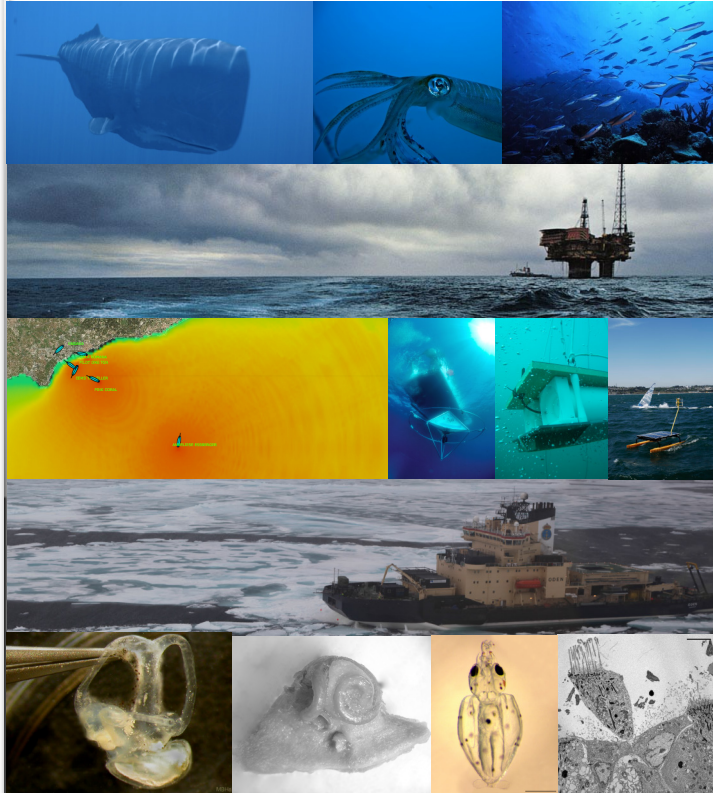


Towards an Acoustically Sound Ocean

An International
Conference and Exhibition
on Ocean Noise



OCEANOISE2015
Vilanova i la Geltrú, BARCELONA 11-15 MAY

SCIENCE COMMITTEE

Michael Ainslie (The Netherlands), Tomonari Akamatsu (Japan), Michel André, Chair (Spain), Fabrizio Borsani (UK), Christine Erbe (Australia), Thomas Folegot (France), Michele Halvorsen (USA), Paul Lepper (UK), Jennifer Miksis-Olds (USA), Stephen Robinson (UK), Peter Sigray (Sweden), Brandon Southall (USA), Pete Theobald (UK), Frank Thomsen (Denmark), Manell Zakharia (France, India)

ORGANIZING COMMITTEE

Michel André, Christophe Brunet, Linda Canty, Steffen De Vreese, Ariane Fresel, Ludwig Houégnigan, Pablo Pla Caro, Joan W. Castell, Helena Querol, Toni Sánchez, Mike Van der Schaar, Marta Solé, Alba Solsona Berga

The growing scientific and societal concern about the effects of underwater sound on marine ecosystems has been recently recognized through the introduction of several international initiatives aiming at measuring the environmental impact of ocean noise at large spatial and temporal scales.

OCEANOISE2015 brings together international experts in noise measurement, modelling and mapping, physiological and behavioural effects as well as regulation and mitigation procedures.

OCEANOISE2015 format aims at favouring a dynamic exchange of the latest findings in the field of ocean noise in order to assist in providing ocean users with the best scientific knowledge and technical solutions to address operational and environmental issues.

<http://www.oceanoise2015.com>

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Making Sense of Sounds

Laboratory of Applied Bioacoustics (LAB)
Technical University of Catalonia, BarcelonaTech

OCEANOISE2015

Vilanova i la Geltrú, BARCELONA 11-15 MAY

Conference programme overview

MAY 11-15	09:00	09:30	10:00	11:30	12:00	14:00	15:30	16:00	17:00	17:30	18:00	18:30	19:00
Monday		AMBIENT NOISE		Gold medal award ceremony	SHIPPING		SEISMIC		5Min Talks & Posters				
Tuesday	PILE-DRIVING			KN* Navy	RENEWABLE ENERGY		SOUNDSCAPES		5Min Talks & Posters				
Wednesday	BEHAVIOUR			KN* Academy	PATHOLOGY		SENSITIVITY		5Min Talks & Posters				
Thursday	POLAR			KN* NGO	RIVERINE		MAPPING						
Friday		KN* Regulation	REGULATION		MITIGATION				*KN: Keynote presentation				

Abstract booklet overview

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Sensitivity	p.94
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OCEANOISE2015 is organised in chaired sessions where invited speakers will present new data and participate to a round table where everyone will be able to interact.

AMBIENT NOISE

Chairs

Doug Cato

Defence Science and Technology Organisation & University of Sydney Australia

Mark Prior

TNO, The Netherlands

Ambient noise in the Perth Canyon: 2008-2014

Christine Erbe

Centre for Marine Science & Technology, Curtin University, Perth, Western Australia

Seasonality in sound measurements from the Japanese East Coast

Mike van der Schaar

Laboratory of Applied Bioacoustics, Technical University of Catalonia, BarcelonaTech (UPC), Spain

Assimilation of real-time measurement for ambient noise prediction

Thomas Folegot

Quiet-Oceans

Marine Soundscape Ecology: the application of acoustic diversity indices

Craig Radford

Leigh Marine Laboratory, Institute of Marine Science, New Zealand

Noise Levels in Shallow Waters Near the Hudson River's Tappan Zee Bridge

Arthur N. Popper

University of Maryland

Underwater ambient noise in the English Channel from 1989-2009 and its spatial and temporal variability

Ayça Eleman

Sualtı Arastirmalari Dernegi (Underwater Research Society)

Recent Results from Large Scale Monitoring of the Ambient Noise in the Baltic Sea

Peter Sigray

Swedish Defence Research Agency, FOI

The importance of natural sources for sound maps of the Dutch North sea: A comparison between wind, rain, and ships as sources of sound

Bas Binnerts

TNO

Harbour seal vocalisation off season

Mathias Andersson

FOI Swedish Defence Research Agency, Sweden

INSTITUTE OF ACOUSTICS - GOLD MEDAL AWARD CEREMONY

Sander von Benda Beckmann, TNO, the Netherlands

SHIPPING

Chairs

Christian Audoly

DCNS, France

Christ de Jong

TNO, The Netherlands

An overview of the Bureau Veritas Rule Note NR614 “Underwater Radiated Noise“

Eric Baudin

Bureau Veritas

Experience with ship noise measurements (standards & uncertainty)

Cédric Gervaise

GIPSA-lab, France

An assessment of the variability associated with the measurement of radiated noise from vessels

Alex Brooker

Institute of Sound and Vibration Research, University of Southampton, UK

Correlation between vessel full-scale measurements and URN numerical prediction in the framework of the AQUO EU project

Raúl Salinas

TSI, Spain

Parametric models of ship source level for use in an underwater noise footprint assessment tool

Christian Audoly

DCNS Research, France

An Acoustic Source Level for Ships

Dietrich Wittekind

DW-ShipConsult, Germany

Modelling Shipping Noise Exposures Using Vessel Tracking Data

Alexander MacGillivray

JASCO Applied Sciences, Canada

Measurements of the shipping levels in the Genoa Canyon system to address the impact on an acoustically sensitive cetacean species *Ziphius cavirostris*

Frazer Coomber

CIMA research foundation, Italy

SEISMIC SURVEYS

Chairs

David Hedgeland

BP, UK

Mike Jenkerson

Exxon-Mobil, USA

Seismic Methods and the Use of Sound

Isabelle Lambert

CGG, France

GeoTechnical & Site Survey Methods

Nick Robinson

Gardline Environmental Limited, UK

The use of better quantification techniques in marine survey assessments

Sean Hayes

Genesis Oil and Gas Consultants Ltd, UK

Sound Model Validation Method

Clara Correa

Repsol, Spain

The Marine Vibrator JIP: Technical and Operational Specifications for the Marine Vibrator

Mike Jenkerson

ExxonMobil, USA

Popcorn source seismic acquisition

Raymond Abma

BP, USA

eSource: The Tuneable Impulsive Seismic Source

Jack Norton

Teledyne-Bolt, USA

5-MINUTE TALKS AND POSTERS

Simulation of Wind-driven Ocean Noise in the West Coast of Taiwan

Ni Chen-Yang

National Taiwan University, Taiwan

Variation of bottlenose dolphin whistles characteristics in relation to the local sea ambient noise in the Norther Adriatic Sea

Nikolina Rako Gospi

Blue World Institute of Marine Research and Conservation, Croatia

Seals and shipping noise in a dynamic sea: seasonal changes in shipping noise exposure experienced by diving seals

Feng Chen

Plymouth University, USA

Improving knowledge and understanding of underwater sound from E&P activities and potential interaction with marine life; an overview of a research programme

Roger Gentry

International Association of Oil & Gas Producers (IOGP), UK

Airgun pulses in shallow water

Line Hermannsen

Aarhus University, Denmark

On the characterization of Seismic Airgun detonation underwater sounds

Ramón Miralles

Universitat Politecnica de Valencia, Spain

Inter-pulse noise field during an Arctic shallow-water seismic survey

Shane Guan

The Catholic University of America, USA

Effects of airgun sounds on bowhead whale calling rates: evidence for two behavioral threshold

Susanna Blackwell

Greeneridge Sciences, Inc., USA

PILE DRIVING & OTHER IMPULSIVE SOURCES

Chairs

Stephen Robinson

NPL, UK

Roberto Racca

JASCO, Canada

Measurements of Pile Driving Noise Attenuation and Sound Propagation in the Hudson River

Alexander MacGillivray

JASCO Applied Sciences, Victoria BC, Canada

Numerical modelling of underwater sound emission from marine pile driving over elastic seabeds

Christine Erbe (for Alexander Gavrilov)

Centre for Marine Science & Technology, Curtin University, Perth, Western Australia

Sediment stiffness effects on piling noise using a wave-equation analysis model

Michael Wood

JASCO Applied Sciences, Droxford, Ha, UK and University of Southampton, UK

Mitigating the impact of pile-driving noise on harbor porpoise (*Phocoena phocoena*) during foundation installation at Borkum Riffgrund 1 Offshore Wind farm

Federica Pace

Baker Consultants Marine Ltd, Matlock, Db, UK

Modelling of impact pile driving noise for assessing the impact on marine animals

Christ de Jong

TNO, Sonar and acoustics, The Netherlands

A standard for piling noise measurement: progress with ISO18406

Peter Theobald

National Physics Laboratory, UK

Analysis of shallow water explosions and the impact on fish

Andreas Holmberg

Swedish Defence Research Agency, Stockholm, Sweden

KEYNOTE PRESENTATION:

NAVY

Walter Zimmer

The NATO STO Centre for Maritime Research & Experimentation

RENEWABLE ENERGY

Chairs

Paul Lepper

Loughborough University, UK

Frank Thomsen

DHI, Denmark

Simultaneous particle motion and sound pressure measurements at two types of offshore wind-farms in operation

Monika Kosecka

DHI Polska, Poland

Characterization of operational underwater noise generated by Wind Park in Belgian water of the North Sea

Alain Norro

RBINS, Belgium

Acoustic characterization of submarine cable installation in the Biscay Marine Energy Platform (bimep)

Juan Bald

AZTI, Spain

Cumulative operational noise of large scale arrays of offshore wind farms

Paul Lepper

Loughborough University, UK

Underwater noise from a wave energy converter

Jakob Tougaard

Aarhus University, Denmark

A framework to predict, validate and review the acoustic footprint of operating tidal turbines

Ben Wilson

SAMS, University of the Highlands and Islands, Scotland

Ambient noise in the Falmouth Bay Test area (FaBTest, UK) – Baseline measurements of shipping, environmental variability and wave-energy converters

Philippe Blondel

University of Bath, UK

Use of Population Viability Analysis to Assess the Potential for Long Term Impacts from Piling Noise on Marine Mammal Populations

Kate Grellier

Natural Power Consultants, UK

SOUNDSCAPES

Chairs

Jennifer Miksis-Olds

Applied Research Laboratory, Penn State University, USA

Kevin Heaney

OASIS, Inc., USA

Characterizing marine soundscapes using temporal patterns

Bruce Martin

JASCO Applied Sciences and Dalhousie University Department of Oceanography, Canada

Measurements and modelling of the spatial dependence of soundscapes

Kevin Heaney

OASIS, Inc., USA

Linking changes in soundscape levels to sources through frequency correlation matrices

Jennifer Miksis-Olds

Applied Research Laboratory, Penn State, USA

Ambient noise measurements at a sheltered coastal location

Anthony Hawkins

Loughine Limited, UK

Soundscapes of the central Pacific

Ana Sirovic

Scripps Institution of Oceanography, UCSD, USA

Soundscapes on coast of British Columbia, Canada: an ocean of opportunity

Kathy Heise

Vancouver Aquarium and WWF Canada, Canada

Spatiotemporal variability in coral reef soundscapes, associations with local biota, and patterns of boat noise

Maxwell B. Kaplan

Woods Hole Oceanographic Institution, USA

A geospatial approach to exploring the soundscape of Stellwagen Bank National Marine Sanctuary

Daniel Mennitt

National Park Service, USA

5-MINUTE TALKS AND POSTERS

Creating an acoustic 'evidence base' for sound emission of wave and tidal devices

Irene Voellmy

University of Bristol, UK

Harbour porpoise in the North Sea: How Offshore Wind Farm developers deliver appropriate, evidence based, and realistic worst cases for cumulative impact assessment for underwater noise?

Jennifer Learmonth

Royal Haskoning DHV, UK

Annually averaged sound maps and total acoustic energy due to selected sound sources in the Dutch North Sea

H. Özkan Sertlek

TNO, The Netherlands

An Introduction to Underwater Soundscape around Taiwan

Jeff Chih-Hao Wu

National Taiwan University, Taiwan

Top-down and down-up physiological effects of noise on marine fauna

Natacha Aguilar

University of La Laguna, Spain

Efficacy of ramp-up of naval sonar (1.3-2.0 kHz): an experimental evaluation with humpback whales

Paul Wensveen

University of St Andrews, UK

BEHAVIOUR

Chairs

Douglas Nowacek

Duke University Marine Laboratory, USA

Patrick Miller

University of St Andrews, UK

Behavioural reactions in cod to a Coast Guard ship in a deep fjord

Mathias Andersson

FOI Swedish Defence Research Agency, Sweden

Behavioural responses of sea turtles to marine anthropogenic sound: Current knowledge, data gaps, and future research directions

Wendy Dow-Piniak

Gettysburg College, USA

Cumulative effects of multiple vessel classes on the communication space of baleen whales in different behavioural contexts

Denise Risch

SAMS, Scottish Association for Marine Science, UK

First indications that northern bottlenose whales are sensitive to behavioural disturbance from anthropogenic noise

Patrick Miller

University of St Andrews, UK

Effects of naval sonar on feeding in humpback whales

Lise Doksæter Slive

Institute of Marine Research (IMR), Norway

Disturbance-specific social responses in long-finned pilot whales

Fleur Visser

Kelp Marine Research, Hoom, the Netherlands & Behavioural Biology Group,
Leiden University, The Netherlands

Behavioral responses of migrating humpback whales to a small air gun and the importance of baseline data

Mike Noad

Cetacean Ecology and Acoustics Laboratory, The University of Queensland, Gatton, Qld
4343, Australia

Laboratory Potential Mechanisms of Responses of Right Whales to Anthropogenic Sound

Douglas Nowacek

Nicholas School of the Environment & Pratt School of Engineering,
Duke University Marine, USA

KEYNOTE PRESENTATION:

ACADEMIA

Ana Širović

Scripps Institution of Oceanography, UCSD, USA

PATHOLOGY

Chairs

Michel André

Laboratory of Applied Bioacoustics, Technical University of Catalonia, BarcelonaTech, Spain

Ursula Siebert

University of Veterinary Medicine, Hannover

Controlled noise exposure experiments on jellyfishes

Marta Solé

Laboratory of Applied Bioacoustics, Technical University of Catalonia, BarcelonaTech (UPC), Spain

Noise induced hearing loss evidence: case of a long-finned pilot whale mass stranding event

Maria Morell

Zoology Department, University of British Columbia & Laboratory of Applied Bioacoustics, Technical University of Catalonia, BarcelonaTech (UPC)

Pile driving is perceived as an acoustic stressor by juvenile European sea bass (*Dicentrarchus labrax*)

Elisabeth Debusschere

Institute for Agricultural and Fisheries Research & Ghent University Belgium

Underwater noise impact investigations on wild harbour porpoises (*Phocoena phocoena*)

Andreas Ruser

Institute of Terrestrial and Aquatic Wildlife Research, University of Veterinary Medicine Hannover, Germany

Susceptibility and potential pathology of temporary threshold shift in marine mammals

Dorian Houser

Department of Conservation and Biological Research, National Marine Mammal Foundation, USA

Pathomorphological changes in the ears of harbour porpoises (*Phocoena phocoena*)

Ursula Siebert

University of Veterinary Medicine Hannover, Germany

Beluga whale hearing in a rapidly changing Arctic environment

Manuel Castellote

National Marine Fisheries Services. NOAA, USA,

SENSITIVITY

Chairs

Klaus Lucke

Curtin University, Australia

Aran Mooney

Woods Hole Oceanographic Institution, USA

Underwater low frequency calibration for the quantitative measurement of ocean noise and auditory sensitivities

Tomonari Akamatsu

National Research Institute of Fisheries Engineering, Fisheries Research Agency, Japan

Sound Pressure and particule motion effects on noise-exposed cuttlefishes

Michel André

Laboratory of Applied Bioacoustics, Technical University of Catalonia, BarcelonaTech (UPC), Spain

Injury response in the hybrid striped bass as a function of number of pile driving strike exposures

Arthur N. Popper

University of Maryland, USA

Responses of wild pelagic fishes to impulsive sounds

Tony Hawkins

Loughine Marine Research, UK

Bigeyes or bigears: first evidence of a fish using a contact call

Craig Radford

Leigh Marine Laboratory University of Auckland, New Zealand

Predators use anthropogenic signals from acoustic tags to locate prey

Amanda L. Stansbury

University of St. Andrews, UK

Investigating the response of coastal dolphins to mine exercise (MINEX) training activities

Marc Lammers

Hawaii Institute of Marine Biology & Oceanwide Science Institute, USA

Individual differences in behavioral hearing sensitivity of killer whales (*Orcinus orca*)

Brian Branstetter

National Marine Mammal Foundation, USA

5-MINUTE TALKS AND POSTERS

The influence of boat noise on the behaviour of Pacific salmon, Pacific herring and Yellowtail rockfish

Inge van der Knaap

Galway Mayo Institute of Technology, Ireland

Numerical modelling of fish in response to underwater noise

Kerry Marten

HR Wallingford, UK

Assessment of underwater noise impact on marine fauna: Perspective from a Scottish Nature Conservation Body

Caroline Carter

Scottish Natural Heritage, UK

Discovery of Sound in the Sea (DOSITS): Results From the Second Needs Assessment of the Regulatory Community

Gail Scowcroft

University of Rhode Island, USA

Application of a noise model for environmental impact assessment of deep sea mining

Kerry Marten

HR Wallingford Ltd., UK

Achieving underwater noise regulation through an ecosystems-based approach: the "Mediterranean strategy on Underwater Noise Monitoring"

Alessio Maglio

Joint ACCOBAMS/ASCOBANS/CMS noise Working Group

The value of opportunistic detections to improve Passive Acoustic Monitoring

Sharon Doake

Gardline Environmental Limited, UK

POLAR

Chairs

Philippe Blondel

University of Bath, UK

Hanne Sagen

Nansen Environmental and Remote Sensing Center, Norway

Synoptic measurements of ambient noise in the Fram Strait Marginal Ice Zone

Dag Tollefsen

Norwegian Defence Research Establishment (FFI), Box 115, 3191 Horten, Norway

Broadband ambient noise and ice-related processes in the Arctic – Multi-year studies of Hans Glacier, Svalbard

Jaroslav Tegowski

Institute of Oceanography, University of Gdansk, Poland

Characteristics of Underwater Noise Sources at the Glacier Ice-Ocean Boundary: Subglacial Discharge and Seiches

Erin C. Pettit

Dept of Geology and Geophysics, University of Alaska Fairbanks, Fairbanks

Passive acoustics from moorings and drifting ice stations in the Fram Strait

Hanne Sagen

Nansen Environmental and Remote Sensing Center (NERSC), Bergen, Norway

Ambient noise in the Arctic Ocean measured with a drifting vertical line array

Peter Worcester

Institute of Geophysics and Planetary Physics, Scripps Institution of Oceanography, UC San Diego, USA

Characteristics of air-gun array pulses and the ambient soundscape in Baffin Bay and Melville Bay, West Greenland

Bruce Martin

JASCO Applied Sciences, Halifax NS, Canada

Measurements of cumulative airgun survey activity in the Beaufort Sea during ice-free conditions, 2008-2012

Aaron Thodes

Scripps Institution of Oceanography, UCSD, USA

KEYNOTE PRESENTATION:

NGO

Sarah Dolman

Whales and Dolphins Conservation, UKW

RIVERINE AND COASTAL

Chairs

Tomonari Akamatsu

National Research Institute of Fisheries Engineering, Fisheries Research Agency, Japan

