6th International Workshop on Detection, Classification, Localization and Density Estimation of Marine Mammals using Passive Acoustics

University of St. Andrews, Scotland
June 2013, 12th – 15th
6th International Workshop on Detection, Classification, Localization and Density Estimation of Marine Mammals using Passive Acoustics

University of St. Andrews, Scotland
June 2013, 12th – 15th

Web: http://soi.st-andrews.ac.uk/dclde2013/
Email: dcldeworkshop@st-andrews.ac.uk
ORGANISED BY

The Sea Mammal Research Unit & Centre for Research into Ecological and Environmental Modelling, Scottish Oceans Institute, University of St Andrews
St Andrews, KY16 8LB, Scotland.

SPONSORS

This workshop would not have been possible without the generous support of our sponsors:

The Office For Naval Research (ONR award number ONRBA12-001)
BP
Seiche Measurements Ltd
Marine Instrumentation Ltd
Acoustical Society of America

ORGANISING COMMITTEE

Douglas Gillespie (SMRU, St Andrews)
Len Thomas (CREEM, St Andrews)
Mark Johnson (SMRU, St Andrews)
Danielle Harris (CREEM, St Andrews)
Marjolaine Caillat (SMRU, St Andrews)
Jamie Macaulay (SMRU, St Andrews)
Peter Tyack (SMRU, St Andrews)

PREVIOUS DCL&DE WORKSHOPS

Halifax, Canada, 2003
Oceanographic Museum of Monaco, 2005
Boston, US, 2007
Pavia, Italy, 2009
Oregon, US, 2011

CONTACT

Web: http://soi.st-andrews.ac.uk/dclde2013/
Email: dcldeworkshop@st-andrews.ac.uk
INTRODUCTION

Welcome to the 6th 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. With this in mind, the workshop agenda has been organized in order to foster as much discussion as possible around the different topics. At the end of each session there will be discussion time in which all presenters from that session will be encouraged to compare their methodologies.

As with previous workshops, a common data set has been provided which will allow participants to directly compare algorithms and methodologies. The 2013 dataset brings us back to where we started in 2001 – the detection of right whales. A great deal has been accomplished since 2001, but right whales remain one of the most endangered great whales on the planet. North Atlantic right whale continue to suffer ship strikes and fishing gear entanglement and it is possible that they will also become impacted by the installation of renewable energy devices in the coming years. In the Southern hemisphere right whales have been dying in unprecedented numbers at Peninsula Valdes, Argentina. There is therefore still a great need to improve detection systems for right whales, both for the analysis of long-term archival data sets and for real time mitigation.
WORKSHOP PROGRAM

AND SOCIAL PROGRAM
TUESDAY 11TH JUNE

Detection Theory, Density Estimation and PAMGuard workshops

18:00  Registration opening
       Parliament Hall

18:30  Drinks reception*
       Parliament Hall

WEDNESDAY 12TH JUNE

08:30  Registration

09:00  Welcome

09:15  Lecture: The effects of variation in cetacean calling behaviour on PAM applications
       Vincent M. Janik

10:00  Unsupervised Segmentation and Classification of Orca Vocalizations using the
       Fundamental Frequency Variation Spectrum
       Florian Hönig, Reyhan Sonmez, Elmar Nöth, Martha Manser

10:15  Man versus machine: a comparison of whistle classifiers developed using auto-detector
       data and manually analyzed data
       Julie N. Oswald, Danielle Cholewiak, Lynne Hodge, Melissa Soldevilla, Sofie Van Parijs, Anthony
       Martinez, Andrew Read

10:30  A comparison of approaches for clustering tonal vocalizations of free ranging Delphinids
       Kaitlin E. Frasier, Marie A. Roch, E. Elizabeth Henderson, Alexa Alldredge, Simone Baumann-
       Pickering, Shannon Rankin, Erin M. Oleson, Ashleigh Kirker, John A. Hildebrand

10:45  Discussion

11:00  Coffee

11:30  Variability of beaked whale clicks characteristics
       Odile Gerard

11:45  Inter-click interval (ICI) as a mechanism for differentiating between Mesoplodon
densirostris (Md), Ziphius cavirostris (Zc), and Grampus griseus (Gg)
       Ronald Morrissey, D. Moretti, S. Jarvis, E. McCarthy, J. Shaffer, and A. Dilley

12:00  Quantitative family classification between Phocoenidae and Delphinidae using simple
       two-band ratio comparison
       Saho Kameyama, Tomonari Akamatsu, Ayaka Amaha Öztürk, Ayhan Dede and Nobuaki Arai
12:15 Feature Selection and Extraction for Real-time Classification of Odontocetes in Open Ocean Environments
Susan Jarvis, David Moretti, Ronald Morrissey, Jessica Ward, Elena McCarthy

12:30 Discussion

12:45 Lunch and Posters (odd numbers)

14:30 (Near) Optimal Signal Processing Approaches for Environmental Calibration of Passive Acoustic Monitoring Results
Gerald L. D’Spain, Tyler A. Helble, John A. Hildebrand, and Marie A. Roch

14:45 Signal conditioning techniques for marine mammal vocalizations
David K. Mellinger

15:00 Signal de-noising, a comparison of techniques for improving acoustic marine mammal classification tasks
Nicole Nichols, Mari Ostendorf

15:15 Robust automatic detection of Gabor-like clicks of biological origin
Shyam Madhusudhana, Christine Erbe, Alexander Gavrilov

15:30 Discussion

15:45 Coffee

16:15 Tracking individual cetaceans with towed compact volumetric arrays
Walter MX Zimmer

16:30 An experimental triplet hydrophone array for determining vertical angle of marine mammals

16:45 Towed arrays and beaked whales: detection and three-dimensional localization of Sowerby's beaked whales (Mesoplodon bidens) on large vessel surveys
Danielle Cholewiak, Robert Valtierra, Simone Baumann-Pickering, Sofie Van Parijs

17:00 Three-dimensional passive acoustic tracking of beaked whales with volumetric small-aperture arrays
Martin Gassmann, and John A. Hildebrand

17:15 Discussion

17:45 Buffet dinner

19:30 Buses leave conference venue for drinks reception at the RRS Discovery*
This event is sponsored by Seiche Measurements Ltd

22:30 Buses return to conference venue
09:00  **Lecture:** Have you heard about it? The perfect passive acoustic density estimation survey is out there and we are looking for it!  
*Tiago A. Marques, Danielle Harris, Len Thomas*

09:45  **The Silbido tonal detector**  
*Micahael MacFadden, Arik Kershenbaum, Marie A. Roch*

10:00  **Automatic detection and classification of walrus pulse series**  
*Marion Bandet, Yvan Simard, Nathalie Roy and Olivier Le Bot*

10:15  **Classification of false killer and short-finned pilot whale echolocation clicks**  
*Simone Baumann-Pickering, Anne E. Simonis, Erin M. Oleson, Robin W. Baird, Marie A. Roch, Shannon Rankin, Sean M. Wiggins, John A. Hildebrand*

10:30  **Improving the performance of marine mammal call classifiers using contextual information.**  
*Xavier Mouy, Julie Oswald, Bruce Martin*

10:45  **Discussion**

11:00  **Coffee**

11:30  **Validation of PAMGuard Automated Detection, Classification and Localization Using Killer Whale Echolocation Signals**  
*Tina Yack, M.B. Hanson, M.M. Holt and T. Norris*

11:45  **Density surface modelling of fin whale calls using a sparse array of seismic instruments in the northeast Atlantic**  
*Danielle Harris, Luis Matias, David K. Mellinger, Len Thomas*

12:00  **Automatic detections of fin whale calls from the Deep Sea Floor Observatory, Kushiro-Tokachi, 2009-2012**  
*IKuo Matsuo, Tomonari Akamatsu, Ryoichi Iwase, Katsuyoshi Kawaguchi*

12:15  **Density estimation of Ligurian Sea sperm whales based on acoustic cues**  
*Adrià Caballé, Michel André, Mike van Der Schaar, Ludwig Houégnigan*

12:30  **Discussion**

12:45  **Lunch and Posters (Even numbers)**

14:30  **Passive acoustic localization using received sound pressure levels**  
*Eva-Marie Nosal*

14:45  **Underwater passive acoustic localization of a Pacific walrus in an uncertain environment**  
*Brendan P. Rideout, Stan E. Dosso and David E. Hannay*

15:00  **An automatic single station multipath ranging technique for 20 Hz fin whale vocalizations**  
*Michelle Weirathmueller and William Wilcock*
15:15  Range-depth tracking of sperm whale sounds over large distances by exploiting the high-latitude sound speed profile
Delphine Mathias, Aaron Thode, Janice Straley, Russel Andrews

15:30  Discussion

15:45  Coffee

16:15  Big data aspects of marine mammal DCL&DE
John A. Hildebrand, Sean M. Wiggins, Simone Baumann-Pickering, Ana Sirovic and Marie A. Roch

16:30  The Tethys Metadata System
Marie A Roch, Simone Baumann-Pickering, Daniel Hwang, Heidi Batchelor, Catherine Berchok, Danielle Cholewiak, Lisa M. Munger, Erin M. Oleson, Shannon Rankin, Denise Risch, Ana Širović, Melissa S. Soldevilla, Sofie M. Van Parijs

16:45  Discussion of training data and future workshop
Gisiner, B., Weise, W., Hidebrand, J., Soukup, R.

17:00  Discussion

19:30  Banquet dinner and Ceilidh*
Lower College Hall
This event is sponsored by BP
09:00  Lecture: Using DCLDE for management and conservation of North Atlantic right whales  
      Sofie Van Parijs

09:45  Detecting a changing signal: impacts of right whales modifying calling behaviour in 
      response to environmental background noise conditions  
      Susan E. Parks, Ildar R. Urazghiildiiev, Karina Groch, Paulo Flores, Renata Sousa-Lima

10:00  Survey of Methods: Comparison of Automated recognition for Right Whale contact calls  
      Peter Dugan, Mohammad Pourhomayoun, Yu Shiu, Marian Popescu, Ildar R. Urazghiildiiev, Ross 
      Goroshin, Xanadu Halkias, Yann LeCun and Chris Clark

10:15  Detection and Classification of Right Whale sounds  
      Douglas Gillespie

10:30  Practical deep neural nets for detecting marine mammals  
      Daniel Nouri

10:45  Discussion

11:00  Coffee

11:30  Real time recognition of Right Whale calls using SoundID  
      Neil J Boucher, Michihiro Jinnai, Hollis Taylor, Edward Pedersen

11:45  Passive acoustic monitoring of North Atlantic right whales using computer-based aural 
      classification  
      Carolyn M. Binder and Paul C. Hines

12:00  Detection of right whale up-calls and gunshots using Random Forest  
      Xavier Mouy, Julie Oswald, Bruce Martin, David K. Mellinger, Jessica L. Crance, Catherine L. Berchok

12:15  Statistical segmentation of spectrograms: a complementary approach to track detection 
      algorithms  
      Florian Dadouchi, Cédric Gervaise, Cornel ioana, Julien Huillery, Jérome I. Mars

12:30  Discussion

12:45  Lunch and Posters (Odd numbers)

14:30  Right Whale activity detector and sound classifier using Mel-frequency Cepstral 
      Coefficients  
      Guillermo Lara, Ramón Miralles, Alicia Carrion

14:45  DCLDE 2013 workshop data set: Detection of Right Whale contact calls with supervised 
      spectrogram templates and chirplet approaches  
      Nathalie Roy, Yvan Simard, Mohammed Bahoura and Samuel Giard

15:00  Discussion of Right Whale detector results

15:45  Coffee
16:15  **Quantifying responsive animal movement during shipboard cetacean line-transect surveys using passive acoustics data**  
*Yvonne Barkley, Lisa Munger, Erin Oleson*

16:30  **Site specific and time dependent probability of passive acoustic detection of humpback whale calls from single fixed hydrophones**  
*Tyler A. Helble, Gerald L. D’Spain, John A. Hildebrand, Greg S. Campbell, Richard L. Campbell, Kevin Heaney*

16:45  **Effects of sea state on the range at which dolphins are detected on passive acoustic surveys**  
*Shannon Rankin, Jay Barlow, Jessica Redfern, Julie Oswald*

17:00  **A detection function for beaked whales**  
*Annamaria Izzi, Douglas Gillespie*

17:15  **Discussion**

20:00  **Whiskey tasting**  
*The Gateway*
**SATURDAY 15TH JUNE**

09:15  **To err is human: A review of localization errors and their effects on abundance estimation, tracking, and other aspects of acoustic monitoring of marine mammals**  
Norris, Thomas, Yack, T. M, Gillespie, D. M., Thomas, L

09:30  **Long-range acoustic detection and localisation of Antarctic blue whales**  
Brian Miller, Jay Barlow, Susannah Calderan, Kym Collins, Russell Leaper

09:45  **Performance of localization algorithms obtained from in situ tests**  
Ildar R. Urazgildiev, C. W. Clark

10:00  **Improving time-delay estimation through pattern recognition techniques: An application to the tracking of fin whales at CTBTO hydroacoustic stations**  
Ludwig Houégnigan, Mike van Der Schaar, Adria Caballe, Michel André

10:15  **A method to investigate fin whale vocalizations using hydrophone and 3-component seismic recordings on the seafloor**  
Luis Matias, Danielle Harris, David K. Mellinger, Len Thomas, Wolfram Geissler

10:30  **Porpoises and tidal turbines, fine scale tracking using passive acoustics to assess and mitigate collision risk**  
Jamie Macaulay, Doug Gillespie, Simon Northridge and Jonathan Gordon

10:45  **Discussion**

11:00  **Coffee**

11:30  **Real-time reporting of baleen whale passive acoustic detections from ocean gliders using the DMON/LFDCS**  
Mark F. Baumgartner, David M. Fratantoni, Mark P. Johnson, Tom Hurst, Moira W. Brown, Tim V.N. Cole, Sofie M. Van Parijs

11:45  **Gliders, floats, and robotic sailboats – a review of recent advances in mobile autonomous passive-acoustic platforms**  
Holger Klinck, David K. Mellinger, Haru Matsumoto, Roland Stelzer, Neil M. Bogue and Jim Luby

12:00  **A Drifting Acoustic Spar Buoy Recorder (DASBR) for passive acoustic surveys and ocean noise measurements**  
Jay Barlow

12:15  **A Bayesian approach to analyse the effects of acoustic misclassification on the estimation of the number of acoustic detections**  
Marjolaine Caillat, Len Thomas, Douglas Gillespie

12:30  **Discussion**

12:45  **Lunch and Posters (Even numbers)**

14:30  **Acoustic cue detection model for abundance estimation of small odontocetes**  
14:45 **Learning to SAMBAH**  
Len Thomas, SAMBAH project team

15:00 **Cetacean Density Estimation from Single Sensors: 3 Species, Different Challenges**  
Elizabeth T. Küsel, Martin Siderius, David K. Mellinger

15:15 **Separation of odontocete click trains by rhythmic analysis**  
Olivier Le Bot, Yvan Simard, Jérôme I. Mars, Cédric Gervaise

15:30 **Discussion**

15:45 **Coffee**

16:15 **The use of automated DCL techniques for estimating receive sound pressure levels that minke and beaked whales are exposed to during a US Naval training event involving mid-frequency active sonar**  
Stephen W Martin, Roanne Manzano-Roth and Brian Matsuyama

16:30 **The derivation of a risk function for Blainville’s beaked whales using passive acoustics**  
David Moretti, Len Thomas, Tiago Marques, John Harwood, Ashley Dilley, Bert Neales, Jessica Ward, Elena McCarthy, Leslie New, Susan Jarvis, Ronald Morrissey

16:45 **Automatic detection & classification of biological, anthropogenic and natural physical sounds for the computation of “sound budgets”**  
Christine Erbe, Shyam Madhusudhana, Alexander Gavrilov

17:00 **Discussion**

17:15 **Close**

---

* ** Licensing Law **

UK licensing law makes it an offence to serve alcohol to anyone under the age of 18. Any guest who appears 25 or under will be asked to produce photographic ID before being served. If no acceptable ID can be provided the guest will not be served. Legally acceptable forms of ID include: passport, UK full driving license, Young Scot card or another card with a pass hologram.
WORKSHOP ABSTRACTS
Acoustic cue detection model for abundance estimation of small odontocetes

Tomonari Akamatsu¹, T. Ura², H. Sugimatsu², R. Bahl³, S. Behera⁴, S. Panda⁵, M. Khan⁵, S. K. Kar⁶, C. S. Kar⁶, S. Kimura⁷, Y. Sasaki-Yamamoto⁸

¹National Research Institute of Fisheries Engineering, Fisheries Research Agency & JST CREST
²Underwater Technology Research Center, Institute of Industrial Science, The University of Tokyo
³Indian Institute of Technology Delhi
⁴WWF India
⁵Chilika Development Authority
⁶Odisha State Forest Department
⁷Graduate School of Environmental Studies, Nagoya University
⁸Wildlife Research Center of Kyoto University

akamatsu@affrc.go.jp

A detection of an acoustic cue of an animal does not mean only one animal exists. One of the animals in a group could produce the sound. Sound production rate of an animal is not always available due to technical and practical limitations in the ocean that makes acoustic abundance estimation difficult. Instead, acoustic-visual mark-recapture method is developed to calculate detection probabilities by both means. Matching between acoustic and visual detections was identified when both cues recognized within a specific time window. However, the calculated detection probability strongly depends on the length of the time window. In the present study, a model to estimate abundance without using pre-fixed time window length is proposed. Separation of single and multiple detections of animals mitigate biases caused by the time window length. The proposed model was evaluated in field observations of Ganges River dolphins and Irrawaddy dolphins in India. These two species represented examples of dispersed and condensed distributions of individuals, respectively. The acoustic detection probability was approximately 80 %, 20 % higher than that of visual detection for both species, regardless of the distribution of the animals in the present study sites. The abundance estimates of Ganges River dolphins and Irrawaddy dolphins using the proposed model fairly agreed with the numbers of animals reported in previous monitoring studies. The detection probability of single animal was smaller than that of larger group size for both species, as predicted by the model and confirmed by field data. In Ganges River dolphins with dispersed distribution, acoustically and visually observed group sizes agreed well. However, those of Irrawaddy dolphins showed heterogeneity due to the clumped distribution of this species.
The use of a networked perimeter of low cost passive buoys to ensure that marine mammals are not exposed to excessive or harmful sound levels associated with offshore construction activity

Mark Armstrong, Ian Pickering, Mark Hadley

Kaon Limited

ijp@kaon.co.uk

The development of a network of sensor buoys positioned to form a perimeter around a man made noise source such that marine mammals can be detected or deterred at a safe distance. The definition of a safe distance is dependent on the activity SPL, the threshold limit (either PTS or TTS) of the species or animals concerned, safety margin applied and a function of range prediction calculations subject to prevailing propagation and sea bed loss factors. The buoys are considered to be low cost, high endurance and low weight devices that are wirelessly networked to a central control station situated ashore or on a nearby support vessel. Buoy spacing and numbers are dependent on the perimeter length and the detection ranges likely to be achieved on the target marine mammals. To minimise RF bandwidth loading, higher frequency detections, such as those associated with porpoise clicks, are made locally on each buoy and retransmitted as detection events to the central control position. Lower frequency moans and calls are retransmitted over RF as acoustic data for analysis and application of detection and classification algorithms at the central control station. This has the added advantage of increasing time on task for the buoys. Detections and events that require further analysis are highlighted to an operator using an advanced low false alarm rate multi species marine mammal detection and classification system hosted on a standard PC. The option of additional algorithms within the system allows for improved localisation on the perimeter array. Localisation is further enhanced through the use of directional, multi hydrophone, arrays on each buoy which are derived from military air launched sonobuoys.
A Marine Mammal Detection (MMAD) system that applies a combination of speech and image processing techniques to obtain detections and classifications from the DCL 2013 datasets. The presentation will describe the algorithms employed and how they are used to detect and classify the target species to facilitate either operator warning or to store in an event based recorder. Recommendations will be made on how to further improve the algorithms and reduce false alarm rates.
Use of drifting broadband autonomous recorders to study beaked whale distribution

Patricia Arranz\textsuperscript{1,2}, Natacha Aguilar\textsuperscript{1,2}, Mark Johnson\textsuperscript{2}

\textsuperscript{1}Dept. Animal Biology, University of La Laguna, Tenerife, Spain
\textsuperscript{2}Scottish Ocean Institute, University of St. Andrews, Scotland

parranz@st-andrews.ac.uk

Passive acoustic monitoring is a promising method for studying the abundance and distribution of visually cryptic species such as beaked whales. Ziphiid species studied to date emit characteristic FM clicks that facilitate their identification. However, they echolocate only for some 20\% of their time and members of a group appear to coordinate their vocal activity. This, and the directionality of their clicks, results in typically low detection rates during line-transect surveys. Here we used an alternative method, a depth-stratified survey with semi-stationary passive acoustic recorders, to investigate the habitat preferences of beaked whales found year round off El Hierro (Canary Islands). Broadband autonomous recorders (DMON) were suspended at 200 m depth from GPS-linked drifting buoys that were deployed daily for 9 days (245 recording hours). Buoys were set 4 km apart, in progressively deeper water on a radial line away from the island. DMONs recorded sound continuously (120 kHz sampling rate, 55 kHz bandwidth) while running a matched-filter click detector that produced 39494 possible beaked whale click detections, each with a set of parameters for post-hoc classification. The proportion of false alarms was estimated as 15-33\% from a manual inspection of 8300 detections. Alternative choices of thresholds for the classifier varied the false alarm rate. The probability of detecting a beaked whale click was considered homogeneous for all listening stations. Click detection rates were significantly higher within 7km of the island, in the upper and medium parts of the slope (mean water depth of stations 750-1400 m, daily means of 124-453 clicks/hour/station), than offshore, in the deeper part of the slope and the rise (2000-2500 m, 65-13 clicks/hour/station) (Kruskal-Wallis, p<0.002, $\eta^2$=0.48, n=30; Tukey-Kramer, n=30). These results highlight the trophic importance of the slope for these species. Detections in deep water may belong to transient individuals of the island-associated populations or to offshore beaked whale populations. Further work will establish if there are species-specific habitat preferences.
Automatic detection and classification of walrus pulse series

Marion Bandet¹, Yvan Simard¹,², Nathalie Roy² and Olivier Le Bot³

¹DFO Chair in acoustics applied to marine mammals and their ecosystem, Marine Science Institute, University of Québec at Rimouski, Canada
²Maurice Lamontagne Institute, Fisheries and Oceans, Canada
³GIPSA-lab, Grenoble Institute of Technology and CNRS, France

bandet.marion@gmail.com

From November 2011 to June 2012, passive acoustic monitoring systems have been deployed in Hudson Strait to record marine mammal use of this overwintering habitat in eastern Canadian Subarctic. Preliminary inspections of the recordings indicated month-long presence of Atlantic walruses in the area during winter. Underwater acoustic signals of walruses in the wild are characterized by series of pulses of various spectral and cadence patterns. These pulses are organized into series of taps and knocks, punctuated at times with bell sounds. Distinctive sequences of underwater walrus songs have been reported and were detected in our recordings. To automatically detect and classify the series of walrus sounds by category, a two-stage algorithm is developed and tested. In a first step of detection of tap and knock events, a kurtosis detector is applied to the amplitude values of the high-pass filtered signals using a low time resolution window. Comparisons with manual detections showed that this approach had a lower false alarm rate than other transient event detectors in time or time-frequency domains. A second pass of the kurtosis detector with a finer time resolution provides accurate detection times. In the second stage of classification, the temporal structure of the tap and knock trains characteristics are extracted. The knock echoes from multiple path propagation are first identified using a rhythm tracker algorithm to ignore them in feature vector computation. The resulting tap or knock train temporal and frequency features are then used to hierarchically classify them by categories. The distinctive characteristics of these series of acoustic transients that are useful for automatic detections of walrus sounds are summarized.
Quantifying responsive animal movement during shipboard cetacean line-transect surveys using passive acoustics data

