7th International Workshop on [Detection, Classification, Localization, and Density Estimation] of Marine Mammals using Passive Acoustics

July 13 - 16, 2015 • La Jolla, CA

at the **Seaside Forum**
Scripps Institution of Oceanography
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7th International Workshop on Detection, Classification, Localization, and Density Estimation of Marine Mammals using Passive Acoustics

Seaside Forum • Scripps Institution of Oceanography

University of California San Diego

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Previous DCLDE Workshops

University of St Andrews, Scotland, 2013
Oregon State University, Oregon, US, 2011
Università degli studi di Pavia, Italy, 2009
Naval Undersea Warfare Center, Boston, US, 2007
Université Paris-Sud, Oceanographic Museum of Monaco, Monaco, 2005
DRDC Atlantic and Dalhousie University, Halifax, Canada, 2003

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Introduction

Welcome to the 7th International Workshop on Detection, Classification, Localization, and Density Estimation (DCLDE) of Marine Mammals using Passive Acoustics. The biennial DCLDE Workshops are intended for exchanging information that advances our understanding of acoustic methods to detect, classify, locate, track, count, and monitor marine mammals in their natural environment. The goal is to encourage interdisciplinary approaches to solve real-world problems related to the study of marine mammals and the effects of human activities.

As with previous workshops, a common dataset has been provided which will allow participants to directly compare algorithms and methodologies. While delegates are encouraged to work with the workshop dataset, contributions using other data will also be accepted. The DCLDE 2015 dataset consists of data from multiple deployments of high-frequency acoustic recording packages deployed in the Southern California Bight. Separate sets of development data are provided for mysticetes and odontocetes. The mysticete data have been decimated to 1 and 1.6 kHz bandwidth and the odontocete data bandwidth consists of data with 100 and 160 kHz of bandwidth. Data were selected to cover all four seasons and from multiple locations. This high-frequency datasets consists of annotated data from multiple odontocete species. Included is Baird's beaked whale (*Berardius bairdii*), Cuvier's beaked whale (*Ziphius cavirostris*), Sperm whale (*Physeter macrorhynchus*), Pacific white-sided dolphin (*Lagenorhynchus obliquidens*), Risso's dolphin (*Grampus griseus*), unspecified porpoise (*Phocoenidae*), and odontocete other than those described above (*Odontoceti*). The goal for this dataset is to identify acoustic encounters of a species during times when animals were echolocating.

The low-frequency dataset consists of annotated data for specific calls from two mysticete species, blue whale (*Balaenoptera musculus*) D calls and fin whale (*Balaenoptera physalus*) 40 Hz calls. The goal for this dataset is to identify specific blue whale D and fin whale 40 Hz calls.

WORKSHOP PROGRAM

AND SOCIAL PROGRAM

	Monday July 13	Tuesday July 14	Wednesday July 15	Thursday July 16	Friday July 17
7:30AM - 8:30AM	Onsite Check-In				
8:30AM - 8:40AM	Welcome: John Hildebrand	Topics of the day	Topics of the day	Topics of the day	
8:40AM - 9:00AM	Ana Širović*	Eva-Marie Nosal	Len Thomas*	Simone Baumann-Pickering*	
9:00AM - 9:20AM	Yu Shiu	Brendan Rideout	Julien Bonnel	Tiago Marques	Towed Array Workshop Part 1: Standards [9:00am - 10:30am]
9:20AM - 9:40AM	Emmanuel Leroy	Frans-Peter Lam	Ildar Urazghildilev	Elizabeth Henderson	
9:40AM - 10:00AM	Katherine Kim	Tyler Helble*	Kerri Seger	Tina Yack	
10:00AM - 10:20AM	Break	Break	Break	Break	
10:20AM - 10:40AM	Julie Oswald	Stephen Martin	Danielle Harris	Jens Koblitz	
10:40AM - 11:00AM	Pina Gruden	Michelle Weirathmueller	Brian Miller	Eiren Jacobson	Towed Array Workshop Part 2: Hardware [10:45am - 12:15pm]
11:00AM - 11:20AM	Sander von Benda-Beckmann	Ludwig Houegnigan	Thomas Norris	Jay Barlow	
11:20AM - 11:40AM	Danielle Cholewiak	William Wilcock	David Mellinger	Discussion	
11:40AM - 12:00PM	Discussion	Discussion	Discussion	Lunch	
12:00PM - 1:00PM	Lunch	Lunch	Lunch		
1:00PM - 1:20PM				Anu Kumar	
1:20PM - 1:30PM			Intro to dataset: John Hildebrand*	Tom Fedenczuk [1:20pm - 1:40pm]	
1:30PM - 1:50PM	Marie Roch*	Shyam Madhusudhana	Scott Lindeneau	Peter Dugan [1:40pm - 2:00pm]	
1:50PM - 2:10PM	Karlina Merkens	Xavier Mouy	Yin Xian	Break	
2:10PM - 2:30PM	Luis Matias	Shannon Rankin	Stephen Lockhart	Olide Gerard [2:20pm - 2:40pm]	
2:30PM - 2:50PM	Dorian Cazau	Selene Fregosi	Tetyana Margolina	Zhenbin Zhang [2:40pm - 3:00pm]	
3:00PM - 3:20PM	Break	Break	Break	Elizabeth Ferguson [3:00pm - 3:20pm]	
3:20PM - 4:00PM	Poster Intros	Poster Intros	Poster Intros	Closing Remarks	
4:00PM - 4:20PM	Yun Trinh	Kaitlin Frasier	Doug Gillespie		
4:20PM - 4:40PM	Susannah Buchman	Alba Solsona Berga	Carolyn Binder		
4:40PM - 5:00PM	Jeremy Karnowski	Susan Jarvis*	Holger Klinck		
5:00PM - 5:15PM	Discussion	Discussion	Discussion		
Evening	Stone Brewery	Birch Aquarium	Poster Reception with Mariachi Band		

- **Detection** [*Chair: Ana Širović]
- **Classification** [*Chair: Marie Roch]
- **Localization** [*Chair: Tyler Helble]
- **Detection/Classification** [*Chair: Susan Jarvis]
- **Density Estimation** [*Chairs: Len Thomas and Simone Baumann-Pickering]
- **Workshop Data** [*Chair: John Hildebrand]
- **Other Topics** [*Chair: Mike Weise]
- **Discussion / Other**

MONDAY 13th July 2015

8:30am – 8:40am	**Welcome** *John Hildebrand*	
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9:00am – 9:20am	**Near-Fully-Automatic Large-Scale Detection and Localization of Baleen Whale Vocalization in Fixed-Hydrophone Array** *Yu Shiu*	18
9:20am – 9:40am	**Robust detection of Antarctic blue whale calls, and comparison with classical spectrogram correlation** *Leroy Emmanuel*	19
9:40am – 10:00am	**Acoustic vector sensors reduce masking effects from underwater industrial noise during passive acoustic monitoring** *Katherine Kim*	20
10:00am – 10:20am	**Break**	
10:20am – 10:40am	**A comparison of automated detectors for tonal signals from delphinds** *Julie Oswald*	21
10:40am – 11:00am	**Multi-target tracking using Probability Hypothesis Density (PHD) filters for whistle contour detection** *Pina Gruden*	22
11:00am – 11:20am	**Modelling detection probabilities for Odontocete echolocation clicks** *Sander von Benda-Beckmann*	23
11:20am – 11:40am	**Shipboard echosounders negatively affect acoustic detection rates of beaked whales** *Danielle Cholewiak*	24
11:40am – 12:00pm	**Discussion**	
12:00pm – 1:30pm	**Lunch**	
Session:	**Classification** *Chair: Marie Roch*	
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1:50pm – 2:10pm	**Classification of Kogia spp. echolocation clicks and temporal trends at Hawai’i Island** *Karlina Merkens*	27
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2:30pm – 2:50pm	**The production-based approach for the study of humpback whale songs: overview and perspectives** *Dorian Cazau*	29
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	- **Near real-time passive acoustic monitoring of baleen whales from autonomous platforms in the Gulf of Maine** *Cara Hotchkin*	31
	- **Two phase efficient sperm whale click detection for autonomous devices** *Edson Bruno Novais*	32
	- **An evaluation of automated and manual methods for detecting Southern right whale (*Eubalaena australis*) contact calls.** *Julia Dombroski*	33
	- **Impact of detector performance and ambient noise levels on biological inferences** *Karolin Thomisch*	34
	- **Do echolocation clicks produced by delphinid species in the northwest Atlantic contain species-specific cues?** *Kerry Dunleavy*	35
	- **Comparison of vocalizations produced by killer whale ecotypes, communities, and pods in the northeastern Pacific Ocean** *Kerry Dunleavy*	36
	- **Statistical Filtering of Whistle Detections** *Michael MacFadden*	37
	- **True or False: Developing Methods for Pruning False and Inaccurate Detections from an Automated Whistle Detector** *Robyn Walker*	38
	- **Detection range and propagation of fin whale calls off Gulf of Cadiz** *Andreia Pereira*	39
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4:20pm – 4:40pm	**Detection of two highly similar blue whale songs in the southeastern Pacific, and possible population implications** *Susannah Buchan*	41
4:40pm – 5:00pm	**Classification of blue whale D calls and fin whale 40-Hz calls using deep learning** *Jeremy Karnowski*	42
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9:00am – 9:20am	**Acoustic multipath arrival time estimation via blind channel estimation** *Brendan Rideout*	45
9:20am – 9:40am	**Supporting CEE experiments with Northern bottlenose whales using a towed hydrophone array** *Frans-Peter Lam*	46
9:40am – 10:00am	**3-D localization and swim track kinematics of humpback whales on the Navy's Pacific Missile Range Facility** *Tyler Helble*	47
10:00am – 10:20am	**Break**	
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11:00am – 11:20am	**Neural Networks for the Localization of Biological and Anthropogenic Sources at Neutrino Deep Sea Telescopes and Deep Sea Observatories** *Ludwig Houegnigan*	50
11:20am – 11:40am	**Tracking blue whales with the Cascadia Initiative ocean bottom seismograph network** *William Wilcock*	51
11:40am – 12:00pm	**Discussion**	
12:00pm – 1:30pm	**Lunch**	
Session:	**Detection/Classification** *Chair: Susan Jarvis*	
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1:50pm – 2:10pm	**Automatic Marine Mammal Monitoring off British-Columbia, Canada** *Xavier Mouy*	54
2:10pm – 2:30pm	**Improving Classification of Dolphin Groups: Compound classification using whistles, echolocation, and burst pulses** *Shannon Rankin*	55

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8:30am – 8:40am	**Topics of the Day**	
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9:40am – 10:00am	**Humpback whale-generated ambient noise levels provide insight into singers' spatial densities** *Kerri Seger*	73
10:00am – 10:20am	**Break**	
10:20am – 10:40am	**Large scale density estimation of blue and fin whales: combined distribution and density estimates using bearing data** *Danielle Harris*	74
10:40am – 11:00am	**Towards passive acoustic density estimation of Antarctic blue whales: Preliminary results from the 2015 NZ-Australia Antarctic Ecosystems Voyage** *Brian Miller*	75
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11:20am – 11:40am	**Density estimation of northeast Pacific fin whales derived from frequency band energy** *David Mellinger*	77
11:40am – 12:00pm	**Discussion**	
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Session:	**Workshop Data** *Chair: John Hildebrand*	
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1:30pm – 1:50pm	**Classification of the DCDLE 2015 Dataset** *Scott Lindeneau*	79
1:50pm – 2:10pm	**Intrinsic structure study of whale vocalizations** *Yin Xian*	80

THURSDAY 16th July 2015

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9:00am – 9:20am	**All together now: understanding at depth group behavior of beaked whales at AUTEC** *Tiago Marques*	98
9:20am – 9:40am	**Using Detections of Foraging Dives to Estimate Density of Blainville's Beaked Whales** *Elizabeth Henderson*	99
9:40am – 10:00am	**From clicks to counts: using passive acoustic monitoring to estimate the density and abundance of Cuvier's beaked whales in the Gulf of Alaska** *Tina Yack*	100
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Session:	**Other Topics** *Chair: Mike Weise*	
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2:40pm – 3:00pm	**A blind source separation approach for humpback whale songs separation** *Zhenbin Zhang*	<u>**109**</u>
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FRIDAY 17th July 2015

9:00am – 10:30am	**Towed Array Workshop Part 1: Standards**
10:45am – 12:15pm	**Towed Array Workshop Part 2: Hardware**

WORKSHOP ABSTRACTS

DETECTION

Chair: Ana Širović

Oral / Monday 13th 2015 / 8:40 AM

Detection of blue whale calls from 7 years of data in Southern California

Ana Širović[1*], Ally Rice[1], Emily Chou[1]

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Spectrogram correlation has been used successfully for automatic detection of baleen whale calls. However, applying this method consistently on long time series presents a number of challenges. To illustrate these potential impacts on the automatic detection process, recordings collected in the Southern California Bight between 2007 and 2012 were used for detection of Northeast Pacific blue whale (*Balaenoptera musculus*) B calls. The effects of the following factors were investigated: blue whale B call frequency shift and appropriate kernel modification, seasonal variability in call abundance, analyst variability, and noise. Due to intra- and interannual changes in call frequency of blue whale B calls, seasonal and annual adjustments to the call detection kernel were needed. To account for seasonal variability in call production, evaluation of the detector against ground truth data was performed at multiple times during the year. Analyst variability did not affect overall long-term trends in detection, but it had an impact on the total numbers of detections, as well as call rate and density estimation. Noise, particularly from shipping, was negatively correlated with detections at hourly time scales. A need for a more detailed accounting of the variability in the performance of spectrogram correlation detectors when applied to long-term acoustic datasets will be discussed.

Oral / Monday 13th 2015 / 9:00 AM

Near-Fully-Automatic Large-Scale Detection and Localization of Baleen Whale Vocalization in Fixed-Hydrophone Array

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For many passive-acoustics-based long-term monitoring projects in fixed hydrophone array, both automatic detection and localization play very important roles in the data analysis process. However, two reasons prevent us from leveraging their full automation. On the one hand, automatic detection generally does not produce results as accurate as those done by human experts. A significant portion of calls are missed whereas false alarms are not uncommon due to the non-white noises and sound clutter. On the other hand, automatic localization requires tremendous amount of human experts' time to prepare its input data, which comprises association of detected calls over hydrophone channels that originates from a single vocalization event. Thus, either high percentage of collected acoustic data end up un-analyzed, or analysis result with inferior resolution is used. For example, daily or hourly presence/absence is preferred to call count in highly sampled days or hours.

In our work, we aim at achieving a fully automatic big-data analysis as extensive as possible, in the context of long-term fixed-hydrophone-array acoustic monitoring. We argue that (i) by exploiting the aggregated acoustic data from both multiple hydrophones and within a large context window and (ii) by achieving a fully automatic call association, can we not only significantly improve both automatic detection and localization of animal vocalization, but also increase the amount of information we can extract on marine mammal vocalization, including but not limited to, animal vocalization' location, unique call counts, sound pressure level, animal movement track, density estimation through spatially-explicit capture recapture (SECR) and etc. In addition, automatic detection and localization is treated as a single, non-separable problem. The result of localization offers numerical measures that help improve the automatic detection. Human experts should only be consulted on the validation of a distilled analysis output from a near fully automation process.

A case study of Northern Atlantic Right Whale, using archival acoustic fixed-array data in Cape Cod Bay and Massachusetts Bay, will be presented. Emphasis will be on how a comprehensive automatic detection and localization leads to a large-scale data analysis with minimum human cost.

Oral / Monday 13th 2015 / 9:20 AM

Robust detection of Antarctic blue whale calls, and comparison with classical spectrogram correlation

Leroy Emmanuelle[1*], François-Xavier Socheleau[2], Andes Carvallo Pecci[2], Flore Samaran[3], Julien Bonnel[3], Jean-Yves Royer[1]

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Most automatic detections of highly stereotyped baleen-whale calls such as the Antarctic blue whale calls (known as Z-calls) are usually performed by matching spectrogram-based templates. However, such approach presents weaknesses, such as its dependence on spectrogram parameters, as well as on *a-priori* subjective choices of a detection template and thresholds. Moreover, interferences (i.e. transient signals that are not a Z-call) in the considered frequency range (18-28 Hz), a main issue for all detection methods, strongly impact the detection performances. Here we propose a detector overcoming these limitations. Our algorithm is based on a subspace detector of the Antarctic blue whale call. Indeed, any Z-call can be modeled as a sigmoidal-frequency signal with unknown time-varying amplitude. The subspace detection strategy takes into account the presence of interferences, as well as intra and inter-annual frequency variations in the blue whale calls, which are commonly observed. Furthermore, the detection threshold adapts automatically to the ambient noise, a major improvement relative to predefined and fixed threshold of spectrogram correlation detectors. Thanks to subspace detection theory the detection performances are analytically known, which is crucial for detailed analyses such as density estimation. As a byproduct, the detector also provides other useful information such as the SNR of each detected Z-call and an estimation of the ambient noise.

The proposed method has been applied on marine data recorded in the southern Indian Ocean, and the detector performances are compared with a classical spectrogram correlator (XBAT). To perform this comparison, three different contexts commonly encountered in acoustic databases have been defined, and our dataset has been divided into three subsets by an experienced human operator (EHO): 1) data containing only Z-calls at various SNR, 2) data containing Z-calls and various types of interferences, 3) and data with interferences only. In total, more than 105 hours of acoustic data were analyzed, displaying more than 2200 Z-calls ("manually" identified by an EHO) and different types of interferences (airguns, earthquakes, sounds with continuous components, ice-rifting sounds, fin whale calls, Australian pygmy blue whale calls, and an unidentified recurrent transient sound). The proposed algorithm has a true detection rate up to 15-20% better than a spectrogram-based correlation detector such as XBAT.