Satoko Kimura

Kyoto University, Japan

Cephalopods' anti-predator responses to sound differ based upon sound level, frequency and prior experience

Aran Mooney

Biology Department, Woods Hole Oceanographic Institution, USA

Mid- and high-frequency noises of small fast-speed boats in shallow water and their potential impacts on the Indo-Pacific humpbacked dolphins (*Sousa chinensis*)

Songhai Li

Marine Mammal and Marine Bioacoustics Laboratory, Sanya Institute of Deep-sea Science and Engineering, Chinese Academy of Sciences, Sanya, China

Ship-originated noise in narrow straits used for international navigation

Bayram Öztürk

Faculty of Fisheries, Istanbul University and Turkish Marine Research Foundation, Turkey

Underwater Soundscape along West Coast of Taiwan

Chen Chifang

Department of Engineering Science and Ocean Engineering, Ocean Technology Research Center, College of Engineering, National Taiwan University

Spatial and temporal variations of biological sound in a shallow marine environment

Tzu-hao Lin

Institute of Ecology and Evolutionary Biology, National Taiwan University, Taipei Republic of China (Taiwan)

Acoustic species identification and monitoring to assess the effect of marine development on marine mammals

Saho Kameyama

Kyoto University, Japan

Passive acoustic monitoring of an isolated finless porpoises population in Ise- and Mikawa-Bay, Japan

Satoko S. Kimura

Kyoto University, Japan

MAPPING AND MODELING

Chairs

Christine Erbe

Centre for Marine Science & Technology, Curtin University, Perth, Western Australia

Thomas Folegot

Quiet-Oceans, France

Fine-scale mapping of pile driving noise in the Cromarty Firth

Nathan Merchant

Centre for Environment, Fisheries and Aquaculture Science (Cefas), UK

The PSSEL model for rapidly mapping the probability of shipping sound exposure level from traffic density

Florian Aulanier

Fisheries & Oceans Canada, Canada

SONIC: model generated sound maps and footprints of ships- Bruce Martin, JASCO Applied Sciences, Canada, Comparison of measured and modeled air-gun array in Baffin Bay, West Greenland

Bas Binnerts

TNO, The Netherlands

Mapping risk and opportunity areas for the management of ship noise in the habitats of 10 marine mammal species off western Canada

Christine Erbe

Centre for Marine Science & Technology, Curtin University, Perth, Western Australia

Mapping anthropogenic noise in European waters: examples from the AQUO and BIAS European projects

Thomas Folegot

Quiet-Oceans, France

Variation in ambient noise levels and acoustic propagation across a tidal flow

Denise Risch

Scottish Association for Marine Science (SAMS-UHI), UK

Sound Source Verification & Marine Mammal Mitigation

Guillermo Jiménez

Seiche Measurements Ltd, UK

From laboratory to novative in-situ calibration practices and systems for hydrophone loggers and digitization systems with focus on propagation in-situ measurement

Luc Simon

RTSYS, France

REGULATION

Chairs

René Dekeling

Ministry of Infrastructure and the Environment, The Netherlands

Leila Hatch

NOAA, USA

Managing terrestrial soundscapes and lessons for sensitive or protected marine places

Karen Trevino

US National Park Service, USA

Application of the Interim PCoD model in a Dutch assessment of the cumulative impact of pile driving sound associated with North Sea wind farm development

Christ de Jong

TNO, Sonar and acoustics, The Netherlands

International harmonization of approaches to define underwater noise exposure criteria

Aylin Erkman

Rijkswaterstaat, The Netherlands

The contribution of the UK Navy to the monitoring process needed for the EU Marine Strategy Framework Directive

Yvonne Mather

Underwater Group, dstl Naval Systems, UK

Considerations for Future Ocean Noise Management

John V. Young

CSA Ocean Science, USA

The NOAA Ocean Noise Strategy

Leila Hatch

Stellwagen Bank National Marine Sanctuary, NOS-NOAA, US

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KEYNOTE PRESENTATION:**REGULATION****Mark Tasker**

Joint Nature Conservation Committee, UK

MITIGATION

Chairs

John Young

CSA Ocean Sciences Inc., USA

Jukka Pajala

Finnish Environment Institute, Finland

Noise Mitigation in Pile driving operations

Michael Bellman

ITAP, Germany

Underwater Noise Mitigation Using Customizable Arrays of Acoustic Resonators

Mark Wochner

AdBm Technologies, Australia

Propeller cavitation reduction studies with CFD

Tuomas Sipilä

Technical Research Center of Finland

Using opportunistic data to refine underwater noise output standards for commercial ships

Michael Jasny

Natural Resources Defense Council, USA

Localization of cetaceans and anthropogenic sources: a didactic pattern recognition framework using neural networks

Ludwig Houégnyan

Technical University of Catalonia, Spain

The Marine Vibrator Joint Industry Project: An Update

Jean-Marc Mougnot

TOTAL, France

Analysis of the effectiveness of ramp-up design in mitigation measure

Doug Cato

Defence Science and Technology Organisation & University of Sydney, Australia

Alternative Seismic Source

David Hedgeland

BP, UK

Utilizing Non-Technical Risk Assessments and Mitigation Strategies to identify, assess and mitigate against risks associated with marine sound

Jack Belcher

HBW Resources Inc.

The same problem - different approach

Maja Nimak-Wood

Gardline.Environmental Ltd., UK

ABSTRACTS

AMBIENT NOISE

AMBIENT NOISE IN THE PERTH CANYON: 2008-2014

Verma, A.; McCauley, R.; Gavrilov, A.; Parnum, I.

Christine Erbe
c.erbe@curtin.edu.au

Centre for Marine Science & Technology, Curtin University
GPO Box U1987, Perth, WA 6845, Australia

Australia's Integrated Marine Observing System (IMOS, <http://www.imos.org.au>) consists of a network of oceanographic and remote sensors, including passive acoustic listening stations around Australia, which are managed by the Centre for Marine Science & Technology at Curtin University, Perth. One such station is in the Perth Canyon at 500 m depth. All of the acoustic recordings are available online for free at <https://acoustic.aodn.org.au/acoustic/>. Over the last six years, ambient noise has been recorded and correlated with wind, rain, shipping density and biological productivity. Strong seasonality but no trends over the years were observed. Passive acoustic data can be used as a proxy for ocean weather, in particular in remote locations without nearby terrestrial stations, and of course to monitor the presence of vocal animals and anthropogenic influences.

SEASONALITY IN SOUND MEASUREMENTS FROM THE JAPANESE EAST COAST

Mike van der Schaar¹, Ryoichi Iwase², Tomonori Akamatsu³, Ichiro Takahashi⁴,
Ludwig Houégnyan¹, Antonio M. Sánchez¹, Michel André¹

Mike van der Schaar
mike.vanderschaar@upc.edu

¹Laboratory of Applied Bioacoustics, Technical University of Catalonia (UPC), Spain

²Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Japan

³National Research Institute of Fisheries Engineering, Japan

⁴Marine Works Japan, Ltd., Japan

Jamstec has deployed various deep-sea sensor platforms around the Japanese coast. Acoustic recordings from the Kushiro-Tokachi and Hatsushima stations were analysed for a time period of three years under the LIDO framework (the analysis is ongoing). Since the sampling rate was too low to analyse the sound in MSFD third octave bands, it was analysed in a frequency band between 15 and 25 Hz. This band was selected as it is an important frequency band for fin whales, which are regularly detected on the sites. An overview will be provided of the received sound levels, comparing them to other deep water recordings.

ASSIMILATION OF REAL-TIME MEASUREMENT FOR AMBIENT NOISE PREDICTION

Thomas Folegot, Mike van der Schaar, Dominique Clorennec, Pierrick Brunet, Lancelot Six, Robert Chavanne, and Michel André

Thomas Folegot
thomas.folegot@quiet-oceans.com

Quiet-Oceans
65 place Nicolas Copernic, 29280 Plouzane, France

“The European AQUO project started in October 2012, in the scope of the FP7 European Research Framework, for three years duration. The final goal is to provide policy makers with practical guidelines and solutions, in order to mitigate underwater noise footprint due to noise radiation from ships.

In the framework of the AQUO project, real-time monitoring of shipping noise has been implemented in three areas across European waters. The monitoring system is composed of (a) acoustic observatories, deployed permanently, which continuously measure the ambient noise, (b) real-time acoustic embedded processing which continuously estimate noise in third octave bands, (c) real-time modeling which predict three dimensional noise field at large scale, (d) real-time acoustic data assimilation processing which calibrate the modeling output to provide noise map, (e) statistical processing which provide monthly and annual averages in order to evaluate trends of the ambient noise at the scale of a basin.

The quality of the ambient noise assimilation process has been evaluated for more than six months and has demonstrated that global and continuous long term noise prediction can be achieved with less than 4dB accuracy.”

“MARINE SOUNDSCAPE ECOLOGY”: THE APPLICATION OF ACOUSTIC DIVERSITY INDICES

Harris, S.

Craig Radford
c.radford@auckland.ac.nz

Leigh Marine Laboratory, University of Auckland
“PO Box 349, Warkworth, 0941 New Zealand”

In the face of accelerated climate change, monitoring biodiversity has become a critical task for ecologists. Habitat loss is occurring at an alarming rate both in terrestrial and marine ecosystems, resulting in endangerment and extinction of species up to 1,000 times faster than natural rates. However, traditional biodiversity measurements are logistically and financially difficult, making biodiversity monitoring a challenging obstacle to conservation efforts. In terrestrial environments, “soundscape ecology” has recently emerged as a potential solution to these problems, providing a mechanism for measuring biodiversity at various temporal and spatial scales using acoustic signatures. Several acoustic diversity indices have proven to be useful indicators of biodiversity in a variety of landscapes. Thus far, this technique has had limited application in the marine environments. The aim of this research was to investigate the potential to use acoustics as a monitoring tool for marine biodiversity in temperate coastal reef habitats. In order to determine the optimal method for acoustic biodiversity monitoring, a set of criteria was created to define successful acoustic diversity indices: 1 - Be positively correlated with biodiversity in both the broadband and low frequency ranges; 2 - Behave consistently over all times of the day and over the entire recording period; 3 - Behave consistently over multiple seasons; and 4 – robustness to anthropogenic noise. Out of the three acoustic diversity indices tested (acoustic entropy (H); acoustic richness (AR); and acoustic complexity index (ACI)), only the ACI met all four of the criteria for successful acoustic diversity indices, with strong positive correlations to traditional diversity measurements (e.g. Pielou’s Evenness (J’)). The index was consistent in the broadband as well as the low frequency ranges, over each time of day as well as each recording period and removing windy hours and anthropogenic noises did not alter the results. Therefore, it is suggested that the ACI can be used as a quick and effective measure of diversity in temperate marine environments.

NOISE LEVELS IN SHALLOW WATERS NEAR THE HUDSON RIVER'S TAPPAN ZEE BRIDGE

Martin, B; Racca, R., MacDonnell, J.

Arthur N. Popper
apopper@umd.edu

University of Maryland

"Department of Biology, Univ. of Maryland, College Park, Maryland USA"

"Most studies of underwater ambient noise have been done in the sea where the water depth is generally over several hundred meters. There have been few studies in shallow oceanic water environments and fewer still in river systems. In both cases sound propagation is quite different than in open waters. This study describes the short and long-term acoustic environment of the Hudson River, near the Tappan Zee Bridge (TZB), located about 40 km north of New York City (USA). The study documented the baseline soundscape before construction and operation of the new bridge. At the location of the TZB the Hudson is about 4900 m wide; bottom ranges from 2 to 15 m deep and is primarily sand and mud. The TZB carries over 125,000 vehicles per day. Continuous digital sound recordings were made at 11 sites north and sound of the TZB for several days during August 2010 (STANM). Additional recordings were made for up to three months at four of these locations (LTANM). Since recordings were continuous, it was possible to determine the contributions to the acoustic soundscape of cars on the TZB, a nearby train line, and boats and aircraft in the vicinity of the bridge. In addition, sounds levels were correlated with wind speed, tides, and other environmental factors. The recorders were placed on the bottom of the Hudson, with the hydrophones 0.25 m above the bottom. Analysis of the recordings were done by trained listeners in order to identify noise sources and determine characteristics of individual events, as well as with automated methods to characterize the overall soundscape and the long-term contribution of identifiable anthropogenic sources. During the STANM the median 1-min rms SPLs at the 12 sites was 97 dB re μ Pa (range 95.6-120.7). Sites near the TZB had median 1-min rms SPLs above 118 dB re μ Pa due to continuous noise from bridge traffic. The median inter-quartile range was 4.7 dB (range 3.0 – 11.9) for the STANM phase, showing that the sound levels do not vary significantly over time. During the LTANM three sites had median 1-min rms SPLs in the range of 97-100 dB re μ Pa, and the level adjacent to the TZB was 120 dB re μ Pa. Inter-quartile ranges were 3-7 dB. All sites except one had high levels of transient anthropogenic noise from pleasure craft, shipping vessels, and aircraft. Intense low frequency (1–10 Hz) events were detected in recordings on the east side of the river and these were likely due to train traffic on the riverbank. All stations had significant levels of biologic activity, especially honk-like sounds in the 500–1000 Hz region. Sounds from cusk eels in the 1,000–2,000 Hz band was also detected at several locations. Overall, results show that the sound level is relatively low compared to other environments, and that there was not substantial input into ambient levels attributable to environmental factors. It is clear that traffic over the bridge and trains running nearby can have an impact on ambient levels."

UNDERWATER AMBIENT NOISE IN THE ENGLISH CHANNEL FROM 1989-2009 AND ITS SPATIAL AND TEMPORAL VARIABILITY

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The English Channel, connecting the North and Baltic Seas to the North-West Atlantic, is one of busiest shipping routes in the world. It is estimated that the Channel is regularly used by over 500 commercial vessels every day. This study aims to investigate the changes in underwater ambient noise in the English Channel over a 20-year period and with respect to distance to main shipping routes in the channel. A total of 396 underwater ambient noise measurements recorded between 1989 and 2009 at frequencies of 55, 305, 850, and 1150 Hz by United Kingdom Ministry of Defense are used. The weighted mean and standard deviation of the noise levels will be presented, as well as the variation between years and seasons. A large proportion of the shipping in the English Channel follows certain: the main shipping route which runs through the Channel, ferry routes which cross the Channel between ferry ports such as Portsmouth, Poole, Cherbourg, and Plymouth, and the 'inshore route' running along the South coast of the England. The relationship between the distance from these shipping routes and ambient noise levels will also be investigated. Preliminary results show that on average ambient noise levels at 305, 850, and 1150 Hz decreased between 1989 and 2009, while noise at 55 Hz remained relatively stable over 20 years.

RECENT RESULTS FROM LARGE SCALE MONITORING OF THE AMBIENT NOISE IN THE BALTIC SEA

Pajala, J; Sairanen, E; Andersson, M; and the BIAS team

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In the BIAS project one year of continuous measurements were performed at 40 locations covering the whole Baltic Sea. The objective measurements were to characterize the ambient sound in accordance with the Marine Strategy Framework Directive (MSFD). The focus of this talk will thus be on the 1/3-octave bands 63 and 125 Hz. The monthly averages of acoustic noise will be presented for a full year for several locations. The results will be discussed with focus on the differences such as ship traffic, and acoustic properties such as seasonal variations of the thermocline. The preliminary analysis shows that soundscape recorded near to a shipping lane can be separated into natural ambient noise and ambient noise including ship-induced sound by using adequate filtering technique. Moreover, the range where the distant shipping assumption is valid was established by combining AIS data and recorded sound levels. The results indicate that the sound pressure levels are independent to singular ships when the distance to the closest ship is longer than 3 to 10 km, which has implication on how to choose position to measure sound in accordance with the MSFD. Finally, there is an indication that the wind direction plays an important role in the generation of natural ambient noise. This phenomenon will be discussed in terms of bubble generation and other potential sources.

THE IMPORTANCE OF NATURAL SOURCES FOR SOUND MAPS OF THE DUTCH NORTH SEA: A COMPARISON BETWEEN WIND, RAIN AND SHIPS AS SOURCES OF SOUND.

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Sound mapping tools can be used to gain insight into the contribution of both natural and anthropogenic sources to the underwater soundscape. Sound distribution maps can be generated when sufficient information is known on the source level, the spatial and temporal distribution of the sources of interest. For instance for shipping, an average representative source level is available. The spatial and temporal distribution of the ships can be obtained from AIS data. The contribution of wind and rain as natural sources of sound can be computed as a function of the local wind speed and rain rate (or precipitation), which can be obtained from meteorological databases. In this work, the relative importance of wind and rain generated sound is illustrated through a variety of sound maps of the exclusive economic zone (EEZ) of the Netherlands. It is compared with predictions of the contribution of shipping to the soundscape in the area. Such sound mapping can be of importance for environmental impact assessment (EIA) studies, to illustrate to which degree shipping is expected to significantly increase underwater sound levels.

HARBOUR SEAL VOCALISATION OFF SEASON

Andersson, MH; Holmberg, A; Lennartsson, M

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“Seals are known to vocalize and numerous publications describe a great variety in underwater calls. Especially harbor seals (*Phoca vitulina*) have been shown to vocalize during breeding and can make several kinds of calls. One kind is called roar, and is suggested to function as a communication signal during the mating season to advertise the presence of males in breeding condition as well as to attract females and/or to be used in male-male competition of territory. These roars are described to occur only during breeding in several areas, both in Europe and North America, commonly during the summer. However, this study found typical harbour seal roars in data acquired in three separate acoustic monitoring expeditions at the Swedish west coast which occurred during August-September 2013, May 2014 and October 2014, respectively. The roars occurred mainly during the night but were noticed a few times during the daytime. They consist of broadband, non-harmonic signals, with a frequency range between 10-2000 Hz with a more low frequent start building up to a more broadband end. The roar was relatively regular during long periods during the night, each roar lasting 5-15 seconds, often with an only an intermediate pause of a few seconds. More than one individual vocalizing was also noticed several times. Although no visual identification of seals was collected simultaneously as the recordings, a directivity analysis of the sounds from the recording sites show that the roars came from an area known to be utilized by harbor seals. An analysis of number roars showed that the seals vocalized up to 23 times per 10 minutes period where the highest intensities were observed during early morning hours when it still was dark. So why do the harbor seal vocalize during outside the breeding season and why do they do so often and why most during the night? There is no clear answer to these questions yet. In general nobody has been listening to harbour seals outside breeding season and thus not linked this behavior to their purpose.“

SHIPPING

AN OVERVIEW OF THE BUREAU VERITAS RULE NOTE NR614 “UNDERWATER RADIATED NOISE“.

LAMAISON, V; SALINAS MULLOR, R; MORENO RODRIGUEZ, A.

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Recently published, the BV additional class notation “URN” aims at proposing a comprehensive on-site measurements procedure focusing on the uncertainties, and a set of limits. Initially based on the work carried out along SILENV project, the final version proposed at this date has been significantly enriched by the expertise gained within AQUO project and throughout the efforts shared with the experts from 13 companies and especially thanks to the collaboration signed with TSI, S.L.

MEASUREMENTS OF RADIATED UNDERWATER NOISE FROM MODERN MERCHANT SHIPS RELEVANT TO NOISE IMPACTS ON MARINE MAMMALSJohn A Hildebrand¹, Megan M McKenna², Sean M Wiggins²Megan M McKenna
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There is mounting concern over the effects of ship noise on marine mammals; however, limited empirical data quantifying this noise impedes our ability to evaluate impacts. An opportunistic approach for measuring radiated ship noise (20-1,000 Hz) was used in this study. Calibrated acoustic data were combined with archived information on modern merchant ships transiting the coast of southern California. Three metrics describing radiated ship noise were applied: received sound levels during one hour passages (RLs), estimated source levels (SLs), and sound exposure levels (SELs). One hour passages provided an estimate of the spatial extent of ship noise. At 40 Hz, container ships elevated noise above background up to 7 km forward of the ship and 19 km aft; bulk carriers elevated noise above background up to 5 km at the bow and stern aspects. These ship-types had similar broad band estimated SL, 186 dB re 1 μ Pa at 1m. The cumulative exposure to ship noise varied by ship type and we present equations for estimating SELs for specific ship types. Statistical models predicting container ship noise were built to understand how design characteristics, operational conditions, and oceanographic setting influenced the estimated source levels. Models with highest predictive power, in order of selection, included ship speed, size, and time of year. Uncertainty in source depth and propagation affected model fit. These results provide insight on the conditions that produce higher levels of underwater noise from container ships. Lastly, we modeled the cumulative levels of ship noise in the region using known patterns of ship traffic and composition, and performed a validation analysis using empirical measurements. In concert, these metrics and models of ship noise provide tools for quantifying ship noise within coastal marine environments, and can be used to assess the impact of ship noise on marine mammals.

