoltification is the process where a fish changes anatomically and physiologically from a fish adapted to a freshwater environment to a fish adapted to a saltwater environment. The steelhead used in this study ranged in size from 65 to 227 millimeters in total length (about 2.5 – 9 inches). They weighed between 26 and 177 grams (0.06 to 0.4 pound) each.

2.3.1.2 Shiner Surfperch

Shiner surfperch were also 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). Shiner surfperch were selected primarily because they are relatively easy to keep alive in small enclosures compared to other wild species, and they are readily available through a local bait dealer (Fraser, personal communication). Shiner surfperch 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 surfperch, member of the Family Embiotocidae (Order Perciformes) are viviparous, giving birth to fully-developed, free-swimming young.

Surfperch (Class osteichthyes, Order: Perciformes, Family Embiotocidae) are a reasonable surrogate for the groups of spiny-rayed fishes that aggregate around physical structures and that do not have specialized hearing apparatus. Thus surfperch roughly represent fish such as striped bass) and the brown rockfish (*S. auriculatus*). During PIDP and PIDP Re-strike activities (Caltrans 2001b, Caltrans 2003), mortalities of shiner surfperch and other members of the surfperch family were observed and were attributed to the acoustic pressure waves caused by pile-driving.

2.3.2 Fish Holding Facilities

The fish holding facility was located at the Romberg Tiburon Center (RTC). See Figure 2-1. Twelve, 1,800-liter (480-gallon), custom-made fiberglass round tanks with flat bottoms were set up in two rows in the fish holding facility. See Figure 2-2. The tanks had a white interior and 5.08-centimeter (2-inch) diameter molded drains. Water flowed into the tanks from overhead pipes that imparted a slow circular flow in the tanks. Each tank had a removable cover made of black plastic mesh in a PVC pipe frame. The water level in the tanks was controlled by standpipe height. The pattern of circular flow tended to push debris to the center of the tank and then up inside the outer pipe and down the center pipe. Water flowed through the tanks directly from and into San Francisco Bay.

Figure 2-1. Fish holding facility at Romberg Tiburon Center for Environmental Studies.

Figure 2-2. Fish holding tanks inside the facility.

The flow rate for the steelhead was approximately 1 tank exchange per hour. The flow rate through the shiner surfperch tanks was slower at a rate of one exchange every few hours. Each tank had two center standpipes; one for a tank nearly full condition and one for a tank nearly empty condition.

Each tank had its own clipboard holder, bucket and small dip net to remove dead fish. The tanks were cleaned before the arrival of each new group of fish and then not cleaned again until after that particular monitoring study was completed unless there was an unusual amount of debris in a tank. This minimized disturbing the fish since they tended to dash about and crash into the sides of the tanks whenever people were near or the lids came off the tanks.

The tanks were aerated via a ¼ horsepower air blower that pumped air through 5 x 5 x 25 centimeter (2 x 2 x 10 inch) air tones. A standby water pump and air pump were available in case of equipment failure. A standby generator was available in the event of electric power failure at the field station.

2.3.3 Bay Water Intake System

Water from San Francisco Bay was brought up from an intake approximately 10-meters (30 feet) off the seawall adjacent to the fish holding facility from near the bottom, approximately 3-meters (9.8 feet) below the surface, by a 1 ¾ horsepower, centrifugal, electric pump. The water was passed along a 5-centimeter (2-inch) diameter PVC pipe to a large (420-kilogram [925 pound]) sand filter and then into the holding facility's water distribution system. Ball valves were used to adjust flow at each individual tank. The filter was back-flushed and rinsed daily. At least once a week, the filter top was removed and the sand was stirred to prevent channeling.

2.3.4 Fish Handling Procedures

Smoltification is a complex anatomical and physiological change that enables a freshwater fish to survive in ocean water with a much higher salinity. The process is typically fairly gradual as fish migrate down stream into an estuary before migrating out to sea. When the steelhead trout were picked up at Nimbus Hatchery, they exhibited freshwater physical characteristics. The shape of the head, spots, body color and body shape were characteristically those of trout. These fish had been raised in fresh water from the American River with a salinity of 0.0 parts per thousand (ppt). A few fish were held for several weeks at the very beginning of the study. After as little as a week these fish started to look like true steelhead with a dramatic change in body color and shape.

The steelhead used in the monitoring study were forced to undergo smoltification in a 24-hour period in order to ready them for salinity levels in San Francisco Bay, which is much faster than they would experience under natural conditions. Attempts to put the Nimbus Hatchery steelhead directly into Bay water resulted in 30% mortality in the first 24 hours. Typically, the steelhead used in this study went from 0.0 ppt to 3 ppt at the time they were picked up at the hatchery. After approximately 3 hours in transit at 3 ppt, they were put into tanks with a salinity of 11 ppt. They were left at 11 ppt for approximately 16-20 hours and then the salinity in the tanks was brought up to San

Francisco Bay salinity (which typically ranges from 23 ppt to 30.5 ppt) over a 4-hour period. The vast majority of the steelhead made this transition without incident, but about 3-6% (one or two per tank of 30-40 fish) succumbed within 48 hours before being exposed to a salt water environment. This rate of attrition typically continued after exposure to pile-driving with the loss of one or two per tank until the end of the study 48 hours later. No physiological tests for stress were conducted but the rate of mortality is consistent with CDFG hatchery and CDFG pathology staff expectations (West, personal communications).

The nutritional state of the steelhead is complex. The steelhead picked up at the hatchery were on reduced rations, being fed only a few days a week to prevent them from growing too fast (West, personal communication). But they tended to gorge themselves on insects that were attracted to the hatchery security lights at night. Initial attempts to simply hold the steelhead in the transport bags overnight as they acclimated to the higher salinity had to be abandoned since the steelhead would defecate in the transport bag, rendering the water nearly brown by morning. In general, steelhead going through smoltification eat very little or do not eat at all. Only one or two fish per tank (3-6%) would feed if food was presented. Though food was offered to the steelhead after exposure to pile-driving, only a few would eat as they continued the process of smoltification. These were robust hatchery fish and there is no reason to believe that lack of food consumption was a factor in the rate of mortality. Fish were collected from the raceways at random by a hatchery technician who often used a handful of food to aggregate the fish. Very large fish were rejected because they consumed so much oxygen and appeared to injure smaller fish when they were thrashing around. A small amount of ice was added to the cooler during the drive back to the fish holding facility. All the transport coolers were checked at the halfway point, about 20 minutes after leaving the hatchery. Occasionally a bag would leak or become deflated and need to be replaced. No steelhead mortalities occurred during transit from the hatchery.

A similar process was employed for transporting shiner surfperch from Loch Lomond Live Bait. Initially many of the shiner surfperch purchased from the local live bait dealer exhibited injuries to their head and snout from crashing into the wire mesh traps that were used to capture them and also from crashing into the sides of the holding pens at the bait dealers shop. With experience the bait dealer and technicians became better at selecting fish with few or no injuries for this monitoring program.

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. A special net was constructed with a vinyl bottom that held water to ensure that the fish remained in water when they were lifted out of the tanks. Fish were placed in large plastic bags with water in the bottom and then poured out of the bags into the cage or tanks (Figure 2-3). The fish were generally transported in bags of water placed in 90-liter coolers with the lids down so that the fish tended to stay in the dark. Keeping fish in darkness during transportation tends to keep the fish calmer since they will not be reacting to visual stimuli. All transport was conducted using industrial-grade oxygen. The bags were fully inflated and then tied off with rubber bands.

Figure 2-3. Fish in transport bag acclimating to the holding tank water.

The oxygenated transport bag method was used instead of a method that relied on air pumps for a number of reasons. Hyperoxygenation tends to pacify fish. They do not have to swim as much to have oxygenated water flow over their gills. Less swimming activity results in fewer collisions with other fish and the walls of the holding container. Experience with mobile aeration systems has not been uniformly successful especially when the containers need to be moved around a great deal. This was especially true when transporting treatment groups of fish from the holding facility, to a truck, then to a boat, then moving the coolers around the boat, and then back onto a truck and to the fish holding tanks. See Figures 2-4 and 2-5.

2.3.5 Cage and Deployment System

A series of cage designs were tested for suitability. The most suitable frame was constructed of 5-centimeter (2-inch) diameter PVC pipe with dimensions of 40.6 x 40.6 x 81.3 centimeters (16 x 16 x 32 inches) with 2.5-millimeter (1/10- inch) mesh netting sewn to fit snugly over the frame. The end of the net was elongated so that it could be tied with a slipknot so the fish could be poured into and out of the net cage. The PVC pipe had numerous 0.3-centimeter (1/8th –inch) holes to allow air to escape from the frame when it was submerged. Two 41-centimeter (16-inch) long sections of steel rebar, 1 centimeter (3/8thinch) 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. The cage frame had a strong cable harness with a quick release pulley. The pulley was used to attach the cage harness to a strong cable anchor line deployed one meter (3.3 feet) off the stern of the research vessel. The anchor line was attached to four concrete-filled buckets weighing 30 kilograms (67 pounds) each (Figure 2-6). The four anchor buckets linked together weighed approximately 122 kilograms (268 pounds).

Figure 2-4. Coolers with fish being loaded onto one of the research vessels.

Figure 2-5. Coolers containing fish stacked on bubble pack.

Figure 2-6. Set of concrete buckets used as an anchor.

This proved adequate to sink several centimeters into the Bay mud and keep the cage anchor cable generally vertical once the research vessel was anchored. The cage anchor line was raised and lowered with a hydraulic puller. A hydrophone was passed through the net mesh of the cage and secured so that it was suspended in the middle of the cage. See Figures 2-7, 2-8 and 2-9.

The research vessel was generally secured with three lines when it was less than 50 meters (164 feet) from the pile being driven. When the research vessel was more than 50 meters (164 feet) out, the vessel was secured with one or two anchors to hold it in position. Considerable planning was necessary to take into account tidal currents and the deployment of the pile-driving barge and support vessels. An infrared range finder (Bushnell 1,000 Yardage Pro ®) was used to determine the distance from the side of the pile to the stern of the vessel.

When the research vessel was secured in position, and the stern anchor line was secure on the bottom, a technician would lower the fish cage half way into the water, keeping the open end up. The bag of fish would be lowered into the cage and upended pouring the fish into the cage water (Figure 2-10). The end of the cage net would be tied off with a quick release slipknot, and the cage would be lowered to the pre-determined depth. The team took care to make sure the net was not tangled in the anchor line and that the line from the hydrophone back up to the deck was clear. The cage was lowered to the pre-determined depth and held at that depth either with a tether line up to the research vessel deck or a small float with just enough line to keep the stern of the cage at the desired depth.

Figure 2-7. Hydrophone being installed in the fish cage.

Figure 2-8. Hydrophone inside the fish cage.

Figure 2-9. Recording sound pressure levels inside the cage.

Figure 2-10. Fish in the half immersed cage just before it is tied shut.

The time was noted from 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, while the fish were still being exposed to pile-driving, was also recorded. The process of bringing the fish back up to the surface and getting them out of the water where they were still being exposed to pile-driving also took approximately one and half minutes. The fish pouring method was used throughout the retrieval process. Bringing the fish from the Bay to the deck of the research vessel 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 2-11. The entire cage with the fish in the water was opened by loosening the slipknot; and at that point, the fish swam into the large perforated bag as the cage was lifted out of the water. Then, the large perforated bag full of fish and water was lifted onto the deck, released from the retrieval net, and the perforated bag was lowered into the water-filled transport bag so that the fish could be poured into their transport bag. The large perforated bag was lifted out of the Bay with about 75 liters (20 gallons) of water that drained rapidly out of holes about 20 centimeters (8 inches) from the bottom, so that there was always water in the bottom of the bag. The fish transport bags had about 16 liters (4 gallons) of water in the bottom at all times. The transport bag was charged with oxygen and the cooler lid was closed. 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.

Figure 2-11. Retrieving the cage and fish.

2.3.6 Near-term Mortality Criteria

After exposure to pile-driving, any dead fish were removed just before the bag was charged with oxygen; these fish were recorded as near-term mortalities. The coolers were opened after one hour to look for fish that had died within that hour. Near-term mortality was defined as when a fish laid on its side on the bottom of the container with no movement at all, including no movement of the operculum for 10 seconds. The transport bag would be opened and an aquarium net would be used to retrieve the dead fish. If it moved at all, it was clearly not dead and left in the bag. The transport bags were inspected for leaks and recharged if necessary. The coolers were opened and inspected every 2 hours until the fish were returned to their holding tanks.

2.3.7 Delayed Mortality Criteria

2.3.7.1 24-Hour Delayed Mortality

The bags of fish and their transport water were placed in their tanks at the fish holding facility and floated in the tanks for 10-20 minutes to allow temperature equilibration of the transport water. Then the bags were opened and the fish were released into the holding tank. Any mortalities were placed in Ziploc® bags and immediately frozen. Fish that were clearly close to death were removed as soon as they were noticed. A slightly different definition for mortality was used for fish at the holding facility. A fish that lay on its side and did not move for 20 seconds other than operculating was termed a mortality and placed in a Ziploc® bag. The reason for this change in definition compared to near-term mortalities was based on experience that indicated these fish always died.

Otherwise they would sit in the tank for approximately 8-12 hours (overnight) before the attendant would remove them.

The tanks were typically inspected twice a day after exposure. Trout chow was provided to the steelhead and frozen brine shrimp and krill was provided to the shiner surfperch. The steelhead rarely ate the trout chow, but the shiner surfperch voraciously consumed the brine shrimp and krill.

2.3.7.2 48-Hour Delayed Mortality

After the first twenty-four hours, tanks were inspected at least once in the morning and mortalities were removed. All the fish were sacrificed at the end of forty-eight hours using bottled CO_2. The dead fish were placed in sealed plastic bags along with their tank label and immediately frozen in a zero degree freezer at RTC for later measurement and necropsy.

2.3.8 Controls

Three types of controls were used to help differentiate between the effects of exposure to pile-driving pulses and other potential causes of injury or mortality. Holding facility controls (HC) remained in their tanks at RTC and did not go through any of the phases of handling experienced by the fish transported or exposed to pile-driving. Transport controls (TC) remained in the transport bags and coolers for the entire monitoring trip, and were never put in a cage and exposed to pile-driving. Cage controls (CC) were fish that were transported, but also put into the cage and lowered to depth for 5-10 minutes when there was no pile-driving.

2.3.9 Necropsies

Necropsies were conducted to provide valuable information on the type and degree of injury, including if they were from barotrauma or not. The necropsy process generally involved two technicians conducting the necropsies and one person taking notes. Groups of fish were removed from the freezer and slowly thawed in tap water and then immediately measured and examined for external and internal injuries. Fish were measured for standard, fork and total lengths. Necropsies on five fish from each group were conducted using a rapid assessment protocol. It took approximately 3-5 minutes for a technician to examine a fish for external signs of injury or disease, cut open the abdomen from anal vent to the isthmus, spread out the internal organs and look at the state of the internal organs using a high intensity dissection light. A light was also used to evaluate the condition of the kidney by shining the light against the external body wall. The transmitted light method worked well for the surfperch and small steelhead. See Figure 2-12. The body wall was too thick for this method to be used on the larger steelhead.

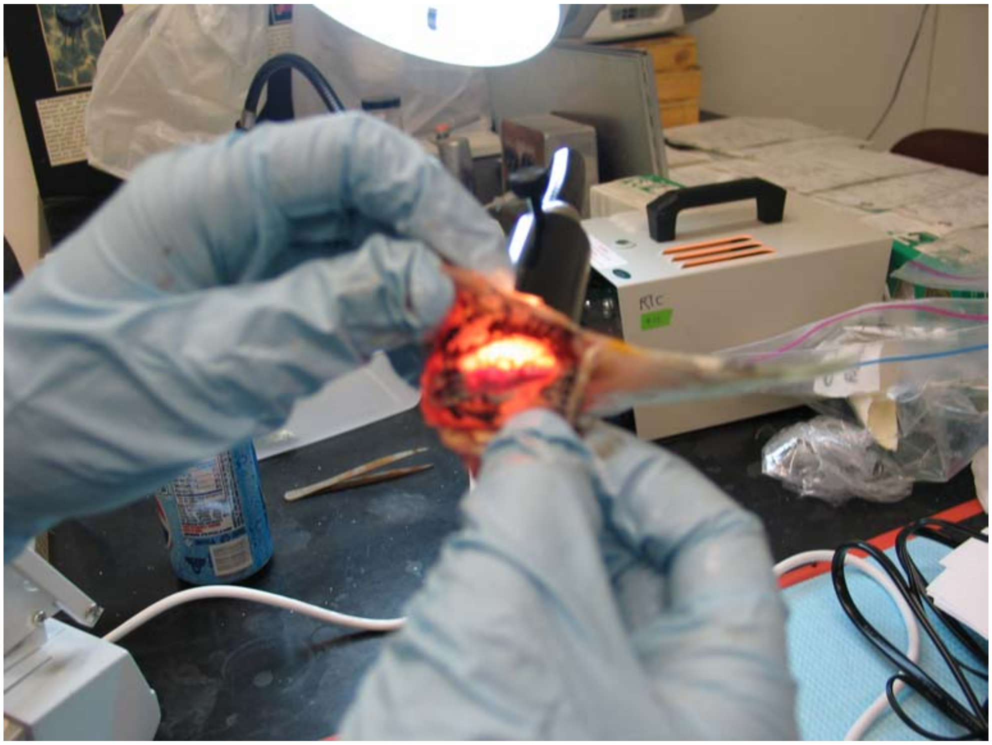


Figure 2-12. Method for quickly evaluating the condition of the kidney.

The work plan called for a six-stage evaluation of the fish, but with experience, the process was refined so that there were only four categories (Kline, personal communication). The six-category process was deemed to be more suitable for refined necropsies with dissecting microscopes and more time per fish. At the end of each necropsy, the technician was asked to make a determination if the fish died of disease, other causes or barotraumas. A group of control fish was always on hand for comparison to fish that had been exposed. In addition, the necropsy team had access to photographs of fish killed by pile-driving barotrauma at other projects. Typically a fish exhibiting Code 3 or greater for internal injuries would be considered to have died from barotrauma. Table 2.3-1 below summarizes the categories.

Table 2.3-1. Summary of revised injury classification system.

Code	External Injury	Internal Injury
1	No discernable external injury.	No discernable internal injury.
2	Some external indication of injury or disease.	Some slight but definite indication of disease or injury.
3	Pronounced injury such as scale loss, red eye, or erythemia at base of fins.	Internal bleeding, burst gas bladder, hyperemia of internal organs.
4	Rupture of the body cavity.	Gross damage to the internal organs.

2.3.10 Data Collection

2.3.10.1 Treatment Group Tracking

Study treatment groups were composed of separate groups of fish obtained at the hatchery or bait fish dealer. Treatment groups were maintained together and their condition tracked by group throughout the caged fish monitoring program. The basic unit of a treatment group was 30 fish acquired at the same time, but could vary by plus or minus three or four fish. Reasonable effort was directed to keeping the treatment group sizes the same and to minimize the need for handling.

When the fish arrived at the holding tank facility, they were placed in a tank (T) in the fish holding facility numbered 1-12. Thus a tank of fish, which was one treatment group, was designated T1-T12. In addition, each monitoring expedition (M) was given a trip name from M01 through M08. Hence each group of fish exposed was given a treatment group designation, such as M05T12 for monitoring trip number 5, tank 12. The treatment group identification information was written on a piece of duct tape with a permanent marker and the tape was moved from the tank to the transport cooler and then back to the tank and finally into the sealed bag holding the fish for necropsy. This labeling method facilitated tracking groups of fish being moved from a tank into a cooler, then loaded on a truck and unloaded from the truck and loaded on to a research vessel, moved around on the research vessel, back onto a truck and then back to their holding tanks. The transport bags were also marked with a permanent marker to keep track of them as fish were loaded and unloaded from coolers.

2.3.10.2 Data Collection Forms

Data collection was recorded on forms printed on water-resistant paper. Tank Data History Forms were kept on clipboards attached to tanks. The overall experience of a monitoring trip was kept on a Monitoring Trip Form. The data on exposure to pile-driving for each treatment group was kept on a Pile-driving Exposure Treatment Group Form. Data from the necropsies and length data were kept on forms developed for these processes. See Appendix A for copies of the forms.

2.3.11 Database

The information on the forms was transferred to an MS Excel spreadsheet that was defined as the “master database”. Not all of the data were suitable for analysis because of excessive mortalities due to handling problems, disease, smoltification stress or parasites. American Society of Testing and Materials (ASTM) standards for fish specify that groups that have more than 10% mortalities that are not related to the treatment need to be excluded from further study or data analysis (Kline, personal communication). The data for all the groups not excluded were combined into what is termed the “analytical database”. The data for the treatment groups that were determined to be suitable for compliance monitoring analysis are listed in Appendix B.

2.3.12 Statistical Analysis

For purposes of this study, each individual fish is referred to as a subject, and a treatment group, or more simply a treatment refers to a cage with approximately 30 fish that were exposed to the same set of parameters. All of the data analyses were carried out using the percentage of survival of a treatment as the input data.

Replicate treatments refer to treatments under the same set of parameters of depth, distance, and duration of exposure as a previous treatment. Under the conditions of the Work Plan, there were going to be 8 replicates for each species at each of the distance or depth treatments, with 2 bubble curtain treatments and 4 duration treatments, which would have resulted in a total of 68 treatments plus controls. However due to the truncated monitoring schedule, the anticipated number of replicates were not obtained. In some cases, there were only one or two replicates of a particular treatment and there were no treatments beyond the delayed mortality zone. A total of 36 treatments plus the controls were completed during the course of the monitoring program. The number of replicates is not nearly as great as planned, but still provided a substantial amount of data suitable for statistical analysis.

The control population was the Cage Control (CC). To assess the instantaneous as well as the delayed responses, the percentage of survival was taken at hour 1, hour 24, and hour 48. The data analyses are presented in Appendix B. The basic form of the analysis used was a Student's t-test for comparing two sample means. The Student's t-test is a special case of Analysis of Variance (ANOVA) for the comparison of differences in just two groups at a time. It is particularly appropriate for use where the sample size is small and the standard deviation of the population is unknown. Though treatment group sizes were large (approximately 30), the number of replicates was small (<4), so the Student's t-test was the method selected to do the statistical analysis.

Unequal samples sizes are corrected for in the analysis. All of the tests used a 5% level of significance (LOS) in a one-tailed test. The reason a one-tailed test was used was based upon the type of experiment where only two results were determined, survival and mortality. It was a uni-directional effect (increasing sound); therefore, the one-tailed test was supported.

The basic premise for each study was to compare control and treatment survival for each treatment parameter of concern. Thus, the percentage of mortality of Cage Controls for five minutes was only compared to treatment group mortalities for five minutes. Cage Control mortality for 24-hours set up as Day 2 (Control 24hr) was compared only to treatment mortality for 24-hours, which described the delayed mortality effect at 24-hours. The Cage Control 48-hour data was compared to the treatment mortality at 48-hours to evaluate the delayed effect at the end of the study (EOS).

The first set of analyses for each species was examined to determine the difference between control and test mortality at:

- Distance < 69 meters (226 feet)
- Distance > 69 meters (226 feet)
- Duration < 5 minutes
- Duration >5 minutes
- Sound pressure level between 180 and 204 dB
- Sound pressure level above 204 dB

A second set of analyses incorporated all of the data for both species to determine if mixed data from both species would yield any significant insight. The same comparative studies as noted above were then conducted. A third analysis was carried out on both species separately to determine if there was a relationship between size and the rate of mortality and to determine if the mortality rate is the same for both species. All of the data sets by treatments are provided in Appendix C.

After examining the data, a fourth analysis, which was not specified in the Work Plan, was performed on the combined species data set to determine if the duration and SPL had a combined effect on mortality. To simplify the analysis, the duration in minutes was multiplied by the SPL dB. This combined short duration, high intensity effects as well as longer term, low intensity effects. The basic mortality data set was then sorted into D*dB files of <1000 and greater than 1000. The Student's t-test was then used to compare survival/mortality rates on both data sets.

2.3.12.1 Mortality Zones

The near-term mortality zone was estimated to extend out from the pile to a distance that corresponded to 204 dB or approximately 69 meters (226 feet) (Greene 2001, Hastings 2002, NMFS 2001). The delayed mortality zone was estimated to extend out from the pile to a distance that corresponded to 180 dB. A total of 22 treatment groups are reported for the near-term mortality zone and 13 for the delayed mortality zone.

2.3.12.2 Duration of Exposure

Because it was not known if the injury and mortality rate increases with the duration of exposure, a set of treatments using different durations of exposure were to be conducted at the very beginning of the study to establish a standard duration of exposure for each mortality zone. According to the Work Plan, the duration of exposure treatment to establish optimum duration in the near-term mortality zone would be conducted where the peak SPL was predicted to be between 215 dB and 220 dB. The initial durations of treatments would be 1 minute, 3 minutes, and 10 minutes. A second set of duration treatments would be conducted in the delayed mortality zone at approximately 175 meters (574 feet) where the SPL was predicted to be 190 dB-195 dB.

On the first day of monitoring, it was determined that it would be physically impossible to move the research vessel close enough to the pile to expose fish to peak SPLs between 215 dB and 220 dB due to the footing box. In fact, measurements found that peak SPLs were 215 dB or less at positions very close to the pile with the bubble curtain operating. The rate of pile-driving was much faster than anticipated and precluded conducting all the duration studies on one pile or conducting the delayed mortality zone treatments on one group of three piles.

Even with the above construction changes, treatment durations were conducted as planned in the Work Plan plus a few additional durations. Duration of exposure treatments in the near-term mortality zone were conducted for 1 minute, 3 minutes, 5 minutes and 10 minutes. Durations of exposure treatments in the delayed mortality zone were conducted for 1, 5, 10, 20 and 60 minutes.

2.3.12.3 Depths

The NMFS Biological Opinion and CDFG 2081 Incidental Take Permit required monitoring at various depths. Monitoring was conducted at 2, 4, 5, 8, and 10 meters (7, 13, 16, 26, and 33 feet) in depth from the surface. For purposes of statistical analysis, the mortality rates for treatment groups at each depth were compared to the control groups. The data were pooled for both species by depth and mortality rates. These rates were then used in a correlation analysis and graphed.

2.3.12.4 Distance

The NMFS Biological Opinion and CDFG 2081 Incidental Take Permit required monitoring at various distances. Monitoring was conducted at 23, 24, 25, 28, 42, 62, 73, 105, and 314 meters (75, 79, 82, 92, 138, 203, 240, 345, and 1,030 feet). For purposes of statistical analysis, the mortality rates at distances less than and greater than 69 meters (226 feet) were compared to the control group mortalities. Finally, the data were pooled by distance and species and presented as a regression analysis.