Oral / Monday 13th 2015 / 9:40 AM

Acoustic vector sensors reduce masking effects from underwater industrial noise during passive acoustic monitoring

Katherine H. Kim[1*], Aaron M. Thode[2], Susanna B. Blackwell[1], Robert G. Norman[1], Charles R. Greene[1]

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Masking from industrial noise can hamper the ability to detect marine mammal sounds near industrial operations, whenever conventional (pressure sensor) hydrophones are used during passive acoustic monitoring. Here we demonstrate how an acoustic vector sensor can be used to suppress noise arriving from a narrow sector of geographic azimuths. Demonstration data have been collected from an autonomous recorder with directional capabilities (DASAR), deployed 4.1 km from an arctic drilling site in Oct 2012. A weighted sum of the pressure and two orthogonal particle velocity sensors yields a classic “cardioid” beam pattern (D’Spain *et al*., J. Acoust. Soc. Am. **120**, 171-185, 2006). This processing has been used in the past by DIFAR sonobuoy sensors to estimate the azimuth of low-frequency baleen whale calls (McDonald, Can. Acoust. **32**, 155-160, 2004; Miller *et al*., Endangered Spec. Res. 26, 257-269). However, this beam pattern can also be used to suppress, or “null” signals arriving from a given azimuth, while maintaining sensitivity to signals arriving from azimuths outside the quadrant surrounding the nulling direction. Improvements in signal-to-noise ratio of at least 8 dB are demonstrated on bowhead whale calls, which were otherwise undetectable using only the conventional hydrophone.

Oral / Monday 13th 2015 / 10:20 AM

A comparison of automated detectors for tonal signals from delphinds

Julie N. Oswald[1*], Kerry Dunleavy[1], Shannon Coates[1], Marie A. Roch[2], Doug Gillespie[3], David K. Mellinger[4]

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[2]San Diego State University, San Diego, California, USA
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Increased use of passive acoustic methods for marine mammal research and monitoring has generated large volumes of data. To analyze and interpret these data efficiently, it is essential to automate the detection, extraction and classification of sounds. We evaluated the performance of three automated whistle detection and contour extraction algorithms: 1) *Silbido* (v. 1.0), 2) Ishmael's tonal detector (v. 1.0), and 3) PAMGuard's whistle and moan detector (v. 1.12.00). Detectors were run on recordings made in the presence of three species: *Tursiops truncatus* (n= 1,637 whistles), *Peponocephala macrocephalus* (n = 2,253 whistles), and *Delphinus delphis* (n = 3,505 whistles). Detector outputs were compared to manually detected and extracted whistle contours using five metrics: precision (the percentage of automated detections that were correct), recall (the percentage of whistles that were detected), frequency deviation (absolute frequency difference between the actual contour and the extracted contour), percent coverage (percentage of the duration of a whistle contour that was extracted) and fragmentation (the number of detections that an individual whistle was divided into). Precision was consistently high across species for PAMGuard (83% - 88%) and Ishmael (74% - 87%) but was somewhat lower and more variable for *Silbido* (65% - 88%). Recall was highest for PAMGuard (72% - 76%) and lowest for Ishmael (22% - 47%) for all species. Ishmael had the lowest average frequency deviation (83 Hz – 95 Hz) and *Silbido* had the highest average percent coverage (78% – 79%) and the lowest average fragmentation (1.2 – 1.3 detections/whistle). The performance of all three detectors decreased in the presence of overlapping whistles and clicks and buzzes. We concluded that all three detectors performed well, albeit with different strengths and weaknesses. As a result, research goals should be taken into consideration when choosing a detector. If the goal is simply to detect whistles, then a detector with high precision and recall (ex. PAMGuard) would be most desirable, whereas, if the goal is to examine time-frequency characteristics, then a detector that produces more accurate extractions (ex. *Silbido*) would be more desirable.

Oral / Monday 13th 2015 / 10:40 AM

Multi-target tracking using Probability Hypothesis Density (PHD) filters for whistle contour detection

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The detection of marine mammal calls has many applications, such as real time monitoring, abundance estimation, mitigation and behavioral research. Due to large quantities of data that are usually collected, automated methods for detection are desired. Generally, automated methods for whistle contour extraction are based on spectrogram techniques, although alternative approaches also exist. These methods are commonly based on algorithms that allow for single target tracking. Alternatively, the whistle contour estimation can be regarded as a multi-target tracking problem, where targets overlap, their number is unknown and varies with time and measurements are noisy. One way to tackle the multi-target problems is to utilize Random Finite Set (RFS) formulation and approximate it with a computationally efficient filter called Probability Hypothesis Density (PHD) filter. The PHD filter is a recursive algorithm for jointly estimating the time-varying number of targets and their states from a sequence of noisy measurements. Here, we present a closed form solution to the PHD filter recursion, the Gaussian Mixture PHD filter, its application to the detection of delphinid whistles and challenges encountered.

Oral / Monday 13th 2015 / 11:00 AM

Modelling detection probabilities for odontocete echolocation clicks

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Passive acoustic monitoring with a single hydrophone has been suggested as a cost-effective method to monitor population density of echolocating marine mammals. The key to this approach involves estimating the distance at which the hydrophone is able to intercept the echolocation clicks and distinguish these from the background. To avoid a bias in the estimated population density, this method relies on an unbiased estimate of the detection range and therefore of the propagation loss (PL). When applying this method, it is common practice to estimate PL at the center frequency of a broadband echolocation click and to assume this narrowband PL applies also to the broadband click. For a typical situation this narrowband approximation overestimates PL, underestimates the detection range and consequently overestimates the population density by an amount that for fixed center frequency increases with increasing pulse bandwidth and sonar figure of merit. We demonstrate how the detection process of broadband clicks can be modeled for different marine mammal species and assess the magnitude of error on the estimated density due to various commonly used simplifying assumptions. Our main purposes are to quantify the bias in the population density estimate for selected species and detector due to use of the narrow band approximation, and to understand the factors affecting the magnitude of this bias to enable extrapolation to other species and detectors.

Oral / Monday 13th 2015 / 11:20 AM

Shipboard echosounders negatively affect acoustic detection rates of beaked whales

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Beaked whales (Family Ziphiidae) are a cryptic group of deep-diving odontocetes that are known to be particularly sensitive to anthropogenic noise in a variety of contexts. As part of the Atlantic Marine Assessment Program for Protected Species, the NEFSC is undertaking shipboard surveys along the U. S. eastern seaboard, combining visual observation and passive acoustic data collection via towed hydrophone arrays. Simrad EK60 shipboard echosounders are also used to collect prey field data in conjunction with this survey. In 2013, a survey was conducted from 1 July – 10 August, in which echosounder use was alternated on/off on a daily basis specifically to test for an effect on cetacean detection rates. Over 2600km of trackline were surveyed during daylight hours. The EK60 was "active" on 17 days (over 1355km), and operated in "passive" mode on 16 days (over 1292km). Pamguard was used to detect, classify, and localize individual beaked whales. Acoustic events were divided into "definite", "probable" and "possible" based on length of train and presence of upsweeps.

Over 100 beaked whale click trains were detected, and were classified as Cuvier's (Ziphius cavirostris), or mesoplodon (Mesoplodon spp.). A GLM was used to test the relationship between acoustic detections and a number of covariates; echosounder and survey leg were both significant ($p<0.05$), with echosounder negatively affecting detection rates. The duration of beaked whale acoustic events was also significantly shorter when echosounders were active (Mann-Whitney U, $p<0.05$). These results suggest that beaked whales are reacting to shipboard echosounders by either interrupting foraging activity or moving away from the area. This decrease in detectability has implications for both management and mitigation activities. The use of these and other echosounders for science and industry is rapidly growing, thus also leading to potentially broad ecological implications for disturbance effects on these sensitive species.

CLASSIFICATION

Chair: Marie Roch

Oral / Monday 13th 2015 / 1:30 PM

Recent trends and directions in bioacoustic classifiers

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In the last decade, the scope of bioacoustic classification systems has grown tremendously, moving from the analysis of tens or hundreds of calls to thousands or millions of calls. This has been driven by the declining costs and increasing maturity of passive acoustic monitoring systems and tools to analyze them, the sharing of data within segments of the bioacoustics community, and the availability of management systems to aid in the organization of large data sets. We examine recent trends in bioacoustic classification systems, ranging from the use of so-called deep neural networks to informational theoretic approaches and the use of multiple lines of evidence. We conclude with a brief overview of alternative metrics for measuring performance and ask the question: “Where do we go from here?”

Oral / Monday 13th 2015 / 1:50 PM

Classification of Kogia spp. echolocation clicks and temporal trends at Hawai'i Island

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The cryptic species of the genus *Kogia*, including the dwarf sperm whale (*K. sima*) and the pygmy sperm whale (*K. breviceps*), are known primarily from strandings and rare sightings throughout the world's tropical and temperate oceans. Their low profile and quiet behavior at the surface make them very difficult to observe in any but the most calm sea conditions. However, recent recordings of signals from wild and captive animals reveal that they echolocate at high frequencies (peak frequencies > 100 kHz), which makes passive acoustic monitoring (PAM) a possibility.

For successful PAM a species must be distinguishable from other species based solely on acoustic characteristics, and sufficient recordings must be made to confidently identify those characteristics. We sought to increase the sample of *Kogia* clicks collected in the wild by deploying a High-frequency Acoustic Recording Package (HARP) sampling at 320 kHz off the Big Island of Hawai'i in the fall of 2014. In this area *Kogia* spp. (primarily *K. sima*) have been sighted with regularity, and no other species that make high-frequency clicks are known to occur. This recording produced a sample of more than 5000 high-frequency clicks from 98 encounters, identified through a combination manual/automated click detection process. Comparison of these clicks to other recordings of *Kogia* and other species with similar high-frequency clicks (e.g. Dall's porpoise, harbor porpoise) show that inter-click interval and click duration can be used to distinguish the *Kogia* spp. from species in other genera. Consistent click characters across encounters and rare sightings of *K. breviceps* in the region suggest our recordings are from *K. sima*, though available data and analyses to date do not allow for absolute determination of species identification.

Examination of *Kogia* clicks recorded at 320 kHz sample rate suggest that it is possible to detect this species using 200 kHz sample rate data, the more common sample rate used with HARPs. Examination of multiple years of HARP data from the Kona site reveal regular occurrence in this region, with clusters of acoustic encounters occurring on average every two weeks.

Oral / Monday 13th 2015 / 2:10 PM

Characterization of fin whale vocalizations in the Gulf of Cadiz using Ocean Bottom Seismometers

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Fin whales (*Balaenoptera physalus*) are classified as an “Endangered” species by the IUCN and therefore knowledge of stock structure, population size, and spatiotemporal patterns of animal distribution is essential for good management strategies. In Portugal, sightings of fin whales off mainland waters are rare and are insufficient to investigate and monitor the population(s) in the area. The most studied fin whale sound is the “20-Hz call” or "regular note". Another note, the "back-beat" is very similar with a lower frequency bandwidth. The patterned song-like sequences of fin whale calls show geographic variation in features like frequency range and inter-call interval. Ocean Bottom Seismometers (OBS) deployed for earthquake and active seismic surveys can opportunistically record both the regular and back-beat notes. Between August 2007 and July 2008, a network of 24 OBS was deployed in the Gulf of Cadiz for the EU funded project NEAREST and during this time fin whale calls were recorded. This dataset has been already used for the location and ranging of fin whales; information that can then be used for population density estimates (Harris et al., 2013). In this work we extended the matching filter detection and classification algorithm to extract the frequency characteristics of vocalizations, allowing for a robust differentiation of regular and back-beat notes and measures of inter-call interval. Patterned calls were grouped to estimate whole song characteristics. We found that in the Gulf of Cadiz most of the songs identified are regular sequences of 20-Hz calls, with only a few of them containing back-beats. Usually, only a single fin-whale can be identified vocalizing simultaneously at the same site. The patterns identified are compared with signals recorded elsewhere in the Atlantic and Mediterranean in an effort to assess if different populations are found in the Gulf of Cadiz.

Oral / Monday 13th 2015 / 2:30 PM

The production-based approach for the study of humpback whale songs: overview and perspectives

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Historically, the temporal structure of humpback whale songs has been studied within the hierarchical framework (songs-themes-phrases-subphrases-sound units) proposed by Payne and McVay (1971). Numerous studies have performed spectrogram analysis to determine salient acoustic features characterizing discrete sound patterns, which are further used to build an organized structure in regards to their relative presence/prevalence within a song. More recently, with the development of computer-based machine learning methods and the growing expansion of digitally available sound datasets, bioacoustics researchers also used computational tools to provide sound representations of humpback whale songs, such as Suzuki et al. (2006) who used information theory techniques to study song structure, or Ou et al. (2013) and Halkias et al. (2013) who developed a cluster-based learning to classify sound units. Some authors (Mercado and Handel, 2012; Adam et al., 2013; Cazau et al., 2013) have recently proposed an alternative approach. This so-called production-based approach consists in making the link between sound-producing anatomy and vocal communication. Methodologically, it employs simple physical-based descriptors which can be related to specific production mechanisms through the predictions of biomechanical models of the sound-producing anatomy.

We present a global overview and perspectives of this production-based approach for the study of humpback whales. We will start with a brief presentation of the pioneer anatomical work of Joy Reidenberg (Reidenberg and Laitman, 2007), which has been of first importance for this approach, as before, the understanding of mysticete vocal mechanisms has remained an elusive subject for a long time, and the idea that mysticetes lack vocal folds was a widespread misbelief. We then review the different base studies exploiting a production-based approach, which propose functional scenarios of the respiratory tract for the generation of vocal sounds (Mercado, 2010; Adam, 2013; Cazau, 2013). Through such scenarios, the production-based approach proves to be a fruitful analytical support to test directly possible functional and behavioural hypotheses originating whale song production. In the same vein, we will also present an ongoing study on non-linear vocal features in humpback whale sounds (Cazau, 2013b). We will also provide an update on biomechanical studies aiming to develop computational and physical models of humpback whale sound generation systems. Finally, we expose the perspectives of this approach, especially towards more short-term practical applications such as performing more intelligent and informed passive acoustic monitoring (for example, by being able to extract individual-specific physiological cues).

Poster M1

Differentiating marine mammal clicks using time-series properties

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Automatic detection of marine animal vocalizations is increasingly used to analyse the extensive acoustic datasets collected from autonomous passive acoustic recorders, resulting in a constant effort to improve detector accuracy and develop new and more efficient detection methods. Differentiating between the clicks produced by various cetacean species can be especially problematic due to overlapping time and frequency characteristics. There has been some limited success using high time-resolution frequency analysis techniques (e.g. short-time Fourier transforms (STFT) and Wigner-Ville transforms) to differentiate between odontocete clicks. These methods tend to work well for general click detection but often do not reliably distinguish between clicks produced by different species. Instead the inter-click-interval is often used to distinguish species. Furthermore, these types of detectors are often computationally expensive.

We propose a computationally efficient method for detecting and differentiating between clicks produced by various odontocete species. This method was tested on recordings obtained from offshore Nova Scotia that included clicks produced by small dolphins, killer, pilot and sperm whales, and at least two species of beaked whales. It was further evaluated against the workshop click dataset. The precision of our detector when evaluated against 48 recorder-months of data from Nova Scotia was 1.0 for dolphins, 0.92 for sperm whales, 0.80 for Sowerby's beaked whales and 0.72 for northern bottlenose whales. The performance on the workshop data set are also presented. This new approach increases the efficiency of analysis and provides reliable species differentiation.

Poster M2

Near real-time passive acoustic monitoring of baleen whales from autonomous platforms in the Gulf of Maine

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The Navy regularly conducts studies of marine mammal distribution and occurrence in association with training exercises to better monitor potential interactions between marine mammals and naval activities. Methods used for these studies include visual surveys and acoustic monitoring via passive acoustic recorders; however, these methods have significant drawbacks. Visual surveys from ships and airplanes are expensive, and cannot be conducted during nighttime or periods of high winds, rough seas, or poor visibility. While passive acoustic recorders have large detection ranges and can be used to persistently detect vocalizing marine mammals regardless of weather conditions, recordings can only be accessed after recovery of the recording instrument, and acoustic analysis by a trained person is time consuming and expensive.

This study aims to demonstrate the monitoring and detection capabilities of autonomous platforms in conducting near real-time passive acoustic monitoring of baleen whales. The demonstration includes three platforms – a moored buoy, Slocum glider, and a Liquid Robotics, Inc. Wave Glider. Each platform uses a digital acoustic monitoring instrument (DMON) equipped with the low frequency detection and classification system (LFDCS) to detect, classify, and report vocalizations from four species of baleen whale in near real-time via iridium satellite. Collocated visual and acoustic surveys allow for ground-truthing of detections and comparisons of platform accuracy. Visual survey methods include land-based surveys near the moored buoy and Wave Glider; ship-based surveys in the vicinity of the Slocum and Wave Glider in May 2015, and aerial surveys of the entire region.

The overall goal of this project is to demonstrate that autonomous platforms are capable of conducting long-term large-scale passive acoustic monitoring of cetaceans in areas of interest to the Navy, and to develop best practices for integrating near real-time acoustic detections from autonomous platforms into persistent visual monitoring programs. Preliminary results from the first few months of the study are presented.

Poster M3

Two phase efficient sperm whale click detection for autonomous devices

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Analysis of raw acoustic data by complex algorithms requires considerable computing effort, therefore, making it hard for autonomous devices with low capabilities to process and share captured data online. To reduce overall data, thus decreasing computing effort, we need to divide the whole process into two phases. The first phase is used only for detection of whale presence, avoiding classification on environmental noise. The second phase is used for classification, adopting complex algorithms to precisely identify the whale. Usually, the detection is carried out by converting time domain data to frequency domain, followed by feature extraction of signal characteristics. The presented approach, performs feature extraction in the time domain, using physical characteristics of the wave.