EXPERIENCE WITH SHIP NOISE MEASUREMENTS (STANDARDS AND UNCERTAINTY)Cédric Gervaise
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AN ASSESSMENT OF THE VARIABILITY ASSOCIATED WITH THE MEASUREMENT OF RADIATED NOISE FROM VESSELS

Humphrey, VF

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Sound mapping tools can be used to gain insight into the contribution of both natural and anthropogenic sources to the underwater soundscape. Sound distribution maps can be generated when sufficient information is known on the source level, the spatial and temporal distribution of the sources of interest. For instance for shipping, an average representative source level is available. The spatial and temporal distribution of the ships can be obtained from AIS data. The contribution of wind and rain as natural sources of sound can be computed as a function of the local wind speed and rain rate (or precipitation), which can be obtained from meteorological databases. In this work, the relative importance of wind and rain generated sound is illustrated through a variety of sound maps of the exclusive economic zone (EEZ) of the Netherlands. It is compared with predictions of the contribution of shipping to the soundscape in the area. Such sound mapping can be of importance for environmental impact assessment (EIA) studies, to illustrate to which degree shipping is expected to significantly increase underwater sound levels.

CORRELATION BETWEEN VESSEL FULL-SCALE MEASUREMENTS AND URN NUMERICAL PREDICTION IN THE FRAMEWORK OF THE AQUO EU PROJECT.

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"Due to its impact on marine life, the abatement of the Underwater Radiated Noise by ships has become the most outstanding novelty and difficult challenge that the Shipbuilding industry has ever faced. Therefore, the industry is trying to provide new solutions in order to comply with the new directives and requirements having been recently developed and promoted by the EU, Marine Institutions and the scientific community.

The underwater numerical prediction of the noise generated by vessels, using FEM, BEM and SEA techniques, still requires some improvements and research to offer optimum design tools to attend this specific market.

In the framework of AQUO, one of the two latest research project funded by the European Commission in underwater acoustics, some specific full scale measurements have been carried out to quantify the different effects present at sea in real scenarios. The conclusions and lessons learnt can reveal, thanks to these full scale measurements on a research vessel and its correlation with the numerical model, the current status in the underwater noise prediction field as well as to suggest the following required steps to optimize the tools. Finally, this paper deals with how these prediction tools can be used inside a comprehensive noise management methodology to get a pragmatic and more efficient approach to built quiet vessels. "

PARAMETRIC MODELS OF SHIP SOURCE LEVEL FOR USE IN AN UNDERWATER NOISE FOOTPRINT ASSESSMENT TOOL

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“Recent researches outline the need to mitigate underwater noise footprint due to shipping, in order to prevent negative impact on marine life. Within this context, the final goal of the European AQUO project (www.aquo.eu), which started in October 2012 for 3 years, is to provide to policy makers practical guidelines, in order to mitigate underwater noise impacts of shipping noise on marine life. Those guidelines will be based on solutions regarding ship design, including propeller and cavitation noise as well as solutions related to shipping control and regulation. This paper focuses on the introduction of the ship as a noise source in a noise map prediction model.

First, a review of existing models show that they are not adapted to the needs of AQUO project, which requires the representation of the source level of different categories of ships in a parametric form along frequency, speed and ship size. As a consequence, a new approach is introduced here, based on the decomposition of total ship radiated noise into three components (machinery noise, propeller noise, and cavitation noise). Each component is defined by a specific “pattern” accounting for the variation of noise with frequency and ship speed. For a particular vessel, the unknown coefficients introduced in the patterns are determined by a “best fit” procedure with respects to experimental data. Note that the method requires the availability of experimental ship radiated noise at different speeds. In a second step, if a sufficient number of data is available for a category of ship, it is possible to build a model for a ship category by introducing a dependency with ship size.

The method has been applied successfully using data available and the new models have been introduced in the noise footprint assessment model used in AQUO Project. In this paper, some results are given on particular vessels and a category of ships. However, the lack of a sufficient amount of relevant experimental data and the variability of radiated noise within a given ship category due to various ship designs would need further studies.”

AN ACOUSTIC SOURCE MODEL FOR SHIPS

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"The source level of ships is a necessary input for modelling the underwater noise distribution. Source levels are commonly taken from statistics derived from measurements at sea from passing ship. A connection to naval architectural features is not made are only in a rough way (like length of the ship). Moreover, field measurements are converted to source level by assuming spherical spreading. However, for an input to a propagation calculation the monopole level is needed.

The model presented here is based on typical features of the ship like displacement and block coefficient and acoustic quality represented by the cavitation inception speed, and particularly the actual speed which is most important nowadays when average ship speed drops in slow steaming.

AIS is commonly used as input for determining the acoustic contribution of ship which is not a straight forward procedure as the AIS protocol does not indicate information directly connected to noise output. However, the most important parameter can be inferred from the protocol with sufficient accuracy using typically features of ships related to type.

Another feature is the directivity of ship noise which reflects the fact that in higher frequencies noise radiated in forward and aft direction is substantial less than in beam direction.

Combining this information in one source model allows to improve interpretation of measurements and yields better quality of noise maps."

MODELLING SHIPPING NOISE EXPOSURES USING VESSEL TRACKING DATA

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Shipping noise is a potential stressor for marine life in many parts of the ocean, but anthropogenic noise exposures of animal populations are often poorly understood. Archival ship-tracking data, now widely available from online sources via the Automated Identification System (AIS), can be used with acoustic propagation models to produce time-based estimates of shipping noise over large spatial and temporal scales. Such models can be combined with agent-based (i.e., animat) simulations to generate noise exposure histories for ensembles of simulated animals. We have developed a computationally efficient model to simulate the time-dependent noise field originating from many ships over a wide geographic area. Acoustic source levels are assigned to vessels based on ship-class information embedded in the AIS records. Frequency-dependent propagation loss functions are pre-computed using an incoherent normal mode sum for discrete zones within the model region. Propagation zones are based on local bathymetry, geoacoustic, and water column properties. The contribution of wind-driven ambient noise may also be included in the model. Results from two case-studies are presented: one offshore Queensland, Australia, and another offshore British Columbia, Canada. Practical limitations and uncertainties in the ship noise model are discussed, particularly with regards to AIS coverage and vessel source level data gaps.

MEASUREMENTS OF THE SHIPPING LEVELS IN THE GENOA CANYON SYSTEM TO ADDRESS THE IMPACT ON AN ACOUSTICALLY SENSITIVE CETACEAN SPECIES ZIPHIUS CAVIROSTRIS.

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“Beaked whales are acoustically sensitive cetacean species whose diving and foraging behaviour has been shown to be altered by exposure to vessel noise. One beaked whale species *Ziphius cavirostris* has an endemic genetically distinct sub-population in the Mediterranean Sea. A species which under the ACCOBAMS resolution 2.16 requires the assessment and impact assessment of man-made noise especially in or nearby areas believed to contain habitat of *Z. Cavirostris*. The Genoa Canyon system, located within the Pelagos Sanctuary is a ‘hot spot’ for this species and is also an area of intense vessel traffic from the port of Genoa. This work aims to inform ACCOBAMS and PELAGOS Sanctuary stakeholders on the level of shipping in an area known to contain *Z. Cavirostris* habitat in order to assess the impact on this species. An AIS terrestrial receiver located at 44.30°N and 8.45°E has been in operation since the beginning of May 2013. Dynamic data recorded until the end of October 2014 has been used to map the distribution of vessel traffic at various temporal and spatial resolutions. During the receiver’s activity, data from a total of 5,821 unique vessels were recorded; the majority of which were cargo (37.7%) and pleasure craft (34.7%). A total of 4,381,609kms of vessel transits was calculated within the extent of the Pelagos Sanctuary with passenger vessels having the highest kilometres of vessel traffic by type (1,902,073kms) followed closely by cargo (1,582,472kms). However, the utilization of each vessel type in this area is significantly spatially distinct. Given the reported range of terrestrial AIS receivers detailed temporal and vessel context analysis was conducted at a reduced extent restricted to 54km from the receiver. In this extent, there appeared to be possible monthly, seasonal and inter-annual trends in the total commercial (passenger, tanker and cargo) shipping, with higher levels in summer compared to winter. Diurnal hourly analysis of the number of transiting vessel displayed a distinct pattern with significantly more vessels at 6 – 8am (utc+2) and less at 9 – 11am (utc+2) compared to the rest of the daylight hours. Vessel context was also different between the diurnal – nocturnal hours with distinct vessels and vessel types behaving differently during daylight and night time hours. The analysis into the levels of shipping has given an indication into the total level of shipping in the Pelagos Sanctuary marine protected area as well as a detailed look at transiting vessels context. Overlapping these results with the species distribution, recorded during the same time period, can clearly identify how the species may be impacted in its preferred habitat. Presently the shipping data act as a proxy for underwater acoustic pollution but the next step in this project will be to model and map the vessel generated underwater noise. However, as it is the data can be used as a guide for best practice for ACCOBAMS and PELAGOS parties.”

SEISMIC SURVEYS

SEISMIC METHODS AND THE USE OF SOUND

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All seismic surveys generate sound waves directed to the earth in order to provide a high resolution image of the subsurface. There are however a wide variety of seismic methods that are tailor-made to achieve specific imaging objectives. This presentation will discuss two-dimensional (2D), three-dimensional (3D), four-dimensional (4D) surveys and various acoustic source and vessel arrangements such as Wide Azimuth (WAZ) surveys.

GEO TECHNICAL & SITE SURVEY METHODS

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Following a licence award, oil and gas operating companies conduct geophysical seismic surveys. Seismic surveys use sound to create maps of the sub seabed geology. These maps help to identify formations under the seabed, which may contain oil or gas. If results indicate that there are structures associated with potential hydrocarbon reservoirs, an operator may then proceed with a site survey. As well as aiming to gain more detailed geophysical information, site surveys are performed to identify the risk of harm to personnel, equipment and the natural environment. The objective of any site survey is to identify all possible constraints and hazards from man-made, natural and geological features, which may affect the operational or environmental integrity of a proposed drilling operation, and to allow appropriate operational practices to be put in place to mitigate any risks identified. Key elements involved in a site survey are: Positioning, Bathymetry, Side scan sonar, Sub-bottom profilers, Magnetometers and Gradiometers, 2D multi-channel high resolution seismic, Seabed samples and Seabed photographs. The majority of the components of a site survey use equipment that use active acoustics to collect data. Surface positioning of the survey vessel is the basis for ensuring all survey activities are conducted in the correct position.

Bathymetry is acquired to measure accurate water depths across the site survey area for use in seabed characterization. Bathymetry data is obtained using hull mounted, high frequency, narrow, single or multi-beam hydrographic echo sounders operating at frequencies as low as 12kHz and up to 220kHz. Side scan sonars are used to obtain seabed imagery to define man-made and natural seabed features across the area. Such systems operate at frequencies between 100kHz and 500kHz with some newer units up to as high as 1600kHz. A suite of sub-bottom profilers, pingers, sparkers, boomers and/or chirpers are operated to provide images of the shallow geological conditions, penetrating to depths of 100m beneath the seabed. These profilers work at a frequency range of 50Hz up to 40kHz. Magnetometers and gradiometers are used to passively measure magnetic field strengths to investigate ferrous objects lying on or buried immediately below the seabed. Multi-channel 2D High Resolution (HR) digital seismic surveys are conducted over proposed drilling locations to investigate geological conditions across the area. HR surveys make use of a seismic source, usually air guns, and a streamer containing an array of hydrophones. These airguns typically produce a sound at frequencies from 20Hz up to 25kHz.

Seabed samples are acquired using a suite of tools appropriate to the soil conditions, grab, box corer, piston corer, gravity corer, vibro-corer or CPT to ground truth seabed and shallow soil provinces that are defined during the site survey. Where appropriate, seabed photographs and/or video footage using equipment such as drop camera, ROV or AUV mounted, towed sledge or fresh-water lens may aid in ground truthing of acoustic data and allow investigation of discrete areas of concern that are identified during a survey. If the results of such site surveys support the identification of a prospect and a safe and environmentally viable drilling location is identified, the operator may develop the site on through the drilling phase to production.

THE USE OF BETTER QUANTIFICATION TECHNIQUES IN MARINE SURVEY ASSESSMENTS

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This presentation looks at case studies where more sophisticated, but proportionate, techniques have successfully been used to reduce the uncertainty around the environmental assessment of acoustic surveys. This responds to the context of increasing protection of marine species and changing expectations around the treatment of traditional seismic surveys, smaller site surveys and other survey methods such as multi-beam echo sounder and sub-bottom profiler surveys which increasingly require assessment. Operators are exposed to detailed public scrutiny of their plans and the cumulative effects of offshore industries is being examined. This presentation will look at the existing assessment process and will describe improvements relating to source characterisation, directionality, propagation modelling and sound exposure calculations. It will describe this in terms of realistic scenarios and will discuss how the outputs are used to draw conclusions on environmental risk.

SOUND MODEL VALIDATION METHOD

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We propose to derive sound levels generated in a seismic survey from direct measurements from the streamer hydrophones. A methodology was established to consider all system gains and scaling factors to transform the results on tape to more conventional units for comparison purposes and for avoidance of ambiguity. Sound pressure levels (SPL) were compared to a very simple theoretical model. This methodology could be routinely used in every marine crew at testing time and during production to show real time estimations of sound at selected traces or to compare with modelled acoustic data. The method has the advantage of not requiring additional equipment deployed in-sea covering a full range of offsets.

THE MARINE VIBRATOR JIP: TECHNICAL AND OPERATIONAL SPECIFICATIONS FOR THE MARINE VIBRATOR

Mike Jenkerson¹, Jean-Marc Mougenot², Brian Schostak³

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“Three major oil and gas producers are working together to develop a commercially and technically viable marine vibrator as an alternative sound source for seismic surveys. ExxonMobil, Shell, and Total are sponsoring a joint industry project managed by Texas A&M University’s Global Petroleum Research Institute (GPRI) to design, and construct marine vibrator prototypes suitable for use in offshore seismic data acquisition programs. Three vendors have been contracted to each design, build, and test their prototype(s).

The output specifications and reliability requirements for the marine vibrator are comparable to the kinds of air gun arrays currently used by industry. The motivation for the project is to mitigate some of the environmental objections to seismic surveying in certain parts of the world and to deliver additional geophysical and operational benefits such as shallow water operations, improved bandwidth control and signal encoding capabilities. Many of the techniques currently used to improve operational efficiency for land vibrators could be adapted for marine vibrators. Testing of prototype marine vibrators is currently underway.

This presentation will give an update on the status of the project and highlight next steps towards technical and operational qualification of the systems.”

POPCORN SOURCE SEISMIC ACQUISITION

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Airgun arrays are a standard marine seismic source. An airgun array is composed of a number of individual airguns that are activated simultaneously. This generates a pulse signal, directed downwards that is suitable for seismic imaging. A proposed alternative to this conventional practice uses individual airguns that are activated over a limited time interval, reducing the peak amplitude of the output signal. Seismic airgun arrays are the most common acoustic sources used in marine seismic surveying. These arrays are comprised of 10 to 40 individual airguns used together to create an acoustic pulse. There have been earlier efforts to reduce the peak amplitude of these acoustic pulses by spreading them out over time (Ziolkowski, 1984), but with new developments in the mathematics of sparse inversion and the availability of high performance computers, these techniques have become fast and accurate enough to become practical (Abma and Ross, 2013, Ross and Abma, 2014, Eick et al. 2012). An example of a comparison between a conventional signal and a Popcorn signal is shown in Figure 1. Signal reconstruction One of the requirements of any new source method is that it produces seismic data of a quality that is as good as or better than present technology. While there is some computational cost in reconstructing data derived from a Popcorn signal to that of a conventional signal, this cost is small compared to the cost of the physical acquisition. An example of data reconstruction using Popcorn signals is shown in Figures 2 to 5. Figure 2 shows an example of some seismic data that would have been acquired with a conventional airgun array. Note that the maximum amplitude is about 1500. Since these are synthetic results computed from digital models, the absolute amplitudes are arbitrary, but the relative amplitudes are accurate. Figure 3 shows the seismic data acquired with Popcorn signals. Notice that the maximum amplitudes in Figure 3 are about 150, a factor of 10 lower than those in Figure 2. The Popcorn signals are low amplitude and have a random look to them. Figure 4 shows the Popcorn signals in Figure 3 reconstructed back to impulsive signals. These data match those seen in Figure 2 well. Figure 5 shows the difference between the conventional data in Figure 2 and the reconstructed data in Figure 4. This reconstruction error is essentially zero, about 74 dB lower than the conventional data. This reconstruction accuracy is well within the needs of seismic imaging. Conclusions The Popcorn source method, while it is still in development, offers an opportunity to reduce the peak amplitudes of airgun array signals while maintaining the necessary quality needed in seismic data. The reconstruction involves some computational cost, but the accuracy of the reconstruction is very good.

eSOURCE: THE TUNEABLE IMPULSIVE SEISMIC SOURCE

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5 MINUTE TALKS AND POSTERS

MONDAY 11/05

SIMULATION OF WIND-DRIVEN OCEAN NOISE IN THE WEST COAST OF TAIWAN

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Ocean noise contains various sound sources and wind-driven noise is the one of important sources. The strength and direction of wind change with time. To estimate the source level of wind-driven noise, the wind field data of the Weather Research and Forecasting Model (WRF), provided by the Central Weather Bureau (CWB), is applied as the noise source in the simulation. To calculate transmission loss, Gaussian Beam Method (GBM) is applied with the sound speed profiles produced by POM-based Taiwan Coastal Ocean Nowcast/Forecast System (TCONFS) which is built by the Industrial Technology Research Institute (ITRI). The TCONFS provide long-term and three-dimensional hourly data included temperature and salinity for calculating hourly simulation results. According to the results of simulation, seasonal, monthly and daily differences can be compared to understand the characteristics of wind-driven ocean noise in the west coast of Taiwan.

VARIATION OF BOTTLENOSE DOLPHIN WHISTLES CHARACTERISTICS IN RELATION TO THE LOCAL SEA AMBIENT NOISE IN THE NORTHER ADRIATIC SEA

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“The Cres-Lošinj archipelago (north-eastern Adriatic Sea, Croatia) is an area subjected to strong nautical traffic which is a major source of disturbance for the resident bottlenose dolphin (*Tursiops truncatus*) population that use the area for feeding and nursing. Systematic monthly sampling of the local sea ambient noise was carried out between 2007 and 2009 at ten predefined acoustic stations. Boat presence, type and distance from the monitoring station data was collected along whilst acoustic monitoring was ongoing. Acoustic recordings were analysed in terms of instantaneous sound pressure level (SPL) (LSP, L-weighted, 63 Hz–20 kHz, root mean square fast). SPL was further calculated for each collected sample in terms of the 1/3 octave band frequencies and for the wideband. Samples containing dolphin whistles, with good signal-to-noise ratios, were further analyzed considering whistle duration, maximum and minimum whistle frequencies, delta frequencies, starting and ending frequencies, number of inflection points and the number of harmonics. When possible, data on the behavioural dolphin group state was collected. Whistle characteristics were compared to the local boat presence and the sea ambient noise levels, with special regards to the 63 Hz and 125 Hz 1/3 octave bands. The results indicate that dolphins tend to produce whistles at higher frequencies when ambient noise levels at low frequencies were higher. Such temporary shifts in whistles characteristics may represent adaptation to noisy habitat conditions enabling dolphin communication. In addition, changes in the whistle characteristics, in the presence of recreational boats appear to be related to dolphin behavioural state being most frequent during their foraging and socializing activities.”

UNDERWATER NOISE ASSESSMENT IN THE GULF OF TRIESTE (NORTHERN ADRIATIC SEA, ITALY) USING AN MSFD APPROACH

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“In the marine environment, underwater noise is one of the most widespread input of man-made energy. Recently, the European Commission has stressed the necessity of establishing threshold levels as a target for the descriptor 11.2.1 “Continuous low frequency sounds” in the Marine Strategy Framework Directive. From 2012 to 2014, a systematic underwater noise monitoring program was conducted in the Gulf of Trieste (Northern Adriatic Sea, Italy), an area of approximately 25 x 15 nautical miles located at the northernmost part of the Adriatic Sea. The Gulf is an underwater environment characterized by multiple inputs of continuous anthropogenic noise due to three important fishing and commercial harbours and multiple smaller and mainly recreational harbours. Despite this, the area is characterized by many unique biological and natural features. Background noise sampling was made each month for duration of 15 min at each of 12 acoustic sampling stations monitored along the same day. Acoustic samples (frequency range: 10-20000 Hz) were analysed in terms of instantaneous sound pressure level (SPL) (LSP, L-weighted, 63 Hz–20 kHz, root mean square fast). SPL was further calculated for each collected sample in terms of the 1/3 octave band frequencies and for the wideband.

A significant spatial but not seasonal difference was found between monitoring stations considering the SPL levels of the 63 Hz and 125 Hz bands, that is related to local routes of the cargo traffic and the location of the main harbours. The average SPL levels resulted similar to those previously measured for proximate areas located in Slovenia and Croatia and indicate that northern Adriatic Sea is exposed to high noise conditions in the coastal waters.”

