California Department of Transportation,
Division of Environmental Analysis
and
Division of Engineering Services, Structures and Geotechnical Services

Hydroacoustic Technical Advisory

HYDROACOUSTIC IMPACT ASSESSMENT FOR PILE DRIVING-

RESEARCH AND APPLICATION OF BEST AVAILABLE SCIENCE

Technical Advisory, Hydroacoustic Research and Best Available Science

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NOTE: This technical advisory applies only to fish and should not be used to assess pile driving impacts to other species, such as marine mammals, birds, or sea turtles. Vibratory pile construction methods create a continuous underwater sound pressure, unlike impact pile driving. Vibratory construction methods are often implemented as avoidance and minimization measure for reducing the total number of strikes to drive the pile to final elevation (refusal). The wave form and impacts from instantaneous sound pressure (e.g., single pile strikes, blasting, hoe ram demolition) differ significantly from those of continuous sound pressure, such as vibratory displacement methods or saw cutting. There is no current agreed upon vibratory threshold implemented to assess potential impacts to fish. However, vibratory methods may affect marine mammals and must be considered when marine mammals are present. Metric distance units are used in this advisory. When research on hydroacoustics began in the early 2000s, typical pile driving reference measurements were taken at 10 meters from the pile.

Executive Summary

The effects of in-water pile driving on fish has been a topic of concern for transportation and resource agencies on the West Coast since the early 2000s. Work on the San Francisco-Oakland Bay Bridge seismic safety project (Caltrans 2001) and other similar projects along the west coast in Oregon and Washington states resulted in an increased awareness of the potential for hydroacoustic impacts (barotrauma) to fishes and other aquatic species from in-water pile driving, impulse actions.

At that time, there was little science available related to the effects of pile driving on fish. To gain an improved, collaborative understanding, Caltrans convened the Fisheries Hydroacoustic Working Group (FHWG) in 2004, which consisted of participants from Caltrans, the Federal Highway Administration (FHWA), the California Department of Fish and Wildlife (CDFW), the U.S. Fish and Wildlife Service (USFWS), the National Marine Fisheries Service/National Oceanic and Atmospheric Administration (NMFS/NOAA) Northwest and Southwest Regions, as well as acoustic consultants and academic experts. After several years and numerous FHWG meetings, the "Agreement in Principle" was signed by all parties in August 2008 and documented as the "Interim Criteria for Injury to Fish from Pile Driving Activities" (FHWG 2008). The criteria were intentionally called "Interim" because it was understood by all involved parties that the criteria were based on limited scientific experience and data and that the efficacy of the criteria would need to be further evaluated and updated as new research emerged in future years. At the time of writing this technical advisory, the 2008 interim injury criteria are still being used to evaluate the effects of impact pile driving underwater sound pressure to fish, despite considerable research, findings, and expert recommendations that the 2008 thresholds are not based on the best available science.

Post 2008, peer reviewed science overwhelmingly indicates that the 2008 Interim Criteria are not based on current science and should be updated to ensure that federal and state resource agency partners are using <u>legally required best available science and data</u> for analysis respective to implementation of state and federal Endangered Species Acts (ESA) consultations, in order to analyze potential impacts to fish, and to develop appropriate and feasible avoidance and minimization measures that are protective of species during the construction of project actions.

This technical advisory summarizes new research that has been conducted since the establishment of the 2008 Interim Criteria, along with literature reviews and other studies that have been conducted since that time. The post-2008 studies demonstrate that the 2008 Interim Criteria are unnecessarily conservative and do not reflect current knowledge for underwater sound pressure levels that align with the onset of effects to fish from impact pile driving actions. The American National Standards Institute (ANSI)-accredited 2014 Guidelines (Popper et al 2014) present updated interim criteria for pile driving that reflect the best available science presented in the post-2008 studies. The Bureau of Ocean Energy

Management (BOEM) has accepted the criteria in these guidelines as primary criteria to be used in pile driving impact assessments, therefore ANSI has further accredited the 2014 Guidelines and criteria and recommended that they be adopted as reflecting the best available science.

The 2014 Guidelines indicate that the onset of injury occurs at a peak sound level of 207 dB, which warrants consideration of a minor increase for the peak sound pressure level, which is currently set at 206 dB. However, the 2014 Guidelines recommend a cumulative sound exposure level (SEL) of 203 dB, which is a significant increase from the current, respective 183/187 dB 2018 threshold. In particular, the outdated cumulative threshold creates unnecessary and significant project and species impact issues, to include extending wet channel project work within rivers and stream habitat areas, creating significant delays to project schedules and costs, and in some instances requiring costly off-site mitigation for perceived impact 'take' of species that are clearly not occurring. It is therefore recommended that the 2008 Interim Criteria be replaced with these criteria, on an interim basis, for all impact pile driving projects in California until such time that additional scientific research and data indicate that further revisions to thresholds are necessary.

Introduction

In October 2000, fish injury and mortality occurred while large, 96-inch piles were being impact driven for the San Francisco-Oakland Bay Bridge seismic safety project (Caltrans 2001). This and other similar work along the west coast in Oregon and Washington states resulted in increased awareness of the potential for hydroacoustic impacts to fishes and other aquatic species resulting from impact pile driving actions conducted in or near waterways that could generate levels of underwater sound pressure that had the potential to injure or cause fish mortality.

When fishes that are protected by state or federal laws (e.g., Federal Endangered Species Act [FESA], California Endangered Species Act [CESA], Essential Fish Habitat provisions of the Magnuson-Stevens Act), are expected to be present during impact pile driving actions, an analysis of pile driving effects to fish must be conducted as part of the project delivery and permitting process. For CESA, CDFW responds with either a Consistency Determination (CD 2080.1) based on the federal Biological Opinion (BO), or if CDFW does not agree with all measures in the BO, CDFW requires an Incidental Take Permit (ITP 2081[b]), which generally requires further measures to *fully* mitigate all perceived impacts that cannot be completely avoided or minimized through reasonable and feasible avoidance and minimization measures.

In relation to the state and federal ESA, recoverable injury is not consistent or in compliance with the FESA or CESA definitions of '*Take'*, therefore thresholds must be protective of injury and potential harm.

- FESA take: "harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect any threatened or endangered species"
- CESA take: "to hunt, pursue, catch, capture, kill, or attempt to hunt, pursue, catch, or kill."

Criteria and methods for assessing impacts are detailed in the Caltrans Manual Entitled "Technical Guidance for the Assessment of Hydroacoustic Effects of Pile Driving on Fish" (Caltrans 2020).

Caltrans, FHWA, CDFW, USFWS, and NMFS/NOAA Northwest and Southwest Regions adopted hydroacoustic interim thresholds intended to avoid and minimize injury and mortality during impact pile driving activities. All parties signed the interim agreement in 2008. This agreement is documented in the "Agreement in Principle" for Interim Criteria for Injury to Fish from Pile Driving Activities" (FHWG 2008). At that time, limited scientific research was available on pile driving's effects on fish. The criteria were intentionally called "Interim" because it was understood by all parties involved that the criteria were based on limited scientific information and would be updated as new research emerged in subsequent years. The 2008 interim injury criteria are still used to evaluate the effects of impact pile driving underwater sound pressure to fish, despite considerable research and findings that the 2008 thresholds are not based on the best available science.

Considerable peer-reviewed research has been conducted since 2008. This newer science overwhelmingly indicates that the 2008 Interim Criteria are not based on the best available science and should be updated to ensure that federal and state ESA consultations use the best available science to analyze the potential impacts to fish and in the development of project actions.

