ANNUAL RANGE COMPLEX MONITORING REPORT

YEAR 2

2 May 2011 to 1 May 2012

For The U.S. Navy's Northwest Training Range Complex

JULY 1, 2012

FINAL

Cover photo credits:

Marine mammal track lines graphic courtesy of Schorr et al. 2012, Cascadia Research Collective

High-frequency recording package courtesy of J. Hildebrand and S. Wiggins, Scripps Institute of Oceanography

YEAR 2 ANNUAL MONITORING REPORT

INTRODUCTION

The U.S. Navy (Navy) prepared this Year 2 Annual Range Complex Monitoring Report covering the period from May 2, 2011 to May 1, 2012 in compliance with the National Marine Fisheries Service (NMFS) Final Rule under the Marine Mammal Protection Act, and Incidental Take Statement under the Endangered Species Act for the Navy's Northwest Training Range Complex.

The Navy met its current Northwest Training Range Complex monitoring obligations as specified in the NMFS Final Rule and subsequent annual Letter of Authorization.

Specifically, during this reporting period:

- 10,617 hours of passive acoustic data was collected from two bottom deployed passive acoustic monitoring devices deployed continuously in the offshore waters of Washington State.

- Ten (10) satellite tracking tags were purchased by the Navy for use within a collaborative study of marine mammal movement patterns within the offshore waters of Washington State. Four tags were attached to three fin whales and one humpback whale and a total of approximately 43 days of animal movement obtained. Tag deployment of the remaining tags will continue through the rest of 2012 as tagging opportunities arise.

Passive Acoustic Monitoring Results

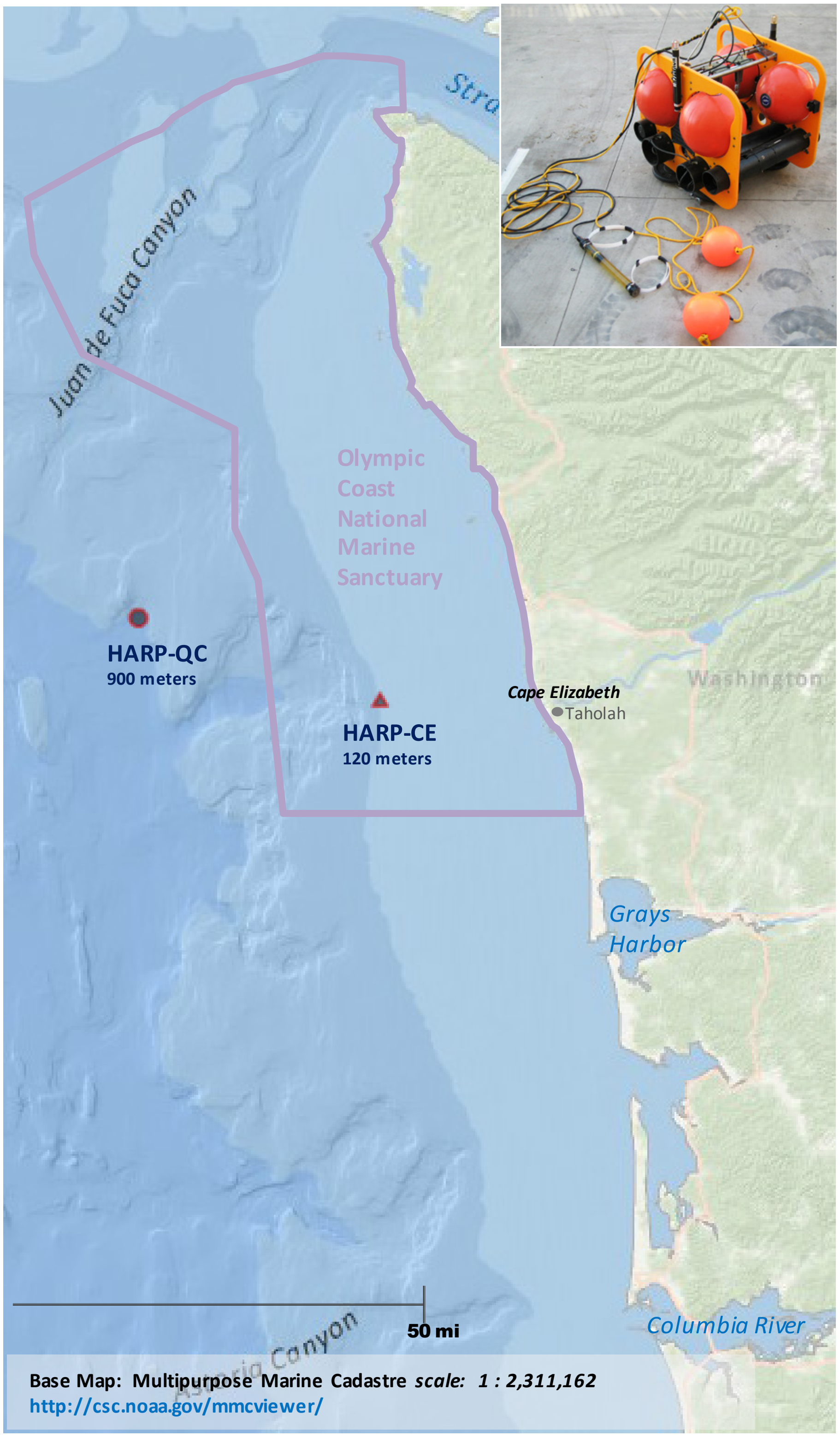
Two High-frequency Acoustic Monitoring Packages (HARP) from the Scripps Institute of Oceanography were deployed and conducted continuous monitoring within the offshore marine waters of Washington State (**Figure 1**).

http://cetus.ucsd.edu/technologies_AutonomousRecorders.html

One HARP was deployed in January 2011 along the central coast of Washington State in the southern part of NOAA's Olympic Coast National Marine Sanctuary (**Figure 1**). Scripps has deployed HARPs in the same approximate location periodically since 2004 (Oleson et al 2009, Oleson and Hildebrand 2012, Širović et al. 2012). A second HARP under the Northwest Training Range Monitoring Plan was deployed in May 2011 near the edge of an underwater canyon west of the Olympic Coast National Marine Sanctuary boundary (**Figure 1**). These devices placed on the ocean floor record marine mammal vocalizations and anthropogenic sounds on internal hard drives that must be retrieved during field service calls approximately every 8-9 months.

Both HARPs were field serviced in early December 2011. Data was collected from the HARPs and returned to Scripps for analysis, and the HARPs redeployed at the same locations.

Passive acoustic analysis from the two Navy-funded Northwest Training Range Complex monitoring HARPs presented in this Year 2 report, therefore, covers the period from January 2011 to November 2011 and is described in detail in **Appendix A**. Over 10,617 hours of passive acoustic data was recorded (6,552 hours at HARP-QC and 4,065 hours at HARP-CE) (Širović, A. personal communication). Subsequent analysis confirmed detection of three baleen whale species to include blue whales, fin whales, and humpback whales; nine toothed whale species; and anthropogenic sounds dominated by shipping noise (Širović et al. 2012, **Appendix A**).



Base Map: Multipurpose Marine Cadastre *scale: 1 : 2,311,162*
http://csc.noaa.gov/mmcviewer/

Figure 1. Location of Navy funded HARPs off Washington State continuously deployed since January and May 2011.

(Upper right picture courtesy of Scripps Institute of Oceanography)

Satellite Tracking Results

Under the previous year's monitoring, the Navy purchased 10 satellite tracking tags suitable for deployment by Cascadia Research Collective on a suite of marine species within the offshore waters of the Northwest Training Range Complex.

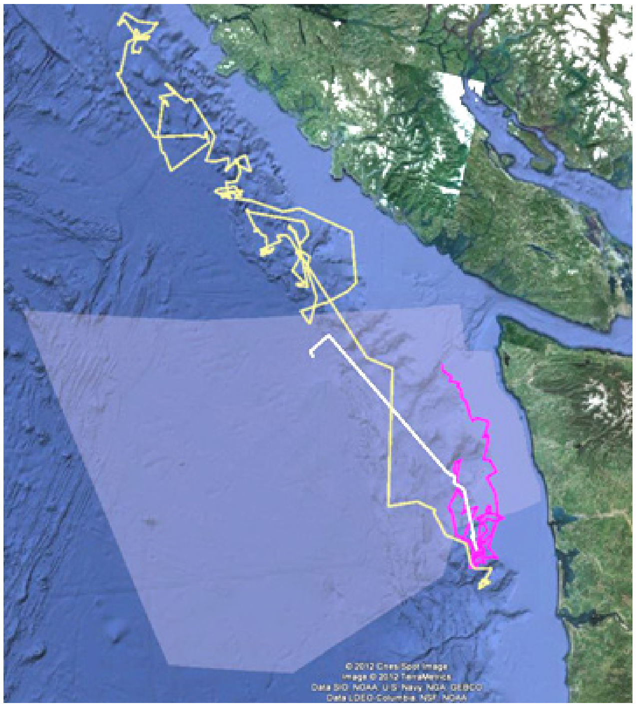
Tags used in the Washington State study were the Andrews-style LIMPET (Low Impact Minimally Percutaneous External Transmitter), in either the location-only Spot5 configuration or the location/dive data Mk10-A configuration (Wildlife Computers, Redmond, Washington) and programmed to species-specific, transmission schedule-based surfacing behavior and transmission data from previous deployments (Schorr et al. 2012). Tags transmit animal movement data via the Argos satellite system. The commercial Argos system consists of data acquisition and relay equipment attached to National Oceanic and Atmospheric Administration (NOAA) low-orbiting weather satellites and ground-based receivers and data processing systems.

The Navy purchased these satellite tracking tags as part of the Northwest Training Range Complex monitoring. However, the tags were deployed opportunistically during field efforts associated with a grant from the NOAA/Alaska Regional Office for fin whale research, a collaborative project with the Washington Department of Fish and Wildlife (WDFW) addressing marine mammal distribution and habitat use off Oregon and Washington (Schorr et al. 2012).

The species of interest in this 3-year joint field project are endangered cetaceans such as blue whales, fin whales, humpback whales, and sperm whales, but may also include high priority cetaceans such as beaked whales, in the event they are encountered in favorable tagging conditions. Other species of interest for tagging could also include seasonal resident gray whales and transient or offshore killer whales.

During this reporting period, three fin whales and one humpback whale were tagged off the Washington coast in 2011 using Navy/NOAA funded tags. Schorr et al. 2012 shows the tagging results for May 2011 to May 2012 field work. A total of approximately 43 days of animal movement was obtained (**Figure 2**).

Five more tags were attached to two humpback whales and three gray whales on May 31, 2012. Given these deployments were after the 1 May 2012 close-out period for this report (Year 2), results from the five and any additional tagging events will be presented in next year's annual monitoring report.



Species	Animal ID	Region tagged	Date tagged	Transmission Duration (days)	Tag Type
Fin Whale	Bp 23	WA coast	2/10/2011	27	Location only
Fin Whale	Bp 24	WA coast	2/10/2011	4	Location only
Fin Whale	Bp 25	WA coast	2/10/2011	4	Location only
Humpback Whale	Mn 02	WA coast	9/6/2011	12	Location only

Figure 2. Deployment data and tag tracks for marine mammals tagged along the Washington coast in 2011.
Table and figure from Schorr et al. 2012; yellow and white tracks are fin whales, and pink track is humpback whale

Following text is from Schorr et al. (2012):

“Three fin whales were tagged off the Washington coast in 2011. One of these tags transmitted, but never provided any locations; the two other whales displayed directional movement out of the tagging area shortly after deployment, both moving north along the shelf edge into Canadian waters. One tag transmitted for 4 days, but the second continued to the track the movements of the whale along the outer coast of Vancouver Island for 27 days. While the whale shifted north throughout most of the period, its irregular path and relatively low displacement rate suggest behavior other than simple travel, though there is a very little existing data on the behavior and movements of fin whales in winter and spring to indicate whether these movements are indicative of migration, feeding, breeding, or some combination of activities. Both whales spent the majority of their time off the shelf edge (mean water depth = 1,728 meter (m); range = 143 m – 2,542 m), and quite far from the nearest point of land (mean shore distance = 65 km; range = 28 km – 127 km) given the breadth of the continental shelf in this region. Both individuals spent time in the W-237 warning area, which is shown as the lighted area. Bp 23 moved a cumulative minimum straight-line distance of 1,750 km and a maximum of 366 km from the tag deployment location.”

“One humpback whale was tagged off the Washington coast in September 2011 and transmitted for 12 days.”
“The tagged humpback remained associated with the shelf edge through the initial transmission period, utilizing both shallower waters on the shelf and deep waters off the edge. This animal then passed through the W-237 warning area as it transited north toward the end of the transmission period.”

Other Navy Funded Results

Navy Research- The Office of Naval Research, Marine Mammals and Biology Program, has an ongoing research program to support basic and applied research and technology development related to understanding the effects of sound on marine mammals, including physiological, behavioral, ecological effects and population-level effects. Current program thrusts include, but are not limited to: Monitoring & Detection; Integrated Ecosystem Research (including Sensor and Tag Development); Effects of sound on marine life: Hearing, Behavioral Response Studies, Physiology (Diving & Stress), Population Consequences of Acoustic Disturbance (PCAD); and Models and Databases for Environmental Compliance.

http://www.onr.navy.mil/Science-Technology/Departments/Code-32/All-Programs/Atmosphere-Research-322/Marine-Mammals-Biology.aspx

Specific Navy funded projects under the Office of Naval Research applicable to the Pacific Northwest include:

USE OF ELECTRONIC TAG DATA AND ASSOCIATED ANALYTICAL TOOLS TO IDENTIFY AND PREDICT HABITAT UTILIZATION OF MARINE PREDATORS- Daniel Costa, Barbara Block, and Patrick Robinson (University of California, Santa Cruz)

FACTORS INFLUENCING THE ACOUSTIC BEHAVIOR AND NEARSHORE RESIDENCE OF THE GRAY WHALE (ESCHRICHTIUS ROBUSTUS) ALONG THEIR MIGRATION ROUTE- Timothy Cowles, Kelly Benoit-Bird, and David Mellinger (Oregon State University)

IMPROVED SATELLITE-MONITORED RADIO TAGS FOR LARGE WHALES: DEPENDABLE ARGOS LOCATION-ONLY TAGS AND A GPS-LINKED ARGOS TO REVEAL 3- DIMENSIONAL BODY ORIENTATION AND SURFACE MOVEMENTs- Bruce Mate (Oregon State University, Marine Mammal Institute)

PASSIVE AUTONOMOUS ACOUSTIC MONITORING USING SEAGLIDER™- Neil Bogue, James Luby, Geoffrey Shilling, William Jump, Trina Litchendorf, David Mellinger*, Holger Klinck* (Applied Physics Laboratory, University of Washington and *Cooperative Institute for Marine Resources Studies, Oregon State University)

Future Field Research 2012-2013

One technology under development is the use of passive acoustic detectors deployed on unmanned underwater gliders that can be set for extended at-sea missions. A Navy funded (Office of Naval Research) glider will be tested and field validated in the offshore waters of Washington State (see PASSIVE AUTONOMOUS ACOUSTIC MONITORING USING SEAGLIDER above). Specifically, two Applied Physics Laboratory, University of Washington Seagliders™ each equipped with single-hydrophone passive autonomous acoustic monitoring systems, will deploy in June 2012 for a two-month marine mammal survey mission. The Seagliders will be recovered in late-July 2012 or early-August 2012 (**Figure 3**). In addition, beaked whale detectors will be run onboard these systems during the mission, and all data will be recorded for future analysis.

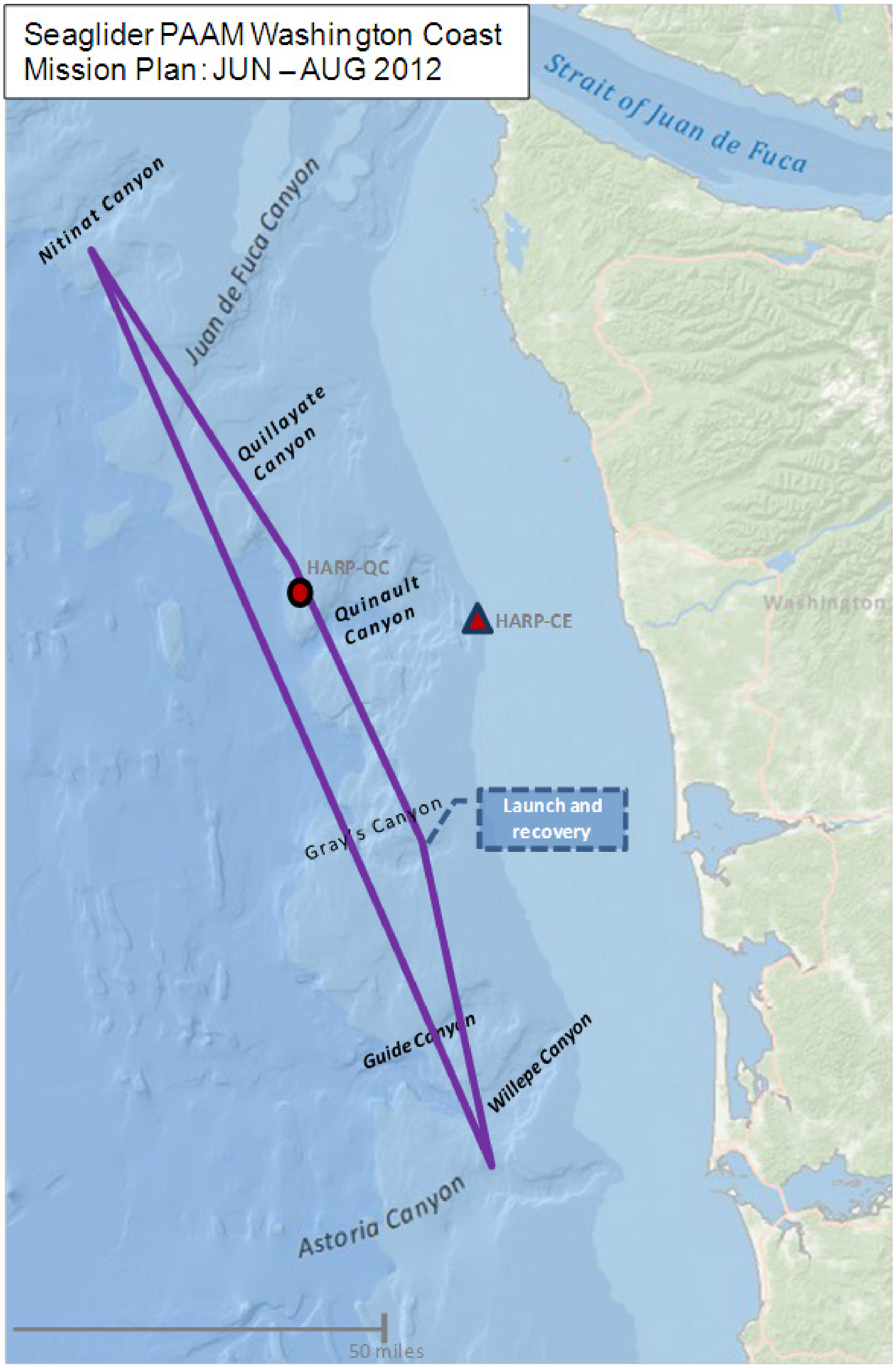


Figure 3. Offshore route for June to August 2012 glider deployment.

(Applied Physics Laboratory, University of Washington and
Cooperative Institute for Marine Resources Studies, Oregon State University)

Behavioral Response Study (BRS) Southern California 2011 (SOCAL-11)- SOCAL-11 is second field season of a multi-year effort (2010-2014), more generally referred to as "SOCAL-BRS" (Behavioral Response Study). It is an interdisciplinary research collaboration, building on previous efforts in the Bahamas and Mediterranean Sea, designed to better understand marine mammal behavior and reactions to sound. The overall objective is to provide a better scientific basis for estimating risk and minimizing effects of active sonar for the U.S. Navy and regulatory agencies. SOCAL-BRS is also part of a larger international collaboration to measure the impacts of noise marine mammals using opportunistic and experimental approaches (including controlled exposure experiments, or "CEEs").

SOCAL-11 follows a successful first season which demonstrated that, at least for the areas and species targeted off southern California, smaller teams and an adaptive approach that optimizes the probability of requisite good weather and of finding and tagging different focal species can be very productive.

Further BRS discussion and information is available at:

www.socal-brs.org

In addition to the 10 tags purchased for Year 2 tagging along the Washington Coast, at the same time the Navy also purchased an additional four tags using US Pacific Fleet Northwest Training Range Complex tag funding. These additional tags were to be deployed during SOCAL-11 or subsequent BRS field efforts. Results from BRS apply across multiple Navy range complexes in that one would anticipate similar reactions or lack of reactions from similar species elsewhere.

Regional Navy Monitoring Efforts- The below ongoing activities are being conducted by the Navy outside of and in addition to the Navy's commitments to the National Marine Fisheries Service for the Northwest Training Range:

Puget Sound Pinniped Surveys: In order to better understand marine mammal presence in the Puget Sound Region, the Navy has been conducting presence/absence surveys of sea lions at known haulout sites on specific Puget Sound Navy installations, as well as opportunistic marine mammal density surveys in the waters adjacent to certain installations. Biologists located at Naval Base Kitsap at Bangor and the Puget Sound Naval Shipyard have been conducting counts of sea lions hauled out on submarines and on floating security fences (**Figure 4**). In the case of Naval Base Kitsap at Bangor, these counts are conducted daily (excluding weekends) and involve identifying the sea lions to species and counting the numbers hauled out on floating security fences and submarines. For Puget Sound Naval Shipyard, sea lion counts are collected during a monthly water quality sampling program. This information has shown seasonal use of each site, as well as trends in the number of animals using the fence. Additional Navy sites, such as Naval Station Everett, will initiate weekday surveys of the floating security fences and adjacent haulout locations (such as the floating log rafts) beginning in the summer of 2012 and continuing over subsequent years.


Photo: 30 September 2011 by A. Balla-Holden, U.S. Navy

Photo: 12 October 2011 by A. Balla-Holden, U.S. Navy

Photo: 13 October 2011 by A. Balla-Holden, U.S. Navy

Figure 4. California sea lions hauled out on floating security fences (top) and submarines (bottom) within Puget Sound

Marine Mammal Surveys In Hood Canal and Dabob Bay- The Navy conducted an opportunistic marine mammal density survey in Hood Canal and Dabob Bay during September and October 2011. Line-transect survey tracklines are shown on **Figure 5** for Hood Canal and **Figure 6** for Dabob Bay.

In the Hood Canal, the surveys followed a double saw-tooth pattern to achieve uniform coverage of the entire Naval Base Kitsap at Bangor waterfront. Transects generally covered the area from Hazel Point on the south end of the Toandos Peninsula to Thorndyke Bay. Surveys in the adjacent Dabob Bay followed a slightly different pattern and generally followed more closely to the shoreline while completing a circular route through the Bay. A large exclusion zone surrounding a Navy ship moored semi-permanently in Dabob Bay made it difficult to perform zigzag transects across the bay; therefore, early attempts at surveys in Dabob did not follow a zigzag pattern, and switching to this survey pattern later in the project would have made density information collected during early "loop pattern" surveys incompatible with later data. Therefore, this loop pattern was followed during all subsequent baseline surveys in the bay. These surveys had a dual purpose of collecting marine mammal and marbled murrelet data, and shoreline surveys tended to yield more marbled murrelet sightings (Hart Crowser 2012). During surveys, the survey vessels traveled at a speed of approximately five knots when transiting along the transect lines. Two observers recorded sightings of marine mammals both in the water and hauled out. Marine mammal sightings data included species identification, GPS animal locations relative to vessel position, and detailed behavioral notes. Data from the line transect surveys can be used to improve estimates of marine mammal density in Hood Canal and Dabob Bay. Detailed information regarding these baseline surveys is included in Appendix B in the Test Pile Programs Marine Mammal Monitoring Report located on NMFS website at (NAVFAC 2012):
http://www.nmfs.noaa.gov/pr/pdfs/permits/navy_kitsap_monitoring_report2012.pdf

In summary, there were 11 survey days for Hood Canal and 10 survey days for Dabob Bay. For Hood Canal, a total of 443.5 km^2 (129.3 nm^2) were covered during 60:13 hours of surveys. The total trackline length was 471.3 km (254.5 nm) (**Figure 5**). For Dabob Bay, a total of 91.8 nm^2 (315 km^2) were covered during 29:40 hours of surveys. The total trackline length was 211.7 nm (392.1 km) (**Figure 6**).

For Hood Canal, a total of 266 sightings were made with the most commonly seen species being the harbor seal (n=197, 74 percent), followed by harbor porpoise (n=34, 13 percent) and California sea lion (n=33, 12 percent) (**Figure 7**). For Dabob Bay, a total of 320 sightings were made with the most commonly seen species being the harbor seal (n=302, 94 percent), followed by the harbor porpoise (n=12, 4 percent) and the California sea lion (n=5, 2 percent) (**Figure 7**). A single sighting of an unknown pinniped was also noted. Throughout Dabob Bay, harbor porpoise had the highest number of individuals seen per sighting at 2.5, followed by the harbor seal (1.5), and the California sea lion (1.4).

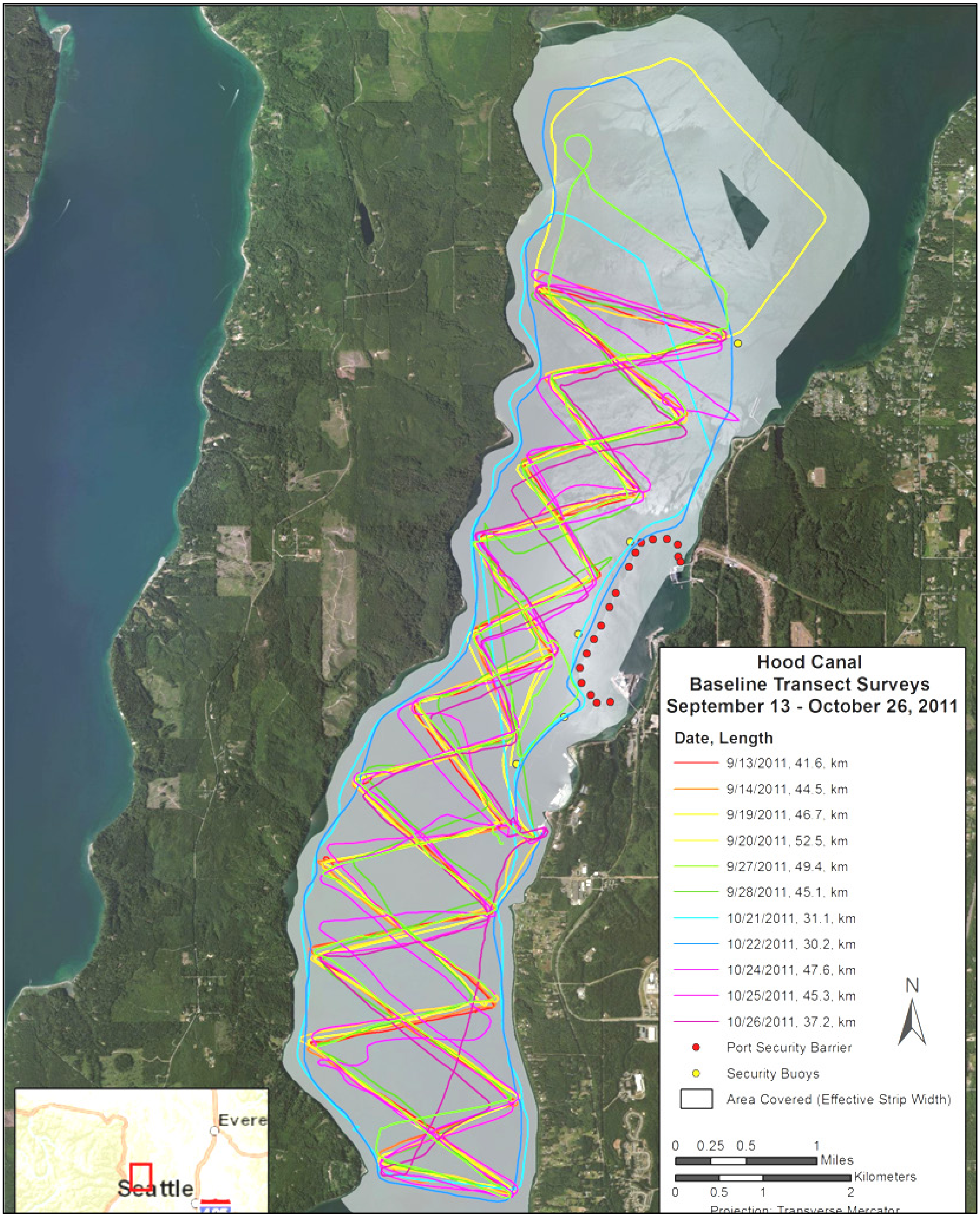


Figure 5. Survey transects and 1,640 ft (500 m) strip width for Hood Canal

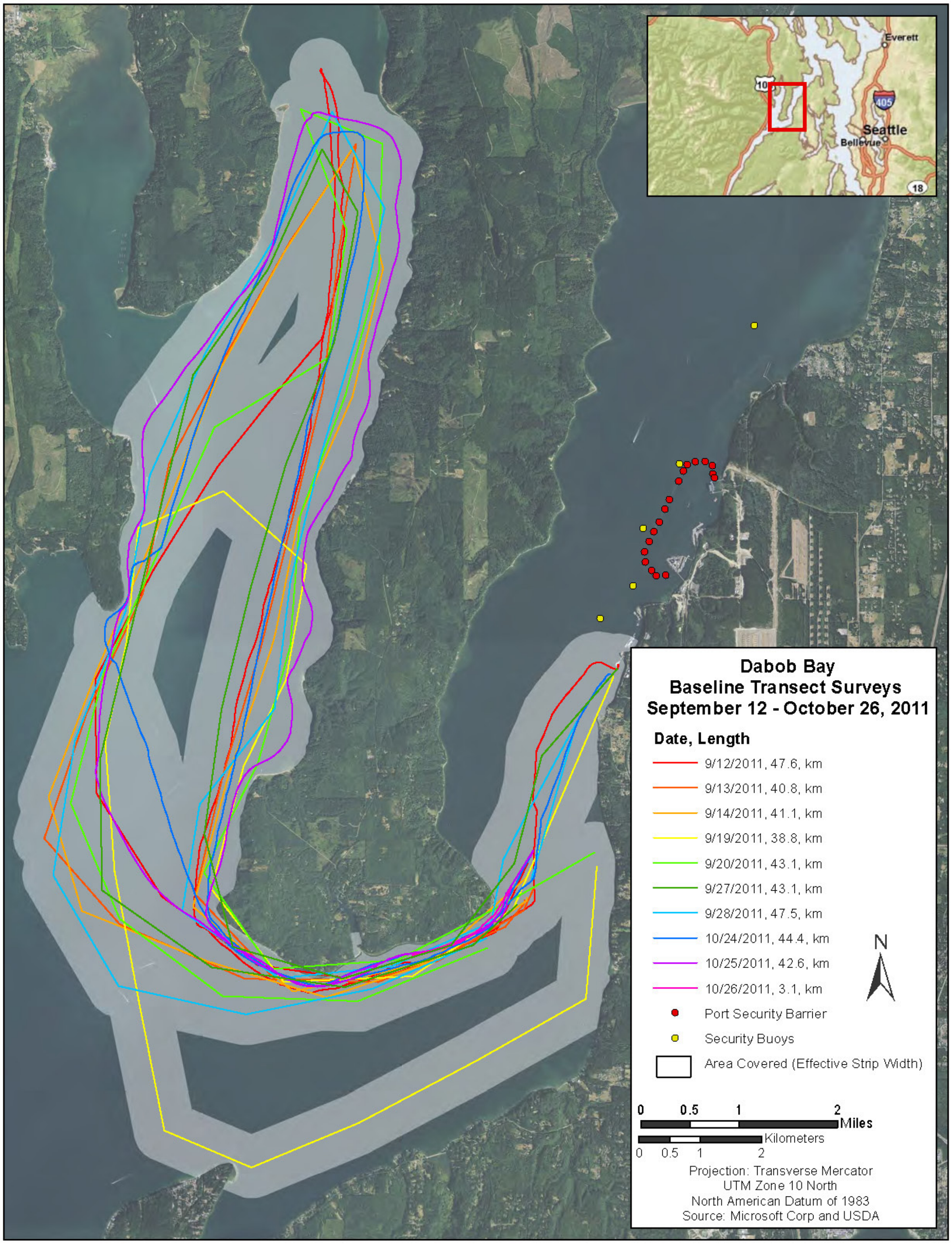


Figure 6. Survey transects and 1,640 ft (500 m) strip width for Dabob Bay.