SEALS AND SHIPPING NOISE IN A DYNAMIC SEA: SEASONAL CHANGES IN SHIPPING NOISE EXPOSURE EXPERIENCED BY DIVING SEALS

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“Anthropogenic noise in the sea is now classed as pollution in accordance with the Marine Strategy Framework Directive (MSFD). Shipping noise is a major contributor to low-frequency anthropogenic noise in the sea, yet we know little about how it impacts marine organisms. This study investigates 1) seasonal changes in spatial patterns of shipping noise; 2) potential shipping noise exposure experienced by seals moving in 3D through the sea. This was achieved by overlaying GPS tracks and dive data from grey seals (*Halichoerus grypus*) in the Celtic Sea, over a state-of-art ocean (POLCOMS) and acoustic (HARCAM) propagation model populated with real-time AIS shipping data in various seasons of the year and range-dependent sediment data. The results showed the clear influence of the seasonal thermocline and fronts (April-November) on shipping noise propagation. In summer the areas of high noise exposure were situated below the thermocline when the ship was located on the onshore side of oceanic fronts, and above the thermocline when the ship was on the offshore side of oceanic fronts. The difference of sound level between the top and bottom parts of the water column was shown to be as high as ~20dB. Shipping noise propagated much further (by tens of kilometres) in winter than in summer. Furthermore, this study showed strong step changes of sound perceived by seals during their descent/ascent through water column. Since seals are bottom foragers, the step-change in shipping noise sound exposure may have negative impacts on their foraging behaviour. It is only through a more realistic understanding of exposure of animals to ship noise that we can set appropriate management and mitigation targets. “

IMPROVING KNOWLEDGE AND UNDERSTANDING OF UNDERWATER SOUND FROM E&P ACTIVITIES AND POTENTIAL INTERACTION WITH MARINE LIFE; AN OVERVIEW OF A RESEARCH PROGRAMME

Ian Voparil (Presentation by David Hedgeland)
Shell Exploration and Production Company, USA

The International Oil and Gas Producers E&P Sound & Marine Life Joint Industry Programme (JIP), a partnership of 13 oil and gas producing companies, is the world's largest non-governmental funder of research to increase understanding of the potential effects of E&P sound on marine life. The JIP provides objective, scientific information that:

- Informs and updates policy decision makers and regulatory development processes that affect E&P operations globally
- Determines the basis for mitigation measures that are protective of marine life, cost effective and credible with outside stakeholders
- Feeds into planning for efficient E&P project development that is environmentally protective

Since 2006 it has spent \$25 million on research and in 2013, the program embarked on a new phase with an additional budget of \$18 million. The JIP regularly consults with regulators regarding their needs for data, to enable development of fact-based regulatory decisions. The programme co-funds selected projects with government agencies. Research is conducted by independent scientists who are encouraged to publish their results in peer-reviewed literature. To date, JIP-funded research has been published in 75 peer-reviewed papers and all final project reports publically available. During this talk results of the previous JIP-funded research will be presented. Furthermore, an overview of ongoing and future studies is provided.

AIRGUN PULSES IN SHALLOW WATER

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Airguns used in seismic surveys are among the most powerful anthropogenic noise sources in marine habitats. Besides the low frequency emphasis of airguns, pulses are reported to contain also medium-to-high frequency components. Thus airguns potentially affect small marine mammals, which have their best hearing sensitivity at higher frequencies. In shallow water environments, the impact of airgun noise may be particularly challenging to assess. This is due to a conjunction of complex phenomena, such as multipath propagation, ray bending and the fact that low frequency sounds propagate poorly in shallow water depths, which makes it difficult to obtain good estimations of impact ranges. To alleviate the current lack of characteristics and propagation of airgun pulses in shallow water, we recorded pulses from a single airgun with three operating volumes (10 in³, 25 in³ and 40 in³) at six ranges (6-1300 m) in a uniform shallow habitat to empirically determine signal parameters at the site of reception. We find that airgun pulses propagate with a transmission loss of around 18logr. However a strong high pass filter effect from the shallow water depth affects the spectral composition of the pulse, causing an increasing fraction of energy above 1 kHz relative to total energy with increasing range. Received levels are considerable at all ranges with pulses containing substantial energy up to 10 kHz even at 1300 m. This highlights the importance of assessing the impact of airguns in shallow water environments on a wide range of marine mammals, including medium-to-high frequency species. We stress that good impact assessments require thorough measurements of both spectral and temporal properties of the propagating pulse, and we suggest to quantify pulses as peak-peak, sound exposure level or rms over 125 ms, or to use audiogram-weighting to obtain a good measure of the noise as perceived by an animal.

ON THE CHARACTERIZATION OF SEISMIC AIRGUN DETONATION UNDERWATER SOUNDS.

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Underwater noise in marine ecosystems has become an important problem in the recent years. Many different techniques and systems for detection and characterization of the submarine noise are being investigated. The particularities of these sounds (highly non-stationarity events, similar frequency components to some animal-made sounds,...) alongside with the big-data problem make this topic an interesting field for the application of advanced signal processing algorithms and real time detector systems. An example of these kind of systems is the programmable passive acoustic monitoring system (SAMARUC). SAMARUC has been used in the region of the Balearic Islands to look for the presence of different species and anthropogenic noises. In this work we are going to present the results of the nonlinear algorithm employed to characterize and enhance the detection of Seismic Airgun detonations and the differentiation from cetacean sounds.

INTER-PULSE NOISE FIELD DURING AN ARCTIC SHALLOW-WATER SEISMIC SURVEY

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Marine seismic surveys using airgun arrays generate intense underwater acoustic pulses. Direct exposure to those intense pulses has been shown to cause hearing impairment and behavioral disturbances in marine mammals. However, few studies have investigated the resulting multipath propagation and reverberation from these pulses. This research uses acoustic recordings collected in shallow coastal waters of the U.S. Beaufort Sea during an open-water seismic survey to characterize the noise field between airgun pulses. The disturbances between pulses are collectively referred to as the inter-pulse sound. Two methods were used to quantify the inter-pulse sound: the incremental computation method and the Hilbert transform method. The incremental computation method calculates the root-mean-squared sound pressure level of 100 millisecond intervals in between pulses. The Hilbert transform method computes the sound pressure levels directly from the envelope of instantaneous acoustic amplitudes. Analyses using both methods yield identical results, showing that the inter-pulse sound field can exceed ambient noise levels by as much as 9 dB during relatively quiet conditions. The results also indicate that inter-pulse noise levels are related to the source distance. These two methods can be used to quantify the impact of anthropogenic transient noises (such as pile driving and sonar) on the marine environment and to address acoustic masking in marine mammals.

EFFECTS OF AIRGUN SOUNDS ON BOWHEAD WHALE CALLING RATES: EVIDENCE FOR TWO BEHAVIORAL THRESHOLD

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PILE DRIVING & OTHER IMPULSIVE SOURCES

MEASUREMENTS OF PILE DRIVING NOISE ATTENUATION AND SOUND PROPAGATION IN THE HUDSON RIVER

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During 2012, JASCO measured underwater sound from pile driving in the Hudson River as part of the Tappan Zee Bridge Pile Installation Demonstration Project. One objective of this study was to evaluate the effectiveness of five different noise attenuation systems (NAS): an unconfined single-tier bubble curtain; an unconfined multi-tier bubble curtain; a hard bubble system; an isolation casing; and a two-stage confined bubble curtain. Another objective of the study was to validate model predictions of pile driving noise propagation loss at the test pile site. A real-time recording system was used to measure sound levels at a range of 10 meters from the test piles, and 12 autonomous acoustic recorders were used to collect data at ranges of 300–3000 metres from the piles. At 10 metres, broadband sound levels were reduced by 12.2–17.0 dB (peak), 10.8–16.1 dB (rms), and 9.9–13.7 dB (SEL). Spectrum analysis showed that NAS performance was most effective in the 100-1000 Hz frequency range. NAS attenuation was significantly reduced at long-range, however, indicating that long-range sound transmission was predominantly sediment-borne. Measured propagation loss in water was greatest in the 100-1000 Hz frequency range. This result was consistent with acoustic modelling predictions of a mid-frequency notch, due to absorption by the predominantly silty-clay sediments at the test pile site. It is also speculated that large construction barges surrounding the piles acted as acoustic barriers, which prevented sound from transmitting in the water column. Thus measured propagation loss in the river was higher than anticipated by pre-program model predictions.

NUMERICAL MODELLING OF UNDERWATER SOUND EMISSION FROM MARINE PILE DRIVING OVER ELASTIC SEABEDS

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Pile driving in marine environments results in high intensity impulsive noise being radiated from the pile into the surrounding water column and seabed. A common approach to modelling the sound radiation from marine piling is to approximate the seabed as a fluid medium. This assumption is generally acceptable for weakly cemented seabed materials with relatively small shear wave speeds, such as sand and silt. However, for seabed materials of higher cementation with comparatively large shear speeds, such as calcarenite and sandstone, the effect of shear in the sediment leads to a noticeable decrease of the sound energy emitted into the water column. Generation of interface waves at the seabed surface is another important effect. The significance of the shear effects for different types of sediment is analysed via numerical modelling of sound emission by a driven pile using a finite element method.

SEDIMENT STIFFNESS EFFECTS ON PILING NOISE USING A WAVE-EQUATION ANALYSIS MODEL

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“Percussive piling noise is a potentially significant contributor to anthropogenic noise in the ocean. Piling operations generate high levels of noise that is able to propagate over long distances. As such, it is important that the levels of noise generated are predicted, so that the impact on marine life can be estimated.

This work presents advances made using a technique known as the Wave-Equation Analysis of Piles. This features a finite-difference code that is used to model the travelling stress wave along the pile following impact from the hammer. The technique is particularly useful in its treatment of the plastic pile-sediment interface. Here, the sediment is split into pile-stick and pile-slip regimes with parameters based on physical sediment attributes.

The results show how changes in the sediment affect the nature of the stress wave reflection at the pile toe. The sediment imparts a continual change of impedance on the embedded section of the pile that is more noticeable at greater depths. As a result, for easy driving, a pulse inversion is visible at the reflection; in heavier driving, however, no such inversion is seen. As the principal radiated noise component is due to the travelling pulse, this has observable consequences on the resulting acoustic wave field. “

MITIGATING THE IMPACT OF PILE-DRIVING NOISE ON HARBOR PORPOISE (*PHOCOENA PHOCOENA*) DURING FOUNDATION INSTALLATION AT BORKUM RIFFGRUND 1 OFFSHORE WIND FARM

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Since the implementation of the Marine Strategy Framework Directive (MSFD) at European level, the introduction of energy including underwater noise (Descriptor 11 of the MSFD) needs to be monitored and its impact assessed. Each member state of the European Union has introduced its own guidance to comply with the MSFD; Germany has imposed strict thresholds for underwater noise emissions associated with piling activities that need to be respected during the installation of offshore wind farms. At Borkum Riffgrund 1 Offshore Wind farm, located in German waters approximately 25 km offshore, underwater noise levels were monitored throughout the installation of its 77 monopiles to assess the efficiency of the mitigation strategy implemented. Noise mitigation was carried out using the IHC Noise Mitigation System (NMS), a double walled cylinder designed to hold the pile in place whilst simultaneously reducing the noise transmitted through the water column. The outer wall of this cylinder is attached to the inner wall using rubber blocks and a volume of air is present between the two to minimize the transfer of sound from inner wall to outer wall. The IHC NMS had been used on previous projects but never for monopiles of such diameter (6 metres) and some modifications were made to improve its performance.

Underwater noise measurements were carried out during the installation of the foundations, between January and August 2014, using bottom mounted autonomous recorders. The results showed consistent noise levels being recorded throughout installation and in different directions around each monopile. Reference measurements were carried out with and without the NMS to determine its efficiency, as according to the StUK4 guidance.

The NMS performance was good, after some adaptations in the beginning and in general a noise reduction of 13-15 SEL was reached. The third-octave band analysis highlighted the difference in measured levels at 750m with and without NMS.. The damping was particularly good at higher frequencies where harbour porpoises are most sensitive. The reduction in noise levels in the frequency bands between 250 Hz - 20 kHz was between 18 and 32 dB re 1?Pa2 SEL. At around 10kHz, the measured noise levels with NMS were overlapping with the ambient background noise meaning that the components of piling at those frequencies are no longer significant and fade in the background.

MODELLING OF IMPACT PILE DRIVING NOISE FOR ASSESSING THE IMPACT ON MARINE ANIMALS

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"Impact pile driving for offshore wind farms generates loud impulsive underwater sounds. In the past year, a Dutch expert group, supported by the government, developed an approach for the assessment of the impact of offshore wind farm development in the North Sea on harbour porpoises and seals.

The approach starts with modelling of the underwater sound generated by impact pile driving for offshore wind turbine foundations. While numerical modelling approaches are being developed, initial estimations are given on the basis of available measurement data, extrapolated via acoustic energy flux propagation modelling. Exposure of porpoises and seals to the impulsive sounds from impact pile driving can result in behavioural and physiological effects. Based on the information on dose-response relationships, threshold sound levels are established above which these effects are likely to occur. The size of the area around the pile in which these threshold levels are exceeded combined with an estimation of the animal density in the area provides an estimate of the number of animals that are affected by a single piling event. By combining this number with the duration of the sound exposure an estimate of the total amount of 'animal disturbance days' is obtained, which is the relevant parameter for the further assessment of the effects on the mammal populations. The focus of this presentation will be on the requirements for the acoustic modelling in the context of the combined steps in this approach."

A STANDARD FOR PILING NOISE MEASUREMENT: PROGRESS WITH ISO18406

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This paper describes work to address the need for standardised measurement methodologies and reporting practices for measurement of marine pile driving noise. This need has been recognised within the International Standards Organisation, with work to draft a new standard (ISO18406) undertaken within Working Group 3 of Technical Committee 43, Sub-Committee 3 (ISO TC43 SC3 WG3), the development now having reached Committee Draft stage. Work to develop the standard builds upon the expertise already gained by researchers in a number of countries (for example UK, Netherlands, Germany and USA). A description is given of the methodology currently proposed in ISO CD 18406 to define appropriate measurement procedures and common acoustic metrics for reporting the radiated sound. Also described is the process for engagement with experts within different countries.

ANALYSIS OF SHALLOW WATER EXPLOSIONS AND THE IMPACT ON FISH

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"Underwater explosions are common activity for both naval purposes as well as civil applications during construction and decommission of offshore constructions. Very high levels of sound are generated by the explosions which kill and injure fish at long distances. However, the estimated received sound pressure levels in an archipelago are difficult to estimate due to islands and varying topography. This projects study the effect on sound propagation of the presence and absence of an island, which lies between an underwater explosion of approximately 300 kg and a hydroacoustic receiver. The project used hydrophones at different locations as well as geophones on the island. When the explosion occur, a compressive shock wave is generated, which travels faster than the speed of sound. When the compressive wave is reflected at the water surface, a rarefaction wave is obtained, which partly eliminates the compressive shock wave. The resulting acoustic wave from this shock, picked up by the hydrophones at distances > 1km will therefore, assuming infinite depth, consist of first a compression peak, followed by intermediate silence before the second peak which will be a rarefaction. With a seabed to take into account however, the result can be much more complex, e.g. due to superposition of compression waves. The explosion may also result in seismic waves, which further away may transfer substantial amounts of energy as acoustic waves in the water volume. The seismic wave is especially important behind islands, certainly in cases where the water propagation path is characterized by a large transmission loss.

For the hydrophone data, a sound pressure level is calculated for each feature of the acoustic signal – as the different parts can affect fish to various degrees. Comparing direct water propagation paths with hydrophones behind the island is a mean to answer the question whether or not the fish are injured behind such obstacles. The geophone data is used for estimation of the size of the explosion. The data is also used for calculation of the speed of the pressure wave propagating through the island and as support in the analysis of the hydroacoustic pulses.

In the end, a risk assessment is done for fish with and without a swim bladder and different distance of injury and behavior are calculated based on literature data.

RENEWABLE ENERGY

SIMULTANEOUS PARTICLE MOTION AND SOUND PRESSURE MEASUREMENTS AT TWO TYPES OF OFFSHORE WINDFARMS IN OPERATION

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As water is an excellent medium for sound transmission, underwater sound impacts from Marine Renewable Energy devices (MREDs) have become a particularly important environmental issue. Sound emission are both in form of pressure and particle motion, the latter being of crucial importance for all teleost fish and elasmobranchs, together with cephalopds and other invertebrates. However, the knowledge on particle motion that is generated during operation of MREDs is scarce. Thus, the impacts of MREDs on marine fish and invertebrates are almost impossible to assess to date. Since the start of 2014, in a project for the European Union (EU) Commission, Directorate-General for Research and Innovation, we undertake a study of the environmental impacts of noise, vibrations and electromagnetic emissions from MREDs (Marine Renewables, Vibrations, Electromagnetics and Noise - MaRVEN). Here, we present the results of MaRVEN with regards to simultaneous particle motion and sound pressure measurements taken during different types of OWF in operation. The investigation was undertaken during July 2014 in Belgian North Sea on two types of windfarms in operation (with monopile and jacket foundations). Particle motion measurements were done using custom built particle motion sensor (FOI). Simultaneous particle motion and sound pressure measurements were taken while drifting through the windfarm areas and at the substations between the two windfarms in order to measure ambient noise levels. Results will be presented and will help to close a gap in knowledge that can be used to improve the risk assessment of noise in relation to MREDs.

CHARACTERIZATION OF OPERATIONAL UNDERWATER NOISE GENERATED BY WIND PARK IN BELGIAN WATER OF THE NORTH SEA

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“The first offshore wind turbine was installed in Belgian water of the North Sea in 2008 and today more than 170 units are operational in the zone.

The existing turbines of 5 MW, 3MW and 6,15 MW are installed in a variety of foundations respectively gravity-based foundation, steel monopile of 5 and 5,2 m diameter and jacket foundation incorporating 4 steel pinepiles of 1,8 m diameter.

Measurements characterizing operational underwater noise generated by low wind condition were obtained drifting in the direct vicinity of the turbine and inside the wind park. Additional measurements were made using moored equipment and characterize the emitted underwater noise of steel monopile foundation during higher wind regime.

The main conclusion of this study for the low wind condition is that the operational levels emitted by gravity based foundation are of the same order of magnitude as the local background noise while jacket foundations emits some 6 dB more than the background level and steel monopile are the noisier source with some 15 dB more than background noise characterizing the zone.”

ACOUSTIC CHARACTERIZATION OF SUBMARINE CABLE INSTALLATION IN THE BISCAY MARINE ENERGY PLATFORM (BIMEP).

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“The Biscay Marine Energy Platform (bimep) is an offshore infrastructure for the demonstration and testing of wave energy harnessing devices promoted by the Basque Entity of Energy (Ente Vasco de la Energía - EVE). Bimep is located close to Arminza town (Basque Country, Northern Spain) and it consists on an 5.3 km² sea area between 50 and 90 m depths where four static submarine cables will be placed, operating at 13kV and 5MW.

On the first of June 2009, the General Council on Environmental Quality Assessment of the Ministry of Rural, Marine and Natural Environment of the Spanish Government, on the light of the Environmental Impact Study (EIS) of the bimep project undertaken by AZTI in 2008, decided not to submit the project to the whole Environmental Impact Assessment (EIA) process. Nevertheless, the Environmental Impact Statement (EIS) of the Ministry, taking into account the great uncertainties about some predicted environmental impacts, underlined the need to implement the proposed Environmental Monitoring Program (EMP) of the EIS. Among other environmental factors, an increase in noise from shipping activity would be expected during installation of submarine cables and consequently may affect marine mammal communities.

Hence, on August 29 of 2013, the EVE entrusted to AZTI to carry out the acoustic EMP of the installation of the submarine cables, which consist on an acoustic characterization of: (i) sound background levels; (ii) cable installation operations; and (iii) a propagation of the measured cable installation sound. The results showed a background level of 70-80 dB. The acoustic signal during cable installation is characterized by a 11 kHz frequency and 188,5 dB re 1 μ Pa which is able to affect a 400 km² area. Impacts over marine mammal's communities were not expected due to the temporality, the season and intensity of the installation operations.”

CUMULATIVE OPERATIONAL NOISE OF LARGE SCALE ARRAYS OF OFFSHORE WIND FARMS

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“In recent years the planning and development of large scale offshore renewables programmes in combination with existing offshore activities and operations has led to growing concerns about potential effects of underwater noise on the marine environment. Offshore wind power in UK waters alone forms a major offshore development with ambitious targets over the next decade. These projects are being followed with on-going development for large-scale arrays of many tens of devices for emerging wave and tidal energy conversion technologies. Similar levels of development are underway in other EU nations and wider internationally. A focus in recent years has been on relatively short term, often high noise levels associated with construction phase noise for example marine piling for offshore wind farms. Models have been developed to consider not just single but multiple sequential construction events looking at whole wind farm construction scenarios.

This work was then extended to prediction of longer-term operational noise from very large arrays of devices (many hundreds to thousands of devices) covering large areas of the ocean. Arrays of these scales are within the potential near future planning for UK waters. Results are presented for modelled operational noise fields for very large-scale arrays. Consideration is made of device-to-device spacing and inter-noise dependences and array-to-array inter-noise dependences based on available measured operational noise data. These predicted levels are also analysed in context of a range of ambient noise conditions potentially experienced by marine species within or nearby these arrays. This work is done as part of the EBAO project (Optimising Array Form for Energy Extraction and Environmental Benefit) where multi-physics/ biological modelling approaches were used to model multi dimensional aspects of the potential interaction of large-scale arrays with the marine environment. This included sound field prediction, hydrodynamic wave energy modelling and eco-system modelling of identical theoretical arrays configurations.”

