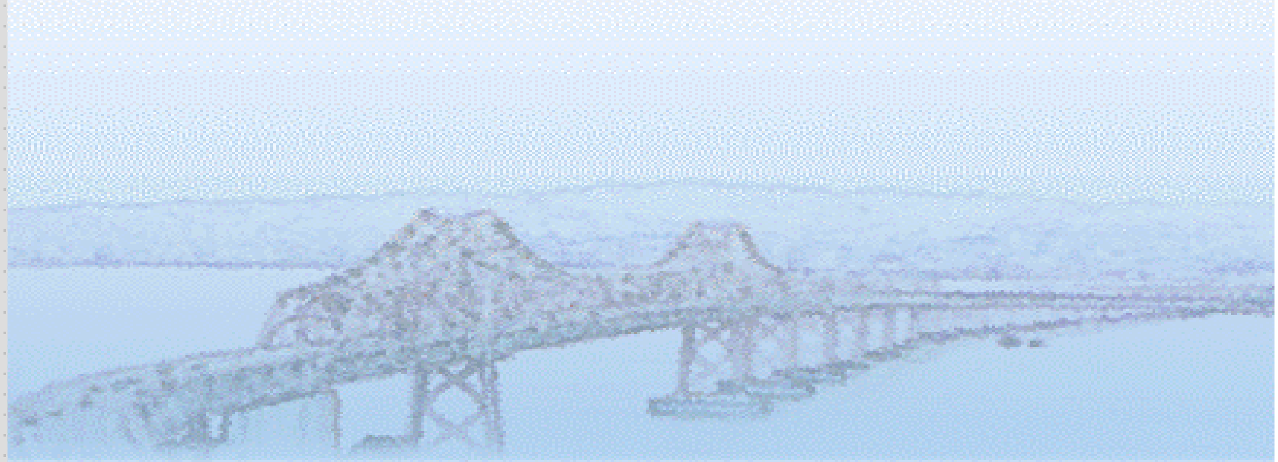
San Francisco – Oakland Bay Bridge
East Span Seismic Safety Project

Pile Installation Demonstration Project

Fisheries Impact Assessment



August 2001

PIDP EA 012081
Caltrans Contract 04A0148
Task Order 205.10.90 **PIDP 04-ALA-80-0.0/0.5**

TABLE OF CONTENTS

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

EXECUTIVE SUMMARY

This report provides an assessment of impacts to fisheries resources in San Francisco Bay during a Pile Installation Demonstration Project (PIDP) for the San Francisco-Oakland Bay Bridge (SFOBB) East Span Seismic Safety Project (East Span Project). This report includes a discussion of regulatory issues and the results of the PIDP fish monitoring and experimental program.

The PIDP was conducted in the central San Francisco Bay between October 23 and December 12, 2000 to evaluate engineering and environmental factors associated with installing large steel piles that would support a replacement structure or with installing piles as an element of retrofitting the existing bridge between Yerba Buena Island and the City of Oakland. The PIDP involved driving three steel pipe piles using two types of hydraulic hammers, one with a maximum energy rating of 500 kilojoules (kJ) (referred to as the small hammer) and one with a maximum rating of 1700 kJ (referred to as the large hammer). The PIDP also tested two different types of in-water sound attenuating equipment, an air bubble curtain and a proprietary fabric barrier system with an aerating mechanism, in addition to driving one pile without sound attenuating devices. As such, the PIDP was a demonstration project to investigate construction requirements, identify potential problems, make modifications to equipment, and examine effectiveness of sound attenuation devices for the East Span Project. Overall, the PIDP included a total of 12 hours and 51 minutes of pile driving for all segments.

Fisheries monitoring activities conducted during the PIDP included:

- Observations on predation by gulls
- Observations on the presence and distribution of schools of fish with a fathometer
- Examination of injured fish collected from the water
- Experiments using shiner surfperch held in cages at different distances

The fisheries monitoring program documented near-term fish mortalities and the likelihood of a high rate of delayed mortality of differing sizes and species of fish that have swim bladders. During installation of Pile 1 without sound attenuation, fish started floating to the surface almost immediately after the start of pile driving using either the small or large hammer. Gulls usually arrived within minutes, feeding on fish floating up to the surface near the pile and up to 500 meters (1,640 feet) down current. The predation rate as indicated by gull foraging behavior varied from approximately 0 to 7 fish per minute.

The predation rate was generally lower when sound attenuating mechanisms were in operation. An air bubble curtain was used during the installation of Pile 2, and a proprietary fabric barrier system with an aerating mechanism (essentially an air bubble curtain surrounded by an additional bubble curtain enclosed by two fabric layers) was used during installation of Pile 3. Both systems reduced but did not eliminate fish mortality related to pile driving.

Surveys with a fathometer before, during, and after pile driving indicated that fish schools did not move away from the PIDP site and suggested that the PIDP barge tended to aggregate fish. Internal examination of the fish collected at the surface of the water near the construction site indicated injuries to the kidneys and liver as a result of the contraction and expansion of the swim bladder. Attempts to recover fish that may have sunk to the bottom were unsuccessful. Observations on where stunned fish surfaced indicated that the Immediate Mortality Zone (IMZ) is approximately 10-12 meters (33-39 feet) from a pile being driven with either the small or large hammer without sound attenuation.

Permanent injury to the inner ear and lateral line organ will result in a reduced ability to orient in the water column, capture prey, avoid predators and delayed mortality. For the purposes of this report, a Delayed Mortality Zone (DMZ) has been defined as the zone in which 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. Based on acoustic measurements and experiments using shiner surfperch held in cages, the DMZ for pile driving using the large hammer without attenuation is estimated to extend out at least about 150 meters (about 500 feet) and possibly up to about 1,000 meters (3,280 feet) from the pile. The size of the IMZ and DMZ will vary with the species, size, physiological condition of the fish and environmental conditions. Fish without swim bladders will probably not be as adversely affected as those with swim bladders. The IMZ and DMZ are presented as estimates only. There is simply an inadequate amount of experimental data on pile driving impacts to draw more than general conclusions.

The impacts of pile driving on different species of fish in San Francisco Bay could vary depending on the time of year. For example, pile driving operations in the summer and early fall could result in the mortality of anchovies, but the quantities killed would not be significant compared to the commercial fishery for anchovies in the Bay. Pile driving operations in the winter months could result in the mortality of some steelhead, salmon and herring. Pile driving at any time throughout the year could result in the mortality of several species of surfperch and a number of federally managed species including brown rockfish and sardines. Losses of federally managed species are not expected to have a population level impact since the main biomass of the federally managed species is in the Pacific Ocean outside San Francisco Bay. The rate of mortality of surfperch due to pile driving is also not expected to amount to a population level impact.

The 1999 Section 7 consultation with the National Marine Fisheries Service (NMFS) requires the utilization of sound attenuation devices, such as an air bubble curtain, during the period January 1 through May 31 to protect salmon and steelhead during the juvenile outmigration period or no pile driving would be permitted. Since sound attenuation devices may not completely eliminate fish mortality, consultation with NMFS for an incidental "take" statement for salmon and steelhead (which are federally listed endangered and threatened fish) is under way.

Mitigation for the East Span Project will be implemented to minimize impacts to herring. Construction activities that occur during the peak herring spawning season, generally January to March, would be monitored by a qualified biologist to watch for the presence of spawning herring. If the biologist (or CDFG) observes spawning in the area, in-water construction activities such as pile driving and dredging would be suspended within 200 meters (660 feet) of observed spawn. In-water construction activities would not resume at that location for a period of up to 14 days (as determined by a qualified biologist), allowing herring eggs to hatch and larvae to disperse.

1.0 INTRODUCTION

This report provides an assessment of impacts to fisheries resources in San Francisco Bay during a Pile Installation Demonstration Project (PIDP) for the San Francisco-Oakland Bay Bridge (SFOBB) East Span Seismic Safety Project (East Span Project). This report includes a discussion of regulatory issues and the results of the PIDP fish monitoring and experimental program.

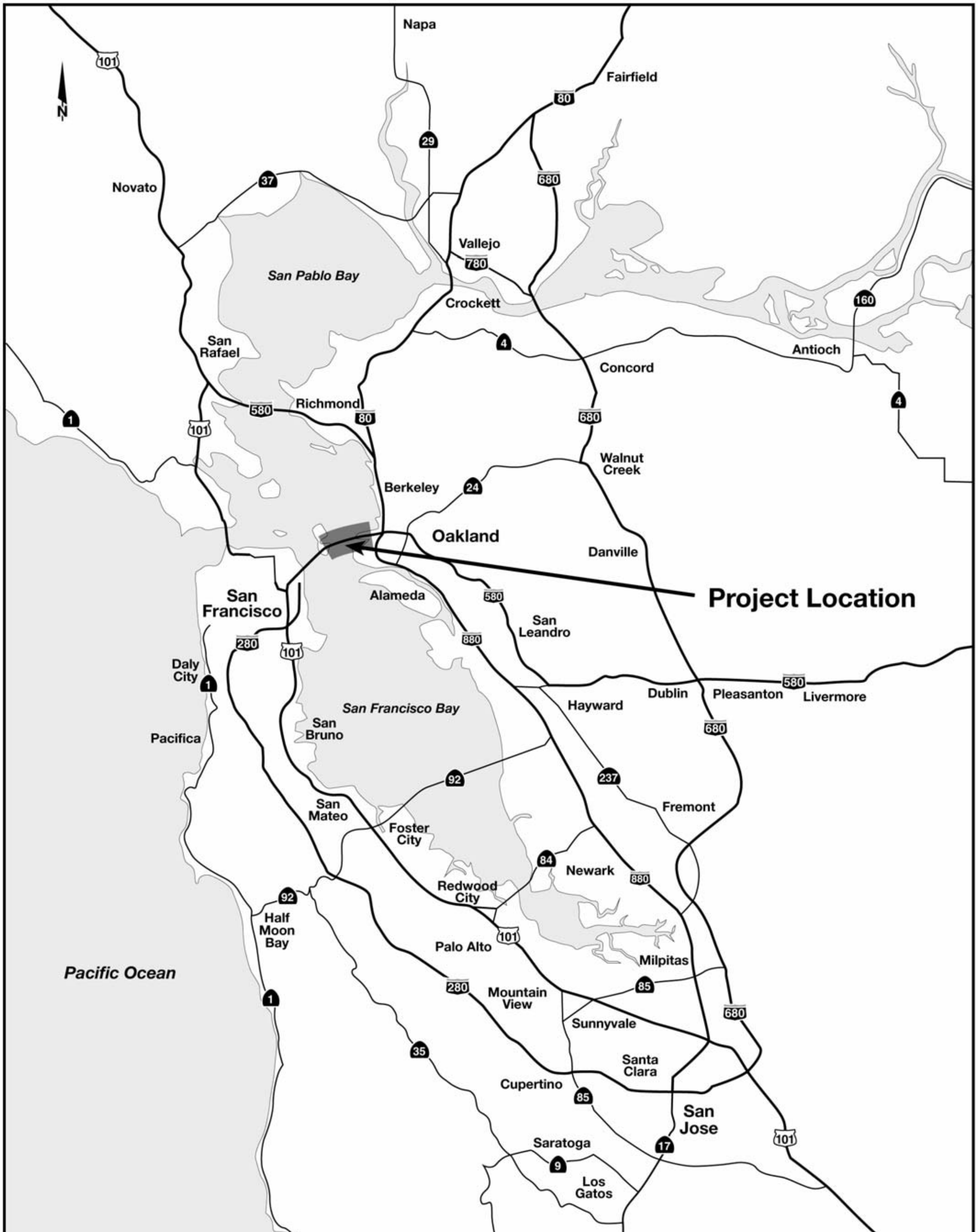
1.1 Project Description

The PIDP was conducted in the central San Francisco Bay between October 23 and December 12, 2000 to evaluate engineering and environmental factors associated with installing large steel piles that would support a replacement structure or with installing piles as an element of retrofitting the existing bridge between Yerba Buena Island and the City of Oakland. Figure 1-1 indicates the project vicinity within San Francisco Bay and Figure 1-2 indicates the PIDP study area.

The PIDP study involved driving three piles, with two different sizes of hammers and the use of two different methods of underwater sound attenuation. The test piles, labeled 1, 2 and 3 were made of steel pipe 2.4 meters (8 feet) in diameter. Pile 1 was driven straight down and did not use any sound attenuation.

Pile 2 was a battered pile angled 1h:6v to the east and used an air bubble curtain. The air bubble curtain provides a curtain of air around the pile to attenuate noise from driving activities. Bubbles emerged from a submerged piping system that surrounded the pile template (used to hold the hammer/pile in place). The piping system was comprised of three 10.2-centimeter (4-inch) diameter perforated polyvinyl chloride (PVC) pipes attached to a steel frame, forming a 30.5-meter (100-foot) diameter octagonal ring. Two rows of 0.1-centimeter (0.04-inch) diameter holes were drilled into the PVC pipes. The bubble curtain system was fabricated and assembled off-site, then transported to the pile-driving site using a barge-mounted crane. The piping system ring was then submerged to the bay floor to encircle the pile template. Air was supplied from a 1600 cubic feet-per-minute (cfm) compressor located on the PIDP barge. Though Pile 2 was driven at an angle, the bubbles streamed straight up to the water surface, potentially providing less attenuation near the surface than at greater depths. A similar system was used by Würsig et al. (2000) for attenuating noise received by dolphins during pile driving activities for an airport expansion.

Pile 3 was a battered pile angled 1h:6v to the west and was surrounded by a proprietary method of sound attenuation referred to as a fabric barrier system with aerating mechanism. The fabric barrier system consisted of an in-water, double-layer fabric curtain with a single 7.6-centimeter (3-inch) diameter pipe between the two fabric sheets and three 7.6-centimeter (3-inch) diameter pipes between the inner fabric layer and the pile. The fabric curtain was made of water-permeable material which enclosed the pile template. The top of the curtain attached to the pile template at a level a few meters above the surface of the water. The bottom was attached with beams to the bottom of the template.