A simple process of symbolic data analysis is used to transform time-domain data into a modal multi-valued data type using a histogram function. One advantage of symbolic data analysis, is the fact that it reduces the amount of data to analyze without loss of generality. Using this new data type and assuming environmental noise as a stationary process, an online approximate maximal margin learning algorithm called IMA is used to detect whale presence by their click, hence defining the first phase. The second phase is defined by execution of complex algorithms for classification on the sound.

Preliminary tests have shown a reduction of processed data by complex algorithms in the second phase of approximately 87%. As a result, a simple Raspberri Pi model B was most of the time idle while receiving and processing data.

Poster M4

An evaluation of automated and manual methods for detecting Southern right whale (*Eubalaena australis*) contact calls.

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Passive acoustic monitoring (PAM) as a research and mitigation method is based on the vital importance of sound for some specie´s ecology. The development of PAM has increased the capacity of data acquisition over different temporal and spatial scales generating substantial amount of information to be processed and analysed by bioacousticians. Therefore, the efficiency of PAM methods depends not only on the ability of researchers to proper interpret acoustic signals; it relies on developing tools that allow specialists to effectively handle massive volumes of acoustic data, as detection tools.

The objective of this study was to evaluate methods for detecting Southern right whales (SRW – *Eubalaena australis*) contact calls. Forty-three hours of recordings were submitted to different detection methods: a) manual inspection; b) an automated detection tool originally designed for the detection of North Atlantic right whales (NARW – *Eubalaena glacialis*) upcalls; and c) a combined technique using the NARW automated tool associated with manual browsing around resulting detection events. Recordings were obtained through bottom-mounted archival acoustic devices deployed off a wintering area in southern Brazil.

The combined tecnique resulted in 635 true detections. It had the best performance among the tested methods and therefore, its detections were considered the true dataset (635=100%). Manual inspection of recordings resulted in 464 upcall detections (73%). Conversely, the automated detection tool alone detected 505 events totalizing 386 (61%) true positives and 119 false positives (detection of noise, other biological sounds and/or duplicated detections of whale calls). Despite differences in the acoustic parameters of SRW and NARW´s upcalls as well as and differences in ambient noise that could affect the detection tool performance, it seems that the NARW tool failed to detect mainly low SNR SRW upcalls in comparison to the manual method. The use of NARW detector associated with manual browsing was more effective in detecting SRW upcalls within a large dataset, consequently contributing to intensify the use of PAM for conservation and scientific proposes in SRW habitats.

Poster M5

Impact of detector performance and ambient noise levels on biological inferences

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Analyses of extensive passive acoustic data sets by means of automatic detection algorithms employ different metrics, methods and parameterizations. For inter-comparisons of results from different studies or recorders from different sites within a study, an understanding of the detector performance is crucial to avoid analytical artefacts which might bias biological inferences based on such data. Such biases may occur because results obtained by automatic detection substantially depend on the detection algorithm, its parameterizations and the environmental background against which it is run.

In the present study, passive acoustic data containing Z-call vocalizations of Antarctic blue whales (ABWs, *Balaenoptera musculus intermedia*) were parsed using a spectrogram correlation based automatic detector. High detection thresholds result in few false positive detections, however, considerable numbers of faint calls may be missed (false negatives). This study tests if and to which degree the detector output (call rates and daily acoustic ABW presence) and in turn, biological inferences were affected by different detection threshold settings.

Furthermore, the influence of ambient noise levels on the detectability of calls and ensuing call rates was explored. The results show that the amplitudes of detected calls increase linearly with growing ambient noise levels, maintaining a constant SNR (signal-to-noise ratio) of about 10 dB. Whether this can be interpreted as increase in true call loudness to compensate for increased noise conditions (Lombard effect) or simply reflects the finite SNR necessary to be able to detect calls (automatically or manually) needs careful scrutiny in each case.

Robust inferences of a species' acoustic behavior from passive acoustic data hence require consideration of each detector's performance characteristics and concurrent environmental conditions, especially when the ensuing results are used for conservation and management related research questions such as assessing the potential impact of noise on marine mammals.

Poster M6

Do echolocation clicks produced by delphinid species in the northwest Atlantic contain species-specific cues?

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Free-ranging dolphins use echolocation signals (clicks) to forage and navigate. Species-specific differences in echolocation signals produced by dolphin species in the northwest Atlantic Ocean were investigated using recordings of visually confirmed single species made from towed hydrophone arrays collected over a three year period by Duke University and Northeast Fisheries Science Center. Echolocation signals were examined for seven species of delphinids; short-beaked common dolphin (*Delphinus delphis*), Risso's dolphin (*Grampus griseus*), short-finned pilot whale (*Globicephala macrorhynchus*), rough-toothed dolphin (*Steno bredanensis*), striped dolphin (*Stenella coeruleoalba*), Atlantic spotted dolphin (*Stenella frontalis*), and bottlenose dolphin (*Tursiops truncatus*). A total of one hundred sixteen independent acoustic encounters were analyzed using PAMGuard's automated click detector to detect clicks and new PAMGuard ROCCA (Real-time Odontocete Call Classification Algorithm) tools to measure echolocation signal parameters. Eight parameters were compared among species; duration, center frequency, peak frequency, -3 dB bandwidth, -10 dB bandwidth, sweep rate, number of zero crossings, and inter-click interval. Differences in duration, center and peak frequency and inter-click interval were evident among species. These differences will be discussed in detail. These results indicate that variables from echolocation signals can be used to discriminate species in the study region. Results from this analysis will be used in conjunction with information extracted from whistles to train automated classifiers for differentiating Atlantic delphinid species from acoustic recordings. Integrating echolocation signal classifiers with already existing whistle classifiers is expected to improve classifier performance and subsequently allow researchers to more effectively and efficiently study these species.

Poster M7

Comparison of vocalizations produced by killer whale ecotypes, communities, and pods in the northeastern Pacific Ocean

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Three distinct ecotypes of killer whales (residents, offshores, and transients) are recognized in the northeastern Pacific Ocean. Within the resident and transient ecotypes there are multiple communities (Northern residents, Southern residents, Southern Alaska residents, Western Alaska North Pacific Resident, West Coast Transients, and AT1Transients). Resident killer whale communities are further organized into pods, which are groups of matrilines that are regularly observed together. These ecotypes, communities and pods can have differences in their behaviors, prey preferences, genetics, and acoustic repertoire. The acoustic repertoire of killer whales includes pulsed calls, whistles, and echolocation signals (clicks). Currently pulsed calls can be used to acoustically classify killer whales to ecotype/community/pod by expert manual analysis, but whistles and echolocation signals have not yet been evaluated for this purpose. Visually validated towed hydrophone array recordings made in the presence of four killer whale communities (northern and southern residents, offshores, and west coast transients) were collected during the Pacific Orca Distribution Surveys (PODS) conducted by the Northwest Fisheries Science Center. These surveys occurred along coastal Oregon and Washington in the winters of 2006-2009, 2012, 2013, and 2015. Using these recordings, pulsed calls, whistles and echolocation signals were measured in order to compare characteristics among ecotypes, communities and pods. PAMGuard's automated click detector module was used to automatically detect echolocation clicks and newly developed PAMGuard ROCCA (Real-time Odontocete Call Classification Algorithm) tools were used to measure eight signal parameters; duration, center frequency, peak frequency, -3 dB bandwidth, -10 dB bandwidth, sweep rate, number of zero crossings, and inter-click interval. Measurements were extracted from whistles and pulsed calls using ROCCA. These measurements included minimum and maximum frequency, duration, slope, percent upsweep and percent downsweep, among others. This information will be used to train automated classifiers for killer whale ecotypes/communities/pods. These classifiers will ultimately allow researchers to more effectively and efficiently study the range and distribution of killer whales in the Northeast Pacific Ocean.

Poster M8

Statistical filtering of whistle detections

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The ocean is becoming an increasingly noisy environment, which poses significant challenges to automated Detection, Classification, Localization, and Density Estimation (DCLDE) systems that aim to extract sounds of interest from large volumes of recorded audio data. A significant body of work has focused on noise reduction techniques to improve processes such as automated whistle extraction. Whistle contour extraction is complicated by the presence of other signals, such as sounds produced by other marine organisms and anthropogenic sources such as active sonar. From an acoustic processing perspective, these sounds represent “signals” in the data rather than background “noise,” but they are not the signals of interest that the system is attempting to detect. Traditional noise reduction techniques do not effectively mitigate these types of sounds and these signals often represent significant false positives output of the *Silbido* tonal detector.

Trained analysts, visually reviewing audio data, are able to differentiate signals of interest from noise signals suggesting that there are discernable characteristics of the sounds of interest that separate them from uninteresting signals. Statistical analysis of annotated audio data has shown that many false detections produced by *Silbido* share similar properties that make them distinguishable from good detection. This work focused on devising a statistical framework for exploring these properties and leveraging them to filter out false positives while not filtering out good detections. This process has significantly improved the overall precision of *Silbido* while maintaining the recall rate. In our evaluation data set a published version of *Silbido* produced a recall rate of 77.6% and a precision rate of 72.6%. After applying the statistical filtering method *Silbidos’s* recall rate was roughly maintained at 77.8%, while the precision increased to 84.8%. Thus a relative increase in precision of over 12% was achieved while taking no penalty in recall.

Poster M9

True or false: developing methods for pruning false and inaccurate detections from an automated whistle detector

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Passive acoustic monitoring (PAM) is recognized as an effective method for obtaining information on marine mammal populations, however it generally produces large volumes of data requiring a great amount of time to analyze. As such, automated methods for analysis are quickly becoming more popular. Automated methods for detecting and extracting delphinid whistles exist, but due to false detections, inaccurate contour extractions and fragmentation of whistles, they may not provide accurate results. In this study, we compared measurements taken from delphinid whistles (bottlenose dolphin, short-beaked common dolphin, Atlantic spotted dolphin, striped dolphin, and pilot whale) detected and extracted using automated methods with those of whistles detected and extracted manually, to determine whether there are significant differences between them. Visually confirmed single species recordings, collected by the Northeast Fisheries Science Center, the Southeast Fisheries Science Center, and Duke University during combined visual and acoustic surveys of the northwest Atlantic, were used for this analysis. Whistles were detected and extracted automatically using PAMGuard's 'whistle and moan detector', and manually using the ROCCA (Real-time Odontocete Call Classification Algorithm) module in PAMGuard. We compared variables including: beginning, ending, minimum and maximum frequencies, duration, slopes and other variables describing the shape of whistles. The results of these comparisons were used to develop methods for identifying and pruning false detections and inaccurate contour extractions, in order to improve the accuracy of the automated whistle measurements.

The results of this study give us insight into the relative performance of automated and manual detection and extraction methods, and provide new methods for identifying false or inaccurate detections. In addition, the information gleaned from this study will aid in the development, training and improvement of new and existing delphinid whistle classifiers to be used with both automated and manual extraction methods.

Poster M10

Detection range and propagation of fin whale calls off Gulf of Cadiz

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The acoustic repertoire of large cetaceans has been increasingly used for management purposes, since it shows differentiation at species and population levels and can be used for spatial analysis and animal density estimates. Some of the calls are highly stereotyped and can be produced in repeated sequences, which eases the sound detection process. Fin whales produce a 20 Hz call that is a downsweep between 15 to 30 Hz, centred around 20 Hz, with ~1 second of duration. Source levels above 180 dB re. 1 μPa at 1 m have been estimated for this call which can reflect its function for long-range signalling. An array of 24 ocean bottom seismometers (OBS) was deployed between August 2007 and July 2008 in the Gulf of Cadiz for seismic monitoring. Besides the collection of the target geological data, these sensors also collected 20 Hz fin whale calls. This dataset has been already used to detect, classify and localize fin whale calls based on a seismic approach and was also explored for the application of animal density estimates. The aim of this study was to use the hydrophone channel of the OBS to detect fin whale calls and call sequences, and to investigate the sound propagation range for the same call on different OBSs in the array. The sound detection algorithm for individual calls and sequences was based on a spectrogram correlation; a visual cross-check of spectrograms between the sensors was also undertaken. Although the results are preliminary they seem to indicate a short propagation range and a degree of directionality of the 20 Hz fin whale calls. Studying the propagation range of these calls is crucial for understanding its influence in the choice of localization method, and the animal abundance estimates that depend on the distance between the animal and the sensors.

Oral / Monday 13th 2015 / 4:00 PM

Unsupervised Clustering of Delphinid Encounters

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There are many regions of the ocean where little is known about odontocete species assemblages and where many species are not acoustically well understood. Standard classification techniques rely on the use of labeled training data, where models are trained with features that are known to be examples or counterexamples of categories that the model is to learn. Unfortunately, labeled data is not always available, particularly in understudied areas. This work presents preliminary results in an effort to perform species classification without the need for labeled data through unsupervised learning techniques.

Our approach relies on constructing models of the distributions of specific echolocation click encounters and the measurements of the distances between these encounters. As the distributions are unknown, we use Gaussian mixture models as a method to model arbitrary distributions. The number of Gaussian components assigned to an encounter is determined via penalized model criteria (e.g. Bayesian Information Criterion). The symmetric Kullback-Leibler distance, a metric that measures an information theoretic distance between pairs of distributions, is used to produce a distance-weighted network of encounters. We show when using network layouts that repel or attract encounters based on the Kullback-Leibler distances, many encounters from the same species lie in close proximity. Future work will use unsupervised learning techniques to build classification functions based on these information-theoretic distances between encounter distribution models.

Oral / Monday 13th 2015 / 4:20 PM

Detection of two highly similar blue whale songs in the southeastern Pacific, and possible population implications

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Southeast Pacific (SEP) blue whales are one of the least understood groups of blue whales worldwide. Distinct song types in blue whales have been used to delineate acoustic groups and even breeding populations with distinct geographical distributions. SEP blue whales produce two highly similar but clearly different songs, known as SEP1 and SEP2. Both have been recorded in the Chiloense Ecoregion (CER) feeding ground in southern Chile and the eastern tropical Pacific (ETP). Understanding the spatial-temporal distribution of both SEP blue whale songs, and whether they represent sub-units that might use different feeding grounds can help elucidate SEP blue whale population structure.

Automatic detection analysis using XBAT was carried out on fixed passive acoustic data from the CER from 2012-2013, and the ETP from 1996-2002, with the aim of determining the temporal variation of the presence of each SEP blue whale song.

We found temporal patterns in SEP blue whale songs that suggested summer-autumn residency of high numbers of blue whales in the CER, but also the year-round presence of lower numbers of animals in the ETP. SEP1 and SEP2 had similar temporal distributions at both sites but were detected in very different proportions (SEP2 significantly more common).

Although firm conclusions cannot be drawn at this stage, we discuss the implications of these results in terms of SEP population structure and recommend future directions for acoustic monitoring of SEP blue whales. We also discuss the distinction between song types and song variants in blue whales. We discuss our approach for detector template design when dealing with two highly similar songs. Lastly, we call for the development of a standard detector performance assessment method, and propose some key features that should be included in such a method.

Oral / Monday 13th 2015 / 4:40 PM

Classification of blue whale D calls and fin whale 40-Hz calls using deep learning

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Blue whales (*Balaenoptera musculus*) and fin whales (*Balaenoptera physalus*) are closely related species that have both experienced declines in population size. The vocalizations of these species provide data on populations sizes and migratory patterns, but the similarity of a subset of their vocalizations presents issues for automated processing. The seasonal variation, proximity to feeding areas, and correlation with feeding behaviors provide evidence that both the blue whale D calls and fin whale 40-Hz calls are feeding-specific calls. The overlapping frequency ranges and frequency modulated nature of the calls, the common genetic background of the two species, and the similar function of the calls are possible contributors to the difficulties in the detection and accurate classification of these calls. Detectors which target downswept call types within this frequency range will experience high recall of both blue whale D calls and fin whale 40-Hz calls, which would require further human annotation to classify each.

Building on the success of using deep neural networks for the detection of low-frequency whale calls and for the classification of high-frequency whale vocalizations, we adapt Caffe's freely available AlexNet implementation to tackle the task of distinguishing between blue whale D calls and fin whale 40Hz calls. We obtained over 1387 hours of audio taken from passive acoustic monitoring recorded between 2009-2013 off the coast of Southern California. Ground truth annotation by human experts provided 4796 D calls and 415 40-Hz calls. Using spectrograms of these vocalizations, we extracted high level features from our network and trained an SVM classifier to predict the call type. Our system achieved an overall 97.6% classification accuracy with a 98.6% precision and 98.8% recall for blue whale D calls. Augmenting current blue whale D call detection methods with an additional classification step will allow researchers to eliminate fin whale 40-Hz calls and move through their data faster. Additionally, this method is very flexible and allows researchers the ability to add additional call types to pursue more fine-grained classifiers.

LOCALIZATION

Chair: Tyler Helble

Oral / Tuesday 14th 2015 / 8:40 AM

Single hydrophone multipath ranging: Dealing with missing and spurious arrivals

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Prior work that uses multipath arrivals to estimate marine mammal range and depth using a single hydrophone usually relies on accurate arrival time estimation and path identification. This process can be straightforward in cases with short-duration, high signal-to-noise ratio sources that produce clear arrival patterns. In more difficult cases, multiple calls/clicks can be combined in various ways to help increase signal-to-noise or to track persistent arrivals as they gradually change with time. Nonetheless, in many cases (e.g. with directional sources or receivers, multiple sources, multi-pulsed clicks, few received calls/clicks) it can be impractical or impossible to accurately pick and assign arrivals, and resulting missed and/or spurious arrivals confound time-of-arrival based localization algorithms. In this presentation, several options are explored and discussed that deal with this arrival time “estimate and identify” problem, including multipath ranging metrics that are robust with respect to missed and spurious arrival labeling, and a “matched field” approach that omits the peak-picking and identification step all together. The methods are tested through simulation and demonstrated using delphinid clicks recorded on the single-channel autonomous AMP-1 hydrophone package (described in Fedenczuk’s abstract). [Work supported by ONR]

Oral / Tuesday 14th 2015 / 9:00 AM

Acoustic multipath arrival time estimation via blind channel estimation

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Several methods for underwater passive acoustic localization involve estimating the direct and/or interface-reflected acoustic arrival times at one or more underwater hydrophones. This estimation task can be more difficult for non-impulsive sound sources than for impulsive sources because later arrivals are more likely to be masked by earlier arrivals.