Yvonne Barkley, Lisa Munger, Erin Oleson

Protected Species Division, Pacific Islands Fisheries Science Center, NMFS, NOAA, USA

Yvonne.barkley@noaa.gov

Abundance of pelagic cetacean stocks is traditionally estimated using visual survey data from shipboard line-transect surveys. These abundance estimates may be biased if the assumptions associated with line-transect analyses are violated. One assumption inherent to this approach is the detection of animals or groups before they respond to the survey platform, which is likely unrealistic for some cetacean species. In this presentation, we explore passive acoustic data in the interest of creating a new statistical approach that will quantify responsive animal movement and allow this bias to be accounted for in line-transect analyses. Passive acoustic monitoring is generally conducted concurrent with visual observations during U.S. National Marine Fisheries Service shipboard line-transect cetacean surveys. Using acoustic data from past NMFS surveys in the Pacific Islands Region, we focus on quantifying responsive movement of false killer whales (Pseudorca crassidens), a species thought to approach the survey platform. Other species are also being examined for comparison. Acoustic data was processed using the PAMGuard whistle and moan detector to obtain bearing information for each whistle. Matlab was then used to visually display and cluster the bearings and create group tracks. Preliminary results for several species will be presented to initiate discussion on how to best quantify responsive animal movement using passive acoustics data and incorporate this information into line-transect abundance estimates.
A Drifting Acoustic Spar Buoy Recorder (DASBR) for passive acoustic surveys and ocean noise measurements

Jay Barlow

NOAA Southwest Fisheries Science

Jay.Barlow@noaa.gov

Drifting near-surface recording systems offer many advantages over other methods for passive acoustic surveys to estimate cetacean abundance. Most importantly, surface buoys can be placed anywhere, thus meeting the distance-sampling assumption of randomness with respect to the animals. The construction and deployment cost of drifting recorders is much less than bottom recorders or autonomous gliders, thus allowing an increase in sample size for a given budget. Here I describe the design and tested of a Drifting Acoustic Spar Buoy Recorder (DASBR). The system uses a Wildlife Acoustics SM2+Bat recorder with coupled GPS receiver to synchronize its clock (+/- 1msec). Two channels are recorded at 192ks/sec from a vertical hydrophone array at 100m. Deployments of 4 months are possible at this sample rate with a 10% duty cycle. Tilt and depth sensors monitor array orientation. Satellite and VHF transmitters aid in buoy recovery. Surface reflections and TDOA are used to determine range and depth for vocalizing beaked whales and sperm whales. Five DASBRs have been built and tested off southern California. An example is given of a detection of Baird’s beaked whale at a distance of 2.5km. Buoy recorders can be deployed as an array to measure source levels or singly for point-transect sampling. With high-quality calibrated hydrophones, the dynamic range if this instrument will also allow measurements of ocean noise. A power analysis shows that 10 randomly distributed buoy recorders drifting for 2 months can estimate sperm whale and beaked whale abundance more precisely than a 120-day visual sighting survey.
Classification of false killer and short-finned pilot whale echolocation clicks

Simone Baumann-Pickering¹, Anne E. Simonis¹, Erin M. Oleson², Robin W. Baird³, Marie A. Roch¹,⁴, Shannon Rankin⁵, Sean M. Wiggins¹, John A. Hildebrand¹

¹ Scripps Institution of Oceanography, University of California, San Diego, USA
² Pacific Islands Fisheries Science Center, NOAA, USA
³ Cascadia Research Collective, USA
⁴ Department of Computer Science, San Diego State University, San Diego, USA
⁵ Southwest Fisheries Science Center, NOAA, USA

sbaumann@ucsd.edu

The Hawai’i insular population of false killer whales (Pseudorca crassidens) is listed as Endangered and faces a variety of threats, including interactions with fisheries. Monitoring for and assessment of false killer whales acoustically requires discrimination of their acoustic signals from those of other species. Short-finned pilot whales (Globicephala macrorhynchus) have overlapping habitat use around the Hawaiian Archipelago and towed-array recordings indicated that both species’ echolocation clicks and whistles occupied similar frequency ranges. Although classification with whistles has shown moderate success, false killer whales and pilot whales are also among the most commonly misclassified using whistles alone, such that exploration of echolocation was warranted. Low noise recordings from autonomous acoustic recorders were necessary to obtain a dataset for species discrimination. A species label was assigned to autonomous data based on the occurrence of satellite tagged animals within 5 nm of the recorder and an acoustic recording of clicks with a frequency range similar to that from towed-array recordings within +/- 2 hours of the satellite time stamp. The center frequencies of false killer whale echolocation clicks were generally lower than those of pilot whales (around 20 versus 27 kHz) and they had a higher -10 dB bandwidth (15 versus 10 kHz). However, the most important discriminating parameter, between the two species’ clicks were two smaller spectral peaks at 12 and 17 kHz in the mean spectra of pilot whales. Automated classification techniques using Gaussian mixture models showed high potential for species classification with a 4% median error rate.
Real-time reporting of baleen whale passive acoustic detections from ocean gliders using the DMON/LFDCS

Mark F. Baumgartner¹, David M. Fratantoni¹, Mark P. Johnson¹,², Tom Hurst¹, Moira W. Brown³, Tim V.N. Cole⁴, Sofie M. Van Parijs⁴

¹ Woods Hole Oceanographic Institution, Woods Hole, MA USA
² Scottish Oceans Institute, University of St Andrews, St Andrews, Fife, UK
³ New England Aquarium, Boston, MA USA
⁴ National Oceanic and Atmospheric Administration Northeast Fisheries Science Center, Woods Hole, MA USA

mbaumgartner@whoi.edu

In the past decade, much progress has been made in real-time passive acoustic monitoring of marine mammal occurrence and distribution from autonomous platforms (e.g., gliders, floats, buoys), but few systems are capable of detecting the calls of multiple species simultaneously. We have integrated the low-frequency detection and classification system (LFDCS; Baumgartner and Mussoline, 2011, JASA 129:2889-2902) with the digital acoustic monitoring (DMON) instrument to detect, classify, and report 14 call types produced by 4 species of baleen whales in real time from Slocum ocean gliders. During a 3-week deployment in the central Gulf of Maine in late November and early December 2012, two gliders reported over 25,000 acoustic detections attributed to fin, humpback, sei, and North Atlantic right whales. Real-time detections were evaluated after recovery of the gliders by (1) comparing the acoustic detections to continuous archived audio recorded by the DMON, and (2) comparing species-specific detection locations with nearby sightings collected from both an aircraft and ship. The overall false detection rate for individual calls was 14%, and for right, humpback, and fin whales, false predictions of occurrence during 15-minute reporting periods were 5% or less. Transmitted pitch tracks, compact representations of sounds, allowed unambiguous identification of both humpback and fin whale song in real time. In 10 cases when whales were sighted during concurrent aerial or shipboard surveys and a glider was nearby (within 20 km and ±12 hours), 9 of those sightings were accompanied by real-time acoustic detections of the same species by the glider.
Passive acoustic monitoring of North Atlantic right whales using computer-based aural classification

Carolyn M. Binder and Paul C. Hines

Defence R&D Canada Atlantic
Caroly旬.binder@drdc-rddc.gc.ca

Passive acoustic methods are in widespread use to detect, classify and localize marine mammals; however, these passive sonar systems are often triggered by other transient sources, producing large numbers of false positives. In order to isolate the true detections and to positively identify marine mammals, large volumes of data are collected that need to be processed by a trained analyst. To reduce acoustic analyst workload, an automatic detector can be implemented with a high false positive rate. Detections from this then can then be passed to an automatic classifier to both significantly reduce the number of false detections and classify the marine mammal species. This process requires the development of a classifier capable of performing inter-species classification as well as discriminating cetacean vocalizations from noise sources. A prototype aural classifier has been developed at Defence R&D Canada that uses perceptual signal features which model the features employed by the human auditory system. This aural classifier will be applied to the workshop dataset to discriminate between North Atlantic right whale vocalizations and false detections. A challenging data set has been made available for the workshop that consists of 12 days of data containing right whale upsweeps and gunshot calls, as well as days with no right whale vocalizations. A classification model has been developed by training the aural classifier with the preliminary workshop data then this classification model is applied to the test data set provided by the workshop’s organizers.
A New Approach to DCLDE

Neil J Boucher\textsuperscript{1}, Michihiro Jinnai\textsuperscript{2}, Hollis Taylor\textsuperscript{3}, Edward Pedersen\textsuperscript{4}

\textsuperscript{1}SoundID Australia  
\textsuperscript{2}Nagoya Women’s University Japan  
\textsuperscript{3}University of Technology Sydney  
\textsuperscript{4}TBA

nboucher@ozemail.com.au

We describe a mature software package (SoundID) that is based on image matching of a spectral transform of sound files. We show that the system is capable of running in real time (or faster) with multiple complex targets, which need bear no relationship one to the other. We show that the package is capable of processing terabytes of data and sorting it “Excel ready” for population density studies. We introduce the Geometric Distance concept which is a robust similarity measure. This measure is designed to imitate human sound recognition. Accuracy is similar to a human expert and the system allows increased accuracy at the expense of CPU time (and vice-versa).
Real time recognition of Right Whale calls using SoundID

Neil J Boucher\textsuperscript{1}, Michihiro Jinnai\textsuperscript{2}, Hollis Taylor\textsuperscript{3}, Edward Pedersen\textsuperscript{4}

\textsuperscript{1}SoundID Australia
\textsuperscript{2}Nagoya Women’s University Japan
\textsuperscript{3}University of Technology Sydney
\textsuperscript{4}TBA

nboucher@ozemail.com.au

We demonstrate real-time (or faster) recognition of Right Whale calls derived from the workshop data set. We show the ability to search for multiple call types simultaneously. With this technique the overall accuracy actually increases with an increasing number of targets. We demonstrate the variability in the calls (which are nominally of the same type) and show how to use this information to enhance recognition accuracy. The accuracy of this method is typically 95\% but can be increased at the expense of CPU time. Conversely, faster processing can be achieved if lower precision is acceptable. We explore the use of S/N as a parameter and the use of negative files to increase the accuracy.
Density estimation of Ligurian Sea sperm whales based on acoustic cues

Adrià Caballé, Michel André, Mike van Der Schaar, Ludwig Houégnigan

Laboratori d’Aplicacions Bioacustiques, Universitat Politècnica de Catalunya, Spain

adria.caballe@lab.upc.edu

ANTARES is the largest European Neutrino telescope but also a deep-sea cabled observatory for sea and earth sciences that allows continuous monitoring of noise and acoustic events. Sperm whales are present in the region year round but no data is available on their density. Passive acoustic methods combined with distance sampling have commonly been used to estimate marine mammal densities, performing an evaluation of the detection/classification stage in a certain time interval and for a given area. This approach usually requires auxiliary surveys with tagged animals to provide the models with a density approximation. Here, we present a different approach, aimed at estimating sperm whale density in the Ligurian Sea, through the analysis of one full year of ANTARES data. In a given time interval, one can detect the presence of an animal by using visual or acoustic information in a sound file. The difficulty is to count the number of occurrences associated with animal presence in a consecutive number of segments. To obtain an automatic estimation of animal presence, a model with a binary response variable (0: no presence, 1: presence) was trained given a set of independent variables (such as the number of signals detected and classified). Knowing the animal presence in a given time interval was not enough to estimate the density of its population. The cluster size had to be estimated too. This was approximated by a Poisson distribution, where knowing the proportion of cases with a single animal was sufficient to draw the entire distribution. The calculation of the density was a function of the number of segments with presence, the average cluster size and the proportion of time where sperm whales were active. The method provided an analysis of the sperm whale abundance in the Ligurian Sea by daily hour and by month.
A Bayesian approach to analyse the effects of acoustic misclassification on the estimation of the number of acoustic detections

Marjolaine Caillat¹, Len Thomas², Douglas Gillespie¹

¹Sea Mammal Research Unit, Scottish Oceans Institute, St Andrews University, UK
²Centre for Research into Ecological and Environmental Modelling, University of St Andrews, UK

mc326@st-andrews.ac.uk

To estimate the density or abundance of a cetacean species using acoustic detection data, it is necessary to correctly identify the species that are detected. Developing an automated species classifier with 100% correct classification rate for any species is likely to stay out of reach. It is therefore necessary to consider the effect of misidentified detections on the number of observed acoustic detection and consequently on abundance or density estimation, and develop methods to cope with these misidentifications. Through a Bayesian approach we showed that if misclassification rates are known, it is possible to estimate the true numbers of detected calls accurately and precisely. However, misclassification and uncertainties in the level of misclassification increase the variance of the estimates. If the true numbers of detections from different species are similar, then a small amount of misclassification between species and a small amount of uncertainty around the classification probabilities does not have a detrimental effect on the overall variance and bias of the estimate. However, if there is a difference in the encounter rate between species calls and a large amount of uncertainty in misclassification rates, then the variance of the estimates becomes larger, the bias increase and this increases the variance and the bias of the final abundance estimate.
Nonlinear phenomena based detector for passive acoustic monitoring

Alicia Carrión, Ramón Miralles, Guillermo Lara

Instituto de Telecomunicación y Aplicaciones Multimedia (iTEAM), Universidad Politécnica de Valencia, SPAIN

alcarga4@upv.es

Marine mammalian calls include a rich set of nonlinear phenomena, the occurrence of which has previously been noted in other species such as chimpanzees, mockingbirds, dogs and penguins. We use the expression “nonlinear phenomena” to refer collectively to subharmonics, biphonation, and frequency jumps or any subset of these events. Such situations are clear indicators of nonlinearities in the sound production mechanisms. In this work, we propose a new approach to the study of marine mammal acoustics. Instead of looking for parameters or features to describe the acoustic particularities of a given call we look for changes in the modality of the signal. We try to extract information of the underlying model generating that sound: whether it is linear or not, whether it is chaotic or not, etc. To tackle this matter, we have developed an algorithm that allows determining the linearity of the recorded waveform. The algorithm is based in a convex combination of adaptive predictors (NLMS and NNGD) with a pre-whitening AR filter to allow the system to successfully track nonlinearities in non-white signals. The proposed technique avoids working in the spectral domain and gives a nonlinearity index related to the system modeling that sound. We have tested the proposed technique using data from the 6th DCL&DE workshop with excellent results detecting the called upsweeps (continuous frequency jumps), and also very good rates with the gunshots (biphonation). The nonlinearity index can be also used in more complex algorithms for detection and classification of passive acoustic monitorization.
Real-time detection of belugas for military mitigation

Manuel Castellote\textsuperscript{1}, Douglas Gillespie\textsuperscript{2}, Andy Maginnis\textsuperscript{2}, Christopher Garner\textsuperscript{3}

\textsuperscript{1}National Marine Mammal Laboratory. National Marine Fisheries Service / NOAA.
\textsuperscript{2}Sea Mammal Research Unit LLC.
\textsuperscript{3}Joint Base Elmendorf Richardson, U.S. Air Force.

\texttt{Manuel.castellote@noaa.gov}

Due to the endangered status of the Cook Inlet Beluga population, there is a requirement to monitor their presence in the coastal portion of the Joint Base Elmendorf Richardson (U.S. Army/Air Force) in Cook Inlet, Alaska. Due to the proposed live firing into the Eagle River flats impact area, both the Eagle River and Eagle Bay are areas of conservation concern for the military. A pilot study was conducted in August 2012 to continuously monitor (24/7) the acoustic presence of belugas in real time during 12 days. A modified version of Pambuoy, a real time detection buoy developed by Marine Instrumentation Ltd and based on Pamguard was installed on land connected to a hydrophone deployed in the mouth of the river. Detections were transmitted in real time via 2.4GHz wireless IP data link to a remote land station running Pamguard for archival and visual control and also uploaded every 15 minutes to a web server. Sound input was processed in real-time on site at 500 kHz sample rate. Visual observers concurrently monitored the area for beluga presence during the daytime and logged sightings in 1 minute intervals. Sighting distances varied from 10 to 1035 m. A combination of a whistle/moan (1-20 kHz) and click detector (10-120 kHz) were used to detect belugas. An event detector based on click detection rate was developed to reduce false click detections. Compared to detections selected by a human operator, the automatic system had a recall of 75% and precision of 98% using an event detector threshold of 20 Beluga like clicks in 10 seconds. Acoustic detection results were also compared to sighting results. All visual sightings (432) were acoustically detected except 2 events corresponding to 99.54% success of detection, indicating that the events selected by the human operator that were missed by the automatic event detector were either of distant animals or were close in time to other clicks which were detected by the automatic detector.
Scattering representation for humpback whale vocalizations: applications to their detection, characterization and classification

Cazau, D.¹, Xue, C¹, Doh, Y², Glotin, H², and Adam, O¹,³

¹Institut Jean Le Rond d’Alembert, LAM team, University UPMC, Paris, France
²Laboratoire des Sciences de l’Information et des Systèmes, University of Toulon, France
³Centre de Neurosciences Paris Sud, Bioacoustics team, Orsay, France

cazau@lam.upmc.fr

Nowadays, classification of cetacean vocalizations is still a challenging task, partly because of the intra-/inter- individual and species diversity of vocal repertoires. It must be added to that signal deformations due to varying acoustic propagation and environment ambient noise. Classical representation methods (e.g. spectrogram, cepstrum, wavelets) give interesting input representations for detection and classification tasks, but could be further improved. As a potential enhancement method, we introduce here the scattering representation, founded by S. Mallat in 2010. It aims to bring stability to deformation, which classical spectrograms lack, by averaging higher frequencies, as it is made when computing Mel Frequency Spectral Coefficients (MFSCs). From here, scattering representation extends MFSCs through a cascade of wavelet decompositions and modulus operators, which allows to recover the high-frequency lost information while preserving stability to deformation. This multiscale operation, combining basic MFSCs with higher-order co-occurrence coefficients, can capture non-stationary behavior resulting from high-frequency interferences, as well as larger scale audio structures. Scattering representation has already been applied to the characterization of musical sounds. In this current work, we applied this representation to three common automatic processing of cetacean vocalizations. First, the task of call detection benefited from the signal-adaptive property of scattering transform, able to adaptively discriminate stationary/transient parts of a signal through its different levels of decompositions. Transients may then be easily peaked, by combining information from bands of maximal energy within higher levels. Furthermore, scattering coefficients are robust to noise, making this detection quite insensitive to environmental acoustic constraints. Classical ROC curves (good against false detections) are computed to evaluate detection performances of the method. Secondly, we investigated the usefulness of scattering representation in extracting production-related vocal features, such as frequency-jumps and vibratos. These features, which are highly meaningful for the understanding of underlying vocal mechanisms, are well captured by scattering transforms as resulting from frequency interferences, extracted in higher levels. Eventually, for the classification, we proposed two approaches. A first hand-made classification, tracking acoustic invariants on a few versions of pre-defined call types of humpback whale vocalizations. Songs are taken from an acoustic dataset recorded in the St Marie channel, in Madagascar. A second approach was to strictly apply a SVM-based mathematical classifier, taking as vector features the scattering coefficients, and compare its performances (error rate with an 1vs1 approach) with a MFCC and delta-MFCC classifier in the classification of right whale vocalization types. Calls of the workshop dataset have been manually extracted and labelled by types.
Towed arrays and beaked whales: detection and three-dimensional localization of Sowerby's beaked whales (*Mesoplodon bidens*) on large vessel surveys

Danielle Cholewiak¹, Robert Valtierra², Simone Baumann-Pickering³, Sofie Van Parijs¹

¹NOAA Northeast Fisheries Science Center, Woods Hole, USA
²Boston University, Department of Mechanical Engineering, USA
³Scripps Institution of Oceanography, University of California, San Diego, USA

danielle.cholewiak@noaa.gov

Beaked whales are notoriously difficult to detect via visual surveys, as they spend long periods of time underwater and tend to be relatively inconspicuous when at the surface. Therefore, the integration of passive acoustic methodologies into visual surveys is critical for increasing our detection of these species and better understanding their distributions. In 2011, the NEFSC conducted a shipboard survey along the U.S. eastern seaboard, combining visual observation and acoustic data collection using towed hydrophone arrays. Beaked whales were sighted on more than 80 occasions, including 12 sightings of Sowerby's beaked whales (*Mesoplodon bidens*). One particularly good encounter with Sowerby's beaked whales allowed for the characterization of their echolocation clicks and three-dimensional localizations of several individuals. A total of 2969 echolocation clicks were included in analyses of frequency and temporal characteristics. The majority of clicks contained a peak frequency of 33 kHz, while the others contained a median peak frequency of 25 kHz (n=324), 51 kHz (n=304), or 67 kHz (n=293). Detected clicks were manually assigned to a series of click trains based on simultaneous comparison of spectrograms and bearing patterns as determined by the software package Pamguard. Target-motion analysis was conducted for thirteen click trains, resulting in two-dimensional localizations for animals up to 456 m from the trackline. Click train series from several individuals were chosen for testing three-dimensional localization methods, using DRTD (direct reflected time difference of arrival). Click characteristics were also used to refine an automated detector in Pamguard and were applied across the broader data set to search for additional encounters with this species. Detection and localization results will be presented within the context of their relevance for marine mammal assessment surveys.
**Statistical segmentation of spectrograms: a complementary approach to track detection algorithms**

Florian Dadouchi\(^1\), Cédric Gervaise\(^1,3\), Cornelia Ioana\(^1\), Julien Huillery\(^1\), Jérome I. Mars\(^2\)

\(^1\)University of Grenoble, Grenoble Cedex, France  
\(^2\)CNRS, Gipsa-Lab, Grenoble Cedex, France  
\(^3\)Ecole Centrale de Lyon, Laboratoire Ampère, Écully, France  

florian.dadouchi@gipsa-lab.grenoble-inp.fr

An efficient statistical method for the segmentation of spectrograms of narrow band bioacoustics sounds is proposed. The method is not an alternative but a complement to standard time-frequency trackers (particle filters, Viterbi-based tracking, Kalman filtering, graph search, time-frequency-phase tracker, etc.) and operates as a pre-processing step: 1. Identification of regions of interest (ROI) in long recordings; 2. Generation of efficient binary spectrograms; 3. Design of time-varying filters to enhance the signal to noise ratio. The approach is designed to deal with real world constraints: large databases, non-stationary/colored noise and multi-component non linear frequency modulations. The method performs a double binary hypothesis test, one on time-frequency bins, the second on regions of the time-frequency plane. An overview of the author’s methodology is the following:

**First step:** The background noise in the spectrogram is modeled as a chi-squared distribution with two degrees of freedom and its parameter is estimated for each time-frequency bin using a minimal statistics approach (small values are realizations of noise only). An adaptive threshold is then computed using a constant false alarm probability (\(p_{FA}\)) for thresholding (Neyman-Pearson (NP)).

