Università degli Studi di Pavia

Dipartimento di Biologia Animale

Centro Interdisciplinare di Bioacustica e Ricerche Ambientali

4th International Workshop on Detection, Classification and Localization of Marine Mammals Using Passive Acoustics

1st International Workshop on Density Estimation of Marine Mammals Using Passive Acoustics

University of Pavia, Italy

Cairoli College - September 2009, 10th - 13th

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University of Pavia, Italy
September 2009, 10th - 13th

Cairoli College - Piazza Cairoli, 1 - Pavia

http://www.unipv.it/cibra/DCLWorkshop2009.html
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ORGANIZED BY:

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Olivier Adam (NAMC, Univ. of Paris, France)
Len Thomas (Univ St Andrews, Scotland; convenor of the DE workshop).

ORGANIZING COMMITTEE

Gianni Pavan, CIBRA (DCL Workshop);
Len Thomas, StAndrews University (DE Workshop)

PREVIOUS DCL WORKSHOPS

I - Halifax, Canada (2003)
II - Oceanographic Museum of Monaco (2005)
III - Boston, U.S. (2007)

SECRETARIAT

PRAGMA Congressi congressi2@pragmacongressi.it

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WORKSHOPS PRESENTATION

The objective of the DCL workshop is to improve general understanding of methods to detect, classify, locate, track and monitor marine mammals in their environment. After three workshops dedicated to individual species, this fourth workshop is focused on a more complex issue: the analysis of real-world complex acoustic scenes and the use of the context for identifying acoustic components of interest.

A set of underwater recordings was made available online to encourage researchers to work on a common dataset, to focus on the same problems, to find original solutions, and to present and compare them at the workshop. Researchers working on their own datasets are welcome as well.

The workshop is introduced by two lectures.

The DE workshop brings together researchers working on estimating absolute density or abundance of marine mammal populations using passive acoustics.

The workshop is introduced by a tutorial overview of the topic, followed by presentations showcasing relevant research.

PROGRAM

Collegio Cairoli, Main Conference Room

Wednesday 9 September

17.00 Registration opening

18.30 Welcome Cocktail

Thursday 10 September - DCL Workshop

8.00 Registration

8.40 Opening

9.00 **Lecture: Lazzaro Spallanzani: a hero of pre-animal welfare experimental biology**
Peter Tyack

9.30 **Lecture: Underwater Noise, Marine Resource Management and Passive Acoustic Monitoring**
Robert Gisiner

10.00 Coffee break

10.40 **Detecting the clicks of beaked whales with wavelets**
Mark Fischer, Jim Nollman

11.00 **Data compression and detection of Blainville beaked whales using non-linear modelling**
Donald McGaughey, Michael Korenberg, Jennifer Stamplecoskie, Jim Therriault

11.20 **A comparison of Blainville's (*Mesoplodon densirostris*), Cuvier's (*Ziphius cavirostris*), and Gervais' (*Mesoplodon europaeus*) beaked whale vocalizations as recorded in the Tongue of the Ocean in the Bahamas**
David Moretti, Charlotte Dunn, Ronald Morrissey, Jonathan Gordon, Nancy DiMarzio, Douglas Gillespie, Jessica Ward, Susan Jarvis, Elena McCarthy, Annamaria Izzi

11.40 **Presence and distribution of Cuvier's beaked whales in the Alboran Sea revealed by wide-band towed arrays**
Gianni Pavan

12.00 **Detection of Beaked Whales using Autonomous Underwater Gliders**
James A. Theriault, Joey Hood, Donald Mosher, and Timothy Murphy

Buffet

14.00 **Comparison of Beaked Whale Detection Algorithms**
Tina M. Yack, Jay Barlow, Marie A. Roch, Holger Klinck, Steve Martin, David K. Mellinger, and Douglas Gillespie

14.20 **Interesting Properties of some Striped Dolphins Buzzes revealed through Multi-Hypothesis Tracking**
Odile Gérard, Craig Carthel, Stefano Coraluppi, Gianni Pavan

14.40 **Automatic detection and identification of odontocetes clicks**
Caillat Marjolaine, Gillespie Douglas, Gordon Jonathan

15.00 **Sperm whale localization with the NEMO ONDE short-baseline platform**
Bénard Frédéric, Hervé Glotin, Pascale Giraudet

15.20 **Tetrahedral hydrophone array used to localize sperm whales**
Eva-Marie Nosal

15.40 Coffee break

16.20 **Evaluation of sperm whale acoustic emissions to understand its presence in the Ionian Sea. The NEMO Project as a unique research opportunity**
F. Zardin, G.F. Ficetola, E. Internullo, G. La Manna, G. Riccobene, G. Pavan

16.40 **Real time classification of sperm whale clicks and shipping impulses from a deep sea antenna**
Serge Zaugg, Mike van der Schaar, Ludwig Houégnigan, Michel André

17.00 **Real-time processing and management of acoustic data streams in LIDO**
Mike van der Schaar, Serge Zaugg, Ludwig Houégnigan, Michel André

17.20 **Integrated passive acoustic approach for detection, localization, and identification of individual marine mammals as applied to Workshop data**
Natalia Sidorovskaia, Philip Schexnayder, George E. Ioup, Juliette W. Ioup, Christopher O. Tiemann, James Sabatier, Alexander Ekimov

17.40 **Detection and Classification of Buzz Clicks in the 3rd Workshop Dataset using a Multi-Hypothesis Tracker**
Odile Gérard, Craig Carthel, Stefano Coraluppi

18.00 Close

Friday 11 September

8.40 **Raising the BARN, a bioacoustic resource network**
Harold Figueroa, David Michael

9.00 **Extracting incidental signals from targeted sound bites**
Jennifer L. Miksis-Olds, Jeffrey A. Nystuen, Susan E. Parks

9.20 **Rejecting unknown species in a species detection task**
Simon Qui, Marie A. Roch, Melissa Soldevilla, and John A. Hildebrand

9.40 **Automated, real-time classification of odontocete vocalizations over large open-ocean areas**
Susan Jarvis, Ronald Morrissey, Nancy DiMarzio, David Moretti, Jessica Ward, Elana McCarthy

10.00 Coffee break

10.40 **Improved Passive Band-limited Energy Detection for Marine Mammals**
Joey D. Hood, David G. Flogeras

11.00 **Bearings tracking with time-bearing displays and particle filters**
Mark L Hadley, Paul R White, Patrick J O Miller

11.20 **Two algorithms for marine mammals detection under transient noise conditions**
C. Gervaise, A. Barazzutti, S. Busson, Y. Simard, N. Roy

11.40 **Whale axis angle variation estimation according to clic energy conservation**
Glotin Hervé, Bénard Frédéric, Patris Julie

12.00 **Identifying delphinid whistle contours using graph search**
Marie A. Roch, Bhavesh Patel, Melissa S. Soldevilla, and John A. Hildebrand

Buffet

14.00 **An algorithm for detection of whistles, moans, and other tonal sounds**
David K. Mellinger, Steve W. Martin, James Yosco, Ronald P. Morrissey, Nancy A. DiMarzio, David J. Moretti, Len Thomas

14.20 **Probability of the detection of calling bouts by a low duty cycle passive acoustic recorder**
Jeffrey A. Nystuen, Jennifer L. Miksis-Olds, Susan E. Parks

14.40 **An autonomous ocean glider using real-time acoustic detection and classification of marine mammal sounds**.
Holger Klinck, David K. Mellinger, Neil Bogue, Jim Luby, Bill Jump, John Pyle, Geoff Shilling

15.00 **Detection, Classification, Tracking with compact volumetric arrays**
Zimmer W.M.X.

15.20 **Passive acoustic monitoring of marine mammals using a directional towed array**
Bruce Martin, Marjo Laurinolli, Xavier Mouy, Trent Johnson, Stephen Turner, Chris Widdis, Eric Lumsden, Bill Streever, Bernard Padovani, and Paul Yeatman

15.40 Coffee break

16.20 **Localization of ultrasonic vocalizing marine mammals using towed arrays**
A.M. von Benda-Beckmann, S.P. Beerens, F.P.A. Lam, S.P. van IJsselmuide

16.40 **Design and Assessment of Five Hydrophone Array-Configurations for Marine Mammal Localization within a Safety Zone**
Jonathan Vallarta

17.00 **Analysis of underwater mammals vocalizations using time-frequency-phase tracker, applications to crossing whistles**.
Cornel Ioana, Cédric Gervaise, Yann Stéphan, Yvan Simard, Jerome Mars

17.20 Poster

18.00 Close

Saturday 12 September

8.40 **Characterisation of sound subunits for humpback whale song analysis**.
F. Pace, P.R. White, O. Adam

9.00 **Passive acoustic detection of Minke whales (*Balaenoptera acutorostrata*) off the West Coast of Kauai, Hi**
Ronald P. Morrissey, Nancy A. DiMarzio, David J. Moretti, Steve W. Martin, David K. Mellinger, James Yosco, Carol Ciminello, Len Thomas

9.20 **Acoustic localization of blue whale (*Balaenopera musculus*) using the hydrophones of the International Monitoring System.**
Samaran Flore, Adam Olivier, Guinet Christophe

9.40 **Detection of Minke whale sounds in the Stellwagen Bank National Marine Sanctuary, USA**
Denise Risch, Christopher W. Clark, Ursula Siebert, Sofie M. Van Parijs

10.00 Coffee break

10.40 **Manual and Automated Detection, Classification, and Localization of Bowhead Whale Calls in the Alaskan Beaufort Sea**
Katherine H. Kim, Aaron Thode, Trent L. McDonald, Christopher S. Nations, Susanna B. Blackwell, Charles R. Greene, Jr., A. Michael Macrander

11.00 **Possibilities of non-intrusive tracking of belugas from their clicks: experiment from a coastal hydrophone array**
Nathalie Roy, Yvan Simard, and Cédric Gervaise

11.20 **Anthropogenic noise and Guiana dolphins (*Sotalia guianensis*) in Brazil: ecological and conservation concerns**
Marcos R. Rossi-Santos, Leonardo L. Wedekin, Flavio J.L. Silva, Felipe P. Garcia, Dalila Leão, Emygdio L.A. Monteiro-Filho

11.40 **Using Passive Acoustic Monitoring to Evaluate the Impact of Anthropogenic Noise on Cetacean Vocal Activity**
Cholewiak Danielle, Vu Elizabeth, McEachern Michelle, Van Parijs Sofie, Hatch Leila, Clark Christopher, Wiley Dave

12.00 **Passive tracking of walruses in the Arctic using a single hydrophone**
Xavier Mouy

Buffet

14.00 **Passive acoustic monitoring in the Ligurian Sea**
Bénard Frédéric, Glotin Hervé, Castellote Manuel, Laran Sophie, Lammers Marc O.

14.20 **Geographic variation in the whistles produced by four delphinid species in the Pacific Ocean and Mediterranean Sea**
Oswald Julie N., Rankin Shannon, Gannier Alexandre, Barlow Jay, FuchsSandra, Rudd Alexis, Au Whitlow W.L.

14.40 **Acoustic identification of mediterranean Odontocetes as a prerequisite for passive acoustic mitigation**
Marta Azzolin, Marc O. Lammers, Alexandre Gannier, Cristina Giacoma

15.00 **Performance of contour extraction software for the classification of five Mediterranean dolphin species**
Alexandre Gannier, Sandra Fuchs, Paméla Quèbre, Julie N. Oswald

15.20 **Passive acoustic monitoring of common bottlenose dolphins using bottom recorders in the Pelagie Islands (Strait of Sicily - Mediterranean Sea)**
Michele Manghi, Gabriella La Manna

15.40 Coffee break

16.20 Poster

18.00 Visit to the Historical Halls and the Museum of the University

19.30 Social Dinner – Rectorate Halls of the University (see map at the end of the book)

Sunday 13 September - DE Workshop

8.40 **Opening**
Len Thomas

8.50 **Review of methods for estimating cetacean density from passive acoustics**
Len Thomas and Tiago A.Marques

9.20 **Beaked whale density estimation from an acoustic survey off the US West Coast**
Jay Barlow, Tina M. Yack, Shannon Rankin, and Robin W. Baird

9.40 **A comparison of the density of delphinids during a combined visual and acoustic shipboard line-transect survey**
Shannon Rankin, Jay Barlow, Julie Oswald, Tina Yack

10.00 Coffee break

10.40 **Accounting for ambient noise in Blainville's beaked whales density estimation**
Tiago A. Marques, Len Thomas, Jessica Ward, Nancy DiMarzio, David Moretti and Peter L. Tyack

11.00 **Sonar equation based approach to estimate the detection function**
Walter Zimmer

11.20 **Density estimation of Blainville's beaked whales (*Mesoplodon densirostris*) from single hydrophones by means of propagation modeling**
Elizabeth T. Küsel, David K. Mellinger, Len Thomas, Tiago A. Marques, David J. Moretti, and Jessica Ward

11.40 **Passive acoustic density estimation of Blainville's beaked whales (*Mesoplodon densirostris*) using group localization combined with click counting**
Nancy DiMarzio, David Moretti, Jessica Ward, Ronald Morrissey, Susan Jarvis, Elena McCarthy, Mark Johnson, Peter Tyack, Diane Claridge, Charlotte Dunn, Tiago Marques, and Len Thomas

12.00 **Acoustic line transect surveys for sperm whales**.
Douglas Gillespie, Rene Swift, Tim Lewis

Buffet

14.00 **Density estimation of Antarctic Blue Whales using automatic calls detection**
Thomas Musikas, Flore Samaran, Michaël Aupetit, Oliver Adam

14.20 **Estimating the abundance of blue whales (*Balaenoptera musculus)* in the northern Indian Ocean using vocalisations recorded by sea-bed mounted hydrophones.**
Danielle Harris, Len Thomas, John Hildebrand, Sean Wiggins, John Harwood

14.40 **SAMBAH – Static Acoustic Monitoring of the Baltic Sea Harbour Porpoise**
Mats Amundin, Ida Carlén, Julia Carlström, Jonas Teilmann, Len Thomas, Jacob Tougaard

15.00 **Static acoustic monitoring of harbour porpoises in the German Baltic Sea – How many devices do you need?**
Dähne Michael, Verfuß Ursula, Adler Sven, Meding Anja, Honnef Christopher, Bräger Stefan, Benke Harald

15.20 **Estimating beluga densities from passive acoustics: Exploration for St. Lawrence belugas frequenting the entrance basin of Saguenay fjord at Tadoussac**
Yvan Simard, N.Roy, S. Giard, C. Gervaise, M. Conversano and N. Ménard

15.40 Coffee break

16.20 **Open discussion: What do we know, and where next ?**

17.30 Close

DCL Workshop

Opening Lectures:

Peter Tyack
Woods Hole Oceanographic Institution, USA

Lazzaro Spallanzani: a hero of pre-animal welfare experimental biology

Bob Gisiner
Marine Mammals Commission, USA

Underwater Noise, Marine Resource Management and Passive Acoustic Monitoring

Opening Lecture

Lazzaro Spallanzani: a hero of pre-animal welfare experimental biology

Peter L. Tyack

Biology Department, Woods Hole Oceanographic Institution

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Lazzaro Spallanzani is perhaps best known for his series of careful experiments disproving spontaneous generation, which were published in 1765 when he was a 36 year old professor of Philosophy at the University of Modena. Spallanzani's fame as an experimental natural historian led the monarchs of the Austrian empire to offer him the directorship of the Museum of Natural History at the University of Pavia in 1769, soon after the Austrians occupied Lombardy. Among his other achievements at Pavia, not far from where we are meeting, Spallanzani started a series of experiments that ultimately led to our understanding of animal sonar. No one knows what led Spallanzani to study bats, but certainly naturalists knew for millennia that bats can fly at night, apparently maneuvering around obstacles in the dark. The key to Spallanzani's experiment was that he took pipistrelle bats into captivity, blinded them, and showed that they could avoid obstacles in a completely darkened room just as well as a bat with sight. By covering the skin, cutting out the tongue, or plugging up the nostrils, Spallanzani and collaborators ruled out a role for touch, taste and smell in obstacle avoidance. The results piqued Spallanzani's interest enough for him to write to collaborators to ask them to repeat the results. Spallanzani and collaborators showed that hoods or white paper on the snout caused bats to strike obstacles. However, when Spallanzani blocked the ears of 11 bats with wax, ten flew normally and only one flew with difficulty. He thought that the eleventh animal was an outlier, and concluded that his research had not led him to the solution to the problem, and that bats might have some sixth sense, a sensory mechanism unknown to us. A critical move that Spallanzani made was to ask colleagues to replicate his results. One of his colleagues in Switzerland, Senebier, had another colleague, Jurine repeat the experiment. After showing good orientation in blinded bats, Jurine showed that when their ears were plugged, the bats blundered into obstacles. Spallanzani immediately recognized the importance of this finding, and concluded that the sense of hearing is critical for obstacle avoidance in flying bats. Jurine and Spallanzani had no way to explain these results, but they were driven by their experimental approach to accept them. Unfortunately neither Jurine's results nor Spallanzani's reaction were published with as wide a distribution as Spallanzani's earlier negative results with respect to hearing. George Cuvier rejected Spallanzani's earlier "sixth sense" hypothesis, arguing that bats had such a sensitive sense of touch that they could sense slight movements of air induced by obstacles. Cuvier also discounted Jurine's experiments, saying that the way Jurine blocked hearing was extremely cruel and might have done more than just lessen hearing. Cuvier's argument that bats avoided obstacles with a sensitive sense of touch was laid out in his influential 1800 book Lessons in Comparative Anatomy. Even though he ignored some of the critical experiments, and added no new data of his own, his view was repeated throughout the nineteenth century. In the first decade of the 1900s, Hahn replicated Spallanzani's experiment with North American bats; by 1920 Hartridge recalled the invention of active sonar in WWI and proposed that bats listen for echoes. The final proof of Spallanzani and Jurine's hypothesis came when Donald Griffin and Charles Pierce used new electronics to measure ultrasonic cries of bats that were inaudible to humans, when high frequency hearing in bats was demonstrated by Galambos, and the neurobiology of bat sonar ultimately uncovered.