Continued application of the outdated 2008 Interim Criteria for state and federal ESA result in the following issues:

- Fish relocation and exclusion as an avoidance measure that often results in unnecessary injury and take, which is currently estimated to be 3-4 percent of handled and relocated fish. However, when fish are exposed to underwater sound pressure levels that exceed the 2008 Interim Criteria, particularly the accumulative SEL (cSEL) criteria, all research, and studies since 2008 indicate that fish would not otherwise have been injured or killed, outside of the mortalities caused specifically by handling and relocation actions that were intended to protect fish.
    - To date no research or project studies have identified even minor physical injuries, and certainly no mortalities, from sizable exceedances of the cSEL. Research reported in 2014 (Popper 2014) recommends a cSEL increase to 203 dB, in alignment with current research and which are protective in consideration of impacts to fish.
- NMFS November 2021, ‘Optional Multi-Species Pile Driving Calculator’ further encourages incorrect vibratory and behavioral threshold application that were not part of the 2008 Interim thresholds. Despite continuous reference to Caltrans manuals and compendium data, the NMFS tool improperly references the outdated and discontinued Hydroacoustic Guidance Manual, and misuses proxy monitoring data for impact and vibratory analysis, as well as attenuation reductions that are not aligned with real attenuation data, or hydroacoustic expert recommendations for attenuation reductions.
    - The 150 dB-RMS behavioral threshold for fishes was intended to be advisory and for general information purposes only. It was never intended to be a threshold for determining impacts, assessing take, or determining mitigation. Some resources agencies are now using this threshold to identify impacts, take, and mitigation. This is an incorrect use of this threshold. There is no science and data to support take or mitigation from this unofficial, and misused threshold.
    - NMFS did not coordinate with Caltrans or the California Hydroacoustic Expert Team on the use of Caltrans guidance materials or compendium data, which are limited and reduce the potential for proxy project data to align with site specific conditions.
    - This problematic tool creates project issues when resource biologists impose incorrect vibratory thresholds for fish consultations. Vibratory methods have been conditioned in consultation efforts for bridge foundation piles that are too large for vibratory methods (e.g., piles greater than 48-inches). Application of this infeasible method increases the duration of the in-water action, while still not achieving pile refusal, and providing no appreciable or effective avoidance or minimization for fish or other aquatic species.
- Biological professionals often try to exclude pile driving as a foundation construction method, based on perceived impacts to fish. This results in requirements to deploy drilled foundation methods for deep water foundation construction, which lead to a significant increase in construction time within the river or creek compared to driven piles, (some instances add

several months of wet channel working days), and which can push project foundation work into multiple seasons further affecting fish, other aquatic species, and critical or other sensitive habitat. Drilling actions are associated with an increased potential for water quality discharges from drilling mud or frac-outs. The cost of drilled shafts can be significantly higher (up to a 50 percent foundation cost increase) compared to that of driven piles, greatly impacting state and local bridge project costs.

- New bridges are often betterments compared to existing culverts or bridges (e.g., longer spans, fewer piers, removing bent walls, and fish and wildlife connectivity remediation projects).
    - More accurately aligning thresholds with the best available science and data would allow for pile driving project implementation efficiencies in the form of fewer working days and seasons in the wet channel while deploying proper avoidance and minimization measures (e.g., driving on land near water and deploying effective and appropriate attenuation measures such as bubble curtains and coffer dams).
- Monitoring underwater sound pressure levels and stopping work prior to exceeding 2008 Interim Criteria threshold levels, creates millions of dollars in project delays based on threshold levels that have been found to be unnecessarily low and not associated with the onset of injury. These delays extend the time it takes to build bridge projects, often adding a year or more of additional construction time, thus increasing impacts associated with contractors and equipment working within the wet channel, rather than completing project work, which would expedite channel restoration and replanting for on-site restoration and mitigation efforts.
- Regulatory agencies and hydroacoustic experts acknowledge that the 2008 Interim Criteria are not the best available science. Therefore, application of the 2008 Interim hydroacoustic thresholds continue to deviate on a project-by-project basis during project consultations and permitting resulting in inconsistent application of thresholds, (e.g., the Tappan Zee Bridge FESA consultation, and Dr. Fine Bridge Coastal Development Permit implemented Popper 2014 thresholds, which are widely considered by experts as the best available science).
    - Inconsistencies are expected to increase as some agencies implement the best available science while others cling to outdated science for consultations, permits, and agreements.
- The criteria are not based on the best available science, the application of which is required by FESA and CESA.

The purpose of this technical advisory is to summarize relevant, scientifically supported research and findings so the best available science can be appropriately implemented during consultations with NMFS, CDFW, the California Coastal Commission (CCC), and other regulatory partners. Updated criteria for fishes that are based on technical expert evaluation of research to date are recommended as the best available science for analysis in current and future consultations, permits, and agreements.

Fundamental Concepts

When a pile is struck with an impact hammer it vibrates and radiates sound energy into the water. Figure 1 below shows a time history of the pressure modulations associated with a single pile strike. The peak sound pressure (Lpeak or Lpk) occurs immediately after the pile is struck. The pile will then continue to ring for a few hundred milliseconds. The sound produced by a single pile strike is measured to determine the peak sound pressure, which is expressed in decibels relative to 1 micro-pascal.

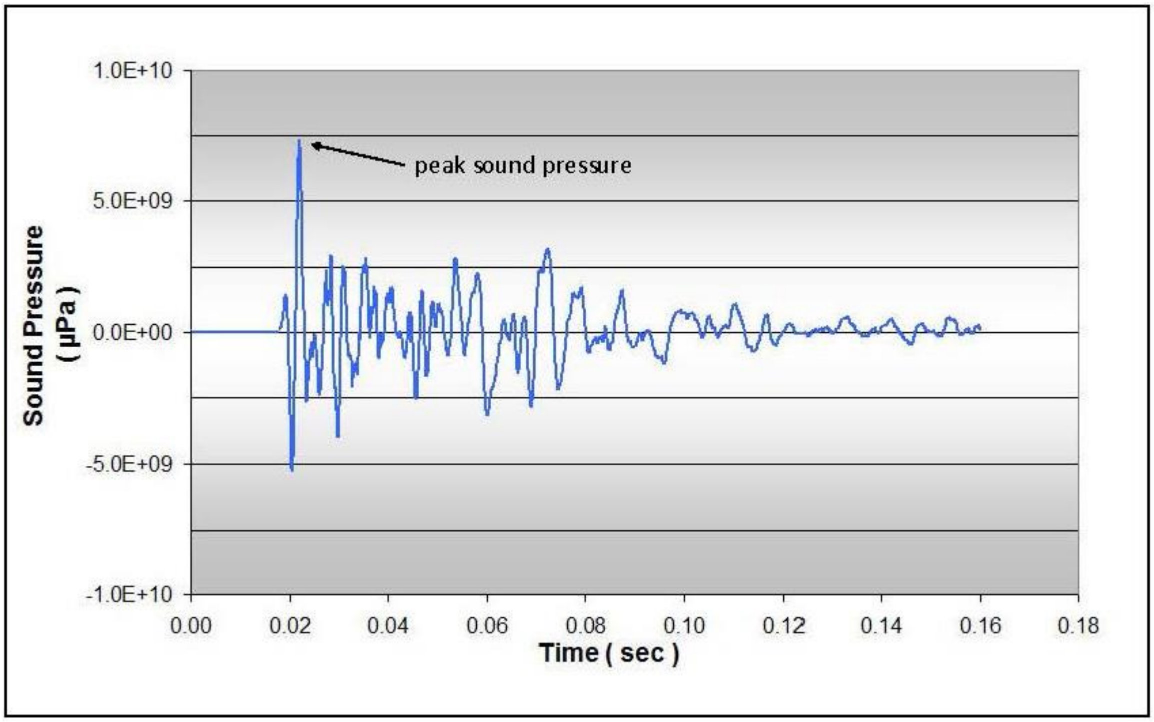
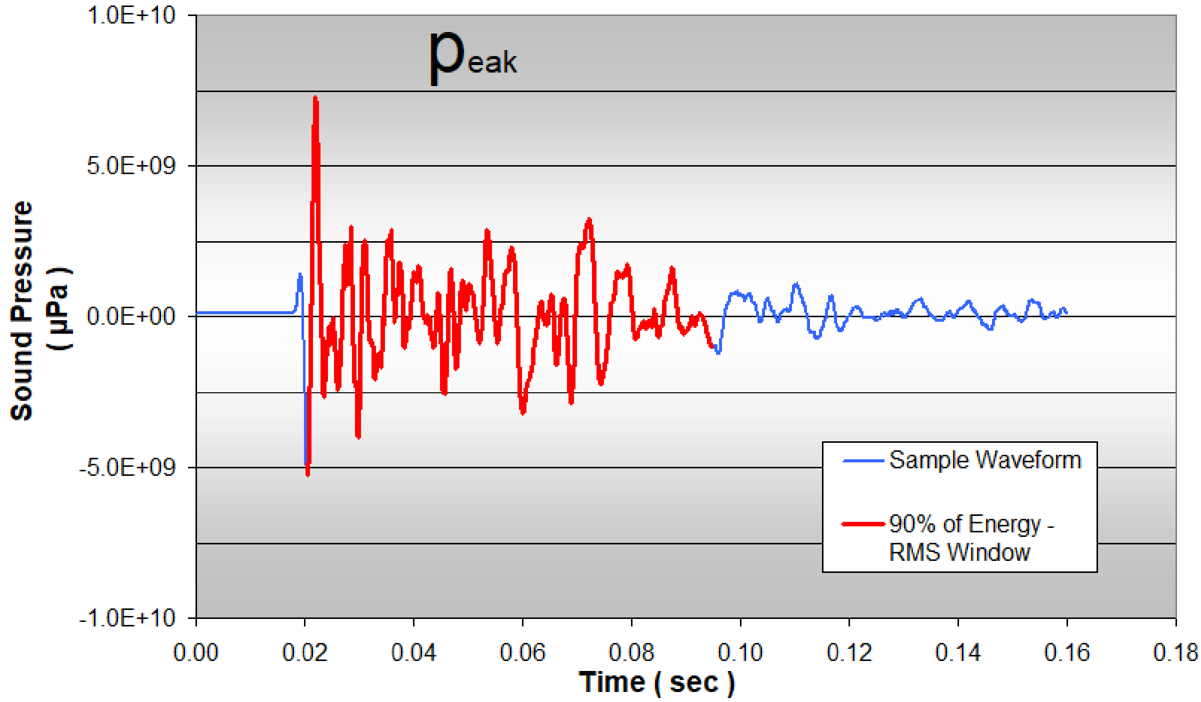