LOCATION:	HOOD CANAL		DABOB BAY	
SPECIES	# of sightings	# of animals	# of sightings	# of animals
California sea lion	33	233	5	7
Harbor seal	197	277	302	442
River otter	1	1	0	0
Steller sea lion	1	1	0	0
Unidentified pinniped	0	0	1	1
Harbor porpoise	34	89	12	30
TOTALS:	**266**	**604**	**320**	**480**

Figure 7. Number of sightings and number of individuals during Hood Canal Baseline Surveys and Dabob Bay Surveys September to October 2011.

Proposed Year 3 Monitoring

The NMFS has acknowledged that the Northwest Training Range Complex monitoring will enhance the understanding of marine mammal distributions within the offshore waters of northern California, Oregon, and Washington. Additionally, NMFS also pointed out that information gained from the investigations associated with the Navy's monitoring may be used in the adaptive management of mitigation or monitoring measures in subsequent NMFS authorizations, if appropriate. Therefore, the Navy's adaptive management of Northwest Training Range Complex monitoring under its Marine Mammal Protection Act responsibilities involves close coordination with NMFS to align marine mammal monitoring with the overall objectives stated within the Introduction to this report. To the best extent practical, the Northwest Training Range Complex monitoring aligns with U.S. Ocean Policy [1].

To date, 2011-2012 monitoring within the Northwest Training Range Complex represents Year 2 of a planned five year effort. As such, it would be premature to draw detailed conclusions or initiate comprehensive monitoring changes without further consultation and public review.

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[1] U.S. Ocean Policy- On 19 July 2010, the President signed a new Executive Order on Stewardship of the Ocean, Our Coasts, and the Great Lakes which adopted the final recommendation of the Interagency Ocean Policy Task Force. Key recommendations include "Use the best available science and knowledge to inform decisions affecting the ocean…" and "Increase scientific understanding of ocean…" (EO 2010, CEQ 2010). Another integral part of these policy directions was to instill a collaborative spirit within the Federal Government in the planning, management, and program execution of ocean science projects. Both of these tenants, improved and using best available science along with increased collaboration, are similar to preceding recommendations of the Joint Subcommittee on Ocean Science and Technology (JSOST) on "Addressing the Effects of Human-Generated Sound on Marine Life: An Integrated Research Plan for U.S. federal agencies "(Southall et al. 2009).

Proposed 2 May 2012 to 1 May 2013 Monitoring

The Navy proposes to keep the same level of monitoring effort in the Northwest Training Range Complex as was committed and accomplished in Year 1 from 12 Nov 2010 to 1 May 2011. **Table 1** highlights these goals. The Navy is committed to structuring the Northwest Training Range Complex monitoring to address both NMFS regulatory required monitoring under the Northwest Training Range Complex Letter of Authorization while at the same time making significant contributions to the greater body of marine mammal science.

Table 1. Navy's proposed Year 3 monitoring goals for the Northwest Training Range Complex from 2 May 2012 to 1 May 2013.

Monitoring Technique	Implementation
Passive Acoustic Monitoring	Maintain and present data analysis from two Navy funded offshore passive acoustic monitoring devices
Marine Mammal Tagging	Report results from marine mammal tagging for remaining tags available that were not deployed between May 2011 and May 2012, leveraging existing field efforts where possible
NO metric changes are envisioned in Year 3 (2012-2013) from the level of effort and funding performed in Year 2 (2011-2012) TOTAL Navy Year 3 Goal: *2 PAM devices and analysis; present results from tag deployments*	

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APPENDIX A

Appendix A contains a data summary of passive acoustic monitoring in the offshore waters of Washington State from January 2011 to November 2011.

Širović, A., J.A. Hildebrand, S. Baumann-Pickering, J. Buccowich, A. Cummins, S. Kerosky, L. Roche, A.S. Berga, S. M. Wiggins. 2012. Passive Acoustic Monitoring for Marine Mammals in the Northwest Training Range Complex 2011. Marine Physical Laboratory, Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA. MPL TECHNICAL MEMORANDUM: MPL-TM 535. 57 pp.

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Passive Acoustic Monitoring for Marine Mammals in the Northwest Training Range Complex 2011

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MPL TECHNICAL MEMORANDUM: MPL-TM 535

Table of Contents

Executive Summary

Passive acoustic monitoring using High-frequency Acoustic Recording Packages (HARPs) was conducted at two sites in the Navy's Northwest Training Range Complex from January until November 2011. In this report, information on the presence of marine mammals and anthropogenic sounds collected at these sites is presented, including the most detailed accounting of presence of a variety of beaked whale species to date for this location. HARPs recorded sounds between 10 Hz and 100 kHz continuously at two sites, one at the shelf slope near Quinault Canyon (QC) and the other on the shelf offshore from Cape Elizabeth (CE). Data analysis methods consisted of automatic detections of select calls and manual scans of long-term spectral averages and spectrograms. The data were divided into three frequency bands and each band was analyzed for sounds from marine mammals and anthropogenic sources. Representative sounds recorded during monitoring, as well their occurrence at these sites, are presented.

Three baleen whale species were recorded off Washington during 2011: blue whales, fin whales, and humpback whales. All species were recorded at both sites, but humpbacks were more common at the shelf site CE, fin whales were slightly more common at QC, and blue whales were detected equally at both sites. Seasonal pattern of all three species was similar, with calls most commonly detected during the fall and winter. Few fin whale calls were detected between May and August and few blue whale calls were detected between April and August. Pinniped barks were recorded during a single day in October at site CE. Signals from at least nine odontocete species were recorded at these two sites. The most common odontocete acoustic detections in the area were of the Pacific white-sided dolphins, with peaks during June-July and again in October and November. Sperm whale echolocation clicks were detected consistently throughout the deployment period at the slope site QC, while their clicks were detected only sporadically at site CE. Risso's dolphin echolocation clicks occurred most commonly on the offshore site, QC, during the summer, from July to September, and mostly during the night. Low levels of killer whale signals were detected year round at both sites, although they were slightly more common at site CE. Stejneger's beaked whales were the most commonly recorded beaked whale, with all their detections occurring only at the slope site QC and exclusively between January and June. Baird's beaked whales, the second most common beaked whale, were detected at both sites, although they were more common at site QC, and their echolocation clicks peaked at that site in February and July. A few detections were made also of Cuvier's beaked whale, and Blainville's beaked whale, as well as additional unidentified beaked whales, almost all of them at the slope site QC. Narrow-bandwidth high frequency clicks, most likely from porpoises, were commonly detected throughout the deployment period at the shelf site CE.

Ship noise was a common anthropogenic sound at site CE from September until November, with lower levels at both sites for the remainder of the year. Mid-frequency active (MFA) sonar events were rare at both sites during the recording periods in 2011 and were recorded on 5 days at site QC and 2 days at site CE. Using automatic detection and measurement method, 171 pings were detected at site CE, with received levels ranging from 111 to 148 dB pp re: 1 μPa. Automatic detection of received levels was not possible at site QC because the received levels were low. Explosions were not common at either site, with no more than 15 hours containing explosions per week recorded at either site.

Project background

The Navy's Northwest Training Range Complex (NWTRC) contains an offshore area that extends west 250 nautical miles (nm) beyond the coasts of Washington, Oregon, and Northern California. This area is a productive ecosystem that is home to many species of marine mammals. It includes deep water habitats, used by beaked and sperm whales, as well as continental shelf waters frequented by coastal cetaceans, pinnipeds and porpoises. Endangered species known to occupy this area include blue, fin, sperm, humpback, and killer whales.

An acoustic and visual monitoring effort for marine mammals was initiated within the boundaries of the NWTRC with a focus on the Quinault Underwater Tracking Range (QUTR), off the coast of Washington, beginning in July 2004. Two High-frequency Acoustic Recording Packages (HARPs) have been deployed near the QUTR, one in deeper water on the shelf slope within Quinault Canyon (QC) and a second on the continental shelf off Cape Elizabeth (CE) intermittently since 2004. In 2011, support for continuation of acoustic monitoring in the NWTRC was provided by the Pacific Fleet, under a contract to the Scripps Institution of Oceanography from the Naval Postgraduate School. The goal of this monitoring effort was to characterize the vocalizations of marine mammal species present in the area, determine their year-round presence, and evaluate the potential for impact from Naval operations. This report documents the analysis of data collected using two High-frequency Acoustic Recording Packages (HARPs) that were deployed within NWTRC from January through November 2011 (Figure 1).

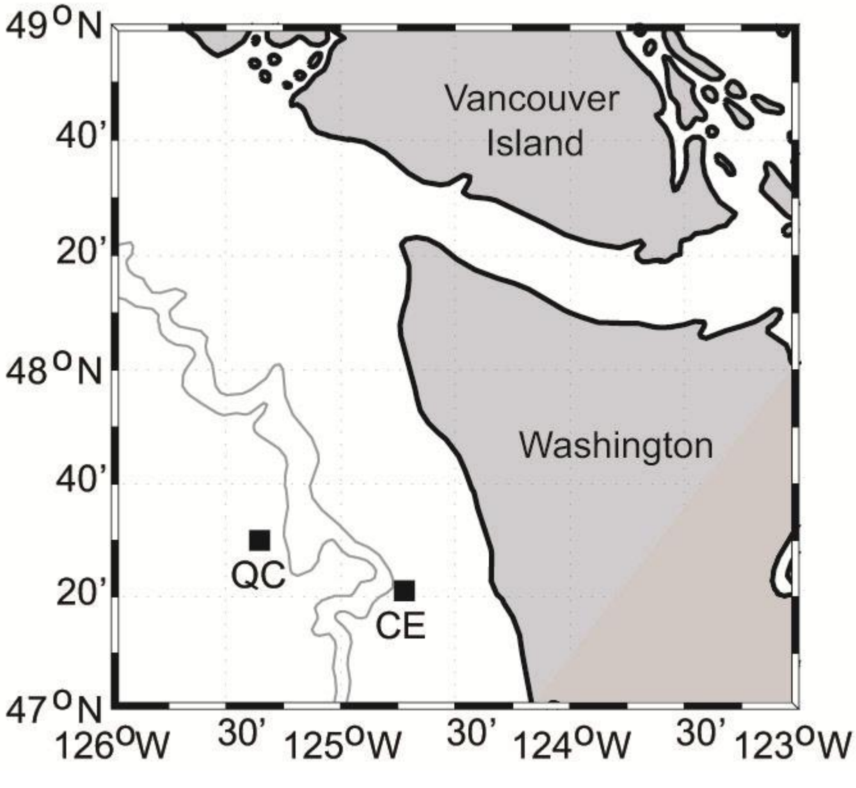

Figure 1. Locations of High-frequency Acoustic Recording Packages, QC and CE (black squares), deployed in the NWTRC during 2011. Grey thin lines represent 500 m and 1000 m bathymetric contours.

Methods

High Frequency Acoustic Recording Packages

HARPs record underwater sounds from 10 Hz to 100 kHz and are capable of up to 250 days of continuous recording (Wiggins and Hildebrand 2007). For the NWTRC deployments, the HARPs were located on the seafloor with their hydrophone suspended 10 m above the seafloor. Each HARP was calibrated in the laboratory to allow a quantitative analysis of the received sound field. Representative data loggers and hydrophones were calibrated at the Navy's TRANSDEC facility to verify the laboratory calibrations.

Data Collected to Date

Acoustic data have been collected at two sites within NWTRC using HARPs since July 2004 (Table 1). The two sites are designated Quinault Canyon, QC (47° 30.00N, 125° 21.20W) and Cape Elizabeth, CE (47° 21.12N, 124° 43.26W). Analysis of recordings collected before 2011 were described by Oleson et al. (2009) and Širović et al. (2011). Here we present the results of the analyses conducted on the data collected at these two sites during 2011.

Table 1. NWTRC acoustic monitoring since 2004. Periods of instrument deployment analyzed in this report are shown in bold. Results of acoustic monitoring through 2010 are described in Oleson et al. (2009) and Širović et al. (2011). Italics show ongoing data collection.

Acoustic Monitoring Period	Sample Rate & Duty Cycle (on/off, in min)	QC: Slope	CE: Shelf
OCNMS01: July – October 2004	80 kHz continuous	Yes	Lost
OCNMS02: October 2004 – January 2005	80 kHz 10/20	Yes	--
OCNMS03: July 2005 – February 2006	80 kHz 6/12	Yes	--
OCNMS04: August 2006 – February 2007	80 kHz 6/12	Yes	Yes
OCNMS05: April – July 2007	80 kHz continuous	Yes	Yes
OCNMS06: July 2007 – June 2008	200 kHz 5/35	Yes	--
OCNMS07: October 2007 – June 2008	200 kHz 5/30	--	Yes
OCNMS08: June 2008 – June 2009	200 kHz 5/35	Lost	Yes
OCNMS09: December 2009 – January 2011	200 kHz 5/30	--	Lost
OCNMS12: January – October 2011	**200 kHz** **continuous**	**Yes**	
OCNMS13: May– November 2011	**200 kHz** **continuous**		**Yes**
OCNMS14: December 2011 –	*200 kHz* *continuous*	*Yes*	*Yes*

Data Analysis

Recording over a broad frequency range up to 100 kHz allows detection of baleen whales (mysticetes), toothed whales (odontocetes) and seal and sea lion (pinniped) species. The hourly presence of acoustic signals from multiple marine mammal species was evaluated in the data. The presence of calls from the following species was examined: blue whales (*Balaenoptera musculus*), fin whales (*B. physalus*), gray whales (*Eschrichtius robustus*), Bryde’s whales (*B. edeni*), minke whales (*B. acutorostrata*), humpback whales (*Megaptera novaeangliae*), sperm whales (*Physeter macrocephalus*), killer whales (*Orcinus orca*), Stejneger's beaked whale (*Mesoplodon stejnegeri*), Baird’s beaked whales (*Berardius bairdii*), Cuvier’s beaked whale (*Ziphius cavirostris*), Blainville’s beaked whale (*Mesoplodon densirostris*), Risso’s dolphins (*Grampus griseus*), and Pacific white-sided dolphins (*Lagenorhynchus obliquidens*). Additionally, pinniped and likely porpoise sounds were also identified in the data, as was the daily presence of anthropogenic noise such as shipping, Naval sonar, and explosions. A few call types were detected automatically in the data, including blue, fin, and humpback whale calls. In addition, all data were analyzed by visually scrutinizing long term spectral averages (LTSAs) in appropriate frequency bands for calls of other species. When a sound of interest was identified in the LTSA, examining the waveform or spectrogram at the time of interest was possible to identify particular sounds to species or source, as necessary. Acoustic classification was carried out either from comparison to species-specific spectral characteristics or through analysis of the time and frequency characters of individual sounds.

To document the data analysis process, we describe the major classes of marine mammal calls and anthropogenic sounds in the NWTRC, and the procedures used to detect them in the HARP data. For effective analysis, the data were divided into three frequency bands and each band was analyzed for presence of sounds from an appropriate subset of species or sources. The three frequency bands are as follows: (1) low frequencies, between 10 – 1,000 Hz, (2) mid frequencies, between 100 – 5,000 Hz, and (3) high frequencies, between 1 – 100 kHz. LTSAs are created by calculating frequency spectra for all the data and each of the three frequency bands. For the analysis of the mid-frequency recordings, data were decimated by a factor of 20, while for the low-frequency analysis, they were decimated by a factor of 100. The LTSAs were created using a 5 s time average with 100 Hz frequency resolution for high-frequency, 10 Hz resolution for mid-frequency, and 1 Hz resolution for low-frequency data analysis. Blue, fin, Brydes’s, and grey whale sounds were classified as low frequency. Humpback, minke, some killer whale whistles, pinnipeds, shipping, mid-frequency active sonar, and explosions were classified as mid-frequency. The remaining odontocete sounds were considered high-frequency. We describe the calls and procedures separately for each frequency band.

In this report, we summarize acoustic data collected during 2011. We discuss seasonal occurrence and relative abundance of calls for different species that can be consistently identified in the acoustic data in the context of earlier visual and acoustic data collections (Oleson et al. 2009, 2010; Širović et al. 2011).

Low Frequency Marine Mammals

The hourly presence of blue whale D, fin whale 40 Hz, Bryde’s whale Be4, and grey whale M3 calls was determined by manual scrutiny of low-frequency LTSAs (5 s temporal and 1 Hz frequency resolution) using custom software program Triton (Wiggins and Hildebrand 2007). Blue whale B calls and fin whale 20 Hz pulses were detected automatically using computer algorithms described below in each corresponding section.

The same LTSA and spectrogram parameters were used for manual detection of all call types. During scrutiny of the data, the LTSA frequency was set to display between 1-500 Hz. To observe individual calls, spectrogram windows were typically set to 120 seconds by 200 Hz. The FFT was generally set between 1,500 and 2,000 data points, yielding about 1 Hz frequency resolution, with an 85-95% overlap. When a call of interest was identified in the LTSA or spectrogram, its presence during that hour was logged using Triton.

Blue Whales

Blue whales produce a variety of calls worldwide (McDonald et al. 2006), but in the eastern North Pacific, B calls (Figure 2) are their most commonly recorded call (Oleson et al. 2007a). These low frequency (15-50 Hz), long duration (20 s) calls can be produced as repetitive sequences (song) or as singular calls and are produced exclusively by males, likely in association with mating behavior (Oleson et al. 2007b). The call generally contains multiple, harmonically related tonals and, owing to greater noise at low frequency, is best identified based on the presence of the 3rd harmonic.

For this report, blue whale B calls were detected automatically using the spectrogram correlation method (Mellinger and Clark 1997). The kernel was based on frequency and temporal characteristics measured from 35 calls recorded in the data set and it was made of four segments, three 1.5 s and one 5.5 s long, for a total duration 10 s. The frequency ranged over those time periods from 47.67 to 47.13; 47.13 to 46.59; 46.59 to 46.23; and 46.23 to 45.43 Hz. The kernel bandwidth was 2 Hz. A similar detector has been used by Oleson et al. (2007a), but the frequency characteristics were adjusted to account for the annual shift in frequency of blue whale B calls (McDonald et al. 2009). The performance of the detectors was tested against two weeks of manual hourly picks of blue whale B calls and we found that hourly false alarm and missed detection rates were 0.9 % and 5.5 %, respectively. In addition, automatic detections during months when blue whales are not common in this area (March through October) were manually reviewed and false alarms during this period were removed from further analysis. Detections were binned into 1 hour bins for consistent result reporting.

Blue whales also produce D calls, which are down-swept in frequency (100-40 Hz) with duration of several seconds (Figure 3). These calls are similar worldwide and are associated with feeding animals; they may be produced as call-counter call between multiple animals (Oleson et al. 2007b). Blue whale D calls were manually detected in the CE data set.

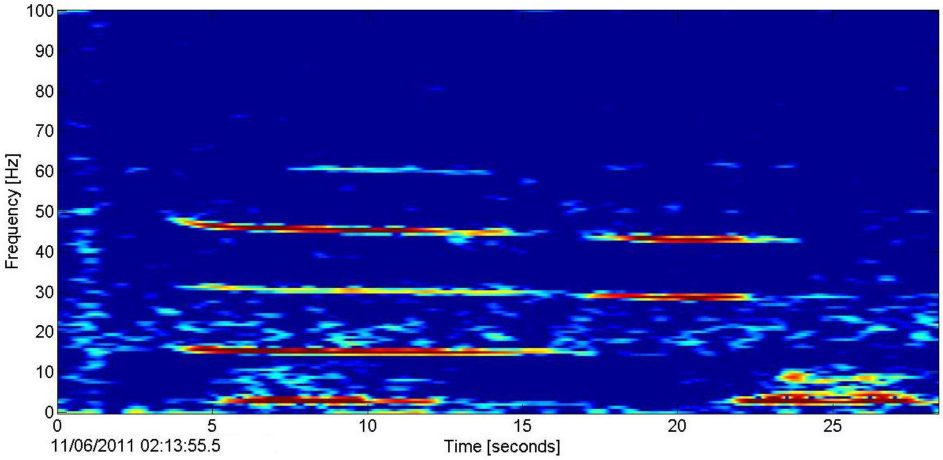

Figure 2. Blue whale B call showing harmonic tones with frequency step near the end of the call (3,500-point FFT, 98% overlap)

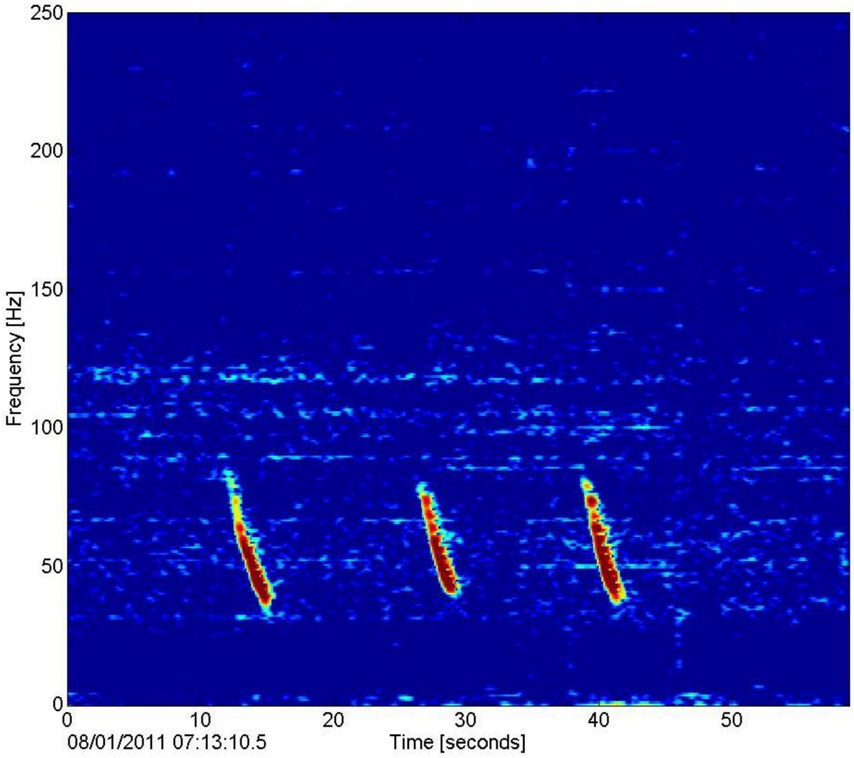

Figure 3. Spectrogram of blue whale D calls recorded at site CE (2,000-point FFT and 90% overlap).

Fin Whales

Fin whales produce two types of short (approximately 1 s duration), low-frequency downswept calls: those that downsweep in the frequency from 30 – 15 Hz, called 20 Hz calls (Figure 4), and downsweeps from 75 – 40 Hz, called 40 Hz calls (Watkins 1981, Širović et al. under review). 20 Hz calls can occur at regular intervals as song (Thompson et al. 1992), or irregularly as call counter-calls among multiple, traveling animals (McDonald et al. 1995). 40 Hz calls most often do not occur in regular patterns.

For this report, fin whale 20 Hz calls were detected automatically using an energy detection method. The method used a difference in acoustic energy between signal and noise at different frequencies, calculated from 5 s LTSA with 1 Hz resolution. The frequency at 22 Hz was used as the signal frequency, while noise was calculated as the average energy between 10 and 34 Hz. All calculations were performed on the logarithmic scale. The performance of the detector was tested to find the optimal rate of false positives and missed detections, which was 13.6 % and 12.7 %, respectively (Figure 5). False detections were generally triggered by shipping noise or various low frequency pulsing sounds, these were particularly prevalent at site CE. Detections during months when fin whales are not common in this area (May through July at the slope site QC and May through August at shelf site CE) were manually verified. False alarms during this period were removed from further analysis. Manual verification stopped after the first day with more than 3 hours of continuous fin whale calling was detected at a location. Detections were binned into 1 hour bins for consistent result reporting.

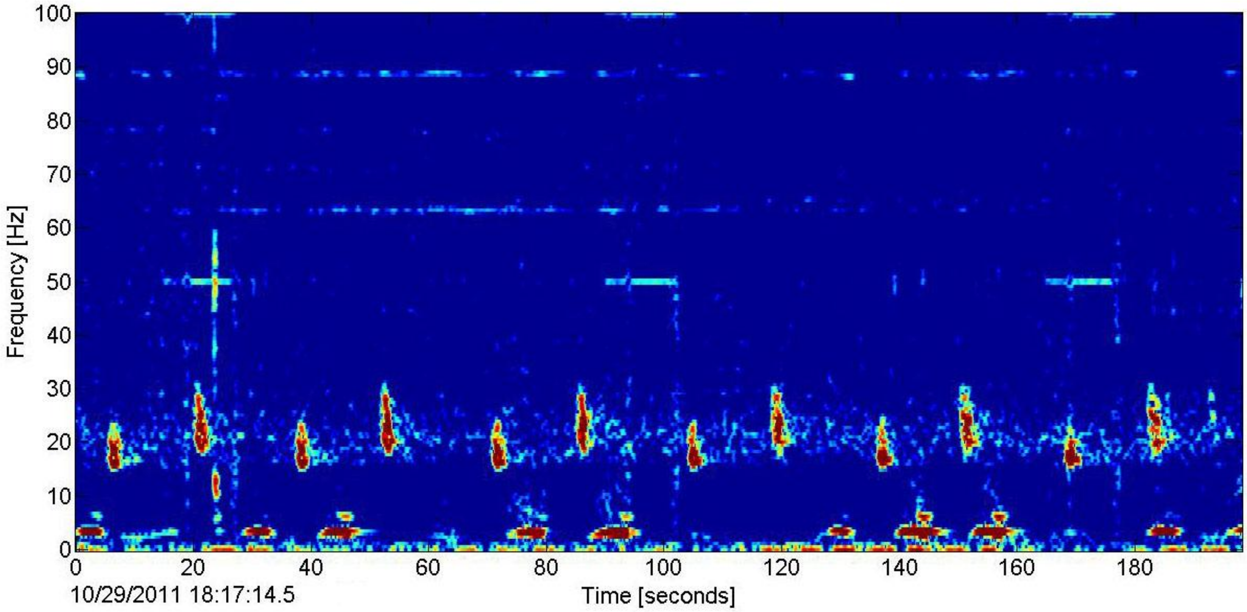

Figure 4. Fin whale 20 Hz pulsed calls, created in a regular pattern or song.

