Final Report: **Bering Sea Right Whales: Acoustic Recordings and Public Outreach**

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Abstract:

This project analyzed acoustic data from the southeastern Bering Sea to characterize the seasonal occurrence of the region's critically endangered North Pacific right whale (*Eubalaena japonica*) population. We collected nearly-continuous acoustic recordings in the southeastern Bering Sea from October 2000 through August 2002. Present in the recordings were baleen whale calls from species including humpbacks (*Megaptera noveangliae*), fin whales (*Balaenoptera physalus),* and the priority species, the North Pacific right whale (*Eubalaena japonica*). The data provided information on the seasonal occurrence and relative abundance of right whale calls in the southeastern Bering Sea. The project also included participation in a NMFS research/survey cruise in the Gulf of Alaska and Bering Sea in summer of 2002, and outreach/education through visits to Alaskan schools and websites geared toward the general public. The research was performed with collaboration and/or contribution of expertise from NOAA/NMFS, NOAA/NMML, NOAA/PMEL, Oregon State University, Whale Acoustics Inc., and Bering Strait School District.

Purpose:

The eastern North Pacific right whale (Figure 1) is one of the most endangered populations of large cetaceans in the world, due to extensive whaling prior to the mid-20th century (Clapham et al. 1999, Brownell et al. 2001). Current population estimates, based on visual and genetic information, place the population total in tens of animals (LeDuc et al. 2001; Tynan et al. 2001). However, population estimates are uncertain and very little is known about the seasonal distribution of right whales or potential anthropogenic threats to the population's survival (LeDuc et al. 2001). Recently, a small number of right whales have been discovered to regularly occur in the southeastern Bering Sea (Goddard and Rugh 1998; Tynan 1998; LeDuc et al. 2001; Tynan et al. 2001, LeDuc 2004, NMFS 2004a, b). Further research is necessary to better understand right whale abundance, distribution, and behavioral ecology, and to inform conservation efforts such as establishing critical habitat for North Pacific right whales and evaluating potential threats to recovery.

A research program was initiated in 1998 by the National Marine Fisheries Service (NMFS) and the National Marine Mammal Laboratory (NMML), to study the Alaska right whale population using visual ship-based and aerial surveys, photographic techniques, and genetic sampling. Traditional visual surveys record whales that are observed at the surface and

operate over a short duration and focused area, providing only a 'snapshot' of whale distribution and abundance; these techniques are also limited by their dependence on daylight and good weather. To complement these traditional techniques, NMFS and NMML incorporated passive acoustic tools into the right whale research program, beginning with the use of Navy-manufactured sonobuoys to record right whale calls during a 1999 vessel survey (McDonald and Moore 2002). In 2000, NMFS/NMML funded Scripps Institution of Oceanography (SIO) to fabricate and deploy long-term, autonomous, passive Acoustic Recording Packages (ARPs) in the southeastern Bering Sea. Whale acoustics research complements traditional cetacean research techniques by providing information on calling, submerged animals, often at greater detection range than visual surveys. Long-term recorders such as ARPs provide data over longer temporal scales than traditional visual techniques and are buffered from surface weather conditions.

Figure 1 North Pacific right whale in the Bering Sea. Photo credit: Lisa Munger, NOAA-Southwest Fisheries Science Center, SPLASH survey, September 2004.

The central goal of the project was to use passive acoustic monitoring to characterize the spatial and temporal distribution of right whales in the Bering Sea. Funding of this project was used to process approximately two years' worth of existing acoustic data from the Bering Sea in 2000-2002, providing valuable information about the little-known right whale population in the Bering Sea. This project is important to understanding the ecology of baleen whales in the Bering Sea, and fulfilled the North Pacific Marine Research Institute's mandate to study marine mammals in the context of the North Pacific ecosystem.

The acoustic data analysis is part of an extensive research effort to better understand the dynamics of the critically endangered North Pacific right whale. The results of the field work and data analysis will be valuable in informing cetacean conservation efforts and enhancing our understanding of this rare and comparatively poorly understood species. The acoustic data have direct applications to assessment of endangered whale stocks (fin, humpback and right whales) in the southeastern Bering Sea. This project also addresses specific concerns of critical habitat for North Pacific right whales. The findings are likely to have implications for conservation efforts and fisheries management decisions, such as seasonal closures or ship traffic routes.