Figure 1. PEAK sound pressure resulting from the maximum absolute value of the instantaneous underwater sound pressure that occurs during a single pile strike

To determine the accumulated underwater sound pressure energy associated with each pile strike, and the total pile driving event over time, it's necessary to measure the total energy associated with each pile strike over the driving duration. This is commonly expressed as the Sound Exposure Level or SEL. The total sound energy associated with each pile strike is summed and normalized to 1 second. The accumulative sound energy associated with a single strike is typically calculated from 90 percent of the sound energy associated with the strike. The upper graphic in Figure 1 below demonstrates 90 percent of the underwater sound pressure energy is determined from a single strike. The lower graphic shows the time history of the accumulated sound energy associated with a single strike. The accumulated energy rises quickly right after the pile is struck. The energy continues to accumulate as the pile rings but at a slower rate. A maximum value is reached once the pile stops ringing.



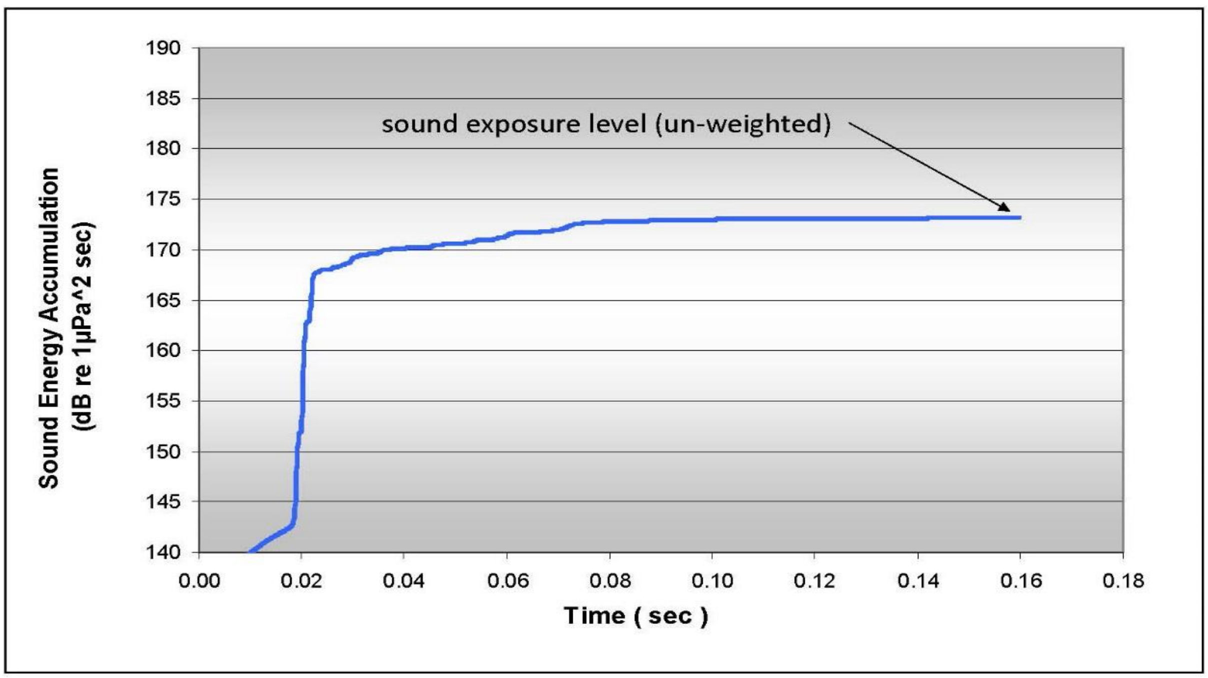


Figure 2. Sound Energy Accumulation Resulting from a Single Pile Strike
Note: *This is an "un-weighted" sound energy scale and does not use the A-weighting scale normally applied to human hearing.*

Because pile driving involves a series of pile strikes throughout the driving action, the cumulative SEL or $SEL_{CUMULATIVE}$ is measured using a hydrophone to monitor all strikes during daily pile driving events. If the single strike SEL and the number of daily strikes is known, the cumulative SEL can be calculated with the following equation:

$$SEL_{CUMULATIVE} = SEL_{SINGLESTRIKE} + 10Log\ (\text{number of strikes}) \qquad \text{eq. 1}$$

A final metric used to characterize pile driving sound pressure is the Root-Mean-Square (RMS) level. This is essentially an average of the sound energy associated with a single strike.

Underwater sound pressure levels reduce or attenuate over distance as a result of many complex factors. For the purposes of hydroacoustic analysis, a simplified approach is taken in which sound pressure is assumed to attenuate at a rate of 4.5 dB per doubling of distance. This rate is called the Transmission Loss and results in a conservative analysis. This rate and attenuation calculation approach should be used unless there is site-specific data indicating that a modified attenuation rate is appropriate. Attenuation is calculated with the following equation:

$$dB_2 = dB_1 - F*\log(D_2/D_1) \qquad \text{eq. 2}$$

where: dB_1 is the sound level at a distance of D_1 from the pile

dB_2 is the sound level at a distance of D_2 from the pile

F = attenuation factor (attenuation is 4.5 dB per doubling of distance where F = 15)

EXAMPLE: If pile driving produces a PEAK sound pressure level of 206 dB_{PEAK} at a distance of 10 meters, the sound pressure level at a distance of 200 meters can be calculated as follows:

$$dB_{200} = dB_{10} - 15\log(200/10) = 206 - 19.5 = 186.5 \sim 187\ dB$$

Interim Injury Criteria

In 2008, interim hydroacoustic criteria were adopted by state and federal resource agencies and transportation departments in a partnership called the FHWG. The intent of the interim thresholds was to avoid and minimize harm and mortality to fish from pile driving activities during bridge foundation and other construction work. When the thresholds were adopted, FHWG was comprised of expert members from Caltrans, FHWA, CDFW, USFWS, NMFS/NOAA Northwest and Southwest Regions, as well as Washington and Oregon state Departments of Transportation (DOT). The "2008 interim injury criteria" are still used routinely to evaluate the effects of impact pile driving sound pressure on fish. **No criteria or threshold have been adopted for vibratory methods, which have a non-transient (longer) wave form, and the sound pressure levels and impacts are not comparable to the highly transient (shorter) wave forms associated with impact pile driving.**

Table 1 summarizes the adopted 2008 Interim Criteria.