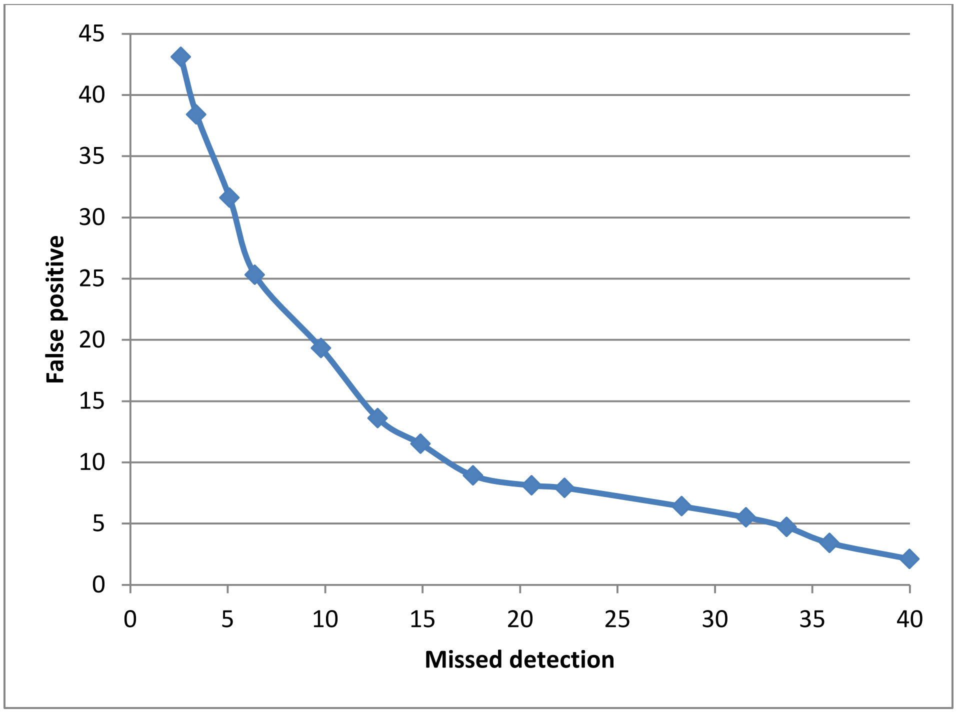

Figure 5. ROC curve for automatic fin whale 20 Hz call detector. Optimal rate of false positives and missed detections was 13.6 % and 12.7 %, respectively.

In addition to the automatic detection of 20 Hz calls, for this report, fin whale 40 Hz calls (Figure 6) were detected in the data via manual scanning of the LTSA and subsequent verification from a spectrogram of the frequency and temporal characteristics of the calls.

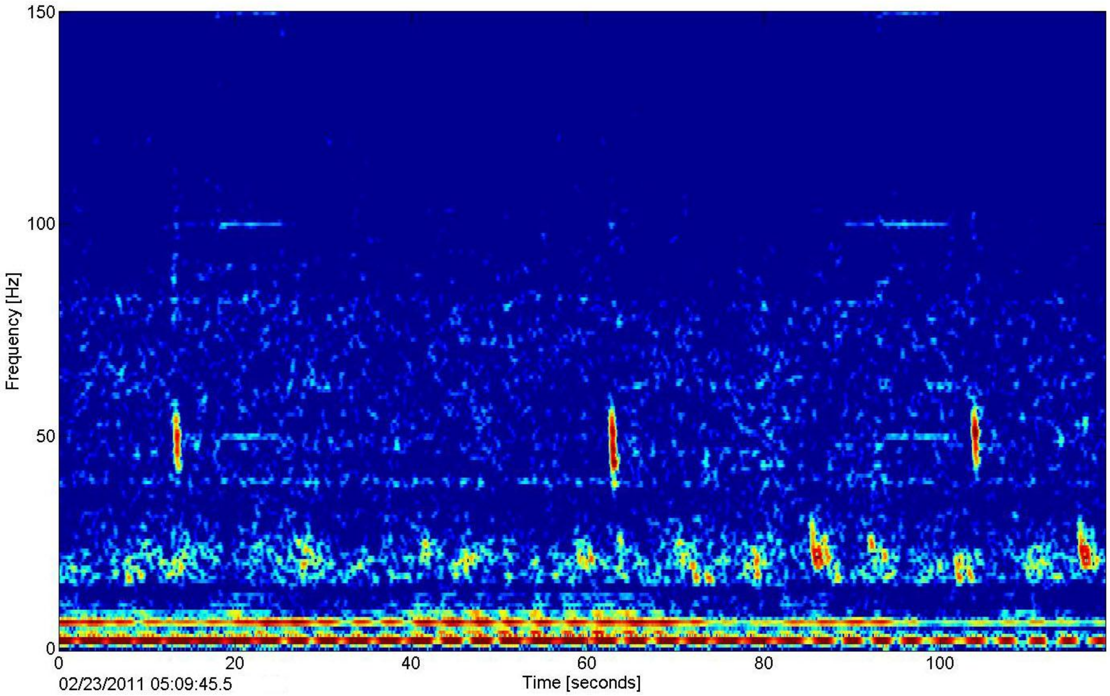

Figure 6. Fin whale 40 Hz call (2,500-point FFT and 95% overlap).

Bryde's Whales

Bryde's whales generally inhabit the warm waters of the eastern tropical Pacific and the Gulf of California, Mexico (Leatherwood et al. 1988, Tershy et al. 1991). The NWTRC region is considered beyond their northerly range limit, although there have been two recent strandings off Washington (J. Calamokidis, pers. comm). The Be4 call is one of several call types in the Bryde's whale repertoire and it is commonly recorded in the eastern North Pacific (Oleson et al. 2003, Kerosky et al. 2012). The Be4 call consists of a short, slightly upswept tone between 50 and 60 Hz. The low frequency data were monitored for the presence of this call.

Gray Whales

Gray whales produce low frequency sounds and four types of sounds have been described along their migration route between Baja California and the Bering Sea (Crane and Lashkari 1996). Call M1 consists of pulses and bonging signals. M3, the most commonly recorded call on the migration route, consists of low frequency moans. M4 are grunts and M5 are subsurface exhalations. Presence of M3 calls was monitored in the data. Detection of gray whale sounds is made more complex when humpback whale song and social sounds are present, owing to the overlap in call frequencies and the large volume of calls associated with humpback call production versus few sounds produced by migrating gray whales.

Mid-Frequency Marine Mammals

Mid-frequency marine mammal sounds monitored in this report include: minke whale boings, killer whale whistles, and pinnipeds. The LTSA search parameters used to detect each sound are given in Table 2. Humpback whale sounds were detected automatically, as described below. The start and end of each call type was logged and their durations were added to estimate cumulative hourly presence of each mid-frequency sound source in the two datasets.

Table 2. Mid-frequency data analysis parameters.

Species / Sound type	LTSA Search Parameters	
	Plot length (hr)	Frequency range (Hz)
Minke	0.5	1,000-2,000
Killer whale	0.75	10-5,000
Pinniped	0.75	200-700

Humpback Whale

Humpback whales produce different call types which can be classified as song or non-song. The song is categorized by the repetition of units, phrases and themes as defined by Payne and McVay (1971). Non-song vocalizations such as social and feeding sounds consist of individual units that can last from 0.2 to 2.5 seconds (Dunlop et al. 2007, Stimpert et al. 2011). Most humpback whale vocalizations are produced between 100-3,000 Hz (Figure 7). For this report we detected humpback calls (both song and non-song) using an automatic detection algorithm based on the power law (see Helble et al. 2012 for a detailed description of the detection algorithm). The detections were subsequently verified for accuracy by a trained analyst.

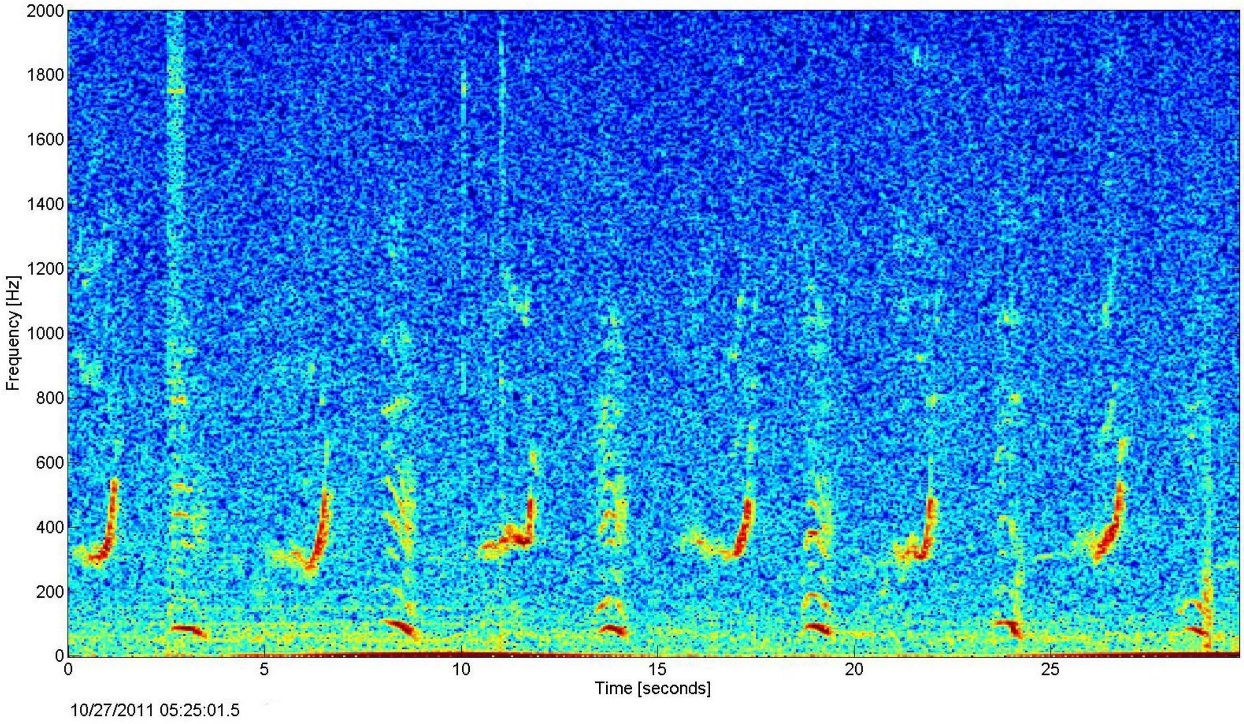

Figure 7. Spectrogram of humpback whale song segment, showing multiple units forming a phrase and a theme.

Minke Whale

Minke whale “boings” consist of 2 parts, beginning with a burst followed by a long buzz, with the dominant signal band just below 1400 Hz. A typical minke boing recorded in the eastern Pacific has an average duration of 3.6 seconds and a pulse repetition rate of 92 Hz (Rankin and Barlow 2005). Presence of minke boings was analyzed manually.

Pinniped

Most pinniped sounds off Washington are barking vocalizations, occurring between 400 and 600 Hz, and of short duration (< 1 s). However, pinniped barking bouts can last several hours at a time. As they are easily confused with humpback vocalizations in the LTSA, it was necessary to examine a short-term spectrogram view to confirm presence of pinnipeds in the data.

High Frequency Marine Mammals

High-frequency, species-specific sounds monitored in this report include: Risso’s and Pacific white-sided dolphins, killer whale, sperm whale, Stejneger’s beaked whale, Baird’s beaked whale, Cuvier’s beaked whale, and Blainville’s beaked whale. Also monitored were narrow-banded high frequency clicks likely from porpoise, and other whistles and echolocation clicks that cannot be attributed to a single species at this time. The start and end of each calling bout was logged and their durations were added to estimate cumulative hourly presence of each high-frequency sound source in the two datasets.

Unidentified Dolphin

Delphinid sounds can be categorized as whistles, buzz pulses, or echolocation clicks. Dolphin echolocation clicks are broadband impulses with the dominant energy recorded on HARPs between 20 and 60 kHz. Buzz pulses are rapidly repeated clicks that have a creak or buzz-like sound quality; they are in approximately the same frequency band as the echolocation clicks. Dolphin whistles are tonal calls predominantly between 5 and 20 kHz that vary in their degree of frequency modulation as well as duration. Some delphinid sounds are not yet distinguishable by species based on the character of their clicks, buzz pulses or whistles (Roch et al. 2007, 2011). Northern right whale dolphins (*Lissodelphis borealis*), short-beaked common dolphin (*Delphinus delphis*), bottlenose dolphins (*Tursiops truncatus*), and striped dolphins (*Stenella coeruleoalba*) make clicks and whistles that are thus far not definitively classifiable to species level and may all be encountered in this area (Jefferson et al. 2008), although only northern right whale dolphin sightings have been confirmed (Oleson et al. 2009). Since these signals are easily detectable in an LTSA as well as the spectrogram (Figure 8), they were monitored during this analysis effort and are characterized as unidentified dolphin signals.

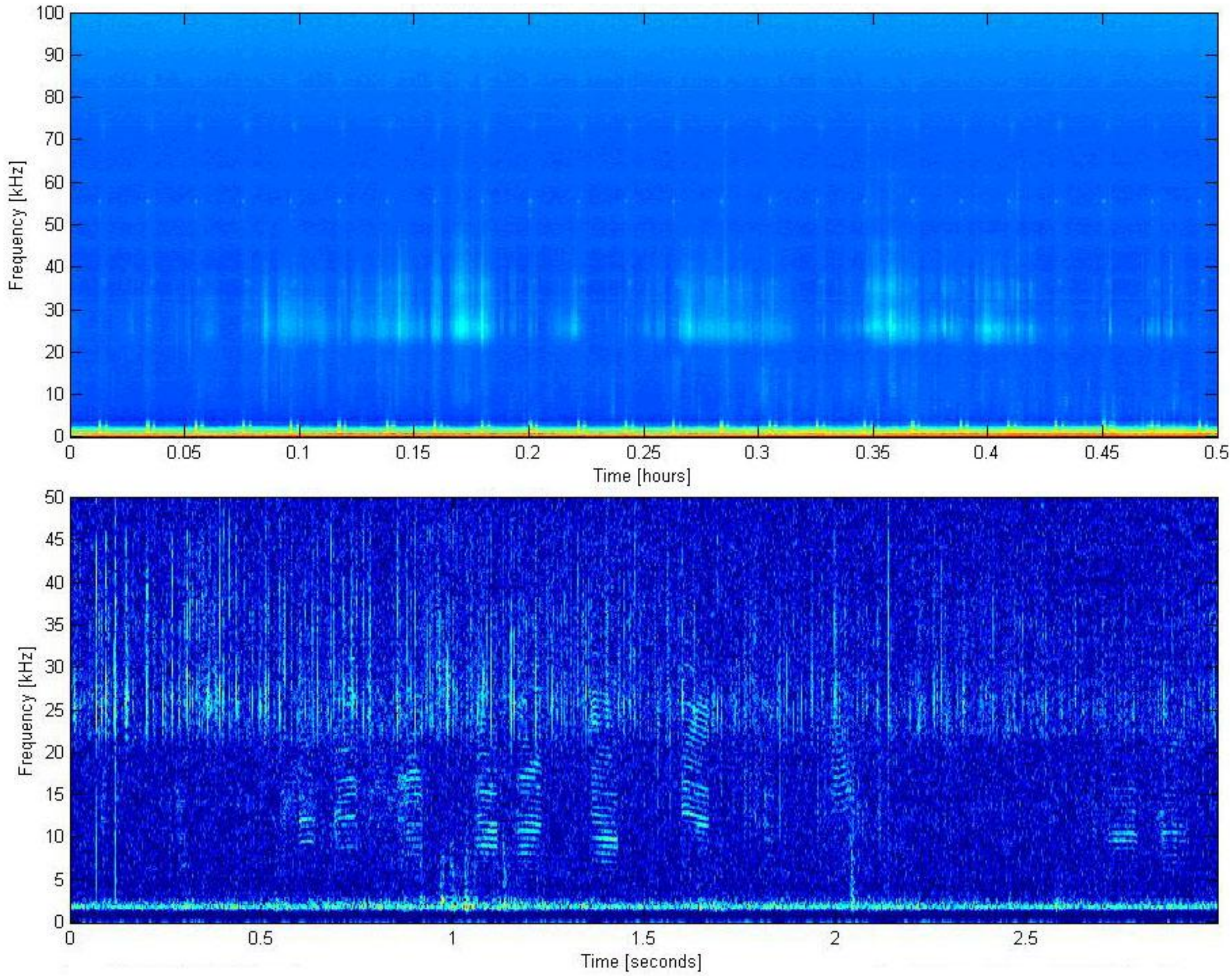

Figure 8. LTSA (top) and spectrogram (bottom; 1,000 point FFT and 50% overlap) of unidentified odontocete signals.

Risso’s Dolphin

Risso’s dolphin echolocation clicks can be identified to species by their distinctive banding patterns observable in the LTSA (Figure 9). Risso’s dolphin echolocation clicks recorded offshore southern California have energy peaks at 22, 26, 30, and 39 kHz (Soldevilla et al. 2008), and it is expected that their energy peaks will be similar in the NWTRC area.

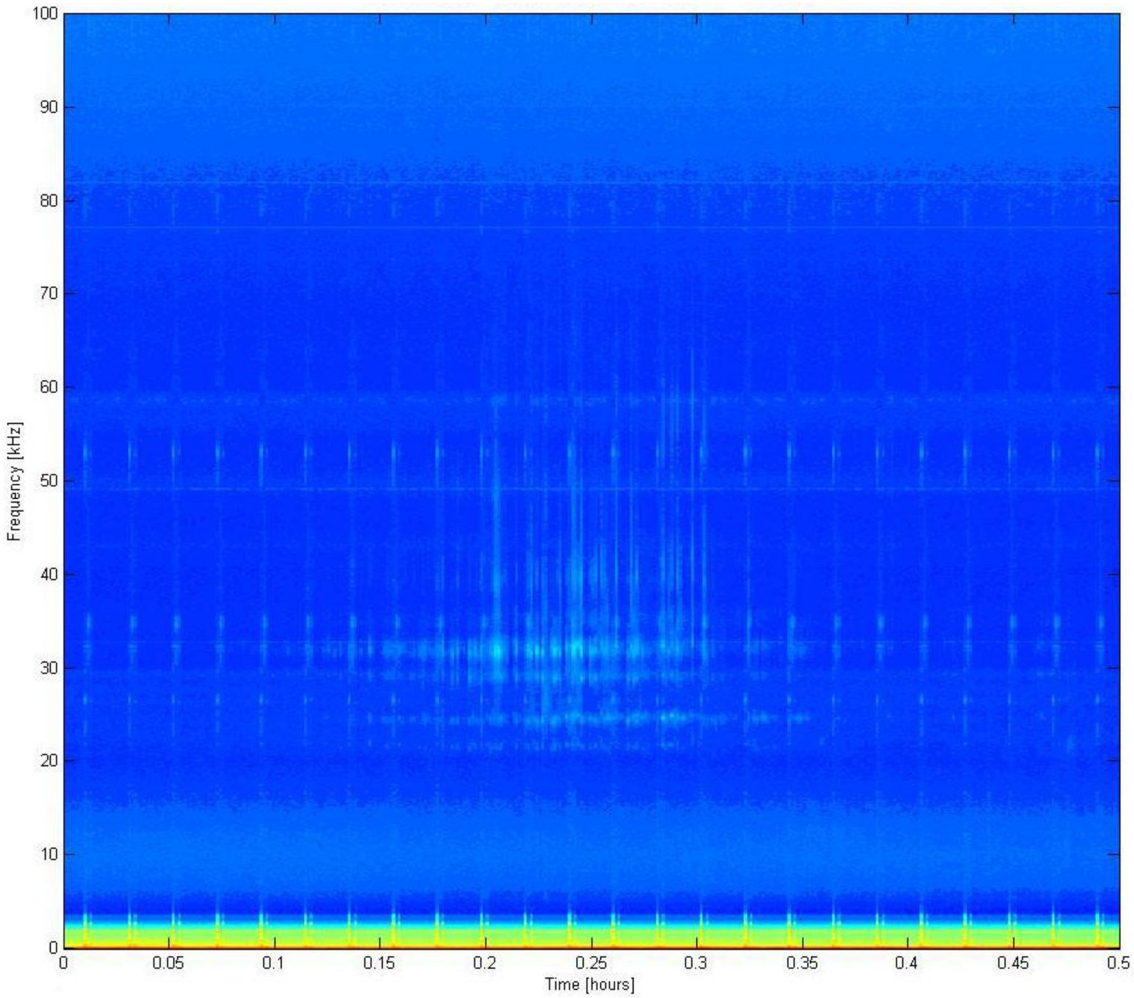

Figure 9. Risso's dolphin click bout in a LTSA. Note a distinctive banding pattern.

Pacific White-Sided Dolphin

Pacific white-sided dolphin echolocation clicks also can be identified to species by their distinctive banding patterns (Figure 10). Pacific white-sided dolphin echolocation clicks recorded offshore southern California have two distinctive patterns of energy peaks, designated type A and type B (Soldevilla et al. 2010). The type A group occupies the northern portion of the southern California Bight, whereas both groups are known from the southern portion of the Bight. Since Pacific white-sided dolphins are thought to seasonally migrate, the type A group is more likely to be found within the NWTRC. The type A dolphins' echolocation clicks have energy peaks at 22, 27, 33, and 37 kHz (Soldevilla et al. 2008).

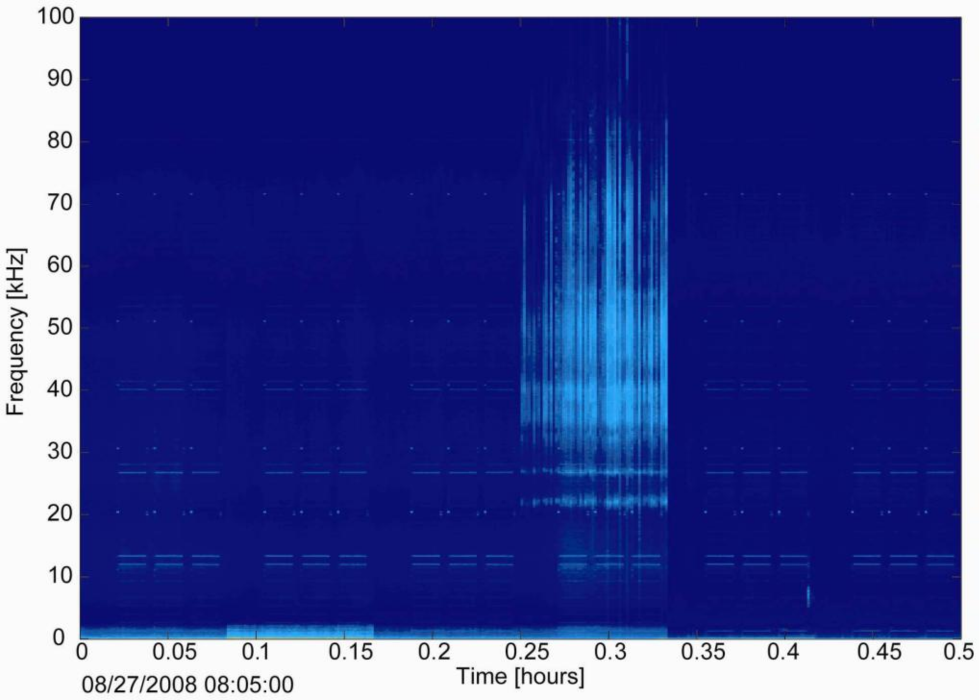

Figure 10. Pacific white-sided dolphin echolocation clicks in a LTSA.

Killer Whale

Killer whales are known to produce four call types: echolocation clicks, low frequency whistles, high-frequency modulated signals, and pulsed calls (Ford et al. 1989, Samarra et al. 2010, Simonis et al. 2012). Killer whale pulsed calls are well documented and are the best described of all killer whale call types. Pulsed calls' primary energy is between 1 and 6 kHz, with high frequency components occasionally >30 kHz and duration primarily between 0.5 and 1.5 seconds (Ford et al. 1989). High frequency modulated signals have only recently been attributed to killer whales in both the northeast Atlantic (Samarra et al. 2010) and the northeast Pacific (Simonis et al. 2012). These whistles have fundamental frequencies between 17 and 75 kHz, the highest of any known delphinid whistles. Pulsed calls and the ultrasonic whistles were used for killer whale species identification in this analysis.

Sperm Whale

Sperm whale clicks generally contain energy from 2-20kHz, with the majority of energy between 10-15 kHz (Møhl et al. 2003). Regular clicks, observed during foraging dives, demonstrate a uniform inter-click interval from 0.25-2 seconds (Goold and Jones 1995, Madsen et al. 2002, Møhl et al. 2003). Short bursts of closely spaced clicks called creaks are observed during foraging dives and are believed to indicate a predation attempt (Watwood et al. 2006). Sperm whales also produce other clicks, which can be classified as slow clicks and codas. Slow clicks are used only by males and are more intense than regular clicks with long inter-click intervals (Madsen et al. 2002). Codas are stereotyped sequences of clicks which are less intense and contain lower peak frequencies than regular clicks (Watkins and Schevill, 1977). Multiple foraging dives and rest periods are often observed over a long period of time in the LTSA. Although ship noise can be confused with sperm whales in the LTSA, in the finer resolution of a spectrogram, the erratic impulses from mechanical noise and propeller cavitation can be easily distinguished from the continuous, regular sperm whale clicks.

Stejneger's Beaked Whale

Stejneger's beaked whales are known to occur with some regularity in the northern Pacific Ocean. Their clicks are easily distinguished from other species' acoustic signals; they have the typical beaked whale polycyclic click structure and frequency-modulated (FM) upsweep with a peak frequency above 50 kHz and uniform inter-pulse interval around 0.1s (Figure 11; Baumann-Pickering et al. 2012).

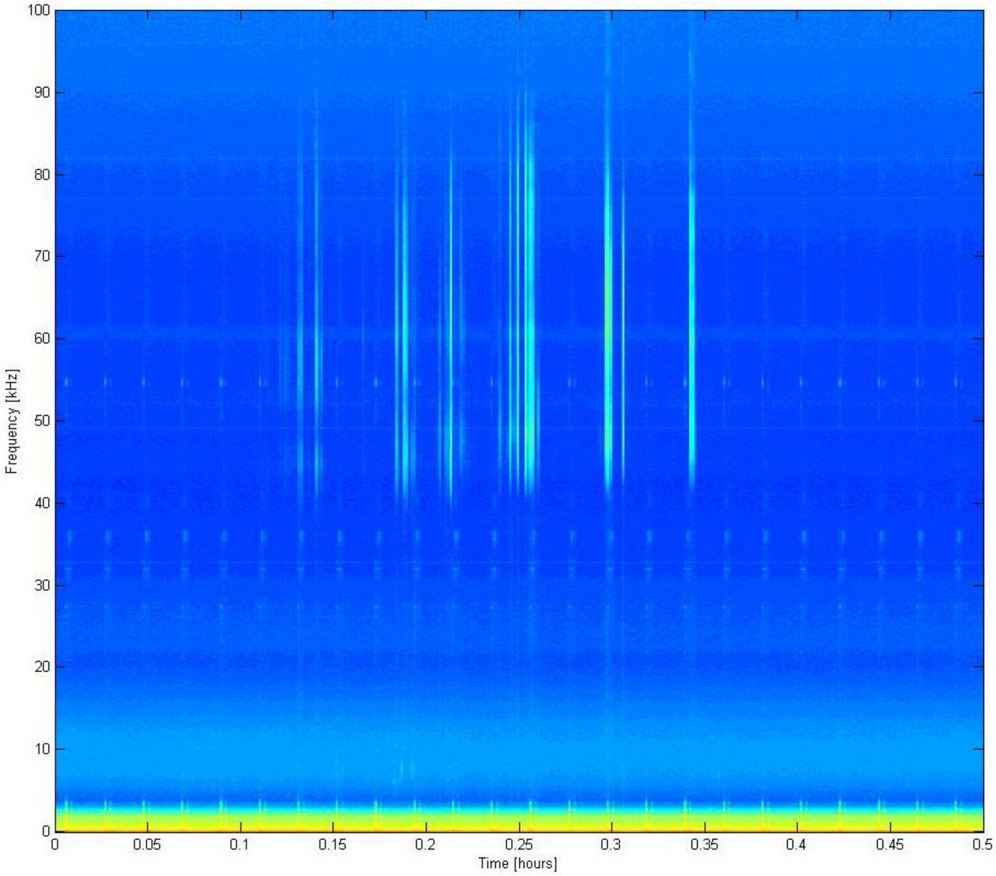

Figure 11. Stejneger's beaked whale clicks in a LTSA.