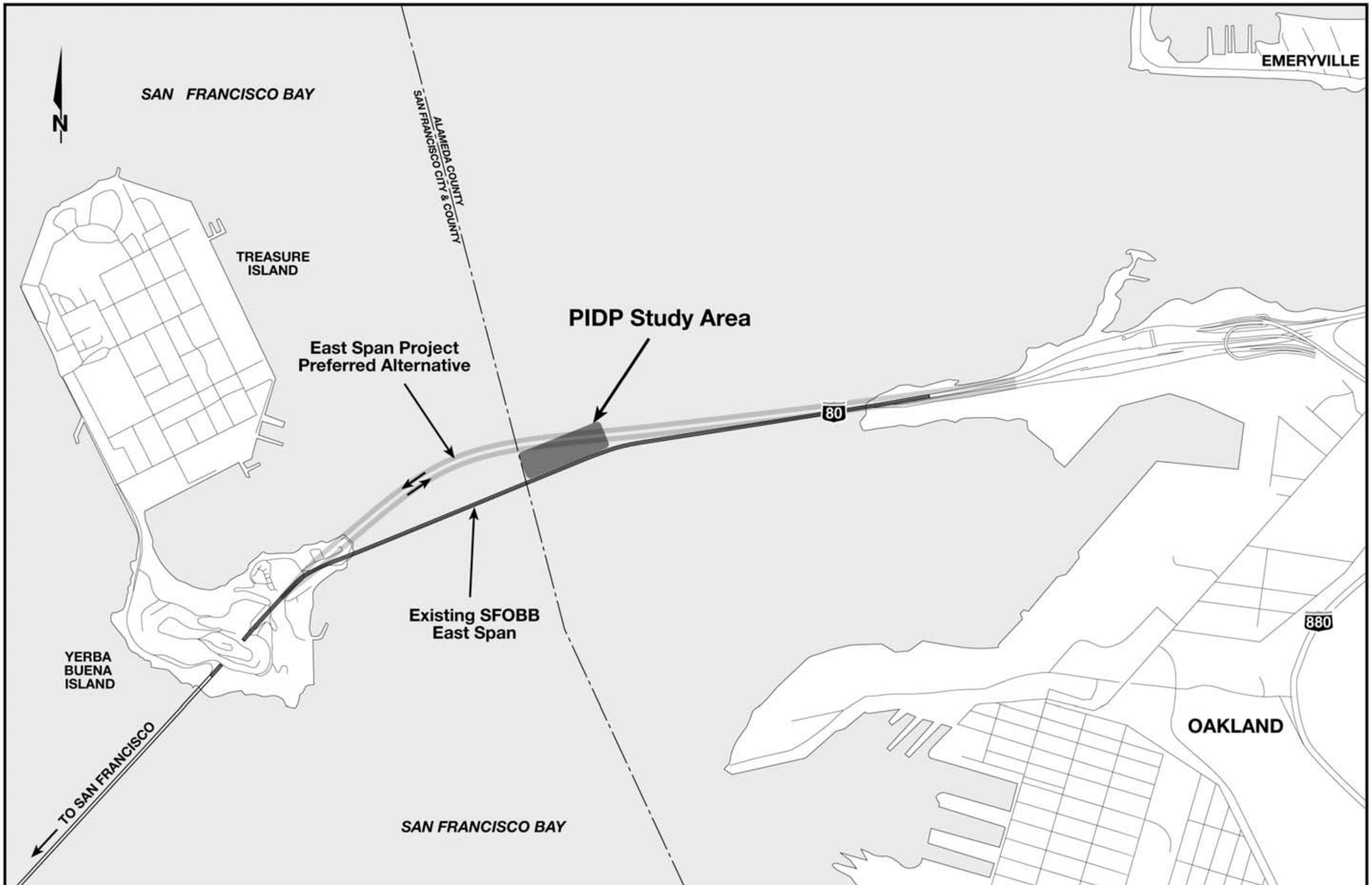
SFOBB
EAST SPAN
SEISMIC SAFETY
PROJECT

Scale
Kilometers 0 5 10 15 20 Kilometers

Project Location

Figure 1-1

3/30/99



SFOBB
EAST SPAN
SEISMIC SAFETY
PROJECT

GRAPHIC SCALE 1:27,500

0 250 500 1000 m

PIDP Study Area

Figure 1-2

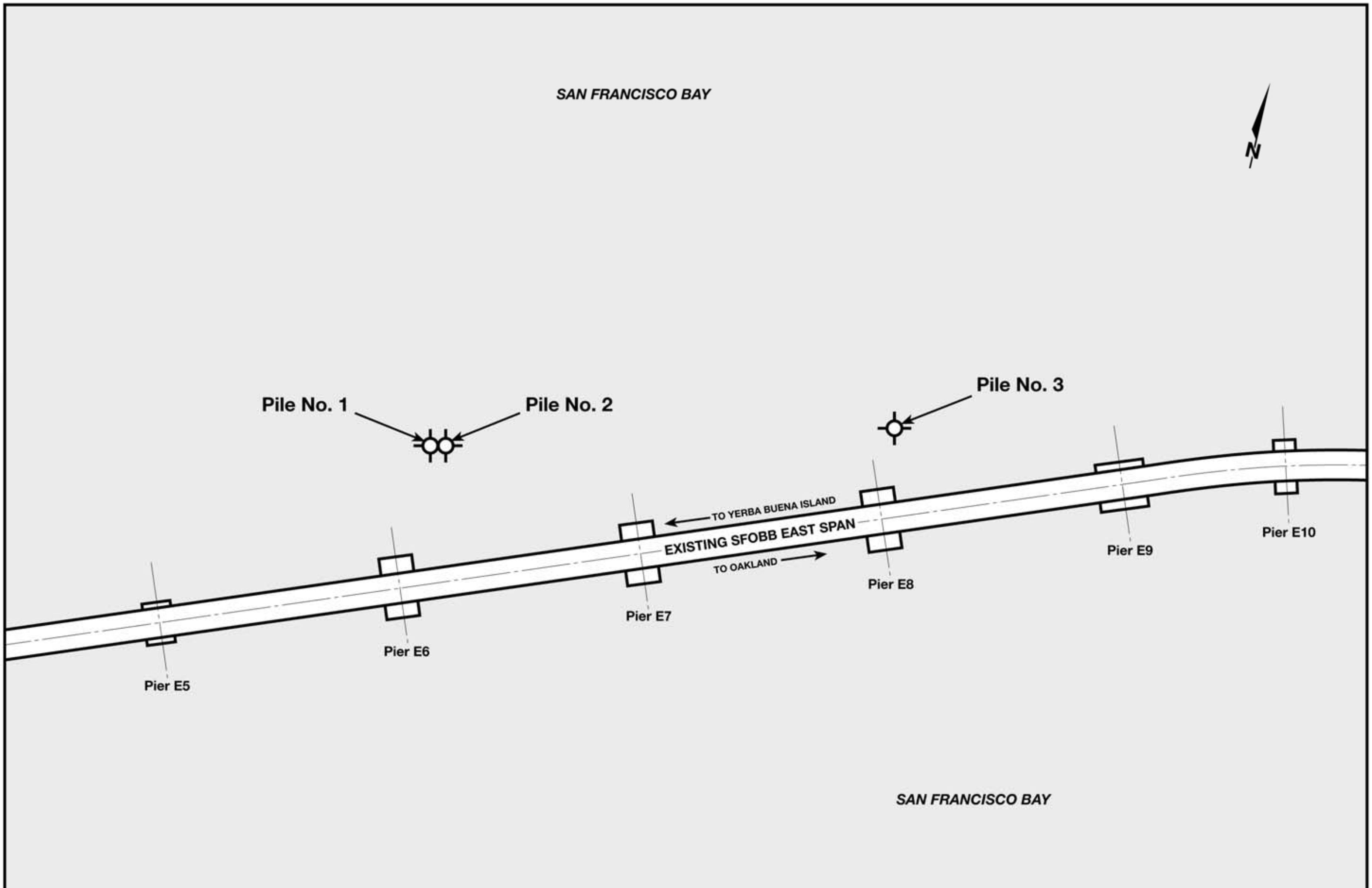
6/4/01

The fabric barrier system with aerating mechanism had a 10.7-meter by 22.9-meter (35-foot by 75-foot) rectangular footprint. This proprietary fabric barrier system with aerating mechanism was assembled and attached to the template off-site. The template/air bubble and fabric barrier was transported by barge to the Pile 3 location. Air was supplied from the same 1600 cfm compressor that was used on Pile 2; however, air was supplied to four pipes which were arranged in a smaller footprint than for the air bubble curtain, thereby providing a higher density of air bubbles around the pile.

Each pile was made up of four 33-meter (108-foot) long sections labeled sections A through D, which were driven and welded together in succession until the full length of the pile was achieved. The first section, Section A, generally required relatively little pounding. The weight of the pile with a moderate level of pounding was enough to drive it down through the soft mud on the bottom of the Bay. Pile Sections B through D required progressively more energy to drive the piles into hard mud and soft rock. Two types of Menke hydraulic hammers were employed to drive the piles; a small hammer rated at 500 kilojoules (kJ), and a large hammer rated at 1,700 kJ. It took approximately ¾ of an hour to several hours to drive one section. There were many work stoppages to weld new sections and make measurements and repairs. The first few hammer strikes were irregular in timing and typically at a lower energy. Once all systems were operating properly, there were typically 25-30 strikes to the pile per minute. Over the two-month period between October 23 and December 12, 2000, pile driving was conducted for a total period of 12 hours and 51 minutes.

The piles were installed at two locations adjacent to the existing SFOBB East Span (Figure 1-3). Piles 1 and 2 were installed north of East Span pier E6, where the water is approximately 9 meters (30 feet) deep. Pile 3 was installed north of East Span pier E8, where the water depths range between approximately 7 meters (25 feet) to the west of the pile and 5 meters (17 feet) deep to the east of the pile. The barge from which pile driving equipment was operated was held in place next to the test pile by a system of anchors and pilings that could be adjusted as needed. A schematic of the PIDP study area is shown in Figure 1-4. Photos of the PIDP barge and the large and small hammers are shown in Figures 1-5 and 1-6. Photos of the air bubble curtain in operation and the fabric barrier system are shown in Figures 1-7 and 1-8.

During the PIDP, several monitoring efforts were undertaken to study the environmental impacts of pile driving. This report summarizes observations on the impact of the PIDP on fisheries resources in central San Francisco Bay, along with a discussion of regulatory issues, results of the fish monitoring and experimental program, and the effectiveness of the sound attenuation devices in terms of effectiveness at reducing noise, costs, and operational/deployment difficulties for the East Span Project.

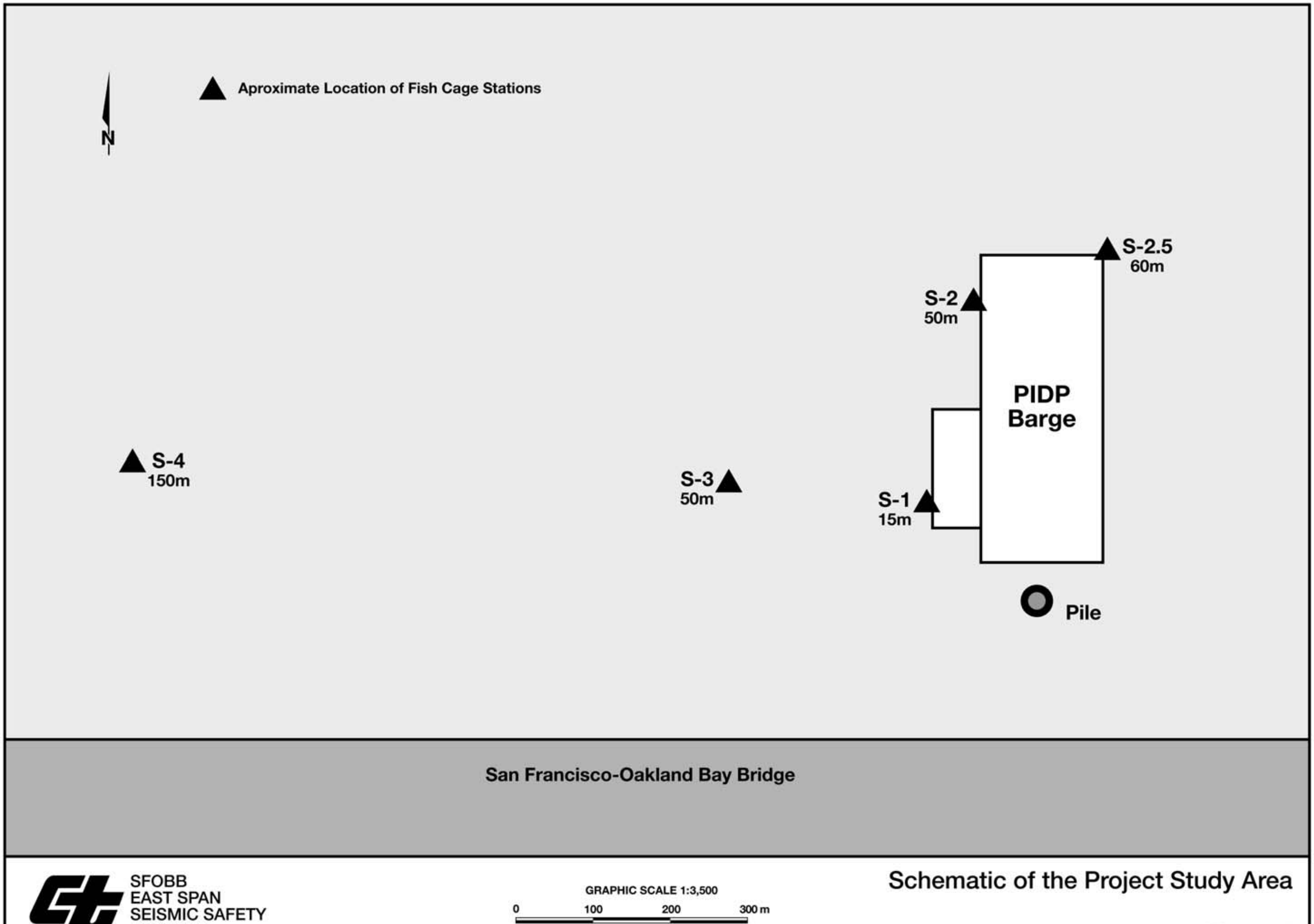


SFOBB
EAST SPAN
SEISMIC SAFETY
PROJECT

Test Pile Locations

Figure 1-3

6/21/01



SFOBB
EAST SPAN
SEISMIC SAFETY
PROJECT

Schematic of the Project Study Area

Figure 1-4

7/19/01

Figure 1-5. PIDP Barge and Large Hammer. (Note: Buoy in the foreground was used to support underwater sound monitoring instruments.)

Figure 1-6. PIDP Barge and Small Hammer. (Note: Birds circling the area.)

Figure 1-7. Air Bubble Curtain in Operation.

Figure 1-8. Fabric Barrier System with Aerating Mechanism (lower right corner of figure).

1.2 Regulatory Environment for Fisheries Resources in San Francisco Bay

The main regulatory agencies concerned with potential impacts on fisheries resources are the National Marine Fisheries Service (NMFS) and California Department of Fish and Game (CDFG). The NMFS is charged with management of the Federal Endangered Species Act (FESA) for salmon and steelhead, and for coastal fisheries resources under the Essential Fish Habitat (EFH) mandate of the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA). The CDFG is responsible for management of the California Endangered Species Act (CESA) and for regulation and conservation of fisheries resources.

1.2.1 National Marine Fisheries Service

The California Department of Transportation (Caltrans) and the Federal Highway Administration concluded initial consultation with the NMFS for the FESA and EFH in September 1999. The NMFS stated that, pertaining to federally listed salmon and steelhead, "noise insulating devices will be used to reduce sound pressure and impulse levels" if pile driving activities occur during the juvenile outmigration period of January 1 through May 31. The following section reviews and updates the regulatory status of fisheries resources in San Francisco Bay.

1.2.1.1 Threatened, Endangered and Special Concern Species

The California Natural Diversity Data Base (CNDDB) was consulted for both federally and state listed endangered and threatened species, and species of special concern (Table 1-1). Federal and state resource agencies were consulted to determine the scope of special status species that could be within the project areas and susceptible to potential pile driving impacts. Winter-run chinook salmon (*Oncorhynchus tshawytscha*) are federally and state listed as endangered. Spring-run chinook salmon are federally and state listed as threatened. Though neither chinook salmon race inhabits tributaries to San Francisco Bay, adults and juveniles can be found in the project area during upstream migration to natal streams in the upper Sacramento River and during juvenile downstream migration to the ocean. San Francisco Bay is part of their essential fish habitat.

Natural spawning chinook salmon of the California coastal Evolutionarily Significant Unit (ESU) are federally listed as threatened and may be found in San Francisco Bay, but their presence in the project area may be considered transitory and incidental since they primarily spawn in coastal streams. There are three creeks flowing into South San Francisco Bay that have small annual chinook salmon migrations: Alameda Creek, Coyote Creek, and the Guadalupe River (Hsueh 1999, Leidy 1984).

The Central Valley fall/late fall-run chinook salmon ESU is a federal candidate species. Fall/late fall-run chinook spawn in the Sacramento and San Joaquin Rivers and their tributaries, and migrate through San Francisco Bay. Late fall-run chinook salmon are listed by the CDFG as a "California Special Concern Species" and by the United States Forest Service as a "Sensitive" species. San Francisco Bay is part of their essential fish habitat though their presence in the project area may be considered transitory and incidental since they are primarily migrating directly between the Pacific Ocean and the Sacramento-San Joaquin Delta.

Central California Coast ESU steelhead and Central Valley ESU steelhead are federally listed as threatened. Some Central California Coast ESU steelhead and California coastal ESU chinook salmon may migrate through the area enroute to East Bay and South Bay tributaries including Alameda Creek, Coyote Creek, Guadalupe River and Stevens Creek (Hsueh 1999, Leidy 1984). Both salmon and steelhead have swim bladders.

The green sturgeon (*Acipenser medirostris*) is federally listed as a species of special concern. Green sturgeon are much less common than white sturgeon (*A. transmontanus*) in San Francisco Bay but they are found throughout the Bay and are commonly called "golden sturgeon" by recreational fishermen. Sturgeons have swim bladders (Conte personal communications 2001).

Table 1-1 Summary of Threatened, Endangered and Special Concern Species

Common Name	Scientific Name	Comments
Winter-run chinook salmon	*Oncorhynchus tshawytscha*	Federal endangered, State endangered
Spring-run chinook salmon	*O. tshawytscha*	Federal threatened, State threatened
Chinook salmon-California coastal ESU	*O. tshawytscha*	Federal threatened
Chinook salmon-Central Valley ESU fall/late fall-run	*O. tshawytscha*	Federal candidate species, California special concern species
Steelhead-Central California Coast ESU	*O. mykiss*	Federal threatened
Steelhead-Central Valley ESU	*O. mykiss*	Federal threatened
Green sturgeon	*Acipenser medirostris*	Federal special concern species

Source: The California Natural Diversity Data Base, January and April 2001.

1.2.1.2 Definitions of Take, Harass, Harm and Critical Habitat

The purpose of the Federal Endangered Species Act (FESA) is to provide a means whereby the ecosystems upon which endangered species and threatened species depend may be conserved (FESA Section 2). Accordingly, the FESA prohibits the "take" of any listed species within the United States (FESA Section 9). Take is defined as "harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect or to attempt to engage in any such conduct" (FESA Section 3). Harass is defined as "an intentional or negligent act or omission which creates the likelihood of injury to wildlife by annoying it to such an extent as to significantly disrupt normal behavioral patterns which include, but are not limited to, breeding, feeding or sheltering" (50 CFR §17.3). Harm is defined as "an act which actually kills or injures fish or wildlife. Such an act may include significant habitat modification or degradation which actually kills or injures fish or wildlife by significantly impairing essential behavior patterns, including, breeding, spawning, rearing, migrating, feeding or sheltering" (50 CFR part 222). Critical habitat is defined as " (1) the specific areas within the geographical area occupied by the species, at the time it is listed in accordance with the provisions of Section 4 of the Act, on which are found those physical or biological features (constituent elements): (a) essential to the conservation of the species and (b) which may require special management considerations or protection" (FESA Section 3 (5)(A)). The 4(d) rule for steelhead listed many examples of "take" that are "likely" to kill or injure salmon and steelhead (Federal Register 1999). Examples include: land use activities that adversely affect salmonid habitat, urban development and altering habitat that makes listed salmonids more susceptible to predation. Central California Coast steelhead critical habitat includes all of San Francisco Bay and its tributaries (Federal Register 2000b).

Underwater shock waves generated by explosives are known to affect the aquatic environment and result in injury and death to fish and wildlife (Keevin et al. 1999). FESA Section 7 consultations are commonly required for the use of explosives in coastal waters such as for the removal of off-shore petroleum platforms and construction (Howorth 1999). Pile driving is known to also produce underwater shock waves (Würsig et al. 2000).

1.2.1.3 Essential Fish Habitat

The amended Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA), also known as the Sustainable Fisheries Act (Public Law 104-297), requires all Federal agencies to consult with the Secretary of Commerce on activities, proposed activities, authorized, or funded or undertaken by that agency that may adversely affect essential fish habitat (Office of Habitat Conservation 1999). The Essential Fish Habitat (EFH) provisions of the Sustainable Fisheries Act are designed to protect fisheries habitat from being lost due to disturbance and degradation. EFH is defined as "those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity." The term "waters" is defined to include "aquatic areas and their associated physical, chemical, and biological properties that are used by fish and may include aquatic areas historically used by fish where appropriate." The term "necessary" is defined as the habitat required to support a sustainable fishery and the managed species' contribution to a healthy ecosystem; and spawning, breeding, feeding, or growth to maturity to cover a species' full life cycle.