In linear system analysis, the impulse response of a system is the system output when the input is an impulse. The recording of a broadband, short-duration call (a sperm whale click, for example) approximates the impulse response for the acoustic channel between the whale and the receiver. In this case, estimating arrival times can be fairly straightforward as arrivals are well-defined in the raw acoustic record. In cases with a non-impulsive source, if the source signal is known (e.g., stereotypical calls or underwater communications), well developed techniques for estimating the underwater acoustic impulse responses can be used. For example, in passive acoustic monitoring applications, simple cross-correlation based methods are effective and commonly used. An especially challenging case occurs when the source is both non-impulsive and unknown. Blind channel estimation (BCE) is the process of estimating the impulse responses between a single, unknown source recorded by multiple receivers. BCE has the potential to help estimate direct and interface-reflected arrivals for non-impulsive marine mammal vocalizations (e.g., humpback whale calls) since it allows impulse responses to be analyzed (instead of recorded waveforms or spectra).

In this paper, recent advances in BCE are applied to simulated marine mammal vocalizations to demonstrate the potential for arrival time estimation via impulse response analysis.

Oral / Tuesday 14th 2015 / 9:20 AM

Supporting CEE experiments with Northern bottlenose whales using a towed hydrophone array

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For many years towed hydrophone arrays are in use for passive acoustic monitoring of vocalizing marine mammals. The capabilities of towed arrays are continuously improving. TNO has developed a dedicated marine mammal detection array ("Delphinus system") that has been upgraded several times for use during controlled (sonar) exposure experiments (CEEs) in the 3S-project in Norwegian waters. In June 2013 an experiment with Northern bottlenose whales was executed near Jan Mayen. Here we describe the latest upgrade of the system and the contribution it could provide to the CEE experiment, both during the execution as well as in the analysis of the results.

The system can display real-time detections and localization solutions of vocalizing whales in two frequency bands (1 – 40 kHz and 10 – 150 kHz). By implementation of a triplet hydrophone it was possible to instantly discriminate detections from port or starboard of the towed array. This supported the capability of tracking the whales during their dives. Acoustic detections were also presented on a tablet displaying a Geographic Information System (GIS), which supported the visual observers in detecting and tracking whales. In the post-analysis of the experiment acoustic sighting maps before and after the sonar exposure were generated, supporting the quantification of the behavioral response of the whales to the sonar transmissions.

Oral / Tuesday 14th 2015 / 9:40 AM

3-D localization and swim track kinematics of humpback whales on the Navy's Pacific Missile Range Facility

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Optimal time difference of arrival (TDOA) methods for acoustically localizing multiple marine mammals have been applied to the data from the Navy's Pacific Missile Range Facility in order to localize and track humpback whales. Modifications to established methods were necessary in order to simultaneously track multiple animals on the range without the need for post-processing and in a fully automated way, while minimizing the number of incorrect localizations. The resulting algorithms were run with no human intervention at computational speeds faster than the data recording speed on over 100 days of acoustic recordings from the range, spanning several years and multiple seasons. Spatial localizations based on correlating sequences of units originating from within the range produce estimates having a standard deviation typically 10 m or less (due primarily to TDOA measurement errors), and a bias of 20 m or less (due to sound speed mismatch). 3-D localizations allow for detailed dive information to be extracted, with many whales diving repeatedly over 100 m in depth. Acoustic modeling and Monte Carlo simulations play a crucial role in minimizing both the variance and bias of TDOA localization methods. These modeling and simulation techniques will be discussed for optimizing array design, and for maximizing the quality of localizations from existing data sets. Methods for extracting track kinematics will also be discussed, as well the importance of these kinematics for density estimation.

Oral / Tuesday 14th 2015 / 10:20 AM

Information on baleen whales derived from localized calling individuals at the Pacific Missile Range Facility, Hawaii

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Passive acoustic monitoring automated processes for detection, classification, model-based localization and tracking have been utilized for multiple species of baleen whales using recorded data from 47 off-shore, bottom-mounted broadband hydrophones at the Pacific Missile Range Facility, Kauai, Hawaii. Automatically detected baleen whales calls' start times are compared with model-based localizations start times for determining locations where calls were emitted. Kinematic tracks are generated from localizations when multiple parameters exceed thresholds. The kinematic tracks support the notion of a single individual being tracked when call types, intervals, swim speeds and behaviors match what is known for a species. Localization and tracking capabilities increase knowledge of the species monitored by providing: density estimates based upon counts of animals which call, which are more informative than density of calls, directly measured cue rates of animals which call, species utilization of the various habitats being monitored, and different behavioral states of animals can be inferred. Information derived from kinematic tracks such as swim speeds and animal headings lead to basic behavioral observations such as 'traveling' (animals moving through the area at fairly constant headings and speeds) and 'milling' (where animals remain in the area for long periods of time with many heading and speed changes).

Examples are provided for rarely sighted, but acoustically localized and tracked, minke (Balaenoptera acutorostrata) and Bryde's (Balaenoptera brydei) whales. Behavioral responses of localized minke whales to Navy training have shown lower densities of calling animals in the area during Navy training compared to other periods of time.

Oral / Tuesday 14th 2015 / 10:40 AM

Range estimation using multipath arrivals from 20 Hz fin whale vocalizations recorded in the NE Pacific Ocean

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The estimation of animal density using point transect distance sampling methods is a topic of interest in the marine environment, where it can be applied to sparse arrays of stationary instruments. The fundamental quantity required for the technique is horizontal range to detected animals. Our approach is to use the timing and amplitude of multipath arrivals to estimate range to vocalizing fin whales using recordings on seafloor seismometers. Our goal is to develop an automated method that can be compared with two existing techniques for estimating call density, one of which uses the relative amplitude measured on the three orthogonal components of a seismometer and the other of which models the energy in the frequency band of fin whale vocalizations. Three datasets from the Northeast Pacific Ocean have been used to explore the viability of the technique in varying acoustic environments. The first dataset is from the bathymetrically complex Endeavour Segment of the Juan de Fuca Ridge. It is the one test location where independently located calls are available for comparison. The second is from a Neptune Canada cabled observatory site located in a flat, sedimented, mid-plate location. The third is from the Cascadia Initiative, an extensive seismic experiment off the coast of the Pacific Northwest. Our focus has been on instruments in water depths of 2000-3000 m. At the Endeavour Segment, the distribution of detections as a function of range compares well with ranges from independently located calls. Ranges are reliably estimated out to ~10 km. At the Neptune Canada site, where the sediment layer is ~300 m deep, reflections from the basement can bias range estimates at shorter ranges if not properly accounted for. At all locations, calls arriving from 10 km or more are sometimes mis-identified as coming from shorter ranges due to ambiguities in identifying multipath arrivals. Absolute amplitude variations are ineffective at discriminating range, so we are exploring alternative methods for identifying long range paths.

Oral / Tuesday 14th 2015 / 11:00 AM

Neural Networks for the Localization of Biological and Anthropogenic Sources at Neutrino Deep Sea Telescopes and Deep Sea Observatories

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Astrophysics and marine biology have recently made outstanding joint efforts at underwater observatories. A good example of this is given by the ANTARES European project which is currently managing the largest neutrino telescope operating in the Northern Hemisphere: the site is equipped with 36 acoustic sensors that make it suitable both for the acoustic detection and localization of neutrinos and marine mammals.

The results of real-time PAM systems developed by LAB and deployed at ANTARES and other sites are displayed on the LIDO website: http://www.listentothedeep.com. The developed methods have proven extremely useful to detect the presence of cetaceans, classify their sounds, localize and track them and eventually evaluate their abundance and animal population density within large observation time frames, which gave way to various publications.

A particular effort was made on adapting localization techniques to the particularities of the NEMO and ANTARES deep sea telescopes. Besides time-delay estimation and beamforming, an extremely interesting part of this research was certainly the use of neural networks to estimate the position of the sensors and/or far-field sources. Whereas a more classical least-mean-squares approach had to deal with the presence of multiple local minima and could sometimes not cope with real-time requirements, the neural networks provided an elegant closed form solution with a satisfying accuracy.

The neural network approach for localization furthermore proved in this context that it would also be a suitable approach for the growing range of systems requiring low energy consumption and thorough resource management such as autonomous underwater vehicles and wavegliders.

Oral / Tuesday 14th 2015 / 11:20 AM

Tracking blue whales with the Cascadia Initiative ocean bottom seismograph network

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A number of studies have demonstrated that networks of ocean bottom seismometers (OBSs) can be used to localize blue whales but the datasets analyzed to date have been small so that the calls could be identified visually and the arrival times handpicked. We are working to develop tools that can be applied to large OBS data sets to locate and estimate the density of blue whales automatically. Our data set comes from the Cascadia Initiative, an amphibious geophysical experiment in the Pacific Northwest. Offshore, the initiative has deployed 70 OBSs annually in alternating north and south footprints in a geographic area that extends from 40°N to 49°N and from the coast to ~400 km offshore. The instrument spacing is 70 km in deep water and ≤35 km landward of the foot of continental slope.

Our initial work has involved the manual analysis of a few well-recorded call sequences identified on sample OBSs near the middle of the network. A visual inspection of spectrograms from nearby OBSs, shows that the B calls of the Northeast Pacific blue whale can generally be identified on enough OBSs to locate the call but that the signal to noise on some of the OBSs is so low that our confidence in call identification stems in large part from the consistency of arrival times with a single location. In addition, there are instances when several whales are vocalizing which complicates the process of associating faint calls.

Our approach to obtaining automatic locations is first to apply a cross-correlation detector to all OBSs with a kernel tuned to the fundamental frequency of the 16 Hz B call of the northeast Pacific blue whale and the detection threshold set low. We then select the subset of detections above a higher threshold, chosen so as to minimize the number of false detections while still ensuring that each call within the network is likely detected on at least one OBS. These high-threshold detections are used as master calls to apply a multiple-animal time of arrival method to find all the detections that associate with each master call. Finally a Bayesian inversion approach is used to a generate probability density functions for the whale locations.

DETECTION / CLASSIFICATION

Chair: Susan Jarvis

Oral / Tuesday 14th 2015 / 1:30 PM

Automatic analysis of the underwater soundscape characteristic to the Australian Northwest Shelf

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Over the past two decades, passive acoustic methods have been employed with considerable success in monitoring marine fauna – their behavioural and migratory patterns and their response to human interference. The existing methods, however, are usually targeted at recognising a limited set of vocalisations of one (or sometimes, up to a few) species observed at one (or a few) study site(s). Automatic detection and classification of ‘signals of interest’ in underwater acoustic recordings containing multiple simultaneous calls of multiple species embedded in various anthropogenic and physical ambient sounds still remains quite a challenge. Little progress has been made in developing a unified approach for a broader separation of underwater acoustic energies. Automatic segregation of signals into categories based on the type of their origin (biological, anthropogenic, and physical ambient) enables determining sound budgets in underwater soundscapes. An inherent difficulty with such an undertaking is the increased and innumerable variety of ‘signals of interest’. Detailed studies of the disparate detection/classification solutions available (prior to this undertaking) led to an understanding that was in alignment with prior concerns about their effectiveness in a unified system for broader classification. In the proposed framework, we revert to a more classical two stage detection-and-classification approach. New detection algorithms have been developed based on certain generalised ‘context-free’ characteristics of commonly occurring signals. With a little additional processing, some of these detection algorithms can also be used as standalone targeted recognition systems. Following detection, a knowledge-based classification sub-system assigns the detected signals to appropriate categories. The per-source-type contribution of acoustic energies can then be readily determined. The architecture of the overall system will be presented along with working details of its components. The rationale for the various choices made in the design of the overall system and of the sub-components will be described.

Oral / Tuesday 14th 2015 / 1:50 PM

Automatic Marine Mammal Monitoring off British-Columbia, Canada

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Monitoring marine mammals off British Columbia (BC) is becoming increasingly important. Planned developments of marine terminals along the BC coast will lead to increase large vessel traffic and underwater noise levels. Long-term monitoring of marine mammal distribution and ambient noise conditions is critical for understanding potential effects of these changes on marine life. Over the last decade, considerable efforts have been made to deploy autonomous acoustic recorders and hydrophones cabled to shore to perform passive acoustic monitoring. However, the time, effort and cost required to manually analyze the massive amount of recordings collected often prevents data from being properly interpreted for biological assessments. In this study we propose a set of techniques to automatically detect and classify sounds produced by several species of cetaceans that frequent BC waters. Blue and fin whale calls are detected using a spectrogram correlation approach. Killer whale, humpback whale and Pacific white sided dolphin vocalizations are first detected by calculating the local variance of energy values in the spectrogram on a 2-dimensional kernel. Transients are defined by areas of the spectrogram with a local variance greater than an empirically defined threshold. Each detected transient in the spectrogram is then represented by a set of 40 features. Each set of features is finally presented to a four-class random forest classifier to determine if the detection corresponds to a killer whale call, a humpback whale call, a Pacific white sided dolphin call or is undefined (i.e., “other” class). The precision and recall performance metrics of each detector is calculated using data from 7 recorders deployed along the BC coast from Prince Rupert to the Washington border between 2009 and 2015. Variation of the detection performance with noise conditions and monitoring locations will be examined. These detectors have also been integrated to Ocean Networks Canada‘s VENUS and NEPTUNE ocean observatories to provide real-time marine mammal detections and classifications through the JMesh web interface. A solution is proposed to semi-automate the acoustic analysis of data collected along the BC coast in anticipation of an array of sensors being deployed in the very near future.

Oral / Tuesday 14th 2015 / 2:10 PM

Improving classification of dolphin groups: compound classification using whistles, echolocation, and burst pulses

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Passive acoustic monitoring of dolphin species for population assessment is limited by our ability to classify their calls (including whistles, echolocation clicks, and/or burst pulses) to species. The significant overlap in call characteristics among species, combined with a wide range of call types and call behavior, complicates correct classification. As part of a larger effort to create a suite of acoustic classifiers for all odontocetes in the California Current, we are developing a compound acoustic classification scheme for dolphins. This classification scheme considers all call types, rather than only one call type, as has been typical for odontocete classifiers. The compound classifier combines output from a ROCCA (Real-time Odontocete Call Classification Algorithm) whistle classifier developed specifically for the California Current, a suite of species-specific click classifiers, and a burst pulse classifier. All classifiers were developed within Pamguard software. To minimize the potential effect of geographic variation, only recordings of single-species detections that occurred within (or near) the California Current were included in the analysis. To our knowledge, this is the first study to consider all species found within a larger geographic region, and the first to consider burst pulses for acoustic species classification of small delphinids. The individual classifiers were tested on recordings collected during a 4.5 month combined visual and acoustic shipboard cetacean survey off the west coast of the United States. Classification results for dolphin schools will be examined for the individual and compound detectors. We will also discuss suggestions for improving classification rates, automation, and to broaden the application of this approach to other geographic regions.

Oral / Tuesday 14th 2015 / 2:30 PM

Field comparison of PAM capabilities between a commercially available glider, a float, and a bottom-moored system

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Advances in autonomous mobile sampling platforms have provided new methodologies for passive acoustic monitoring of marine mammals. These mobile platforms allow for high spatial and temporal resolution, resolution previously unobtainable using ship-towed or bottom-mounted recording systems. However, results obtained using such mobile technologies to monitor marine mammals and ocean noise levels have yet to be directly compared to those from traditional bottom-moored systems.

In spring 2015, two commercially available mobile platforms, a Seaglider™ (Kongsberg Underwater Technology, Lynnwood, WA, USA) and QUEphone float (Matsumoto et al. 2013, JASA 133:731-740), each equipped with acoustic sensors, were deployed at the Quinault Training Range (QUTR) in Washington State at the site of a concurrently deployed bottom-moored recording package (HARP, SIO). Each mobile platform is buoyancy-driven and deep-diving, capable of submerging to depths of 1000 m (glider) to 2000 m (float). The glider is steered via satellite and typically operates in a sawtooth pattern, continuously diving and surfacing. The float's horizontal movement is determined by ocean currents, but it can remain in the deep sound channel for prolonged periods of time. The glider and float both contained an acoustic sensing and recording system developed by Oregon State University, now commercially available (Embedded Ocean Systems, Seattle, WA, USA). A sampling rate of 125 kHz allowed detection of most cetacean species except porpoises.

Comparison of presence/absence patterns of odontocetes detected by the mobile platforms and the HARP as well as float and glider comparisons of instrument noise (electronic, steering mechanisms, water flow over body shape differences) was conducted and results are presented here.

Poster T1

A comparison of methods used in call classification

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Variation in call repertoires is correlated with population structure in many species of birds and mammals. In the marine environment, killer whales exhibit acoustic variation in their call structure, which has recently been quantitatively studied to improve understanding of socially-driven population structure. Here we compare recently published methods used to characterize killer whale calls by applying these techniques to another social cetacean, the short-finned pilot whale.

Pilot whale vocalizations exist along a continuum from burst pulse to whistles, and we found that many calls exhibit simultaneous burst pulse and whistle components. They also exhibit repeated complex calls made of several independent subunits. Two genetically and morphologically distinct types of short-finned pilot whale have been identified in the Pacific Ocean, with non-overlapping distributions. Recordings from both types reveal qualitative differences in the complexity and frequency distribution of social vocalizations from the two types. In order to compare the efficacy of previously published call characterization techniques, we used each method to characterize 300 calls from 10 encounters for each type of short-finned pilot whale. We then use a Gaussian Mixture Model to look for acoustic variability in calls between the two types. The results of the characterizations are compared to determine which method performs best in characterizing call variability in short-finned pilot whales. We anticipate that including population-specific information may improve species classification for short-finned pilot whales.

