UNDERWATER ACOUSTIC HABITAT TECHNICAL MEMORANDUM

DECEMBER 1, 2005

Prepared by

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Underwater Acoustic Habitat Technical Memorandum

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ABSTRACT

The National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (Fisheries) has determined that noise from anthropogenic activities is a potential threat to restoring the Eastern North Pacific Southern Resident Killer Whales (Southern Residents) to an optimal sustainable population. NOAA Fisheries contracted with Concurrent Technologies Corporation to identify existing underwater acoustics studies and recording efforts conducted within the inland marine waters of Puget Sound, including the Strait of Juan de Fuca and the Strait of Georgia, and the coastal marine waters of Washington, Oregon, Northern California, and British Columbia.

Fifty-nine underwater acoustic studies and recording efforts were identified within the study area. Studies and recording efforts were sponsored by academic institutions, government, commercial entities, and non-governmental organizations for the purposes of monitoring anthropogenic and natural sources of noise and ambient (background) noise levels. Anthropogenic sources of noise included pile driving, trenching, active transmissions, vessel traffic, and U.S. Geological Survey activities. Studies and recording efforts took place between 1970 to the present, with most efforts occurring during the Spring and Summer.

Only 30 studies and recording efforts specifically stated that the hydrophones used were calibrated. Fifteen more used hydrophones that were probably calibrated. Twelve studies and recording efforts did not use calibrated hydrophones and two others were unknown. Four studies and recording efforts utilized active sonar transmissions from acoustic projectors and all 59 utilized passive receiving hydrophones. The usable frequency bands of 28 of the 32 studies that provided sufficient information to estimate usable bandwidth were limited to less than 50 kHz by the Nyquist frequency limit from the digitizing sample rate and/or low-pass filtering. Of these, 20 were limited to less than 25 kHz for similar reasons. Eleven studies and recording efforts provided non-duplicative estimates of approximate acoustic levels from the primary sources being monitored. The measurements recorded were sound pressure levels received at the hydrophone and not the actual source level referenced to one meter from an idealized point source. The lower ranges of the monitored sources varied widely between 90 and 194 dB.

Recommendations focus on improving and standardizing data collection and documentation efforts, prioritizing data collection efforts to first target the gaps in the most important habitats of the Southern Residents, developing correlations between localized acoustic surrogate indicators and actual acoustic levels for use as proxy values when actual data collection is cost prohibitive, and fostering increased cooperation and information sharing between acoustic data collectors locally and nationally.

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EXECUTIVE SUMMARY

The Eastern North Pacific Southern Resident Killer Whales (Southern Residents) have been designated as depleted under the Marine Mammal Protection Act (MMPA) and as endangered under the Endangered Species Act (ESA). The National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (Fisheries) is responsible for developing appropriate management plans to address threats to the Southern Residents. NOAA Fisheries has determined that noise from anthropogenic activities, such as vessel traffic, is a potential threat to restoring the stock to its optimal sustainable population.

NOAA Fisheries hosted a series of workshops in 2003 and 2004 to define research questions related to these threats. Questions covering the primary concerns about characterizing the underwater acoustical habitat of the Southern Residents were developed. These questions covered topics that included baseline acoustic conditions; spectral characteristics of vessel noise and its propagation; sources of noise most likely to affect the Southern Residents; and spatial, temporal, and seasonal variations of sound propagation in the habitat of the Southern Residents.

NOAA Fisheries contracted with Concurrent Technologies Corporation to identify existing underwater acoustics studies and recording efforts conducted within the project study area, defined as the inland marine waters of Puget Sound, including the Strait of Juan de Fuca and the Strait of Georgia, and the coastal marine waters of Washington, Oregon, Northern California, and British Columbia. The project team identified and evaluated the studies and recording efforts. From this evaluation, the project team developed recommendations for NOAA Fisheries' consideration.

Fifty-nine underwater acoustic studies and recording efforts were identified within the study area. These studies and recording efforts were sponsored by academic institutions (31), government agencies (19), commercial entities (five), and non-governmental organizations (four). The University of Washington sponsored the highest number of studies and recording efforts.

Based on the available information, specific data collection locations were determined for only 25 of the studies and recording efforts. General text descriptions of data collection locations were obtained for all but two studies and recording efforts.

Most studies and recording efforts were conducted for the purpose of monitoring anthropogenic sources of noise (34). The primary purpose of 20 studies and recording efforts was to monitor natural sources of noise, e.g., whale vocalizations. Another five studies monitored ambient, or background, noise level. Anthropogenic sources of noise included pile driving, trenching, active transmissions, vessel traffic, and U.S. Geological Survey activities.

Underwater acoustics studies and recording efforts dating back to 1970 were identified. Most studies occurred since 2003 with some studies being ongoing. Approximately 75% of the identified studies and recording efforts involved monitoring activities during the Spring and Summer.

Only 30 studies and recording efforts specifically stated that the hydrophones used were calibrated. Fifteen more used hydrophones that were probably calibrated. Twelve studies and recording efforts did not use calibrated hydrophones and the calibration status of two other studies is unknown.

Of the 59 identified studies and recording efforts, only four utilized active sonar transmissions from acoustic projectors and all 59 utilized passive receiving hydrophones. The active transmissions were from the following sources:

- Acoustic scintillation measurements of stratification layer refraction
- Acoustic tomography
- Acoustic modem communication link
- Echo-sounder demonstration

Of the 32 studies and recording efforts that provided sufficient information to make a reasonable estimate, the lower usable analysis bandwidth ranged from 1 Hertz (Hz) to 100 Hz with a median lower frequency of 30 Hz, an arithmetic mean lower frequency of 51 Hz and a standard deviation of 43 Hz. The estimated upper usable analysis bandwidth ranged from 4.7 kilohertz (kHz) to 100 kHz, with a median upper frequency of 22 kHz, an arithmetic mean of 33 kHz and a standard deviation of 22 kHz. The usable frequency bands of 28 of the 32 studies that provided sufficient information to estimate usable bandwidth were limited to less than 50 kHz by the Nyquist frequency limit from the digitizing sample rate and/or low-pass filtering. Of these, 20 were limited to less than 25 kHz for similar reasons.

Of the 59 identified studies and recording efforts, 11 provided non-duplicative estimates of approximate acoustic levels from the primary sources being monitored. The measurements recorded were sound pressure levels received at the hydrophone and not the actual source level referenced to one meter from an idealized point source. The lower ranges of the monitored sources varied widely between 90 and 194 dB, with a median of 145 dB, a mean of 146 dB, and a standard deviation of 34.2 dB. The upper end of the source level estimates ranged from 113 to 205 dB, with a median of 169 dB, a mean of 160 dB, and a standard deviation of 33.6 dB. The upper levels of pile driving ranged from 131 to 205 dB. A trencher was recorded as high as 205 dB. Whale watching boats were recorded as high as 169 dB. Oceanographic tomography was recorded at 120 dB.

The 59 studies and recording efforts highlight that there is currently no standard methodology or data structure to consistently document and share the large amount of metadata related to acoustic datasets. This significantly limits the value of the identified historical data for uses other than its original purpose, and often even for repeatable use of the data for its original purpose. Without a standardized framework for presenting the body of recorded acoustic data, its use is very limited for broader purposes such as decision support; comparing data over temporal and spatial ranges; or establishing baselines, averages, trends, or patterns.

In general, the available information obtained from identified studies and recording efforts in the study area are insufficient to adequately address any of the question topics at a level of detail that will allow NOAA to develop appropriate management actions to address potential threats to the Southern Residents. Further research is needed.

Recommendations focus on improving and standardizing data collection and documentation efforts. For example, a standardized data / metadata structure would enable the following:

- Development of a comprehensive listing of all useful data and metadata elements pertaining to Southern Residents and more broadly to other marine mammals
- Standardization of the definitions and units of measure of acoustic data and metadata elements (a significant need in the acoustic discipline)
- Development of a consistent storage mechanism that would facilitate information sharing and collaboration, especially as data and metadata are stored in common, web-accessible databases
- Effective data and metadata queries, especially web-enabled queries

Equipment performance specifications, study parameters, standard methods, and best practices specifically for Southern Residents and more generally for marine mammals should be developed and disseminated to researchers. These specifications should be based on international standards including American National Standards Institute (ANSI) Standard S1.20-1988 and National Institute of Standards and Technology (NIST) standards. In addition to conforming to these standard practices, researchers should be encouraged to collect pertinent physical parameters of the propagation path, e.g., sound velocity profile and sea state. These parameters are important to understanding the range and depth dependent characteristics of sound propagation.

Data collection should be prioritized to fill both temporal and spatial gaps in the data record. Spatially, data collection efforts should first target the gaps in the most important habitats of the Southern Residents, i.e., in and around the San Juan Islands. Temporally, data collection efforts should be targeted during the primary habitat occupancy range between May and October.

All research data collectors should be encouraged to collect as much background noise as their particular research objectives and budgets allow, especially the ambient levels preceding and following any particular source monitoring so that the two levels can be compared.

An alternative to maintaining a costly long-term empirical field monitoring regimen (extending years and decades) would be to develop correlations between localized acoustic surrogate indicators and actual acoustic levels (e.g., shipping density for shipping sources and wind speed or sea-state for surface noise) for use as proxy values when actual data collection is cost prohibitive.

Every effort should be made to foster increased cooperation and information sharing between acoustic data collectors in the habitat of the Southern Residents to develop common objectives and improve standardization. It is also important to coordinate and align Puget Sound acoustic research with national and international standardization efforts to leverage similar objectives and share pertinent information. Federal leadership is needed to maintain awareness and disseminate information so that Northwest researchers can effectively coordinate with and contribute to national long-term ocean noise monitoring efforts. As norms of standard data and metadata evolve, it is important to increase public education of undersea acoustic concepts and their relationship to viability of Southern Residents. Such public education would facilitate informed public dialogue and policy development.

1.0 INTRODUCTION

1.1 Background

The National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (Fisheries) is dedicated to the stewardship of living marine resources through science-based conservation and management and the promotion of healthy ecosystems. On May 29, 2003, NOAA Fisheries published a notice in the *Federal Register* designating the Eastern North Pacific Southern Resident stock of killer whales (*Orcinus orca*) as depleted under the Marine Mammal Protection Act (MMPA). The notice also announced preparation of a Conservation Plan to restore the stock to its optimal sustainable population. Additionally, on November 18, 2005, NOAA Fisheries published a notice in the *Federal Register* designating this same population of whales as endangered under the Endangered Species Act (ESA). NOAA Fisheries must now develop a Recovery Plan for the Eastern North Pacific Southern Resident stock of killer whales, hereafter referred to as the Southern Residents.

The Southern Residents consist of three pods totaling approximately ninety individual whales. The habitat range of these whales surrounds Vancouver Island in British Columbia, occupies the inland waters of Puget Sound, and runs down the western coast of the United States to Monterey Bay in California. These whales are typically seen in Puget Sound during the summer.

Throughout the process to designate the Southern Residents as endangered, NOAA Fisheries has evaluated available information to determine what factors may be contributing to the population decline of the whales. NOAA Fisheries has determined that the primary potential risk factors for the Southern Residents are prey availability, pollution and related effects, and noise and stress associated with anthropogenic (manmade) activities, particularly vessel traffic.

NOAA Fisheries hosted a series of workshops in 2003 and 2004 to define research questions related to these risk factors. Of the many questions defined during the workshops, three questions encompass the primary concerns related to characterizing the underwater acoustical habitat of the Southern Residents:

- "What are the baseline acoustic conditions and spectral characteristics of vessel noise and its propagation in SR [Southern Residents] habitat for the purpose of predicting received levels under varying conditions and the contributions from multiple vessels?"
- "What sources of noise most likely affect SRKW [Southern Resident Killer Whales] reproduction, survival, etc.?"
- "How does sound propagation vary spatially, temporally, and seasonally in the SRKW habitat?" (NOAA April 22, 2004).

NOAA Fisheries further refined these research questions in the *Preliminary Draft Conservation Plan for Southern Resident Killer Whales (Orcinus orca)*, March 2005 (Draft Conservation Plan). In the Draft Conservation Plan, NOAA Fisheries presents information about threats to the long-term sustainability of the Southern Resident population and outlines actions deemed necessary to address risk factors affecting the whales. The Draft Conservation Plan emphasizes the need to "determine the acoustic environment of the southern residents" (NOAA 2005, p.119). Additionally, NOAA Fisheries' Draft Conservation Plan states,

> "Little information exists on the types and levels of marine noise to which the whales are exposed. Inventories of acoustic conditions are needed throughout the range of the southern residents, but especially in areas of high vessel traffic, such as the San Juan Islands. Studies of noise production by vessels and ambient sound conditions are the highest priority, but other noise sources should also be described. Historical trends in noise levels should be estimated as well. An additional need is to examine the characteristics of sound propagation in the areas used by whales" (NOAA 2005, p. 119).

1.2 Purpose

To support improved understanding of the underwater acoustic environment of Southern Residents in the habitat range of the whales, NOAA Fisheries contracted with Concurrent Technologies Corporation (*CTC*) to gather and assess available information and to provide recommendations for filling identified data gaps. This effort focused on gathering and evaluating existing information about studies and recording efforts conducted within the habitat range of the Southern Residents.

For the purposes of this document, the habitat range of the Southern Residents, or project study area, is defined as the inland marine waters of Puget Sound, including the Strait of Juan de Fuca and the Strait of Georgia, and the coastal marine waters of Washington, Oregon, Northern California, and British Columbia.

This document presents a summary of the information gathered and evaluated. It also outlines recommendations for NOAA Fisheries' consideration on how to address data and information gaps and how to improve underwater acoustics research in the study area. The recommendations included herein account for current efforts being conducted by multiple researchers such that duplication of efforts is minimized.

An electronic copy of this document is included on a compact disc (CD) provided to NOAA Fisheries. The CD also includes an electronic copy of the Underwater Acoustics Module of the Marine Mammals Data Management System (MMDMS) and an electronic copy of a map illustrating the locations of underwater acoustic studies and recording efforts.

2.0 METHODS, ASSUMPTIONS, AND PROCEDURES

2.1 Overview

NOAA Fisheries directed the project team to identify existing underwater acoustics studies and recording efforts conducted within the project study area. The project team identified and then evaluated the studies and recording efforts. From this evaluation, the project team developed recommendations for NOAA Fisheries' consideration. The following sections describe the project team's approach.

2.2 Underwater Acoustic Study and Recording Effort Identification

The project team identified potential sources of information about underwater acoustic studies and recording efforts through the use of existing professional contacts, knowledge of underwater acoustics studies being conducted in the study area, the Internet, and a review of materials previously gathered by the project team related to underwater acoustics and/or marine mammals. The effort to identify potential sources of information, while extensive, was not all inclusive. Efforts to identify potential sources of information began in late 2004. These efforts continued through September 2005, with most activities being completed between February and April 2005. The project team used a Microsoft Access® database to compile contact information and to track its progress in engaging each contact or potential lead.

2.2.1 Referral Contact Search

The project team developed a list of personal contacts and organizations that likely had access to or knowledge of applicable information based on the team's existing knowledge of underwater acoustics and sources of anthropogenic noise. The project team added additional contacts and organizations to this list as they were identified.

A project team member telephoned and/or sent electronic mail (email) to each contact soliciting their cooperation for this project. Each initial telephone conversation and email sent included a brief summary of the purpose of the solicitation; definition of the geographic area of interest; the type of information being sought; a request for any available data; and information about applicable datasets or reports. Additionally, each telephone conversation and email included a request for leads to other persons or organizations that might have knowledge of applicable information to support a subsequent secondary search. Each conversation and email was customized as needed to support effective communication with the person or organization being contacted. Each telephone conversation and email often included reference to how the person or organization was identified as a potential source of information and specific reference to information that the person or organization was believed to have, if known in advance. Initial contacts were frequently followed by additional telephone conversations and/or emails to further support the identification and collection of applicable information. Appendix A presents a typical email sent to contacts.

2.2.2 Internet Search

The project team identified additional information or sources of information using the Internet. Internet searches included focused searches related to previously identified organizations or information, such as known research partners of NOAA Fisheries and regional university libraries, and Boolean searches at Internet search engines using terms related to underwater acoustics. Appendix B presents a list of terms included in the Boolean searches. The project team used these terms in multiple combinations using several Internet search engines including the following:

- Google.com
- Kartoo.com
- Mamma.com
- Scirus.com
- Snap.com
- Webcrawler.com
- Yahoo.com

2.2.3 Literature Reference Search

In addition to soliciting contacts and completing Internet searches, project team members reviewed materials previously gathered by the project team related to underwater acoustics and/or marine mammals, e.g., publications and lists of acoustic workshop and conference attendees, to identify additional persons or organizations of interest. This information was then used to expand the list of contacts and enhance Internet searches.

2.3 Initial Characterization of Data and Information

Through its contacts and Internet searches, the project team identified several datasets and study reports related to underwater acoustics in the study area. The project team used a Microsoft Access® database to compile available information about each dataset or study report. When available, the project team compiled the following list of information for each dataset or report:

- Dataset or study report name
- Dataset or study report owner
- Dataset or study report source or manager
- Purpose (Why was the information originally collected?)
- When was the information gathered?
- In what format, i.e., file type and storage medium, is the information?
- What instrumentation or equipment was used to collect the information?

- Were instruments or equipment calibrated? If yes, what methods were used?
- Where were the data collected?
- Are there any known problems with the data, e.g., known data quality or access issues?

2.4 Prioritization of Information Gathering and Review

On March 28, 2005, the project team provided NOAA Fisheries a list of contacts that had been solicited and a summary of their response to the information request. The project team also provided NOAA Fisheries an inventory of underwater acoustics datasets and study reports that it had identified thus far. NOAA Fisheries reviewed the contact list and inventory and identified those contacts, datasets, and study reports of most interest to NOAA Fisheries. The project team used this information to guide its subsequent efforts to gather additional information from contacts and to characterize identified datasets and study reports.

Following March 28, 2005, the project team also continued its efforts to solicit information from personal contacts and to identify additional datasets and study reports in an effort to develop a comprehensive inventory of underwater acoustics information for the study area. Appendix C presents the final inventory of underwater acoustics datasets and study reports applicable to the study area.

2.5 Analysis of Available Information

The project team reviewed each applicable dataset and study report. Descriptive characterization parameters were then developed to parameterize essential characteristics of the studies and recording efforts. General parameters include the following:

- Unique study or dataset identification number
- Study or dataset name
- Study or dataset source material type (how was the information obtained, e.g., email, spreadsheet, or website)
- Study or dataset summary descriptive text, e.g., a study report abstract.

Following this effort, the project team performed a more detailed analysis of the available information. The overall phased approach to this analysis of available information was to:

1. Categorize available information about the datasets and studies into standardized descriptive categories, i.e., who, where, why, when, how, and what. Categories are further described in the following subsections.

2. Characterize each dataset or study with uniform characterization parameters, i.e., attributes within each descriptive category above, developed to consistently describe each dataset and study in terms of metadata attributes of interest, e.g., dataset owner organization, type, contact name, and address.

3. Summarize the general characteristics of identified acoustic information from available metadata in terms of who is collecting which types of data, for what purposes, when, in what locations, using which methods and equipment, in what frequency ranges, in what formats, etc.

4. Conduct a gap analysis from the metadata, in the standard categories of interest between identified data and data needed to characterize adequately the underwater acoustic habitat of the Southern Residents.

2.5.1 Categorization of Available Information into Descriptive Categories

The project team developed descriptive characterization parameters and organized these parameters according to the following questions about the available datasets and study reports:

- **Who** has collected potentially relevant marine acoustic information?
- **Why** has potentially relevant marine acoustic information been collected?
- **Where** has potentially relevant marine acoustic information been collected?
- **When** has potentially relevant marine acoustic information been collected?
- **How** has potentially relevant marine acoustic information been collected?
- **What** potentially relevant acoustic information has been collected?

A georeferenced data structure was then developed in Microsoft Access® with records created for every distinct study or dataset identified and record attributes created to represent the various characterization parameters. The specific characterization parameters for each of the above question categories are further described under the following subsections.

Note that some of the records included in the Microsoft Access® database represent general data sources which include multiple datasets, e.g., more than 1,000 datasets for the Fisheries and Oceans Canada entry. In these cases, the parameters associated with the general data source record represent general metadata characteristics of the included multiple datasets, as described by the dataset owner. Additional breakout into individual records occurred only for datasets that could be divided by distinctly different date, location, equipment configuration, or other attribute based on the available information.

2.5.2 Development and Population of Characterization Parameters in the Who Category

In order to analyze who has been collecting potentially relevant acoustic information, the following dataset and study report characterization parameters were developed and populated within the database, as information was available and provided by the point of contact:

- Study/Dataset Source
- Study/Dataset Author Name
- Study/Dataset Author Contact Information
- Study/Dataset Owner Organization Name
- Study/Dataset Owner Organization Address
- Study/Dataset Sponsor Category, i.e., Government, Academic, Commercial, and Non-Governmental Organization (NGO)
- Study/Dataset Sponsor Category Level 2, e.g., Federal or State for Government and University name for Academic
- Study/Dataset Sponsor Category Level 3 (Sub-organization name)

2.5.3 Development and Population of Characterization Parameters in the Why Category

In order to analyze why various organizations had collected potentially relevant undersea acoustic information, the following dataset and study report characterization parameters were developed and populated within the database, as information was available and provided by the point of contact:

- Study/Dataset Purpose (brief descriptive text)
- Primary, Secondary, and Tertiary Purpose Categories Level 1 (Anthropogenic, Natural, and Ambient)
- Primary, Secondary, and Tertiary Purpose Categories Level 2 (Shipping, Construction, Oceanography, etc.)
- Primary, Secondary, and Tertiary Purpose Categories Level 3 (Whale Vocalization, Pile Driving, Wind/Rain Monitoring, etc.)