The MSFCMA requires that EFH must be identified for all federally managed species including all species managed under the Pacific Fisheries Management Council (PFMC). The PFMC is responsible for managing commercial fisheries resources along the coast of Washington, Oregon, and California. Managed species are covered under three fisheries management plans:

- Coastal Pelagics Fishery Management Plan
- Pacific Groundfish Fishery Management Plan
- Pacific Salmon Fishery Management Plan

Most of the federally managed species are not found in central San Francisco Bay. The NMFS published on the web a listing of "Fisheries Management Plan" (FMP) species in San Francisco Bay. FMP species that may be found in the project area include species that are found in the South-Central and Central parts of San Francisco Bay. See Table 1-2.

Table 1-2 Federally Managed Species Found in San Francisco Bay

Name	Scientific Name	Swim Bladder (Yes/No)	Presence in the Project Area
Northern anchovy	*Engraulis mordax*	Yes	Present, Most abundant species in the project area
Pacific sardine	*Sardinops sagax*	Yes	Present, but not common
Jack mackerel	*Trachurus symmetricus*	Yes	Present, but not common
Chinook salmon	*Oncorhynchus tshawytsscha*	Yes	Present
Leopard Shark	*Triakis semifasciata*	No	Present
Soupfin shark	*Galeorhinus zyopterus*	No	Present
Spiny Dogfish	*Squalus acanthias*	No	Present
Big Skate	*Raja binoculata*	No	Present
Brown Rockfish	*Sebastes auriculatus*	Yes	Abundant
Lingcod	*Ophiodon elongatus*	Yes	Present
Pacific Sanddab	*Citharichthys sordidus*	No	Present
English Sole	*Parophrys vetulus*	No	Abundant
Starry Flounder	*Platichthys stellatus*	No	Abundant
Curlfin Sole	*Pleuronichthys decurrens*	No	Present
Sand Sole	*Psettichthys melanostictus*	No	Present
Cabezon	*Scorpaenichthys marmoratus*	Yes	Few
Pacific whiting (hake)	*Merluccius productus*	Yes	Present
Kelp greenling	*Hexagrammos decagrammus*	Yes	Present
Bocaccio	*Sebastes paucispinis*	Yes	Rare

Source: Helfman, et. al., 1997 and Southwest Regional, National Marine Fisheries Service, National Oceanographic and Atmospheric Administration website, www.swr.nmfs.noaa.gov, November 2000.

1.2.2 California Department of Fish and Game

The historical responsibility of the CDFG has been to manage fisheries resources for a maximum or optimum sustainable yield. As the fisheries resources of California have declined, the role of CDFG has increasingly turned towards conservation and restoration-oriented management. The management emphasis has been shifting from maximizing long-term commercial and sport fishing yields to the adoption of the Precautionary Principal that is focused around a conservative approach to resource management.

Many species of fish are not formally listed as threatened or endangered, but are tightly managed to limit fisheries impacts or the loss of essential habitat. Species such as striped bass, sturgeon, and herring are all rigorously managed by CDFG, which sets specific limits on the size and number that can be taken in any year. The population status of the group of fish collectively called surfperch has become a matter of concern and CDFG is in the process of developing a management plan to protect this group from further decline (Ota personal communication 2001).

1.2.2.1 Herring

The Pacific herring commercial fishery in San Francisco Bay is unique in that it is the only commercial fishery in the United States that is conducted entirely within an urban setting. It is also one of the most tightly regulated fisheries in the nation. Last year's quota was set at 5,377 tonnes (5,925 tons) (Martin 2000). Herring have swim bladders. Herring schools form into large prespawning aggregations that pulse throughout the deeper parts of San Francisco Bay, including the channel between Yerba Buena Island and Oakland. When conditions are right, the herring surge into shallow water to lay their eggs on aquatic plants such as eelgrass or kelp, but the eggs may end up on virtually all surfaces above the bottom sediments (Suer 1987). Known spawning areas include Treasure Island and eelgrass beds from Richmond to Alameda. Figure 1-9 shows the location of the December 1990-January 1991 herring spawn.

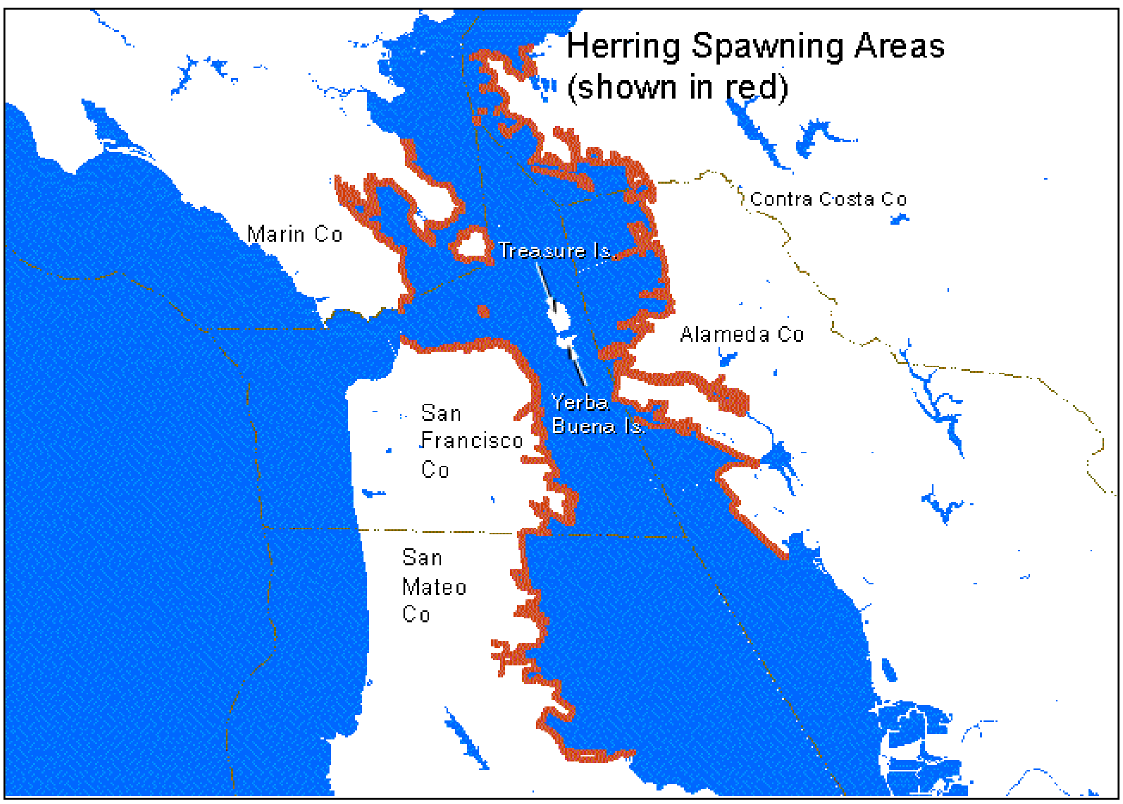


Figure 1-9. Known Spawning Areas in Central San Francisco Bay. (Adapted from the California State Lands Commission website.)

1.2.2.2 Surfperch

Fourteen species of the surfperch family (*Embiotocidae*) are regularly found in San Francisco Bay (Orsi 1999). All surfperch have swim bladders. They are characteristically found in shallow water using a variety of habitats such as rocky areas, emergent vegetation, surf, kelp forest, and structures such as pilings and piers. They all bear their young alive in shallow areas. CDFG is increasingly concerned about the population status of some species of surfperch and measures to increase their protection are under consideration (Ota personal communication 2001).

1.2.2.3 Northern Anchovy

The northern anchovy (*Engraulis mordax*) has the largest biomass and is the most abundant fish in San Francisco Bay (as cited in San Francisco Bay Area Wetlands Ecosystem Goals Project 2000). Although northern anchovy can be found in the Bay throughout the year, their seasonal peak is generally April to October. Females can produce up to 130,000 eggs per year in batches of about 6,000. They spawn oval, pelagic eggs in channels, while larvae seek out shallow water (San Francisco Bay Area Wetlands Ecosystem Goals Project 2000). A commercial fishery for anchovies that are used as live bait by the recreational and charter sport fishing industry exists in San Francisco Bay (Kuljis personal communication 2001). Anchovies are sold by the “scoop” which may have as many as 400 fish per scoop (depending on the size). A single commercial sport fishing boat may take as many as 20-30 scoops for a full day sport fishing charter (Howorth 1996). All anchovies have swim bladders.

2.0 MATERIALS AND METHODS

Fish monitoring was conducted on eight of the 14 days of pile driving, including representative days when the small and large hammer were used without sound attenuation, with the air bubble curtain, and with the fabric barrier system. The following section describes the approach for monitoring and assessing the effects of the PIDP on fish in the project area.

2.1 Access to Site and Sample Stations

Access to the project study area was facilitated by a 7-meter (22-foot) 'Boston Whaler'. This support vessel was used to transport observers and equipment to the project area and the monitoring stations located some distance off the PIDP barge. The support vessel was equipped with an Interphase Echo 600 depth sounder or fathometer and had sufficient open work-space on the deck to carry nets, cages, experimental fish, ice chests, and monitoring equipment. Two people were on the support vessel at all times. A U.S. Coast Guard-licensed skipper operated the support vessel while a fisheries scientist made observations. The boat was permanently moored at the Sausalito Bay Adventures dock in Sausalito, a distance of approximately 13 kilometers (8 miles) north of the study site. Each sampling day, the crew departed from the marina in Sausalito a minimum of 2 hours before pile driving was scheduled to commence. Access to the site was usually gained in approximately 30-40 minutes. Field notes were taken throughout the day. Numerous photographs were taken of the pile driving operations, bird behavior and fish collected.

2.2 Observations of Fish Impacts

The impacts on fish were assessed by means of fathometer transect surveys, observations of bird behavior and predation on injured fish, examination of injured fish collected from the Bay and experimental studies with fish held in cages.

2.2.1 Transect Surveys

Transect surveys were conducted by observing the appearance of schools of fish on the fathometer at known distances from the pile. Transects were conducted prior to, during, and immediately following driving operations in order to assess any changes in fish distribution patterns. Counts were made of fish schools appearing on the screen of the fathometer while the boat slowly covered areas at pre-established distances from the pile. Schools appeared as dense black spotted areas in an otherwise clear gray screen between the seabed and seafloor, both of which were always clearly indicated. A note was taken of the schools' locations (bottom, mid-water or surface), and schools were designated as small, medium or large and diffuse or compact.

Transects were usually conducted in straight lines, traveling in a square formation, northwest to northeast to southeast to southwest, around the pile. Transects were conducted at distances of between 5 meters (16 feet) and 300 meters (984 feet) from the PIDP barge. Distance estimates were initially made based on a best estimate of the distance with reference to buoys placed at known distances from the pile to mark the location of underwater sound monitoring equipment. Later in the project, a Bushnell Yardage pro® compact 800 optical distance measurement device was employed to measure the distance.

2.2.2 Gull Behavior

Upon arrival at the site, a note was made of the birds present in the area, usually within 500 meters (1,640 feet) of the PIDP barge station. At intervals before, during and after pile driving operations, a note was made of the number and species of birds present in the immediate area and their activity. During pile driving, birds were observed to dive into the water preying on moribund fish. The number of dives was monitored and the number of fish removed by diving birds was counted for discreet time periods, usually 1-minute intervals, providing an estimate of the mortality rate for fish that drifted to the surface. The location of fish being taken by the sea gulls varied and was closely related to ambient tidal currents. Moribund fish were found to be carried by the current to distances of up to 500 meters (1,640 feet) from the pile before they surfaced.

2.2.3 Fish Mortalities

Attempts were made to collect fish that were killed or stunned by pile driving. Gull diving behavior was usually a clear indicator of where the fish were surfacing. Personnel on the support vessel attempted to collect moribund fish from the water using long handled dip nets while the boat was allowed to drift or else slowly circled in the area. Attempts were also made to capture any fish that may have drifted down to the bottom of the Bay. One method employed a 75-centimeter (29.5-inch) diameter ring-net shrimp trap which was cast over the side, allowed to sink to the bottom and then quickly hauled to the surface. A cast net was also employed to try to catch any fish in the water column. A third method employed a seine net (4 meters length by 1 meter depth) [13 feet by 3.3 feet] suspended from the PIDP barge and designed to capture any moribund fish floating mid-water in the tidal current. The long handled dip nets proved to be the only successful method for collecting fish, although only 13 fish were captured in this way. The low collection rate was due to the fact that the birds moved in quickly and were observed to take fish more than 0.3 meter (1 feet) below the surface. Therefore they were usually able to remove fish from the water before they became visible to the observer on the support vessel.

Once moribund fish were collected, they were immediately placed into a bucket of fresh seawater and their condition and behavior were noted. The status of the fish was noted as (a) swimming normally, (b) buoyancy impaired or swimming head down, (c) moribund, lying on the bottom of the bucket with some gill movement or (d) dead. The fish were allowed to remain in the bucket for a minimum of 15 minutes in order to assess recovery, if any. Then each fish was placed in a separate labeled plastic bag and stored on ice, in an ice-chest located on board the support vessel.

2.3 Caged Fish Experiments

Shiner perch (*Cymatogaster aggregata*) were purchased from a local bait shop and maintained in an aerated tank on board the support vessel. Approximately 60 to 80 fish were purchased on each monitoring day; however, not all fish were used for experiments. Experimental subjects were selected from the tank and examined for injuries, parasites, behavior and size. Unsuitable fish were released once the support vessel returned to dock in Sausalito. Though the fish were in generally good condition, many had frayed tail fins from being held in a cage at the bait vendor's float, and most harbored parasitic copepods around their gills.

The experimental procedure involved placing the shiner perch in small live bait holding cages (Memphas Net and Twine Collapsible wire fish bag stock No. cw 81) at predetermined distances from the pile being driven. The cages consisted of an oval shaped black plastic-coated, wire mesh, measuring approximately 45 centimeters (18 inches) in length and approximately 30 centimeters (12 inches) wide at the widest part. The cages were equipped with a spring-hinged door on the top and bottom permitting easy access to the fish. Figure 2-1 shows a cage with a model fish to illustrate the relative size of the fish and the cage. Figure 2-2 is a photograph of a shiner surfperch prior to dissection.

The following is a summary of the primary locations where fish cages were positioned (see Figure 1-4). These locations were adjusted depending on tidal currents and other conditions near the PIDP barge.

Station 1 Southwest corner of the PIDP office barge, approximately 15 meters (49 feet) northwest of the pile.

Station 2 Northwest corner of the PIDP barge, approximately 50 meters (164 feet) northwest of the pile

Station 2.5 Northeast corner of the PIDP barge, approximately 60 meters (196 feet) northeast of the pile. This station was used as a control when there was no driving to see if there were any swim bladder injuries due to handling and transportation to the project site.

Station 3 Approximately 50 meters (164 feet) to the west of the pile.

Station 4 Approximately 150 meters (492 feet) to the west of the pile.

Station 5 Near the eelgrass bed in the cove between Treasure Island and Yerba Buena Island approximately 1,100 meters (3,608 feet) west of the pile.

Figure 2-1. Experimental Fish Cage With Model Fish to Illustrate the Relative Size of the Fish and Cage.

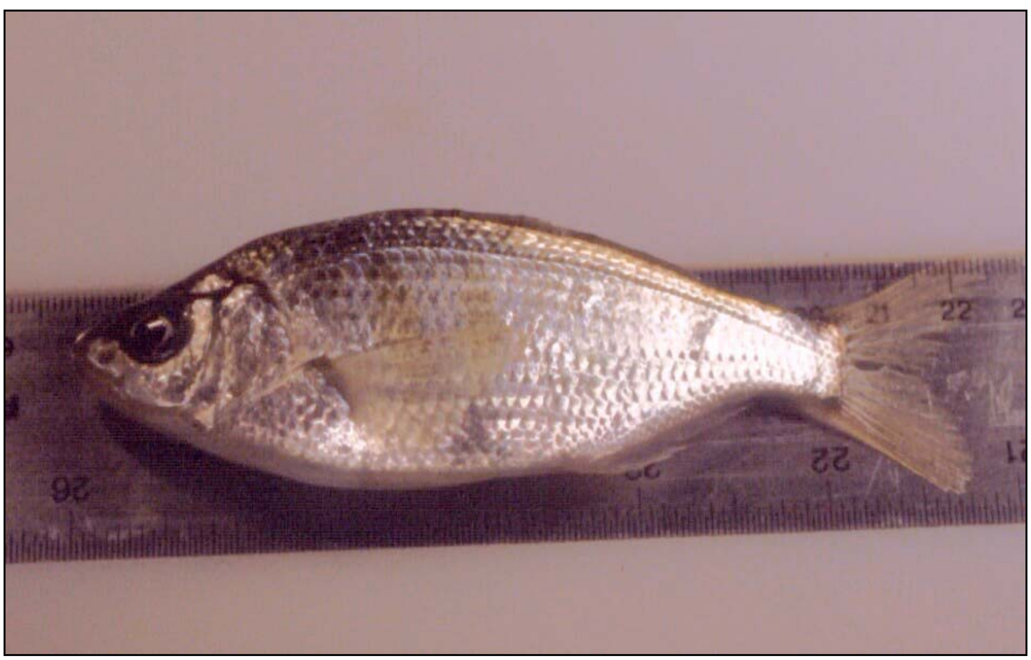


Figure 2-2. Shiner Perch Used in Experiments.

Each cage was weighted by two spherical 900-gram (2-pound) weights attached to the bottom of the cage to help hold the cage approximately vertical in the water column in the strong tidal currents. A 1-centimeter (0.4-inch) diameter nylon rope tied to the top of the cage was used to suspend it from a floating buoy or cleat on the PIDP barge.