Poster T2

Detection and recognition of Atlantic cod (Gadus morhua) grunts

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Protecting the spawning aggregations of Northwest Atlantic cod is crucial to stock rebuilding after years of overfishing. Atlantic cod produce identifiable grunts during spawning. Passive acoustic technology can identify spawning aggregations, their seasonal duration, and their persistence across years. Unfortunately, processing large quantities of passive acoustic data and detecting Atlantic cod grunts has been hampered by the lack of a grunt detector.

The main goal of this work was to reduce the man hours required to analyze these large volumes of data. To solve this problem, we designed an automatic grunt detection technique, applicable to processing yearlong passive acoustic data recordings. The proposed technique is represented as a two-stage hypothesis testing algorithm. First, the spectrogram-based detector detects all grunt-like sounds in a data set. In the second stage, a statistical feature vector testing algorithm recognizes the detected events using six features extracted from the detected sounds.

Test results demonstrated that the algorithm provided a detection probability of 0.93 for grunts with signal-to-noise ratio (SNR) higher than 10 dB and 0.8 for grunts with SNR from 3 to 10 dB. This detector is being used to identify Atlantic cod in current and historical data within US waters.

Poster T3

Burst pulse detector for California Current odontocetes using PAMGUARD

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Burst pulses are comprised of pulsed sounds similar to echolocation clicks with extremely short inter-click intervals and share characteristics of both whistles and clicks. Anecdotal evidence suggests that consideration of burst pulse characteristics would improve acoustic species classification. Currently there are no widely available algorithms for acoustic detection of odontocetes using burst pulses. As part of a larger effort to create a suite of acoustic classifiers for all odontocetes in the California Current, we have developed a method for detecting burst pulses using the whistle and moan detector within PAMGUARD. Detection of burst pulses has been notoriously difficult using conventional click detectors. Burst pulses tend to be detected by the whistle and moan detector within PAMGUARD, due to the presence of what appear to be tonal bands (which are, in truth, an artifact of the FFT size and click repetition rate). The methods presented here take advantage of this feature; burst pulses from archived recordings were extracted and processed using the whistle and moan detector for analysis. We found that few burst pulses were detected using the typical settings designed for whistles; however, modification to these settings improved detection of burst pulses. Burst pulses from several species of dolphins within the California Current and synthesized burst pulses generated in MATLAB were used to establish the capabilities of the detector. Preliminary results suggest the use of burst pulse detectors within PAMGUARD will be simple to implement in an automated format for most species. We suspect that acoustic species classification for some odontocetes will improve with the consideration of burst pulses and are currently testing this for cetaceans in the California Current.

Poster T4

Applying double-difference methods for long range tracking of sperm whales (Physeter macrocephalus) on a small aperture vertical array

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Ray refraction effects allow sound to propagate over large ranges in deep water environments with a sound speed minimum, and multiple ray paths often exist between a single source and a given receiver. Ray propagation modeling can estimate a source's depth and range by measuring the elevation angles and relative arrival times of these ray paths on a vertical array. However, a lack of knowledge about the range-dependence of the sound speed profile in the region, as well as limits on array angular resolution, can yield scattered dive trajectories whenever applying standard ray tracing methods.

Concepts similar to the double-difference technique, previously applied to fin whales (Wilcock, *J Acoust Soc Am*, Vol. 132, 2012), are adapted for tracking sperm whales (*Physeter macrocephalus*), using acoustic data recorded in February 2014 off the coast of Southern California. Data were acquired on a 128-hydrophone vertical array with 10 cm spacing, located at 330 m depth in 4 km deep water, near the sound speed minimum of the water column. Double-difference measurements can improve track precision by examining relative changes in multipath arrivals' timing and elevation angle over the course of a dive.

Data sequences from two whales, estimated to be approximately 55 km from the array, show how this approach can identify distinct components of a dive profile and discern higher-resolution spatial trajectories.

[Work supported by Office of Naval Research – Marine Mammals and Biology and Ocean Acoustics Program]

Poster T5

Evaluating modeling methods for calculating Time-Difference of Arrivals (TDOA) for humpback whale calls

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Passive acoustic monitoring is a powerful tool for collecting data to localize and track marine mammals. The data can be useful for understanding animal behavior and obtaining population information of marine mammal species, which aids in the development and execution of mitigation requirements during U.S. Navy training exercises in compliance with the Marine Mammal Protection Act and Endangered Species Act.

Calculating expected arrival times for humpback whale localization in shallow water can be difficult because of the multipath environment. This study investigates whether it is possible to improve 2-D and 3-D localization accuracies using simulated TDOA of humpback whale calls bottom mounted hydrophones in shallow water. The approach is to use the OASIS peregrine C-based RAM which has integrated historic environmental databases and allows for broadband multipath to calculate the complex pressure for creating a simulated humpback whale call.

By using the peregrine acoustic model to simulate a received whale call, environmental effects such as bathymetry, historic range dependent sound speed profiles, and complex boundary conditions are introduced to the signal. This is expected to create more realistic results because of its ability to model the broadband frequency components of a real whale call with multipath spreading, which exists in real underwater detections. In addition, the simulated calls are fed into detection and localization software; such that the expected time-difference of arrivals (TDOAs) can be computed with exactly the same detection, localization and tracking software as real data. Localization and timing results from data collected at the Pacific Missile Range Facility in Hawaii will be compared between the peregrine model-based approach, and a ray method using sound speed profiles and a constant sound speed.

Poster T6

Click trains temporal parameters variability among three delphinid species in the western South Atlantic Ocean

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The pulsed signaling is broadly used by delphinids in a variety of ways. Nevertheless, there are still some issues concerning how to accurately distinct click train variability among different species. Herein, a comparison was performed among the echolocation signals of spinner (*Stenella longirostris*), rough-toothed (*Steno bredanensis*) and Risso's (*Grampus griseus*) dolphins. Acoustic recordings were carried out on the South Brazilian continental shelf break, through a one-element hydrophone array (spinner and rough-toothed dolphins recordings) and a Cetacean Research™ C54XRS hydrophone (Risso's dolphin recording), both connected to a digital Fostex® FR-2 LE, performing continuous mono recording at 96kHz/24bits. The most relevant pulsed signals were chosen based upon their signal-to-noise ratio (SNR). On account of the large volume of overlapping click trains, each species was analyzed from the most distinct echolocation click trains, composed of visible distinguished clicks that could be attributed to a single animal emission. Based on the extracted temporal parameters (Inter Click Interval – ICI and duration, which values are given as medians with first and third quartiles in squared brackets), the Kruskal-Wallis test pointed out a significant ($H= 243.57$, $p<0.001$) difference among the ICI's of the three species (*S. longirostris*: 0.10 [0.06-0.17]; *S. bredanensis*: 0.06 [0.02-0.12]; *G. griseus*: 0.11 [0.04-0.25]), as well as among the click-trains duration (*S. longirostris*: 1.70 [1.12-3.03]; *S. bredanensis*: 0.94 [0.36-1.87]; *G. griseus*: 2.91 [1.23-7.05]) ($H= 26.80$, $p < 0.001$). When compared in pairs through the Dunn test, there was no significant difference between spinner and Risso's dolphins ICI's value ($z= -1.31$, $p=0.096$). On the other hand, when the Linear Discrimination Analysis, considering the median of the ICI's values and click-train duration, was performed it indicated a significant ($F= 11.58$, $p<0.001$) discrimination of Risso´s dolphin from the other two species, particularly based on its ICI's values. Rough-toothed and spinner dolphin were not significant discriminated ($F=1.95$, $p=0.146$). These differences could be related to the anatomic features, behavior and ecological factors. The acoustical study of such abundant cosmopolitan species contributes to Delphinidae detection and classification systems.

Poster T7

Volumetric Towed Hydrophone Arrays: Two alternative designs to improve localization

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Passive acoustic towed hydrophone arrays are routinely used during shipboard cetacean abundance surveys to detect, localize, and track cetacean groups and individuals. Most towed arrays are designed for localizing vocal groups using the time-difference-of–arrival method with two linearly-positioned hydrophones to obtain a series of two-dimensional bearings (with left/right ambiguity) that converge as the ship moves along the trackline. The series of bearing estimates results in an estimate of perpendicular distance from the trackline. These localization methods work well for single animals or tightly clustered schools that move slowly relative to the vessel speed, and where slant angle and horizontal angle may be considered the same. However, these methods begin to deteriorate for large, widely-dispersed, or fast-swimming groups or individuals and for animals that call at considerable depth. The time required to obtain adequate bearings for a distance estimate could also violate an assumption of line-transect sampling that the location of the initial detection occurs prior to any response of the animals to the research vessel. We present two volumetric array prototypes designed to capture three-dimensional bearings for more accurate and efficient localization. Design considerations included building an array structure manageable for one person to handle and suitable for towing at 10 knots while maximizing the distance between hydrophones in order to detect and localize a variety of species. Several field tests were conducted and results revealed high levels of flow noise and considerable rotational movement while under tow. Modifications to each prototype helped resolve these issues, but further testing is necessary to adequately assess the performance of each array. While the prototypes are not fully functional for shipboard surveys at 10 knots, it is a substantial step towards building a robust localization tool to improve the accuracy of passive acoustic data.

Poster T8

Whistles Source levels of free-ranging Indo-Pacific humpback dolphins (*Sousa chinensis*) in Pear River Estuary and Beibu Gulf, China

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Understanding the baseline data of the species-specific vocalization characteristics such as source levels (SL) is critical for mitigating the threats facing many species such as the underwater acoustic pollution and better protecting the animals especially those are endanger. A two-dimentional over-determined cross hydrophone array systems were adapted to record the whistle of free-ranging Indo-Pacific humpback dolphins (*Sousa chinensis*) in shallow-water environment of Pearl River Estuary (PRE) and Beibu Gulf (BG), China. Hyperbolic fixing, a geometric passive acoustic localization method exploits time of arrival differences between pairs of hydrophone receivers, incorporating a TOADY software based depth function was applied for source location estimate for each whistle. The SL_{pp}, SL_{rms} and SL_{rms200} in PRE and BG were 157.1 dB (±9.4 SD), 138.5 dB (±6.8 SD), 140.3 dB (±7.3 SD) and 161.3 dB (±13.4 SD), 137.2 dB (±7.0 SD), 139.3 dB (±6.9 SD), respectively. The source EFD in PRE and BG was 135.2 dB (±7.4 SD) and 134.0 dB (±6.8 SD), respectively. No significant differences were observed in the whistle SLs and EFD between sites. Significant difference was observed in SLs among different whistle tonal types, which may be associated with their different function in different behavioral context. These baseline data can shed some light for evaluating the appropriate noise exposure level and regulation of underwater acoustic pollution.

Poster T9

First study of presence of humpback whales vocalizations in a feeding ground of the Southern Chile.

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Humpback whales, *Megaptera novaeangliae* inhabit all major ocean basins and undertake long-distance seasonal migration between productive high-latitude areas where whales feed in the summer and fall, and low-latitude tropical waters where mating and calving occur during winter and spring.

Southern Chile, especially the Chiloense Ecoregion, have been recognized as an important summer feeding ground for the southeastern Pacific humpback whale.

The song of humpback whales is a loud, complex series of sounds repeated over and over. It occurs primarily (although not exclusively) during the breeding season, is sung only by males, and its composition changes as it is being sung with all singers in a population singing the same version at any one time.

In this investigation, we used the songs of humpbacks whales to study the seasonal patterns in the presence of humpback whales in this area.

We deployed one marine autonomous recordings unit (MARUs) during six months (January to June 2012). We used SONS-DCL software to automatically extract acoustic events from this unit. Our results indicated that there was a constant presence of humpback whale in the south of Chiloense Ecoregion, but there were an increases in the presence in the last months studied. So, in June we found the maximum presence of humpback whale vocalizations. In addition, we studied the diary or circadian pattern of these vocalizations for understanding more of the activities they were doing in these months over this area. In this context, our results showed that were more vocalizations in periods with low light or in dark (at night).

These are the first recorders of humpback whale in this area, so for complete this investigation, we continue studying these vocalizations, as well as other sounds and biology variables that maybe will be influenced in humpback whale behavior.

Oral / Tuesday 14th 2015 / 4:00 PM

Passive acoustic monitoring of dolphins in the Gulf of Mexico: 2010 to 2013

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Dolphin populations were monitored at five sites in the Gulf of Mexico from 2010 to 2013, using High-frequency Acoustic Recording Packages (HARPs). Two sites on the continental shelf allowed monitoring of near-shore species, including bottlenose dolphin (*Tursiops truncatus*) and Atlantic spotted dolphin (*Stenella frontalis*). Three sites located on the continental slope focused on pelagic species including Risso's dolphin (*Grampus griseus*), pilot whales (*Globicephala sp.)* and oceanic stenellids (*Stenella spp*.). The HARPs passively recorded delphinid echolocation clicks continuously for up to ten months at a time. Ship-based towed array recordings of echolocation clicks produced by visually identified species were also collected in the region. Echolocation clicks from these identified recordings were compared to those detected in long term recordings. Frequency content and inter-click interval were used to putatively identify echolocation clicks to genus or species. The probability of detecting echolocation clicks at each HARP site was modeled using a Monte Carlo simulation framework. These probabilities were then used to estimate the true number of clicks produced at each site on a weekly basis for long term trend analysis. Diel and seasonal patterns are visible in the click time series', as are potential longer term trends in the multi-year records at some sites.

Oral / Tuesday 14th 2015 / 4:20 PM

Automated Real-Time Acoustic Monitoring of Mediterranean beaked whales at ANTARES underwater observatory

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Beaked whales are known to produce frequency-modulated echolocation pulses, which have been used for the identification of their presence. Most recently published literature reveals that the majority of beaked whale species have some ideal characteristics for PAM techniques including unique spectral and temporal features of their echolocation clicks.

ANTARES is the largest European Neutrino telescope and also an underwater cabled observatory for sea and earth sciences that allows continuous monitoring of noise and acoustic events. ANTARES observatory located off the South coast of France at a depth of 2475m is part of the – Listening to the Deep Ocean Environment (LIDO) – international project. LIDO is aimed at processing underwater sounds in real time (DCL) measuring noise under standardized protocols and determining how artificial noise sources may impact the conservation status of marine fauna.

Here we present preliminary results on the performance of a real-time beaked whale detector and classifier under the LIDO architecture. Each detected impulse is characterized using 21 features that represent the distribution of acoustic energy over time and frequency. Automated classification is performed using Gaussian mixture models, with the model order determined by Bayesian information criterion (BIC) model selection.

Oral / Tuesday 14th 2015 / 4:40 PM

Automated Detection and Classification of Beaked Whale Buzzes using Bottom-mounted Hydrophones

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Beaked whales, like several other odontocetes, produce bouts of very rapid clicking just prior to a prey capture attempt. For Blainville's and Cuvier's beaked whales (*Mesoplodon densirostris* and *Ziphius cavirostris* respectively) these rapid click sequences have been dubbed "buzzes". Buzz clicks have a structure that is markedly different from and source level that is significantly lower than the foraging clicks from these animals. To date most of the analysis of beaked whale echolocation behavior, including buzz production, has relied on analysis of data from acoustic recording tags (DTAGs) placed on the vocalizing animal. While the data from DTAGs has proved invaluable and irreplaceable it is also limited. Tagging beaked whales is quite difficult thus the spatial and temporal coverage of tagged animals remains relatively sparse. This paper presents a method and algorithm for automatically detecting buzzes from foraging Blainville's and Cuvier's beaked whales using fields of widely-spaced bottom mounted hydrophones. We believe the system is the first to specifically target detection of buzzes over a wide area. The detected buzzes can be used as a proxy for prey capture attempts and can be factored into models for assessing population health. However, the source level for buzz clicks is ~20 dB lower than that of foraging clicks and the buzzes also appear to be highly directional. As a result, the probability of detecting an individual buzz can be low. Our goal, therefore, is to thoroughly characterize the detection performance of the algorithm and to then borrow techniques from spatially explicit capture recapture (SECR) density estimation to estimate the "abundance" of buzzes across the field of sensors. We present results from the automated detection of buzzes across 86 sensors from the AUTEC range in the Tongue of the Ocean, Bahamas, and 89 sensors from the SCORE range off Southern California.

DENSITY ESTIMATION

Chair: Len Thomas

Oral / Wednesday 15th 2015 / 8:40 AM

DE: The state of the art

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Density estimation (DE) is an important application of passive acoustic studies of marine mammals. The topic has seen considerable recent methodological development, whereby wildlife population assessment methods originally developed for visual or trapping surveys have been adapted to the passive acoustic context (for both fixed and towed acoustic sensors). Methods include plot sampling, distance sampling and spatially explicit capture recapture (SECR). Many case studies now exist, where data from passive acoustic surveys have been re-tooled to provide estimates of absolute animal density or abundance. More recently, focus has shifted from analysis of pre-existing data to the design of new surveys, specifically created for passive acoustic DE. In this talk, we review the available methods and briefly cover a selection of historical case studies, as well as introducing some purpose-built surveys currently underway or planned. We highlight current knowledge gaps and (therefore) future research needs. From the ecological perspective, the DE community needs a better understanding of acoustic behavior (specifically average phonation rates) of many species; from the statistical perspective one priority is to develop a framework for the use of slow-moving platforms such as gliders and drifting sensors.