Baird's Beaked Whale

Baird's echolocation clicks are distinguishable from other species' acoustic signals and one of their signal types demonstrates the typical beaked whale polycyclic, FM upsweep (Dawson et al 1998). These clicks are easily identifiable because they are lower frequency than other beaked whale clicks. Spectral peaks are notable around 15, 30 and 50 kHz (Figure 12).

Cuvier's Beaked Whale

Cuvier's echolocation clicks are also well differentiated from other species' acoustic signals as polycyclic, with a characteristic FM upsweep, peak frequency around 40 kHz, and uniform inter-pulse interval of about 0.4s (Johnson et al. 2004, Zimmer et al. 2005). An additional feature that helps with the identification of Cuvier's signals is that they have two characteristic spectral peaks around 17 and 23 kHz (Figure 13).

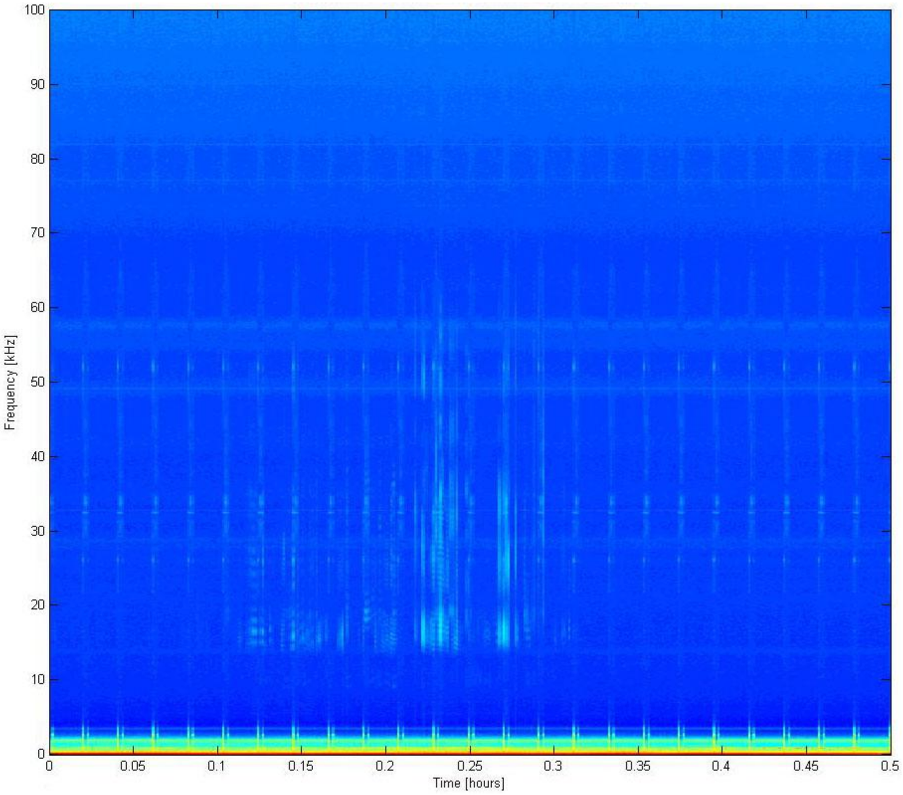

Figure 12. Baird's beaked whale clicks in a LTSA.

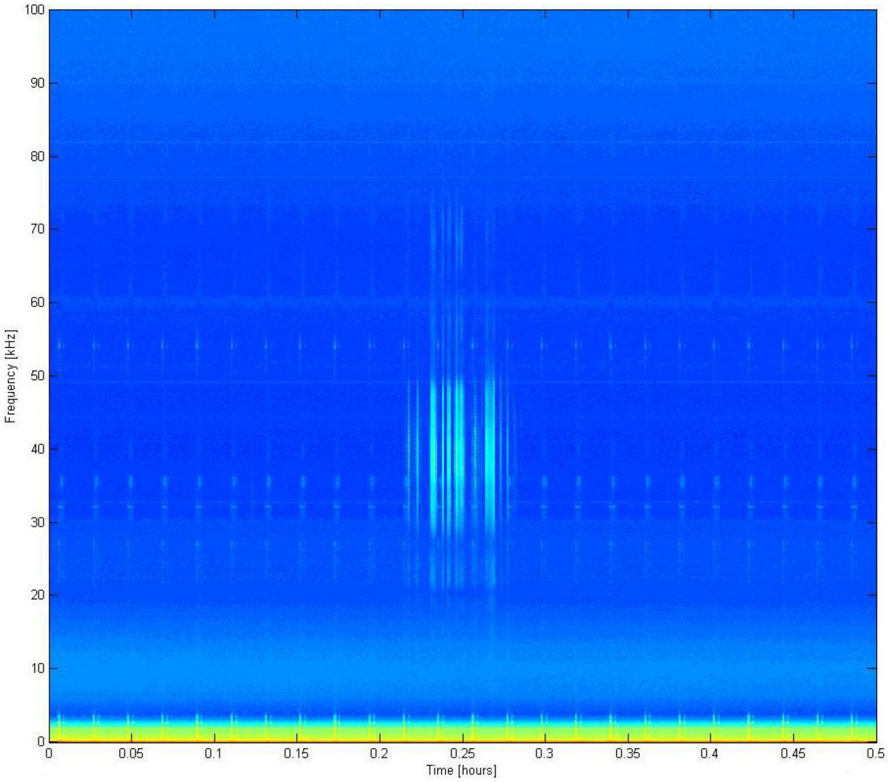

Figure 13. Cuvier's beaked whale clicks in a LTSA.

Blainville's Beaked Whale

Blanville's beaked whales produce a distinctive echolocation click with a typical wide FM upsweep with a -10 dB bandwidth from 26-51 kHz, a well differentiated sharp cut-off below 25 kHz, and a peak frequency around 30 kHz (Figure 14). These clicks also have a regular inter-pulse interval of about 0.3 s (Johnson et al. 2006).

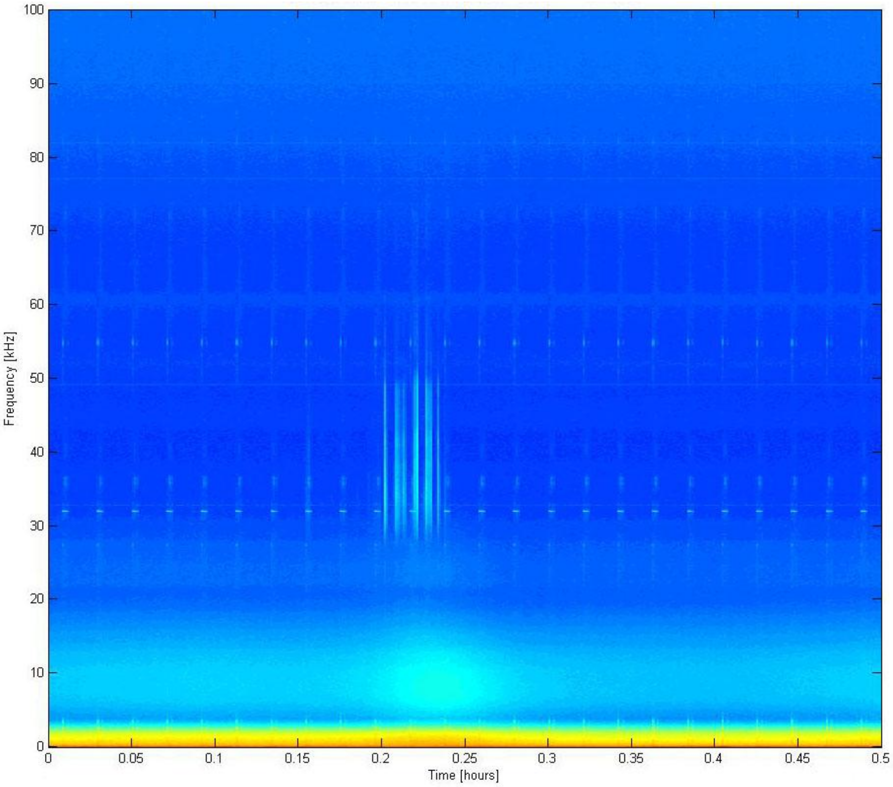

Figure 14. Blainville's beaked whale clicks in LTSA.

Unidentified Beaked Whale

All other beaked whale-type frequency modulated pulses that had a constant inter-pulse interval, but their signal quality was not sufficient for species identification, were categorized and logged as unidentified beaked whale signals.

Unidentified Porpoise

Harbour porpoises (*Phocoena phocoena*) and Dall's porpoises (*Phocoenoides dalli*) were the most frequently sighted marine mammals during visual surveys in the area (Oleson et al. 2009, 2010). Both Dall's and harbour porpoises produce clicks that contain energy from 115-150 kHz (Verboom and Kastelein 1995), higher frequency than the bandwidth of these recordings. Narrow-banded high frequency (NBHF) clicks, with energy from 55-85 kHz and a narrower bandwidth than typical delphinid clicks, were frequently identified in this dataset (Figure 15). There is no known cetacean in the study area which produces echolocation clicks of this description and these NBHF clicks are most likely a result of spectral aliasing (mirroring of energy from above the recording band into the recording band) of porpoise clicks produced with high source levels in very close proximity to the recorder.

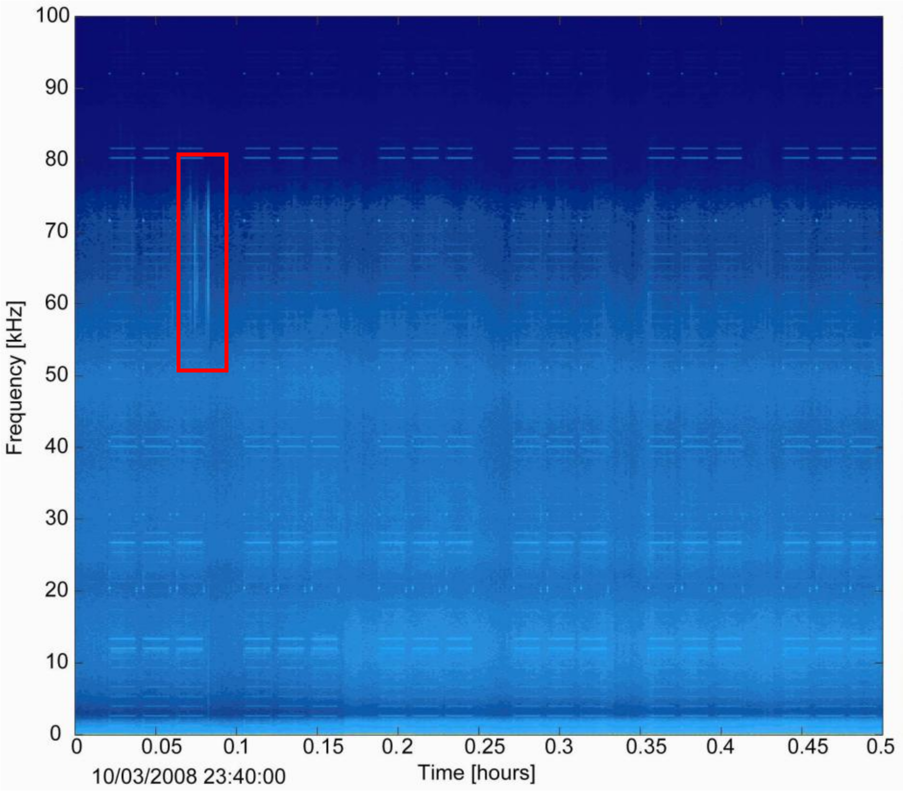

Figure 15. LTSA of narrow-banded high frequency (NBHF) pulses (outlined by a red box), likely aliased porpoise pulses recorded at site CE.

Anthropogenic Sounds

Several anthropogenic sounds occurring at mid-frequency ranges (<5 kHz) were also monitored for this report: broadband ship noise, mid- frequency active (MFA) sonar, and explosions. The LTSA search parameters used to detect each sound are given in Table 3. The start and end of each sound or session was logged and their durations were added to estimate cumulative hourly presence of each mid-frequency sound source in the two datasets.

Table 3. Mid-frequency anthropogenic sound data analysis parameters.

Species / Sound type	LTSA Search Parameters	
	Plot length (hr)	**Frequency range (Hz)**
Broadband Ship Noise	3.0	10-5,000
MFA Sonar	0.75	1,000-5,000
Explosions	0.75	10-5,000

Broadband Ship Noise

Broadband ship noise occurs when a ship passes relatively close to the HARP. Ship noise can occur for many hours at a time, but broadband ship noise typically lasts from 10 minutes up to 3 hours. Ship noise has a characteristic interference pattern in the LTSA. Combination of direct paths and surface reflected paths produce constructive and destructive interference (bright and dark bands in the spectrogram) that varies by frequency and distance between the ship and the HARP (Figure 16). This noise can extend to well above 10 kHz, though typically falls off above a few kHz.

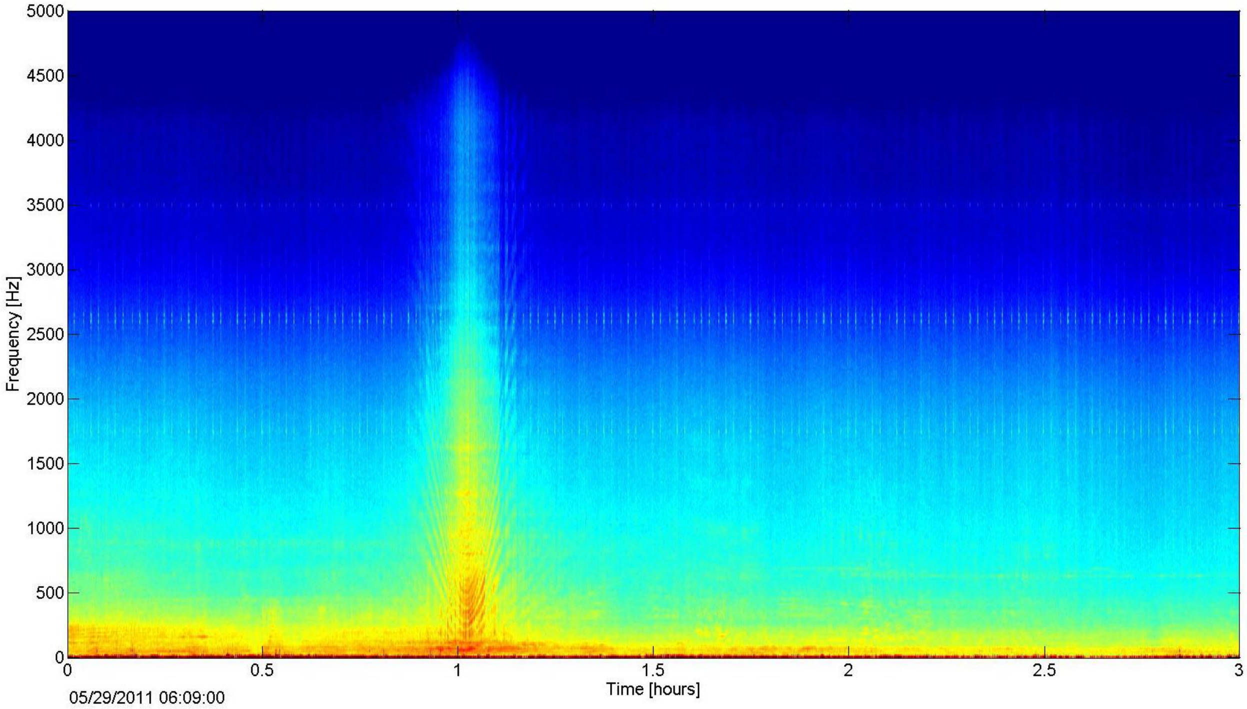

Figure 16. Broadband ship noise in the LTSA.

Mid-Frequency Active (MFA) Sonar

Sounds from MFA sonar vary in frequency and duration and can be used in a combination of frequency modulated (FM) sweeps and continuous wave (CW) tones. While they can span frequencies from about 1 kHz to over 50 kHz, many are between 2.0 and 5.0 kHz and are more generically known as ‘3.5 kHz’ sonar. In this section, we describe the process for identifying sessions or events of MFA sonar in recordings from HARPs and how pings from these sessions were analyzed, including counts and distributions of sonar levels.

The first step in analyzing MFA sonar was conducted by visual scanning of LTSAs for periods of sonar activity. Individual MFA sonar pings typically span 1 - 3 s, but are intense enough to show up as ‘pulses’ in LTSA plots (Figure 17). Start and end times of MFA sonar events were logged manually to provide target periods for automatic detections. A custom-developed MATLAB routine was used to detect sonar pings and calculate peak-to-peak (PP) received sound pressure levels using manually picked target periods. For this detector, a sonar ping was defined as the presence of sonar within 5 s. The average spectrum level across the frequency band from 2.4 to 4.5 kHz for each 5 s time bin was calculated. This provides a time series of the average received levels in that frequency band. Minimum values were noted for each 15 time bins, and used as a measure of background noise level over the sonar event period. Spectral bins that contained system noise (disk writing) were eliminated to prevent contamination in the results. Each of the remaining average spectral bins was compared to the background minimum levels. If levels were more than 3 dB above the background, then a detection time was noted. These detection times were used to index to the original time series to calculate peak-to-peak (PP) levels. Received PP levels were calculated by differencing the maximum and minimum amplitude of the time series in the 5 s window. The raw time series amplitudes are in units of analog-to-digital converter (ADC) counts. These units were corrected to µPa by using the HARP calibrated transfer function for this frequency band. The HARP response is not flat over the 2.4 – 4.5 kHz band, so a middle value at 3.5 kHz was used. The transfer function value used was 84.3 dB re µPa^2/counts^2. For sonar pings less than this middle frequency, the levels are overestimated up to about 7 dB and for higher frequency sonar the levels are underestimated up to about 1 dB.

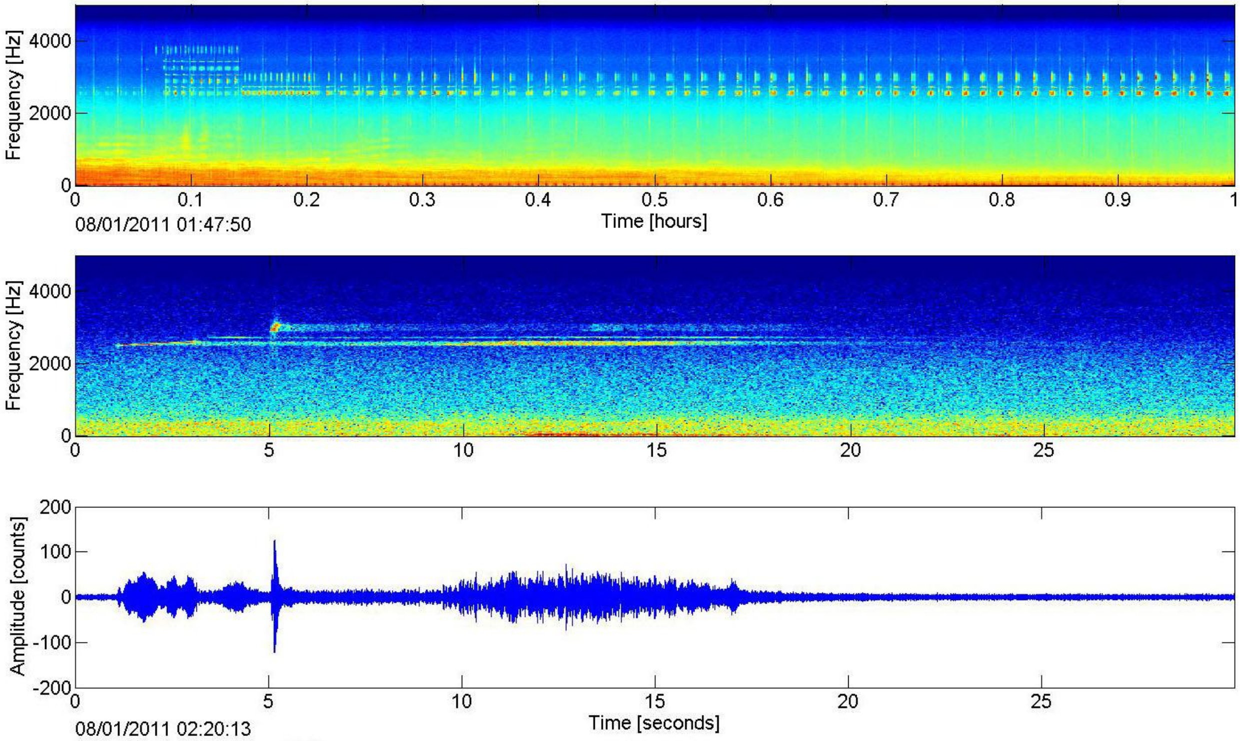

Figure 17. Mid-frequency active (MFA) sonar event. LTSA of one-hour of data (top) with 30 seconds of the event with multiple sonar pings showed zoomed in on a spectrogram (middle) and in a time series (bottom).

Explosions

Explosive sounds logged in the HARP data can include military explosions, shots from sub-seafloor exploration, and seal bombs used by the fishing industry. An explosion appears as a vertical spike in the LTSA which, when expanded in the spectrogram, has a sharp onset with a reverberant decay (Figure 18). These sounds have peak bandwidth as low as10 Hz but often extend over 2,000 Hz, lasting for a few seconds including the reverberation.

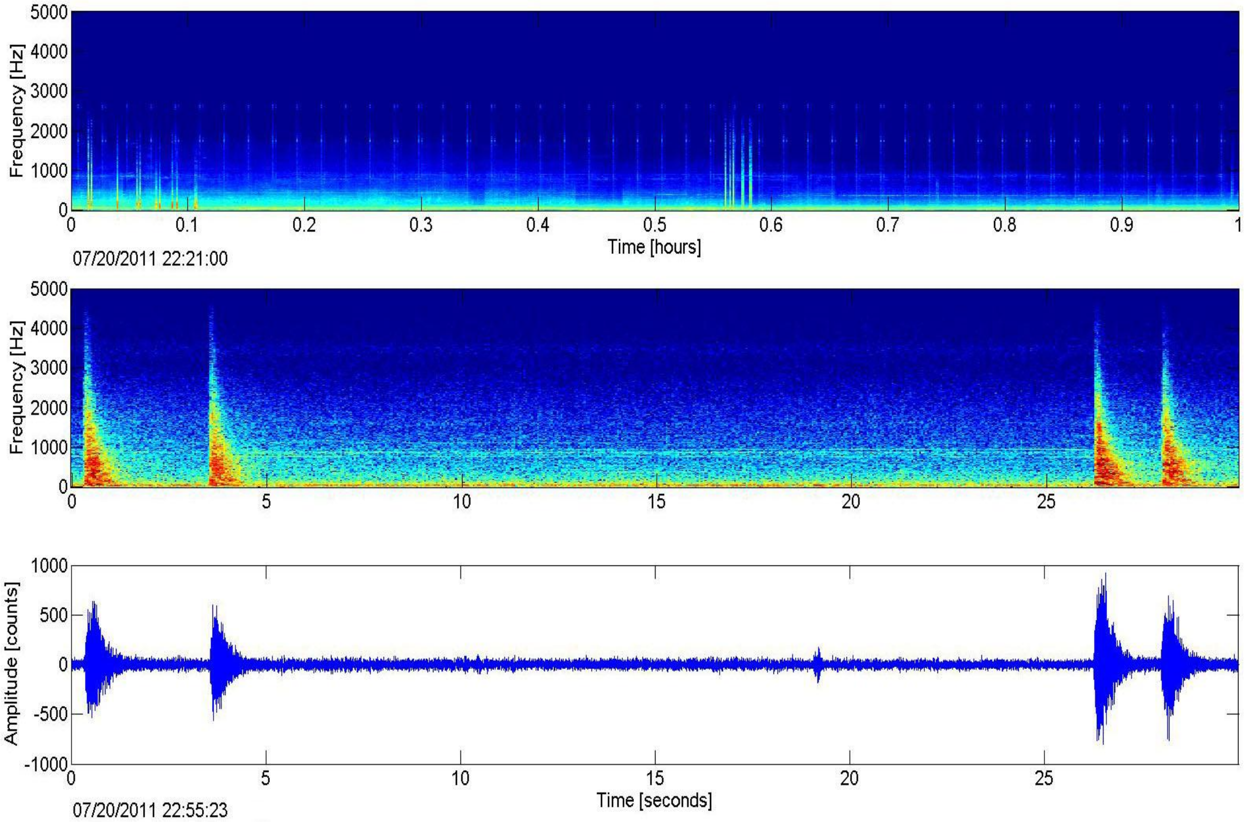

Figure 18. Multiple explosions are seen in the LTSA (top) and four individual events of these are expanded in the spectrogram (middle) and time series (bottom).

Results

This report summarizes the results of acoustic data collection at two sites in the NWTRC from January through November 2011. We present ambient noise levels and the seasonal occurrence of marine mammal species and anthropogenic sounds recorded at these two locations.

Ambient Noise

Underwater ambient noise at sites QC (slope) and CE (shelf) shows little seasonal variation (Figure 19). The noise levels are typically higher at QC than at CE at frequencies < 100 Hz, but the trend is reversed at frequencies above 100 Hz. At site QC, there is a clear contribution from distant ship noise at frequencies <100 Hz. At frequencies above 100 Hz, local wind and waves dominate the noise (Hildebrand 2009) and are generally lower during the summer. Ambient noise at site CE does not show contribution from distant shipping, but is more influenced by local boating activity, as evidenced by the jagged appearance of the spectra. There is a prominent seasonal peak in noise at 20-30 Hz during the fall and winter, indicative of the presence of blue and fin whale calls.

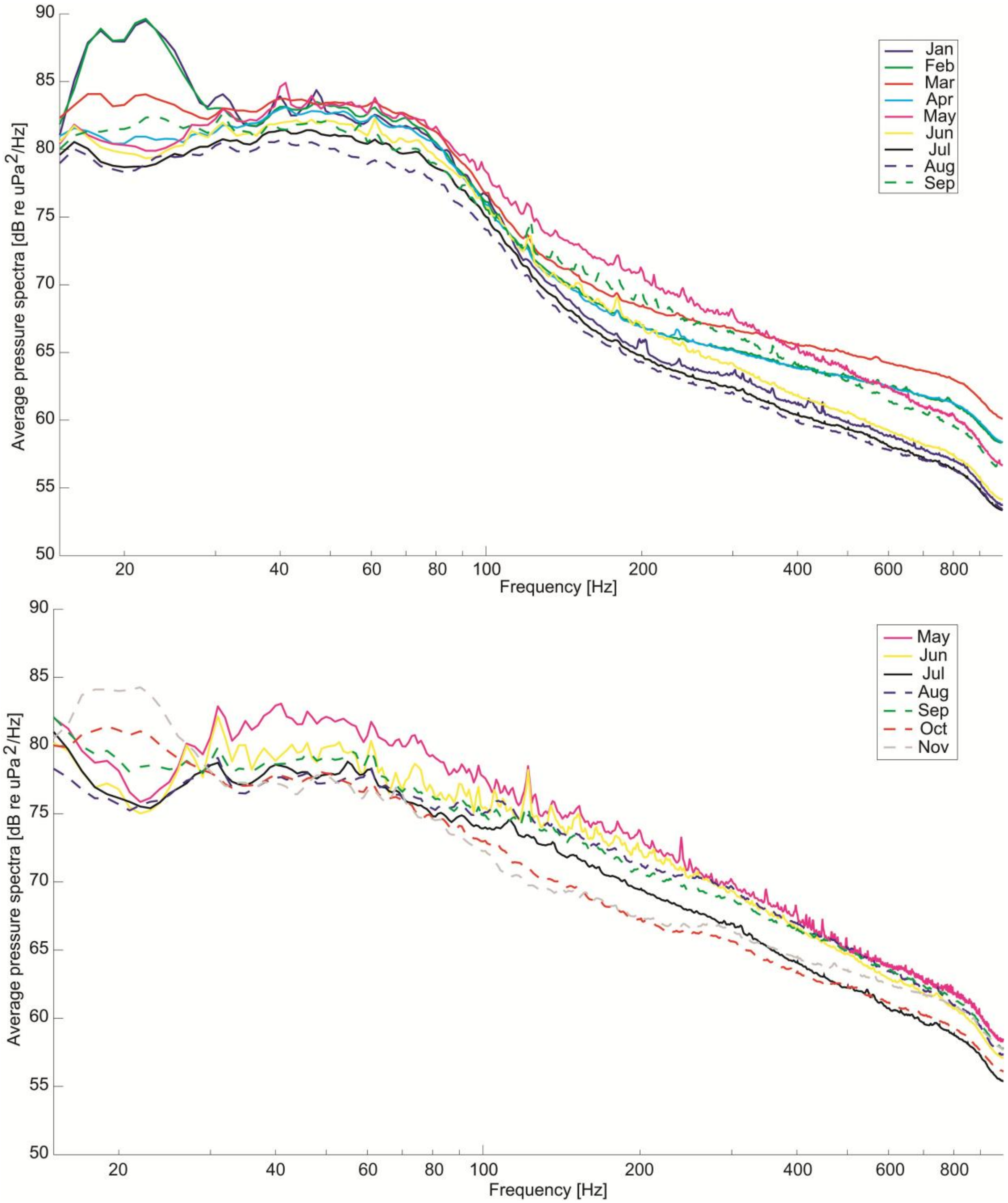

Figure 19. Monthly averages of ambient noise at sites QC (top) and CE (bottom) from January through November 2011. Legend gives color-coding by month.