The cages were suspended at various depths but were never more than 10 meters (33 feet) from the surface. The project area was generally less than 10 meters (33 feet) deep. The cage was submerged into the baitfish holding tank and a maximum of five fish were then placed in the cage. The cage was then quickly lifted overboard and lowered to depth. The cage was attached by its rope to either a floating buoy in the case of stations 3 and 4, or to a mooring cleat on the PIDP barge for stations 1, 2 and 2.5.

A note was taken of the time the fish were placed in the water. After a measured period of time during which the fish were exposed to pile driving sound pressure, the cages were pulled up and the fish removed. Care was taken to haul the cages slowly to the surface so as not to inflict any additional damage to the fish. Once on the surface the fish were removed and placed into a bucket of fresh Bay water located on board the support vessel or on the PIDP barge for the last few trials. The time that the fish were removed from the water was noted. The status of the fish was assessed according to the same scale noted previously for the fish collected from the Bay. The fish were allowed to remain in the bucket for a minimum of 15 minutes in order to assess recovery, if any. Finally, each fish was placed in a separate labeled plastic bag and stored on ice until later examination in the laboratory.

2.4 Environmental Parameters

Temperature, salinity and Secchi depth readings (a measure of water visibility) were taken on each sample day. A note was also made of the ambient weather conditions, including tidal status.

2.5 Laboratory Procedures

All fish samples were returned to the laboratory for analysis within 24 hours. In each case, the fish were removed from the plastic bag, measured for length and examined for external signs of damage. Notes were taken of any damage to the external body surface of the fish, including the mouth, eyes, vent, fins and gills. A representative number of fish were also photographed. The fish were then dissected by means of a longitudinal slit along the ventral surface from the vent to the gills. The body cavity and its contents were then examined and damage assessed according to the following numerical scale as used by Hubbs *et. al.* (1960), and Gaspine *et. al.* (1976):

- **(0)** No damage.
- **(1)** Only light hemorrhaging, principally in the tissues covering the kidney.
- **(2)** Gas bladder intact, but with light hemorrhaging throughout the body cavity, with some damage to the kidney.
- **(3)** No external indication of damage but the gas bladder usually burst. Hemorrhaging and organ disruption less extreme than in (4) or (5), but with gross damage to the kidney.

(4) Incomplete break-though the body wall, but with bleeding around the anus. The gas bladder almost always broken and the other organs damaged as noted under (5).
(5) Rupture of the body cavity. The break is usually a slit just to the side of the mid-ventral line. Associated with this severe damage is a burst gas bladder and gross damage to the other internal organs. The abdominal contents are often completely lost or homogenized.

3.0 FACTORS INFLUENCING PILE DRIVING IMPACTS ON FISH

To understand the impact of the PIDP on fish in the project area, it is necessary to understand some of the main characteristics of underwater sound and how fish detect and respond to underwater sounds and shock waves. This explanation is followed by a discussion of the nature and degrees of impacts of pile driving on fish.

3.1 Characteristics of Underwater Sound

The aquatic environment is a rich matrix of acoustic and hydrodynamic activity (Urick 1986). Accordingly, fish have evolved with a remarkable set of hydrodynamic-acoustic detection mechanisms that allow them to discern disturbances and patterns of underwater sound that facilitate survival. The following section briefly describes some of the characteristics of underwater sound and the physiological and morphological mechanisms that enable fish to detect and respond to it. There are several attributes of underwater sound that determine the degree of its impact on fish including; frequency, sound pressure level, acoustic impulse, near-field effect, cavitation, distance from the source, and sound scattering.

3.1.1 Frequency

Frequency, which is measured in cycles per second (cps) or Hertz (Hz), describes the pitch (high or low) of a sound. Fish generally detect only relatively low frequency sounds <400 Hz (Popper 1997). Optimum sound detection for salmon and steelhead is below 200 Hz (Abbott 1973, Popper 1997). Humans and marine mammals hear sounds as high as 20,000 Hz (Fiest et. al. 1992, Popper and Carlson 1998). Most pile driving acoustic energy is relatively low frequency (<2000 Hz). Analysis of frequency spectra for each pile condition indicates that most noise energy from the PIDP was in the range of 80 to 1250 Hz (Illingworth & Rodkin 2001). The relationship between sound frequency and injury to fish was not studied as part of the PIDP.

3.1.2 Sound Pressure Level

The conventional way to quantify underwater sound is in terms of the pressure, as in pounds per square inch (psi), atmospheres (atm) or Pascals (Pa). The relative loudness of the sound is conventionally defined in terms of a reference pressure such as one micro-Pascal (μPa) and expressed using the decibel (dB) scale. The decibel scale, which is logarithmic, is used because the pressures of interest range over many orders of magnitude, from just barely detectable to the threshold of pain and injury. Sound pressure is what is detected by hydrophones and underwater pressure transducers and converted into voltages. The voltages are then converted to sound pressure levels (SPL) in decibels by reference to a transducer calibration curve. Underwater SPLs are presented in terms of “dB re 1 μPa”.

3.1.3 Acoustic Impulse

Experimental studies with explosives indicate the acoustic impulse (*I*) or time integral of the pressure is a better method to predict tissue damage than the SPL (Yelverton et. al. 1973). The acoustic impulse for explosives is reported in pressure-millisecond units such as psi-msec. The acoustic impulse reflects the shape of the sound pulse (e.g., slow rise and fall or sharp rise and fall). Large fish are able to withstand a much larger impulse than small fish. Table 3-1 illustrates the acoustic impulse associated with a 50-percent mortality (LD50) response to underwater blasts for different size fish. Although the characteristics of underwater sound generated by pile driving and explosives are not the same, acoustical information related to explosives is presented because of the relative similarity of a pile driving shock wave and explosives and the lack of literature on pile driving acoustic properties and impacts. The data expressed in psi-msec in the table was extrapolated from published response curves for illustrative purposes only, showing that larger fish are much less susceptible to underwater sounds than small fish.

Table 3-1. The 50-Percent Mortality Response to Underwater Blasts Based on Impulse

Size of Fish by Weight (grams)	Impulse	
	psi-msec[(1)]	dB-msec[(2)]
0.1	2	203
1.0	5	211
10	15	220
100	25	225
500	40	229
1000	50	231

Sources: [1] Adapted from Yelverton et. al. 1975.
[2] Caltrans Office of Environmental Engineering (Jones personal communication 2001).

Explosives have a very brief almost instantaneous rise time and high positive peak lasting 5-10 milliseconds (Helweg 1998). The acoustic signature of a pile driving strike is much longer by comparison, lasting 300 to 500 milliseconds (Illingworth & Rodkin 2001).

Recently the NMFS has used the root-mean-square (RMS) pressure during the pulse as the criteria for reaction thresholds for marine mammals (Illingworth & Rodkin 2001). This value is the square root of the energy divided by the duration, which represents the average pulse pressure. It is presented in this report as the RMS impulse and is expressed in dB re 1 μPa. Table 3-1 shows the RMS impulse that corresponds to a 50-percent mortality response for different size fish, based the impulse data reported in psi-msec (see Section 6.0 for the conversion factor).

3.1.4 Near-Field Effect

The extent of the near-field effect, or molecular displacement, is directly correlated with the frequency of the sound. Low frequency sounds have larger near-field effects than high frequency sounds. The component of underwater sound detected at very low frequencies (<20 Hz) is particle acceleration. The motion of a fish through the water will result in a near-field effect as water is pushed aside. Fish use near-field vibrations for detecting objects in the water such as a predator moving towards them or other fish in their school. The spectral analysis of the PIDP shows sound pressure levels at 150 dB RMS re 1 μPa at 50 Hz (Illingworth & Rodkin 2001). This suggests a strong near-field effect extending at least one meter outward from the pile.

3.1.5 Cavitation

Cavitation occurs as a pressure wave is followed by a rarefaction wave that tears the water into tiny bubbles (Christian 1973). Cavitation will only occur near the epicenter of the acoustic source such as on the water surface just above a depth charge or underwater explosive. Cavitation results in instantaneous production of small air bubbles in the water and presumably in fish tissue. The shear and strains on tissues can be expected to be fatal to fish whether or not they have a swim bladder (Craig and Hearn 1998). The water near the pile tended to appear whitish at times, suggesting the presence of many tiny air bubbles and that cavitation was occurring around the pile-driving site even with the use of the small hammer.

3.1.6 Sound Pressure Levels and Distance

The sound pressure level of a spherically spreading underwater sound wave, such as would emanate from a large hollow pipe pile being driven by a hammer, drops off or attenuates over distance. However, many factors increase the rate of attenuation, such as the presence of air bubbles which scatter sound. Also, high frequency sounds attenuate much faster than low frequency sounds (Meyers and Holm 1969).

Because the sound pressure drops off with distance there has been considerable work by the US Navy to define the “safe zone” or safe distance for people, marine mammals and fish (Yelverton 1973, Young 1991). Safe zones have been defined for a certain size organism relative to the impulse from a given size explosive. No comparable safe zones have been defined relative to the impulse from a given size pile driving hammer.

3.1.7 Sound Scattering and Attenuation

The rate of sound propagation is directly related to the density and compressibility of the material through which the sound is traveling. Water is almost incompressible. A small volume of air in the water column increases the compressibility of water by several orders of magnitude above bubble free water, reducing the rate of underwater sound propagation and absorbing the sound energy (Keevin 1997). Underwater sound attenuates or decreases depending on many environmental factors such as the temperature, salinity and hydrostatic pressure. Air bubbles in the water column also tend to scatter or reflect the sound wave in all directions reducing the amount of energy propagated outward. Scattering can also occur due to the irregular surface of the water from wave action.

Bubble curtains have been used to protect underwater structures from damage caused by demolition blasting. They have also been shown to be successful in protecting fish and marine mammals (Keevin 1997, Würsig et al. 2000, Salomi personal communication 2000, Wright personal communication 2000).

3.2 The Acoustico-Lateralis System of Fish

Fish detect underwater sound through the acoustico-lateralis system which includes the swim bladder, lateral line organ and the inner ear (Popper and Carlson 1998). The swim bladder is an air-filled sack that is generally located near the center of gravity between the dorsal kidney and the liver and other internal organs below. Most pelagic fish such as herring, salmon, anchovies, striped bass, surfperch and sardines have swim bladders. Many bottom fish such as brown rockfish also have swim bladders but some such as flatfish, bat rays and sharks do not have swim bladders. Fish without swim bladders are generally much less susceptible to injury from explosives than fish with swim bladders (Gaspin 1975, Goertner et al. 1994). Increased pressure compresses the swim bladder and decreasing pressure results in its expansion. All fish used in the experiments and collected floating on the surface near the PIDP had swim bladders. It is not known if fish without swim bladders suffer the same degree of damage to their lateral line organs as fish with swim bladders for the same sound pressure level.

All fish, with or without swim bladders, have lateral line organs. The lateral line organ runs the length of the body of the fish. It consists of fluid filled canals with microscopic sensory hairs that respond to vibrations in the water. The inner ear is comprised of three symmetrically paired sets of chambers containing small bony otoliths. The chambers are lined with fine sensory hairs. Hearing in fish is affected by the differential displacement of the bony otoliths against the sensory hairs and the vibration of the sensory hairs along the lateral line organ. The proper functioning of the inner ear and lateral line organ are essential for avoiding predators, feeding and maintaining position in a school.

3.3 Previous Studies on the Impacts of Acoustics on Fish

Studies have been performed in both laboratory and field settings to assess acoustic impacts on fish. In a laboratory study, it was found that goldfish experience temporary hearing loss when exposed to a continuous 140 dB re 1µPa sound level for four hours. The sensory hairs of oscars (*Astronotus ocellatus*) were damaged by continuous sound pressure levels of 180 dB re 1 µPa for one hour (Hastings et. al. 1996). This kind of damage may not be immediately lethal, but it results in the fish not being able to swim normally, detect predators, stay oriented relative to other fish in the school, feed or breed successfully.

Sound spectral measurements at a fish farm in Korea indicated the loudest underwater sounds were in the 2,000 to 3,000 Hz frequency range and that the underwater noise, airborne noise and ground vibrations levels at 90 meters (295 feet) from the pile driving operation were 36 dB re 1 µPa, 23 dB re 0.0002 µbar and 5.9 µmeters above pre-operation or ambient levels (Shin 1995). Fish increased their swimming speed and buried themselves in the pond bottom mud.

Underwater acoustic measurements from the demolition pounding of a “hoe ram” on Baldwin Bridge piers, Connecticut, were recorded by Dolat, 1997. The ram struck the pier approximately four times per second creating loud pulsed sine waves with each blow. The underwater sound pulse had a duration of 20 milliseconds. The frequency of the peak energy was near 500 Hz with a secondary peak between 1,500 and 2,000 Hz. Peak sound pressure levels were estimated for 30 meters (98 feet) from source of the sound. The maximum instantaneous sound pressure level was equivalent to the peak sine wave of 190 dB re 1µPa. Each strike was equivalent in energy to a 20 millisecond sine wave with an SPL of 180 dB re 1µPa. Four strikes per second was equivalent to a continuous 170 dB re 1µPa. Based on these estimates of the peak SPL, the report concluded that fish less than 30 meters (98 feet) away could experience permanent auditory system damage, temporary and possibly permanent loss of equilibrium or complete incapacitation. The report included a brief discussion of previously unreported studies that show that beyond a brief startle response associated with the first few acoustic exposures, fish do not move away from areas of very loud noises and can be expected to remain in the area unless they are carried away by the river currents.

Pile driving operations have been reported to disrupt juvenile salmon behavior in Puget Sound, Washington (Feist et. al. 1992). Though no underwater sound measurements are available from that study, comparisons between juvenile salmon schooling behavior in areas subjected to pile driving/construction and other areas where there was no pile driving/construction indicate that there were fewer schools of fish in the pile driving areas than in the non-pile driving areas. The results are not conclusive but there is a suggestion that pile driving operations may result in a disruption in the normal migratory behavior of the salmon in that study, though the mechanisms salmon may use for avoiding the area are not understood at this time.

3.4 Mortality and Injury Criteria

The effects of underwater sounds created by pile driving on fish may range from a brief acoustic annoyance to instantaneous lethal injury depending on many factors including:

- Size and force of the hammer
- Distance from the pile
- Depth of the water around the pile
- Depth of the fish in the water column
- Amount of air in the water
- The texture of the surface of the water (amount of waves on the water surface)
- The bottom substrate composition and texture
- Size of the fish
- Species of fish
- Physical condition of the fish

3.4.1 Mortality

The main cause of mortality for examined fish was the rapid expansion and contraction of the swim bladder. The criterion for mortality is the cessation of all gill movements. Shock waves result in injuries to the swim bladder, kidney and liver at a macroscopic level (Yelverton et. al.1975). A fish floating on the surface or sinking to the bottom may be easily categorized as a mortality. However, experiments with explosives indicate that many fish with injuries do not die immediately. Studies on fish exposed to detonation shock waves indicate that 90 percent die within four hours (Yelverton et. al. 1975). However, there is some indication that fish may die up to five days after an exposure to a shock wave. The delayed mortality study was not conducted with predators in the immediate environment. Few injured fish live more than a few hours in a natural setting with a balanced community of predators.

3.4.2 Injury

Any macroscopically discernable injury or change in behavior is likely to result in excessive predatory pressure and near term mortality even though many fish might be able to recover in a protected environment. No standard criterion for fish injury or harassment exists at this time (Keeven personal communication). The FESA criteria for harm pertain to all listed species including fish. The rupture of the swim bladder, the loss of function of the lateral line organ and inner ear are equivalent to the loss of a body organ and would constitute a "take" under the FESA.

3.4.3 Acoustic Discomfort

The criteria for "acoustic discomfort" is not defined for fish in the literature, but for purposes of this study may be defined as the level of acoustic energy that elicits a startle response. The startle response is a quick burst of swimming that may be involved in avoidance of predators (Popper 1997). It is associated with the Mauthener cell in the base of the brain. A fish that exhibits a startle response is not in any way injured, but it is exhibiting behavior that suggests it perceives acoustic stimuli indicating potential danger in its immediate environment. Fish do not exhibit a startle response every time they experience a strong hydro-acoustic stimulus. The startle response extinguishes after a few repeated exposures. A startle response for fish was not monitored in the field.

3.4.4 Sinking vs. Floating

Most pelagic fish such as anchovy, sardine and herring sink when they die even though some may flounder on the surface for a few minutes (Kuljis personal communication 2001). Observations of fish mortalities after underwater explosions indicate a good deal of variability in floating versus sinking between species of fish injured, the type of explosive, and circumstances of the explosion; however, a general conclusion is that approximately 50 percent of the fish sink to the bottom immediately (Fitch and Young 1948, Gitschlag 1994). Fish closest to the explosion tend to have the air from the swim bladder forced out of their body and sink (Hempen personal communication 2001). The same factors probably apply to pile driving.

4.0 RESULTS OF PILE INSTALLATION DEMONSTRATION PROJECT MONITORING

4.1 Oceanographic Conditions

A decline in water temperature was recorded during the five-week duration of this study from a maximum of 14.3^{o} Celsius (C) [57.7^{o} Fahrenheit (F)] in early November to a minimum of 11.7^{o}C (53.1^{o}F) on the last sample date (December 11). Salinity was relatively consistent at 30 ^{o}/oo to 31 ^{o}/oo, while Secchi depth varied slightly with a maximum visibility of just 1.4 meters (4.6 feet) recorded. Winds were generally from a northwest direction and usually between 9.3 and 18.5 kilometers/hour (5 and 10 knots), although wind speeds of up to 46.2 kilometers/hour (25 knots) occurred occasionally. Full moons occurred on November 11 and December 10-11 and there were very strong tidal currents in the area making it difficult to set and retrieve the experimental cages. Table 4-1 summarizes conditions that occurred during the survey period.