2.3.12.5 Species

Six treatment groups each of shiner surfperch and steelhead were brought along on each monitoring trip, with only a few exceptions. To the greatest extent possible, the treatments provided to surfperch for duration, depth, and distance were duplicated with the same treatments for steelhead. This was not always possible due to the variable schedule of pile-driving operations.

2.3.12.6 Sizes

There was no attempt to segregate the fish by size groups in the cage. The amount of handling required to have equal numbers of fish in three equal-sized groups would have increased the rate of mortality. The lengths of all fish were taken during the necropsy phase of the study and compared to the lengths of the fish that died after treatment. For purposes of statistical analysis, the lengths of all fish were ranked by standard length and then divided into three size groups of approximately 317 fish per group for both species. These size groups were then compared to the lengths of the mortalities for each species using the Student's t-test.

2.3.12.7 The Duration * SPL Analysis

An additional statistical test was conducted to evaluate the combined effect of the duration of exposure and SPL. This entailed creating a new metric D*dB or the duration multiplied by the SPL. For example, 20 minutes times 208 dB = 416 dBMin. The dBMin number was compared to the rate of mortality using the Student's t-test.

2.3.13 Compliance Tests

The Work Plan list three caged fish compliance tests based on distance and SPL. The tests for compliance were not articulated as an hypothesis, but as a simple confirmation or rejection of test criterion. The test criterion is barotrauma injuries or mortalities. The methodology employed was a search of the database, looking for data collected which contradicted the test.

2.3.13.1 No Near-term Mortalities at Distances Greater Than 69 Meters (226 feet)

The compliance test results were based on a search of all monitoring data for treatment groups exposed to pile-driving in the near-term mortality zone to determine if there were any barotrauma mortalities within one hour.

2.3.13.2 No Near-term Mortalities at SPL Less Than 204 dB

The compliance test results were based on a search of all monitoring data for treatment groups exposed to pile-driving peak SPLs less than 204 dB that died within one hour of exposure from barotrauma injuries. Barotrauma mortalities were defined as those fish mortalities exhibiting the distinctive external, internal and behavioral indications of barotrauma injury or Code 3 or 4 for multiple organs as described in Section 2.3.10.

2.3.13.3 No Delayed Mortalities at Distances Greater than 440 Meters (1,444 Feet)

The compliance test results were based on a search of all monitoring data for barotrauma mortalities of treatment groups exposed to pile-driving at distances greater than 440 meters (1,444 feet). Barotrauma mortalities were defined as those fish mortalities exhibiting the distinctive external, internal and behavioral indications of barotrauma injury or Code 3 or 4 for multiple organs as described in Section 2.3.10.

2.3.13.4 No Delayed Mortalities at SPLs Less Than 180 dB

The compliance test results were based on a search of all monitoring data for treatment groups exposed to pile-driving peak SPLs less than 180 dB that died within 48 hours of exposure from barotrauma injuries. Barotrauma mortalities are defined as those fish exhibiting the distinctive external, internal and behavioral indications of barotrauma injury or Code 3 or 4 for multiple organs.

2.4 BUBBLE CURTAIN ON/OFF STUDIES

2.4.1 NOVEMBER 21, 2003

Construction delays resulted in the first day of pile-driving with use of the bubble curtain starting in November 2003 instead of the summer months of 2003. The November 21, 2003 pile-driving date was the only opportunity to conduct the bubble curtain on/off study during the period allowed by CDFG and NMFS (June 1 - November 30). This monitoring trip was marked as a learning experience since the fish handling team and vessel captain had not previously worked together during pile-driving operations.

Pile-driving with the large hammer did not produce the anticipated peak SPLs. There were also problems in positioning the research vessel closer to the pile-driving than 25 meters (82 feet) without risk to the vessel. The task of anchoring to conduct the first part of the study and then pulling up the anchor and moving the vessel during the bubble curtain off stage was very problematic given the inexperience of the team. In addition, there were considerable concerns about the condition of the fish due to induced smoltification and disease. There was a risk that trying to use only one species would not produce any meaningful results. For these reasons, monitoring was modified to try to stay at the same position with the bubble curtain on and off and use two species at 4 meters (13 feet) in depth for 5 minutes each. All procedures were the same as noted above.

2.4.2 JANUARY 24, 2004

By special permission from CDFG and the NMFS, a second bubble curtain on/off study was conducted on January 24th, 2004 on Pier E3E. This was the pier nearest to the deep water shipping channel. The stipulated duration of bubble curtain off was to be for only ten pile strikes. Due to potential construction delay costs, there was not enough time to move the research vessel between bubble curtain on and bubble curtain off events. In order to keep the vessel stabilized at 23-24 meters (75-79 feet) from the pile being driven, the vessel was tied up with one anchor, a line was tied onto a temporary pile, and another line was tied to a cleat on the support barge. Because the first few strikes of the hammer were not full strength, the total full force driving time was approximately a minute without the bubble curtain on. Two cages were deployed at the same time, one above the other, with the hydrophone in the top cage. The bottom cage was at 10 meters (33 feet) and the upper cage was at 8 meters (26 feet). Otherwise, all the other procedures were the same as noted above.

3.0 RESULTS

3.1 HYDROACOUSTIC MONITORING RESULTS

3.1.1 Pile-driving in Dewatered Cofferdams

The dewatered cofferdam provided the greatest reduction in peak SPLs created by impact pile-driving into the water column. This is due to the air within the dewatered cofferdam mostly decoupling the pressure wave from the surrounding water column. This results in substantially lower underwater sound pressures transmitted outside of the cofferdam. However, flanking of sound through the ground substrate was detected in the region that was generally south of the pile. Sound pressures in this region reached about 200 dB peak (190 to 192 dB $RMS_{impulse}$) at about 100 to 150 meters (328 to 492 feet) from the pile. Sound pressures in other directions were typically 180 dB peak (170 dB RMS) or less.

3.1.1.1 Pier E16E Characterization

The first set of underwater sound measurements was made during the driving of the top sections of piles at Pier E16E. Only the smaller Menck 500 kJ hammer was used for this pier. Results of these limited measurements are presented in Table 3.1-1. Measurements 65 meters (213 feet) from the pile indicate peak pressures less than 185 dB and $RMS_{impulse}$ levels less than 175 dB. Surprisingly high sound pressures were measured at 95 meters (312 feet) west of the pile. SPLs measured at 95 meters (312 feet) were 196 dB peak (184 dB $RMS_{impulse}$), about 20 dB higher than sound pressures measured at other closer positions. The lowest sound pressures were measured 25 meters (82 feet) from the pile, although they were similar to pressures measured at 50 and 65 meters (164 and 213 feet) from the pile. The higher sound pressures measured at 95 meters (312 feet) are hypothesized to be the result of relatively efficient transmission of vibration from the pile into the bottom substrates and then into the water column. This transmission path seemed to be much less efficient at 25, 50, and 65 meters (82, 164, and 213 feet) where the sound did not appear to be concentrated in identifiable pulses.

Table 3.1-1. Summary of measurements - Pier E16E, 02/27/2003.

Position	Water Depth	Center Pile Hammer: Menck 500	
		$RMS_{impulse}$	Peak
25m West	6m	**164**	<180
50m West	4.5m	**167**	177
65m South*	3m	**165-175**	175-185
95m West	4m	**184**	196

* Continuous measurement

3.1.1.2 Pier E10E Characterization

Underwater sound measurements were made around Pier E10E, where piles were driven in a cofferdam similar to Pier E16E. Measurements were made for the top sections of the Group A piles. Each pile was driven twice during the measurements: first, with the smaller Menck 500 kJ hammer, and then with the larger Menck1,700 kJ hammer. Numerous measurements were made at distances of approximately 50 to 500 meters (164 to 1,640 feet) in several different directions from the piles. One measurement was made 1,000 meters (3,280 feet) northwest from the pier. Underwater sound pressures varied considerably with distance and direction. Measurements to the west, north and east indicated relatively low underwater sound pressures: typically 182 to 187 dB peak and 173 to 177 dB $RMS_{impulse}$ at distances of about 50 to 100 meters (164 to 328 feet). These pressures were lower as distances increased beyond 100 meters (328 feet) in these directions. Sound pressures measured to the south-southeast indicated relatively high levels. For instance, measurements made at approximately 120 meters (361 feet) southeast of the piles typically resulted in peak pressure levels of 196 to 202 dB ($RMS_{impulse}$ levels of 185 to 192 dB). At 500 meters (1,640 feet), peak pressures were 186 dB in the southeast direction, and less than 170 dB in westerly and northerly directions. The $RMS_{impulse}$ levels were about 8 to 12 dB lower in all directions. At 1,000 meters (3,280 feet) northwest, peak pressures and $RMS_{impulse}$ levels were 160 dB or lower. Measurement results for Pier E10E are shown in Table 3.1-2. Waveform analysis indicated that similar to results for Pier E16E, most of the sound energy was contained at low frequencies.

Table 3.1-2. Summary of measurements - Pier E10E, 08/20/2003.

Position	**Water Depth**	**North Pile Hammer: Menck1700**		**South Pile Hammer: Menck1700**		**Center Pile Hammer: Menck1700**	
		$RMS_{impulse}$	**Peak**	**$RMS_{impulse}$**	**Peak**	**$RMS_{impulse}$**	**Peak**
50m Barge*	4-5m	170-173	182-187	164-169	174-178	168-171	176-180
90m Northwest*	4-5m	173-176	182-186	173-177	184-186	173-175	181-183
120m Southeast*	4-5m	185-188	196-200	188-192	200-202	188-190	200-202
110m East	4-5m			172	181		
500m Southeast	4m					176	186
500m West	7m	161	169				
500m Northwest	5m			161	168		
1000m Northwes	7m			<155	159		

*Continuous measurement

The characterization of the underwater sound pressure field around the piles at Pier E10E was supported by limited measurements made for pile-driving at Pier E9E when the Menck 1,700 kJ hammer was used. Pier E9E is about 150 meters (492 feet) west of Pier E10E and the piles there were also driven in a dewatered cofferdam. At about 200 meters (656 feet) southeast, sound pressures were 194 dB peak (185 dB $RMS_{impulse}$). Peak pressures and $RMS_{impulse}$ SPLs were much lower in the other directions (i.e., west and north) for all distances.

Additional measurements for a dewatered cofferdam were conducted for Pier E7E when piles were driven with the Menck 1,700 kJ hammer. Pier E7E is the most westerly pier and in the deepest water where a dewatered cofferdam was used. Interestingly, Pier E7E is located near Pile 3 of the PIDP. These relatively high sound pressures seemed to be concentrated southeast of the pile, at a distance of 175 to 300 meters (574 to 984 feet). Measurements indicated that reduced levels were present in the northerly direction as well as the southerly direction. However, higher levels were seen in a highly focused area to the southeast. The highest measured sound pressures in that direction were about 195 dB peak (184 dB RMS_{impuls}e) at 220 meters (722 feet). Sound pressures were typically lower to the southwest.

3.1.2 Pile-driving With Use of a Bubble Curtain

Pile-driving began at Pier E6E and continued to Pier E3E. Extensive measurements were made for Piers E6E and E4E, with supplemental measurements at Pier E5E and E3E. An air bubble curtain system was used to reduce sound pressures. At 50 meters (164 feet), sound pressures typically ranged from 195 to 205 dB peak (185 to 195 dB $RMS_{impulse}$). At 100 meters (328 feet), sound pressures typically ranged from 190 to 200 dB peak (180 to 185 dB $RMS_{impulse}$). At 500 meters (1,640 feet), sound pressures were generally below 180 dB peak (170 dB $RMS_{impulse}$), but did reach 189 dB peak (177 dB $RMS_{impulse}$) downstream of Pier E4E at 485 meters (1,591 feet) south. Measurements at 1,000 meters (3,280 feet) ranged from less than 165 dB peak (<150 dB $RMS_{impulse}$) to 176 dB peak (168 dB $RMS_{impulse}$). It appeared that the larger hammer may have resulted in slightly higher sound pressures (by 0 to 2 dB), but there was considerable variation from pile to pile and throughout the drive resulting in difficulty in identifying any definite relationship. At this time, there does not appear to be any simple relationship between hammer energy and sound pressure. There was also considerable directional variation in measured sound pressures.

3.1.2.1 Hydroacoustic Results – Pier E6E Bottoms (11/12/2003)

Measurements were made during the first day of pile-driving with use of the bubble curtain on the bottom sections with the Menck 500 kJ hammer (November 12, 2003). These measurements were made to establish the initial marine mammal safety zones. Peak sound pressures ranged from 193 to 200 dB peak (182-189 dB $RMS_{impulse}$) within 100 meters (328 feet) of the pile. Sound pressures were higher to the south, which indicated that bubble curtain performance was affected by the ebb tide current. At about 100 meters (328 feet) from the pile, peak pressures ranged from 184 dB (174 dB $RMS_{impulse}$) north to 194 dB (184 dB $RMS_{impulse}$) west, and 200 dB (189 dB $RMS_{impulse}$) to the south. Measurements were not taken in the easterly direction. Measurements made continuously within 100 meters (328 feet) indicated that sound pressures slowly increased by 10 dB during the drive of the bottom section of the pile. The highest levels tended to flatten out over time during the last 5 minutes of the approximately 55-minute drive. Field results are summarized in Table 3.1-3.

Table 3.1-3. Summary of measurements- Pier E6E Group A Bottoms, 11/12/2003.

Position	Water Depth	Center Pile Hammer: Menck 500	
		$RMS_{impulse}$	Peak
80m Southwest*	9m	182-189	193-200
60m West*	8m	183-187	196-200
100m North	8.5m	174	184
95m South	9m	182	194
90m West	9m	184	194
500m South	7m	167	177

*Continuous measurement.

3.1.2.2 Hydroacoustic Results – Pier E6E Tops (11/21/2003 and 12/10/2003)

Measurements were made during the driving of three different piles using the Menck 1,700 kJ hammer. An air bubble curtain on/off test was conducted. The results of the on/off test are discussed in Section 3.1.3 of this report. Measurement results are summarized in Table 3.1-4. At about 100 meters (328 feet), SPLs ranged from 188 dB peak (177 dB $RMS_{impulse}$) in the north to about 195 dB peak (184 dB $RMS_{impulse}$) in the west and southerly directions. The highest levels, 206 dB peak (195 dB $RMS_{impulse}$), were measured at 55 meters (180 feet) north during the driving of the last pile. The flood current seemed to have an effect on the bubble curtain performance causing higher SPLs to the north, especially at 50 meters (164 feet).

Hydroacoustic characterization at this pier occurred again on December 10, 2003 when the last sets of top piles (Group B) were driven with the Menck 1,700 kJ hammer. These results are presented in Table 3.1-5. Again, there was a range in SPLs at about 100 meters (328 feet) from 191 to 196 dB peak (181 to 184 dB $RMS_{impulse}$) depending on direction and the pile being driven. At 500 meters (1,640 feet) and beyond, sound pressures were less than 175 dB peak (165 dB $RMS_{impulse}$).

Table 3.1-4. Summary of measurements- Pier E6E Group A Tops, 11/21/2003.

Position	Water Depth	Center Pile Hammer: Menck 1700		North Pile Hammer: Menck 1700		South Pile Hammer: Menck 1700	
		RMS$_{impulse}$	**Peak**	**RMS$_{impulse}$**	**Peak**	**RMS$_{impulse}$**	**Peak**
40m West*	8m			187	200	191	203
50m North*	8m	193	203	193	202	195	206
100m West*	8m	183	196	182	194	184	194
100m South*	8m	184	193				
120m North*	9m			177	188		
485m South	6m	170	181	172	182	171	181
420m West	10m					172	182

*Continuous measurement.

Table 3.1-5. Summary of measurements - Pier E6E Group B Tops, 12/10/2003.

Position	Water Depth	North Pile Hammer: Menck 1700		Center Pile Hammer: Menck 1700		South Pile Hammer: Menck 1700	
		RMS$_{impulse}$	**Peak**	**RMS$_{impulse}$**	**Peak**	**RMS$_{impulse}$**	**Peak**
50m South*	8m	**188**	201	**190**	204	**191**	205
50m North*	8m	**190**	202	**189**	201	**187**	199
55m East*	8m	**187**	198	**185**	195	**183**	195
100m South	9m	**184**	195				
100m North	7m			**181**	191		
100m East*	7m	**183**	196	**180**	192		
120m Southeast	8m					**182**	194
540m North	6m			**164**	174		
525m South	4m					**160**	170
1000m Southeast*	5m	**162**	172	**162**	174	**162**	172

*Continuous measurements

3.1.2.3 Hydroacoustic Results – Pier E5E Tops (12/22/2003)

Measurements were made at Pier E5E on December 22, 2003 close to the pile template to characterize the air bubble curtain performance in different directions. With an ebb current (flowing south to north), underwater sound pressures were found to vary considerably from north to south. Sound pressures were much lower on the north side than the south. On the downstream side (north) and sides adjacent to the pile template, sound pressures were typically 205 dB peak (193 dB $RMS_{impulse}$) or less at about 7 to 10 meters (23 to 33 feet) from the pile. On the upstream (south) side at about 7 meters (23 feet) from the pile, the sound pressures were about 10 dB higher with peak sound pressures of about 215 dB (199 dB $RMS_{impulse}$). At a 45 to 55-meter (148 to 180-foot) position to the north, sound pressures varied by pile and current condition. A continuous measurement at 45 meters (148 feet) north of the pile indicated the effect of the current on sound pressures. During the driving of the north pile with a slack to slightly flood current, sound pressures were about 198 dB peak (186 dB $RMS_{impulse}$) with the Menck 500 kJ hammer. Driving then stopped and resumed on the same pile later with the Menck 1,700 kJ hammer when an ebb current developed, putting the measurement position on the downstream side of the pile.

Sound pressures during this portion of the drive varied considerably, about 187 to 194 dB peak (175 to 184 dB $RMS_{impulse}$). Interestingly, the $RMS_{impulse}$ levels were not affected as much. There was considerable range in sound pressures from impulse to impulse when the bubble curtain was operating in relatively strong current conditions. These measurements indicated about a 10 dB change in sound pressures that was probably attributable to the effect of current on bubble curtain performance. Results from these measurements are summarized in Table 3.1-6.

Table 3.1-6. Summary of measurements - Pier E5E Group B Tops taken from Barge, 12/22/2003.

Position	Water Depth	Center Pile Hammer: Menck 1700		North Pile Hammer: Menck 1700		South Pile Hammer: Menck 1700	
		$RMS_{impulse}$	Peak	$RMS_{impulse}$	Peak	$RMS_{impulse}$	Peak
50m East*	11m	186	198				
45-55m East*	10m	179	190	179	189	182	193
7m West*	10m	193	205				
7m North*	10m			186	200		
7m South*	10m					199	215

Note: Measurement at 50 meters from center pile made continuously from 9:50 until 16:20. Measurement of the center pile was made at 50 meters when the Menck 500 kJ hammer was used under flood/slack current conditions and then again for the Menck 1,700 kJ hammer under ebb current conditions. Ebb current conditions persisted during the driving of the north and south piles.

*Continuous measurements

Additional measurements made at Pier E3E on January 24, 2004 supported the finding that under relatively strong current conditions, there was a 10 dB difference in peak pressures between up current and down current measurements. Under a flood current (flowing from north to south), sound pressures 25 meters (82 feet) north of the pile were 205 dB peak (189 dB $RMS_{impulse}$) as compared with 193 dB peak (182 dB $RMS_{impulse}$) at the 25-meter (82-foot) southeast position. Again, the levels measured downstream that benefit the most from the air bubble curtain varied considerably from impulse to impulse. These results are summarized in Table 3.1-7.

Table 3.1-7. Summary of measurements - Pier E3E Group A Tops taken from Barge, 01/24/2004.

Position	Water Depth	Center Pile Hammer: Menck 500		Center Pile Hammer: Menck 1700		North Pile Hammer: Menck 1700	
		$RMS_{impulse}$	Peak	$RMS_{impulse}$	Peak	$RMS_{impulse}$	Peak
25m North	11m	187	198	188-190	200-201	189	205
50m North	11m	183	194	186-187	197-199	187	201
25m South	11m	180	190	181-182	191-193	179	190

Note: Strong flood current, especially during the driving of the center pile with the Menck1700 hammer and driving of the north pile.

3.1.2.4 Hydroacoustic Results – Pier E4E Tops (2/05/2004)

The last set of hydroacoustic measurements for the eastbound structure were made at Pier E4E on February 5, 2004. These measurements focused on positions of 100 to 1,000 meters (328 to 3,280 feet) from the piles, although one continuous measurement was made at 50 meters (164 feet) east. Again, sound pressures on the upstream side of the north-south moving tidal current were higher than levels measured east, west or downstream. At about 100 meters (328 feet) from the piles, sound pressures were about 192 to 195 dB peak (177 to 183 dB $RMS_{impulse}$) in the north (downstream), east, and west positions. To the south (upstream), sound pressures were 199 dB peak (186 dB $RMS_{impulse}$). At 500 meters (1,640 feet) from the piles, SPLs were 185 dB peak (172 dB $RMS_{impulse}$) or less in the north, east, and west directions. At almost 500 meters (1,640 feet) south, sound pressures were 190 dB peak (179 dB $RMS_{impulse}$). Sound pressures were below 180 dB peak (170 dB $RMS_{impulse}$) at 1,000 meters (3,280 feet) in all directions. The highest levels measured at 1,000 meters (3,280 feet) were to the north where sound pressures were 176 dB peak (168 dB $RMS_{impulse}$). At 2,000 meters (6,562 feet) northwest they were 170 dB peak and 162 dB $RMS_{impulse}$. Overall, sound pressures were lowest in the easterly direction, which generally had shallower water. Results are summarized in Table 3.1-8.

Table 3.1-8. Summary of measurements - Pier E4E Group B Tops, 02/05/2004.

Position	Water Depth	Center Pile Hammer: Menck 1700		North Pile Hammer: Menck 1700	
		$RMS_{impulse}$	Peak	$RMS_{impulse}$	Peak
50m East*	11-13m	186	198	185	197
130m North	12m	183	192		
500-600m North	12m	175	185		
1000m North	13m	168	176		
1500m North	12m	168	177		
2000m Northwest	10m			162	170
130m West	11m	179	193		
530m West	--	168	181		
Near YBI Haul Out	+15m	<150	<165		
100m South	12m			186	199
460m South	13m			179	190
1000m South	7m			~160	<180
100m East	12m			185	196
500m East	6m			166	177
1000m East	3m			<155	<165

3.1.3 Bubble Curtain On/Off Monitoring

Bubble curtain on/off tests were conducted during the driving of two piles at Pier E6E on November 21, 2003 and during ten strikes at Pier E3E on January 24, 2004. The underwater sound measurements obtained from these tests indicated that sound pressures were reduced by about 5 to 20 dB at positions of about 100 meters (328 feet) or closer. The reduction was less for positions further away. Both tests were conducted under relatively strong currents, which had an effect on the attenuation performance. The bubble curtain performance can be reduced somewhat under relatively strong currents. On the upstream side, the current tends to wash the bubbles past that side of the pile, resulting in higher sound pressures on that side of the pile. The pier cap appears to provide some attenuation of the impulse, since unattenuated sound pressures measured at 100 meters (328 feet) for Pier E6E were lower than unattenuated sound pressures measured during the PIDP, and at Pier E3E. Pier E6E is fairly close to Pile 3 of the PIDP.

Each pier includes two rows of piles (i.e., Group A and B piles). Each row consists of three piles oriented in a generally north to south direction; a north, center and south pile. The air bubble curtain system was turned on and off during the driving of the north and south piles at Pier E6E. A fairly strong north to south flood current was present during these tests. Measurements were made at several positions during these tests. Pier E6E was not the ideal pier to conduct the on/off tests since it is in the shallowest water where piles are driven in without a cofferdam and the pier box extends about 2/3rds of the way below the water surface, leaving only 1/3rd of the pile or about 3 to 5 meters (10 to 16 feet) exposed to the water. Measurements made at positions 45 meters (148 feet) west, 50 meters (164 feet) north, 100 meters (328 feet) west, 100 meters (328 feet) south and 100 meters (328 feet) north found that sound pressures were 8 to 10 dB higher when the bubble curtain was turned off during the first test. A 1 to 2 dB reduction was measured 500 meters (1,640 feet) south. During the second test, a 2 to 9 dB reduction was measured. The 9 dB difference measured at 100 meters (328 feet) south was consistent with the first test. The 2 dB difference measured at 50 meters (164 feet) north was not consistent with the first test and indicated poorer bubble curtain performance in the upstream side; however, the overall unattenuated level was 3 dB lower than the first test. A 1-2 dB difference was measured at about 500 meters (1,640 feet) south and 400 meters (1,312 feet) west. Results of these tests are shown in Table 3.1-9.

Table 3.1-9. Summary of measurements - Pier E6E Bubble Curtain ON/OFF Test, 11/21/2003.

Position	Water Depth	ON		OFF	
		$RMS_{impulse}$	Peak	$RMS_{impulse}$	Peak
North Pile					
45m West	6m	187	200	196	210
50m North*	6m	191	203	196	210
100m West	6m	182	194	188	201
120m North	6m	177	188	184	196
485m South	8m	172	182	174	182
South Pile					
45m West	6m	191	203	196	210
50m North	6m	195	206	197	208
100m West	6m	184	194	190	203
420m West	7m	171	181	173	183
485m South	8m	172	182	173	184

* Measured by Caltrans (G. Fleming)

A brief test with the bubble curtain off for 10 hammer strikes was conducted at Pier E3E. Measurements were made at 25 meters (82 feet) north, south, and west, as well as an additional position 50 meters (164 feet) north. No distant measurements were made during this test. A strong flood current (flowing from north to south) was present during the test. At the 25-meter (82-foot) positions, differences of 11 to 18 dB peak (9-15 dB $RMS_{impulse}$) were measured. At the downstream position (south) the difference was 18 dB (15 dB $RMS_{impulse}$). At the position normal to the current, the reduction was similar. The upstream positions had differences of only 10 dB at 25 meters (82 feet) and 13 dB at 50 meters (164 feet). There was a typical variation of 5 to 7 dB from impulse to impulse (or strike to strike) at the south position when the bubble curtain was on. The variation at the north and west positions was only about 1 to 2 dB. Results are shown in Table 3.1-10.

Table 3.1-10. Summary of measurements - Pier E3E Bubble Curtain On/Off Test, 1/24/2004.

