LARSON DAVIS
A PCB DIVISION

GUIDE TO MARINE MAMMAL PROTECTION NOISE MEASUREMENTS

Contents

Introduction

The effects of anthropogenic noise (noise caused by humans) on ocean ecosystems are complex. Noise interferes with an ocean animal's ability to understand environmental cues vital to their survival. Underwater noise caused by things like pile driving on large construction sites can confuse, stress, or disorient these animals, which can affect their communication, behavior, physiology, ability to avoid predators, and reproduction. High underwater acoustic pressures can even be fatal to fish or marine mammals in extreme circumstances.

Regulations

National Marine Fisheries Service (NMFS) has specified underwater noise limits and the metrics used to characterize noise exposure for the protectional of five (5) specific marine mammal groups from the effects of impulsive noise. These mammal groups include

- Low-frequency (LF) cetaceans (baleen whales)
- Mid-frequency (MF) cetaceans (dolphins, toothed whales, beaked whales, bottlenose whales)
- High-frequency (HF) cetaceans (porpoises, sperm whales, river dolphins)
- Phocid pinnipeds (PW) (true seals)
- Otariid pinnipeds (OW) (seal lions and fur seals)

The Marine Mammal Protection Act of 1972 prohibits harassment of marine mammals and established NMFS as the organization responsible for compliance. The act was amended in 1994 to provide a definition of "harassment" with two classes of harassment defined:

- Level A harassment is the injury of marine mammals or stocks in the wild

- Level B harassment is the disturbance of marine mammals in the wild thatleads to behavioral changes.

Any underwater noise that leads to permanent hearing damage or injury to internal organs is classified as Level A harassment. Noise that leads to behavioral changes such as an inability to locate prey or communication difficulties is classified as Level B harassment.

ISO 18406:2017 Underwater acoustics — Measurement of radiated underwater sound from percussive pile driving specifies a method that aligns with the NMFS recommendations. Larson Davis offers Marine Mammal Monitoring System to measure and report compliance using this method.

Definitions and Metrics

Permanent Threshold Shift (PTS): Loss of hearing in which the baseline hearing level changes and does not recover within hours, days, or weeks

Temporary Threshold Shift (TTS): Loss of hearing in which the hearing level changes, but returns to baseline within hours, days, or weeks

Single Strike: A common source of impulsive noise underwater is pile driving. Each strike of a pile driver is considered a "single strike."

Single Strike Sound Exposure Level SEL_{ss} (L_{E100}): Sound exposure level from a single impulse, often a single pile driver strike

$$L_{E100} = 10 \times LOG_{10}\left[\frac{1}{1\,uPa^2 s}\int_{i=t_0}^{t_{100}}\{p^2(t_i)\}\right]$$

Equation 1

where the period of integration, t0 to t100 is chosen to capture 100% of the strike energy. In practice this can be difficult because it's possible the energy from one strike can overlap the next, making it impossible to distinguish between the two strikes. In the sample strike waveform shown below, there area highlighted shows the portion of the strike that could be considered to contain 100% of the strike energy.