**Second step:** The second binary hypothesis test applies on regions of the binary spectrogram. The histogram of the number of detections in regions of the binary spectrogram is computed. The probability distribution of the number of false detections is modeled as a Binomial distribution which parameter is estimated. Regions are decided as “hosting signal” or “not hosting signal” using a NP approach. To enhance the robustness of the overall methodology, a multi-thresholding approach is applied. The optimal \(p_{FA}\) at step 1 is unknown, \(N\) binary spectrograms are then generated. Step 2 solves the binary hypothesis test for each of the \(N\) binary spectrograms using a unique false alarm probability and selects the one maximizing the number of detections.
(Near) Optimal Signal Processing Approaches for Environmental Calibration of Passive Acoustic Monitoring Results

Gerald L. D’Spain, Tyler A. Helble, John A. Hildebrand, and Marie A. Roch

Scripps Institution of Oceanography, University of California San Diego, USA
San Diego State University, San Diego, USA

gdspain@ucsd.edu

Detection, Classification, and Localization (DCL) are intimately intertwined with passive acoustic Density Estimation (DE). The purpose of this talk is to discuss some aspects of this relationship. Data processing begins with the “L” and “D” parts of the problem. Over a half century of research by the radar and sonar signal/array processing communities has resulted in optimal and near optimal approaches to source detection and source localization. "Optimal" indicates that these algorithms, assuming the assumptions and approximations under which they were developed are approximately satisfied, are THE best - one can do no better. The physics of sound propagation in the ocean also play an important role given that the properties of underwater acoustic recordings are determined not only by the acoustic sources themselves, but also the characteristics of the ocean environment. In addition, the ability to detect the presence of a sound of interest also is determined by all the other sources of ocean sound. Therefore, to learn something about a particular sound source (marine mammals in this case) from underwater acoustic recordings, the effects of the environment must be removed, or somehow taken into account. Detection, through the formulation of animal (or call) density estimation, provides a framework for performing this environmental calibration. This talk borrows liberally from the material being presented by Tyler Helble. The overall theme is that passive acoustic monitoring is (or should be) strongly multi-disciplinary in nature. [Work supported by the Office of Naval Research, Code 322 MMB].
Computing at scale: A new client server based system for high performance computing for automatic signal recognition

Peter Dugan, Marian Popescu, John Zollweg, Adam Mikolajczyk, Aaron Rice and Chris Clark

Bioacoustic Research Program, Cornell University

pjd78@cornell.edu

From Biology to technology, the rate of data collection often far exceeds the ability to process the information. Large data is becoming a major point of interest for every field of science. This talk focuses on a new system developed by Cornell University that uses high performance computing (HPC) to process large passive acoustic sounds. This work will discuss how the HPC system was developed using commercial off the shelf (COTS) tools creating a flexible client server model that is expandable, flexible and portable. The presentation will demonstrate a strategy for providing a flexible software interface for running a plurality of data mining algorithms using a dense computer cluster called the Acoustic Data Accelerator, or HPC-ADA. In addition a variety of tools have been developed to complement the system, providing efficient methods for data processing. The authors will also showcase a specific example for processing 44 months of multi-channel, continuous data recorded in the Stellwagen Bank National Marine Sanctuary, MA, USA. Results show distinct seasonal distribution patterns of species-specific vocalization for minke and fin whales. Automated detectors for other species are in development and can easily be applied to large datasets using this system.
A comparative summary of three different frameworks is provided for the recognition of North Atlantic Right Whale contact calls. The first is based on what is known as a “deep learning” approach. Deep learning strategies have demonstrated a significant advantage in recognition performance over classical methods in a variety of machine learning tasks. Specifically the work presented relies on the use of a popular deep learning algorithm known as the convolutional neural network, or ConvNet. The second framework, referred to as the Advanced Segmentation Recognition (ASR) algorithm, relies on a multi-stage process, using region based detection and popular feature extraction coupled with a plurality of advanced classification algorithms such as Support Vector Machines (SVMs) and Neural Networks (NNs). The third method is a multiple-stage hypothesis-testing technique implemented in a software system ISRAT. This technique involves the spectrogram-based detector in the first stage and the feature vector testing algorithm in the final stage. The different frameworks are employed on three major datasets used at the: International Kaggle resource, St. Andrews Workshop (DCLDE) and Workshop on Machine Learning for Bioacoustics under the 2013 International Conference on Machine Learning (ICML). Collectively, the data represents over 100,000 unique Right Whale contact calls. A brief overview regarding both frameworks is provided and performance metrics across the three datasets yielding a range of accuracies from 93% to beyond 96%. A closer comparison of the three architectures will be discussed, offering insights on future directions and design decisions.
Automatic detection & classification of biological, anthropogenic and natural physical sounds for the computation of “sound budgets”

Christine Erbe, Shyam Madhusudhana, Alexander Gavrilov

Centre for Marine Science & Technology, Curtin University, Perth, Australia
c.erbe@curtin.edu.au

The regulation of underwater noise has historically focussed on single operations (events) limited in space and time. As regulators around the globe are being pushed towards a more holistic approach considering cumulative noise exposure and cumulative stressors, environmental impact assessments of proposed operations are trying to determine how much additional noise a specific operation would add to an already noisy environment. To answer this question, baseline soundscape monitoring is undertaken for a season or an entire year. Noise budgets are computed to determine how much acoustic energy is due to physical ambient sources (e.g. wind, precipitation), anthropogenic and biological sources. It doesn’t matter which animal generates which sound, as all biological sounds are meant to be lumped together. One approach would be to establish a sound catalogue for the region and to search for all signals one by one. This is a very laborious approach. Also, while there is now a plethora of auto detection tools, most of these excel under highly specific conditions (i.e. they were developed for specific calls or call types in specific noise). Furthermore, we often don’t know enough about a soundscape to establish a catalogue that is even vaguely complete. Our approach establishes properties that are characteristic for sounds of biological versus anthropogenic versus natural physical origin and then performs a high-level search for such characteristics. Examples for tropical marine soundscapes off north-western Australia will be presented. Problems (such as categorising the vast amount of “unstructured” acoustic energy, and mooring and equipment artefacts) and alternative (better?) approaches will be discussed.
An acoustic survey to estimate the population abundance of sperm whales in the Canary Islands: are vessel strikes sustainable?

Andrea Fais¹, Tim Lewis², Omar Álvarez¹, Natacha Aguilar¹,³

¹ Dept. Animal Biology, University of La Laguna, Tenerife, Spain
² International Fund for Animal Welfare, London, UK
³ Scottish Ocean Institute. University of St. Andrews. Scotland

anfais@ull.es

Sperm whales (Physeter macrocephalus) are found year-round in the deep waters off the Canary Islands. Here we present the results of a line-transect acoustic survey aimed to study the abundance and distribution of the population of sperm whales in the Archipelago. A randomized set of lines summing 3122 km was designed with Distance to cover the shelf edge of the islands and up to 30 km offshore from it. This included the abyssal plain and two sets of seamounts currently proposed for protection as Nature 2000 areas, summing up 53749 km². Sperm whales were detected acoustically using a two-element hydrophone array towed at 7 kn and ~12m depth. Acoustic data were sampled at 96 kHz and high-pass filtered to reduce engine and water flow noise. Rainbow Click software was used to monitor acoustic signals in real-time and for post-processing of the data, in combination with Matlab. We applied Distance for the estimation of the population abundance. The effective detection range for this survey was estimated as 4 km due to the high noise level of the vessel. The assumption g(0)=1 was accepted because the mean fraction of time that sperm whales are not available for acoustic detection was smaller than the time window during which they can be acoustically detected. This was independently calculated from 94 h of recordings of acoustic DTAGS in 7 sperm whales, showing that on average they are vocal for 60% of their time, while the time window in this survey was 0.6. In the last two decades two sperm whales strand on average in the Canary Islands each year with signs of vessel strikes. Given the size of the population estimated here, the strike-related mortality seems higher than the sustainable potential biological removal for the local population. This highlights the need to develop efficient mitigation measures to minimize collisions between whales and ships in the Archipelago.
Estimation of Acoustic-Based Detection Functions for Sperm Whale Encounters in the Northern Mariana Islands

Elizabeth Ferguson, T.M. Yack and T. Norris

Bio-Waves, Inc., 364 2nd Street, Suite #3, Encinitas, CA 92024, USA
eferguson@bio-waves.net

A three month visual and acoustic line-transect survey of a large (584,800 km²) study area centered on the Northern Mariana Islands (MISTCS) was conducted in winter of 2007 (DoN 2007). Line-transect survey and analytical methods are well developed for estimating abundance of marine mammals using visual sighting data. These methods also can be applied to acoustic data when a perpendicular distance from the trackline to the "detection" is obtained. Sperm whales produce distinctive broadband (100 Hz to 25 kHz) echolocation signals. Although sperm whales typically produce "regular" clicks, males are known to produce high amplitude clicks with slow inter-click intervals (i.e. "slow" clicks). Previous studies have used a combination of acoustic and visual survey methods to estimate sperm whale densities. The aim of this study was to use acoustic localizations of sperm whales to estimate a detection function for the MISTCS study area. Sperm whale acoustic encounters were post-processed using PAMGuard software to obtain "click files" that were then processed using Rainbow Click software (IFAW). Rainbow Click was used to visualize time/bearing and map displays of detected clicks and associated bearing estimates, and mark individual click trains ("events") for each encounter. Target motion analysis methods utilizing a least squares algorithm to calculate perpendicular distances to each "animal/event" were applied using custom MATLAB code that interfaced with Rainbow Click. Next, perpendicular distances and transect length data were imported into the software program Distance (6.0 release 2) to model detection functions. Models were fit for all clicks types combined, regular clicks only, and slow clicks only. Slow and regular click localizations exhibited different shapes in their distribution, likely because slow clicks have higher amplitudes and can be detected over greater ranges than regular clicks. A discussion of these results and comparisons to similar research using acoustic-based line-transect data will be presented.
A comparison of approaches for clustering tonal vocalizations of free ranging Delphinids

Kaitlin E. Frasier¹, Marie A. Roch¹², E. Elizabeth Henderson³, Alexa Alldredge¹, Simone Baumann-Pickering¹, Shannon Rankin⁴, Erin M. Oleson⁵, Ashleigh Kirker¹, John A. Hildebrand¹

¹Scripps Institution of Oceanography, UC San Diego
²San Diego State University
³National Marine Mammal Foundation
⁴NMFS, NOAA. Southwest Fisheries Science Center
⁵NMFS, NOAA. Pacific Islands Fisheries Science Center

kefrasie@ucsd.edu

The ability to cluster similar signals is a crucial step in the process of training an algorithm to distinguish delphinid species using the time-varying frequency content of their vocalizations. A successful clustering method maximizes intra-cluster similarity and inter-cluster differences, while moderating the number of clusters created. Processing time and statistical consistency are also important considerations. This work seeks to test the effectiveness of a range of techniques aimed at clustering frequency modulated delphinid vocalizations ("whistles") extracted from field recordings. Whistles from four species of free ranging delphinids (Tursiops truncatus, Stenella longirostris, Globicephala macrorhynchus, and Pseudorca crassidens) were analyzed using a series of different methods, ranging from simple to complex. Clustering routines can operate on full whistles or on subunits that have been delimited by salient features of the signal itself (e.g. extrema), or by some external segmentation choice (e.g. a particular duration). Here we examine the usefulness of the following methods: (1) Manual clustering, (2) K-means clusters, (3) Adaptive resonance with dynamic time warping (DTW), (4) Clique identification within a graph weighted by dynamic time warp distance.
Effects of acoustic propagation on echolocation click detectability in the marine environment

Kaitlin E. Frasier¹, Karlina P. Merkens¹, Sean M. Wiggins¹, Tiago A. Marques², Danielle Harris², Len Thomas², Mark A. McDonald³ and John A. Hildebrand¹

¹Scripps Institution of Oceanography, University of California San Diego
²Centre for Research into Ecological and Environmental Modelling, University of St Andrews
³WhaleAcoustics

kefrasie@ucsd.edu

Ocean conditions modify the amplitude and frequency content of odontocete echolocation clicks between production by an animal and reception by a passive acoustic monitoring (PAM) device. The directional nature of echolocation clicks further influences their acoustic characteristics at the time of reception. These factors affect the acoustic detectability of a clicking animal, which in turn impacts passive acoustic density estimates. Here we use oceanographic acoustic propagation models to predict the probability of detecting vocalizing odontocetes across a range of sites and conditions. The results are compared with experimental detection rates of sperm whales and delphinids. Bottom-mounted instruments and towed arrays are considered. Comparison of the models with experimental data suggests that beam pattern affects the shape of an acoustic detection function (detection probability as a function of distance from a sensor) at close range. Oceanographic factors (particularly bathymetry) seem to affect detectability at longer ranges. Temperature profiles also affect the detectability of animals located near the surface for both deep and shallow PAM. These findings indicate that propagation models can help explain the shape of an acoustic detection function. Models may also improve acoustic density estimation assumptions for situations involving directional, high frequency signals.
Acoustic observations of high-frequency cetaceans in the eastern North Pacific using a glider

Selene Fregosi¹, Holger Klinck¹, David K. Mellinger¹, Neil M. Bogue² and James C. Luby²

¹Cooperative Institute for Marine Resources Studies, Oregon State University and NOAA Pacific Marine Environmental Laboratory, Newport, USA.
²Applied Physics Laboratory, University of Washington, Seattle, USA.

selene.fregosi@noaa.gov

Visual surveys of small odontocetes are limited in the eastern North Pacific to daylight hours and by adverse weather conditions and sea state. Elusive species, such as beaked whales that inhabit deep offshore waters and spend little time at the surface, are especially difficult to study visually. Passive acoustic monitoring has been used to detect and classify high-frequency cetaceans but ship-based or bottom-moored acoustic observations are often constrained in temporal and/or spatial resolution. A remotely operated passive acoustic glider can be used to efficiently screen areas of interest for cetaceans with high temporal and spatial resolution. A Seaglider™ was equipped with a passive acoustic recording system and deployed in the eastern North Pacific along the continental shelf break, repeatedly diving to 1000m depth. One minute loss-less compressed audio files were collected throughout glider dives at depths below 400 m, at a sufficient sampling rate to enable detection of a broad range of odontocete vocalizations up to 96 kHz. Recordings were analyzed visually and aurally using long term spectrogram analysis and automated detectors to determine cetacean species present. Several delphinid and beaked whale species were identified. Acoustic encounters were analyzed in respect to geospatial and temporal scales to identify any patterns in species occurrence in the study area.
Three-dimensional passive acoustic tracking of beaked whales with volumetric small-aperture arrays

Martin Gassmann, and John A. Hildebrand

Scripps Institution of Oceanography, USA

mgassmann@ucsd.edu

For tracking the directional echolocation clicks from odontocetes, passive hydrophone arrays with small apertures can be used to receive the same narrow-beam click on each sensor. A seafloor instrument with a four-hydrophone small-aperture array was coupled to an autonomous acoustic recorder to provide long-term monitoring and tracks of odontocete clicks. Two of these recorders and three additional single-hydrophone seafloor recorders were deployed as a large aperture array in a known beaked whale habitat in the Southern California Bight. By taking advantage of the varied spatial distribution of the hydrophones and the refractive oceanic waveguide, a three-dimensional tracking algorithm was developed. To illustrate the capabilities of the algorithm, 50-minute long tracks of clicking and buzzing beaked whales dives will be presented. This technique provides a tool to study the characteristics of beaked whale echolocation, their behavior during deep diving and potentially their responses to mid-frequency active SONAR.
Variability of beaked whale clicks characteristics

Odile Gerard

DGA Naval Systems, Toulon, France

odigea@gmail.com

Beaked whales are a group of more than twenty genetically confirmed species. They are very elusive and were among the least known species until few years ago. Strandings of beaked whales have been reported to occur in conjunction with sonar exercises, although the exact mechanism is unclear. These strandings lead to an increased research effort dedicated to these very sensitive species and in particular to their signals. Despite this effort, the signals of some beaked whale species remain unknown. Until now, all known signals of beaked whale 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 to classify beaked whale species. The Centre for Maritime research and experimentation (CMRE, former NURC, NATO Undersea Research Centre) conducted various sea-trials in the last five years, most of them in the Mediterranean Sea and one in Eastern Atlantic Ocean, Southwest of Portugal. Cuvier's beaked whales were recorded in the Mediterranean Sea and three unknown species of beaked whales were recorded in Eastern Atlantic. In addition to these datasets the recordings of Blainville's beaked whales provided for the 2007 DCL workshop will be used. Variability of click amplitude and Inter Click Interval of successive clicks will be calculated and compared for all the species of the aforementioned datasets.
Detection and Classification of Right Whale sounds

Douglas Gillespie

Sea Mammal Research Unit, Scottish Oceans Institute, University of St Andrews, UK

Dg50@st-andrews.ac.uk

Vocalisation rates from right whales are generally low compared to other species which often inhabit the same areas. Therefore, useful right whale detectors need not only to efficiently detect right whale calls, but they need to be particularly good at not detecting calls from those other species. Here, I present the performance of a two stage detection and classification process for right whale upsweeps. In the first stage, sounds are detected by operating on a spectrogram of sound data using a variety of noise cancellation techniques and then searching for connected regions of the spectrogram that rise above some threshold. Detected sounds are then classified based upon the time-frequency contour of the detected sounds. The detector found 83% of all calls in the training dataset and over 99% of calls with a signal to noise ratio greater than 6dB. However, it was only possible to correctly classify approximately 50% of calls if a low false alarm rate of < 10 false detections per day is to be achieved.
Field evaluation of acoustics detectors and detection functions for Blainville’s beaked whales Mesoplodon densirostris

Kalliopi Gkikopoulou¹, Natacha Aguilar², Mark Johnson¹

¹University of St Andrews, UK
²University of La Laguna, Spain

Kg366@st-andrews.ac.uk

The distinctive echolocation clicks produced by beaked whales appear to be ideal for acoustic monitoring and abundance surveys for these visually cryptic species. But although a number of detection algorithms have been proposed, there have been few attempts to evaluate these and so the best method, and the resulting detection performance, remains uncertain. A major stumbling block is the difficulty in recording animals at known distances as needed to estimate the detection function. Here we present a method for evaluating beaked whale detectors using field data combining acoustic recording tags (DTAG) and drifting acoustic recorders. Five Blainville's beaked whales were tagged offshore of El Hierro in the Canary Islands resulting in 9 foraging dives and about 35000 clicks within 5 km of the drifting recorders. Each recorder comprised an array of 2-3 GPS-synchronized autonomous hydrophones at various depths from 20 to 300 m providing the opportunity to assess the effect of receiver depth on detection performance. Clicks from tagged animals were located in the remote recordings using a synchronized time-click display. Distances from the tagged animal to each recorder were then estimated using a clock prediction method based on surface bounce time lags. Estimated ranges for visually identified clicks were from 400 m to 4.5 km. To simulate a wider range of distances and ambient noise conditions, we used a Monte Carlo simulation. Clicks received at ranges of less than 2 km were filtered to simulate high frequency attenuation due to longer-range propagation, and ambient noise samples were added to reduce the SNR by a corresponding amount. The resulting waveforms were used to estimate the ROC curves and detection functions of five detectors including matched filter, band pass energy, and energy ratio designs. Differences in performance for shallow and deep receivers were also evaluated. The approach used here is applicable to other species and acoustic environments but a wider range of noise waveforms will be required to achieve a more realistic assessment of detectors. To this end, we propose the creation of a library of ambient noise waveforms.
Abundance Estimation of sperm whales in the Hellenic Trench, Eastern Mediterranean

Gkikopoulou, Kalliopi¹,², Frantzis, Alexandros², and Matthiopoulos, Jason³

¹University of St Andrews, UK
²Pelagos Cetacean Research Institute, Greece
³University of Glasgow, UK

Kg366@st-andrews.ac.uk

The Mediterranean Sperm whale population has been characterized as endangered from the IUNC, hence abundance estimation for the different parts of the population, as the one in the Hellenic Trench, is critical. The use of passive acoustics is efficient for detecting highly vocal animals such as the sperm whale. Here we present a combined visual and acoustic analysis for abundance estimation of sperm whales. The data was obtained by the Pelagos Cetacean Research Institute (PCRI), using point distance sampling through passive acoustics. An experimental fieldwork dataset was used to fit the detection function as a Generalized Linear Model (GLM) with factors that influence their detectability. The detected distances derived from the combined acoustic and visual survey. Due to the size range of different clusters, of the sperm whale social groups present in the area, a stratification method was used. The data were divided into three strata I) 1 to 3, II) 4 to 7 and III) 8 to 15 animals. The detectability of clusters was influenced by distance and by the number of whales existing on each cluster, and an effective acoustic radius of 13km 18km and 21 km was obtained from the analysis for stratum I, II and III, respectively. The study area was divided in poor, medium and good quality habitat based on a habitat modelling analysis. Abundance estimation was calculated for each of the different habitats and strata, deriving in 9 abundance sub-estimations while using the total dataset from 12 years of summer surveys. The analysis indicates that 27 ([19.7, 32.08] 95% CI) animals are in the area at any time during the summer period with the good quality habitat to include the 0.5 of the total population. Comparisons with abundance estimations obtained through the available photo-identification data from the same population unit may provide useful results for further improvement of both methods and possibly a combined and more accurate estimation of absolute abundance.
The effect of cetacean movement on density estimation using passive acoustics sensors


University of St. Andrews, St Andrews, UK

rpg2@st-andrews.ac.uk

Distance sampling is one of the most widely used methods for estimating animal population abundance. As visual methods can be cost-ineffective under many scenarios, passive acoustic methods using long-term fixed sensors have been increasingly used to monitor abundance of cetaceans. Distances to detected animals are used to estimate the average probability of detection, allowing missed animals to be accounted for. The method relies on three assumptions: (i) animals are detected with certainty at the point, (ii) measurements are exact, and (iii) animals don’t move while within detection range (snapshot survey). If the first assumption fails, spatially explicit capture-recapture (SECR) or mark recapture distance sampling (MRDS) methods may be used. Failure of the second assumption could be accounted for using measurement error models. Both of these have the potential to be fulfilled to a reasonable extent given carefully chosen field and data processing methods. In cetacean surveys, especially from fixed sensors, movement can be a major issue and therefore, the estimates of abundance are potentially biased. We assess the effects of animal movement in point transect sampling. First of all, we suppose that all animals in the covered area are detected. Each animal is assumed to be moving at the same constant speed and random direction. An analytic expression for the bias from random animal movement is derived, as well as a corrected abundance estimate. Secondly, some animals in the covered area may be undetected. We assess the effects of their movement by simulation. Within the study region, we simulate animals moving in constant but random directions and constant speed or according to a correlated random walk. The detection process is modelled as a two-dimensional hazard-rate process. Our goal is to describe how movement leads to bias, and how that bias can be corrected for, leading to more robust density estimates.
Density surface modelling of fin whale calls using a sparse array of seismic instruments in the northeast Atlantic

Danielle Harris, Luis Matias, David K. Mellinger, Len Thomas

1Centre for Research into Ecological and Environmental Modelling, University of St. Andrews, St. Andrews, UK
2Scottish Oceans Institute, St. Andrews, UK
3Instituto Dom Luiz, Lisboa, Portugal
4Cooperative Institute for Marine Resources Studies, Oregon State University, Hatfield Marine Science Center, Oregon, USA

dh17@st-andrews.ac.uk

A challenge of monitoring marine mammals using fixed passive acoustic instruments is creating a survey design that provides (a) a satisfactory number of sampling points and (b) adequate spatial coverage of the study area. When ranges to calling animals are desired, these aspects of survey design may be compromised in order to use multiple-instrument localisation methods. In this study, we demonstrate the utility of a sparsely distributed array where individual instruments could range to calling fin whales (Balaenoptera physalus). An array of 24 ocean bottom seismometers (OBSs) was deployed off the south coast of Portugal between 2007 and 2008. Each OBS had a hydrophone and a 3-component seismometer. Spacing between instruments was at least 30 km. Automatic detection methods were used to detect fin whale calls and ranges to detected calls were estimated from the seismometers using a standard seismological method. A three-stage analysis of these data was then conducted. Firstly, point transect sampling, a form of distance sampling (a popular wildlife abundance estimation method), was used to estimate the average probability of detecting a fin whale call. This was achieved by fitting a detection function model to the range data, which included ambient noise and OBS location as covariates. The detection probability estimates were then used to estimate call density around each OBS. Secondly, the spatial and temporal patterns of call density were explored using a generalised additive model (GAM) that incorporated environmental covariates (e.g., chlorophyll concentration and sea surface temperature). Finally, using the results from the GAM, a call density surface was fitted across the study area, predicting the spatial and temporal patterns of fin whale calling in this region. Variance of the density surface was estimated using bootstrapping techniques.
Site specific and time dependent probability of passive acoustic detection of humpback whale calls from single fixed hydrophones