2.5.4 Development and Population of Characterization Parameters in the Where Category

When possible, the project team identified the location where data were collected for each dataset and study report. The project team was unable to determine specific locations for all datasets and study reports. When no specific location was known, e.g., no latitude and longitude coordinates were available, but a general location could be identified, the project team included a description of the general location for the data collection effort.

In order to analyze the spatial distribution of various acoustic information collection efforts, the following dataset and study report characterization parameters were developed and populated within the database, as information was available and provided by the point of contact:

- Study/Dataset Location Descriptive Text
- Study/Dataset Map
- Study/Dataset Location Latitude
- Study/Dataset Location Longitude

2.5.5 Development and Population of Characterization Parameters in the When Category

In order to analyze the temporal distribution of various acoustic information collection efforts, the following dataset and study report characterization parameters were developed and populated within the database, as information was available and provided by the point of contact:

- Study/Dataset Start (Month, Day, and Year)
- Study/Dataset End (Month, Day, and Year)

2.5.6 Development and Population of Characterization Parameters in the How Category

In order to characterize the various data and information collection technologies used, an overall acoustic reference model was hypothesized that follows the standard parameters of the general sonar equation and is described in more detail in Appendix D. Additionally, a typical acoustic receiving system was hypothesized from which the various parameters were developed to characterize the receiving system.

The following general descriptive text field parameters were developed in order to analyze the wide range of technical approaches used during the identified studies and data collection efforts:

- Overall Study/Dataset Method Descriptive Text (provided a summary overview of the technical approach)
- Overall Instrumentation Descriptive Text (summarized the technologies used)
- Active/Passive (Categorized whether the study or data collection effort involved active transmissions, passive listening, or both).

The methodology for analyzing the significant technical detail of the various approaches for data and information collection efforts was divided into the following three physical process aspects of underwater acoustics, which are described in more detail in subsequent subsections:

- Acoustic Transmitter System (for studies and data collection efforts involving active transmissions)
- Acoustic Propagation Path
- Acoustic Receiver System

2.5.6.1 Acoustic Transmitter System Analysis

Some potentially relevant studies and recording efforts involved active sonar transmissions from underwater projector transducers. The following parameters were identified for studies and recording efforts that involved active transmissions from underwater transducers:

- Projector Transducer :
  - Manufacturer and Model
  - Descriptive Text
  - Horizontal Beamwidth (degrees)
  - Vertical Beamwidth (degrees)
  - Calibration (yes/no)
  - Calibration Method
  - Lower Frequency Response (Hertz, or Hz)
  - Upper Frequency Response (Hz)
  - Resonant Frequency (Hz)
  - Impedance (ohms)
  - Transmitting Sensitivity (decibels relative to 1 micro-Pascal per volt, or dB re1µPa/volt, at 1 meter)
  - Transmitting Current Response (dB re 1µPa/amp at 1 meter)
  - Source Level (dB re 1µPa at 1 meter)
  - Depth (feet)
- Projector Transducer Array:
  - Number of Transducers
  - Array Geometry (configuration, spacing, etc.)
  - Array Wiring Configuration (series or parallel)
  - Array Gain (dB re to a single transducer)
  - Array Directivity (dB re omni-directional)
  - Array Horizontal Beamwidth (degrees at three dB down from center)
  - Array Vertical Beamwidth (degrees at three dB down from center)
  - Array Current Response at 1 meter (dB re 1µPa/amp)
  - Array Source Level (dB re 1uPa at 1 meter)

- Projector Source Signal:
  - Type (amplitude modulation, frequency modulation, phase modulation, complex, etc.)
  - Lower Frequency (Hz)
  - Upper Frequency (Hz)
  - Duration (seconds)
  - Repetition Rate (pulses per second or Hz)
  - Input Current (amps, or root mean square [rms] if periodic)
  - Input Voltage (volts, or rms if periodic)
  - Input Power (watts, or rms if periodic)

2.5.6.2 Acoustic Propagation Path Analysis

The following fields were developed to capture any relevant available information regarding the propagation path from the source to the receiver:

- Bottom Depth (feet)
- Bottom Type
- Bottom Loss Descriptive Text
- Sea State
- Surface Reflection Descriptive Text
- Reverberation Descriptive Text
- Spreading Loss Descriptive Text
- Absorption Loss Descriptive Text
- Sound Velocity Profile
- Sound Velocity Profile Method Descriptive Text

2.5.6.3 Acoustic Receiver System Analysis

The following parameters were identified to characterize the acoustic receiver system and elements including, hydrophone specifications, signal processing, and data storage:

- Receiver Hydrophone
  - Manufacturer and Model
  - Hydrophone Descriptive Text
  - Lower Frequency Response (Hz)
  - Upper Frequency Response (Hz)
  - Resonant Frequency (Hz)
  - Impedance (ohms)

- Sensitivity (dB re 1volt/µPa)
- Acoustic Overload Pressure (dB re 1µPa)
- Capacitance (picofarad [pF])
- Horizontal Directivity
- Vertical Directivity
- Minimum Depth (feet)
- Maximum Depth (feet)
- Calibrated (yes/no)
- Calibration method

- Receiver Hydrophone Array
  - Single hydrophone or array
  - Number of hydrophones
  - Array Geometry (e.g., linear, planar, spherical, cylindrical, horizontal, vertical, etc.)
  - Array Wiring Configuration (series or parallel)
  - Array Gain (dB signal-to-noise ration [SNR] re single hydrophone)
  - Array Directivity Index (dB re single omni)
  - Array Beamwidth (degrees between three dB down points)
  - Array shading (e.g., binomial, Dolf-Chebyshev, Lagrangian, and Phase)
- Received Signal Processing
  - Analog Pre-amplification Gain (dB)
  - Analog Pre-amplification Descriptive Text
  - Analog Filtering Passband Lower Frequency (Hz)
  - Analog Filtering Passband Upper Frequency (Hz)
  - Analog Filtering Descriptive Text
  - Analog to Digital Conversion (ADC) Sample Rate (Hz)
  - ADC Resolution Bits
  - ADC Descriptive Text
  - Pre-Storage Digital Filtering Descriptive Text
  - Pre-Storage Other Processing Descriptive Text
  - Usable Analysis Bandwidth Lower Frequency (Hz)
  - Usable Analysis Bandwidth Upper Frequency (Hz)
- Data Storage
  - Data Storage (analog or digital)
  - Data Storage Media
  - Data Storage File and Data Structure Descriptive Text

If applicable, ADC methods were evaluated to determine, if possible from available information, whether false alias frequency components were prevented by either sampling above the Nyquist rate or anti-aliasing low-pass filtering prior to digitizing in order to determine the actual usable analysis bandwidth.

2.5.7 Development and Population of Characterization Parameters in the What Category

In order to analyze what potentially relevant acoustic information has been collected, the following dataset and study report characterization parameters were developed and populated within the database, as information was available and provided by the point of contact:

- Primary, Secondary, and Tertiary Source Approximate Level Range – Lower and Upper
- Primary, Secondary, and Tertiary Source Level Descriptive Text
- Ambient (Background) Approximate Source Level – Lower and Upper
- Ambient (Background) Source Level Descriptive Text
- Predominant Ambient Source
- Ambient Directivity Descriptive Text

2.5.8 Potential Additional Parameters

Due to the limited quantity of information available for the identified studies and recording efforts, some parameters that are important to characterizing the underwater acoustic environment were excluded from the database. A list of these parameters is provided in Appendix E.

2.6 General Assumptions

The project team made the following assumptions:

- Information made available was the most current and best available information related to data collection efforts and studies of underwater acoustics within the study area.
- The underwater acoustics information gathered by the project team, while not all inclusive, is representative of existing underwater acoustics information for the study area.
- Information about anthropogenic sources of underwater noise presented in the literature, though not specific to the study area, does provide value to this assessment and can support NOAA Fisheries' efforts to address conservation issues of the Southern Residents.

3.0 RESULTS AND DISCUSSION

3.1 General

Efforts to identify and review underwater acoustics datasets and reports applicable to the study area, while extensive, were not all inclusive. To the project team's knowledge, no previous effort had been made to amass underwater acoustics information applicable to the study area. Efforts to identify and then review underwater acoustics datasets were hindered by the number of organizations, accessibility of the data, multiplicity of data formats (many proprietary or customized), and, in limited instances, classification of the data. As a result, owners of the datasets and study reports were frequently relied upon for information to characterize the datasets and study reports.

The project team successfully contacted 106 persons from more than 100 organizations, i.e., a project team member communicated with one or more persons believed to have sufficient cognizance of relevant information to provide a meaningful response to the solicitation for information. The project team attempted approximately 48 other contacts, but was unsuccessful in its efforts to reach a person cognizant of relevant information. Appendix F presents a list of persons successfully contacted and their organizations.

There was no consistent methodology identified in common usage between researchers to document important information about their data (metadata). Confusion sometimes arose between the sponsoring, collecting, and holding/owning organizations for a particular dataset. In some instances, commercial underwater acoustic consultants collected and held data that was sponsored by underwater construction firms. In other instances, government entities sponsored academic institutions to perform studies and collect data. Equipment specifications were often not included in the study reports and had to be obtained separately from manufacturers, if the manufacturers were still in business and the equipment was not obsolete. Based on available information, calibration of hydrophones and receivers was only conducted on 50 percent (%) of the studies and data collection efforts and was not done uniformly, e.g., in accordance with the American National Standards Institute (ANSI) standard, nor documented consistently. Spatial data documentation varied from general descriptions of the study or data collection area to latitude and longitude, and measurements were provided in various formats and units, e.g., decimal degrees and degrees, minutes, and seconds. Environmental parameters ranged from non-existent to very detailed, but again, in widely varied formats.

3.2 Sponsorship Analysis

As illustrated in Figure 1, of the 59 separate studies and recording efforts, 31 (53%) were from academic institutions, 19 (31%) were from government organizations, five (8%) were from commercial entities, and four (8%) were from NGOs. The University of Washington accounted for 17 (55%) of the academic contributions with other contributions from University of California (Scripps Institution of Oceanography), University of British Columbia, Oregon State University, Cornell University, University of Georgia, University of St. Andrews, University of Victoria, and Colorado College. Of the 19 government contributions, the federal sector provided 15, including eight from the U.S. Navy, three from NOAA, and four from Canada. Two contributions were from State government, and two from local government (Port of Everett). Of the five contributions from the commercial sector, all were from organizations monitoring in-water construction activities. The four contributions from NGOs were from the North Pacific Marine Mammal Research Consortium, the Pacific Orca Society, The Whale Museum, and the American Cetacean Society.

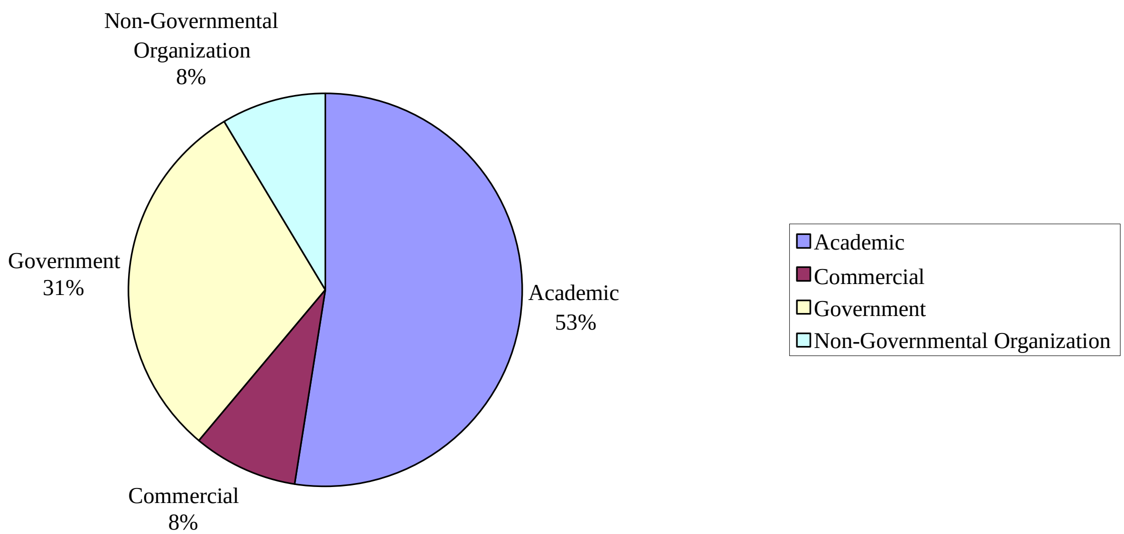

Figure 1. Distribution of Underwater Acoustic Studies and Recording Efforts by Organization Type

3.3 Spatial Analysis

Figure 2 presents the locations where data were collected for each dataset and study report for which latitude and longitude were available. The project team could not determine a specific or general location, i.e., no spatial coordinates or general description of the study sites were available, for the following datasets and study reports:

- Cornell University - Puget Sound
- The Whale Museum

Although no specific spatial coordinates were available for the following studies and recording efforts, general descriptions of the study sites were made available to the project team:

- BioSonics Demonstration
- Fisheries and Oceans Canada
- Friday Harbor Ferry Terminal Restoration Project
- Mukilteo Public Access Dock Pile Driving - Air Bubble Curtain and Acoustic Monitoring Mukilteo, Washington -1 and 2
- Naval Undersea Warfare Center (NUWC) Keyport -1, 2, and 3
- Opportunistic Recordings of Orcas -1 and 2
- Pacific Orca Society/OrcaLab
- Potential Impacts of Pile Driving on Juvenile Pink (*Oncorhynchus gorbuscha*) and Chum (*O. keta*) Salmon Behavior and Distribution -1, 2, 3, and 4
- Systematic Recordings of Transient Orcas -1 and 2
- VENTS Program Data and Navy Sound Surveillance System (SOSUS)
- Washington Sea Grant Program Funded Researchers, University of Washington -1, 2, 3, 4, 5, 6, and 7

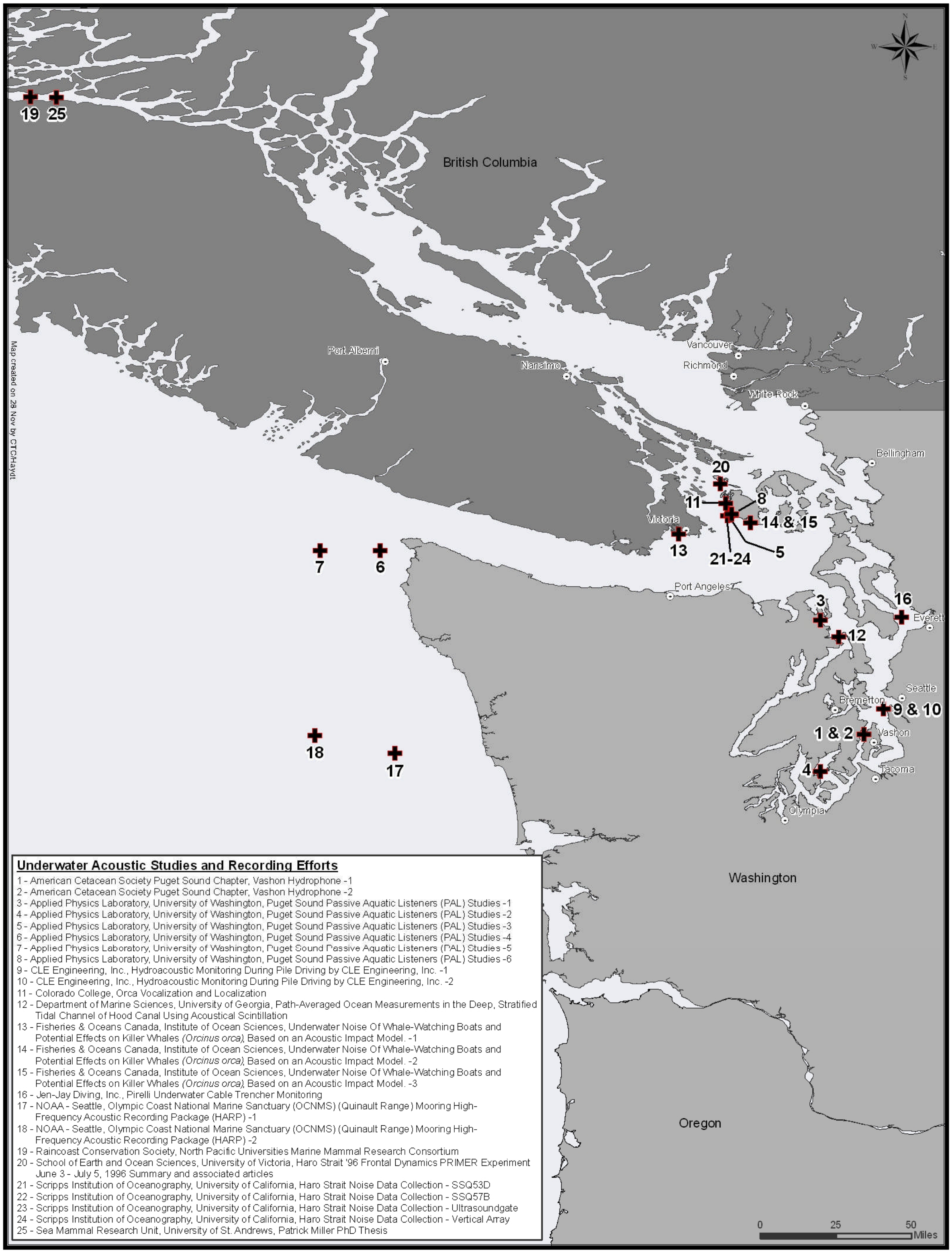

Figure 2. Study Locations of Identified Underwater Acoustic Studies and Recording Efforts within the Study Area

3.4 Purpose Analysis

As illustrated in Figure 3, of the 59 separate studies and recording efforts, 34 (58%) were collected with a primary purpose to monitor anthropogenic sources, 20 (34%) were primarily collected to monitor specific natural sources, and five (8%) were collected to primarily monitor ambient (background) acoustic levels. Of the 34 studies and recording efforts monitoring anthropogenic sources, 13 (38%) were monitoring underwater construction (12 pile driving and one underwater trenching), ten (29%) were monitoring shipping (six multiple vessels, three whale-watching boats, and one ferries), seven (20%) were monitoring U.S. Geological Survey (USGS) activities, and four (12%) were monitoring active sonar transmissions (two from oceanographic current and tomography studies, one from an echo-sounder demonstration, and one from an acoustic communication link). Of the 20 studies and recording efforts monitoring natural sources, 14 (24%) were monitoring orca vocalizations, three (15%) were monitoring surface sounds (wind and wave), and three (15%) were monitoring seismic activity.

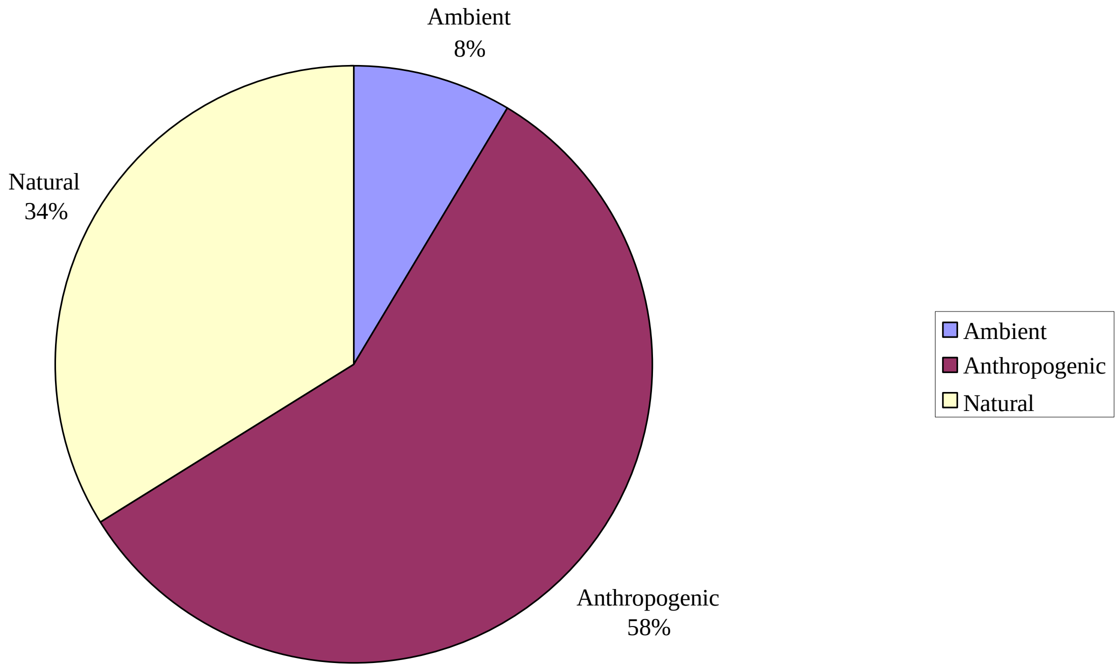

Figure 3. Distribution of Studies and Recording Efforts by Primary Monitoring Purpose

3.5 Temporal Analysis

Analysis of the temporal distribution of 59 identified studies and recording efforts revealed acoustic information starting as early as 1970 and continuing to the present. Figure 4 illustrates the commencement and duration of identified studies and recording efforts since 1970.