Table 1. Interim Injury Criteria for Fish

Interim Injury Criteria	**Agreement in Principal**
Peak	206 dB
Cumulative SEL	187 dB – for fish size of 2 grams (g) or greater 183 dB – for fish size of less than 2 g

NMFS/NOAA identified an additional assessment threshold level of 150 dB_{RMS}, which is used to assess the potential for behavioral impacts from pile driving actions.

The cumulative SEL assumes that the total pile driving energy delivered to a fish determines the extent of injuries regardless of how the underwater sound pressure energy is delivered. This assumption is called the "equal energy" hypothesis. The equal energy hypothesis predicts that no matter how the cumulative SEL is reached (e.g., a few strikes or many strikes), the effects on fishes would be the same. As an example, a driven pile installation with a single strike SEL of 165 dB and 1000 strikes has a cumulative SEL of 195 dB. A pile installation with a single strike SEL of 168 dB and 500 strikes also has a cumulative SEL of 195 dB. The equal energy hypothesis assumes that the effect on fish is the same for both conditions.

Effective Quiet

"Effective quiet" is an important concept to consider when assessing hydroacoustic impact for fish. Based on NMFS/NOAA interpretation of effective quiet, when the SEL from an individual pile strike is below 150 dB, then the accumulated sound pressure energy from multiple strikes would not contribute to injury, regardless of how many pile strikes occur at this same SEL. **Effective quiet establishes a limit on the maximum distance from the pile where injury to fishes is expected. This is the distance at which the single-strike SEL diminishes to 150 dB. Beyond this distance, no physical injury is expected, regardless of the number of pile strikes.**

Summary of Related Hydroacoustic Research Completed Since 2008

The following research reports and peer-reviewed studies are relevant and contribute to the body of best available science for pile driving effects to fish. They are listed in chronological order and summarized.

Behavioral Response and Survival of Juvenile Coho Salmon Exposed to Pile Driving Sounds (Ruggerone et al 2008)

Summary of Research

The study was conducted at Fishermen's Terminal, located on the Lake Washington Ship Canal, Washington, from December 28, 2006, to January 17, 2007. Exposure of juvenile coho salmon to impact pile driving occurred on one day. The water depth was 14 to 17 feet, the lake elevation was constant, and there were no currents. Surface substrate was soft mud overlying dense glacial soils. No large rocks or boulders were known to be present.

Approximately 100 juvenile coho salmon—approximately 3.5 to 5.5 inches in length—were placed in cages near to (6 to 22 feet) and distant from (50 feet) the driven steel piles. A total of 14 piles were driven over a 4.3-hour period. Each pile was driven with 1,627 strikes.

Findings Relevant to Updating Interim Thresholds

Peak sound pressure levels (SPLpeak) reached 208 decibels (dB), RMS pressure levels (SPLrms) reached 194 dB, and SEL reached 179 dB, leading to a cumulative SEL of approximately 207 dB during the 4.3-hour period. No juvenile salmon died in either of the test groups or control group (exposed only to background sound levels) while holding the fish in cages for 10-19 days after the exposure. Behavioral responses of salmon to pile strikes were subtle. Startle responses of a small portion of total fish were observed in only 4 of 14 first strikes and tended to occur when cages were close (6 feet) to the piles and SPLpeak (avg. 207 dB) and SEL (avg. 177 dB) were relatively high.

Visual stimuli caused a greater startle response. An avoidance response was not apparent among fish for all but one pile, and no fish exhibited a fright response. No gross external or internal injuries associated with pile driving sounds were observed. Underwater video revealed that the coho salmon readily consumed hatchery food on the first day of feeding (day 5) after exposure to pile driving underwater sound pressure and most test salmon contained food when examined during necropsies 10 days after exposure. Although auditory system, cellular, and stress responses of coho salmon were not examined, this study suggests that coho salmon did not experience the onset of physical injury by exposure to SPLpeak of 208 dB and were not affected significantly by the cumulative SEL of 207 dB.

Swimming and feeding behavior of the coho salmon within the study period indicated that potential physical injury caused by exposure to underwater sound pressure, if any, was not life-threatening. External signs of stress, such as scale loss, excess mucus, and fungus, were not apparent among test fish or control fish.

Risks, Assumptions, and Potential Flaws Related to Updating Interim Thresholds

The submerged test cages did not allow salmon to access surface air for opportunities to gulp air and refill their swim bladders.

Acoustic Monitoring and In-situ Exposures of Juvenile Coho Salmon to Pile Driving Noise at the Port of Anchorage Marine Terminal Redevelopment Project Knik Arm, Anchorage, Alaska (URS Corporation 2009)

Summary of Research

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

This report summarizes the implementation and results of the study, conducted in June 2009, to determine the potential effects of pile driving activities on out-migrating juvenile salmonids. During this study, caged juvenile coho salmon were exposed to pile driving and the associated hydroacoustic measurements were made. Extended behavioral observations of exposed fish were followed by necropsies to look for any delayed or sublethal adverse effects.

Findings Relevant to Updating Interim Thresholds

There were 3 reference exposures and 11 exposures to impact pile driving sound pressure. A small impact hammer (BSP SL30) and a large impact hammer (J&M 115) were deployed.

Hydroacoustic monitoring of the smaller impact hammer (BSP SL30) was completed for 3 tests and involved a total of 10 pile driving events. Measurements were collected approximately 10 to 25 meters (m) from the pile driver. At 10 m from the pile driver, peak sound pressures were approximately 180 dB and SEL levels were 155 dB. At 20 to 25 m, peak sound pressure levels were 170 dB and SEL levels were 145 dB.

Hydroacoustic monitoring of the J&M 115 impact pile driver was completed for 8 tests and a total of 24 different pile driving events. The highest levels measured per pile strike were 195 dB peak and 171 dB SEL at less than 5 m from the pile. At 10 m from the pile, underwater sound pressure levels were approximately 185 to 190 dB peak and 160 to 165 dB SEL (per pile strike).

Cumulative SEL values for all tests were in the range of 179.2 to 190.6 dB.

The following is a summary of key results:

1. Over the 48-hour post-exposure observation period, no acute or delayed mortality of any juvenile coho salmon was observed as a result of exposure to in-water pile driving actions.

2. During the 48-hour post-exposure observation period, no short- or long-term behavioral abnormalities were observed in fish exposed to pile driving underwater sound pressure.
3. The vast majority of the fish examined exhibited no external or internal injuries consistent with barotrauma. A small number of fish examined (3.9 percent of exposed fish; 10.5 percent of reference fish) displayed a minor amount of reddening or light hemorrhaging of the internal wall of the body cavity (in tissue surrounding the ribcage). There was no evidence that these abnormalities were caused by barotrauma. The authors concluded that these likely resulted from normal handling during the live cage experiments.

Risks, Assumptions, and Potential Flaws Related to Updating Interim Thresholds

No risks or potential flaws specifically related to updating the interim thresholds were identified.

Mad River Bridges Replacement Project Effects of Pile Driving Sound on Juvenile Steelhead (Caltrans 2010)

Summary of Research

This study was conducted during the installation of 87-inch-diameter steel shell piles for the Mad River Bridge project. This study used caged fish deployments within the Mad River to expose juvenile steelhead to a variety of peak sound pressures levels (SPL) and cumulative SELs from pile installation using an impact pile driver. The piles were driven on land adjacent to the Mad River.

Four experimental trials were conducted. Each trial consisted of driving one pile section (20 to 24 m). During each trial, cages containing juvenile steelhead were placed at four exposure locations at different distances from the pile driving activity (approximately 115 to 490 feet away) and at a control location (1,150 feet away). Underwater sound pressure levels (peak and SEL) were monitored and recorded at each location during the study.

