In-Water Noise and Pile Driving

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Regulatory and Permitting Context
Impacts from Noise

• Fish
  – Rupture of gas-filled organs
  – Damage to auditory systems
  – Avoidance
  – Delayed migration

• Marine mammals
  – Interference with communication or echolocation
  – Damage to auditory systems
  – Avoidance
Regulatory Authority

• National Oceanic and Atmospheric Administration
  – ESA-listed species
  – All marine mammals
• U.S. Fish and Wildlife Service
  – ESA-listed fish
• Washington Department of Fish and Wildlife
  – All fish

Chinook Salmon; Source: NOAA
Orca whale; Source: NOAA
Bull trout; Source: USFWS
ESA, MMPA, or Both?

Project

In-water pile driving

Endangered Species Act

Not likely to adversely affect

Likely to adversely affect

Marine Mammal Protection Act

IHA

LOA
Defining “Take”

Endangered Species Act

harass, harm, pursue, hunt, shoot, wound, kill, trap, capture or collect, or to attempt to engage in any such conduct

Marine Mammal Protection Act

harass, hunt, capture, or kill, or attempt to harass, hunt, capture or kill any marine mammal
Harassment and Exclusion Zones
Other BMPs to Reduce Impacts

- In-water work timing restrictions
- Bubble curtains
- Soft-start/ramp-up
- Reducing the fuel setting
- Pile pads or bumpers
Hydroacoustic Monitoring
Hydroacoustics 101 (Divergence)

• Airborne noise dissipates by 6 dB per doubling of distance
  – Hemispherical spreading allows sound to spread out over distance

• Underwater noise only dissipates by ~4.5 dB per doubling of distance (depends on water depth, etc.)
  – Sound is bound by water surface; seafloor creates a channel, which prevents sound from dissipating
Hydroacoustics 101 (dB and Hz)

• Sound pressure level is defined as follows:

\[ dB = 20 \log_{10} \left( \frac{\text{acoustic pressure}}{\text{reference pressure}} \right) \]

• Airborne and underwater sound pressure levels cannot be directly compared
  – A reference pressure of 20 \( \mu \)Pa is used in air, 1 \( \mu \)Pa in water

• Sound pressure also varies as a function of frequency, units are Hz (cycles per second)
  – 1,000 Hz is often referred to as 1 kHz
# Hydroacoustics 101 (common sound levels)

<table>
<thead>
<tr>
<th>Underwater Source</th>
<th>Distance</th>
<th>SPL (dB, water)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact pile driving</td>
<td>10 meters</td>
<td>170-205</td>
</tr>
<tr>
<td>Humpback whale songs</td>
<td>1 meter</td>
<td>144-174</td>
</tr>
<tr>
<td>Gray whale moans</td>
<td>1 meter</td>
<td>142-185</td>
</tr>
<tr>
<td>Bottlenose dolphin whistles</td>
<td>1 meter</td>
<td>125-173</td>
</tr>
</tbody>
</table>

Sources:
http://www.dosits.org/science/soundsinthesea/commonsounds/
WSDOT BA Prep Training Manual

<table>
<thead>
<tr>
<th>Airborne Source</th>
<th>Distance</th>
<th>SPL (dBA, air)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact pile driving</td>
<td>10 meters</td>
<td>105</td>
</tr>
<tr>
<td>Busy street</td>
<td>-</td>
<td>80</td>
</tr>
<tr>
<td>Quiet car at low speed</td>
<td>-</td>
<td>50</td>
</tr>
<tr>
<td>Average office</td>
<td>-</td>
<td>40</td>
</tr>
</tbody>
</table>

Sources:
US Department of Housing and Urban Development, Aircraft Noise Impact Planning Guidelines for Local Agencies
FTA Noise and Vibration Guidance Manual
Hydroacoustics 101 (RMS, SEL, and Peak, cont.)

• Peak sound pressure level (Peak)
  – Typically used for impact, but also can be used for vibratory

• Root-mean-square (RMS)
  – Vibratory: common durations range from 10 to 30 seconds
  – Impact: a 90% RMS (RMS$_{90}$) value is often used

• Sound exposure level (SEL)
  – Typically used for impact
  – SEL value possible for each pile strike
  – SEL value also possible for multiple pile strikes. Most commonly a “cumulative SEL” (cSEL) that combines all pile strike SELs into one value for a day’s worth of driving
# Injury and Disturbance Thresholds

<table>
<thead>
<tr>
<th>Hearing Group</th>
<th>Disturbance*</th>
<th>Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vibratory Pile Driving</td>
<td>Impact Pile Driving</td>
</tr>
<tr>
<td>Cetaceans</td>
<td>120 dB RMS</td>
<td>160 dB RMS</td>
</tr>
<tr>
<td>Pinnipeds</td>
<td>120 dB RMS</td>
<td>160 dB RMS</td>
</tr>
<tr>
<td>Fish &gt;= 2 grams</td>
<td>150 dB RMS</td>
<td></td>
</tr>
<tr>
<td>Fish &lt; 2 grams</td>
<td></td>
<td>183 dB cSEL</td>
</tr>
<tr>
<td>All Fish Sizes</td>
<td></td>
<td>206 dB Peak</td>
</tr>
</tbody>
</table>