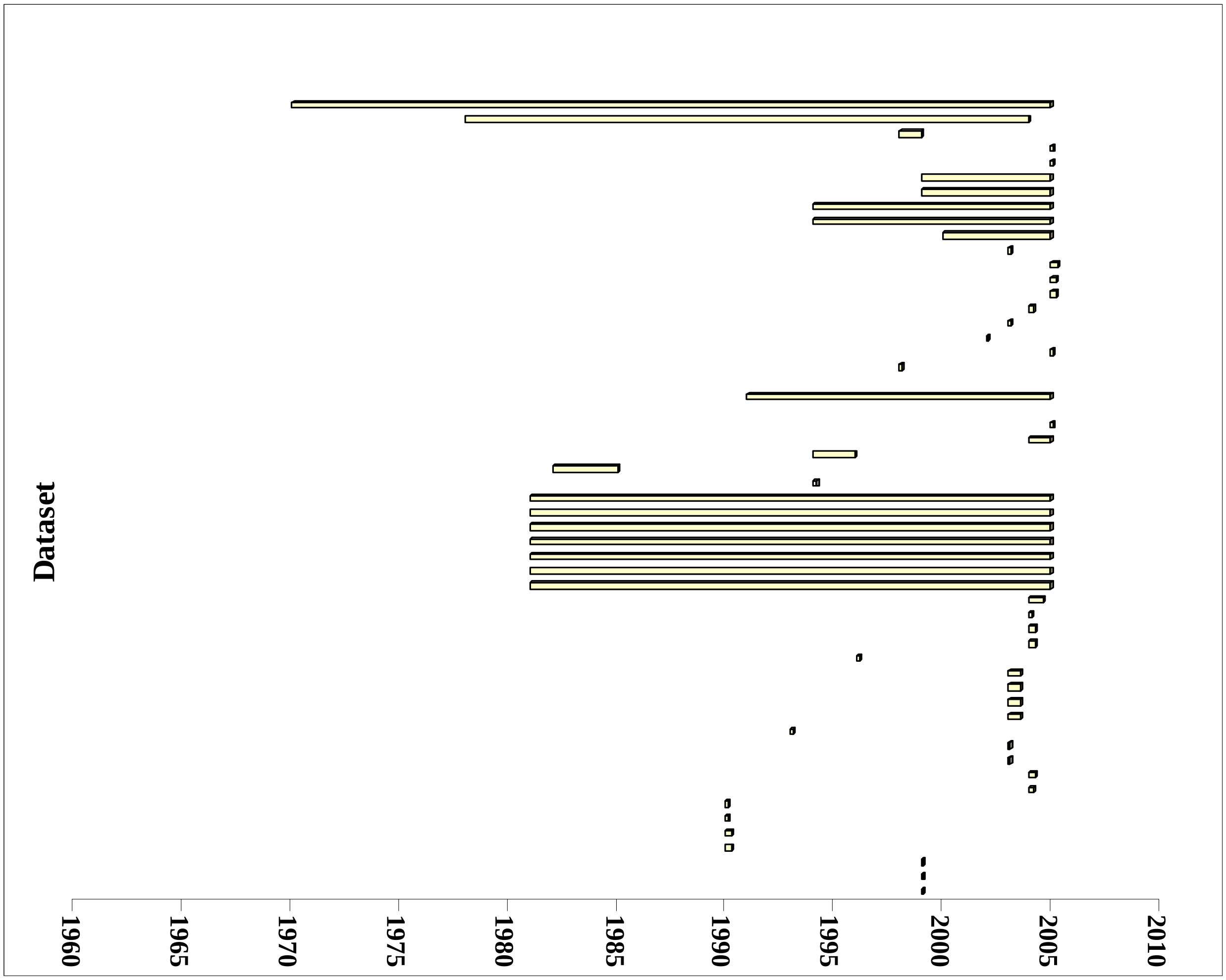

Figure 4. Temporal Distribution Studies and Recording Efforts by Year

Figure 5 illustrates the number of study and datasets that commenced since 1970 and whether their primary purpose was monitoring of natural sources, anthropogenic sources, or ambient background sound.

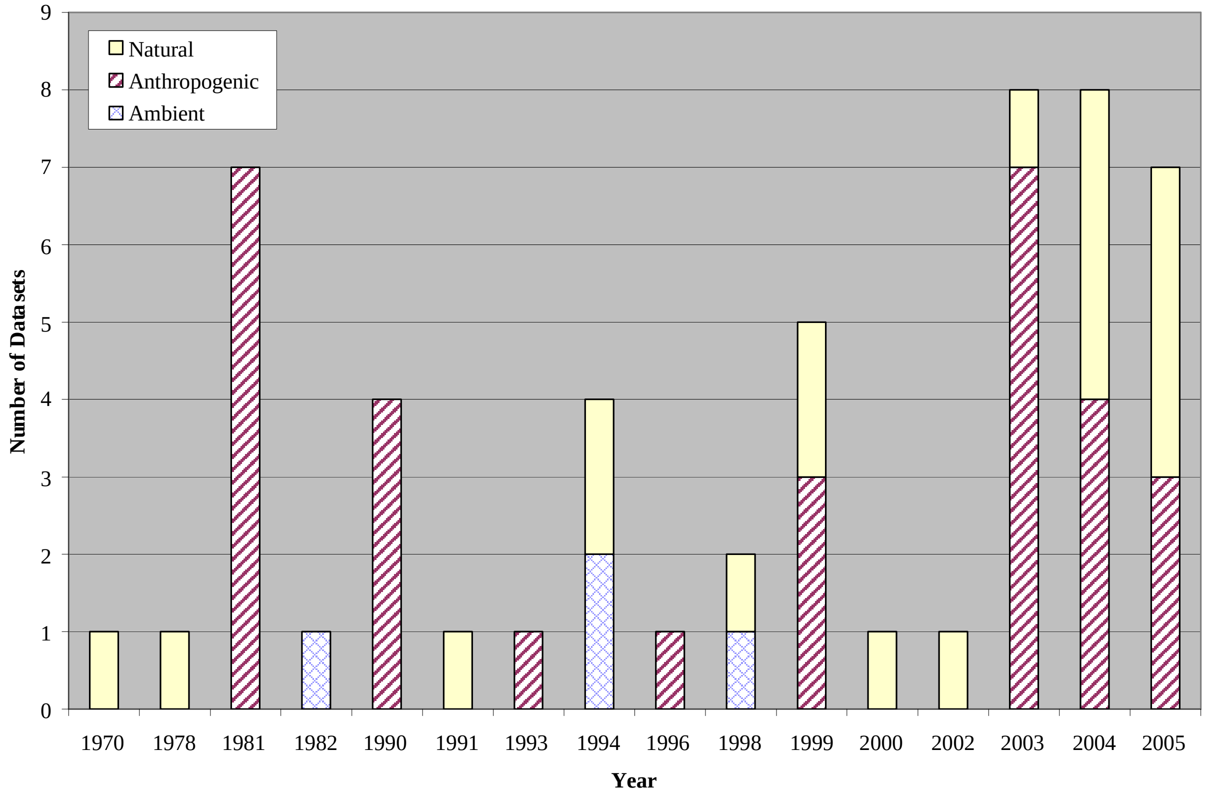

Figure 5. Temporal Distribution Studies and Recording Efforts by Year and Primary Monitoring Purpose

Although some studies and recording efforts were ongoing collections of various data, 32 were specific undertakings lasting less than one year and in many cases only a few days or weeks. Figure 6 illustrates the seasonal distribution of the 32 studies and recording efforts that were less than one year in duration. Note that, based on available information, some studies and recording efforts do begin in October and continue through the Winter to May.

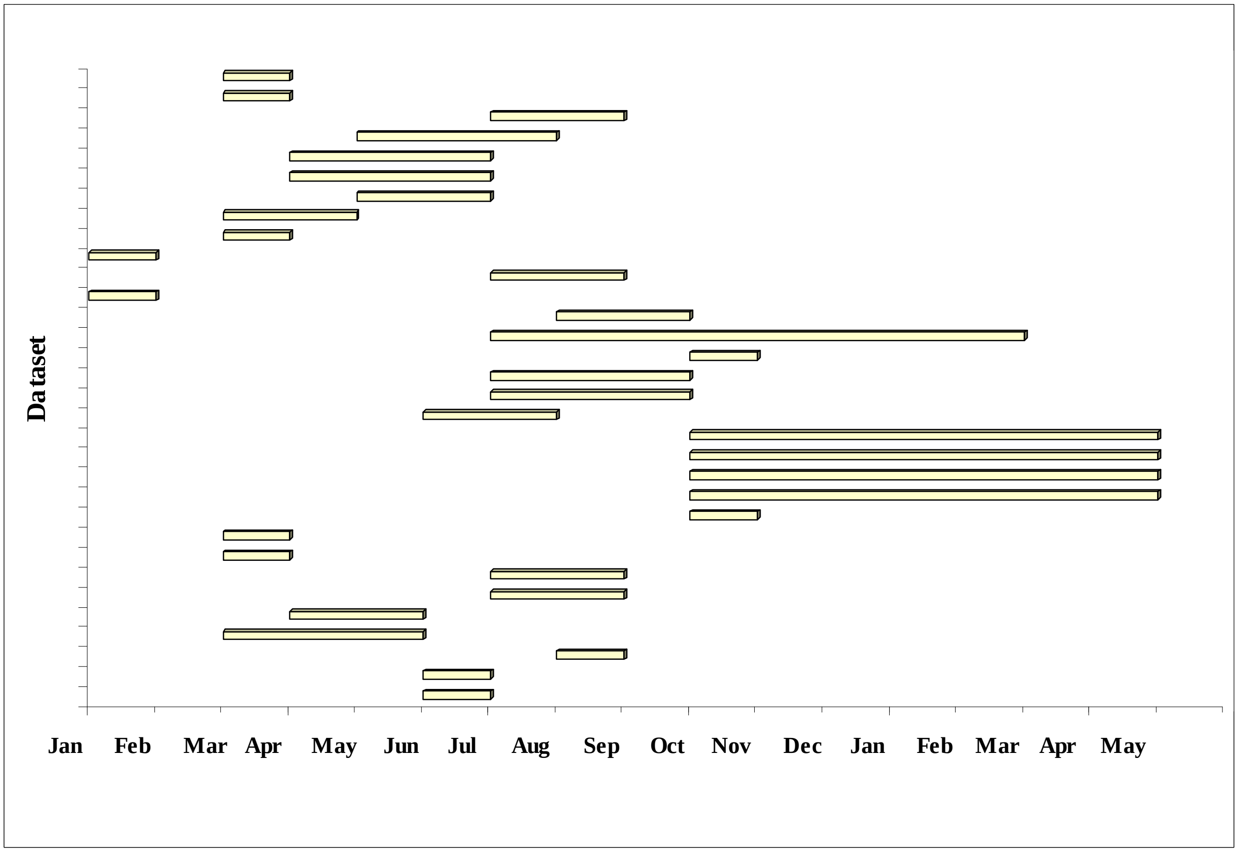

Figure 6. Seasonal Distribution of Short-Term Studies and Recording Efforts

Approximately 75% of the identified studies and recording efforts involved monitoring activities between March and October. Figure 7 depicts the number of studies or dataset collection efforts that were identified to be occurring during individual calendar months by primary monitoring purpose, e.g., monitoring of ambient (background) noise.

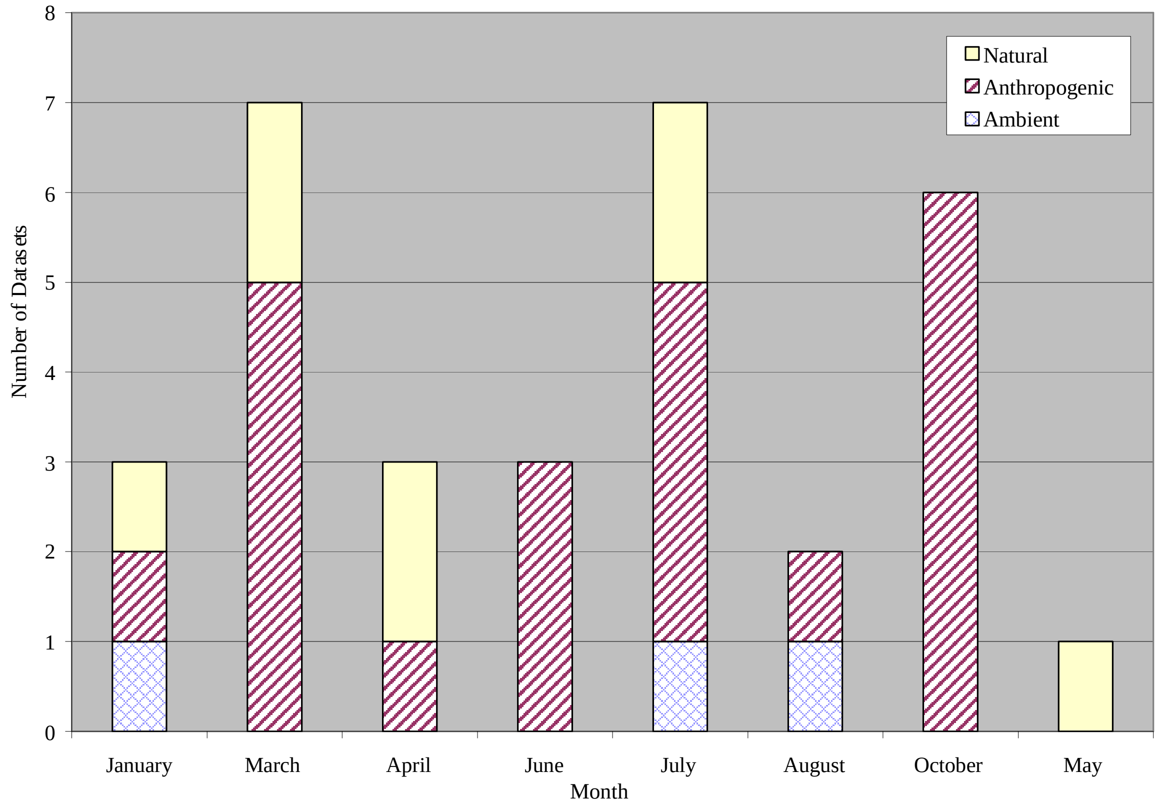

Figure 7. Seasonal Distribution of Studies and Recording Efforts by Primary Monitoring Purpose

3.6 Collection Technology Analysis

3.6.1 System Calibration

Of the 59 total studies and recording efforts identified, 30 studies specifically stated that the hydrophones were calibrated, an additional 15 were probably calibrated from the context of the study, 12 studies specifically stated that hydrophones were not calibrated, and two studies did not discuss calibration and context did not allow inference regarding calibration.

Of the 31 academic studies and recording efforts, ten were calibrated, ten were probably calibrated, and one was not calibrated. Of the 18 government studies and recording efforts, 14 were calibrated and another four were probably calibrated. Of the five commercial studies and recording efforts, three were calibrated, one was probably calibrated, and one was unknown. Of the five NGO studies and recording efforts, three were calibrated, one was not calibrated, and one was unknown (see Figure 8).

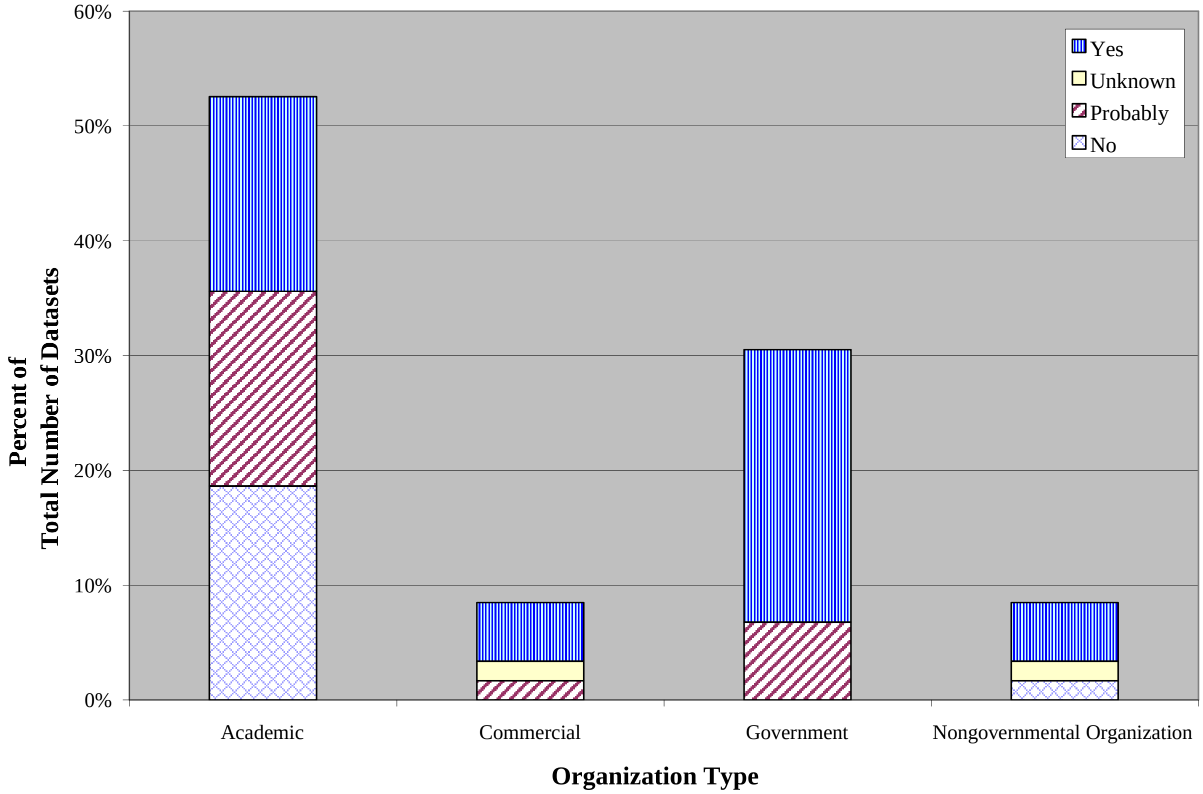

Figure 8. Underwater Acoustic Studies and Recording Efforts by Organization Type and System Calibration

Of the 34 studies and recording efforts monitoring anthropogenic sources, 19 were calibrated, seven more were probably calibrated, seven were not calibrated, and one was unknown. Of the 20 studies and recording efforts monitoring natural sources, seven were calibrated, seven more were probably calibrated, five were not calibrated, and one was unknown. Of the five studies and recording efforts monitoring ambient noise, four were calibrated, and one was probably calibrated (see Figure 9).

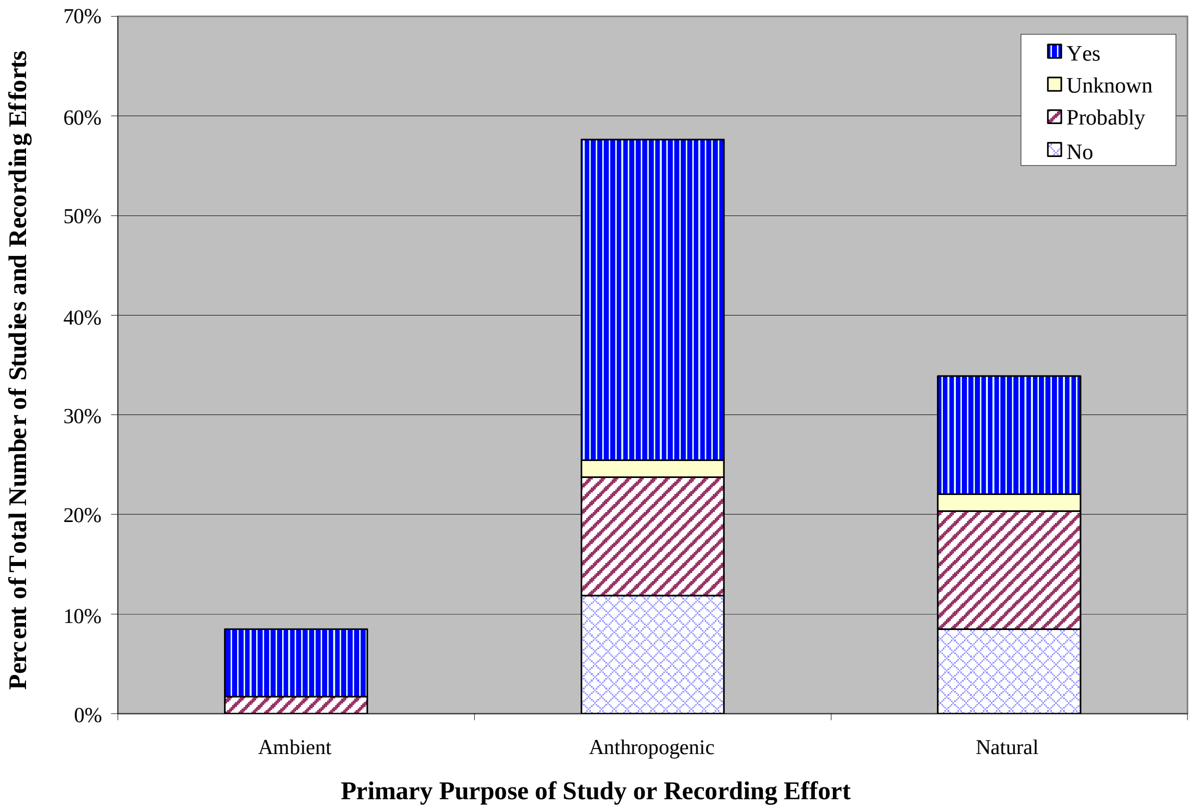

Figure 9. Percent of Underwater Acoustics Studies and Recording Efforts by Primary Monitoring Purpose and System Calibration

3.6.2 General Study or Recording Effort Method

Of the 59 identified studies and recording efforts, only four utilized active sonar transmissions from acoustic projectors and all 59 utilized passive receiving hydrophones. The active transmissions were from the following sources:

- Acoustic scintillation measurements of stratification layer refraction
- Acoustic tomography
- Acoustic modem communication link
- Echo-sounder demonstration

Of the 59 identified studies and recording efforts, 44 utilized single hydrophones, 11 utilized hydrophone arrays, and four had an unknown number of hydrophones. Of the 11 arrays, seven were linear vertical arrays (three, five, or 16 hydrophones), one was a towed linear horizontal array (16 hydrophones), one was a “T”-shaped planar array (four hydrophones), and two had unknown configurations.