UNDERWATER NOISE FROM A WAVE ENERGY CONVERTER

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"A recent addition to the anthropogenic sources of underwater noise is offshore wave energy converters. Underwater noise was recorded from the Wavestar wave energy converter located at Hastholm, Denmark (57°7.73'N, 8°37.23'E). The Wavestar is a full-scale test and demonstration converter of the absorber type. During recordings the converter was operating close to maximum power output (nominal capacity of 110 kW). During operation the independently operating absorbers float semi-submerged in the water and wave-generated up-and-down motion is converted into hydraulic pressure by means of pistons connected to the arms of the absorbers. The hydraulic pressure then in turn drives the generator. A 57 minute sequence of noise from the converter was recorded by a Loggerhead datalogger deployed in 7 m deep water 25 m from the converter. This sequence contained recordings of ambient noise, the converter in full operation and start and stop of the converter. Median broad band (10 Hz – 20 kHz) sound pressure level (Leq) was 123 dB re. 1 uPa, irrespective of status of the wave energy converter (stopped, running or starting/stopping). The most pronounced peak in the third-octave spectrum was in the 160 Hz band during start and stop of the converter, attributed to the hydraulic pump responsible for lifting and lowering the absorbers. Less pronounced, but still statistically significant differences were seen in the bands 125, 160, 200 and 250 Hz when operation and ambient were compared. No statistically significant noise above ambient could be detected above the 250 Hz band. The absolute increase in noise above ambient was very small. L50 third-octave levels in the four bands with the converter running were thus only 1-2 dB above ambient L50 levels. The noise recorded 25 m from the wave energy converter was barely detectable above ambient noise and only in the range 125-250 Hz. Harbour seals have good low frequency hearing and third-octave levels of the converter noise are well above their hearing threshold. Harbour seals are thus expected to be able to hear the converter noise, although the elevation in noise levels is so low (1-2 dB) that it is likely to be close to inaudible even at the close range where recordings were obtained. In contrast to seals, harbour porpoises have poor low frequency hearing and it seems unlikely that the converter noise would have been audible to porpoises. Wave energy converters come in different designs and work according to different principles. Other types of converters could be expected to be noisier, perhaps also to generate noise at other frequencies than those reported from the Wavestar. Therefore the conclusion that noise levels from the Wavestar are unlikely to affect seals and porpoises cannot be generalised. Nevertheless, the results clearly demonstrate that it is possible to harvest wave energy in a way which does not add substantially to the increasing levels of anthropogenic noise in the ocean."

A FRAMEWORK TO PREDICT, VALIDATE AND REVIEW THE ACOUSTIC FOOTPRINTS OF OPERATING TIDAL TURBINES.

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The rapid growth and diversification of the tidal-stream energy sector has led to many sites and device concepts being considered for imminent development. Though the UK has been the focus for many companies, other countries notably France, Canada, China and the US have begun to scope, lease and develop sites. With tidal-stream energy being renewable, installations are likely to represent long-term changes to what are usually discrete and biologically important habitats. This brings significant environmental responsibility in terms of determining and mitigating short and long-term effects on marine life. A potentially key impact that will feature in most environmental assessments is the acoustic emissions of operating devices. Initial drivers were the determination of whether devices might produce sounds loud enough to produce auditory damage in sensitive species but the potential for barrier effects in narrow channels is another obvious concern. Less obvious but perhaps more important is whether the sounds emitted by turbines will be loud enough to be heard by approaching animals like marine mammals with sufficient distance/time that they can avoid harmful collisions with the moving blades.

Currently the information to make these assessments is lacking. In particular, little is known about turbine sound emissions because of the small number of devices that have been built and recorded and the constantly evolving designs that are being proposed. Likewise, little is known about the levels of ambient noise in the coastal high-flow speed waters where such installations will be sited.

In this presentation we will outline a method that uses a combination of predictive modelling, propagation and empirical at-sea measurement to better inform assessments of the audibility of tidal turbines for marine mammals. For this, precise information on the physical configuration of the turbines, (blades, gearboxes, substructure and so on) are used to determine the characteristics of sound production of the component moving parts and their modes of sound transmission into the surrounding water. Site specific propagation modelling is then used to determine how the sound will emanate into the environment and this is compared with on-site ambient sound measurements taken using drifting recorders at a range of tidal states and water flow speeds. When put together these provide a predictive footprint for single devices or arrays and most importantly (when decision making) for devices of different specifications or design envelopes.

In addition to EIA stage decisions, the proposed methods may also inform other predictive studies of animal behaviour. Particularly those considering what information and options acoustically sensitive animals have when manoeuvring within turbine arrays and therefore collision risk and the need or otherwise for acoustic mitigation.

AMBIENT NOISE IN THE FALMOUTH BAY TEST AREA (FaBTest, UK) – BASELINE MEASUREMENTS OF SHIPPING, ENVIRONMENTAL VARIABILITY AND WAVE-ENERGY CONVERTERS

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Marine renewable energy is a key component of the drive towards sustainable energy and reduction in greenhouse gas emissions. Wave and tidal energy generation on their own can provide 20% of the UK's current electricity demand (DECC, 2013). But the environmental impact of new devices is not always easy to quantify, especially in marine areas already heavily influenced by human activities. This presentation will summarise measurements and analyses of ambient noise in Falmouth Bay (UK) since 2010, next to a test area for wave-energy converters, resulting from on-going collaborations between the University of Exeter, the University of Bath and several industrial partners.

Falmouth Bay is a large and deep natural harbour at the western entrance to the English Channel. It is in a direct line of sight from one of the busiest shipping lanes in the world, with ca. 45,000 ship transits annually. Recreational boating and bunkering of large vessels also occur in the Bay, adding to the overall noise budget. Marine fauna includes bottlenose dolphins, harbour porpoises and fish. The amount and diversity of noise sources, along with their variability, are direct challenges to the assessment of impacts from specific activities, like the installation of marine renewable devices. Baseline measurements from 2010 onwards will be presented along with measurements of the installation and operation of a wave-energy converter, trialled at the Falmouth Bay Test Site (FaBTest) for several years. The broadband measurements (10 Hz – 32/48 kHz) were all acquired with Autonomous Multichannel Acoustic Recorder (AMAR; Jasco Applied Sciences Ltd.), and processed using similar methodology (Merchant et al., 2012), allowing for meaningful comparisons. Sound levels and frequency bands of interest will be analysed in the context of environmental regulations and consenting processes for renewables. They will also provide a backdrop to current efforts in characterising the acoustic emissions from wave-energy converters.

The technical assistance of Dave Parish and David Raymond (U. Exeter) at different stages of these projects is gratefully acknowledged.

USE OF POPULATION VIABILITY ANALYSIS TO ASSESS THE POTENTIAL FOR LONG TERM IMPACTS FROM PILING NOISE ON MARINE MAMMAL POPULATIONS

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The greatest impact on marine mammals from offshore wind developments is widely considered to occur primarily during the construction phase of projects, when turbine foundations are being driven into the seabed. Marine mammals rely heavily on sound to navigate, feed and conduct social interactions and are sensitive to increased underwater noise. Potential effects (of pile driving noise on marine mammals) include lethal effects and physical injury, auditory injury (including Permanent Threshold Shift (PTS) onset) and behavioural displacement. Standard mitigation should be effective in negating or significantly reducing the potential for lethal effects and physical injury but, even with mitigation, PTS onset and behavioural displacement have the potential to occur. Given the number of projects currently being proposed in the UK, and the duration of pile driving activity in specific regions likely to extend over periods of several years, the potential for long term effects on marine mammals may exist. The consideration of long term effects is an important part of UK Environmental Impact Assessment (EIA) and Habitats Regulations Appraisal (HRA). Data from three proposed offshore wind projects off the Scottish east coast were used to investigate the potential for long term effects of cumulative pile driving noise on bottlenose dolphins and harbour seals (which both have local protected sites (Special Areas of Conservation (SACs)) designated under the EC Habitats Directive). Noise impact contours were modelled by Subacoustech Environmental Ltd using their INSPIRE model. The harbour seal density surface was produced by SMRU using their telemetry and haul out count data while the bottlenose dolphin density surface was inferred using the best available information. The numbers of animals predicted to have the potential to be affected by PTS onset and behavioural displacement were then estimated using a dose-response approach. Because the consequences of PTS onset and behavioural displacement were unknown, conservative assumptions were made (about how exposure to pile driving noise might influence demographic parameters) in order to model potential impacts on population dynamics in the Population Viability Analysis (PVA). The mortality risk of PTS onset was assumed to be similar to that of old age and behavioural displacement was assumed to result in breeding failure due to a reduction in condition of breeding females. PVA indicates that the worst case cumulative construction scenario (concurrent pile driving at two locations at each of the three projects) could lead to short term impacts but not to longer term impacts on population viability. Application of PVA to inform EIA and HRA has proved useful.

SOUNDSCAPES

CHARACTERIZING MARINE SOUNDSCAPES USING TEMPORAL PATTERNS.

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“One of the primary goals of soundscape analysis is to identify the contribution of sound sources to the acoustic environment. Sound sources may be biologic, anthropogenic, or geologic, which includes wind, waves, surf, rain etc. In the acoustic recordings of a marine environment individual sound sources can often be identified in the foreground when they are louder than the background sounds. However, diffuse sources such as fish choruses, distant vessel traffic or distant seismic airgun activity are often not individually detectable, but are apparent using tools such as percentile or spectral probability density plots. Many of these sources also have temporal patterns, for example fish choruses occur at dusk and dawn in many environments. Similarly anthropogenic activity may have a daily, weekly and seasonal patterns. Anthropogenic fishing activity can also be correlated with tidal patterns. The noise of small rocks and sediment can also be correlated with tidal current patterns, as can pseudo-noise from tidal currents around a hydrophone. Here we compare and contrast soundscapes from shallow and deep waters as well as tropical reefs, temperate regions and isolated arctic areas to demonstrate how temporal analysis can help identify patterns in the soundscapes. We show how comparing daily, weekly and tidal cycles can reveal new information about the soundscape.”

MODELLING THE SPATIAL DEPENDENCE OF SOUNDSCAPES

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The application of the methodology and terminology of soundscapes to the underwater acoustic environment is new. The importance of Ambient Noise, however, particularly in its relation to the passive sonar problem has been studied via measurements and analysis since World War II. The term soundscapes implies the identification of the varied sources of acoustic energy, their spatial and temporal structure and the impact they could have on the associated ecosystem (and therefore mammals present). In this paper, we present the importance of the spatial structure of the acoustic field and the approaches taken to model the space-time dependence of the field. All animals that use sound, including humans and marine mammals have (at least) binaural hearing. The impact of a sound fields spatial dependence has implications to masking as well as threat identification and response. In this paper, horizontal array measurements of ambient acoustic energy, which includes surface tankers, pleasure craft, wind and rain will be presented. A range-dependent modelling approach to simulated the temporal-spatial extent of the soundscape will be presented.

EXPLORING CHANGES IN SOUNDSCAPE LEVELS TO SOURCES THROUGH FREQUENCY CORRELATION MATRICES

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Interest in underwater soundscapes stems from three overarching applications: 1) those seeking to maximize efforts to detect signals in the marine environment, 2) those attempting to determine how changes in ocean sound may impact marine ecosystems, and 3) those using indices of the soundscape to monitor ecosystem health and recovery. Information contained in soundscapes provide a means for better understanding the influences of environmental parameters on local acoustic processes, for assessing habitat quality and biodiversity, and for better understanding the impacts and risks of human contributions to the soundscape on marine life. Underwater soundscapes are dynamic in that they vary in space and time within and between habitats, and an ongoing challenge in underwater soundscape work has been to determine how best to characterize changes in the soundscape. Tracking soundscape changes through traditional parameters such as sound level or shifting frequency spectra often don't capture the interacting source contributions that combine to create the overall soundscape. Here we present the use of frequency correlation matrices to understand source contributions and changes to the soundscape over time. Changing soundscapes at three locations of the Comprehensive Nuclear Test-Ban Treaty Organization International Monitoring System (CTBTO IMS) illustrate regional shifts in soundscape source drivers.

AMBIENT NOISE MEASUREMENTS AT A SHELTERED COASTAL LOCATION

Spiga. I

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“The sea is a noisy environment and marine habitats often have their own distinctive soundscapes. However, there are still large gaps in our knowledge of marine soundscapes. This paper describes the results of monitoring ambient noise levels at a sheltered inshore location: Lough Hyne, on the south coast of Ireland, over an extended period.

Lough Hyne was designated Europe's first marine reserve and is recognised for its high biodiversity. Geological and environmental conditions within the lough have resulted in diverse marine habitats co-existing within a relatively small area. The connection of the lough to the sea by a narrow, shallow channel affords protection from the effects of wind and waves and minimises marine traffic.

Regular monitoring of noise levels at Lough Hyne, using a variety of hydrophone systems, has shown that great care must also be taken in performing noise measurements. Artefacts from equipment handling frequently occur when recording underwater sounds and it is important to exclude these from any analyses of ambient noise levels.

Ambient noise monitoring was carried out at a number of locations and noise levels and characteristics associated with different benthic habitats were compared. Transient broadband pulses or snaps were recorded at a majority of locations and were attributed to the presence of snapping shrimp (family Alpheidae) at several locations within the lough. Other distinctive sounds of suspected biological origin were also identified. Overall, the presence of the high-energy snaps, dominated soundscapes in most parts of the lough, indicating that location with respect to these dominant biological sources of sound was especially important in determining soundscape characteristics.

The high acoustic connectedness of marine habitats underlines the need for evaluating the impact of anthropogenic activities on soundscapes, particularly for locations with unique biophonies in need of protection. Much remains to be learned about the nature of marine soundscapes: how they are created and how changes to them might affect marine organisms. Noise produced by human activities represents a real threat to those marine organisms that make use of sounds in their everyday lives.”

SOUNDSCAPES OF THE CENTRAL PACIFIC

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Long-term passive acoustics recordings can be used for evaluating changes in soundscape over long time periods. Long term changes in ocean ambient noise have been measured in the North Pacific and North Atlantic, but these long-term trends are poorly described for most of the worlds' oceans. Calibrated passive acoustic recordings were collected from 2006 until 2013 at three locations in the tropical and subtropical Pacific, Palmyra Atoll, off Kona coast in Hawaii and near Saipan. After calculating monthly and hourly mean power spectra up to 1 kHz for the entire duration of the recordings, seasonal and interannual variability in soundscapes at these locations were investigated. Sources of ambient sound included anthropogenic sources, mostly shipping, biological source such as several species of baleen whales, and physical sources like wind and rain. Overall, ambient noise at frequencies < 100 Hz at these sites was 10-20 dB lower than reported recently for most other locations in the North Pacific. Palmyra was the quietest site in this frequency range, although there was interannual variation across the sites. There was seasonal variation in ambient noise at frequencies > 200Hz at all sites with higher levels recorded in the winter than in the summer, corresponding to higher sea states at those times. The Palmyra site showed the least variability in sound levels due to sea state. Baleen whale species that substantially contributed to the soundscapes on a seasonal scale at these sites included humpback (*Megaptera novaeangliae*), blue (*Balaenoptera musculus*), and fin (*B. physalus*) whales. At Palmyra Atoll, both Northeast Pacific blue whale and Antarctic blue whale songs could be discerned, but there was no seasonal overlap between the two song types. Humpback whales dominated the soundscape off Hawaii at frequencies above 100 Hz during the winter and spring. At Saipan, the contributions of baleen whales to soundscape were least prominent.

SOUNDSCAPES ON COAST OF BRITISH COLUMBIA, CANADA: AN OCEAN OF OPPORTUNITY

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The coast of British Columbia, (BC), Canada is the focus of proposals for a number of large industrial development projects largely centred around the energy industry, and which are very likely to increase noise levels in the underwater soundscape. Fortunately, acoustic monitoring has been underway for over 40 years in some areas, and presently there are over 50 hydrophones deployed in various remote locations. The initial focus of these efforts was to acoustically detect killer whales (both fish eating and mammal eating). More recently, the geographical area and the species focus has broadened, and there are initiatives by a number of governmental and non-governmental organizations to collect calibrated acoustic data ranging from the southern Salish Sea to the Alaskan border, on species ranging from harbour porpoise to fin and blue whales. Many of these areas are relatively pristine. The acoustic data they provide can reveal a baseline for characterizing ambient noise levels as well as information on habitat use by cetaceans. The individuals and citizen science groups maintaining a number of these sites have proven track records in year-round monitoring and data collection on relatively low budgets. The amount of data they collect is substantial, and they are seeking academic collaborators to help with data analysis and synthesis. In this presentation we will provide information on the nature of the data being collected, and welcome opportunities to discuss potential future collaborations.

SPATIOTEMPORAL VARIABILITY IN CORAL REEF SOUNDSCAPES, ASSOCIATIONS WITH LOCAL BIOTA, AND PATTERNS OF BOAT NOISE

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Coral reef soundscapes are diverse and include natural biological sounds produced by various fish and invertebrates, as well as noise from nearby boats. These sounds may provide a way to track both natural animal activity, the biodiversity of the reef, and patterns of human behaviors. Such information may be useful for scientists, managers and policy makers as they seek to examine or preserve reef ecosystems under stress, as well as quantify the levels noise-stress that reefs may face. However, there is generally a poor understanding of noise levels on reefs, and the relationship between coral reef soundscape variability and the actual taxa present remains largely unknown. This study presents a comparative evaluation of the soundscape of three reefs in the U.S. Virgin Islands National Park. Using multiple recorders per reef we characterized spatial and temporal variation in biological sound production within and among reefs that varied in their benthic and fish diversity. Further, the diel, weekly and summer trends in boat noise were also quantified. Analyses of sounds recorded over ~4 months indicated diel trends in both fish (100-1000 Hz) and snapping shrimp (2000-20,000 Hz) bands with crepuscular peaks at all reefs. The strength of diel trends in lower fish-frequency bands were correlated with coral cover and fish density, yet no such correlation was found with the shrimp sounds suggesting that low-frequency fish sounds may be of higher relevance to tracking certain coral reef conditions. There were small but statistically significant acoustic differences among recorders on a given reef raising the possibility of potentially localized acoustic habitats. Boats were detected at all three reefs throughout the deployment period indicating few times with effective quiet. The reef of greater fish and coral diversity had greater boat traffic. Boat presence increased during the daylight and crepuscular hours on all reefs. The presence of boats had lower peak frequencies and higher sound pressure values, reflecting a change in soundscape and overlap with the sounds and hearing abilities of many fish. These findings suggest that, in spite of considerable spatial and temporal variability within reef soundscapes, diel trends in low-frequency sound production correlate with reef species assemblages. The relative abundance of boat noise on these protected but stressed reefs was surprising. Yet, boat noise also stands out as an obvious cue to monitor human activity on these reefs. Recreational human use is often challenging to quantify, and perhaps these passive acoustic measures could aide in evaluating the ecosystem services that these reefs provide.

A GEOSPATIAL APPROACH TO EXPLORING THE SOUNDSCAPE OF STELLWAGEN BANK NATIONAL MARINE SANCTUARY

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In this talk, we introduce a method that exploits geospatial data to assess the spatially varying health of marine ecological communities and degree of human activity. Noise from shipping, energy development, and other human activity has become a significant component of marine soundscapes, resulting in changes to or loss of habitat and biodiversity. Effective management of these effects requires techniques that can rapidly characterize contributions to soundscapes, accounting for variation introduced spatially, temporally and spectrally. Marine animal vocalizations can provide valuable information about the occurrence, distribution, and relative abundance of species. However, species-specific analyses are often infeasible on large temporal and spatial scales and further hindered by the complex nature of underwater soundscapes. Instead, methods which can find relationships within large amounts of data, especially acoustical and geophysical data, can be used to quantify the relative presence of various taxa, human activities, and abiotic activity. Stellwagen Bank National Marine Sanctuary off the northeast coast of the U.S. provides an ideal case study. The sanctuary is home to many vocally-active, and federally-managed, marine species and is a busy place for human commerce and recreation which contribute noise to its underwater acoustic environments. Designation as a national marine sanctuary has concentrated research and monitoring efforts within the area, including efforts to map the seafloor and benthic habitats, describe the distributions, densities and behaviors (including acoustic behaviors) of marine invertebrates, fishes and mammals and measure and map noise contributions from shipping and other human activities. Recent efforts in the terrestrial domain have demonstrated the feasibility of models using geospatial data to predict sound pressure levels across the United States. These models do not directly apply the physics of sound propagation or characteristics of individual sound sources. Instead, these geospatial sound models incorporate spatial representations of physiographical and anthropogenic factors to assess expected contributions to the existing sound pressure level from both anthropogenic and natural sources. The goal of the current project is to apply similar methods to the "reverse problem": to predict geospatial information of interest, such as ecological composition and human activity profiles using explanatory acoustical measurements. Preliminary progress towards this goal will be discussed, including lessons learned in deriving metrics of interest from measured acoustic and geospatial datasets, preparing "ground-truthing" detection-based datasets and results from early phases of integration.