Opening Lecture

Underwater Noise, Marine Resource Management and Passive Acoustic Monitoring

Robert Gisiner

Marine Mammal Commission, Bethesda, MD USA.

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Rather than review current concepts and practices for managing underwater noise, I have chosen to emphasize three topics that may offer new perspectives for managing underwater noise.

First I will describe some interesting results from studies of both human and terrestrial animal responses to anthropogenic noise in the environment.

Second, I will explore how behavioral effects of noise might be translated into biologically meaningful metrics of environmental risk, drawing mainly from the 2005 National Research Council report on the Population Consequences of Acoustic Disturbance, along with other research on the cumulative effects of natural and anthropogenic stressors.

Third, I will discuss implications of the current focus on global climate change for all environmental management in the 21st century, including underwater noise. Traditionally, the aims of resource management have been to restore and preserve the natural environment at some recent historical level of species composition and abundance. We often speak of ecosystem stability or balance, when in fact the physical, biological and anthropogenic influences on that ecosystem are all inconstant. In an inconstant world, what should our goals be in order to achieve a healthy ocean ecosystem, and how will an understanding of underwater acoustics help us achieve those goals?

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Detecting the clicks of Beaked Whales with Wavelets

Mark Fischer, Jim Nollman

AguaSonic Acoustics, Interspecies Inc.

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Most of the algorithms used for classifying cetaceans by call operate by analyzing acoustic data displayed by spectrographic analysis. Because spectrograms are based on Fourier transforms, this standardized technique works well at classifying the frequency modulated calls that Fourier transforms are most capable of illuminating. This includes the whistles and rhythmic pulses produced by many whale species. By contrast, the foraging clicks of Ziphidae consist almost entirely of exceedingly short duration, wide frequency, and fast-repeating click trains. Fourier-based algorithms provide a clumsy tool at best to interpret such transient data. Wavelet transforms operate by mathematical coordinates rather than by frequency and time, and displaying certain types of data, especially transient data, in wavelet space can vastly improve the task of classifying Ziphidae clicks. By calibrating the scales of individual transforms, wavelets can also be fine-tuned to provide a better match with particular kinds of clicks. The result of this optimization process is called a "wavelet profile", which we define as the combination of a wavelet transform with a range of scales matched to the clicks of a particular species. This paper explains our process for tuning and programming the selection of such profiles to match cetacean clicks. The objective of this work is to suggest a better method for automatically classifying the calls of the cetacean species at risk from US Navy active sonar. In some circumstances, we have found that these profiles reveal so much detail, that we have been able to discern beaked whale dialects.

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Data compression and detection of Blainsville beaked whales using non-linear modelling.

Donald McGaughey, Michael Korenberg, Jennifer Stamplecoskie, Jim Therriault

Royal Military College of Canada, Queen's University

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Detection of remote Blainville's beaked whale clicks poses significant problems due to limited communication bandwidths. High bandwidth sampling (typically 100+ kHz) and processing is required in order to detect the clicks, but transmitting the data from a remote sensor (e.g. Glider or Autonomous Sensor) using a low bandwidth (4800 baud) satellite link results in a real-time bottleneck. Even if auto-detection algorithms were used on the remote sensor, some data would need to be relayed to a human operator to verify the classification. Hence, the ability to compress the data in a manner that does not impede the ability to detection and classify the transient signal is required. Typical audio compression techniques have a maximum sampling rate of 48 kHz which is too low to collect beaked whale clicks and still obey the Nyquist criteria. In addition, audio compression algorithms also have a psycho-acoustic model that aids in the compression of the signal but distorts the audio signal.

This paper presents a compression algorithm that uses a non-linear modelling technique called the Fast Orthogonal Search (FOS) to create functional expansion of the acoustic data. The candidate functions used in the functional expansion are transient signals that model Blainsville's beaked whale clicks as well as sinusoidal functions for modelling whale songs. Compression is achieved by transmitting candidate numbers and weights for only the candidate functions that are chosen by the FOS algorithm. The acoustic signal is recreated using the weights and candidate numbers transmitted. The reconstructed time series is used as an input to the band-limited energy detector. The raw data and the reconstructed data have a comparable probability of detection, probability of false alarm, and probability of missed detections.

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A comparison of Blainville's (*Mesoplodon densirostris*), Cuvier's (*Ziphius cavirostris*), and Gervais' (*Mesoplodon europaeus*) beaked whale vocalizations as recorded in the Tongue of the Ocean in the Bahamas

David Moretti[1], Charlotte Dunn[2], Ronald Morrissey[1], Jonathan Gordon[3], Nancy DiMarzio[1], Douglas Gillespie[3], Jessica Ward[1], Susan Jarvis[1], Elena McCarthy[1], Annamaria Izzi [1]

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2-Bahamas Marine Mammal Research Organization, Marsh Harbour, Bahamas
3-University of St. Andrew's, St. Andrews, Scotland

Blainville's (*Mesoplodon densirostris*), Cuvier's (*Ziphius cavirostris*), and Gervais' (*Mesoplodon europaeus*) beaked whales have been visually verified in a deep ocean canyon in the Bahamas known as the Tongue Of The Ocean (TOTO). Vocalizations from all three species as recorded on bottom-mounted hydrophones at the Atlantic Undersea Test and Evaluation Center, (AUTEC) along with those made by trained observers from a suspended hydrophone(s) are compared. Both time and frequency analysis are included. Distinct differences are observed. The lower frequency bound of M*e* is ~30 kHz, M*d* is ~25 kHz, and Z*c* is ~16 kHz. The ICI of M*e* is ~0.27 sec, M*d* is ~0.32 sec, and Z*c* is ~0.52 sec. Results from a simple classifier are presented where the three species are separated based on the frequency distribution of their clicks along with distinct differences in ICI.

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Presence and distribution of Cuvier'beaked whales in the Alboran Sea revealed by wide-band towed arrays

Gianni Pavan

University of Pavia, Centro Interdisciplinare di Bioacustica e Ricerche Ambientali, Italy

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A combined visual and acoustic survey (SIRENA '08) was organized by NURC and other Institutions to estimate the diversity, abundance and distribution of marine mammals in the Alboran Sea (Western Mediterranean Sea). The survey was planned to cover the investigation area four times in 18 days to possibly estimate the coherence of results in different passages. Passive acoustic equipment was used 24h/day; visual observations were conducted during daylight hours; the visual effort was severely affected by negative weather conditions (Beaufort ≥ 4).

In 18 days of survey on transects, divided in four passages totalling 3333 kilometers at an average speed of 4.8 knots, 390 hours of acoustic monitoring was performed with a wideband (>80kHz) low noise towed array connected to the CIBRA SeaPAM workstation.

Acoustic detections in 60% of the recording time revealed the presence of many Odontocete species (*Physeter macrocephalus, Ziphius cavirostris, Globicephala melas*, recognized at species level, and *Stenella coeruleoalba* and *Delphinus delphis* not separated acoustically, and *Grampus griseus* whose clicks appear to have distinctive features). Cuvier's beaked whales, critical cetaceans for passive acoustics and one of the target species of the survey, were detected in real-time in more than 300 minutes (time slots); then, in post processing, detections have been verified and grouped in near to 100 "acoustic contacts" with single individuals or pairs; in few cases multiple pairs have been detected.

The mapping of the presence of Cuvier's beaked whales was particularly successful and further demonstrated the efficacy of passive acoustic surveys conducted with a quiet dedicated platform, the NRV Alliance, equipped with high quality detection and monitoring instruments connected to a real-time sound processing workstation and a GIS system.

Selected recordings made in the SIRENA '08 cruise have been made available for the Dataset #1 of the DCL Workshop.

Pavan G., Fossati C., Priano M., Manghi M., 2009. Acoustic detection of Cuvier's beaked whales *(Ziphius cavirostris).* In: Dolman S., McLeod C. & Evans P.G.H. (Eds.), 2009. Proceedings of the Workshop " Beaked Whale Research". ECS Special Publication Series n. 51. 21st Annual meeting of the European Cetacean Society, San Sebastian, Spain, 26th April 2007. Pag. 31-35

Zimmer W.M.X., Pavan G., 2008 Context driven detection/classification of Cuvier's beaked whale (Ziphius cavirostris) IEEE Proc. Passive 08.

Notes____

Detection of Beaked Whales using Autonomous Underwater Gliders

James A. Theriault[1], Joey Hood[2], Donald Mosher[1], and Timothy Murphy[1]

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Development of robust, practical systems for detection and localization of marine mammals poses many difficulties. This is especially true for deep diving species such as the Blainville's Beaked whale (Mesoplodon densirostris) whose click frequency ranges from 23 kHz to greater than 40 kHz. Detecting such species using autonomous systems requires low-noise sensor and electronics design, high sampling rates, and efficient low-power processing. A number of passive acoustic systems were deployed during a January/February 2006 beaked whale detection sea trial at the US Atlantic Undersea Test and Evaluation Center (AUTEC) in the Bahamas. These included Slocum gliders, broadband sonobuoys, and over-the-side hydrophones. This paper presents two detection algorithms and their application to low-power, autonomous sensor packages such as those used on the DRDC Slocum Gliders. The detection algorithms were based on a matched filter and a band-limited energy detector. This paper includes a representative subset of the data recorded on a glider from the 2006 trial that demonstrates the relative performance of the algorithms. The initial portion of the selected data was consistent with previously published Blainville's beaked whale click trains, but the latter portion contained a downward frequency shift which remains unexplained. The detection performance was similar, until guard bands were employed, where an improvement in false alarm rate was achieved for the energy detector. A further benefit of the energy detection algorithm was reduced processing requirements.

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Comparison of Beaked Whale Detection Algorithms

Tina M. Yack[1,2,3] , Jay Barlow[1], Marie A. Roch[4], Holger Klinck[5], Steve Martin[6], David K. Mellinger[5], and Douglas Gillespie[7].

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Beaked whales are now easier to detect acoustically than visually during line-transect surveys. Beaked whales can be discriminated from other cetaceans by the unique characteristics of their echolocation clicks (duration >175 µs, center frequencies between 30-40 kHz, inter-click intervals between 0.2-0.4 sec and frequency upsweeps). Furthermore, these unique characteristics make these signals ideal candidates for testing automated detection and classification algorithms. There are several different beaked whale detectors currently available for use; however, no comparative analysis of detectors exists. Therefore, comparison between studies and datasets is difficult. The purpose of this study was to test and validate beaked whale detection algorithms for detection of beaked whales in acoustic line-transect survey data. Six different detection algorithms (XBAT, Ishmael, PAMGUARD, ERMA, Roch and Martin) were evaluated and compared. Detection trials were run on three sample days of NOAA Southwest Fisheries Science Center (SWFSC) recordings during which there were confirmed beaked whale visual sightings. Detections were also compared to manually verified detections for a subset of the data. In order to obtain a census of false detection probability, each detector was also run on three sample recordings containing Risso's dolphin (*Grampus griseus*) echolocation clicks. The detection performance of the different algorithms will be discussed.

Notes

Interesting Properties of some Striped Dolphins Buzzes revealed through Multi-Hypothesis Tracking

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Toothed whales are known to click to find prey. The characteristics of the clicks and repetition rates vary from one species to another, but clicks are fairly regular during the phase in which the animals are looking for prey. Once they have found prey the repetition rate of the clicks increases; these sequences are called buzzes.
Some previous work shows that the buzz clicks spectrum slowly vary from one click to the next for various species [1-2]. This similarity permits their association as a sequence using multi-hypothesis tracking algorithms [1-2]. Thus buzz classification follows the automatic tracking of clicks.
This method has been applied to striped dolphin (*Stenella coeruleoalba*) buzzes recorded during Sirena02, a NATO Undersea Research Centre trial held in the Mediterranean Sea in 2002. The property of slowly varying spectrum is often true, but in some cases a variant of this property has been found, whereby sub-sequences of clicks exhibit slowly varying characteristics. This new finding is discussed from a physiological point of view.

[1] Odile Gerard, Craig Carthel and Stefano Coraluppi, Classification of Odontocete Buzz Clicks using a Multi-Hypothesis Tracker, *Proceedings of Ocean'09*, May 2009, Bremen, Germany.

[2] Odile Gerard, Craig Carthel and Stefano Coraluppi, Classification of odontocete buzz clicks using an MHT tracker, *submitted to the 4th International Workshop on the Detection and Classification of Marine Mammals using Passive Acoustics*, Pavia, September 2009.

Notes

Automatic detection and identification of odontocetes clicks

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Clicks are an important class of sounds produced by odontocetes. They are mainly used for echolocation to navigate and to find preys and in some cases also seem to have a role in social communication. To date, most odontocetes classification has been attempted using tonal calls such as whisltes. However, some species rarely is ever produce tonal calls and for these, classification based on clicks is essential, while for whistling species characteristics of clicks could provide additional useful information to improve species classification. The frequency range and power of clicks is highly variable. At the two extremes there are the load, broadband clicks of sperm whale and the narrow band, much quieter, ultrasonic clicks of harbour porpoise. The clicks of these two species are relatively easy to automatically identify. But between these extremes, several species like common dolphin, spotted dolphin, bottlenose dolphin, Blainville's and Cuvier's beaked whales produce clicks with overlapping frequency ranges which makes species identification more challenging.

An automatic classifier is presented which uses a number of temporal and spectral parameters extracted from each click to classify them to species. The classifier has been tested with a variety species, including those listed above. While the mean correct classification rate is higher than 80%, there is considerable variation by species. Beaked whale clicks can be classified with more than 90% of accuracy, however separation of clicks from spotted and common dolphin is very poor. Results using both our own training data and the workshop training data set will be presented.

Notes____

Sperm whale localization with the NEMO ONDE short-baseline platform

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During the last past years, we developed a real-time system for tracking a plurality of sperm whale using a large-baseline from the AUTEC BAHAMAS. The algorithm is mainly based on correlation techniques (see "Whales cocktail party: a real-time tracking of multiple whales," *International Journal Canadian Acoustics 2008)*, and Time Delay of Arrival (TDOA) computation for each couple of hydrophones to estimates the whales' positions. We adapted the algorithm herein for the Nemo Onde platform. Firstly we detect each click on each channel. Secondly, the processor determines the relative time delay between signal arrivals at the different receiver elements with cross-correlation technics. A first static method consists in computing the position of each target, relative to the platform, using directly TDOA estimates, resolving the acoustic model with a maximum likelihood estimator for example. In parallel, we propose a more dynamic tracking system base on particle filtering in presence of false alarms and an unknown and varying number of targets. This takes into account the problem of data association and is called the Rao-Blackwellized Monte Carlo data association (RBMCDA) algorithm . Thus, we trajectography the whales and we can increase the state dimension to estimate other features such as speed. We compute the Cramér-Rao Lower Bound (CRLB) for the given array geometry and the confidence ellipses. This method allows us to locate several sperm whales with a reasonable accuracy.

Notes____

Tetrahedral hydrophone array used to localize sperm whales

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A model-based time-of-arrival method is used to localize sperm whales in the 3rd dataset of the 4th DCL Workshop. Compared with localization datasets from previous DCL Workshops which used widely-spaced hydrophones, this dataset uses closely-spaced (~1m) hydrophones in tetrahedral array. The tetrahedral configuration presents some unique advantages and also difficulties. For example, establishing TDOAs can be accomplished more easily and with higher precision since the signals arriving at the hydrophones follow nearly the same propagation path. On the other hand, errors associated with animal position estimates can become very large. These and similar matters related to the dataset will be addressed.

Notes____

Evaluation of Sperm whale acoustic emissions to understand its presence in the Ionian sea. The NEMO project as a unique research opportunity.