3.6.3 Usable Analysis Band

Usable analysis band was estimated by evaluating the most limiting upper and lower frequency response of the hydrophones, filters, analog-to-digital converter, and data storage medium. Although all hydrophones were not specified, identified hydrophones included various ITC models (e.g., 4123 and 6050), Cetacean Research Technology models (e.g., C10, C13, and C54), Bruel & Kjaer models (e.g., 8104 and 8105), Spartan Electronics/Magnavox SSQ-57 LOFAR Sonobuoy and SSQ-53 DIFAR Sonobuoy, Reson 4013, Wilcoxon H507, Bethos AQ-H2TS, Instantel Series III, Atlantic Research LC-32, and unknown models from Offshore Acoustics and HiTech, Inc. Hydrophone specification sheets were obtained, when available, for analysis of frequency range.

Of the 32 studies and recording efforts that provided sufficient information to make a reasonable estimate, the lower usable analysis bandwidth ranged from 1 Hz to 100 Hz with a median lower frequency of 30 Hz, an arithmetic mean lower frequency of 51 Hz and a standard deviation of 43 Hz. The estimated upper usable analysis bandwidth ranged from 4.7 kilohertz (kHz) to 100 kHz, with a median upper frequency of 22 kHz, an arithmetic mean of 33 kHz and a standard deviation of 22 kHz. As Figure 10 illustrates, the usable frequency bands of 28 (88%) of the 32 studies that provided sufficient information to estimate usable bandwidth were limited to less than 50 kHz by the Nyquist frequency limit from the digitizing sample rate and/or low-pass filtering. Of these, 20 (63% of the total) were limited to less than 25 kHz for similar reasons.

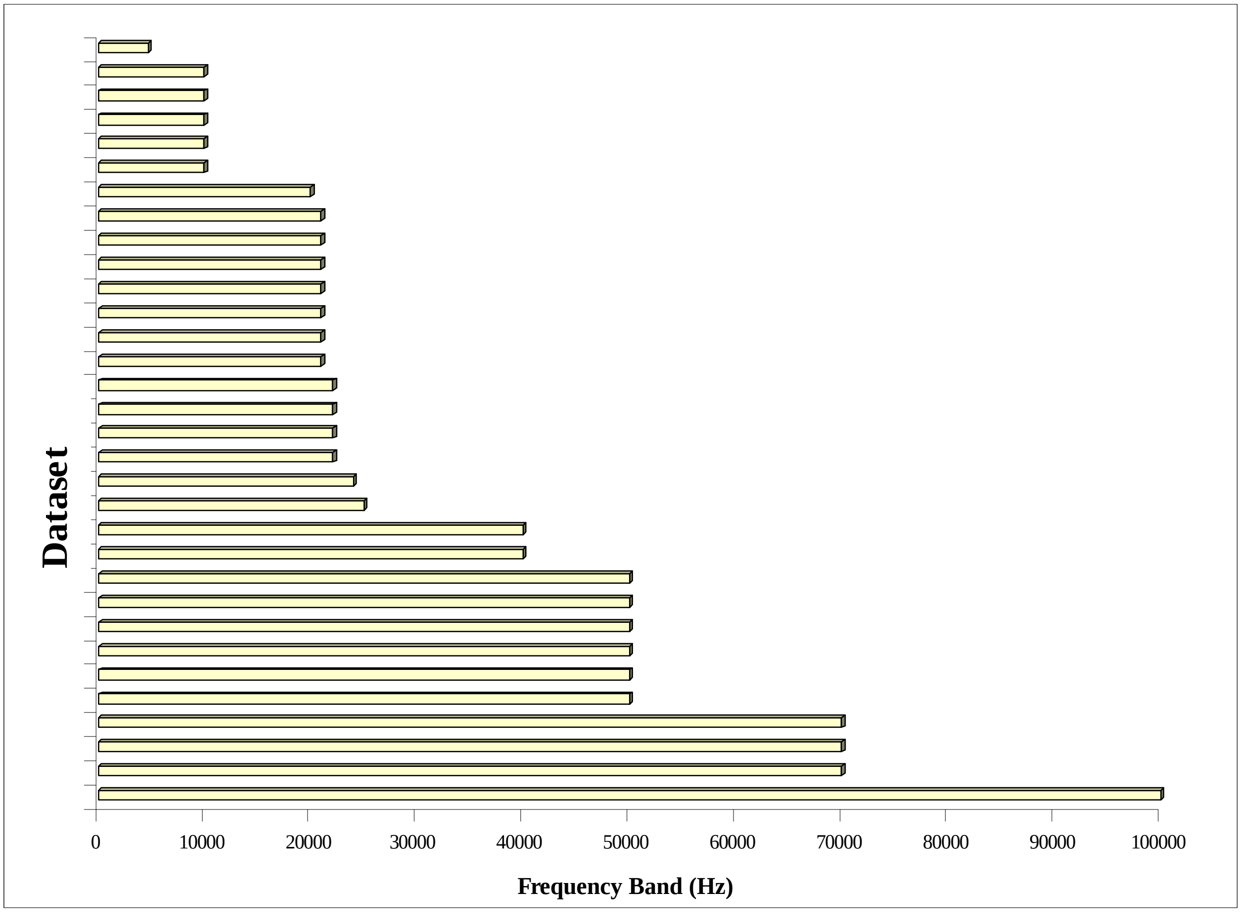

Figure 10. Estimated Usable Frequency Bands of Studies and Recording Efforts

Of the 32 studies and recording efforts that provided sufficient information to develop an estimate, all 32 (100%) had an upper usable frequency of at least 4.7 kHz and 26 (80%) had a usable band of at least 10 kHz. However, only 12 (38%) had upper usable frequencies exceeding 25 kHz. Only four of the studies and recording efforts are estimated as high as 70 kHz (depending on digital Video Home System [VHS] tape playback ability) and only one potentially reaches 100 kHz.

Of the 32 studies and recording efforts with estimated usable frequency bands, 19 (59%) of the studies and recording efforts had usable frequencies as low as 30 Hz but only 11 (34%) as low as 20 Hz, with just five (16%) as low as 1 Hz.

Gap analysis compared the frequency range of interest of killer whales to the usable frequency band of identified studies and recording efforts. The frequency range of killer whale hearing extends from 1 Hz to at least 120 kHz, and is most sensitive in the range of 18 to 42 kHz with the highest sensitivity at 20 kHz, corresponding to peak energy frequency of the animal’s echolocation clicks (National Marine Fisheries Service 2005). Orca hearing sensitivity declines below 4 kHz and above 60 kHz.

The low frequency component of killer whale vocalizations, consisting of a fundamental tone between 250 and 1,500 Hz and harmonics ranging to about 10 kHz, is relatively omni-directional but with most energy directed forward and to the sides. The high frequency component is more directionally beamed forward with a fundamental tone between 5-12 kHz and harmonics ranging to over 100 kHz (National Marine Fisheries Service 2005). Killer whales produce the following three categories of sounds:

1. **Echolocation Clicks –** Brief pulses of ultrasonic sound produced singly or more often in series known as click trains. Clicks are associated with whale navigation and discriminating prey and other objects, but are also heard in social interactions. Individual clicks are highly variable in structure, lasting from 0.1 to 25 milliseconds and containing a range of frequencies typically between 4-18 kHz, but may extend up to 50-85 kHz. Most click trains last 2-8 seconds but some exceed 10 seconds. Typical repetition rates are between 2-50 clicks per second, but may be up to 300 clicks per second (National Marine Fisheries Service 2005).

2. **Tonal Whistles –** Primary type of vocalization produced during close-range social interactions, infrequently produced during foraging and most types of traveling (Thomsen et al. 2002). Tonal sounds with an average dominant frequency of 8.3 kHz (range = 3-18.5 kHz), an average bandwidth of 4.5 kHz (range = 0.5-10.2 kHz), and an average of 5.0 frequency modulations per whistle (range = 0-71 frequency modulations). Mean duration is 1.8 seconds (range = 0.06-18.3 seconds) (National Marine Fisheries Service 2005).

3. **Pulsed Calls –** The most common type of killer whale vocalization, characterized by rapid changes in tone and pulse repetition rate. Typical frequencies are between 1-6 kHz, but may exceed 30 kHz. Pulse repetition rate may exceed 4,000 or more pulses per second. Duration is usually less than two seconds (National Marine Fisheries Service 2005).

Gap analysis between the usable frequency bands of identified studies and recording efforts and the vocalization and hearing frequency ranges of killer whales indicates that almost all studies and recording efforts cover the typical range of the dominant tonal frequencies of vocalization. However, because the total hearing range and the higher harmonics of those fundamental tonals (reaching over 100 kHz) are captured over 25 kHz in only 38% of the recordings/datasets and over 70 kHz in only 13% of the studies and recording efforts, an information gap exists, which increases significantly above 25 kHz. Virtually all studies and recording efforts had usable frequency bands down to at least 100 Hz, below which there is little vocalization energy projected. However, since the killer whales overall hearing range extends to as low as 1 Hz, a gap exists for 84% of the studies and recording efforts without usable ranges reaching down to 1 Hz, 72% reaching to 10 Hz, 66% reaching 20 Hz, and 41% reaching 30 Hz.

3.6.4 Digital or Analog Data Storage

Of the 59 total studies and recording efforts, 37 were recorded digitally, five were recorded analog, eight included both digital and analog, and nine were unknown. Of the 31 academic studies and recording efforts, 18 were recorded digitally, four were analog, seven were both, and two were unknown. Of the 18 government studies, 12 were recorded digitally, none were analog only, one was both, and five were unknown. Of the five commercial studies and recording efforts, four were digital, and one was unknown. Of the five NGO studies and recording efforts, three were digital, one was analog, and one was unknown. Figure 11 illustrates the number of studies and recording efforts that were recorded digitally, analog, both, or unknown according to the organizational categories of academic, commercial, government, and NGO.

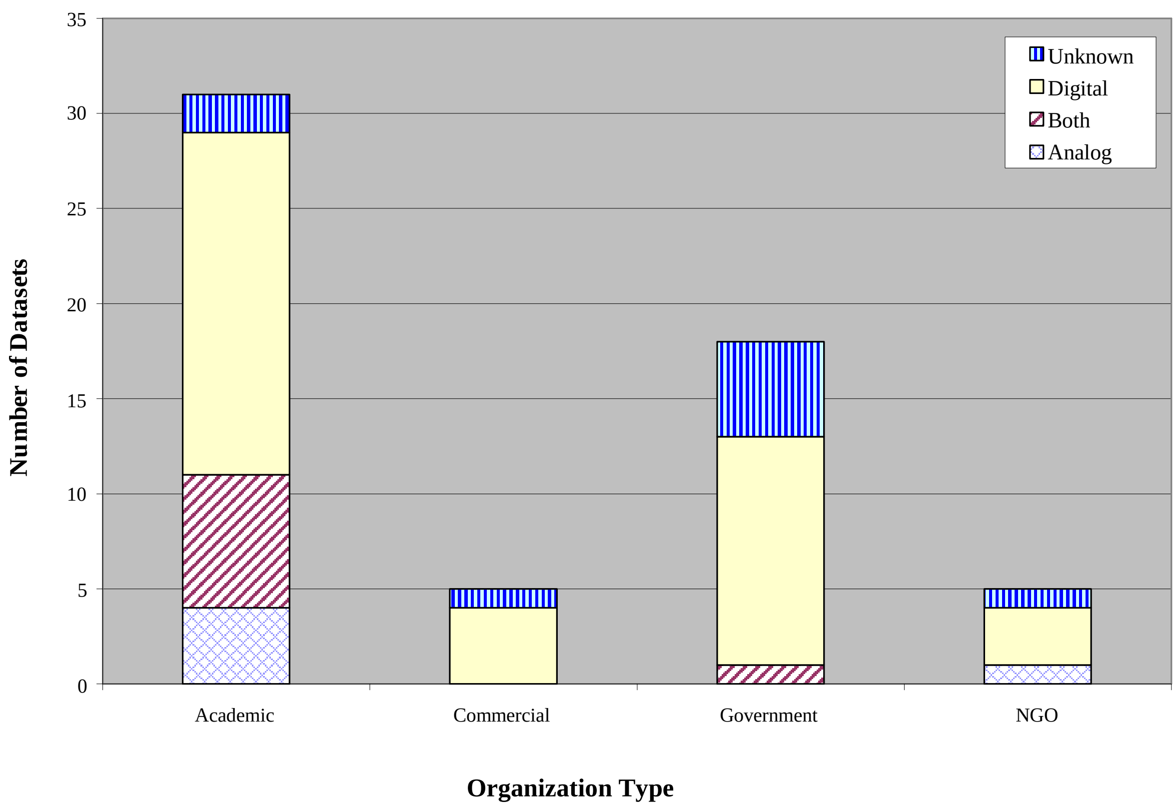

Figure 11. Distribution of Studies and Recording Efforts by Organization Type and Data Storage Media

3.7 Primary Acoustic Sources Analysis

3.7.1 Primary Source Levels

Of the 59 identified studies and recording efforts, 11 provided non-duplicative estimates of approximate acoustic levels from the primary sources being monitored. The measurements recorded were sound pressure levels received at the hydrophone and not the actual source level referenced to one meter from an idealized point source. The lower ranges of the monitored sources varied widely between 90 and 194 dB, with a median of 145 dB, a mean of 146 dB, and a standard deviation of 34 dB. The upper end of the source level estimates ranged from 113 to 205 dB, with a median of 169 dB, a mean of 160 dB, and a standard deviation of 33.6 dB. The upper levels of pile driving ranged from 131 to 205 dB. A trencher was recorded as high as 205 dB. Whale watching boats were recorded as high as 169 dB. Oceanographic tomography was recorded at 120 dB.

Figure 12 illustrates the approximate range of levels recorded for the 11 non-duplicative studies and recording efforts.

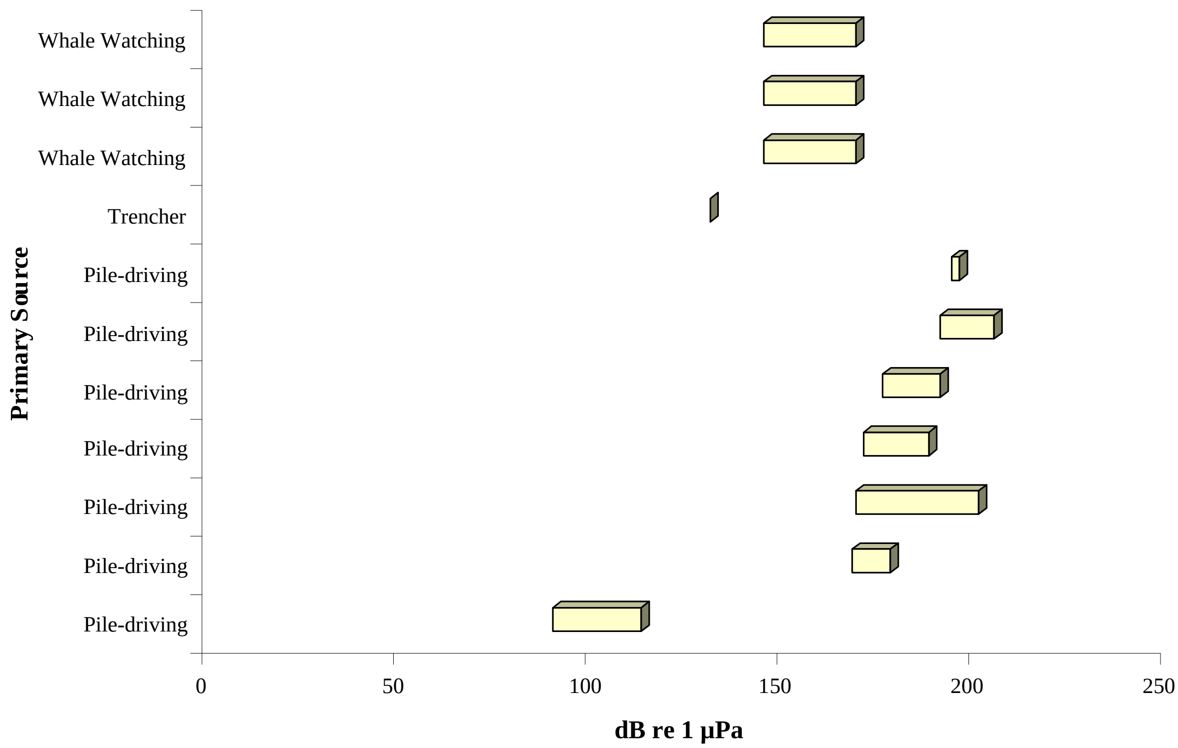

Figure 12. Approximate Received Levels of Anthropogenic Sources

3.7.2 Ambient Levels

The sparse data collected as part of this study were only sufficient to support a very wide order-of-magnitude range of ambient noise levels found throughout Puget Sound. The levels ranged from 80 to 162 dB. Figure 13 illustrates the five approximate upper ranges of received ambient levels available, plotted with the approximate level of the associated source being monitored, as well as other sources that did not provide ambient levels for relative reference.

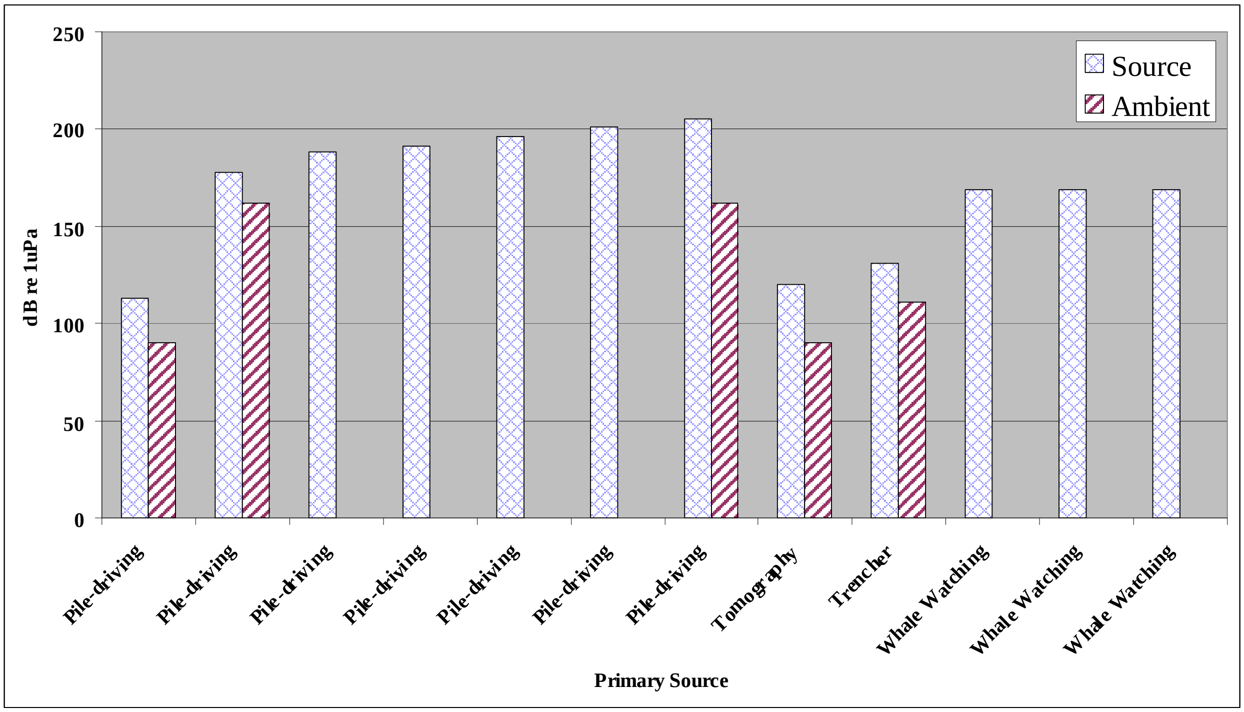

Figure 13. Received Source and Ambient Noise Levels

4.0 CONCLUSIONS

4.1 Quantity and Quality of Available Information

There is currently no standard methodology or data structure in which to consistently document and share the large amount of metadata related to acoustic datasets. This significantly limits the value of the identified historical data for uses other than its original purpose, and often even for repeatable use of the data for its original purpose. Without a standardized framework for understanding the body of recorded acoustic data, its use is very limited for broader purposes such as decision support; comparing data over temporal and spatial ranges; or establishing baselines, averages, trends, or patterns.

