ExxonMobil Production Company
P.O. Box 4358
Houston, Texas 77210

March 3, 2014

Ms. Jolie Harrison
Office of Protected Resources, NMFS
1315 East-West Highway, Silver Springs, MD 20910

Re: Cover Letter to IHA Application – Harmony Platform, Santa Ynez Production Unit

Dear Ms. Harrison,

Enclosed please find ExxonMobil Production Company's application for an Incidental Harassment Authorization (IHA) associated with a proposed project to install six conductor pipes via hydraulic hammer driving at Harmony platform, located in the Santa Barbara Channel, offshore California.

We have structured our IHA application to meet NMFS' 14 informational requirements, and we believe our document to be complete. Presented below is other pertinent information for your consideration in the evaluation of our application:

NMFS Section 7 Consultation:

ExxonMobil plans to initiate an Endangered Species Act Section 7 Consultation through NOAA Fisheries West Coast Region office, Long Beach, CA (Ms. Monica DeAngelis) in support of our request for a total of five incidental Level B (disturbance) takes of endangered whales. The species consist of the blue, fin, humpback, sei, and sperm whale, all of which occur in the Santa Barbara Channel. Although our calculated take estimates are very low, ranging from 0.011-0.109 organism · days, we are requesting authorization for one Level B harassment take of each species from noise exposure to minimize any potential risk of disrupting the project, in the rare event that an ESA/MMPA listed animal enters our buffer zone (i.e., 325 m from the conductor pipe sound source). We are confident that there is no risk of any of these species entering our 10-m Level A shut-down zone, as this area is within the jacket structure of the platform, and inaccessible to large marine mammals.

Project schedule:

ExxonMobil would like to start the project by mid-August, providing this allows sufficient time for review, revision, commentary, and authorization of our IHA application, as well as the 135 days required for our ESA Section 7 consultation. We are respective of the time required to complete the regulatory process, and will work with NMFS in as responsive manner as possible to facilitate the process. A start date no later than mid-August would allow us to complete the project by early November. This schedule is desirable to further minimize potential impact to gray whales during periods of peak migration (i.e., fall [Nov-Dec] and winter/spring [Jan-Mar/Apr-May]), which includes transiting through the Santa Barbara Channel and the project site.

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24-hour operations:

The target depth of each approximately 505-m long conductor is 90 m below the seabed, of which only the last 60 m is estimated to require hammer driving. Installation of long conductors requires continuous hammer driving of each 12-m long pipe section for approximately 2.5-3.3 hours to prevent the pipe from ceasing up in bed sediment, which is comprised mostly of cohesive, fine-grained particles (<63 µm diameter). Each drive interval will be followed by minimal downtime, which is necessary to clean, weld, and prepare the next pipe section. This procedure will result in a portion of the hammer driving being performed at night, posing challenges to effective monitoring of marine mammals in the Level B buffer zone. We are aware that commercially available nighttime monitoring aids (e.g., night-vision binoculars, infra-red equipment) are not wholly effective. Therefore, we propose to use daytime visual counts of marine mammals as an estimate of the number of marine mammals present during non-daylight hours (within a 24-hour period), noting that diurnal activities for most marine mammals are expected to vary somewhat. In addition, conducting operations on a 24-hour basis would result in an estimated 91 day project, compared with approximately 180 days if restricted to daylight hours, thereby encroaching on seasonal migrations of gray whales.

Monitoring of the Level A zone will not be a problem, as the area will be illuminated during nighttime operations.

Acoustic Modeling:

ExxonMobil contracted JASCO Applied Sciences (Victoria, B.C., Canada) to model the sound for a 90 kJ energy hammer near the sound source and throughout the 366-m water column of the exposed conductor pipe. The general approach, based on a point source to represent a typical pile (<15 m long) and estimate sound pressure levels at distance was not appropriate due to the long length of the conductor pipes being installed for this project. Therefore, JASCO modeled sound as a line array of sources along the pipe. JASCO's report is included as an addendum to this cover letter, and the modeling approach and results are summarized in our IHA application.

If you have any questions or need any additional information or assistance, please contact me at (713) 431-1077 or by e-mail at bryan.l.chapman@exxonmobil.com.

Sincerely,

Bryan L. Chapman
Sr. Regulatory Specialist
ExxonMobil Production

Addendum: Assessment of Airborne and Underwater Noise at Harmony Platform (JASCO, rev 5.1, 2/27/14)

ADDENDUM

JASCO ACOUSTIC MODELING REPORT

(REV 5.1, 27 Feb 2014)

Assessment of Airborne and Underwater Noise from Pile Driving Activities at the Harmony Platform

Preliminary Assessment

Submitted to:
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Geophysical Advisor
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1. Introduction

ExxonMobil Exploration Co. (ExxonMobil) is proposing to install six well conductor pipes within the jacket structure of the Harmony platform. The 26-inch by 1-inch conductor pipes will be lowered in sections along conductors guides, which are metal rings affixed to the jacket structure that guide the conductor pipe. Once the pipe has reached the seabed, it is expected to sink approximately 100 ft into the ocean bottom. A hydraulic hammer (S-90 IHC) will then drive the conductor pipe to its final depth of ~300 ft below the seafloor.

In this study, JASCO Applied Sciences (Canada) estimated airborne and underwater sound levels at the pile (i.e., source levels) and received sound levels up to 1 km from the pile during impact pile driving operations. This report summarizes the method used to estimate the source levels and received levels, and discusses potential effects from the surrounding jacket structure, conductor guides, mitigation systems, and hammer position on the sound field.

2. Background

2.1. Acoustic Metrics

Underwater sound amplitude is measured in decibels (dB) relative to a fixed reference pressure of p_o = 1 μPa. The reference pressure used to measure underwater sound is different from the reference pressure used to measure airborne sound. Airborne decibels are based on a standard reference pressure of 20 μPa, which is 20 times greater than for underwater. Due to differences in compressibility and density between the two media, the impedance relationship between sound pressure and sound intensity differs between air and water. When the differences in reference pressure and acoustic impedance for a sound wave with the same intensity in both media are accounted for, the hydroacoustic decibel value (dB re 1 μPa in water) is approximately 63 dB greater than the airborne decibel value (dB re 20 μPa in air).

Because the loudness of impulsive noise, from impact pile driving operations for example, is not generally proportional to the instantaneous acoustic pressure, loudness of impulsive noise and its effects on marine life are commonly evaluated with the following sound level metrics.

The zero-to-peak sound pressure level (SPL), or peak SPL (L_{pk}, dB re 20 μPa in air, dB re 1 μPa underwater), is the maximum instantaneous sound pressure level in a stated frequency band attained by an acoustic event, $p(t)$:

$$L_{pk} = 10\log_{10}\left(\frac{\max\left(\left|p^2(t)\right|\right)}{p_o^2}\right) \tag{1}$$

Although impulsive sounds are commonly expressed with the peak SPL metric, this metric does not account for the duration or bandwidth of the noise. At high intensities, the peak SPL can be a valid criterion for assessing whether a sound is potentially injurious; however, because the peak SPL does not consider the event duration, it is not a good indicator of perceived loudness.