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The NEMO-OvDE platform, deployed on the sea floor at a depth of 2050 m, 21 km off the coast of Catania, Sicily (Italy), has provided the opportunity to understand the presence and behaviour of sperm whales in the area.
Equipped with four wideband hydrophones (30Hz-40kHz) forming a tetrahedral array of 1 m each side, the platform sent digital data to the land station 24h a day from January 2005 to November 2006. The acoustic range of the system was 20 km. A 5 minutes file was recorded hourly every day, for a total of 2.5 TB of data. Unfortunately it wasn't possible to collect information continuously for the entire period. However, 7359 samples, for a total of 613 hours, that represent 314 days, were recorded and analysed by trained operators with the use of SeaPro, a real-time spectrographic software, to distinguish species, number of individuals present and sound categories emitted.
Sperm whale presence is considered as low density in the Ionian sea by an acoustic survey of IFAW in 2004 and by other works done in the vicinity.
In our study an unexpected presence of animals was found, with 23% of files containing animals in both years.
Chi-squared test and GAMs were performed to establish annual and seasonal variations and demonstrated spring and autumn peaks. In addition the periods with more positive contacts show a greater number of animals present at the same time.
Sperm whale sounds were used to describe the habitat usage and their behaviour during the course of the year. Codas and creaks were thoroughly analysed giving additional information about the population using the area.
OvDE enabled us to open an interesting observatory on cetaceans communication and biology and created the basis for a further project, named LIDO (Listening Into Deep Ocean) with the first new platform to be deployed at the end of 2009.

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Real time classification of sperm whale clicks and shipping impulses from a deep sea antenna.

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The automated acoustic detection of cetaceans in real time is an important tool to study their behaviour and distribution in the field and for mitigating human activities that are potentially harmful to them. However the classification in a fully automated way is challenging due to the diversity of acoustic events and background noises. Acoustic data from the NEMO ONDE deep sea antenna (-2000 m) indicated that impulsive ship noise was present in 10 % of the recordings. These anthropogenic impulses pose a serious challenge to the detection of sperm whale clicks, since they often share similar time frequency properties and hence could be the cause of many false positive detections.
As part of an integrated classification system, we present a classification module aimed at the automated and real time classification of clicks from sperm whales and click-like sounds produced by shipping. The module is composed of two stages: A first stage, detects segments that contain impulsive sounds within a specifiable frequency band and returns their location. A second stage uses a feed forward neural network to classify impulses that have been detected in the first stage as sperm whale clicks or shipping impulses.
The module's reliability was tested on data from the NEMO ONDE antenna (including the dataset made available for the Workshop). The achieved classification performance indicates that the module reliably separates a large proportion of sperm whale clicks from shipping impulses.

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Real-time processing and management of acoustic data streams in LIDO

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Acoustic recordings can easily grow very large. This does not only make storage complicated, but also the management and redistribution of the data itself. Large amounts of data may remain on storage unanalysed simply because it is not known beforehand if there is anything in the recordings that could be interesting and there is no student available to manually go over them. Other complications for especially redistribution are that these data are often not standardized, the equipment and measurement protocols are not always fully documented and analysis information is stored in e.g. Excel sheets where it is not readily available for other analysis software.
There has been a considerable effort in the last years by the OGC to properly standardise and document data acquisition, its storage and its redistribution through open specifications as Sensor Web Enablement and SensorML. Within the ESONET there is great interest in following these standards to optimize the research potential. The LIDO project is designed to acquire acoustic data from systems ranging from a single hydrophone on an autonomous system to cabled platforms as for example Antares that offers a maximum of 36 hydrophones sampling at 250 kHz. In order for these data to be useful to the research community, a protocol has been designed to minimise storage of 'uninteresting' data that could waste bandwidth, storage space and research time, and to make available relevant information from acquisition hardware, the acoustic data and the acoustic analysis from LIDO in a format following OGC standards. The aim is to make the analysis results available in real time, while the raw data would be made available for download at a later time depending on local bandwidth limitations.

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Integrated passive acoustic approach for detection, localization, and identification of individual marine mammals as applied to Workshop data

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Components of an integrated approach for detection, tracking, and identification of individual marine mammals developed by the Littoral Acoustic Demonstration Center (LADC) are presented. As the first step, rhythmic analysis of a band–limited energy function is performed. The algorithm allows simultaneous detection of the species of interest in a continuous stream of passive acoustic data and association of rhythmic frequencies with individual marine mammals. Temporal associations supplied to localization techniques provide, at a minimum, bearing estimation, and with sufficient detections, three-dimensional tracking of individuals. Independently, individual animal identification is performed using multi-attribute similarity analysis by a self-organizing map algorithm. The results of all three methods are compared to provide identification of individuals. The performance is demonstrated by application to Workshop data for both sperm whale and beaked whale clicks. The proposed algorithms are useful for passive acoustic behaviour studies and population assessment. Results of the application of the methods to multi-sensor passive acoustic recordings collected by LADC in the Gulf of Mexico beaked and sperm whale experiment in 2007 have been promising and will be discussed.
[Research supported by SPAWAR, ONR, and Louisiana Optical Network Initiative (LONI)]

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Detection and Classification of Buzz Clicks in the 3rd Workshop Dataset using a Multi-Hypothesis Tracker

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The Blainville's beaked (*Mesoplodon densirostris*) whale buzz clicks are known to be different than the regular clicks [1] and have been found to have characteristics that can vary significantly [2]. Single buzz click classification appears infeasible, however the click spectrum is slowly varying over time [2]. This property can be exploited in a feature based multi-hypothesis tracking algorithm [3]. The association is based on the assumptions of slowly-varying click amplitude, Inter-Click Interval (ICI) and click spectrum. The tracker forms track which can then be classified as buzzes based on ICI values. Thus buzz classification follows automatic tracking of click. This property of slowly varying spectrum of buzz clicks is true for other species as well [4].
In this work, we improve the calculation of the inter-click-interval as reported in [4]. This methodology is applied to find the buzzes of the dataset provided by the organizers of the *3rd International Workshop on the Detection and Classification of Marine Mammals using Passive Acoustics*, Boston, July 2007.

[1] M. P. Johnson, P.T. Madsen, W.M.X. Zimmer, N.A. Aguilar de Soto and P.L. Tyack, Foraging Blainville's beaked whales produce distinct click types matched to different phases of echolocation, *The Journal of experimental biology*, vol. 209 (24): 5038-5050, 2006.

[2] O. Gérard, S. Coraluppi and C. Carthel, "Analysis and classification of beaked whale buzz clicks", *Proceedings of Passive 08*, October 2008, Hyères, France.

[3] Odile Gerard, Craig Carthel and Stefano Coraluppi, Estimating the number of beaked whales using an MHT tracker, *Proceedings of Passive 08*, October 2008, Hyères, France.

[4] Odile Gerard, Craig Carthel and Stefano Coraluppi, Classification of Odontocete Buzz Clicks using a Multi-Hypothesis Tracker, *Proceedings of Ocean'09*, May 2009, Bremen, Germany.

Notes____

Raising the BARN, a bioacoustic resource network

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The marine-mammal acoustic monitoring community has developed various tools to perform tasks related to detection, classification, and localization. However, usability on different datasets and tool interoperability are poor. This challenges the ability of users to apply these tools to their problem of interest, or to integrate a family of tools into an effective data analysis workflow.

Community strategies have developed to counter the above challenge. Freely available and open-source software, which allows capable users to understand and possibly modify existing tools, is progress. However, this strategy is limited to a small subset of the community. Domain-centric programming interfaces, that allow an application to be extended to support a new technique (for detection, classification, or localization) within a larger system also constitute progress, but still have limited reach. The currently missing keystone strategy is developing and supporting domain-centric data-stores and communication protocols that allow data reuse and tool interoperability. This last strategy is the focus of the BARN project. BARN is developing openly-available software tools to support creation and maintenance of networked annotated sound libraries, tools that allow for the authoring, consumption, and sharing of persistently accessible and richly annotated sound collections.

Through a BARN server users and groups can maintain web-based sound collections along with recording metadata, richly and accurately annotate sound with computer-assistance and human review, and use BARN data feeds and export formats to integrate various tools in support of a desired workflow. The BARN architecture offers simple programmatic access to data through a REST application programming interface (API) as well as mechanisms for distributed data storage and computer-assisted annotation. The BARN API realizes the openness afforded by the network environment and federation mechanisms for storage and computation make BARN scalable.

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Extracting incidental signals from targeted sound bites

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Remotely deployed Passive Aquatic Listeners (PALs) operate according to an adaptive sampling protocol as opposed to recording continuously. Adaptively sub-sampling overcomes hardware and power limitations by reducing the amount of data acquired, while maintaining a high probability of detection and classification of targeted signals; thus, enabling data collection for a full year at a sampling rate of 100 kHz. The PAL creates and stores a time series of power spectra in addition to targeted "sound bites" containing signals of interest. A sound bite is a 4.5 second time series recorded at 100 kHz. Power spectra provide information on ambient acoustic conditions, while sound bites provide an audio confirmation for sound source identification. A sample containing a signal of interest is identified when a temporal feature exceeding a set threshold within a chosen frequency band is detected. Real-time feature detectors targeted the following sources: marine mammal vocalizations (clicks and tonals), watercraft, and geophysical events (e.g. rain, ice). Post-processing of sound bites recorded in the Bering Sea revealed secondary marine mammal detections in addition to the primary trigger detections. Species with high vocalization rates (fin whales, bowhead whales, and bearded seals), were more likely to be recorded incidentally compared to species with low vocalization rates (right whales). Utilizing information from primary and incidental detections provides data needed to address questions of species richness, temporal distribution of animals in an area, and response to changes in the acoustic environment without the deluge of data obtained by continuous recorders.

Notes____

Rejecting unknown species in a species detection task

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Results of the 3rd Intl. Workshop on Detection, Classification, and Localization showed that the rejection of species for which training data is unavailable is problematic for current classification schemes. For any classification scheme, there will be one species whose model is “closest” to features drawn from the vocalizations of an impostor species which can lead to increased false positives.
We frame this problem as an acceptance or rejection of the hypothesis that features derived from echolocation clicks are associated with a specific species. Posterior log likelihood scores are computed for a model associated with a specific species versus a model where features are not attributable to the species in question. We adopt a technique proposed by Reynolds et al. (2000) to address this problem for a human speaker verification task. The alternative hypothesis is trained using data from multiple classes, thus creating a generic background model. The probability mass associated with this model is more broadly distributed across the feature space than that of an arbitrary individual species model, and is in general more likely to match impostor features. In this study, the background model is a Gaussian mixture model trained using cepstral feature vectors derived from odontocete echolocation clicks.
Species specific models are derived from the background model using Bayesian adaptation of the mean vectors. After adaptation, log likelihood ratios of groups of feature vectors are examined and standard threshold based metrics such as the detection error tradeoff curve (similar to the receiver operating characteristic curve) are used to examine the efficacy of the method.

Notes____

Automated, real-time classification of odontocete vocalizations over large open-ocean areas

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Monitoring and mitigating the effects of anthropogenic noise on marine mammals are active areas of research. In particular, passive acoustic methods have been shown to be a highly effective for the study of whales over large, open ocean areas. Key to enabling the efficient monitoring of large (400-500+ sq. Nmi) areas is the ability to both automatically detect vocalizations and to identify the species of animals present. The class-specific support vector machine (CS-SVM) has been shown to be promising methodology for automated classification of the broadband click vocalizations produced by odontocetes. The original CS-SVM configuration was particularly adept at classifying the foraging clicks from *Mesoplodon densirostris* correctly identifying Md clicks over 95% of time. CS-SVM classifiers have also been implemented for click vocalizations from short-finned pilot whales (*Globicephala macrorhynchus*), Risso's dolphins (*Grampus griseus*), pan-tropical spotted dolphins (*Stenella attenuata*) and sperm whales (*Physeter macrocephalus*). One benefit of the CS-SVM approach is that new classes can be added to the classifier suite without retraining of existing classes. Most recently, a CS-SVM for Cuvier's beaked whale, *Ziiphius cavirostris,* was added. In April 2009, a real-time version of the current suite of CS-SVM classifiers was deployed to monitor 88 wide-band hydrophones, covering 500 sq. Nmi. Of open ocean, off of San Clemente Island, California. This paper will present preliminary results from the CS-SVM monitoring these sensors over the summer of 2009. In addition, the a performance of the CS-SVM on the 2009 DCL WORKSHOP Data Set will be presented.

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Improved Passive Band-limited Energy Detection for Marine Mammals

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Robust marine mammal detection is a difficult problem due to the variability of marine mammal calls and the presence of non-stationary, non-Gaussian background noise. One common detection method is based on processing band-limited energy to produce estimates of signal and noise likelihood. A detection function is formed using a common likelihood ratio test (LRT). These detectors suffer from false alarms when broadband signals overlap the band of interest, triggering detection. Some estimators only consider previous samples, causing further false alarms. The authors propose a method of reducing false alarms by defining a guard band that is not expected to contain energy from the species of interest. A second LRT is performed by testing the ratio of the signal estimate in the signal band with the guard band. This method is shown to reduce false alarms with an acceptable reduction in detection rate. An estimation method is also proposed that can be optimized for high processing efficiency, while improving false alarm rejection from signals that are longer in duration than the signal of interest. Performance is demonstrated on real marine mammal recordings and ocean noise. The proposed detection algorithm is implemented in PAMGUARD, an open source Java application designed for passive acoustic monitoring (PAM) of marine mammals.

Notes____

Bearings tracking with time-bearing displays and particle filters

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Acoustic tracking and localising of marine mammals using towed hydrophone arrays typically utilises two acoustic data channels to achieve a bearing to source estimate. For Odontocetes the process can be summarised as click detection followed by click source bearing estimation between 0° and 180°. In noisy environments accurate click detection becomes more difficult since click detections are based on overall received energy levels. This means that, for instance, a noisy towing vessel or louder animal may mask quieter clicks regardless of bearing thereby reducing detection rates. Additionally it is unknown if the bearing estimate is to the left or right and how far away the animal is.

It is proposed that utilising more hydrophone elements within the array aperture, in conjunction with beam-forming and particle filtering algorithms, can improve detection rates and tracking performance and provide more useful animal positioning information. Beam-forming is widely used in other applications for improving the signal to noise ratio of received wave-fronts, acoustic or electro-magnetic, from a given direction by filtering out signals received from all other directions. An energy-based time-bearing display is constructed by beam-forming over a range of bearings and displaying the received energy at each bearing for which a beam has been formed. This allows for an improved click detection rate as quieter clicks aren't hidden by louder acoustic signals received from other bearings. The error rate in bearing estimate can then be reduced and a degree of additional information inferred through utilisation of particle filters (recursive Bayesian estimators), using the computed bearing estimates and own ship motion information. The breakdown of the proposed solution into two parts also carries the benefit of versatility as to the degree to which the proposed solution is adopted into existing systems.

Notes____

Two algorithms for marine mammals detection under transient noise conditions

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Passive acoustic monitoring (PAM) applications are rapidly growing in number and diversity worldwide. The first function of PAM is to detect bioacoustic emissions embedded in noise. This is usually done by computing their spectrograms and comparing their levels with an estimate of noise, assumed to be stationary over periods longer than the targeted sounds. This assumption may hold in some cases such as deep sea observatories. However, in coastal areas, in presence of ship noise, or under ice floe noise, it is generally not true. In these cases, detectors assuming stationary noise will unduly create false alarms and missed detections.
In this paper, we design two PAM detection algorithms to deal with transient noise. The first one, for whistle detection, postulates that whistles can be modeled by a frequency modulation where the noise is random, wideband and transient. It is shown that the signal to noise ratio of the time-frequency bins from Fast Fourier Transforms of increasing window lengths follow a parametric law for whistles whereas it is constant for noise. This SNR versus FFT length law is proposed as a whistle detection statistic under transient noise environments.
The second algorithm, dedicated to click detection, postulates that click trains are embedded in transient but gaussian noise (which is true for breaking waves or cavitations noises from ship propellers). Here, high order moments (HOM) such as skeness or kurtosis are known to be null for Gaussian random data and high for clicks. HOM are therefore chosen as the detection statistics.
These two detectors are successfully applied to recordings of whistles and clicks from: a) belugas under intense transient shipping noise from whale watching boats and ferries in the Saguenay-St. Lawrence Marine Park in May 2009, and b) bottlenose dolphins in Mer d'Iroise marine national park (France) where cavitations noise from ships and transient noise from breaking waves are present.

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Whale axis angle variation estimation according to clic energy conservation

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We propose to compare the ICI modulation for a foraging behaviour (see FIG 2) with the energy modulation (FIG 1) in the case of a sperm whale emission. We evaluate the head sweep speed of the whale analysing the energy of the clicks and taking into account a model considering the whale's position to the hydrophone and the models in FIG 2.