Communication with the public via outreach was also an objective, to provide aesthetic, emotional and educational value to students and their communities in the Bering Sea area, as well as the public and students via websites and outreach events in the San Diego area. Outreach funding was also used to travel to native Alaskan communities around the Bering Sea, where we visited schools and interacted with K-12 students and adult members of the community. We presented background on our research, did hands-on marine science activities with students, and discussed local ecological knowledge with residents. In addition, we augmented our website (www.cetus.ucsd.edu) with materials related to right whale research.

Approach:

Our passive acoustic data sets are derived from two types of recorders: long-term deployments of Acoustic Recording Packages (ARPs) and temporary hydrophones (sonobuoys) (Figure 2). ARPs sampled continuously at 500 Hz, effectively recording a bandwidth of about 5 Hz to 250 Hz (Wiggins 2003). This bandwidth encompasses most of the range used by right whales, the entire known range of fin whales, and the lower part of the range used by humpback whales. The directional (DIFAR) sonobuoys used during ship surveys recorded frequencies from about 10 Hz up to 2500 Hz and receive killer whale and sperm whale calls as well as most baleen whale sounds (McDonald 2004).

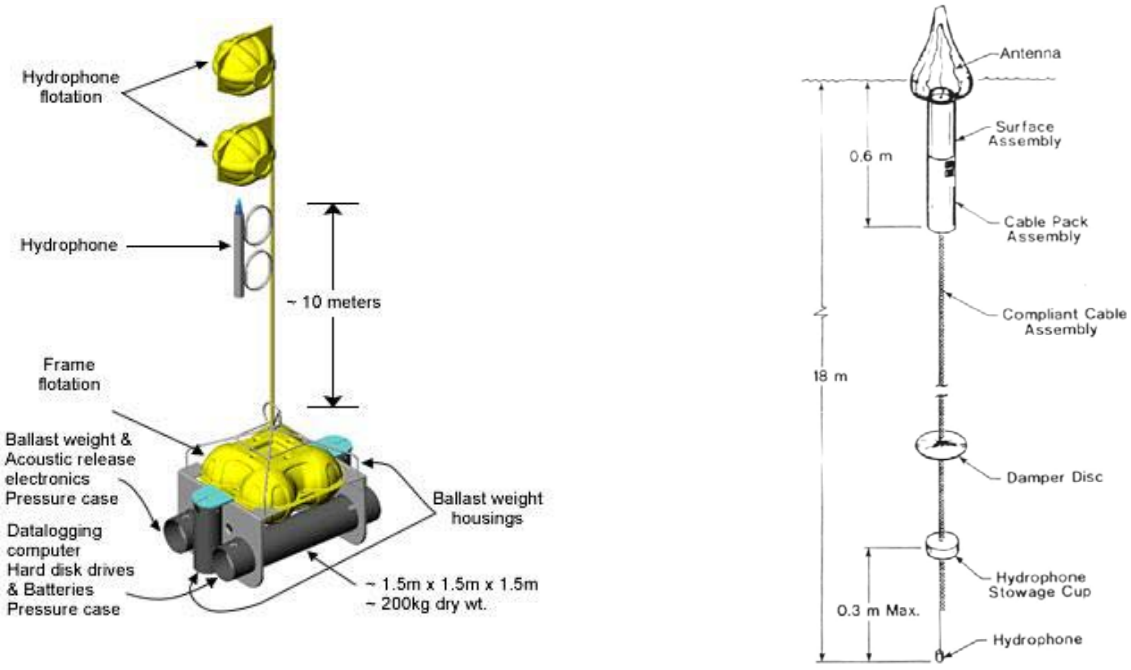

Figure 2. a) ARP schematic b) sonobuoy schematic.

Most right whale sightings in the past decade have been within the southeastern Bering Sea, enclosed by a 'box' bounded by 56º30' N and 57º30'N, and 162º 30'W to 166º 00' W (LeDuc et al. 2001, LeDuc 2004). The acoustic data sets available to us during the 2002-2003 NPMRI funding period included 1) recordings from Oct. 2000-May 2001 and August 2001-

July 2002 by ARPs deployed in the 'box' (Figure 3), and 2) recordings in July-Aug 2002 by sonobuoys.