Following the completion of pile driving, blood samples were drawn from each fish for hematocrit (i.e., packed cell volume) and plasma cortisol level, and a necropsy was performed on each fish. Organ samples were also collected for histopathology by an experienced fish veterinary pathologist from UC Davis. During pile driving actions, fish were exposed to underwater peak SPLs ranging from 69 to 188 dB relative to 1 micropascal (re 1 µPa), which is considerably lower than the interim criteria of 206 dB for peak SPL. However, cumulative SELs were measured in which, over the course of a pile driving event (total pile driving in one day), fish were exposed to cumulative SELs ranging from 179 to 194 dB re 1 µPa2-sec. The cumulative SEL exceeded the interim cumulative SEL threshold of 187 dB during the last two pile driving events, both times in the two cages closest to the pile being driven (thus, four exposure groups experienced cumulative SELs in excess of 187 dB). Control fish experienced SELs of 132 to 141 dB, far below the 150 dB threshold above which SELs are presumed to accumulate.

Findings Relevant to Updating Interim Thresholds

On-site necropsies of all exposed and control fish were conducted following each trial, as well as histopathology of the fish from the cages closest to the pile driving and control fish. No physical trauma or injuries related to exposure to underwater sound pressure from pile driving was observed, and no statistically significant differences between experimental and control fish were detected. Similarly, hematocrit and plasma cortisol levels were not elevated significantly related to exposure to underwater sound pressure generated by pile driving. In summary, there were no immediate, significant, physical effects or injuries from exposure to peak SPLs or cumulative SELs less than or equal to 194 dB from pile driving at the project site.

The study results indicate that exposure to underwater sound levels of up to 194 dB (cumulative SEL) did not result in immediate physical injuries to juvenile steelhead.

Risks, Assumptions, and Potential Flaws Related to Updating Interim Thresholds

Fish could not be held for later observation because of ongoing pile driving and high river temperatures. However, research conducted by Ruggerone et al. (2008) using juvenile coho salmon found that there was no immediate or latent (10 to 19 days) mortality in fish exposed to 207 dB cumulative SEL from pile driving.

Hydroacoustic Impacts on Fish from Pile Installation (Halvorsen 2011)

Summary of Research

The goal of this study was to provide the FHWG with quantitative data in consideration of the 2008 Interim Criteria levels for tissue damage onset. This research was conducted by a team comprised of internationally recognized researchers from the University of Maryland and Battelle – Pacific Northwest Division. The principal investigators were Michele B. Halvorsen, Thomas J. Carlson, and Arthur N. Popper, assisted by Brandon M. Casper and Christa M. Woodley. This research was reported in National Highway Cooperative Research Program Research Digest 163.

To examine the effects of pile driving on fishes, a High-Intensity Controlled Impedance Fluid-filled Wave Tube (HICI-FT) was developed that enabled replication of aquatic, far-field, plane-wave acoustic conditions in the laboratory. The HICI-FT was constructed of a thick, stainless-steel tube with a moving coil shaker at either end for underwater sound pressure simulation. The HICI-FT system enabled realistic presentation of pile driving underwater sound pressure in the laboratory setting and allowed for control of the parameters that affect pile driving signals. Juvenile Chinook salmon, a federally protected species of great concern on the U.S. west coast, were exposed to pile driving signals that had been recorded in the field during real pile driving actions.

One project objective was to demonstrate a correlation between the cumulative SEL and the response level of barotrauma injury and/or mortality. Another objective was to test the validity of the “equal energy” hypothesis that had been accepted implicitly for management of activities that generate impulsive underwater sound pressure.

Researchers did not determine the onset of physical injury; however, the data has contributed to further insight related to the onset of injury. In the examination of barotrauma injuries, the researchers demonstrated that not all injuries had the same physiological significance for survival of fish following exposure. The researchers further ranked, weighted, and categorized injury based on physiological effects. These data were then used in the computation of a response weighted index (RWI). Injuries were categorized as mild, moderate, or mortal.

Findings Relevant to Updating Interim Thresholds

The results distribution from experimental treatments of 1,920 and 960 pile driving strikes showed a statistically significant correlation between RWI and cumulative SEL. Additional statistical analysis showed that as cumulative SEL increased, there was an increase in RWI values. The increase in RWI was the result of the number of injuries each exposed fish experienced as well as the physiological significance of those injuries. Results also showed that fish exposed to 960 strikes had a significantly higher RWI value than fish exposed to 1,920 strikes at the same value of cumulative SEL. In other words, for the same values of cumulative SEL, higher single-strike SEL levels resulted in increases in the number and severity of injuries observed. These injury trends, when quantified using the assessment model, resulted in significantly higher RWI values for 960 versus 1,920 strikes. This is understandable if the energy in a strike and the accumulated number of strikes are viewed as factors in producing the RWI.

This data shows that the equal energy hypothesis does not apply to effects of pile driving, thereby showing that a single metric of total energy (SELcum) is not sufficient to determine criteria. Other metrics are necessary and should be taken into consideration. Those metrics include but are not limited to, SELcum, single strike sound exposure levels (SELss), and total number of strikes.

Figure 3 below plots several types of data. The vertical axis is the number of pile strikes, and the horizontal axis is single strike SEL. The single strike SEL changes based on the size and type of pile being driven. The cumulative SEL is determined from both the single strike SEL and the number of strikes. The Figure also shows the cumulative SEL (dotted lines) calculated from any given combination of single strike SEL and the number of strikes. RWI is plotted with the cumulative SEL.

According to the authors, an RWI of 1 would be a single mild injury, and an RWI of 2 would be any two mild injuries (see Table S-1 in the report for injury descriptions). An RWI of 1 or 2 can only be achieved by 1 or 2 mild injuries. Because in a controlled environmental there are no life-threatening effects from these mild injuries, the authors consider an RWI of 2 to be an acceptable level of effect and one that is sub-onset of injury. In contrast, an RWI of 3 could be any three mild injuries or a single moderate injury. The RWI contours in Figure 3, along with Table S-1 in the report, would first be used to determine an acceptable level of injury (i.e., an RWI of 2). Second, the cumulative SEL contours and x axis would then be used to determine which single strike SEL and cumulative SEL values, in combination with the number of strikes, define the acceptable limits for exposure.

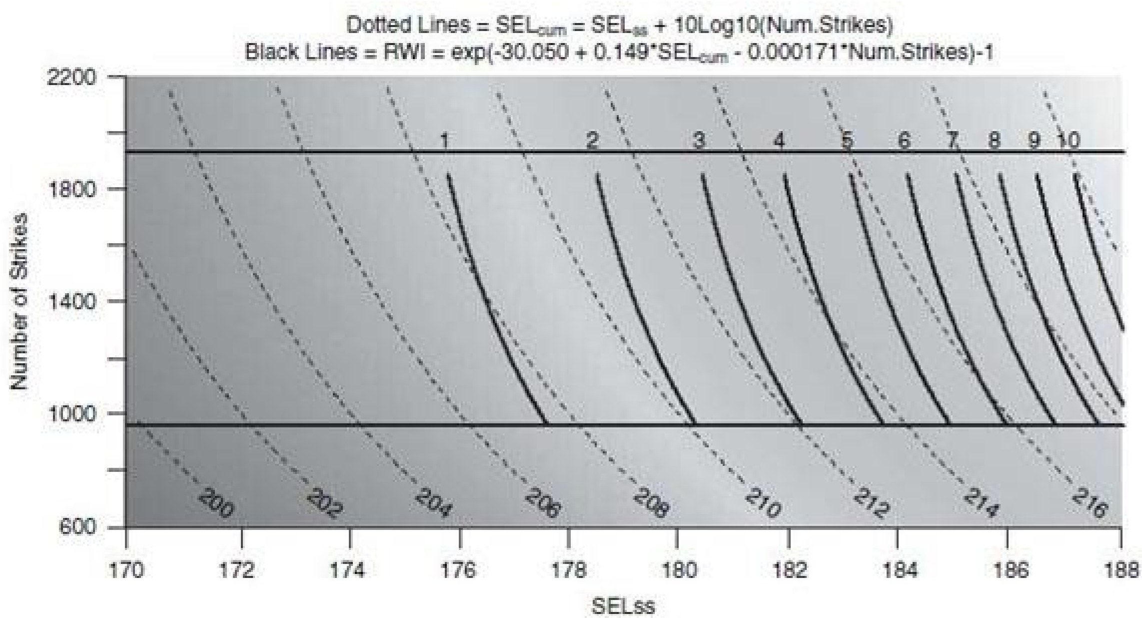


Figure 3. Treatment RWI and SEL_{cum} by SEL_{ss} and number of strikes for all treatments. A contour plot of RWI (the darker curved lines labeled 1-10) illustrates value increases as SEL_{ss} increase. The dashed lines represent the SEL_{cum} curves. The upper horizontal line indicates the 1,920 strike-line, and the bottom horizontal line indicates the 960 strike-line. The darker curved RWI linear contours are the result of testing at only 1,920 and 960 strikes. It is not known whether the functional relationship shown would persist if additional levels of strike numbers were tested. (Note: the two unlabeled curved lines in upper right corner of plots are 218 and 220 dB.)