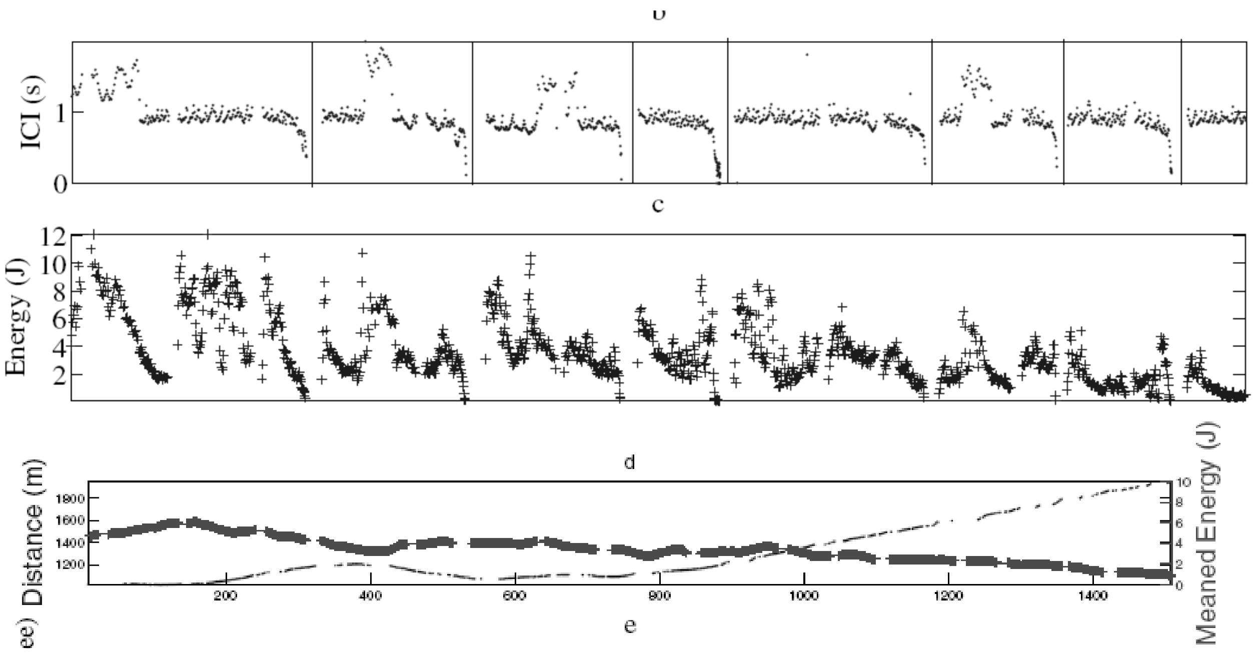

FIG 1: Energy and ICI versus time of recording in a dataset of 25min containing one whale. All graphics are versus time. Lines in figure (b) underline ingestions of the preys. (c) is the energy of each click. In figure (d), distance (.) in blue and meaned energy (+) in green are plotted, so we can see the influence of the distance to the energy bias, the energy is lower while the distance increases.

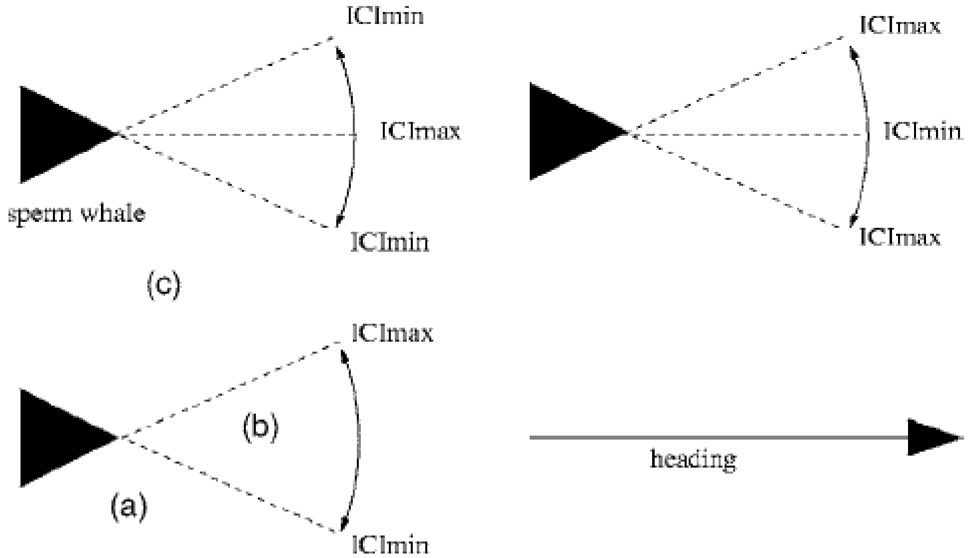

FIG 2: Three models describing the fast, periodic movement of the whale in sync with its ICI. Only the third model could lead to the synchronization ICI_max <=> delta_max using a hydrophone located either in front of or behind the whale (it is located in (a)). The click apparent level and the ICI are in sync (ICI_max<=>AL_max) if the hydrophone is located in (c). There is no apparent synchronization between the ICI, the off-axis angle, and the click AL if the hydrophone is in sector (b).

Notes____

Identifying delphinid whistle contours using graph search

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A graph search algorithm is presented to extract tonal contours from audio signals in a fully automated manner. Search is done in the short-time spectral domain, with contours being treated as paths through a phase-magnitude space. These paths are tracked using a graph search formalism that consists of edges between phase-magnitude nodes. Edges are added to the graph based upon constraints which account for local trajectories. This method permits the tracking of multiple candidate paths that may overlap or cross. Once a set of nodes become isolated with no new edges being added, tonals are analyzed within the set. Node and edge sets that represent overlapped or crossed contours are disambiguated using trajectory and the first derivative of phase.

The algorithm is general in nature and applicable to tonal calls from many animals with little modification. We target this work specifically toward delphinid whistles and demonstrate its efficacy on calls from bottlenose (Tursiops truncatus), short- and long-beaked common (Delphinus delphis and D. capensis), and Risso's (Grampus griseus) dolphins recorded in the Southern California Bight. The algorithm is robust to the presence of click trains even when the animals are observed in large groups, although burst-pulse clicks remain a challenge to be further investigated.
Potential applications of this algorithm include animal-specific localization and call comparison techniques that take into account finer grained detail than the typically used contour statistics (e.g., number of inflection points, minimum, and maximum frequencies). A hybrid Matlab/Java implementation of the algorithm typically processes 192 kHz data in two to three times real-time when executed on an Intel 3 GHz Core 2 processor running Windows XP. [This work is sponsored by the Office of Naval Research.]

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An algorithm for detection of whistles, moans, and other tonal sounds

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An algorithm is described for detection of narrow-band tonal sounds – odontocete whistles, mysticete moans, and other narrow-band vocalizations. The algorithm begins by computing a spectrogram and, optionally, applying spectrum equalization. Starting at the first time slice of the spectrogram, the algorithm finds spectral peaks that become ‘candidate’ whistles. These candidates are then tracked over time, following spectral peaks in successive time slices. To handle multiple whistles that cross one another, the algorithm fits a line or curve at each time step to the last few points of each candidate or true whistle, and the curve is used to estimate its frequency in the next time slice. The spectral peak nearest that frequency is then used. Candidate whistles must also be a certain distance in frequency from existing whistles to count as independent whistles; this principle is enforced because whistles often have secondary candidate whistles that are no more than small bits of noise in the spectrogram on the side of the main whistle. Whenever a candidate whistle persists for a sufficiently long time without exceeding specified limits for the rate of frequency change, the algorithm promotes it to a ‘true’ whistle detection.

This algorithm has nine parameters, each of which can be tuned for better detection. Because of the large number of parameters, a gradient-descent procedure may be used to optimize the parameters. This procedure tests detection performance on its test data using an initial parameter set, then tweaks each parameter up or down in turn and re-evaluates performance. The best-performing tweaked value is these used to make a new parameter set, and the process is repeated until tweaking no longer improves performance.

This algorithm has been used for real-world problems in detecting dolphins, humpback whales, bowhead whales, and other species, and for density estimation of minke whales.

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Probability of the detection of calling bouts by a low duty cycle passive acoustic recorder

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While the recording technology of remote passive acoustic recorders is rapidly advancing, processing the huge amounts of data collected remains a practical issue. Ultimately remote acoustic recorders will use adaptive sampling and onboard processing to generate and deliver short efficient messages that describe the acoustic environment to end users. These recorders will only be useful if they can reliably detect and identify events of interest, such as calling bouts from specific animal species. Passive Aquatic Listeners (PALs) were developed to detect and identify rainfall events, but have been adapted to successfully detect and identify calling bouts from killer whales, right whales, bearded seals and other vocalizing animals. Estimating the probability of detection for a particular species depends on 1) the characteristics of the typical call for a particular calling bout activity (frequency and duration), 2) an estimate of the percentage of time that sound is present in the water during a calling bout, and 3) an estimate of the duration of a typical calling bout. The duty cycle of the recorder is incorporated into the prediction as the number of samples taken during the calling bout. For example, if a pod of whales fills the water with sound 20% of the time for 20 minutes, and the sampling interval of a recorder is every 2 minutes, then the probability of detection is 90%. Experience with PALs verifies this relatively high probability of detection and encourages deployment of small, low duty cycle recorders for monitoring the marine environment.

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An autonomous ocean glider using real-time acoustic detection and classification of marine mammal sounds.

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We are developing an autonomous passive-acoustic platform based on the Seaglider™ (http://www.seaglider.washington.edu/) for monitoring beaked whales (family *Ziphiidae*) and mitigating human impacts on them. Here we focus on the real-time data processing system to determine the presence of a target species, including a brief overview of the data acquisition system and the challenges of continuously operating a detection and classification system. The real-time detection system is based on the energy ratio mapping algorithm (ERMA), which was developed to detect species-specific odontocete echolocation clicks with low computational cost. ERMA can be operated continuously over extended periods of time in low-energy processing environments such as acoustic gliders. The detector operates in the time domain and takes advantage of the species-specific differences in the power spectra and the inter-click interval (ICI) of echolocation clicks to minimize the number of false positive detections. We will demonstrate the operation of ERMA using the clicks of Cuvier's beaked whales (*Ziphius cavirostris*) with clicks of other odontocete species as potentially confounding signals. Ongoing work is focused on the development of a classifier to verify the detected echolocation clicks and the implementation of the classifier in the acoustic system of the Seaglider™. First field tests are intended to be conducted in Lake Washington and possibly the San Juan Islands, Washington State, USA in July 2009. Results of these experiments and future challenges will be presented.
[Work funded by Office of Naval Research grant N00014-08-1-1082 and Naval Postgraduate School grants N00244-07-1-0005 and N00244-08-1-0029.]

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Detection, Classification, Tracking with compact volumetric arrays

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Passive acoustic detection of sounds made by whales and dolphins is considered an efficient complement to visual sightings of surfacing animals remaining effective at night and in poor weather. Sirena08, a sea trial conducted by NURC in the Alboran Sea demonstrated clearly that acoustic detection opportunities outperform visual sightings. As to be expected, detection performance varies strongly with species, in particular detection of deep diving beaked whales resulted as a challenging task. Beaked whales can only be detected over relatively short distances requiring an increased effort both in monitoring time and hardware. The CPAM (compact acoustic monitor) is the attempt to implement portable passive acoustic monitoring tools to detect, classify and localize (DCL) deep diving echolocating whales and dolphins. The CPAM is conceived as small volumetric (3-D) array using a modular approach to allow easy integration of 3-D passive acoustic DCL on a variety of portable systems. Here I present concept and technological approach for implementing the CPAM and describe some candidates for DCL suited for both semi- and full autonomous systems and report on first results. In particular I show how statistical data analysis may be used to classify the detected cetacean sound and how directional information may support not only localization of individuals but also species classification.

Notes

Passive acoustic monitoring of marine mammals using a directional towed array

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JASCO Applied Sciences performed a towed array trial of their new Cetacean Towed Array System (CETAS) for passive acoustic monitoring of marine mammals off Nova Scotia, Canada. CETAS has two acoustic modules separated by 400 meters, towed 400 meters behind the vessel. Each module has two high frequency (150 kHz) omni-directional hydrophones and two low frequency (100 – 2000 Hz) directional hydrophones. Localizations of marine mammals were obtained by combining cross-dipole calculations of two bearings and a time difference of arrival hyperbola. Vocalization playbacks were used to test the data acquisition systems and to determine the ranges of detections and signal-to-noise requirements. A subsequent trial was executed during a seismic survey by BP Exploration Company Ltd. in the Beaufort Sea north of Tuktoyaktuk, NT. The goal of this trial was to quantify the detection performance of the directional sensors in the presence of high tow ship noise levels. The recorded data were archived and analyzed for marine mammal vocalizations, seismic shots, and ambient sound levels. The greatest challenge to the localizations was the signal-to-noise ratio of low frequency bowhead calls above the noise of the anchor-handling tug used to tow the array and the noise of the seismic survey. Marine mammal detection, classification and localization were attempted in real time. The technical details of the array and data processing will be presented as well as results from both surveys.

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Localization of ultrasonic vocalizing marine mammals using towed arrays

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There is an increasing demand for the ability to localize marine mammals in a mobile and automated manner. For this purpose we have developed an algorithm that enables the determination of bearing and range of marine mammals by making use of high frequency vocalizations ($f \geq 10$ kHz). Our newly developed algorithm is of special interest for high frequency vocalizing species such as beaked whales, which cannot be localized using conventional low frequencies systems.
The algorithm is based on measuring the wave-front curvature, by determining the arrival-time differences of the received signal on three linearly spaced hydrophones on a towed array. Three hydrophones allow for the determination of a reliable bearing and range using triangulation techniques, provided that the spacing is large, and the frequencies and SNR of the signal are high enough.
In this paper we will demonstrate the bearing-, and in some cases even ranging capability of towed arrays by applying the algorithm to recorded acoustic data of beaked whales (*Mesoplodon densirostris*), and sperm whales (*Physeter macrocephalus*). These datasets were recorded recently using the high frequency modules of the Delphinus and Quad towed arrays. The Delphinus is a dedicated array designed at TNO specifically for the use of passive marine mammal DCL. The Quad array has a longer baseline, and is designed for LFAS purposes. The performance of the algorithm will be assessed using recordings from sources with known location.

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Design and Assessment of Five Hydrophone Array-Configurations for Marine Mammal Localization within a Safety Zone.

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The design of five hydrophone array-configurations is assessed for marine mammal localization to meet the requirements of the current mitigation regulations for a safety zone.
This work uses the *Time Difference of Arrival (TDOA)* of cetacean vocalizations with a three-dimensional hyperbolic localization algorithm. A MATLAB simulator was developed to model five array-configurations (Shifted-pair, Square, Trapezium, Triangular, Y-shape) and to assess their performance in source localization. The aperture and geometry of each array-configuration are explored.
Mitigation measures for a safety zone include ceasing transmissions of all sonar when a marine mammal is detected within 500m of the sonar dome. The square and trapezium arrays perform poorly because of their partial or total ambiguity for locating sources on a broadside position. The triangular array constitutes a recommendable array-configuration to deploy but only for locating shallow sources (i.e. 60m). The Y-shape array is accurate over slant ranges of 500m, however, it is sensitive to angle-positioning-error when the geometry is seriously distorted. The Shifted-pair array overcomes these limits, performing accurately even when the array changes its static position.
This work demonstrates that the array-geometry and the array-aperture are important parameters to consider when designing and deploying a hydrophone array. It is shown that certain array-configurations can significantly improve the accuracy of source localization in determined scenarios where marine mammals are vulnerable to anthropogenic sound.

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Analysis of underwater mammals vocalizations using time-frequency-phase tracker, applications to crossing whistles.

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Passive acoustic monitoring (PAM) applications are rapidly growing in number and diversity worldwide. The functions of PAM are to detect, classify, localize and evaluate density of marine mammals. Understanding underwater mammal vocalizations could be of great help for underwater fauna protection and, in the same time, preserving the human activities.
It is well known that the underwater vocalizations have a complex time-frequency behavior. The time-frequency content of underwater mammal vocalization could be very different from one specie to other. In such conditions, the application of the conventional time-frequency tools could be a difficult task, mainly because of the non-linearity, crossing and the closeness of the time-frequency components as well as the presence of interferences with other underwater signals. Moreover, while the mammals are generally moving and communicating between them, the signals are highly non-stationary.
In this challenging context, we define a time-frequency-phase analyser of whistles which is composed by three steps. The first one consists of modeling the short-time segments of the vocalization by a set of third order polynomial phase modulations. The second step deals with the fusion of local polynomial phase modulations in order to approximate each individual time-frequency component of the vocalization. At the end of our algorithm, the time-frequency scene and the waveform is divided in several time-frequency tracks and several signals with allowable phase information along each track. Then, this information may be useful to connect 2 tracks using a phase continuity criteria as it is required for separation and characterization of crossing whistles.
Our algorithm is successfully applied to recordings of whistles from bottlenose dolphins in Mer d'Iroise marine national park (France) and b) in the Saguenay-St. Lawrence Marine Park .