As an example, Figure 20 shows percentile distributions of sound spectrum levels during the month of August at each site. Distributions are long-tailed for higher values, as is typical for noise, with median values in Figure 20 less than the means in Figure 19. Overall, there is approximately 4 dB difference between the sites at frequencies <100 Hz (site CE is quieter), but at higher frequencies the noise levels across all distributions are 7-8 dB higher at site CE.

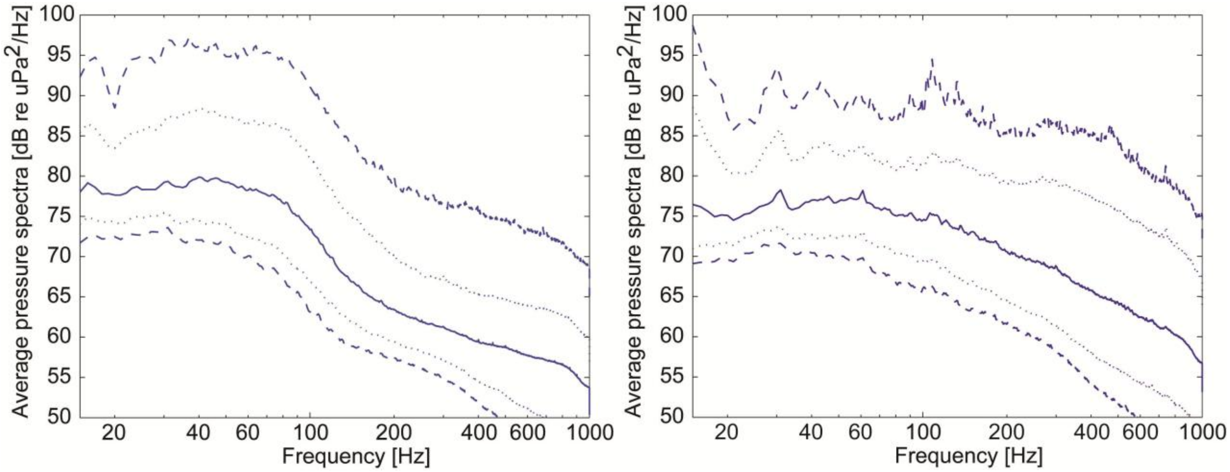

Figure 20. Sound spectrum levels in the month of August at sites QC (left) and CE (right). Distributions are represented by the median (50th percentile; full line), 90th and 10th percentiles (dotted lines), and 99th and 1st percentiles (broken lines).

Mysticetes

Three baleen whale species were detected during 2011 at sites QC and CE: blue whales, fin whales, and humpback whales. Relative calling abundance varied among sites and species; blue whale B calls were equally common at both sites, fin whale calls were more common on the slope site QC, and humpback whale calls were more common closer to shore at site CE. No Bryde's or minke whale calls were detected at either site. More details of each species' presence at these sites are given below.

Blue Whales

Blue whale B calls were detected at both sites during this monitoring period. Peak in hours with detections occurred in February at site QC, while the peak at CE site was in September (Figure 21). No calls were detected at either site between April and July, with summer detections starting later at site CE. Blue whale D calls were detected on two days in August at site CE. This seasonal presence is consistent with previously reported seasonal occurrence of blue whale calls off Washington (Watkins et al. 2000, Burtenshaw et al. 2004, Širović et al. 2011).

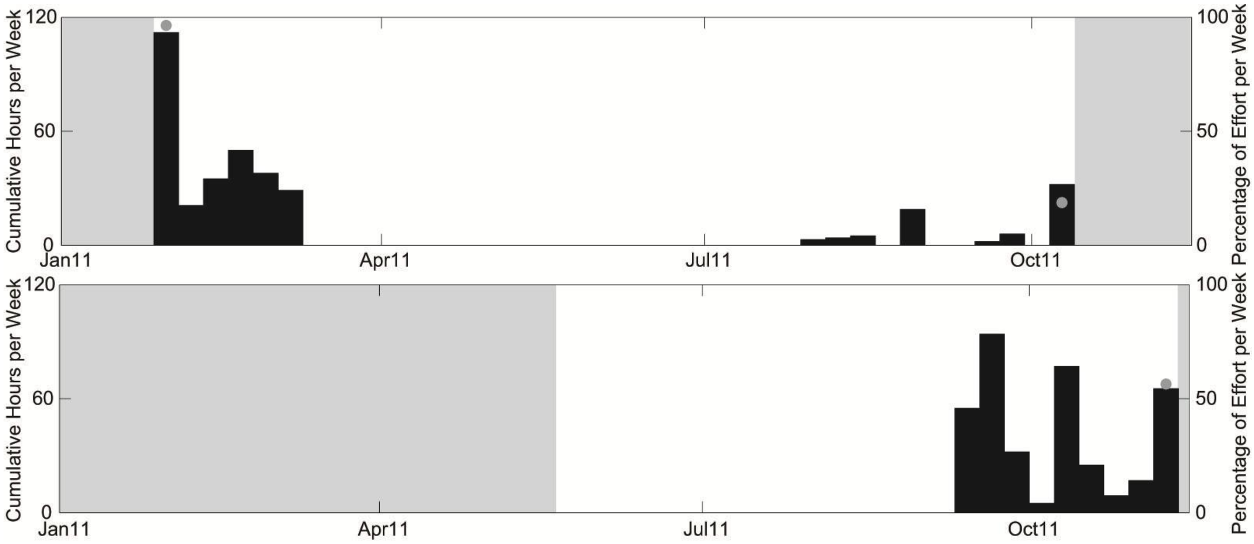

Figure 21. Weekly presence of blue whale B calls (black bars) at sites QC (top) and CE (bottom) during 2011. Grey dot represents percent of effort per week in weeks with less than 100% recording effort and grey shading marks show periods with no recording effort. Where grey dots or shading are absent, full recording effort occurred for the entire week.

Fin Whales

Fin whales were the most common acoustically detected baleen whale at both sites and their calls were detected at both sites with peak calling in fall and winter and low calling during the summer (Figure 22). High number of hours with calls was detected at site QC from January to April and again in October. At site CE, number of hours with calls increased through the fall with a peak in November. Farther offshore in the eastern North Pacific, fin whale calls are generally detected from October through April (Watkins et al. 2000), corresponding to the pattern we observed at our sites during 2011.

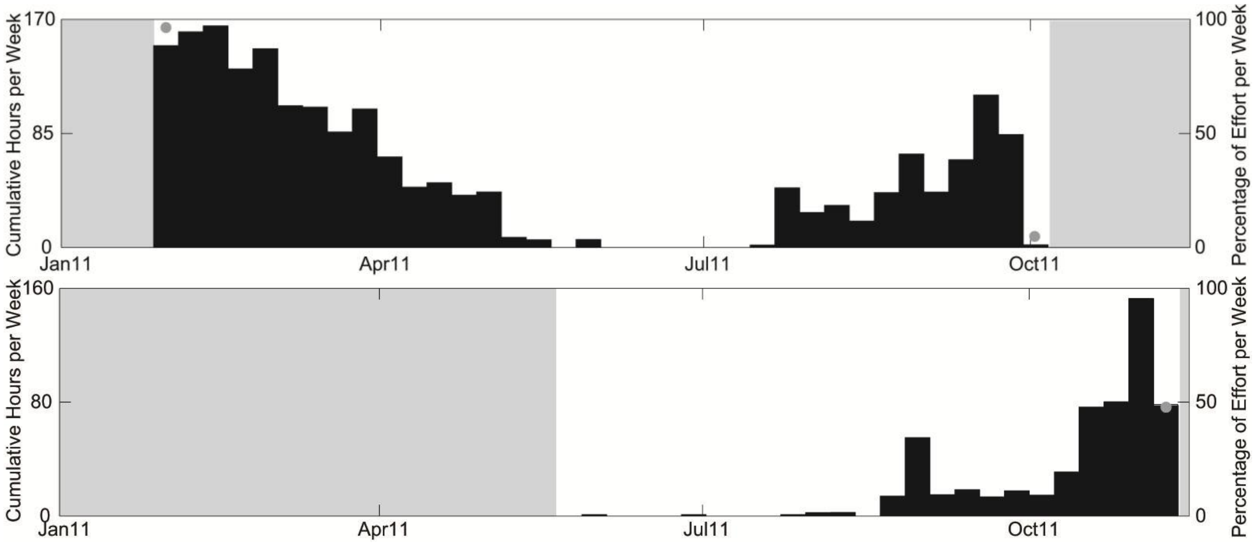

Figure 22. Weekly fin whale 20 Hz call presence at sites QC (top) and CE (bottom) between January and November 2011. Effort markings are as described in Figure 21.

An additional fin whale sound, 40 Hz call, was only recorded at site QC (Figure 23). While there were generally fewer hours with 40 Hz calls than the 20 Hz calls, the seasonality of the 40 Hz call was similar to that of the 20 Hz calls, although it may show a slight lag. Calling was most common from March through May, with a decrease during the summer and absence of calls in the fall. There was no increase in 40 Hz calls in the fall as was evident in 20 Hz calls. It is possible that no 40 Hz calls were detected at site CE because of masking, as there were long periods of low frequency pulsing sounds prevalent at this site that overlapped in frequency with the bandwidth of 40 Hz calls and may have made it impossible to distinguish their presence in LTSAs.

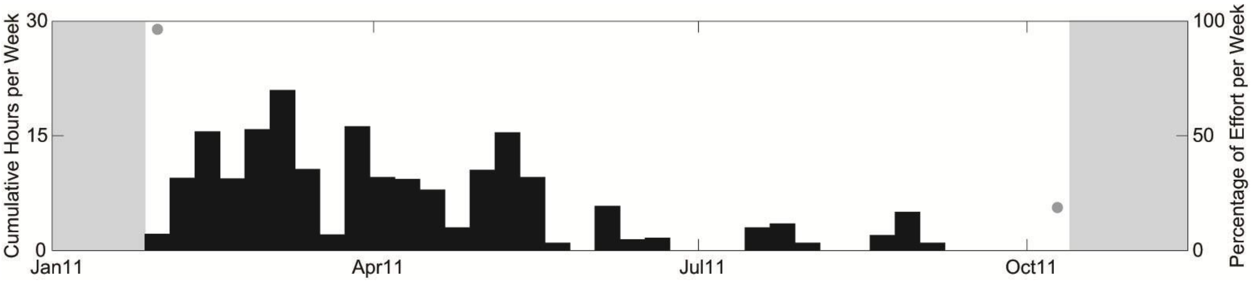

Figure 23. Weekly fin whale 40 Hz call presence at site QC during 2011. No 40 Hz calls were detected at site CE. Effort markings are as described in Figure 21.

Bryde's Whales

No Bryde's whale calls were detected at either of the sites during the monitoring period. While there have been a few recent strandings of Bryde's whales off Washington, this area is generally beyond their normal range (Kerosky et al. 2012).

Gray Whales

No confirmed gray whale calls were recorded at either site, even though the coastal location is on their migratory path, there is a known summer-resident population in this area, and gray whales calls were previously reported at the shelf site CE nearly year-round (Širović et al. 2011). The detection of gray whale calls was difficult due to the abundance of humpback whale social sounds during most of the recording period at site CE. These humpback sounds covered much of the same bandwidth as gray whale M3 calls, and since some parts of humpback signals bore a resemblance to those gray whale calls, assigning species to calls was often impossible. These types of social humpback whale sounds were not previously detected at this site with the same abundance. More details on the acoustic repertoire of the resident gray whale population, as well as details of social call structure by humpback whales in this region would be beneficial for future efforts of gray whale call detection at these sites.

Humpback Whales

Both song and non-song call types were grouped for this analysis of humpback whale presence. Humpback whales were detected more commonly at site CE, with detections increasing from September through November, which is consistent with previous recordings showing overwintering presence at this site (Oleson et al. 2009, Širović et al. 2011). This time is the peak time for humpback singing (Širović et al. 2011) so it is likely that a large portion of the hourly detections were songs. The lower level of calling from February through July is also consistent with previous findings (Oleson et al. 2009, Širović et al. 2011). Visual and acoustic detections of humpback whales in this area do not fully overlap (Oleson et al.

2010), which is likely due to the difference in the availability of animals for different types of surveys based on their behavioral state.

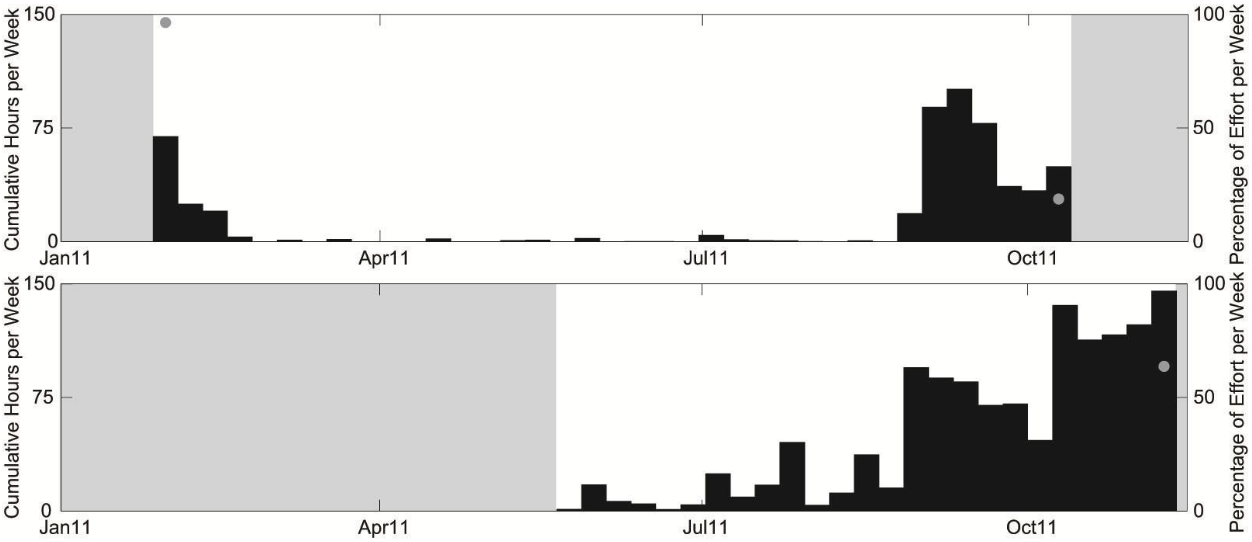

Figure 24 Weekly presence of all humpback whale calls (black bars) at sites QC (top) and CE (bottom) during 2011. Effort markings are as described in Figure 21.

Minke Whales

No minke whale boings were detected at either of the monitored sites. This is consistent with the results of previous monitoring efforts in this area (Širović et al. 2011).

Pinnipeds

Pinniped barks were detected only twice during a single day (27 October 2011) at site CE (Figure 25). Both calls occurred during nighttime (Appendix). Site QC may be too far from shore to be suitable habitat for barking pinnipeds. Pinniped sounds are not frequent at this site (Širović et al. 2011), but a variety of pinnipeds, including California sea lions (*Zalophus californianus*), Steller sea lions (*Eumetopias jubatus*), northern fur seals (*Callorhinus ursinus*), harbor seals (*Phoca vitulina*), and northern elephant seals (*Mirounga angustirostris*), have been sighted in this area over the last decade (Oleson et al. 2009).

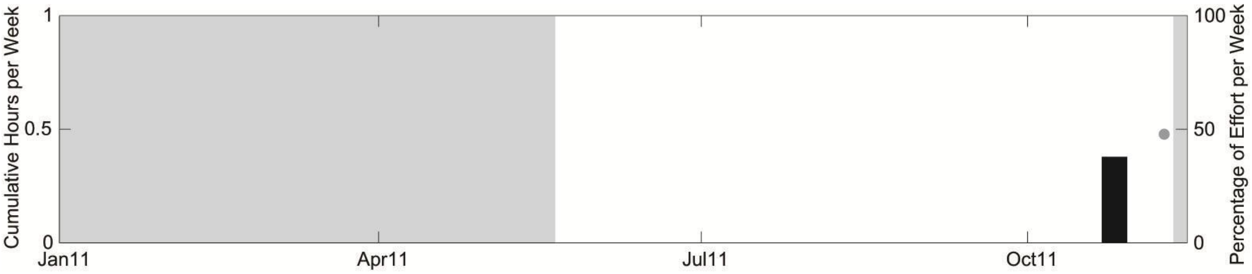

Figure 25. Weekly pinniped bark presence at site CE between May and November 2011. Effort markings are as described in Figure 21. No pinnipeds were detected at site QC during this time period.

Odontocetes

Unidentified Dolphin

A large number of odontocete detections for echolocation clicks and whistles were attributed to the "unidentified dolphin" category. Unidentified dolphins were detected during most of the year at both sites, but they were more common on the slope site QC (Figure 26). It is likely that the detections at the offshore site were from either short-beaked common dolphins or northern right whale dolphin, while the detections at CE may be from either of those two species or even bottlenose dolphins.

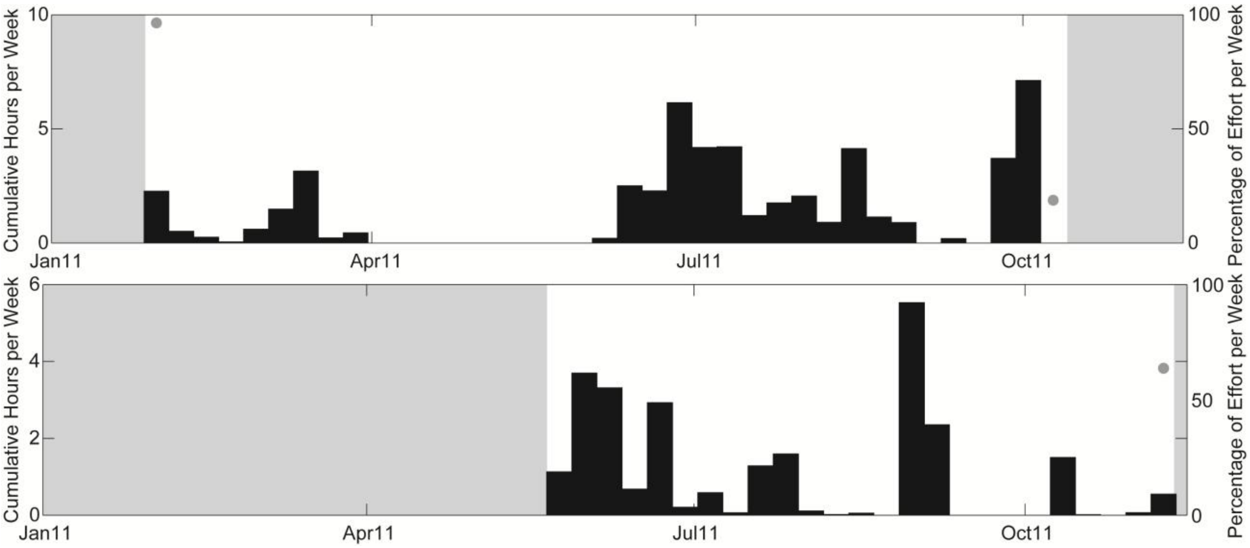

Figure 26. Weekly unidentified odontocete whistles, buzz pulses, and echolocation click presence at sites QC (top) and CE (bottom) during 2011. Note that the y-axis scale is different at the two locations. Effort markings are as described in Figure 21.

Risso's Dolphin

Risso's dolphin echolocation clicks were most common on the offshore site, QC, during the summer, from July to September (Figure 27). There was a diel pattern in their echolocation clicks, with higher activity at night indicating nighttime foraging (see Appendix). This diel activity is consistent with previous reports in other areas (Soldevilla et al. 2010), but Risso's clicks were not previously reported from the inshore site (Širović et al. 2011) and were less common in previous years on the slope site (Oleson et al. 2009).

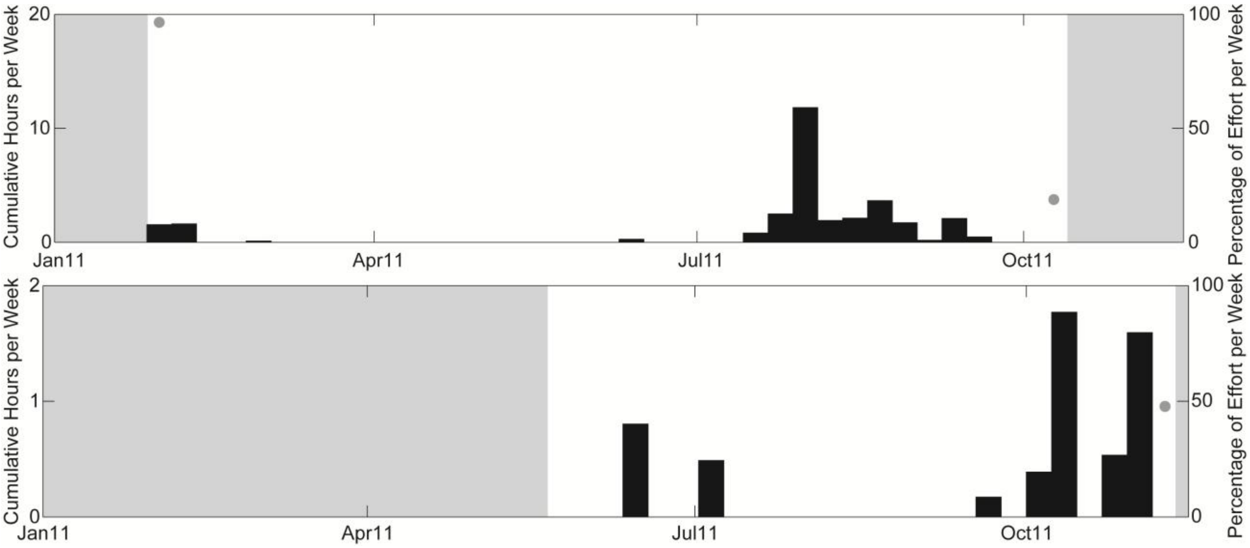

Figure 27. Weekly Risso's dolphin echolocation click presence at sites QC (top) and CE (bottom) during 2011. Note that the y-axis scale is different at the two locations. Effort markings are as described in Figure 21.

Pacific White-Sided Dolphin

After a decrease in Pacific white-sided dolphin echolocation clicks at site CE in 2008 and 2009, there was again a larger number of detections in 2011 (Figure 28) of this commonly sighted species in this area (Oleson et al. 2009). The detections at both sites largely coincided temporally, with peaks in June-July and again in October and November. Most echolocation clicks were detected during the night with very little activity during the day outside the June-July window, when daytime echolocation was relatively common (see Appendix).

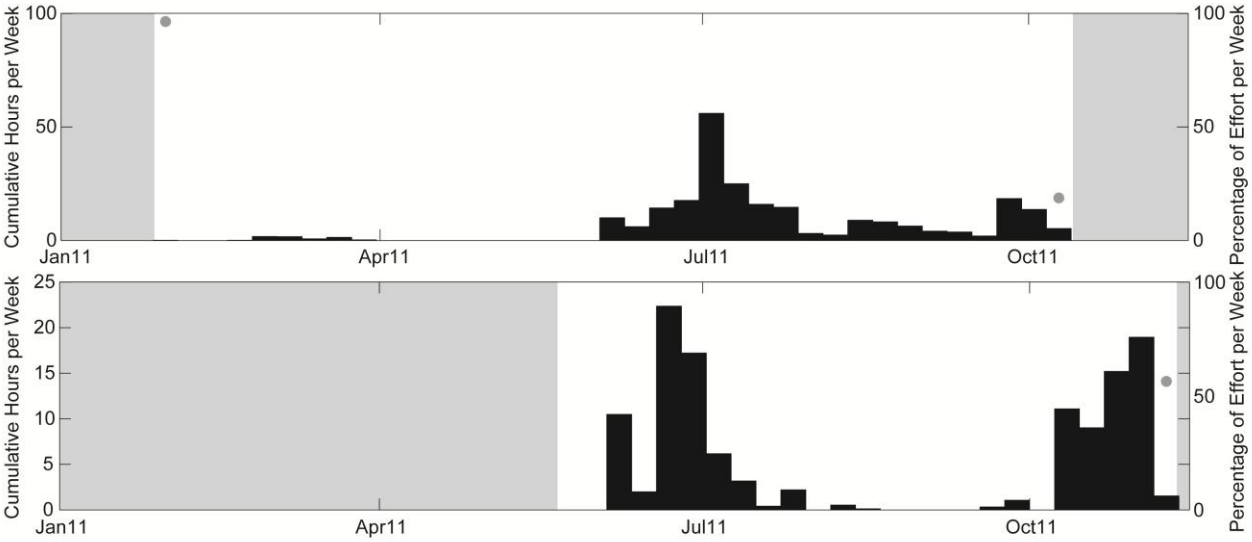

Figure 28. Weekly Pacific white-sided dolphin echolocation click presence at sites QC (top) and CE (bottom) during 2011. Note that the y-axis scale is different at the two locations. Effort markings are as described in Figure 21.

Killer Whale

There were generally few killer whale detections, but they were more common at site CE than QC (Figure 29 and 30). Most detections occurred between June and October at site CE and in general, higher frequency vocalizations were more common (Figure 30). Year-round presence of killer whale detections is consistent with previous reports of killer whale calling in this area (Oleson et al. 2009, Širović et al. 2011), although further analyses are required to attribute the detected calls to specific killer whale ecotypes.

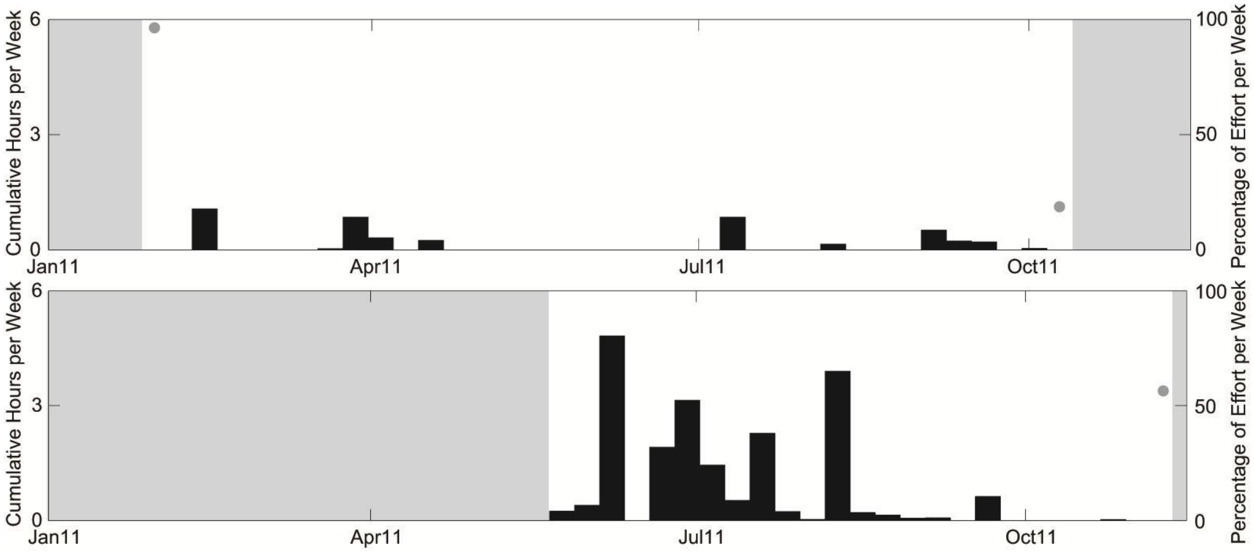

Figure 29. Weekly killer whale whistle (<5 kHz) presence at sites QC (top) and CE (bottom) during 2011. Effort markings are as described in Figure 21.

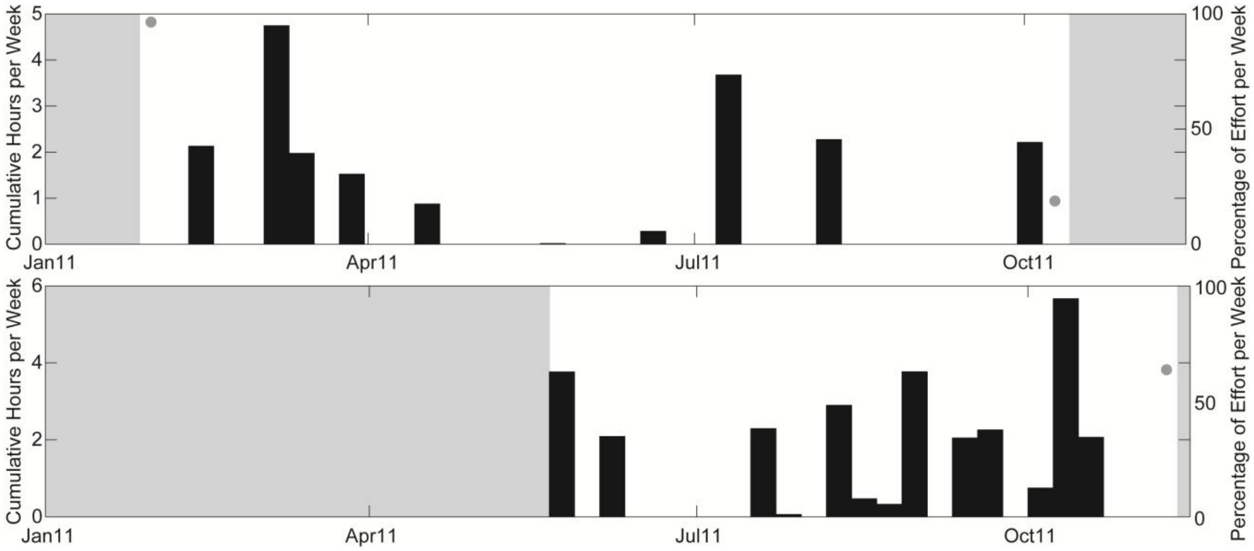

Figure 30. Weekly killer whale whistle and echolocation click presence at sites QC (top) and CE (bottom) during 2011. Note that the y-axis scale is different at the two locations. Effort markings are as described in Figure 21.