In its 2003 report, *Ocean Noise and Marine Mammals*, the National Research Council (NRC) found the same conditions nationally and internationally stating:

> Currently, data regarding noise produced by shipping, seismic surveying, oil and gas production, marine and coastal construction, and other marine activities are either not known or are difficult to analyze because they are maintained by separate organizations such as industry database companies, shipping industry groups, and military organizations. It would be advantageous to have all data in a single database in order to improve the ability of interested parties to access the data sets and use them in research, for scientific publications, in education, and for management and regulatory purposes. This database could be a distributed network of linked databases, using a standardized series of units of measure. International cooperation in this database development effort, as well as international access to the information, should be encouraged since the marine mammal and ocean noise issue is global. (NRC 2003, p.7)

4.2 Contributors to Acoustic Knowledge Base

At 53%, academic studies are the primary contributor to the identified usable acoustic knowledge base in the Puget Sound Region. The University of Washington leads with 55% of the academic contributions with the remaining 45% from a variety of academic institutions. Academic contributions are primarily from monitoring anthropogenic sources (61%) with the remainder monitoring natural sources (39%).

At 32%, government organizations are the second largest contributor of the identified studies and recording efforts with contributions from the U.S. Navy, NOAA, State of Washington, and Port of Everett. The government studies and recording efforts are primarily from monitoring anthropogenic sources (53%), with the remainder split between monitoring natural sources (21%) and ambient background noise (21%). It should be noted that many academic studies and recording efforts are actually government funded, bringing the total government contribution to a much higher percentage, perhaps approaching the combined government and academic sum of 85%.

Various commercial entities monitored anthropogenic sources (100%) such as pile driving and trenching, typically to comply with permit requirements. NGOs also provided information about studies and recording efforts that included monitoring of natural sources (80%) and ambient background noise (20%), as well as providing reference to additional stored studies and recording efforts.

4.3 Spatial Distribution

Of the 59 separate studies and recording efforts only 40 were conducted or collected within the Puget Sound, Strait of Juan de Fuca, and Strait of Georgia. This study concurs locally with the NRC's global finding that, "Efforts to measure ocean noise should be targeted toward important marine mammal habitats. Until these habitats are fully described, it is reasonable to begin a long-term monitoring program in coastal areas, locations close to known marine mammal migration paths, foraging areas, and breeding grounds" (NRC 2003, p.8).

The findings of this study point to very sparse temporal and spatial data density and broad data quality gaps that must be filled in order to understand the undersea acoustic environment of the Southern Residents. Therefore, the habitat of the Southern Residents falls within the national prioritization criteria stated by the NRC.

4.4 Purpose of Monitoring

The majority (58%) of studies and recording efforts were for monitoring anthropogenic sources. While 38% of the anthropogenic studies and recording efforts were monitoring underwater construction (pile driving and trenching) as a permit requirement, and contribute to the overall noise budget, these activities were conducted in harbors, a considerable distance from the most probable Southern Resident habitat areas. However, these underwater construction studies do characterize the levels and frequency components of underwater construction and can be used as a baseline for evaluating the appropriateness of similar activities acoustically near the Southern Resident habitat. Monitoring of shipping (29% from various vessels including whale-watching boats and ferries), USGS bottom surveys (20%), and active transmissions (12% from oceanography, echo-sounders, and acoustic modem links) constituted the remainder of the anthropogenic studies and recording efforts.

Of all the studies and recording efforts identified, those that involved primary or collateral monitoring of shipping (including fathometers and fish-finders), bottom surveys, orca vocalizations, and ambient background noise appeared most relevant to a greater understanding of the acoustic environment of the Southern Residents.

4.5 Temporal Distribution

A significant increase in acoustic monitoring activity (of both natural and anthropogenic sources) seems apparent beginning in 2003. Additionally, a seasonal bias in acoustic monitoring is apparent, especially between March and October, with the highest concentration of monitoring between May and September, favorably coinciding with Southern Resident habitat residency. It also appears that the monitoring of natural sources increases in the summer months April to October, while anthropogenic monitoring seems relatively constant throughout the year except peaks in March and October and a minimum in September. Ambient monitoring also appears relatively constant with a slight increase between July and October.

This study concurs with the NRC finding that, "Addressing the challenge of both short- and long-term effects of ocean noise on marine mammals is a difficult problem and will require a multidisciplinary effort between biologists and acousticians to establish a rigorous observational, theoretical, and modeling program" (NRC 2003, p. 8). A long-term undersea noise monitoring program is needed within the primary habitat of the

Southern Residents, with particular emphasis on the annual residency season in Puget Sound.

4.6 Technology Systems and Methodologies

4.6.1 Hydrophones

Most identified acoustic monitoring was conducted with a relatively small variety of hydrophones, favorites being the ITC models 4123 and 6050, Cetacean Research Technology models C10, C13, and more recently C54, Reson 4013, Bruel & Kjaer 8104 and 8105, and Spartan Electronics/Magnavox model SSQ-57 LOFAR and SSQ-53 DIFAR Sonobuoys. Other hydrophones were referenced and used less frequently, but Internet research indicates that some of the other manufacturers are no longer in production and some systems are limited in intended use to audio listening or integrated input to dynamic spectrum analyzers (such as the Instantel Series III).

4.6.2 Calibration

Of the 59 studies or datasets, only 30 (51%) definitely utilized calibrated hydrophones. The use or probable use of calibrated hydrophones was highest for government studies and recording efforts, followed by academic, commercial, and then NGOs. Calibrated hydrophones (and ideally calibrated systems from hydrophones to recording device) are necessary to reconstruct actual sound pressure levels in the water at the location of the hydrophone.

4.6.3 Recording Devices

Although 37 of the 59 datasets were recorded digitally, again, unless the systems were calibrated, the recorded digital signals can only be used for relative signal comparisons and NOT actual measurements of sound pressure level. Although the five analog recordings can be subsequently digitally sampled, they can only be used as measures of actual sound pressure levels, if the entire system, including the recording device, is calibrated.

4.6.4 Propagation Path

With the exception of the recent Scripps Institution of Oceanography study and the Haro Strait '96 Frontal Dynamics Primer Experiment, even the other 28 studies and recording efforts that used calibrated hydrophones only measured the acoustic sound pressure level at the hydrophone. Without also determining the propagation path and associated loss mechanisms, it is impossible to reconstruct the actual source level referenced to a distance 1 meter from an idealized point source. It then becomes difficult to accurately evaluate or make model predictions of sound pressure levels as a function of range and direction from the source. Parameters of interest to evaluate the propagation path effects include spherical and cylindrical spreading as a function of water depth and density, refraction as a function of sound velocity, surface and bottom reflection, bottom absorption, volume absorption, reverberation, etc. Vertical linear arrays, which enable beamforming, are particularly useful to determine signal arrival directions, timing and phasing of multiple propagation paths. Without establishing propagation paths, it is difficult to estimate or predict primary propagation loss mechanisms or to extrapolate estimated source levels to range- or depth-dependant sound pressure levels.

Propagation path effects may be modeled using Parabolic Equation, Normal Mode, Wavenumber Integration, and Ray techniques to estimate or predict effects of the ocean environment on noise characteristics. However, approaches to model underwater acoustic propagation represent attempts to simplify the complexities of the real world environment and the acoustic wave equation. Since many underwater acoustic models are based on open-water propagation, and contain critical assumptions regarding the acoustic signal (e.g., many are applicable only below 1 kHz or do not apply to transients), extreme care must be taken when selecting and validating models for the shallow, complex density environment representative of the Southern Resident habitat. Classic spherical and cylindrical spreading, refractive ray tracing, etc., may be wholly inadequate to simulate the rock canyons of Haro Strait, high vertical and horizontal temperature and salinity gradients from freshwater runoff, solar heating, underwater sills, range of water depth, and high variability of planktonic biomass, sediment loading, tidal bore, etc. This conclusion is consistent with NRC's conclusion that, "physics-based approaches that incorporate actual source mechanisms are still in their infancy in underwater acoustics. In contrast, empirical models such as the Knudson curves (Knudsen et al, 1948) and the Wenz curves (Wenz, 1962) have been extremely successful; they remain the basis of standardized noise spectra used by the U.S. and British navies" (NRC 2003, p. 110). In addition, as NRC noted, the conventional approach that utilizes an average pressure spectrum budget is limited in its application to marine mammal conservation since it does not account for both transient events and continuous sources.

4.6.5 Usable Analysis Band

The usable analysis band of the receiving systems (considering hydrophone response, filtering, and digitizing Nyquist frequency) are constrained for the most part (90%) to less than 50 kHz with 65% limited to less than 25 kHz. This appears primarily to be a result of using digital sampling rates of less than 48 kHz designed for human hearing (e.g., DAT tape) which results in a usable analysis frequency less than 24 kHz. Tradeoffs of sample rate for data storage economy, primary purpose of monitoring, technology vintage, and cost of systems, significantly limits usability of available datasets to analyze the higher frequencies (above 25-50 kHz) of the orca hearing frequency range.

Gaps in usable analysis band from identified studies and recording efforts exists as follows:

- Below 100 Hz, with increasing gap as frequencies decrease to 1 Hz
- Above 25 kHz, with increasing gap as frequencies increase to 120 kHz.

4.7 Measured Sound Levels

The spatially and temporally sparse data collected while monitoring for specific sources and ambient noise generally only provided anecdotal evidence of received levels at the hydrophones and was insufficient to establish trends or patterns of contributing sources or generalized ambient noise. The wide range of sources from 90 to 205 dB re 1µPa, reflected the wide range of sources being monitored from vocalizing orcas to pile driving. Since 1) most of these sound pressure levels are the levels measured at the receiving hydrophones and NOT the source levels referenced to 1 meter from an idealized point source, and 2) the propagation path is rarely identified and parameterized or modeled, it is very difficult to analyze or estimate the range dependency of the sound sources. Additionally, the frequency dependency of measured levels was only available for a few of the studies and recording efforts.

Of the four active acoustic transmission monitoring studies or datasets, only transmissions from an echo-sounder would be anticipated to occur rather routinely or ubiquitously. Research studies utilizing sources such as acoustic scintillation, acoustic tomography, or acoustic modem data links would be expected to occur infrequently, in geographically localized positions, and would likely be from a limited number of academic and governmental organizations. However, echo-sounding equipment, including fathometers and fish-finders have source levels in the range of 190 dB re 1 µPa at 1 meter and are widely used on commercial and recreational vessels throughout the habitat range of the Southern Residents.

Ambient levels were also sparse in the available information for this analysis but would be expected to be retrievable before and after specific source recordings. It is important to understand the ambient background noise environment of the Southern Residents since it determines how loud (or, in other words, how close) a source must be before a whale detects the source above the background noise. This applies whether the source is a disturbing anthropogenic source (e.g., shipping) or a natural source (e.g., orca communication or echo return off prey). Since ambient noise is a combination of distant anthropogenic and natural sources, it should correlate to the level of anthropogenic and natural activity in the appropriate frequency bands for those activities. It is reasonable that the level and frequency distribution of anthropogenic contributions to ambient background noise could be roughly correlated to and/or predicted from levels of shipping/boating activity, permitted underwater construction, bottom surveys, etc. Likewise, it is reasonable that the natural contributions to ambient background noise could be roughly correlated to and/or predicted from seasonal or actual sea state, wind speed, precipitation, biologic activity, seismic activity, etc. This conclusion corresponds to NRC's global finding that, "Identifying reliable indicators for anthropogenic sources will provide an additional modeling tool and predictive capability that will be particularly useful in areas where long-term monitoring may be difficult or impossible" (NRC 2003, p.9).

5.0 RECOMMENDATIONS

5.1 General

- Standard methods of data collection to support underwater acoustic habitat characterization should be developed and disseminated to prospective researchers and data collectors. One avenue to accomplish this would be to use acoustic environment characterization datasheets that had blanks to be filled in corresponding to a standardized acoustic metadata data structure.

- Norms for metadata essential to the Southern Resident habitat characterization and/or other purposes should be developed to consistently characterize, categorize, catalog, and summarize underwater acoustic data. This echoes the NRC recommendation, that:

> Existing data on marine noise from anthropogenic sources should be collected, centralized, organized, and analyzed to provide a reference database, to establish the limitations of research to date, and to better understand noise in the ocean. Recommendation: Acoustic signal characteristics of anthropogenic sources (such as frequency content, rise time, pressure and particle velocity time series, zero-to-peak and peak-to-peak amplitude, mean squared amplitude, duration, integral of mean squared amplitude over duration, repetition rate) should be fully reported. For transients, publication of actual acoustic pressure time series would be useful. Particular attention should be paid to the sources that are likely to be the large contributors to ocean noise in particularly significant geographical areas and to sources suspected of having significant impacts on marine life. Each characteristic of noise from anthropogenic sources may differentially impact each species of marine mammals. The complex interactions of sound with marine life are not sufficiently understood to specify which features of the acoustic signal are important for specific impacts. Therefore as many as characteristics as possible should be measured and reported. (NRC 2003, p.7)

5.2 Who

- Increased cooperation and information sharing between the various governmental, academic, commercial, and NGO data collectors should be fostered to develop common objectives and to improve standardization of methods and metadata for broader applicability, especially for characterization of underwater habitat. Avenues to accomplish this might include developing and disseminating standard methods and metadata, linking data collection requirements to funding sponsorship, and acoustic permit requirements.

- Underwater acoustics research for the Southern Residents in Puget Sound should be coordinated and aligned with national and international marine mammal acoustic research and standardization efforts. This is consistent with the NRC recommendation that:

    > A federal agency should be mandated to investigate and monitor marine noise and the possible long-term effects on marine life by serving as a sponsor for research on ocean noise, the effects of noise on marine mammals, and long-term trends in ocean noise. Federal leadership is needed to (1) monitor ocean noise, especially in areas with resident marine mammal populations; (2) collect and analyze existing databases of marine activity; and (3) coordinate research efforts to determine long-term trends in marine noise and the possible consequences for marine life. (NRC 2003, p.7)

5.3 Where

- Underwater acoustics research for the Southern Residents should target the most important Orca habitat first (foraging areas, breeding grounds, and migration paths). This recommendation is consistent with NRC's advice that, "Efforts to measure ocean noise should be targeted toward important marine mammal habitats. As new marine mammal habitats are identified, these should be added to the acoustic surveys in order to provide a complete picture of the acoustic environment in important marine mammal ecosystems" (NRC 2003, p. 129).

- To improve spatial analysis, standardized spatial information should be gathered for all studies that includes sufficient detail to allow accurate analysis, i.e., latitude and longitude.

- The project team recommends development of correlations between localized acoustic indicators and acoustic levels such as shipping density near shipping lanes or higher sea states/wind speeds and ambient noise in predominantly ambient areas.

5.4 Why

- To establish temporal and spatial baselines of the acoustic environment, monitoring should be increased.

- As a basis to conduct depth and range dependent modeling in various propagation conditions, standardized source levels relative to 1 meter from an idealized point source for common sources (ship classes, pile-driving, trenching, fathometers, airguns, etc.) should be established.

5.5 When

- Acoustic research should be prioritized to correspond to the habitat occupancy of the Southern Residents in the Puget Sound (primarily May to September).

5.6 How

- Efforts should be made to encourage data collection in the 1 Hz to 120 kHz Southern Resident hearing range and prioritized between 100 Hz and 25 kHz for analysis in the Southern Resident vocalization range. Additional emphasis however is needed to fill the increasing gap as frequency decreases from 100 to 1 Hz and as frequency increases from 25 kHz to 120 kHz. This is consistent with the Southern Resident's acoustic range and with NRC's more global marine mammals recommendation that, "A long-term ocean noise monitoring program over a broad frequency range (1 Hz to 200kHz) should be initiated" (NRC 2003, p.8).

- Hydrophones should be selected with a relatively flat frequency response (e.g., ±3dB) between 1 Hz and 120 kHz, if possible. If data is digitized, it should be sampled at least twice the desired upper analysis frequency (Nyquist frequency) and anti-aliasing low-pass filtered to block frequencies above the Nyquist frequency. Analog data recorders should have a dynamic range sufficient to accommodate the desired frequency band and fidelity to reproduce the data with low signal to noise ratio. Digital recorders should have data capacity to accommodate the required sample rate and resolution bits sufficient to accommodate measurement precision requirements (e.g., ± dB).

- Full specifications of the entire system including projector, hydrophone, pre-amp, filters, other pre-processing, analog-to-digital converter, data recorder, etc. should be documented in a standardized metadata format.

- Entire data collection systems should be calibrated, preferably using ANSI Standard S1.20-1988 methods to calibrate hydrophones and traceable back to the National Institute of Standards and Technology (NIST) standards to ensure recorded data can be converted to actual sound pressure levels at the hydrophone in dB re 1 μPa (see Appendix G).

- Metadata affecting the propagation path should be collected with acoustic data in order to understand the range- and depth-dependant aspects of the acoustic environment and support modeling. Propagation path metadata includes surface and bottom conditions, sound velocity profiles, spreading and absorption parameters, etc. If propagation paths are adequately described, receiver levels may be translated into source levels and source levels may be translated to range- and depth-dependent sound pressure fields.

- Modeling the Southern Resident acoustic habitat may have limited value until the model parameters and physical/acoustic oceanographic characteristics are better defined by empirical field studies. Any acoustic modeling of the complex marine environment of Puget Sound should be closely scrutinized to ensure model assumptions and methods are appropriate to in situ conditions and properly validated against similar empirical evidence. At the very least, modeling efforts should be closely associated with data and metadata collection efforts to empirically characterize the undersea acoustic environment and perhaps fill gaps as an interim measure by extrapolation of existing data. Any local/regional modeling efforts should be coordinated with national initiatives and follow NRC recommendation that, "as with all models of the physical world, uncertainties in parameters and approximations in the modeling techniques are inevitable and must be accounted for using statistically valid means when interpreting the model predictions" (NRC 2003, p. 109).

- Use of long-term, moored, calibrated acoustic data loggers in key habitat areas should be investigated as a cost-effective alternative to cost-prohibitive ship-based acoustic surveys. Data retrieval could be by periodic physical retrieval, electronic or digital query, or by radio link for real-time access.

- Efforts should be made to coordinate and contribute to NRC's recommended national "long-term ocean noise monitoring program over a broad frequency range (1 Hz to 200kHz)" (NRC 2003, p.8).

5.7 What

- Specific natural contributions to the overall marine noise budget (e.g., marine mammals, other biologics, seismic, and wind/rain surface noise) should be characterized.

- Specific anthropogenic source levels in dB re 1µPa at 1 meter from an idealized point source should be determined. These levels and frequency components could be characterized for specific classes of sources such as shipping types (e.g., tanker, freighter, tug, and trawler), underwater construction (e.g., pile driving and trenching), and sonar (e.g., fish finder, fathometer, and naval).

- Surrogate indicators or predictors in key areas (e.g., shipping densities near designated shipping lanes) should be developed. This is consistent with NRC's recommended, "Research to determine quantitative relationships between levels of anthropogenic activity and noise should be conducted. For example, if there is a robust relationship between vessel type and noise, vessel traffic data could be used to predict shipping noise" (NRC 2003, p. 129). Additionally, "A research program should be instituted to investigate the possible causal relationships between the ambient and identifiable source components of ocean noise and their short- and long-term effects on marine organisms" (NRC 2003, p. 8).

- Standardized measures of source and background sound levels that fully accommodate characterization of both transient and continuous sources should be developed and disseminated.

6.0 SUMMARY

6.1 General

As stated in the introduction, the purpose of this study was to gather and assess available acoustic information and to provide recommendations for filling identified data gaps. In order to assess the current level of knowledge about sources of underwater noise within the habitat range, this study focused on existing data and available information to identify and characterize sources of underwater noise that occur within the habitat range of the Southern Residents. The following general questions are answered based on information from identified studies and recording efforts:

- **Question:** What anthropogenic sources of underwater noise, e.g., shipping vessel traffic, have been identified within the study area? Where are these sources located?
    - **Answer:** Specific sources are described in Section 3.4 and include underwater construction (pile driving and trenching), shipping (commercial, military, fishing, whale-watching, recreational, ferries), seismic surveys, active sonar (fathometer, tomography, current profiler, and data link).
- **Question**: Does sufficient information exist to determine whether the level of underwater noise from anthropogenic sources within the study area has changed over time? If so, what further analysis might determine which anthropogenic sources have most likely contributed to that change and how?
    - **Answer**: Insufficient information was identified to determine any significant multi-year temporal variation or trends in the actual levels of anthropogenic sources within the study area.
- **Question**: Does sufficient information exist to determine if there are seasonal changes in underwater noise within the study area? If so, what further analysis

might determine which anthropogenic sources of underwater noise account for these seasonal changes and how?