Tyler A. Helble, Gerald L. D’Spain, John A. Hildebrand, Greg S. Campbell, Richard L. Campbell, Kevin Heaney

Scripps Institution of Oceanography
Ocean Acoustical Services and Instrumentation Systems

tyler.helble@gmail.com

Passive acoustic monitoring of marine mammal calls is an increasingly important method for assessing population numbers, distribution, and behavior. A common mistake in the analysis of marine mammal acoustic data is formulating conclusions about these animals without first understanding how environmental properties such as bathymetry, sediment properties, water column sound speed, and ocean acoustic noise influence the detection and character of vocalizations in the acoustic data. The approach to be presented uses simulations with a full wave field acoustic propagation model in order to characterize the site specific and time dependent probability of detection of six types of humpback whale calls at three passive acoustic monitoring locations off the California coast. Results show that the probability of detection can vary by factors greater than ten when comparing detections across locations, or comparing detections at the same location over time, due to environmental effects. An example is presented from an acoustic dataset off the California coast recorded from 2008-2010 in which shipping noise declined due to a weak global economy. Uncorrected detections result in considerably more acoustic humpback detections in the second year, while corrected call densities remain similar between years. Effects of uncertainties in the inputs to the propagation model are also quantified. The model accuracy is assessed at the 3 monitoring sites by comparing calling statistics amassed from a total of 24,690 humpback units recorded in the month of October 2008. Under certain conditions, the probability of detection can be estimated with uncertainties sufficiently small to allow for accurate call density estimates. Estimates of the density of animals themselves require accurate estimates of the average “cue rate”, i.e., the number of calls by each animal.
**Big data aspects of marine mammal DCL&DE**

John A. Hildebrand\(^1\), Sean M. Wiggins\(^1\), Simone Baumann-Pickering\(^1\), Ana Sirovic\(^1\) and Marie A. Roch\(^1,2\)

\(^1\)Scripps Institution of Oceanography, University of California, San Diego, USA  
\(^2\)Department of Computer Science, San Diego State University, San Diego, USA

jhildebrand@ucsd.edu

Recent advances in digital data storage capacity and low power electronics have made it possible to collect long-term continuous broadband passive acoustic data and thereby capture the full range of marine mammal sound production in an ocean setting. Concomitant advances are needed in data curation, search, analysis, and visualization. We have developed methods to analyze and manage passive acoustic monitoring data that we are now acquiring at a rate of approximately 25 Tb/month. Initial stages of data processing include converting the data from the internal instrument format to a standard audio file format with metadata extensions and preparation of both working and archival copies of the data. Standardized spectra are calculated for all data using a minimum of three frequency bands: (1) high frequency up to 160 kHz, (2) mid frequency up to 5 kHz, and (3) low frequency up to 1 kHz. A set of 16 CPUs are operated in parallel for timely initial data processing. A number of automatic detectors are run on the data including: spectrogram correlation for blue whale call detection, energy detection for fin whale calls and anthropogenic sounds, power-law detector for humpback whale units, and Teager-energy based echolocation click detection and an expert system for beaked whale echolocation clicks. Software (Triton) has been developed for efficient manual scanning and signal discovery. The key feature of Triton is the capability to display spectrograms on virtually any time scale and provide an index between long-term spectral averages (minutes to days) and short-term spectrograms (sec to msecs). Analysis effort is also standardized using a detection logger feature, allowing multiple analysts to contribute to the same dataset with uniform coverage. Detections are aggregated into a database (Tethys) that allows combination of multiple datasets and association with environmental or other data.
Unsupervised Segmentation and Classification of Orca Vocalizations using the Fundamental Frequency Variation Spectrum

Florian Hönig\(^1\), Reyhan Sonmez\(^2\), Elmar Nöth\(^{1,3}\), Martha Manser\(^2\)

\(^1\)Pattern Recognition Lab, Friedrich-Alexander University Erlangen-Nuremberg, Germany
\(^2\)Institute of Evolutionary Biology and Environmental Studies, University of Zurich, Switzerland
\(^3\)Electrical & Computer Engineering Department, Faculty of Engineering, King Abdulaziz University, Jeddah 21589, Saudi Arabia.

hoenig@informatik.uni-erlangen.de

Orca acoustic dialects have been studied and recorded intensively for the past 20 years. The enormous amount of audio data available for this species calls for efficient and intelligent methods for automatic segmentation and classification into meaningful categories. We suggest applying automatic speech recognition (ASR) algorithms to this problem. Key components of ASR systems are Hidden Markov Models (HMMs) and an acoustic frontend. The HMMs model the temporal evolution of probability densities for observations created by the acoustic frontend. The latter captures the coarse shape of a short-time spectrum and its temporal dynamics. In order to successfully apply this technology to orca vocalizations, a specialized acoustic frontend needs to be developed. Fundamental frequency plays a crucial role in mammal vocalizations. In orca calls, pitch and its temporal trajectory seem to be one of the main information carriers, resulting in complex and diverse pitch curves. However, automatic pitch tracking is principally error-prone, especially in low signal-to-noise conditions. We therefore propose the application of the Fundamental Frequency Variation (FFV) Spectrum, which is an implicit representation of the derivative of pitch along time for a given short-time patch of audio. It has the advantage of being robust to noise, and does not suffer from the (octave) ambiguity in harmonic pitch detection. Thus, it seems an ideal candidate for the acoustic frontend needed for ASR techniques. The present study investigates the feasibility of this approach by using the FFV, a clustering technique and a simple single-state HMM to carry out an unsupervised segmentation task of continuous orca recordings. Resulting classes correspond well to human segmentations of the same data, with a precision approaching inter-annotator agreement. This automatic detection and classification system can easily be applied to other species and may enhance objectivity and comparability in the study of animal communication.
Improving time-delay estimation through pattern recognition techniques: An application to the tracking of fin whales at CTBTO hydroacoustic stations

Ludwig Houégnigan, Mike van Der Schaar, Adria Caballe, Michel André

Laboratori d’Aplicacions Bioacustiques,
Universitat Politècnica de Catalunya, Barcelona Tech
Vilanova i la Geltrú, Spain

Ludwig.houegnigan@lab.upc.es

In most approaches for passive acoustic localization of marine mammals, time-delay estimation is a decisive and challenging task. Adverse conditions such as low SNR and reverberation may induce corrupted position estimates with large bias and variance. A posteriori statistical filtering can improve results, yet a significant gain can also be achieved by improving as a prior step the time-delay estimation. Firstly, simulations and experiments were performed in air in a smart room with ground-truth data. This provided a closer look at the effect of different time-delay estimation models. The widely used "ideal model" (e.g. Cross-Correlation, GCC, LMS filter) was compared to the more complex multipath model and to the reverberant model. Both theoretically and practically, it was shown that under heavy noise, methods based on eigenvalue decomposition or signal subspace analysis outperformed the standard or generalized cross-correlation methods inasmuch as they permitted to better take into account the effects of the propagation channel. Secondly, the application of such methods to faint signals with little coherence was tested by identifying fin whale tracks at underwater observatories from the CTBTO networks (Cape Leeuwin Australia, Ascension Islands) and yielded more consistent results.
A detection function for beaked whales

Annamaria Izzi, Douglas Gillespie

Sea Mammal Research Unit, Scottish Oceans Institute, University of St Andrews, St Andrews, UK

ai7@st-andrews.ac.uk

The problems facing beaked whales are well documented. Passive acoustic monitoring offers one possible solution to the problem of better defining the distribution of beaked whales, and real time detection may play a role in protecting them from some anthropogenic activities. It has been suggested that the detection range for beaked whale clicks beyond 4 km is unlikely. In order to make an empirical assessment of the detection range, multiple passes at random distances from visually sighted beaked whales were made from a sailing vessel in 2008 at El Hierro. Beaked whales were detected using the PAMGuard click detector. Encounters were labeled as either Cuvier’s or Blainville’s beaked whale based on the spectral properties of clicks within each encounter. 126 click trains (58 Cuvier’s and 68 Blainville’s) provided a sufficiently clear track for localization using target motion analysis. To determine the perpendicular distance, detection functions were created with the Distance software using slant ranges, shallow depths (457 m for Cuvier’s and 426 m for Blainville’s), and deep depths (1000 m for Cuvier’s and 900 m for Blainville’s). Pooled and post-stratified species models were created to test whether there was a difference in the detection range. The detection function for slant range violated all goodness-of-fit (GOF) tests at the 95% level. The detection function using shallow depths only violated the K-S test. Using deep depths passed all GOF tests. Pooled models had better AIC scores and QQ-plots. The model with the best AIC and GOF was a pooled, deep depth hazard rate model, with an effective strip half-width of 2140 m, and a 95% confidence interval of 1595 – 2872 m (CV= 0.15). These results provide an empirical measurement, which is in line with theoretical expectations of detection range for these species. However, it should be noted that the detection range is likely to vary for different types of vessels (with different noise levels) and for different types of equipment.
The effects of variation in cetacean calling behaviour on PAM applications

Vincent M. Janik

Sea Mammal Research Unit, School of Biology, University of St Andrews

vj@st-and.ac.uk

Passive acoustic monitoring (PAM) is a widely used method to investigate cetacean presence and abundance in the wild. It is also a popular choice for monitoring cetaceans in areas of industrial activity either for mitigation or to study the effects of anthropogenic disturbance. While PAM is superior to visual surveys at night or in poor weather conditions, it is hampered by relying on consistent calling behaviour in animals. Unfortunately only few cetaceans show such consistency. Problems can be found at many levels: (1) Individual call rates vary greatly and small groups or single animals often do not vocalise for long periods of time. (2) Many species use adaptive silence when faced with a threat, which can compromise the usefulness of PAM for mitigation. (3) Geographic variation in call parameters is common due to the development of dialects through vocal learning. (4) Inter-group variation in call parameters in the same location can be as large as geographic variation. (5) Calling behaviour changes significantly with context, potentially leading to species misidentification. I will illustrate these problems with examples from bottlenose dolphins, where all of these patterns are an issue when using PAM. These problems in a well-studied cetacean should make us cautious when developing PAM methods for other species. Large data sets from a variety of locations and contexts are therefore required when developing and testing PAM and species identification methods.
Feature Selection and Extraction for Real-time Classification of Odontocetes in Open Ocean Environments

Susan Jarvis, David Moretti, Ronald Morrissey, Jessica Ward, Elena McCarthy

NUWC, Newport RI, USA

sjarvis@ece.wpi.edu

Monitoring and mitigating the effects of anthropogenic noise on marine mammals are active areas of research. Passive acoustics is an effective modality for remote monitoring of marine mammals. Key to both monitoring and mitigation using passive acoustics is the ability to automatically detect and classify animals in situ. A critical part in the development of automated detection and classification methods is the selection of the features which are used to differentiate among vocalizations from different marine mammal species, and also to differentiate marine mammal vocalizations from both ambient and anthropogenic noise. In practice, feature selection can be at least as important as algorithm selection in determining the efficacy of a classification system. This paper will discuss the selection of features specifically for detecting and classifying click vocalizations from two species of beaked whales (Mesoplodon densirostris and Ziphius cavirostris) as well as clicks from interfering dolphin species such as Grampus griseus. The detection and classification algorithms discussed are intended for processing high bandwidth streams of acoustic data in real-time. Thus, an important consideration in evaluating the efficacy of candidate feature sets is the computational cost of extracting the features. Results from real-time monitoring exercises using a class-specific support vector machine classifier will be presented.
A low cost open hardware/software platform for acoustic recording, detection, and monitoring.

Mark Johnson¹, John Atkins²

¹Scottish Oceans Institute, University of St Andrews, UK
²Leigh Marine Laboratory, University of Auckland, New Zealand

mj26@st-andrews.ac.uk

Passive acoustic monitoring (PAM) is providing key information about the presence/absence, abundance and habitat use of at-risk species. But as management decisions rely increasingly on PAM, it is critical that the methods used are reliable, well understood, and, to some extent, standardised. The open-source PAMGUARD software provides this for PC-based evaluation of acoustic data but there is currently no open hardware design for collecting and processing sound in the field. To address this, we have designed a miniature low-cost sound recording and detecting device for PAM, which is entirely open. The device is based on a low-power digital signal processor and is able to sample at up to 500 kHz while consuming less than 50 mW (e.g., giving 7 weeks endurance on a Lithium D cell). The software for the processor is multi-tasking allowing it to run real-time detection algorithms, compute noise spectra and store sound samples to an SD card concurrently. Sound can be recorded continuously, periodically or when detections are registered. A lossless compression algorithm increases the effective SD memory card capacity by a factor of 3-5. Detections and summary data can be reported in real-time through a serial port connected, for example, with a GSM or Iridium modem. Circuitry is included for self-calibration and self-noise measurements, making it possible to evaluate performance in situ. Our intention is that the device be a readily available reference platform for developing detection algorithms and for evaluating other PAM systems. Under the Gnu Public License, algorithms implemented on the device must themselves be open ensuring the full transparency of the methods.
Quantitative family classification between Phocoenidae and Delphinidae using simple two-band ratio comparison

Saho Kameyama\textsuperscript{1}, Tomonari Akamatsu\textsuperscript{2}, Ayaka Amaha Öztürk\textsuperscript{3,4}, Ayhan Dede\textsuperscript{3,4} and Nobuaki Arai\textsuperscript{1}

\textsuperscript{1}Graduate School of Informatics, Kyoto University
\textsuperscript{2}National Research Institute of Fisheries Engineering, Fisheries Research Agency
\textsuperscript{3}Faculty of Fisheries, Istanbul University
\textsuperscript{4}Turkish Marine Research Foundation (TUDAV)

kamesaho@bre.soc.i.kyoto-u.ac.jp

Passive acoustic monitoring has been widely used for the detection and density estimation of cetaceans. However, the acoustic classification of species is not fully established yet. Previous studies used the difference in acoustic characteristics of the clicks to identify Phocoenidae out of Delphinidae. However, the accuracy of this method was not well documented so far. In this study, we used two-band spectrum intensity ratio at 130 kHz and 70 kHz (we call it two-band ratio hereafter) to identify Phocoenidae and Delphinidae comparing with visual identification of species to assess accuracy of acoustic detection probability. In the Istanbul Strait, Turkey, one phocoenid species, harbor porpoise, and two delphinid species, short-beaked common dolphin and bottlenose dolphin have been observed. An acoustic event recorder (A-tag) with two hydrophones, which are most sensitive at 130 kHz and 70 kHz, respectively, was fixed at the bank of the middle of the Strait from 12 April to 1 June 2012. We obtained 639 click trains of delphinids, 104 click trains of harbor porpoise simultaneously confirmed by the visual observation of species. Averaged two-band ratio for each click train was calculated. We introduced two types of threshold, fixed threshold and dynamic threshold. The fixed threshold is the constant value at the intersection point of each distribution of two-band ratio and the dynamic threshold is selected depending on the mixed ratio of two families. Even changing mixed ratio of species between 26\% and 80\%, the dynamic threshold provided >80\% correct detection and <20\% false alarm for both species. Meanwhile, the fixed threshold provided 55\% correct detection for Phocoenidae and 93\% for Delphinidae. Results suggested the simple two-band comparison enables us to classify Phocoenidae and Delphinidae with high accuracy. In addition, proposed dynamic threshold had better classification performance than using fixed threshold for family classification.
Detection of noise and biological sound at America’s first offshore wind farm

Kaplan, Maxwell B, Sayigh, Laela S, and Mooney, T. Aran

Biology Department. Woods Hole Oceanographic Institution. USA

mkaplan@whoi.edu

Offshore wind farms can impact the marine acoustic environment in multiple ways, including through the introduction of substantial low-frequency impulse construction sounds (e.g., pile driving) and long-duration operational noise. These sounds may alter the spatial distribution of sound-producing marine organisms, but effects are unknown. We are currently collecting baseline soundscape recordings at the first proposed US wind farm site, Horseshoe Shoals, and an adjacent ‘control’ site within Nantucket Sound. This area may be used by dolphins, porpoises, minke, fin, humpback, and endangered North Atlantic right whales. It is also important habitat for seals, turtles and many fish species. This investigation seeks to (i) establish baseline sounds levels of human and biological activity at both sites and (ii) detect/characterize the natural variability of specific sound types and the overall noise level. Acoustic recorders have been deployed since April 2012, recording on a duty cycle (1 minute every 10 minutes) at a sample rate of 80 kHz. These recordings have been initially examined to identify characteristic biological and anthropogenic sounds in the area. Preliminary results suggest a high abundance and diurnal patterns of fish signals (likely cusk eel; Family Ophidiidae) and limited marine mammal vocalizations. On-going investigations involve parameterizing the characteristic call types that have been identified thus far in order to create automatic detection and classification algorithms.
Whistle classification in the California Current: A complete whistle classifier for a large geographic region with high species diversity

Jennifer L. Keating\textsuperscript{1}, Julie Oswald\textsuperscript{2}, Shannon Rankin\textsuperscript{1} and Jay Barlow\textsuperscript{1}

\textsuperscript{1}Marine Mammal & Turtle Division, Southwest Fisheries Science Center, NOAA National Marine Fisheries Service, La Jolla, USA
\textsuperscript{2}Bio-Waves Inc., Encinitas, USA

jennifer.keating@noaa.gov

The value of passive acoustics as a tool for studying marine mammals relies on the ability to detect and classify sounds associated with these species. Species classifications typically focus on a single species, or occasionally on a few species found within a geographic region. In an effort to improve our ability to classify species during shipboard population surveys, we have developed a complete automated classification algorithm that includes all whistling species found within a large geographic region, the California Current. We only included recordings acquired in or near the study area to minimize differences due to geographic variation in whistle structure. Whistles were extracted from archived recordings collected by Southwest Fisheries Science Center, Northwest Fisheries Science Center, Cascadia Research Collective, and Scripps Institution of Oceanography; species included: Baird’s beaked whale (Berardius bairdii), bottlenose dolphin (Tursiops truncatus), killer whale (Orcinus orca), long-beaked common dolphin (Delphinus capensis), short-beaked common dolphin (Delphinus delphis), Risso’s dolphin (Grampus griseus), and striped dolphin (Stenella coeruleoalba). Whistles used to train the classifier were taken from visually confirmed single-species detections that were at least 3 nm from visual or acoustic detections of other whistling species. PAMGUARD’s ‘Whistle and Moan Detector’ was used to automatically detect and extract whistles contours from recordings. Extracted contours were automatically sent to the ROCCA (Real-time Odontocete Call Classification Algorithm) module in PAMGUARD, which provides species identification. Future work will include testing the classifier on novel recordings and combining the results of the whistle classifier with click classifiers to improve the accuracy of odontocete species identification in the California Current.
Gliders, floats, and robotic sailboats - a review of recent advances in mobile autonomous passive-acoustic platforms

Holger Klinck¹, David K. Mellinger¹, Haru Matsumoto¹, Roland Stelzer², Neil M. Bogue³ and Jim Luby³

¹Cooperative Institute for Marine Resources Studies, Oregon State University and NOAA Pacific Marine Environmental Laboratory, Newport, USA
²Austrian Society for Innovative Computer Sciences, Vienna, Austria
³Applied Physics Laboratory, University of Washington, USA

Holger.Klinck@oregonstate.edu

Passive acoustic monitoring (PAM) is widely used for marine mammal research. It is typically conducted using hydrophone arrays towed behind ships, providing real-time data from large areas over short time spans (days to weeks), or using fixed autonomous hydrophones, providing non-real-time data from small areas over long time spans (months to years). In contrast, mobile autonomous passive-acoustic platforms can supply near-real-time data over spatiotemporal scales large in both space and time. These systems communicate via satellite with shore stations for navigation and control updates, and report in near-real time upon detecting marine mammal or other target signals on-board. Acoustically equipped gliders are buoyancy-driven devices capable of traversing long distances (hundreds of kilometres) over weeks to months of autonomous operation. Autonomous floats such as QUEphones drift with currents or park on the seafloor, rising to the surface upon detecting sounds of interest. Robot sailboats such as the Roboat use wind to propel themselves quickly over long distances. All platforms [1] use sophisticated low-power PAM boards to process acoustic data in real time, [2] can carry additional sensors (e.g., temperature, salinity, chlorophyll, pH, O₂), and [3] store large acoustic and environmental data sets. Autonomous mobile instruments are therefore well suited for investigating broader oceanographic and ecological questions. Advantages and disadvantages of these platforms for various applications as well as recent advances will be discussed.
Using Passive Acoustics to Monitor the Presence of Marine Mammals during Naval Exercises

Anurag Kumar¹, Jene Nissen², Joel Bell¹, Tom Norris³, Julie Oswald³, Tina Yack³, Elizabeth Ferguson³

¹Naval Facilities Engineering Command Atlantic, Norfolk, USA
²United States Fleet Forces Command, Norfolk, USA
³Bio-Waves, Inc., Encinitas, USA

anurag.kumar@navy.mil

Passive acoustic data collected from Marine Autonomous Recording Units during fall (13 September to 8 October) and winter (3 December to 8 January) 2009-2010 were analyzed for acoustic detections of marine mammals and patterns resulting from these detections. The study site coincided with the United States (U.S.) Navy’s planned Undersea Warfare Training Range (USWTR) located approximately 60-150 kilometers off Jacksonville, Florida. Acoustic data consisted of both 2-kilohertz (kHz) and 32-kHz sample rate recordings. Data were initially reviewed using long-term spectral averages, and then evaluated in greater detail from spectrograms using the MATLAB program Triton (Wiggins 2007). Probability of vocalization event occurrence was calculated for each species relative to sonar events. Species and species groups detected included minke whale, North Atlantic right whale, sei whale, (probable) humpback whale, sperm whale, blackfish, and unidentified delphinids. Results indicated that minke whales were present almost continuously during the winter deployment period. Right whale vocalizations were most concentrated during winter, as expected, but were also detected at deep sites (>300 meters), which was somewhat unexpected. Sperm whales occurred exclusively near the continental shelf break, and showed a strong diel pattern with almost all vocalization events occurring between dawn and dusk. There were less obvious patterns for delphinid vocalization events, perhaps because of the grouping of species. Future efforts will include improving species-specific analysis of delphinids. Blackfish were detected relatively infrequently but were most common at the shallow-water sites. Minke whales showed the strongest relationship between sonar events and vocalizations. The probability of minke whale vocalization events occurring in the presence of sonar activity was much less than in the absence of sonar. The results reported here provide an assessment of marine mammal occurrence and distribution within the U.S. Navy’s planned USWTR and insights on species-specific vocal responses to sonar events.
Cetacean Density Estimation from Single Sensors: 3 Species, Different Challenges