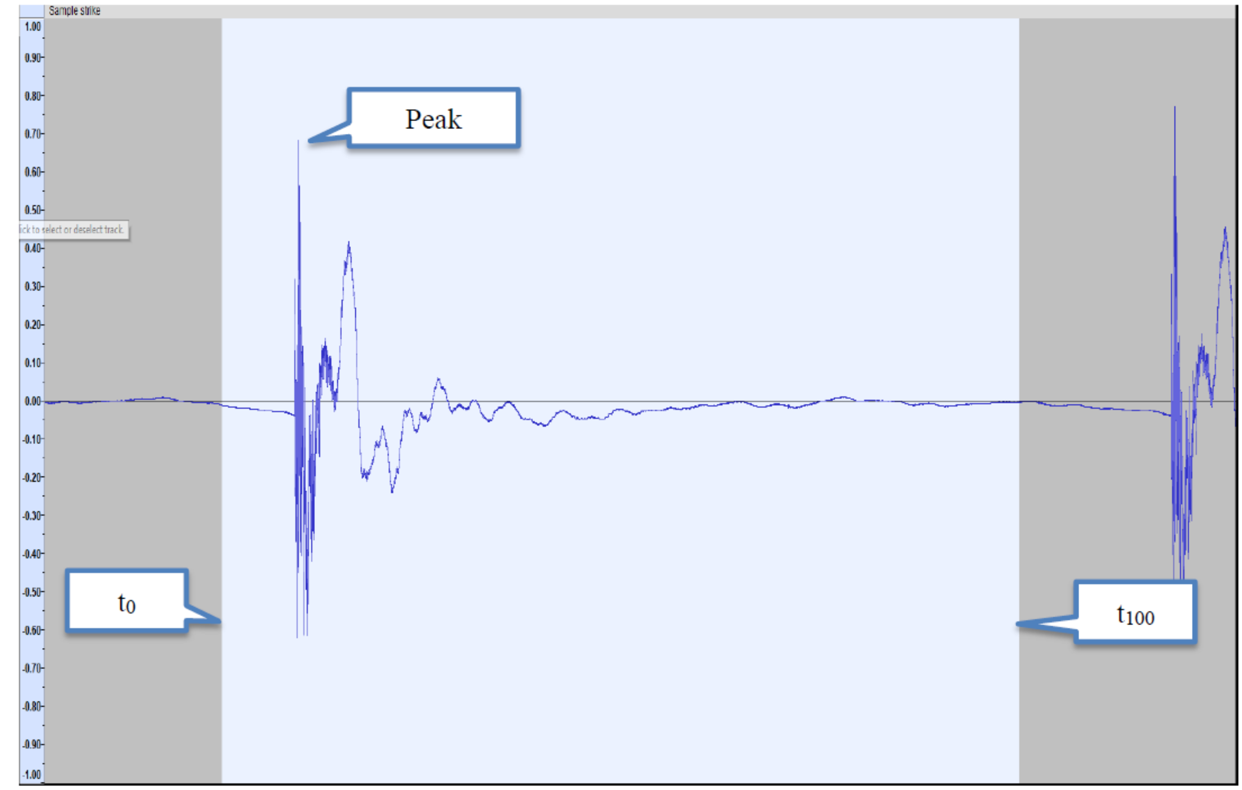

Figure 1 Sample Waveform from Single Strike

Peak Level (L_p): The maximum absolute value of the sound pressure in dB re 1 µPa

$L_{E,xx,24h}$: Noise exposure over a 24 hour period, defined as the accumulation of all single strike SEL measurements (SELss) during a 24 hour period.

SELcum (L_{Ecum}): The combined energy of multiple impulses or pile driving strikes, defined as

$$L_{Ecum} = 10 \times LOG_{10}\left[\sum_{n=1}^{N} 10^{SELss/10}\right]$$

Equation 2

Where N is the total number of impulses measured.

$L_{E,xx,24h}$: This metric is referenced in the NMFS thresholds, and captures all of the impulses during a 24 hour period. When the frequency of strikes or impulses and SELss levels remain consistent and unchanged, **$L_{E,xx,24h}$** is estimated using the following equation

$$L_{E,xx,24h} = L_{Ecum} + 10LOG_{10}\left[\frac{T_{Pile\ driving}}{T_{LEcum}}\right]$$

Equation 3

Where T_{LEcum} is the total elapsed time of the L_{Ecum} measurement and $T_{Pile\ driving}$ is the total time of pile driving activity during a 24-hour period.

TSEL90: The period of time over which 90% of the SELss energy occurs. TSEL90 is computed by first determining SEL5 and SEL95.

$$SEL5 = 0.05 \times SELss$$

Equation 4

$$SEL95 = 0.95 \times SELss$$

Equation 5

$$T_{SEL90} = T_{SEL95} - T_{SEL5}$$

Equation 6

Using Equation 1 and beginning at t = t_0, integrate forward in time until L_E is as close as possible to *SEL5* and note the time, T_{SEL5}. Continue integrating forward in time until L_E is as close as possible to *SEL95* and note the time, T_{SEL95}. Compute T_{SEL90} using Equation 6. See example in Figure 2 below.