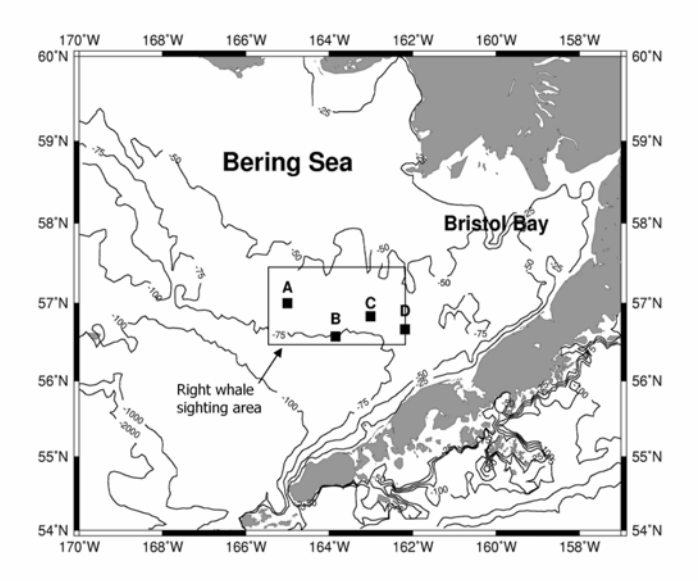

Figure 3. ARP deployment sites and right whale sighting 'box'.

Sonobuoy and ARP recordings contain right whale calls (Figure 4) similar to those described from previous Bering Sea recordings by McDonald and Moore (2002). The predominant right whale call type was the 'up' call, a signal sweeping from about 90 Hz to 150 Hz in 0.7s (McDonald and Moore, 2002). Right whales commonly produced calls in series lasting several minutes and then became silent for an hour or more, with some animals not calling for periods of at least four hours.

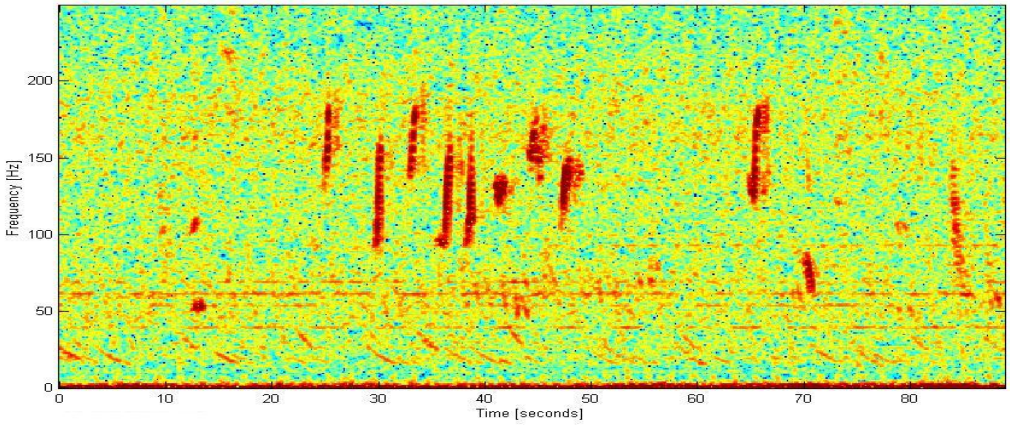

Figure 4. Right whale call spectrogram. Right whale 'up' calls in 100-200 Hz band, 'down' call (90-50Hz), and fin whale calls (35-15 Hz).

We used a combination of automated call detection software and manual data processing to detect right whale calls in ARP recordings. We used the software *Ishmael*, by David Mellinger (available freely online at http://cetus.pmel.noaa.gov/cgi-bin/getinfo.pl?dirname=ishmael) to

transform acoustic time series to frequency spectra and cross-correlate the recorded spectral data with a synthetic kernel based on the right whale 'up' call (Munger et al. in press). The spectrogram correlator also detected calls from humpback whales in the same frequency band used by right whales. We used *Ishmael* and *Triton*, a Matlab-based software program (Wiggins 2003) to view spectrograms of each detected call and identify to species by comparison with known characteristics of right whale and humpback whale calls (McDonald and Moore 2002; Mellinger et al. 2004).