Oral / Wednesday 15th 2015 / 9:00 AM

Range estimation of bowhead whales in shallow Arctic waters using a single hydrophone

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Bowhead whales generate low-frequency vocalizations in shallow-water Arctic environments. Their acoustic propagation is conveniently described using normal mode theory, which describes the received signal in terms of several propagating modes (i.e. frequency-dependent multipath), each traveling with its own frequency-dependent group velocity (propagation speed). This frequency dependence means the ocean acts as a dispersive waveguide, distorting broadband calls during propagation. If a whale emits a call a few kilometers away from a receiving hydrophone, the recorded signal can be substantially different from the emitted vocalization. However, this modal dispersion phenomenon carries information about the source range and depth. At large distances the relative arrival times of different modes can be measured from a spectrogram, and the range of the source can be estimated (Wiggins *et al*. 2004). At closer ranges a vertical arrays of synchronized hydrophones can be used to isolate modes and thus range (Abadi *et al* 2014). A third approach is presented here: a nonlinear signal processing method called warping that filters modes on a single receiver, even when modes cannot be recognized on a conventional spectrogram.

This ranging technique is illustrated on several bowhead whale vocalizations recorded near Kaktovik (Alaska) in 2010, at ranges between 3 and 35 km. The estimated ranges are consistent with those obtained independently via triangulation from a sparse network of directional sensors and a concurrently deployed vertical array. The original source signal structure is obtained as a by-product of the methodology. Preliminary results of joint range/depth estimation using a single hydrophone will also be presented.

This approach can actually be applied on baleen whale calls recorded in shallow water on a singe hydrophone, provided that a substantial portion of the call is a monotonic upsweep or downsweep (i.e. no inflection points). Thus a large body of archived bioacoustic data may embed information about whale range and even depth, even if modal effects are not visible in standard spectrograms.

Oral / Wednesday 15th 2015 / 9:20 AM

Estimating spatial densities of vocalizing animals using bearings of signals detected with a directional acoustic recorder

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While passive acoustic density estimation (PADE) of vocalizing animals is a very innovative method to gather animal abundance information in areas difficult to monitor by visual survey, the methodology faces a number of analytical and practical challenges one being the unknown probabilities of true signal detections, false detections, and calling rates that can cause problems detecting the number of vocalizing individuals in a given space accurately. Since each vocalizing animal, regardless of the type of sounds it produces, is unambiguously characterized by its location, the number of vocalizing animals can be estimated as the number of different bearings or bearing tracks created using a directional array of acoustic recorders.

This study focused on the problem of estimating the number of vocalizing animals within a continuously monitored area. The goal of this work was to represent a new PADE technique based on the bearing estimates of the detected signals. We demonstrate that bearing distributions can be obtained with fixed directional sensors that provide information about the bearings of detected signals which allow tracking individuals over time and express their relative location to each other. The results presented closed form representations of the number of vocalizing animals at any given time, and describe the sensor requirements.

The ability to evaluate the number of vocalizing animals in realistic scenarios, as well as an example of implementation of a near-real time detection and localization system is demonstrated by the results of in situ tests. In situ tests were performed with a small tetrahedral array of underwater Autonomous Multichannel Acoustic Recorders (AMARs, JASCO Applied Sciences) deployed on two of the VENUS ocean observatories operated by Ocean Network Canada off the coast of British Columbia, Canada.

Oral / Wednesday 15th 2015 / 9:40 AM

Humpback whale-generated ambient noise levels provide insight into singers' spatial densities

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Previous research has investigated whether diffuse ambient noise levels can be used to estimate relative baleen whale abundance in environments where the whales' vocal activity dominates ambient noise levels. Presented here is an analytical model of ambient noise levels as generated by random distributions of singing humpback whales. The model exploits earlier ones (Kuperman and Ingenito, 1980; Perkins et al., 1993; Jensen et al., 1994) that derive ambient noise levels by assuming randomly distributed wind-driven breaking waves on the ocean surface. Using a parameterized acoustic propagation environment and various assumptions about humpback whale singing behavior, the current model predicts ambient noise levels as a function of frequency and population size. It also predicts that the "sensitivity" of ambient noise levels to changes in population size should be relatively independent of individual humpback whale singing behavior, but does depend strongly on the spatial density of singers. Two extreme scenarios in singing behavior are identified: (1) a "constant area" scenario, whereby whales sing within a confined region and increase their density as more singers arrive, and (2) a "constant density" scenario, whereby whales space themselves evenly to sing over a constantly expanding region as more singers arrive. During the 2013 and 2014 humpback whale breeding seasons off Los Cabos, Mexico, visual line transect surveys were conducted in conjunction with acoustic data collection from four bottom-mounted acoustic recorders. A generalized linear model was used to estimate the sensitivity of song-generated ambient noise levels across several frequency bands, while compensating for diel cycles. The resulting sensitivities are most consistent with the constant density scenario of the analytical model predictions. However, the results also suggest that individual singers may slightly increase their source levels or singing duration with increasing singer population, or may tolerate a slight increase in density between individual singers.

Oral / Wednesday 15th 2015 / 10:20 AM

Large scale density estimation of blue and fin whales: combined distribution and density estimates using bearing data.

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A new approach for estimating cetacean density using passive acoustic data is presented. This work is part of an effort to estimate blue and fin whale densities over large spatial scales, taking into account spatial variation in animal density. The method is designed to be used on data from widely spaced, or sparse, instrument arrays such as the Comprehensive Nuclear Test Ban Treaty Organization International Monitoring System (CTBTO IMS). Measured horizontal bearings to calls and call signal-to-noise ratios (SNR) are required, as well as information about call source levels, sound propagation and call production rates. The bearing and SNR measurements, source level data and transmission loss predictions are used to estimate the location of each call (multiple candidate locations can be considered). The probability of detecting each received call is estimated as a function of SNR. Call “abundance” at the location of each call can then be estimated; each detected call is scaled by its associated probability of detection, which accounts for undetected calls at the same location. If an appropriate call production rate is available, the local call abundances can be rescaled to animal abundances. The resulting estimates are then smoothed using a spatial Generalized Additive Model to give an estimated density surface. A simulation was conducted using “Sri Lankan” blue whale call recordings from the CTBTO IMS instruments in the Indian Ocean as a motivating example. From 150 preliminary simulation runs, the median bias in estimated call density was 3.2%. Method development will be extended by refining the spatial model. The method will also be applied to data from a deployment of Ocean Bottom Seismometers (OBS) in the Atlantic Ocean. The OBS dataset will also be analysed using distance sampling, a standard density estimation method, providing a valuable comparison between the two methods.

Oral / Wednesday 15th 2015 / 10:40 AM

Towards passive acoustic density estimation of Antarctic blue whales: Preliminary results from the 2015 NZ-Australia Antarctic Ecosystems Voyage

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We present preliminary results of acoustic tracking of Antarctic blue whales (ABWs) during the 2015 NZ-Australia Antarctic Ecosystem Voyage. During this multi-disciplinary voyage, two non-consecutive weeks were allocated for dedicated research on ABWs, including close approach for photographic identification, group size estimation, and focal follow. Real-time passive acoustic tracking of ABWs using directional sonobuoys provided a reliable and efficient means of finding whales for further study, and these acoustic tracking methods were not only employed during the 14 days of dedicated research but also throughout the entire 42 day voyage.

During the voyage, over 520 hours of passive acoustic recordings containing ABW calls were made. Real time monitoring of these recordings yielded over 40,000 calls that were selected for localisation of bearings and measurement of received level. The spatial distribution of calling locations of ABWs was confined within a broad-scale *vocal aggregation* where both tonal (i.e. song) and frequency modulated calls (e.g. D calls) were detected. Similar to a previous voyage conducted in 2013, 26 Hz tonal calls from the vocal aggregation were detectable from more than a thousand kilometres away, while frequency modulated calls were detectable from hundreds of kilometres away.

Acoustic measurements made while approaching and departing the vocal aggregation yielded a consistent inverse relationship between received level of tonal calls and distance to the aggregation, thus suggesting the feasibility of distance-sampling of vocal aggregations using passive acoustics. During the voyage there were 35 encounters with groups of blue whales (mean group size of 2.7), and all but one of these groups were located within the main vocal aggregation. Further analysis of the visual and acoustic data from within this vocal aggregation and those from the 2013 voyage will be used to investigate the relationship between the number of whales in the aggregation and the number of calls detected, and this relationship may eventually allow for passive acoustic density estimation of ABWs from measurements of bearing and intensity of calls.

Oral / Wednesday 15th 2015 / 11:00 AM

A Comparison of Acoustic Based Line-Transect Density Estimates for Sperm Whales and Minke Whales in the Northern Marianas Islands

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Density was estimated for minke whales (*Balaenoptera acutorostrata*) and sperm whales (*Physeter macrocephalus*) using archived acoustic data recorded from a towed hydrophone array during a vessel based line-transect survey. This acoustic and visual survey was conducted in the winter/spring and encompassed a large study area (616,000 km^2) in the Northern Marianas Islands. Greater than 65% of the visual survey effort was conducted in Beaufort sea states of five or higher, thus visual efforts were greatly compromised. The towed array system was used during daylight hours in all conditions up to, and sometimes exceeding, Beaufort 6 sea state. For sperm whales, semi-automated detection and localization was conducted using PAMGuard software. This resulted in more than twice the number of acoustic localizations than were obtained in the field, and encounter rates that were about four times greater than used in the visual based density estimates. The acoustic based estimate was 0.84 animals/1000 km^2, compared to the visual based estimate of 1.23 animals/1000 km^2. More importantly, the CV of the acoustic estimate (CV = 26%) was 34% lower than that of the visual estimate (CV= 60%). We were able to post-stratify results by click-type, allowing separate estimates for males (0.11 animals/1000 km^2) versus females and juveniles (0.73animals/1000 km^2). For minke whales, data were post-processed using a customized algorithm to detect, localize and estimate distances to animal calls. This resulted in over 30 acoustic localizations which were used to estimate densities of 0.13 (CV= 38%) and 0.15(CV=40%) animals/1000 km^2 (based on a detection function that was right truncated, or both left and right truncated, respectively). To our knowledge, this is the first acoustic-based density estimate of minke whales using line-transect methods. We will use examples from these analyses to highlight some important issues for acoustic based line-transect density estimation methods and will provide recommendations to improve these methods.

[Work sponsored by NAVFAC-Pacific and Pacific Fleet]

Oral / Wednesday 15th 2015 / 11:20 AM

Density estimation of northeast Pacific fin whales derived from frequency band energy

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Fin whale (Balaenoptera physalus) song consists of tonal pulses between 15 and 25 Hz. The combined sound from a large number of distant fin whales results in a peak in spectral energy in this frequency band. The energy received in this band at a number of sites off the northwest coast of the U.S. is used to estimate the population density of this species. This is done using a simulation: A given density of fin whales is simulated, and parameters on fin whale pulse sound pressure level and average pulse period are combined with acoustic propagation modeling to estimate the amount of energy that would arrive at a given sensor location for that simulated density. This process results in a function mapping density to received level; the function is then inverted to obtain a function mapping received level to fin whale population density. The method is applied to acoustic data from the study area, with discussion of the issues arising from this population of fin whales, including uncertainties in fin whale song parameters, propagation modeling, and acoustic interference.7

WORKSHOP DATASET

Chair: John Hildebrand

Oral / Wednesday 15th 2015 / 1:30 PM

Classification of the DCDLE 2015 Dataset

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We present results of classification to species from odontocete echolocation click data collected in the Southern California Bight as part of the DCLDE 2015 dataset. Echolocation clicks are identified via a multi-stage detection process that examines spectral content and Teager energy. Click spectra are normalized for background noise via spectral means subtraction, a process that has been shown to be effective for mitigating for site and instrument variability in the classification of echolocation clicks. Noise regions are verified for echolocation click contamination by the use of a second detector with a low threshold.

Features are extracted from echolocation spectra using cepstral features that offer a compaction of the feature space, thus reducing dimensionality. These features are classified with a Gaussian mixture model. We introduce techniques to clean the input data, such as reducing the number of false detections triggered by sources such as echosounders or ship passages.

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Intrinsic structure study of whale vocalizations

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By understanding the inherent low dimensional structure of the whale vocalizations, we can effectively address high dimensional classification problems. A distinctive feature of many marine mammal calls lies in the fact that they are frequency modulated and can be modeled as polynomial phase signals. This implies that the intrinsic dimension of whale vocalizations can be described and estimated by the number of polynomial phase parameters. Traditional dimensional reduction methods, such as PCA, do not take into account the intrinsic physical and geometric information in the data. In this study, we explore the use of nonlinear manifold mapping methods, in particular Laplacian Eigenmap and ISOMAP, to examine the underlying but hidden manifold structure of the data in the time-frequency plane. Experimental results show that nonlinear manifold methods outperform PCA in classification on the DCLDE data (as released early this year), which suggests that the intrinsic structure of whale acoustic data is nonlinear, rather than linear.

Oral / Wednesday 15th 2015 / 2:10 PM

Detecting Blue Whale Calls By Extending a Speech Processing Algorithm: A Proof of Concept

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A detection/classification algorithm was developed to analyze bioacoustic signals that contain harmonics. It leverages a speech signal processing algorithm which models each formant of a vowel as having not only frequency modulation (FM) but also amplitude modulation (AM).

When applied to blue whale calls, one can imagine that each component of the signal starts out as a chirp in a common “base-band”; it then gets into its sub-band by amplitude-modulating that sub-band’s carrier sine wave.

So, if we take the received signal and perform the appropriate amplitude-*demodulation* per sub-band, we can retrieve the “base-band” components. Now that the components are all in a common “base-band”, we can then look for correlation across these demodulated components. A certain pattern of correlation across the sub-bands indicates the presence of our signal.

Whereas the performance of a matched filter may be degraded by multipath, this approach may not be impacted by multipath; if some of the source signal’s demodulated components are well correlated, this correlation should be preserved regardless of the path(s).

The performance of this algorithm will be evaluated using the DCLDE low-frequency training data set.

Oral / Wednesday 15th 2015 / 2:30 PM

Object-oriented rule-based classifier for blue and fin whales

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A rule-based classifier of whale calls, integrated with computer vision and object recognition techniques has been developed to detect and identify whale calls in passive acoustic data. The classifier is based upon specific rules used by an analyst to recognize different types of cetacean vocalizations in spectral displays of long time series of acoustic recordings.

The developed technique has been applied previously to fin whale 20 Hz calls and blue whale A and B calls, and its feasibility and performance skill has been estimated. The classifier proved to be more effective and robust than a traditional matched filtering, when the signal-to-noise ratio is low, for example, in presence of shipping noise.

Here the rule-based classifier is applied to D calls of blue and 40 Hz calls of fin whales. As compared to other calls of baleen whales, the feeding calls are much less stereotyped and have much higher variability. This makes it challenging to detect and identify these calls using traditional methods. Data from several locations off Central and South California and different seasons are used, including the DCLDE 2015 low frequency dataset.

Poster W1

Investigating variables influencing click emission rate of franciscana dolphin (*Pontoporia blainvillei*)

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Passive acoustics have been developed and applied to estimate marine mammal density. A key required parameter is sound production rate, which in cetaceans can be influenced by factors like season, group size, gender, density, and possibly by anthropogenic noise. We investigate potential factors that could affect the production of high-frequency clicks in a resident population of franciscana dolphins.

Fieldwork was conducted on 22-31 January 2014 at Babitonga Bay (26º15´S; 48º40´W), southern Brazil. Acoustic data, group sizes, calf presence, and water transparency were registered when animals were within visual range at maximum distance of 50 meters. Recordings were made in 18 occasions in the presence of a single engine helicopter (Robson R-44) flying at 150 feet high over the groups and 14 times in the absence of the helicopter. Recordings were made with a Cetacean Research™ hydrophone coupled with an Analogic/Digital IOtech board and stored as wav-files. The Franciscana high-frequency clicks were acoustically and visually confirmed with Raven software. The files were set at a maximum of 5 minutes of recording when in the presence of the animals.

An energy summation algorithm was developed for detection. It first ignores unnecessary frequencies by applying a high pass filter of 100 kHz. Then an energy summation on the frequency domain is applied, giving the features used for the classifier. The classification algorithm used was KNN. The machine training consisted of 15621 samples divided into two classes (with signal and non signal). A cross validation was applied in the training set, resulting in an error rate of 0.5%. A simple linear model was used to assess whether the average frequency of clicks per minute was influenced by the presence of the helicopter, by group size, by calf presence, and/or by water transparency. Group size was the only significant ($p=0.0464$) predictor and indicated that click frequency increases with the number of individuals in the group. The results corroborate that the use of an average franciscana individual emission rate should be appropriate to obtain estimates of abundance using acoustic signals. This study was supported by the IWC Small Cetacean Conservation Fund, ICMBio, Petrobras, Fundo de Apoio à Pesquisa/UNIVILLE.

Poster W2

SAMBAY: A dedicated study for Density Estimation from Passive Acoustic Monitoring

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Understanding the patterns in the distribution of marine mammals is complicated by the elusiveness and mobility of these animals, the difficulty of working at sea, as well as for some species, by their massive decline in abundance due to commercial hunting. Knowledge on marine mammal critical habitats and habitat usage is nevertheless of key importance in the context of policy decisions on catch permits and designation of marine protected areas.

Passive acoustic monitoring (PAM) provides an affordable technique to collect presence observations over extended periods of time. For long term monitoring, autonomous acoustic recorders are usually distributed over the study area on moorings or buoys, and can record data over several years without the need of maintenance. In recent years there has been a substantial effort to develop statistical methods which allow calculation of abundances from passive acoustic observations. Even though the statistical background is sound, several assumptions (i.e. rates of possibly context and sex dependent vocalizations) are necessary to be able to calculate abundance. The errors of these assumptions, which result in false estimates of population size, might be large, and their knowledge is essential to correct for biases in the abundance estimations.

SAMBAY (San Antonio Model Bay) aims to substantiate the influence of different covariates on the density estimation using passive acoustic monitoring. During austral summer the San Antonio Bay is host to about 120 southern right whales. We will estimate abundance using four different methods, which allows us to establish a ground truth abundance as well as contextual covariates and time budgets for several different individuals. This will directly allow measurement of the effects of different assumptions made during density estimation from passive acoustics monitoring by selecting subsets of the acoustic dataset and repeat the density estimation. Here we present and discuss the study design and implementation.