The research results depicted in Figure 3 indicate that a cumulative SEL of approximately 208.5 dB that is associated with approximately 1,800 total strikes would result in an RWI of less than 1 (the threshold of a single mild injury). A cumulative SEL of approximately 207.5 associated with approximately 1,000 total strikes would similarly result in an RWI of less than 1. The results further indicate that a cumulative SEL of less than 206 for any total number of strikes between 600 and 2,200 would result in an RWI of less than 1. These results indicate that the threshold for a single mild injury is well above the 187 dB cumulative SEL threshold currently used in interim injury criteria and that a cumulative sound pressure level of 206 dB would be well below an RWI of 1. A conservative interpretation of this data indicates that a cumulative SEL threshold of 206 dB should be below the onset of injury.

Risks, Assumptions, and Potential Flaws Related to Updating Interim Thresholds

No risks or potential flaws specifically related to updating the interim thresholds were identified.

Biological Assessment for the Tappan Zee Hudson River Crossing Project (Popper et al 2012)

This paper discusses the following criteria selected for assessing the potential onset of physiological injury to fish from construction related impact pile driving for the Tappan Zee Bridge/Interstate 287 (I-287) Corridor Project.

> Peak SPL: 208 dB re 1 µPa (micro-Pascal)3
> Single strike SEL: 187 dB re 1µPa2-s
> Cumulative SEL (cSEL): 197 dB re 1µPa2-s

These criteria were selected based on: (1) an analysis of the best available and most current science by researchers generally considered to be leading international experts on fish bioacoustics and effects of sound on fish, and (2) data that has become available since 2007 on effects of pile driving and other non-pile driving intense sound sources on fish.

The recommended criteria for this project in the Hudson River are similar to the 2008 Interim Criteria (Table 1) in that there are peak and cumulative SEL criteria. These criteria differ from the 2008 Interim Criteria in that single strike SEL is also included. The peak criterion is 2 dB higher than the interim peak criterion of 207 dB and the cumulative SEL criterion is 10 dB higher than the interim cumulative SEL criterion of 187 dB. The authors note that these single strike peak and SEL values are not often reached in most pile driving operations, whereas a long pile driving operation may more likely reach a cumulative strike SEL of at least 197 dB. Therefore, the major focus for this project is the cumulative SEL criteria.

This paper provides the scientific background for the cumulative sound levels proposed for the project and cites several studies that are discussed in this technical advisory. The authors conclude that new data strongly support the argument that the 2008 Interim Criteria, in particularly the cSEL, can be raised substantially without physiological harm to fishes. The authors consider the criteria values listed above to be conservative in order to protect sensitive species and indicate that it is likely that the actual onset of injury would occur at higher levels than these designated levels.

Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee SE3/SC1 and registered with ANSI (Popper et al 2014)

This report, hereafter referred to as the 2014 Guidelines, presents the outcome of an expert working group that was established to evaluate and recommend updated, broadly applicable underwater sound pressure exposure guidelines for fishes and sea turtles. The working group consisted of 13 internationally recognized experts. After consideration of the diversity of fishes and sea turtles, the experts developed guidelines for broad groups of species, defined by the way they detect sound. Different sound sources were considered in terms of their acoustic characteristics and appropriate metrics were defined for measurement of the received underwater SPL. The resultant underwater sound exposure guidelines were presented in a set of tables. In some cases, numerical guidelines were provided and are expressed in appropriate metrics. When there were insufficient data to support numerical values, the relative likelihood of effects occurring was evaluated, although the actual likelihood of effects depends on the received levels of underwater sound pressure.

The underwater sound pressure exposure guidelines presented in this report are based on the best scientific information available at the time of writing and should be treated as interim. The expectation is that with more research, the guidelines can be refined continuously and additional cells within the tables would be completed. Recommendations are put forward defining the research requirements of highest priority for extending these interim exposure guidelines.

Effects on fish from underwater sound include:

Mortality or mortal injury – This is immediate death or delayed death.

Recoverable injury – This includes injuries, including hair cell damage, minor internal or external hematoma, etc. None of these injuries are likely to result in mortality.

Temporary threshold shift (TTS) – TTS is defined as any reduction in hearing threshold of 6 dBA or greater in terms of sound pressure. temporary reduction in hearing sensitivity caused by exposure to intense sound

Masking – Masking is the impairment of the ability to detect sounds, including the auditory scene, by a reduction in signal to noise ratio of greater than 6 dB.

Behavior – For the purposes of these guidelines, effects on behavior refer to substantial changes in behavior for a large proportion of the animals exposed to a sound. This may include long-term changes in behavior and distribution, including moving from preferred sites for feeding and reproduction or alteration of migration patterns.

The recommended guidelines for the effects of underwater sound pressure exposure to fishes are summarized in Table 7.3 of the report. Table 7.3 is reproduced on page 15.

Table 7.3 Pile driving. Data on mortality and recoverable injury are from Halvorsen et al. (2011, 2012a, c) based on 960 sound events at 1.2 s intervals. TTS based on Popper et al. (2005). See text for details. Note that the same peak levels are used both for mortality and recoverable injury since the same SEL_{ss} was used throughout the pile driving studies. Thus, the same peak level was derived (Halvorsen et al. 2011).

Type of Animal	Mortality and potential mortal injury	Impairment			Behavior
		Recoverable injury	TTS	Masking	
Fish: no swim bladder (particle motion detection)	>219 dB SEL_{cum} or >213 dB peak	>216 dB SEL_{cum} or >213 dB peak	>>186 dB SEL_{cum}	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder is not involved in hearing (particle motion detection)	210 dB SEL_{cum} or >207 dB peak	203 dB SEL_{cum} or >207 dB peak	>186 dB SEL_{cum}	(N) Moderate (I) Low (F) Low	(N) High (I) Moderate (F) Low
Fish: swim bladder involved in hearing (primarily pressure detection)	207 dB SEL_{cum} or >207 dB peak	203 dB SEL_{cum} or >207 dB peak	186 dB SEL_{cum}	(N) High (I) High (F) Moderate	(N) High (I) High (F) Moderate
Sea turtles	210 dB SEL_{cum} or >207 dB peak	(N) High (I) Low (F) Low	(N) High (I) Low (F) Low	(N) High (I) Moderate (F) Low	(N) High (I) Moderate (F) Low
Eggs and larvae	>210 dB SEL_{cum} or >207 dB peak	(N) Moderate (I) Low (F) Low	(N)Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low	(N) Moderate (I) Low (F) Low

Notes: peak and rms sound pressure levels dB re 1 µPa; SEL dB re 1 $\mu Pa^2 \cdot s$. All criteria are presented as sound pressure even for fish without swim bladders since no data for particle motion exist. Relative risk (high, moderate, low) is given for animals at three distances from the source defined in relative terms as near (N), intermediate (I), and far (F).

San Francisco–Oakland Bay Bridge East Span Seismic Safety Project FINAL SFOBB Pier E3 Implosion Demonstration Project Report (2016)

The California Department of Transportation (Department), as part of the San Francisco–Oakland Bay Bridge (SFOBB) East Span Seismic Safety Project (SFOBB Project), dismantled the original east span of the SFOBB. As part of the dismantling phase, the Department completed a demonstration project to remove Pier E3 via highly controlled charges (Demonstration Project).

Controlled implosion was expected to result in fewer in-water workdays, have a reduced impact on the aquatic resources of San Francisco Bay (Bay), and require a shorter time frame for completion. For these reasons, it was proposed as an alternate method to the original, permitted, mechanical methods of building a large coffer dam and dismantling Pier E3. To minimize impacts to biological resources and determine the level of hydroacoustic sound elevation levels from the Demonstration Project, the Department implemented hydroacoustic monitoring. The purpose of this report is to provide a concise summary of the biological monitoring program and the results from the Demonstration Project.