Sperm Whale

Sperm whale echolocation clicks were detected consistently throughout the deployment period at site QC, while their clicks were detected only sporadically at site CE (Figure 31). Unlike previous reports from this area (Širović et al. 2011), there was no clear diel preference in sperm whale echolocation clicks (see Appendix). Their year-round prevalence at site QC and more sporadic occurrence at site CE are consistent with previous reports from this area (Oleson et al. 2009).

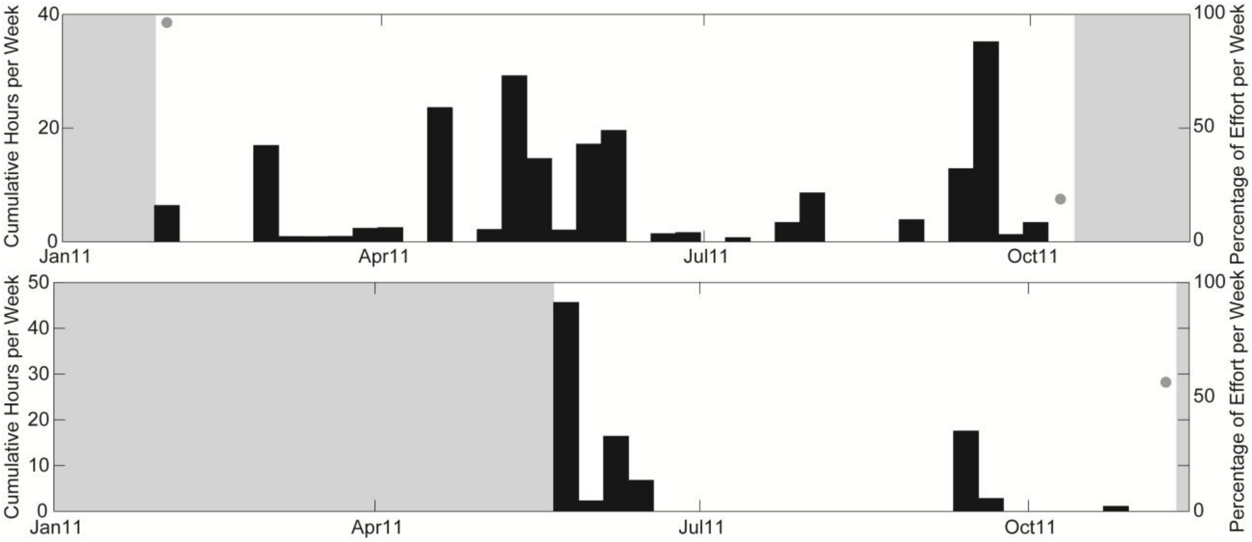

Figure 31. Weekly sperm whale echolocation click presence at sites QC (top) and CE (bottom) during 2011. Note that the y-axis scale is different at the two locations. Effort markings are as described in Figure 21.

Stejneger's Beaked Whales

Even though Stejneger's beaked whales were only detected at site QC, they were the most common beaked whale detected off Washington. Their detection off Washington was seasonal though, with calls detected only between January and June (Figure 32). It is possible these animals move farther north during the summer, to the more northerly parts of their range.

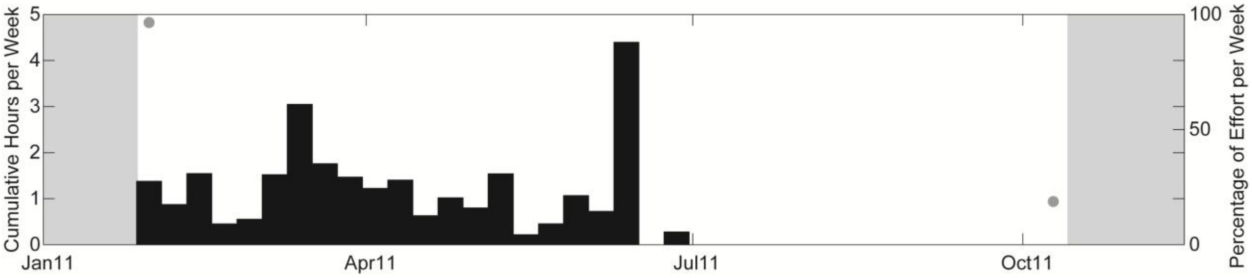

Figure 32. Weekly Stejneger's beaked whale frequency modulated pulse presence at site QC during 2011. No Stejneger's beaked whale signals were detected at site CE. Effort markings are as described in Figure 21.

Baird's Beaked Whale

Detections of Baird's beaked whale FM pulses, second most common beaked whale signal in these data, were more common at site QC than CE, showing peaks in detections in February and July (Figure 33). There was no apparent diel pattern in their pulses during this period at either site.

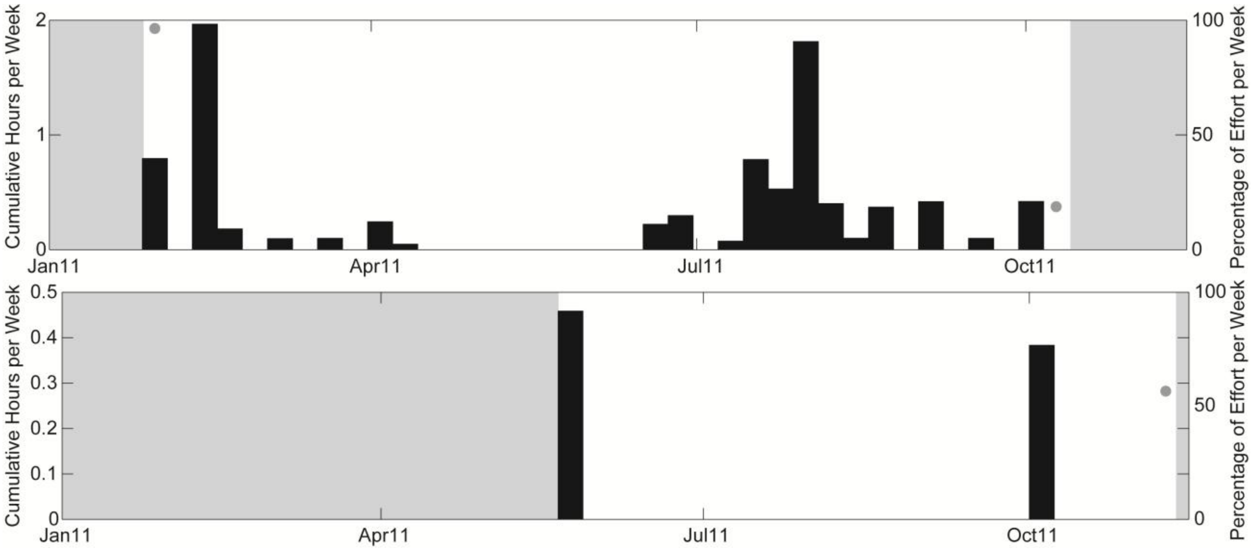

Figure 33. Weekly Baird's beaked whale frequency modulated pulse and click presence at sites QC (top) and CE (bottom) during 2011. Note that the y-axis scale is different at the two locations. Effort markings are as described in Figure 21.

Cuvier's Beaked Whale

Cuvier's beaked whales were detected throughout the year at low levels, but only at site QC (Figure 34). There was no preferred time of the day for echolocation click detections.

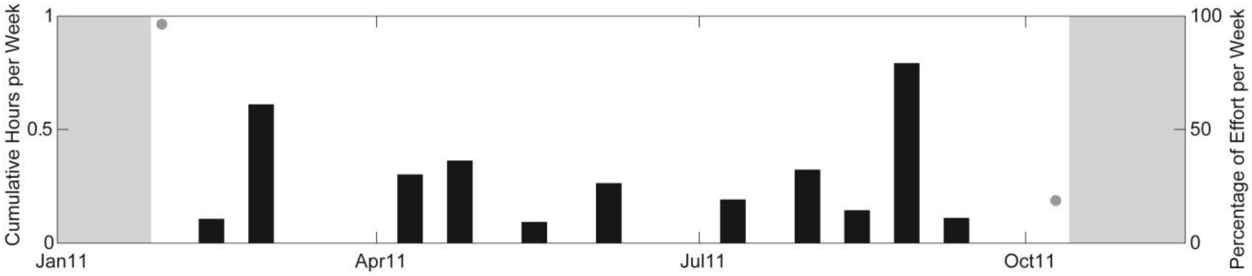

Figure 34. Weekly Cuvier's beaked whale frequency modulated pulse presence at site QC during 2011. No Cuvier's beaked whale signals were detected at site CE. Effort markings are as described in Figure 21.

Blainville's Beaked Whales

Blainville's beaked whale clicks were identified only once, in March, at site QC (Figure 35).

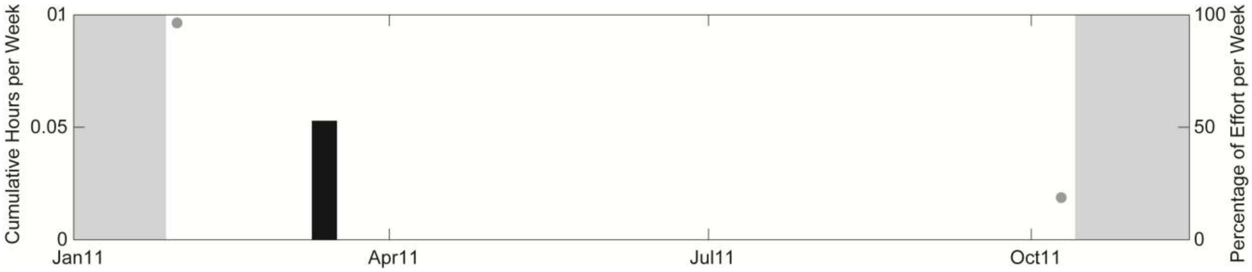

Figure 35. Weekly Blainville's beaked whale frequency modulated pulse presence at site QC during 2011. No Blainville's beaked whale signals were detected at site CE. Effort markings are as described in Figure 21.

Unidentified Beaked Whales

Detections of unidentified beaked whale FM pulses were very rare and due to the small sample size, with no apparent diel or seasonal pattern. They were detected only once at site QC, in October (Figure 32 top), and in one long encounter in June and one short one in August at CE (Figure 326 bottom).

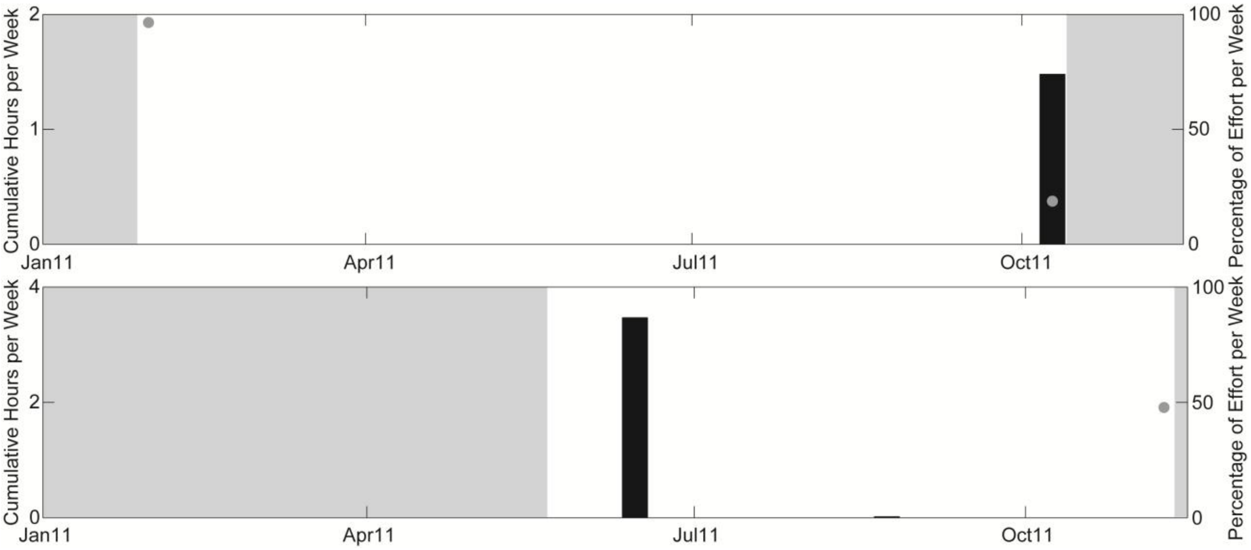

Figure 36. Weekly unidentified beaked whale frequency modulated pulse presence at sites QC (top) and CE (bottom) during 2011. Note that the y-axis scale is different at the two locations. Effort markings are as described in Figure 21.

Unidentified Porpoise

While Dall's porpoises are more frequently sighted in the vicinity of the CE site on the shelf (Oleson et al. 2009), the only site where these calls were recorded, since no recordings are available during known presence of either species we cannot confirm the species more likely identified by the presence of these clicks. Unlike in previous years when peak presence of NBHF clicks occurred in the fall (Oleson et al. 2009, Širović et al. 2011), however, detections during 2011 were relatively constant (Figure 37). There was no diel pattern in the acoustic activity (see Appendix).

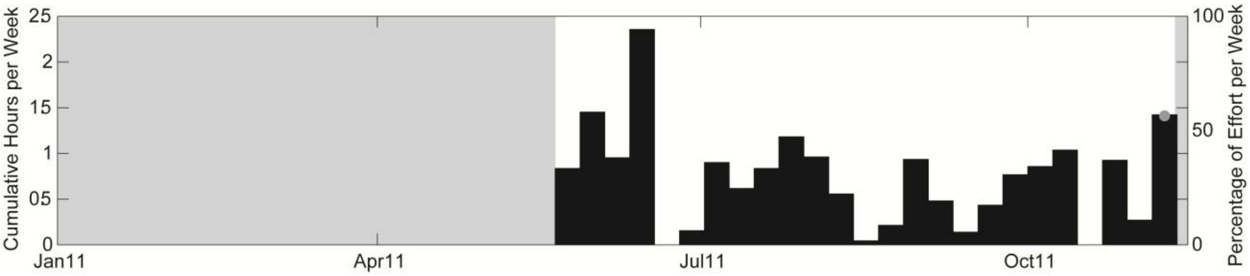

Figure 37. Weekly unidentified NBHF porpoise click presence at site CE during 2011. No porpoise clicks were detected at site QC. Effort markings are as described in Figure 21.

Anthropogenic Sounds

Broadband Ship Noise

Ship noise was a nearly constant anthropogenic sound at site CE from September until November, while levels of ship noise were relatively consistent and lower at both sites for the remainder of the year (Figure 38). Inshore location of site CE, the site with increased shipping noise in the fall, is an indication that these boats are likely local (fact also corroborated with noise spectra from this site, Figure 19) and could represent a seasonal increase in a local fishery.

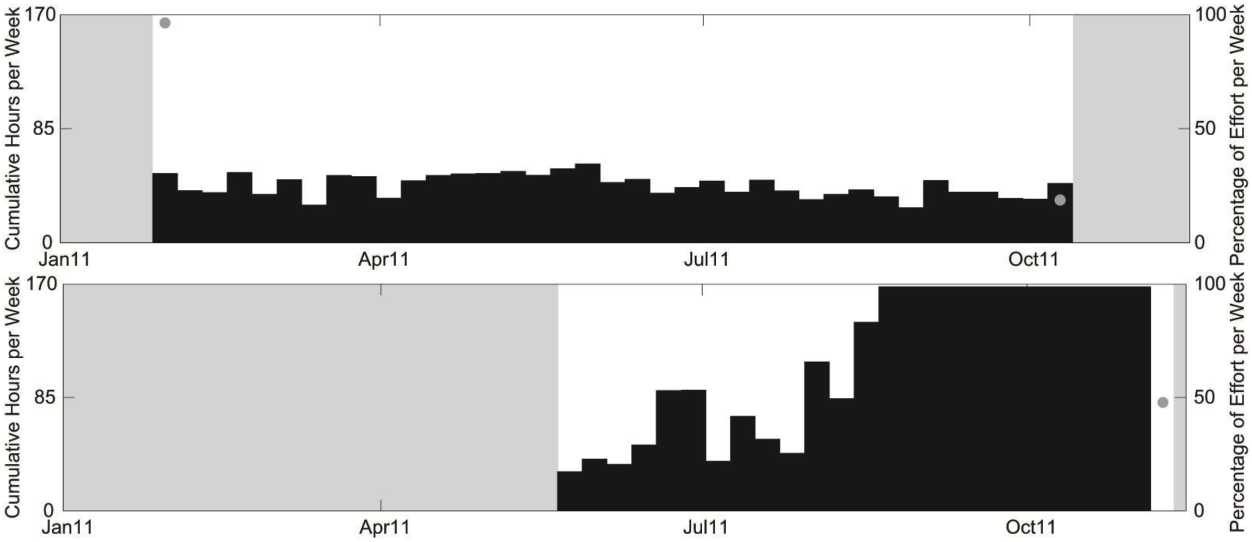

Figure 38. Weekly hours with broadband ship noise at sites QC (top) and CE (bottom) during 2011. Effort markings are as described in Figure 21.

Mid-Frequency Active Sonar

During our recording periods in 2011, there were 5 days with MFA events at site QC and 2 days at CE (Figure 39). Total time over which the events occurred was 8 hr 32 min at QC and 3 h 14 min at site CE (Appendix). During one of the days with recorded events, the detected sonar was just below 1 kHz (940-970 Hz) and occurred over approximately 1 hr 16 min at site QC and 27 minutes at site CE. This event was not used for automatic evaluation of received levels, as it fell outside the standard range for MFA sonar. Even though MFA sonar events were recorded at site QC, the received levels at that site were lower than at site CE, which prevented the use of the automated detection and received level calculation routine on those events, thus we only report the levels recorded at site CE. At site CE, 171 MFA sonar pings were detected, ranging from 111 to 148 dB pp re: 1 µPa. There were bimodal peaks in ping levels at site CE, one around 132 dB pp re: 1 µPa, and another at the minimum value (Figure 40); the minimum value is likely a threshold limit based on the automatic detection methods used. Half of the pings detected were above 135 dB pp re: 1 µPa (Figure 41), indicating there was a long-tailed distribution around that second peak of 132 dB pp re: 1 µPa.

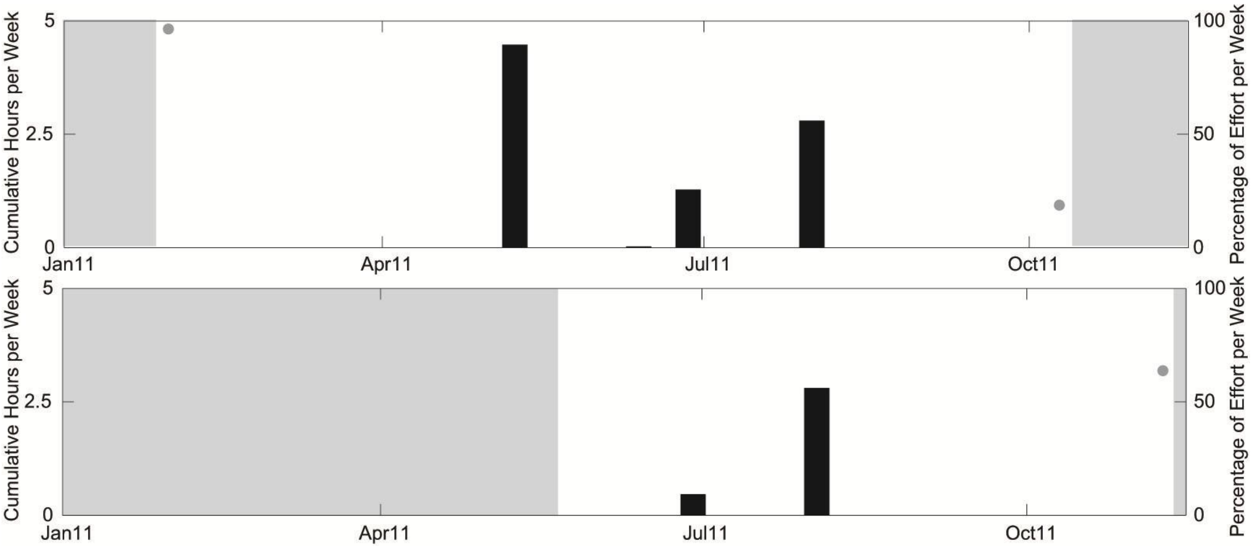

Figure 39. Weekly mid-frequency active (MFA) sonar presence at sites QC (top) and CE (bottom) during 2011. Effort markings are as described in Figure 21.

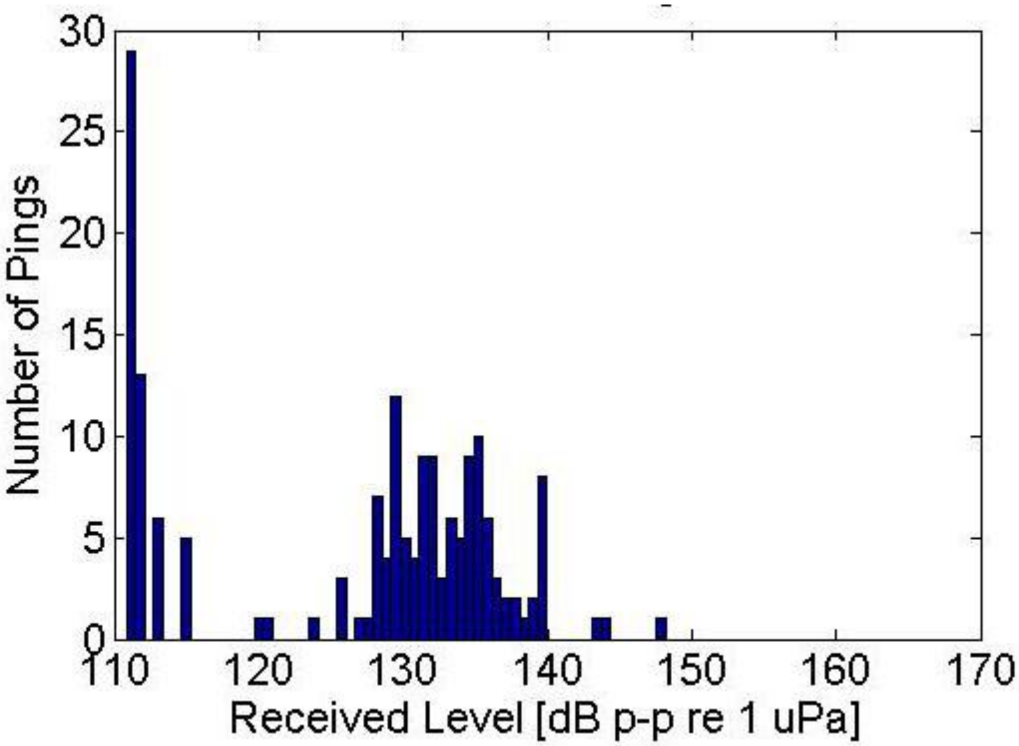

Figure 40. Distribution of the number of MFA sonar pings by received levels at site CE in 1 dB bins. Minimum level (111 dB pp re: 1 µPa) is likely related to the detection threshold.

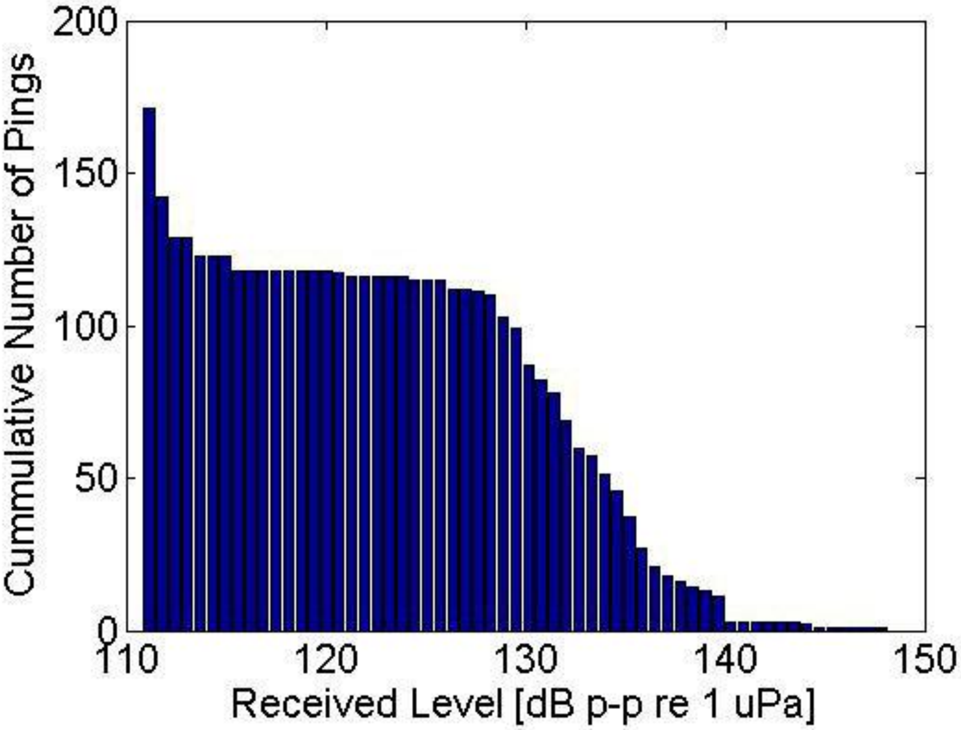

Figure 41. Cumulative distribution of the number of MFA sonar pings detected at site CE by received level in 1 dB bins.

Explosions

Explosions were not very common at either site, with no more than 15 hours with explosion detections per week recorded at either site (Figure 42). While the explosions at site QC were sporadic, there was an apparent peak at site CE in early July. Most explosions are likely from seal-bombs associated with fishing.

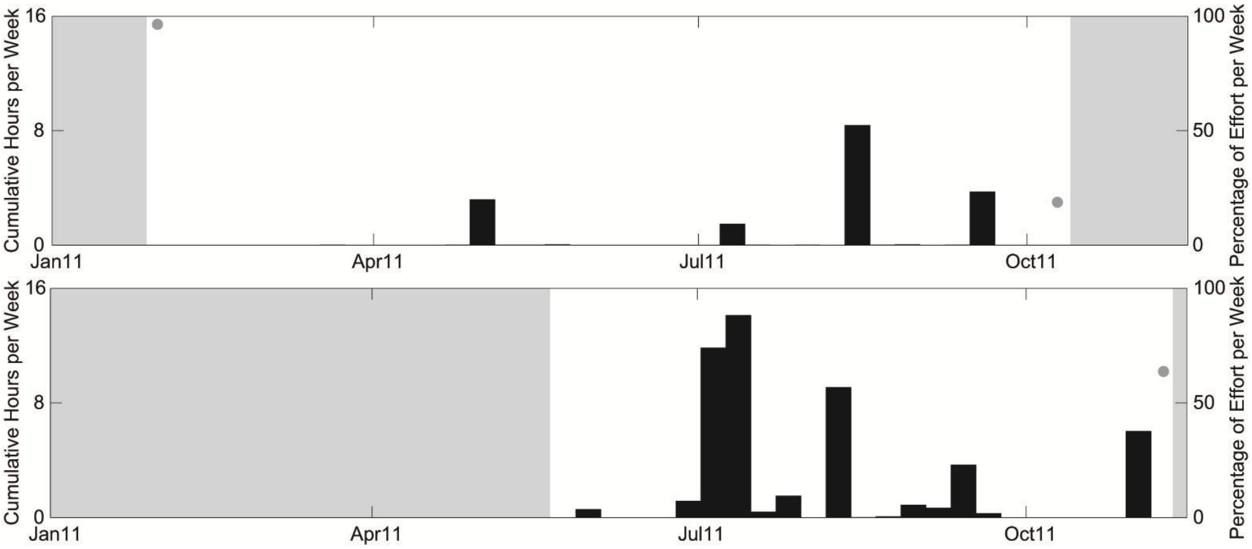

Figure 42. Weekly hours with explosions at sites QC (top) and CE (bottom) during 2011. Effort markings are as described in Figure 21.