The root-mean-square (rms) SPL (L_p, dB re 20 μPa in air, dB re 1 μPa underwater) is the rms pressure level in a stated frequency band over a time window (T, s) containing the acoustic event:

$$L_p = 10\log_{10}\left(\frac{1}{T}\int_T p^2(t)dt \Big/ p_o^2\right) \tag{2}$$

The rms SPL can be thought of as a measure of the average pressure or as the “effective” pressure over the duration of an acoustic event, such as the emission of one acoustic pulse or sweep. Because the window length, T, is a divisor, acoustic events more spread out in time have a lower rms SPL for the same total acoustic energy.

The sound exposure level (SEL, symbolized L_E, dB re 20 µPa²·s in air, dB re 1 µPa²·s underwater) is a measure of the total acoustic energy contained in one or more acoustic events. The SEL for a single event is computed from the time-integral of the squared pressure over the full event duration (T_{100}):

$$L_E = 10\log_{10}\left(\int_{T_{100}} p^2(t)dt \Big/ T_o p_o^2\right) \tag{3}$$

where T_o is a reference time interval of 1 s. The SEL represents the total acoustic energy delivered over the duration of an acoustic event at a receiver location. It measures the sound energy to which an organism at that location would be exposed.

Because the rms SPL and SEL are both computed from the integral of square pressure, these metrics are related by a simple expression, which depends only on the duration of the energy time window T:

$$L_p = L_E - 10\log_{10}(T) \tag{4}$$

SEL can be a cumulative metric if it is calculated over periods containing multiple events. The cumulative SEL (L_{EC}) can be computed by summing (in linear units) the SELs of the N individual acoustic events (L_{Ei}).

$$L_{EC} = 10\log_{10}\left(\sum_{i=1}^{N} 10^{\frac{L_{Ei}}{10}}\right) \tag{5}$$

2.2. Marine Mammal Exposure Criteria

2.2.1. Underwater

National Marine Fisheries Service (NMFS) currently uses criteria based on the Marine Mammal Protection Act (MMPA 2007). For impulsive sound sources, broadband received rms SPLs of 160 dB re 1 µPa or greater are assumed to disrupt marine mammal behavioral patterns (i.e., Level B harassment) (MMPA 2007). For non-explosive sources (impulsive and non-impulsive), concerns about temporary and/or permanent hearing impairment (Level A harassment) exist at broadband received rms SPLs of 180 dB re 1 µPa or greater for cetaceans, and broadband received rms SPLs of 190 dB re 1 µPa or greater for pinnipeds in water (MMPA 2007).

Expressed in rms SPL units, these criteria account for not only the energy of the acoustic event, but also the duration of the event (see Equation 2). The rms SPL criteria do not, however, consider attributes of exposure duration, sound frequency composition, repetition rate, and animals' hearing sensitivity.

2.2.2. In-air

National Marine Fisheries Service (NMFS) currently has no official criteria for marine mammals (pinnipeds) out of the water (in air). Dual criteria for pinnipeds have been proposed by Southall et al. (2007). In this study, no attempt was made to estimate distances to Southall's criteria since several assumptions on the airborne source spectrum and impulse shape would have to be made to transfer source levels from the A-weighted rms SPL metric to the criteria's metrics (peak SPL and cumulative SEL). An airborne sound level threshold of 100 re 20 µPa (unweighted rms SPL) has been proposed as criterion for behavioral disturbance to non-harbor seal pinnipeds (USDOC 2013, U.S. Navy 2013, NOAA 2014). Because of the limited information available on airborne source levels for the proposed pile and hammer, this is the only criterion for pinnipeds (in air) discussed in Section 6.1.

3. Scenario

The Harmony platform is located at 34° 22′ 35.906″ N, 120° 10′ 04.486″ W, approximately six miles offshore and 27 miles southwest of Santa Barbara, California (Figure 1). ExxonMobil is proposing to install six well conductors within the jacket structure of the platform. The 26-inch by 1-inch conductor pipes will be lowered in sections along conductor guides, i.e., metal rings affixed to the jacket structure that will act as guide to the conductor pipe. Once a pipe has reached the seabed, it is expected to sink approximately 100 ft into the ocean bottom. A hydraulic hammer (S-90 IHC) will then be used to drive the conductor pipe to its final depth of ~300 ft below the seafloor.

The hammer energy proposed for use in this project will vary between 9 and 90 kJ. The S-90 IHC hammer has an estimated blow rate of about 46 blows per minute. The proposed steps to install each well conductor include five to seven sequences of 2.5 to 3.3 hr of pile driving operations followed by 3.5 to 7.3 hr of “quiet time”, i.e. a time at which other activities are performed in preparation for the next section of pile. The complete installation of the conductors is estimated at 14 days of continuous operation.

The purpose of this study was to estimate maximum distances from the pile driving operations to sound level thresholds at which injury and/or behavioral disturbance to marine mammals may occur. The marine mammals of concern at and around the Harmony platform include sea lions (otariid pinnipeds), which are present in and out of the water within and around the platform jacket structure, as well as various cetaceans including dolphins, porpoises, the grey, blue, minke, humpback, right whales, and killer whales, which could be present around the platform.