Table 4-1. Summary of Environmental Parameters Collected During Survey Period

Date	Temp. ^{o}C (^{o}F)	Salinity (^{o}/oo)	Secchi Depth centimeters (inches)
11/03	14.3 (57.7)	30	137 (54)
11/04	14.4 (57.9)	30	114 (45)
11/09	13.2 (55.8)	30	91 (36)
11/11	13.2 (55.8)	30	122 (48)
11/12	13.0 (55.4)	N/A	122 (48)
11/19	N/A	31	91 (36)
11/20	N/A	31	91 (36)
12/03	12.5 (54.5)	30	137 (54)
12/11	11.7 (53.1)	30	91 (36)

N/A = Not available

4.2 Presence and Behavior of Fish Populations in Study Area

Transect surveys of the fish populations in the project area were conducted with a fathometer on three occasions, including two surveys conducted while pile driving was in progress (November 3, 2000 and November 12, 2000). See Table 4-2 for details. On November 4, 2000, transect surveys around the PIDP barge prior to driving operations indicated the presence of numerous fish and fish schools from a distance of 300 meters (984 feet) out from the pile to within 5 meters (16 feet) of the barge. The species of fish observed was not determined but it is likely that most fish observed were northern anchovy (*Engraulis mordax*), Pacific herring (*Clupea harengus*), Pacific sardine (*Sardinops sagax caeruleus*) and various species of surfperch. These species are commonly found in this area at this time of year (Orsi 1999). The presence of large numbers of fish in the area close to the PIDP barge suggests that the structure may attract some species of fish, such as surfperch that are naturally found close to harbor jetties and pier pilings. Objects floating in the water tend to aggregate fish very quickly. For example, a fairly large community of perch could be expected to be in the barge area within 24 hours. During driving operations on November 12, an abundance of fish was observed in the area within 300 meters (984 feet) of the PIDP barge and as close as 50 meters (16 feet) from the pile during pile driving. Observations indicate fish in the area before pile driving stayed in the area after pile driving started. There was no indication of fish moving out of the area during pile driving operations. No transect surveys were made for Pile 3.

Table 4-2. Fathometer Indication of Fish Schools in the Project Area

Date	Time	Pile Section	Monitoring Condition	Distance meters (feet)	Number of Fish Schools and Size *
11/03/00	10:25 am	2A	Before Pile Driving	60 (197)	1c
	10:45 am		During Pile Driving	80 (262)	1b
11/04/00	12:40 pm	1C	Before Pile Driving	300 (984)	3a, 3c
	12:55 pm		Before Pile Driving	150 (492)	3a, 3b, 1c
	1:02 pm		Before Pile Driving	50 (164)	3a, 2m, 2c
	1:06 pm		Before Pile Driving	5 (16)	2a, 2c
11/12/00	10:55 am	2B	During Pile Driving	50 (164)	2c, 2a, 1b
	11:00 am		During Pile Driving	150 (492)	1d, 2a
	11:03 am		During Pile Driving	300 (984)	Numerous-d
	11:40 am		After Pile Driving	50 (164)	5d

* a = small, b = medium, c = large school, d = size not determined

4.3 Bird Behavior as Indicative of Impact on Resident Fish

The principal bird species recorded in the area were gulls, the California gull (*Larus californicus)* and Herring gull (*Larus argentatus*). A number of Brandt's cormorants (*Phalacrocorax penicillatus*) were also observed, although this species was usually present at a considerable distance from the PIDP area and they were never observed taking fish from the water. A few brown pelicans (*Pelecanus occidentalis*) were also noted in the area, but only one was observed to dive for floating fish and only at a considerable distance [>300 meters (>984 feet)] away from pile driving operations.

In general, few gulls were recorded in the area prior to pile-driving operations. Usually, there were only 3-6 gulls to be seen in the area with no more than 20 gulls either overhead, on the water or sitting on the piers of the SFOBB. However, as soon as pile driving commenced, the gulls quickly gathered in the project area, with many birds landing on the water a distance of up to 500 meters (1,640 feet) from the pile, and flocks of birds in the air immediately surrounding the PIDP barge. On November 4, 2000, between 100 and 150 birds were observed flying, diving and sitting on the water, although many of them were observed to not be actively feeding. Similar observations were made on other occasions. Subsequently, observations on bird activity were limited to counting only the birds that appeared to be actively foraging as indicated by diving, flying in tight circles and plunging their heads into the water. Birds sitting on the water were not observed to be feeding on fish.

Diving for moribund fish was observed in the area immediately around the pile within a few minutes after the first blow of the hammer (See Figure 4-1). Gulls were seen to take fish from the water in the area immediately around the pile for a short time after the beginning of driving and then spread out. Thereafter, depending on tidal current strength and direction, the gulls were observed to gradually move away from the PIDP barge and concentrate on removing moribund fish surfacing up to 500 meters (1,640 feet) from the pile.

Figure 4-1. Gulls Preying on Fish Near the PIDP Site.

Gull foraging activity was examined in detail on five different dates. For every fish actually removed, there were many dives by birds that appeared to be unsuccessful. Only dives where fish were seen to be removed from the water were recorded. However, it was difficult to observe very small fish in the gulls' mouths. Therefore, the rate of predation noted below is likely to be underestimated. The results of these observations are summarized in Table 4-3. Data on bird predation rates were collected in one-minute intervals when other types of monitoring activity were not being conducted. The number of one minute counts (n) over a period of time is noted along with the average number of birds foraging and the average number of fish taken for each set of counts conducted. Observations were made at various times during pile driving sessions; therefore, the time period during which counts were conducted does not necessarily correspond to the entire pile-driving period.

The predation rate data for November 12 and 19, 2000 suggest the air bubble curtain is effective in reducing fish mortalities during pile driving using the small hammer. The data for November 20, 2000 during pile driving using the large hammer are not consistent with data for November 12 and 19, 2000 during pile driving with the small hammer, however other factors discussed below may have affected the gull activity in the area. The fabric barrier system when used in conjunction with aerating mechanism seemed to be effective in reducing fish mortalities during pile driving with either the small and large hammer. During driving of Pile 3B with the small hammer and during driving of Pile 3D with the large hammer, when the aerating mechanism was on, gulls were present in the area but none were observed diving for fish. When the aerating mechanism was turned off during driving of Pile 3D with the large hammer, however, birds were observed diving and removing fish from the water.

Irregularities in sample size, data sequences, time of data collection, and the non-normal distribution of gulls over time and space and non-normal distribution of fish over time and space preclude a rigid interpretation of this gull predation data. Tides, seasonal cycles, and time of day all affect distribution of birds and fish. There could be times when the gulls moved out of the area to follow a fishing boat or a boiling bait school. There could also be many gulls in the general area but relatively few fish in the area to be stunned and float up. At other times, most injured fish may have sunk to the Bay bottom instead of floated to the surface. The data is presented acknowledging that use of fish mortality counts due to bird predation is probably very limited as a monitoring tool unless it is done with many more cycles of air on/air off in the same time frame.

Table 4-3. Fish Predation Rate by Gulls During Pile Driving With and Without Sound Attenuation

Date	Pile Number and Hammer Size	Air On/Off	Time Period of Gull Observations	Number of 1-Minute Counts (n)	Mean Number of Birds Foraging	Mean Number of Fish Removed per Minute
11/12/00	2B small	Off	10:37-11:06 am	13	20	1
	2B small	On	11:26-11:30 am	3	6	0
11/19/00	2D small	On	9:40-9:46 am	7	12	0.1
	2D small	Off	10:35-10:51 am	17	30	3
11/20/00	2D large	On	9:22-10:27 am	54	12	1
	2D large	Off	11:10-11:27 am	14	3	0.3
12/03/00	3B small	On	11:25-11:45 am	2	25*	0
	3B small	Off	12:20-12:45 pm	3	10*	0
	3B small	On	1:20-1:21 pm	1	10*	0
12/11/00	3D large	On	12:20-1:10 pm	8	3*	0
	3D large	Off	2:11-2:16 pm	4	18	2
	3D large	Off	2:27-2:31 pm	5	14*	0

* These birds were present in the area, but none were observed diving for fish.

The predation rate also varied considerably within each driving period where hammer size, energy and driving rate appeared consistent. An examination of the data from November 20, 2000 illustrates this more clearly. Table 4-4 below provides details of the number of fish observed being taken by the gulls per minute, continuously over a 30-minute period. On this occasion, the large hammer was used and the air bubble curtain was in operation throughout.

Table 4-4. Fish Predation by Birds on November 20, 2000 With Air Bubble Curtain in Operation

Time	Number of Birds	Number of Fish Taken	Time	Number of Birds	Number of Fish Taken
9:22 am	0	0	9:39	8	0
9:23	0	0	9:40	11	0
9:24	4	0	9:41	12	2
9:25	6	0	9:42	15	1
9:26	13	0	9:43	10	0
9:27	10	0	9:44	6	0
9:28	15	1	9:45	7	0
9:29	20	0	9:46	6	0
9:30	20	0	9:47	15	7
9:31	20	1	9:48	30	6
9:32	15	1	9:49	30	2
9:33	10	0	9:50	35	5
9:34	10	1	9:51	20	1
9:35	10	0	9:52	20	0
9:36	15	1	9:53	12	0
9:37	10	2	9:54	10	1
9:38	10	0			

While the overall average number of fish taken per minute for the entire time period was 0.97, the actual predation rate varied from zero on many occasions to a maximum of 7 fish per minute at 9:47 a.m. Data indicate that a total of 21 moribund/dead fish appeared at the surface during a 5 minute time period, from 9:47 to 9:51 a.m. This was accompanied by an increase in the number of gulls in the immediate area. The cause of this sudden increase in fish mortality is unclear, but it may be due to a school of fish moving into the area immediately around the pile due to tidal currents, foraging or predator avoidance.

4.4 Collection and Examination of Floating Fish

A total of 13 fish were removed with dip nets from the area around the pile and PIDP barges. These fish were later identified as six anchovy, three herring, one sardine, one pile perch, one white surfperch and one shiner surfperch (Table 4-5). Other species of fish may have been injured during pile driving, however only a limited number of fish were collected using dip nets. Most fish were retrieved within 50 meters (160 feet) from the pile, with the exception of the sardine which was found floating in the water about 180 meters (591 feet) north of the barge on November 20, 2000. In some cases, the fish were still alive on capture but their ability to maintain an upright orientation in the water was severely impaired, and most fish were bleeding from the vent and had varying degrees of bleeding on the head and around the eyes. Two anchovies had lesions on the flank, with the internal organs exposed. Examination of the internal organs indicated that nine fish had burst gas bladders and the internal organs were severely damaged.

Table 4-5. Summary of Injuries to Moribund Fish Collected in the Project Area

Date	Pile	Hammer Size	Species	Length cm (in)	Status	External Damage	Gas Bladder	Damage Value*
11/19/00	2D	S (+A)	A	8.2 (3.2)	moribund	flank	burst	5
			A	9.2 (3.6)	moribund	flank	burst	5
			A	9.0 (3.5)	moribund	vent, head	burst	4
			A	9.2 (3.6)	moribund	vent, head	intact	4
			H	10.5 (4.1)	moribund	vent, head	intact	3
11/20/00	2D	S (+A)	H	9.4 (3.7)	moribund	vent, head, eyes	intact	3
			H	7.1 (2.8)	dead	vent, gills	burst	4
			S	-	moribund	extensive predator damage	burst	3
11/20/00	2D	S (-A)	A	9.3 (3.7)	moribund	vent, head, eyes	intact	4
			A	9.3 (3.7)	moribund	vent, head, eyes	burst	4
12/11/00	3D	L (-A)	PP	25.4 (10.0)	moribund	none	burst	3
			WS	29.2 (11.5)	moribund	none	burst	3
			SP	10.2 (4.0)	moribund	none	burst	3

Species: A=Anchovy, H=Herring, S=Sardine, PP=Pile surfperch, WS=White surfperch, SP=Shiner Surfperch
Drive Conditions: S= small hammer, L= large hammer, (+A) = with air bubble curtain, (-A) = no air bubble curtain
* See Section 2.5 for damage assessment scale.

A number of fish were photographed to illustrate the varying degrees of damage observed. See Figures 4-2 through 4-7.

Figure 4-2. Anchovy Collected November 19, 2000 Showing Ruptures Behind the Gill Plate and at the Vent.

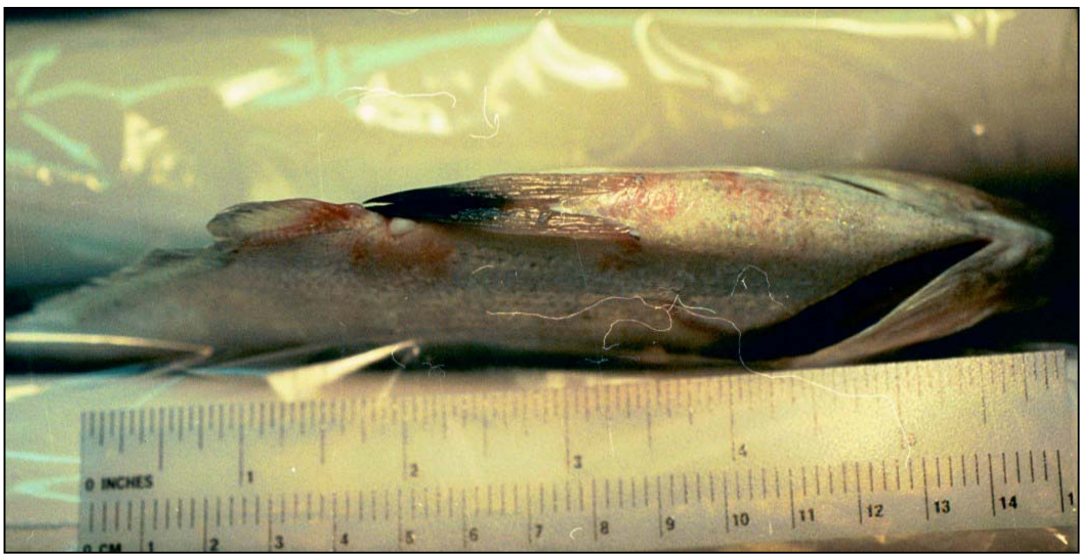


Figure 4-3. Ventral Surface of a Surfperch Showing Areas of Redness Where Blood Vessels Were Ruptured.

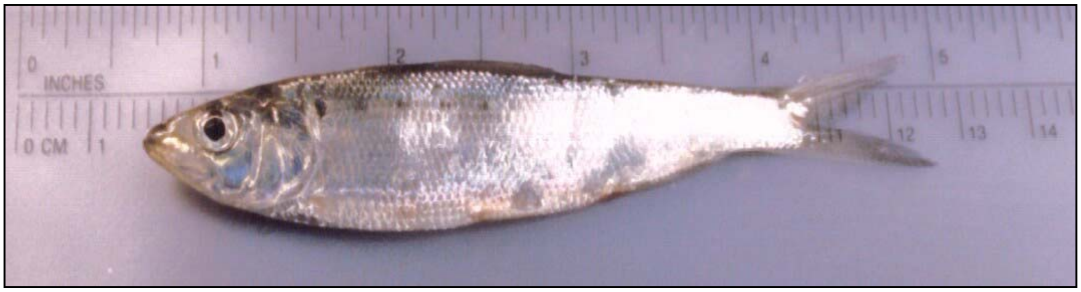


Figure 4-4. Sardine Recovered November 20, 2000 Showing Redness Along Ventral Surface

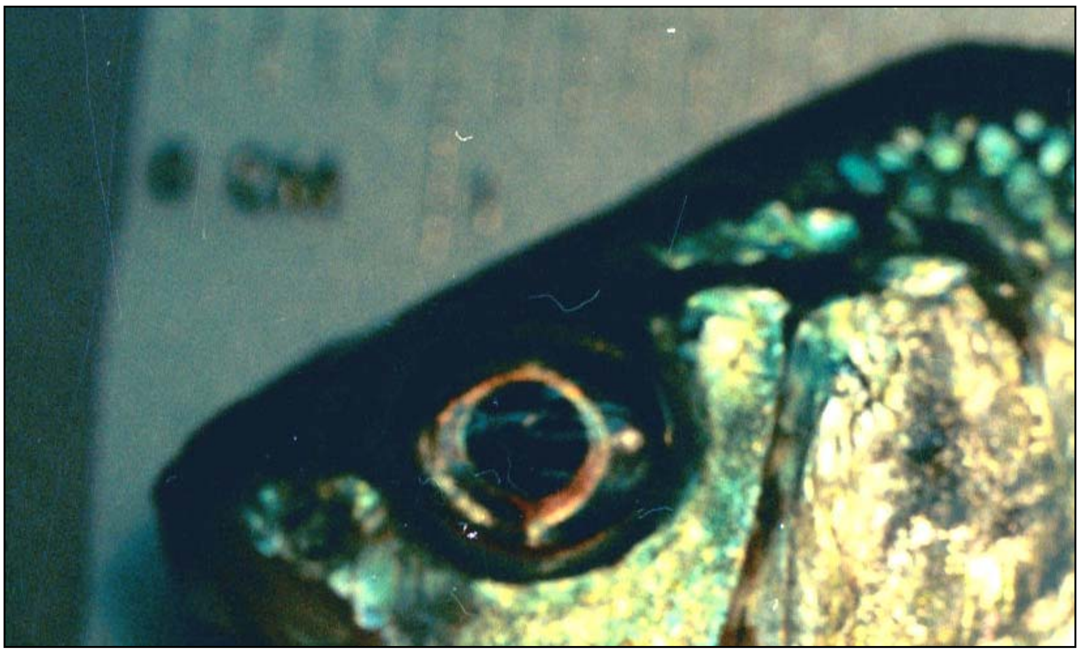


Figure 4-5 Surfperch With Broken Blood Vessels in the Eye

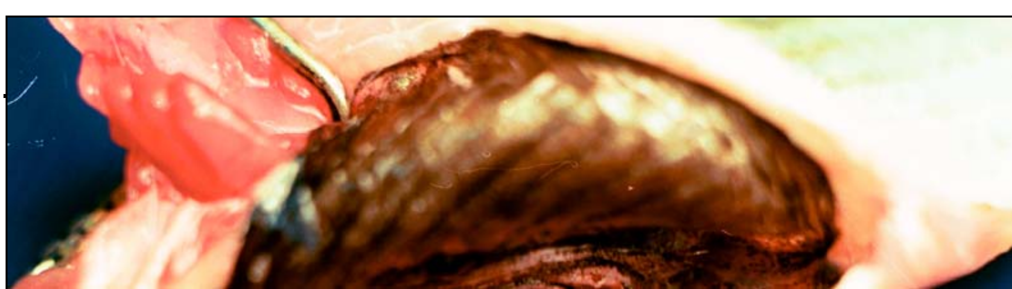


Figure 4-6. Ruptured Swim Bladder of a Pile Surfperch.

