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**DATASETS OF ODONTOCETE SOUNDS ANNOTATED
FOR DEVELOPING AUTOMATIC DETECTION
METHODS, FY09-10**

by

David K. Mellinger

September 2012

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Prepared for: Chief of Naval Operations
Energy and Environmental Readiness Division,
Washington, D.C.

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14. ABSTRACT Detection, classification, and localization (DCL) research on marine mammal vocalizations has been in development for decades, and methods for marine mammal population density estimation using acoustic data have been in development since at least 2007. These efforts have been supported by MobySound, an archive of cetacean sounds used for studying call detection and localization that are annotated to facilitate research in DCL. This project was aimed to begin development of high-performing automatic detection methods for the sounds of beaked whales and other odontocetes. Specifically, this report [1] details the newly collected odontocete recordings that have been added to the MobySound archive; [2] documents continuing development of methods for detection and classification, including improvements to the Energy Ratio Mapping Algorithm (ERMA) method for use on gliders and its extension to new species and populations; [3] reports on development of a new method for estimating the population density of baleen whales using the summed energy in a frequency band in which they vocalize; and [4] also reports on the successful production of datasets focused on odontocete whistles and clicks and baleen whale calls for the Fifth Workshop on Detection, Classification, Localization, and Density Estimation of Marine Mammals using Passive Acoustics.					
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**Datasets of odontocete sounds annotated for developing automatic detection
methods, FY09-10**

Report submitted pursuant to award number N00244-09-1-0079

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Project Overview

The Navy is required by environmental laws, including the Endangered Species Act, the Marine Mammal Protection Act, and the National Environmental Policy Act, to conduct its research and operations with minimal impacts on marine mammals, and to mitigate any adverse impacts caused by those transactions. In compliance, the Navy has been compelled to monitor the occurrence and behavior of marine mammals before, during and after research and operational activities. Acoustic methods have become a primary tool used for this task; they are now routinely and widely used in marine mammal research, monitoring, and mitigation.

Item 9 of the document “U.S. Navy Living Marine Resource and Sound Research Requirements” calls for the Navy to “Determine what real time observation, detection, and classification measures are required to develop effective monitoring and mitigation procedures,” with special emphasis on sub-part (a), “Means to detect whether priority species have been affected by Navy sounds,” and (c), “Means to test the effectiveness of mitigation measures.” The advancement of methods and software for *detection*, *classification*, and *localization* (DCL) of marine mammal sounds has been one area of research which supports the Navy in fulfilling this requirement.

DCL research on marine mammal vocalizations has been in development for decades, and methods for marine mammal population density estimation using acoustic data have been in development since at least 2007. These efforts have been supported by MobySound, an archive of cetacean sounds used for studying call detection and localization that are annotated to facilitate research in DCL.

Since the inception of MobySound in the mid 1990s, it has expanded from being an archive of baleen whale (mysticete) sounds to include annotated recordings of toothed whale (odontocete) species. This expansion converged with the advent of the biennial Workshops on the Detection, Classification, and Localization (DCL) of Marine Mammals using Passive Acoustics. There have now been five of these workshops, and the data sets for all of them are part of MobySound. With the additions to MobySound in recent years, there are now 22 datasets covering 18 species in the archive.

Some of the better detection and classification methods that have been developed by using data sets in MobySound have been on endangered species, including sperm [1-4], blue [5-6], and right [7-19] whales, and high-priority species, including beaked whales [20-25]. These projects have used click characteristics as the feature for automatic detection, classification and identification; a recent application has been development of a low-power detection method known as ERMA [21, 23, 26-28] suitable for use on ocean gliders. MobySound data are being used to develop, test, and improve ERMA.

The major aim of this project was to begin development of high-performing automatic detection methods for the sounds of beaked whales and other odontocetes. The specific aims were to collect recordings with calls; annotate these sound files to make them useful to researchers working on automatic call detection and classification; make them publicly available in an archive on the Internet; continue developing and publishing detection and classification methods and software; integrate these methods with new autonomous platforms and detection systems; develop a new method for population density estimation based on sound density and apply it to field recordings; and prepare a workshop dataset for the 2011 International Workshop on the Detection, Classification, and Localization of Marine Mammals using Passive Acoustics, which occurred August 21-25, 2011, in Oregon.