  - **Answer:** Insufficient information was identified to determine any significant single year or seasonal variation or patterns in the actual levels of anthropogenic sources within the study area.

- **Question**: What underwater acoustics studies or monitoring efforts have been completed or initiated within the study area? For each study or effort, what information was learned about the underwater acoustics environment that is applicable to conservation of the Southern Residents?

  - **Answer:** The list of identified underwater acoustics studies or monitoring efforts and associated information learned (data and metadata) are fully described in the accompanying database (see Appendix C)

- **Question:** Based on data describing where in Puget Sound the Southern Residents have been observed in the past, is there a relationship between portions of the whales' habitat range and areas of high anthropogenic noise levels? If so, where are those areas? What anthropogenic sounds likely contribute to the noise levels in those areas? Are these areas affected by seasonal variations in noise levels?

  - **Answer:** Insufficient information was identified to determine any significant relationship between portions of the whale's habitat range and areas of high anthropogenic noise levels. It is postulated that seasonal variations in vessel noise (due to increased recreational vessel traffic) do exist near the San Juan Islands, the Southern Residents core summer habitat, though no data are available that support this.

The following subsections summarize previous specific recommendations to establish an initial roadmap for filling identified knowledge gaps that limit an understanding of the Southern Residents undersea acoustic environment. The recommendations attempt to account for ongoing efforts being conducted by multiple researchers such that duplication of efforts is minimized.

6.2 Standardized Data and Metadata

In order to obtain the most value from expensive undersea acoustic data collection efforts, it is important that standard data and data-elements be developed, disseminated, and accepted into common use. The data elements should include data and metadata definitions in a data dictionary to standardize terminology and units of measure. The myriad ways of quantifying acoustic levels (e.g., peak-to-peak, rms, instantaneous, time averaged, frequency dependent, and time-averaged) and the importance of acoustic levels in decision support and policy development warrants particular attention to defining standard useful means to accurately characterize and communicate acoustic levels. Spatial data should be not only standardized but also consistently geo-referenced for compatibility and analysis within geographic information systems (GIS).

A data / metadata structure similar to the one created to store data from this study could serve as an initial prototype that could be further refined to accommodate individual needs for common use. A standardized data / metadata structure would enable the following:

- Provide a comprehensive listing of all useful data and metadata elements pertaining to Southern Residents and more broadly to other marine mammals
- Standardize the definitions and units of measure of acoustic data and metadata elements (a significant need in the acoustic discipline)
- Provide a consistent storage mechanism that would facilitate information sharing and collaboration, especially as data and metadata are stored in common, web-accessible databases
- Enable effective data and metadata queries, especially web-enabled queries

Although all the data / metadata elements may not apply to (or be affordable for) each individual data collection effort, a standardized data structure would still provide consistent, searchable place-holders for collected data, and a de facto communication of the gap between collected and desired data and metadata.

6.3 Optimum Data Collection Equipment and Methods

Undersea acoustic data collection in the habitat of the Southern Residents is being performed by multiple organizations for multiple purposes. These researchers can be expected to continue to design data collection systems and methods specifically to meet the objectives of individual studies. However, it is not unreasonable to expect that if equipment performance specifications, study parameters, standard methods, and best practices were developed and disseminated specifically for Southern Residents and more generally for marine mammals, then data collectors would incorporate them to the maximum extent possible, consistent with their individual study objectives and budgets.

If possible, data collection equipment should have a flat frequency response (i.e., ± 3dB) between 1 Hz and 120 kHz. When this full frequency spectrum cannot be accommodated, the dominant Southern Residents vocalization range between 100 Hz and 25 kHz should be prioritized. In order to preclude introduction of false low frequency aliasing frequency components into the recorded signal, the digitizing sampling rate should be at least twice the highest frequency of interest (e.g., 240 kHz to prevent aliasing below 120 kHz).

Ideally, the entire data collection system should be calibrated using ANSI Standard S1.20-1988, traceable back to NIST standards. When the entire system cannot be calibrated, individual components should be calibrated such that the recorded signal can be reconstructed back to the actual sound pressure levels, again traceable back to NIST standards. Equipment manufacturer technical specifications and actual operating performance specifications for each component of the data collection system should be fully documented.

During data collection, as much information as possible should be collected pertaining to the physical parameters of the propagation path (sound velocity profile, bathymetry, bottom type, bottom absorption coefficients, volume absorption coefficients, sea state or wave height, precipitation, etc). These parameters are important to understanding the range and depth dependent characteristics of sound propagation, especially when attempting to model or estimate the actual source level referenced to 1 meter from an idealized point source. When source levels are known, accurate propagation path information can support modeling estimation of the 3-dimensional range-, depth-, and azimuth-dependent sound field.

6.4 Temporal and Spatial Data Collection Priorities

Data collection should be prioritized to fill both temporal and spatial gaps in the data record. Spatially, data collection efforts should first target the gaps identified above in the most important Southern Residents habitat (foraging, breeding grounds, migration paths, etc). Temporally, data collection efforts should be targeted during the primary habitat occupancy range between May and October.

In general, almost all data collection efforts, even those specifically monitoring defined sources should be able to also record ambient noise levels when the specific source is absent. All data collectors should be encouraged to collect as much background noise as their particular objectives allow, especially the ambient levels preceding and following any particular source monitoring so that the two levels can be compared.

Most data collection efforts represent single or few geographic locations and single or few snapshots in time. The cost of field operations for undersea acoustic data collection, especially from shipboard platforms, limits the spatial and temporal density of available and currently collected data. Alternative approaches to fill the temporal gaps in ambient and specific source noise levels could include deploying long-term, calibrated acoustic data loggers in key habitat areas or statistical methods to estimate temporal means and variances for various types of sound in given areas during various periodic time intervals (e.g., day, week, or month of the year). Similarly, geospatial statistical methods might be able to develop spatial means and variances for areas of relatively homogeneous acoustic levels or properties.

6.5 Acoustic Surrogate Indicators

Another alternative to maintaining a costly long-term empirical field monitoring regimen (extending years and decades) would be to develop correlations between localized acoustic surrogate indicators and actual acoustic levels (e.g., shipping density for shipping sources and wind speed or sea-state for surface noise) for use as proxy values when actual data collection is cost prohibitive.

Contributions to the overall marine noise budget could be generally characterized and parameterized with increasing accuracy as additional data and metadata is collected using standard methods in standardized, sharable format.

Additionally, source levels could be empirically developed, estimated from reverse modeling, obtained from other sources, or a combination of the above (e.g., typical source levels from common shipping types, active sources, and biologics). Source levels should be in dB re 1µPa at one meter from an idealized point source.

These source levels can then be used as the basis for modeling the 3-dimensional sound field if sufficient propagation path information is known or can be reasonably estimated. Acoustic modeling and interpretation of the results of such modeling should be done cautiously, until model parameters, physical and acoustic oceanographic characteristics are better defined by empirical field studies and/or can be accounted for using statistically valid means.

Since even characterization, correlating surrogates, determining source levels, or modeling validation can involve costly field monitoring, efforts should still be prioritized to the gaps within key habitat areas as described above.

6.6 Local, National, and International Coordination

Every effort should be made to foster increased cooperation and information sharing between acoustic data collectors in the habitat of the Southern Residents to develop common objectives and improve standardization. It is also important to coordinate and align Puget Sound acoustic research with national and international standardization efforts to leverage similar objectives and share pertinent information. Federal leadership is needed to maintain awareness and disseminate information so that Northwest researchers can effectively coordinate with and contribute to the national long-term ocean noise monitoring program recommended by the NRC.

7.0 REFERENCES

Bain, David E. 2002. A Model Linking Energetic Effects of Whale Watching to Killer Whale (*Orcinus orca*) Population Dynamics. Friday Harbor, Washington. Friday Harbor Laboratories, University of Washington.

Barton, Allan. 2002. Multipath Tracking and Acoustical Oceanography Measurements in a Stratified Coastal Tidal Channel. Master's Thesis, Georgia Institute of Technology.

Barton, Allan and Daniela DiIorio. 2000. A Maximum Likelihood Estimation Algorithm for Tracking Two Multipaths. Proceedings Acoustical Society of America 139th Meeting May 30-June 3; Atlanta, GA. 15 slides.

Betcher, Chris and Dr. Lee Bodensteiner. 2004. Underwater Decibel Measurements. Report for Pirelli High Voltage Systems Submarine Group.

BioSonics, Inc. 2001. Acoustic and Video Measurements of Fish Passage in the Hiram M. Chittenden Locks: A Year 2000 Focus on the Salt Water Drain and Spill Bay #2. Seattle, Washington. Environmental Division, Seattle Water District, US Army Corps of Engineers.

Chapman, N.R., L. Jaschke, M.A. McDonald, H. Schmidt, M. Johnson. 1997. Matched Field Geoacoustic Tomography Experiments Using Light Bulb Sound Sources in the Haro Strait Sea Trial. Ocean Acoustics team of the Office of Naval Research Grant N00014-96-1-0721: 763-768.

Demko, Joe. 2005. Email from Joe Demko at Keyport, to Chuck Tilly at *CTC*.

Erbe, C. 2002. Underwater noise of whale-watching boats and potential effects on killer whales (*Orcinus orca*), based on an acoustic impact model. Marine Mammal Sciences Vol. 18, No. 2: 394-418.

Hildebrand, John. 2004. Haro Strait Noise Data Collection: Final Report for WASC-3-962. Scripps Institution of Oceanography, University of California San Diego.

Iorio, D.D. and A.D. Barton. 2003. Path-averaged ocean measurements in the deep, stratified tidal channel of Hood Canal using acoustical scintillation. Journal of Geophysical research, Vol.108, No. C10: 3312.

Miner, Robert F. 2004. Underwater Sound Level Measurements July 29-Sept. 29, 2004. Naval Submarine Base Bangor, Silverdale, Washington.

Mintz, Jonathon and Ronald Filadelfo. ND. Estimating Vessel Traffic in Areas of Interest. Center for Naval Analysis. 15 slides.

Mintz, Jonathon and Ronald Filadelfo. 2004. Estimates of Navy Ship Traffic in Puget Sound and Adjacent Coastal Waters. Center for Naval Analysis. 14 slides.

National Marine Fisheries Service. March 2005. Preliminary Draft Conservation Plan for Southern Resident Killer Whales (*Orcinus orca*). NOAA. Seattle, Washington.

NOAA. April 22, 2004. Southern Resident Killer Whale Research Plan Workshop Summary Report. NOAA Seattle, Washington.

NRC, Committee on Potential Impacts of Ambient Noise in the Ocean on Marine Mammals. 2003. Ocean Noise and Marine Mammals. The National Academies Press. Washington, D.C.

Nystuen, Jeffrey and Barry Ma. 2005. Using Ambient Sound to Passively Monitor Sea Surface Processes. http://staff.washington.edu/Jan4/porsec_c.htm. 9 pages.

Pentec Environmental. 2003. Mukilteo Public Access Dock Pile Driving – Air Bubble Curtain and Acoustic Monitoring, Mukilteo, Washington. Port of Everett. 102 pages.

Pignot, Patrick and N. Ross Chapman. 2001. Tomographic inversion of geoacoustic properties in a range-dependent shallow-water environment. J. Acoustical Society Am. 110(3) Pt. 1. 1338-1349.

Schmidt, Henrik. 1997. Haro Strait '96 Frontal Dynamics Primer Experiment June 3-July 5, 1996. Summary and Cruise Reports. Massachusetts Institute of Technology, Cambridge, Massachusetts. 67 pages.

University of Georgia, Dept. of Marine Sciences [Internet]. Physical and Acoustical Oceanography at UGA – Hood Canal, Puget Sound, WA [cited 2005 July 7]. Available from: http://alpha.marsci.uga.edu

Wiggins, Sean. OCNMS Preliminary Results – Spectra and descriptive text. 7 slides. Email Sue Moore to Lisa Moss May 12, 2005.

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APPENDICES

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Appendix A

Typical Email Message Sent to Contacts

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Dear ___________,

This email is sent to request your assistance for an effort being undertaken by the National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (Fisheries) to characterize the underwater acoustic environment to which Orcas are exposed in Puget Sound; Georgia Basin; and marine coastal waters of Oregon, Washington, and British Columbia. Concurrent Technologies Corporation (*CTC*) is assisting NOAA Fisheries with this effort by attempting to identify, and later perhaps obtain, recordings and other processed data of ambient (natural) and anthropogenic (manmade) sound (e.g., vessel noise).

At this time, we are contacting persons and organizations that may reasonably be expected to have acoustics data for the study area or have knowledge of who may have such information. You have been identified as one such person.

We hope you will agree to help us with this data identification effort. Please let me know if you are aware of or are able to share any recordings of ambient or anthropogenic sound in the water or other processed noise data that may support NOAA Fisheries efforts within the study area (Puget Sound; Georgia Basin; and marine coastal waters of Oregon, Washington, and British Columbia). Data collected outside that area that may be indicative of the acoustic habitat in the study area are also of interest. If you know of someone working in this field who may be able to assist NOAA Fisheries and *CTC* in this effort, it would be helpful if you would provide that person's name and contact information.

Thank you for your assistance with this effort. If you have any questions, please contact me directly at ____________.

Sincerely,

[Signature]

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Appendix B

Boolean Search Terms

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Boolean Search Terms

acoustical	acoustical oceanography
acoustics	air gun
ambient	anthropogenic
array	audiograph
boat	British Columbia
coast	commercial
dredge	dredging
earthquake	Georgia Basin
Haro Strait	hydrophone
mammal	marine
noise	Oregon
Pacific Ocean	physical oceanography
pile	pile driving
Puget Sound	record
recording	recreational
sea	ship
shipping	sound
Strait of Juan de Fuca	tectonic
test	tomography
transducer	under water
underwater	vessel
vessel classification	vessel type
Washington	water

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Appendix C

Underwater Acoustic Datasets and Study Reports

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ORGANIZATION NAME	AUTHOR	INFORMATION SOURCE	DATASET NAME	PURPOSE	START DATE	END DATE	LOCATION DESCRIPTION	LATITUDE	LONGITUDE
American Cetacean Society Puget Sound Chapter	Ann Stateler and Joe Olson	Ann Stateler and Joe Olson	Vashon Hydrophone -1	Collect data on behalf of the American Cetacean Society Puget Sound Chapter	01-Jan-05	01-Aug-05	Colvos Passage off the west side of Vashon Island	47.4545	-122.5124
American Cetacean Society Puget Sound Chapter	Ann Stateler and Joe Olson	Ann Stateler and Joe Olson	Vashon Hydrophone -2	Collect data on behalf of the American Cetacean Society Puget Sound Chapter	01-Jan-05	01-Aug-05	Colvos Passage off the west side of Vashon Island	47.4545	-122.5124
Applied Physics Laboratory, University of Washington	Dr. Jeffrey A Nystuen	Dr. Jeffrey A Nystuen, University of Washington, Applied Physics Laboratory	Puget Sound Passive Aquatic Listeners (PAL) Studies -1	Passive acoustic sampling of the underwater environment. The data are interpreted for 1) rainfall measurement, 2) wind speed, 3) ship detections and 4) whale detection. Overall sound budgets (levels, frequencies, sources) are produced.	15-Mar-02	28-Mar-02	Admiralty Straits, shipping channel, northern Puget Sound	48.0000	-122.7200
Applied Physics Laboratory, University of Washington	Dr. Jeffrey A Nystuen	Dr. Jeffrey A Nystuen, University of Washington, Applied Physics Laboratory	Puget Sound Passive Aquatic Listeners (PAL) Studies -2	Passive acoustic sampling of the underwater environment. The data are interpreted for 1) rainfall measurement, 2) wind speed, 3) ship detections and 4) whale detection. Overall sound budgets (levels, frequencies, sources) are produced.	25-Mar-02	14-May-03	Carr Inlet, southern Puget Sound	47.2780	-122.7200

ORGANIZATION NAME	AUTHOR	INFORMATION SOURCE	DATASET NAME	PURPOSE	START DATE	END DATE	LOCATION DESCRIPTION	LATITUDE	LONGITUDE
Applied Physics Laboratory, University of Washington	Dr. Jeffrey A Nystuen	Dr. Jeffrey A Nystuen, University of Washington, Applied Physics Laboratory	Puget Sound Passive Aquatic Listeners (PAL) Studies -3	Passive acoustic sampling of the underwater environment. The data are interpreted for 1) rainfall measurement, 2) wind speed, 3) ship detections and 4) whale detection. Overall sound budgets (levels, frequencies, sources) are produced.	27-May-04	07-Jul-04	HARP mooring, Haro Strait, near San Juan Island	48.5031	-123.1482
Applied Physics Laboratory, University of Washington	Dr. Jeffrey A Nystuen	Dr. Jeffrey A Nystuen, University of Washington, Applied Physics Laboratory	Puget Sound Passive Aquatic Listeners (PAL) Studies -4	Passive acoustic sampling of the underwater environment. The data are interpreted for 1) rainfall measurement, 2) wind speed, 3) ship detections and 4) whale detection. Overall sound budgets (levels, frequencies, sources) are produced.	08-Apr-05	01-Jul-05	Cape Flattery (outside of mouth of Juan de Fuca Strait)	48.3334	-124.8263
Applied Physics Laboratory, University of Washington	Dr. Jeffrey A Nystuen	Dr. Jeffrey A Nystuen, University of Washington, Applied Physics Laboratory	Puget Sound Passive Aquatic Listeners (PAL) Studies -5	Passive acoustic sampling of the underwater environment. The data are interpreted for 1) rainfall measurement, 2) wind speed, 3) ship detections and 4) whale detection. Overall sound budgets (levels, frequencies, sources) are produced.	08-Apr-05	01-Jul-05	Cape Flattery (outside of mouth of Juan de Fuca Strait)	48.3334	-125.1149

ORGANIZATION NAME	AUTHOR	INFORMATION SOURCE	DATASET NAME	PURPOSE	START DATE	END DATE	LOCATION DESCRIPTION	LATITUDE	LONGITUDE
Applied Physics Laboratory, University of Washington	Dr. Jeffrey A Nystuen	Dr. Jeffrey A Nystuen, University of Washington, Applied Physics Laboratory	Puget Sound Passive Aquatic Listeners (PAL) Studies -6	Passive acoustic sampling of the underwater environment. The data are interpreted for 1) rainfall measurement, 2) wind speed, 3) ship detections and 4) whale detection. Overall sound budgets (levels, frequencies, sources) are produced.	15-May-05	01-Aug-05	Haro Strait (near San Juan Island)	48.5069	-123.1454
BioSonics, Inc.	Dr. John Horne	BioSonics, Inc.	BioSonics Demonstration	Training cruise demonstrating capabilities of BioSonics DT-X digital scientific echosounder systems	31-Jul-03	01-Aug-03	Orcas Island, WA		
Center for Naval Analysis	Jonathan Mintz	Center for Naval Analysis	Estimating Vessel Traffic in Areas of Interest	Estimate vessel traffic			Coastal areas of Washington, Oregon, and California		
CLE Engineering, Inc.	Carlos Pena	CLE Engineering, Inc.	Hydroacoustic Monitoring During Pile Driving by CLE Engineering, Inc. -1	Satisfy permit requirement associated with repair activities to the Harbor West Condominiums following the February 28, 2001 Nisqually Earthquake	23-Mar-05	23-Mar-05	3717 Beach Drive SW, Seattle, WA	47.5758	-122.4191
CLE Engineering, Inc.	Carlos Pena	CLE Engineering, Inc.	Hydroacoustic Monitoring During Pile Driving by CLE Engineering, Inc. -2	Satisfy permit requirement associated with repair activities to the Harbor West Condominiums following the February 28, 2001 Nisqually Earthquake	23-Mar-05	23-Mar-05	3717 Beach Drive SW, Seattle, WA	47.5758	-122.4191
Colorado College	Dr. Val Veirs	Dr. Val Veirs	Orca Vocalization and Localization	Record orca vocalizations and background underwater noise measurements	01-Jan-00	01-Aug-05	West side of San Juan Island	48.5589	-123.1751
Cornell University	Christopher Clark	Christopher Clark	Cornell University - Puget Sound						