*can also be a function of ambient conditions (reduce take?)*
## Marine Mammal Functional Hearing Groups

<table>
<thead>
<tr>
<th>Species</th>
<th>Functional Hearing Group</th>
<th>Frequency Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humpback, Gray and Minke Whales</td>
<td>Low-Frequency Cetaceans</td>
<td>7 Hz – 20 kHz</td>
</tr>
<tr>
<td>Orcas</td>
<td>Mid-Frequency Cetaceans</td>
<td>150 Hz – 20 kHz</td>
</tr>
<tr>
<td>Harbor and Dall’s Porpoises</td>
<td>High-Frequency Cetaceans</td>
<td>200 Hz – 20 kHz</td>
</tr>
<tr>
<td>Steller and California Sea Lions, Harbor and Elephant Seals</td>
<td>Pinnipeds</td>
<td>75 Hz – 20 kHz</td>
</tr>
<tr>
<td>All</td>
<td>Fish</td>
<td>20 Hz – 20 kHz</td>
</tr>
</tbody>
</table>

*Source: Wikipedia*
## Differences in Monitoring Requirements

<table>
<thead>
<tr>
<th></th>
<th>ESA</th>
<th>LOA</th>
<th>NOAA Guidance Documents</th>
<th>NOAA Supplemental Guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vibratory Pile Driving Analysis</strong></td>
<td>10 second RMS values</td>
<td>30 second RMS values</td>
<td>10 second RMS values</td>
<td>No guidance</td>
</tr>
<tr>
<td><strong>Hydrophone Depths</strong></td>
<td>1 meter below surface and 1 meter above seafloor, <strong>also lists</strong> 1 meter below surface and 70%-85% of water depth</td>
<td>1 meter below the surface and 1 meter above seafloor</td>
<td>1 hydrophone 70%-85% of the water depth</td>
<td>1 hydrophone located at mid-water depth</td>
</tr>
<tr>
<td><strong>Background Monitoring</strong></td>
<td>No guidance</td>
<td>No guidance</td>
<td>500-1,000 meters from pile driving location</td>
<td>10 meters from pile driving location</td>
</tr>
</tbody>
</table>
Vibratory Pile Driving Requirement Interpretation

• Report 10-second RMS, peak, and SEL values (range, mean, standard deviation for each)

• Report the RMS, peak and SEL values for all marine mammal functional hearing groups

• Provide a representative frequency spectrum of the pile drive
Impact Pile Driving Requirement Interpretation

- Determine the portion of each pile strike containing 90% of the energy and report the RMS\text{90}, peak, and SEL values (range, mean, standard deviation)

- Calculate the cSEL

- Report the RMS\text{90}, peak, SEL and cSEL values for all marine mammal functional hearing groups

- Provide a representative frequency spectrum of the pile drive
Measured Underwater Sound Levels

Vibratory Sheets dB re: 1 µPa

<table>
<thead>
<tr>
<th></th>
<th>Peak</th>
<th>RMS</th>
<th>SEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured</td>
<td>182</td>
<td>166</td>
<td>166</td>
</tr>
<tr>
<td>MMPA</td>
<td>182</td>
<td>165</td>
<td>-</td>
</tr>
</tbody>
</table>

Impact Sheets dB re: 1 µPa

<table>
<thead>
<tr>
<th></th>
<th>Peak</th>
<th>RMS\textsubscript{90}</th>
<th>SEL</th>
<th>cSEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured</td>
<td>198</td>
<td>185</td>
<td>170</td>
<td>202</td>
</tr>
<tr>
<td>MMPA</td>
<td>205</td>
<td>190</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Vibratory Pile Driving Waveform
Impact Pile Driving Waveform
Challenges – Data Analysis
Challenges - Logistics

• Measurement equipment is sensitive to moisture
• Monitoring takes place in marine environments on construction sites
• Equipment must adapt to last minute changes
Future Considerations
MMPA Noise Thresholds for Elliott Bay Seawall

<table>
<thead>
<tr>
<th>Pile Type and Approximate Size</th>
<th>Method</th>
<th>Average Peak Sound, in dB</th>
<th>Average RMS, in dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.5-inch, concrete</td>
<td>Impact</td>
<td>188</td>
<td>176</td>
</tr>
<tr>
<td>48-inch steel sheetpile pair</td>
<td>Vibratory</td>
<td>182</td>
<td>165</td>
</tr>
<tr>
<td>48-inch steel sheetpile pair</td>
<td>Impact</td>
<td>205</td>
<td>190</td>
</tr>
</tbody>
</table>
Monitoring Zones
Exclusion Zones and Stop-Work Actions

Source: Michael Morris, at www.tripadvisor.com
New Technology: Reinhall Piles

The outer pile serves as a sound shield to inhibit noise propagation through the water.

A proprietary driving shoe joins the inner and outer piles to limit noise propagation through the seabed.

Source: www.marinecontech.com
Questions?