In more detail, project tasks were as follows:

- (1) **Annotate recordings** of odontocete sounds (whistles, clicks) and add these to MobySound.
- (2) **Detection/classification:** Continue developing detection and classification methods and software, and integrating these methods with new platforms including gliders and robotic sailboats.
- (3) **Density estimation:** Apply a newly-developed method for population density estimation to field recordings.
- (4) **Workshop dataset:** Produce datasets for detection, classification, and localization for the 2011 DCL conference, which my lab is organizing.

Results

The results by task are as follows:

- (1) [**Annotate recordings**] We collected data sets of odontocete recordings containing whistles and clicks for addition to our archive site MobySound.org. These recordings include sounds of Baird's beaked whale (*Berardius bairdii*), Pacific white-sided dolphin (*Lagenorhynchus obliquidens*), northern right whale dolphin (*Lissodelphis borealis*), long-beaked common dolphin (*Delphinus capensis*), short-beaked common dolphin (*Delphinus delphis*), Risso's dolphin (*Grampus griseus*), bottlenose dolphin (*Tursiops truncatus*) and killer whale (*Orcinus orca*) from the U.S. West Coast; sperm whale (*Physeter macrocephalus*), pantropical spotted dolphin (*Stenella attenuata*), striped dolphin (*Stenella coeruleoalba*), short-finned pilot whale (*Globicephala macrorhynchus*), false killer whale (*Pseudorca crassidens*), melon-headed whale (*Peponocephala electra*), bottlenose dolphin (*Tursiops truncatus*), rough-toothed dolphin (*Steno bredanensis*), and spinner dolphin (*Stenella longirostris*) from the eastern tropical Pacific; killer whale (*Orcinus orca*) from the south Atlantic; and gray whales (*Eschrichtius robustus*) from the eastern Pacific (Mexico). Many of these recordings have been annotated for clicks and whistles. Recordings of Dall's porpoise (*Phocoenoides dalli*), harbor porpoise (*Phocoena phocoena*) and killer whales

(*Orcinus orca*) from the north Pacific were also collected for eventual addition to MobySound.org.

The MobySound archive has been accessed increasingly often since being moved to a new host. The website has had approximately 900 unique visitor usages in a one-year span and many thousands of accesses (hits). The front page of this website is shown in Appendix 2.

We also developed a new method for measuring signal-to-noise ratio (SNR) of whistle sounds. Existing MobySound recordings comprise baleen whale moans and odontocete clicks; the methods for measuring SNR for these are not applicable to whistles-- particularly whistles mixed with clicks, as are found in most whistle recordings. We developed a new method in MATLAB, `snrWhistle.m`, for measuring the SNR of whistles in the presence of clicks, and published it via the MobySound website.

- (2) **[Detection/classification]** We continued to develop methods for detection and classification, including improvements to the ERMA method for use on gliders [26-28], and extended it to new species and populations. The methods were employed in the glider deployments collected in the Navy's AUTECH range in the Bahamas in summer 2010 and off the Kona coast of Hawaii in late 2009. Species for which ERMA detectors have been developed now include Cuvier's beaked whales (*Ziphius cavirostris*), Blainville's beaked whales (*Mesoplodon densirostris*), and killer whales (*Orcinus orca*). ERMA, as part of its detection algorithm, incorporates information about confounding species in the geographic region where it is used; the list of regions for which this has been done now includes Washington state (Haro Strait area), Hawaii (Kona coast of the big island of Hawai'i), and the Bahamas (Andros Island area). Detection results from the Kona experiment showed that during the mission ERMA detected beaked whale vocalizations on 10 out of 85 glider dives. Manual analysis revealed that 7 of these detections were actual beaked whale encounters. During the other 3 glider dives the detection system was mistakenly triggered by delphinid vocalizations. The analyst identified a total of 109 sound files containing beaked whale clicks. The automated system correctly detected calls in 79 out of these 109 sound files (72%). Results from this development were recently published in a peer-reviewed journal [37].
- (3) **[Density estimation]** A new method was developed for estimating the population density of baleen whales using the summed energy in a frequency band in which they vocalize. The method was not applied to the case study of humpback whales in the Bering Sea, because that dataset turned out to have too much confounding noise; instead, the case study used was of fin whales. The method produced a number for the population density, but has not been verified yet. A separate effort is under way (the Cheap DECAF project) to estimate the density of fin whales using other methods; and when that is done, the results from that project will be compared to results from this method. The method is the subject of a forthcoming paper [38] defining the method and showing its results for this case study.