We have investigated three techniques for localizing or ranging to calling animals within our data set: hyperbolic localization, which is based on differences in call arrival times on multiple hydrophones (Figure 5); range estimation based on normal mode dispersion (Wiggins et al. 2004); and directional cross-fixing using bearings obtained from directional hydrophones. The former two techniques can be applied to recordings from either moored or temporary hydrophones (i.e., ARPs or sonobuoys); the third method is only applicable to directional hydrophone (DIFAR sonobuoy) recordings. Hyperbolic localization and directional cross-fixing depend on receiving a call on multiple hydrophones; however, the mode dispersion method, which gives range but not exact location, may be used for calls recorded by a single hydrophone. Animal locations resulting from these techniques may aid in local abundance estimates and provide insight into some aspects of behavioral ecology.

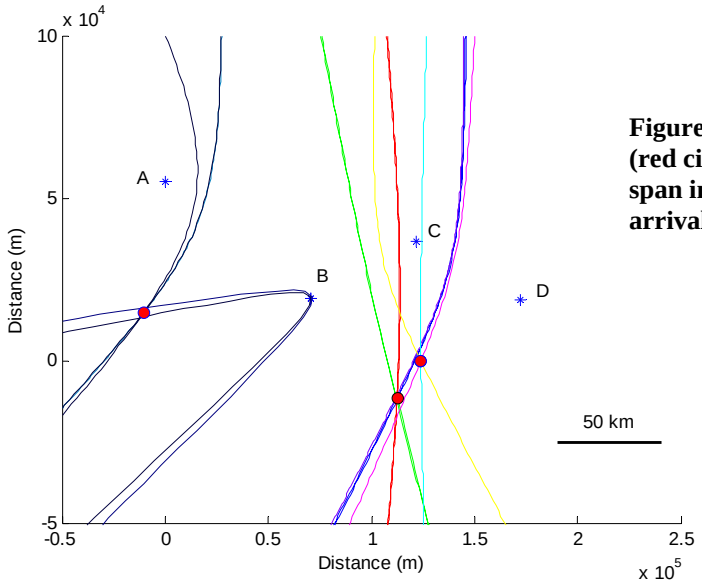

Figure 5. Three different whale locations (red circles) obtained over a two-hour time span in the data set, using times of call arrivals on ARPs (blue asterisks).

Project Management:

The principal investigator (PI) of the project is Dr. John Hildebrand at Scripps Institution of Oceanography (SIO). He oversaw the research and contributed to collaborative efforts. Current and past research by Dr. Hildebrand and collaborators includes use of ARPs to monitor baleen whale populations off the California coast, in the Gulf of Alaska, and off the Antarctic peninsula. Lisa Munger, a Ph.D. student at SIO, worked with Dr. Hildebrand to analyze data and report findings. Expertise was also contributed by Sean Wiggins and Allan Sauter (both scientists in the SIO whale acoustics research group).

This research is part of ongoing collaboration with other research efforts, including visual surveys, photogrammetry studies, and tagging studies by Sue Moore, Rick LeDuc, Lisa

Ballance, Paul Wade, Robert Pitman, Jay Barlow and colleagues (NOAA-NMFS: SWFSC, AFSC, NMML). David Mellinger (NOAA/PMEL, Oregon State Univ.) provided software support and expertise. Mark McDonald (Whale Acoustics, Inc.) provided expertise in acoustics instrumentation and processing. John Concilus and Chick Beckley (Bering Strait School District) facilitated educational outreach visits to native Alaskan villages.

Findings & Accomplishments:

Using a combination of automated spectrogram cross-correlation and manual examination of data, we processed the entire data set and detected hundreds of right whale calls. The ARPs provided new information on the seasonality of right whales occurring in the southeast Bering Sea: the latest calls of the year were detected in late October/early November in both 2000 and 2001; the earliest calls of the year were detected in late May 2002 (Figure 6). The presence of right whales in the Bering Sea into November was later in autumn than previously assumed from sightings; the first appearance of right whales there in spring has not been documented before.