Notes____

Characterisation of sound subunits for humpback whale song analysis

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The songs produced by male humpback whales, *Megaptera novaeangliae,* during the breeding season have been increasingly studied in the last couple of decades with methods based mainly on their spectrographic characteristics.
Songs were characterised as series of units - defined by Payne as continuous sounds between two silences - associated in specific patterns, similarly to the way in which bird songs are formed.
Previous work highlighted the need for objective methods for humpback whale sound units classification; for this purpose, various automatic clustering algorithms were developed to study how units are associated to produce themes that are repeated throughout the song duration and to compare them across whale populations and from year to year. However, detailed analysis of the vocalisations showed that the features of a unit can change abruptly throughout its duration making it difficult to characterise and cluster them systematically.
We propose a new approach for song segmentation based on the identification of subunits that are characterised by looking at the changes of their frequency content through time.
Typically units within a song consist of several elements - which we refer to as subunits - that have distinct structure, i.e. units are formed as combination of subunits.
The distinction between subunits and units should improve the accuracy of classification algorithms, especially for those vocalisations that present a complex structure that varies significantly with time.

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Passive acoustic detection of Minke whales (Balaenoptera acutorostrata) off the West Coast of Kauai, Hi

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An algorithm for real-time detection of vocalizing Minke whales (Balaenoptera acutorostrata) has been developed as part of the Density Estimation for Cetaceans using Passive Acoustics (DECAF) project. This algorithm is based on a tonal detector previously developed for detecting narrow band tonal calls The algorithm is designed to detect the "boing" call that has been attributed to these animals. The dominant component of these calls occur in the frequency band between 1350 and 1440 Hz, with additional components extending past 2 KHz. Call characteristics include an initial sharp rise in frequency followed by a tonal which may have some slope. The data is sampled at 96 KHz and down-sampled to 12 KHz using a decimating low pass filter. An FFT is run on the data. Each spectrogram slice is whitened using an exponential running mean. Local peaks in the spectrogram slice are selected and fed to an algorithm which combines the individual peaks into a call. Receiver Operating Characteristic (ROC) curves was determined using synthetic data corrupted by known amounts of white Gaussian noise. As the conditions under which the ROC curves were compiled does not match real world conditions, data from the bottom mounted acoustic hydrophones at the Pacific Missile Range Facility (PMRF) were analyzed by hand and a data set consisting of recognized Minke whale calls was compiled. The detectors output was compared with the human generated output and the performance evaluated. A detailed description of the algorithm is presented, along with performance analysis on both real and synthetic data.

[1] David K. Mellinger, "An algorithm for detection of whistles, moans, and other tonal sounds"

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Acoustic localization of blue whale (*Balaenopera musculus*) using the hydrophones of the International Monitoring System

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Long-term deployment of passive acoustic recorders for blue whales would help to identify areas of concentration, to assess seasonal occurrence, and to potentially facilitate long-term monitoring of abundance through variations in call rates over years. Acoustic data from the International Monitoring System (IMS) were available and analysed for this biological purpose. IMS station was composed of 5 hydrophones located in the northern and southern part of Possession Island (Crozet archipelagos, South-West Indian Ocean). Hydrophones were suspended near the sound channel axis at a depth of 300m. Data that were collected for one year were then scanned for specific calls attributed to 2 blue whale subspecies (Antarctic blue whale and pygmy blue whale 'Madagascar type') using both automatic and visual detection methods (cf. Samaran et al., 2008 Canadian acoustic vol. 36). Vocal activity was found to be highly seasonal and varied between subspecies. To explore the feasibility of localizing calling blue whales with these instruments, we used two methods. The potential movements were investigated by using the time difference of arrival (TDOA) of calls to assess the bearing of the sound source. Tracking whales was possible when whales are concentrated of the hydrophone array. This method offered the possibility to estimate the source level of calls. To investigate the maximum detection range, the fully Range-dependent Acoustic Model (RAM) was applied. Based upon parabolic equation propagation loss models adapted for characteristics of each blue whales subspecies calls, hydroacoustic stations and environment of the study area, the potential call detection areas was estimated. Our results show that the variation of maximum detection range is (1) highly dependent of the choice of source level value and is (2) different for the both subspecies; pygmy blue whale seems to be present closer to the array than Antarctic blue whale. In further work, additional continuous acoustic monitoring at the scale of the Indian and Southern Ocean basins will be conducted with the same methods to precise seasonal occurrence, distribution and movements of blue whale subspecies.

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Detection of Minke whale sounds in the Stellwagen Bank National Marine Sanctuary, USA

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The seasonal occurrence of pulse trains attributed to minke whales (*Baleanoptera acurostrata*) was investigated using data from 5-10 acoustic recording units (MARUs), deployed in the Stellwagen Bank National Marine Sanctuary in 2006. Recorded minke whale vocalizations displayed considerable variability in duration, frequency content and pulse repetition rate. The most commonly recorded vocalizations were “slow-down” pulse trains, which lasted 37.6 ± 6.2 sec. The average inter-pulse interval changed from 0.4 ± 0.04 sec at the start to 0.7 ± 0.05 sec at the end of these trains, and most energy was contained in the 50-300 Hz band. Automatic detection, based on a band-limited energy detector (K. Cortopassi), was used to determine the seasonal occurrence of these vocalizations. Several versions of the detector, focusing on different frequency bands, were run on a test data set, consisting of one day/month of hand-browsed data for one MARU.
Minke whale vocal activity was strongly seasonal. Pulse trains were detected between February and November. While detection rates were low during spring, vocalizations peaked in late summer and were detected in more than 80% of all recording days in August and September. Detection rates decreased in the autumn and no vocalizations were detected in December and January. This strong seasonality mirrors the scarce visual data that exist for minke whales in this area. Largely absent during the winter, visual sightings show a distinct peak from July to September (Murphy 1995). Although more research is needed to interpret the vocalization data with respect to minke whale ecology, this study demonstrates that year-round passive acoustic monitoring can play an important role in understanding minke whale temporal and spatial distribution patterns, particularly when visual sightings data are sparse or absent.

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Manual and Automated Detection, Classification, and Localization of Bowhead Whale Calls in the Alaskan Beaufort Sea

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Bowhead whales (*Balaena mysticetus)* conduct their fall migration in the Beaufort Sea concurrent with seismic exploration activities. Acoustic data from this area were recorded between mid-August through early October 2008, using 40 Directional Autonomous Seafloor Acoustic Recorders (DASARs), deployed as five arrays in 15–52 m water depth and covering a region 55 km offshore and 280 km alongshore. For the manual call processing, trained analysts, utilizing GUI-based software on 30 computer workstations, identified and classified each whale call into several "simple" and "complex" call type categories by viewing spectrograms and listening to the acoustic data. For the automated call processing, a seven-stage algorithm was applied to the approximately 1 TB acoustic data set. The first stage begins by applying an incoherent "energy" detector to flag events with greater than 6 dB SNR, then attempts to remove airgun signals via interval detection. Image processing techniques then extract 25 features for every detection, with the resulting feature vector passed through a feedforward neural network. The ten-unit hidden layer network was trained using 140,000 whale calls and 1.15 million other transient signals measured by manual analysts over six non-consecutive days across all arrays. Detections that pass the neural network stage are linked with corresponding detections on other DASARs in the same array via spectrogram correlation. For both manual and automated call analyses, when a call was detected on two or more DASARs, the measured bearings to that call were used to estimate its location and corresponding error via the Huber maximum likelihood estimator. Comparisons between the manual and automated results indicate that automated passive acoustic detection, classification, and localization is a viable alternative to manual methods, even when faced with challenges such as highly variable calls, interfering noise sources, and complex acoustic propagation characteristics. [Work supported by Shell Exploration and Production Company.]

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Possibilities of non-intrusive tracking of belugas from their clicks: Experiment from a coastal hydrophone array.

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Tracking wild belugas in their natural environment from the sounds they emit has never been tempted to our knowledge. Tracking these animals with passive acoustics techniques appears as an interesting non-intrusive and non-disturbing observation tool for acquiring new ecological knowledge about their behaviour in the wild. This vociferous marine mammal emits click trains in the 30-60 kHz frequency band, sometimes with a low frequency component. In 2008 and 2009, wild beluga clicks were recorded from a small-aperture coastal hydrophone array in a regularly frequented habitat in Eastern Canada. Despite the 125-250 m distances between the four hydrophones of the bottom deployed array, at depths of ~50 and 150 m, and the narrow beams of the clicks, several trains were simultaneously detected on several hydrophones. Some clicks were accompanied with bottom or surface reflections from multipath propagation, which allowed using additional virtual hydrophone images for easing their three-dimensional localizations. The spectrogram of click trains was occasionally characterized by a path of nulls in time-frequency, due to constructive and destructive interferences from direct and reflected paths. The exploitation of this Lloyds mirror propagation pattern provided additional information to track the animals in 3D in the monitored area. Results show that it is possible to acquire dive information from high-frequency clicking marine mammals in the wild using non-intrusive passive acoustics.

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Anthropogenic noise and Guiana dolphins (*Sotalia guianensis*) in Brazil: ecological and conservation concerns

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The Guiana dolphin is distributed along the western Atlantic Ocean, from Brazil to Central America. As a coastal species, it is constantly facing potential anthropogenic impacts. In this paper we describe and compare anthropogenic noise and dolphin repertoire for three populations in the Brazilian coast: Cananéia Estuary/CAN (25° 04'; 47° 56'), Caravelas Estuary/CVL (17° 30'; 39° 30') and Praia da Pipa/PIP (06° 10'; 35° 05'). Data were collected in boat surveys, with hydrophones plugged in audio recorders, approaching the objects within a 100m area. Sounds were analyzed utilizing software CANARY 1.2 and RAVEN 1.3 Pro. Our results show that Guiana Dolphins produce whistles ranging in frequency from 2.4 to 34.7 kHz and duration of 0.02 to 0. 61 sec. Pulsed calls were registered between 0.25 and 17.2 kHz, with 1 to 24 harmonics and mean duration of 0.25 sec. The boat traffic ranged in Intensity from 19.66 to 95.3 dB and in frequency from 0.38 to 35.71 kHz for boats with inboard/diesel engines (11 – 260 Hp) while for boats with offboard/gasoline engines (8 – 150 Hp) ranged from 7.02 to 90.7 dB and from 0.84 to 46.8 kHz. The hopper dredge in CVL produced noise frequency ranging from 0.15 to 17.3 kHz, and intensity of 80 to 105 dB, while wood barges were from 0.02 to 20 kHz and 70 to 104 dB. In PIP we recorded a water suction bomb to fill a sea swimming pool of a luxury resort, producing a noise of 75.5 to 99.1 dB and from 0.0 to 13.1 kHz. Comparing the noises produced by boat traffic and dredging activity with the dolphins repertoire is notable the overlapping of acoustic niches. The use of the passive acoustic technology would be helpful in Brazil to a broader comprehension of the Guiana dolphin biology, contributing to its conservation.

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Using Passive Acoustic Monitoring to Evaluate the Impact of Anthropogenic Noise on Cetacean Vocal Activity

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Increasing levels of anthropogenic noise within the marine environment have recently become a topic of great concern. Many marine animals rely on the use of sound to coordinate social activities, find food, and advertise to potential mates. However, in many coastal areas, noise produced by human activities has the potential to interfere with the ability for marine animals to successfully communicate with one another.
The Stellwagen Bank National Marine Sanctuary is currently engaged in a collaborative research project to map low-frequency (<1000Hz) ocean noise throughout sanctuary waters, with the goals of quantifying the sources of anthropogenic noise and evaluating the potential impact this noise may have on marine mammals in the area. During April 2008, an array of ten passive acoustic recorders ("pop-ups") were deployed in the southwestern area of the sanctuary, recording continuously at a sampling rate of 2kHz. Upon retrieval, analyses were conducted on the acoustic record of one unit to measure levels of ambient noise and quantify the numbers of "up calls" produced by right whales. For the ambient noise measurements, root-mean-square (RMS) sound pressure levels were calculated for the bandwidth 30-400Hz for each 15 minutes, from 1-30 April (n=2880 samples). The mean RMS sound pressure level was 105.6 ± 5.4dB re: 1uPa, with a minimum of 94.7dB re: 1uPa and maximum of 130.4dB re: 1 uPa. RMS levels were greater than 120 dB re:1 uPa in 20% of the sampled periods. To quantify right whale calling behavior, a template detector for right whale "up calls" was employed using the software package ISRAT (Urazghildiiev & Clark 2006). This presentation will discuss our methodology for quantifying cetacean vocal behavior in different acoustic conditions as well as the relationship between ambient noise levels and right whale calling activity as evaluated using time-series analyses.

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Passive tracking of walruses in the Arctic using a single hydrophone

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Pacific Walruses summering in the eastern Chukchi Sea produce underwater sound pulses called *knocks*. The Chukchi Sea is a flat shallow environment that favors reflections of the sound on the surface and bottom interfaces. In underwater acoustic data collected in the Chukchi Sea in 2007, the knocks emitted by walruses were recorded with up to 7 bottom/surface reflections. Knowing the average sound speed profile of the medium and the bottom and hydrophone depths, it is possible to use the relative time of arrivals (RTOA) of the received reflections to find the depth and range of the vocalizing animals. This paper investigates the use of a localization technique based on the RTOA between the echoes to monitor walruses for potential vocal behavior studies. The three steps of the localization process are 1) the detection of the knocks on recordings, 2) the extraction of the echoes and, 3) matching of the measured RTOA with a ray tracing model. The knocks are detected by calculating the kurtosis of the signal on 18 ms frames. Parts of the signal with high kurtosis values correspond to knock events and are automatically extracted by thresholding. The echoes of the knocks are extracted by decomposing the signal into 14 scales using a continuous wavelet transform and by retaining only the highest wavelet coefficients. The ray-tracing model Bellhop is used to model the RTOAs received by the hydrophone for each possible source location (maximum range: 1 km, range resolution: 1 m, depth resolution: 0.5 m). An index representing the match between the measured echoes and the model is calculated at each point of the model grid. The highest matching index indicates the depth and range of the walrus. Walrus tracks were extracted at up to 600 m from the hydrophone and diving profiles were observed.

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Passive acoustic monitoring in the Ligurian Sea.

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Knowledge of the cetologic population in the PELAGOS Sanctuary in winter has improved in recent years. However prospecting effort is still very low, and adverse weather predominance, makes seasonal gaps difficult to be avoided. The acoustic recorder device that we have installed in the open sea of Nice will obtain new results outside of the summer season.
The Ligurian Sea attracts a large number of whales, especially striped dolphins (*Stenella coeruleoalba*), fin whales (*Balaenoptera physalus*) and sperm whales (*Physeter macrocephalus*). We propose various methods to detect the presence of those cetaceans, and possibly other species vocalizing in the band 5-32000 Hz.
Signal detection is done with various methods of matching filtering, spectral and wavelet processing. First of all, our work relies on the identification of recording sequences containing high energy in the whistling frequency band (3-15 kHz), lower echolocation band (30-32 kHz) and low frequency pulse band (10-30 Hz). The signals of interest are detected automatically on all the recordings, using a correlation method based on the signature association for each type of signal (whistles, clicks, low frequency pulses) using template detectors from the Matlab XBAT code and taking care of minimizing the false alarms.
Clasification of cetacean species by their different types of vocalizations is easy for the sperm whale or fin whale. For a varied and layered repertory between species, such as striped dolphin and common dolphin (*Delphinus delphis*), the classification is possible only if the number of detected signals is high, measuring their acoustic parameters (initial frequency, duration of the whistle, etc.) Individual’s quantification is feasible for the sperm whale. If the number of acoustic detections is sufficiently high through the sampling period, this method will also describe the circadian rhythm of the different species in the study area.

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Geographic variation in the whistles produced by four delphinid species in the Pacific Ocean and Mediterranean Sea

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Characteristics of whistles produced by four delphinid species in the Pacific Ocean and Mediterranean Sea were examined to evaluate the differences that exist between species, subspecies, and populations. Fourteen variables describing frequency, shape and duration were measured (t-tests and Mann-Whitney U tests, α=0.05). Between species comparisons showed that the degree of difference varied with location. Few significant differences were found between whistles produced *D. delphis* and *S. coeruleoalba* in the Pacific. In the Mediterranean, however, many significant differences were found between these species. Correct classification was significantly greater than chance (χ^2 test, α = 0.05) when classifying whistles of the same species to study area and when classifying Mediterranean whistles to species (discriminant function analysis, DFA). Correct classification of Pacific whistles to species was not significantly greater than chance (χ^2 test, p = 0.37). This implies that inter-specific differences within the Pacific are smaller than both inter-specific differences in the Mediterranean and intra-specific differences across study areas. When comparisons were made within Pacific species, results varied. Many significant differences were found between subspecies of *S. attenuata* (coastal – *S.a. graffmani*, and offshore – *S.a. attenuata*) and between populations of *D. delphis* recorded in the North and South Pacific. DFA classified 80% of *S. attenuata* whistles and 95% of *D. delphis* whistles to the correct subspecies or population. In contrast, few significant differences were found between the whistles of two subspecies of *S. longirostris* (eastern – *S.l. orientalis*, and whitebelly – a likely subspecies hybrid) in the Pacific. These results suggest that degree of sympatry is not always a good predictor of divergence in whistle structure and that significant geographic variation can exist within species. Therefore, location must be taken into account when developing species identification algorithms. Different algorithms may be necessary depending on location and on what other species are present in the area.