(4) **[Workshop dataset]** We coordinated the production of datasets focused on odontocete whistles and clicks and baleen whale calls for the Fifth Workshop on Detection, Classification, Localization, and Density Estimation of Marine Mammals using Passive Acoustics, which we hosted at Timberline Lodge, Mt. Hood, Oregon, from August 22-25, 2011. We prepared these datasets as common ground for comparing methods in collaboration with Marie Roch (Scripps Institution of Oceanography and San Diego State University) for the classification dataset and Eva-Marie Nosal (University of Hawaii) and Steve Martin (SPAWAR) for the localization dataset. This dataset was released approximately six months before the workshop on the MobySound web site and was used by conference attendees. A comparison of results of methods tested on this dataset was included.

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Appendix 1:

Status summary of recordings in or available to the archive

Species	Common Name	Region	N sounds	N files	N (s)	Source
<i>CURRENT</i>						
Mysticetes (baleen whales)						
<i>Balaena mysticetus</i>	bowhead whale	northern Alaska	589	128	3580	NOAA/CIMRS
		northeastern Alaska		45	2500	Greenridge Sciences, Inc.
		northwestern Alaska		9	18313	JASCO
<i>Balaenoptera acutorostrata</i>	Minke whale	north Atlantic	178	5	13185	NOAA/CIMRS
		western tropical Pacific		29		Biowaves, Inc.
<i>Balaenoptera borealis</i>	Sei whale	western tropical Pacific		4		Biowaves, Inc.
<i>Balaenoptera edeni</i>	Bryde's whale	eastern tropical Pacific	1402	12	364600	NOAA/CIMRS
		western tropical Pacific		2		Biowaves, Inc.
<i>Balaenoptera musculus</i>	blue whale	north Atlantic	405	9	1401	NOAA/CIMRS
<i>Balaenoptera physalus</i>	fin whale	north Atlantic	3066	15	75320	NOAA/CIMRS
<i>Eschrichtius robustus</i>	Gray whale	Baja Mexico	9697			Independent researcher
<i>Eubalaena australis</i>	southern right whale	South Africa	67	5	2273	Independent researcher
<i>Eubalaena glacialis</i>	north Atlantic right whale					NOAA/CIMRS
<i>Eubalaena japonica</i>	north Pacific right whale	Bering Sea	38	6	4496	NOAA/CIMRS
<i>Megaptera novaeangliae</i>	humpback whale	north Atlantic	2310	14	7600	NOAA/CIMRS
		western tropical Pacific		11		Biowaves, Inc.
Odontocetes (toothed whales and dolphins)						
<i>Globicephala macrorhynchus</i>	short-finned pilot whale	AUTEC, North Atlantic	55933	9	13500	NUWC
		north Atlantic, Canary isles		1	2000	MEER e.V.
		northwestern Pacific		2		Biowaves, Inc.
<i>Globicephala melana</i>	long-finned pilot whale	Mediterranean		16		Univ. Pavia, Italy
<i>Grampus griseus</i>	Risso's Dolphins	SCORE, Southern Calif.		10	17100	SIO
		Mediterranean		6		Univ. Pavia, Italy
<i>Peponocephala electra</i>	Melon-headed whale	northwestern Pacific		1		Biowaves, Inc.
<i>Physeter macrocephalus</i>	sperm whale	AUTEC, North Atlantic		3	2790	NUWC
		western tropical Pacific		61		Biowaves, Inc.
		Mediterranean		6		Univ. Crete
<i>Pseudorca crassidens</i>	False killer whales	western tropical Pacific		10		Biowaves, Inc.
<i>Stenella attenuata</i>	pantropical spotted dolphin	western tropical Pacific		11		Biowaves, Inc.
<i>Stenella coeruleoalba</i>	Striped Dolphin	western tropical Pacific		9		Biowaves, Inc.