ORGANIZATION NAME	AUTHOR	INFORMATION SOURCE	DATASET NAME	PURPOSE	START DATE	END DATE	LOCATION DESCRIPTION	LATITUDE	LONGITUDE
Department of Marine Sciences, University of Georgia	Daniela D. Di Iorio and Alan Dodd Barton	Journal of Geophysical Research, Vol. 108, No. C10, 3312, doi:10.1029/2003JC001796, 2003	Path-averaged ocean measurements in the deep, stratified tidal channel of Hood Canal using acoustical scintillation	To test the application of acoustical scintillation measurement techniques for currents and refractive index fluctuations in a long-range, tidally forced, stratified coastal channel	19-Oct-93	23-Oct-93	Northern entrance to Hood Canal, Puget Sound, WA	47.9199	-122.6342
Fisheries & Oceans Canada, Institute of Ocean Sciences	Christine Erbe	Marine Mammal Science, 18 (2): 394-418, April 2002	Underwater Noise Of Whale-Watching Boats and Potential Effects on Killer Whales (*Orcinus orca*), Based on an Acoustic Impact Model – 1	To estimate zones around whale-watching boats where boat noise was audible to killer whales, interfered with their communication, caused behavioral avoidance, and potentially caused hearing loss.	01-Jun-99	04-Jun-99	Victoria Harbor near Brotchie Ledge	48.4129	-123.3991
Fisheries & Oceans Canada, Institute of Ocean Sciences	Christine Erbe	Marine Mammal Science, 18 (2): 394-418, April 2003	Underwater Noise Of Whale-Watching Boats and Potential Effects on Killer Whales (*Orcinus orca*), Based on an Acoustic Impact Model – 2	To estimate zones around whale-watching boats where boat noise was audible to killer whales, interfered with their communication, caused behavioral avoidance, and potentially caused hearing loss.	08-Jun-99	10-Jun-99	Haro Strait along the west coast of San Juan Island	48.4659	-123.0552
Fisheries & Oceans Canada, Institute of Ocean Sciences	Christine Erbe	Marine Mammal Science, 18 (2): 394-418, April 2004	Underwater Noise Of Whale-Watching Boats and Potential Effects on Killer Whales (*Orcinus orca*), Based on an Acoustic Impact Model – 3	To estimate zones around whale-watching boats where boat noise was audible to killer whales, interfered with their communication, caused behavioral avoidance, and potentially caused hearing loss.	30-Aug-99	30-Aug-99	Haro Strait along the west coast of San Juan Island	48.4659	-123.0552
Fisheries and Oceans Canada, Conservation Biology Section	John Ford	John Ford, Fisheries and Oceans Canada, Conservation Biology Section	Fisheries and Oceans Canada	Various scientific purposes, primarily to record killer whale vocalizations	01-Jan-78	01-Dec-04	Coast of British Columbia		

ORGANIZATION NAME	AUTHOR	INFORMATION SOURCE	DATASET NAME	PURPOSE	START DATE	END DATE	LOCATION DESCRIPTION	LATITUDE	LONGITUDE
Jen-Jay Diving, Inc.	Chris Betcher and Dr. Leo Bodensteiner	Jen-Jay Diving, Inc.	Pirelli Underwater Cable Trencher Monitoring	Monitor underwater cable trencher operations	02-Oct-04	02-Oct-04	Gedney Island by Everett Washington	48.0143	-122.3319
Naval Undersea Warfare Center (NUWC) Keyport	Joseph R. Demko	Joseph R. Demko	Naval Undersea Warfare Center (NUWC) Keyport - 1	Analyze ambient noise levels	01-Aug-94	01-Oct-94	Jervis Inlet (just off the Strait of Georgia)		
Naval Undersea Warfare Center (NUWC) Keyport	Joseph R. Demko	Joseph R. Demko	Naval Undersea Warfare Center (NUWC) Keyport - 2	Analyze ambient noise levels	01-Jan-82	01-Jan-85	Nanoose		
Naval Undersea Warfare Center (NUWC) Keyport	Joseph R. Demko	Joseph R. Demko	Naval Undersea Warfare Center (NUWC) Keyport - 3	Analyze ambient noise levels	01-Jan-94	01-Nov-95	Dabob Bay		
NOAA - Seattle	Sue Moore	Emails dated 5/6/05 and 5/12/05 from Sue Moore and Joint Institute for Marine Observations	Olympic Coast National Marine Sanctuary (OCNMS) (Quinault Range) Mooring High-Frequency Acoustic Recording Package (HARP) -1	Construct and deploy high-frequency acoustic recording packages (HARPs) offshore from Washington to augment and extend the acoustic/oceanographic data series in that area.	09-Jul-04	07-Oct-04	Olympic Coast National Marine Sanctuary (OCNMS) (Quinault Range)	47.3633	-124.7564
NOAA - Seattle	Sue Moore	Emails dated 5/6/05 and 5/12/05 from Sue Moore and Joint Institute for Marine Observations	Olympic Coast National Marine Sanctuary (OCNMS) (Quinault Range) Mooring High-Frequency Acoustic Recording Package (HARP) -2	Construct and deploy high-frequency acoustic recording packages (HARPs) offshore from Washington to augment and extend the acoustic/oceanographic data series in that area.	09-Jul-04	07-Oct-04	Olympic Coast National Marine Sanctuary (OCNMS) (Quinault Range)	47.4482	-125.1384

ORGANIZATION NAME	AUTHOR	INFORMATION SOURCE	DATASET NAME	PURPOSE	START DATE	END DATE	LOCATION DESCRIPTION	LATITUDE	LONGITUDE
NOAA - Seattle	Dr. Robert Dziak	NOAA	VENTS Program Data and Navy Sound Surveillance System (SOSUS)	Monitoring low-level seismicity on the Juan de Fuca Ridge in the Northeast Pacific	28-Aug-91	01-Aug-05	Worldwide including coastal Oregon, Washington, and California, see website: http://www.pmel.noaa.gov/vents/acoustics/haru_locations.html		
Northwest Fisheries Science Center	Blake E. Feist, James J. Anderson, Robert Miyamoto	University of Washington	Potential Impacts of Pile Driving on Juvenile Pink (*Oncorhynchus gorbuscha*) and Chum (*O. keta*) Salmon Behavior and Distribution -1	To assess the potential effects of pile driving activities on the behavior and distributions of schools of juvenile pink (*O. gorbuscha*) and chum (*O. keta*) salmon.	24-Mar-90	15-Jun-90	Everett		
Northwest Fisheries Science Center	Blake E. Feist, James J. Anderson, Robert Miyamoto	University of Washington	Potential Impacts of Pile Driving on Juvenile Pink (*Oncorhynchus gorbuscha*) and Chum (*O. keta*) Salmon Behavior and Distribution -2	To assess the potential effects of pile driving activities on the behavior and distributions of schools of juvenile pink (*O. gorbuscha*) and chum (*O. keta*) salmon.	09-Apr-90	01-Jun-90	Elliott Bay Marina west of Pier 91, below eastern end of Magnolia Bluff		
Northwest Fisheries Science Center	Blake E. Feist, James J. Anderson, Robert Miyamoto	University of Washington	Potential Impacts of Pile Driving on Juvenile Pink (*Oncorhynchus gorbuscha*) and Chum (*O. keta*) Salmon Behavior and Distribution -3	To assess the potential effects of pile driving activities on the behavior and distributions of schools of juvenile pink (*O. gorbuscha*) and chum (*O. keta*) salmon.	09-Apr-90	01-Jun-90	Bremerton Ferry Terminal, Washington State Department of Transportation passenger-only terminal adjacent to and northeast of large ferry terminal		

ORGANIZATION NAME	AUTHOR	INFORMATION SOURCE	DATASET NAME	PURPOSE	START DATE	END DATE	LOCATION DESCRIPTION	LATITUDE	LONGITUDE
Northwest Fisheries Science Center	Blake E. Feist, James J. Anderson, Robert Miyamoto	University of Washington	Potential Impacts of Pile Driving on Juvenile Pink (*Oncorhynchus gorbuscha*) and Chum (*O. keta*) Salmon Behavior and Distribution -4	To assess the potential effects of pile driving activities on the behavior and distributions of schools of juvenile pink (*O. gorbuscha*) and chum (*O. keta*) salmon.	09-Apr-90	01-Jun-90	Kingston Ferry Terminal		
Pacific Orca Society/OrcaLab	Paul Spong	Paul Spong	Pacific Orca Society/OrcaLab	Collect killer whale vocalizations	01-Jan-70	01-Aug-05	Johnstone Strait area, northern Vancouver Island		
Pentec Environmental, Hart Crowser, Inc	Jonathan P. Houghton Ph.D.; Jim Starkes	Port of Everett	Mukilteo Public Access Dock Pile Driving - Air Bubble Curtain and Acoustic Monitoring Mukilteo, Washington -1	Measure and record the sound frequencies generated by the impact hammer with the bubble curtain activated and deactivated at two locations, measure and record sound pressure changes generated by the impact hammer with the bubble curtain activated and deactivated	07-Mar-03	10-Mar-03	Mukilteo Public Access Dock near the Mulkilteo Ferry Terminal		
Pentec Environmental, Hart Crowser, Inc	Jonathan P. Houghton Ph.D.; Jim Starkes	Port of Everett	Mukilteo Public Access Dock Pile Driving - Air Bubble Curtain and Acoustic Monitoring Mukilteo, Washington -2	Measure and record the sound frequencies generated by the impact hammer with the bubble curtain activated and deactivated at two locations, measure and record sound pressure changes generated by the impact hammer with the bubble curtain activated and deactivated	07-Mar-03	10-Mar-03	Mukilteo Public Access Dock near the Mulkilteo Ferry Terminal		

ORGANIZATION NAME	AUTHOR	INFORMATION SOURCE	DATASET NAME	PURPOSE	START DATE	END DATE	LOCATION DESCRIPTION	LATITUDE	LONGITUDE
Raincoast Conservation Society	Rob Williams	Rob Williams	North Pacific Universities Marine Mammal Research Consortium	Monitor marine mammals	01-Jul-98	01-Aug-98	Land-based observation site on the south shore of West Cracroft Island in Johnstone Strait, British Columbia	50.5000	-126.5000
School of Earth and Ocean Sciences, University of Victoria	Henrik Schmidt; Patrick Pignot and N. Ross Chapman, N.R. Chapman, L. Jaschke, M.A. McDonald, H. Schmidt, M. Johnson	Patrick Miller; Journal of Acoustical Society of America, Vol. 110, No. 3, Pt. 1, Sep. 2001	Haro Strait '96 Frontal Dynamics PRIMER Experiment June 3 - July 5, 1996 Summary and associated articles	Demonstrate a new, vertically and horizontally integrated concept for real-time assessment of highly dynamic, multi-scale coastal processes. Estimate the geoacoustic properties of the ocean bottom over a large area in shallow water.	03-Jun-96	05-Jul-96	Haro Strait, south of Stuart Island, west and northwest of San Juan Island	48.6500	-123.2000
Scripps Institution of Oceanography, University of California	John Hildebrand	Scripps Institution of Oceanography, University of California San Diego	Haro Strait Noise Data Collection - SSQ53D	Conduct a survey of environmental noise in the Haro Strait region at different depths using a calibrated vertical hydrophone array. Measure and calculate the frequency and depth dependent propagation curves from standardized sources.	11-Oct-03	31-May-04	West side of San Juan Island, near Limekiln Lighthouse in Haro Strait	48.5000	-123.1667
Scripps Institution of Oceanography, University of California	John Hildebrand	Scripps Institution of Oceanography, University of California San Diego	Haro Strait Noise Data Collection - SSQ57B	Conduct a survey of environmental noise in the Haro Strait region at different depths using a calibrated vertical hydrophone array. Measure and calculate the frequency and depth dependent propagation curves from standardized sources.	11-Oct-03	31-May-04	West side of San Juan Island, near Limekiln Lighthouse in Haro Strait	48.5000	-123.1667

ORGANIZATION NAME	AUTHOR	INFORMATION SOURCE	DATASET NAME	PURPOSE	START DATE	END DATE	LOCATION DESCRIPTION	LATITUDE	LONGITUDE
Scripps Institution of Oceanography, University of California	John Hildebrand	Scripps Institution of Oceanography, University of California San Diego	Haro Strait Noise Data Collection - Ultrasoundgate	Conduct a survey of environmental noise in the Haro Strait region at different depths using a calibrated vertical hydrophone array. Measure and calculate the frequency and depth dependent propagation curves from standardized sources.	11-Oct-03	31-May-04	West side of San Juan Island, near Limekiln Lighthouse in Haro Strait	48.5000	-123.1667
Scripps Institution of Oceanography, University of California	John Hildebrand	Scripps Institution of Oceanography, University of California San Diego	Haro Strait Noise Data Collection - Vertical Array	Conduct a survey of environmental noise in the Haro Strait region at different depths using a calibrated vertical hydrophone array. Measure and calculate the frequency and depth dependent propagation curves from standardized sources.	11-Oct-03	31-May-04	West side of San Juan Island, near Limekiln Lighthouse in Haro Strait	48.5000	-123.1667
Sea Mammal Research Unit, University of St. Andrews	Patrick Miller	Patrick Miller, University of St. Andrews	Patrick Miller PhD Thesis	Scientific research of killer whale vocalizations	01-Jan-98	01-Dec-99	Johnstone Strait	50.4975	-126.3769
The Whale Museum	Rich Osborne	Rich Osborne	The Whale Museum						
University of British Columbia (UBC)	Volker Deecke	Volker Deecke, University of British Columbia (UBC)	Opportunistic Recordings of Orcas -1	Study of call structure in resident killer whales	01-Jan-94	01-Aug-05	Coastal waters from southern British Columbia to Southeast Alaska, mainly Johnstone and Queen Charlotte Straits		

ORGANIZATION NAME	AUTHOR	INFORMATION SOURCE	DATASET NAME	PURPOSE	START DATE	END DATE	LOCATION DESCRIPTION	LATITUDE	LONGITUDE
University of British Columbia (UBC)	Volker Deecke	Volker Deecke, University of British Columbia (UBC)	Opportunistic Recordings of Orcas -2	Study of call structure in resident killer whales	01-Jan-94	01-Aug-05	Coastal waters from southern British Columbia to Southeast Alaska, mainly Johnstone and Queen Charlotte Straits		
University of British Columbia (UBC)	Volker Deecke	Volker Deecke, University of British Columbia (UBC)	Systematic Recordings of Transient Orcas -1	Study of frequency of occurrence of vocal behavior in transient killer whales	01-Jan-99	01-Aug-05	Coastal waters from central British Columbia to Southeast Alaska, mainly Johnstone and Queen Charlotte Strait, as well as Glacier Bay, Icy Strait, and Stephens Passage		
University of British Columbia (UBC)	Volker Deecke	Volker Deecke, University of British Columbia (UBC)	Systematic Recordings of Transient Orcas -2	Study of frequency of occurrence of vocal behavior in transient killer whales	01-Jan-99	01-Aug-05	Coastal waters from central British Columbia to Southeast Alaska, mainly Johnstone and Queen Charlotte Strait, as well as Glacier Bay, Icy Strait, and Stephens Passage		
University of Washington	David Bain	David Bain	Washington Sea Grant Program Funded Researchers, University of Washington -1	Whale vocalizations; Numerous recordings of baseline and airgun measurements, generally in support of USGS activities	01-Jan-81	01-Jan-05	Johnstone Strait, BC; Central Coast of BC; Puget Sound; Haro Strait; Juan de Fuca Strait; Georgia Strait; Hood Canal		

ORGANIZATION NAME	AUTHOR	INFORMATION SOURCE	DATASET NAME	PURPOSE	START DATE	END DATE	LOCATION DESCRIPTION	LATITUDE	LONGITUDE
University of Washington	David Bain	David Bain	Washington Sea Grant Program Funded Researchers, University of Washington -2	Whale vocalizations; Numerous recordings of baseline and airgun measurements, generally in support of USGS activities	01-Jan-81	01-Jan-05	Johnstone Strait, BC; Central Coast of BC; Puget Sound; Haro Strait; Juan de Fuca Strait; Georgia Strait; Hood Canal		
University of Washington	David Bain	David Bain	Washington Sea Grant Program Funded Researchers, University of Washington -3	Whale vocalizations; Numerous recordings of baseline and airgun measurements, generally in support of USGS activities	01-Jan-81	01-Jan-05	Johnstone Strait, BC; Central Coast of BC; Puget Sound; Haro Strait; Juan de Fuca Strait; Georgia Strait; Hood Canal		
University of Washington	David Bain	David Bain	Washington Sea Grant Program Funded Researchers, University of Washington -4	Whale vocalizations; Numerous recordings of baseline and airgun measurements, generally in support of USGS activities	01-Jan-81	01-Jan-05	Johnstone Strait, BC; Central Coast of BC; Puget Sound; Haro Strait; Juan de Fuca Strait; Georgia Strait; Hood Canal		
University of Washington	David Bain	David Bain	Washington Sea Grant Program Funded Researchers, University of Washington -5	Whale vocalizations; Numerous recordings of baseline and airgun measurements, generally in support of USGS activities	01-Jan-81	01-Jan-05	Johnstone Strait, BC; Central Coast of BC; Puget Sound; Haro Strait; Juan de Fuca Strait; Georgia Strait; Hood Canal		
University of Washington	David Bain	David Bain	Washington Sea Grant Program Funded Researchers, University of Washington -6	Whale vocalizations; Numerous recordings of baseline and airgun measurements, generally in support of USGS activities	01-Jan-81	01-Jan-05	Johnstone Strait, BC; Central Coast of BC; Puget Sound; Haro Strait; Juan de Fuca Strait; Georgia Strait; Hood Canal		

ORGANIZATION NAME	AUTHOR	INFORMATION SOURCE	DATASET NAME	PURPOSE	START DATE	END DATE	LOCATION DESCRIPTION	LATITUDE	LONGITUDE
University of Washington	David Bain	David Bain	Washington Sea Grant Program Funded Researchers, University of Washington -7	Whale vocalizations; Numerous recordings of baseline and airgun measurements, generally in support of USGS activities	01-Jan-81	01-Jan-05	Johnstone Strait, BC; Central Coast of BC; Puget Sound; Haro Strait; Juan de Fuca Strait; Georgia Strait; Hood Canal		
Washington State Department of Transportation	Jim Laughlin	Washington State Department of Transportation	Friday Harbor Ferry Terminal Restoration Project	Monitor pile driving activities	24-Jul-04	01-Mar-05	Friday Harbor Ferry Terminal		

Appendix D

Acoustic Reference Model

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In order to characterize the various data and information collection technologies used and the various source parameters, propagation path effects, ambient background noise, and receiver parameters, an overall standard acoustic reference model was hypothesized that follows the standard parameters of the general sonar equation where:

- The sound pressure level excess (SE) above a detection threshold equals the originating source level (SL)
- Minus transmission losses (TL) due to sound propagation through the water
- Minus the ambient background noise level (NL)
- Plus the directivity index of the receiver minus (DI)
- Minus the detection threshold of the receiver (DT)

In standard notation, the sonar equation is SL – TL – NL + DI – DT = SE and is described further in the subsequent paragraphs.

Source Level: The source level is measured in decibels (dB) relative to 1 µPa at 1 meter from an idealized point source. The source level is a function of frequency and emanates from the source at a particular depth and either as an omni-directional spherical pressure wave or with some vertical and horizontal directivity. The source level, frequency, directivity, and depth may be constant or vary over time. For sources that cycle on and off, the duration expresses the length of time that the source emanates energy and the duty cycle expresses the percent of time the source emanates sound energy.

Transmission Loss: The transmission or propagation loss is the reduction in sound pressure level as the sound travels from the source to the receiver along the propagation path, which is a vector normal to the front of the expanding pressure wave. As a hypothesized spherical pressure wave expands from the assumed point source, the same amount of sound energy is distributed across an expanding spherical surface (spherical spreading) so the sound pressure level is reduced as the reciprocal of the surface area of a sphere (in other words, proportional to $1/\text{range}^3$). As the theoretically uniform sphere expands to reach the surface and bottom of the water column, the expanding sound pressure wave resembles an expanding cylinder (cylindrical spreading) and the sound pressure level is reduced as the reciprocal of the area of the cylinder (that is proportional to $1/\text{range}^2$). In practice, the expanding pressure wave is rarely perfectly cylindrical or spherical but rather is refracted toward higher sound velocity (corresponding to higher temperature, salinity, or pressure). As the energy propagates through the water along the surface of the expanding pressure wave, some energy is transferred to the water volume by absorption due to molecular vibration. Absorption loss is a function of an empirically determined absorption constant times the propagation distance (range). Some sound energy is absorbed into the bottom each time the pressure wave interacts with the bottom. Sound energy is also reflected in various directions from both the surface and bottom, as well as, reflectively scattered from various suspended particulate matter in the water.

Noise Level: The noise level is the sound pressure level of ambient background noise not attributable to the source of interest. It may be omni-directional or may vary based on direction. Sources of ambient background noise may be a combination of natural and anthropogenic sound such as seismic, shipping, wind/wave noise, rain, biologic, thermal, industrial, sonar, etc.

Detection Threshold: The detection threshold is the sound pressure level above which a detector system can just detect the presence of the sound. For biologic hearing systems, the detection threshold varies with parameters such as frequency, species, and history of exposure. For electro-mechanical systems (hydrophones/electronics), the detection threshold varies with system frequency response, sensitivity, signal processing, etc.