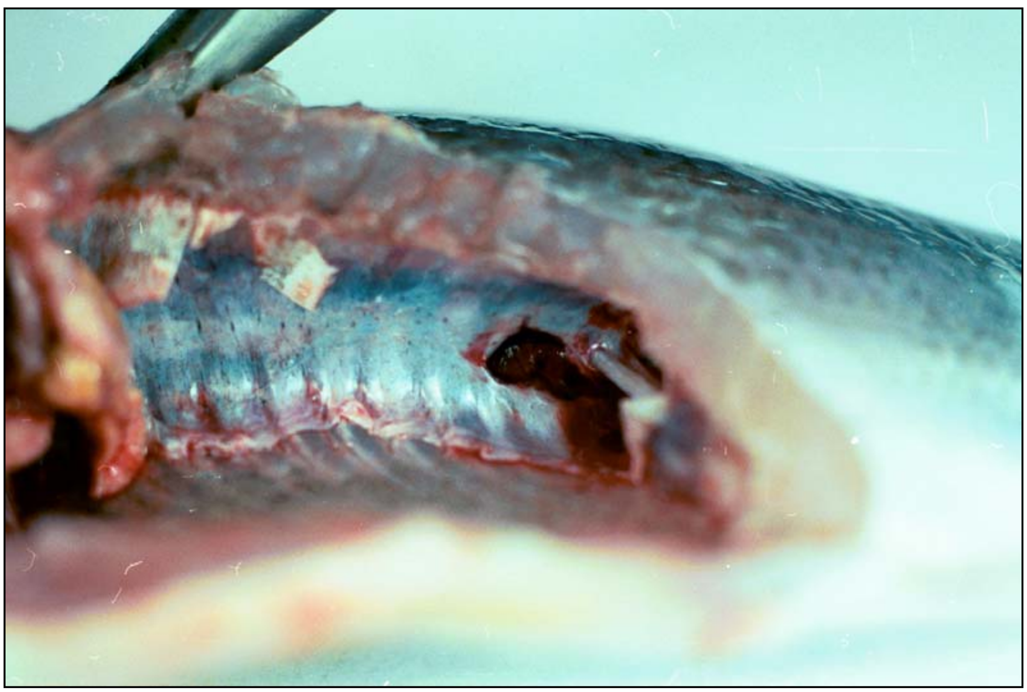


Figure 4-7. Ruptured Swim Bladder of a White Surfperch.

4.5 Caged Fish Experiments

The following discussion of the experimental exposure of surfperch held in cages is very preliminary. There are no examples from the literature on the use of fish held in cages to study the impact of pile driving, though there is a considerable body of literature on the use of fish held in cages to study the impact of explosives (Christian 1973, Teleki and Chamberlain 1978, Yelverton 1975, 1978, McAnuff and Booren 1997, Keevin, Hempen and Schaeffer 1997). Though pile driving is mechanically quite different from an explosion, the available information indicates that the resulting underwater acoustics of pile driving and small explosive charges are similar in many respects.

Conditions under which these fish were experimentally exposed to underwater sounds from pile driving were highly variable, making it difficult to interpret the results. Nevertheless some patterns did seem consistent with the field observations on bird predation of moribund fish and the literature on the impact of underwater explosives.

4.5.1 Controls

A series of control experiments were conducted to assess if there were injuries to the experimental fish just from the handling alone. On November 11, 2000, two groups of fish were placed in cages at Station 2, lowered 5 meters (16 feet) and then retrieved after 10 minutes without any exposure to pile driving. All the fish were found to swim normally on removal from the cages. On later dissection, 70 percent of the fish were observed to exhibit no injury to the internal organs, while 30 percent showed very slight erythma or reddening of the internal organs. This indicates that there may be a small negative impact on the fish caused solely from handling. The slight reddening of the internal organs observed may be associated with the pummeling each fish gets from its neighbor as they are crowded together and scooped up in a net by the baitfish dealer.

4.5.2 Data Summary

The results of the experiments on fish held in cages are summarized in Table 4-6. To the extent possible, the cages were all lowered to the same depth (5 meters) [16 feet] but the distance from the surface was not consistent due to the cages being pushed upwards by the strong tidal currents. The conditions under which the experimental fish were exposed to pile driving were highly variable. Hammer size and driving energy varied as well as the duration of exposure and distance from the pile. In many cases, the same fish were exposed to pile driving both with and without the use of an air bubble curtain or fabric barrier system. In many instances, the driving rhythm also varied making it difficult to assess the exact degree of exposure. The different monitoring stations used also had confounding factors. Stations 1 and 2 were located at the PIDP barge. These large metallic structures may have acted to either amplify the sound or reduce the exposure level depending on whether or not the currents were pushing the cages up under the barge or away from them. In some cases the cages may have been in an acoustic shadow due to the complex of structures underneath the barge required to stabilize them in the face of strong tidal currents.

Table 4-6. Summary of Results of the Caged Fish Experiments

Date	Pile	Hammer Size (* = with air)	Distance m (ft)	Duration (mins)	% Injured	% Seriously injured[a]
Nov 4, 2000	1C	Small	15 (49)	1	0	0
"	"	Small	15 (49)	6	80	80
Nov 9, 2000	1D	Large	15 (49)	5	100	60
"	"	Large	20 (66)	3	80	60
"	"	Large	30 (98)	7[b]	50	0
"	"	Large	50 (164)	67	70	40
"	"	Large	150 (492)	84	60	40
"	"	Large	500 (1,640)	84	10	0
Nov 11, 2000	1D	Large	15 (49)	10	70	20
"	"	Large	50 (164)	10	30	0
Nov 12, 2000	2B	Small	15 (49)	36	60	40
"	"	Small	40 (131)	46	10	0
"	"	Small*	50 (164)	10	22	0
"	"	Small	50 (164)	46	0	0
"	"	Small*	150 (492)	12	40	0
"	"	Small	150 (492)	36	16	0
Nov 19, 2000	2D	Small*	15 (49)	57	50	0
"	"	Small*	20 (66)	57	60	0
"	"	Small	20 (66)	32	60	0
"	"	Small*	30 (98)	57	80	0
"	"	Small*	50 (164)	57	80	20
"	"	Small*	150 (492)	34	0	0
"	"	Small + Large[c]	15 (49)	29	100	50
"	"	Small + Large[c]	30 (98)	24	80	20
"	"	Large	15 (49)	5	75	0
"	"	Large	30 (98)	5	30	0
Dec 3, 2000	3B	Small	15 (49)	17	40	0
"	"	Small	15 (49)	23	20	0
"	"	Small	15 (49)	40	40	0
"	"	Small	15 (49)	42	40	40
"	"	Small	15 (49)	64	60	40
"	"	Small	30 (98)	17	40	0
"	"	Small	30 (98)	23	20	0
"	"	Small	30 (98)	40	40	0
"	"	Small	30 (98)	46	40	0
"	"	Small	30 (98)	64	50	25
Dec 11, 2000	3D	Large*	15 (49)	6	80	20
"	"	Large	15 (49)	53	100	100
"	"	Large	15 (49)	64	100	100
"	"	Large*	30 (98)	19	60	0
"	"	Large*	30 (98)	28	100	20
"	"	Large	30 (98)	36	100	0
"	"	Large	30 (98)	44	40	0
"	"	Large	30 (98)	64	40	0

a. Damage value 2 or greater. See Section 2.5
b. Sporadic driving period, therefore exposure likely to be less than this figure
c. Fish in cages were exposed to pile driving with the small hammer, remained in the water for a period of time and exposed to pile driving with the large hammer, which was used for only for a period of about 5 minutes on November 19, 2000.

4.5.3 Hammer Size

Overall, the effects of pile-driving to fish were greater when exposed to sound pressure by the large hammer compared to the small hammer. Comparing the results of two experiments, both at equal distance from the pile (15 meters) [49 feet] and for the same duration (5 to 6 minutes), 80 percent of the fish exposed to sound pressures by the small hammer were injured (November 4, 2000) and had serious injuries (damage value of 2 or greater), while all fish in cages exposed to the large hammer (on November 9, 2000) exhibited injuries but only 60 percent had serious injuries. When the large hammer was used with the fabric barrier in place and aerating mechanism in operation, the percentage of injured fish was 80 percent and only 20 percent of the fish showed signs of serious injuries (December 11, 2000). Comparable data for the air bubble curtain is not available.

4.5.4 Distance

Experiments conducted on November 9, 2000 and November 12, 2000, showed fish with damage to their internal organs in cages as far away as 150 meters (492 feet) from the pile with or without sound attenuation. On November 9, when the large hammer was used without sound attenuation, 60 percent of the fish at 150 meters (492 feet) were injured, and 40 percent exhibited major tissue damage. On November 12, when the small hammer was used with the air bubble curtain in operation, 40 percent of the fish exposed to pile driving at this distance were damaged, but only minor hemorrhaging was observed. In general, the greatest impacts were observed within a 30-meter (98-foot) radius of the pile, and later experiments were concentrated within this zone. On December 3 and 11, cages were deployed and retrieved at Station 1 (15 meters [49 feet] from pile) and Station 2 (30 meters [98 feet] from pile) at approximately the same time, thereby exposing the fish to almost identical pile-driving conditions. It is evident from Table 4-6 that the fish located nearest the pile suffered significantly greater damage. For example, on December 3, during pile driving using the small hammer, fish exposed to pile driving for 64 minutes at Station 1 experienced more injuries than those exposed for the same duration of time at Station 2. The data indicate that approximately 60 percent of the fish at Station 1 were injured and 40 percent had serious injuries, while 50 percent of the fish at Station 2 were injured and 25 percent had serious injuries.

4.5.5 Duration of Exposure

In the first survey conducted, it appeared that there was an increase in the degree of damage and number of fish impacted with increasing duration of exposure. On November 4, all fish exposed to driving for one minute were unaffected, while 80 percent of the fish exposed for six minutes exhibited significant tissue damage. This trend was observed in later surveys, although it was not always as distinct. In the experiment conducted on December 3, a greater proportion of fish were damaged at longer exposure times than for the shorter exposure times. Only fish exposed 40 minutes or longer were seriously injured. However, in the experiment on December 11, 100 percent of the fish exposed for 36 minutes were injured while only 40 percent of fish exposed for 64 minutes showed signs of damage. This result is confounded by the use of the large hammer in conjunction with the irregular use of the aerating mechanism for the fabric barrier system. There was no macroscopic evidence for a cumulative effect on the fish tissues examined. Tissues from fish with ruptured gas bladders from short exposures were similar to those from fish that were exposed for longer periods of time.

4.6 Underwater Acoustic Measurements

Underwater acoustic measurements were made using a calibrated LC-10 hydrophone manufactured by Celesco Transducer Products. A Larson Davis Model 3100 real time analyzer was used to pick up the signal and stored it on a Sony Model TC-D5M Stereo Cassette Recorder. The system was field calibrated using a Bruel & Kjaer Type 4220 Pistonphone calibrator with a pistonphone adaptor. The calibration signal was 150 dB re 1uPa (Illingworth & Rodkin 2001).

Table 4-7 provides a summary of noise measurements taken during driving of the last segment of each pile. Noise levels reported were root-mean-square (RMS impulse) and Linear Peak Level (LPL).

Table 4-7. Root-Mean-Square (RMS Impulse) and Linear Peak Level (LPL) Noise Measurements

Date	Pile	Hammer Energy Level kJ	Sound Attenuation	Distance m (ft)	RMS Impulse dB re 1 μPa	LPL Sound Pressure dB re 1 μPa	Depth m (ft)
11/9/00	1-D	900-1,000	None	103 (338)	185	197	1 (3.3)
"	"	"	"	"	196	207	6 (19.7)
"	"	"	"	358 (1,175)	167	181	1 (3.3)
"	"	"	"	"	179	191	6 (19.7)
11/19/00	2-D	500	Bubble Curtain on	200 (656)	184	197	1(3.3)
"	"	"	"	"	189	201	3 (9.9)
"	"	"	"	"	181	197	6 (19.7)
11/20/00	2-D	900-1,000	Bubble Curtain on	206 (676)	187	199	1 (3.3)
"	"	"	"	"	190	201	3 (9.9)
"	"	"	"	"	188	199	6 (19.7)
12/11/00	3-D	900	Fabric Barrier – Aerating Mechanism on	95 West (312)	175	188	1 (3.3)
"	"	900	Fabric Barrier – Aerating Mechanism on	100 East (328)	172	186	1 (3.3)
"	"	1,400	Fabric Barrier – Aerating Mechanism off	100 East (328)	179	193	1 (3.3)
"	"	1,600	Fabric Barrier – Aerating Mechanism on	500 North (1,640)	160	170	1 (3.3)
"	"	1400	Fabric Barrier – Aerating Mechanism off	95 West (312)	184	197	1 (3.3)

Source: Illingworth & Rodkin, 2001.

The RMS impulse levels calculated for the PIDP study provide a conservative measure of RMS sound pressure. RMS sound pressure is the root square of the energy divided by the duration of the impulse, or average pulse pressure. The 5 percent of energy at the start of the rise of the pulse and the 5 percent at the end of the pulse are excluded from the averaging process. Since most of the energy from a pile driving strike occurred within the first 30 to 50 milliseconds, a 1/32 second time constant was used in the calculation of the RMS impulse (Illingworth & Rodkin 2001). By using a standard 1/32 second time constant instead of a varying time constant, the RMS impulse yields an accurate and conservative measure of the RMS sound level. The linear peak sound level indicates the maximum instantaneous SPL during the pile driving period.

The NMFS issued an Incidental Harassment Authorization (IHA) with a Marine Mammal Safety Zone (MMSZ) that included all areas where the RMS sound pressure level was equal to or exceeded 190 dB re 1 μPa. The estimated extent of the 190 dB MMSZ (based on RMS impulse levels), assuming no excess attenuation, for different degrees of pile driving hammer energy is summarized in Table 4-8. Numerous factors in the environment would tend to attenuate underwater sound propagation in shallow water. Attenuation may be the result of microbubbles in the water column resulting from phytoplankton growth, absorption of the sound in soft Bay mud, scattering of the sound by the surface waves, bubbles in the water from turbulence and the reflection of sound waves off objects such as the SFOBB piers, the PIDP barges and irregularities on the bottom. Estimated excess attenuation was approximately 0.02 dB per meter (Illingworth & Rodkin 2001). Therefore, the values presented in Table 4-8 are conservative, since excess attenuation may be expected to reduce the sound pressure levels at these distances.

Table 4-8. Estimated Distance to 190 dB RMS (Impulse) Level For Different Sound Attenuation Systems

Hammer Energy kJ	Estimated Distance (Meters) to the 190 dB RMS (impulse) Levels Assuming No Excess Attenuation		
	No Sound Attenuation	Bubble Curtain System	Fabric Barrier with Aerating Mechanism Operating
750	185	185	<100
1000	215	215	<100
1250	240	240	<100
1500	265	265	<100
1750	285	285	<100
Note: The bubble curtain changed the shape of the impulse and attenuated higher frequency noise, but did not change the overall sound pressure level. It is recommended that the distance to the 190 dB contour should not be assumed to be less than 185 meters regardless of hammer energy or hammer size.			

Source: Illingworth & Rodkin, 2001.

The limited amount of data gathered with the bubble curtain in place indicated that there was no reduction in the overall linear sound pressure level (Illingworth & Rodkin 2001). The bubble curtain was apparently effective in attenuating the higher frequency component of the noise (above about 800 Hz), as shown in Figure 4-8 (Illingworth & Rodkin 2001). The correlation between sound frequency and injury to fish was not studied as part of the PIDP. The air bubble curtain also changed the shape of the impulse, resulting in a more gradual accumulation of energy at the start of pile driving (see Figure 4-9). As mentioned in Section 3.1.3, acoustic impulse may be a more appropriate indicator for predicting tissue damage than the SPL and has been shown to correlate with the size of fish that may be injured due to underwater shock waves (Yelverton et. al. 1973).