Poster W3

A MATLAB based HPC toolset for noise analysis of large acoustic datasets

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A suite of acoustic analysis tools were developed as part of the Bioacoustics Research Program's Raven-X software suite. The tools process, analyze and visualize acoustic data and analysis products from recording units and are capable of dealing with large, high-frequency (16 kHz and higher) arrays deployed for over a year.

The Acoustic Analyzer Tool utilizes MATLAB© High performance computing (HPC), and allows rapid and efficient processing of acoustic data to produce calibrated, spectrographic, narrow-band and third-octave band metrics.

The Project Management GUI (PMGUI) is designed to manage and store information on data required for various forms of analysis. Information is stored hierarchically by geographic region, project, deployment and recording unit. The tool manages the integration of different datasets such as acoustics, vessel, biological, oceanographic and metrological data allowing the user to synchronize navigate and visualize the data both in the spatial and temporal dimensions. The tool is used to launch a suite of acoustic analysis tools.

These include the Noise Report Browser which is designed to process and browse the data files allowing the user to view narrow-band spectrographic, third-octave band, broad-band and frequency distributions at different time scales and averaging times across multiple channels, and to save the analyses results as spreadsheets, figures, and animations. The tool includes batch processing capabilities.

Another tool includes the Acoustic Ecology toolbox designed to measure the loss of communication space from anthropogenic sound sources. The tool enables the user to navigate and visualize the results both spatially and temporally and save results as spreadsheets, figures, and spatio-temporal animations. Propagation modelling is achieved through incorporation of Heat Light and Sound's Acoustic Toolbox.

An example of the capabilities of these analyses tools is presented here with the analysis of a 19 element acoustic array covering an area of approximately 400 square miles that was deployed over a period of over 5-years in Massachusetts Bay, also an analysis of a combination of three simultaneous deployments entailing 38 recording units covering 1000 square miles.

Poster W4

Design of the Drifting Acoustic Spar Buoy Recorder (DASBR)

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The Drifting Acoustic Spar Buoy Recorder (DASBR) is an autonomous, free-floating recording system which provides a practical, low-cost alternative for high-quality bioacoustic recordings and ocean noise monitoring. The DASBR is comprised of a Wildlife Acoustics SM2Bat+ ultrasonic recorder with a GPS localization option housed within a PVC spar buoy designed to survive storms and ship strikes. Two HTI-96-min hydrophones (200 cm separation) and a depth sensor (pressure transducer at bottom) are suspended vertically in a 300 cm castor oil-filled polyurethane tube at a depth of 100 meters. Amplification is provided by an internal pre-amp (20 dB gain / 100 Hz high pass filter, HPF) and an external differential pre-amp (40 dB gain / 159 Hz HPF). Hydrophone pre-amps flatten the noise spectrum and allow >70 dB of dynamic range over a broad spectrum (10 Hz to 96 kHz). Stereo sounds are recorded (16-bits/channel @ 192 ksamples/sec) to flash memory cards (up to 2 Tb) using a duty cycle based on the anticipated deployment time. Hydrophone depth, surface temperature, and GPS positions are recorded once per sound file. DASBRs are powered by 16 D-cell batteries contained in the keel of the PVC spar buoy. For stability, a dampener and drogue are affixed to the cable just above the hydrophone array, and a 3 kg anchor at the bottom keeps the array vertical and prevents it from drifting ashore. Recovery is facilitated by a low-cost satellite locator which provides at least one location per day and a VHF radio beacon. Species ranging from blue whales to 70 kHz beaked whales have been detected in preliminary testing. Surface reflections are commonly recorded for beaked whale echolocation clicks which allows estimation of horizontal detection range.

Poster W5

U.S. Navy East Coast Passive Acoustic Monitoring Efforts from 2009 to Present

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The U.S. Navy's Atlantic Fleet conducts training and testing activities within the Northwest Atlantic Ocean and Gulf of Mexico, including the use of active sonar and explosives. In order to evaluate the impacts of these activities on marine mammals and other protected marine species, the Navy implemented a monitoring program to collect data on baseline animal presence, as well as exposure and response to Navy training and testing activities. Passive acoustic monitoring is an important component of the Navy's monitoring efforts.

Between 2009 and 2013, the Navy utilized effort-based monitoring metrics and targeted a number of different training and testing events for monitoring. Passive acoustic data was collected to monitor mysticete migration patterns in the mid-Atlantic, the effects of MFAS on odontocete vocalizations in North Carolina and Florida, and the potential effects of explosive training events off the coast of Virginia Beach, VA. Platforms included Marine Autonomous Recording Units (MARUs), High-Frequency Acoustic Recording Packages (HARPs), Ecological Acoustic Recorders (EARs), and sonobuoys, among others. Additionally, the Marine Species Monitoring Program has funded the deployment of acoustic recording tags on several marine species including pilot whales and North Atlantic right whales, as well as behavioral response playback experiments with short-finned pilot whales off Cape Hatteras, North Carolina.

In November 2013, the Navy began replacing effort-based monitoring metrics with objective-based monitoring projects as a result of new environmental permits for Atlantic Fleet Training & Testing (AFTT). Passive acoustic monitoring remains a cornerstone of the revised long term goals, and continues to provide key data on marine mammal presence and behavior. Future work will focus on species classification and animal behavior.

Poster W6

Estimation of the sound-level and three-dimensional beam pattern of a pilot-whale through joint use of passive acoustics, machine learning and D-Tag data

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How loud are they? Though seemingly basic, this question concerning large marine mammals vocalizations entails careful, complex and long-term acoustic investigation, which in turn can strongly influence our understanding of animal behaviour (social communication, foraging, etc.). While sperm whales received most of the attention in recent years, the present contribution is likely to significantly enrich the knowledge on pilot whales acoustics, in particular by providing sound level estimates and by introducing a basic estimate of a three dimensional beampattern (azimuth and elevation) supporting the hypotheses of a strong directivity.

Data collected during 9 hours in May 2009 in the Norwegian Sea from the Delphinus towed array designed by TNO and from a D-tagged pilot whale allowed us to derive information on the sound level and three-dimensional beam pattern of the concerned pilot whale. 1570 clicks were processed for which parameters were extracted (detection time, range, angle from the animal to the array, true bearing from tag and estimated bearing for each detection) to reconstruct information on the directivity and animal sound level. Within a timeframe from 12 to 9 pm the pilot whale performed 11 dives below 100 meters and after 5 pm it performed 8 dives of 15 up to 30 minutes that exceeded 200 meters depth. The research boat could approach the animal several times which completed the information that was extracted from the clicks. In addition to the information concerning the whale and array heading, spectral and level features (centroid frequency, time-bandwidth product, energy distribution, directivity and apparent source level, etc) were extracted from the recorded clicks.

Supervised neural networks were also used to predict distance from individual clicks and retrieve useful information from this rich dataset.

Poster W7

Heaviside's and dusky dolphin abundance and acoustics within the Namibian Islands' Marine Protected Area, Namibia

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The southern African sub-region is a global hotspot of cetacean diversity. However, very little data are available on the abundance and distribution patterns of cetaceans in Namibia, and those existing data are outdated. The Namibian Islands' Marine Protected Area (NIMPA) is Namibia's only MPA and the largest MPA along the southern African coastline. The NIMPA is a regionally unique environment for fish, shore birds, and cetaceans. This research will assess the effectiveness of the NIMPA as a sanctuary to protect cetaceans. Although data will be collected on all cetaceans, effort will be focused on the endemic Heaviside's dolphin (*Cephalorhynchus heavisidii*) and the dusky dolphin (*Lagenorhynchus obscurus*). We will build on three years of baseline photo-identification data, acoustic recordings, and behavioral and survey data to investigate behavioral and ecological changes in these two species at both the population and individual level. Although still being processed, key findings to date have highlighted substantial differences in habitat use between the two main dolphin species in both latitude and depth. Our objective is to investigate changes in abundance, distribution, and habitat use of cetaceans within the NIMPA as a baseline of cetacean community structure beginning shortly after the NIMPA was implemented in 2009. Individual and group distribution will be assessed using visual surveys as well as static acoustic monitoring (using C-PODs and Loggerhead DSGs). Behavior will be assessed using visual sampling of surface behaviors and acoustic recordings to study vocal characteristics. This project will provide insight on the abundance, distribution, and behavioral dynamics of cetaceans utilizing the NIMPA. The outcomes of this research will be used to frame management advice provided to the Ministry of Fisheries and Marine Resources and conservators in the region.

Poster W8

3D whale tracking using animal borne tags

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The use of electronic tags like the DTAG has allowed unprecedented views into the ecology and behavior of deep diving cetacean species. Such tags include high sampling rate acoustic, depth and three axial magnetometer and accelerometer sensors. After calibration this allows one to infer at each moment in time the depth of the animal (via the pressure sensor) as well as the animal orientation with respect to the Earth frame. While not the original intention, there has been increasing temptation to use such data and dead-reckoning procedures to estimate 3D tracks. Therefore, methods to do so in an optimal way and with quantifiable precision are much needed.

Existing methods remain unevaluated, typically ignore the precision of the estimated track and assume that the main body axis and the direction of movement coincide.

We present a general model which allows us to separate the main longitudinal body axis direction and the direction of movement, by leveraging on independent information about animal speed contained within the tag acoustic flow noise. We present a state space model approach for tracking the animal 3D position and orientation over time, estimating the parameters of the model via the implementation of a Kalman filter.

We demonstrate the methods by showing the results of a model fitted to a 3D track of a deep foraging dive of a Blainville beaked whale fitted with a DTAG within AUTEC, for which a set of independent localizations were available.

Poster W9

JMesh – A Web Visualization Platform for Monitoring Marine Mammals

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Visual presentation of the outputs from marine mammal detectors is key for efficient mining of large acoustic datasets. Operators must be able to easily navigate through large time series of detections, examine spectrograms, listen to detected sounds, validate detections, and compare detections for different species and different detectors over time and space. The JMesh web platform has been designed with these constraints in mind. The interface is organized around three interconnected visualization panels: 1) a geographic interface displays maps shows the total number of detections for each species at all monitoring locations within an adjustable time period, 2) a detection time series plot displays temporal variations of detections for several species at a given monitoring location, and 3) a multimedia panel allows the user to visualize spectrograms, listen to sounds and validate detections. All three panels are interactive and allow the user to navigate intuitively between them. On the server side, JMesh uses the Java Spring Boot micro-services framework, which allows scalability and facilitates agile developments and frequent release deployment. Outputs from detectors, information about the recorders (locations, deployment dates, etc.) and definition of the marine mammal vocalizations are transmitted via XML files to a MongoDB non-relational database, which provides high scalability (i.e., designed for the “big data” world) and responsiveness (i.e., fast execution of queries). JMesh can display detections from cabled hydrophones or telemetric buoys in real-time, and therefore can be used for mitigation purposes. Compatibility with smart phones and tablets through the Bootstrap framework simplifies access to the data from the field. Future planned developments include an authentication system that will allow users to access and manipulate their own (private) data, or to validate detections from public data (i.e. crowd sourcing). Connectivity with the Tethys database system is also under consideration. A demonstration of JMesh will be performed during the poster session using real-time data from the VENUS and NEPTUNE ocean observatories.

Poster W10

The application of passive acoustic methods to estimating the cumulative effect of sonar on Blainville's beaked whales

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Moretti et al. used passive acoustic methods to derive a Blainville's beaked whale (*Mesoplodon densirostris*) behavioral risk function in terms of foraging dive disruption. The detection of echolocation clicks produced by groups of animals during deep foraging dives both with and without the presence of Mid-Frequency Active Sonar (MFAS) was used as estimate behavioral disruption. These deep foraging dives can also be used as a proxy for caloric intake. By using passive acoustics to detect foraging both with and without sonar over multiple years, an estimate of dives lost is obtained. These data are used to inform a Population Consequences of Disturbance (PCoD) model which uses dive disruption as a proxy for calories lost along maternal lines with the hypothesis that a cumulative impact will be reflected in the ratio adult females to dependent juveniles. The output of the model is compared to the demographic data compiled by Claridge et al. through visual observation on both the Atlantic Undersea Test and Evaluation Center (AUTEC) where MFAS is routinely used and a site off Abaco approximately 130 km to the north.

Oral / Wednesday 15th 2015 / 4:00 PM

Detection and Classification of blue and fin whale calls using the PAMGuard Whistle and Moan detector

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The PAMGuard "Whistle and Moan" detector has been well tested with Odontocete whistles and has been demonstrated to detect 79% of human identified whistles that have a signal to noise ratio above 10dB with 88% of all detections being valid. The same detector has now been tested with the baleen whale dataset provided for the 7th DCLDE workshop which contained a mixture of fin and blue whale calls. Of 320 fin whale 40Hz and 4506 blue whale D calls marked by a human operator, the detector successfully detected 277 (86.5%) and 4455 (98.9%) calls respectively for each call type. However, classification to species level and discrimination from other sounds, both biological and electromechanical in the data remains a significant challenge. This presentation will discuss detector performance and present preliminary results of a classifier designed to pick out specific call types for these species and discriminate genuine calls from background noise.

Oral / Wednesday 15th 2015 / 4:20 PM

Automated passive acoustic detection and aural classification of blue and fin whale calls

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Passive acoustic monitoring (PAM) is widely used for long-term monitoring of marine mammals; however, PAM systems are often triggered by other transient sources, producing large numbers of false positives. Large volumes of data are collected during these monitoring efforts. A trained acoustic analyst is typically used to process the long acoustic records to isolate the true detections and positively identify marine mammal species. One method to reduce the analyst's workload is to employ a two-stage process beginning with an automatic detector that permits a high false positive rate to ensure all, or most, true positives are identified; detections are then passed to an automated classifier to reduce the number of false detections and identify the vocalizing marine mammal species. This operating paradigm requires a classifier capable of performing inter-species classification as well as discriminating vocalizations from confounding noise sources.

An aural classifier has been developed at Defence R&D Canada that uses perceptual signal features which model the features used by the human auditory system. This classifier will be applied to the low-frequency workshop dataset to identify the presence of blue whale D and fin whale 40 Hz calls. The aural classifier will first be trained using the initial workshop data set and then its performance will be validated using the evaluation data provided by the workshop's organizers.

Oral / Wednesday 15th 2015 / 4:40 PM

Automated identification of blue and fin whale vocalizations using an ensemble-based classification system

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The goal of this study was to develop an ensemble-based classification system using the 2015 DCLDE Workshop data set to reliably identify blue whale (*Balaenoptera musculus*) D calls and fin whale (*Balaenoptera physalus*) 40 Hz calls.

The provided data were pre-processed as follows: In a first step, we extracted the annotated *Balaenoptera* calls (as well as ~100,000 *non-Balaenoptera* sounds) from the training data sets. The sound clips were stored as individual sound files of 5 s duration (wav files; 200 Hz sampling rate). In a second step, we calculated spectrograms for each of the sound files using the following parameters: a frame size of 60 samples, 50 samples overlap, 40 samples zero padding, and a Hanning window. The resulting spectrograms were normalized in frequency (median subtraction in each frequency bin) and cropped to 30×50 pixels for an effective frequency range and duration of 20-80 Hz and 2.63 s, respectively.

The generated images were used to train an ensemble-based classification systems based on Haar-like and extended Haar-like features. To avoid overfitting, precautionary measures including bootstrapping, pruning of weak learners, and using a high number of validation samples was incorporated into our training process.

Preliminary results for the blue whale D call identification system show a promising performance of > 90% correct classification rate with a false-positive rate of < 5% (using 200 positive and negative samples for training and 1,200 samples for validating). We are currently working on the fin whale 40 Hz identification system and anticipate to have this completed prior to the release of the 2015 DCLDE Workshop evaluation data set.

DENSITY ESTIMATION

Chair: Simone Baumann-Pickering

Oral / Thursday 16th 2015 / 8:40 AM

Relative densities and spatial distributions of beaked whales in southern California

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Cuvier's beaked whales are the dominant beaked whale species offshore of southern California. Their abundance, distribution, possible habitat preference, and seasonality are poorly understood. Insights into the relative densities and spatial distributions of both Cuvier's beaked whales and another, but rarely encountered, beaked whale with echolocation signal type BW43, most likely Perrin's beaked whale, were derived from long-term autonomous recordings of beaked whale echolocation clicks.

Acoustic recordings were collected at 18 sites offshore of southern California since 2006, resulting in a total of ~26 years of recording effort. Over 100,000 minutes of acoustic encounters with Cuvier's beaked whales were detected. In contrast, there were less than 400 minutes of acoustic encounters of the BW43 signal type. On rare occasions, acoustic encounters with Stejneger's beaked whales (16 minutes) and the BW70 signal type (7 minutes), presumably produced by pygmy beaked whales, were found. There was no detection effort for Baird's beaked whales.

Cuvier's beaked whales were predominantly detected at deeper, more southern, and farther offshore sites. A seasonal pattern, as well as a relationship to temperature anomalies, of their relative densities was observed, with lower abundance during summer and early fall and during La Niña conditions. The BW43 signal type had higher relative densities in the central basins, indicating a possible difference in habitat preference and niche separation between the two species. Future analysis will convert these relative density numbers into absolute densities using passive acoustics.

Oral / Thursday 16th 2015 / 9:00 AM

All together now: understanding at depth group behavior of beaked whales at AUTEC

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Being almost unknown twenty years ago, beaked whales have become some of cetaceans for which sound production and behavior is known best, namely due to intensive research related to the impact of navy sonar use on these animals. These animals occur in groups and routinely dive to the deep foraging layer, where they produce highly characteristic echolocation sounds. At the Atlantic Undersea Test and Evaluation Center (AUTEC) in the Bahamas, Blainville's beaked whales *Mesoplodon densirostris* are routinely detected year round with passive acoustics. Much of what is known about this species is also due to tagging experiments. One of the least known aspects of their life cycle is the at-depth within group behavior. This is particularly relevant because it has direct consequences on the acoustical footprint of a group, in itself important for passive acoustic monitoring.