Position	Water Depth	ON		OFF	
		$RMS_{impulse}$	Peak	$RMS_{impulse}$	Peak
Center Pile					
50m North	11m	187	199	197	212
25m North	11m	190	201	199	212
25m South	11m	182	193	198	211
25m West*	11m	180	191	195	209

* Measured during fish in cage test (M07)

3.1.4 Hydroacoustic Monitoring Results for Caged Fish Studies

Hydroacoustic data were collected for all caged fish monitoring and figures and tables of data are voluminous. Figures 3-1 and 3-2 present data specifically related to a typical bubble curtain on and a bubble curtain off pulse during caged fish monitoring. This particular example was for the bubble curtain test during driving at Pier E6E, where a 10 dB reduction in peak pressures was measured when the bubble curtain was on compared to when the bubble curtain was off. A report illustrating the effects of the bubble curtain on waveform and barotrauma will follow in late 2004 if an additional bubble curtain on/off test is approved by CDFG and NMFS.

Note the difference in absolute magnitude between the upper left panels of Figures 3-1 and 3-2. The absolute peak or highest or lowest spike is lower in the bubble curtain on scenario (Figure 3-1). Comparing the two frequency spectrum graphs shows a loss of the higher frequencies, especially above 2,000 Hz. Sound pressures were reduced with the bubble curtain on by about 10 dB at the lower frequencies where most sound energy was contained. In each case, most sound energy was contained over the frequencies below 800 Hz. Comparison of the two lower left panels shows a gradual increase in accumulated energy for the attenuated pulse and an abrupt accumulation of energy when the bubble curtain is off as indicated by the gradual slope. Similar graphs for each caged fish exposure are available for review at www.biomitigation.org or by contacting Caltrans environmental planner Ahmad Hashemi at (510) 286-5961 or ahmad_hashemi@dot.ca.gov.

Signal Analysis - Fish in Cage Test # M01T01 - 11/21/03

Figure a. Waveform

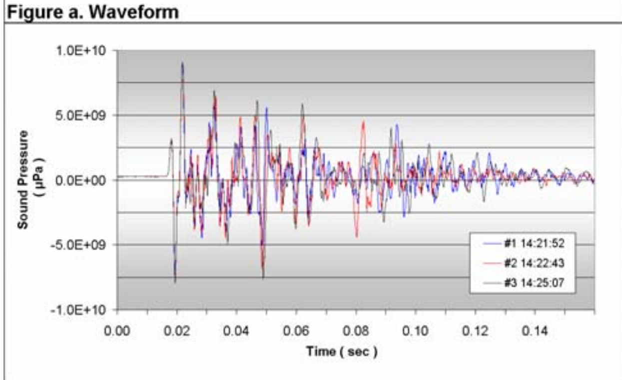


Figure b. Narrow Band Frequency Spectra

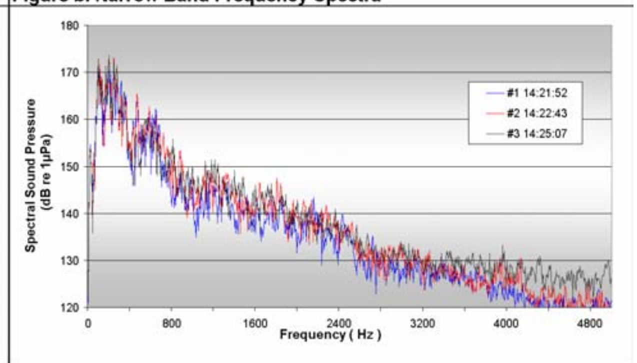


Figure c. Accumulation of Sound Energy

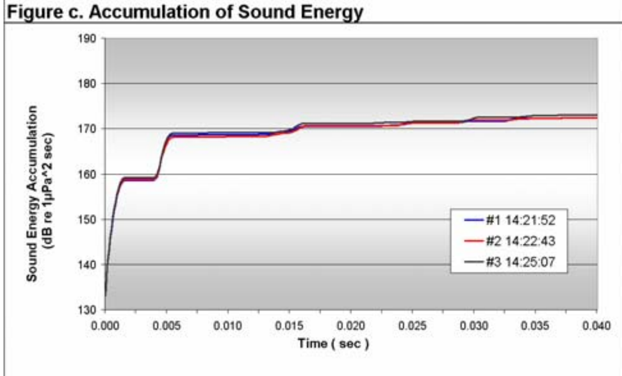


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

	Peak	$RMS_{90\%}$*	SEL
#1 14:21:52	199	184	174
#2 14:22:43	198	185	174
#3 14:25:07	199	185	175

Typical Sound Pressure / Energy Levels Throughout Test

	Peak	RMS_{35ms}**
Reported Average/Typical	199	187
Reported Maximum	206	192

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure 3-1. Graphic illustration of characteristics of an attenuated (bubble curtain on) pile-driving pulse. The upper left panel shows the spikes of over-pressure and under-pressure. The upper right panel shows the frequency of the pulse. The lower left panel shows the rate of accumulation of all the energy in the pulse.

Signal Analysis - Fish in Cage Test # M01T02 - Bubble Curtain Off - 11/21/03

Figure a. Waveform

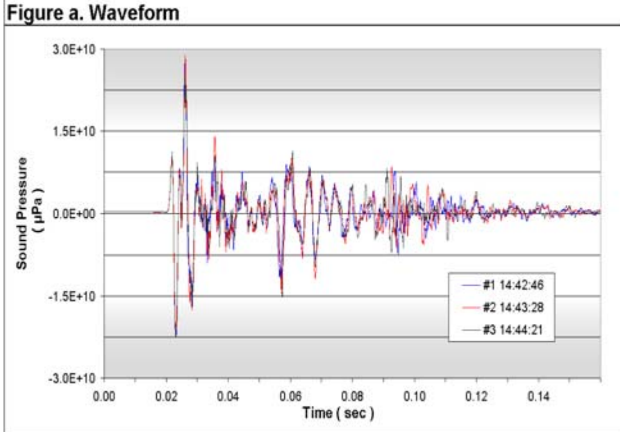


Figure b. Narrow Band Frequency Spectra

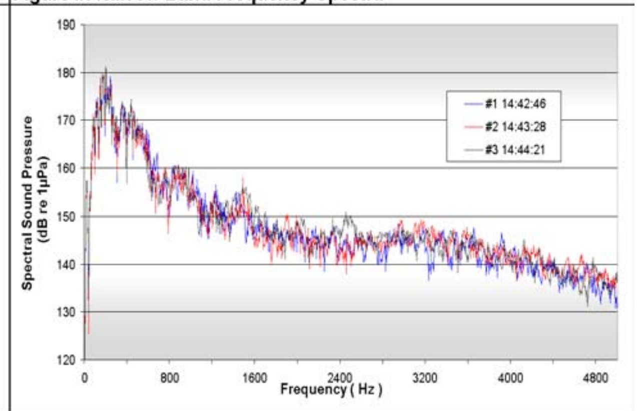


Figure c. Accumulation of Sound Energy

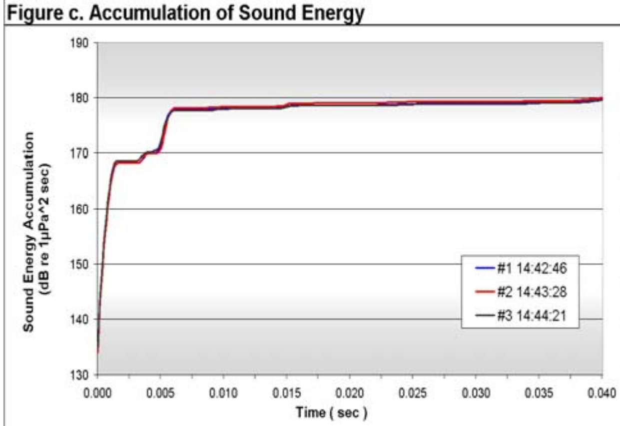


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

	Peak	RMS90%*	SEL
#1 14:42:46	209	192	181
#2 14:43:28	209	192	181
#3 14:44:21	208	192	181

Typical Sound Pressure / Energy Levels Throughout Test

	Peak	RMS35ms**
Reported Average/Typical	208	195
Reported Maximum	210	196

*Impulse averaged over 90% of accumulated energy (5% to 95%)

**Standard 35 msec "impulse" RMS time window

Figure 3-2. Graphic illustration of characteristics of an unattenuated (bubble curtain off) pile-driving pulse. The upper left panel shows the spikes of over-pressure and under-pressure. The upper right panel shows a narrow band breakdown of the frequency of the pulse. The lower left panel shows the rate of accumulation of all the energy in the pulse.

3.1.5 Hydroacoustic Compliance Tests

A study objective was to determine compliance with the requirement to meet peak sound pressures of 204 dB at less than or equal to 69 meters (226 feet) from pile-driving activities, 180 dB at less than or equal to 440 meters (1,444 feet) from pile-driving activities, and 150 dB at less than or equal to 4,400 meters (14,436 feet) from pile-driving activities.

Based on study results, it was determined that there was no simple, concentric relationship between distance from pile-driving activities and the measured peak sound pressure. Figure 3-3 shows measurements plotted by distance from the pile for pile-driving with the bubble curtain on.

Based on the best-fit interpolation of the data, compliance levels were met for 204 dB at 69 meters (226 feet). Compliance levels at 440 meters (1,444 feet) for 180 dB were generally met, although the extrapolated level was 181 dB, or one dB higher than predicted. It appears that flanking of sound through the ground resulted in a much lower drop-off rate at further distances than predicted. As a result, it appears that the compliance level at 4,400 meters (14,436 feet) for 150 dB was not met. However, hydroacoustic data was not collected to verify this; the most distant measurements were 170 dB at 2,200 meters (7,218 feet) northwest of pile-driving activities.

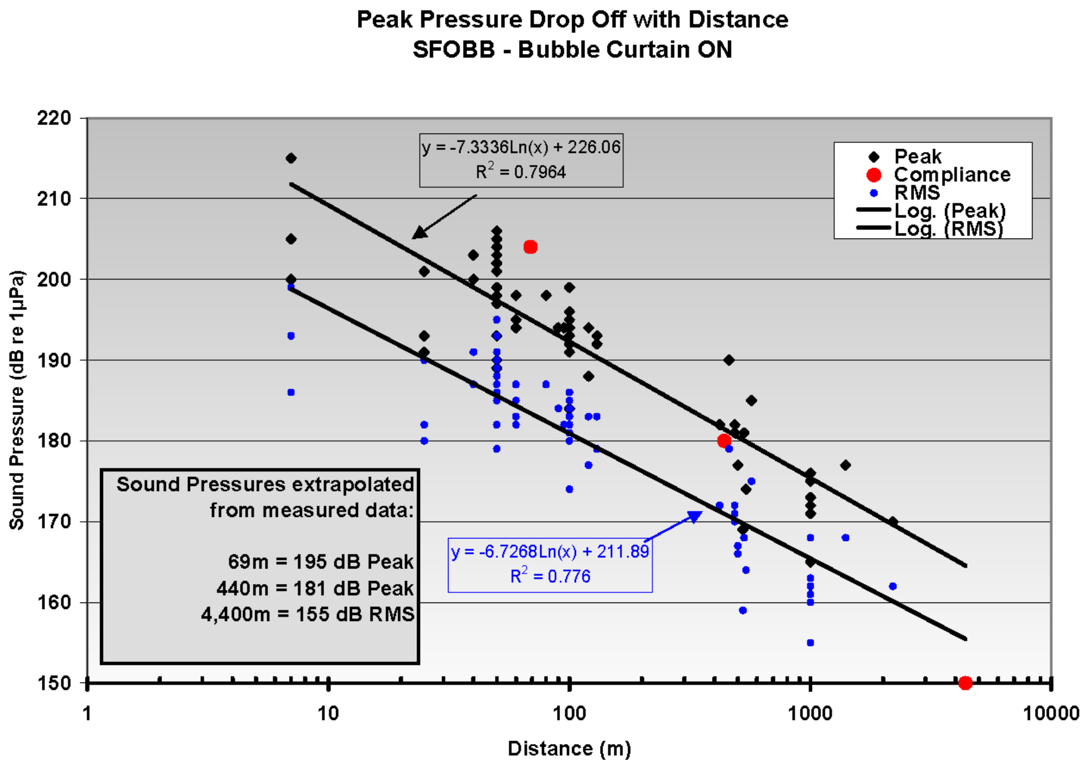


Figure 3-3. Calculated rate of attenuation over distance for purpose of estimating compliance with monitoring criteria.

3.2 CAGED FISH MONITORING RESULTS

The data collected in the caged fish monitoring program is summarized in Appendix B. The data is assessed in a variety of ways to determine if there were relationships between the rate of mortality and duration of exposure, depth, distance, species or size. The first exercise was to assess the difference between the control treatment groups.

3.2.1 Controls

The control treatment groups data are summarized in Table 3.2-1. There were no mortalities in the holding facilities control treatment groups for either surfperch or steelhead. There were also no mortalities in the surfperch transport control treatment groups. The total mortality for the surfperch cage control treatment groups was approximately 2.6%. The steelhead transport control treatment group and cage control treatment groups were both approximately 3.8% with a slightly higher number in the cage control treatment groups.

Table 3.2-1. Summary of all treatment groups that were used as treatment controls.

Holding Facility Controls		Transport Controls		Cage Controls	
Treatment Group ID	**Mortality %**	**Transport Group ID**	**Mortality %**	**Treatment Group ID**	**Mortality %**
Surfperch					
M01T05	0	M01T04	0	M01T03	0
M05T06	0	M02T05	0	M02T06	0
M08T05	0	M02T02	0	M03T01	0
		M03T02	0	M04T06	6.67
		M04T01	0	M05T03	0
		M05T05	0	M06T03	6.90
		M06T06	0	M07T01	0
		M07T02	0	M08T03	7.14
		M08T02	0		
MEAN	0	MEAN	0	MEAN	2.59
Steelhead					
M01T06	0	M01T07	6.67	M03T12	3.30
M05T12	0	M02T12	13.33	M04T12	13.30
		M03T10	0	M05T07	0
		M04T11	3.33	M06T08	0
		M05T11	0	M07T12	6.60
		M07T10	3.33	M08T10	0
		M08T08	0		
MEAN	0	MEAN	3.81	MEAN	3.87

3.2.2 Exposure Parameters

The next series of statistical assessments involved an evaluation of the exposure parameters of duration, depth, distance, species and size.

3.2.2.1 Duration

Statistical analysis comparing mortality rates for five minutes to mortality rates for all durations greater than five minutes were conducted using the Student's t-test. The results of the correlation analysis are presented in Figure 3-4. There was no significant difference in the rate of mortality between the 5-minute exposure and the other durations of exposure. The Student's t-test results are detailed in Appendix C. The correlation analysis and Student's t-test ($p=0.05$) showed absolutely no correlation between the duration of exposure and the rate of mortality in either the near-term mortality zone or in the delayed mortality zone.

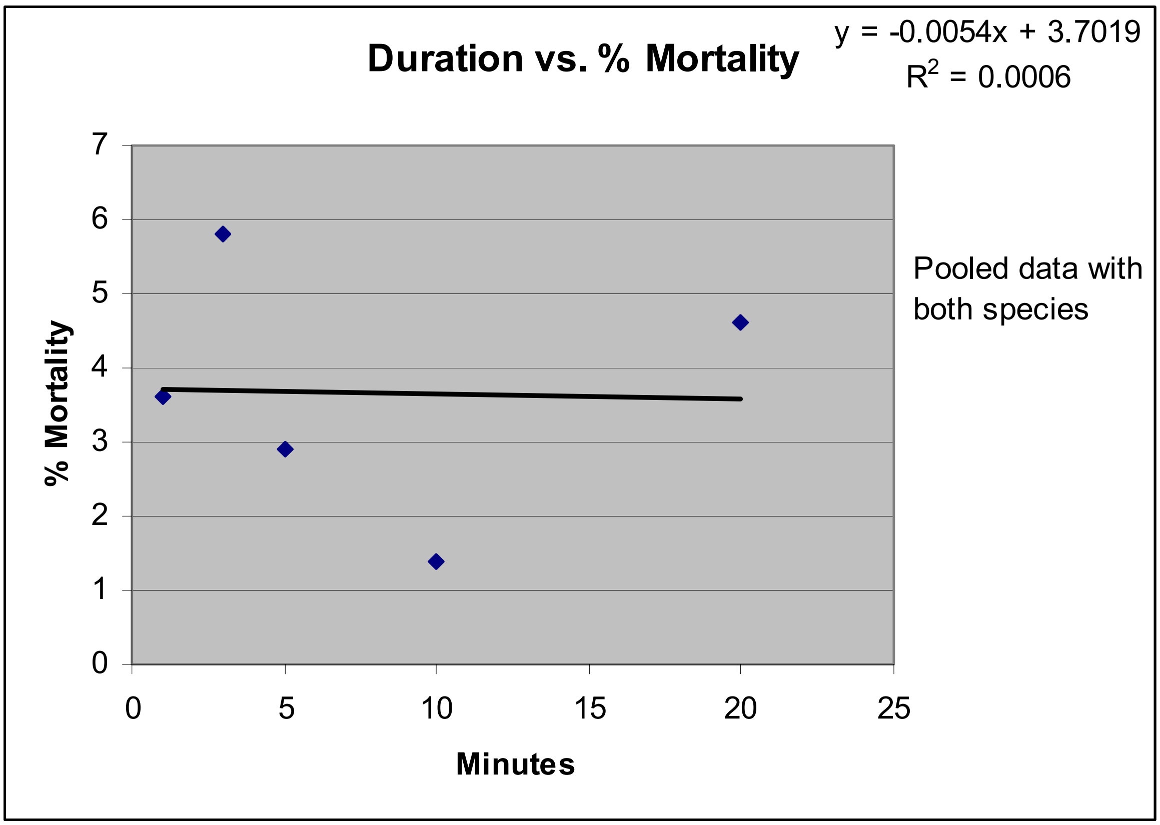


Figure 3-4. Scatter plot of pooled average durations of exposure and the mortality rate.

3.2.2.1.1 Near-Term Mortality Zone

Table 3.2-2 summarizes the mortality rates for all treatment groups that were within 69 meters (226 feet) of the pile that were exposed to pile-driving for periods from 1 minute to 20 minutes. There was no statistical difference between 5 minutes of exposure and any other duration of exposure or the cage control treatment groups (p=0.05).

Table 3.2-2. Summary of treatment groups mortality rates associated with different durations of exposure in the near-term mortality zone

	Surfperch					
	1 Min.	3 Min	5 Min	10 Min	20 Min	Cage Control
	6.52	3.33	0	0	7.69	
	0	13.79	0	3.33	0	
			0			
MEAN	3.26	8.56	0	1.67	3.85	2.59
	Steelhead					
	1 Min.	3 Min	5 Min	10 Min	20 Min	Cage Control
	6.25	0	0	0	3.7	
		0	3.30	3.23	8.3	
			3.13	0		
MEAN	6.25	0	2.14	1.08	6.0	3.87

3.2.2.1.2 Delayed Mortality Zone

Table 3.2-3 summarizes the durations of exposure for both species that were beyond 69 meters (226 feet) from the pile for durations of exposure from 5 to 20 minutes. Due to the truncated monitoring schedule there was no data collected for perch for 10 minutes and steelhead for 20 minutes in the delayed mortality zones. There was no statistical difference in the mortality rate for the different durations of exposure and the control treatment groups (p=0.05.)

3.2.2.2 Depth

Over the course of the eight monitoring trips, cages were placed at depths ranging from 2 to 10 meters (7 to 33 feet) deep. The data are summarized graphically below in Figure 3-5. A visual inspection of the data indicates a possible relationship between increasing mortality and depth, but a correlation analysis and Student's t-test determined that the relationship for the pooled data is not statistically significant (p=0.05). Statistical analysis using the Student's t-test showed a statistically significant difference between the controls and perch at a depth less than 4 meters (13 feet), but not for steelhead. However, the necropsies indicated that the perch at a depth less than 4 meters (13 feet) did not experience mortality due to barotraumas. See Appendix C.

Table 3.2-3. Summary of treatment groups mortality rates associated with different durations of exposure in the delayed mortality zone.

	Surfperch				
	1 Min.	5 Min	10 Min	20 Min	Cage Control
	3.45	7.40		0	
		6.45		3.50	
		7.41			
MEAN	3.45	7.09		1.75	2.59
	Steelhead				
	1 Min.	5 Min	10 Min	20 Min	Cage Control
	0	0	0		
		0	3.33		
		3.33			
MEAN	0	1.11	1.67		3.87

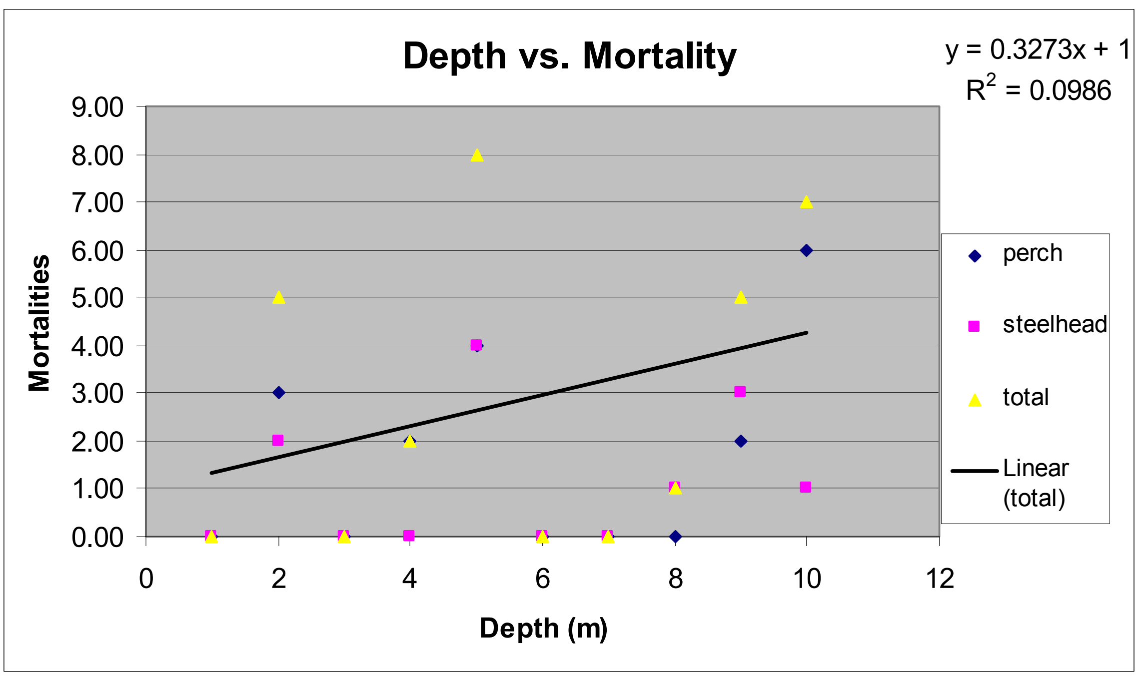


Figure 3-5. Scatter plot of depth and rate of mortality.

3.2.2.3 Distance

A change in distance is a surrogate for a change in SPLs. The data does not include enough barotrauma injuries to reliably model a mortality/distance relationship with the bubble curtain on (see Figure 3-6). There were no near-term mortalities at a distance of greater than 69 meters (226 feet). There was no statistically significant difference in the mortality rates between the cage controls and treatment groups within the near-term mortality zone or the delayed mortality zone for either species. See Appendix C.

3.2.2.4 Comparison Between Species

The mortality rates comparison between species using the Student's t-test showed no statistical difference in the rate of mortality ($p=0.05$). See Table 3.2-4 for a summary of mortalities by species for 1-hour, 24-hour and 48-hour time frames.

3.2.2.5 Comparison Between Sizes

The length frequency data by 5-millimeter size groups for surfperch and steelhead are presented in Figures 3-7 through 3-10 below. The one-tailed Student's t-test comparison for steelhead and surfperch showed no statistically significant size effect ($p=0.05$).

3.2.3 Caged Fish Compliance Tests

3.2.3.1 Compliance Test: Were There Any Near-term Mortalities at Distances Greater than 69 Meters (226 Feet)?

Test Results: There were no near-term barotrauma mortalities in any of the treatment groups exposed to pile-driving beyond 69 meters (226 feet) of the pile.

3.2.3.2 Compliance Test: Were There any Near-term Mortalities at SPLs less than 204 dB?

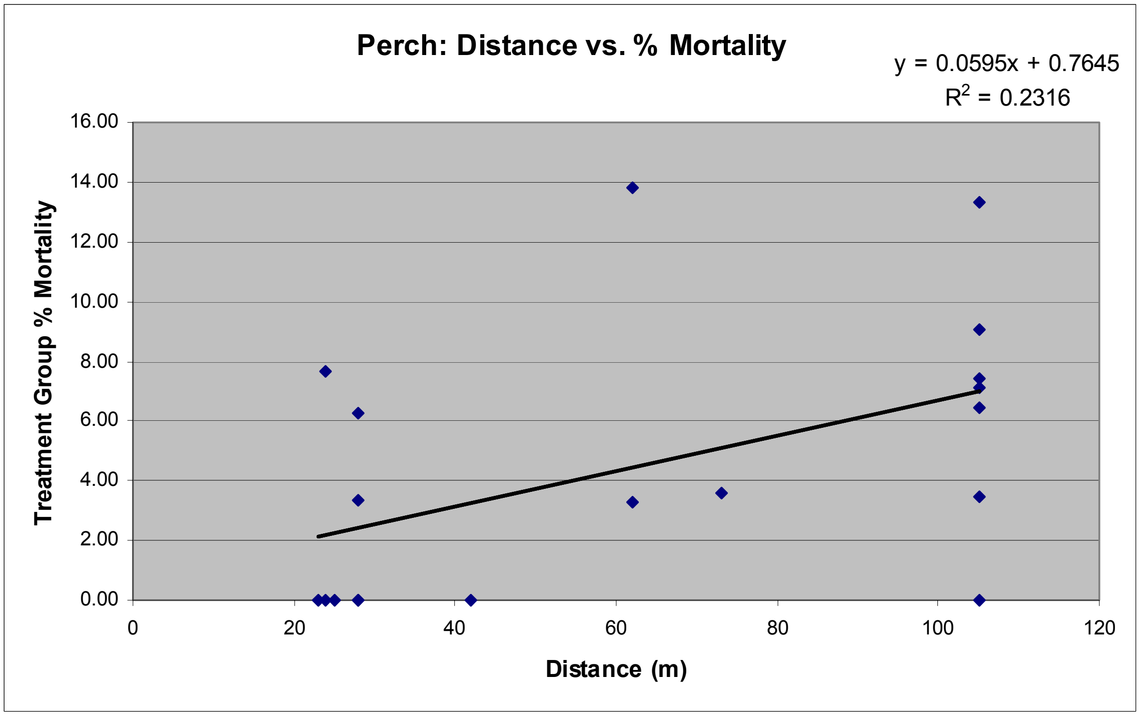
Test Results: There were no near-term mortalities at SPLs less than 204 dB.