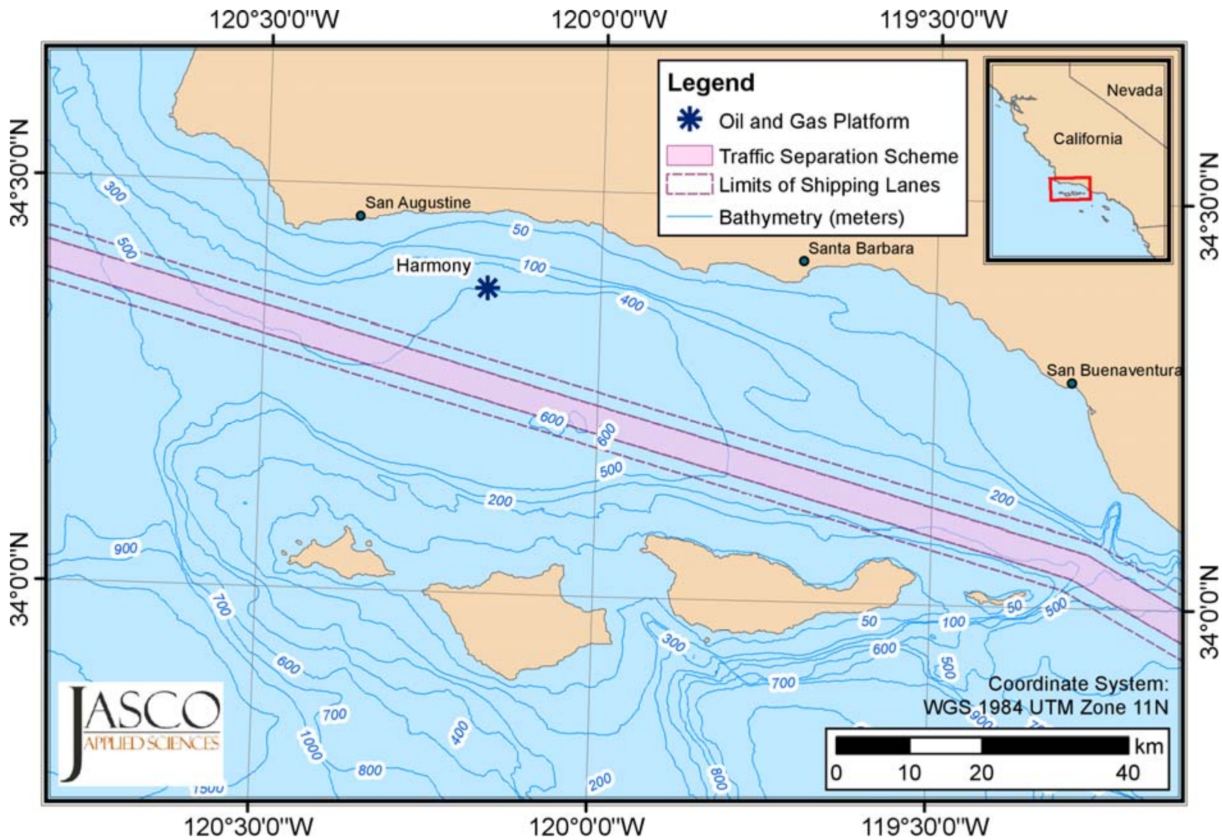

Figure 1. Location of the modeled site, Harmony.

4. Underwater Sound

4.1. Methods

4.1.1. Source levels

Estimating rms SPLs requires time-domain representations of source impulses generated in the water during pile driving. Direct-path measurements of source waveforms from pile driving are generally difficult to extract from recorded data because this operation tends to take place in shallow water where, even at close ranges, multiple bottom and surface reflections interfere with the direct-path waveforms. When measured data are not available, source impulses can be calculated by estimating the source levels (SLs, i.e., the sound levels generated at the pile walls) as a function of frequency, and then deriving the source wavelets along the pile via spectral factorization.

Since no underwater recordings of the proposed pile and hammer were available, measurements of underwater sound levels reported by Illingworth and Rodkin (2007) were used to estimate SLs from impact hammering 26-inch pipe piles. Technical guidelines generally advocate estimating pile driving SLs from past measurements (CALTRANS 2009, §4.6.2, WSDOT 2010a, §7.2.4). JASCO has applied this method in several projects to predict underwater noise from pile driving activities (Gaboury et al. 2007a, Gaboury et al. 2007b, Austin et al. 2009, Erbe 2009, MacGillivray et al. 2011).

The broadband SL for pile driving at the Harmony platform (SL_H) was estimated based on the SL for the tallest steel pipe piles of the reported 24- to 30-inch diameter piles: 175 dB re 1 μPa^2·s, measured at 10 m from the pile, in 12 m of water (Illingworth and Rodkin 2007). Since little is known about the acoustic environment at the recorded locations, this level was backpropagated assuming spherical spreading ($20\times\log_{10}(R)$), leading to a reference source level (SL_{ref}) of 195 dB re 1 μPa^2·s at 1 m (SEL). The broadband SL for pile driving at the Harmony platform (SL_H) was estimated based on the SL_{ref}, scaled according to the proposed maximum (90 kJ) and minimum (9 kJ) hammer energy (E_H):

$$SL_H = SL_{ref} + 10\log_{10}\left(E_H / E_{ref}\right) \quad (6)$$

where SL_{ref} is equal to 195 dB re 1 μPa^2·s (SEL). Thus, a maximum hammer energy of 90 kJ generates a $SL_{H\,max}$ of 190 dB re 1 μPa^2·s (SEL), and a minimum hammer energy of 9 kJ generates a $SL_{H\,min}$ of 180 dB re 1 μPa^2·s (SEL). This scaling method was previously used by JASCO in modeling studies (e.g., MacGillivray et al. 2011) and has reliably predicted SLs for piles less than 10 ft in diameter.

The SL spectra associated with the proposed maximum and minimum hammer energy levels were estimated based on the spectra in 1/3-octave bands provided by MacGillivray et al. (2011). The spectrum for a small diameter pile was scaled to the calculated broadband $SL_{H\,max}$ (190 dB re 1 μPa^2·s) and $SL_{H\,min}$ (180 dB re 1 μPa^2·s). Figure 2 presents resultant spectra in 1/3-octave-bands.

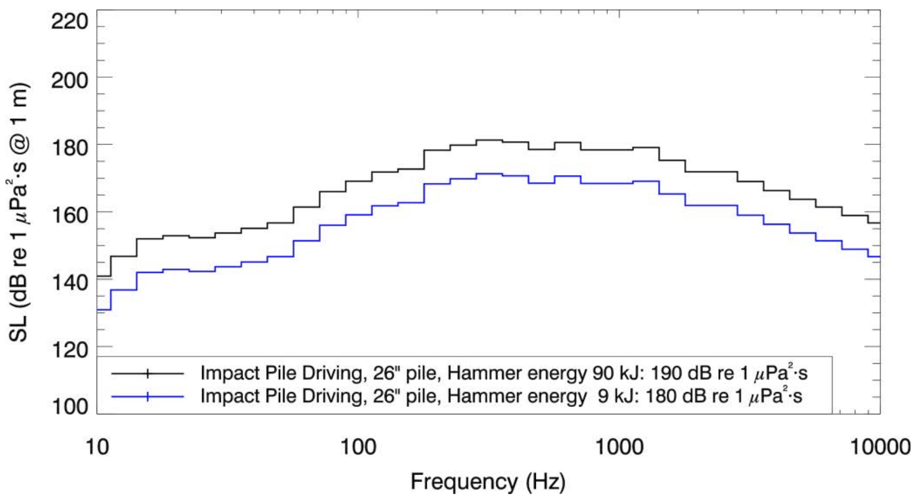

Figure 2. Estimated 1/3-octave-band source level spectra for impact pile driving a 26-inch pipe pile associated with 90 kJ (black) hammer energy and 9 kJ (blue) hammer energy.

In this study, source wavelets along the pile were mathematically derived from the 1/3-octave-band source levels via spectral factorization (Claerbout 1976). The spectral factorization algorithm derives a unique time-domain waveform from a given power spectrum by compressing the maximum amount of signal energy into the shortest causal period, known as the minimum-phase condition. Far-field source waveforms derived via spectral factorization are expected to provide a realistic but conservative estimate (i.e., higher than the average) of pressure levels generated during impact pile driving.

For modeling purposes, a point source is generally used to represent the pile and estimate received levels at long ranges (greater than 1 or 2 water depths). In the present study, however, because the pile at the Harmony platform is long (366 m in water), the point-source assumption is inappropriate. Thus, the pile at the Harmony platform was modeled as an array of sources.

During impact pile driving operations, the hammer strike produces a compressional wave that propagates down the pile. The wave is then reflected up and down the pile a number of times because of the mismatch in impedance between the pile and sediment at the bottom of the pile, and the pile and air at the top of the pile (Reinhall and Dahl 2011). In the present study, each source along the pile was modeled as propagating a wavelet with the appropriate time delay— calculated using 5100 m/s, the compressional sound speed of steel— to represent the sound propagating down, up, and down again, i.e., the direct wave and its two reflected waves. Based on Reinhall and Dahl (2011), the amplitude of the reflected compressional wave was 3/8 of the direct wave. The amplitude of all wavelets was scaled so the sum of all wavelets at 1 m from the pile generated the far-field wavelet derived from the 1/3-octave-band source level spectrum. The 366 m pile was modeled based on 12 sources spaced every 30 m along the pile. The number of sources was chosen by optimizing the minimum number of sources necessary for convergence of the received far-field from a 366-m pile.