Elizabeth T. Küsel¹, Martin Siderius¹, David K. Mellinger²

¹NW Electromagnetics and Acoustics Research Lab., Portland State University, USA
²Cooperative Institute for Marine Resources Studies, Oregon State University, USA

kusele@alum.rpi.edu

Passive acoustic monitoring of marine mammals from data recorded by single sensors is a common practice. Recently, techniques have been developed to use such data sets to estimate population density of marine mammals. An important component of density estimation methods using passive acoustics is determining the probability of acoustically detecting an animal as a function of its distance from the receiving sensor. To this end, the distribution of signal-to-noise ratio (SNR) of detected calls can be compared to that of simulated SNRs of a large enough sample in order to estimate the detection function. To simulate SNR of a specific call type, a random distribution of animals in 3D space is created by taking into account depths where they are likely to produce such call, and their orientations with respect to the hydrophone. The passive sonar equation is then used along with a sound propagation model to estimate the SNR of received calls, and hence probability of detection. Probability of detection is finally converted into a density estimate by a statistical formula that takes into account false positive detections, the rate of call production, the maximum detection distance, and the time period of data analyzed. This technique has been applied to three different cetacean species namely, beaked whales (Mesoplodon densirostris), and sperm whales (Physeter macrocephalus) in the Bahamas, and false killer whales (Pseudorca crassidens) off the Kona coast of the Island of Hawaiʻi. They all produce high frequency foraging clicks, which was the type of call chosen for the studies. Density estimates are presented for the three species along with the different approaches to the modeling technique and the challenges encountered. Possible model improvements and future directions will also be discussed.
Automated vs. manual detection of delphinid signals in long-term passive acoustic data from the Northwestern Hawaiian islands

Marc Lammers$^{1,2}$, Helen Ou$^1$, Whitlow Au$^1$, Maegan Krauss$^2$, Helen Meigs$^2$

$^1$Hawaii Institute of Marine Biology, Kaneohe, Hawaii, USA
$^2$Oceanwide Science Institute, Honolulu, Hawaii, USA

lammers@hawaii.edu

Detecting the occurrence of odontocete sounds in long-term passive acoustic data is challenging because signal-to-noise ratios and signal characteristics can be highly variable. Manual analysis is generally time consuming and results in a trade-off between the detection precision/recall rate and the labour hours expended. Automated detection algorithms are therefore an attractive alternative, but these must be validated to establish their functionality. Here we present the results of an effort to compare the performance of an automated odontocete whistle detector with a manual analysis effort. The detector used a filter bank consisting 15 band pass filters, from 4.5 kHz to 19.5 kHz, with 1 kHz bandwidth. The outputs from each filter were analyzed using an envelope energy detector to extract segments with higher-than-background (envelope) amplitudes. Whistle signals were reconstructed synthetically based on segments extracted from all the frequency bands. Manual analysis of the data was conducted by inspecting long-term spectral averages (LTSAs) for the presence of dolphin signals using the Matlab program Triton. The data used for the comparison were from four Ecological Acoustic Recorders (EARs) deployed in the Northwestern Hawaiian Islands between 2010-11. The detector had generally high precision (low rate of false positive detections), with rates ranging between 100% and 73.4% correct, depending on location. However, it had a more variable recall rate (a measure of false negative detections), ranging between a 68.7% and 38.7% correct. In comparison, manual analysis yielded a precision between 100% and 85.2% correct, and a recall rate between 95.8% and 81.7% correct, depending on location. In addition, there was evidence of seasonal variability, with the detector’s performance generally higher in summer than in winter. These results highlight the utility of automated detectors, but also the need to verify their performance under different in situ circumstances.
Right Whale activity detector and sound classifier using Mel-frequency Cepstral Coefficients

Guillermo Lara, Ramón Miralles, Alicia Carrión

Instituto de Telecomunicación y Aplicaciones Multimedia (iTEAM), Universidad Politécnica de Valencia, SPAIN.

guilamar@iteam.upv.es

Mel-frequency cepstral coefficients (MFCCs) have proven to be a valuable tool in speech synthesis and recognition as well as in music information retrieval applications such as audio similarity measures. The mel scale approximates many animals auditory system’s response more closely than the linear-spaced frequency bands and gives, in some species, superior classification percentages than some other features extraction techniques. Following this idea, we present an algorithm that applies the MFCCs for classification and detection of cetacean sounds, particularly to the right whales. The choice of this approach is motivated by a desire to obtain a more accurate detection and classification of a given whale sound specie in low Signal to Noise Ratio (SNR) recordings. Additionally, using MFCCs makes not necessary to compute spectrogram related features making this algorithms more appropriated to work in real time automatic detection systems. The performance of the proposed algorithm is illustrated using data from the 6th DCL&DE workshop dataset. The results show that it is possible to obtain high detection and classification percentages in the given categories: gunshots and upsweeps. The method provides robust detection of upsweeps even in low SNR scenarios and very good detection ratios of gunshots in moderate SNR conditions. In addition the method can be used to identify sounds from other species.
Separation of odontocete click trains by rhythmic analysis

Olivier Le Bot\textsuperscript{1,2}, Yvan Simard\textsuperscript{3,4}, Jérôme I. Mars\textsuperscript{2}, Cédric Gervaise\textsuperscript{2,5}

\textsuperscript{1}Pôle STIC, ENSTA Bretagne, Brest, France
\textsuperscript{2}GIPSA-lab, Grenoble Institute of Technology, Université de Grenoble, France
\textsuperscript{3}Marine Science Institute, University of Quebec at Rimouski, Quebec, Canada
\textsuperscript{4}Maurice Lamontagne Institute, Fisheries and Oceans Canada, Quebec, Canada
\textsuperscript{5}Chaire CHORUS, Foundation of Grenoble Institute of Technology, Grenoble Cedex 1, France

olivier.le_bot@ensta-bretagne.fr

Most odontocetes live in pods of several individuals, resulting in an overlapping of click trains recorded by passive acoustic monitoring systems. Localization algorithms and click classifiers are usually used for train separation. However, their performances fall down if individuals are too close to each other or if acoustical parameters vary greatly from click to click, respectively. Assuming odontocete clicks follow rhythmic patterns, we propose to use a rhythm analysis to separate mixed click trains using a single hydrophone. The proposed algorithm is based only on inter-click-intervals (ICI) to cluster clicks into trains. It uses information given by complex-valued autocorrelation to compute a histogram, which will exhibit peaks at ICIs corresponding to interleaved trains. By this technique, sub harmonics corresponding to multiples of ICIs are automatically suppressed. The algorithm is then extended by a time-period analysis leading to a time-varying ICI spectrum. A threshold can be applied on this spectrum to detect the different interleaved trains. The final result is a binary time-ICI map on which trains can be fully and easily distinguished. From this binary map we can retrieve which clicks belong to each identified click-train and extract them so that click trains of each individual are now isolated from the others. We check that all clicks belonging to the same click train have similar temporal and spectral features and suppress misclassified clicks according to these features. We validate our method on real click trains of Beluga Whales recorded in the Saint Lawrence gulf. The proposed algorithm is particularly suitable as a pre-processing tool prior to localization, density estimation and classification schemes.
Abundance estimates for sperm whales in the south western and eastern Mediterranean Sea from acoustic line-transect surveys

Tim Lewis¹, Justin Matthews¹, Oliver Boisseau¹, Magnus Danbolt¹, Douglas Gillespie², Claire Lacey³, Russell Leaper¹, Richard Mclanaghan¹ and Anna Moscrop¹

¹International Fund for Animal Welfare, London, UK
²Sea Mammal Research Unit & ³Sea Mammal Research Unit Ltd., Scottish Oceans Institute, University of St. Andrews, UK

tim.p.lewis@gmail.com

The Mediterranean is a semi-enclosed sea containing a sub-population of sperm whales (Physeter macrocephalus), proposed for listing in the IUCN Red List classified as endangered by the IUCN and believed to be isolated from the Atlantic population. Evidence shows that sperm whales are being impacted by various anthropogenic threats in the Mediterranean, especially from drift-netting which continues despite international and national regulations banning their use, and that the population is declining. Further data are needed to assess population changes and inform conservation actions. In 2004 an acoustic line-transect survey was conducted in the south-western basin of the Mediterranean. Analysis of recordings from 3,946 km of acoustically surveyed track produced perpendicular distances to 159 sperm whales. Distances to individual whales were determined even when animals were in large aggregations, the largest of which comprised over 23 animals. Conventional Distance Sampling (CDS) analysis gave an effective strip half-width (ESW) of 10.0km. Assuming that \( g(0) = 1 \) this gives an abundance estimate for the survey block of 586 animals [95% CL 333-1,033]. The results show a considerable density of sperm whales concentrated in the central abyssal part of the south-western basin. In 2007 an acoustic line-transect survey was conducted in six survey blocks in the eastern Mediterranean. A total of 9,460km of track were surveyed acoustically; yielding detections of 21 sperm whales in just three blocks: Hellenic Trench (19), S Adriatic (1) and Herodotus Rise (1). This provided too few detections to determine stratum-specific detection functions, so data were pooled with the 2004 SW Mediterranean data, resulting in an ESW of 9.8km and the following abundance estimates: Hellenic Trench: 39 animals [15-100], S. Adriatic: 2 [1-18] and Herodotus Rise: 4 [1-41]. Refinements to the data analysis were investigated; these included assessing the potential bias introduced from using ‘slant’ distances to diving whales instead of perpendicular distances, and addressing the issue of manual attribution of temporally isolated click trains to individual whales with a probabilistic analysis.
Porpoises and tidal turbines, fine scale tracking using passive acoustics to assess and mitigate collision risk

Jamie Macaulay, Doug Gillespie, Simon Northridge and Jonathan Gordon

Sea Mammal Research Unit, Scottish Oceans Institute, University of St. Andrews, UK

jdjm@st-andrews.ac.uk

The growing interest in generating electrical power from tidal currents using tidal turbine generators raises a number of environmental concerns, including the risk that cetaceans might be injured or killed through collision with rotating turbine blades. To understand this risk we need to understand better how cetaceans use tidal rapid habitats and in particular their underwater movements and dive behaviour. Porpoises, which are the most abundant small cetacean at most European tidal sites, are difficult animals to tag, and the limited size of tidal habitats means that any tagged animal is likely to spend only a small proportion of time within them. Using wide aperture hydrophone arrays we have developed a practical passive acoustic system to accurately track porpoises and other echolocating cetaceans in tidal areas. Probabilistic localisation algorithms, echo-detection and hydrophone movement models have been integrated into a new localisation module within PAMGUARD, allowing terabytes of data from large scale surveys to be processed efficiently. We summarise the hardware and software developments that have made this possible. Our results show 3D underwater movements, echolocation and foraging behaviours of porpoises from several sites. We directly assess the accuracy of acoustic tracking in tidal areas through calibration experiments and discuss the potential of this system to provide the information needed by industry to exploit these poorly understood habitats whilst also limiting impacts on cetaceans.
The Silbido tonal detector

Michael MacFadden¹, Arik Kershenbaum², Marie A. Roch¹,³

¹Department of Computer Science, San Diego State University, San Diego, USA
²National Institute for Mathematical and Biological Synthesis, The University of Tennessee, Knoxville, USA
³Scripps Institution of Oceanography, University of California, San Diego, USA

marie.roch@sdsu.edu

Silbido is a tonal detector that assembles time frequency peaks into graph structures. Whistle crossings in complex scenes become internal nodes of the graph that are subsequently analysed to determine individual calls using information surrounding tonal crossing points. Alternate work by the authors has proposed using ridge tracking to exploit morphological features in spectrogram space (The image processing ridge tracker: IPRiT). The alternate approach improves the precision of the detections at the cost of missed detections. In this work, we examine the performance of a hybrid system that uses tonal ridges and time-frequency peaks in areas adjacent to ridges. Performance is evaluated using the metrics developed for the 2011 DCLDE conference.
Robust automatic detection of Gabor-like clicks of biological origin

Shyam Madhusudhana, Christine Erbe, Alexander Gavrilov

Centre for Marine Science & Technology, Curtin University, Perth, Australia
s.madhusudhana@postgrad.curtin.edu.au

The Teager-Kaiser Energy Operator (TKEO) has been used by several bioacousticians for the automatic detection of underwater echolocation clicks. Prior research has shown that underwater echolocation clicks of several species can be modelled as Gabor functions. We briefly present the mathematical theory of applying the TKEO to discrete Gabor signals and then present the real-world performance of an automatic click detector based on the TKEO output of largely Gabor-type signals. We show, both theoretically and with simulations, that the output of the TKEO on discrete Gabor signals can be approximated by a Gaussian function. The dependence of the TKEO outputs on the form parameters of the input Gabor signals and on the sampling rate of the recordings is discussed, as well as the effect on the detectability of the underlying clicks. Two different filters, a Gaussian and a rectangular filter, are applied to the TKEO output in real-time. We show that the ratio of the two filter outputs is an effective detector for clicks and more robust to changing noise conditions and low signal-to-noise ratios than if an absolute threshold were applied directly to the TKEO output. The overall system exhibits low computational complexity, works several thousand times faster than real-time, and works readily with a wide range of recording scenarios without requiring any modifications. The validity of the theoretical findings and of the simulations is supported by a case study using real world recordings containing odontocete echolocation clicks. Detector performance as a function of signal-to-noise ratio is assessed. Receiver-operator curves are presented for our detector and conventional TKEO detectors.
Long term remote monitoring of cetaceans using a solar powered autonomous detector

Andy Maginnis¹, Doug Gillespie², Gordon Hastie², Cormac Booth³, Dick Baggaley¹

¹MIL Ltd, St Andrews
²Sea Mammal Research Unit, University of St Andrews
³SMRU Ltd, St Andrews

jam@smru.co.uk

The use of autonomous passive acoustic devices is now well established as a method for long term cetacean monitoring. However, the duration of most deployments are restricted by battery life and, particularly when monitoring at high frequencies, by available storage space. We present a system for long term monitoring of cetaceans using a solar powered system in which real time detection algorithms for multiple species can run concurrently on an embedded processing platform. Sample rates of up to 500kHz can be achieved, making the system suitable for the detection of all known cetacean calls. Data volumes of detected calls were typically below 1 Megabyte a day, meaning that data could be transmitted ashore in near real time using cell or satellite phone networks. The combination of solar power, real time processing and data transmission means that deployment lifetimes are limited only by the mechanics of the mooring and the need to remove bio-fouling from hydrophones. We present to results of a deployment to date (approximately 10 months) off the east coast of Scotland in terms of numbers of dolphin and harbour porpoise detections, and discuss the potential possibilities and pitfalls associated with long term passive acoustic datasets.
Have you heard about it? The perfect passive acoustic density estimation survey is out there and we are looking for it!

Tiago A. Marques$^{1,2}$, Danielle Harris$^1$, Len Thomas$^1$

$^1$Centre for Research into Ecological and Environmental Modelling, University of St Andrews, UK  
$^2$Centro de Estatística e Aplicações da Universidade de Lisboa, Lisboa, Portugal

tiago@mcs.st-and.ac.uk

Passive acoustic density estimation is becoming a blooming field, especially for animals like cetaceans which are often elusive and difficult to detect visually but are readily available for acoustic detection. A number of papers have been published in recent years, covering a variety of species and analytical methods. However, most of these have been proof-of-concept approaches; often under hard to recreate conditions (e.g., leveraging costly navy ranges facilities). In this talk we will review what are the potential characteristics of an optimal survey, in terms of sensors to be used, sensor location, species, types of signal to be considered, analysis method to apply, etc. We will also provide examples of existing cases studies in which some, but never all of these characteristics, were present. We finish by presenting a hypothetical example of such a survey, and hope that, as a group, we can leave the DCL knowing where the perfect survey might be, and that at the next DCL we might be reporting its first results.
The use of automated DCL techniques for estimating receive sound pressure levels that minke and beaked whales are exposed to during a US Naval training event involving mid-frequency active sonar

Stephen W Martin, Roanne Manzano-Roth and Brian Matsuyama

Space and Naval Warfare Systems Center Pacific
San Diego, CA, USA

steve.w.martin@navy.mil

Automated passive acoustic detection, classification and localization (DCL) methods are utilized to deal with large volumes of acoustic data for a variety of reasons. Automated DCL methods are utilized to support estimating the sound pressure levels (SPLs) that marine mammals are exposed to from mid-frequency active sonar (MFAS) during US Naval training events. Estimating these SPLs requires knowing where the ship is when it transmits sonar and where the animal(s) are at the time of sonar transmissions. Automated DCL methods are applied to a training event involving MFAS conducted February 2011 in Hawaiian waters with thirty one hydrophones of data collected continuously over an 11 day period. The automated methods determine locations of marine mammals, specifically minke and beaked whales, and the times of the MFAS transmissions. The amount of time required to perform the automated processing is reduced by employing custom C++ algorithms. Streamlined manual validation methods utilize Matlab display functions. Animal locations have uncertainty associated with them ranging from a few dozen meters in the case of the minke whales to multiple kilometers in the case of beaked whales. Once the transmitting ship and animal locations are determined acoustic propagation modelling is utilized to estimate the sound pressure levels (in dB re micro Pascal) that an animal, or group of animals, were exposed to. Surface ducted propagation conditions can result in species such as beaked whales being exposed to over 30dB higher SPL’s when they return to the surface to breathe compared to when at depth foraging.
Range-depth tracking of sperm whale sounds over large distances by exploiting the high-latitude sound speed profile

Delphine Mathias¹, Aaron Thode¹, Janice Straley², Russel Andrews³

¹Marine Physical Laboratory, Scripps Institution of Oceanography, UCSD, CA, USA
²University of Alaska, Southeast, Sitka, AK, USA
³Alaska SeaLife Center, Seward, AK, USA

athode@ucsd.edu

Sperm whales (Physeter macrocephalus) have followed fishing vessels off the Alaskan coast for decades, in order to remove sablefish ("depredate") from longlines. The Southeast Alaska Sperm Whale Avoidance Project (SEASWAP) has found that whales respond to distinctive acoustic cues made by hauling fishing vessels, as well as to marker buoys on the surface. Between 15-17 August 2010 a simple two-element vertical array was deployed off the continental slope of Southeast Alaska in 1200 m water depth. The array was attached to a longline fishing buoyline at 300 m depth, close to the sound-speed minimum of the deep-water profile. The buoyline also served as a depredation decoy, attracting seven sperm whales to the area. One animal was tagged with both a LIMPET dive depth-transmitting satellite and bioacoustic “B-probe” tag. Both tag datasets were used as an independent check of various passive acoustic schemes for tracking the whale in depth and range, which exploited the elevation angles and relative arrival times of multiple ray paths recorded on the array. Analytical tracking formulas were viable up to 2 km range, but only numerical propagation models yielded accurate locations up to at least 35 km range at Beaufort sea state 3. Neither localization approach required knowledge of the local bottom bathymetry. The tracking system was successfully used to estimate the far-field apparent source level of an individual sperm whale's "clicks" and "creaks", predict the maximum detection range of the signals as a function of sea state in Northern Pacific Waters, measure the drift of several whales away from the decoy over time, and estimate source levels of several animals. [Work supported by the North Pacific Research Board, the Alaska SeaLife Center, ONR, and NOAA].
A method to investigate fin whale vocalizations using hydrophone and 3-component seismic recordings on the seafloor

Luis Matias¹, Danielle Harris²,³, David K. Mellinger⁴, Len Thomas²,³, Wolfram Geissler⁵

¹Instituto Dom Luiz, Lisboa, Portugal  
²Centre for Research into Ecological and Environmental Modelling, St. Andrews, UK  
³Scottish Oceans Institute, St. Andrews, UK  
⁴Cooperative Institute for Marine Resources Studies, Oregon State University, USA  
⁵Alfred Wegener Institute, Bremerhaven, Germany

lmatias@fc.ul.pt

Monitoring marine mammals using static acoustic sensors is a common practice but a costly one particularly in the deep ocean. For this reason datasets acquired for other purposes, like seismic monitoring, are extremely useful and valuable. Here we describe the procedures and methodology used to analyse fin whale (Balaenoptera physalus) calls recorded on an array of 24 ocean bottom seismometers (OBSs). The array was deployed in the Gulf of Cadiz for nearly one year, between the summer of 2007 and the summer of 2008. Each OBS had one 3-component seismometer and one hydrophone providing a 4 component continuous dataset. The sensors are located far from each other and so traditional triangulation methods cannot be applied. Instead we propose a single-station location algorithm that is adequate for sparse arrays of OBS, typical of passive seismic experiments in the ocean. First the fin whale calls are detected using a matching filter. The detection process generates a number of diagnostic parameters that is used to select the signals that correspond to primary arrivals with an incidence on the seafloor less than the critical angle. Finally the position of the sound source is recovered at the surface by geometrical optics that takes into consideration the properties of the sediments and water layer. The proposed method was tested using data from an air-gun seismic survey and results obtained proved its usefulness and accuracy. When applied one year continuous datasets the method reveals a clear seasonal variation in fin whale vocalizations.
Automatic detections of fin whale calls from the Deep Sea Floor Observatory, Kushiro-Tokachi, 2009-2012

IKuo Matsuo¹, Tomonari Akamatsu², Ryoichi Iwase³, Katsuyoshi Kawaguchi⁴

¹Tohoku Gakuin University, Izumi-ku, Sendai, Miyagi, Japan
²National Research Institute of Fisheries Engineering, Fisheries Research Agency, Hasaki, Kamisu, Ibaraki, Japan
³JAMSTEC, Kanazawa-ku, Yokohama, Japan
⁴JAMSTEC, Yokosuka, Kanagawa, Japan

matsuo@cs.tohoku-gakuin.ac.jp

Automatic acoustic detection and tracking are useful methods in gathering information regarding behaviour and population statistics of marine animals. Acoustic data were recorded at a sampling frequency of 100 samples per second with four hydrophones located on the ocean floor off Kushiro and Tokachi subprefectures, Hokkaido Prefecture, Japan. The fin whale calls, consisting of frequency down-sweeps over the range 20-15 Hz with a duration of about 1 second, were automatically identified by extracting such down-sweep signals from the acoustic data gathered over 1457 days between 2009 and 2012. Using manually detected calls, correct detection and false alarm of the algorithm was 82.6 % and 7.7 %, respectively. The number of detected calls showed clear seasonal difference, high in October-February period. Additionally, whale movements can be estimated by computing time differences between calls detected at two well-separated hydrophones.
Signal conditioning techniques for marine mammal vocalizations

David K. Mellinger

Cooperative Institute for Marine Resources Studies, Oregon State University and NOAA Pacific Marine Environmental Laboratory, Newport, OR 97365, USA

David.Mellinger@oregonstate.edu

Bioacoustic signals in the marine environment typically contain certain types interfering sounds and wideband background noise. Several conditioning techniques can be applied to these signals to reduce or even remove this noise and interference, thus making the biological sounds – particularly marine mammal vocalizations – more prominent, and also putting signals into a canonical form. Both of these effects make DCL tasks easier. The most widespread method uses automatic gain control to adjust the signal level according to a long-term average intensity, making it simpler to set a threshold. An extension of this is to make a long-term estimate of the noise level in each frequency band of a spectrogram and subtracting this estimate from the spectrogram, thus whitening the noise spectrum and removing relatively stationary noise sources such as propellers and motors. However, this method affects relative spectrum levels, which are used, for instance, in detection and classification of echolocation clicks. Another method involves estimating the spectrum in a series of narrow bands at each time step and subtracting this spectrum estimate from the corresponding spectrogram frame; this method is useful for tonal sound detection and classification in that it removes short-duration clicks from snapping shrimp and echolocating animals. Another method uses mathematical morphology techniques (opening and closing) to smooth a spectrogram and remove extraneous bits of noise. Examples and performance characterization of these methods are presented. [Funding for this work was provided by Navy N45 and ONR.]
Long-range acoustic detection and localisation of Antarctic blue whales