Basic Physics of Sound: The model defines underwater sound according to basic physics of a vibrating force (wind, propeller, sonar, pile driver, etc.) acting on an elastic medium (water) and the sound energy traveling as a compression/expansion (pressure) wave moving through the water. The underwater sound is detected when the wave impinges on a receiving device (hydrophone, ear, etc.) causing sufficient mechanical vibration amplitude to be detected by a detector (electronics, software processing, nervous system, etc.) above the ambient background noise. The pressure amplitude change from equilibrium hydrostatic pressure (due to water depth) is measured in Pascals, but the range is so large, it is typically expressed in decibels (dB) relative to 1 micro-Pascal (µPa). The sound velocity (c) is dependent on density, which in turn is primarily dependant on temperature, pressure, and salinity. A sound velocity profile over the water depth provides a means to predict refraction of the sound energy as it travels outward from the source in accordance with Snell's Law. The rate of pressure fluctuations about the equilibrium (or in other words the rate of oscillation of the sound energy) is referred to as the sound frequency and is measured in Hertz (Hz). Sound signals of interest are often composed of multiple frequency components. Fourier analysis of sound energy signals enables decomposition of a complex signal into its discrete frequency components. The wavelength of a periodic (single frequency) sound is the physical distance between similar points of a repeating (cyclic) signal waveform. Wavelength, sound velocity, and frequency are related by the following formula:

Wavelength = Sound Velocity / Frequency

Receiving System Model: In order to characterize the acoustic receiving system, a typical receiving system reference model was hypothesized as depicted in Figure 14 and described in the subsequent paragraphs.

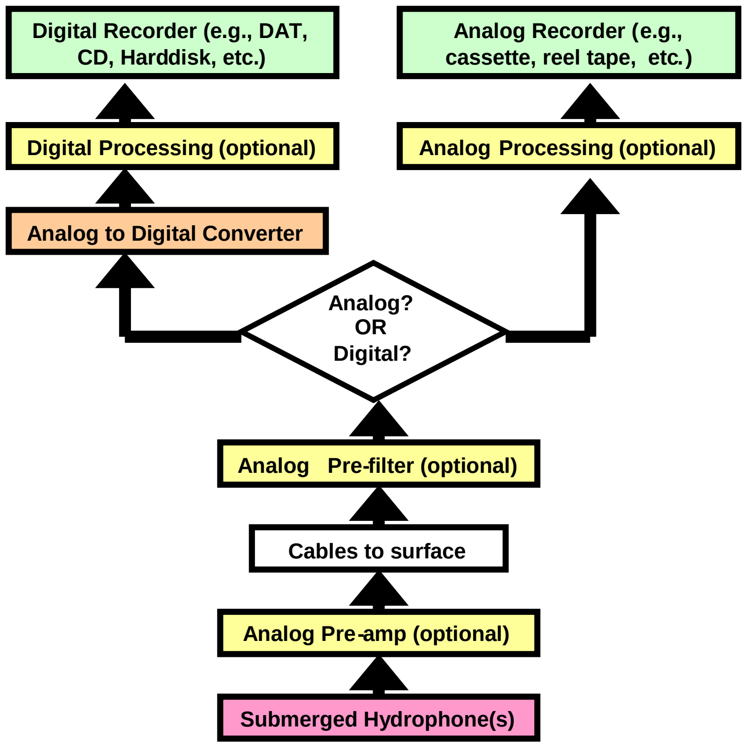


Figure 14. Typical Receiving System Reference Model

Hydrophones: In a typical receiving system, mechanical pressure oscillations (compression and rarefaction) around the steady-state hydrostatic pressure (due to water depth) are converted to electrical voltage or current signal oscillations by a piezo-electric hydrophone or transducer. Ideally, these hydrophones are calibrated such that the magnitude of the electrical signal oscillation can be directly related to the magnitude of the acoustic pressure oscillation through the hydrophone sensitivity (with calibration curves). Calibration should be traceable back to the standards of the National Institute of Standards and Technology (NIST). For scientific purposes (where accuracy and precision matter), the entire receiving system is often calibrated as a whole to enable accurate and precise interpretation of the recorded results. The magnitude of the pressure oscillation is typically given in dB relative to 1 µPa. The sensitivity of the hydrophone is given typically in dB relative to 1 volt/µPa. The frequency response of the hydrophone is the range of frequencies for which the hydrophone sensitivity is relatively constant within defined bounds of variation (e.g., ± 3 dB).

Pre-Amp: Often, but not always, a pre-amplifier is located close or integral with the hydrophone package to amplify the signal in order to overcome additional electrical noise that is inevitably introduced in the subsequent cabling and other electric/electronic components, keeping the overall signal-to-noise ratio (SNR) high enough to be useful for analysis.

Pre-filters: Analog pre-filters are often, but not always, used to remove unwanted noise. Pre-filtering can remove noise from transducer movement and prevent unwanted higher frequency artifacts from being introduced in subsequent digitizing. As further described below, if low-pass filtering is not performed, non-signal artifacts can be introduced at frequencies above 50% of the digitizer sampling frequency.

Analog Signal Processing: Additional amplifiers are used occasionally to match hydrophone output range to recording device input range or other purposes. Additional filters are used occasionally to block or pass certain frequencies of interest and relevance to the purpose of the recording.

Analog Recording: In some receiving systems, the analog signal is recorded directly onto an analog magnetic recording device such as a cassette recorder or reel-to-reel tape. In this case, the relative magnitude of the voltage amplitude oscillations can be retrieved from the stored magnetic signal. The fidelity of the retrieved signal would be dependant upon the fidelity of the recording device. However, in order to accurately determine the magnitude of the pressure oscillations that originally created the electrical signal, a calibrated hydrophone/pre-amp/filter system (with a known gain and frequency response), would need to be fed into a calibrated analog recording device.

Analog-to-Digital Converter (ADC): An ADC (or digitizer) samples the magnitude of electrical signal oscillations at a fixed, pre-determined rate to capture a series of digital snapshots of the signal as numbers where each number captures the magnitude of the sampled electrical signal and the time of the sample. The precision of the sample measurement is a function of 1) the accuracy of the ADC digital voltmeter, 2) the accuracy of the internal digital clock of the ADC, and 3) the resolution or number of data bits that the ADC uses to store the measurement of time and voltage. According to Nyquist's Theorem, the analog signal must be sampled at twice the highest frequency of interest to avoid introducing unwanted aliasing into the signal due to the sampling process. The inverse of Nyquist's Theorem implies that the usable higher end (alias-free bandwidth) of a digitized signal is only as high as 50% of the sampling frequency (also known as the Nyquist Frequency). This is especially limiting in technologies designed for the human hearing spectrum such as Digital Audio Tape (DAT) recorders that typically sample at 32, 44, or 48 kilohertz (kHz), limiting the usable analysis band to below 16, 22, or 24 kHz, respectively. Often, low-pass (anti-aliasing) filters are utilized to eliminate frequency components higher than the Nyquist Frequency. Depending on the purpose of the acoustic monitoring and recording, tradeoffs are often made between data storage capacity, upper frequency, number of recording channels, and data bit resolution. Often, the usable analysis band is limited to less than the upper frequency response of the hydrophones by low-pass filtering or ADC sample rate effects of the Nyquist Theorem.

Digital Signal Processing: Additional digital signal amplifiers, filters, and other digital processing techniques are used occasionally to condition the signal for purposes of the specific study or dataset monitoring and recording. A very commonly used process uses a software technique called the Fast Fourier Transform (FFT) to transform the captured time series of sampled voltage amplitudes from the time domain into the frequency domain, resulting in amplitude as a function of frequency. Many other digital processing techniques are readily available in common signal processing software packages for various purposes. These various digital signal processing techniques are typically applied as post-processing after the raw digitized signal has been stored, thus not altering the stored data.

Digital Recording Device: Digital recording devices store the digital number representations of sampled voltage data onto media such as Hard disks, optical disks, CD-read only memory (ROM), DVD, DAT, and digital cassette tape. The data and file structure varies widely from customized single and multi-dimensional arrays of numbers specified by customized software programs to widely-accepted data format standards such as DAT, WAV, or MP3 files.

ADDITIONAL TERMS

Aliasing: A false lower frequency component that appears in sampled data, resulting from a digital sampling rate below twice the highest frequency of interest (Nyquist Frequency). In order to perform accurate measurements using sampled data, the sampling rate must be set high enough to prevent aliasing, or an optional anti-aliasing filter must be introduced before the A/D converter to restrict the bandwidth of the input signal to meet the sampling (Nyquist) criteria. The actual bandwidth in which correct measurements can be made without aliasing is called the alias-free bandwidth. Once aliasing has been introduced into a sampled signal, there is no general way to remove it. Two general methods (anti-aliasing) are followed to prevent aliasing:

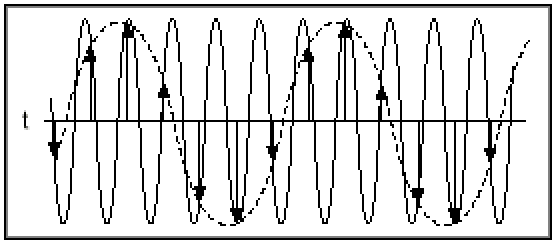
1. Ensure the digital sampling rate of the Analog to Digital Converter (ADC) is at least twice the highest frequency of interest.

2. Utilize a low-pass anti-aliasing filter to block frequency components above 50% of the sampling frequency.

Nyquist Frequency: A frequency equal to one half of the sample rate of an analog-to-digital converter (ADC), that according to the Nyquist Theorem, artificial frequency artifacts are introduced (aliasing) due to the sampling process.

Nyquist Theorem: The Nyquist theorem states that a signal must be sampled at least twice the rate of the highest signal frequency of interest in order to accurately reconstruct the waveform and prevent a false (alias) lower frequency component from appearing in the digitally sampled spectrum of interest (passband).

As a simplified example of sampling at too low a rate, the following figure shows a 5 kHz sine wave digitized by a 6 KS/s Analog to Digital Converter (ADC). The dotted line indicates the 1 kHz false (aliased) signal recorded by the ADC at that sample rate.



The 5 kHz frequency (and any frequency components above the Nyquist frequency of ½ the sampling frequency, or 3 kHz, had they been present) aliases back in the passband, falsely appearing as a 1 megahertz (MHz) sine wave. To prevent aliasing in the digitized passband, a lowpass filter limits the frequency content of the input signal to the ADC above the Nyquist frequency.

Appendix E

List of Additional Underwater Acoustics Parameters

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- Absorption coefficient
- Shallow-water cutoff frequency
- Frequency content
- Transient rise-time
- Transient duration
- Zero-to-peak amplitude
- Peak-to-peak amplitude
- Mean-squared amplitude
- Integral of mean-squared amplitude over duration
- Particle velocity (magnitude & direction of vector)
- Pressure time series
- Characteristic Acoustic Impedance
- Specific Acoustic Impedance
- Group Speed
- Phase Speed
- Acoustic Density
- Fluid Ambient Density
- Spectral Density
- Broadband Spectral Level
- Spectrum (variance as a function of frequency) for stochastic (random) sound
- Vertical Directivity of sound field
- Azimuthal Directivity of sound field
- Acoustic Energy Density (kinetic & potential)
- Acoustic Intensity or Energy Flux Density (active & reactive)
- Acoustic Power
- Adiabatic Incompressibility (or bulk modulus)
- Signal time series
- Fourier Transform of time series
- FFT filter bin-width
- Window function (i.e. rectangular, Hamming, etc)
- Octave Band Level
- One-third-Octave Band Level
- Source Level
- Transmission Loss
- Noise Level
- Volume Scattering Strength
- Reverberation Level
- Sound Velocity Profile (Water and Bottom)
- Salinity Profile
- Density Profile (Water and Bottom)
- Surface Rayleigh Coefficient
- Surface Wave-length

- Surface Scattering Strength
- RMS Surface Wave Height
- Bottom density
- Bottom sound speed
- Bottom absorption coefficient
- Duct leakage coefficient

Appendix F

List of Persons Successfully Contacted

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NAME	ORGANIZATION	ADDRESS	TELEPHONE	EMAIL
Jim Cummings	Acoustic Ecology Institute	45 Cougar Canyon Santa Fe, New Mexico 87508	(505) 466-1879 fax 505-466-4930	Jim@acousticecology.org
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Appendix G

List of Standards Related to Underwater Acoustics Measurement

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ANSI S1.20-1988 (R2003) American National Standard Procedures for Calibration of Underwater Electroacoustic Transducers

British Standard (BS) 5652:1979 Specification for the calibration of hydrophones
BS 5653:1978 Specification for hydrophones for calibration purposes

International Electrotechnical Commission (IEC) 60500:1974 IEC Standard Hydrophone

German Institute for Standardization (DIN) EN 60565 - DRAFT Document - Underwater acoustics - Hydrophones - Calibration in the frequency range 0.01 Hz to 1 MHz (IEC 87/274/CDV:2004)

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Appendix H

List of Symbols, Abbreviations, and Acronyms

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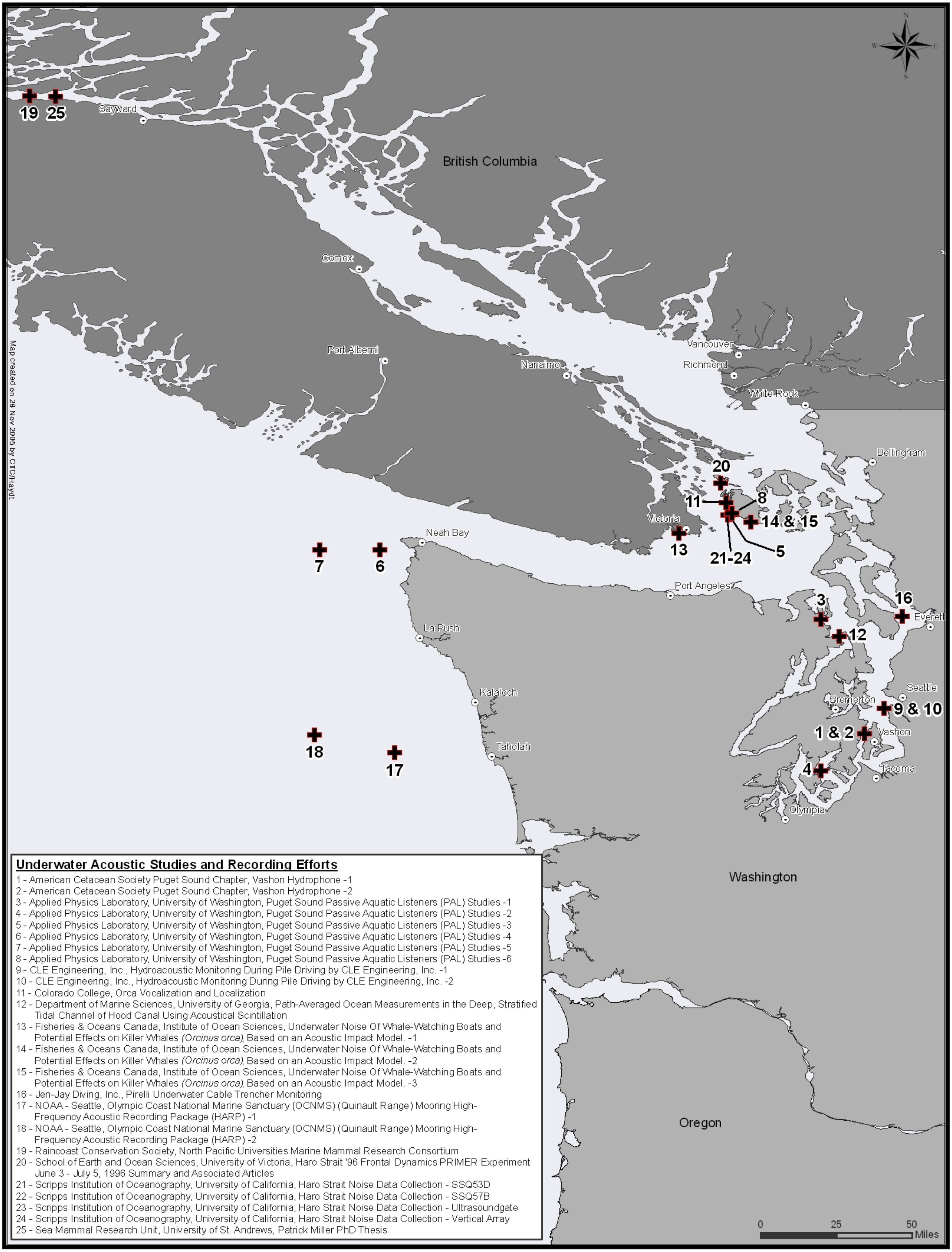
ADC	Analog to Digital Conversion
ANSI	American National Standards Institute
BS	British Standard
c	sound velocity
CD	compact disc
CTC	Concurrent Technologies Corporation
DAT	Digital Audio Tape
dB	decibel
DI	directivity index
DIN	German Institute for Standardization
DT	detection threshold
email	electronic mail
ESA	Endangered Species Act
Fisheries	National Marine Fisheries Service
GIS	geographic information system
HARP	High-Frequency Acoustic Recording Package
Hz	Hertz
IEC	International Electrotechnical Commission
kHz	kilohertz
MHz	megahertz
MMDMS	Marine Mammals Data Management System
MMPA	Marine Mammals Protection Act
µPa	micro-Pascal
NGO	Non-Governmental Organization
NIST	National Institute of Standards and Technology
NL	noise level
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council
NUWC	Naval Undersea Warfare Center
OCNMS	Olympic Coast National Marine Sanctuary
PAL	Passive Aquatic Listeners
pF	picofarad
%	percent
±	plus or minus
re	relative
rms	root mean square
ROM	read only memory

SE	sound pressure level excess (also known as signal excess)
SL	source level
SNR	signal-to-noise ratio
SOSUS	Sound Surveillance System
SR	Southern Residents
SRKW	Southern Resident Killer Whales
TL	transmission loss
UBC	University of British Columbia
USGS	U.S. Geological Survey
VHS	Video Home System


British Columbia
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Sayward
Comox
Port Alberni
Nanaimo
Vancouver
Richmond
White Rock
Bellingham
Victoria
Neah Bay
Port Angeles
La Push
Kalaloch
Taholah
Everett
Seattle
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Map created on 28 Nov 2005 by CTC/Haydt
Underwater Acoustic Studies and Recording Efforts
1 - American Cetacean Society Puget Sound Chapter, Vashon Hydrophone -1
2 - American Cetacean Society Puget Sound Chapter, Vashon Hydrophone -2
3 - Applied Physics Laboratory, University of Washington, Puget Sound Passive Aquatic Listeners (PAL) Studies -1
4 - Applied Physics Laboratory, University of Washington, Puget Sound Passive Aquatic Listeners (PAL) Studies -2
5 - Applied Physics Laboratory, University of Washington, Puget Sound Passive Aquatic Listeners (PAL) Studies -3
6 - Applied Physics Laboratory, University of Washington, Puget Sound Passive Aquatic Listeners (PAL) Studies -4
7 - Applied Physics Laboratory, University of Washington, Puget Sound Passive Aquatic Listeners (PAL) Studies -5
8 - Applied Physics Laboratory, University of Washington, Puget Sound Passive Aquatic Listeners (PAL) Studies -6
9 - CLE Engineering, Inc., Hydroacoustic Monitoring During Pile Driving by CLE Engineering, Inc. -1
10 - CLE Engineering, Inc., Hydroacoustic Monitoring During Pile Driving by CLE Engineering, Inc. -2
11 - Colorado College, Orca Vocalization and Localization
12 - Department of Marine Sciences, University of Georgia, Path-Averaged Ocean Measurements in the Deep, Stratified Tidal Channel of Hood Canal Using Acoustical Scintillation
13 - Fisheries & Oceans Canada, Institute of Ocean Sciences, Underwater Noise Of Whale-Watching Boats and Potential Effects on Killer Whales (Orcinus orca), Based on an Acoustic Impact Model. -1
14 - Fisheries & Oceans Canada, Institute of Ocean Sciences, Underwater Noise Of Whale-Watching Boats and Potential Effects on Killer Whales (Orcinus orca), Based on an Acoustic Impact Model. -2
15 - Fisheries & Oceans Canada, Institute of Ocean Sciences, Underwater Noise Of Whale-Watching Boats and Potential Effects on Killer Whales (Orcinus orca), Based on an Acoustic Impact Model. -3
16 - Jen-Jay Diving, Inc., Pirelli Underwater Cable Trencher Monitoring
17 - NOAA - Seattle, Olympic Coast National Marine Sanctuary (OCNMS) (Quinault Range) Mooring High-Frequency Acoustic Recording Package (HARP) -1
18 - NOAA - Seattle, Olympic Coast National Marine Sanctuary (OCNMS) (Quinault Range) Mooring High-Frequency Acoustic Recording Package (HARP) -2
19 - Raincoast Conservation Society, North Pacific Universities Marine Mammal Research Consortium
20 - School of Earth and Ocean Sciences, University of Victoria, Haro Strait '96 Frontal Dynamics PRIMER Experiment June 3 - July 5, 1996 Summary and Associated Articles
21 - Scripps Institution of Oceanography, University of California, Haro Strait Noise Data Collection - SSQ53D
22 - Scripps Institution of Oceanography, University of California, Haro Strait Noise Data Collection - SSQ57B
23 - Scripps Institution of Oceanography, University of California, Haro Strait Noise Data Collection - Ultrasoundgate
24 - Scripps Institution of Oceanography, University of California, Haro Strait Noise Data Collection - Vertical Array
25 - Sea Mammal Research Unit, University of St. Andrews, Patrick Miller PhD Thesis