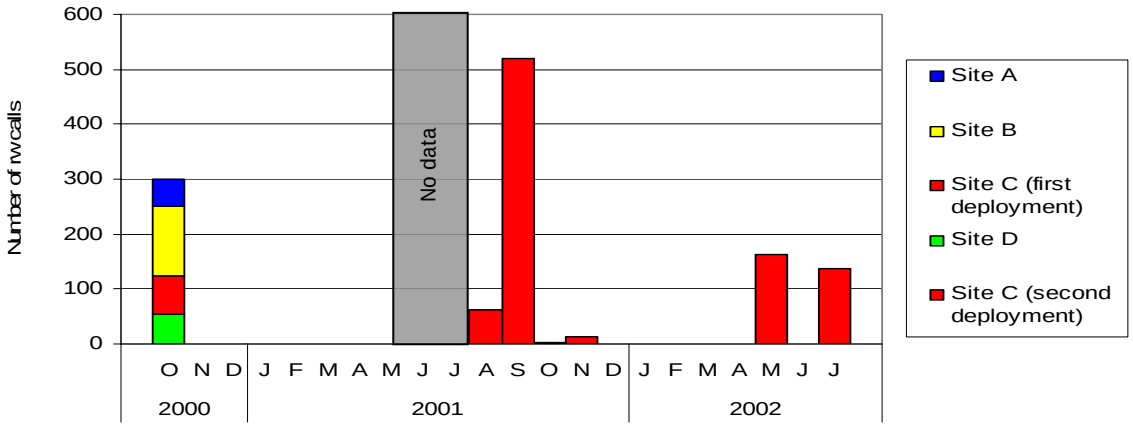

Figure 6. Right whale call seasonality in the southeast Bering Sea, 2000-2002, as determined from Acoustic Recording Package deployments.

Right whale calls were clustered in 'bouts' (Figure 7), similarly to previously described calling behavior in North Pacific and North Atlantic right whales (McDonald and Moore, 2002; Matthews et al., 2001). Humpback whale calls varied in frequency and duration, but occurred in repetitive patterns throughout the 2000-2001 recording period, and occurred less frequently in the 2001-2002 recording period.

The acoustic environment in the southeast Bering Sea has enabled us to detect calling right whales over 90 km from sonobuoys (Munger et al. unpub. data)., and to localize them up to 60 km from calls received on ARPs (Wiggins et al. 2004). These acoustic detection ranges greatly aided visual surveys and enabled vessels to find right whales and collect photographic and genetic data (NMFS 2004a).

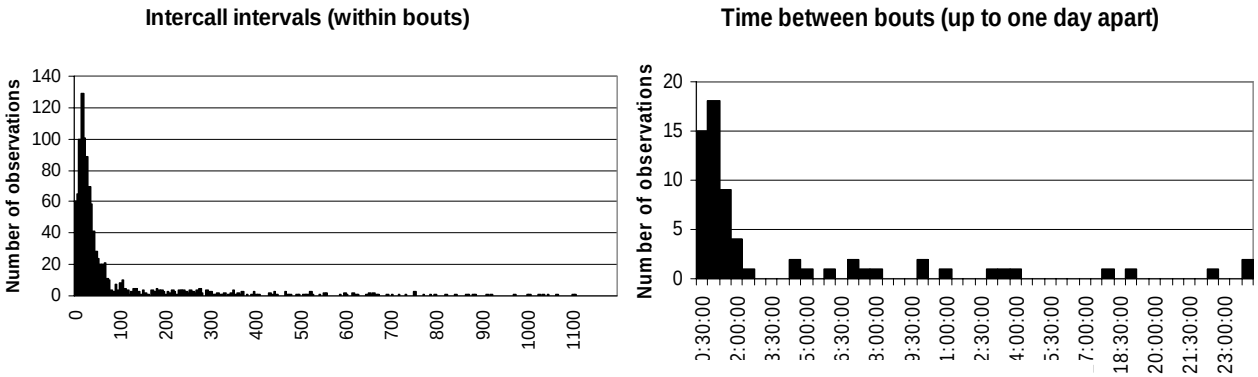

Figure 7. Temporal characteristics of right whale call bouts.