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Acoustic identification of Mediterranean Odontocetes as a prerequisite for passive acoustic monitoring

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The present project has been developed to contribute to the conservation of Mediterranean cetaceans, trough the adjustment of a method for their passive acoustic monitoring, for increasing knowledge on their ecology and biology. Acoustic observation can complement visual observation to provide more accurate estimates of marine mammal populations. For effective acoustic censuses, calibration methods must be determined by joint visual and acoustic studies. Research is still needed in acoustic species identification, particularly for smaller odontocetes, in order to allow their passive acoustic monitoring. From 1994 to 2004, during visual-acoustic surveys, whistles of seven odontocetes species were recorded in different area of the Mediterranean Sea, in order to determine how reliably these vocalizations can be classified to species, based on simple spectrographic measurements. Recordings were attributed to species by simultaneous visual sighting. Different research groups and platforms contributed to the study by data collection. The acoustically monitored species were: Common dolphin, Bottlenose dolphin, Striped dolphin, Pilot whale, Risso's dolphin. 36 hours of recording were analyzed and 4000 whistles were extracted. After a selection of whistle of suitable quality, spectrographic analysis has been conducted on about 2200 of them, using Cool Edit. The best whistles were also analyzed by using Matlab and a semi-automated algorithm named TRIA. Statistical analysis showed significant differences for almost all the variables and parameters measured among whistles emitted by the different species. Multivariate discriminant function analysis (DFA) allowed the correct classification of 70% of whistles to species using manual analysis, and 47% of the whistle using TRIA. Frequency parameters as maximum and minimum frequency showed a negative correlation with species mean size. The results would be discussed in detail.

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Performance of contour extraction software for the classification of Five Mediterranean delphinid species

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Whistles and calls from five delphinids common in the western Mediterranean Sea (*Stenella coeruleoalba*, *Grampus griseus*, *Delphinus delphis, Tursiops truncatus, Globicephala melas*) were taken from GREC sound archives. FFT contours (window size 512, hanning, sampling frequency 44.1 kHz) were extracted with custom developed Matlab software: 277 samples of striped dolphins (Sc), 158 whistles of Risso's dolphin (Gg), 120 of common dolphins (Dd), 76 of bottlenose dolphins (Tt), and 66 of pilot whales (Gm) were selected. The same FFT settings were used to extract variables from pilot whale pulsed calls. *Seafox* software extracted fifteen variables from the digitized contours, including: duration, initial, final, maximal and minimal frequency slopes, frequency range, number of frequency extrema, beginning, ending, maximal and minimal frequencies, presence of harmonics. Four of five species were significantly different (Mann-Whitney test) for average durations (respectively 0.73, 0.65, 0.47 and 0.90 seconds for Sc, Gg, Dd, Gm) while the average duration of bottlenose dolphins was 0.71 sec. On the contrary, bottlenose dolphins and pilot whales whistles/calls had a different average frequency (resp. 9.5kHz and 4.6kHz) compared to the other species (range 10.5-11 kHz). Frequency ranges (respectively 7.3, 6.3, 4.6, 6.3 and 3.2 kHz) were significantly different for all species pairs, with the exception of bottlenose and Risso's dolphins. Initial slopes were generally significant to discriminate species. From a global point of view, pilot whale calls were the most distinct, with 48 significant pair-wise tests out of a total of 60, followed by the common dolphins; Risso's dolphin whistles were closer to other species whistles. A multivariate discriminant analysis showed that the data set could be discriminated with a good global confidence level (χ^2 test, $\alpha = 0.05$): 57.6% of vocalizations were correctly classified. CART classification method achieved a better classification rate of 62.9%.

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Passive acoustic monitoring of common Bottlenose Dolphin, using bottom recorders, in the Pelagie Islands (Strait Of Sicily - Mediterranean Sea)

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Common bottlenose dolphin (*Tursiops truncatus*) is the most frequent species of Cetacean sighted in the coastal water of the Pelagie Islands, Marine Protected Area in the Strait of Sicily – Central Mediterranean Sea. An originally designed low cost bottom recorder, based on a quality commercial wideband audio recorder and on custom control electronics was developed within the LIFE NAT/IT/000163 project to monitor the presence and acoustic behaviour of bottlenose dolphin in this area. Interaction with commercial fishing gear was also considered in the planned data analysis. As a complimentary test we considered the hypothesis that acoustic monitoring carried out using bottom recorder (PAM) is a methodology alternative to standard visual monitoring of dolphin presence. We compared the visual and acoustic sighting frequency of 3 sample units collected in May, June and September 2006. The acoustic recordings and the visual survey are analyzed in subsample 10 sec long, the presence of dolphins was counted for each independent subsample and acoustic and visual sighting frequency was estimated. The acoustic and visual sighting frequency in the first sample unit (n= 2658) was respectively 0.30 and 0.15. The acoustic and visual sighting frequency in the second sample unit (n=2838) was 0.11 and 0.14. In the last sample unit (n=4230) both the frequencies were 0.09. These current results show a higher efficiency of the acoustic monitoring. All sample units are being analyzed to verify this trend.

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DE Workshop

Opening Lecture:

Len Thomas and Tiago A.Marques

Review of methods for estimating cetacean density from passive acoustics

Opening Lecture

Review of methods for estimating cetacean density from passive acoustics

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For the past two years, we have been working on a large collaborative project, with the soothing acronym “DECAF”, to develop general methods for estimating whale density from fixed underwater hydrophones. We start by introducing distance sampling based methods and contrasting visual surveys against acoustic surveys. We then give an overview of the potential approaches, and show how the methods available for any particular circumstance are constrained by the hydrophone configuration (e.g., number, placement and sensor characteristics), whale behaviour (vocal, social and movement) and sound propagation through water, as well as what is known from auxiliary data, or can be assumed, about these things. We illustrate the talk with various applications, mostly based on data from US Navy testing ranges.

Notes

Beaked whale density estimation from an acoustic survey off the US West Coast

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We estimate the density of beaked whales off the west coast of the US from towed hydrophone data collected during a combined visual and acoustic line-transect survey in 2008. Acoustic data from two high-frequency hydrophones (160 kHz) were sampled at 192k samples/sec and processed in real-time using PAMGUARD software to detect beaked whale echolocation clicks. A subset of these detections was localized in real time using bearing angles from ISHMAEL software. A total of 96 beaked whales groups were detected acoustically during 9,323 km of survey effort, and only 17 groups were detected by visual observers. All of the visual detections (mostly *Ziphius cavirostris* and *Berardius bairdii*) were later detected acoustically when the ship was directed to pass over the location where they last dove. We estimate the percentage of vocally active groups (35%) by estimating the percentage of daylight time spent by *Ziphius cavirostris* at depth greater than 500 m (depths at which other studies showed this species to be vocally active). Using an assumed effective search width of 2 km and mean group size estimate of 3.2 from visual observers, line-transect methods yield a total estimated beaked whale density of 24 individuals per 1000 km^2 within the 1,142,000 km^2 study area (assuming that all vocalizing groups are detected on the trackline). This estimate is considerably higher than the pooled beaked whale densities (6 individuals per 1000 km^2) estimated from previous visual surveys. Many assumptions contribute to uncertainty in these preliminary estimates. In order for acoustic methods to gain wide acceptance for estimating beaked whale abundance, effective search widths will need to be estimated empirically and species will need to be better discriminated. Ultimately, acoustic density estimates are likely to be more precise than visual estimates because data can be collected over a broader range of sea states and because a higher fraction of trackline groups are detected.

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A comparison of the density of delphinids during a combined visual and acoustic shipboard line-transect survey

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Passive acoustic detection of cetaceans has proven valuable during shipboard surveys, and these methods will likely play a greater role in population surveys in the future. The use of passive acoustics to estimate cetacean density will depend on reliable and precise detection, localization, species identification, and group size estimation. For dolphins, in particular, there are significant complications that must be addressed before useful results can be obtained. This study examines the potential role for passive acoustics during shipboard surveys. We look at acoustic detection, localization, species identification, and group size estimation of dolphin schools using data collected during eight years of combined visual and acoustic line-transect shipboard surveys conducted in the Pacific Ocean. Generalized additive models were used to examine acoustic detection distance, which varied according to mixed layer depth ($F < 0.00$), but not sea state ($F = 0.37$). An experiment testing detection and localization of dolphin whistles using towed hydrophones showed that localization accuracy is directly related to bearing angle. Localization is problematic when the sound source is less than 30° from the ships' heading, but is generally accurate as the sound source passes the beam of the ship. Acoustic species identification and group size estimation are considerably more complicated than detection and localization, and we evaluate alternative approaches to address each issue. Examination of two acoustic species identification programs, ROCCA (for whistles) and PAMGUARD (for echolocation clicks), show that each method is useful for different species, and some combination of the two may be optimal for groups that produce both types of sounds. Group size estimation using acoustic detections alone may never be possible given the variability in vocal activity of dolphins. Alternative methods to determine group size are considered. Finally, we examine the role that acoustics may play in dolphin population surveys given these limitations.

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Accounting for ambient noise in Blainville's beaked whales density estimation

Tiago A. Marques, Len Thomas, Jessica Ward, Nancy DiMarzio, David Moretti and Peter L. Tyack

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We review a method recently proposed for the estimation of Blainville's beaked whale density at AUTEC (Marques et al., JASA, 2009). The joint use of information from DTag data and AUTEC hydrophone data allowed estimating whale density by combining the number of clicks detected over a 6 day period with information about click rate, proportion of false positive detections and probability of detection of a beaked whale click.
However, said estimate assumes that the detection function estimated based on the DTag data is representative of the detection function that operated during the survey period. One reason for why that might not be the case is that DTag's are only deployed under optimal weather conditions, and therefore optimal detection periods due to low levels of ambient noise.
We report on the investigations to assess the effect of ambient noise on beaked whale clicks detection function and evaluate the possible implications for the obtained density estimates.

Tiago A. Marques, Len Thomas, Jessica Ward, Nancy DiMarzio, and Peter L. Tyack (2009). Estimating cetacean population density using fixed passive acoustic sensors: An example with Blainville's beaked whales 125: 1982-1994.

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Sonar equation based approach to estimate the detection function

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Beaked whales were considered for long time as elusive and difficult to detect. They spend most of their time submerged and expose themselves only small fraction of time for visual detection. Because beaked whales, as all other toothed whales, use sound while foraging, the use of passive acoustics is thought to be a good candidate to complement, or even replace the visual survey. The detection function $g(r)$ plays an important role in assessing the population density using survey methods. For classical survey methods, e.g.: line and point transects, the detection function is frequently approximated by simple analytic functions or the result of a general smoothing process. Recently, two detection functions have been presented for two species of the same family of cetaceans: Cuvier's beaked whale *Ziphius cavirostris* (Zimmer et al. 2008) and Blainville's beaked whale *Mesoplodon densirostris* (Marques et al. 2009). Comparing the two detection functions one notes sufficient differences to merit some discussion. To understand more the results presented by Marques et al. (2009) and Zimmer et al. (2008) and to gain insight into the detection process and where potential problems are laying, the data set used by Marques et al. (2009) were re-analyzed considering the constraints as suggested by acoustics.

Zimmer, Walter MX, John Harwood, Peter L. Tyack, Mark P. Johnson, and Peter T. Madsen (2008) "Passive acoustic detection of deep-diving beaked whales", Journal of the Acoustical Society of America 124(5):2823-2832.

Marques, Tiago A., Len Thomas, Jessica Ward, Nancy DiMarzio, and Peter L. Tyack, (2009) "Estimating cetacean population density using fixed passive acoustic sensors: An example with Blainville's beaked whales", Journal of the Acoustical Society of America 125(4):1982-1994.

Notes

Density estimation of Blainville's beaked whales (*Mesoplodon densirostris*) from single hydrophones by means of propagation modeling

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This work is a case study of the project Density Estimation for Cetaceans from passive Acoustic Fixed sensors (DECAF). The objective of this component is to estimate the density of beaked whales, in particular Blainville's beaked whales (*Mesoplodon densirostris*), from single sensors by using propagation modeling to obtain the medium transmission loss patterns needed to estimate the probability of detecting an animal as a function of its distance from the receiving sensor. The study area is the Atlantic Undersea Test and Evaluation Center (AUTEC) in the Tongue of the Ocean, Bahamas where acoustic tags (DTags) were applied to a sample of animals. A ray-tracing acoustic propagation model is used to estimate the environmental transmission loss as a function of depth and range, from each click in one dive, obtained from DTag measurements, to a single-hydrophone receiver associated to the same dive. The computed transmission loss is compared to ambient noise levels and source level distributions to estimate the detection probability as a function of range. The analysis is repeated for all hydrophones associated with the same dive, whether clicks were detected or not. Results will be compared to beaked whale data recorded on bottom-mounted sensors at AUTEC, where the location of clicks is relative to one hydrophone. The detection threshold is characterized from the signal-to-noise ratio of detected clicks. Information on source level and beam pattern for this species available in the literature will also be accounted for in the detection model, and beaked whale spatial density will be estimated. The detection probability function will provide a relevant comparison to both the detection function and the spatial density of whales derived empirically from the DTag data by Marques et al. (2009).

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Passive acoustic density estimation of Blainville's beaked whales (*Mesoplodon densirostris*) using group localization combined with click counting

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Group localization is a technique for estimating the density of Blainville's beaked whales by isolating groups of animals acoustically and using an average group size to estimate the number of animals present. Initial work has previously been presented on click counting, a method of acoustically estimating the number of Blainville's beaked whales in a group using average click rate and detection ratio statistics derived from DTags, combined with click detections from bottom-mounted hydrophones. The estimated number is then compared to the group size logged by visual observers. In this presentation group localization and click counting are combined to estimate the density of Blainville's beaked whales at the Atlantic Undersea Test and Evaluation Center (AUTEC) in the Tongue of the Ocean, Bahamas. The efficacy of click counting to estimate group size in varying sea states is also analyzed by adding simulated ocean noise to the AUTEC range hydrophone data to investigate the impact on detection ratio statistics.

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Acoustic line transect surveys for sperm whales.

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Abundance estimation methods using distance sampling (line transects) are well established for many cetacean species. Although great progress has been made in recent years in the detection and localisation of many cetacean species, acoustic data often violate the basic assumptions of line transect theory, i.e. that all animals on the transect line are detected, that animals do not move prior to detection and that distances are measured accurately. Acoustic detections of sperm whales fit well with the distance sampling framework since periods between vocalisation are small (so all animals on the transect line are likely to be detected), animals are generally detected far enough from the vessel that they are unlikely to have moved prior to detection and distances can be accurately measured using modest equipment. Results from a number of surveys will be presented and the detail of how sperm whales, beaked whales and harbour porpoise conform to the line transect framework discussed.

Notes

Density estimation of Antarctic Blue Whales using automatic calls detection

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More than 99% of blue whales were hunted in the Southwestern Indian Ocean. Today, the number of individuals and their distribution are still unknown. The objective of our scientific program endeavors to contribute the estimation about the size of their population. We focussed on 2 sub-species: the Antarctic blue whales and the Pygmy blue whales.
We have used the acoustic recordings from the Commissariat à l'Energie Atomique (CEA) used in the International Monitoring System (IMS) deployed near the Possession Island (French Austral and Antarctic Territory). We defined the automatic detector, called Borie, for extracting all the recorded blue whale calls. This detector was presented at the previous workshop in Boston.
The objective of the present work is to give the estimation of the number of whales from the number of detected calls. In previous studies, the conclusions were that these blue whales calls are very similar. We show that it is possible to find some features from these calls to distinguish different individuals. The steps of our method are: 1) denoising the recordings, 2) focussing on the call, 3) extracting 22 parameters for one call, 4) using the curvilinear component analysis for simplifying the representations of the data and 5) using the Monte-Carlo simulations for characterizing the pertinence of the classification.
This method was applied on simulated data with different signal-to-noise ratio to confirm the interest of this approach and its resistance to noise. Afterward, we applied on real signals recordings during a complete year (2003-04) and we will give the results of this study during our oral presentation at the workshop.

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Estimating the abundance of blue whales (*Balaenoptera musculus)* in the northern Indian Ocean using vocalisations recorded by sea-bed mounted hydrophones.