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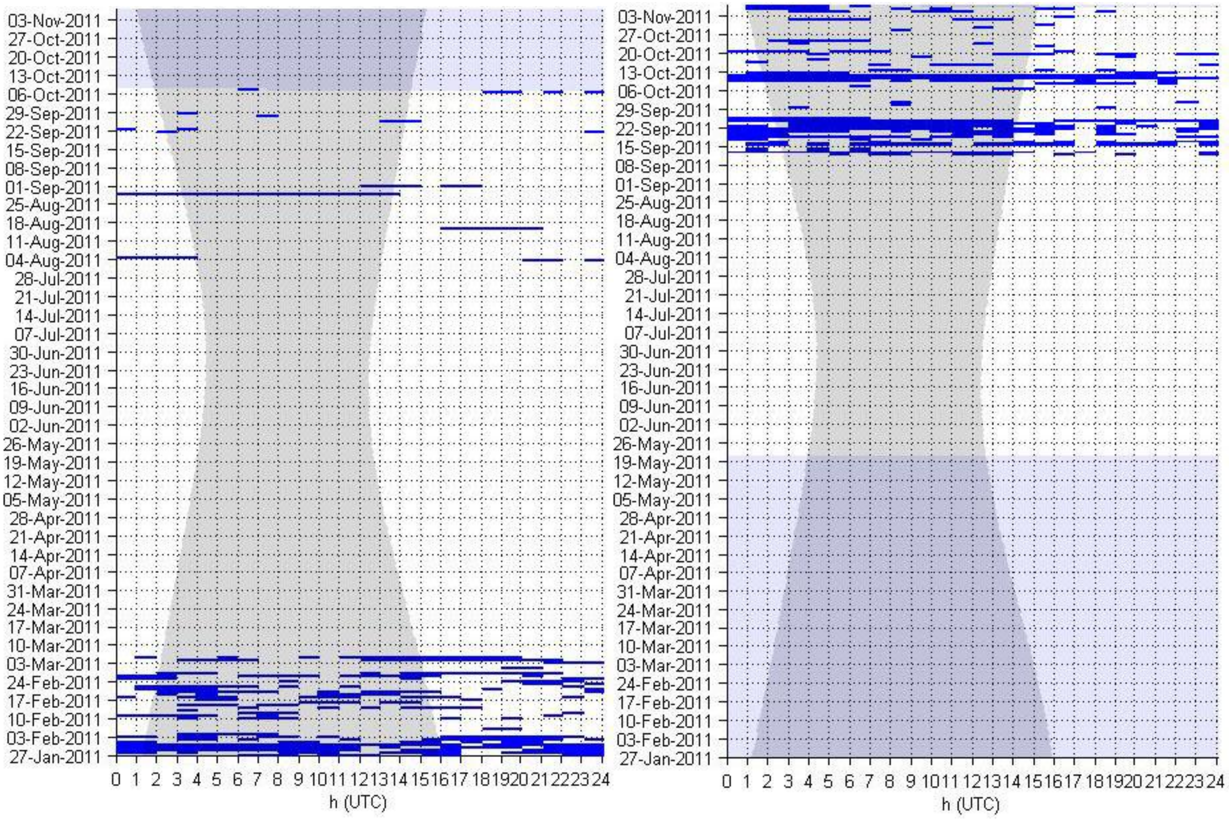
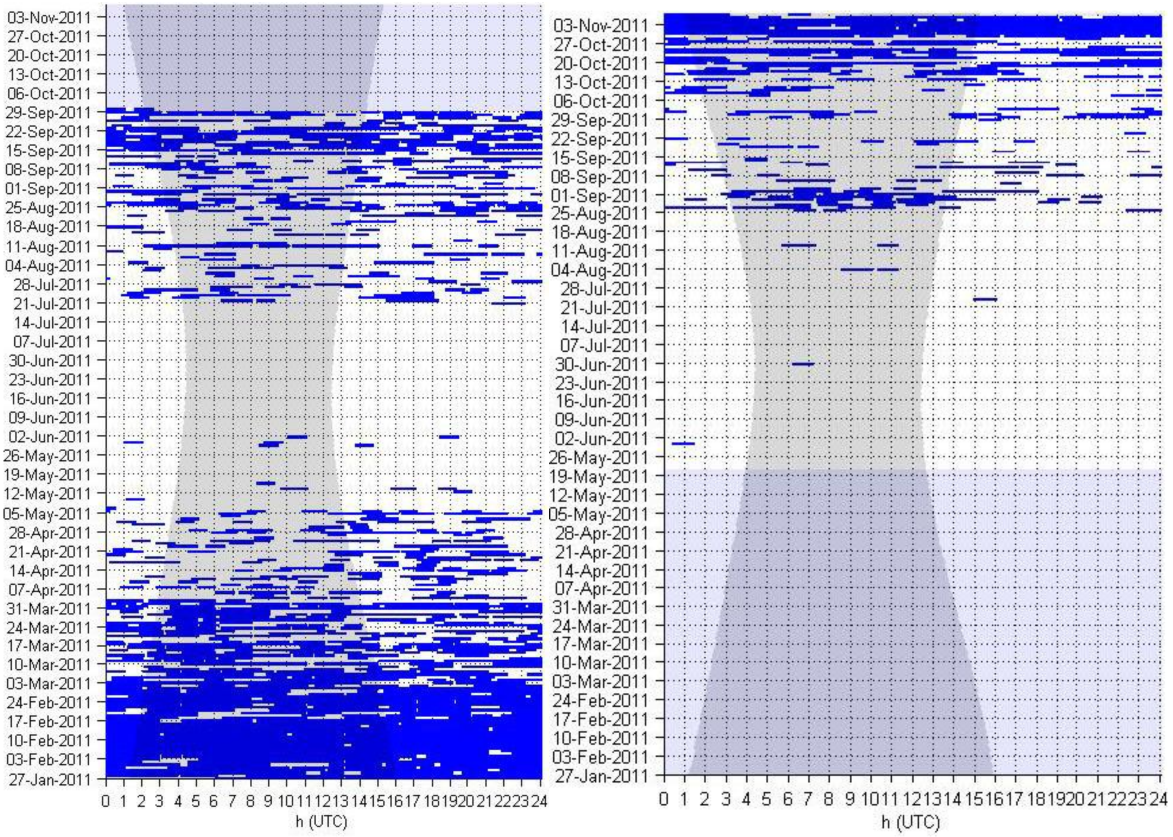
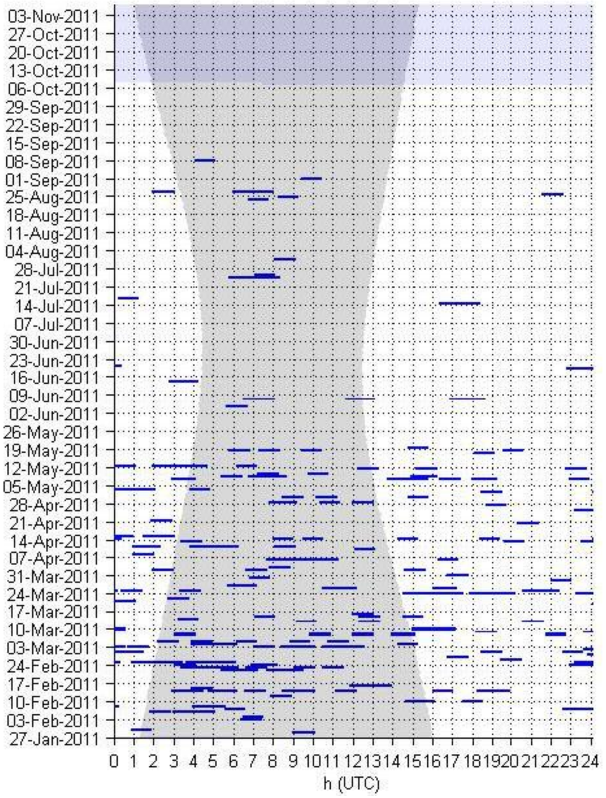
Appendix - Seasonal/Diel Occurrence Plots



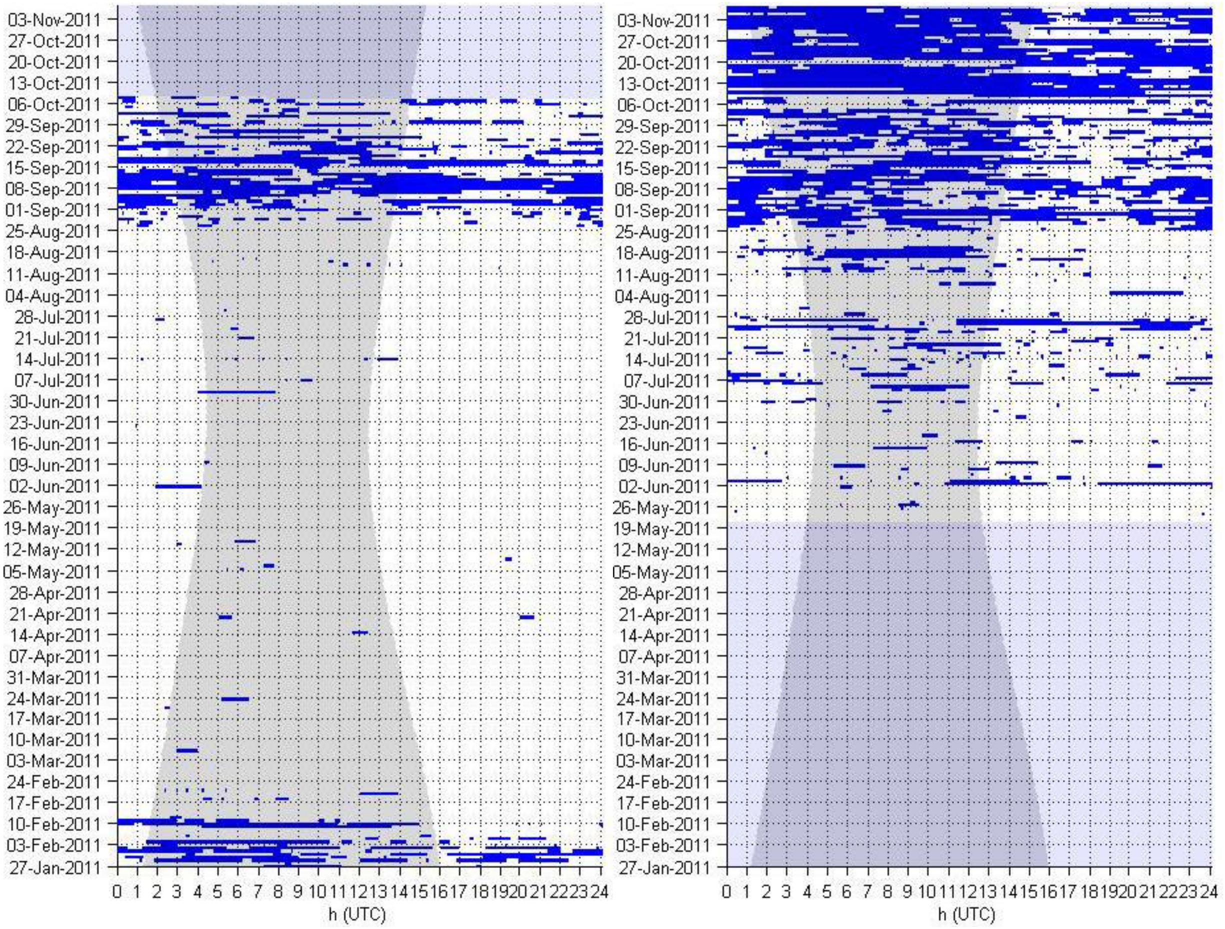
Blue whale –B call in hourly bins at sites QC (left) and CE (right)



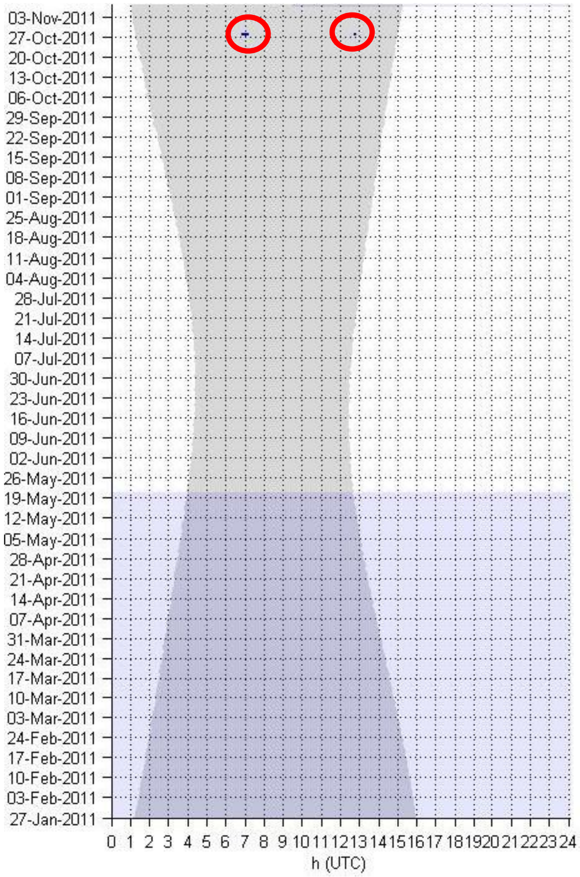
Fin whale – 20 Hz call in hourly bins at sites QC (left) and CE (right)



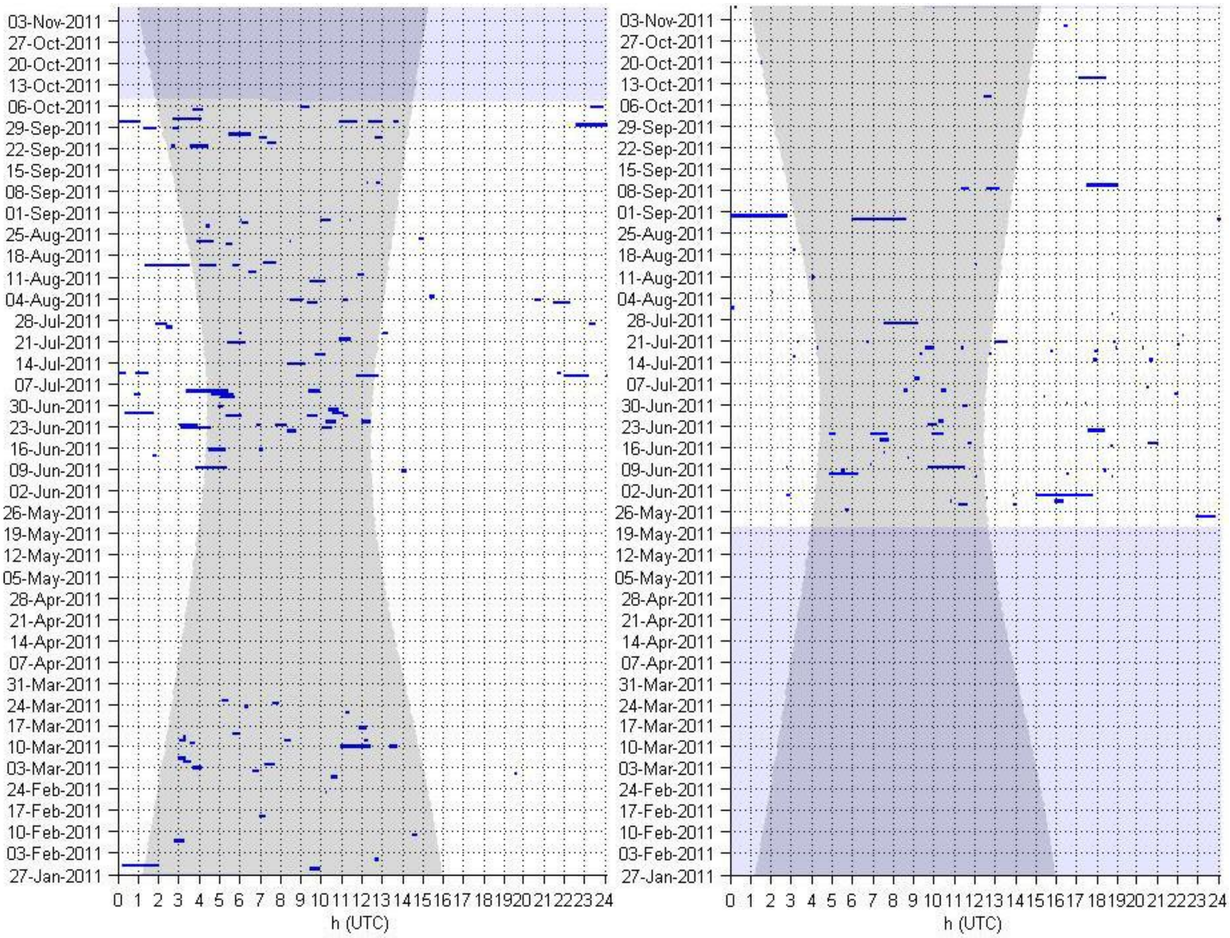
Fin whale – 40 Hz call in hourly bins at sites QC. No calls were detected at CE



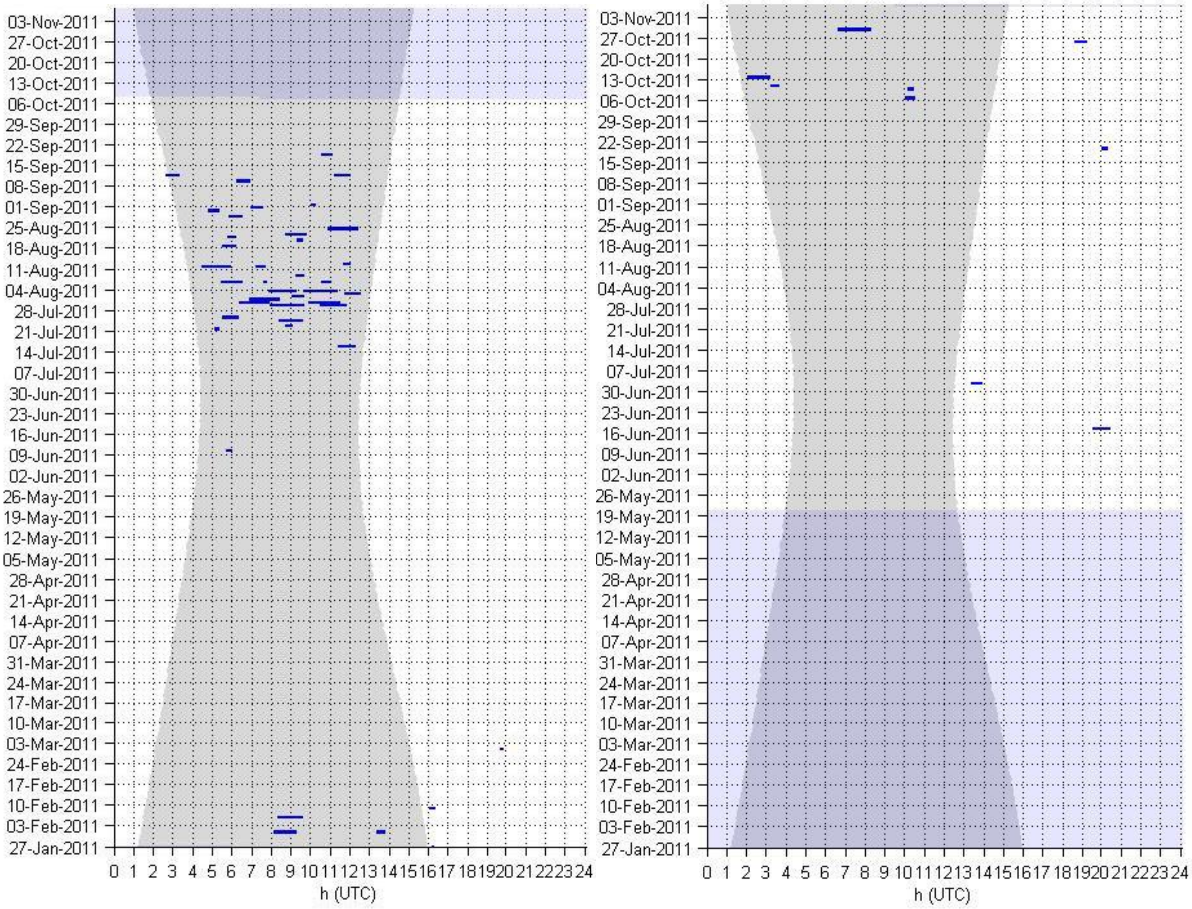
Humpback whale – Song and non-song calls in five-minute bins at sites QC (left) and CE (right)



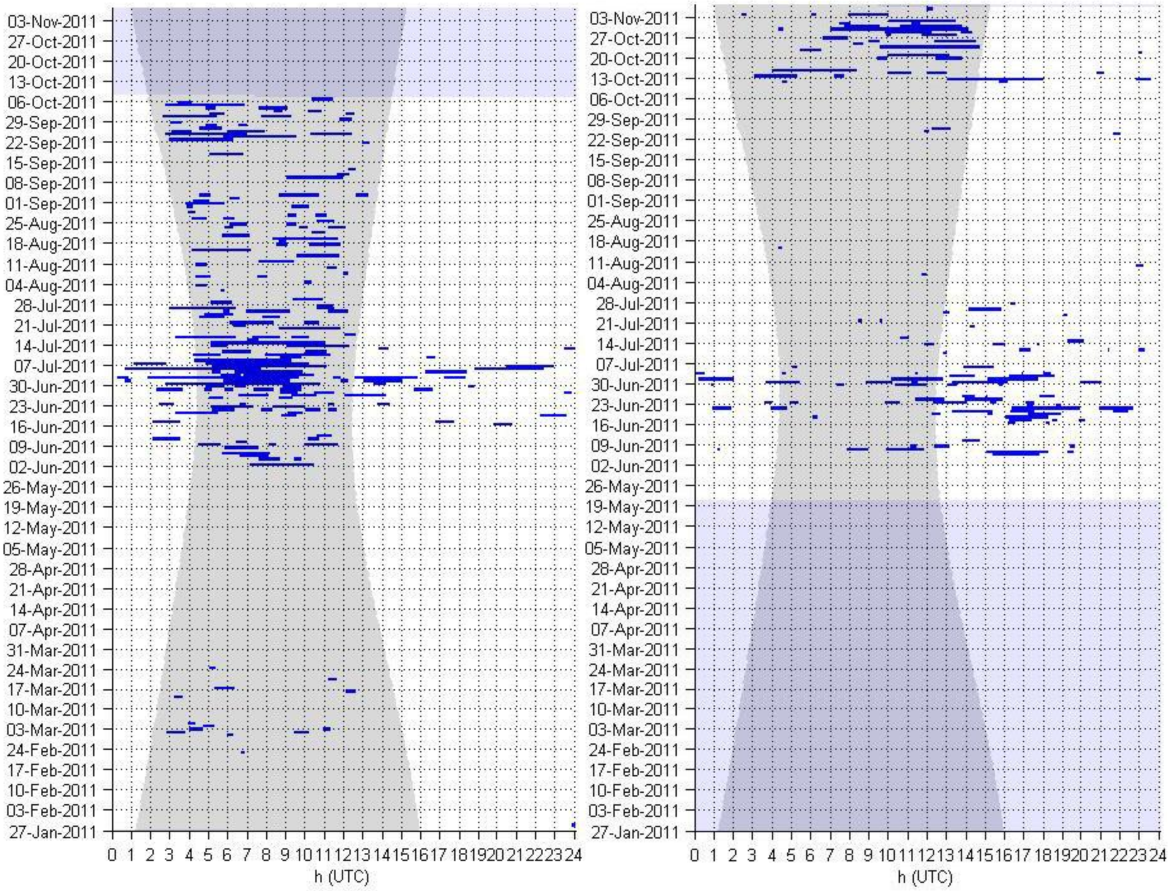
Pinnipeds – Barks in five-minute bins at site CE. No pinniped barks were detected at site QC.



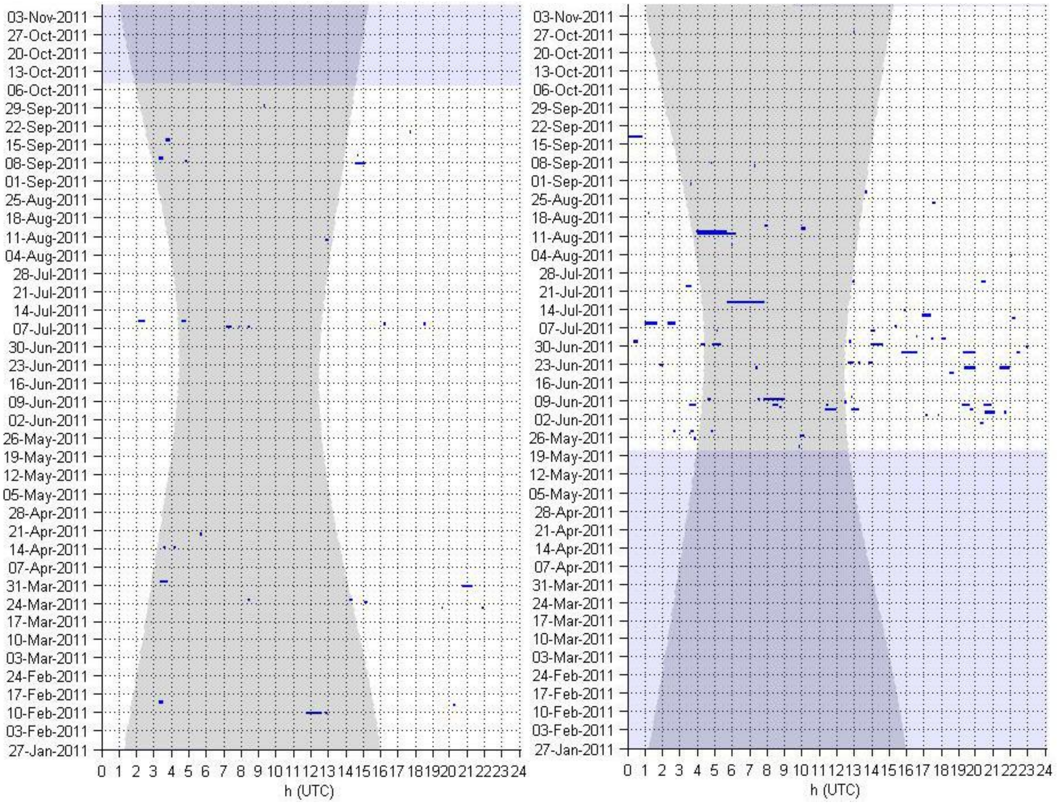
Unidentified dolphin –Whistles and echolocation clicks in five-minute bins at sites QC (left) and CE (right).



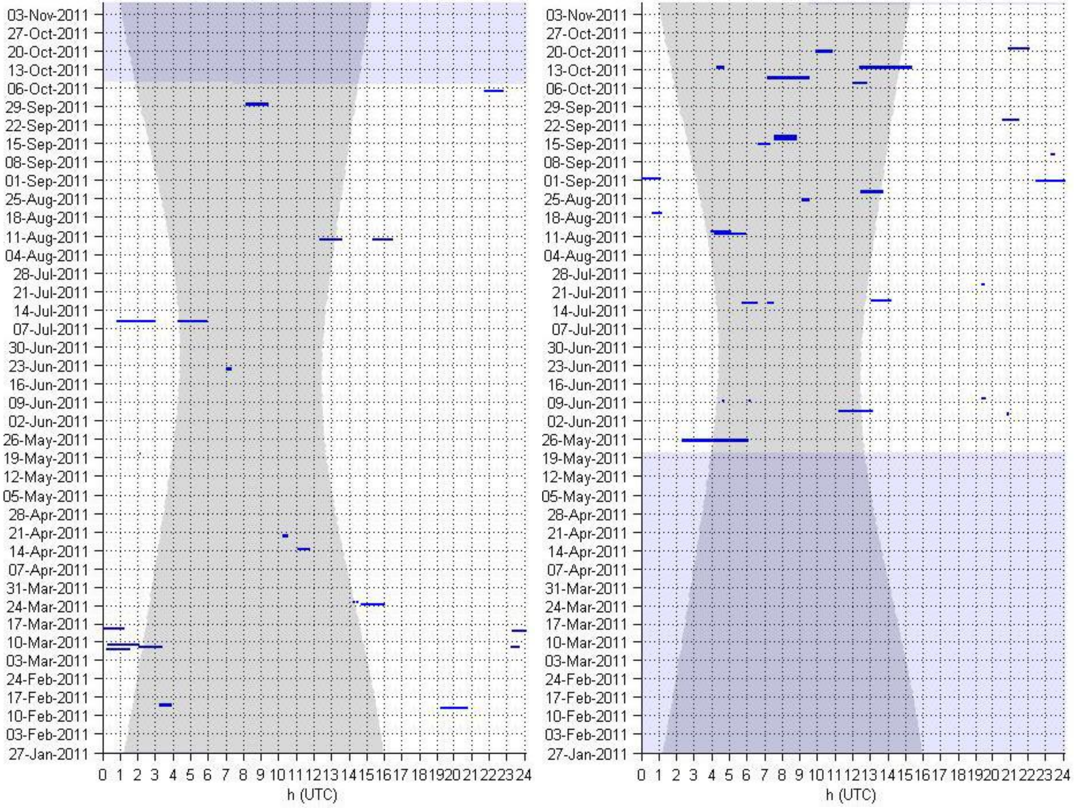
Risso's dolphin – Echolocation clicks in five-minute bins at sites QC (left) and CE (right).