The SFOBB Project implemented innovative, low-blast implosion techniques in combination with substantial bubble curtain attenuation devices to significantly reduce years of demolition that would have been needed if the original mechanized demolition methods and large coffer dams had been used. As part of the implosion demonstration, the project entailed a caged fish study, as well as a CDFW-imposed trawl study, with similar species impact findings, as previously described (SFOBB Pier E3 2016). In this instance, CDFW required the trawl study to demonstrate the impacts and mortality that the agency believed would occur within the accumulation threshold isopleth. CDFW trawled the project area within the SEL cumulative zone for approximately 70 minutes. For each trawl, a record was kept of species and a count for all fish, which distinguished between live, dead, and moribund fish. Moribund fish were identified by an inability to maintain an upright orientation, particularly when the water was “swirled” in the tub or when new water was added. Live fish were identified by an ability to remain oriented in an upright position, and then were counted and released immediately back into the Bay. All fish of 7.8 inches fork-length or greater were measured before release. After all live fish were returned to the Bay, dead and moribund fish were counted, recorded, and then returned to the Bay. Permit conditions required that any collected and dead or moribund federally or state-protected species, including salmonids, Longfin Smelt, or Green Sturgeon, be retained and turned over to the respective agencies; however, none of these fish species were collected. For non-listed species, up to 10 representative individual fish per species were retained from each tow (Caltrans 2016).

Fish from the SFOBB trawl were retained for necropsies, which were conducted by a mutually acceptable fisheries expert who was responsible for assessing the effects of the underwater sound pressure on individual fish. Necropsy parameters included parameters similar to the Mad River Bridge necropsies. A total of 71 out of 1,158 fish captured in the trawls were moribund or dead. The expert performed necropsies on 37 of those 71 fish and determined that none of the injuries were consistent with barotrauma, but that they were likely attributed to the result of the trawling net and handling, not the blast or impacts in the SELcumulative exceedance area. Figure 4 shows the Pier E3 location, bubble curtain, and general impact area of the implosion demonstration project.

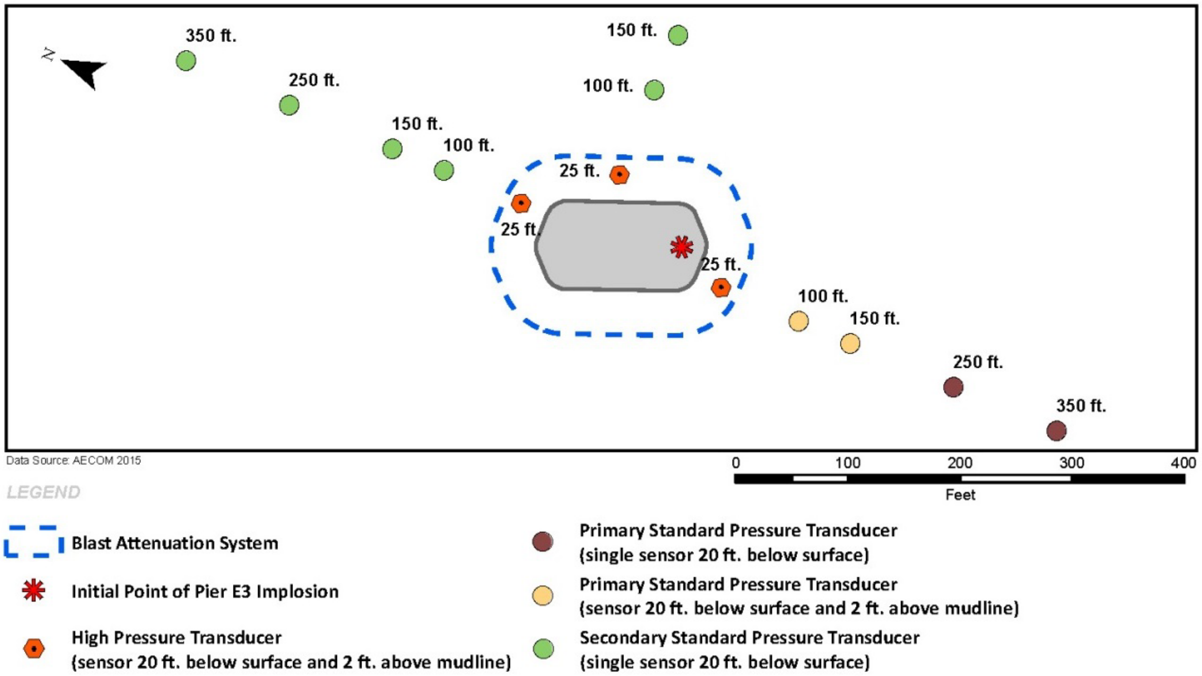


Figure 4. Pier E3 location, Bubble Curtain, and General Impact Area of the Implosion Demonstration Project

Anthropogenic Sound and Fishes (Popper et al 2019)

The objective of this report was to obtain the best available scientific data to determine potential effects on fishes exposed to elevated levels of underwater sound pressure produced by impulsive sources in the aquatic environment, especially impact pile driving. In 2008, FHWG used a similar literature review and research recommendation, prepared by recognized expert hydroacoustic engineering and fisheries scientists, to provide science-based recommendations to support the establishment of interim threshold levels for underwater sound pressure generated by impact pile driving, respective of physical injury and TTS to fishes. The intent of this effort was to evaluate research and literature that had been published to consider new best available science and data related to the 2008 thresholds. Considerable subsequent research had been conducted to justify an updated evaluation. The effectiveness of the current thresholds for protection of fish species was also considered.

The series of recent peer-reviewed papers discussed in this report provide a quantitative approach to assessing onset of physical impacts to fishes. The studies have provided the first dose response curves for injury to fishes, and the first quantified data on potential physical effects of pile driving underwater sound pressure for fish species. New research has provided data on the exposure levels that result in the onset of barotrauma as well as damage to the sensory cells of the inner ear. Furthermore, it has been shown that the number and severity of injuries increases with higher SELss. The results also demonstrated the complexity of the effects regarding the acoustic metrics, including SELs, how sound energy is accumulated, the number of pulses, and that physical effects will likely never be described by a single metric like the cumulative SEL, or provide a simple formula describing the relationship between the number of injuries and sound parameters. However, the studies provided a good estimate of the sound pressure levels that result in the onset of even minor injuries and further demonstrated that onset levels vary by species.

These recent studies clearly demonstrate that the onset of physical injury from pile driving signals begins at sound exposure levels that are substantially higher than those in the applied 2008 Interim Criteria. Indeed, these studies demonstrate that onset of physical responses occurs at least 16 dB above the cumulative SEL levels specified in 2008 Interim Criteria and possibly up to and over 23 dB higher. Other factors are likely to play a major role in potential physical effects of impulsive sounds. For example, pulse rise time is likely to have an impact on the movement of the swim bladder and, thus, the way that its wall strikes the surrounding tissues. Other factors may include the overall duration of exposure and the frequency spectrum of the source. The authors therefore recommend that the levels proposed by the 2014 Guidelines (Popper et al 2014) be adopted until more data are available.

An important issue to consider is that resource agencies currently use onset to be the start of a single injury, while the 2014 Guidelines are not that specific. The data from which the 2014 Guidelines were derived show that there is no injury at levels a few decibels below the criteria for onset of injuries. However, these levels vary by species, fish size, and whether there is a swim bladder present. Because there is so much potential variability for the onset of a single injury, the authors recommend that each consultation modify the onset criteria to be used based on the different species groups presented in the 2014 Guidelines. At the same time, it is clear that any recommendations for onset criteria in individual consultations must be far closer to those recommended in the 2014 Guidelines than to the 2008 Interim Criteria.

Coastal Development Permit for Replacing the Dr. Fine Bridge over the Smith River (California Coastal Commission 2021)

This project was for replacement of the Dr. Fine Bridge over the Smith River on U.S. 101 north of Crescent City. Because the project location is within the California Coastal Zone a Coastal Development Permit from CCC was required.