Brian Miller¹, Jay Barlow², Susannah Calderan¹, Kym Collins¹, Russell Leaper¹

¹Australian Marine Mammal Centre, Australian Antarctic Division
²NOAA, Southwest Fisheries Science Centre

brian.miller@aad.gov.au

The Southern Ocean Research Partnership (SORP) has developed an Antarctic Blue Whale Project which includes research to derive a mark-recapture abundance estimate for Antarctic blue whales. Tracking blue whales through passive acoustic monitoring has been identified as a potential means for increasing encounter rates, and thus facilitating abundance estimates through photo-identification and biopsy. This methodology was pursued by the Australian Antarctic Division (AAD) using DIFAR sonobuoys to detect, localise and track Antarctic blue whales on a research cruise from 165° W to 140° E, and south of 60°S between January and March 2013. Antarctic blue whales make loud and distinctive calls, comprising ‘Z’ and ‘D’ calls. The loudest element of the ‘Z’ call (a 26Hz tone) was detected at a range of hundreds of kilometres. 26Hz calls were detected on all DIFAR sonobuoys deployed south of 52°S (n= 298). Whilst these calls often apparently merged into a continuous tone, it was still possible to select individual calls which could be localised. Bearings from these vocalising whales allowed them to be acoustically tracked and targeted. Multiple sonobuoys were used to triangulate the location of individuals or groups. Received levels of detections increased with decreasing range to eight acoustic ‘hotspots’ in the survey area, where whales were sighted. At these closer distances, full ‘Z’ calls and ‘D’ calls were also detected. 90% of acoustic targets where these vocalisations were detected were encountered visually, yielding 40 encounters with groups of blue whales. Acoustic propagation models were investigated to help explain the long-range detections that were observed. Source levels were estimated for different call-types from whales at known locations.
Melon-headed whale (Peponocephala electra) whistle characteristics for use in automatic detections

Mooney, T. Aran¹, Kaplan, Maxwell B¹ and Baird, Robin W.²

¹ Biology Department. Woods Hole Oceanographic Institution. Woods Hole, USA
² Cascadia Research Collective, Olympia, USA

mkaplan@whoi.edu

Melon-headed whales (Peponocephala electra) are found throughout the tropics, primarily in pelagic waters but near-shore around oceanic islands. To date, only a small number of investigations of the vocal behavior of this species have been carried out, which has limited the capacity to define acoustic signals. As a result there is currently a lack of automatic acoustic classification algorithms for this rarely sighted species. Passive acoustic tools, including suction-cup attached acoustic tags (DTAGs) and a novel recording tool, the DMON, were used to gather baseline bioacoustic behavior data from two distinct melon-headed whale populations – the Hawai‘i Island Resident stock (HIR) and the Hawaiian pelagic stock (HIP). Three animals were tagged for ~40 minutes each, two from the HIR population (estimated group sizes 280 and 350 individuals) and one from the HIP population (estimated group size of 350 individuals) over the course of a two-year period. In total, 1096 and 329 whistles have been identified from the HIR and HIP tag recordings, respectively. Analysis of these recordings includes spectral and temporal characteristics of the whistles, variability of these signals and whistle type categorizations. Preliminary investigations suggest some but limited variation between melon-headed whale populations in whistle duration (mean: HIR - 0.7 s; HIP - 0.8 s), start frequency (mean: HIR – 3.7 kHz; HIP – 4.1 kHz), end frequency (mean: HIR – 11.6 kHz; HIP – 12.1 kHz), and peak frequency (mean: HIR – 9.0 kHz; HIP – 7.4 kHz). Additional data describing a larger whistle sample size and with further measurements will be examined in order to parameterize automatic detection and classification algorithms for melon-headed whales in Hawaiian waters.
The derivation of a risk function for Blainville’s beaked whales using passive acoustics

David Moretti\textsuperscript{1}, Len Thomas\textsuperscript{2}, Tiago Marques\textsuperscript{2}, John Harwood\textsuperscript{2}, Ashley Dilley\textsuperscript{1}, Bert Neales\textsuperscript{1}, Jessica Ward\textsuperscript{1}, Elena McCarthy\textsuperscript{1}, Leslie New\textsuperscript{3}, Susan Jarvis\textsuperscript{1}, Ronald Morrissey\textsuperscript{1}

\textsuperscript{1}Naval Undersea Warfare Center, Newport, RI, USA
\textsuperscript{2}University of St Andrews, St. Andrews, Scotland
\textsuperscript{3}U.S. Marine Mammal Commission, Bethesda, MD, USA

David.moretti@navy.mil

A risk function that relates the probability of disturbance to a received level of sound is a critical component of environmental compliance. For deep diving, sonar-sensitive beaked whales that spend little time on the surface, derivation of a risk function for sound exposure is difficult. In this study, passive acoustic techniques were applied to the derivation of an empirical risk function for Blainville’s beaked whales (Mesoplodon densirostris). The hydrophone array at the Atlantic Undersea Test and Evaluation Center range was used to locate vocalizing groups of beaked whales and sonar transmissions before, during, and after Mid-Frequency Active sonar operations. Sonar transmission times and source levels were combined with ship tracks using a Comprehensive Acoustic Simulation System Gaussian Ray Bundle (CASS/GRAB) model to estimate the receive level at each hydrophone. Baseline data from the period before sonar operations were compared to data recorded during sonar operations to derive the probability of disturbance. Data on the presence or absence of Blainville’s beaked whale foraging dives and the corresponding sonar Root Mean Squared (RMS) receive level (dB re µPa) on the hydrophone were fitted to a Generalized Linear Model. This model was then used to parameterise a risk function that can be used to estimate the number of behavioral changes, in this case cessation of foraging, that a population of Blainville’s beaked whales might experience during a period of anthropogenically-induced disturbance.
Inter-click interval (ICI) as a mechanism for differentiating between Mesoplodon densirostris (Md), Ziphius cavirostris (Zc), and Grampus griseus (Gg)

R. Morrissey, D. Moretti, S. Jarvis, E. McCarthy, J. Shaffer, and A. Dilley

Naval Undersea Warfare Center, Newport, RI, USA

Ronald.morrissey@navy.mil

Automated identification of beaked whales based on their acoustics is an active research area due to their involvement in mass stranding events linked to mid-frequency active SONAR (MFA). Many detection algorithms detect and classify on a per-click basis based on the spectral and temporal characteristics of the click. However, due to both the directionality of the emitted click and the effects of noise, clicks from multiple species are easily confused. This is particularly true for clicks from Zc and Gg. This paper discusses a histogram based method of determining inter-click interval, and uses that method to analyze click trains from Md, Zc, and Gg. Mean ICIs are derived for each species, as well as stability estimates. Real-time performance on data from the AUTEC and SCORE acoustic ranges is included.
**Improving the performance of marine mammal call classifiers using contextual information**

Xavier Mouy¹, Julie Oswald¹, Bruce Martin²

¹JASCO Applied Sciences, Victoria, British Columbia, Canada.
²JASCO Applied Sciences, Dartmouth, Nova Scotia, Canada.

xavier.mouy@jasco.com

The sensitivity of automated classifiers can typically be modified by adjusting a decision threshold. Results from a classifier are accepted only if their confidence index exceeds the decision threshold value set by the operator. A typical approach for choosing the threshold is to calculate the performance of the classifier using several threshold values and select the one that provides the best trade-off between false alarms and missed calls. In this approach, the decision threshold is constant for the entire analysis, which may not be optimal as acoustic conditions change over time. For instance, presence of noise at certain times will tend to create false alarms and is likely to require a more restrictive decision threshold. In this paper, we investigate a method based on a Random Forest regression model that automatically adapts the value of the decision threshold over time based on the acoustic context of the recordings. Inputs to the regression model include features describing acoustic context, such as the number and frequency of vessel tonals and classification results from other marine mammal call classifiers. The output of the model is the value of the decision threshold. The model was trained and tested on two independent acoustic datasets collected in the Arctic Ocean, each containing more than 100 hours of manually reviewed and annotated recordings. To test the efficiency of this approach, the method was tested on a walrus classifier where false alarms included seismic survey activity and bowhead calls, and a beluga classifier where false alarms were mostly due to ice sounds. Performance of the regression model was quantified by calculating the root mean squared log error between the predicted and optimal threshold values from the model and the human analysts respectively. The overall increase in performance of the classifiers was also calculated using precision and recall metrics.
Detection of right whale up-calls and gunshots using Random Forest

Xavier Mouy\textsuperscript{1}, Julie Oswald\textsuperscript{1}, Bruce Martin\textsuperscript{2}, David K. Mellinger\textsuperscript{3}, Jessica L. Crance\textsuperscript{4}, Catherine L. Berchok\textsuperscript{4}

\textsuperscript{1}JASCO Applied Sciences, Victoria, British Columbia, Canada
\textsuperscript{2}JASCO Applied Sciences, Dartmouth, Nova Scotia, Canada
\textsuperscript{3}Cooperative Institute for Marine Resources Studies, Oregon State University, USA
\textsuperscript{4}National Marine Mammal Laboratory, Alaska Fisheries Science Center, NOAA Fisheries, Seattle, USA

xavier.mouy@jasco.com

North Atlantic (Eubalaena glacialis) and North Pacific (Eubalaena japonica) right whales are both critically endangered. The main threats to these species are ship strikes and entanglement in fishing gear. Understanding and mitigating the impact of human activities on these species is critical for their survival. Passive acoustic monitoring is an effective tool that allows detection of vocalizing animals over large distances and extended periods of time. A limitation of this approach is the ability to accurately process the data collected in a timely manner. In this paper, we investigate two techniques for the automatic detection of right whale up-calls and gunshot sounds. The detection of gunshots was performed in three steps. 1) A band-limited energy detector was used to detect impulsive events in the 10-800 Hz frequency range, 2) each detected impulse was characterized using 22 features that represented the distribution of acoustic energy over time and frequency, and 3) detections were presented to a 2-class Random Forest classifier (“noise” vs. “gunshot”). Up-calls were detected by 1) extracting time-frequency contours of tonal sounds from the spectrogram, 2) characterizing each contour using 46 features, and 3) presenting features to a 2-class Random Forest classifier (“noise” vs. “up-call”). The number of trees in the Random Forest and the importance of features used were defined during the training phase and will be discussed. Both methods were trained on one third of the DCL workshop dataset and tested on the two remaining thirds. Detection performance was evaluated based on the precision and recall metrics for various signal-to-noise ratios. Detectors/classifiers were also tested on 6 months of acoustic recordings collected in the Bering Sea in summer 2009 and containing North Pacific right whale up-calls and gunshots. Applicability of the developed methods for real-time monitoring will also be discussed.
Signal de-noising, a comparison of techniques for improving acoustic marine mammal classification tasks

Nicole Nichols, Mari Ostendorf

University of Washington

nmn3@uw.edu

Effective removal of noise is a significant obstacle to working with real-world acoustic data. Marine mammal detection, classification, and localization tasks are essential for long term habitat monitoring but these tasks are frequently hindered by poor signal-to-noise ratios associated with a large variety of natural and man-made noises, most of which are non-stationary in nature. In this research we compare different noise reduction strategies generally based on spectral subtraction but using different methods for estimating noise, with a focus on detecting whistles from different species. One method uses an unsupervised observation-dependent noise estimate that first iteratively detects and removes clicks and then estimates slowly varying noise via 2d median smoothing on the spectrogram. Another method uses supervised training of non-negative matrix factorization (NMF) bases to represent different noise types. The first method can handle unseen noises, but the second is particularly well suited for dynamic noise sources. The two approaches are somewhat complementary and can be combined to improve detection of whistles. Analysis is performed using data from the 5th International Workshop on Detection, Classification, Localization, and Density Estimation (DCLDE) of Marine Mammals. The different methods are compared for both whistle detection and species classification tasks using classifiers based on Gaussian mixture models.
To err is human: A review of localization errors and their effects on abundance estimation, tracking, and other aspects of acoustic monitoring of marine mammals

Norris, Thomas¹, Yack, T. M¹, Gillespie, D. M.², Thomas, L³

¹Bio-Waves Inc. 364 2nd Street, Suite #3, Encinitas, CA 92024
²Sea Mammal Research Unit, Scottish Oceans Institute, University of St Andrews, St Andrews, UK
³C.R.E.E.M., University of St. Andrews, St. Andrews, UK

Thomas.f.norris@bio-waves.net

Localization errors are inherent in all marine mammal acoustic localization systems, but often are ignored when presenting results. We review the main sources of localization error and discuss their affects on density/abundance estimation, animal tracking, mitigation exclusion zones, and other aspects of acoustic monitoring of marine mammals. Sources of error can be due to violations of assumptions (e.g. that animals are stationary relative to the survey vessel), errors in the localization methods, or other factors. Because errors are unavoidable, localizations should be considered as ‘estimations’ of animal positions, not as absolute locations. As such, sources of error should be evaluated and presented with the results. In practice, this is rarely done. However, some recent programs (e.g. PAMguard) allow error estimates to be included for sound speed, hydrophone depth and other variables used in the localization algorithms. We present case studies from our field studies on minke whales, sperm whales, killer whales and other cetacean species to provide examples of errors and their effects on results. For example, distance errors in line transect surveys can bias density estimates, even if the distance measurements are, on average, correct. In some cases the bias can be corrected if the average error is known. Other examples of errors include unaccounted animal movements, bearings to different animals in a group used for a localization, uncertainty in depths of animals, uncertainty in sensor (i.e. hydrophone) locations, uncertainty in sound propagation effects, and errors in cross-correlations (i.e. time delays). Some errors (e.g. hydrophone locations) can be assessed or accounted for relatively easily. Others errors, such as those due to propagation effects, can be modelled. Our conclusion is that it is important to address and, if possible, assess the errors and uncertainty in localizations so they can be presented or incorporated in the final results.
Passive acoustic localization using received sound pressure levels

Eva-Marie Nosal

Department of Ocean and Resources Engineering, University of Hawaii at Manoa

Nosal@hawaii.edu

Most marine mammal localization methods rely solely on arrival times. Although arrival times tend to be effective and robust for localization purposes, there are often other pieces of information that depend on animal position and can consequently be used to obtain/improve position estimates. One such piece of information is received sound pressure level (SPL). This presentation will review and explore the use of SPL in passive acoustic localization. Algorithms will be presented and applications and limitations will be discussed. Results using datasets in which location estimates obtained using SPL alone can be compared to positions obtained otherwise (e.g. using algorithms that rely on arrival times) will be presented.
Practical deep neural nets for detecting marine mammals

Daniel Nouri
daniel.nouri@gmail.com

In recent years, deep neural networks have revolutionised the field of machine learning for a large variety of tasks. From speech recognition for mobile phones to image detection of traffic signs, deep learning now outperforms other traditional machine learning techniques, and is widely used in commercial software from companies such as Google and Apple. Not only do neural networks today achieve state-of-the-art performance for the most challenging pattern recognition problems, they are also incredibly easy to use and flexible, requiring little domain knowledge or feature engineering from the implementer. Take image detection, where classic machine learning has to rely on complicated computer vision algorithms to achieve good performance. With neural networks, it is the network itself that extracts relevant features from the raw data. The author of this presentation very successfully used deep neural networks in the Marinexplore and Cornell University Whale Detection Challenge, where the task was to detect North Atlantic right whale calls from 30,000 2-second audio samples. Among more than 120 competitors from all over the world, his deep neural network achieved the best performance. After only two afternoons of work, he was able to reach a score of 97%, which represents a big improvement over Cornell's in-house program. This success highlights the universal applicability of his easy-to-use technique, as the author had no prior knowledge of whales and knew only little about sound detection. In this presentation, you'll learn about the practical details of the solution, about the freely available software libraries that were used to build it, and about how deep learning can be applied to other problems related to the detection of marine mammals.
Man versus machine: a comparison of whistle classifiers developed using auto-detector data and manually analyzed data

Julie N. Oswald\textsuperscript{1}, Danielle Cholewiak\textsuperscript{2}, Lynne Hodge\textsuperscript{3}, Melissa Soldevilla\textsuperscript{4}, Sofie Van Parijs\textsuperscript{2}, Anthony Martinez\textsuperscript{4}, Andrew Read\textsuperscript{3}

\textsuperscript{1}Bio-Waves, Inc., Encinitas, USA
\textsuperscript{2}Northeast Fisheries Science Center, Woods Hole, USA
\textsuperscript{3}Division of Marine Science and Conservation, Nicholas School of the Environment, Duke University, USA
\textsuperscript{4}Southeast Fisheries Science Center, Miami, USA

Julie.oswald@bio-waves.net

Automated methods for detection and classification of cetacean vocalizations are necessary to efficiently analyze the large volumes of data generated during passive acoustic monitoring efforts. Whistles produced by delphinids are highly variable and their characteristics often overlap among species. Therefore, it is difficult to develop species-specific auto-detectors for whistles, and classification is a necessary second step. To fully automate the detection/classification process, algorithms must be able to detect and measure whistles accurately, and/or classifiers must be robust to errors resulting from automating the process. We used recordings of dolphin whistles made in the western Atlantic Ocean to test the hypothesis that classifiers created using contours detected and measured automatically perform comparably to classifiers created using manually measured whistles. We included recordings of visually-validated, single-species schools (n=123) of five species: Delphinus delphis, Globicephala macrorhynchus, Stenella coeruleoalba, Stenella frontalis, and Tursiops truncatus. The ‘whistle and moan detector’ in PAMGuard was used to automatically detect and measure whistles. Whistles from the same detections also were analyzed manually using PAMGuard’s ROCCA module. We created classifiers using random forest analysis. Correct classification scores ranged from 17\% (S. coeruleoalba) to 69\% (G. macrorhynchus) for the classifier created using manual measurements and from 37\% (D. delphis) to 94\% (T. truncatus) for the classifier created using automatic measurements. Correct classification scores were significantly greater for the auto-detector classifier than the manual classifier for three species (S. coeruleoalba, p=0.02, S. frontalis, p=0.0008, T. truncatus, p=0.0001, $\chi^2$ test) and not significantly different for the two classifiers for two species (D. delphis, p=0.08, G. macrorhynchus, p=0.18, $\chi^2$ test). These results show that it is possible to create a fully automated whistle detector/classifier for species in the western Atlantic Ocean. This development will significantly decrease the effort and cost of processing acoustic data both in real-time and during post-processing.
Automatic Detection and Characterization of Mid-Frequency Active Sonar and Its Impact on Marine Mammal Vocalizations

Michael Oswald¹, Mariana Melcón², Elizabeth Ferguson¹, Thomas F. Norris¹, Kerry Dunleavy¹

¹ Bio-Waves Inc., Encinitas, USA
² Fundacion Cethus, Buenos Aires, Argentina

mike.oswald@bio-waves.net

Mid-Frequency Active (MFA) sonar includes a variety of constant-frequency and frequency-modulated signal types, ranging between 1 kHz and 10 kHz. Studies have shown correlations between MFA sonar and marine mammal strandings, behavioral reactions, and potential temporary threshold shifts. Presently, there are no standardized methods available for detection and quantification of sonar signals, or assessment of their impacts on marine mammal acoustic behavior. ‘SonarFinder’ is a semi-automated Matlab-based program we have developed to fill that need. SonarFinder is intended for use on large acoustic datasets such as those collected from autonomous recorders and other passive acoustic systems. It can batch process all wav-format files in a folder unsupervised, and save results to multiple spreadsheets. SonarFinder uses a 3-step testing scheme to separate true sonar from noise and transients. Step 1 uses an amplitude threshold, step 2 an ‘amplitude integrated over time’ threshold, and step 3 the power spectral density of a predefined band. Only detections which pass all three steps are logged as sonar. Measurements in the frequency and time domains are used to characterize and classify sonar pings. Output from the detector can be automatically compared to a user-supplied list of marine mammal detections. A dose response parameter and the probabilities of animal vocalizations occurring in the presence and absence of sonar are calculated based on this comparison to allow assessment of the relationship between sonar presence and marine mammal acoustic behavior. We tested SonarFinder using several autonomous recorder datasets. Precision and recall for these tests ranged from .56 to .71 and .33 to .89, respectively. Based on these results, SonarFinder is a valuable tool for quantifying the presence of sonar with respect to marine mammal vocalizations. The output of SonarFinder will allow a deeper understanding of how marine mammals may be responding to this anthropogenic sound.
Using DCLDE for management and conservation of North Atlantic right whales.

Sofie Van Parijs

Northeast Fisheries Science Center, 166 Water Street, Woods Hole, MA 02543, USA.

Sofie.vanparijs@noaa.gov

The North Atlantic right whale, *Eubalaena glacialis*, is the most endangered large whale population in the Atlantic. As a result of historic whaling, ship collisions, and entanglements in fishing gear, fewer than 500 individuals exist today in the western North Atlantic. In addition, ships and right whales co-occur throughout their entire migratory route as they move between 5 major geographic regions: south-east coast of the United States, Great South Channel, Massachusetts Bay, Bay of Fundy, and Scotian Shelf. The distribution of right whales is well documented in these main habitats, but less is known about their movement patterns elsewhere, particularly during the fall and winter months. Such information is crucial for identifying areas and time periods in which concentrations of whales are present in order to reduce the likelihood of anthropogenic mortality events. Millions of US dollars are spent annually on studying and mitigating impacts on NARWs through numerous federal agencies, industry and NGOs. Until recently information on right whale distribution and occurrence was based on visual sightings, but passive acoustic monitoring (PAM) is increasingly being applied to augment and in some instances used instead of these surveys. Unlike vessel-based or aerial efforts, passive acoustic devices can operate continuously in adverse weather and all light conditions, and can survey remote areas over long time scales. Current limitations of PAM, however, include labor-intensive analysis, subjectivity of species classification, limited knowledge of associated gender, behavior and number of callers, development of reliable automated call detectors, and missing calls due to silent animals. As the use of PAM increases, solutions for all of these current limitations are being worked on and this meeting in particular presents many new ways forwards. Here, I present some of the DCLDE techniques currently being used for real time mitigation, long term monitoring of regions and management of ocean noise on this population. I will show some examples of how each one of the DCLDE components is already or could be used for future efforts to improve the conservation and management of this species. In addition I'll discuss how important it is to understand the object and appropriate scale over which to conduct a study in the marine environment in order to achieve appropriate scientific, management, mitigation and conservation objectives.
Detecting a changing signal: impacts of right whales modifying calling behaviour in response to environmental background noise conditions

Susan E. Parks¹, Ildar R. Urazghildiiev², Karina Groch³, Paulo Flores⁴, Renata Sousa-Lima²,⁵

¹Department of Biology, Syracuse University, NY USA
²Bioacoustics Research Program, Cornell University, Ithaca, USA
³Projeto Baleia Franca, Instituto Australis, Imbituba, SC, Brazil
⁴Laboratório de Bioacústica, Departamento de Fisiologia, Universidade Federal do Rio Grande do Norte, Natal, Brazil
⁵Centro Nacional de Pesquisa & Conservação de Mamíferos Aquáticos, ICMBio, MMA CMA SC, Florianópolis, Brazil

sparks@syr.edu

A ‘stereotyped’ call produced by right whales, the upcall or contact call, is often used for detection in passive acoustic monitoring. Research on the sound production behaviour of right whales indicates differences in the average frequency range and bandwidth of upcalls produced by different species of right whale. Further, call parameters shift between habitat areas within the same species. This study investigates the role of behavioural plasticity in the sound production of right whales in response to short term changes in the ambient background noise conditions. Data were collected from southern right whales (Eubalaena australis) in Brazilian waters where increasing numbers of right whales have been sighted over the past decade along with an increase in anthropogenic activities such as shipping and fishing. Bottom-mounted archival acoustic recorders were deployed in October and November 2011 in two coastal locations in central Santa Catarina State, southern Brazil. The goals of this study were to assess the differences in vocalizations recorded in three conditions: low background noise as a control, fish chorus noise and vessel noise. The noise conditions are spectrally distinct and consisted of narrow band noise from chorusing fish that is higher in frequency than right whale upcalls and noise from vessel traffic that is broadband and overlaps the frequency of right whale upcalls. Automated detectors and noise statistic analysis tools developed for North Atlantic right whale upcalls were utilized to analyse the dataset. Variations in call parameters were detected among the three noise conditions and implications for detector algorithm function will be discussed.
Large scale detection classification: case study of four examples using an applied high performance distributed computing platform