3.2.3.3 Compliance Test: Were there any Delayed Mortalities at Distances Greater Than 440 Meters (1,444 feet)?

Test Results: Since there were no delayed mortalities at distances greater than approximately 30 meters (98 feet), it is logically assumed that there were would be no delayed mortalities at distances greater than 440 meters (1,444 feet).

3.2.3.4 Compliance Test: Were There Any Delayed Mortalities at SPLs less than 180 dB

Test Results: There were no barotrauma delayed mortalities while the bubble curtain was on at SPLs less than 206 dB; therefore, it is logically assumed that there could not be any delayed mortalities at SPLs less than 180 dB.



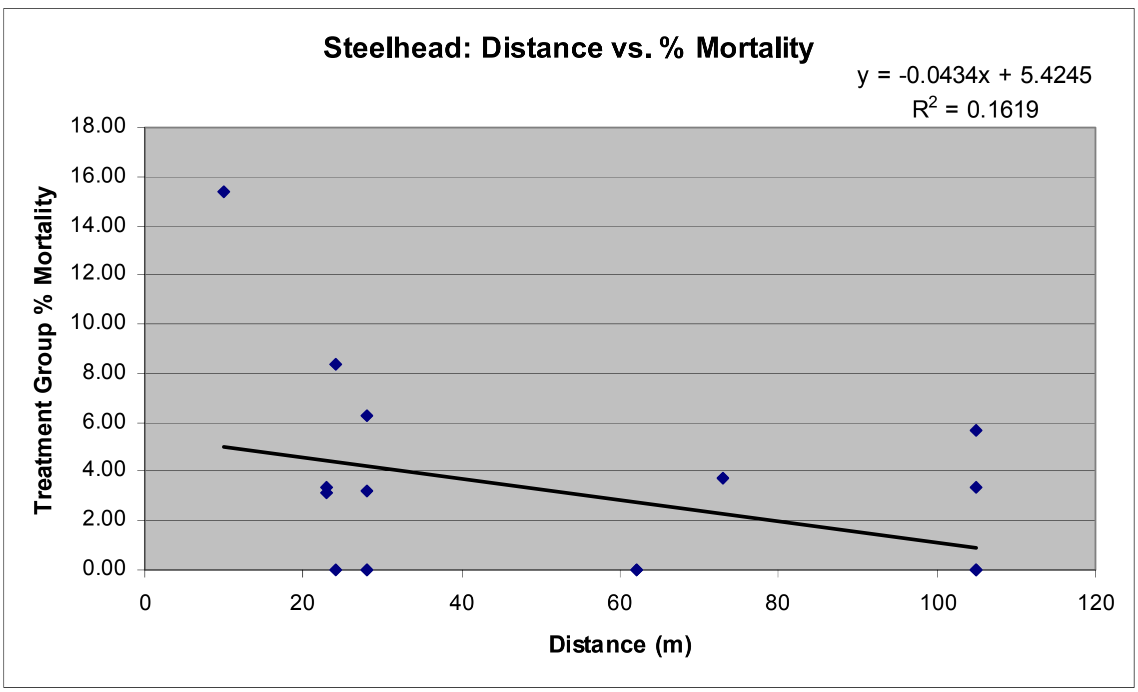


Figure 3-6. Plot of distance and rate of mortality.

Table 3.2-4. Table of treatment groups for comparison between treatment groups of surfperch and steelhead showing the numbers in each treatment group and the 1-hour, 24-hour and 48- hour mortality rates.

Surfperch						
Treatment Group ID	No.	1 Hr.	24 Hr.	48 Hr.	Total	Mortality %
M01T01	29	0	0	0	0	0.00%
M02T01	29	0	1	0	1	3.45%
M02T03	28	0	1	1	2	7.14%
M02T04	22	0	0	2	2	9.09%
M03T03	31	0	1	1	2	6.45%
M03T04	27	0	2	0	2	7.41%
M03T05	25	0	0	0	0	0.00%
M03T06	30	2	2	0	4	13.33%
M04T02	28	0	0	0	0	0.00%
M04T03	31	0	0	0	0	0.00%
M04T04	30	0	1	0	1	3.33%
M04T05	32	0	0	2	2	6.25%
M05T02	30	0	1	0	1	3.33%
M05T04	29	0	4	0	4	13.79%
M06T04	26	0	1	1	2	7.69%
M06T05	25	0	0	0	0	0.00%
M07T04	14	0	0	0	0	0.00%
M07T05	20	0	0	0	0	0.00%
M08T04	28	0	0	1	1	3.57%

Steelhead						
Treatment Group ID	No.	1 Hr.	24 Hr.	48 Hr.	Total	Mortality %
M02T07	20	0	0	0	0	0.00%
M02T09	30	0	0	0	0	0.00%
M02T11	30	0	0	0	0	0.00%
M03T07	29	0	0	0	0	0.00%
M03T08	30	0	0	1	1	3.33%
M03T11	35	0	2	0	2	5.71%
M04T07	28	0	0	0	0	0.00%
M04T08	31	0	1	0	1	3.23%
M04T09	30	0	0	0	0	0.00%
M04T10	32	0	0	2	2	6.25%
M05T08	30	0	0	0	0	0.00%
M05T09	30	0	0	0	0	0.00%
M05T10	29	0	0	0	0	0.00%
M06T09	26	2	2	0	4	15.38%
M06T10	24	1	1	0	2	8.33%
M06T12	30	0	1	0	1	3.33%
M07T08	32	0	1	0	1	3.13%
M07T11	29	0	0	0	0	0.00%
M08T09	27	0	0	1	1	3.70%

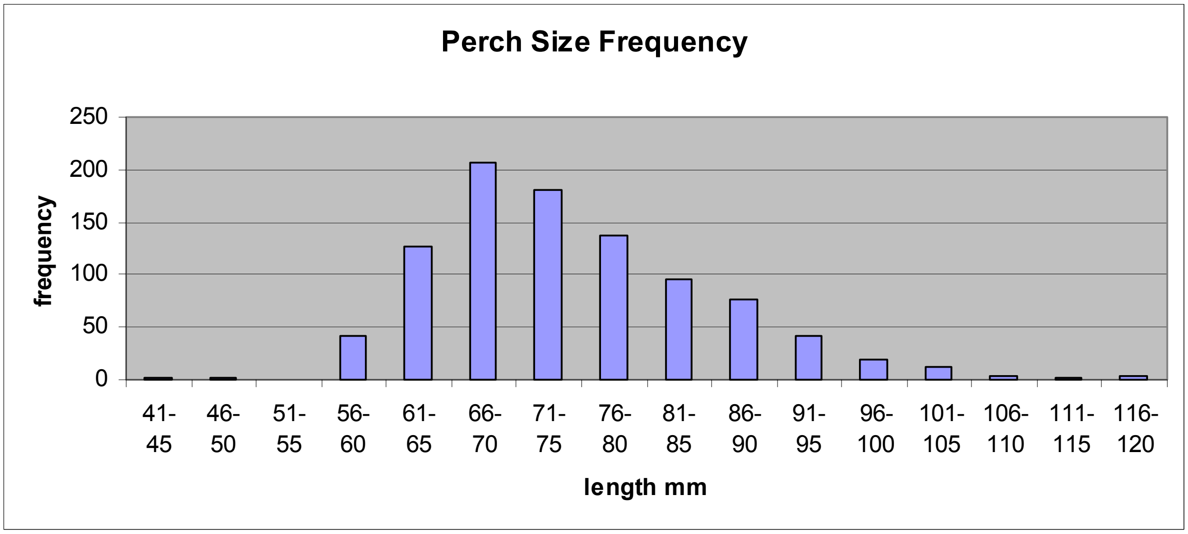


Figure 3-7. Length frequency histogram for all surfperch.

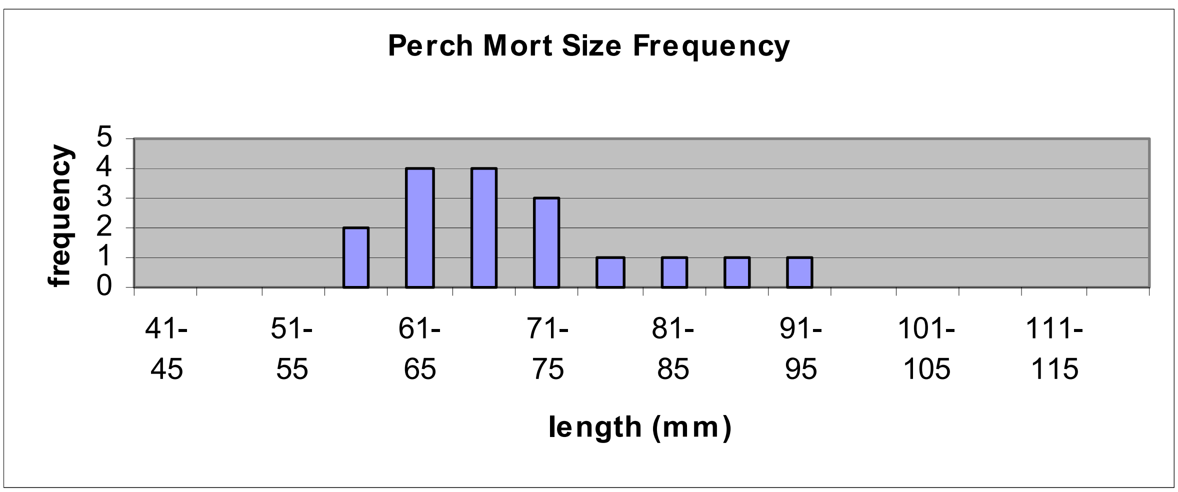


Figure 3-8. Length frequency histogram of surfperch mortalities.

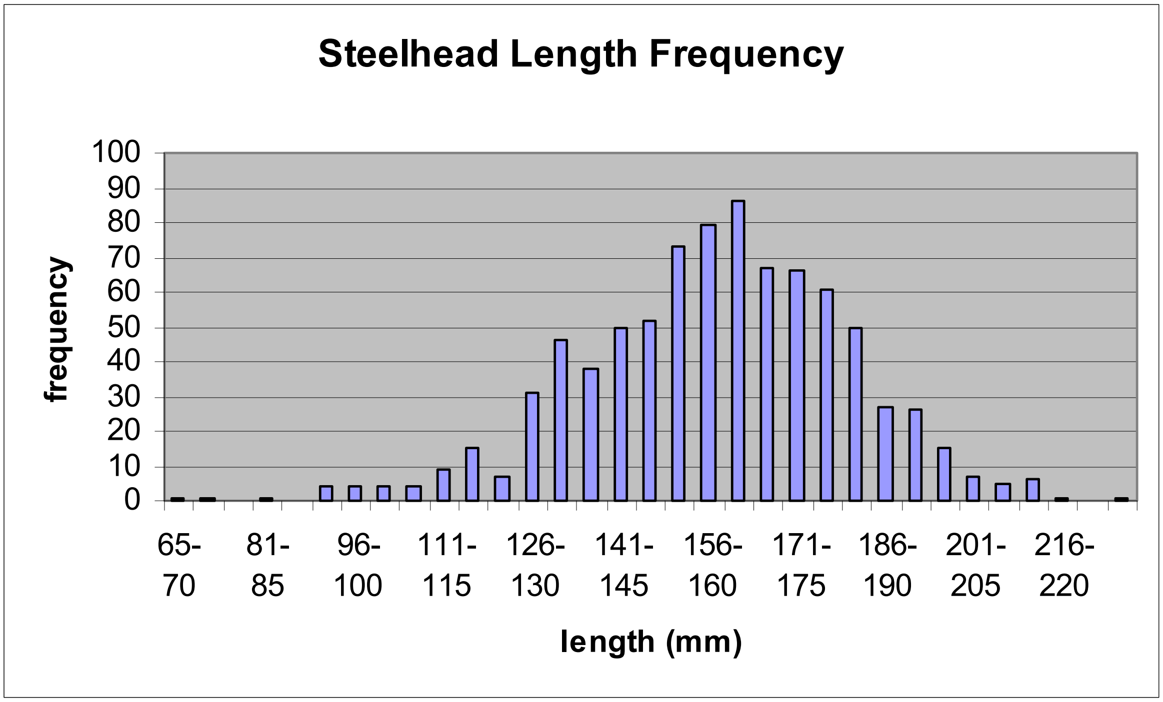


Figure 3-9. Length frequency histogram for all steelhead.

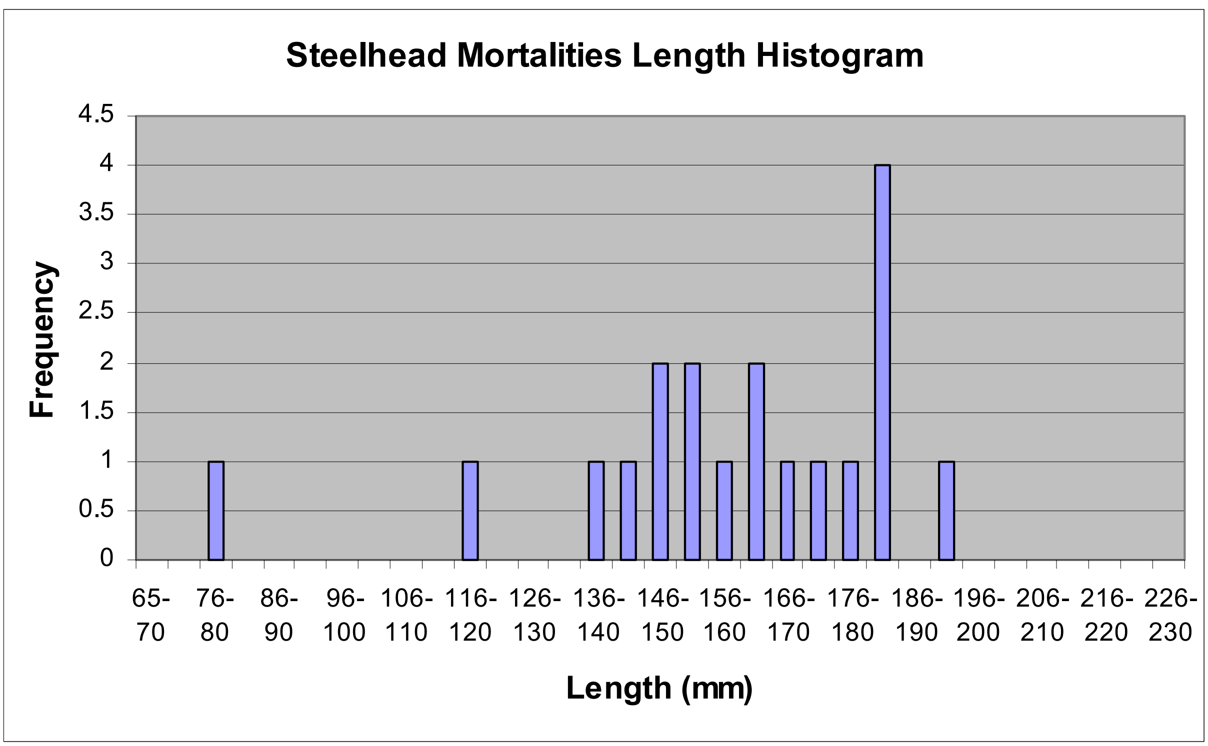


Figure 3-10. Length frequency histogram for steelhead mortalities.

3.3 BUBBLE CURTAIN ON/OFF MONITORING

The results of the bubble curtain on/off monitoring are presented in Tables 3.2-5 and 3.2-6. The most notable results of the November bubble curtain on/off study was the very high SPLs that did not result in any near-term or delayed mortalities in one treatment group of steelhead that was exposed to 208 dB for five minutes with the bubble curtain turned off. The other mortalities were not barotrauma mortalities.

The most notable result of the January bubble curtain on/off study is the 31% mortality of treatment group M07T03 when the bubble curtain was off compared to 0.0% mortality for the treatment group when the bubble curtain was on at the same location. There was a 19dB drop in SPL between when the bubble curtain was on and off in that study. The other notable result was that the steelhead exposed to a SPL (>204 dB), which were predicted to result in barotrauma, experienced no barotrauma. The other mortalities were not barotrauma mortalities.

There were only two brief bubble curtain on/off tests. The test procedures were different between the two and technical problems resulted in not having matched pairs of all the on/off treatments; therefore a meaningful statistical test is problematic. Pooling all the on and off data for both species and using the Student's t-test with 2 degrees of freedom indicates a significant difference ($p=0.05$). The mean mortality rate when the bubble curtain was off is 9.4% compared to 1.04% with the bubble curtain on and the cage control mean mortality for both species was 2.02%. If CDFG and NMFS approve a repeat of the bubble curtain on/ off study at either Pier E3W or E4W, a report with additional statistical analyses will be prepared in late 2004.

3.3 BIRD PREDATION MONITORING AND THE EXAMINATION OF FISH COLLECTED FROM THE WATER

There is no data available at this time. Data will be collected during pile-driving for Pier E3W and during the next bubble curtain on/ off test if approved by a CDFG and NMFS.

Description of abbreviations used in the tables below:

NO = The number of fish in the treatment group. A dead fish in the transport bag will be removed before the cage is lowered.
EXP = Type of exposure or control status. HC = Holding Facility Control, CT = Control Transport. CC = Control Caged with no pile-driving exposure.
PSPL = Peak Sound Pressure Level in dB re 1 µ Pascal
DUR = Duration of exposure at depth from 1-20 minutes
DEPTH = Depth in meters from the surface for the cage during exposure other than the brief periods they are going up or down
DIST = Distance in meters from the pile being driven as measured with an infrared range finder from the stern of the vessel to the pile itself.
MIT = Mitigation
1 = Near-term mortalities or the number of fish that died within approximately one hour of the cage being brought up
24 = Delayed mortality between 1 hour and 24 hours after the cage comes up
48 = Delayed mortality between 24 hours and 48 hours after the cage comes up
Tot = The total number of fish that died within 48 hours
% = Percent of the group that are mortalities. A mortality is defined as laying on its side on the bottom with no, or little, opercular activity

Table 3.2-5. Bubble curtain monitoring results for November 21, 2003.

Treatment Group ID	NO	EXP	PSPL	DUR	DEPTH	DIST	MIT	1	24	48	TOT	%
SURFPERCH												
M01T01	29	5	199	5	4	42	BCON	0	0	0	0	0.00%
M01T02	28	5	208	5	4	40	BCOFF	0	0	1	1	3.57%
M01T03	26	CC	174	5	4	ND	NA	0	0	0	0	0.00%
M01T04	30	CT	NA	NA	NA	NA	NA	0	0	0	0	0.00%
STEELHEAD												
M01T06	15	HC	NA	NA	NA	NA	NA	0	0	0	0	0.00%
M01T07	30	CT	NA	NA	NA	NA	NA	0	2	0	2	6.67%
M01T10	29	5	209	5	4	40	BCOFF	0	0	0	0	0.00%
M01T12	32	5	210	2	4	37	BCOFF	0	3	0	3	9.38%

Table 3.2-6. Bubble monitoring results for January 24, 2004.

Treatment Group ID	NO	EXP	PSPL	DUR	DEPTH	DIST	MIT	1	24	48	TOT	%
SURFPERCH												
M07T01	29	CC	167	10	8	24	BCOFF	0	0	0	0	0.00%
M07T02	29	CT	NA	NA	NA	NA	NA	0	0	0	0	0.00%
M07T03	29	1	209	1	8	24	BCOFF	1	4	4	9	31.03%
M07T04	14	1	190	1:04	8	25	BCON	0	0	0	0	0.00%
STEELHEAD												
M07T07	29	1	209	1	10	24	BCOFF	0	0	0	0	0.00%
M07T08	32	1	190	5	10	24	BCON	0	1	0	1	3.13%
M07T10	30	CT	NA	NA	NA	NA	NA	0	0	1	1	3.33%
M07T12	33	CC	167	10	8	24	BCON	0	2	0	2	6.06%

4.0 DISCUSSION

Underwater anthropogenic noise has become an international issue because of a confluence of new technologies and the concerns of the environmental community (Malakoff 2001, Popper 2003). Underwater noise produced by large ships, pile-driving, the U.S. Navy's low frequency monitoring program, and air guns used for seismic exploration are increasingly seen as pollutants and another factor resulting in habitat degradation.

The issue of underwater acoustics is now seen as extremely important to fish (Fay 1997, Popper 2003). Fish use the acoustic field to inform them of food, predators, mates, and migratory markers. Their perception of the acoustic field is via the octavolateralis system, which includes organs innervated by the eighth cranial nerve and the lateral line nerves (Popper 1997). There is a tremendous variation in these organs and different species of fish have very different hydroacoustic perception capabilities (Fay 1997, Popper 2003). The presence of a gas-filled sac, such as a swim bladder, is a key element in facilitating hearing in many species of fish. The fish with the best hearing capabilities have specialized organs for transforming sound pressure changes in the swim bladder into particle velocity in the inner ear. Injuries to the inner ear or swim bladder may not result in fish mortality, but are likely to render them acoustically blind, dramatically reducing their chance of survival and reproduction (Fay 1997, Popper 2003).

This report confirms Caltrans' compliance with the terms and conditions of its permits directed at protection of fish and the aquatic environment in relation to underwater noise generated by aquatic pile-driving and its responsibility for exercising responsible environmental stewardship.

The effectiveness of attenuation methods, including the use of a dewatered cofferdam and a bubble curtain, to significantly reduce SPLs and protect fisheries resources was confirmed. The bubble curtain met virtually all compliance monitoring standards. Hydroacoustic monitoring results indicated that the dewatered cofferdams substantially attenuated SPLs in all directions; however, some flanking of sound through the ground substrate was detected generally south of pile-driving. The caged fish monitoring program confirmed the benefits to fish.

There were some mortalities, but these were not determined to be caused by barotrauma. However, there were some barotrauma injuries. The most severe barotrauma injuries occurred when the bubble curtain was off. Some internal injuries suggestive of barotrauma occurred when the bubble curtain was on. The statistical analysis confirms that there were no greater number of mortalities in the treatment groups than in the cage control groups when compared for duration, distance, sound pressure level, depth and between species. There were in fact remarkably few mortalities given the amount of manipulation, transport and exposure to high levels of sound pressures from pile-driving. The few mortalities observed are typical of mortality rates using wild organisms for biological impact tests and do not invalidate the study (Kline, personal communication). They are well within the parameters and guidelines of the U.S. Environmental Protection Agency (EPA) and the American Society for Testing and Materials (ASTM). The following discussion elaborates on the controls, the assessment of duration, depth, distance, size, and factors that may have influenced the results of the compliance tests.

4.1 CONTROLS

The three levels of controls document the various effects of handling and transport. The five holding facility control groups had no mortalities at all. The transport controls had a few mortalities and the cage controls had the most mortalities of any of the control groups. The statistical analysis was done using only the cage control treatment groups because the only variable was exposure to pile-driving.

4.2 DURATION EFFECT

The durations of exposure used in the FHMP did not result in barotrauma mortalities. The treatment group exposures were generally less than 20 minutes. There were a few that exceeded the test durations described in the Work Plan; one treatment group was exposed for 30 minutes and one for 60 minutes. There was no statistically significant relationship between the duration of exposure and mortality.

The reason there were no significant difference between effects due to different durations is because tests were performed using the bubble-curtain attenuation system where there were no mortalities even at the highest SPLs and longest durations of exposure. The exposure levels were below the threshold of barotrauma mortality. A duration effect may have occurred if treatment groups were exposed to higher SPLs with use of the bubble-curtain or if treatment groups were exposed to lower SPLs without the bubble curtain for longer periods of time.

Fish exposed to SPLs greater than 206 dB with the bubble curtain turned off were seriously injured within a minute.

4.3 DEPTH EFFECT

The depth of the water greatly affects the average peak SPL with up to a 20 dB reduction between the surface and the bottom (James Reyff, personal communication). This drop is largely due to pressure release at the surface and wave interference, as the wave is reflected off the surface, there is a change in waveform. In a natural, salmonids tend to migrate near the surface and thus would not be expected to be exposed to the full impact of each pile-driving pulse of hydroacoustic energy. In contrast, surfperch tend to stay near the bottom and thus would be expected to be exposed to the full force of each pile-driving pulse. A visual inspection of the regression analysis trend line suggests the possibility of a weak positive correlation of mortality with depth, but there is so much scatter in the data that there was no statistically significant correlation for the treatments used in this study. The statistical Student’s t-test for comparison on mortality rates for perch at depths shallower than 4 meters (13 feet) compared to cage controls did show a statistical difference by a small margin. Due to the small sample size, this could also be a Type I statistical error where the null hypothesis has been rejected when in fact the null hypothesis is correct. Alternatively, perch may in fact be more vulnerable to barotrauma stress in shallow water. That is, in deep water, the swim bladder is more compressed and will not vibrate as much as it would in shallow water. These possibilities should be examined in future bioacoustic research. However, this research would not be done as part of Caltrans compliance monitoring.

4.4 DISTANCE AND RADIUS OF IMPACT

Distance was considered a surrogate for lower SPLs. There was no statistically significant difference in the rate of mortality for the near-term mortality zone and the delayed mortality zone. Results support the conclusion that the SPLs with the bubble curtain on were not great enough to result in fish mortalities at any monitoring distance used in this project.

4.5 SOUND PRESSURE LEVEL EFFECT

The FHMP was developed in response to NMFS's Biological Opinion and was designed to confirm expected levels of injury and mortality with use of the bubble curtain. The data collected confirms effectiveness.

Although this study was not designed to determine the effects of SPL on barotrauma injury or mortality, an analysis might have been performed to examine this question, but is not possible given that there is no statistically significant relationship between SPL and injury for the sound pressures monitored in this study. The sound pressure exposure levels were all sub-threshold for injury. With the bubble curtain on, there were no near-term barotrauma mortalities; therefore, there is no data to generate a regression of near-term mortality on SPL. There are no unequivocal barotrauma delayed mortalities with the bubble curtain on. Therefore, it is not possible to generate a curve relating barotrauma to SPL.