<i>Stenella longirostris</i>	Spinner Dolphin	western tropical Pacific		1		Biowaves, Inc.
<i>Steno bredanensis</i>	rough-toothed Dolphin	AUTEC, North Atlantic		2	3600	NUWC
		north Atlantic, Canary isles		1	900	MEER e.V.
		western tropical Pacific		1		Biowaves, Inc.
<i>Stenella spp.</i>	spotted dolphin	AUTEC, North Atlantic		1	1800	NUWC
		north Atlantic, Canary isles		1	900	MEER e.V.
<i>Tursiops truncatus</i>	bottlenose dolphin	north Atlantic, Canary isles		1	900	MEER e.V.
		western tropical Pacific		1		Biowaves, Inc.
Odontocetes- beaked whales						
<i>Berardius arnuxii</i>	Arnoux's Beaked Whale	Antarctic	3379	3	8409	Univ. New S. Wales
<i>Berardius bairdii</i>	Baird's Beaked Whale	north Pacific		21	7233	NMML/APL/NOAA
		Baja Mexico		60	3600	NMML/NOAA
<i>Mesoplodon densirostris</i>	Blainville's Beaked Whale	AUTEC, North Atlantic	3637	41	67613	AUTEC
		north Atlantic, Canary isles.	3000	1	1260	WHOI
		eastern tropical Pacific		3	19.7	NOAA
<i>Mesoplodon spp.</i>	Beaked whales	western tropical Pacific				Biowaves, Inc.
<i>Ziphius cavirostris</i>	Cuvier's Beaked Whale	Mediterranean	3137	1	1800	WHOI
		Mediterranean		10		Univ. Pavia, Italy
Pinnipeds (seals)						
<i>Lobodon carcinophagus</i>	crab eater seal	Antarctic	3940	714	42840	PALAOA
<i>Hydrurga leptonyx</i>	leopard seal	Antarctic	7249	3923	235440	PALAOA
<i>Erignathus barbatus</i>	bearded seal	northern Alaska		2	1000	Greenridge Sciences, Inc.
<i>EXTANT: Annotated and available to archive</i>						
Mysticetes (Baleen whales)						
<i>Balaenoptera acutorostrata</i>	Minke whale	eastern tropical Pacific				Bio-Waves Inc.
<i>Megaptera novaeangliae</i>	humpback whale	north Atlantic				OASIS, Inc.
		eastern tropical Pacific				Bio-Waves Inc.
Odontocetes (toothed whales and dolphins)- beaked whales						
<i>Delphinus capensis</i>	long-beaked common dolphin	SCORE, Southern Calif.				SIO
<i>Delphinus delphis</i>	short-beaked common dolphin	SCORE, Southern Calif.				SIO
<i>Orcinus orca</i>	killer whale	Southern Puget Sound				Independent Researcher
<i>Physeter macrocephalus</i>	sperm whale	Mediterranean				Univ. Crete
		Gulf of Mexico				Univ. New Orleans
Pinnipeds (seals)						
<i>Phoca vitulina</i>	harbor seals	California coastline				NMFS/NOAA

*Abbreviations:

AUTEC Atlantic Undersea Test and Evaluation Center
 CIMRS Cooperative Institute for Marine Resources Studies
 NMML National Marine Mammal Laboratory
 NOAA National Oceanic and Atmospheric Administration
 NUWC Naval Undersea Warfare Center

PALAOA Perennial Acoustic Observatory in the Antarctic Ocean
 SCORE Southern California Offshore Range
 SIO Scripps Institution of Oceanography
 UW-APL University of Washington, Applied Physics Laboratory
 WHOI Woods Hole Oceanographic Institute

Appendix 2: Home page of open access website



The screenshot shows the home page of MobySound.org in a Mozilla Firefox browser window. The browser's address bar displays the URL <http://www.mobysound.org/>. The website's header features a large image of a whale with sound waves emanating from its head, and the text "Moby Sound.org". Below the header is a navigation menu with links: [home](#), [about mobysound](#), [odontocetes](#), [mysticetes](#), [pinnipeds](#), [workshops](#), [copyright](#), and [disclaimer](#).