5 MINUTE TALKS AND POSTERS **TUESDAY 12/05**

CREATING AN ACOUSTIC ‘EVIDENCE BASE’ FOR SOUND EMISSION OF WAVE AND TIDAL DEVICES

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Tidal and wave energy devices offer secure, renewable exploitation of energy with low carbon emission. Thus, Increasing numbers of these devices are planned for construction in the UK. However, data on environmental impacts of renewable energy devices are scarce, including acoustic data. Construction and operation of renewable energy devices will introduce anthropogenic noise to the oceans, but not much is known about the effect on marine organisms. Most acoustic data are collected in collaboration with commercial partners and are subjected to copyright agreements. As a consequence, they are not publicly accessible. Knowledge of acoustic conditions at renewable energy device sites is essential to build realistic research scenarios, improve acoustic survey methods, refine sound propagation models, and to prevent resource-consuming duplication of data collection and research. A knowledge exchange project funded by the Natural Environmental Research Council (NERC), UK, is currently aimed towards increasing acoustic data accessibility by creating a central acoustic evidence base that will collect existing data of sound recorded around marine renewable energy devices in the UK. In order to meet copyright protection issues and to limit the required amount of storage space, the database will focus on the collection of metadata rather than original recordings. A standardisation of recording methods and acoustic analysis will be necessary to improve comparability and quality of metadata. Therefore, the database will promote recent developments of sound analysis and standardisation by providing links to most recent guidelines and analysis tools for underwater sound measurements. This database will be beneficial to acoustic impact research, as well as mitigation and regulation processes. This poster will showcase how this database can be accessed and used.

HARBOUR PORPOISE IN THE NORTH SEA: HOW OFFSHORE WIND FARM DEVELOPERS DELIVER APPROPRIATE, EVIDENCE BASED, AND REALISTIC WORST CASES FOR CUMULATIVE IMPACT ASSESSMENT FOR UNDERWATER NOISE?

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In the UK the National Policy Statement for Renewable Energy Infrastructure states that “assessment of the effects on marine mammals should include details of: duration of the potentially disturbing activity including cumulative effects with other plans or projects”. While a simple statement, such an approach offers developers a massive challenge: in finding their way through the minefield of providing appropriate, evidence based, and realistic worst case cumulative impact assessments (CIAs). In this study we highlight how different approaches to CIA can lead to large variation in the complexity of the assessment, and therefore wide ranging conclusions about the potential significance of any impacts.

An ‘appropriate’ approach to assessment considers which plans and projects should be scoped in, and should be driven by the stage in the planning process they are at. However, limitations of considering only the stage in the planning process may provide an unrealistic representation of what is particularly relevant the CIA. For example, following an extensive review of offshore wind projects in the North Sea in a CIA for harbour porpoise, a total of 174 offshore wind farm plans or projects have been identified that require consideration; this is before the scope of the CIA is opened up to consider other non-windfarm plans or projects which may also increase levels of underwater noise over the same time period.

Next, the ‘evidence base’ for the CIA needs to be considered, which should reflect the confidence in existing assessments completed by all of the plans and projects deemed ‘appropriate’. The evidence based approach aims to refine the list of projects. However, often there is no clear link between the evidence base and the stage in the planning process that a project is at. For example, certainty and confidence in the potential impacts may be lacking in consented projects where baseline data or assessment methods may be out of date. Reconciliation of such issues provides a further challenge to the developer, and raises questions as to how other developers have completed their assessments, and how confident one can be in their conclusions.

The final challenge is consideration of ‘realistic worst case scenario’ where a further level of uncertainty needs to be addressed. For example, each windfarm project, in its own right, considers a worst case scenario. For harbour porpoise this may range from a quantitative assessment of the number of individual displaced from maximum hammer energy, to a maximum number of piles, and maximum construction period duration. However, in a CIA, consideration of multiple worst cases may lead to unrealistic estimates of potential magnitude of effect, and a multitude of ‘what if’ scenarios. This provides a massive challenge to developers, and ultimately Regulators in reconciling the huge amount of uncertainty encompassed within even a seemingly appropriate, evidence based, and realistic worst case approach to CIA.

ANNUALLY AVERAGED SOUND MAPS AND TOTAL ACOUSTIC ENERGY DUE TO SELECTED SOUND SOURCES IN THE DUTCH NORTH SEA

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In the recent years, there has been growing interest in investigating the potential impact of sound on marine life due to Descriptor 11 of the Marine Strategy Framework Directive (MSFD). MSFD aims to have 'Good Environmental Status' by 2020 . Sound mapping by mathematical methods provides insights about the contribution of individual sources to the soundscape. In this work, natural (rain and wind) and anthropogenic (shipping, explosions, seismic surveys) sound producing activities in the Dutch North Sea have been considered. In order to overcome the computational load problems associated with multiple sources, multiple receivers and multiple frequencies, an analytical hybrid propagation model which is based on Weston's energy flux and mode theories is developed for use in shallow water. The use of this propagation model allows to generate sound maps in the high spatial and spectral resolution. Sound maps for the North Sea are calculated for different averaging times (weekly, monthly and annual) for the different sources. The average acoustic energy associated with each source is compared at one-third octave centre frequencies in the different regions of the Dutch North Sea. The ratio between free-field energy and shallow water energy is investigated. These annual energy comparisons can provide an estimate for noise compounds in the North Sea. On the other hand, the sound maps, which can be weighted according to the different swimming depths and hearing sensitivities, can be a practical tool for the biologist to investigate.

AN INTRODUCTION TO UNDERWATER SOUNDSCAPE AROUND TAIWAN

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Soundscape, which includes diverse sources like waves, ships, and marine life, is an important topic in underwater acoustics. In the waters around Taiwan, complex and various ocean environment (bathymetry, sediment, and sound speed profiler) plays an important role in the underwater soundscape. It is only less than 100 meters in the Taiwan Strait, but over 3,000 meters in the eastern Taiwan. Since 2009, due to the applications of science, military, and engineering, two types of underwater recording systems, Several Hydrophone Recording Unit (SHRU) and SM2M marine recorder, were deployed in different seasons and locations around Taiwan, and collected over 1000-day data. Because of the limit of SM2M's working depth, SM2Ms are usually deployed in the west coast of Taiwan, and SHRUs in other deeper waters. According to results of spectrograms and hearing recognition, various sound sources are found and diversely distributed in different locations. The goal of this study is quantifying the ambient noise using statistical methods for understand the special and temporal changes, and analyzing the characteristics of transient noises produced by marine mammals, ships, wind-driven waves for soundscape. This material is based upon work supported by Ministry of Science and Technology, Forestry Bureau, Council of Agriculture, Taiwan Generations Corporation and Swancor Ind. Co., Ltd.

TOP-DOWN AND DOWN-UP PHYSIOLOGICAL EFFECTS OF NOISE ON MARINE FAUNA

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Noise can affect fauna via behavioural, physiological, cellular and genetic mechanisms. These mechanisms include physiological and behavioural responses that can be recoverable. However, alteration of DNA or gene expression and a variety of cell and tissue damages in different vital organs have also been recorded. These effects may not be reversible, especially if they occur at key developmental stages. For example, larval malformations and reduction in egg survival were recently observed in experiments where scallop and sea-hare eggs and larvae were subjected to noise exposures. Acute behavioural reactions to noise may have lethal effects also, and have been widely reported in cases of mass-strandings of large and charismatic marine fauna (beaked whales, giant squid) related to naval sonar or seismic activities. However, little is known about the possible population level effects of noise, nor the mechanisms influencing the vulnerability of different species or individuals to noise. It is expected that there will be some common physiological mechanisms of noise effects when noise acts as a stressor. In contrast, heterogeneity in responses to noise is expected for many reasons, e.g.: species will be adapted to cope with different sound levels in their habitat, and thus develop tolerance or sensitisation to noise; animals may be more vulnerable in particular ontogenetic stages; the life style (including physiological adaptations to it) of complex animals may influence their resilience to stress, etc. Also, synergistic effects of noise should be considered. For example, temporal reductions in the availability of prey, such as recorded decreases of up to 70% in fish captures caused by seismic surveys, may have a greater foraging-stress effect on top-predators if the activity occurs in an area with already depleted foraging resources due to overfishing. In this scenario, the diet flexibility of the top-predator will influence its resilience to changes in prey availability. In summary, we are confronted with two main avenues by which noise can impact animals, both with potential population-level effects: bottom-up responses, where genetic, cellular and physiological level responses affect the individual; and top-down effects, where these base responses are modulated by the life style of an animal. Of course these two avenues are interrelates, but the difference is that bottom-up base responses/mechanisms are expected to be shared in many taxa and to be related mainly to the characteristics of the received sound. In contrast, top-down responses, i.e. behavioural reactions driven by the life style of each species, which may result in physiological damage and even death, will be modulated by the overall characteristics of the animal, including internal factors and how it relates to its environment.

EFFICACY OF RAMP-UP OF NAVAL SONAR (1.3-2.0 kHz): AN EXPERIMENTAL EVALUATION WITH HUMPBACK WHALES

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There is a risk that naval active sonars may harm marine animals near the sound source. To reduce this risk, several navies have adopted a mitigation procedure known as 'ramp-up' whereby the source level (SL) is gradually increased to full-power. To test the hypothesis that ramp-up reduces the received sound pressure levels and cumulative sound exposure levels of a whale through the mechanism of inducing an avoidance response, we conducted 31 experimental vessel approaches with a towed sonar source (1.3-2.0 kHz; maximum SL: 214 dB re 1 μ Pa m). Thirteen solitary humpback whales and/or pairs in the waters north of Norway were tagged with DTAGs and Fastloc-GPS loggers. The 10-min experimental vessel approaches were either silent approaches, ramp-up runs with SLs increasing over the first 5 min, or no-ramp-up runs with a full-power start after the first 5 min. Fine-scale movement tracks of the whales were determined using Bayesian state-space models. Received level calculations were based upon acoustic measurements and propagation modelling. Ramp-up triggered avoidance behaviour that led to a reduction in received level at the whale but not all animals were equally responsive, and attraction to the source was also observed. Our study shows that the efficacy of ramp up is intrinsically linked to within-species variation in responsiveness, and most effective for responsive animals such as mother-calf pairs.

BEHAVIOUR

BEHAVIOURAL REACTIONS IN COD TO A COAST GUARD SHIP IN A DEEP FJORD

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"Cod have been shown to react to ship and trawl noise at levels 30 dB over their hearing threshold in the frequencies 40-250 Hz. We instructed a Swedish Coast Guard ship to enter an area wherein 40 cod from a local cod population had been equipped with acoustical transmitters sending depth and id-number data. The ship acoustical signature was measured at two different stations, with 4 hydrophone loggers at each site, since the depth of the area varies between 20 to 80 m and the cod were distributed throughout the area. The ship engine and propeller was set to generate as much noise as possible in order to have a strong stimulus in the experimental area. The ship passed through the experimental area six times during three days. Twenty acoustical receivers were placed at the bottom to record cod movements in a large scale, without startle reactions from the cod. An area of approx. over 5 square kilometres was covered. The design of the experiment was set to detect movements of 50 m or more, which would indicate that the cod is responding to the noise in a way that would result in loss of energy and displacement from habitat.

The total source level of the ship in the hearing frequency range of the cod, i.e. 10-500 Hz, was estimated to be 229 dB re 1 μ Pa at 1 m. This meant that the tagged cod were subjected levels of noise high enough to – based on the literature – induce strong behavioral reactions. In total, data from 30 individuals were used in the analysis of reactions to the noise. Reactions were analyzed based on the first passage on the first day, the first passage of the third day and on a combined disturbance of the three days. The results show a highly individual response to the noise. Several of the fish were noticed to react to the noise during the first passage. The reactions were mostly horizontal as the fish mainly live near the bottom, implying that a diving behavior is most of the times impossible. However, the cod did not leave the area even though some individuals were subjected to levels of above 180 dB re 1 μ Pa that is more than 100 dB above hearing threshold. Some of the cod showed a different behavioral pattern and a change in residence area during the three days of ship passages, compared to the days before and after the experiment. Overall the behavioral reactions were smaller than expected; this is most likely a result of the local cod population's normal behavior of being very stationary and only rarely moving out of the area."

BEHAVIOURAL RESPONSES OF SEA TURTLES TO MARINE ANTHROPOGENIC SOUND: CURRENT KNOWLEDGE, DATA GAPS, AND FUTURE RESEARCH DIRECTIONS

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Recent and planned increases in the spatial scale and intensity of activities producing marine anthropogenic sound in many parts of the marine ecosystem underscore the importance of understanding the impacts of sound on sensitive and threatened marine organisms such as sea turtles. Rising concerns about these impacts have led to increased research examining the potential physiological and behavioural effects of anthropogenic sound. While research focused on marine mammals and fish has greatly increased over the last decade, research on sea turtles has lagged behind, largely due to lacking fundamental knowledge of their auditory sensitivities. Recent research has improved our understanding of the hearing sensitivities of sea turtles and indicates that loggerhead, green, leatherback, hawksbill, and Kemp's ridley sea turtles are able to detect low-frequency (<2,000 Hz) underwater and aerial acoustic stimuli with maximum sensitivity between 100 and 500 Hz. Sea turtle hearing sensitivity overlaps with many low-frequency sources of marine anthropogenic sound including oil and gas exploration and extraction, pile driving, low-frequency sonar, and shipping vessels. While very few studies have directly examined sea turtle behavioural responses to sound, researchers have demonstrated that sea turtles can detect and behaviorally respond to low-frequency natural and anthropogenic sounds within their hearing range in laboratory settings and natural environments. Of the few behavioral response studies conducted, nearly all have focused on loggerhead or green sea turtle responses to seismic airguns and were conducted in enclosed environments, limiting our ability to discern or evaluate the potential behavioural responses of freely swimming turtles. Many gaps remain in our knowledge of the acoustic ecology of sea turtles, particularly with respect to behavioural responses. This study presents a review of the state of our knowledge on the acoustic ecology of sea turtles, evaluates the potential behavioural effects of anthropogenic sound, identifies data gaps, and proposes recommendations for future research needed in order to assess and mitigate the impacts of anthropogenic sound on sea turtles. Behavioural responses of sea turtles to marine anthropogenic sound: Current knowledge, data gaps, and future research directions

CUMULATIVE EFFECTS OF MULTIPLE VESSEL CLASSES ON THE COMMUNICATION SPACE OF BALEEN WHALES IN DIFFERENT BEHAVIORAL CONTEXTS

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“Baleen whales loose ‘communication space’ (CS) from chronic exposure due to anthropogenic underwater noise. CS is a novel metric for measuring cumulative impacts of noise. The few studies on this topic that have been undertaken have included a single anthropogenic noise source, sound type and/or species. Here we extend this approach by evaluating the levels of masking resulting from multiple vessel classes on four baleen whale species, and several sound types, using data collected by an array of bottom-mounted autonomous acoustic recorders deployed in the Stellwagen Bank National Marine Sanctuary, Massachusetts, USA. The week of peak occurrence for humpback whale social sounds, minke whale pulse trains, North Atlantic right whale up-calls and gunshots, respectively were chosen for data analysis. Integrative tools applied to the sound fields estimated that ‘signal excess’ (SE) for the different sound types averaged between 0 and 15dB under present-day background noise conditions, and was negative, with the addition of specific anthropogenic noise sources (vessels). When compared to CS available under historic ambient noise conditions (~1950s, i.e. prior to rise of industrial shipping), right whale up-calls, minke whale pulse trains and humpback whale social sounds have been most dramatically reduced with respect to their relative CS levels. The percent of CS lost was influenced by presence or absence of each vessel class. One of the more extreme examples was the loss of CS for humpback whale social sounds. These are primarily produced during the summer season when vessel traffic of all types was high; when analyzed separately, large commercial vessels contributed most to loss of CS, followed by whale-watching and fishing vessels. In conclusion, the behavioral context of acoustic activity, and seasonal vessel activity, changes the implications of lost CS, and thus the biological significance thereof.”

FIRST INDICATIONS THAT NORTHERN BOTTLENOSE WHALES ARE SENSITIVE TO BEHAVIOURAL DISTURBANCE FROM ANTHROPOGENIC NOISE

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Beaked whales are particularly sensitive to anthropogenic noise. Northern bottlenose whales were the most heavily hunted beaked whale, but their sensitivity to acoustic disturbance is unknown. We attached dataloggers to thirteen northern bottlenose whales in the Gully and Jan Mayen and compared their natural sounds and movements to those of one individual exposed to escalating levels of 1-2 kHz upsweep naval sonar signals in the waters near Jan Mayen. At a received sound pressure level (SPL) of 98 dB re 1 μ Pa the whale turned to approach the sound source, but at a received SPL of 107 dB re 1 μ Pa, the whale began moving in an unusually straight course and then made a near 180° turn away from the source, and performed the longest and deepest dive (2339 m, 94 min) recorded for this species (n = 79 dives from 12 whales). The whale did not produce any foraging-related click and buzz sounds during the deep dive. Diving kinematic parameters differed significantly from baseline for > 7 hours until the tag fell off 33-36 km away. No clicks were emitted during the response period, indicating cessation of normal echolocation-based foraging. A sharp decline in both acoustic and visual detections of conspecifics after exposure suggests other whales in the area where the experiment conducted responded in a similar fashion as the tagged whale. Though more data are needed to fully describe the acoustic sensitivity of this beaked whale species, our results indicate high sensitivity of this species to acoustic disturbance, with consequent risk from marine industrialisation and naval activity.

EFFECTS OF NAVAL SONAR ON FEEDING IN HUMPBACK WHALES

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Long range, powerful naval sonars use sound pulses which are potential disturbances to cetaceans. Studies of behavioral effects of naval sonar on cetaceans show that sonar exposure can lead to cessation of on-going feeding activity in several species. Humpback whales (*Megaptera novaeangliae*) are among the most numerous baleen whales in the Barents Sea, and disrupted feeding in an important feeding ground has the potential to affect individual energy reserves and to disturb a female's ability to nurse offspring. This study examines the feeding behavior of humpback whales before, during and after controlled exposure experiments using 1-2 kHz naval sonar signals, and acoustic and motion sensor archival tags (DTAG) placed temporarily on the animal with suction cups. Humpback whales feed by lunge feeding, a technique involving accelerating to increase speed before engulfing a prey patch. The acoustic signature of a lunge comprises a period of a few seconds of high-level flow noise followed by a rapid reduction in noise level on the tag. We used this acoustic signature to identify lunge events. Over two succeeding seasons, a total of 13 humpback whales were tagged, and 20 sonar exposures, 11 no-sonar control pass (same source ship with no transmission) and 8 playbacks of mammal-feeding killer whale sounds (as a positive control) were conducted. Results show that humpback whales significantly decreased their foraging activity during sonar exposure compared to a no-sonar control pass. Such a decrease was however not found during a second sonar exposure on the same animal, indicating habituation to the signal. However, playbacks of mammal-eating killer whale sounds simulating potential predator presence consistently led to abrupt cessation of lunge feeding, indicating that this stimulus induced a stronger response than sonar.

DISTURBANCE-SPECIFIC SOCIAL RESPONSES IN LONG-FINNED PILOT WHALES

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Group-level response strategies can be a major fitness benefit for animals living in groups, but have remained poorly understood in social toothed whales. We investigated the group-level behavioural responses of long-finned pilot whales (*Globicephala melas*) to 3 disturbance stimuli: predator/competitor-presence, vessel pursuit (tagging effort) and intense naval sonar signals. Pilot whale responses strongly differed in nature and magnitude to the different disturbance stimuli. Targeted boat pursuit (tagging effort) resulted in stronger group cohesion and vocal crypsis, whereas sonar exposure elicited a response with increased social calling and more aggregation and resting near the surface, most notably post-exposure. Killer whale playbacks also resulted in animal aggregation with high call rates, but also an investigative approach towards the sound source, indicating a mobbing strategy. We propose that the group-level response strategy involving animal aggregation and social calling aims to reduce risk of potential loss of coordination and/or a need for enhanced social cohesion in response to a high risk disturbance that can or cannot be defended against. Our study stresses the importance of group-level responses in social cetaceans, and suggests that these whales perceive different levels of risk for different disturbance stimuli.

BEHAVIORAL RESPONSES OF MIGRATING HUMPBACK WHALES TO A SMALL AIR GUN AND THE IMPORTANCE OF BASELINE DATA

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Behavioral response studies can be used to determine responses of whales to sounds where the source and its movement are under experimental control but the whales are free swimming. Whale movement and behavior, however, can be highly variable due to natural social and environmental factors even for matched cohorts in the same place at the same time of year. This can make it difficult to detect a behavioral change or, if observed, determine whether the change is due to the sound exposure, the presence of the source vessel, or other social or environmental factor. In 2010 and 2011 we performed the first of a series of behavioral response experiments on humpback whales using seismic survey air guns off the coast of Australia. Air guns produce high level, impulsive sounds, and while in many jurisdictions surveys are obliged to shut down to prevent injury to whales when they are in close proximity, behavioral disturbance may occur at much greater distances. Despite this, studies of behavioral effects have been limited in number and scope. We conducted behavioral focal follows of groups of southward migrating whales for one hour before, during and after exposure to a 20 cubic inch air gun towed by a vessel, either across the migratory path or directly into the migratory path ($n = 32$ groups). We also conducted focal follows using the same methodology where the air gun was deployed and towed but did not fire ($n = 35$ groups). These 'active' and 'control' treatments were complemented by 'baseline' focal follows conducted when the source vessel was not in the area ($n = 25$ groups). The 'baseline' data were first used to determine which social and environmental variables best explained variation in the normal behavior of the whales. These were then included in subsequent models testing if there was a response to the air gun stimulus during 'active' trials, or to the vessel during 'control' trials. When compared to 'baseline' groups, both 'active' and 'control' groups significantly decreased their dive time and speed of southward movement in the 'during' phase. However this response was not significantly different between the 'control' and 'active' trials suggesting the response was at least partly due to the source vessel itself rather than the air gun. Had we not included the baseline dataset, we would have found no significant response in the 'during' phase (when comparing 'control' groups to 'active' groups). Further, by incorporating the important social and environmental predictor variables in the analysis, we accounted for factors that had a significant effect on the whales' behavior. Failing to do either may have led to erroneous conclusions about the likely drivers of observed behavior. This experiment shows that, in addition to having adequate sample size and silent controls, studies should use baseline data to take into account factors explaining variability in normal behavior and as a control for all experimental treatments.