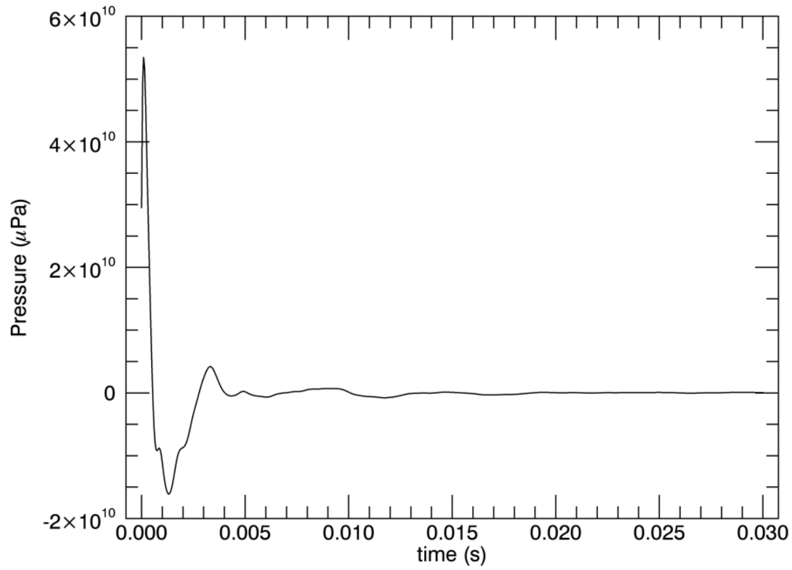

Figure 3. Wavelet derived from the 1/3-octave-band source level spectrum associated with 90 kJ hammer energy (black; Figure 2).

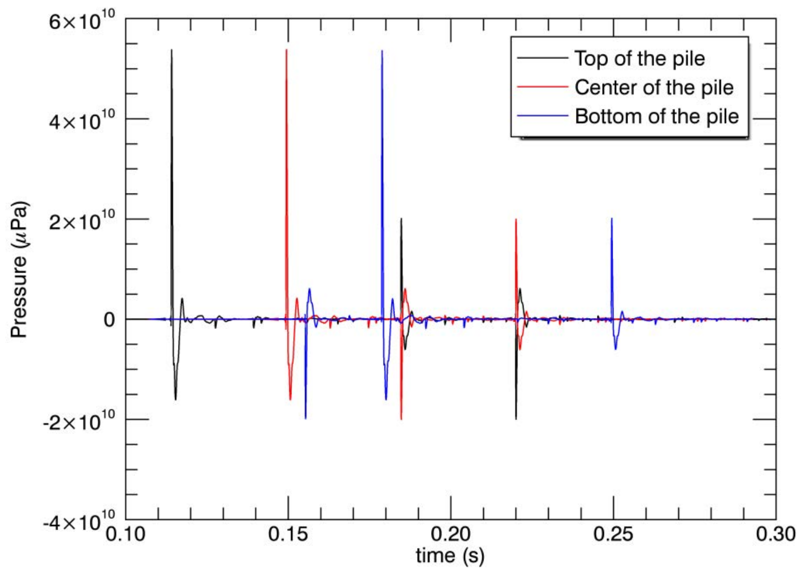

Figure 4. Example of a wavelet at three points (top, center, and bottom) along the pile.

4.1.2. Sound propagation

Underwater sound propagation (i.e., transmission loss) at frequencies of 10 Hz to 10 kHz was predicted with JASCO's Full Waveform Range Dependent Acoustic Model (FWRAM).

FWRAM computes pressure waveforms via Fourier synthesis[1] of the modeled acoustic transfer function in closely spaced frequency bands, and is based on a version of the U.S. Naval Research Laboratory's Range-dependent Acoustic Model (RAM), which has been modified to account for an elastic seabed (Zhang and Tindle 1995). The parabolic equation method used in RAM has

[1] The operation of rebuilding a function from simpler pieces (Fourier series).

been extensively benchmarked and is widely employed in the underwater acoustics community (Collins et al. 1996). FWRAM accounts for the additional reflection loss at the seabed due to partial conversion of incident compressional waves to shear waves at the seabed and sub-bottom interfaces, and it includes wave attenuation in all layers. It incorporates the following site-specific environmental properties: a bathymetric grid of the modeled area, underwater sound speed as a function of depth, and a geoacoustic profile based on the overall stratified composition of the seafloor. Since FWRAM conducts time-domain calculations, it is appropriate for computing time-averaged rms SPL values for impulsive sources.

4.2. Model Parameters

4.2.1. Bathymetry

Water depths throughout the modeled area were obtained from the National Geophysical Data Center's U.S. Coastal Relief Model (NGDC 2013). These bathymetry data have a resolution of 3 arc-seconds, i.e., ~75 × 90 m at the studied latitude. Bathymetry for a 184 × 86 km area was extracted and re-gridded, by minimum curvature gridding, onto a Universal Transverse Mercator (UTM) Zone 10 coordinate projection with a regular grid spacing of 200 × 200 m.

4.2.2. Geoacoustics

FWRAM requires specific values that describe the acoustic properties of the sediment in the propagation area:

- Sediment layer thickness
- Density
- Compressional sound speed
- Compressional attenuation
- Shear sound speed
- Shear attenuation

In November 1992, a drilling survey was conducted in the Santa Barbara Basin (ODP 2013). The reported data provided information about the sediment properties to a depth of 190 m below the seafloor (bsf) near the Harmony platform. The sediment column is composed of silty clay and clayey silt. The high sedimentation rate in the area creates a low density sediment immediately below the seafloor, estimated at 1.26 g/cm^3. The porosity is very high at the top of the sediment column, about 80%, and decreases to 60% at 50 m bsf. The high porosity results in very low shear wave speed and a low attenuation factor for the compressional wave. The compressional sound speed of the surficial sediments is about 1500 m/s (Reid 2005). According to the sonic velocity well-log at ODP leg 146 Site 893, the estimated sound speed is constant with depth in the top 200 m (ODP 2013). This information was used to estimate the rest of the necessary geoacoustic properties (Table 1) based on empirical formulae (Hamilton 1980, Buckingham 2005).

Table 1. Estimated geoacoustic profile at the modeled site.

Material	Depth below seafloor (m)	Density (g/cm^3)	Compressional sound speed (m/s)	Compressional attenuation (dB/λ)	Shear sound speed (m/s)	Shear attenuation (dB/λ)
Silty clay and clayey silt	0–200	1.75	1500	0.5	100	1.5
Silty clay and clayey silt	200–500	1.75–1.97	1850–2374	0.4–0.095		
Semi-consolidated sediment	> 500	2.4	2374	0.095		

4.2.3. Sound speed profile

For this preliminary assessment of the received sound levels, the ocean sound speed profile was derived from location-specific temperature and salinity profiles from the U.S. Naval Oceanographic Office's Generalized Digital Environmental Model (GDEM) database (NAVO 2003, Teague et al. 1990, Carnes 2009). The latest release of the GDEM database (version 3.0) provides average monthly profiles of temperature and salinity for the world's oceans on a latitude/longitude grid with 0.25° resolution. Profiles in GDEM are provided at 78 fixed depth points, to a maximum depth of 6800 m and are based on historical observations from the U.S. Navy's Master Oceanographic Observational Data Set (MOODS).