4.6 COMPARISON BETWEEN SPECIES

Though surfperch and steelhead have different swimbladder systems, between the two species, the rate of mortality was not statistically different. These results concur with previous studies (Fay 1997, Popper 2003). When the bubble curtain was on, there was no statistically significant difference in the rate of mortality between species. The most severely injured fish were the surfperch in treatment group M07T03 when the bubble curtain was off. Many had severe vestibular injuries and 31% percent died within 48 hours. Steelhead exposed to the same SPL at the same time as the above noted surfperch had no injury at all. One hypothesis to explain this is the ability of salmonids to partially empty their swimbladders of air, which could have potentially enabled them to better avoid barotrauma injury than physoclistous species. However, this was an observation based on one treatment group with the bubble curtain off. This is an issue for possible future research in examining differing vulnerabilities based on species differences, and cannot be addressed through compliance monitoring.

4.7 SIZE ANALYSIS

There was no statistical difference between the sizes of the surviving and dead fish for either species. The surfperch were all sexually mature adults and the steelhead were large juveniles and a few showed some degree of sexual development. Inspection of the data suggests that small surfperch died more than large surfperch; however, this was not statistically significant and was due to handling, not barotrauma.

Yelverton et al. (1975) determined that small fish were much more vulnerable to explosive shock waves than large fish. His study used explosives on fish that ranged in size from 0.47 to 744 grams (0.001 to 1.6 pounds). The size range of fish, sound source, SPLs, and waveform in the Yelverton et al. study were substantially different than those in the FHMP and a direct comparison is not possible.

4.8 VESTIBULAR INJURY

The inner ear, which has three semicircular canals and three otolithic organs, is designed to detect movement of the fish head relative to gravity and underwater sound (von Holst 1935, Platt 1983, Popper and Platt 1993, Popper and Fay 1999). Vestibular function tends to keep the more darkly colored dorsal side towards the surface of the water and lighter colored abdomen towards the bottom. Normal vestibular function is governed by a combination of the eye detecting the direction of light and the inner ear responding to gravity. Injury to the vestibular apparatus results in a very disoriented pattern of slow swimming, rolling over, unusual eye movements and head-down orientation for a period until the fish learns to use light or other neural muscular input as its sources of information for alignment and orientation relative to its environment (Gibbs and Northmore 1996, Ott and Platt 1988, Platt 1983). Fish may regain a normal swimming pattern in about half an hour, but a major injury to the system can still be indicated by an abnormal orientation to the direction of light or the long-term loss of vestibular function and the ability to detect some types of underwater sound (McCauley et al. 2003).

Vestibular injury was noted during the bubble curtain on/off study for one treatment group of surfperch. The hydroacoustic signature of the pulse that resulted in vestibular injury to the surfperch in treatment group M07T03 had a peak SPL of 209 dB with a pronounced under-pressure wave. The treatment groups that exhibited abnormal swimming behavior also had a 31% rate of mortality.

4.9 ACOUSTIC SIGNAL ANALYSIS

Representative impulses from caged fish tests were analyzed to illustrate waveforms, provide narrow band frequency (i.e., 6 Hz resolution) spectra, 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. Pile-driving produces underwater acoustical impulses that are characterized by rather fast fluctuations of pressure. Typically, the peak-to-peak rise times are on the order of 1 to 2 milliseconds. The duration of the impulse varies considerably, depending on the pile-driving condition (i.e., dewatered cofferdam or use of a bubble curtain) and distance from pile.

4.9.1 Acoustical Impulses

For the caged fish trials, the impulses measured for the unattenuated pile-driving were similar to those of other unattenuated measurements. The impulses were characterized by fast rise times that translated into higher frequency sound energy content. Typically, the peak-to-peak rise time for unattenuated impulses was about 1 to 2 milliseconds and the duration, where 90% of the energy occurs, was typically on the order of 50 to 90 milliseconds. Much of the sound energy was contained over the frequency range of 50 to 500 Hz.

4.9.1.1 Sound Pressure Analysis and Metrics

Researchers have indicated that high peak pressures along with the rate of change (i.e., rise time) are important considerations in assessing potential biological impacts (i.e., injury or mortality) (Wardle 2001). Descriptors such as the peak pressure, $RMS_{90\%}$, and SEL or accumulated energy are useful descriptors in describing the magnitude of these impulses. None of these descriptors 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 among several which can cause 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 "energy" in this sense is the integral of pressure squared (p^2) over some time interval. It can be determined in either the time domain or frequency domain. In the time domain, the integral is approximated numerically as the sum of the p^2's in a small time interval multiplied by the time interval or time step. The units are μPa^2 sec. When it is referenced to 1 μPa^2 sec, it can be expressed as a level in dB. The value of this measure depends both on the magnitude of the pressure and the total time interval over which the quantity is calculated. In the frequency domain, this accumulated energy can also be determined to obtain either a total energy term in units of μPa^2 sec as that determined in the time domain or also to determine a spectral density of the energy at discrete frequencies. The units of the energy spectral density are in μPa^2 sec/Hz. It should be noted that because the Fourier coefficients used to determine the energy spectral density are not normalized by the length of the time window, the spectrum calculated in this manner is not the (pressure) auto power spectrum often calculated for acoustic measurements. It is, however, related by a constant determined from the length of the time window of the Fourier Transform.

Although the time domain and frequency domain approaches lead to the same end accumulated energy level (or SEL) over the same time window, the information available in each technique is different. In the time domain, no frequency content information is available; however, by varying the start point and duration of the accumulation of the energy, the energy contained in varying portions of the impulse can be readily examined. In the frequency domain approach, the duration of accumulation of energy is fixed once a time window is established. The time window is established such that the beginning and end of the impulse are at very low values or a windowing (filtering) technique must be used.

However, the SEL and energy spectral density determined in this manner can provide useful information in terms of the frequency content of the impulse.

One of the difficulties with using an SEL approach to quantifying an impulse is that it contains no information on the nature of the impulse itself. It also is a function of the time window selected for the analysis. Applying this metric to pile-driving impulses requires that conventions must be established in order to compare the SELs from one pile-driving situation to another when the impulses are significantly different. One solution to this is to normalize the SEL by the length of the time window thereby forming an RMS quantity. In principle, this approach does provide some information on the rate of energy arrival in that the level is not a function of time as is the SEL. In other words, if an RMS level is higher, it implies that the rate of energy arrival is greater over the RMS time interval. On the other hand, if the SEL is higher for one impulse than another, this could be due to greater energy (higher p^2's) or longer time.

Like the SEL metric, the RMS metric needs to have some convention on where to position the RMS time window. This has been typically done in two manners. One is to let the accumulated energy define the window. An example is the $RMS_{90\%}$ metric where the RMS is taken between the 5% and 95% times of the energy accumulation. It should be noted in this case, if the 95% amount is achieved in 30 milliseconds instead of 60 milliseconds, the RMS level will be 3 dB higher indicative of the faster arrival time. A second approach is to select a time window, which is generally appropriate for pile-driving impulses and letting that window continuously slide until the maximum RMS level is obtained for the impulse. This approach has the advantage that it can be executed directly on the analog pressure signal in real-time if an appropriate averaging time constant is available.

Beyond the SEL and RMS approaches, it is also instructive to examine directly the pressure versus time and energy versus time representations. The pressure waveforms show the individual characteristics of these strikes; however, it can be 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.

4.9.1.2 Relationship Between Accumulated Energy and Acoustic Energy Flux

The expressions for accumulated energy and energy spectral density need to be clearly distinguished from the terms "energy flux" and "energy flux spectral density". Energy flux is in fact the acoustic intensity, which is defined as the instantaneous sound pressure times the acoustic particle velocity. While sound pressure is scalar quantity, particle velocity is vector quantity with specific direction. As a result, the acoustic intensity also has a direction associated with it that is aligned with the velocity vector. In other words, the sound intensity vector always "points" in the (net) direction that the acoustic disturbance is propagating. However, both the instantaneous sound pressure and particle velocity are complex quantities and are not necessarily in phase. Their phase relationship is also not stationary or fixed in time and can also be a function of frequency as well as position. This is particularly true near a sound source (within $\lambda/4$) where single point measurements of acoustic intensity are of little meaning.

4.9.2 Acoustical Impulses from the Caged Fish Studies

4.9.2.1 Data Analysis Methods

The results of the underwater pile sound measurements that corresponded to the caged fish tests were analyzed in several ways consistent with what has been done in recent other pile-driving analysis. The results of direct in-the-field measurements obtained with a Larson Davis Model 820 Precision SLM are first considered. These provided the peak pressure and RMS impulse level where the impulse response function provided a 35-millisecond averaging rise-time. This RMS level is referred to as the RMS_{imp} level. Use of the Larson Davis 820 instrument allows for efficient measurement of these acoustical descriptors over relatively long periods of time or numerous pile strike impulses. As previously discussed, the RMS_{imp} that is commonly reported in this document is the SPL averaged over the loudest 35-millisecond period during an impulse. This descriptor has been used to approximate the $RMS_{90\%}$ level, which is calculated later using the digitized pressure signal. Data analysis from the PIDP, which were mostly made up of distant unattenuated measurements, found that the RMS_{imp} over estimated the $RMS_{90\%}$ by about 1 dB. The attenuated strikes measured for the production piles appear to have a different relationship. The RMS_{imp} measured inside the fish cages was about 2 to 3 dB higher than the $RMS_{90\%}$ (with a range of 1 to 5 dB). The larger differential occurs because the averaging time, between 5% and 95% of the accumulated sound energy, is longer for the attenuated impulses.

In addition to the RMS and peak descriptors, the SEL or total accumulated energy was calculated from selected impulses. The waveforms where also compared for differences in rise times and form. The level of the accumulated pressure energy was also determined. Finally, spectral analyses (auto power spectrum) of the impulses were completed for a 160-millisecond time window yielding a frequency range from 0 to 5,000 Hz with a 6.25 Hz frequency resolution. A typical comparison of these data for the November 21, 2003 bubble curtain off test in which fish were not killed and for the January 24, 2004 bubble off test in which some fish were killed are given in Figure 4-1.

4.9.2.2 Discussion of Acoustical Measurement Results

Prior to discussing the data from the two bubble curtain off test events, it should be noted that the physical circumstances of each test were different. In the January test, where some mortality was observed, the cage and acoustical measurements were made at distance of 24 meters (79 meters) from the pile at a depth of 10 meters (33 feet). For the November test, where mortality was not observed, the cage and instrumentation were 42 meters (138 feet) from the pile and at a depth of about 4 meters (13 feet).

From a review of the two waveforms in Figure 4-1, it is seen that they are remarkably similar given the difference in depth and distance. Although there are subtle differences between the waveforms, there appears to be little difference in amplitude and arrival rate to account for the observed difference in fish mortality. Inspection of the accumulated energy indicates that the January signals actually occurred at a slower rate than the November data and that it took longer to meet its final amplitude. Similarly, examination of the peak, RMS and SEL descriptors indicates very little acoustic difference between these two tests. The narrow band spectra are similar in shape in an overall sense from 0 to 5,000 Hz in that the majority of the energy is concentrated below 800 Hz. However, for the January test, there are appreciably higher levels than the November data below about 138 Hz. In this region, the average difference in level is 8 dB while the average energy difference for those level differences is about 21 dB. It is not known if or how significant this difference is in terms of the observed mortality; however, based on comparison of the signals, this is the most outstanding acoustical difference.

Fish in Cage Test # M01T02 (11/21/03) **& # M07T03** (01/24/04)

Figure a. Waveform

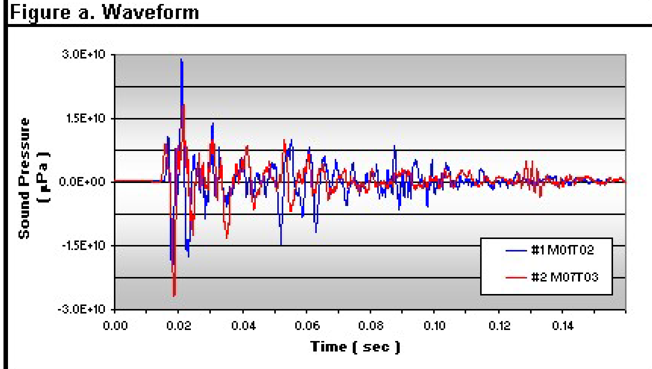


Figure b. Narrow Band Frequency Spectra

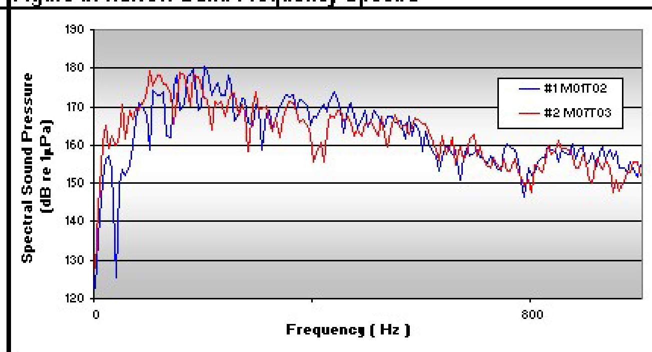


Figure c. Accumulation of Sound Energy

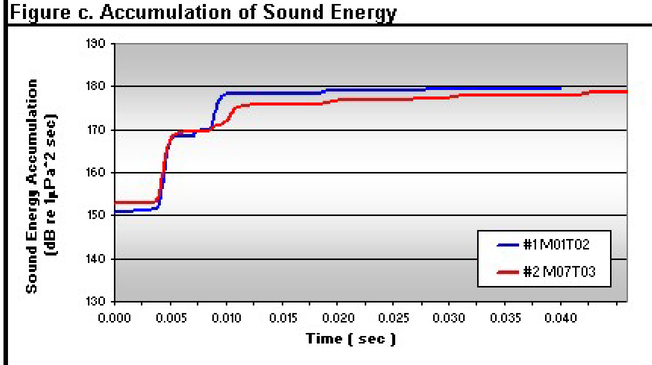


Figure d. Sound Pressure and Sound Energy Levels

Signal Analysis Sound Pressure / Energy Levels

	Peak	RMS90%*	SEL
- 14:43:28	209	192	181
- 11:00:36	209	189	180

Typical Sound Pressure / Energy Levels Throughout Test

	Peak	RMSimp**
Reported Average (M01T02)	208	195
Reported Average (M07T03)	209	194

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

Figure 4-1. A graphic comparison of the acoustic characteristics of the November 21, 2003 and January 24, 2004 bubble curtain off tests.

4.10 FACTORS THAT MAY HAVE CONFOUNDED THE RESULTS

4.10.1 Causes of Fish Mortality and Injury

4.10.1.1 Causes of Shiner Surfperch Mortality

The main causes of shiner surfperch mortality were parasites and disease, not barotrauma. Shiner surfperch are known to carry a heavy burden of parasites and mortality due to parasitic infestation may be a significant factor in natural mortality (Lane et al. 2002, Arai et al. 1988). California shiner surfperch typically carry the myxosporidan protozoa

(*Phyllobothrium sp.*) and a parasitic worm (*Corynosoma sp*.), in addition to numerous parasitic copepods and nemoatods (Arai et al. 1998). See Figure 4-2 for an example of a fish with a parasite. Virtually all shiner surfperch examined in this study carried one or two large parasitic isopods in their gill chamber. It appeared that the isopods cut away gill lamellae and part of the operculum to make room for themselves as they grew.

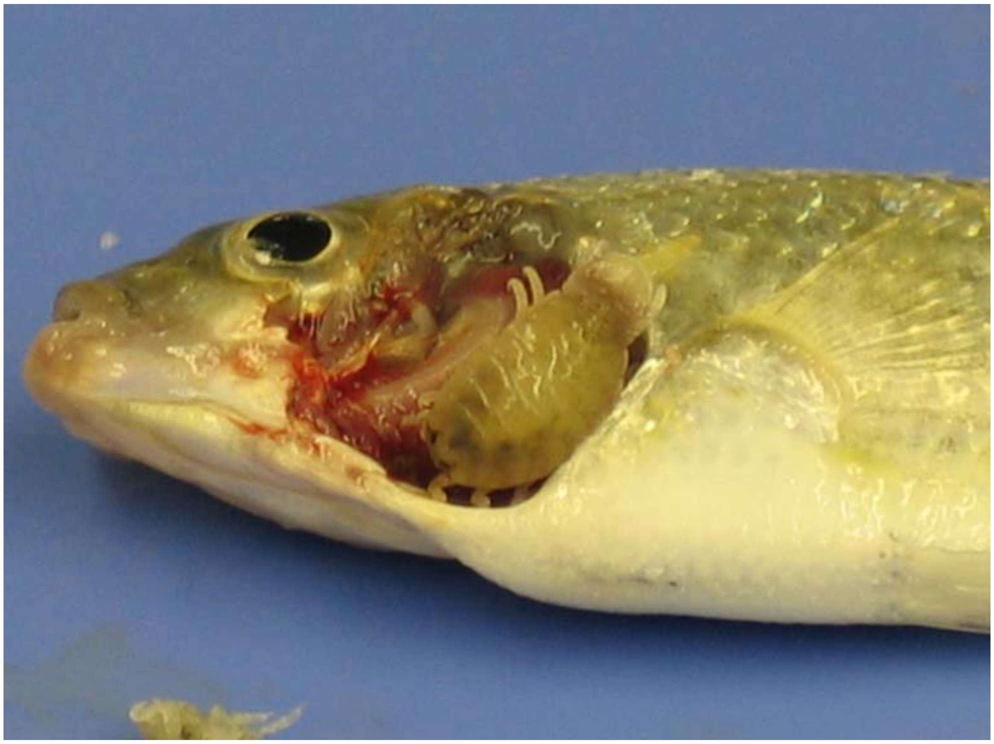


Figure 4-2. Surfperch with a large parasitic isopod in the gill pouch.

On December 4, 2003, CDFG fish pathologist, Joe Maret, examined a number of shiner surfperch used in this study. He reported that they had a heavy load of the bacteria *Flavobacterium sp.* and high numbers of motile bacteria were observed microscopically on scrapes of skin and fins along with large numbers of the parasitic worm *Gyrodactylus sp*. Many of the shiner surfperch appeared to have recovered from injuries to the head as indicated by indentations on the cranium and nasal bones. Shiner surfperch are reported to recover quickly from conditions such as the loss of their tail fin when conditions are right (Fraser, personal communication).

The surfperch had empty stomachs when they were exposed to pile-driving. Typically they were captured a few days before they were brought to the laboratory. The bait dealer typically fed them ghost shrimp parts and day-old bread. Shiner surfperch were not fed in the 48 hours before being exposed to pile-driving. Not feeding fish the day before transportation is a standard aquaculture practice so the fish will not defecate into the transport water. No food in their digestive track may have also prevented the production of gases in the gastrointestinal tract that may have confounded the results. Shiner surfperch were presented with frozen brine shrimp and krill each day after exposure to pile-driving. They readily fed the first time these items were presented. Surfperch were never observed to be in low oxygen distress. In general, they were much smaller than the steelhead and did not have the same metabolic demand for oxygen.

The net effect of all the handling, collisions, and jostling during transport is stress. The minimization of handling stress was a major focus of the fish handling team. An informal rule of thumb in the fish culture and aquarium trade is 1%-10% mortality every time a group of fish is handled due to loss of scales, bacterial infections in small injuries, physiological changes, and impact injuries from fish colliding into the sides of tanks, cages, nets and each other. With the exception of a few treatment groups of surfperch that had serious disease or handling problems, and therefore excluded from further analysis, there was only a 2.2 % [23/1044] mortality for all the control and exposure groups of surfperch combined. The mortality rate for fish exposed to pile- driving compared to the fish that were controls and not exposed to pile-driving was not statistically significant (p=0.05).

4.10.1.2 Causes of Steelhead Mortality

The main cause of steelhead mortality is believed to be attributed to osmoregulatory stress as the fish went through smoltification. In addition, handling stress and disease were likely causes of steelhead mortality.

On December 4, 2003, A number of moribund steelhead were examined by CDFG fish pathologist Joe Maret. Scrapes of skin and gills indicated the steelhead had a heavy load of columnar bacteria and microscopic parasites. Upon the advice of the CDFG pathologist, the flow rate in the tanks was increased. The amount of time the fish were in the transport bags was also reduced. These two steps appeared to improve steelhead health and survival.

One of the main causes of mortality for steelhead was low dissolved oxygen stress during transport. In general, the average size of the steelhead was much larger than planned. The large size resulted in a high rate of dissolved oxygen consumption and the need to recharge the transport bag with oxygen. Stress due to dissolved oxygen is indicated by change in behavior and coloration. The steelhead would become almost black in color and could be seen at the surface as if gulping for air. A few were observed slowly swimming on their side or simply laying on the bottom with only the exaggerated movement of their operculum to indicate they were alive. When the fish team noted any of these conditions, they would immediately recharge the bag with oxygen. Within a minute nearly all the fish were behaving normally, but these treatment groups were eliminated from the study.

Progressive deoxygenation stress in fish results in increased blood lactate, as a result of anaerobic metabolism, decrease in blood pH and the opercular stroke volume increases. There is a 13-fold increase in ventilation volume (Holeton and Randall 1967). Most of these factors could not be observed during the course of transport. Deoxygenation stress, combined with handling stress, smoltification stress, parasites and bacterial infections killed a number of fish. It is somewhat surprising that this combination of factors did not kill more steelhead. In fact, they killed comparatively few. Where these non-barotrauma type mortalities were higher than 10% in any given treatment group, there was concern that they might confound the interpretation of the compliance monitoring effort; therefore, they were excluded from the analytical process. Four treatment groups were excluded as a result.

4.10.2 Water Conditions

The air-water interface acts as both a pressure relief outlet and an acoustic mirror reflecting sound waves back into the water. The amount reflected back depends to some degree on the smoothness of the water surface. A water surface that is very wavy will reflect back less than a smooth surface. In general, the water surface near the caged fish monitoring operations was smooth with the exception of when the tides were moving against the direction of the wind or when large vessels passed. In general, there were few windy days and the amount of wind and waves were probably not enough to affect the results of this monitoring study, especially as the team became more proficient at avoiding rough water effects with experience.

In general, the water quality of central San Francisco Bay tracks the water quality of the Pacific Ocean with a minor degree of influence from the freshwater inflow from the Sacramento-San Joaquin River systems to the north. The salinity ranged from 28 to 30 ppt. The temperature ranged from 10^{o} to 11.5 ^{o}C (50 to 52.7 ^{o}F). The water column was generally well mixed by strong tidal flows and no indication of a thermocline was found, though the temperature was about 0.5 degrees cooler at 5 meters (16 feet) than at the surface.

Tidal currents ranged from slack tide to 3.7 knots. The 113-kilogram (250-pound) stern anchor tended to keep the research vessel fairly steady. Deployment of cages was generally after the research vessel was stabilized in the prevailing current. Typically, the vessel needed to be moved at least once during each monitoring trip to adjust for the reversal in the direction of the tidal current. The mud pattern on the stern anchor indicated it sank approximately 25 centimeters (10 inches) into the soft Bay mud. On several occasions abrupt tidal current changes resulted in dragging the anchor but, in general, the research vessel was very stable and there is no reason to believe that changes in tidal currents introduced a variable in monitoring operations.

4.10.3 Benthic Features

The benthic features surrounding the study area affected the hydroacoustic field. All eight monitoring trips were associated with Piers E3E – E6E. These piers are approximately 200-300 meters (656 to 984 feet) from the existing bridge piers. The existing bridge piers are large concrete structures that could potentially affect the propagation of sound. The bottom is a very soft mud with underlying harder mud and rocks. The acoustic energy originating from the underlying rock formations being penetrated by the pile contributed to the overall sound pressure level.

4.10.4 Footing Box

The footing box is a large concrete and steel shell that surrounds the piles to a depth of 3.5 meters (11.5 feet) below the surface. The piles are driven through elliptical holes in the base of the box. The bubble curtain system sits below the footing box. The footing box decoupled the pile from the water and it is likely that it provided some degree of hydroacoustic attenuation. Monitoring at Piers E6E and E5E involved a number of trials where the cage was less than 4 meters (13 feet) deep. There were no barotrauma mortalities in treatment groups that were exposed at a depth of 4 meters (13 feet) or less with or without the bubble curtain.

4.10.5 Bubble Curtain Effect

The contractor did not operate the bubble curtain between pile-driving episodes. All control cages were put down when there was no pile-driving. It is possible, but not likely, that the bubble curtain functioned as an additional stressor due to intensified background sound, mobilization of sediment particles, or the supersaturation of the water column with gas bubbles. However these factors were probably minimal in terms of the overall cumulative stress on caged fish in cages being exposed to pile-driving. Comparison between controls with bubble curtain off and no pile-driving showed no statistically significant difference in mortality. The lower-most bubble manifold was well above the bottom, specifically to prevent the mobilization of sediment.

4.10.6 Cage Effect

The hydroacoustic data from the hydrophones in the cage compared to the hydrophone outside the cage demonstrated that there was no discernable cage effect. The cage did not reduce the amplitude, affect the frequency pattern, or alter the waveform.

4.10.7 Hammer Energy

The contractor would attempt to drive the pile down about 2.5 centimeters (1 inch) on each blow. That meant that, at the start of the drive, the force would be comparatively smaller than at the end of the drive. But this varied as the pile was pushed down through various layers of hard clay and sandstone. This meant that the energy used during a single drive varied somewhat between the start of driving and the end. The amount of hydroacoustic sound that came up through the bottom sediments and into the water as the pile tip was pushed deeper into the ground was not anticipated. This resulted in higher SPLs around the cofferdams than what was anticipated, and an irregular pattern of sound pressures at different distances from the pile.

4.10.8 Bubble Curtain On/Off Studies

4.10.8.1 November 21, 2003

There were many difficulties experienced in executing this study. November 21st, 2003 had one of the strongest tides of the month. The hydroacoustic data suggest that the bubble curtain was pulled away from the pile to some degree so that the test of the bubble curtain on was not exactly a full bubble curtain on. The currents abruptly shifted right in the middle of the 5-minute exposure and the research vessel rapidly swung around perilously close to the pile template. The cages were at 4 meters (13 feet) below the surface and it seems likely that the footing box muffled the sound pressure wave. Several treatment groups of steelhead experienced low dissolved oxygen stress and an excessive number of mortalities; therefore, they could not be used in the data analysis. The steelhead treatment group for the bubble curtain on suffered excessive mortalities due to a hole in the transport bag and their data could not be used in the study.