Marian Popescu, Peter Dugan, John Zollweg, Adam Mikolajczyk, and Chris Clark

Bioacoustic Research Program, Cornell University, USA

pjd78@cornell.edu, cp478@cornell.edu, cwc2@cornell.edu

Passive acoustic monitoring (PAM) has become a key component in understanding marine ecology. The Bioacoustic Research Program at Cornell University has recorded approximately one petabyte of data, with a large portion of the data unexplored due to limitations in technology. In this poster we will summarize four projects that use a new system based on distributed computing, designed to fully process large acoustic datasets. The system allows researchers to efficiently develop, build, test and execute detection-classification algorithms on a high performance computing (HPC) platform. The four projects include: (1) detection, classification and metric extraction of seismic airgun pulses on 45 days, 5 channels, 16kHz sampling rate, continuous recording in the Baffin Bay, Greenland; (2) detection and classification of sperm whale on 526 days, 1 channel, 8 kHz, duty cycle recording in the Gulf of Mexico; (3) detection-classification of northern Atlantic right whale on 44 months, multi-channel, 2 kHz, continuous recording in the Stellwagen Bank National Marine Sanctuary; (4) detection-classification northern Atlantic right whale on the DCLDE 2013 dataset. Using an interactive software tool (Deep Learning Machine Architecture - DeLMA) the authors will show additional system capability to implement and execute external DC algorithms. We will show how the HPC architecture along with the DeLMA tools provide a flexible and relatively easy method for applying different algorithms on a distributed computing system. The poster will also summarize the high level hardware architecture running 128 independent processors using a client server model.
Effects of sea state on the range at which dolphins are detected on passive acoustic surveys

Shannon Rankin¹, Jay Barlow¹, Jessica Redfern¹, Julie Oswald²

¹NOAA Southwest Fisheries Science Center
²Bio-waves, Inc.

shannon.rankin@noaa.gov

Passive acoustic methods are being used increasingly to detect and locate cetaceans during shipboard surveys. Previously, these surveys relied on visual detection of animals; however, visual methods are negatively affected by conditions such as rain, fog, and sea state. We empirically examined whether acoustic detection range (the greatest distance at which animals are detected using passive acoustic methods) varies with sea state conditions while controlling for other factors. Data from 1,722 dolphin detections collected during seven years of visual and acoustic cetacean surveys were used for this analysis. We found little or no effect of Beaufort scale or wind speed on acoustic detection range for combined or individual surveys. We did find significant effects of mixed layer depth, surface temperature, group size, and swell height on acoustic detection range for the combined surveys. Given the general lack of relationship between Beaufort scale and acoustic detection range, passive acoustic methods can complement visual surveys, which are more limited by weather conditions. In regions where poor weather conditions minimize the effectiveness of visual observation methods, the use of passive acoustic methods may greatly facilitate the detection of cetaceans, especially species with cryptic surface behavior.
Building A Better Array: Developments in towed hydrophone arrays improve identification and localization of cetacean groups

Shannon Rankin¹, Jay Barlow¹, Robert Valtierra², Yvonne Barkley³

¹NOAA Southwest Fisheries Science Center
²Boston University
³NOAA Pacific Islands Fisheries Science Center

shannon.rankin@noaa.gov

Localization of sounds using towed hydrophone arrays from shipboard platforms typically relies on using the time-difference-of-arrival of the sound between two hydrophones to determine the bearing angle and the convergence of several bearing angles over time to identify a location (with a left/right ambiguity). These localization methods are successful for single animals or tight schools that are moving slowly relative to the vessel speed. However, these methods break down for groups that are large and spread-out, fast swimming, or when there are multiple distinct groups with overlapping calls. Likewise, the time required to obtain a location using these methods potentially violates a key requirement for line-transect surveys that the location of the initial detection occurs before the animals have responded to the vessel. Instantaneous localization using more complicated towed hydrophone array designs can eliminate these problems. A simple, robust design is needed that covers a wide range of frequencies, provides sufficient baseline to allow instantaneous localization, and is modular to allow flexibility in configurations and to allow easy replacement of broken components. Here we present two hydrophone array designs: a tetrahedral array that provides improved 3D localization of high frequency sounds and a modular linear towed array that meets these design criteria at a price that cetacean researchers can afford. Future developments will include adding the tetrahedral array as a component in the modular array design.
Underwater passive acoustic localization of a Pacific walrus in an uncertain environment

Brendan P. Rideout\textsuperscript{1}, Stan E. Dosso\textsuperscript{2} and David E. Hannay\textsuperscript{3}

\textsuperscript{1}Department of Ocean and Resources Engineering, University of Hawaii at Manoa
\textsuperscript{2}School of Earth and Ocean Science, University of Victoria, Canada
\textsuperscript{3}JASCO Applied Sciences, Ltd., Victoria, British Columbia, Canada.

bprideou@hawaii.edu

This paper presents a linearized Bayesian approach for estimating the three-dimensional (3D) location of a vocalizing underwater marine mammal using acoustic arrival-time measurements at three spatially-separated receivers which also provides rigorous location uncertainties. To properly account for the uncertainty in receiver parameters (3D locations and synchronization times) and environmental parameters (water depth and sound speed correction), these quantities are treated as unknowns constrained by prior estimates and prior uncertainties. Unknown scaling factors on both the prior and data uncertainties are estimated by minimizing Akaike’s Bayesian information criterion. Maximum a posteriori estimates for sound source locations and times, receiver parameters, and environmental parameters are calculated simultaneously. Posterior uncertainties calculated for all unknowns incorporate data and prior uncertainties. Monte Carlo simulation results demonstrate that, for the case considered here, linearization errors are generally small. The primary motivation for this work was to develop an algorithm for locating underwater Pacific walruses in the coastal waters northwest of Alaska. Three underwater acoustic receivers were placed in a triangular arrangement approximately 400 m apart near the Hanna Shoal (where the water depth is ~30 m) in the northeastern Chukchi Sea from August to October 2009 to record marine mammal vocalizations. A sequence of walrus vocalizations from this data set is processed using the localization algorithm, yielding a track with relative source location uncertainties of 1-2 m and an estimated swim speed that is consistent with knowledge of normal walrus speeds.
On blind channel estimation for passive acoustic monitoring of marine mammals

Brendan P. Rideout¹, Eva-Marie Nosal¹, Anders Host-Madsen²

¹Department of Ocean and Resources Engineering, University of Hawaii at Manoa
²Department of Electrical Engineering, University of Hawaii at Manoa

bprideou@hawaii.edu

A common problem in signal transmission is that the transmission environment modifies the source signal before it reaches the receiver (e.g., through multipath propagation). Blind channel estimation (BCE) is a well-known signal processing technique commonly associated with the improvement of signal integrity through a communication channel (e.g., reducing the impact of multipath propagation on wireless signal transmission) whereby the impulse response between a source and a set of receivers is estimated. In this work, we investigate whether BCE may be used to estimate ocean waveguide impulse responses from marine mammal vocalizations recorded on spatially-separated receivers. We use a non-parametric formulation of BCE that assumes no prior knowledge of the environmental model (e.g., bathymetry, sound-speed profile, or source/receiver positions). The impulse response is estimated for each source/receiver combination under the assumption that each receiver is exposed to the same sufficiently-complex source. Potential uses of this approach include recovery of the original sound signal and localization of the vocalizing animal. It will be particularly useful for longer-duration vocalizations and/or complicated propagation conditions which are difficult to deal with using conventional passive acoustic monitoring techniques. Simulation results showing estimated impulse responses in realistic ocean environments using synthetic marine mammal vocalizations will be shown.
The Tethys Metadata System

Marie A Roch\textsuperscript{1,2}, Simone Baumann-Pickering\textsuperscript{2}, Daniel Hwang\textsuperscript{2}, Heidi Batchelor\textsuperscript{2}, Catherine Berchok\textsuperscript{3}, Danielle Cholewiak\textsuperscript{4}, Lisa M. Munger\textsuperscript{5}, Erin M. Oleson\textsuperscript{5}, Shannon Rankin\textsuperscript{6}, Denise Risch\textsuperscript{4}, Ana Širović\textsuperscript{2}, Melissa S. Soldevilla\textsuperscript{7}, Sofie M. Van Parijs\textsuperscript{4}

\textsuperscript{1}Department of Computer Science, San Diego State University, San Diego, USA
\textsuperscript{2}Scripps Institution of Oceanography, University of California, San Diego, USA
\textsuperscript{3}NOAA NMFS Alaska Fisheries Science Center, Seattle, USA
\textsuperscript{4}NOAA NMFS Northeast Fisheries Science Center, Woods Hole, USA
\textsuperscript{5}NOAA NMFS Pacific Islands Fisheries Science Center, Honolulu, Hawaii, USA
\textsuperscript{6}NOAA NMFS Southwest Fisheries Science Center, USA
\textsuperscript{7}NOAA NMFS Southeast Fisheries Science Center, Miami, USA

marie.roch@sdsu.edu

A growing number of passive acoustic monitoring (PAM) systems have resulted in a wealth of annotation information, or metadata, for recordings. These metadata are semi-structured. Some parameters are essentially mandatory (e.g. time of detection and what was detected) while others are highly dependent upon the question that a researcher is asking. Tethys is a metadata system for spatial-temporal acoustic data that provides structure where it is appropriate and flexibility where it is needed. Networked metadata are stored in an extended markup language (XML) database, and served to workstations over a network. The ability to export summary data to OBIS-SEAMAP is in development. The second purpose of Tethys is to serve as a scientific workbench. Interfaces are provided to networked databases, permitting the import of data from a wide variety of sources, such as lunar illumination or sea ice coverage. Interfaces currently exist for Matlab, Java, and Python. Writing data driven queries using a single interface enables quick data gathering from multivariate sources to address hypotheses. Examples showing the results of analysis of acoustic data from acoustic deployment from twenty-six sites across the Northern Pacific will be shown.
DCLDE 2013 workshop data set: Detection of Right Whale contact calls with supervised spectrogram templates and chirplet approaches

Nathalie Roy¹, Yvan Simard¹,², Mohammed Bahoura³ and Samuel Giard⁴

¹ Maurice Lamontagne Institute, Fisheries and Oceans Canada, Canada
² DFO Chair in acoustics applied to marine mammals and their ecosystem, Marine Science Institute, University of Québec at Rimouski, Canada
³ Department of Engineering, University of Québec at Rimouski, Canada
⁴ 6253 Chateaubriand, Montréal, QC, Canada

Nathalie.Roy@dfo-mpo.gc.ca

The DCLDE 2013 data set consists of a series of single-channel recordings collected in Right Whale habitat off Massachusetts coast, containing typical ~2-s low-frequency upsweep contact calls that characterize this species and which were annotated by an expert using multi-channel information. Two algorithms are tested here to detect these typical calls. The first algorithm is based on the well-known comparison of the spectrogram in the call bandwidth with binary time-frequency stencils the typical call. The comparison of the binary-transformed equalised spectrogram of the band-passed signal is done within a time window that includes pre- and post-call periods. The match of the time-frequency pixels is computed separately for the call space and non-call space, and the results are combined into a detection function. The second algorithm uses the chirplet transform to approximate the band-passed signal of contact calls in two overlapping windows. The detection occurs when the three parameters of the estimated chirplets (frequency, chirp rate, and duration) exceed pre-set thresholds in both overlapping windows. The performances of the two algorithms as function of the signal-to-noise ratio are estimated by comparison with the annotated contact calls, before and after manual rejection of false alarms with the assistance of a detection browsing tool. Rhythmmed detections are then tagged to assist in distinguishing likely Right Whale contact calls from confounding calls from other sympatric species.
Localization with two DIFAR sonobouys

Alexis Rudd¹, Whitlow Au¹, Seibert Murphy²

¹Hawaii Institute of Marine Biology
²Guidestar Engineering

rudd@hawaii.edu

For many years, the navy has been using directional frequency analysis and recording (DIFAR) sonobouys to record and track ships. DIFAR sonobouys compute the acoustic particle velocity for two bimodal perpendicular hydrophone elements which, with a magnetic compass, gives a directional bearing to the sound recorded on a third omnidirectional hydrophone. In this study, we used two tethered DIFAR sonobouys over a period of two hours to record and track multiple singing humpback whales (Megaptera novaeangliae) off of Kaena Point, Oahu, Hawaii. The digital signal was recorded at the sonobouy before multiplexing. Over 300 song units were recorded on both sonobouys, and then matched between sonobouys using the time from onboard GPS. To localize the signals, azimuths from the DIFAR sonobouys were combined with the time difference of arrival parabola to create a three-dimensional likelihood surface that gives the probabilities that a signal originated at a specific point in space. The locations with maximum likelihood were used to estimate source level of whale calls, and singing whales were tracked over time. Comparisons will be made between DIFAR methods and other methods of localization, with a focus on technical and experimental design.
Who is vocalising? Acoustic localisations of broadband clicks plotted onto video recordings of individual dusky dolphins (Lagenorhynchus obscurus) in New Zealand

Michiel Schotten¹, Bernd Würsig³, Dara Orbach³, Ken Sexton⁴, Sarah Piwetz³, Marc Lammers⁵

¹Ocean Ecosystems, University of Groningen, The Netherlands
²Dolphin Recording Tools, ZG De Rijp, The Netherlands
³Department of Marine Biology, Texas A&M University at Galveston, USA
⁴The Sexton Corporation, 2130 Davcor St. SE, Salem, USA
⁵Hawaii Institute of Marine Biology, University of Hawaii, USA

micschotten@hotmail.com

Broadband acoustic and video recordings were obtained from dusky dolphins (Lagenorhynchus obscurus) in New Zealand, both during the austral summer (Kaikoura) and winter (Admiralty Bay). Recordings were made using the 4-channel UDDAS (Underwater Dolphin Data Acquisition System), which is a 4-hydrophone diver-operated video-acoustic recorder developed to record echolocation and communication behaviours of wild dolphins, localise recorded sounds in 3D using differences in time of arrival from distances up to approx. 15-30 m, assign acoustic recordings up to 240 kHz to individual dolphins visible on video, and thus correlate acoustic signal parameters to different dolphin behaviours. A custom-written Matlab code was used to select click trains from the broadband recordings, extract the time of arrival of each click on each of the four channels, as well as a number of other click parameters, localise each click and plot the (x,y,z) coordinates in a 3D plot. Dusky dolphin echolocation clicks extended in frequency to the upper recording limit of 240 kHz. Additionally, a large portion of recorded clicks had no energy in the human audio range (i.e., no energy <20 kHz), but these were made audible by slowing them down 10 times. The calculated 3D positions of recorded clicks corresponded to the positions and movements of different dolphins recorded on video, and were animated into the video as flashing dots on the dolphins’ foreheads. In Admiralty Bay, one occasion of coordinated feeding by dusky dolphins was recorded, where dolphins encircled and aggregated fish into a tightly packed stationary bait ball near the water surface. Recordings of this bait ball behaviour contained many overlapping click trains, which proved difficult to localise due to many recordings being off-axis, often causing a different cycle within each click to peak on different channels. Possible improvements to the Matlab code to further automate this are discussed.
Implementation of automatic blue whale call detectors to multi-year data sets

Ana Širović, Sara M. Kerosky, Madeleine Parsell, John A. Hildebrand
Scripps Institution of Oceanography, University of California San Diego
asirovic@ucsd.edu

Spectrogram correlation is used commonly for automatic detection of stereotyped blue whale songs, such as the B calls common off California. While this method generally performs with relatively good results, the simple evaluation metrics (missed call and false alarm rate) do not adequately represent the complexity of the detection situation. Multi-year, passive acoustic recordings collected off the Southern California Bight were analysed and tested with automatic detectors and it was found that a nuanced detection process is needed. Three factors affect the performance of the detector within and between years. First, changes in the relative abundance of blue whale calls result in a seasonally variable missed call and false alarm rate. Thus single numbers tend to overstate the performance of the detector during periods with lower calling, and understate it during periods of high calling. Secondly, short-term changes in background noise also affect the detectability of calls, resulting in transient variability of missed call and false alarm rates. Finally, the performance of the detector is also affected by a change in the frequency of the call. Interannual decrease in the frequency of blue whale B call has been well documented. This interannual change has been previously accounted for in automatic detection, with annually adjusting kernel parameters. However, the frequency of the call changes intra-annually; the call frequency exhibits a slow decrease over the course of the calling season that is not accounted in precise kernels. The variability in the calls, as well as the environmental conditions, needs to be better accounted in reports on the performance of these automated detectors.
The Impact of Site and Instrument Variability on the Classification of Echolocation Clicks

Johanna Stinner-Sloan¹, Simone Baumann-Pickering², Marie A. Roch¹,²

¹Department of Computer Science, San Diego State University, USA
²Scripps Institution of Oceanography, University of California, USA

marie.roch@sdsu.edu

In this work, we focus on the echolocation clicks of two species that are readily distinguishable from their echolocation clicks: Risso’s dolphins (Grampus griseus), and Pacific White-Sided dolphins (Lagenorhynchus obliquidens). Starting from the point of previously published methods [Roch et al. 2011, JASA 129(1)], we examine the impact of how training and test data are partitioned during classifier development. Using data collected from high frequency acoustic recording packages (HARPs) deployed at six different sites throughout the Southern California Bight, we examine differences due to site and instrument variation and show methods that compensate for instrumentation differences.
SAMBAH (Static Acoustic Monitoring of the Baltic Sea Harbour Porpoise) is an international project, involving all EU countries around the Baltic Sea, with the primary goal of using passive acoustics to estimate the abundance of the critically endangered Baltic harbour porpoise. To this end, approximately 300 static acoustic monitoring devices called C-PODs were deployed in the Baltic (between 5 and 80m depth) using a systematic random design, between May 2011 - 2013. These autonomous devices can be used to detect “trains” of porpoise echolocation clicks. We describe several approaches for converting the number of detections into estimates of porpoise abundance. Each approach requires auxiliary information about false positive and false negative detection rates, acoustic behaviour (e.g., click production rate) and, for some approaches, additional quantities such as average group size. We describe our progress in obtaining the required information. In some cases, additional data has been gathered while servicing the C-PODs – for example, we used playbacks of artificial porpoise-like clicks at a set of ranges around each C-POD to help estimate false negative rate. In other cases, we have relied on information gathered by associated studies; these include other playback studies, detectability studies on porpoises accidentally caught in fishing pound nets and acoustic tagging studies. We have also gathered information from historical data, for example on group sizes from incidental sightings. We present preliminary results from these studies. Further data analysis is on-going – the project is scheduled to finish at the end of 2014. Outputs will include country-specific estimates of average abundance, as well as spatio-temporal models of density through the surveyed region. We hope that the project will aid conservation efforts, as well as demonstrating best practice for cost-effective large-scale surveillance a marine mammal that occurs at very low density.
Performance of localization algorithms obtained from in situ tests

I.R. Urazhildiiev, C. W. Clark

The Lab of Ornithology, Cornell University

Iru2@cornell.edu

Localization algorithms based on the time-difference-of-arrival (TDOA) of the signals detected by multiple hydrophones are used in various passive acoustic monitoring systems. Although different algorithms are known from the literature, there is little information regarding the accuracy and precision of location estimates provided in real situations. In this presentation, the problem of TDOA-based localization of transient, underwater sound sources using sparse arrays of bottom-mounted synchronized hydrophones working in the low-frequency band (< 1000 Hz) is addressed. The goal of this work is to evaluate the statistical properties of location estimates provided by the maximum likelihood locator (ML), Correlation Sum Estimator, search-free algorithm, and hyperbolic fixing locator. The accuracy and precision of position, range, and bearing estimates as a function of the distance to the source and SNR are investigated using both statistical simulations and in situ measurements. In situ field tests were conducted in Cape Cod Bay, MA, on 20 May 2008, 23 March 2011, and 15 March 2012. A transducer deployed off the back of a research vessel was used as the sound source at different location test sites. Both statistical simulations and in situ tests demonstrated that the ML locator provided the highest precision and accuracy. The location estimation errors provided by the ML locator are close to the Cramer-Rao bound.
An experimental triplet hydrophone array for determining vertical angle of marine mammals


sander.vonbenda@tno.nl

Ship-based real-time monitoring during activities involving loud sound sources (e.g. seismic surveys, naval exercises) requires fast and reliable localization of marine mammals. Often towed hydrophone arrays are used to estimate the position by measuring the time delay on multiple hydrophones. Linear hydrophone arrays provide bearing information but require ship-maneuvering to discriminate between animals situated left, right or below of the array. An experimental hydrophone triplet is designed to estimate vertical angle for high frequency vocalizations. The triplet is embedded within the hose of a towed array, allowing for normal deployment, recovery and high ship speeds. The system was built and tested using transmitted signals that resemble high frequency (> 10 kHz) sweeps and echolocation clicks. Initial results show that such a triplet design can provide left/right discrimination, but that obtaining reliable vertical angles remains a challenge.
Frequent and long time occupation the port area during nighttime by Yangtze finless porpoise: forced choice for feeding?