Outreach:

Lisa Munger visited several rural Alaskan communities around the Bering Sea during this project, including Nelson Lagoon, Cold Bay, Unalakleet, Diomede, Wales, Gambell, and Savoonga. Activities with students in these communities included disassembling an ARP that had drifted to shore, deploying hydrophones at the ice edge and listening to and recording bearded seals in real-time, and multimedia presentations and hands-on science demonstrations in classrooms. In additions to these educational visits, L.Munger participated in several outreach activities locally in 2004, including an e-mail correspondence with 3rd -4th grade students in Montana, and hands-on marine science activities with local elementary students. We contributed educational material to our website, at http://www.cetus.ucsd.edu. This website is dynamic and content will continue to be added as research progresses.

Conferences Attended:

January 2003: Marine Science Symposium (EVOS/NPRB/NPMRI et al.), Anchorage AK. Presented talk and poster (L. Munger).

November 2003: Acoustic Detection and Localization of Marine Mammals (Defense Research and Development Canada), Halifax, Nova Scotia. Presented talks (L. Munger, M. McDonald, S. Wiggins, D. Mellinger).

January 2004: Marine Science Symposium (EVOS/NPRB/NPMRI et al.), Anchorage AK. Distributed fliers. (L. Munger).

November 2004: meeting of the Acoustical Society of America, San Diego, CA. Presented talks (J. Hildebrand, S. Wiggins, D. Mellinger, and others).

Ongoing work:

We continue to augment our acoustic data sets via long-term ARP deployments (Table 1) and short-term recordings during vessel surveys. Some of these new deployments include ARPs that were incorporated onto PMEL biophysical moorings in the Bering Sea (with funding from Alaska Department of Fish and Game), which will provide simultaneous data on temperature, salinity, currents, productivity, and nutrients, allowing for analysis of the relationship between oceanographic conditions and marine mammal distributions on the same temporal and spatial scales.

Ongoing and future research goals include 1) investigating the relationship between right whale calling patterns and other behavioral observations during vessel surveys and 2) investigating correlations between right and fin whale distributions and oceanographic data, such as remotely-sensed data (Figure 8) or in situ data collected by moorings such as NOAA-PMEL sites M2 and M4. Results of NPMRI and NPRB-funded work will form the basis for L. Munger's doctoral thesis, expected to be defended in the 2006-07 academic year.

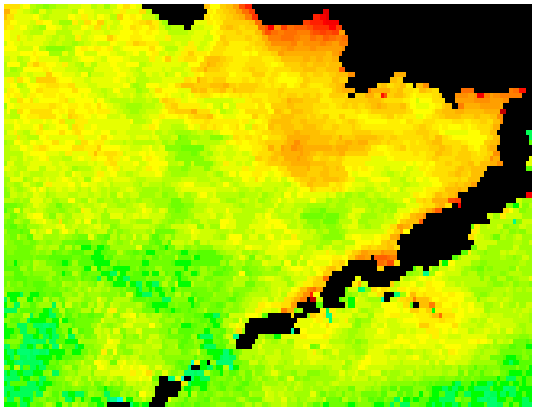

Figure 8. SeaWIFS average chlorophyll composite image for the Bering Sea and adjacent regions, 1997-2002.

Evaluation:

We developed techniques for processing existing acoustic data from the Bering Sea (Munger et al. in press), and used these techniques to detect right whale calls in our long-term recordings from 2000-2002. Results provided information on right whale seasonality and calling patterns. In addition, we developed techniques for localizing calling whales (Wiggins et al. 2004), which may aid in abundance estimates.

Ongoing objectives of right whale research include furthering our understanding of their behavioral ecology, and ultimately using this understanding to better inform conservation efforts.