The missing data for some of the treatment groups preclude meaningful statistical analysis for comparison between species, and for the bubble curtain on compared to the bubble curtain off. In addition, the footing box covered 50% of the pile. Therefore, the footing box provided a substantial amount of attenuation, preventing the hydroacoustic monitors from collecting accurate readings of how effectively the bubble curtain was attenuating. However, there were several striking observations; for example, there were no mortalities in a treatment group of steelhead exposed to peak SPLs as great as 209 dB with the bubble curtain off (M01T10).

4.10.8.2 January 24, 2004

Due to potential construction delay costs, the contractor minimized start and stop procedures during pile-driving operations. This and the very short duration of exposure created a number of problems for interpreting the data. The steelhead bubble curtain off treatment group actually had one minute of bubble curtain off exposure and three minutes of bubble curtain on. The difference between treatments precludes meaningful statistical analysis for comparison between the bubble curtain on and bubble curtain off and between species.

4.10.8.3 Comparison between the November and January Bubble Curtain On/Off Studies

The small sample size, loss of steelhead in November due to low dissolved oxygen stress and differences in treatment depth, distance and duration preclude meaningful statistical comparison. One notable observation is the comparison between the surfperch treatment groups in November and January. The November treatment groups were at a depth of 4 meters (13 feet) and a distance of 42 meters (138 feet). The January surfperch treatment group was at depth of 10 meters (33 feet) and at a distance of only 24 meters (79 feet). The November surfperch had 0.0% mortality at 209 dB while the January surfperch had 31% mortality at the same SPL. The cause for mortalities in the January treatment group is unknown, since both groups were exposed to similar sound pressures. This is an area of suggested future research. However, this research would not be done as part of Caltrans compliance monitoring.

4.11 COMPLIANCE TESTS

4.11.1 Hydroacoustic Compliance Tests

There was no simple relationship between distance and measured peak sound pressure. Figure 3-3 shows measurements plotted by distance from the pile for pile-driving with use of a bubble curtain. Based on the best-fit interpolation of the data, compliance levels were met for 204 dB at 69 meters (226 feet). Compliance levels at 440 meters (1,444 feet) for 180 dB were generally met, although the extrapolated level was 181 dB, or one dB higher than predicted. It appears that flanking of sound through the ground resulted in a much lower drop-off rate at further distances than predicted. As a result, the peak sound pressures would exceed 150 dB at 4,400 meters (14,436 feet). However no data was collected beyond 2,200 meters (7,218 feet) to confirm this. Additional measurements will be made during pile-driving for Pier E3W.

4.11.2 Caged Fish Compliance Tests

Monitoring with the bubble curtain on resulted in a finding of no barotrauma mortalities at any sound pressure, duration or distance. There was no statistically significant difference between species or size of fish. Treatment groups exposed to pile-driving experienced a rate of mortality statistically no different than cage control groups. However, there were barotrauma injuries and some injuries may have been severe enough to increase the probability of predation compared to fish that had not been exposed to pile-driving pulses of hydroacoustic sound. Treatment groups survived SPLs predicted to result in mortalities. Sound pressure alone appears not to be the only predictor of injury and mortality. It is not known if a hearing specialist would have faired as well as the two hearing generalists used in this study. The likely reason for the absence of a predicted effect is due to the effectiveness of the bubble curtain in changing the waveform and peak particle velocity.

5.0 CONCLUSIONS

The evaluation of compliance monitoring results determined that the FHMP met its study objectives with the exception of peak SPLs being 150 db or less at 4,400 meters (14,436 feet) and comparing fish mortality rates with the bubble curtain on to those with the bubble curtain off. It appears that flanking of sound through the ground resulted in a much lower drop-off rate at further distances than predicted. As a result, the peak sound pressures exceed 150 dB at 4,400 meters (14,436 feet); however no data was collected beyond 2,200 meters (7,218 feet) to confirm this. Additional measurements will be made during pile-driving for Pier E3W. Caltrans is also currently in discussion with CDFG and NMFS regarding a possible third bubble curtain on/off study, which would be completed at Pier E3W or E4W, and would allow for completion of the bubble curtain compliance test.

In addition, there has been a very limited amount of bird predation monitoring to date and no fish have been collected from the water for examination. This is due to the limited amount of bubble curtain on/off monitoring that has occurred. A report summarizing observations on moribund fish and gull predation will be presented at a later date after pile-driving has occurred at Pier E3W as well as during the next bubble curtain on/off study, if approved by the CDFG and NMFS.

5.1 PEAK SPLS AT OR LESS THAN 204 DB AT 69 METERS (226 FEET)

The criterion was met and sound pressures greater than 204 dB were never recorded at distances greater than 69 meters (226 feet).

5.2 PEAK SPLS AT OR LESS THAN 180 AT 440 METERS (1,444 FEET)

The criterion was generally met, but the regression of SPLs on distance using all the distance monitoring data showed SPLs exceeded the criteria by one dB. One data point was 10 dB over the criterion, while another was 11 dB below.

5.3 PEAK SPLS AT OR LESS THAN 150 DB AT 4,400 METERS (14,436 FEET)

It appears that flanking of sound through the ground resulted in a much lower drop-off rate at further distances than predicted. As a result, it appears that peak sound pressures would exceed 150 dB at 4,400 meters (14,436 feet). The most distant measurements were 170 dB at 2,200 meters (7,218 feet) northwest of pile-driving activities.

5.4 NO NEAR-TERM MORTALITIES AT DISTANCES GREATER THAN 69 METERS (226 FEET)

There were no near-term mortalities caused by pile-driving injuries beyond 69 meters (226 feet).

5.5 NO NEAR-TERM MORTALITIES AT SPLS LESS THAN 204 DB

There were no near-term mortalities at SPLs less than 204 dB.

5.6 NO DELAYED MORTALITIES AT SPLS LESS THAN 180 DB

There was no monitoring at SPLs below 180 dB. It was concluded that since there were no barotrauma delayed mortalities for fish exposed to pile-driving at SPLs below 206 dB with the bubble curtain on, there could not be any mortalities for fish at less than 180 dB.

5.7 NO DELAYED MORTALITIES AT DISTANCES GREATER THAN 440 METERS (1,444 FEET)

There was no monitoring at distances greater than 440 meters (1,444 feet). It was concluded that since there were no barotrauma mortalities for fish exposed to pile-driving at distances up to 300 meters (984 feet), there was no basis for expecting mortalities at greater distances.

5.8 BUBBLE CURTAIN ON/OFF STUDIES

The bubble curtain on/off studies demonstrated approximately a five-fold, or 15 dB drop, in SPL and an approximately doubling of the rise time for the peak pressure. The caged fish monitoring program supports the conclusion that the bubble curtain was effective in protecting fish from barotrauma; however, the amount of data collected was not enough to statistically be able to determine if there was a significant reduction in the rate of mortality when the bubble curtain was on compared to when it was off. Caltrans is currently in discussion with CDFG and NMFS regarding a possible third bubble curtain on/off study, which would be completed at Pier E3W or E4W.

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6.5 DEFINITIONS AND ACRONYMS

Ambient Sound Level - The background sound level, which is a composite of sound from all sources near and far. The normal or existing level of environmental sound at a given location.

Cage Control Group – One cage of fish that is on the research vessel, put into cages and lowered into the water when there is no pile-driving. The control group will be brought up after 5 minutes and placed in a transport tank for observation. The control group will also be held 48 hours for observation of handling mortalities.

Decibel (dB) – A unit describing the amplitude of sound, equal to 20 times the logarithm to the base 10 of the ratio of the pressure of the sound measured to the reference pressure. The reference pressure for water is 1 micro Pascal (µPa) and air is 20 micro Pascals (the threshold of healthy human audibility).

Delayed Mortality – For purposes of this project, delayed mortality is when a fish dies more than 1 hour and less than 48 hours after removal from the fish cage.

Delayed Mortality Zone – The radius around a pile being driven where the peak sound pressure level and impulse are not great enough to result in immediate death, but result in mortality several hours to several days later.

Dependent Variable – Effect of hydroacoustic wave on subjects.

Frequency Spectrum – Distribution of sound pressure vs. frequency for a waveform, dimension in RMS pressure and defined frequency bandwidth.

Gas Bladder – An air-filled sac located between the alimentary canal and the kidneys. It is filled with CO_2, O_2 and N_2 in different proportions than found in air. It is also called the swimbladder. It is functionally a hydrostatic organ to help control buoyancy, but also plays an important role in sound reception in some species of fish.

Hematuria – The presence of blood, specifically red blood cells, in the urine.

Hertz (Hz) – Hertz, frequency or cycles per second. The number of complete pressure fluctuations per second above and below atmospheric pressure. Normal human hearing is between 20 Hz and 20,000 Hz. Infrasonic sounds are below 20 Hz and Ultrasonic sounds are above 20,000 Hz.

Hyperemia – Increased blood flow, as in an area of inflammation. Active *hyperemia* occurs when arterial and arteriolar dilatation produces an increased flow of blood into capillary beds, with opening of inactive capillaries, which imparts a red appearance to the tissue.

Impulse – Impulse is the time integral of the peak pressure. It recognizes that a short pulse may do less damage than a longer duration pulse of the same pressure. Sound pressure is equivalent to kilowatts while impulse is equivalent to kilowatt-hours. It is typically described in units of psi/msec.

Independent Variables – Fish size, fish species, distance from the pile, depth of the water, depth in the water column, duration of exposure hammering energy, sound pressure level at the fish cage, and waveform (rise time).

Kilojoule (kJ) – The basic unit of force moving a body a unit distance in the metric system is 1 Newton-meter or 1 Joule. One Joule is 0.7376 ft-lbs. A thousand Joules or one kilo Joule is represented as kJ.

Mean Lower Low Water – Zero tidal elevation. Minus tides are below MLLW.

Micro Pascal (µPa) – Most underwater acoustic sound pressure measurements are stated in terms of a pressure relative to one micro Pascal.

Monitoring Pile – A large (2.5-meter) diameter steel pipe pile. Each pile is expected to consist of two or more sections. Monitoring was conducted only when the last section of the pile was driven. Small temporary piles were not monitored as recognized in NMFS's Biological Opinion and CDFG's 2081 Incidental Take Permit.

Monitoring Trip – A day of monitoring pile-driving using the research vessel.

Mortality – Cessation of all activity including movements of the operculum, or when all respiration stops and the fish lays motionless.

Near-field – Hydrodynamic flow or molecular displacement close to the sound source where the pressure falls off according to the square of the distance ($1/r^2$).

Near-term Mortality – For purpose of this project, near-term mortality is when a fish dies in less than one hour after it is removed from the cage. Fish may be dead in the cage but observations on their condition were not be made until they were removed from the cage. Near-term mortality is considered the same as instantaneous mortality.

Near-Term Mortality Zone – Radius around a pile being driven where the peak sound pressure level and impulse are great enough to kill a fish immediately resulting in the fish floating up to the surface or sinking to the bottom. Immediate mortality and near-term mortality are identical.

Otolith – Small irregularly shaped bones found in the head of fish that contribute to hearing.

Pascal (Pa) – A Pascal is a unit of pressure equal to one Newton per square meter.

Peak Sound Pressure (unweighted), dB re 1 µPa - Peak sound pressure level based on the largest absolute value of the instantaneous sound pressure over the frequency range from 20 Hz to 20,000 Hz. This pressure is expressed in this report as a decibel (referenced to a pressure of 1 µPa) but can also be expressed in units of pressure, such as µPa or PSI.

Pier – The new East Span will consist of two side-by-side bridge structures, supported by a series of piers. Each pier will be supported by 4 to 6 piles. Piers that will be driven in water as part of the YBI/SAS contract include Pier 1 (the largest pier, which will support the Self-Anchored Suspension span) and Pier E2. Piers for the Skyway, located to the east of the SAS, are labeled E2 through E16.

Pile-driving Time – The number of minutes to drive a second section pile to its predetermined elevation.

Piscivorous – Fish-eating animals.

Propagation Loss – The decrease in sound pressure level due to the spherical spreading of the sound wave. In the farfield the rate of decrease in the sound pressure level is proportional to the distance or 1/r. In an unbounded, homogeneous medium, propagation loss will be on the order of 6 dB for every doubling of the distance.

Predation – The act of preying on another animal.

PSI – Pounds per square inch.

Rate – Percentage probability of an effect.

Rise Time – Time interval a signal takes to rise from 10% to 90% of its highest peak.

Root Mean Square (RMS) – The average of the squared pressures over the time that comprise that portion of the waveform containing 90 percent of the sound energy for one pile-driving impulse. Commonly used in repetitive or relatively continuous measurements such as in speech or highway noise. It is not applicable to transient signals such as explosions. It is used in calculating longer duration sound pulses such as a pile-driving pulse of sound.

RMS Impulse – Root square of the energy divided by the duration. It is the mean square pressure level of the pulse of sound from a strike of the hammer on the pile. It is described as the average pulse pressure and accepted as the reaction threshold for whales to seismic signals. RMS impulse is expressed in dB re 1 micro Pascal. It is the unweighted root mean square sound level (20 Hz to 20 kHz) in dB re 1 μ Pa averaged over the duration of an impulse of sound.

Series – A sequence of trials in one pile-driving event.

Sound Exposure Level (SEL) – A common unit of sound energy used in airborne acoustics to describe short-duration events. The time integral of frequency weighted squared instantaneous sound pressures. Proportionally equivalent to the time integral of the pressure squared and can be described in terms of μ Pa^2 sec over the duration of the impulse.

Sound Pressure Level (SPL) – Sound pressure is the sound force per unit area, usually expressed in micro Pascals (or 20 micro Newtons per square meter), where 1 Pascal is the pressure resulting from a force of 1 Newton exerted over an area of 1 square meter. The sound pressure level is expressed in decibels as 20 times the logarithm to the base 10 of the ratio between the pressure exerted by the sound to a reference sound pressure (e.g., 20 micro Pascals) SPL = 20 log $\left\{ {P_1}/{1 \mu P_\partial} \right\}$. Sound pressure level is the quantity that is directly measured by a sound level meter.

Student's t-test - The Student's t-test was developed by William Gosset who published his approach to the comparison of test groups under a pseudonym "Student". The t distribution approaches the standard normal distribution as the sample size increases. It is one of the most commonly cited tests methods reported in the biomedical literature.

Subject – One individual fish. Data collected is species, sex, standard length, external indications of injury, time after exposure to death. Some fish will also have an internal examination for signs of injury.

Swimbladder – See gas bladder.

Tank Farm: Twelve tanks or aquariums with flow-through water and independent aeration that held fish for the caged fish experiments. Each tank held approximately 30 fish. The fish were held and acclimated for a period of time before being used for the caged fish monitoring and then 48 hours after exposure to a treatment.

Time Expended – This field operation term refers to the time to bring up a cage, unload the fish, put a new group in and drop the cage back to depth.

Total Acoustic Energy, dB re 1 µPa^2 sec - Proportionally equivalent to the time integral of the pressure squared and is described in this report in terms of µPa^2 sec over the duration of the impulse. Similar to the unweighted Sound Exposure Level (SEL) standardized in airborne acoustics to study noise from single events

Transect – A line or strip along which samples are taken.

Transducer – A device to convert underwater sound into electrical voltage.

Treatment – Exposure of subjects to hydroacoustic shock waves due to pile-driving. Treatment variables include duration of exposure, sound pressure level (Peak SPL and Peak RMS), shock wave rise time, distance from the pile, depth in the water, and bubble curtain on/off.

Trial – Repetition of one treatment.

Waveforms, µPa over time - A graphical plot illustrating the time history of positive and negative sound pressure of individual pile strikes shown as a plot of µPa over time (i.e., seconds)

In the American Fisheries Society *Common and Scientific Names of Fishes* 1991 5th ed. *Cymatogaster aggregata* are referred to as having the common name shiner perch.

Appendix A

Data Collection Forms

TANK DATA HISTORY FORM

FISH TANK ACTIVITY FORM **TANK #__________**

DATE	TIME	SALINITY (ppt)	DO (mg/L)	TEMP. (C)	# ADDED	# MOVED	MORT.	TOTAL # FISH	FED	DESCRIPTION/COMMENTS

MONITORING TRIP FORM

Caged Fish Pile Driving Monitoring Trip Form

SFSU-ROMBERG TIBURON CENTER

TRIP DATA

Date_________ Time__________ Monitoring Trip ID ___________________ Vessel ________________

Crew members__________________________ Recorder ___________________________________

Pier ID__________________ Group ID _______________ Hammer ID____________________

Distance from pile________________________ Mitigation Method ___________________________

Species on board__________________ ______________ Total Number of bags________________

ENVIRONMENTAL CONDITIONS

Weather conditions: Wind________________ Clouds______________ Precipitation_____________

Secchi Disk Depth __________Waves/Surface ____

Water Quality: Surface Temp.___ Bottom Temp._____ Surface Salinity_____ Bottom Salinity__________

Additional Notes:

PILE DRIVING EXPOSURE BATCH FORM

	Caged Fish Monitoring Batch Form SFSU-ROMBERG TIBURON CENTER		
BATCH ID:			RECORDER
TANK #:			
TRIP SUMMARY DATA			
DATE		MONITORING TRIP ID	
TIME		VESSEL	
PIER ID	PILE GROUP ID		HAMMER ID
DISTANCE FROM PILE		MITIGATION METHOD	
DEPTH	SPECIES		# IN BAG
EXPOSURE DATA			
TIME IN	START@DEPTH	STOP@DEPTH	TIME OUT
DURATION		PEAK SOUND PRESSURE	
COMMENTS			
BEHAVIORAL OBSERVATIONS			
IMMEDIATE POST EXPOSURE OBSEVATIONS			
COMMENTS			
ONE HOUR MORTALITY			
COMMENTS			
24 HOUR MORTALITY			
COMMENTS			
24-48 HOUR MORTALITY			
COMMENTS			
BATCH NECROPSY SUMMARY			

FISH NECROPSY FORM

FISH NECROPSY FORM
SFSU-ROMBERG TIBURON CENTER

Today's Date		Recorder	
Dissector		Exposure Time	
Date of Trial		Mort/Bag Time	
Species	**SHSP** **RBSH**	TANK #	Standard Length = SL Fork Length = FL Total Length = TL
SL	FL	TL	

1 – no visible sign of injury
2 – slight or questionable injury
3 – visible injury
4 – severe trauma/bleeding

External Examination	1	2	3	4	Notes
Eyes					
Dorsal Fin					
Pectoral Fin					
Anal Fin					
Pelvic Fin					
Caudal Fin					
Snout/Mouth					
Gills					
Urogenital opening					
Other visible effects					
Internal Examination					
Visible blood in cavity					
Gas Bladder					
Liver					
Kidney					
Free Ribs					
Food in Intestine					
Other visible effects					
Likely Cause of Death	Barotrauma	Disease	End of Study		Other Injury
Notes:					

LENGTH FREQUENCY FORM

Lengths	Today’s Date		
Tank		**SHSP** **RBSH**	
Date/Time		**EOS**	
Standard	Fork	Total	Notes

APPENDIX B

DATABASE

Table B-1. Description of abbreviations used in the database tables below.

Treatment Group ID = Group Identification Number. M = Monitor Trip, T corresponds to the tank the fish were held in prior to and after exposure
The Group ID tracks the fish from their origin to the termination of the monitoring program.
No = The number of fish in the group. A dead fish in the transport bag will be removed before the cage is lowered.
Exp = Type of exposure or control status. HC = Holding Facility Control, CT = Control Transport. CC = Control Caged with 10 minutes no pile-driving exposure.
Ham = Size of the pile-driving hammer; S is for the 500 kJ hammer and L for the 1,700 kJ hammer
PSPL = Peak Sound Pressure Level in dB re 1 µ Pascal
Dur = Duration of exposure at depth from 1-20 minutes
Depth = Depth in meters from the surface for the cage during exposure other than the brief periods they are going up or down
Distance = Distance in meters from the pile being driven as measured with an infrared range finder from the stern of the vessel to the pile itself.
1 = Near-term mortalities or the number of fish that died within approximately one hour of the cage being brought up
24 = Delayed mortality between 1 hour and 24 hours after the cage comes up
48 = Delayed mortality between 24 hours and 48 hours after the cages comes up
Tot = The total number of fish that died within 48 hours
% = Percent of the group that are mortalities. A mortality is defined as lying on its side on the bottom with no, or little, opercular activity.

Table B-2. Summary surfperch exposure parameters and mortality.

Treatment Group ID	NO	EXP	HAM	PSPL	DUR	DPTH	DIST	1	24	48	TOT	%	COMMENTS
11/21/2003													
M01T01	29	5	L	199	5	4	42	0	0	0	0	0.00	8 out of 29 showed some sign of external injury or disease
M01T03	26	CC	NA	174	5	4	ND	0	0	0	0	0.00	
M01T04	30	CT	NA	NA	NA	NA	NA	0	0	0	0	0.00	Bag fell on deck. 1/3 exhibit fin erosion and/or head injuries
M01T05	34	HC	NA	NA	NA	NA	NA	0	0	0	0	0.00	Fish holding facility control
12/4/2003													
M02T01	29	1	L	195	1	2	105	0	1	0	1	3.45	One escaped after landing on the deck and one died that night
M02T02	28	CT	NA	NA	NA	NA	NA	0	0	0	0	0.00	Control transport
M02T03	28	5	L	186	5	2	105	0	1	1	2	7.14	One tap then stop. Waited 14 minutes then 5 min exposure
M02T05	30	CT	NA	NA	NA	NA	NA	0	0	0	0	0.00	Control transport
M02T06	29	CC	L	165	10	2	105	0	0	0	0	0.00	Cage control
12/10/2003													
M03T01	27	CC	NA	154	NA	0.25	105	0	0	0	0	0.00	Strong tidal currents pushed cage up towards surface
M03T02	30	CT	NA	NA	NA	NA	NA	0	0	0	0	0.00	Control transport
M03T03	31	5	L	188	5	4	105	0	1	1	2	6.45	One had no caudal fin. Cause of mortality for other unknown
M03T04	26	5	L	190	4:57	5	105	0	1	0	1	3.85	Disease erosion of abdominal wall in one fish.
M03T05	25	20	L	188	20:03	1	105	0	0	0	0	0.00	Pushed under boat by change in currents
12/22/2003													
M04T01	29	CT	NA	NA	NA	NA	NA	0	0	0	0	0.00	Control transport
M04T02	28	5	L	195	5:01	5	28	0	0	0	0	0.00	Started as a CC, but pile-driving started.
M04T03	31	10	L	202	9:54	5	28	0	0	0	0	0.00	Note high SPL and no mortalities
M04T04	30	3	L	203	3:01	5	28	0	1	0	1	3.33	Some internal injuries suggestive of barotrauma.
M04T05	32	1	L	200	1:52	5	28	0	0	2	2	6.25	Very rough transfer from cage.
M04T06	29	CC	L	164	10	NA	28	0	1	1	2	6.90	Degraded in tank. Peaks SPL based on M05T12 CC

Table B-2 Continued. Summary surfperch exposure parameters and mortality.

Treatment Group ID	NO	EXP	HAM	PSPL	DUR	DPTH	DIST	1	24	48	TOT		COMMENTS
1/12/2004													
M05T02	30	10	S	194	10	10	62	0	1	0	1	3.33	Indication of kidney injury, possible barotrauma or disease. Startle at 180 dB
M05T03	30	CC	NA	172	10	10	62	0	0	0	0	0.00	Cage control
M05T04	29	3	S	193	3	10	62	0	4	0	4	13.79	One may have barotrauma injury, but not cause of mortality
M05T05	33	CT	NA	NA	NA	NA	NA	0	0	0	0	0.00	Control transport
M05T06	30	HC	NA	NA	NA	NA	NA	0	0	0	0	0.00	Fish holding facility control
1/16/2004													
M06T03	29	CC	L	160	10	9	23	1	0	1	2	6.90	Cage control near term mortality. Note 166 dB at depth
M06T04	26	20	L	205	20:10	9	24	0	1	1	2	7.69	Fin erythemia, bleeding at operculum. Parasite gill injury, Startle @ 198 dB
M06T05	25	5	L	205	5	9	23	0	0	0	0	0.00	High sound pressure level and no mortalities
M06T06	30	CT	NA	NA	NA	NA	NA	0	0	0	0	0.00	High sound pressure level and no mortalities
1/24/2004													
M07T01	29	CC	L	167	10	8	24	0	0	0	0	0.00	Cage control
M07T02	29	CT	NA	NA	NA	NA	NA	0	0	0	0	0.00	Transport control
M07T04	14	1	L	190	1:04	8	25	0	0	0	0	0.00	One swimming on its side, but did not die
M07T05	14	20	L	195	25:03	8	24	0	0	0	0	0.00	Some stolen the day before exposure
1/30/2004													
M08T02	29	CT	NA	NA	NA	NA	NA	0	0	0	0	0.00	
M08T03	28	CC	S	ND	10	10	115	0	1	1	2	7.14	Erythemia at base of fins, but no exposure to pile-driving.
M08T04	28	20	S	196	20	10	73	0	0	1	1	3.57	Badly eroded fins. Startle response @ 180dB
M08T05	30	HC	NA	NA	NA	NA	NA	0	0	0	0	0.00	Fish holding facility control
Total	1044							1	13	9	23		

Table B-3. Summary of exposure parameters and mortality for steelhead.

Treatment Group ID	NO	EXP	HAM	PSPL	DUR	DPTH	DIST	1	24	48	TOT	%	COMMENTS
11/21/2003													
M01T06	15	HC	NA	NA	NA	NA	NA	0	0	0	0	0.00	Fish holding facility control
M01T07	30	CT	NA	NA	NA	NA	NA	0	2	0	2	6.67	Control transport. Both mortalities were very small
12/4/2003													
M02T07	20	10	L	194	10	2	105	0	0	0	0	0.00	8 died in cooler before exposure
M02T09	30	5	L	191	5	2	105	0	0	0	0	0.00	Intermittent pile-driving with a long delay.
M02T11	30	1	L	196	1	2	105	0	0	0	0	0.00	Some survivors had pectoral fin discoloration
M02T12	30	CT	NA	NA	NA	NA	NA	0	4	0	4	13.33	Control transport. Probably died of low dissolved oxygen (D.O.) stress or handling
12/10/2003													
M03T07	29	5	L	191	5	4	105	0	0	0	0	0.00	5.7% died the day before exposure
M03T08	30	5	L	189	5:08	5	105	0	0	1	1	3.33	Smoltification or disease. Cage on bottom as indicated by mud
M03T10	30	CT	NA	NA	NA	NA	NA	0	0	0	0	0.00	Control transport
M03T11	31	5	L	199	5:02	2	105	0	2	0	2	6.45	Purplish coloration at base of fins from disease.
M03T12	30	CC	NA	160	9:55	1	105	0	1	1	2	6.67	Dark coloration at base of fins. Probably disease
12/22/2003													
M04T07	28	10	L	192	10:59	5	28	0	0	0	0	0.00	Poor water quality in holding tanks for all M04 fish
M04T08	31	10	L	198	11:02	5	28	0	1	0	1	3.23	Pile-driving stopped then started again after a few minutes.
M04T09	27	3	L	202	3:04	5	28	0	0	0	0	0.00	All M02 survivors have some degree of internal injuries or fin rot
M04T10	32	1	L	202	1:08	5	28	0	0	2	2	6.25	Mortality was associated with tail degeneration
M04T11	29	CT	NA	NA	NA	NA	NA	0	1	0	1	3.45	Several fins badly eroded, bladder 2/3 empty.
M04T12	30	CC	NA	164	10:01	5	NA	0	4	0	4	13.33	Cage Control, but some had partially deflated swim bladders

Table B-3 Continued. Summary of exposure parameters and mortality for steelhead.