The GDEM temperature-salinity profiles were converted to sound speed profiles according to the equations of Coppens (1981):

$$\begin{aligned} c(z,T,S,\phi) &= 1449.05 + 45.7t - 5.21t^2 - 0.23t^3 \\ &\quad + (1.333 - 0.126t + 0.009t^2)(S-35) + \Delta \\ \Delta &= 16.3Z + 0.18Z^2 \\ Z &= (z/1000)(1 - 0.0026\cos(2\phi)) \\ t &= T/10 \end{aligned} \tag{7}$$

where z is water depth (m), T is water temperature (°C), S is salinity (psu), and ϕ is latitude (radians).

In the warmer months (March to November), a decrease in sound speed with depth is observed (Figure 5). This feature refracts sound downward, i.e., toward the seabed, which results in increased interactions with the seabed and increased attenuation with range. Between December and February, the sound speed is more or less constant with depth in the top ~30 m. This feature generally results in the sound propagating to longer distances. To represent the seasonal variation in sound propagation, the sound field along one azimuth (south) was modeled using sound speed profiles for January, April, August and November. The profile for January was used to produce conservative estimates of the distances to significant sound levels thresholds along four azimuths (north, south, east, and west) around the platform.

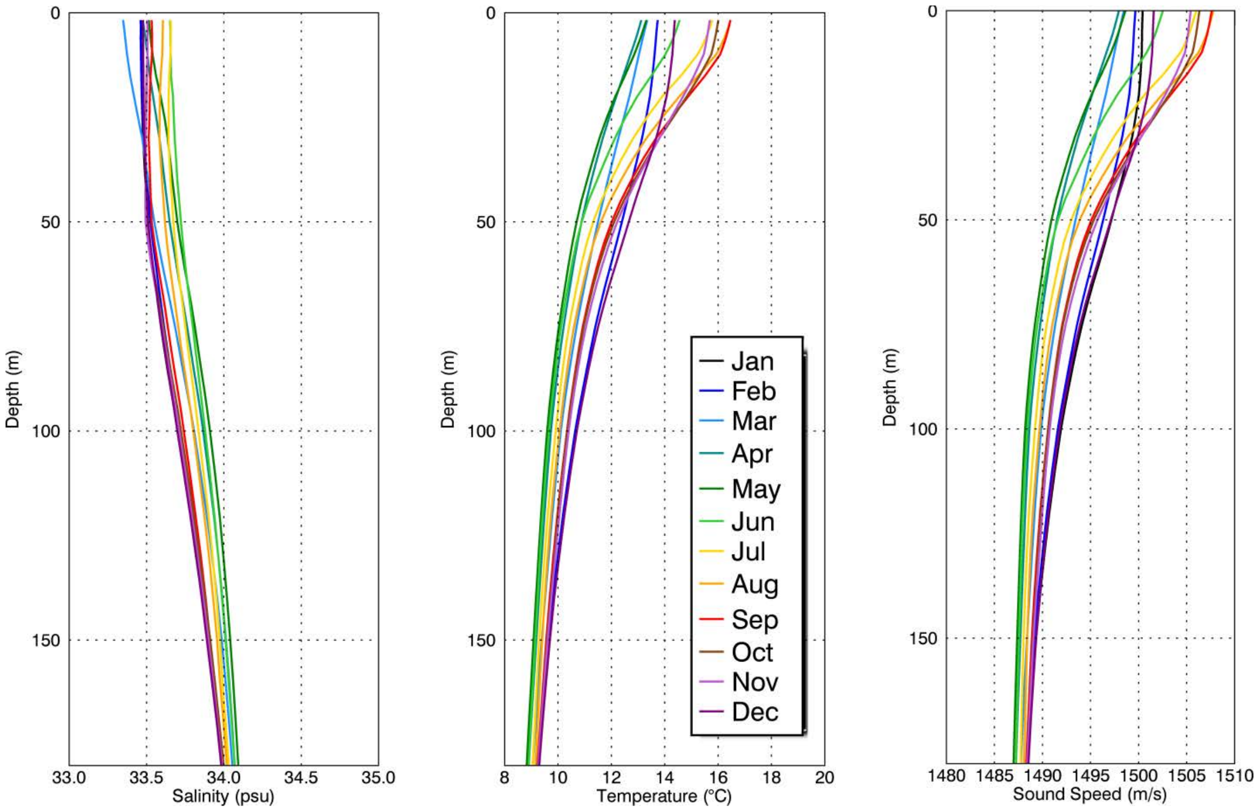

Figure 5. Salinity, temperature, and sound speed profiles derived from GDEM data near the Harmony platform.

4.3. Results

4.3.1. Seasonal variation

Received sound levels for January, April, August, and November were modeled along one azimuth, south of the platform. The maximum seasonal variation in modeled maximum-over-depth received levels is less than 1 dB, up to the maximum modeled range (1 km). Thus, there are no significant seasonal variations in distances to level thresholds up to 1 km from the platform.

4.3.2. Directional variation

Received sound levels up to 1 km from the platform were modeled along four azimuths around the platform: 000˚, 090˚, 180˚, and 270˚ from UTM north. The maximum directional variation in modeled maximum-over-depth received levels is less than 1 dB, up to the maximum modeled range (1 km). Thus, there are no significant directional variations in distances to level thresholds up to 1 km from the platform.

4.3.3. Maximum distances to marine mammal exposure criteria

Maximum distances to level thresholds are presented for the NMFS rms SPL criteria. The results are presented in three formats: tables of maximum distances to sound level thresholds, graphs of sound level isopleths as a function of depth and distances from the pile, and graphs of maximum-over-depth levels as a function of distance from the platform. The predicted maximum distances to specific thresholds were computed from the maximum-over-depth sound fields along the four modeled azimuths. The model used the January sound speed profile.

The maximum distances to received level thresholds for the NMFS criteria for marine mammals (Section 2.2.1) were calculated using the maximum level over all modeled depths. Figures 6 and 7 illustrate the variation of rms SPL as a function of depth and range south of the pile for the maximum and minimum hammer energy. These figures show that the received rms SPLs are generally higher in the top 200 m of the water column. Maximum-over-depth rms SPLs as a function of range for the minimum and maximum hammer energy are compared in Figure 8. Since we assumed the relationship between the hammer energy and the source level of the operation followed Equation 6, received levels are 10 dB higher using the maximum hammer energy (90 kJ) than with the minimum hammer energy (9 kJ).

The maximum rms SPL over all depths at 1 m from the pile were calculated to be 192 and 202 dB re 1 µPa using a hammer energy of 9 and 90 kJ, respectively. These levels are found at a depth of 150 m, approximately halfway down the pile. This depth is dependent on the assumptions made to calculate wavelet at each modeled source along the pile (Section 4.1.1).