The main content area is divided into two columns. The left column has a "news" section with a sub-header "23 March 2009: Upcoming Conferences..." and a vertical stack of five small images showing marine mammals: a whale, a whale, a seal, two dolphins, and a whale. The right column contains the main text, starting with a "HOME" tab and the text "by Sara Heimlich, Dave Mellinger and Holger Klinck".

Welcome to MobySound.org

Welcome to **MobySound.org**, a database for research in automatic recognition of marine animal calls.

This website is maintained by **Sara Heimlich, Holger Klinck and Dave Mellinger**. Please send us an email about any needed additions and corrections.

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MobySound.org is funded in part by the [Office of Naval Research](#) and the Office of the Chief of Naval Operations.

Remarks:

- File compression (zip) was via Microsoft Windows standard compression option.
- For optimal download, use a download manager (e.g. [Free Download Manager](#)).
- This website is optimized for [Mozilla Firefox 3](#)

Appendix 3: Publications and Presentations

Articles in peer-reviewed journals

- KLINCK, H., AND D. K. MELLINGER. 2011. The energy ratio mapping algorithm (ERMA): a tool to improve the energy-based detection of odontocete clicks. *J. Acoust. Soc. Am.* **129(4)**: 1807-1812.
- KLINCK, H., D. K. MELLINGER, K. KLINCK, J. HAGER, L. KINDERMANN, AND O. BOEBEL. 2010. Long-range underwater vocalizations of the crabeater seal (*Lobodon carcinophaga*). *J. Acoust. Soc. Am.* **128(1)**: 474-479.
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- YACK, T. M., J. BARLOW, M. A. ROCH, H. KLINCK, S. MARTIN, D. K. MELLINGER, AND D. GILLESPIE. 2010. Comparison of beaked whale detection algorithms. *Applied Acoust.* **71(11)**: 1043-1049.

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- MELLINGER, D.K. 2011. Signal processing and analysis (detection, classification and localization of marine mammal sounds). *In*: BINGHAM, G. Status and Applications of Acoustic Mitigation and Monitoring Systems for Marine Mammals: Workshop Proceedings. (17-19Nov. 2009. Boston, Massachusetts) *U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement, Gulf of Mexico OCS Region, New Orleans OCS Study BOEMRE 2011-002*: 35-38.
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- MARTIN, S. W., T. NORRIS, E.-M. NOSAL, D. K. MELLINGER, R. P. MORRISSEY, AND S. JARVIS. **2011.** Automatic localization of individual Hawaiian minke whales from boing vocalizations. *J. Acoust. Soc. Am.* **129(4)**: 2506(A).
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Data exchanges

- Hundreds of data downloads from the MobySound.org web site (see above)
- Univ. Washington – beluga and bowhead whale recordings from the Beaufort Sea
- NOAA-NMML – recordings of many species from the Bering Sea
- Univ. New South Wales – Arnoux’s beaked whale recordings from Antarctica
- JASCO Applied Sciences, Inc. – bowhead whale recordings from the Chukchi Sea
- Greenridge Sciences, Inc. – bowhead whale recordings from the eastern Beaufort Sea
- *Mamíferos, Encuentros, Educación, Reconocimiento* (MEER) – short-finned pilot whale recordings from the Canary Islands
- Alfred Wegener Institute – crabeater seal recordings from Antarctica
- Univ. Crete – sperm whales from the Mediterranean Sea

Dissertations/graduate theses

None.

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| 36. | Chip Johnson
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| 37. | CDR Len Remias
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| 38. | LCDR Robert S. Thompson
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| 39. | Jene J. Nissen
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| 40. | W. David Noble
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56.	David Moretti NUWC Newport, RI	1
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58.	Dan Costa University of California, Santa Cruz Santa Cruz, CA	1
59.	Lori Mazzuca Marine Mammal Research Consultants, Inc. Honolulu, HI	1
60.	Jim Eckman Office of Naval Research Arlington, VA	1
61.	Ari Friedlaender Duke University Beaufort, NC	1
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