POTENTIAL MECHANISMS OF RESPONSES OF RIGHT WHALES TO ANTHROPOGENIC SOUND

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Among the many potential mechanisms by which right whales might respond to anthropogenic sound are chronic stress, displacement, and changes in vocalization or the duration of foraging behavior. Whales that are habituated to sound or tolerate sound may not displace. Additionally, masking of communication space may affect physiological and social processes that ultimately affect probabilities of persistence. These responses likely are functionally related to health, fitness, and vital rates. A dozen experts on right whales, related taxa, and acoustics developed a conceptual model of potential mechanisms by which right whales might respond to sound. The group documented, for each class of response or mechanism, existing data that might inform models, strength of evidence for the response or mechanism, major uncertainties, possible ways to test hypothesized relations, and feasibility and priority for testing. On this basis of the compiled information and expert judgment, the group identified three priorities. First, use empirical data from Cape Cod Bay to test hypothesized relations between sound and commensal food-finding and mate finding. Second, conduct an expert elicitation on whether masking of sound is related to the probability of ship strike. Third, parameterize response models of survival, morbidity, and reproduction to chronic stress. At different points in time over the next decade, it might be possible to parameterize these models of chronic stress and responses (acoustic and/or motor behavior) on the basis of an assessment of evidence and uncertainty, expert elicitation, existing empirical data, or new data from studies that compared habitats, populations, or sample types. We assert that exercises like the one described here can be a useful and important step in identifying gaps in knowledge and research needs for a given species in evaluating the behavioral response(s) to ocean noise.

PATHOLOGY

CONTROLLED NOISE EXPOSURE EXPERIMENTS ON JELLYFISHES

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Recent findings on cephalopods showed that exposure to artificial noise had a direct consequence on the functionality and physiology of the statocyst, a sensory organ, which is responsible for their equilibrium and movements in the water column. Those previous experiments demonstrated the marine invertebrate sensitivity to sound exposure. Owing to a lack of available data on the pathological effects on statocyst of other species of invertebrates, we conducted noise exposure comparative experiments, including the use of a 50–400 Hz sweep (RL=157±5 dB re 1µPa with peak levels up to SPL=175 dB re 1 µPa) on two species of Scyphozoan medusa presents in the Mediterranean Sea, *Cotylorhiza tuberculata* (Cepheidae) and *Rhizostoma pulmo* (Rhizostomatidae). Scanning electron microscopy (SEM) revealed injuries in the statocyst sensory epithelium after exposure to sound. These lesions described are new to Cnidarians pathology. The extensive damage in the sensory epithelia, that were regionally severe, was quantified and compared over time.

NOISE INDUCED HEARING LOSS EVIDENCE: CASE OF A LONG-FINNED PILOT WHALE MASS STRANDING EVENT

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There is an increasing need to develop methods for assessing the effects of underwater man-made noise on cetaceans. By including ear removal and fixation in the routine necropsy protocol in the cases where the stranded or euthanized cetaceans are very fresh, it is possible to determine if the individuals experienced permanent hearing loss. Based on studies performed with terrestrial mammals, it is known that structural alterations of the organ of Corti, or hearing organ, can be observed as a consequence of sound overexposure. Here, we present an analysis of the ears from a mass stranding event on the 2nd of September 2012 in Scotland. Twenty-one long-finned pilot whales (*Globicephala melas*) stranded and died between Anstruther and Pittenweem, East Scotland. A full diagnostic necropsy was undertaken on all animals over the following 24-48 hours. No infectious, metabolic or traumatic cause was identified from the pathological investigation which was considered to be definitively causal or contributory to the stranding event. During the necropsies, twenty-nine ears were collected and fixed with 10% neutral buffered formalin between 4 and 22 hours post-mortem. Six of the best preserved cochleas were analysed by scanning electron microscopy for evidence of potential acoustic impact. Five ears still proved too autolysed for meaningful diagnosis, but the freshest ear, removed within 4 hours of death, exhibited clear lesions at the apex of the cochlear spiral, consistent with underwater noise overexposure. Specifically, focal scarring had replaced the outer hair cells responsible for enhancing auditory sensitivity and frequency selectivity. The scarring was located in the first 380 µm from the apex of the cochlea that corresponds with the section of the ear responsible for transducing the lowest frequencies of the pilot whale hearing spectrum. It was not possible to establish the chronicity of the lesion nor, given the small sample size, interpret this pathology as being causal to the mass stranding. Nonetheless, this first pathological legacy of noise overexposure in a cetacean stranding event clearly emphasises the need for the implementation of a specific protocol to document the presence of acoustic trauma in stranded cetaceans. It further confirms that acoustic trauma can be diagnosed in fresh cases and the protocol could be successfully implemented as part of any investigation of future cetacean stranding events.

PILE DRIVING IS PERCEIVED AS AN ACOUSTIC STRESSOR BY JUVENILE EUROPEAN SEA BASS (DICENTRARCHUS LABRAX)

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An increasing amount of anthropogenic underwater sound is induced in the marine environment. Consequently, a better understanding of the impact on marine life of underwater sound, and especially of impulsive sound, is needed. This particular study tackles the impact of impulsive sound related to pile-driving activities for offshore wind energy development, on the mortality, stress and condition of post-larval and juvenile European sea bass *Dicentrarchus labrax*.

A 'worst-case scenario' field experiment was carried out on board of a piling vessel, exposing 68 and 115 days post hatching (dph) fish (< 2 g wet weight) to the sound generated during 1.5 hours of pile-driving. The number of strikes ranged from 1740 to 3070, with a single strike sound exposure level ranging between 181 and 188 dB re $1\mu\text{Pa}^2\cdot\text{s}$, resulting in cumulative sound exposure levels ranging between 215 and 222dB re $1\mu\text{Pa}^2\cdot\text{s}$. Immediate and long-term survival of the exposed fish was high and comparable to the control groups. Although not significant, control fish had elevated whole-body cortisol levels (31.7 ± 12 ng/g fish) compared to unhandled fish (5 ± 3.7 ng/g fish) which reflects the impact of handling and transport onto the piling vessel. Fish exposed to pile driving had high whole-body cortisol levels (87 ± 50 ng/g fish), which confirms that pile driving is perceived as an acoustic stressor. Additionally, a 50 % reduction in the oxygen consumption rates was observed in the exposed fish compared to the control fish. Lactate levels were similar in exposed, control and unhandled fish. Together these results suggest a reduction in movement. Whether this is involuntary immobility or strategic freezing is unclear. Back in the lab, the fish were held under optimal lab conditions over a 30-day period. In this period, no differences were observed in length, weight and condition.

Overall, a strong stress response was observed during the pile driving exposure but no long term detrimental effects were seen, at least not under laboratory conditions. During the sound exposure, the lower energy levels might negatively affect the general alertness, anti-predator response and activity levels, making the fish more vulnerable. Laboratory experiments performed with a SIG Sparker, used in seismic research and the larvaebator, were used to compare the stress responses with the in situ experiment. Both sound sources produce impulsive sound but the larvaebator is limited to the lower frequency range whilst the SIG Sparker covers mid and high frequencies. At the moment, the stress indicators are under analysis. A second goal is to distinguish the sound metrics which excited the stress responses.

UNDERWATER NOISE IMPACT INVESTIGATIONS ON WILD HARBOUR PORPOISES (*PHOCOENA PHOCOENA*)

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Hearing tests on marine mammals are mostly based on studies of animals in captivity and therefore sample sizes are usually low for most species. To better generalize findings of susceptibility of hearing to anthropogenic noise we developed and tested an auditory evoked potential method to determine hearing thresholds of wild animals in outdoor conditions using auditory evoked potentials to test hearing abilities as well as potential temporary effects of airgun pulses on hearing thresholds. Auditory thresholds were measured in the frequency range from 10 to 160 kHz on live stranded animals from the North Sea after rehabilitation shortly before release into the wild and animals incidentally caught in pound nets in Denmark (Baltic Sea). Results indicate that while variability between individuals is wide, the hearing curve in general is similar to previously published results from behavioural trials. A change in methodology during the trials indicated that 1/3 octave band level hearing tests reduces the fine scale resolution of the lowest hearing threshold characteristics. Animals incidentally caught in the Baltic Sea were exposed to impulsive broadband sounds of a seismic airgun at a sound exposure level of 164 dB re $\mu\text{Pa}^2\text{s}$. In a previous study on a captive animal it was observed that a temporary threshold shift could possibly be provoked at this level. The sample size of these trials is still too low for a conclusive evaluation of TTS in harbour porpoises.

SUSCEPTIBILITY AND POTENTIAL PATHOLOGY OF TEMPORARY THRESHOLD SHIFT IN MARINE MAMMALS

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PATHOMORPHOLOGICAL CHANGES IN THE EARS OF HARBOUR PORPOISES (*PHOCOENA PHOCOENA*)

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Hearing represents the major sense in harbour porpoises and impairment of hearing compromises their chance of survival. The ears of 21 incidentally by-caught or live stranded freshly dead harbour porpoises originating from German and Danish waters of different age groups and gender were investigated histologically. Hyperplastic lymphatic tissue at the entrance to the middle ear cavity points to an immune response to antigens ascending most likely the Eustachian tube. Chronic infestation of the nematode *Stenurus minor* in the middle ear cavity represents the most common finding observed in subadult and adult harbour porpoises associated with meta- and hyperplastic epithelial changes. Mycotic otitis and fractured tympanic bones were observed in single animals. Acute haemorrhages occurred in almost all investigated animals and represent most likely agonal changes. An unusual bone formation at the base of the corpus cavernosum was a common finding even in young individuals. Whether it is a normal structure or a metaplastic change, remains yet undetermined. Lipofuscin deposition in neurons of the spiral ganglion in adults was considered as an age-related change without clinical relevance. Occasionally degenerative changes were observed in the organ of CORTI. Histological examination of the ears reveals various lesions that might have an impact on hearing ability of harbour porpoises.

SENSITIVITY

UNDERWATER LOW FREQUENCY CALIBRATION FOR THE QUANTITATIVE MEASUREMENT OF OCEAN NOISE AND AUDITORY SENSITIVITIES

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Major anthropogenic noises created by shipping, pile driving, seismic survey and electric power generators are in low frequency range. Fish and baleen whales are known to be sensitive to the low frequency sounds, which travel long distance in the ocean. For evaluating the effect of the low frequency noise for these organisms, reliable physical measurement of intensity, spectrum and temporal structure of low frequency sounds has been required. In an acoustic experiment in a tank, reverberation is unavoidable because of the long wavelength comparing with the dimension of an experimental tank in low frequency that makes the quantitative measurement of sound pressure difficult in laboratory conditions. For instance, unnatural waveform of a fish sound can be observed in a small tank comparing with the ground truth measurement using identical fish in open water. Noise map in a breeding tank of prawns shows no range dependent sound field from a noise source. Consequently, measurement of auditory sensitivity of fish in a small water tank must be conducted with great care.

In contrast, an experiment in the ocean is ideal to avoid artifacts, but expensive and fragile calibrated hydrophone is not always available. These days, numbers of stand-alone recording devices are used in the monitoring of ocean noise and exposure level to marine creatures. The devices used for these purposes should be calibrated periodically in advance to the experiments. Here we propose a simple yet practical calibration method for a hydrophone using a small tank. A small tank (1.5 m in diameter and 0.6 m in depth) could be used for the measurement of hydrophone sensitivity at the fundamental resonant frequency of the tank. Sound pressure field in the tank was location independent except for the area nearby the boundary such as the tank wall and the surface. Sound pressure should be equal to the air pressure at the boundary since the tank wall is soft enough. The stable exposure level could be observed within 28 cm in the center of the tank within 3 dB, which is large enough comparing with the size of an acoustic sensor of a recording device. Projection of a pure tone sound, which frequency is higher than the fundamental resonant frequency, caused complicated sound field. Received sound pressure changes location by location even within a few centimeters due to the reverberation. Pure tone sound having lower frequency than the resonant frequency attenuated exponentially. Quick reduction of the received level was observed within 1 m. In either case, exposed sound pressure is location sensitive that makes the calibration of a hydrophone difficult. Only at the resonant frequency of the tank, relatively constant sound field area appears at the center of the tank that can be used for quantitative measurement of the sensitivity of the hydrophone.

SOUND PRESSURE AND PARTICLE MOTION EFFECTS ON NOISE-EXPOSED CUTTLEFISHES

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Previous Controlled Exposure Experiments in laboratory conditions showed that cephalopods were sensitive to sound exposure. Why the relatively low levels of low-frequency sound caused such lesions required further investigation, in particular to determine the onset mechanism of the acoustic trauma in order to determine whether these animals were more sensitive to particle motion or acoustic pressure, or to a combination of both. We conducted offshore noise exposure comparative experiments on common cuttlefish (*Sepia officinalis*) in similar conditions as during the laboratory study, in terms of sound characteristics, received levels and time exposure. Particule motion measurements were also conducted at the same locations and depths where the individuals were exposed. The total amplitude and the frequency were calculated using Hilbert transform. The amplitudes (total sum of x, y and z components) were decreasing with increasing distance between the source and the sensor, except for 5 m, which was assumed to come from some unknown error handling. Scanning electron microscopy (SEM) revealed similar injuries in the inner structure of the statocysts, as those found in cuttlefish in previous laboratory experiments. The statocyst of exposed cuttlefish presented extensive damage to their sensory epithelia that could be quantified.

INJURY RESPONSE IN THE HYBRID STRIPED BASS AS A FUNCTION OF NUMBER OF PILE DRIVING STRIKE EXPOSURES

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A number of recent experiments by our group using the High Intensity Controlled Impedance Fluid-filled wave Tube (HICI-FT) have examined the effects of exposure to pile driving on five species of fishes (e.g., Halvorsen et al., 2012, Proc. Roy. Soc. B. 279, 4705-4714). These studies demonstrated that onset of physiological effects only start at cumulative sound exposure levels (SEL) of over 203 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$ and that mortal injuries never occur until the cumulative SEL is over 210-215 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$. Our studies, however, always focused on effects of exposure to 960 or 1920 simulated pile strikes, representing a scenario in which fishes do not leave an ensonified area. The single strike and cumulative energy in these strikes were set to reach a desired SEL. While these data are exceptionally useful in defining onset levels of potential damage, they did not show the expected pattern of effect as the number of strikes changed. Questions that resulted from initial experiments were whether a "linear" relationship (equal energy hypothesis) existed between the number of strikes (increased level of exposure) and increased physiological effects, and whether the frequency of occurrence and severity of all the effects increased in the same way.

In order to answer these questions, hybrid striped bass (white bass *Morone chrysops* x striped bass *Morone saxatilis*) were exposed to varying numbers of strikes from eight to 384 at three different single strike SEL paradigms (used previously in HICI-FT experiments with this species). At the highest SEL single strike level, swim bladder related injuries began to appear in as few as eight pile strike exposures suggesting that fishes could be at risk to injury even if they are present in an ensonified area for only a short period of time. Further evidence also refutes the equal energy hypothesis relative to number of pile driving exposures. Injury patterns in hybrid striped bass exposed to similar cumulative SEL paradigms but different numbers of pile strikes were not consistent, suggesting that single strike SEL is a more likely indicator for predicting injury, particularly when fishes are exposed to fewer numbers of pile strikes. These results have important implications for pile driving operations where sound levels of individual pile strikes meet or exceed the levels of exposures tested in this study.

RESPONSES OF WILD PELAGIC FISHES TO IMPULSIVE SOUNDS

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Current expansion of industrial activities in the sea has led to increasing concern about the impact of man-made sounds upon marine animals. Offshore oil and gas exploration and developments, wind farm construction and operations, other renewable energy sources, dredging, construction activities, naval sonars, and increases in commercial shipping are all contributing to increased noise in the sea.

A succession of reports and scientific papers has now emphasized the potential risks to marine animals from exposure to man-made noise. Environmental impact assessments are now required to consider the effects of underwater noise seriously and in detail.

As part of the risk assessment process, it is necessary to predict the levels of different types of sounds that may have potential impacts on marine animals. Criteria for the responses of animals are usually provided in terms of threshold values expressed in a particular acoustic metric, above which particular effects upon the animal may occur. In establishing these criteria not only the level of the sound but the frequency range, rise time, duration, repetition rate, and a number of other parameters are important. However, very few experimental observations have been made on the effects of exposing wild, free-living animals to sounds. In particular, there have been very few observations of changes in the behaviour of marine fishes in response to sounds.

This paper describes changes in the behaviour of wild sprat and mackerel schools in response to sound playback, observed with a sonar/echo sounder. The fish were exposed to a short sequence of repeated impulsive sounds, simulating the strikes from a pile driver, at different sound pressure levels. Clear behavioural responses occurred, the sprat schools breaking up and fish dispersing, and the mackerel schools diving. The method of observation by means of a sonar/echo sounder, deployed from a small vessel, proved highly successful in examining the behavior of unrestrained fish exposed to different sound levels. The technique may allow further testing of the relationship between responsiveness, sound level, and sound characteristics for different types of man-made sound, for a variety of fish species under varied conditions.

BIGEYES OR BIGEARS: FIRST EVIDENCE OF A FISH USING A CONTACT CALL

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Many social animals, including mammals, birds, reptiles and amphibians, move in groups, often using vocalisations, or contact calls, to maintain group cohesion. Fish species too are social, and visual and hydrodynamic group cohesion cues have been extensively studied, but, despite the fact that many fish vocalise, there is currently no direct evidence of contact calls being used for group cohesion in fishes. Contact calling to maintain group cohesion may be particularly important in nocturnal fishes that associate in loose shoals where visual and hydrodynamic cues are unavailable. Bigeyes (*Pempheris adspersa*) are nocturnal planktivorous reef fish, they feed in loose shoals and are soniferous. Bigeyes produce pop calls with a peak frequency of 400 Hz, which coincides with the most sensitive part of their hearing range. Our laboratory experiments show that they significantly increased their group cohesion when exposed to recordings of ambient reef sound at three sound levels (125, 130 and 135 dB re 1 μ Pa) while also decreasing vocalisations – effectively reducing their “active space” and also shows patterns of behaviour consistent with acoustic masking. When exposed to playback of conspecific vocalisations, the group cohesion and vocalisation of *P. adspersa* were both significantly increased. These results, along with previously reported behaviours in wild provide evidence that vocalisations are used as contact calls to maintain group cohesion. These results appear to be the first experimental evidence of contact calls being used for group cohesion in fishes. Making fish the evolutionarily oldest vertebrate group in which this phenomenon has been observed.

PREDATORS USE ANTHROPOGENIC SIGNALS FROM ACOUSTIC TAGS TO LOCATE PREY

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Anthropogenic noise can have negative effects on animal behaviour and physiology. However, noise is often introduced systematically and potentially provides information for navigation or prey detection. In this previously published study (Stansbury et al. (2015) Proc Roy Soc B 282: 20141595) we show that grey seals (*Halichoerus grypus*) learn to use sounds from acoustic fish tags as an indicator of food location. In 20 randomized trials each, 10 grey seals individually explored 20 foraging boxes, with one box containing a tagged fish, one containing an untagged fish and all other boxes being empty. The tagged box was found after significantly fewer non-tag box visits across trials, and seals revisited boxes containing the tag more often than any other box. The time and number of boxes needed to find both fish decreased significantly throughout consecutive trials. Two additional controls were conducted to investigate the role of the acoustic signal: (i) tags were placed in one box, with no fish present in any boxes and (ii) additional pieces of fish, inaccessible to the seal, were placed in the previously empty 18 boxes, making possible alternative chemosensory cues less reliable. During these controls, the acoustically tagged box was generally found significantly faster than the control box. Our results show that animals learn to use information provided by anthropogenic signals to enhance foraging success. Such a shift in foraging behaviour can have profound effects on an ecosystem. Thus, when introducing artificial sound sources into an environment it is important to take into consideration all potential effects on local species, both detrimental and beneficial.

INVESTIGATING THE RESPONSE OF COASTAL DOLPHINS TO MINE EXERCISE (MINEX) TRAINING ACTIVITIES

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The naval forces of many countries conduct mine detonation exercises in coastal waters as part of their regular training. These exercises have the potential to disturb, injure or even kill marine mammals occurring in the same area. To address concerns about this possibility at the U.S. Navy's Virginia Capes (VACAPES) Range Complex, an effort was begun in August 2012 to monitor odontocete activity at the mine exercise (MINEX) training range using passive acoustic methods. The objectives of the project were to establish the daily and seasonal patterns of occurrence of dolphins in the VACAPES MINEX training area, to detect explosions related to MINEX activities, and to determine whether dolphins in the area show evidence of a response to MINEX events. Up to four Ecological Acoustic Recorders programmed to achieve continuous monitoring were deployed and refurbished approximately every two months. The data were analyzed for the daily presence/absence of dolphins and their acoustic activity was quantified in detail for the period prior, during and after MINEX activities, as well as at various distances from the training site. The results indicate that dolphins are present daily in or near the MINEX range, a finding that supplements limited visual survey information due to restricted regular access to the MINEX area. The data also reveal that dolphins exhibit a short-term acoustic response immediately following an explosion event. Acoustic activity increases briefly and then declines substantially. There is also evidence of a decrease in overall acoustic activity lasting several hours following the exercise. Current analyses aim to establish whether the observed response represents a shift in acoustic behavior or a spatial redistribution of the animals. These results underscore the value of long-term monitoring to inform the military on the potential impacts on marine mammal populations from training exercises involving underwater explosions.