The underwater propagation loss, up to 1 km from the pile (Figure 8), may be estimated using a spreading loss coefficient of 16.7 dB.

Table 2. Maximum distances (m) to rms sound pressure level (rms SPL) thresholds based on NMFS criteria.

Threshold type	Threshold level	Distance (m) for minimum hammer energy (9 kJ)	Distance (m) for maximum hammer energy (90 kJ)
Injury (pinnipeds)	190 dB re 1 µPa	1.5	3.5
Injury (cetaceans)	180 dB re 1 µPa	4.0	10
Behavioral Disturbance	160 dB re 1 µPa	100	325

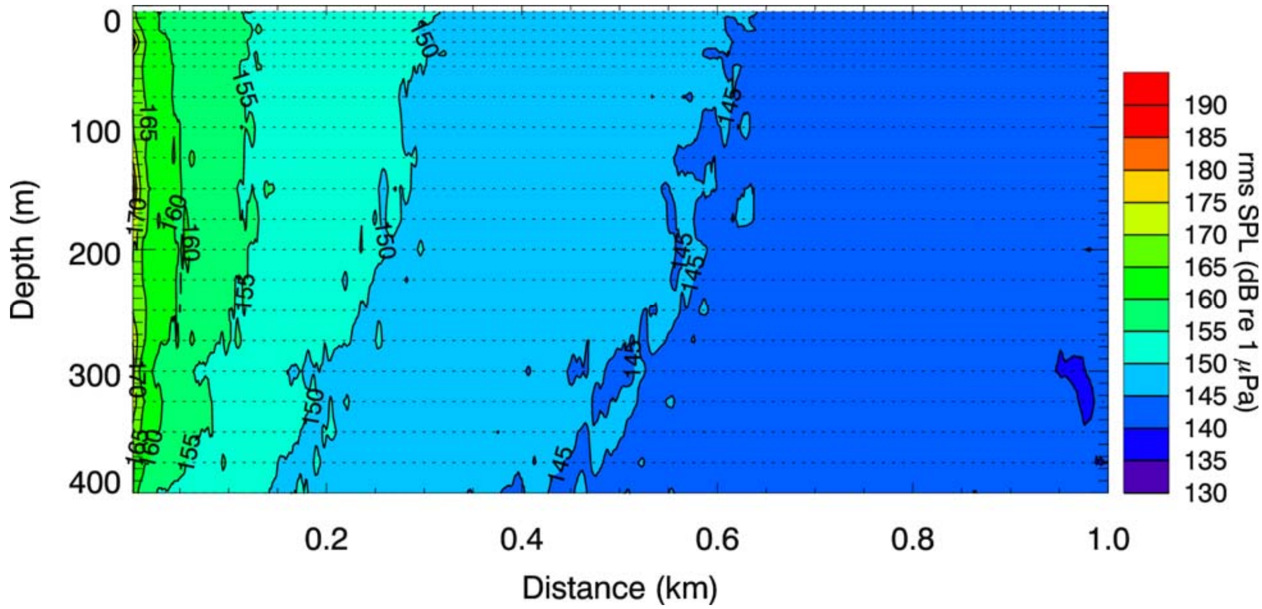

Figure 6. *Minimum Hammer Energy (9 kJ)*: root-mean-square sound pressure levels (rms SPLs) along depth and range south of the pile. Dotted lines represent depths at which received levels were modeled. In this figure, values between modeled depths were linearly interpolated.

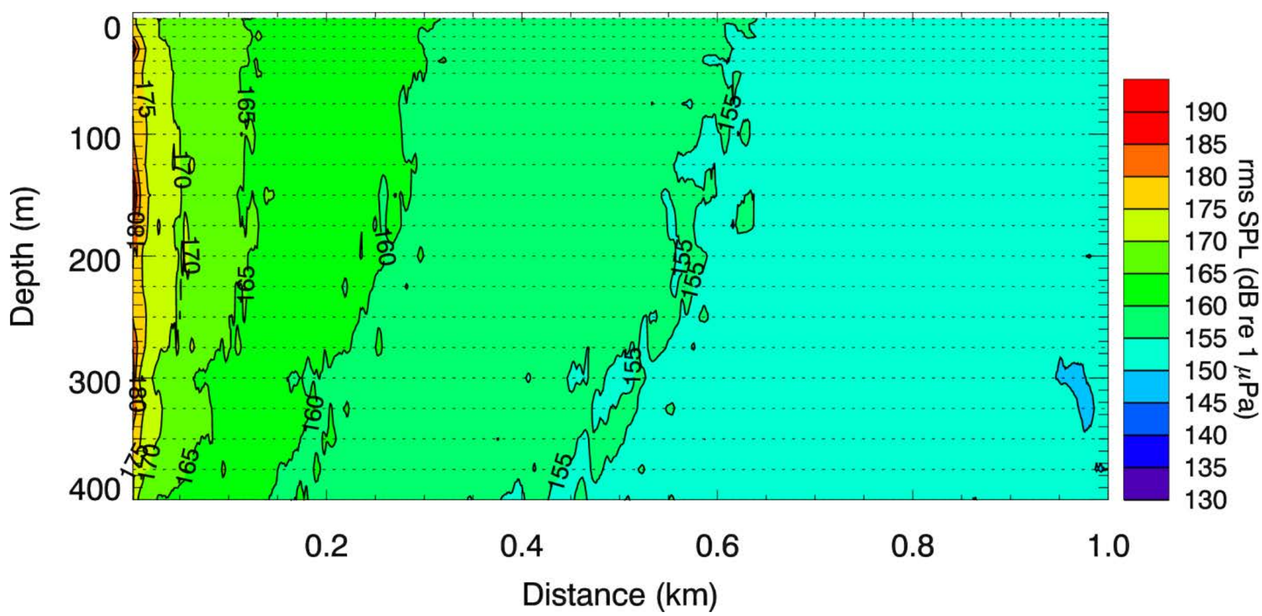

Figure 7. *Maximum Hammer Energy (90 kJ)*: root-mean-square round pressure levels (rms SPLs) along depth and range south of the pile. Dotted lines represent depths at which received levels were modeled. In this figure, values between modeled depths were linearly interpolated.