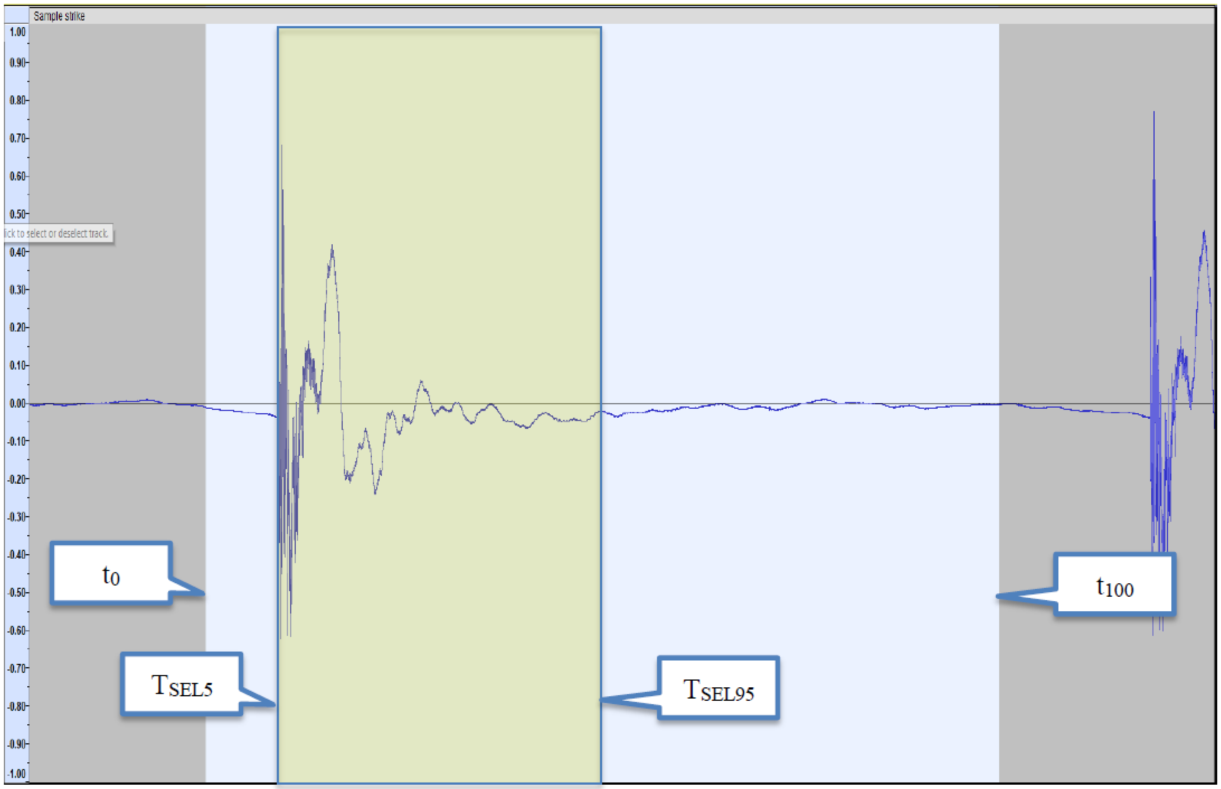

Figure 2 Sample TSEL90

Harassment Limits

Hearing Group	PTS Impulsive Thresholds	TTS Impulsive Thresholds	Behavioral Threshold (multiple detonations)
Low-Frequency (LF) Cetaceans	$L_{p,0\text{-pk, flat}}$ 219 dB $L_{E,LF,24h}$ 183 dB	$L_{p,0\text{-pk, flat}}$ 213 dB $L_{E,LF,24h}$ 168 dB	$L_{E,LF,24h}$ 163 dB
Mid-Frequency (MF) Cetaceans	$L_{p,0\text{-pk, flat}}$ 230 dB $L_{E,MF,24h}$ 185 dB	$L_{p,0\text{-pk, flat}}$ 224 dB $L_{E,MF,24h}$ 170 dB	$L_{E,MF,24h}$ 165 dB
High-Frequency (HF) Cetaceans	$L_{p,0\text{-pk, flat}}$ 202 dB $L_{E,HF,24h}$ 155 dB	$L_{p,0\text{-pk, flat}}$ 196 dB $L_{E,HF,24h}$ 140 dB	$L_{E,HF,24h}$ 135 dB
Phocid Pinnipeds (PW) (Underwater)	$L_{p,0\text{-pk, flat}}$ 218 dB $L_{E,PW,24h}$ 185 dB	$L_{p,0\text{-pk, flat}}$ 212 dB $L_{E,PW,24h}$ 170 dB	$L_{E,PW,24h}$ 165 dB
Otariid Pinnipeds (OW) (Underwater)	$L_{p,0\text{-pk, flat}}$ 232 dB $L_{E,OW,24h}$ 203 dB	$L_{p,0\text{-pk, flat}}$ 226 dB $L_{E,OW,24h}$ 188 dB	$L_{E,OW,24h}$ 183 dB

Table 1 PTS Onset, TTS Onset, and Behavioral Thresholds (Multiple Detonations) for Underwater Explosives (NMFS 2018) Note: for metrics with dual thresholds, measured level must be below both thresholds.