Here we present preliminary results on GROUPAM, a recently funded ONR project, aiming to understand the at-depth behavior of groups of animals leveraging on the AUTEC hydrophone network. By combining the data processed automatically by the M3R system with under-development state-of-the-art detection, classification, localization and tracking algorithms, we are hoping to collect enough information to estimate group sizes based on acoustical footprints and to parameterize a model of within group animal movement. Preliminary results indicate that automated long term density estimation at AUTEC using dive counting methods is feasible, where actual group sizes are incorporated in the procedure rather than assuming a mean group size based on the literature. We also present a conceptual model for describing the group movement in terms of a center of attraction and corresponding parameters estimates obtained from a small set of multi-animal groups reconstruction.

Using Detections of Foraging Dives to Estimate Density of Blainville's Beaked Whales

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Acoustic recordings from 31 seafloor mounted hydrophones were made at least two days a month at the Pacific Missile Range Facility (PMRF) from January, 2011 through August, 2012. Thirty-one additional hydrophones were recorded from September, 2012 through December, 2013. These archived data provide the ability to classify and localize validated detections from a variety of marine mammal species in order to assess diel and seasonal distribution patterns and estimate density. Minimum density estimations can be made for lone individuals that can be detected on multiple hydrophones and therefore tracked across the range (e.g. minke whales [*Balaenoptera acutorostrata*]). However, density estimations are more difficult to obtain from beaked whale detections as group sizes are unknown, groups may not be detected by more than one hydrophone, the movement of groups across the range is difficult to quantify, the density of animals does not appear uniform across the range, and the non-uniform distribution of hydrophones on the range precludes the assumption of equal detectability (e.g. not all beaked whale vocalizations may be detected). These barriers were overcome for Blainville's beaked whales (*Mesoplodon densirostris*) at PMRF using estimates of group size, cue rates, and dive rates derived from other beaked whale studies. In addition, only the subsample of the 62 hydrophones that were in the southern portion of the range was used, where the hydrophone spacing is such that any dive that occurred on that area of the range was likely to be detected. The number of dives detected on the subsampled 62 hydrophones was compared against the number of dives detected on the equivalent 31 hydrophones, and then a scaling factor was calculated. Finally, basic density estimates were derived using the number of dives per hour from the 62 hydrophone subsample, and then the scaling factor was used to estimate density when fewer hydrophones were recorded.

Oral / Thursday 16th 2015 / 9:40 AM

From clicks to counts: using passive acoustic monitoring to estimate the density and abundance of Cuvier's beaked whales in the Gulf of Alaska

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A visual and acoustic line-transect survey of marine mammals was conducted in the central Gulf of Alaska (GoA) during the summer of 2013. The survey area was divided into four sub-strata to reflect four distinct habitats; 'inshore', 'slope', 'offshore' and 'seamount'. Passive acoustic monitoring was conducted using a towed-hydrophone array system. One of the main objectives of the acoustic survey was to obtain an acoustic-based density estimate for beaked whales. Three species of beaked whales were identified; Cuvier's (*Ziphius cavirostris*), Baird's (*Berardius bairdii*) and Steijneger's (*Mesoplodon stejnegeri)*. A preliminary total of 124 acoustic encounters (including 93 localizations) of beaked whales during 6,304 km of effort were obtained compared to 13 visual encounters during 4,155 km of effort. Two distance sampling analytical methods will be used to obtain density and abundance estimates for Cuvier's beaked whales; (1) conventional distance sampling (cds) and (2) distance sampling using a depth distribution model (dsddm). Beaked whales vocalize in a three-dimensional context, so the vertical position of the animal has to be considered along with its horizontal location. Target motion analysis was used to obtain slant ranges to individual beaked whales for the cds approach. When the calling animal is deeper than the towed array, the estimated range will be an overestimate of the perpendicular range required for cds. This will result in an overestimate of the average probability of detection and an underestimate of density. Using the dsddm approach, information about the depth distribution of the study species can be directly incorporated into the maximum likelihood estimator of the detection function parameters, thereby eliminating the slant range bias in the estimate. The density and abundance estimate results from these two analyses will be compared and the advantages and disadvantages of acoustic-based density estimates will be presented. Applications of these methods to other species and areas will also be discussed.

Oral / Thursday 16th 2015 / 10:20 AM

Determinants for the detection function of passive acoustic data loggers

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The detection functions and resulting EDRs of devices used in a passive acoustic monitoring projects are influenced by numerous factors. The sources behavior and signal parameters determine what is emitted. The environment then alters the emitted signal in numerous ways and the PAM properties determine what could possibly be detected. The interactions of these factors have been studied using the harbor porpoise as species of interest and the click logger C-POD within the SAMBAH project. The acoustic detection function of C-PODs has been measured by playing back porpoise-like clicks using an omni-directional transducer and revealed an influence of the devices sensitivity, water depth and season on the EDR. A 15 channel hydrophone array, deployed next to 12 C-PODs, was used to localize porpoises and determine their geo-referenced swim paths using the ship's GPS and motion sensors. The detection function of C-PODs was then computed using the distance between the animals and each C-POD. The low EDR for harbor porpoises in the Baltic Sea is due to a combination of factors.

Oral / Thursday 16th 2015 / 10:40 AM

Using visual survey data to estimate passive acoustic detection parameters for harbor porpoise abundance estimates

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Passive acoustic monitoring is a promising approach for monitoring long-term trends in harbor porpoise *(Phocoena phocoena)* abundance along the U.S. West Coast. Before passive acoustic monitoring can be implemented to estimate absolute abundance, ancillary information is needed to convert recorded numbers of echolocation clicks to harbor porpoise densities. In particular, an echolocation rate for individual animals and the effective radius monitored by each sensor are needed. Obtaining these values via direct observation can be difficult and time consuming, and estimates are often imprecise due to variability in animal behavior, oceanographic properties, and sensor sensitivity.

In the present study, we used paired data from an array of passive acoustic click detectors (C-PODs, Chelonia Ltd.) and simultaneous aerial line-transect visual surveys to estimate the product of the echolocation rate and detection radius for our study site in Monterey Bay, California. We deployed an array of 11 C-PODs and conducted three days of aerial surveys in our 295 sq km study area. During these aerial surveys 245 groups of harbor porpoise were detected and we calculated an average density of 0.77 harbor porpoise per sq km. On the dates when aerial surveys were flown, the C-PODs detected 72,503 high-quality echolocation clicks or an average of 112 clicks per instrument-hour. We used the aerial survey data in a density surface model to estimate the densities of harbor porpoises at each of the acoustic monitoring sites on each of the days of aerial survey effort. By substituting these visually estimated porpoise densities along with the observed number of echolocation clicks into a cue-counting density estimation framework, we solved for the product of the two unknown passive acoustic detection parameters. We considered the visual density estimates along with previously published harbor porpoise click rates and C-POD detection radii as informative priors in a Bayesian hierarchical model. This model-based approach resulted in a posterior distribution of the product of echolocation rate and detection radii comparable to previously published values. We were unable to estimate the echolocation rate and effective radius individually, but an estimate of their product is sufficient for density estimation applications. This technique may be a viable alternative for obtaining passive acoustic detection parameters when intensive experimental approaches are not feasible.

Oral / Thursday 16th 2015 / 11:00 AM

Range estimation to echolocating beaked whales using a two-element vertical hydrophone array

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Detection range is a critical element for estimating cetacean density using point-transect methods. We investigate methods to estimate the range at which echo-locating beaked whales can be detected using data from free-floating, two-element vertical hydrophone arrays suspended at 100 m depth in the Catalina Basin. Four Cuvier's beaked whales and one BW-43 beaked whale were recorded. Using repeated measures from echolocation clicks received within a few seconds, the standard deviations of time-differences of arrival (TDOA) were 0.013 msec for the direct-path and 0.090 msec for the surface-reflected path. The reflected signals were an incoherent sum of signals from different wave faces. Due to variation in arrival times for reflected signals, we could not simultaneously solve for range, depth and array tilt. However, declination angle could be estimated accurately from the TDOA for direct-path signals received on two hydrophones or from the TDOA for direct and reflected signals on a single hydrophone. A distribution of detection ranges can be estimated from a single declination angle given a distribution of echolocation depths from other sources (e.g., D-tags). Moderate array tilt (<5 degrees) do not appreciably bias this distribution of range estimates when declination angles are greater than 15 degrees from horizontal. Declination angles for five different beaked whales varied from 17° to 44° below horizontal which correspond to a detection range from 3.2 to 1.0 km (respectively) for a beaked whale at an assumed depth of 1000 m below the array. Surface reflections were not detectable for all echolocation clicks, but their presence was not obviously related to declination angle in our small sample.

OTHER TOPICS

Chair: Mike Weise

Oral / Thursday 16th 2015 / 1:00 PM

Overview of the Living Marine Resources (LMR) program

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In its ongoing effort to reduce potential impacts to marine mammals while meeting at-sea training and testing requirements, the U.S. Navy supports both basic and applied research to improve the understanding of the occurrence, exposure, response, and consequences to marine mammals from Navy at-sea training and testing activities. The Living Marine Resources (LMR) program is responsible for applied research, and works to address the Navy's key research needs and transition the results and technologies for use within the Navy's at-sea environmental compliance and permitting processes, with the goals of improving marine species impact analysis (including marine mammal take estimates), mitigation measures, and monitoring capabilities. The program's funding priorities includes: 1) Data to support risk threshold criteria; 2) Improved collection and processing of protected species data in areas of Navy interest; 3) Monitoring & mitigation technology demonstrations; 4) Standards and metrics; 5) Education and outreach, emergent opportunities.

The LMR program is currently heavily invested in passive acoustic monitoring technologies and automated methods of acoustic data analysis. These methods are seen as an integral component of the Navy's current monitoring plan. We plan to give an overview of the LMR program and present on the current investments related to DCLDE. The LMR program is sponsored by the Chief of Naval Operations (CNO) Energy and Environmental Readiness Division (N45) and managed by the Naval Facilities Engineering and Expeditionary Warfare Center (EXWC). An advisory committee, comprised of representatives within the US Navy, oversees the funding priorities for the program.

Oral / Thursday 16th 2015 / 1:20 PM

Single and four channel Acoustic Monitoring Packages (AMP-1 and AMP-4) for passive acoustic monitoring

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We developed two autonomous, high-frequency acoustic monitoring packages (AMPs) for various applications, including marine mammal, ambient, and anthropogenic noise monitoring. AMP-1 is a single-hydrophone system capable of sampling at up to 250 kHz and AMP-4 is a four channel, variable hydrophone configuration system with 150 kHz synchronized and simultaneous sampling capability. Both systems have adjustable gains, high pass filters and duty cycles. Lithium battery packs allow for continuous recording of up to 45 days which can be extended through duty cycling. Temperature, tilt, pressure, and rotation sensors log data for environmental monitoring and correction of sensor placement. A telemetry system allows the unit to be acoustically released and/or interrogated at depth from a surface vessel; relayed information includes battery voltage, remaining disk space, and environmental information. AMPs have been successfully deployed off of small vessels at depths of up to 60 m, with pressure vessels and hydrophones currently rated for use to 150 m. The systems are deployable in various configurations; Initial deployments were bottom-mounted using a 2-4 m tether connected to clump weights to raise the hydrophone off the seafloor. The tether was used to reduce noise from seafloor processes (including ground vibrations and noise from snapping shrimp) and to enable use of bottom reflections in classification and localization efforts (details in Nosal's abstract). The first generation of AMP-1 and AMP-4 will be described and results from data recorded during the testing phases and the first several long-term deployments will be presented. [Work supported by the U.S. DHS and DOE]

Oral / Thursday 16th 2015 / 1:40 PM

Scalable, efficient high performance computing model for bioacoustic sound archives

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Big data technologies have grown in recent years, making hardware and high-level software packages readily available to the user community. Keeping pace with big data for current software analyses technologies, such as Raven™, is where the daunting logistical and financial challenges exist. We propose a new software model specially designed to handle parallel and distributed processing and is offered as a collaborative development project currently managed in GIT called RavenX. This new HPC model adds fast-efficient data processing to sound analysis by using powerful software libraries which perform data mining tasks using parallel and distributed computing resources. Unique data and algorithm distribution allows this technology to work on desktop computers as well as remote, enterprise–level, server environments. The object oriented interfaces encompassed in this design provide a structured approach for integrating standard detection-classification algorithms. Using the HPC model, we will demonstrate how a multi-core, single computer is converted to a parallel processing engine. This concept will be expanded, showing how multiple parallel engines are coupled together to make an efficient distributed cluster, which spans four computers using a total of 64 nodes. Powerful data mining capabilities will be displayed through the discussion of two data processing applications. For the first application, we will compare processing performance for a 200 kHz sound archive, showing how 64 nodes of distributed processing was able to run 10-16 times faster than parallel architectures. In the second application, a mixture of data mining algorithms are run across > 1.1M channel hours of sounds and data, spanning 26 TB of storage space; efficiency factor for running simultaneously will be discussed. Both examples will demonstrate the scalable nature of the HPC model for parallel-distributed design, while pointing out various residual pitfalls due to resource limitations. In conclusion, we will also summarize a list of projects that have successfully used this technology in recent years.

Oral / Thursday 16th 2015 / 2:20 PM

Comparison of Cuvier's beaked whale signals recorded in different environmental conditions

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Beaked whale are the most sensitive species to acoustic noise. Strandings have been reported to occur in conjunction with sonar exercises, although the exact mechanism is unclear. Cuvier's beaked whale is one of the most common beaked whale species (and the most common stranded species in conjunction with sonar exercises).

Automatic detection and classification of these species is very important in order to mitigate stranding risks. Until now, most known signals of beaked whales are upsweep frequency modulated clicks which seem species specific. The inter click interval of these species also seems to be regular and is a characteristic that helps classify beaked whale species.

Previous work on detection and classification based on a featured aided multi-hypothesis algorithm provided promising results. For the next phase, classification performance improvement is expected through better signal characterization.

The Centre for Maritime Research and Experimentation (CMRE, former NURC, NATO Undersea Research Centre) conducted various sea-trials, most of them located in the Mediterranean Sea and one in the Eastern Atlantic Ocean, Southwest of Portugal. Cuvier's beaked whale signals were recorded during these sea-trials. In addition to these datasets, recordings collected with High-frequency Acoustic Recordings Packages (HARPs), provided for this workshop, and one dataset from the Mobysound website will be used.

These datasets have been recorded at different deployment depths and locations. Detailed characteristics of Cuvier's beaked whale signals of these various datasets will be analyzed and compared.

Oral / Thursday 16th 2015 / 2:40 PM

A blind source separation approach for humpback whale songs separation

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Acoustics is one of the most effective methods for monitoring underwater environments. One problem is to separate the vocalizations of an individual when a recording contains calls from multiple animals. This problem represents a particular challenge in the underwater environment where the propagation paths may be long and the noise levels high. In this research, a fixed hydrophone array was employed to record humpback whales songs in the Sainte-Marie channel, Madagascar. At this site, for the vast majority of the time, the received signals contain a mixture of multiple humpback whale songs. Our goal is to separate the mixtures and obtain the individual vocalization automatically.

The methods we employ are based on Blind Source Separation (BSS), which deals with recovering independent signals from observed mixtures only. It is blind in the sense that it requires no knowledge of the propagation conditions or the hydrophone locations. We require BSS methods which can effectively operate in conditions with strong reverberation and potentially cope with underdetermined mixtures (where there are more sources than sensors). The specific algorithm that we utilized is adapted from that proposed by Sawada et al. [(2011) ‘‘Underdetermined convolutive blind source separation via frequency bin-wise clustering and permutation alignment,’’ IEEE Trans. Audio, Speech and Language Processing 19(3), 516-527]. Therefore, we refer to it as the Sawada algorithm.

The effectiveness of the Sawada algorithm is verified through separation of artificial humpback song mixtures generated by the underwater impulse response model. However, the separation of real humpback songs, the Sawada algorithm is unreliable as a consequence of severe background noise. We propose a noise reduction method based on weighted median threshold scheme that is applied to the Sawada algorithm, which significantly improves source separation performance of real recording in severe noise environments.

Oral / Thursday 16th 2015 / 3:00 PM

Geographic Variation in Sperm Whale Echolocation Clicks

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Geographic variation in marine mammal vocalizations exists for a variety of call types and species, including bottlenose dolphins, blue whales, and fin whales. Sperm whales (*Physeter macrocephalus*) are a deep diving, large species of cetacean that produce echolocation clicks during much of time they are submerged. Their repertoire includes broadband pulsed clicks (100 Hz to 25 kHz) associated with foraging and navigation ('regular clicks'), high amplitude clicks with lower peak frequencies (400 Hz to 6 kHz) presumably produced only by mature males ('slow clicks'), and patterned short sets of clicks linked to social behavior ('codas'). Sperm whales are considered one of the most acoustically distinguishable and recognizable species of marine mammal, primarily because their echolocation clicks extend to low frequency ranges that are unused by other cetaceans. Although geographic variation in sperm whale coda dialects has been studied, similar variation in regular and slow clicks has not been documented. In this study, we compare and contrast the 'regular click' type from several regions including the Gulf of Alaska, the Hawaiian Islands, the Central Northern Mariana Islands, the Gulf of Mexico, the southern California coast, and the U.S. Atlantic coast. Both on and off axis clicks were included in the analysis if they met a high signal to noise ratio criteria (>10dB). We evaluate spectral and temporal characteristics of these clicks including peak frequencies, center frequency, - 3dB and -10dB bandwidth, inter-click intervals, number of zero crossings and click duration. Differences in click characteristics between regions will be discussed in relation to other potential contributing factors to this variation (e.g., instrumentation, recorder depth, animal orientation).

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