Treatment Group ID	NO	EXP	HAM	PSPL	DUR	DPTH	DIST	1	24	48	TOT	%	COMMENTS
1/12/2004													
M05T07	29	CC	S	158	10	10	310	0	0	0	0	0.00	Cage control
M05T08	30	60	S	180	60	10	314	0	0	0	0	0.00	Same SPL as M05T01
M05T09	30	3	S	192	3	10	62	0	0	0	0	0.00	All M05 fish were exposed to low SPLs
M05T10	29	10	S	191	10	10	62	0	0	0	0	0.00	All M05 fish were exposed to low SPLs
M05T11	30	CT	NA	NA	NA	NA	NA	0	0	0	0	0.00	Transport control
M05T12	30	HC	NA	NA	NA	NA	NA	0	0	0	0	0.00	Fish holding facility control
1/16/2004													
M06T08	29	CC	NA	160	10	9	23	0	0	0	0	0.00	Hydroacoustic data not available. Used M06T03 cage control data
M06T10	25	20	L	206	19:58	9	24	1	1	0	2	8.00	Possible barotrauma mortalities.
M06T12	24	5	L	205	5	9	23	0	1	0	1	4.17	1 fish found in front of tank on the ground. Some had deflated swim bladders.
1/24/2004													
M07T08	32	1	L	190	4:48	10	24	0	1	0	1	3.13	Same SPL as M07T04
M07T10	30	CT	NA	NA	NA	NA	NA	0	0	1	1	3.33	Same SPL as M07T05
M07T11	29	20	L	195	32:36	10	24	0	0	0	0	0.00	Two of the survivors had partially deflated swim bladders.
M07T12	33	CC	L	167	10.00	8	24	0	2	0	2	6.06	Estimated because SPL was below sensors threshold
1/30/2004													
M08T08	25	CT	NA	NA	NA	NA	NA	0	0	0	0	0.00	Control transport
M08T09	27	20	S	195	22	8	62	0	0	1	1	3.70	Two fish were impaired at the end of the day at the holding facility
M08T10	22	CC	S	?	9	10	115	0	0	0	0	0.00	Saw bubbles
Total	936							1	20	6	27		

Table B-4. Treatment groups with excessive numbers of non-barotrauma mortalities due to disease, parasites or handling stress. These treatment groups were eliminated from further analysis since they did not reflect effects of exposure to pile-driving.

Treatment Group ID	Species	Mortality%	Comments
M05T01	Surfperch	28.13	Mortalities due to injuries by larger steelhead
M02T04	Surfperch	9.09	50% of group had disease or injuries
M03T06	Surfperch	13.33	Excess of fish with frayed caudal fins indicative of disease
M01T08	Steelhead	24.14	Transport bag had a leak. Low D.O. stress
M01T09	Steelhead	20.00	Low D.O. stress noted before pile-driving exposure
M01T11	Steelhead	25.81	Low D.O. stress noted before pile-driving exposure
M02T08	Steelhead	46.67	Low D.O. stress. Used as control transport
M02T10	Steelhead	50.00	Low D.O. stress. Used as cage control
M03T09	Steelhead	31.03	Disease problem. 8.6% died in days before exposure
M06T09	Steelhead	15.38	Over exposure control, different cage excessive handling

APPENDIX C

STATISTICS

Test 1

H_0: Pile-driving produced no barotrauma mortalities in caged fish at various distances, durations of exposure, and SPLs.

H_a: Pile-driving produced barotrauma mortalities in caged fish at various distances, durations of exposure, and SPLs.

Test 2

H_0: Distance- There are no statistically significant immediate barotrauma effects at distances <69 meters (226 feet).

H_a: Distance- There are statistically significant immediate barotrauma effects at a distances <69 meters (226 feet).

Test 3

H_0: Distance- There are no statistically significant delayed barotrauma effects at distances >69 meters (226 feet).

H_a: Distance- There are statistically significant delayed barotrauma effects at distances >69 meters (226 feet).

Test 4

H_0: Intensity of sound- There are no statistically significant near-term barotrauma effects at SPLs between 180dB and 204dB.

H_a: Intensity of sound- There are statistically significant near-term barotrauma effects at SPLs between 180dB and 204dB.

Test 5

H_0: Intensity of sound- There are no statistically significant delayed barotrauma effects at a SPL between 204dB and 209dB.

H_a: Intensity of sound- There are statistically significant delayed barotrauma effects at a SPL between 204dB and 209dB.

Test 6

H_0: Duration of exposure- There are no statistically significant barotrauma effects at a duration <5 minutes.

H_a: Duration of exposure- There are statistically significant barotrauma effects at a duration <5 minutes.

Test 7

H_0: Duration of exposure: There are no statistically significant barotrauma effects at a duration >5 minutes.

H_a: Duration of exposure: There are statistically significant barotrauma effects at a duration >5 minutes.

Test 8

H_0: Species: There is no statistically significant difference between the rate of mortality for the steelhead compared to the surfperch.

H_a: Species: There is a statistically significant difference between the rate of mortality of the steelhead compared to the surfperch.

Test 9

H_0: Size: There is no statistically significant difference between the rate of mortality for the size of survivors compared to the size of the fish that were mortalities.

H_a: Size: There is a statistically significant difference in the rate of mortality for the size of the survivors compared to the size of the fish that were mortalities.

Test 10

H_0: Depth: There is no statistically significant difference between the rate of mortality for the depths of 4 meters (13 feet) or less compared to depths greater than 4 meters (13 feet).

H_a: Depth: There is a statistically significant difference in the rate of mortality for depths of 4 meters (13 feet) of less compared to depths greater than 4 meters (13 feet).

Notes:

1. All of the control and treatment data are presented as percent mortality.

2. All statistical analyses were carried our using the Student's t-test at a 5% level of significance.

3. All tests are paired test between treatment and control groups.

Table C-1. Parameters: Treatment mortality vs. control mortality. Distance, duration, SPL.
Species: Surfperch

	Control Groups			Treatment Groups					
Replicate/ID	1hr % mort	24hr % mort	48hr % mort	1hr % mort	24hr % mort	48hr % mort	Distance (m)	Duration (min)	dB
21-Nov M01T01	0	0	0	0	0	0	42	5	199
4-Dec M02T01	0	0	0	0	3.45	3.45	105	1	195
4-Dec M02T03				0	3.51	7.14	105	5	186
10-Dec M03T03	0	0	0	0	3.23	6.45	105	5	188
10-Dec M03T04				0	3.85	3.85	105	5	190
10-Dec M03T05				0	0	0	105	20	188
22-Dec M04T05	0	3.45	6.9	0	0	6.25	28	1	200
22-Dec M04T04				0	3.33	3.33	28	3	203
22-Dec M04T03				0	0	0	28	5	202
22-Dec M04T02				0	0	0	28	10	195
12-Jan M05T04	0	0	0	0	13.79	13.79	62	3	193
12-Jan M05T02				0	3.33	3.33	62	10	194
16-Jan M06T05	3.45	3.45	6.9	0	0	0	24	5	205
16-Jan M06T04				0	3.85	7.69	24	20	205
24-Jan M07T04	0	0	0	0	0	0	25	1	190
24-Jan M07T05				0	0	0	25	20	195
30-Jan M08T04	0	3.51	7.14	0	0	3.57	73	20	196
N=	8	8	8	17	17	17			
Mean=	0.43	1.30	2.62	0.00	2.26	3.46			
Variance=	1.49	3.23	13.06	0.00	11.89	14.93			
df=	7	7	7	16	16	16			
Stdev	1.22	1.80	3.61	0.00	3.45	3.86			
HoV=				NC	0.271	0.874			
Sum DF=				23	23	23			
t-calc=				**1.396**	**0.683**	**0.485**			
t-critical				**2.069**	**2.069**	**2.069**			
Significant?				No	No	No			

Table C-2. Test parameter: Treatment mortality vs. control. Within 69 meters of pile-driving
Species: Surfperch.

	Control Groups			Treatment Groups			
Replicate/ID	1 hr % mort	24 hr % mort	48 hr % mort	1 hr % mort	24 hr % mort	48hr % mort	Distance (m)
21-Nov M01T01	0	0	0	0	0	0	42
22-Dec M04T05	0	3.45	6.9	0	0	6.25	28
22-Dec M04T04				0	3.33	3.33	28
22-Dec M04T02				0	0	0	28
22-Dec M04T03				0	0	0	28
12-Jan M05T04	0	0	0	0	13.79	13.79	62
12-Jan M05T02				0	3.33	3.33	62
16-Jan M06T04	3.45	3.45	6.9	0	0	0	24
16-Jan M06T04				0	3.85	7.69	24
24-Jan M07T04	0	0	0	0	0	0	25
24-Jan M07T05				0	0	0	25
N=	5	5	5	11	11	11	
Mean=	0.69	1.38	2.76	0.00	2.21	3.13	
Variance=	2.38	3.57	14.28	0.00	17.35	20.30	
df=	4	4	4	10	10	10	
Stdev	1.54	1.89	3.78	0.00	4.17	4.51	
HoV=				NC	0.206	0.704	
Sum DF=				14	14	14	
t-calc=				**1.381**	**0.374**	**0.933**	
t-critical				**2.145**	**2.145**	**2.145**	
Significant?				No	No	No	

Table C-3. Parameter: Treatment mortality vs. control. Beyond 69 meters from pile-driving
Species: Surfperch.

	Control Groups			Treatment Groups			
Replicate/Id	1 hr %mort	24hr %mort	48hr % mort	1 hr %mort	24 hr %mort	48 hr %mort	Distance (m)
4-Dec M02T01	0	0	0	0	3.45	3.45	105
4-Dec M02T03				0	3.51	7.14	105
10-Dec M03T03	0	0	0	0	3.23	6.45	105
10-Dec M03T04				0	3.85	3.85	105
10-Dec M03T05				0	0	0	105
30-Jan M08T04	0	3.51	7.14	0	0	3.57	73
N=	3	3	3	6	6	6	
Mean=	0.00	1.17	2.38	0.00	2.34	4.08	
Variance=	0.00	4.11	16.99	0.00	3.32	6.47	
df=	2	2	2	5	5	5	
Stdev	0.00	2.03	4.12	0.00	1.82	2.54	
HoV=				NC	1.235	2.628	
Sum DF=				7	7	7	
t-calc=				**0.000**	**0.704**	**1.478**	
t-critical				**2.365**	**2.365**	**2.365**	
Significant?				No	No	No	

Table C-4. Parameter: Treatment mortality vs. control mortality. Exposure duration <5 minutes.
Species: Surfperch.

	Control Groups			Treatment Groups			
Replicate/ID	1hr % mort	24hr % mort	48hr % mort	1hr % mort	24hr % mort	48hr % mort	Duration (min)
21-Nov M01T01	0	0	0	0	0	0	5
4-Dec M02T01	0	0	0	0	3.45	3.45	1
4-Dec M02T03				0	3.51	7.14	5
10-Dec M03T03	0	0	0	0	3.23	6.45	5
10-Dec M03T04				0	3.85	3.85	5
22-Dec M04T05	0	3.45	6.9	0	0	6.25	1
22-Dec M04T04				0	3.33	3.33	3
22-Dec M04T03				0	0	0	5
12-Jan M05T04	0	0	0	0	13.79	13.79	3
16-Jan M06T05	3.45	3.45	6.9	0	0	0	5
24-Jan M07T04	0	0	0	0	0	0	1
N=	7	7	7	11	11	11	
Mean=	0.49	0.99	1.97	0.00	2.83	4.02	
Variance=	1.70	2.83	11.34	0.00	16.25	18.15	
df=	6	6	6	10	10	10	
Stdev	1.30	1.68	3.37	0.00	4.03	4.26	
HoV=				NC	0.174	0.624	
Sum DF=				16	16	16	
t-calc=				**1.178**	**1.052**	**0.991**	
t-critical				**2.120**	**2.120**	**2.120**	
Significant?				No	No	No	

Table C-5. Parameter: Treatment group mortality vs. control group mortality. Exposure duration >5 minutes. Species: Surfperch

	Control Groups			Treatment Groups			
Replicate/ID	1hr %mort	24hr %mort	48hr% mort	1hr %mort	24hr %mort	48hr %mort	Duration (min)
10-Dec M03T05	0	0	0	0	0	0	20
22-Dec M04T06	0	3.45	6.9	0	0	0	10
12-Jan M05T02	0	0	0	0	3.33	3.33	10
16-Jan M06T04	3.45	3.45	6.9	0	3.85	7.69	20
24-Jan M07T01	0	0	0	0	0	0	20
30-Jan M07T04	0	3.51	7.14	0	0	3.57	20
N=	6	6	6	6	6	6	
Mean=	0.58	1.74	3.49	0.00	1.20	2.43	
Variance=	1.98	3.61	14.62	0.00	3.46	9.50	
df=	5	5	5	5	5	5	
Stdev	1.41	1.90	3.82	0.00	1.86	3.08	
HoV=				NC	1.043	1.540	
Sum DF=				10	10	10	
t-calc=				**0.905**	**0.448**	**0.477**	
t-critical				**2.228**	**2.228**	**2.228**	
Significant?				No	No	No	

Table C-6. Parameter: Treatment group mortality vs. control group mortality. SPLs 180dB - 204dB.
Species: Surfperch.

	Control Groups			Treatment Groups			
Replicate/ID	1hr % mort	24hr % mort	48hr % mort	1hr % mort	24hr % mort	48hr % mort	dB
21-Nov M01T01	0	0	0	0	0	0	199
4-Dec M02T01	0	0	0	0	3.45	3.45	195
4-Dec M02T03				0	3.51	7.14	186
10-Dec M03T03	0	0	0	0	3.23	6.45	188
10-Dec M03T04				0	3.85	3.85	190
10-Dec M03T05				0	0	0	188
22-Dec M04T05	0	3.45	6.9	0	0	6.25	200
22-Dec M04T04				0	3.33	3.33	203
22-Dec M04T03				0	0	0	202
22-Dec M04T02				0	0	0	195
12-Jan M05T04	0	0	0	0	13.79	13.79	193
12-Jan M05T02				0	3.33	3.33	194
24-Jan M07T04	0	0	0	0	0	0	190
24-Jan M07T05				0	0	0	195
30-Jan M08T04	0	3.51	7.14	0	0	3.57	196
N=	7	7	7	15	15	15	
Mean=	0.00	0.99	2.01	0.00	2.30	3.41	
Variance=	0.00	2.88	11.74	0.00	13.04	14.93	
df=	6	6	6	14	14	14	
Stdev	0.00	1.70	3.43	0.00	3.61	3.86	
HoV=				NC	0.221	0.786	
Sum DF=				20	20	20	
t-calc=				**0.000**	**0.833**	**0.758**	
t-critical				**2.086**	**2.086**	**2.086**	
Significant?				No	No	No	

Table C-7. Parameter: Treatment group mortality vs. control group mortality SPL > 204dB, insufficient data.
Species: Surfperch.

	Control Groups			Treatment Groups			
Replicate/ID	1hr % mort	24hr % mort	48hr % mort	1hr % mort	24hr % mort	48hr % mort	dB
16-Jan M06T05	3.45	3.45	6.9	0	0	0	205
16-Jan M06T04				0	3.85	7.69	205
N=	1	1	1	2	2	2	
Mean=	3.45	3.45	6.90	0.00	1.93	3.85	
Variance=	NC	NC	NC	0.00	7.41	29.57	
df=	NC	NC	NC	1	1	1	
Stdev	NC	NC	NC	0.00	2.72	5.44	
HoV=				NC	NC	NC	
Sum DF=				NC	NC	NC	
t-calc=				**NC**	**NC**	**NC**	
t-critical				NC	NC	NC	
Significant?				NC	No	No	

NC: Not calculated

Table C-8. Parameter: Treatment group mortality vs. control group mortality. Duration, distance, and SPL. Species: Steelhead.

	Control Groups			Treatment Groups					
Replicate/ID	1hr % mort	24hr % mort	48hr % mort	1hr % mort	24hr % mort	48hr % mort	Distance (m)	Duration (min)	dB
4-Dec M02T11	0	13.3	13.3	0	0	0	105	1	196
4-Dec M02T09				0	0	0	105	5	191
4-Dec M02T07				0	0	0	105	10	194
10-Dec M03T07	0	3.33	6.67	0	0	0	105	5	191
10-Dec M03T08				0	3.33	3.33	105	5	189
10-Dec M03T11				0	6.45	6.45	105	5	199
22-Dec M04T10	0	13.33	13.33	0	0	6.25	28	1	202
22-Dec M04T09				0	3.33	3.33	28	3	202
22-Dec M04T08				0	3.23	3.23	28	10	198
22-Dec M04T07				0	0	0	28	10	192
12-Jan M05T09	0	0	0	0	0	0	62	3	192
12-Jan M05T10				0	0	0	62	10	191
12-Jan M05T08				0	0	0	314	60	180
16-Jan M06T12	0	0	0	0	4.17	0	24	5	205
16-Jan M06T10				4	8	8	24	20	206
24-Jan M07T08	0	6.06	6.06	0	3.13	3.13	24	1	190
24-Jan M07T11				0	0	0	24	20	195
30-Jan M08T09	0	0	0	0	3.7	3.7	115	20	195
N=	7	7	7	18	18	18			
Mean=	0.00	5.15	5.62	0.22	1.96	2.08			
Variance=	0.00	36.17	35.75	0.89	6.45	7.23			
df=	6	6	6	17	17	17			
Stdev	0.00	6.01	5.98	0.94	2.54	2.69			
HoV=				NC	5.606	4.942			
Sum DF=				23	23	23			
t-calc=				**0.569**	**1.752**	**1.920**			

t-critical	5% LOS, one-tailed			**2.070**	**2.070**	**2.070**
Significant?				No	No	No

Table C-9. Parameter: Treatment group mortality vs. control group mortality. Within 69 meters of pile-driving.
Species: Steelhead.

	Control Groups			Treatment Groups			
Replicate/ID	1hr % mort	24hr % mort	48hr % mort	1hr % mort	24hr % mort	48hr % mort	Distance (m)
22-Dec M04T10	0	13.33	13.33	0	0	6.25	28
22-Dec M04T07				0	0	0	28
22-Dec M04T08				0	3.23	3.23	28
22-Dec M04T09				0	3.33	3.33	28
12-Jan M05T09	0	0	0	0	0	0	62
12-Jan M05T10				0	0	0	62
16-Jan M06T12	0	0	0	0	4.17	0	24
16-Jan M06T10				4	8	8	24
24-Jan M07T08	0	6.06	6.06	0	3.13	3.13	24
24-Jan M07T11				0	0	0	24
N=	4	4	4	10	10	10	
Mean=	0.00	4.85	4.85	0.40	2.19	2.39	
Variance=	0.00	40.14	40.14	1.60	7.21	8.56	
df=	3	3	3	9	9	9	
Stdev	0.00	6.34	6.34	1.26	2.69	2.93	
HoV=				NC	5.565	4.687	
Sum DF=				12	12	12	
t-calc=				**1.000**	**1.148**	**0.880**	
t-critical	5% LOS, one-tailed			**2.180**	**2.180**	**2.180**	
Significant?				No	No	No	

Table C-10. Parameter: Treatment group mortality vs. control group mortality. Beyond 69 meters of pile-driving. Species: Steelhead.

	Control Groups			Treatment Groups			
Replicate/ID	1hr % mort	24hr mort	48hr % mort	1hr % mort	24hr % mort	48hr % mort	Distance (m)
4-Dec M02T07	0	13.3	13.3	0	0	0	105
4-Dec M02T09				0	0	0	105
4-Dec M02T11				0	0	0	105
10-Dec M03T07	0	3.33	6.67	0	0	0	105
10-Dec M03T08				0	3.33	3.33	105
10-Dec M03T11				0	6.45	6.45	105
10-Dec M03T12				0	3.33	6.67	105
12-Jan M05T08				0	0	0	314
30-Jan M08T10	0	0	0	0	3.7	3.7	115
N=	3	3	3	9	9	9	
Mean=	0.00	5.54	6.66	0.00	1.87	2.24	
Variance=	0.00	47.90	44.22	0.00	5.76	8.22	
df=	2	2	2	8	8	8	
Stdev	0.00	6.92	6.65	0.00	2.40	2.87	
HoV=				NC	8.317	5.380	
Sum DF=				10	10	10	
t-calc=				**0.000**	**1.184**	**1.365**	
t-critical	5% LOS, one-tailed			**2.230**	**2.230**	**2.230**	
Significant?				No	No	No	

Table C-11. Parameter: Treatment group mortality vs. control group mortality. Exposure duration less than 5 minutes. Species: Steelhead.

	Control Groups			Treatment Groups			
Replicate/ID	1hr % mort	24hr % mort	48hr % mort	1hr % mort	24hr % mort	48hr % mort	Duration (min)
4-Dec M02T11	0	13.3	13.3	0	0	0	1
4-Dec M02T09				0	0	0	5
10-Dec M03T07	0	3.33	6.67	0	0	0	5
10-Dec M03T08				0	3.33	3.33	5
10-Dec M03T11				0	6.45	6.45	5
22-Dec M04T10	0	13.33	13.33	0	0	6.25	1
22-Dec M04T09				0	3.33	3.33	3
12-Jan M05T09	0	0	0	0	0	0	3
16-Jan M06T12	0	0	0	0	4.17	0	5
24-Jan M07T08	0	6.06	6.06	0	3.13	3.13	1
N=	6	6	6	10	10	10	
Mean=	0.00	6.00	6.56	0.00	2.04	2.25	
Variance=	0.00	37.23	35.52	0.00	5.48	6.90	
df=	5	5	5	9	9	9	
Stdev	0.00	6.10	5.96	0.00	2.34	2.63	
HoV=				NC	6.795	5.151	
Sum DF=				14	14	14	
t-calc=				**NC**	**1.700**	**1.833**	
t-critical	5% LOS, one-tailed			**2.148**	**2.148**	**2.148**	
Significant?				No	No	No	

Table C-12. Parameter: Treatment group mortality vs. control group mortality. Exposure durations more than 5 minutes. Species: Steelhead.

	Control Group			Treatment Group			
Replicate/ID	1hr % mort	24hr % mort	48hr % mort	1hr % mort	24hr % mort	48 hr % mort	Duration (min)
4-Dec M02T07	0	13.3	13.3	0	0	0	10
10-Dec M03T12	0	3.33	6.67	0	3.33	6.67	30
22-Dec M04T08				0	3.23	3.23	10
22-Dec M04T07	0	13.33	13.33	0	0	0	10
12-Jan M05T10	0	0	0	0	0	0	10
12-Jan M05T08	0	0	0	0	0	0	60
16-Jan M06T10	0	0	0	4	8	8	20
24-Jan M07T11	0	6.06	6.06	0	0	0	20
30-Jan M08T09	0	0	0	0	3.7	3.7	20
N=	8	8	8	9	9	9	
Mean=	0.00	4.50	4.92	0.44	2.03	2.40	
Variance=	0.00	34.32	34.59	1.78	7.77	10.10	
df=	7	7	7	8	8	8	
Stdev	0.00	5.86	5.88	1.33	2.79	3.18	
HoV=				NC	4.416	3.426	
Sum DF=				15	15	15	
t-calc=				**0.875**	**1.056**	**1.041**	
t-critical	5% LOS, one-tailed			**2.132**	**2.132**	**2.132**	
Significant?				No	No	No	

Table C-13. Parameter: Treatment group mortality vs. control group mortality. SPLs 180dB - 204dB.
Species: Steelhead.

	Control Groups			Treatment Groups			
Replicate/ID	1hr % mort	24hr % mort	48hr % mort	1hr % mort	24hr % mort	48hr % mort	dB
4-Dec M02T11	0	13.3	13.3	0	0	0	196
4-Dec M02T09				0	0	0	191
4-Dec M02T07				0	0	0	194
10-Dec M03T07	0	3.33	6.67	0	0	0	191
10-Dec M03T08				0	3.33	3.33	189
10-Dec M03T11				0	6.45	6.45	199
22-Dec M04T10	0	13.33	13.33	0	0	6.25	202
22-Dec M04T09				0	3.33	3.33	202
22-Dec M04T08				0	3.23	3.23	198
22-Dec M04T07				0	0	0	192
12-Jan M05T09	0	0	0	0	0	0	192
12-Jan M05T10				0	0	0	191
12-Jan M05T08				0	0	0	180
24-Jan M07T08	0	6.06	6.06	0	3.13	3.13	190
24-Jan M07T11				0	0	0	195
30-Jan M08T09	0	0	0	0	3.7	3.7	195
N=	6	6	6	16	16	16	
Mean=	0.00	6.00	6.56	0.00	1.45	1.84	
Variance=	0.00	37.23	35.52	0.00	4.28	5.51	
Df=	5	5	5	15	15	15	
Stdev	0.00	6.10	5.96	0.00	2.07	2.35	
HoV=				NC	8.706	6.445	
Sum DF=				20	20	20	
t-calc=				**NC**	**2.538**	**2.490**	
t-critical	5% LOS, one-tailed			**2.086**	**2.086**	**2.086**	
Significant?				Yes	Yes	Yes	

Note: control mortality exceeded treatment mortality at 24 and 48 hrs

Table C-14. Parameter: Treatment group mortality vs. control group mortality. SPLs > 204dB. Insufficient data.
Species: Steelhead.