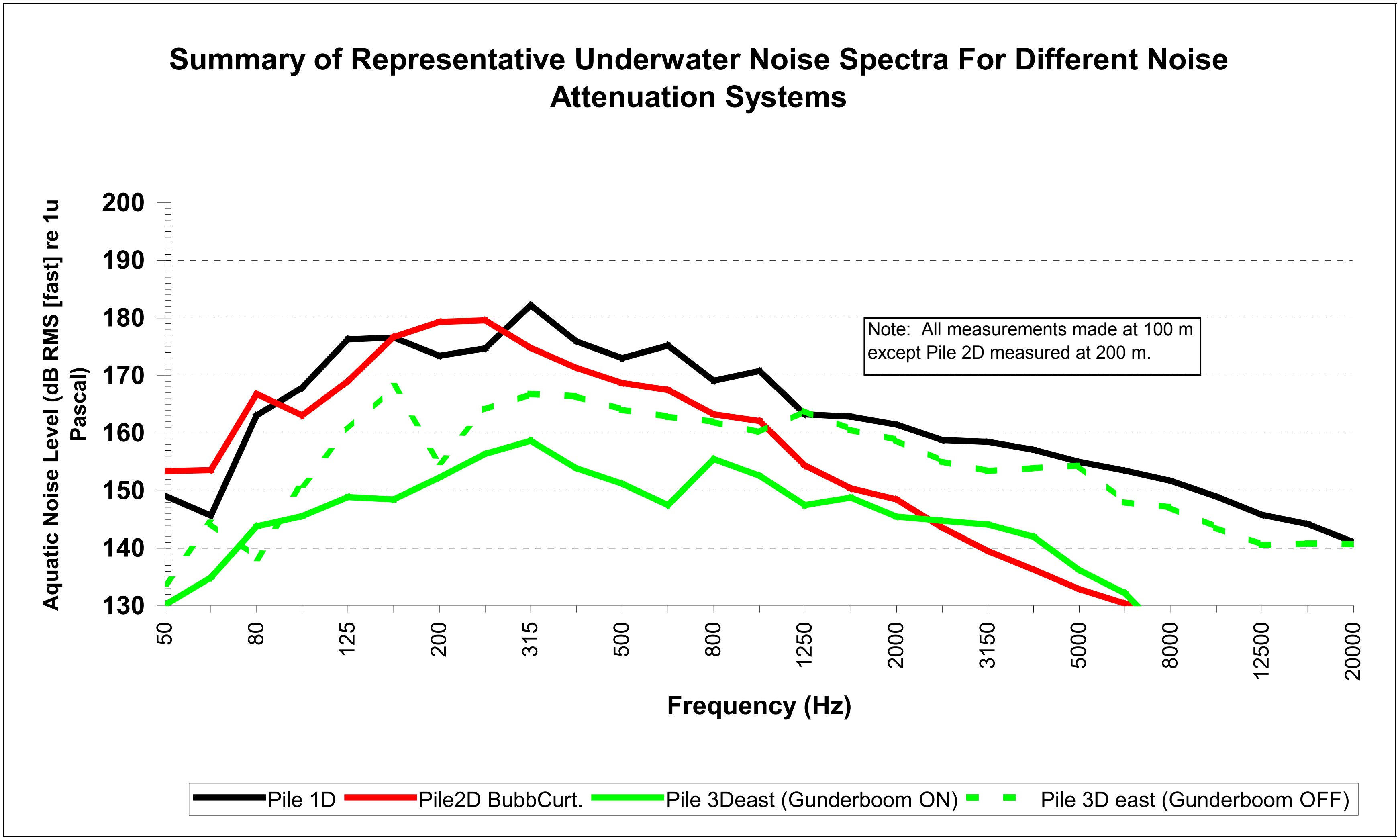
Although there was not a measurable reduction in sound pressure levels recorded when the air bubble curtain system used for the PIDP was in operation, other studies on the use of air bubble curtains have shown that they are effective in reducing underwater sound pressure levels. Bubble curtains are recommended in the Blasters Handbook by E. I. du Pont de Nemours because they reduce sound pressure levels (E.I. du Pont de Nemours 16th edition). Bubble curtains are standard recommended procedures by the Canadian Government because they reduce sound pressure levels from explosives (Wright, 1997). Three states (New Jersey, Oregon and Washington) require bubble curtains to protect natural resources from the sound pressure and shock wave from explosives (Keevin, Hempen and Schaeffer 1997). Recently bubble curtains were shown to reduce pile driving sound pressure levels 3-5 dB in a project near Hong Kong, China (Würsig, Green and Jefferson 2000).

The effectiveness of bubble curtains depends on many factors. The State of Alaska rescinded a bubble curtain requirement because so many were used improperly (Hempen personal communication 2001). Bubble curtains may be more effective where there is less current, the water is shallower and with different pile driving substrates. Bubble curtains that are operating very snugly around the pile may be more effective than a bubble curtain further away from the pile.

Previous data, research and publications indicate that the effectiveness of bubble curtains to reduce sound pressure levels due to explosives and pile driving appears to depend heavily on the configuration of the system and actual field conditions.

The fabric barrier system effectively reduced the RMS impulse sound pressure (Illingworth & Rodkin 2001). Acoustic data collected indicate that the distance to the 190 dB RMS (impulse) level was always less than 100 meters (328 feet) with the fabric barrier system with aerating mechanism in operation. It is not possible from the measured data to estimate the distance more accurately than to say that it is less than 100 meters (328 feet) with the fabric barrier system with aerating mechanism in operation. Figures 4-8 and 4-9 show that the fabric barrier system with aerating mechanism also reduced the higher frequency component of pile driving noise (above about 800 Hz) and changed the shape of the acoustic impulse.

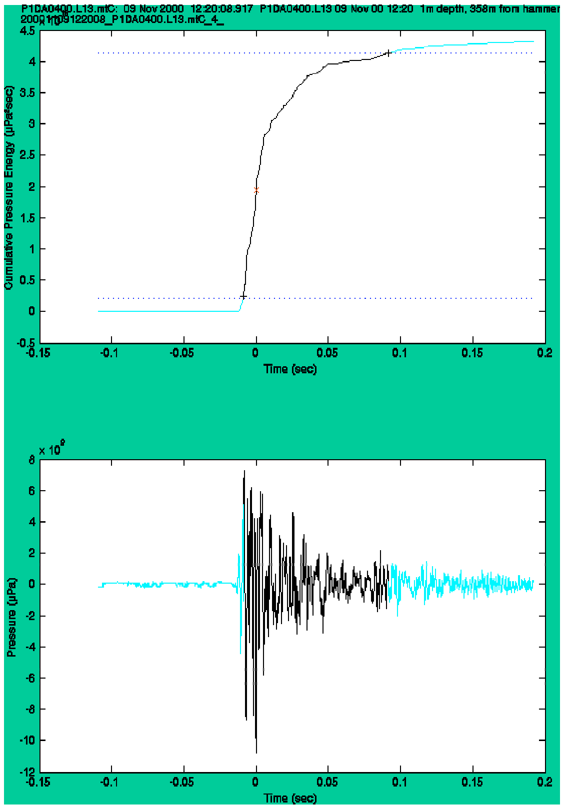
Figure 4-8



Source: Illingworth & Rodkin, 2001.

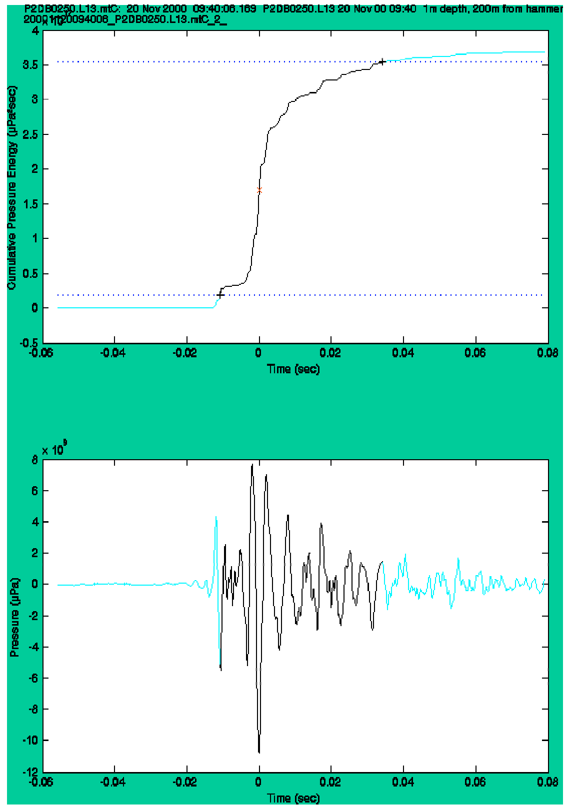
Figure 4-9 Comparison of Cumulative Energy and Impulse During Driving of Pile Segments 1D, 2D and 3D

Pile 1D



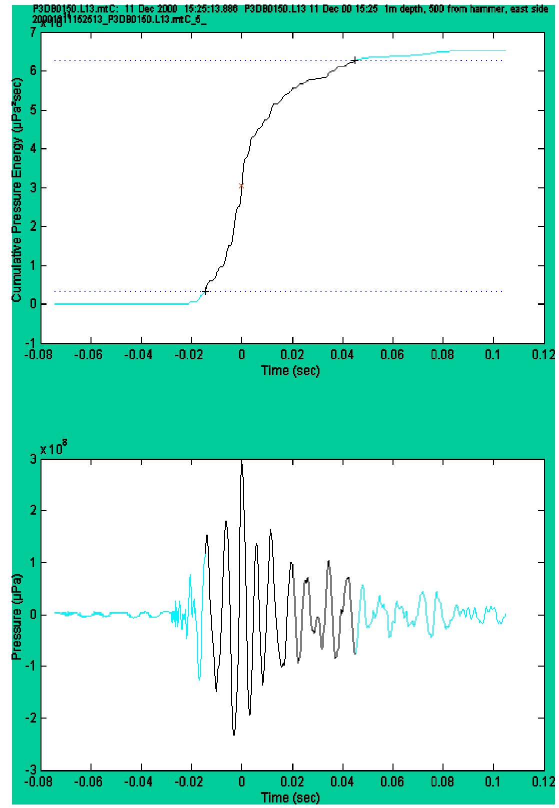
No Attenuation Mechanism1 meter deep @ 358 meters

Pile 2D



Bubble Curtain 1 meter deep @ 200 meters

Pile 3D



Fabric Barrier with Aerating 1 meter deep @ 500 meters

Source: Illingworth & Rodkin, 2001.

5.0 CONCLUSIONS

The PIDP fisheries impact assessment documented near-term fish mortalities and the likelihood of a high rate of delayed mortality of differing sizes and species of fish with swim bladders.

5.1 Fish Mortality

Observations on bird predation indicate many fish with swim bladders that were near active pile driving operations were stunned or killed and drifted up towards the surface where they were quickly consumed by gulls. Observations of gull predation on stunned fish suggested that 0 to 7 fish per minute were killed during pile driving operations. The mortality was undoubtedly much larger since many pelagic fish sink when they die, and many very small juvenile fish would not have been seen by observers. Some critically injured fish may have stayed in the water column or drifted down to the bottom but there is no direct evidence to indicate the number of fish critically injured that did not come to the surface. A review of the literature suggests at least as many fish sink as come to the surface.

Fish survey transects using a fathometer indicated schools of fish did not move away from the pile being driven or the general area of the pile driving barges during pile driving operations. The barges appeared to act as a focus for fish aggregation, especially for those species of fish, such as surfperch, that are attracted to vertical structures.

External examination of stunned fish collected from the water near pile driving operations showed a full range of injuries from no external indication of injury to a complete rupture of the body cavity. The type and range of injury are very similar to the injuries caused by underwater explosives.

Internal examination of stunned fish collected from the water revealed a range of injuries from slight reddening of the dorsal surface of the liver to a complete rupturing of the swim bladder and massive internal bleeding due to the rapid contraction and expansion of the swim bladder.

Unattenuated hammering from both the small hammer and the large hammer resulted in fish mortalities. Based on the sample of fish collected from the water, the larger hammer resulted in mortalities to larger fish. The largest fish recovered was a 29.2-centimeter (11.5-inch) long white surfperch (*Phanerodon furcatus*).

Experiments with fish held in cages close to pile driving operations indicated that many exposed fish may not be stunned or killed immediately, but they may sustain life threatening injuries such as a ruptured swim bladder or limited damage to their internal organs and the inner ear and lateral line organs. Fish with these types of injuries would still be able to swim upright but with their head down and thus they would not typically drift to the surface. In the field, fish with these types of injuries would likely be eaten by predators in subsequent days.

Preliminary results indicate the longer the duration of exposure, the more likely the swim bladder of the fish will be ruptured or that the fish will become moribund and float to the surface or sink to the bottom.

The general impression is that pelagic fish were entrained in the tidal currents and passively drifted into the zone of high acoustic pressure.

5.2 Estimated Radius Of Impact

There are no observations of fish floating to the surface outside the width of the barges. The main barge was 24.4 meters (80 feet) wide. This observation suggests the immediate stun/kill radius or Immediate Mortality Zone (IMZ) at the PIDP site is on the order of 10-12 meters (33-39 feet) for either the small or large hammer without sound attenuation.

Permanent injury to the inner ear and lateral line organ will result in a reduced ability to orient in the water column, capture prey, and avoid predators, thereby leading to delayed mortality. An effort was therefore made to establish the likely radius of the Delayed Mortality Zone (DMZ) for most fish less than several inches long. Results from Hastings et al. (1996), underwater acoustic sound pressure measurements for the PIDP, and results from the experimental fish cages used in the PIDP were considered in this effort.

For the purposes of this report, the DMZ has been defined as the zone in which 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. It is assumed that the rate of mortality and injury drops off with distance in relation to the decrease in sound pressure levels. The DMZ could not be defined as a zone with a precise radius. The analysis below indicates its possible boundaries.

5.2.1 Hastings et al. (1996)

Hastings et. al. (1996) reported that sensory hairs of oscars (*Astronotus ocellatus*) were damaged by continuous sound pressure levels of 180 dB re 1 μPa for one hour. This was the highest sound pressure level applied to the fish in their study. They also applied two lower sound pressure levels (100 dB and 140 dB re 1 μPa), which did not result in injury. They note that extrapolation of their results to other signals and other species should be done with caution. They also note that their findings cannot be interpreted to indicate that sound of shorter duration or lower intensity is not damaging. Nevertheless, their study suggests a possible threshold for continuous sound pressure levels that may result in injury to small fish.

The sound pressure levels that would have resulted in delayed injury to small fish during the PIDP cannot be directly extrapolated from Hastings et. al. (1996). For the PIDP, delayed mortality would have occurred as a result of variable and intermittent sound pressure levels rather than continuous sound pressure levels. Since their study does not identify a threshold that can be applied to the PIDP, underwater acoustic measurements and the results of the experimental fish cages from the PIDP were also considered in defining the DMZ.

5.2.2 Underwater Acoustic Data

The underwater acoustic sound pressure measurements for the PIDP were used to determine the distances at which certain sound pressure levels may be expected at the PIDP site. The data show RMS impulse sound pressure levels as high as 196 dB re 1 µPa at 103 meters (338 feet) from the pile, during driving of Pile 1D using the large hammer without sound attenuation on November 9, 2000 (Illingworth & Rodkin 2001). This was the highest sound pressure level reported. Sound pressure levels drop off at the rate of approximately 6 dB for every doubling of the distance (Illingworth & Rodkin 2001). Table 5-1 presents the estimated RMS sound pressure levels at different distances.

Table 5-1 Estimated RMS Impulse Sound Pressure Level Contours Based on Data for Pile Driving Using the Large Hammer Without Sound Attenuation on November 9, 2000

RMS Impulse Sound Pressure Level (dB re 1 µPa)	Distance meters (feet)
196	103 (338)
190	206 (676) *
184	412 (1,352) *
178	824 (2,703) *

* Estimated distance based on approximate sound pressure level decrease of 6 dB with every doubling of the distance. Not adjusted for excess attenuation.

As discussed in Section 4.6, numerous factors in the environment would tend to attenuate underwater sound propagation in shallow water. Attenuation may be the result of microbubbles in the water column resulting from phytoplankton growth, absorption of the sound in soft Bay mud, scattering of the sound by the surface waves, bubbles in the water from turbulence and the reflection of sound waves off objects such as the SFOBB piers, the PIDP barges and irregularities on the bottom. Estimated excess attenuation was approximately 0.02 dB per meter (Illingworth & Rodkin 2001). Therefore, the values presented in Table 5-1 are conservative, since excess attenuation may be expected to reduce the sound pressure levels at these distances.

5.2.3 Results From Caged Fish Experiments

During the PIDP, shiner surfperch held in cages were positioned at varying distances and depths, for different pile segments. The results of the fish cage experiments were used to help determine a range for the DMZ. At about 150 meters (about 500 feet) away from pile driving operations, 60 percent of experimental fish in cages sustained injuries, and 40percent were seriously injured. This was during the driving of Pile 1D, using the large hammer without sound attenuation (See Table 4-6). Based on this data, the Delayed Mortality Zone (DMZ) may extend at least 150 meters (about 500 feet) from pile driving with the large hammer without sound attenuation.

For the driving of Pile 1D, using the large hammer with no sound attenuation, results from the caged fish experiments also show that at about 500 meters (about 1,650 feet), 10 percent of the fish sustained injuries, and no fish sustained serious injuries (See Table 4-6). Based on the acoustic measurements recorded on November 9, 2000, the sound pressure level at 500 meters (1,650 feet) was approximately 183 dB. Although the highest sound pressure level was recorded during driving of Pile 1D with the large hammer on November 9, 2000, the hammer was not used at maximum energy on that day. If the hammer were used at maximum energy (about 1,750 kJ), the estimated 180-183 dB contour would be between approximately 665 meters and 950 meters (assuming no excess attenuation).

Based on these findings, the DMZ at the PIDP site for the unattenuated large hammer is estimated to extend out at least about 150 meters (about 500 feet) and up to about 1,000 meters (about 3,280 feet) for small fish. The size of the IMZ and DMZ will vary with the species, size, physiological condition of the fish and environmental conditions. Fish without swim bladders will probably not be as adversely affected as those with swim bladders. The IMZ and DMZ are presented as estimates only. There is an inadequate amount of experimental data on pile driving impacts to draw more than general conclusions.

The furthest distance to where no behavioral response can reasonably be expected to occur is not known and cannot be reasonably estimated based on existing PIDP data. This project did not study the startle response of fish at great distance from pile driving. Shin (1995) found that fish behaved differently when the noise in the water was 36 dB re 1 µPa above ambient. The ambient underwater noise SPL level near the barge was 121 dB re µPa (Rodkin personal communication 2001). SPLs in excess of 160 dB re 1µPa at frequencies between 60 Hz and 160Hz can elicit a startle response in clupeids (Sonalysts 1997).