Traditional Measurement System Limitations

Commonly, data used to determine compliance with the NMFS threshold is gathered in the field with a hydrophone paired with a time data recorder. A known calibration tone is recorded in the field and used in post-processing to calibrate the measurement data. It is difficult to validate this type of system in the field to ensure it is measuring correctly. Post processing can be complex, requiring the development and maintenance of analysis algorithms.

Marine Mammal Noise Monitoring System based on SoundAdvisor Sound Level Meter Model 831C

Larson Davis, with support from Illingworth and Rodkin, has built a solution to compute and report results for the protection of marine mammals. Using this system, a hydrophone is connected directly to a SoundAdvisor Sound Level Meter Model 831C and calibrated using a pistonphone.

System Requirements

- SoundAdvisor Sound Level Meter Model 831C with options 831C-ELA and 831C-SR
- ADP005 adapter to connect hydrophone to PRM831
- Reson Hydrophone, such as Model TC4040
- G4 software (free download from Larson Davis' website) with Marine Mammals Protection enabled
- Pistonphone for hydrophone calibration, such as GRAS Model 42AA
- Protective Cage, such as Model TL8040
- Calibration Adapter, such as Model RA0047

Figure 3 Sound Level Meter with preamplifier and hydrophone adapter

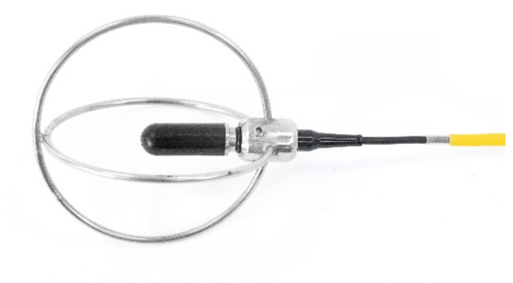

Figure 4 Hydrophone in protective cage

Figure 5 Hydrophone connection to adapter

Figure 6 Calibrating hydrophone with pistonphone

After the measurement, data is downloaded to a PC where it is automatically post-processed. Sample results are shown in Table 2.

Trig. Level	MM RMS	MM SEL	MM Peak	MM 90% (s)	Sound Record
93.0	110.0	105.7	121.8	0.3778	Sound Record 1
93.0	111.0	105.9	121.1	0.3113	Sound Record 2
93.0	110.3	105.6	122.0	0.3440	Sound Record 3
93.0	110.4	105.3	121.6	0.3109	Sound Record 4
93.0	110.2	105.6	122.1	0.3454	Sound Record 5
93.0	113.8	107.2	121.0	0.2157	Sound Record 6
[redacted]					
93.0	110.4	104.9	122.4	0.2819	Sound Record 28
93.0	109.7	105.7	121.9	0.3971	Sound Record 29
93.0	112.9	106.9	124.2	0.2529	Sound Record 30
93.0	110.3	105.3	121.5	0.3180	Sound Record 31
93.0	113.3	106.3	123.3	0.1955	Sound Record 32
	RMS	SEL	Peak	90% (s)	
Maximum	113.8	109.0	124.6	0.4414	
Mean	111.0	106.3	122.7	0.3488	
Median	110.7	106.3	122.7	0.3603	
Mammals Cumulative		121.3			
Fish Cumulative		-99.9			
Count	32				

Table 2 Marine Mammal measurement results with Larson Davis Marine Mammal Noise Monitoring System

Marine Mammal Noise Monitoring System Benefits

Larson Davis' Marine Mammal Noise Monitoring System simplifies the process of determining compliance with the Marine Mammals Protection Act to the thresholds specified by NMFS. The system

- Provides calibrated measurement results
- Supports in-field calibration using a pistonphone
- Displays L_{peak} and SEL,1s for in-field validation of the system
- Reports on relevant metrics

LARSON DAVIS
A PCB DIVISION

3425 Walden Avenue, Depew, NY 14043 USA

larsondavis.com | sales@larsondavis.com | 888 258 3222 | +1 716 926 8243

MD-0509 revNR 0623