	Control Groups			Treatment Groups			
Replicate/ID	1hr % mort	24hr % mort	48hr % mort	1hr % mort	24hr % mort	48hr % mort	dB
16-Jan M06T12	0	0	0	0	4.17	0	205
16-Jan M06T10				4	8	8	206
N=	1	1	1	2	2	2	
Mean=	0.00	0.00	0.00	2.00	6.09	4.00	
Variance=	NC	NC	NC	8.00	7.33	32.00	
Df=	NC	NC	NC	1	1	1	
Stdev	NC	NC	NC	2.83	2.71	5.66	
HoV=				NC	NC	NC	
Sum DF=				NC	NC	NC	
t-calc=				NC	NC	NC	
t-critical	5% LOS, one-tailed			NC	NC	NC	
NC: Not Calculated							

Table C-15. Parameter: Treatment group mortality vs. control group mortality. Distance, duration, SPL.
Species: Surfperch and Steelhead.

	Control Groups			Treatment Groups					
Replicate/ID	1hr %mort	24hr %mort	48hr %mort	1hr %mort	24hr %mort	48 hr %mort	Distance (m)	Duration (min)	dB
Surfperch									
21-Nov M01T01	0	0	0	0	0	0	42	5	199
4-Dec M02T01	0	0	0	0	3.45	3.45	105	1	195
4-Dec M02T03				0	3.51	7.14	105	5	186
10-Dec M03T03	0	0	0	0	3.23	6.45	105	5	188
10-Dec M03T04				0	3.85	3.85	105	5	190
10-Dec M03T05				0	0	0	105	20	188
22-Dec M04T05	0	3.45	6.9	0	0	6.25	28	1	200
22-Dec M04T04				0	3.33	3.33	28	3	203
22-Dec M04T03				0	0	0	28	5	202
22-Dec M04T02				0	0	0	28	10	195
12-Jan M05T04	0	0	0	0	13.79	13.79	62	3	193
12-Jan M05T02				0	3.33	3.33	62	10	194
16-Jan M06T05	3.45	3.45	6.9	0	0	0	24	5	205
16-Jan M06T04				0	3.85	7.69	24	20	205
24-Jan M07T04	0	0	0	0	0	0	25	1	190
24-Jan M07T05				0	0	0	25	20	195
30-Jan M08T04	0	3.51	7.14	0	0	3.57	73	20	196
Steelhead									
4-Dec M02T11	0	13.3	13.3	0	0	0	105	1	196
4-Dec M02T09				0	0	0	105	5	191
4-Dec M02T07				0	0	0	105	10	194
10-Dec M03T07	0	3.33	6.67	0	0	0	105	5	191
10-Dec M03T08				0	3.33	3.33	105	5	189
10-Dec M03T11				0	6.45	6.45	105	5	199

22-Dec M04T10	0	13.33	13.33	0	0	6.25	28	1	202
22-Dec M04T09				0	3.33	3.33	28	3	202
22-Dec M04T08				0	3.23	3.23	28	10	198
22-Dec M04T07				0	0	0	28	10	192
12-Jan M05T09	0	0	0	0	0	0	62	3	192
12-Jan M05T10				0	0	0	62	10	191
12-Jan M05T08				0	0	0	314	60	180
16-Jan M06T12	0	0	0	0	4.17	0	24	5	205
16-Jan M06T10				4	8	8	24	20	206
24-Jan M07T08	0	6.06	6.06	0	3.13	3.13	24	1	190
24-Jan M07T11				0	0	0	24	20	195
30-Jan M08T09	0	0	0	0	3.7	3.7	115	20	195
N=	15	15	15	34	34	34			
Mean=	0.23	3.10	4.02	0.11	2.11	2.75			
Variance=	0.79	21.06	24.26	0.46	8.84	11.13			
df=	14	14	14	33	33	33			
Stdev	0.89	4.59	4.93	0.68	2.97	3.34			
HoV=				1.736	1.470	1.462			
Sum DF=				47	47	47			
t-calc=				**0.483**	**0.873**	**1.020**			
t-critical				**2.020**	**2.020**	**2.020**			
Significant?				No	No	No			

Table C-16. Parameter: Treatment mortality vs. control mortality. Within 69 meters of pile-driving.
Species: Surfperch and Steelhead.

	Control Groups			Treatment Groups			
Replicate/ID	1hr % mort	24hr % mort	48hr % mort	1hr % mort	24hr % mort	48 hr % mort	Distance (m)
Surfperch							
12-Nov M01T01	0	0	0	0	0	0	42
22-Dec M04T05	0	3.45	6.9	0	0	6.25	28
22-Dec M04T04				0	3.33	3.33	28
22-Dec M04T02				0	0	0	28
22-Dec M04T03				0	0	0	28
12-Jan M05T04	0	0	0	0	13.79	13.79	62
12-Jan M05T02				0	3.33	3.33	62
16-Jan M06T05	3.45	3.45	6.9	0	0	0	24
16-Jan M06T04				0	3.85	7.69	24
24-Jan M07T04	0	0	0	0	0	0	25
24-Jan M07T05				0	0	0	25
Steelhead							
22-Dec M04T10	0	13.33	13.33	0	0	6.25	28
22-Dec M04T09				0	3.33	3.33	28
22-Dec M04T08				0	3.23	3.23	28
22-Dec M04T07				0	0	0	28
12-Jan M05T09	0	0	0	0	0	0	62
12-Jan M05T10				0	0	0	62
16-Jan M06T12	0	0	0	0	4.17	0	24
16-Jan M06T10				4	8	8	24
24-Jan M07T08	0	6.06	6.06	0	3.13	3.13	24
24-Jan M07T11				0	0	0	24
N=	9	9	9	20	20	20	
Mean=	0.38	2.92	3.69	0.19	2.20	2.78	
Variance=	1.32	20.18	23.40	0.76	11.92	14.15	

df=	8	8	8	19	19	19
Stdev	1.15	4.49	4.84	0.87	3.45	3.76
HoV=				1.736	1.329	1.328
Sum DF=				27	27	27
t-calc=				**0.470**	**0.447**	**0.520**
t-critical				**2.050**	**2.050**	**2.050**
Significant?				No	No	No

Table C-17. Parameter: Treatment group mortality vs. Control Group mortality. Beyond 69 meters from pile–driving. Species: Surfperch and Steelhead.

	Control Groups			Treatment Groups			
Replicate/ID	1hr % mort	24hr % mort	48hr % mort	1hr % mort	24hr % mort	48hr % mort	Distance (m)
Surfperch							
4-Dec M02T02	0	0	0	0	3.45	3.45	105
4-Dec M02T03				0	3.51	7.14	105
10-Dec M03T03	0	0	0	0	3.23	6.45	105
10-Dec M03T04				0	3.85	3.85	105
10-Dec M03T05				0	0	0	105
30-Jan M08T04	0	3.51	7.14	0	0	3.57	73
Steelhead							
4-Dec M02T07	0	13.3	13.3	0	0	0	105
4-Dec M02T09				0	0	0	105
4-Dec M02T11				0	0	0	105
10-Dec M03T07	0	3.33	6.67	0	0	0	105
10-Dec M03T08				0	3.33	3.33	105
10-Dec M03T11				0	6.45	6.45	105
12-Jan M05T08				0	0	0	314
30-Jan M08T09	0	0	0	0	3.7	3.7	115
N=	6	6	6	14	14	14	
Mean=	0.00	3.36	4.52	0.00	1.97	2.71	
Variance=	0.00	26.54	29.97	0.00	4.75	7.36	
df=	5	5	5	13	13	13	
Stdev	0.00	5.15	5.47	0.00	2.18	2.71	
HoV=				0.000	1.708	1.667	
Sum DF=				18	18	18	
t-calc=				**NC**	**0.789**	**0.913**	
t-critical				**NC**	**2.100**	**2.100**	
Significant?				**No**	**No**	**No**	

Table C-18. Parameter: Treatment group mortality vs. control group. Exposure duration less than 5 minutes.
Species: Surfperch and Steelhead.

	Control Groups			Treatment Groups			
Replicate/ID	1hr % mort	24hr % mort	48hr % mort	1hr % mort	24hr % mort	48hr % mort	Duration (min)
Surfperch							
21-Nov M01T01	0	0	0	0	0	0	5
4-Dec M02T01	0	0	0	0	3.45	3.45	1
4-Dec M02T03				0	3.51	7.14	5
10-Dec M03T03	0	0	0	0	3.23	6.45	5
10-Dec M03T04				0	3.85	3.85	5
22-Dec M04T05	0	3.45	6.9	0	0	6.25	1
22-Dec M04T04				0	3.33	3.33	3
22-Dec M04T02				0	0	0	5
12-Jan M05T04	0	0	0	0	13.79	13.79	3
16-Jan M06T05	3.45	3.45	6.9	0	0	0	5
24-Jan M07T04	0	0	0	0	0	0	1
Steelhead							
4-Dec M02T11	0	13.3	13.3	0	0	0	1
4-Dec M02T09				0	0	0	5
10-Dec M03T07	0	3.33	6.67	0	0	0	5
10-Dec M03T08				0	3.33	3.33	5
10-Dec M03T11				0	6.45	6.45	5
22-Dec M04T10	0	13.33	13.33	0	0	6.25	1
22-Dec M04T09				0	3.33	3.33	3
12-Jan M05T09	0	0	0	0	0	0	3
16-Jan M06T12	0	0	0	0	4.17	0	5
24-Jan M07T08	0	6.06	6.06	0	3.13	3.13	1
N=	13	13	13	21	21	21	
Mean=	0.27	3.30	4.09	0.00	2.46	3.18	

Variance=	0.92	23.71	26.14	0.00	10.75	13.00
Df=	12	12	12	20	20	20
Stdev	0.96	4.87	5.11	0.00	3.28	3.61
HoV=				#DIV/0!	1.344	1.286
Sum DF=				32	32	32
t-calc=				**1.232**	**0.582**	**0.585**
t-critical				**2.040**	**2.040**	**2.040**
Significant?				No	No	No

Table C-19. Parameter: Treatment group mortality vs. Control group mortality. Exposure durations more than 5 minutes. Species: Surfperch and Steelhead.

	Control Groups			Treatment Groups			
Replicate/ID	1hr % mort	24hr % mort	48 hr % mort	1hr % mort	24hr % mort	48 hr % mort	Duration (min)
Surfperch							
10-Dec M03T05	0	0	0	0	0	0	20
22-Dec M04T03	0	3.45	6.9	0	0	0	10
12-Jan M05T02	0	0	0	0	3.33	3.33	10
16-Jan M06T04	3.45	3.45	6.9	0	3.85	7.69	20
24-Jan M07T05	0	0	0	0	0	0	20
30-Jan M08T04	0	3.51	7.14	0	0	3.57	20
Steelhead							
4-Dec M02T07	0	13.3	13.3	0	0	0	10
22-Dec M04T08	0	13.33	13.33	0	3.23	3.23	10
22-Dec M04T07	0	13.33	13.33	0	0	0	10
12-Jan M05T10	0	0	0	0	0	0	10
12-Jan M05T08	0	0	0	0	0	0	60
16-Jan M06T10	0	0	0	4	8	8	20
24-Jan M07T11	0	6.06	6.06	0	0	0	20
30-Jan M08T09	0	0	0	0	3.7	3.7	20
N=	13	13	13	13	13	13	
Mean=	0.25	4.03	4.78	0.29	1.58	2.11	
Variance=	0.85	29.05	30.38	1.14	6.09	8.37	
Df=	12	12	12	12	12	12	
Stdev	0.92	5.39	5.51	1.07	2.47	2.89	
HoV=				0.744	2.552	2.268	
Sum DF=				24	24	24	
t-calc=			**t-calc**	**0.096**	**1.430**	**1.486**	
t-critical			**t-crit**	**2.060**	**2.060**	**2.060**	
Significant?				No	No	No	

Table C-20. Parameter: Treatment group mortality vs. control group mortality. SPLs 180dB – 204dB.
Species: Surfperch and Steelhead.

	Control Groups			Treatment Groups			
Replicate/ID	1hr % mort	24hr % mort	48hr % mort	1hr % mort	24hr % mort	48hr % mort	dB
Surfperch							
21-Nov M01T01	0	0	0	0	0	0	199
4-Dec M02T01	0	0	0	0	3.45	3.45	195
4-Dec M02T03				0	3.51	7.14	186
10-Dec M03T03	0	0	0	0	3.23	6.45	188
10-Dec M03T04				0	3.85	3.85	190
10-Dec M03T05				0	0	0	188
22-Dec M04T05	0	3.45	6.9	0	0	6.25	200
22-Dec M04T04				0	3.33	3.33	203
22-Dec M04T03				0	0	0	202
22-Dec M04T02				0	0	0	195
12-Jan M05T04	0	0	0	0	13.79	13.79	193
12-Jan M05T02				0	3.33	3.33	194
24-Jan M07T04	0	0	0	0	0	0	190
24-Jan M07T05				0	0	0	195
30-Jan M08T04	0	3.51	7.14	0	0	3.57	196
Steelhead							
4-Dec M02T11	0	13.3	13.3	0	0	0	196
4-Dec M02T09				0	0	0	191
4-Dec M02T07				0	0	0	194
4-Dec M02T09	0	3.33	6.67	0	0	0	191
10-Dec M03T08				0	3.33	3.33	189
10-Dec M03T11				0	6.45	6.45	199
22-Dec M04T10	0	13.33	13.33	0	0	6.25	202
22-Dec M04T09				0	3.33	3.33	202
22-Dec				0	3.23	3.23	198

M04T08							
22-Dec M04T07				0	0	0	192
12-Jan M05T09	0	0	0	0	0	0	192
12-Jan M05T10				0	0	0	191
12-Jan M05T08				0	0	0	180
24-Jan M07T08	0	6.06	6.06	0	3.13	3.13	190
24-Jan M07T11				0	0	0	195
30-Jan M08T09	0	0	0	0	3.7	3.7	195
N=	13	13	13	30	30	30	
Mean=	0.00	3.31	4.11	0.00	1.86	2.60	
Variance=	0.00	23.71	26.25	0.00	8.41	10.36	
df=	12	12	12	29	29	29	
Stdev	0.00	4.87	5.12	0.00	2.90	3.22	
HoV=				NC	1.778	1.580	
Sum DF=				41	41	41	
t-calc=				**NC**	**1.165**	**1.126**	
t-critical				**NC**	**2.020**	**2.020**	
Significant?				No	No	No	

Table C-21. Parameter: Treatment group mortality vs. control group mortality. SPLs >204dB. Species: Surfperch and Steelhead.

	Control Groups			Treatment Groups			
Replicate/ID	1hr % mort	24hr % mort	48hr % mort	1hr % mort	24hr % mort	48hr % mort	dB
Surfperch							
16-Jan M06T05	3.45	3.45	6.9	0	0	0	205
16-Jan M06T04				0	3.85	7.69	205
Steelhead							
16-Jan M06T12	0	0	0	0	4.17	0	205
16-Jan M06T10				4	8	8	206
N=	2	2	2	4	4	4	
Mean=	1.73	1.73	3.45	1.00	4.01	3.92	
Variance=	5.95	5.95	23.81	4.00	10.68	20.53	
Df=	1	1	1	3	3	3	
Stdev	2.44	2.44	4.88	2.00	3.27	4.53	
HoV=				1.488	0.431	0.880	
Sum DF=				4	4	4	
t-calc=				**0.265**	**0.573**	**0.079**	
t-critical				**2.770**	**2.770**	**2.770**	
Significant?				No	No	No	

Table C-22. Parameter: Treatment group mortality vs. control group mortality. Exposure duration multiplied by SPL (D*dB). D*dB < 1000. Species: Surfperch and Steelhead.

	Control Groups			Treatment Groups					
Replicate/ID	1hr %mort	24hr %mort	48hr %mort	1hr %mort	24hr %mort	48hr %mort	Duration (min)	dB	D*dB
Surfperch									
21-Nov M01T01	0	0	0	0	0	0	5	199	995
4-Dec M02T01	0	0	0	0	3.45	3.45	1	195	195
4-Dec M02T03	0	0	0	0	3.51	7.14	5	186	930
10-Dec M03T03	0	0	0	0	3.23	6.45	5	188	940
10-Dec M03T04	0	0	0	0	3.85	3.85	5	190	950
22-Dec M04T05	0	3.45	6.9	0	0	6.25	1	200	200
22-Dec M04T04	0	3.45	6.9	0	3.33	3.33	3	203	609
12-Jan M05T04	0	0	0	0	13.79	13.79	3	193	579
24-Jan M07T04	0	0	0	0	0	0	1	190	190
Steelhead									
4-Dec M02T11	0	13.3	13.3	0	0	0	1	196	196
4-Dec M02T09	0	13.3	13.3	0	0	0	5	191	955
10-Dec M03T07	0	3.33	6.67	0	0	0	5	191	955
10-Dec M03T08	0	3.33	6.67	0	3.33	3.33	5	189	945
10-Dec M03T11	0	3.33	6.67	0	6.45	6.45	5	199	995
22-Dec M04T10	0	13.33	13.33	0	0	6.25	1	202	202
22-Dec M04T09	0	13.33	13.33	0	3.33	3.33	3	202	606
22-Dec M04T07	0	0	0	0	0	0	3	192	576
24-Jan M07T08	0	6.06	6.06	0	3.13	3.13	1	190	190
N=	18	18	18	18	18	18			
Mean=	0.00	4.23	5.17	0.00	2.63	3.71			
Variance=	0.00	28.25	28.98	0.00	11.73	13.22			
df=	17	17	17	17	17	17			
Stdev	0.00	5.32	5.38	0.00	3.43	3.64			
HoV=				0.000	1.608	1.395			
Sum DF=				34	34	34			
t-calc=				**NC**	**1.043**	**0.929**			

t-critical				**2.040**	**2.040**	**2.040**
Significant?				NC	No	No

Table C-23. Parameter: Treatment group mortality vs. control group mortality. Exposure duration multiplied by SPL (D*dB). D*dB > 1000. Species: Surfperch and Steelhead.

	Control Groups			Treatment Groups					
Replicate/ID	1hr % mort	24hr % mort	48hr % mort	1hr % mort	24hr % mort	48hr % mort	Duration (min)	dB	D*dB
Surfperch									
21-Nov M01T01	0	0	0	0	0	0	5	199	995
4-Dec M02T01	0	0	0	0	3.45	3.45	1	195	195
4-Dec M02T03	0	0	0	0	3.51	7.14	5	186	930
10-Dec M03T03	0	0	0	0	3.23	6.45	5	188	940
10-Dec M03T04	0	0	0	0	3.85	3.85	5	190	950
22-Dec M04T05	0	3.45	6.9	0	0	6.25	1	200	200
22-Dec M04T04	0	3.45	6.9	0	3.33	3.33	3	203	609
12-Jan M05T04	0	0	0	0	13.79	13.79	3	193	579
24-Jan M07T04	0	0	0	0	0	0	1	190	190
Steelhead									
4-Dec M02T11	0	13.3	13.3	0	0	0	1	196	196
4-Dec M02T09	0	13.3	13.3	0	0	0	5	191	955
10-Dec M03T07	0	3.33	6.67	0	0	0	5	191	955
10-Dec M03T08	0	3.33	6.67	0	3.33	3.33	5	189	945
10-Dec M03T11	0	3.33	6.67	0	6.45	6.45	5	199	995
22-Dec M04T10	0	13.33	13.33	0	0	6.25	1	202	202
22-Dec M04T09	0	13.33	13.33	0	3.33	3.33	3	202	606
22-Dec M04T07	0	0	0	0	0	0	3	192	576
24-Jan M07T08	0	6.06	6.06	0	3.13	3.13	1	190	190
N=	18	18	18	18	18	18			
Mean=	0.00	4.23	5.17	0.00	2.63	3.71			
Variance=	0.00	28.25	28.98	0.00	11.73	13.22			
df=	17	17	17	17	17	17			
Stdev	0.00	5.32	5.38	0.00	3.43	3.64			
HoV=				0.000	1.608	1.395			
Sum DF=				34	34	34			
t-calc=				**NC**	**1.043**	**0.929**			

t-critical				**2.040**	**2.040**	**2.040**
Significant?				NC	No	No

Table C-24. Length analysis between mortality treatment fish and survivor treatment fish by species.

	Steelhead		Surfperch	
	Survivors	Mortalities	Survivors	Mortalities
N	837	19	950	18
Mean	159.66mm	158.16mm	75.38mm	76.06mm
Var	509.31	734.25	113.11	570.76
DF	836	18	949	17
St. dev	22.57mm	27.10mm	10.64mm	23.89mm
H_0V		0.694		0.198
df		854		966
t-calc		**0.285**		**0.256**
t-crit		**1.960**		**1.960**
Significant		**no**		**no**
Note: only fish with length data were used				

Table C-25. Parameter: Treatment group mortality vs. control group mortality. Depth less than or equal to 4 meters (13 feet).
Species: Steelhead.

Replicate/ID	Control 1 hr	Control 24 hr	Control 48	Test 1 hr	Test 24 hr	Test 48 hr	Depth
4-Dec M02T07	0	13.3	13.3	0	0	0	2
4-Dec M02T09				0	0	0	2
4-Dec M02T11				0	0	0	2
10-Dec M03T07	0	3.33	6.67	0	0	0	4
10-Dec M03T11				0	6.45	6.45	2
N=	2	2	2	5	5	5	
Mean=	0.00	8.32	9.99	0.00	1.29	1.29	
Variance=	0.00	49.70	21.98	0.00	8.32	8.32	
df=	1	1	1	4	4	4	
Stdev	0.00	7.05	4.69	0.00	2.88	2.88	
HoV=				NC	5.973	2.641	
Sum DF=				5	5	5	
t-calc=				**NC**	**-1.364**	**-2.444**	
t-critical	5% LOS, one-tailed			**2.570**	**2.570**	**2.570**	
Significant?				No	No	No	

Table C-26. Parameter: Treatment group mortality vs. control group mortality. Depth greater than 4 meters (13 feet).
Species: Steelhead.

Replicate/ID	Control 1 hr	Control 24 hr	Control 48 hr	Test hr	Test 24 hr	Test 48 hr	Depth
10-Dec M03T08	0	3.33	6.67	0	3.33	3.33	5
22-Dec M04T10	0	13.33	13.33	0	0	6.25	5
22-Dec M04T09				0	3.33	3.33	5
22-Dec M04T08				0	3.23	3.23	5
22-Dec M04T07				0	0	0	5
12-Jan M085T08	0	0	0	0	0	0	10
12-Jan M05T09				0	0	0	10
12-Jan M05T10				0	0	0	10
16-Jan M06T12	0	0	0	0	4.17	0	9
16-Jan M06T10				4	8	8	9
24-Jan M07T08	0	6.06	6.06	0	3.13	3.13	10
24-Jan M07T11				0	0	0	10
30-Jan M08T09	0	0	0	0	3.7	3.7	8
N=	6	6	6	13	13	13	
Mean=	0.00	3.79	4.34	0.31	2.22	2.38	
Variance=	0.00	27.89	29.14	1.23	6.11	7.12	
df=	5	5	5	12	12	12	
Stdev	0.00	5.28	5.40	1.11	2.47	2.67	
HoV=				NC	4.567	4.096	
Sum DF=				17	17	17	
t-calc=				**1.000**	**-0.691**	**-0.844**	
t-critical	5% LOS, one-tailed			**2.109**	**2.109**	**2.109**	
Significant?				No	No	No	

Table C-27. Parameter: Treatment group mortality vs. control group mortality. Depth less than or equal to 4 meters (13 feet).
Species: Surfperch.

Replicate/ID	Control 1 hr	Control 24 hr	Control 48 hr	Test 1 hr	Test 24 hr	Test 48 hr	Depth
21-Nov M01T01	0	0	0	0	0	0	4
4-Dec M02T01	0	0	0	0	3.45	3.45	2
4-Dec M02T03				0	3.51	7.14	2
10-Dec M03T03	0	0	0	0	3.23	6.45	4
10-Dec M03T05	0	0	0	0	0	0	2
N=	4	4	4	5	5	5	
Mean=	0.00	0.00	0.00	0.00	2.04	3.41	
Variance=	0.00	0.00	0.00	0.00	3.47	11.60	
df=	3	3	3	4	4	4	
Stdev	0.00	0.00	0.00	0.00	1.86	3.41	
HoV=				NC	0.000	0.000	
Sum DF=				7	7	7	
t-calc=				**NC**	**2.446**	**2.237**	
t-critical				**2.069**	**2.069**	**2.069**	
Significant?				NC	Yes	Yes	

Table C-28. Parameter: Treatment group mortality vs. control group mortality. Depth greater than 4 meters (13 feet).
Species: Surfperch.

Replicate/ID	Control 1 hr	Control 24 hr	Control 48 hr	Test 1 hr	Test 24 hr	Test 48 hr	Depth
10-Dec M03T04	0	0	0	0	3.85	3.85	5
22-Dec M04T05	0	3.45	6.9	0	0	6.25	5
22-Dec M04T04				0	3.33	3.33	5
22-Dec M04T02				0	0	0	5
22-Dec M04T04				0	0	0	5
12-Jan M05T04	0	0	0	0	13.79	13.79	10
12-Jan M05T02				0	3.33	3.33	10
16-Jan M06T05	3.45	3.45	6.9	0	0	0	9
16-Jan M06T04				0	3.85	7.69	9
24-Jan M07T04	0	0	0	0	0	0	8
24-Jan M07T05				0	0	0	8
30-Jan M08T04	0	3.51	7.14	0	0	3.57	10
N=	6	6	6	12	12	12	
Mean=	0.58	1.74	3.49	0.00	2.35	3.48	
Variance=	1.98	3.61	14.62	0.00	16.00	17.49	
df=	5	5	5	11	11	11	
Stdev	1.41	1.90	3.82	0.00	4.00	4.18	
HoV=				NC	0.226	0.836	
Sum DF=				16	16	16	
t-calc=				**1.000**	**0.439**	**-0.003**	
t-critical				**2.110**	**2.110**	**2.110**	
Significant?				No	No	No	

Table C-29. Parameter: Bubble Curtain On Mortalities vs. Bubble Curtain Off Motalities.
Species: Surfperch and Steelhead.

Replicates/IDs	Bubble Curtain Off	Bubble Curtain On	CONTROLS
21-Nov - Surfperch M01T02/M01T01	3.57	0	0
24-Jan - Surfperch M07T03/M07T04	31.03	0	0
24-Jan Steelhead M07T07/M07T08	0	3.13	6.06
21-Nov - Steelhead M01T12	9.38		
	3.1		
N=	5	3	3
Mean=	9.42	1.04	2.02
Variance=	157.47	3.27	12.24
df=	4	2	2
Stdev	12.55	1.81	3.50
HoV=		48.221	
t-calc=		**13.181**	**6.230**