5.3 Air Bubble Curtain and Fabric Barrier System

Based on observations of fish floating to the surface and the foraging behavior of birds, the air bubble curtain and the fabric barrier system were effective in decreasing fish mortalities to varying degrees. Both sound attenuation systems reduced the incidence of fish floating to the surface and gull foraging behavior during pile driving with the small hammer. The gull foraging observations and caged fish experiments indicate that the fabric barrier system with aerating mechanism was also effective in reducing fish mortalities and injuries during pile driving with the large hammer. There is limited observation and experimental data on the effectiveness of the air bubble curtain during pile driving with the large hammer. The results of this study indicate that the use of an air bubble curtain or fabric barrier system with an aerating mechanism will reduce, but may not eliminate, fish mortalities.

Use of the two sound attenuation systems on the PIDP provided information about the benefits and disadvantages of each. The air bubble curtain is effective and adaptable to a seafloor with either a sloping or flat bottom. As seen at the installation of Pile 2, the air bubble curtain has a disadvantage in that fast currents in deep water may divert the air bubbles at an angle thereby reducing the effectiveness of the curtain. However, even with strong currents during the PIDP, the bubbles always surrounded Pile 2. Assembly of the bubble ring must typically be done off-site where sufficient land area is available for construction. For repeated use during the proposed East Span Project, this system could be redesigned to better withstand the pressures of being repeatedly raised to the surface. When compared to the fabric barrier system with aerating mechanism, there would be a larger economy of scale if it were designed for multiple reuse. The air bubble curtain is advantageous in that it does not need to be attached to the pile template itself, and marine construction equipment can easily maneuver around and over the site without any hindrance from the air bubble curtain. Marine construction equipment does not appear to affect the operation of the bubble curtain. For reuse, the air bubble system's lack of bulk reduces the deployment logistics of relocating it to other pile locations. Once deployed, this system requires minimal inspection. With easier deployment, maneuverability, and minimal inspection, the chances for time consuming delays would likely be decreased. For the PIDP, the bid cost was $120,000 for one installation at Pile 2.

The fabric barrier system with aerating mechanism, used at Pile 3, would be most effective in an area where a flat bottom exists. Differences in bottom contour would result in a gap between the bottom of the curtain and the seafloor where sound would not be attenuated. For the proposed East Span Project, this system might be redesigned to be smaller for a single pile or much larger for a whole pier system. When compared with the air bubble curtain, there would be a smaller economy of scale if this system were designed for multiple reuse. Designing this system for reuse may include moving the template off-site, fitting different length curtains to it, and returning the refitted template back out to the project site. This could reduce the possibility of a gap between the bottom of the curtain and the sloping seafloor bottom. Costs would increase if the system needed to be redesigned for varying bottom elevations. Strain on the system from currents is less of a problem with this device than with the air bubble curtain alone, as the weight of the curtain typically keeps the system nearly vertical. For the PIDP, the fabric barrier system was attached to the pile template by the proprietor of the system. In future applications, this can be expected to be performed off-site. The bulkiness of this arrangement makes movement to the project site and movement between piles to be driven very difficult. The first attempt to deploy this system at the PIDP had to be postponed because in windy weather the curtain and template effectively acted as a sail. The height of this system and having it welded to the template also does not allow for easy maneuverability for the marine equipment. For example, a derrick barge cannot maneuver over it, and equipment on the barge must reach over the barrier to the pile being driven. Once deployed, this system requires inspection of the condition of the zippers in the fabric and the bottom alignment. Any damage to the fabric barrier system would likely require removing the template and barrier from the water to conduct repairs. This would cause time-consuming delays to the pile driving operations. For the PIDP, the bid plus change order cost was $580,000 for one installation at Pile 3. This included an additional bubble ring between the curtain and the pile, which was not in the project specifications, but likely aided in sound attenuation.

5.4 Anticipated Impacts from Pile Driving Operations

The PIDP was conducted in a time outside the peak outmigration period of juvenile salmon. No salmon or steelhead were recovered during the PIDP. Juvenile outmigrants are approximately the same size as the anchovies collected. Physiologically they are very similar and have the same kind of swim bladder. Therefore, it is likely that juvenile salmon and steelhead would have been injured or killed had they been present. Experimental studies with fish have shown that larger fish are able to withstand shock waves generated by explosives better than small fish (Yelverton 1975). Similar response to pile driving would be anticipated.

A relatively continuous mortality of federally managed (EFH) species of fish with swim bladders can be anticipated during the use of the small and large hammer without attenuation. Acoustic attenuation with an air bubble curtain or fabric barrier system using an aerating mechanism would reduce but may not eliminate all mortalities. Losses of federally managed species are not expected to have a population level impact since the main biomass of the federally managed species is in the Pacific Ocean outside San Francisco Bay.

Mitigation for the East Span Project will be implemented to minimize impacts to herring (Caltrans 2001). Construction activities that occur during the peak herring spawning season, generally January to March, would be monitored by a qualified biologist to watch for the presence of spawning herring. If the biologist (or CDFG) observes spawning in the area, in-water construction activities such as pile driving and dredging would be suspended within 200 meters (660 feet) of observed spawn. In-water construction activities would not resume at that location for a period of up to 14 days (as determined by a qualified biologist), allowing herring eggs to hatch and larvae to disperse.

There would be some loss of surfperch expected during pile driving without attenuation but the rate of mortality is not expected to amount to a population level impact.

6.0 DEFINITIONS AND ACRONYMS

DEFINITIONS

Decibel (dB) – A dB or decibel is a logarithmic unit of measure for describing differences in loudness or sound pressure relative to reference loudness. The reference pressure for water is 1 micro Pascal or 0.0002 newtons/m^{-2}.

Delayed Mortality Zone (DMZ) – 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.

Environmentally Significant Unit (ESU) – a population that 1) is substantially reproductively isolated from the conspecific populations and 2) represents an important component of the evolutionary legacy of the species (Busby et al. 1996).

Hertz (Hz) – Hertz, frequency or cycles per second.

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. The conversion of psi-msec to dB-msec uses a conversion rate of $6.9 * 10^9$ µPa per psi.

Immediate Mortality Zone (IMZ) – Radius around a pile being driven where the peak sound pressure level and impulse are great enough to kill a fish resulting in the fish floating up to the surface or sinking to the bottom.

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 kilojoule is represented as kJ.

Linear Peak Level (LPL) – Linear peak level of sound pressure is the largest absolute value of the instantaneous sound pressure (Illingworth & Rodkin 2001).

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

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.

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.

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

Root-Mean-Square (RMS) – An average wave height 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 Sound Pressure – 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 sound pressure is expressed in dB re 1 micro Pascal.

RMS Impulse – Root square of the energy divided by a 1/32 second RMS time constant (Illingworth & Rodkin 2001). The use of this standard time constant results in a conservative measure of the RMS sound pressure. RMS impulse is expressed in dB re 1 micro Pascal.

Secchi disk - A Secchi disk is a 20 cm flat plastic disk with black and white pie shaped sections that is lowered into the water to indicate the transparency of the water. A high reading indicates the water is clear. A low reading indicates the water is turbid.

Sound Pressure Level (SPL) – Sound pressure levels are expressed as a ratio between a measured level and a reference level of power per unit area. SPL = 20 log $\left\{ {P_1}/{1\mu P_\partial} \right\}$

Swim bladder – Gas filled sac in the body cavity of most species of fish.

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

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

ACRONYMS

CDFG – California Department of Fish and Game.

Caltrans – California Department of Transportation.

EFH – Essential Fish Habitat.

ESA – Endangered Species Act.

ESU – Evolutionarily Significant Units.

IHA – Incidental Harassment Authorization.

NMFS – National Marine Fisheries Service.

NRDC – Natural Resources Defense Council.

MSFCMA – Magnuson-Stevens Fishery Conservation and Management Act.

USFWS – U.S. Fish and Wildlife Service.

7.0 LITERATURE CITED

Abbott, Robert. 1970. Hearing in salmonids with reference to the use of sound in fish culture. Thesis. University of Washington.

Abbott, Robert. 1973. Acoustic sensitivity of salmonids. Thesis. University of Washington.

Banner, Arnold and Martin Hyatt. 1973. Effects of noise on eggs and larvae of two estuarine fishes. Trans. Amer. Fish Society. (No.1) 134-136.

Busby, P.J., T. C. Wainwright, G. J. Bryant, L. J. Lierheimer, R. S. Waples, F. W. Waknitz and I. V. Loagomarsino. 1996. Status review of west coast steelhead from Washington, Idaho, Oregon, and California. NOAA Technical Memorandum NMFS-NWFSC-27.

Caltrans. 2000. Seismic Retrofit Project: Pile Installation Demonstration Project Contract No. 04-012084. Sacramento/Oakland.

Caltrans. 2001. Final Environmental Impact Statement/Statutory Exemption And Final Section 4(f) Evaluation, Volume 1 – FEIS.

Craig, James C. and Christian W. Hearn. 1998. Physical impacts of explosions on marine mammals and turtles. Appendix D. Shock testing the Seawolf submarine, FEIS Department of Navy, North Charleston SC.

Christian, Ermine. 1973. The effects of underwater explosions on swim bladder fish. NOLTR 73-103 Naval Ordnance Laboratory, White Oak, Silver Spring, Maryland 1-33

Dolat, S. W. 1997. Acoustic measurements during the Baldwin Bridge Demolition. Sonalysts, Inc. Waterford CT 06385.

Feist, Blake E., James J. Anderson and Robert Miyamoto. Potential impacts of pile driving on juvenile pink (Oncorhynchus gorbuscha) and chum (O. kept) salmon behavior and distribution. FRI-UW-9603. Fish. Res. Inst., U. Washington. Seattle.

Fitch , John E. and Parke H. Young. 1948. Use of underwater explosives in California coastal waters. California Fish and Game 34(2) 53-73.

Federal Register 2000. Endangered and threatened species; final rule governing take of 14 threatened salmon and steelhead evolutionarily significant units (ESUs). 50 CFR part 223 Vol. 65, No 132. 42422-42481.

Federal Register 2000b. Designated critical habitat: critical habitat for 19 evolutionarily significant units of salmon and steelhead in Washington, Oregon, Idaho and California. 50CFR Part 226 Vol. 65, No. 32. P7764-7787.

Federal Register 1999. Endangered and threatened species; proposed rule governing take of threatened Snake River, Central California Coast, South/Central California Coast, Lower Columbia River Central Valley, California, Middle Columbia River, and Upper Willamette, River evolutionarily significant units (ESUs) of West Coast Steelhead. Vol. 64. No. 250 73479-73505.

Gaspin, Joel B. 1975. Experimental investigations of the effects of underwater explosions on swimbladder fish, 1: 1973 Chesapeake Bay Tests. Naval Surface Weapons Center, Silver Springs, Maryland 20910. NSWC/WOL/TR 75-58

Gaspin, Joel, Martin L. Wiley and Greig B. Peters. 1976. Experimental investigations of the effects of underwater explosions on swim bladder fish. Naval surface Weapons Center Silver Springs Maryland.

Goertner, M. L. Wiley, G. A. Young, and W. W. McDonald. 1994. Effects of underwater explosions on fish without swimbladders. Weapons Research and Technology Department NSWC TR 88-114.

Hastings, Mardi. 1997. The Acoustic environment of fishes *in* Using sound to modify fish behavior at power production and water-control facilities. A workshop December 12-13, 1995. Portland State University, Portland Oregon Phase II: Final Report *ed.* Thomas Carlson and Arthur Popper 1997. Bonneville Power Administration Portland Oregon.

Hastings, M. C. 1990 Effects of underwater sound on fish. AT&T Bell Labs International memorandum.

Hastings, M.C., Popper, A.N., Finneran, J.J., Lanford, P. J. 1996. Effects of low-frequency underwater sound on hair cells of the inner ear and the lateral line of the Teleost fish (*Astononus ocellatus)*. J. of the Acoustic. Soc. Am. 99: 1759-1765.

Helfman, G.S., B.B. Collette and D.E. Facey. 1997. The Diversity of Fishes. Blackwell Science, Inc. Massachusetts, USA.

Howorth, Peter. 1996. Marine mammal mitigation plan for the 4H platform removal project. Report for Chevron in satisfaction of agency requirements.

Howorth, Peter. 1998. Wildlife protection during the decommissioning of the Mobil Seacliff Pier Complex northwest of Ventura, California.

Hubbs, C.L., Shultz, E.P. and Wisner, R.L. 1960. Preliminary report on investigations of the effects on caged fishes of underwater nitro-carbonitrate explosions. Data report, University of CA, Scripps Inst. Oceanography.

Hsueh, N. 1999. Santa Clara Valley Water District: Lower Coyote Creek flood control project reaches 1 through 3. Report of mitigation and monitoring programs 1996 to 1998 (Dixon Landing Road to Montague Expressway cities of San Jose and Milpitas, CA). SCVWD Project No. 402111, 55 pp.

Illingworth & Rodkin. 2001. Noise and vibration measurements associated with the pile installation demonstration project for the San Francisco-Oakland Bay Bridge East Span. Petaluma CA.

Keevin, T. M., Hempen, G. L. and D. J. Schaeffer. 1997. Use of a bubble curtain to reduce fish mortality during explosives demolition of Locks and Dam 26, Mississippi River *in* Proceedings of the Twenty-third Annual Conference on Explosives and Blasting Techniques, Las Vegas, Nevada. International Society of Explosive Engineers, Cleveland, OH. 197-205.

Keevin, T. M., Gaspin, J. B. Gitschlag, G. R., Hemnpen, G. L. Linton, T. L. Smith, M., and D. W. Wright. 1999. Underwater explosions: Natural resource concerns, uncertainty of effects and data needs. Proceedings of the 25th Annual Conference on Explosive and Blasting Techniques. International Society of Explosives Engineers 105-116.

Leidy, R.A. 1984. Distribution and ecology of stream fishes in the San Francisco Bay drainage. *Hilgardia* 52 (8) : 1-176.

Martin, Glen. 2000. The hunt is on for herring in S.F. Bay, San Francisco Chronicle Jan. 21, 2000.

Myers, John J. and Carl H. Holm. 1969. Handbook of ocean and underwater engineering. McGraw-Hill. New York.

NRDC 1999. Sounding the Depths. Supertankers, sonar and the rise of undersea noise. http//www.nrdc.org

Orsi, James. 1999. Report on the 1980-1995 fish, shrimp, and crab sampling in the San Francisco Estuary, California. *Ed*. California Department of Water Resources and California Department of Fish and Game.

Popper, A., and T. Carlson 1998. Application of sound and other stimuli to control fish behavior. Trans. Am. Fish. Soc. (No. 5) 673-707.

Popper, Arthur N. 1997. Sound detection by fish: structure and function *in* using sound to modify fish behavior at power production and water-control facilities. A workshop December 12-13, 1995. Portland State University, Portland Oregon Phase II: Final Report *ed.* Thomas Carlson and Arthur Popper 1997. Bonneville Power Administration Portland Oregon.

Richardson, John W., Charles R. Greene Jr., Charles Malme, and Denis H. Thompson. 1995. Marine Mammals and Noise. Academic Press.

San Francisco Bay Area Wetlands Ecosystem Goals Project. 2000. Baylands Ecosystem Species and Community Profiles: Life Histories and Environmental Requirements of Key Plants, Fish and Wildlife.

Shin, Hyeon Ok. 1995. Effect of the piling work noise on the behavior of snakehead (*Channa argus*) in the aquafarm. J. Korean Fish. Soc. 28(4) 492-502.

Suer, Anna L. 1987. The herring of San Francisco and Tomales Bay. Ocean Research Institute, San Francisco, CA.

Teleki, G. C. and A. J. Chamberlain. 1978. Acute effects of underwater construction blasting on fishes in Long Point Bay, Lake Erie. Fish. Res. Board. Can. 35: 1191-1198.

Urick, R. J. 1986. Ambient noise in the sea. Peninsula Publs., Los Altos. CA.

U.S. Fish and Wildlife Service. 2000. Endangered Species Act of 1973 as amended through the 100th Congress.

Wright, Dennis G. 1982. A discussion paper on the effects of explosives on fish and marine mammals in the waters of the Northwest Territories. Dept. Fisheries and Oceans, Winnipeg, Manitoba, Canada.

Wright, Dennis G. 1997. Guidelines for the use of explosives in Canadian fisheries waters – an introduction of the guidelines and the process of their development. International Society of Explosive Engineers.

Würsig, B, C. R. Greene Jr. and T.A. Jefferson 2000. Development of an air bubble curtain to reduce underwater noise of percussive piling. Marine Environmental Research 49 (2000) 79-93.

Yelverton, John T., Donald R. Richmond, William Hicks, Keith Saunders, and Royce Fletcher. 1975. The relationship between fish size and their response to underwater blast. Lovelace Foundation for Medical Education and Research, Albuquerque, NM.

Yelverton, John T., Donald R. Richmond, E. Royce Fletcher, and Robert K. Jones. 1973. Safe distances from underwater explosions for mammals and birds. Lovelace Foundation for Medical Education and Research Albuquerque, NM.

Young, George A. 1991. Concise methods for predicting the effects of underwater explosions on marine life. Naval Surface Warfare Center Maryland.

8.0 PERSONAL COMMUNICATION

Conte, Fred. University of California at Davis, Davis, CA. August 2001.

Hempen, Greg. United State Army Corps of Engineers, St. Louis, MO. August 2001.

Ota, Becky. California Department of Fish and Game, Menlo Park, CA. March 2001.

Jones, Keith. Caltrans Office of Environmental Engineering, Sacramento, CA. July 2001.

Keevin, Tom. United State Army Corps of Engineers St. Louis, MO. 1999.

Kuljis, Mark. The Bait Guys. Sausalito, CA. March 2001.

Rodkin, Richard. Illingworth & Rodkin, Inc., Petaluma, CA. August 2001.

Salomi, Corino. Canadian Department of Fisheries and Oceans, B.C., Canada. August 2000.

Wright, Dennis. Department of Fisheries and Oceans, Coordinator, Environmental Affairs, Science, C&A, DFO, 501 University Crescent, Winnipeg, Canada. August 2000.