PAST DEPLOYMENTS

Study area	Sampling frequency	Deployment Lat/Lon (N,W)	Depth	Recording Coverage	Calls detected
SEBS middle-shelf	500 Hz	57-00.00 164-59.97	~70 m	10/01/2000-05/08/2001	RW, fin, humpback
SEBS middle-shelf	500 Hz	56-40.37 163-50.74	~70 m	10/01/2000-12/13/2000	RW, fin, humpback
SEBS middle-shelf	500 Hz	56-49.89 163-00.48	~70 m	10/01/2000-05/03/2001	RW, fin, humpback
SEBS middle-shelf	500 Hz	56-40.05 162-10.80	~70 m	10/01/2000-05/07/2001	RW, fin, humpback
SEBS middle-shelf	500 Hz	56-49.97 163-00.49	~70 m	08/31/2001-07/28/2002	RW, fin, humpback
SEBS middle-shelf (M2-PMEL)	80 kHz	56-51.60 164-03.60	72 m	04/26/04-07/28/04	TBD
Bering shelf break	1000 Hz	56-21.482 169-39.736	125 m	05/01/04-06/10/04	TBD
Gulf of AK (Kodiak)	1000 Hz	56-57.016 150-59.806	802 m	04/19/03-08/31/03	Fin, blue, poss. humpback

CURRENT DEPLOYMENTS

Study area	f_s (Hz)	Deployment date	Deployment location	depth
Bering shelf break	1000	04/30/04	56-45.56 N, 170-28.83 W	103m
Bering shelf break	1000	05/02/04	54-0.0 N, 170-0.0 W	1880m
Bering shelf break	1000	08/17/04	54-10.84 N, 166-53.77 W	1520m
SEBS middle-shelf (M2-PMEL)	32000	09/27/04	56-51.614 N, 164-03.652 W	71m
SEBS middle-shelf (M4-PMEL)	32000	09/30/04	57-51.18 N, 168-52.2 W	70m

Table 1. Acoustic Recording Packages previously and currently deployed in the Bering Sea.

Dissemination of project results:

In 2004, we published two papers as a result of right whale acoustics research: the first was related to range estimation for calling right whales in the Bering Sea (Wiggins et al. 2004), and the second presented information on right whale calls recorded in the Gulf of Alaska (Mellinger et al. 2004). A manuscript describing the automated detection process we used for right whale calls is in press (Munger et al. in press). Two manuscripts are in preparation: 1) A manuscript on acoustic detection of right whales during real-time surveys is under revision to be submitted to Aquatic Mammals. 2) A manuscript describing right whale seasonality is in the final stages of preparation and will be submitted to Marine Mammal Science.

Related publications:

Mellinger, D.K., Stafford, K.M., Moore, S.E., Munger, L., and Fox, C.G. 2004. Detection of North Pacific right whale (*Eubalaena japonica*) calls in the Gulf of Alaska. Marine Mammal Science 20: 872-879.

Munger, L.M., Mellinger, D.K., Wiggins, S.M., Moore, S.E., and Hildebrand, J.A.. In press. The performance of spectrogram correlation in detecting right whale calls in long-term recordings from the Bering Sea. Canadian Acoustics (accepted).

Munger, L.M., A. Sauter, S.E. Moore, and J. Benson. In revision. Finding North Pacific right whales by acoustic localization.

Munger, L.M., S.E. Moore, S.M. Wiggins, and J.A. Hildebrand. In preparation. Seasonal occurrence of North Pacific right whale calls in the southeast Bering Sea, 2000-2002.

Munger, L.M., Moore, S., Hildebrand, J., Wiggins, S., and McDonald, M. Calls of North Pacific right whales recorded in the southeast Bering Sea. Abstract *in* Marine Science in the Northeast Pacific, Joint Scientific Symposium, Anchorage, AK, January 2003.

Munger, L.M.. Tracking critically endangered North Pacific right whales (Eubalaena japonica) in Alaskan waters using passive acoustics. Abstract *in* Marine Science in Alaska: 2005 Symposium, Anchorage, AK, January 2005.

Wiggins, S.M., McDonald, M.A., Munger, L.M., Hildebrand, J.A., and Moore, S.E. 2004. Waveguide propagation allows range estimates for North Pacific right whales in the Bering Sea. Canadian Acoustics, 32: 146-154.

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Mellinger, D.K., Stafford, K.M., Moore, S.E., Munger, L., and Fox, C.G. 2004. Detection of North Pacific right whale (*Eubalaena japonica*) calls in the Gulf of Alaska. Marine Mammal Science 20: 872-879.

Munger, L.M., Mellinger, D.K., Wiggins, S.M., Moore, S.E., and Hildebrand, J.A.. In press. The performance of spectrogram correlation in detecting right whale calls in long-term recordings from the Bering Sea. Canadian Acoustics (accepted).

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