Zhitao Wang\textsuperscript{1,2}, Tomonary Akamatsu\textsuperscript{3}, Zhigang Mei\textsuperscript{1,2}, Lijun Dong\textsuperscript{1,2}, Tomohito Imaizimi\textsuperscript{3}, Kexiong Wang\textsuperscript{1} and Ding Wang\textsuperscript{1}

\textsuperscript{1}The Key Laboratory of Aquatic Biodiversity and Conservation of Chinese Academy of Sciences, Institute of Hydrobiology, China
\textsuperscript{2}University of Chinese Academy of Sciences, Beijing, China
\textsuperscript{3}National Research Institute of Fisheries Engineering, Ibaraki, Japan

wangd@ihb.ac.cn

Yangtze finless porpoise (Neophocaena asiaeorientalis Pilleri & Gihr, 1972) were observed acoustically by miniature stereo acoustic pulse event data logger (A-tag) when we anchored in port area during the upstream survey of the Yangtze Freshwater Dolphin Expedition 2012 from Zhenjiang to Ezhou mainly during nighttime. Of all the 6566 minutes nighttime monitoring, 488 (7.43 \%) minutes were observed with the presence of porpoise sonar and the longest echolocation encounter time span of 102.9 min was obtained of all the 81 encounters, suggesting frequent and long time port area occupation. A combined total of 2091 click trains were recorded and 129 (6.2 \%) of them with the minimum Inter-click intervals (ICIs) below 10 ms (also termed the buzz). Buzz with decreasing in ICIs and possess search and approach phases which resemble the echolocation for feeding account for 44.2 \% (N=52), whereas buzz with increasing in ICIs which showed a mirrored prey capture phase occupy 20.2 \% (N=26) and could be functional as relocation the potentially escaped prey, since it was observed linked with a follow up feeding resemble echolocation. Although port areas were naturally adjacent to the boat traffic and anecdotal of avoidance reaction of porpoise to passing vessel were observed. The monitored accumulation of porpoises near the port area could be hypothesized as a forced choice for feeding due to the high amount of fishery stocks in port areas compared with otherwise probably overfished area in the Yangtze river.
An automatic single station multipath ranging technique for 20 Hz fin whale vocalizations

Michelle Weirathmueller and William Wilcock

University of Washington, School of Oceanography

michw@uw.edu

The Cascadia Initiative is a seismic experiment off the west coast of North America, extending a thousand kilometers along the coast and several hundred kilometers offshore. A network of 70 ocean bottom seismometers is being deployed between 2011-2015 at a total of 160 widely spaced locations. Although the experiment’s purpose is to monitor earthquakes, the instruments also record 20 Hz fin whale vocalizations. The spatial and temporal coverage of the instrument array provides a unique opportunity to study seasonal distributions of vocalizing fin whales on a regional scale, and correlations with environmental parameters such as sea surface temperature, salinity, chlorophyll-a concentration, and mixed layer depth. Our approach will be to convert call counts at each instrument to call density using point transect distance sampling, which relies on estimates of horizontal range to each call. The amplitude and timing of multipath arrivals can be diagnostic of range, and a technique is being developed to explore this relationship using a test dataset collected at three sites between 2003-2006. At a mid ocean ridge site with rough topography and extensive basaltic outcrops call locations were determined previously using arrival times at closely spaced instruments. At the other two sites on the abyssal plain and continental slope, single instruments were deployed on thick sediments. Ranges obtained using the multipath technique can be verified using tracked calls at the mid-ocean ridge site, and preliminary results suggest that estimates are reliable for whales out to 10 km. Absolute and relative amplitudes are being incorporated to constrain the ranges so that more distant whales are not mis-located closer to the instrument. We are presently expanding our analysis to include the sedimented test sites to evaluate the performance of the multipath ranging technique in different acoustic environments.
The use of passive acoustic data to predict beaked whale habitat in the California Current Ecosystem

Tina M. Yack\textsuperscript{1,2,3}, Alyson Fleming\textsuperscript{1,4}, Jay Barlow\textsuperscript{1}, Jessica Redfern\textsuperscript{1}, Elizabeth Becker\textsuperscript{1}, Peter Klimley\textsuperscript{5} and Marcel Holyoak\textsuperscript{6}

\textsuperscript{1}Marine Mammal & Turtle Division, Southwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, USA
\textsuperscript{2}Bio-Waves, Inc, Encinitas, USA
\textsuperscript{3}SDSU/UCD JDPE, Ecology Doctoral Program, Department of Biology, San Diego State University, USA
\textsuperscript{4}Scripps Institution of Oceanography, University of California, San Diego, USA
\textsuperscript{5}Department of Wildlife, Fish, & Conservation Biology, University of California-Davis, USA
\textsuperscript{6}Department of Environmental Science and Policy, University of California-Davis, USA

\texttt{tina.yack@bio-waves.net}

Beaked whales spend the majority of their time at depth, typically occur in small groups, and behave inconspicuously at the surface. These factors make them extremely difficult to detect using standard visual survey methods. To date, beaked whale habitat models have been limited in utility due primarily to small samples of visual observations available to inform models. Recent advancements in acoustic detection capabilities have made passive acoustic monitoring a viable alternative method to monitor beaked whales. We used beaked whale acoustic encounters to inform Generalized Additive Models (GAMs) of encounter rates for beaked whales in the California Current Ecosystem (CCE) and compare these to visual based models. Acoustic and visual based models were independently developed for a ‘small beaked whale species’ group and Baird’s beaked whales (Berardius bairdii). Distributions were modelled using a combination of fixed spatial features and dynamic oceanographic variables. Two models for each species group were evaluated for both visual and acoustic encounters, one using only fixed spatial features and dynamic oceanographic variables and one that also included Beaufort scale as a predictor. The visual models that included Beaufort scale retained this variable in the resulting best fit models, whereas the acoustic models did not, confirming this variable’s effect on visual detection probability. The visual and acoustic models differed markedly for both small beaked whales and Baird’s beaked whales in the predictor variables retained and the regions of high encounter rate prediction. Model results indicate Baird’s beaked whale habitat preferences may be distinctive from other beaked whale species. This study demonstrates the effectiveness of using acoustic data to develop habitat models and improves current understanding of beaked whale distribution and habitat use in the CCE. Our results can be used to better inform management and conservation efforts for beaked whales.
Validation of PAMGuard Automated Detection, Classification and Localization Using Killer Whale Echolocation Signals

T. M. Yack¹, M.B. Hanson², M.M. Holt² and T. Norris¹

¹Bio-Waves, Inc, Encinitas, USA
²Marine Mammal & Seabird Ecology Team, Conservation Biology Division, NOAA/NMFS Northwest Fisheries Science Center, Seattle, USA

tina.yack@bio-waves.net

Endangered Southern Resident Killer Whales (SRKW) of the Northwest Pacific consist of three pods (J, K and L). Little is known about distribution, behavior, and general movements in winter and spring when pods leave Puget Sound for ‘outer coast’ waters. This vociferous population has a unique and well documented vocal dialect of social sounds (pulsed calls and whistles), allowing reliable acoustic identification. For the past eight years, the Northwest Fisheries Science Center (NWFSC) and Bio-Waves Inc. have conducted vessel based surveys using combined visual and towed-array passive acoustic monitoring and tracking techniques to study the winter/spring distribution and behaviors of this ecotype. Use of passive acoustics is essential in initial detection of killer whales and responsible for most encounters during these surveys. In 2012, PAMGuard software was implemented to automatically detect and classify killer whale echolocation signals. In 2013, during a ten day survey, a combination of satellite tag, acoustic, and visual monitoring methods facilitated nearly continuous tracking of SRKW pods (K and L). This provided a unique opportunity to test semi-automated tracking and localization features of PAMGuard relative to ‘manual’ methods (e.g. operator based localization using Ishmael and WhaleTrack II software). Over 60 localizations from each method were compared to one another and to visual sighting locations in real-time. Preliminary results illustrate the effectiveness of PAMGuard to help researchers track and localize individuals and groups with a high degree of accuracy. Application of this technology made it possible to track killer whales from greater ranges, acoustically visualize the convergence and splitting of groups, predict surfacing events, and quantify foraging events. We will use examples from this study to highlight the utility of passive acoustic detection, classification, and localization methods for real time monitoring and tracking. This work emphasizes the important role of passive acoustic monitoring in directing research activities and ultimately, conservation and management of endangered populations.
Tracking individual cetaceans with towed compact volumetric arrays

Walter MX Zimmer

NATO Centre for Maritime Research and Experimentation, La Spezia, Italy

zimmer@cmre.nato.int

Passive acoustic monitoring (PAM) is the method of choice to detect whales and dolphins that are acoustically active and to monitor their underwater behavior. PAM may be implemented with a variety of complexity, from single hydrophones suspended from drifting boats to multi-hydrophone arrays towed by ships. The NATO Centre for Maritime Research and Experimentation (CMRE) has recently implemented CPAM, a compact passive acoustic monitor, consisting of three arrays of two hydrophones each that are combined in a fixed three-dimensional arrangement and that may be towed at depths exceeding 100 m. Having a volumetric configuration, the CPAM is suited for estimating unique directions of arriving cetacean sounds and using their surface reflection delays, one may also estimate the range to the individual animals and therefore one should be able to track these individuals. Here, in addition to a description of the implemented hardware, a complete Detection, Classification, Localization and Tracking (DCLT) processing suite is presented and discussed using Cuvier’s beaked whale data collected during CMRE’s Sirena11 sea trial in the Ligurian Sea. Special attention is paid to the overall performance assessment of such a compact monitoring system.
<table>
<thead>
<tr>
<th>Author</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adam, O.</td>
<td>17</td>
</tr>
<tr>
<td>Aguilar, N.</td>
<td>4, 24, 32</td>
</tr>
<tr>
<td>Akamatsu, T.</td>
<td>1, 44, 62, 92</td>
</tr>
<tr>
<td>Alldredge, A.</td>
<td>26</td>
</tr>
<tr>
<td>Álvarez, O.</td>
<td>24</td>
</tr>
<tr>
<td>André, M.</td>
<td>13, 39</td>
</tr>
<tr>
<td>Andrews, R.</td>
<td>60</td>
</tr>
<tr>
<td>Arai, N.</td>
<td>44</td>
</tr>
<tr>
<td>Armstrong, M.</td>
<td>2, 3</td>
</tr>
<tr>
<td>Arranz, P.</td>
<td>4</td>
</tr>
<tr>
<td>Atkins, J.</td>
<td>43</td>
</tr>
<tr>
<td>Au, W.</td>
<td>50, 85</td>
</tr>
<tr>
<td>Baggaley, D.</td>
<td>57</td>
</tr>
<tr>
<td>Bahl, R.</td>
<td>1</td>
</tr>
<tr>
<td>Bahoura, M.</td>
<td>84</td>
</tr>
<tr>
<td>Baird, R. W.</td>
<td>8, 65</td>
</tr>
<tr>
<td>Bandet, M.</td>
<td>5</td>
</tr>
<tr>
<td>Barkley, Y.</td>
<td>6, 80</td>
</tr>
<tr>
<td>Barlow, J.</td>
<td>7, 46, 64, 79, 80, 94</td>
</tr>
<tr>
<td>Batchelor, H.</td>
<td>83</td>
</tr>
<tr>
<td>Baumann-Pickering, S.</td>
<td>2, 8, 18, 26, 37, 83, 88</td>
</tr>
<tr>
<td>Baugartner, M. F.</td>
<td>9</td>
</tr>
<tr>
<td>Becker, E.</td>
<td>94</td>
</tr>
<tr>
<td>Behera, S.</td>
<td>1</td>
</tr>
<tr>
<td>Bell, J.</td>
<td>48</td>
</tr>
<tr>
<td>Benda-Beckmann, A.M.</td>
<td>91</td>
</tr>
<tr>
<td>Berchok, C. L.</td>
<td>69, 83</td>
</tr>
<tr>
<td>Binder, C. M.</td>
<td>10</td>
</tr>
<tr>
<td>Bogue, N. M.</td>
<td>28, 47</td>
</tr>
<tr>
<td>Boisseau, O.</td>
<td>53</td>
</tr>
<tr>
<td>Booth, C.</td>
<td>57</td>
</tr>
<tr>
<td>Boucher, N. J.</td>
<td>11, 12</td>
</tr>
<tr>
<td>Brown, M. W.</td>
<td>9</td>
</tr>
<tr>
<td>Buckland, S.</td>
<td>34</td>
</tr>
<tr>
<td>Caballé, A.</td>
<td>13, 39</td>
</tr>
<tr>
<td>Caillat, M.</td>
<td>14</td>
</tr>
<tr>
<td>Name</td>
<td>Page Numbers</td>
</tr>
<tr>
<td>------------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Calderan, S.</td>
<td>64</td>
</tr>
<tr>
<td>Campbell, G. S.</td>
<td>36</td>
</tr>
<tr>
<td>Campbell, R. L.</td>
<td>36</td>
</tr>
<tr>
<td>Carrión, A.</td>
<td>15, 51</td>
</tr>
<tr>
<td>Castellote, M.</td>
<td>16</td>
</tr>
<tr>
<td>Cazau, D.</td>
<td>17</td>
</tr>
<tr>
<td>Cholewiak, D.</td>
<td>18, 74, 83</td>
</tr>
<tr>
<td>Clark, C.</td>
<td>21, 22, 78, 90</td>
</tr>
<tr>
<td>Cole, T. V. N.</td>
<td>9</td>
</tr>
<tr>
<td>Collins, K.</td>
<td>64</td>
</tr>
<tr>
<td>Crance, J. L.</td>
<td>69</td>
</tr>
<tr>
<td>D´Spain, G. L.</td>
<td>20, 36</td>
</tr>
<tr>
<td>Dadouchi, F.</td>
<td>19</td>
</tr>
<tr>
<td>Danbolt, M.</td>
<td>53</td>
</tr>
<tr>
<td>Dede, A.</td>
<td>44</td>
</tr>
<tr>
<td>Der Schaar, M. v</td>
<td>13, 39</td>
</tr>
<tr>
<td>Dilley, A.</td>
<td>66, 67</td>
</tr>
<tr>
<td>Doh, Y.</td>
<td>17</td>
</tr>
<tr>
<td>Dong. L.</td>
<td>92</td>
</tr>
<tr>
<td>Dosso, S. E.</td>
<td>81</td>
</tr>
<tr>
<td>Dugan, P.</td>
<td>21, 22, 78</td>
</tr>
<tr>
<td>Dunleavy, K.</td>
<td>75</td>
</tr>
<tr>
<td>Erbe, C.</td>
<td>23, 56</td>
</tr>
<tr>
<td>Fais, A.</td>
<td>24</td>
</tr>
<tr>
<td>Ferguson, E.</td>
<td>25, 48, 75</td>
</tr>
<tr>
<td>Fleming, A.</td>
<td>94</td>
</tr>
<tr>
<td>Flores, P.</td>
<td>77</td>
</tr>
<tr>
<td>Frantzis, A.</td>
<td>33</td>
</tr>
<tr>
<td>Frasier, K. E.</td>
<td>26, 27</td>
</tr>
<tr>
<td>Fratantoni, D. M.</td>
<td>9</td>
</tr>
<tr>
<td>Fregosi, S.</td>
<td>28</td>
</tr>
<tr>
<td>Garner, C.</td>
<td>16</td>
</tr>
<tr>
<td>Gassmann, M.</td>
<td>29</td>
</tr>
<tr>
<td>Gavrilov, A.</td>
<td>23, 56</td>
</tr>
<tr>
<td>Geissler, W.</td>
<td>61</td>
</tr>
<tr>
<td>Gerard, O.</td>
<td>30</td>
</tr>
<tr>
<td>Name</td>
<td>Pages</td>
</tr>
<tr>
<td>-----------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>Gervaise, C.</td>
<td>19, 52</td>
</tr>
<tr>
<td>Giard, S.</td>
<td>84</td>
</tr>
<tr>
<td>Gillespie, D.</td>
<td>14, 16, 31, 40, 53, 54, 57, 71</td>
</tr>
<tr>
<td>Gkikopoulou, K.</td>
<td>32, 33</td>
</tr>
<tr>
<td>Glennie, R.</td>
<td>34</td>
</tr>
<tr>
<td>Glotin, H.</td>
<td>17</td>
</tr>
<tr>
<td>González, R. P.</td>
<td>34</td>
</tr>
<tr>
<td>Gordon, H.</td>
<td>57</td>
</tr>
<tr>
<td>Gordon, J.</td>
<td>54</td>
</tr>
<tr>
<td>Goroshin, R.</td>
<td>22</td>
</tr>
<tr>
<td>Groch, K.</td>
<td>77</td>
</tr>
<tr>
<td>Hadley, M.</td>
<td>2, 3</td>
</tr>
<tr>
<td>Halkias, X.</td>
<td>22</td>
</tr>
<tr>
<td>Hannay, D. E.</td>
<td>81</td>
</tr>
<tr>
<td>Hanson, M. B.</td>
<td>95</td>
</tr>
<tr>
<td>Harris, D.</td>
<td>27, 35, 58, 61</td>
</tr>
<tr>
<td>Harwood, J.</td>
<td>66</td>
</tr>
<tr>
<td>Heaney, K.</td>
<td>36</td>
</tr>
<tr>
<td>Helble, T. A.</td>
<td>20, 36</td>
</tr>
<tr>
<td>Henderson, E. E.</td>
<td>26</td>
</tr>
<tr>
<td>Hildebrand, J. A.</td>
<td>8, 20, 26, 27, 29, 36, 37, 87</td>
</tr>
<tr>
<td>Hines, P. C.</td>
<td>10</td>
</tr>
<tr>
<td>Hodge, L.</td>
<td>74</td>
</tr>
<tr>
<td>Holt, M. M.</td>
<td>95</td>
</tr>
<tr>
<td>Holyoak, M.</td>
<td>94</td>
</tr>
<tr>
<td>Hönig, F.</td>
<td>38</td>
</tr>
<tr>
<td>Host-Madsen, A.</td>
<td>82</td>
</tr>
<tr>
<td>Houégnigan, L.</td>
<td>13, 39</td>
</tr>
<tr>
<td>Huillery, J.</td>
<td>19</td>
</tr>
<tr>
<td>Hurst, T.</td>
<td>9</td>
</tr>
<tr>
<td>Hwang, D.</td>
<td>83</td>
</tr>
<tr>
<td>IJsselmuide, S. P. v.</td>
<td>91</td>
</tr>
<tr>
<td>Imaizimi, T.</td>
<td>92</td>
</tr>
<tr>
<td>ioana, C.</td>
<td>19</td>
</tr>
<tr>
<td>Izzi, A.</td>
<td>40</td>
</tr>
<tr>
<td>Iwase, R.</td>
<td>62</td>
</tr>
<tr>
<td>Janik, V. M.</td>
<td>41</td>
</tr>
<tr>
<td>Name</td>
<td>Pages</td>
</tr>
<tr>
<td>---------------------</td>
<td>-------</td>
</tr>
<tr>
<td>Jarvis, S.</td>
<td>42, 66, 67</td>
</tr>
<tr>
<td>Jinnai, M.</td>
<td>11, 12</td>
</tr>
<tr>
<td>Johnson, M. P.</td>
<td>4, 9, 32, 43</td>
</tr>
<tr>
<td>Kameyama, S.</td>
<td>44</td>
</tr>
<tr>
<td>Kaplan, M. B.</td>
<td>45, 65</td>
</tr>
<tr>
<td>Kar, C. S.</td>
<td>1</td>
</tr>
<tr>
<td>Kar, S. K.</td>
<td>1</td>
</tr>
<tr>
<td>Kawaguchi, K.</td>
<td>62</td>
</tr>
<tr>
<td>Keating, J. L.</td>
<td>46</td>
</tr>
<tr>
<td>Kerosky, S. M.</td>
<td>87</td>
</tr>
<tr>
<td>Kershenbaum, A.</td>
<td>55</td>
</tr>
<tr>
<td>Khan, M.</td>
<td>1</td>
</tr>
<tr>
<td>Kimura, S.</td>
<td>1</td>
</tr>
<tr>
<td>Kirker, A.</td>
<td>26</td>
</tr>
<tr>
<td>Klimley, P.</td>
<td>94</td>
</tr>
<tr>
<td>Klinek, H.</td>
<td>28, 47</td>
</tr>
<tr>
<td>Krauss, M.</td>
<td>50</td>
</tr>
<tr>
<td>Kumar, A.</td>
<td>48</td>
</tr>
<tr>
<td>Küsel, E. T.</td>
<td>49</td>
</tr>
<tr>
<td>Lacey, C.</td>
<td>53</td>
</tr>
<tr>
<td>Lam, F.P.A.</td>
<td>91</td>
</tr>
<tr>
<td>Lammers, M.</td>
<td>50, 86</td>
</tr>
<tr>
<td>Lara, G.</td>
<td>15, 51</td>
</tr>
<tr>
<td>Le Bot, O.</td>
<td>5, 52</td>
</tr>
<tr>
<td>Leaper, R.</td>
<td>53, 64</td>
</tr>
<tr>
<td>LeCun, Y.</td>
<td>22</td>
</tr>
<tr>
<td>Lewis, T.</td>
<td>24, 53</td>
</tr>
<tr>
<td>Luby, J. C.</td>
<td>28, 47</td>
</tr>
<tr>
<td>Macaulay, J.</td>
<td>56</td>
</tr>
<tr>
<td>MacFadden, M.</td>
<td>55</td>
</tr>
<tr>
<td>Madhusudhana, S.</td>
<td>23, 56</td>
</tr>
<tr>
<td>Maginnis, A.</td>
<td>16, 57</td>
</tr>
<tr>
<td>Manser, M.</td>
<td>38</td>
</tr>
<tr>
<td>Manzano-Roth, R.</td>
<td>59</td>
</tr>
<tr>
<td>Marques, T. A.</td>
<td>27, 34, 58, 66</td>
</tr>
<tr>
<td>Mars, J. I.</td>
<td>19, 52</td>
</tr>
<tr>
<td>Martin, B.</td>
<td>68, 69</td>
</tr>
</tbody>
</table>
Martin, S. W. 59
Martinez, A. 74
Mathias, D. 60
Matias, L. 35, 61
Matsumoto, H. 47
Matsuo, I. 62
Matsuyama, B. 59
Matthews, J. 53
Matthiopoulos, J. 33
McCarthy, E. 42, 66, 67
McDonald, M. A. 27
Mclanoghan, R. 53
Mei, Z. 92
Meigs, H. 50
Melcón, M. 74
Mellinger, D. K. 28, 35, 47, 49, 61, 63, 69
Merkens, K. P. 27
Mikolajczyk, A. 21, 78
Miller, B. 64
Miralles, R. 15, 51
Mooney, T. A. 45, 65
Moretti, D. 42, 66, 67
Morrissey, R. 42, 66, 67
Moscrop, A. 53
Mouy, X. 68, 69
Munger, L. M. 6, 83
Murphy, S. 85
Neales, B. 66
New, L. 66
Nichols, N. 70
Nissen, J. 48
Norris, T. F. 25, 48, 71, 75, 95
Northridge, S. 54
Nosal, Eva-Marie 72, 82
Nöth, E. 38
Nouri, D. 73
Oleson, E. M. 6, 8, 26, 83
Orbach, D. 86
Ostendorf, M. 70
Oswald, J. N. 45, 48, 68, 69, 77, 74
Oswald, M. 75
Ou, H. 50
Öztürk, A. A. 44

Panda, S. 1
Parijs, S. M. V. 9, 18, 74, 76, 83
Parks, S. E. 77
Parsell, M. 87
Pedersen, E. 11, 12
Piwetz, S. 86
Popescu, M. 21, 22, 78
Pourhomayoun, M. 22

Rankin, S. 8, 26, 46, 79, 80, 83
Read, A. 74
Redfern, J. 79, 94
Rice, A. 21
Rideout, B. P. 81, 82
Risch, D. 83
Roch, M. A. 8, 20, 26, 37, 55, 83, 88
Roy, N. 5, 84
Rudd, A. 85

SAMBAH project team 89
Sasaki-Yamamoto, Y. 1
Sayigh, L. S. 45
Schotten, M. 86
Sexton, K. 86
Shaffer, J. 67
Shiu, Y. 22
Siderius, M. 49
Simard, Y. 5, 52, 84
Simonis, A. E. 8
Širović, A. 37, 83, 87
Soldevilla, M. S. 74, 83
Sonmez, R. 38
Sousa-Lima, R. 77
Spellen, M. V. 91
<table>
<thead>
<tr>
<th>Name</th>
<th>Page(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stelzer, R.</td>
<td>47</td>
</tr>
<tr>
<td>Stinner-Sloan, J.</td>
<td>88</td>
</tr>
<tr>
<td>Straley, J.</td>
<td>60</td>
</tr>
<tr>
<td>Sugimatsu, H.</td>
<td>1</td>
</tr>
<tr>
<td>Taylor, H.</td>
<td>12</td>
</tr>
<tr>
<td>Thode, A.</td>
<td>60</td>
</tr>
<tr>
<td>Thomas, L.</td>
<td>14, 27, 34, 35, 58, 61, 66, 71, 89</td>
</tr>
<tr>
<td>Ura, T.</td>
<td>1</td>
</tr>
<tr>
<td>Urazghildiiiev, I.R.</td>
<td>22, 75, 90</td>
</tr>
<tr>
<td>Valtierra, R.</td>
<td>18, 80</td>
</tr>
<tr>
<td>Wang, D.</td>
<td>92</td>
</tr>
<tr>
<td>Wang, K.</td>
<td>92</td>
</tr>
<tr>
<td>Wang, Z.</td>
<td>92</td>
</tr>
<tr>
<td>Ward, J.</td>
<td>42, 66</td>
</tr>
<tr>
<td>Weirathmueller, M.</td>
<td>93</td>
</tr>
<tr>
<td>Wiggins, S. M.</td>
<td>8, 27, 37</td>
</tr>
<tr>
<td>Wilcock, W.</td>
<td>93</td>
</tr>
<tr>
<td>Würsig, B.</td>
<td>86</td>
</tr>
<tr>
<td>Xue, C.</td>
<td>17</td>
</tr>
<tr>
<td>Yack, T. M.</td>
<td>25, 48, 71, 94, 95</td>
</tr>
<tr>
<td>Zimmer, W. M. X.</td>
<td>96</td>
</tr>
<tr>
<td>Zollweg, J.</td>
<td>21, 76</td>
</tr>
</tbody>
</table>