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Blue whale (*Balaenoptera musculus)* vocalisations have been recorded at Diego Garcia, part of the Chagos Archipelago in the Indian Ocean, by International Monitoring System hydrophone stations. These stations are primarily used to detect nuclear explosion test activity but also record low frequency cetacean vocalisations.
A 2-year dataset (2002-2003) from Diego Garcia is currently being analysed. This work is part of a PhD, funded by the UK Defence Science and Technology Laboratory. The overall goal of the project is to develop statistically robust methods to estimate absolute whale abundance using data from seabed-mounted hydrophone systems, illustrated by several case studies. The main methodology used will be based on point transect sampling, a form of distance sampling, which is commonly used to estimate bird abundance.
Three previously described blue whale call types have been identified in the data. The "Southern Ocean" and "Madagascan" call types have been attributed to two different subspecies – the Antarctic blue whale (*B. m. intermedia*) and the pygmy blue whale (*B. m. brevicauda*) respectively (Ljungblad *et al.*, 1998). Much less is known about the third call type – the only documented description is based on recordings of 2 animals made near Sri Lanka in 1984 and 1985 (Alling & Payne, unpublished). The "Sri Lankan" call is the focus of this study.
As a first step to estimating abundance, an automatic detector is being developed to identify Sri Lankan calls using spectrogram correlation. The final results of this analysis will provide the first description of the seasonal occurrence of the Sri Lankan call type in the northern Indian Ocean.
Propagation modelling and estimated source level of the calls will then be incorporated to calculate absolute call abundance in the area. Lastly, an average call rate per individual whale would be required to estimate absolute whale abundance.

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SAMBAH – Static Acoustic Monitoring of the Baltic Sea Harbour Porpoise

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The harbour porpoise (*Phocoena phocoena*) in the Baltic Sea is listed as critically endangered. In the habitat directive, it is listed in Annexes 2 and 4. However, proper management of this population is impeded as the current population estimates are very uncertain, and its geographic distribution and habitat use are unknown.
Due to the low density, traditional survey methods cannot provide adequate estimates of abundance. Instead static acoustic monitoring (SAM) is considered a cost-effective method for estimating porpoise abundance. In a new project called "SAMBAH", almost 300 SAM devices will be deployed in all Baltic waters except Germany and Russia (although cooperation with Germany is planned).
The SAM devices will be placed in a random systematic grid and recordings of echolocation will indicate presence of porpoises. Density estimates will be calculated using adaptations of traditional point transect distance sampling methods, applied to the detection of groups of porpoises by the SAM devices. In order not to overestimate density due to animal movement, successive snapshots in time will be defined. Other methods that do not require snapshots, but assumptions about animal movement, will be developed and tested. Detection probability of SAM devices has been estimated in independent studies, and will be supplemented with data from sites where specially developed ranging SAM devices will be deployed. The method yields a group density estimate, which is then multiplied by an independent estimate of mean group size to estimate animal density and abundance.
Habitat preferences and possible hotspots will be analysed using spatial modelling, relating porpoise density variations from SAM data and extrapolations from other areas, to quantified environmental variables.
SAMBAH will allow formulating appropriate management objectives and identify conservation and mitigation measures. SAMBAH also provides a tool for monitoring the population and evaluating the success of future conservation measures.

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Static acoustic monitoring of harbour porpoises in the German Baltic Sea – How many devices do you need?

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Five marine protected areas (MPAs) in the German Baltic EEZ have been proposed by the German government as future Natura-2000 sites according to the EU-Habitats Directive. As MPAs can only be effective when protective legislation is translated into conservation measures, a monitoring needs to be commenced. The harbour porpoise (*Phocoena phocoena*), the only reproducing cetacean species in the German Baltic Sea, is protected under annex II and IV of the Habitats Directive. The German Oceanographic Museum has conducted a passive acoustic monitoring with up to 42 measuring positions, where T-PODs (Chelonia Ltd., UK), automatic cetacean click loggers, were deployed between 2002 and 2007. All T-PODs were calibrated and (from 2005 on) set to a standard sensitivity of 127 dB_{P-P} re 1 µPa. Generalized additive models (GAM) of the results show significant annual repeating seasonal patterns and geographical differences in the number of porpoise positive days (PPD), as being the percentage of days with porpoise registrations. The variation of PPD among five measuring positions in each of the proposed MPAs 'Kadet Trench' and 'Fehmarnbelt' was calculated. This allowed for the conduction of a power analysis for a paired t-test. Results show that it is feasible to use passive acoustic monitoring for these two MPAs with a reasonable and affordable number of devices. SAM shows tremendous potential for future monitoring in comparison to observer surveys, because short as well as long term variations in porpoise density can be detected and analysed. This is a key issue for evaluating the harbour porpoise population status. For future monitoring of harbour porpoises in the proper Baltic Sea and other low density areas, SAM appears to be the best practical solution, as with decreasing densities aerial and boat surveys become less cost-effective.

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Estimating beluga densities from passive acoustics: Exploration for St. Lawrence belugas frequenting the entrance basin of Saguenay fjord at Tadoussac.

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The Saguenay Fjord entrance at Tadoussac, Québec, Canada is frequently visited by belugas from the St. Lawrence population. This area forms a small basin about 2.5 x 4 km and 150 m deep, which is isolated from the adjacent St. Lawrence estuary by a shallow (< 20-m deep) sill. The basin size offers a high probability of detecting belugas from their calls while its isolated configuration minimizes contaminations from external sound sources, notably distant beluga calls from St. Lawrence. Therefore beluga calls detected by a hydrophone deployed in the basin are only from individuals that are present in the basin. Belugas can be visually localized over the whole basin from centrally located points on both shores. These characteristics make this area an ideal location to compare overlapping acoustic and visual density estimates for a same detection area. In Fall 2008 and Spring 2009, a 4-hydrophone coastal array was deployed in the basin to detect beluga calls while they were visually estimated from systematic shore observations. Two signal processing approaches were used to automatically detect beluga calls, pulsed tones and clicks from their time frequency patterns. Results were summarized in two frequentation metrics. These metrics were compared with the corresponding visual observations over the same periods. The possibility to assess the beluga density in the basin from passive acoustics is explored through a regression estimate framework combining visual and acoustic observations.

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POSTERS

From deep-sea observatories Passive Acoustic Monitoring to RT mitigation of noise impact

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Understanding the interactions between natural and anthropogenic acoustic processes is essential for predicting the magnitude and impact of human activities in the oceans. Deep-sea observatories have the potential to play a key role in the assessment and monitoring of these processes and thus to be used as test platforms for the development of mitigation systems. ESONET is a European Network of Excellence of deep-sea observatories that includes 55 partners belonging to 14 countries. ESONET NoE provides data on key parameters from the subsurface down to the seafloor at representative locations and transmits them in real time to shore. The strategies of deployment, data sampling, technological development, standardisation and data management are being integrated with projects dealing with the spatial and near surface time series. LIDO (Listening to the Deep Ocean Environment) is one of these projects and it particularly addresses the real-time and long-term monitoring of marine ambient noise in the Mediterranean Sea and the adjacent Atlantic waters. Specific activities focus on the characterisation and interactions of this ambient noise with marine mammal sounds and anthropogenic noise sources. Here, we present how the development of LIDO - and its ongoing results with a special emphasis on cetacean bioacoustics and the real-time display of acoustic data and statistics - can be extended to other subsea observatories to increase the performance of future real-time mitigation systems. Because cetaceans are often found in noisy areas heavily overloaded with several other sound sources, (natural, biological or associated to human activities), the challenge is to identify and classify them to reduce the detection ambiguity of the target signals. Based on the data stream from an underwater observatory site in Sicily, the Laboratory of Applied Bioacoustics of the Technical University of Catalonia has developed a modular application that analyses (i.e. detects and classifies) in real-time the acoustic events coming from a tetrahedral hydrophone array to monitor the presence of species at risk and implement the technique in specific mitigation areas.

Sperm whale clicks train rebinding using HMM

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In this paper we consider the problem of separating sperm whale click trains in a recording containing several emitting whales. Click train separation is a single-sensor problem of grouping the clicks from each animal together when the clicks of more than one animal are present at a given sensor. We first detect the clicks and extract the click time, the click duration, the click amplitude, the spectral information and some other features. Those features allow us to discriminate and assemble the click with an HMM modelling. The association is based on the assumptions of slowly-varying click amplitude and intra-click timing.
For separation, we employ an algorithm inspired by dynamic programming. Finally we can estimate the number of whale thanks to train separation. We demonstrate the algorithm on real data from the *2nd International Workshop on the Detection and Classification of Marine Mammals using Passive Acoustics*, Monaco, July 2005. We use the first set from the dataset containing one whale to train our algorithm and the multi-emissions set to test it.

The Continuous Development for Passive Acoustic Monitoring in Offshore Commercial Industry

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Passive Acoustic Monitoring Systems (PAMS) were developed for commercial use from an academic prototype in the 1970s. Commercial operators have pressed for progress of PAMS due to mounting concerns of the harmful effects of noise disturbance to marine mammals. PAMS hard and software has developed continuously into a best practise mitigation tool used in over 25 seismic surveys in 2008 in UK waters alone. JNCC consider PAMS as the only available mitigation tool for operations at night or in poor visibility when visual techniques are inadequate. Throughout commercial industry, generic PAMS allow widespread availability, at reasonable cost, with ease of mobility and assembly as well as operation by personnel with a range of skills. However, commercially, PAMS is still in early development and is currently not effective as a standalone mitigation tool due to a several limitations. For example, inaccurate detection and classification of marine mammals by PAMS means Irish Guidelines restrict commencement of seismic operations to daylight hours and good visibility. PAMS with improved reliability would allow operations to continue 24 hours per day and potentially half survey time and cost. Additionally, there is presently little available knowledge on species vocalisation, therefore PAMS software is currently unable to distinguish accurately between species. As a result, PAMS is not used in Australia where Guidelines only apply to 'whale' species. In addition to mitigation, PAMS is used to obtain distribution and population data of cetaceans in areas prior to industry development. Although widely used the data collected by these techniques is limited due to a lack of knowledge on detection probability.Overcoming the limitations discussed would benefit offshore industry from improving mitigation techniques for conservation to economical benefits of reducing survey time. As a result, industry parties have come together to partly fund the research and development of mitigation software.

PAMGUARD: Open Source Software for Real-Time Acoustic Detection and Localisation of Cetaceans

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For many species, passive acoustic monitoring (PAM) has become an important field tool with application in population survey and mitigation monitoring as well as behavioural research. While there is still an important role for aural monitoring, computer-based systems have distinct advantages in that they are generally more consistent than human operators and are able to detect and classify infrasonic and ultrasonic sounds outside of the human auditory range. They can also accurately localise sounds detected on multiple hydrophones.
Cetaceans are known to make a wide variety of sounds, from the ultrasonic clicks of harbour porpoise to the low frequency moans of large baleen whales. There is no one detection or localisation algorithm that is suitable for all of these types of sound. For any particular study the choice of algorithm may depend not only on the target species, but also on the hydrophone system available and the nature of background noise.
PAMGUARD is intended to provide standard software to address the needs of both developers and users of PAM systems. For the user, PAMGUARD provides a flexible and easy to use suite of modules performing a variety of detection, localisation and mapping tasks. These are contained within a standard interface with the flexibility to allow multiple detectors to be added, removed and configured according to the species of interest or the particular hardware configuration on a project. For developers of PAM systems, an Application Programming Interface (API) has been developed which contains standard classes for the efficient handling of many types of data, which interfaces to acquisition hardware and to databases, and provides a GUI framework for data display.
PAMGUARD already replicates and exceeds the capabilities of earlier real-time monitoring programs such as the IFAW Logger Suite and Ishmael. Ongoing developments include improved real time location and automated species classification.

New automatic classification for Humpback whale songs

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Since the mid 80's, the segmentation of Humpback Whales (HW) songs is based on the Payne's definition of sound units. Many researchers have proposed different approaches for the classificaiton of these units like neural networks.
The main drawback of this method is that the number of sound units seems to be unlimited. We propose here a totally new approach for HW songs analysis, based on the definition of sub-units. One or more than one sub-units are present in one sound unit. The interest of this work is to show that the number of sub-units is still limited and could be used for characterizing the HW songs.
First the signal is characterised by Mel-frequency cepstral coefficients. We do not directly duplicate this approach dedicated to human speech to humpback whale vocalizations, but we show its application for analysing the harmonic parts of each sound unit or subunit, as Greenwood (1961) found that many mammals perceived frequency on a logarithmic scale along the cochlea. Then we apply the recent Affinity Propagation clustering algorithm that is robust to cluster center initialisation. We thus build the unit dictionaries, at different time scales from 1/2 to 32 seconds. Then the songs are coded with these items, and we reveal new song structures.
This work was initiated in 2007 in collaboration with the Megaptera association (Madagascar, Ste Marie Island).

Temporal patterns of North Atlantic right whale vocalizations in the Northwest Atlantic, USA.

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Visual and acoustic surveys have shown that endangered North Atlantic right whales overwinter in the waters of the Northeast US. Detailed knowledge of this population's distribution is critical to reducing anthropogenic mortality events. Passive acoustic studies have confirmed that Stellwagen Bank National Marine Sanctuary (SBNMS) and Jeffreys Ledge are areas of high baleen whale acoustic activity. Right whales produce three main types of calls, the up-call, gun-shot and tonal calls. However, no thorough assessment has yet been made of whether up-call is the most appropriate one to use. SBNMS has been part of an ongoing passive acoustic study since 2006 and provides an opportunity for understanding the relationship between up-calls and gun-shots for this region. From December 2007 an array of 10 marine acoustic recording units was deployed in SBNMS. An automated detector was used to determine seasonal occurrence of calls. Gun-shots and up-calls occurred throughout the winter period, with gun-shots peaking in January, and up-calls peaking in December. Comparative analyses of up-calls and gun-shots show that they occur simultaneously around 17:00. Gun-shots primarily tended to occur between 16:00 and 4:00, while up-calls primarily occurred between 11:00 and 18:00. Average gun-shot activity was 2.15 calls/min, while average up-call activity was 3.45 calls/min. Future research should be directed towards assessing occurrence of different call types between seasons, and in the south-east US breeding grounds and northern foraging areas.

A real time three-dimensional localization and tracking algorithm for acoustic events in noisy marine environments

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Passive localization has shown to be a powerful and non invasive tool for biological and behavioural study, especially for the conservation of marine mammals. Within the field of passive localization of marine mammals, the class of space-time processing methods (STPM, e.g. beamforming or so-called high resolution methods) has been scarcely used even though they have been developed and applied for many years and with great success in the field of digital communications. STPM's theoretical robust estimation of bearing and the possibilities they offer for sound enhancement may however not always overcome the fact that they require certain array configurations and that they leave range estimation up to further processing. Therefore, most algorithms rely on a combination of time-difference of arrival (TDOA) estimation and geometrical exact solutions to provide an estimate of the position of the marine mammal. Usually TDOA estimation methods see their estimation error reduced when the dimensions of an array are large enough. However, the relatively small size of the array in the NEMO configuration, reintroduces STPM as a good candidate for localization. After a pre-processing stage to detect relevant acoustic events, our algorithm firstly uses a high resolution STPM method to estimate the bearing of a source; secondly it uses matched field beamforming to estimate TDOA and range which ultimately provides an estimate of the source position. The algorithm provided consistent clustered estimates of bearing and range over various time series from recordings at NEMO which were then used for the spatial separation of the sources and their tracking.

Who is whistling? Localizing and identifying phonating dolphins in captivity

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Acoustic communication through whistles is well developed in dolphins. However, little is known on how dolphins are using whistles because localizing the sound source is not an easy task. In the present study, the hyperbola method was used to localize the sound source using a two-hydrophone array. A combined visual and acoustic method was used to determine the identity of the whistling dolphin. In an aquarium in Mexico City where two adult bottlenose dolphins were housed we recorded 960 whistles during 22 days. We found that a dolphin was located along the calculated hyperbola for 76.0% of the whistles. Possible effects due to reverberation were responsible of the poor performance in computing time of arrival differences for 24.0% of the whistles. Due to the behavior of dolphins, only for 59.3% of the whistles we could determine the identity of the whistling dolphin. However, sometimes it was possible to use other behavioral cues to identify the whistling dolphin. The whistling dolphin could be the animal located closest to the hydrophone that captured the whistle or it could be the animal that performed a behavior named "observation" at the time whistling occurred. Whistles identified to a dolphin using one of these two options were further verified by computing the stereotypy of whistles by individual. Using these behavioral cues, 11.5% of the whistles were further ascribed to either dolphin, to obtain an overall identification efficiency of 70.7%. Our results show that a very simple and cheap acoustic setup can lead to a reasonable number of identifications of the captive whistling dolphin. This method can be applied in other aquaria where not many dolphins are housed. However, the actual efficiency of this method will depend on how often dolphins spend time next to each other and on the reverberation conditions of the pool.