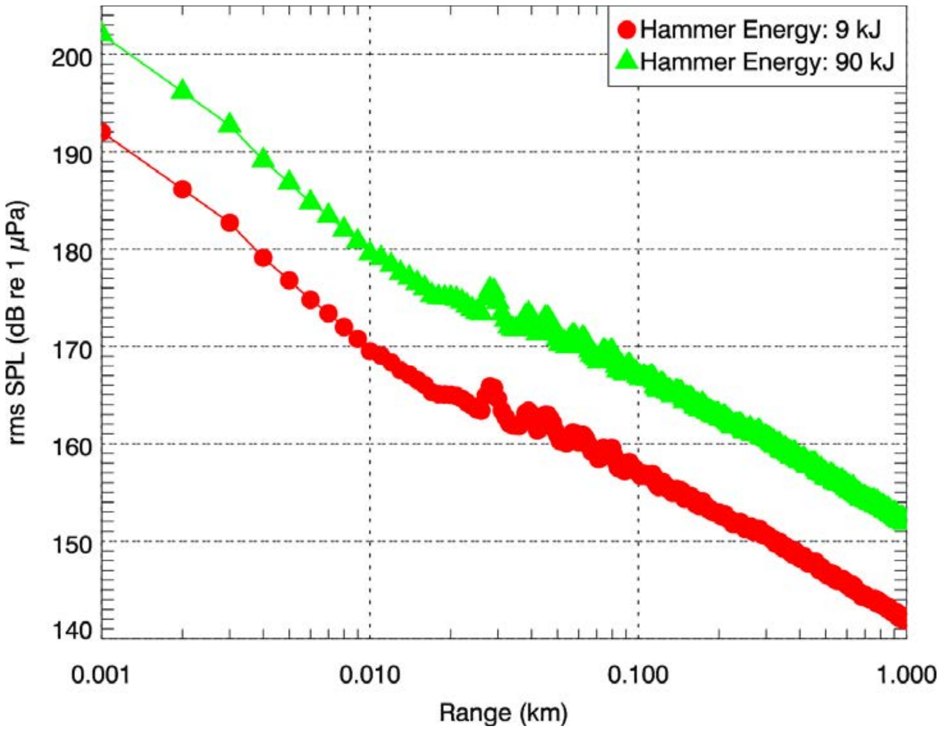

Figure 8. Root-mean-square sound pressure levels (rms SPLs) as a function of range south of the pile driving operations, for the minimum (9 kJ) and maximum (90 kJ) hammer energy.

5. Airborne Sound

ExxonMobil provided JASCO with airborne sound levels calculated from recordings of pile driving tests. These tests used the S-90 hammer at 90% of its maximum energy with a steel pile of unknown size. The provided sound levels represent A-weighted received levels calculated at 6 distances between 0 and 12 m. These levels indicate a source level of 132.4 dB(A) re 20 µPa.

Preliminary estimates of distances to airborne received levels were calculated using three types of spreading loss: spherical, cylindrical, and a higher rate of loss based on measurements at an unknown on-land site:

$$RL = SL - a \times \log_{10}(r) \tag{8}$$

where *RL* is the received levels at a distance *r*, *SL* is the source level, and *a* is equal to 20 for spherical spreading, 10 for cylindrical spreading, and was averaged to 27.5 from measured levels. In addition to the spreading loss, in-air acoustic absorption coefficients were applied; coefficients were based on an average temperature of 15.1 °C and an average relative humidity of 69%. Although acoustic absorption coefficients are frequency dependent, an average absorption coefficient of 4.98 dB/km, equal to the absorption coefficient at 1000 Hz, was used to estimate preliminary broadband levels. At short distances (less than ~200 m), this type of transmission loss is negligible (< 1 dB).

Estimated distances to 60–120 dB(A) rms SPLs, in 10 dB steps, are presented in Table 3.

Table 3. Distances (m) to A-weighted root-mean-square sound pressure levels (rms SPLs) based on spherical, cylindrical, and measured in-air spreading loss.

rms SPL (dB(A) re 20 µPa)	Spherical spreading loss (m)	Cylindrical spreading loss (m)	Measured spreading loss (m)
120	4.2	17	2.8
110	13	147	6.5
100	41	742	15
90	123	1921	34
80	343	3425	78
70	823	5087	173
60	1634	6838	369

6. Discussion

6.1. Estimated Distances to Exposure Criteria

The main species of concern at the Harmony platform are sea lions (pinnipeds), which are present on, within, and around the jacket structure, and cetaceans, which are present around that structure.

For airborne sounds from pile driving at the Harmony platform, spherical spreading may be used up to a distance equal to the vertical distance from the hammer to the sea level: 49 m; cylindrical spreading should be used at longer distances. The estimated distance from the hammer to 100 dB(A) re 20 µPa (sound level threshold used as behavioral disturbance criterion in the present study) is less than the distance from the hammer to the sea lions that have climbed onto the platform substructure (41 m vs 47.5 m; Table 3).

Results from the underwater modeling study indicate there is a potential for behavioral disturbance and injury to marine mammals during impact pile driving activities at the Harmony platform. The National Marine Fisheries Service (NMFS) proposes using root-mean-square sound pressure levels (rms SPL) as impact criteria. For impulsive sounds, like those produced during impact pile driving, a broadband received sound pressure level of 160 dB re 1 µPa (rms) or greater is estimated to disrupt marine mammals' behavioral patterns (MMPA 2007). In this preliminary modeling study, the maximum distances to this level were estimated between 100 and 325 m for hammer energy between 9 and 90 kJ. Concerns about pinnipeds experiencing temporary and/or permanent hearing impairment exist at a broadband received sound pressure level of 190 dB re 1 µPa rms SPL (MMPA 2007). The maximum distances to this level were estimated between 1.5 and 3.5 m when using hammer energy between 9 and 90 kJ. Concerns about temporary and/or permanent hearing impairment to cetaceans exist at a broadband received sound pressure level of 180 dB re 1 µPa rms SPL (MMPA 2007). The maximum distances to this level were estimated between 4 and 10 m when using hammer energy between 9 and 90 kJ.

6.2. Influence of Jacket Structure and Conductor Guides

When a driving hammer strikes the pile, it produces a radiating acoustic field in the water. The strike on the pile produces a pressure wave causing a radial displacement of the pile wall followed by an oscillation of the wall, which propagates along the pile.

Depending on the geometry of the jacket structure, sound propagating from the pile might be scattered within the structure. The complex pattern of constructive and destructive interference within the structure is difficult to model. Generally, a ±3–6 dB variation within the structure would be expected and a maximum decrease in received sound levels of 6 dB away from the platform structure would also be expected.

Since the conductor guides are metal rings affixed to the structure, we expect sound from the pile to be coupled to the structure through these metal rings. The presence of metal rings is expected to contribute to the complex pattern of constructive and destructive interference within the structure.

6.3. Mitigation Systems

The following mitigation systems are discussed from an underwater acoustic perspective ExxonMobil is reviewing the feasibility and cost of applying the systems discussed below.

The sound field propagating in the water column originates from the compressional sound wave propagating down and up the pile, rather than directly from the hammer strike. Placing the hammer below the water surface could potentially influence the received sound levels since it would shorten the length of the pile, thus varying the frequency content of the propagating wave. Locating the hammer below the water surface, however, is not feasible in this application since the hammer must be located on the upper drill deck of the platform.

Bubble curtains are often used to mitigate sound from impact pile driving; they have been shown to reduce sound levels by 5 to 35 dB (Illingworth and Rodkin 2001, MacGillivray and Racca 2005, CALTRANS 2009, WSDOT 2010b, MacGillivray et al. 2011). However, because the pile at Harmony platform is so large, it may be difficult or impossible to maintain a constant air bubble density along the pile, making this method impractical.

Other possible mitigation systems for pile driving include foam-walled and double-walled Temporary Noise Attenuation Piles (TNAPs). These temporary piles completely enclose the pipe pile being hammered, thus attenuating sound throughout the water column. They are as effective as bubble curtains at reducing sound levels (MacGillivray et al. 2007). The use of TNAPs is not considered feasible, however, since the conductor will pass through a number of conductor guides that would damage a TNAP system.