CCC determined that the 2014 Guidelines (Popper et al 2014) are currently the best available science regarding the effects of pile driving on fish and requested that the hydroacoustic analysis for potential impacts to species for be based on those guidelines.

To align the 2014 Guidelines with the intent of CESA and FESA, CCC recommended that injuries termed as “recoverable” are appropriately considered take. The 2014 Guidelines indicate that the onset of recoverable injury occurs at a peak sound level of 207 dB and a cumulative SEL of 203 dB. The Coastal Development Permit therefore states that exceedance of either criterion shall be deemed injurious or lethal to exposed fish.

Discussion and Conclusions

This technical advisory summarizes new research that has been conducted subsequent to establishment of the 2008 Interim Criteria, along with literature reviews and other studies that have been conducted since that time.

The post-2008 studies demonstrate that the 2008 Interim Criteria are excessively conservative and do not reflect current knowledge of the levels at which there may be an onset of effects from impact pile driving. The 2014 Guidelines present updated interim criteria for pile driving that reflect the best available science presented in the post-2008 studies. Therefore, it is recommended that the 2014 Guidelines and criteria be adopted as reflecting the best available science.

The 2014 Guidelines indicate that the onset of recoverable injury occurs at a peak sound level of 207 dB and a cumulative SEL of 203 dB. It is therefore recommended that the 2008 Interim Criteria be replaced with these criteria on an interim basis for all impact pile driving projects in California until such time that additional research indicates further revisions are necessary.

In summary, other agencies and experts continue to acknowledge that the 2008 Interim Criteria are not the current best available science. They are instead identifying ways to implement the best available science on a project-by-project basis. Additional inconsistencies are anticipated as the services continue to use old, outdated science.

BOEM Nationwide Recommendations for Impact Pile Driving Sound Exposure Modeling and Sound Field Measurement for Offshore Wind Construction and Operations Plans (BOEM 2022).

BOEM is a federal agency whose mission is to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way. All proposed offshore wind energy projects (described in a Construction and Operations Plan [COP]) that are submitted for review to BOEM are required to include assessments of potential environmental impacts resulting from project construction.

Because underwater sound pressure generated from impact pile driving for construction of offshore energy projects can impact marine species near the project area, an important aspect of BOEM's environmental impact assessment is to estimate and validate the ensonified area. Specifically, two processes are typically performed: (1) a noise impact assessment is conducted during the pre-construction phase, via modeling and analyses, and (2) ensonified areas are validated during the construction phase via sound field measurements. The document provides recommendations and guidance developed by BOEM for conducting these two-processes specific to impact pile driving in water.

The primary outputs from this modeling are the sound fields associated with the design envelope of the project and an estimate of "exposures" for each species of interest in a project development area. An "exposure" occurs when a particular individual of a particular species is exposed to underwater sound pressure levels above a given threshold. BOEM notes that a single "exposure" does not necessarily equate to a "take" under the Endangered Species Act (ESA) or the Marine Mammal Protection Act (MMPA).

In consideration of fish injury, this document provides the following guidance:

- Threshold standards developed for injury to fishes (Table 3 from the document reproduced below): The ANSI-accredited thresholds (Popper et al. 2014) should be the standard for reporting. NMFS lists separate "interim guidance" of peak onset of injury or mortality from impact pile driving regardless of fish size or hearing type, and an SEL onset of injury or mortality for fish 2 g or larger (FHWG 2008) and for fish smaller than 2 g. These criteria apply to impact pile driving only.
    - Until these thresholds are updated for both impact and vibratory pile driving, BOEM has asked for COPs to include both the ANSI-accredited acoustic thresholds for fish as well as the 2008 Interim Criteria.
- Fish Behavioral Response: NMFS interim guidance for the onset of behavioral response – 150 dB re 1 µPa SPL. Currently, there are no ANSI-accredited or other recommended behavioral threshold for fish available.

Table 3. Acoustic thresholds for potential injury and TTS for fishes

Fish Group	Impulsive Signals			Non-impulsive Signals	
	Injury		TTS (temporary, recoverable hearing effects)	Injury	TTS (temporary, recoverable hearing effects)
	SEL[a] (unweighted)	Lpk[a] (unweighted)	SEL[a] (unweighted)	Lpk[a] (unweighted)	Lpk[a] (unweighted)
Fish without swim bladder[b]	> 216	> 213	≫ 186	--	--
Fish with swim bladder not involved in hearing[b]	203	> 207	>186	--	--
Fish with swim bladder involved in hearing[b]	203	> 207	186	170 (for 48 h)	158 (for 12 h)
All Fish mass ≥ 2 g[c]	187	206	--	--	--
All Fish mass < 2 g[c]	183	206	--	--	--

[a] Threshold units: SEL in dB re 1 µPa²·s; Lpk in dB re 1 µPa
[b] Popper et al. (2014)
[c] NMFS recommended criteria adopted from the Fisheries Hydroacoustic Working Group (2008)

Findings Relevant to Updating Interim Thresholds

This document identifies the ANSI-accredited thresholds (Popper et al. 2014) as the primary injury criteria that should be used for assessing impact pile driving impacts to fish. It also acknowledges the 2008 interim injury thresholds. BOEM has asked lessees to include both the ANSI-accredited acoustic thresholds for fish as well as the 2008 Interim Criteria in pile driving assessments until these thresholds are updated for both impact and vibratory pile driving. This is an important acceptance of the ANSI-accredited thresholds by a federal agency that oversees pile driving installation.

Discussion and Conclusions

This technical advisory summarizes new research that has been conducted subsequent to establishment of the 2008 Interim Criteria along with literature reviews and other studies that have been conducted since that time.

Post-2008 studies demonstrate that the 2008 Interim Criteria are excessively conservative and do not reflect current knowledge of the levels at which there may be an onset of effects from impact pile driving. The ANSI-accredited 2014 Guidelines present updated interim criteria for pile driving that reflect the best available science presented in the post-2008 studies. BOEM has accepted the criteria in these guidelines as primary criteria to be used in pile driving impact assessments. Therefore, it is recommended that the ANSI-accredited 2014 Guidelines and criteria be adopted as reflecting the best available science.

The 2014 Guidelines indicate that the onset of recoverable injury occurs at a peak sound level of 207 dB and a cumulative SEL of 203 dB. It is therefore recommended that the 2008 Interim Criteria be replaced with these criteria on an interim basis for all impact pile driving projects in California until such time that additional research indicates that further revisions are necessary.

DEDICATION

This Technical Advisory is dedicated to Caltrans Senior Bridge Engineer Ryan Stiltz who passed away in July 2023. Ryan has played a key role in evaluation of geotechnical and foundations design methods for bridge building and the effects of pile driving underwater sound pressure on fish. Ryan's contributions toward foundations analysis methods and application of hydroacoustic analysis has been a great benefit to Caltrans and the larger bridge and hydroacoustic science community.

References

BOEM. 2022. “DRAFT BOEM Nationwide Recommendations for Impact Pile Driving Sound Exposure Modeling and Sound Field Measurement for Offshore Wind Construction and Operations Plans.”

California Coastal Commission. 2021. “Coastal Development Permit for Replacing the Dr. Fine Bridge over the Smith River.”

Caltrans. 2010. “Mad River Bridges Replacement Project Effects of Pile Driving Sound on Juvenile Steelhead.”

Caltrans. 2016. “San Francisco–Oakland Bay Bridge East Span Seismic Safety Project FINAL SFOBB Pier E3 Implosion Demonstration Project Report.”

Halvorsen. 2011. “Hydroacoustic Impacts on Fish from Pile Installation.”

Popper et al. 2012. “Biological Assessment for the Tappan Zee Hudson River Crossing Project.”

Popper et al. 2014. “Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI.“

Popper et al. 2019. “Anthropogenic Sound and Fishes.”

Ruggerone et al. 2008. “Behavioral Response and Survival of Juvenile Coho Salmon Exposed to Pile Driving Sounds”

URS Corporation. 2009. “Acoustic Monitoring and In-situ Exposures of Juvenile Coho Salmon to Pile Driving Noise at the Port of Anchorage Marine Terminal Redevelopment Project Knik Arm, Anchorage, Alaska.”