The efficacy of SQS 53F GPS modified sonobuoys and a 4-element bearing array for the detection of Blainville's beaked whales

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Blainville's beaked whales (*Mesoplodon densirostris*) are routinely detected on the Atlantic Undersea Test and Evaluation Center (AUTEC) bottom-mounted hydrophones. During a week-long test, a 4-element bearing array and SQS53F GPS modified sonobuoys were tested for the detection of these deep diving cetaceans. The devices were deployed from the Defense Research and Development Canada (DRDC) research ship Quest. Vocal groups of animals were located using the AUTEC sensors and the ship was directed to these vocally active areas. The statistics for detection probability and detection range for both devices are derived using the AUTEC system as a means of comparison.

An Exploration of Killer Whale Acoustic Identification

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The goal of our research is to establish an acoustic identification system for killer whale (*Orcinus orca*) individuals. With such a system, acoustic remote monitoring can be expanded in a cost effective manner to cover greater geographic regions and long term studies. To achieve this goal we apply human speaker recognition methods to acoustic recordings of killer whales. Our initial data set consists of 23 vocalizations from four captive whales of Icelandic origin, which constitutes approximately 11.5 seconds of data per whale. Recordings were taken at Hubbs-SeaWorld and the identity of the calling whale is known with a high degree of certainty for each vocalization, allowing us to validate our method results. Baseline studies have been performed using a simplified version of human speaker recognition. In a system using 12 mel-frequency cepstral coefficients, a single 12-dimensional Gaussian distribution with diagonal covariance was used to classify. An overall accuracy of 47% was achieved and chance performance was 25%. Recognition performance differed substantially between whales, which suggests the need for increased data to better model variance in the training model. It was also observed that the mel-frequency cesptral coefficients were more complex than could be represented with a single Gaussian model. We extend this baseline study by increasing our data set and implement Gaussian mixture models, which are better suited for non-Gaussian data. The feature space strongly influences the separability of the data so we have also explored the use of modulation based features. These features improve accuracy in human speaker recognition and could hold similar potential for killer whales. Fisher discriminant analysis compares the correlation between each cepstral coefficient to caller identification to determine the coefficients important for classification. This results in a dimensionality reduction of the feature vector for testing and training while maintaining or improving performance.

BOING! Acoustic Localization, Characterization and Comparison of Minke Whale Songs from the Hawaiian Islands and Other Areas in the North Pacific Ocean

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The minke whale (*Balaenoptera acutorostrata*) is a small and elusive baleen whale that is rarely sighted in tropical waters of the North Pacific Ocean. During winter and spring, they produce songs, also known as 'boings,' that are commonly detected at deep water hydrophones located around the Hawaiian Islands. We acoustically monitored minke whales using a seafloor hydrophone array encompassing a large (>2000 km^2), deep-water area northwest of the island of Kauai. Simultaneous visual-acoustic surveys of the same region were conducted from a quiet motor-sailing vessel towing a 4 element hydrophone array. The combination of the towed and fixed hydrophone arrays allowed animals to be localized and tracked in near real-time. Using these methods, we were able to visually confirm the location of a minke whale that was initially detected and localized using the fixed hydrophone array and later with the towed hydrophone array. These data are being collected to help validate statistical methods that are being developed to estimate densities of marine mammals using acoustic signals they produce. In a related study, boings recorded in the Hawaiian Islands (central North Pacific) were acoustically characterized and compared to boings recorded in the western and eastern North Pacific. These results are discussed in relation to the behavior and population biology of this species. We provide recommendations for tracking, monitoring behaviors, and estimating the abundance and distribution of these vocally active, but visually elusive whales.

[This research was supported by a grant from the Office of Naval Research]

PAM package for real-time multichannel sound monitoring, analysis and display

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The concern that man-made acoustic signals can affect marine mammals has increased over the past few years, mainly within the context of low and mid-frequency active sonars and seismic surveys. Whether it is in support of acoustic risk mitigation measures, or in the larger context of environmental monitoring, recent years have seen an increasing use of passive acoustics at sea.
Passive acoustics is a powerful tool to be used for expanding knowledge about marine mammals' distribution, monitoring underwater noise, monitoring critical habitats, evaluating the effects of sound exposure on animals' behaviour, implementing mitigation policies by detecting animals within or approaching a possibly dangerous sound exposure area, planning and enforcing conservation policies.
To improve research capabilities and to support the Acoustic Risk Mitigation Policies being developed by many national and international civil and military organizations, a complete set of equipment was designed and extensively tested to provide an affordable and flexible tool for wide band acoustic detection and monitoring. It provides detection, processing, storage and advanced display capabilities and is used for both wide area surveys and local monitoring needs.
The package includes wideband low-noise towed arrays of hydrophones, autonomous recorders to be used either floating or bottom deployed, a PC based multichannel data acquisition front-end and a complete software suite to assist the researchers in collecting, visualizing and analyzing data either in real-time or in post processing.
Software allows recording and analyzing sounds received by up to 8 wide band sensors, managing sonobuoys' radio receivers, recording and distributing NMEA navigation data, logging and classification of acoustic contacts, logging visual contacts, sharing data among a network of PCs, and plotting georeferenced data on a GIS.
The system is modular and flexible to fit different contexts, platforms and needs. It requires at least one PC dedicated to sound recording and one to GIS and navigation; additional networked PCs can be used to distribute processing and visualization needs. Depending on the acoustic interface and on storage capabilities, 2 to 10 channels with bandwidth up to 96 kHz can be continuously recorded 24 hours/day. Acoustic data is stored in standard *wav* files, in user defined time cuts; each file is time- and geo-referenced for easy retrieval.
A set of sensors (towed arrays, stationary hydrophones, sonobuoys), either commercial or CIBRA designed and made, has been also tested to set up a reliable, self contained, easy to install and use equipment for passive acoustic research.
All our equipment has been successfully used in recent sea trials (SIRENA 08 and MED 09) to detect Cuvier's beaked whales and map their distribution in the Alboran Sea (Western Mediterranean Sea). Latest improvements during MED09 include the use of two arrays towed in parallel to allow acoustic tracking of beaked whales to assist WHOI's D-tags programs.

The development and testing of concepts and prototypes has been mainly carried out within the NATO URC MMRMP Project with ONR Grants N00014-99-1-0709, N00014-02-1-0333, N00014-03-1-0901 and N00014-09-1-0804.

Anthropogenic sound exposure of marine mammals from seaways: Estimates for the St. Lawrence Seaway

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Marine mammals make extensive use of sounds to accomplish their vital functions of communicating, remote sensing their environment, navigating and finding preys in an opaque medium by echolocation. These functions require low noise conditions to maximise the probability of adequate detection, classification and localization of the signals of interest. Various levels of noise are however always present, either from natural sources, to which the animals were adapted to through evolution, or from anthropogenic sources, which are relatively new from an evolutionary perspective, and have considerably changed in the last century. A major anthropogenic contribution to ocean noise is shipping, a critical link for maintaining world global supply. Recent studies have shown that shipping have doubled ambient noise levels in the low frequency band every decade since the 1960's. Shipping is intensive and ubiquitous around the mid-latitude belt of the planet. It includes busy seaways and choke points in several parts of the world. Despite these facts and the importance of noise for marine mammals and other marine organisms, very few data are available on the noise levels animals are exposed to on seaways.
This paper present an analysis of noise levels on a busy seaway of North America, the St. Lawrence Seaway, which cuts through the Gulf of St. Lawrence and crosses several areas of intensive feeding by several species of cetaceans and pinnipeds. Noise was continuously recorded for a 5-month period in summer 2005 by an AURAL autonomous hydrophone moored on the bottom at a depth of 285 m in the middle of the seaway. The received noise level in the 20 Hz to 1 kHz band exceeded 112 dB re $1\mu Pa_{rms}$ 50% of the time, in response to transiting merchant ships. Strong spectral rays were common at low frequencies and in the 400-800 Hz band. M-weighting applied for several groups of cetaceans and pinnipeds indicate maximal wideband levels reaching 100 to 135 dB-M re 1 μPa_{rms}, mainly from contributions from the 10-120 Hz band. As expected the highest levels were for low-frequency specialists and pinnipeds. Time required to reach the critical exposure level of 215 dB re 1 μPa^2-s proposed for hearing damage is longer than the life expectancy of the animals.

OBIS-SEAMAP: Incorporating passive acoustic detections and localizations into a global database

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OBIS-SEAMAP, an online information system for marine mammal, seabird and sea turtle data, has recently expanded its capabilities to include data collected through passive acoustic monitoring. OBIS-SEAMAP brings together georeferenced observation and telemetry data with tools to query and assess these species in a dynamic and searchable environment. By combining data from individual data collections on small spatial and temporal scales into a global database, a more complete picture of the biology, distribution and conservation status of these widely distributed animals can be developed. The open-access web-based approach utilized by OBIS-SEAMAP allows a global audience of researchers, students, and mangers to 1) map species distributions together with oceanographic information; 2) visualize species distributions with a multi-resolution, spatially and temporally interactive online map interface; and 3) search and download data of interest using multi-faceted criteria. Similarly, data providers benefit from increased data quality assurance and quality control, increased geographical and temporal data accessibility, and increased data dissemination. The incorporation of passive acoustic monitoring data offers an exciting opportunity to expand knowledge of marine mammal species at time scales and in regions that are not feasible with traditional survey methods. Recent developments in OBIS-SEAMAP allow acoustic detection and localization data from a variety of sources, including towed hydrophone arrays, single moored instruments and instrument arrays, and acoustic tags, to be incorporated and visualized within the OBIS-SEAMAP framework. The continued participation, collaboration, and data sharing between researchers, managers, and educators throughout the globe enabled by OBIS-SEAMAP is essential for us to better understand these animals and to develop better management decisions.

Mesoplodon densirostris Transmission Beam Pattern estimated from Passive Acoustic Bottom Mounted Hydrophones and DTag Recordings on Multiple Whales

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The transmission beam pattern of four *M. densirostris* tagged in the Tongue of the Ocean, Bahamas is estimated using data from Woods Hole Oceanographic Institution DTags and broadband, bottom mounted hydrophones at the Atlantic Undersea Test and Evaluation Center, Andros Island, Bahamas. The bottom mounted hydrophones are used to localize the position of the tagged animal and measure the received level and spectral characteristics of each click. Pitch, roll and heading from the DTag are used to determine the horizontal and vertical aspect angles relative to the hydrophone. A composite of the *M. densirostris* horizontal and vertical transmission beam pattern based on thirteen dives from four animals will be presented.

A real time classification system for acoustic events in the marine environment

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The automated, real time classification of acoustic events in the marine environment is an important tool to study how anthropogenic sound pollution affects marine mammals and for mitigating human activities that are potentially harmful to them. However the classification in a fully automated way is challenging due to the diversity of acoustic events and background noises typically found.

We present a real time classification system targeted at many important groups of acoustic events (clicks, buzzes, calls, whistles from several cetacean species, tonal and impulsive shipping noise and explosions). The system is composed of two stages: The first stage, made of several detection algorithms, detects segments that contain acoustic events and tags them according to broad classes (e.g. low frequency impulses, ultrasonic impulses, short tonals). The second stage, made of several classification algorithms, classifies events that have been detected in the first stage into more specific classes, which have practical relevance (e.g. impulsive ship noise, ultrasonic cetacean clicks, cetacean buzzes, whistles).

The system's reliability was tested on data from several sites, including the datasets made available for the workshop. The achieved classification performance indicates that the system is reliable to automatically classify acoustic events in real time. This system will be useful to pre-process the very large data volume that can be gathered during long term PAM campaigns or to detect the presence of cetaceans in real time for mitigation.

Four Channel Reconfigurable Hardware for Real-time Acoustic Data Acquisition and Elaboration

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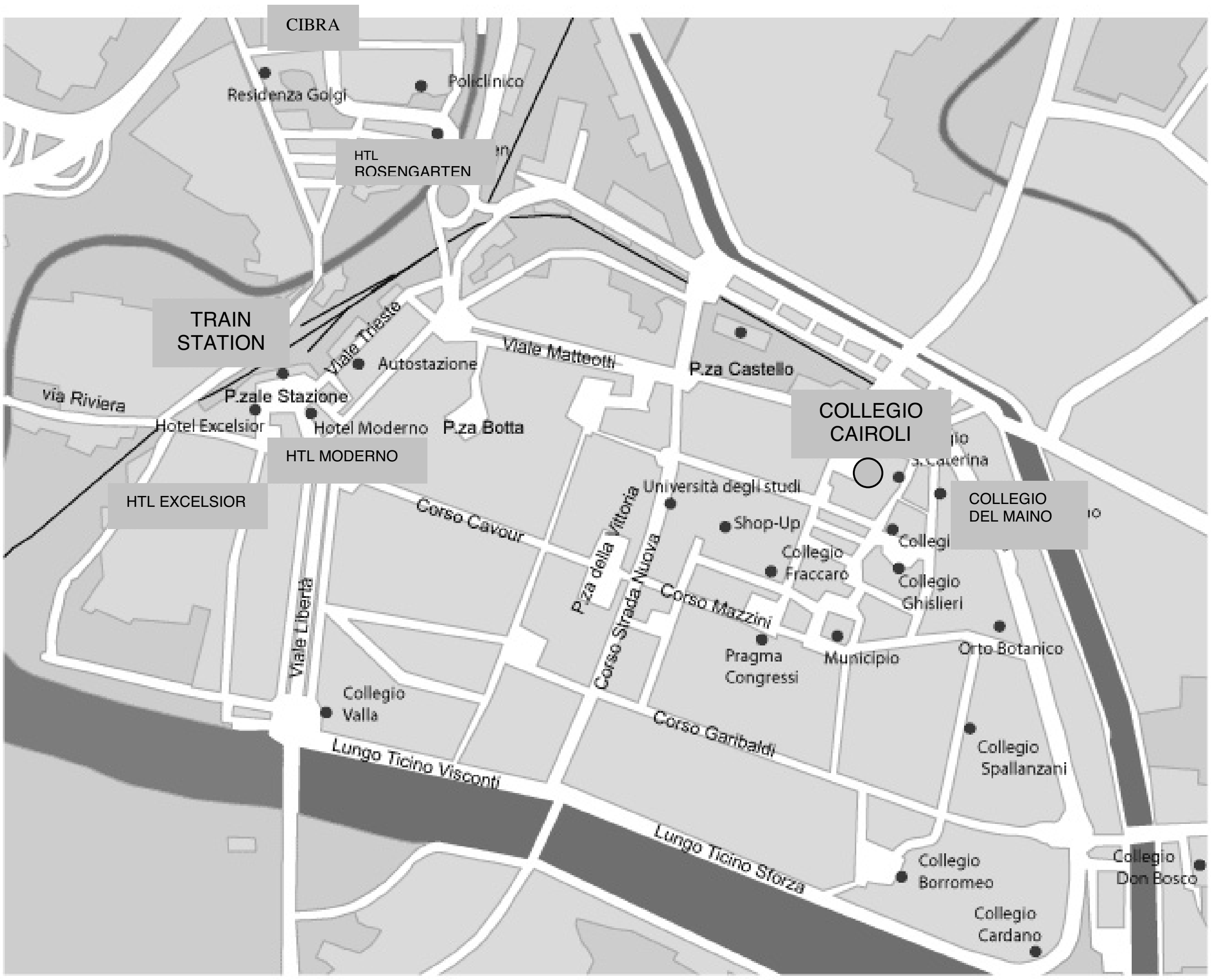
A new compact system for acoustic data acquisition and elaboration was made by the Advanced Electronic Laboratory development team of Capo Granitola IAMC-CNR. The system based on FPGA (Field Programmable Gate Array) allows passive localization of the acoustic source in a custom board that measures only 10cm x 7.5cm, thanks to four parallel data acquisition chains with variable gain, charge preamplifier, selectable low-pass filter and Analog to Digital converter up to 1.33 MS/s and a 16 bit sample resolution.
All electronic signals and control lines flow in a single FPGA that manage the low level I/O operations of the whole board.
Over the years, FPGA devices has became a vital part of modern electronic design in many field of application and can provide millions of gates to implement full systems on a single chip. Today, high performance, small footprint and low cost FPGA allow to make compact reconfigurable instruments that can be software re-configured to work in new scientific applications.
Unlike a microprocessor, where operations are strictly sequential, in the FPGA operations can be also concurrent, improving speed performance of many real-time algorithms.
The electronic board is provided with an RTC (Real Time Clock) circuit and a standard SD-card connector that enable to save acoustic data not requiring an external PC.
Through a bus connector it is possible, however, to connect the board to a PC (for example to a VIA-pico ITX board, that have the same form factor) and realize a compact data acquisition and elaboration system with advanced communication interface and a small power consumption, ideal in many battery powered applications.

AUTHORS INDEX

PAVIA MAP

Venue

Collegio Cairoli
Piazza Cairoli 1 – Pavia, Italy



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FINANCIAL SPONSOR

The workshops are supported by Office of Naval Research US, Award N00014-09-1-0894,
and by Office of Naval Research Global, Grant Number N62909-09-1-1088.