Wood caps (or cushions) are also commonly used to dampen noise during impact pile driving. These caps, unlike the TNAP or bubble curtain, only affect the impulse delivered to the piles by the hammer, not the underwater propagation environment. Thus, the attenuation in received levels is expected to be less for wood caps than from TNAP, and proportional to the resulting reduction in hammer energy transferred from the hammer to the pile.

Literature Cited

Marine Mammal Protection Act of 1972 as Amended. 2007. United States Pub. L. No. 92-522, 16 U.S.C. 1361 (Oct. 21, 1972). http://www.nmfs.noaa.gov/pr/laws/mmpa/text.htm.

[NAVO] Naval Oceanography Office (US). 2003. *Database description for the Generalized Digital Environmental Model (GDEM-V) (U)*. MS 39522-5003. Oceanographic Data Bases Division, Stennis Space Center.

[NGDC] National Geophysical Data Center. 2013. U.S. Coastal Relief Model. National Geophysical Data Centre, National Oceanic and Atmospheric Administration, US Department of Commerce. http://www.ngdc.noaa.gov/mgg/coastal/crm.html.

[NOAA] National Oceanic and Atmospheric Administration. 2014. *Interim Sound Threshold Guidance* (webpage). http://www.westcoast.fisheries.noaa.gov/protected_species/marine_mammals/threshold_guidance.html.

[ODP] Ocean Drilling Program Legacy. 2013. Ocean Drilling Data - Leg 146, Site 893. Janus data (Exp 1-312). http://iodp.tamu.edu/janusweb/general/dbtable.cgi?leg=146&site=893.

[USDOC] United States Departemnt of Commerce, [NOAA] National Oceanic and Atmospheric Administration, and [NMFS] National Marine Fisheries Service. 2013. *Incidental harassment authorization*. 5 p.

Austin, M., J. Delarue, H.A. Johnson, M. Laurinolli, D. Leary, A. MacGillivray, C. O'Neill, H. Sneddon, and G. Warner. 2009. *NaiKun Offshore Wind Energy Project Environmental Assessment. Volume 4–Noise and Vibration*. Technical report for NaiKun Wind Development Inc. by JASCO Applied Sciences.

Buckingham, M.J. 2005. Compressional and shear wave properties of marine sediments: Comparisons between theory and data. *Journal of the Acoustical Society of America* 117(1): 137-152.

CALTRANS. 2009. *Technical guidance for assessment and mitigation of the hydroacoustic effects of pile driving on Fish*. Technical report prepared by ICF Jones & Stokes and Illingworth and Rodkin, Inc, for California Department of Transportation, Sacramento CA.

Carnes, M.R. 2009. *Description and Evaluation of GDEM-V 3.0*. NRL Memorandum Report 7330-09-9165. US Naval Research Laboratory, Stennis Space Center, MS. 21 p.

Claerbout, J.F. 1976. *Fundamentals of geophysical data processing: With applications to petroleum prospecting*. Related Information: International Series in the Earth and Planetary Sciences. 286 p.

Collins, M.D., R.J. Cederberg, D.B. King, and S. Chin-Bing. 1996. Comparison of algorithms for solving parabolic wave equations. *Journal of the Acoustical Society of America* 100(1): 178-182.

Coppens, A.B. 1981. Simple equations for the speed of sound in Neptunian waters. *Journal of the Acoustical Society of America* 69(3): 862-863.

Erbe, C. 2009. Underwater noise from pile driving in Moreton Bay, Qld. *Acoustics Australia* 37(3): 87-92.

Gaboury, I., R. Gaboury, and S. Carr. 2007a. *Downeast LNG import terminal: assessment of underwater noise impacts*. Technical report for Resource Systems Engineering Inc. by JASCO Research Ltd. 45 p.

Gaboury, I., M. Zykov, S. Carr, and D. Hannay. 2007b. *Ladd deepwater marine coal terminal: assessment of underwater noise*. Technical report for DRven Corporation by JASCO Applied Sciences. 65 p.

Hamilton, E.L. 1980. Geoacoustic modeling of the sea floor. *Journal of the Acoustical Society of America* 68: 1313-1340.

Illingworth and Rodkin. 2007. *Compendium of Pile Driving Sound Data*. Prepared for the California Department of Transportation by Illingworth & Rodkin. 129 p. www.dot.ca.gov/hq/env/bio/files/pile_driving_snd_comp9_27_07.pdf.

Illingworth and Rodkin, Inc. 2001. NMFS Marine Mammal Safety Zone. (Chapter 4) In *Final Data Report: Noise and Vibration Measurements Associated with the Pile Installation Demonstration Project for the San Francisco-Oakland Bay Bridge East Span*. Prepared for the California Department of Transportation, Petaluma, CA. www.dot.ca.gov/dist4/documents/appendix_d_8901.pdf.

MacGillivray, A. and R. Racca. 2005. *Sound pressure and particle velocity measurement from marine pile driving at Eagle Harbor maintenance facility, Bainbridge Island WA*. Technical report by JASCO Research Ltd. for Washington State Department of Transportation.

MacGillivray, A., E. Ziegler, and J. Laughlin. 2007. *Underwater Acoustic Measurements from Washington State Ferries 2006 Mukilteo Ferry Terminal Test Pile Project*. Technical report prepared by JASCO Research, Ltd for Washington State Ferries and Washington State Department of Transportation. 27 p.

MacGillivray, A., G. Warner, R. Racca, and C. O'Neill. 2011. *Tappan Zee Bridge construction hydroacoustic noise modeling: Final report*. Report by JASCO Applied Sciences for AECOM. 63 p.

Reid, J.A. 2005. *Point Coverage SCASMPL: Sediment sample data for the Channel Islands and Santa Barbara Channel Region*. U.S. Geological Survey.

Reinhall, P.G. and P.H. Dahl. 2011. *An investigation of underwater sound propagation from pile driving*. WA-RD 781.1. Research Office, Washington State Department of Transportation. 39 p.

Southall, B.L., A.E. Bowles, W.T. Ellison, J.J. Finneran, R.L. Gentry, C.R. Greene Jr., D. Kastak, D.R. Ketten, J.H. Miller, et al. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. *Aquatic Mammals* 33(4): 411-521.

Teague, W.J., M.J. Carron, and P.J. Hogan. 1990. A comparison between the Generalized Digital Environmental Model and Levitus climatologies. *Journal of Geophysical Research* 95(C5): 7167-7183.

U.S. Navy, Naval Facilities Engineering Command (NAVFAC). 2013. *Incidental harassment authorization application for the navy's fuel pier replacement project at naval base point loma*. Update 2 – Apr 2013 (original submission Sep 2012). Prepared by NAVFAC. Submitted to Office of Protected Resources, NMFS, NOAA. 148 p.

WSDOT. 2010a. *Biological Assessment Preparation Advanced Training Manual*. Technical report by Washington State Department of Transportation.

WSDOT. 2010b. *Underwater sound levels associated with driving steel piles for the State Route 520 bridge replacement and HOV project pile installation test program.* . Technical report for Washington State Department of Transportation by Illingworth and Rodkin Inc.

Zhang, Y. and C. Tindle. 1995. Improved equivalent fluid approximations for a low shear speed ocean bottom. *Journal of the Acoustical Society of America* 98(6): 3391-3396.