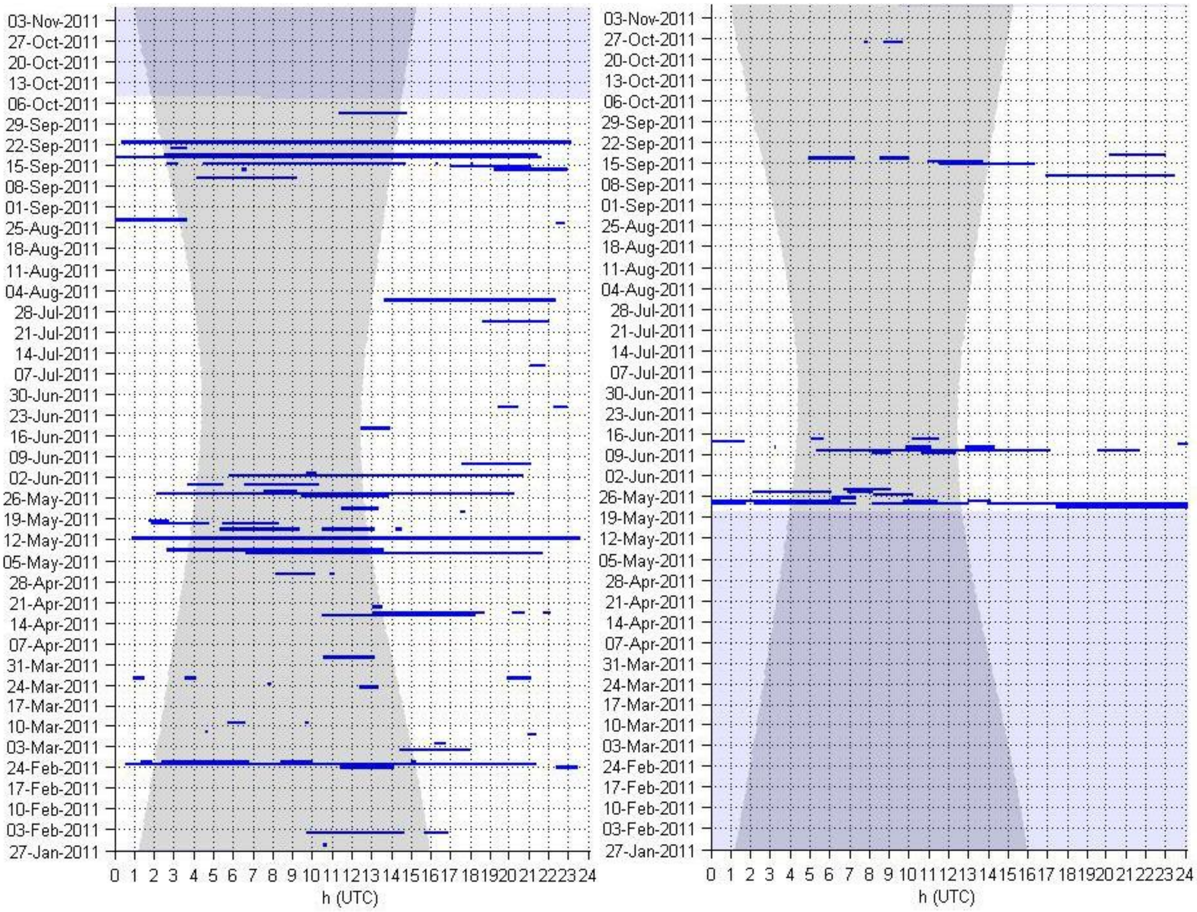
Pacific white-sided dolphin – Echolocation clicks in five-minute bins at sites QC (left) and CE (right).



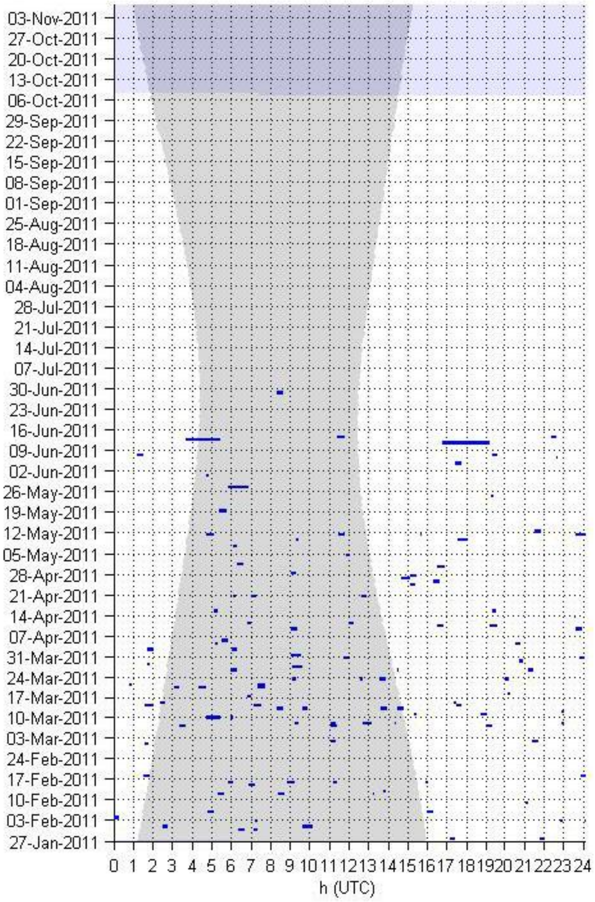
Killer whale –Whistles (<5 kHz) in five-minute bins at sites QC (left) and CE (right).



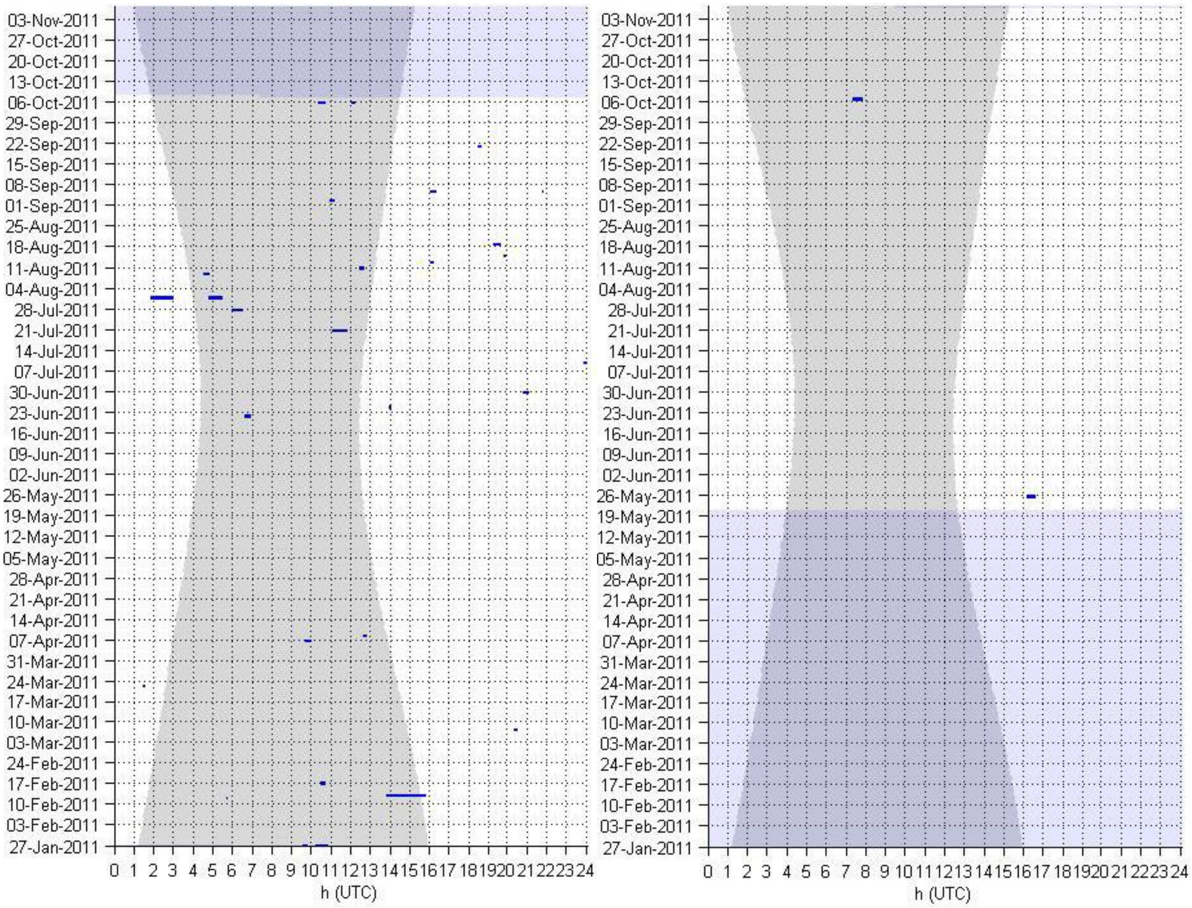
Killer whale –Whistles (5 kHz) and echolocation clicks in five-minute bins at sites QC (left) and CE (right).



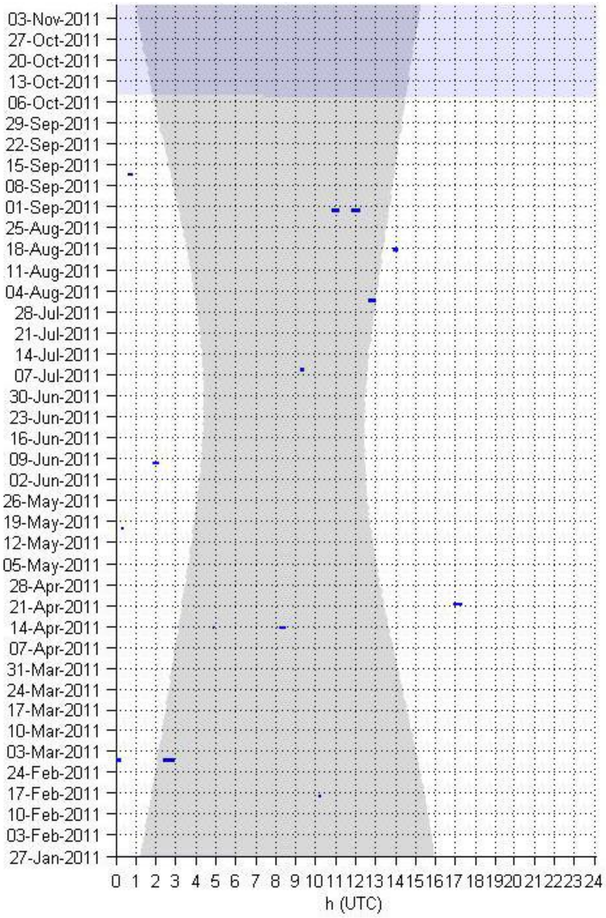
Sperm whale – Echolocation clicks in five-minute bins at sites QC (left) and CE (right).



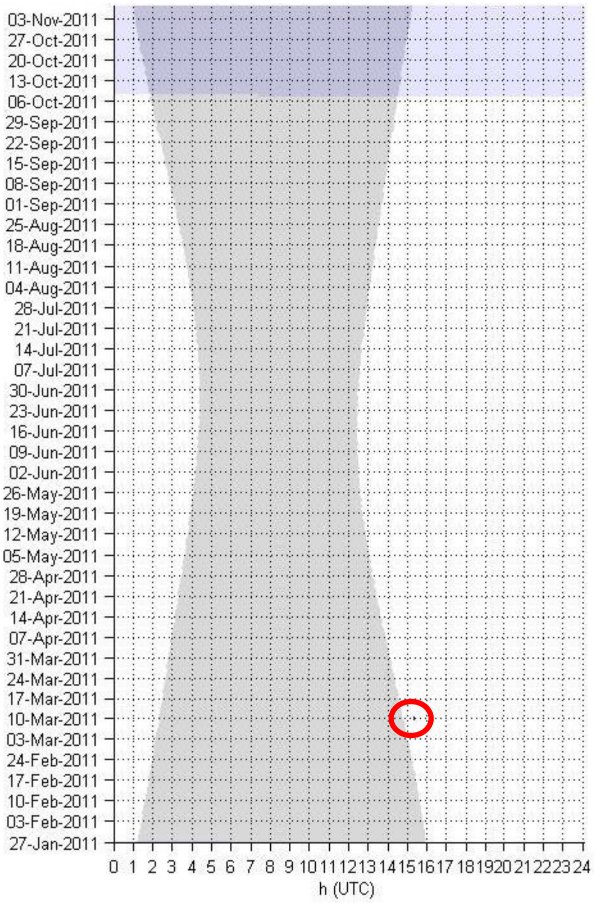
Stejneger's beaked whale – Frequency-modulated pulses in five-minute bins at site QC.



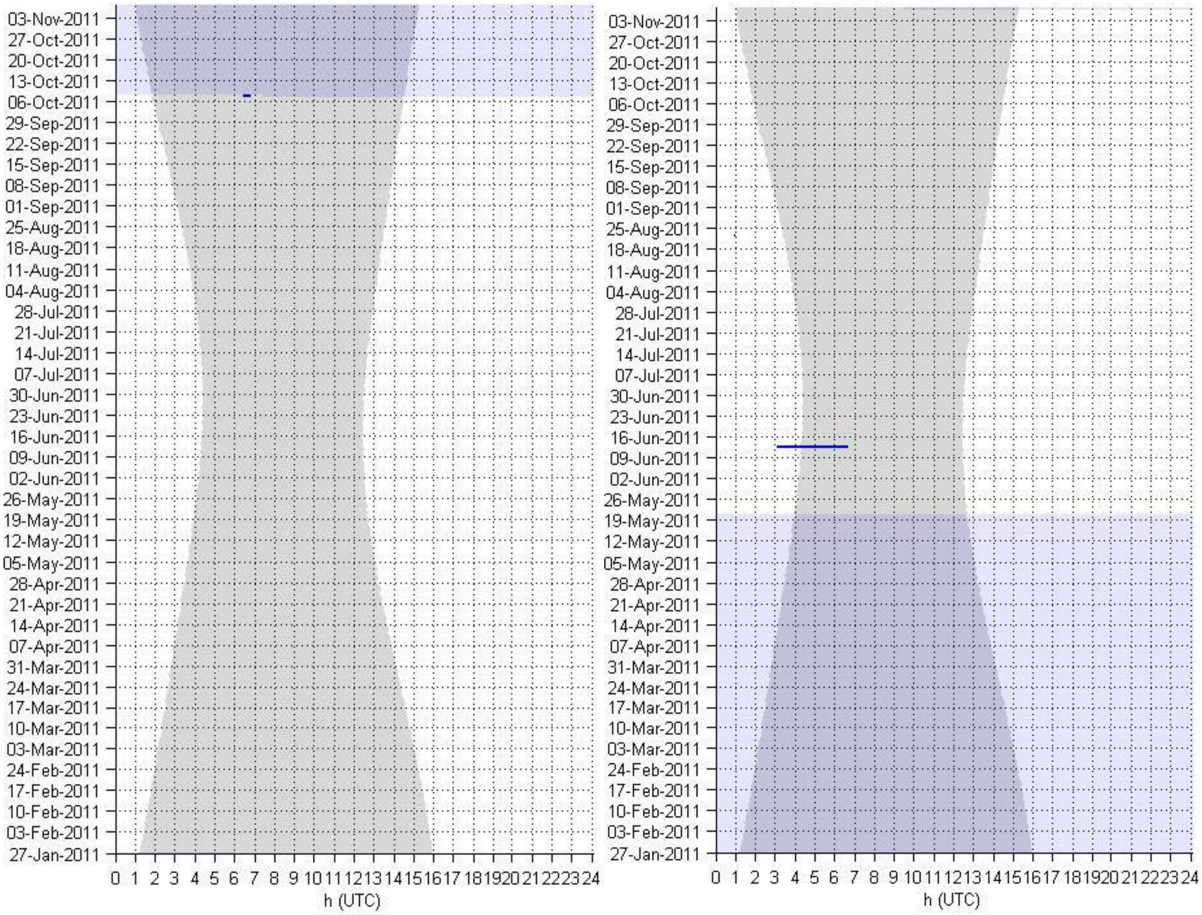
Baird’s beaked whale – Frequency-modulated pulses in five-minute bins at sites QC (left) and CE (right).



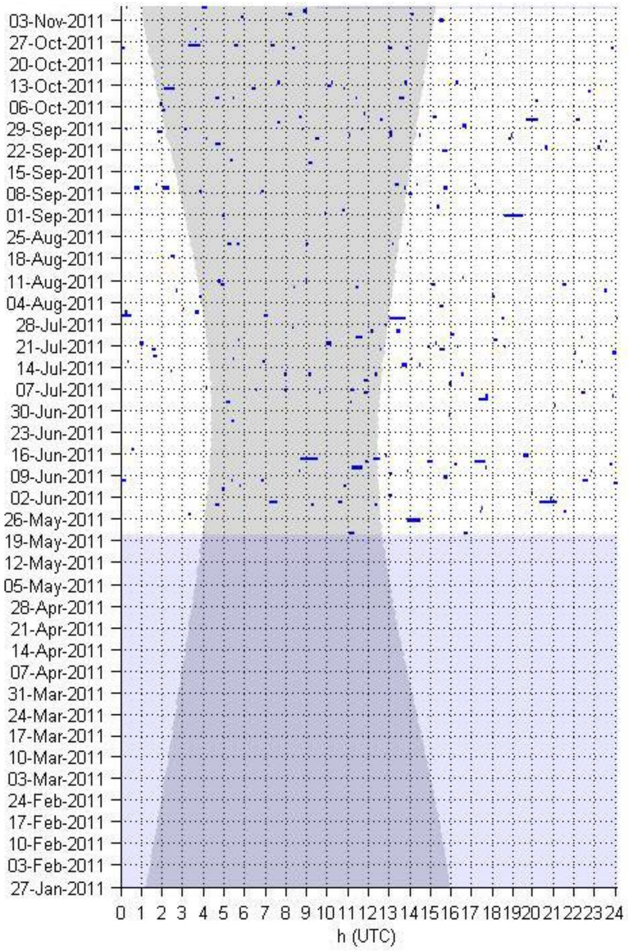
Cuvier’s beaked whale - Frequency-modulated pulses in five-minute bins at site QC.



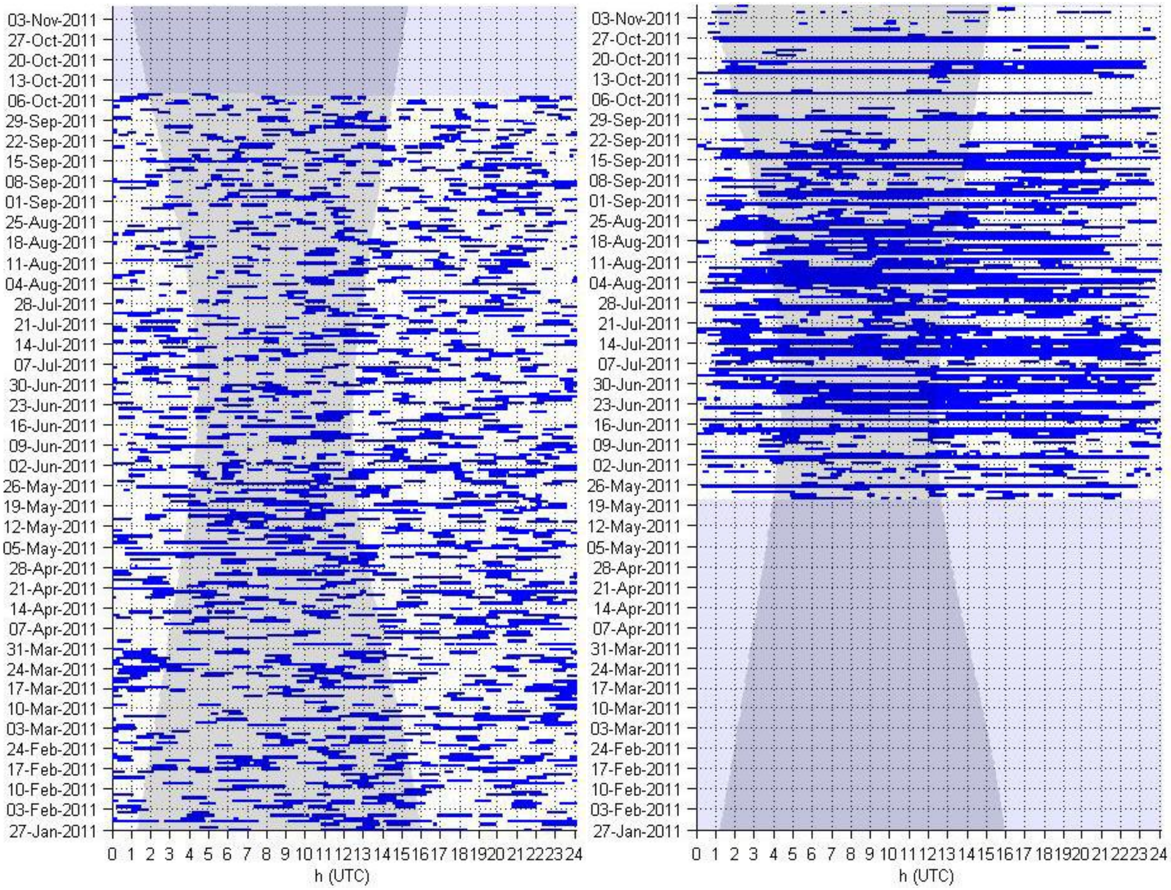
Blainville's beaked whale - Frequency-modulated pulses (circled) in five-minute bins at site QC.



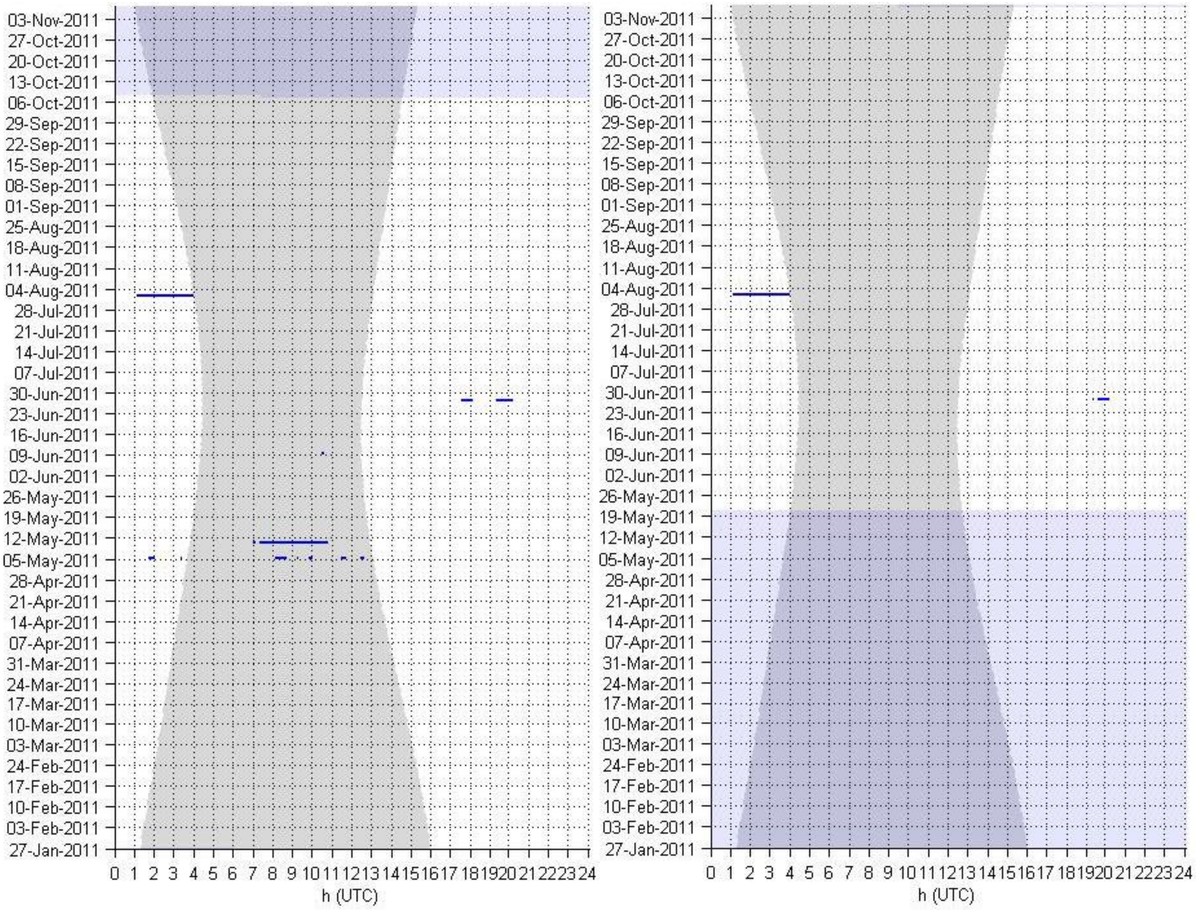
Unidentified beaked whale – Frequency-modulated pulses at sites QC (left) and CE (right).



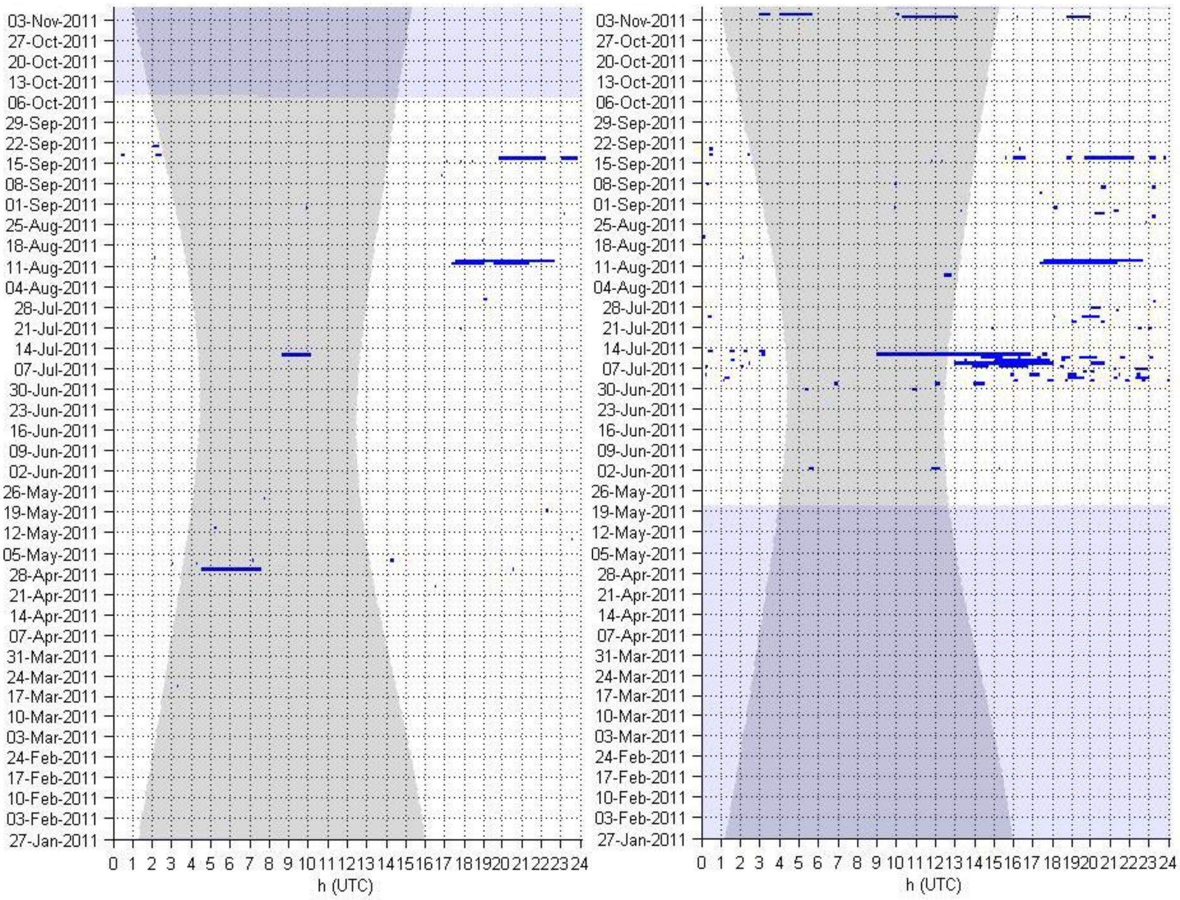
Unidentified Porpoise – Narrow-banded high-frequency pulses in five-minute bins at site CE.



Broadband ship noise – presence in one-minute bins at sites QC (left) and CE (right)



Mid-frequency active sonar – presence in five-minute bins at sites QC (left) and CE (right)



Explosions – Presence in five-minute bins at sites QC (left) and CE (right)