INDIVIDUAL DIFFERENCES IN BEHAVIORAL HEARING SENSITIVITY OF KILLER WHALES (*ORCINUS ORCA*).

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Audiometric data for a broad range of cetacean species is critical to a comprehensive understanding of the potential effects of anthropogenic sound on marine mammals. Killer whales (*Orcinus orca*) are the most widely distributed marine mammal species, the largest delphinid odontocete, and the apex predator of the ocean. Recently, published studies have also suggested that they may be particularly sensitive to acoustic disturbance. There are currently only two complete behavioral audiograms of killer whales obtained from two adult females (Szymanski et al., 1999). Thresholds from this study are lower than any odontocete tested and require replication and validation. Furthermore, the limited sample size fails to provide any insight into individual differences or demographic variability (e.g., age, sex). In the current study, auditory thresholds from multiple killer whales (ages 12 – 50 yrs) were measured using a “go, no-go” response paradigm in conjunction with an adaptive staircase procedure. Although all animals tested to date, have maximum sensitivity at 40 kHz, large individual differences exist with respect to best sensitivity and the high frequency limit of hearing. In general, these differences can be caused by aging, viral infections, trauma, excessive noise, or ototoxic medications. A review of subject management records allows evaluation of these potential etiologies. The increase in sample size accomplished through this ongoing study will allow the first assessment of the variation in hearing sensitivity for the killer whale, which will be a critical starting point for estimating the impact of anthropogenic sound on this species.

5 MINUTE TALKS AND POSTERS **WEDNESDAY 13/05**

THE INFLUENCE OF BOAT NOISE ON THE BEHAVIOUR OF PACIFIC SALMON, PACIFIC HERRING AND YELLOWTAIL ROCKFISH

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Engine noise produced by vessels has an impact on the marine environment and can affect the behaviour of various marine species. Sound travels three times faster in water than it does in air and with the numbers of ships still increasing, anthropogenic noise can be a big disturbance for many marine animals that rely on sound for feeding, eco-location and communication. The effect boat noise has on the behaviour of marine mammals, like cetaceans and pinnipeds, is becoming a well studied subject. A group of aquatic species that is however getting less attention in this research area are the fish. There are approximately 32,000 known fish species, of which roughly half are marine, making it the most diverse group of vertebrates. Fish can detect vibrations in the water using the receptors on their lateral line and some species might even produce sounds themselves. In this pilot study we investigated the influence of noise produced by a small, one engine, tender on the behaviour of three fish species (Pacific salmon, Pacific herring and Yellowtail Rockfish) in their natural environment. The fish were held inside net pens suspended on a floating platform inside a sheltered bay of the Broughton Archipelago on the west coast of BC Canada. They were filmed before, during and after the exposure to boat noise and the noise level was measured using a hydrophone (Reson TC4032) suspended at mid net depth. The analysis of the data collected is still ongoing as part of my master dissertation of the Erasmus Mundus master in Marine Conservation and Biodiversity. However, this will be finished by the end of April and I would therefore very much like to present my results during the Oceannoise2015 convention if there is any interest in this.

NUMERICAL MODELLING OF FISH IN RESPONSE TO UNDERWATER NOISE

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The impacts of anthropogenic underwater noise on the marine environment are of interest at present due to the increase in human activities in our seas. As part of the EIA process the response of species to underwater noise needs to be assessed, although this is often difficult due to lack of data on the sound detection abilities of a species and their likely behavioural responses. The use of numerical modelling for predicting the responses and movements of species to an environmental change are a well developed technique for terrestrial species and for some birds. They are less well used for marine species, often due to the lack of data available, the perceived data needs and the potential difficulties with collecting information on parameters required for realistic predictive modelling. However, these techniques are being developed for use in the marine environment to assess the potential responses of marine species to anthropogenic underwater noise.

Individual, or Agent, Based Models offer the opportunity to apply several different scenarios of sound exposure to a sensitive receptor and to obtain data which could aid in the decision making process when consenting offshore activities and also offer opportunities to study energetic costs and potential long term impacts on populations. This type of modelling is not often used outside of theoretical research as data for many parameters thought to be essential to obtain realistic results do not exist for many species of interest. Proxy species could be used, although this brings with it potential errors as even closely related species may not exhibit the same behaviours or have the same sound detection abilities. However, as EIA are often now taking a precautionary approach to the potential impacts of noise on marine species where data is limited or non-existent, models of this type may be able to provide a range of potential impacts based on best available scientific data to better inform the EIA process.

Here we present a model which has been developed to predict the response of fish to underwater noise from anthropogenic activities. We discuss the parameters which are needed for the model to run, the type of data required and the availability for this information.

ASSESSMENT OF UNDERWATER NOISE IMPACT ON MARINE FAUNA: PERSPECTIVE FROM A SCOTTISH NATURE CONSERVATION BODY

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The aim of this five minute presentation and poster is to explore some of the challenges in assessing the impacts of underwater noise on our natural heritage interests, from a Scottish perspective. As a statutory advisor to the Scottish Government, part of our remit is to offer advice relating to anthropogenic development in the marine environment. We advise on the potential natural heritage implications, options for avoidance or management of impacts and advice on baseline surveys and monitoring. Sound advice depends upon an accurate understanding of the stressor and receptor. Many marine species and habitats are protected by law. One key piece of legislation is the EC Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Flora and Fauna (the 'Habitats Directive') Article 12, which requires a system of strict protection for all populations of animal species listed on Annex IV (a) of the Directive in their natural range wherever they occur. It details what measures are required e.g. prohibition of deliberate capture, killing, injury & disturbance. In particular there is provision for the designation of protected sites for specific species and habitats; also there is protection for any cetacean species from mortality, injury or disturbance. In addition, Environmental Impact Assessment legislation requires the developer to present information on the potential impact their proposal may have, addressing all likely significant effects. It is under this legislative framework that consenting advice and decisions have to be made. We are asked to advise on developments such as marine renewables, harbour developments, seismic surveys and the use of acoustic deterrents. Anthropogenic noise in the marine environment has the potential to deliberately disturb under the EU Habitats Directive, with legal implications if not considered fully. The assessment of the potential impact of underwater noise is far from straightforward. The use of different metrics, propagation models and impact thresholds are one such issue making it very difficult to assess impact, compare across projects, much less to consider cumulative impacts. Currently, because of the levels of uncertainties, consenting decisions have been made by drawing on expert opinion. This poster will explore approaches that have been used in submissions thus far and highlight what knowledge needs to be improved to reduce uncertainty.

DISCOVERY OF SOUND IN THE SEA (DOSITS): RESULTS FROM THE SECOND NEEDS ASSESSMENT OF THE REGULATORY COMMUNITY

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Discovery of Sound in the Sea (DOSITS; www.dosits.org) is a comprehensive, educational website on underwater sound, designed to provide accurate scientific information at levels appropriate for all audiences, including regulators and decision makers. Regulators have needs for comprehensive, easy to understand, and rapidly accessible resources. To meet these needs, the DOSITS team is developing targeted resources for the regulatory and decision maker community. The first of these resources, a tutorial on the effects of underwater sound on marine life, is now available online. The team developed and administered a survey designed to identify high priority topics and resource formats in 2014. A second survey has been administered in 2015 to further identify topics that the DOSITS team can address in developing new resources for the regulator and decision maker community. All members of the community that deal with underwater sound and/or marine animals were encouraged to complete the survey, including government employees, federal and state contractors, non-governmental organization employees, and industry representatives. The survey data will directly influence the development of new resources, which will be publicly available on the DOSITS website. Survey results and an overview of the timeline and content for additional new resources will be discussed.

APPLICATION OF A NOISE MODEL FOR ENVIRONMENTAL IMPACT ASSESSMENT OF DEEP SEA MINING

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The Chatham Rise is a submarine feature extending eastward from the South Island of New Zealand. The rise has water depths of 80-500 m and hosts economically significant amounts of rock phosphate captured in nodules on/within the seabed. Chatham Rock Phosphate are planning to mine the phosphate using conventional dredging methodology adapted for deep water.

This paper addresses the underwater sound modelling undertaken to inform the environmental impact assessment into the potential effects on mining on commercial fish in the area.

Modelling of underwater sound propagation was undertaken using the Hammer tool developed by HR Wallingford which is a parabolic equation model similar in principle to RAM. The modelling represented two sound sources, one near the sea surface representing the engine of the mining vessel and one near the sea bed representing the pumps. Estimates of source levels for both were obtained via the scientific literature and in consultation with the project team. The modelling took into account seabed sediment type and bathymetry of the study area as well as water temperature and salinity. Estimates of background underwater sound were also made.

The model predicted the propagation of underwater sound at discrete frequencies covering the sensitivity range of the marine species of interest. As the focus of this assessment was potential impact of underwater sound on commercial fisheries, the range of frequencies selected for modelling were below 1 kHz as the majority of fish species are most sensitive to this range.

The results of the sound modelling indicated that low frequency sound propagates as far as the mainland of New Zealand and the Chatham Islands. The wide extent of underwater sound occurs because of the depth of the water at the site. Low frequency sound, particularly under 1 kHz, does not dissipate as quickly in deep water compared to higher frequencies.

The paper will discuss the potential impact of noise from the proposed mining on local fisheries and will discuss the lessons learnt during the study.

**ACHIEVING UNDERWATER NOISE REGULATION THROUGH AN ECOSYSTEMS-BASED APPROACH: THE
“MEDITERRANEAN STRATEGY ON UNDERWATER NOISE MONITORING”**

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The Ecosystems Approach (EcAp) initiative, as implemented in the framework of the Barcelona Convention, is structured in 11 Ecological Objectives, where the eleventh is energy including underwater noise (EO11). In this context, the Agreement on the Conservation of Cetaceans in the Black Sea, the Mediterranean Sea and the contiguous Atlantic area (ACCOBAMS), in accordance with the Secretariat of the Mediterranean Action Plan of the United Nations Environment Program (UNEP/MAP), launched a study to develop a basin-wide strategy for underwater noise monitoring in the Mediterranean. Hence, a technical guidance was developed, outlining the indicators related to EO11, and providing the necessary information for stakeholders to secure a correct and straightforward implementation. The basis for developing such strategy was the Descriptor 11 of the Marine Strategy Framework Directive (MSFD) of the European Union and therefore two separate indicators are used for impulsive noise and continuous noise (indicator 11.1.1 and 11.1.2, respectively). Indicator 11.1.1 addresses space-time distribution of impulsive noise sources, while the 11.1.2 addresses levels of continuous noise through the use of measurements and models. The proposed strategy on noise monitoring recommends several adaptations for the Mediterranean case. Particularly, both indicators are more closely related to the acoustic biology of key marine mammal species of the Mediterranean which are known to be sensitive to noise, i.e. the fin whale, the sperm whale and the Cuvier's beaked whale. The proposed monitoring strategy, which will be presented to the next EcAp Meeting end of March 2015, represents a further important progress towards an effective and widely agreed regulation of underwater noise at a regional scale.

THE VALUE OF OPPORTUNISTIC DETECTIONS TO IMPROVE PASSIVE ACOUSTIC MONITORING

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"Passive acoustic monitoring (PAM) is an ever-increasing tool used during real-time mitigation within the energy industry. Information on characteristics of clicks and whistles for different cetacean species permits classifiers to be created thus making detection and species identification more effective during real time mitigation. In South Africa in 2012 a group of Heaviside dolphins (*Cephalorhynchus heavisidii*), endemic to the west coast of South Africa and Namibia, were detected using PAM. This species produces high frequency clicks ranging from 120 – 140 kHz, similar to other species in the same genus, although relatively few studies of the acoustic properties of these dolphins exist. Data extrapolated from this detection includes frequency range, inter-click intervals and pattern of click trains which increases the ability of classifiers within PAMGuard to make detections of this species more effective. "

POLAR

SYNOPTIC MEASUREMENTS OF AMBIENT NOISE IN THE FRAM STRAIT MARGINAL ICE ZONE

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This presentation will give an overview of three ambient noise experiments conducted in the Marginal Ice Zone of the Fram Strait in the years 2010-12. Fields of sonobuoys were deployed by P-3C aircraft over large (150 km x 150 km) areas under varying ice conditions in different seasons. Noise spectra from 20 Hz to 1 kHz are presented and compared with historical data from similar experiments conducted in 1987. The spectra are categorized by environmental parameters that include wind force and direction, ice concentration derived from satellite images, ocean wave and swell, and sound propagation conditions. Biological and anthropogenic components of the noise fields that are discussed include sound due to marine mammals, tomographic transmissions, and distant seismic exploration.

BROADBAND AMBIENT NOISE AND ICE-RELATED PROCESSES IN THE ARCTIC - MULTI-YEAR STUDIES OF HANS GLACIER, SVALBARD

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The rapid climate warming observed in the last decades is strikingly noticeable in the Arctic, where ice cover and thickness decrease whilst the melt rates of individual glaciers increase. This translates into louder underwater noise at a range of frequencies. Starting in 2009, we have measured these levels in Svalbard fjords, contrasting different types of ice covers and glaciers. Hornsund Fjord, surrounded by glaciers, can be contrasted with Murchison Fjord, covered with marine ice floes. In 2010, we measured noise contributions from individual growlers in anechoic tanks, investigating melting, colliding, scraping and capsizing. The latest results from the 2013 and 2014 field surveys in Hornsund Fjord use long-term deployment of broadband hydrophones close to the glaciers: point measurements of broadband noise and its directionality, combined with time-lapse photography; and more tank measurements of fresh growlers and slabs of ice, simultaneously measuring noise and high-speed photography. Four frequency bands were identified and analysed: 20 Hz-200 Hz, 200 Hz – 800 Hz, 800 Hz – 4,000 Hz and 4,000 Hz – 16,000 Hz. They can be confidently associated with distinct geophysical phenomena, such as the noise generated by the bursting of air bubbles trapped in melting growlers and icebergs, waterfalls from glaciers and calving glacier noise. We observed significant fluctuations of Sound Pressure Level caused by changes in weather, waves and flows of noisy growlers and icebergs from the calving glacier. Specific signatures were identified with bespoke, advanced signal processing techniques and they will be presented in this paper. Long-term measurements over several years are continuing now, and because glaciers around Hornsund Fjord are typical of the Atlantic sector of the Arctic, our results are applicable to many other, similar areas around the world.

This work was supported by the National Science Centre of Poland (research projects no. UMO-2011/03/B/ST10/04275 and UMO-2013/11/N/ST10/01729), the US Office of Naval Research, Ocean Acoustics Program (grant no. N00014-14-1-0213) and the statutory activity of the Institute of Geophysics, Polish Academy of Sciences.

CHARACTERISTICS OF UNDERWATER NOISE SOURCES AT THE GLACIER ICE-OCEAN BOUNDARY: SUB-GLACIAL DISCHARGE AND SEICHES

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Passive underwater acoustics have revolutionized many fields including marine biology and physical oceanography, but have only recently been applied to explore glacier ice/ocean interactions. Sources of sound near glacier and ice-sheet margins include calving events and ice shelf rifting events, iceberg motion and collision, glacier ice melting, ocean surface-ice-cover conditions, ocean wave action (including seiches), rain and snow, and subglacial discharge. Among these, only ice melting and calving have been characterized through acoustic recordings combined with synchronous observations. The other sources are more difficult to characterize due to the difficulty of isolating the acoustic signal and/or collecting synchronous observations. For example, subglacial discharge is a subtle, yet important, tremor-like source that should have a diurnal and seasonal variability, punctuated by outburst flood events. Because it is a localized source along the glacier ice-ocean boundary, the geometry of the subglacial conduit and fjord relative to the position of hydrophones affect this noise characteristics making this source is difficult to infer. Seiche action, on the other hand, is a distributed surface source whose characteristics, while dependent on fjord geometry, are more distinct because they are primarily due to the seiche wave interacting with and reflecting off the coastline and ice terminal cliff. Here we present the theoretical and observed noise characteristics produced by subglacial discharge, seiche action, and surface-ice cover from Meares Glacier, Alaska; Icy Bay, Alaska; and Anvdord Bay Antarctica.

PASSIVE ACOUSTICS FROM MOORINGS AND DRIFTING ICE STATIONS IN THE FRAM STRAIT.

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Recent results from acoustic measurements from drifting ice station in the marginal ice zone and from moorings in the Fram Strait will be presented. Focus is on describing the ambient noise characteristics in this very dynamic environment. As part of the WIFAR and UNDER-ICE projects passive acoustic recordings were obtained by an autonomous Integrated Ice Station (IIS). The IIS was drifting with the ice for several days in the Fram Strait marginal ice zone during late summer 2012 and 2013. The IIS was developed for NERSC, integrating components from Scripps Institution of Oceanography, Woods Hole Oceanographic Institution and Christian Michelsen Research. The recorded noise was analyzed in detail to separate and quantify different sounds. Spectral analysis of acoustic spectrograms was used to identify regularly varying sounds. This helped especially in the identification of man-made noise, which dominated noise levels at frequencies below 100 Hz.

Furthermore, we will present preliminary results from analysis of low frequency passive acoustics from the multipurpose acoustic network implemented in the Fram Strait as part of the ACOBAR project. The system was operating for two years in the deep part of the Fram Strait. The hydrophones on the receiver mooring were recording 300 s every three hours for 2 years. Sample rate is 1000 Hz, and low frequency passive acoustic information is available.

AMBIENT NOISE IN THE ARCTIC OCEAN MEASURED WITH A DRIFTING VERTICAL LINE ARRAY

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In mid-April 2013 a Distributed Vertical Line Array (DVLA) with 22 hydrophone modules over a 600-m aperture immediately below the subsurface float was moored near the North Pole. The top ten hydrophones were spaced 14.5 m apart. The distances between the remaining hydrophones increased geometrically with depth. Temperature and salinity were measured by thermistors in the hydrophone modules and ten Sea-Bird MicroCATs. The mooring parted just above the anchor shortly after deployment and subsequently drifted slowly south toward Fram Strait until it was recovered in mid-September 2013. The DVLA recorded low-frequency ambient noise (1953.125 samples per second) for 108 minutes six days per week. Previously reported noise levels in the Arctic are highly variable, with periods of low noise when the wind is low and the ice is stable and periods of high noise associated with pressure ridging. The Arctic is currently undergoing dramatic changes, including reductions in the extent and thickness of the ice cover, the amount of multiyear ice, and the size of the ice keels. The ambient noise data collected as the DVLA drifted will test the hypothesis that these changes result in longer and more frequent periods of low noise conditions than experienced in the past.

CHARACTERISTICS OF AIR-GUN ARRAY PULSES AND THE AMBIENT SOUNDSCAPE IN BAFFIN BAY AND MELVILLE BAY, WEST GREENLAND

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MEASUREMENTS OF CUMULATIVE AIRGUN SURVEY ACTIVITY IN THE BEAUFORT SEA DURING ICE-FREE CONDITIONS, 2008-2012

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“Every year since 2007 a collection of at least 35 “Directional Autonomous Seafloor Acoustic Recorders” (DASARs) have been deployed across a 280 km swath of the Beaufort Sea continental shelf, in water depths between 15 and 50 m. The ability of these instruments to estimate the arrival azimuth of transient signals has facilitated the development of an automated algorithm for the detection of airgun survey activity, which has been applied to five field seasons of data. The contributions of airgun survey activity to the overall ambient noise background of the ice-free shallow-water Beaufort environment is quantified with a variety of metrics, in terms of both level (peak-to-peak, rms, sound exposure level), frequency, and time (intervals and fraction of time present). During some years, up to four airgun operations could be detected simultaneously, and a random one-second time sample yielded a 30% chance of containing an airgun signal, but the levels detected are generally within the bounds of natural wind-driven ambient noise levels. This dataset provides useful empirical insight into discussions about the cumulative contributions of anthropogenic noise to an environment extensively used by several marine mammal species. [Work sponsored by the Shell Exploration and Production Company.]

RIVERINE AND COASTAL

CEPHALOPODS' ANTI-PREDATOR RESPONSES TO SOUND DIFFER BASED UPON SOUND LEVEL, FREQUENCY AND PRIOR EXPERIENCE

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Cephalopods are an ecologically key taxon that likely use sound and may be impacted by increasing anthropogenic ocean noise. Yet little is known regarding the behavioral responses or adaptations to sound stimuli for these or many other marine invertebrates. Here we describe experiments that identify the acoustic range and levels that elicit a wide range of secondary defense behaviors such as inking, jetting, and rapid coloration change in squid (*Doryteuthis pealeii*) and cuttlefish (*Sepia officinalis*). Animals responded to tones across a broad range frequencies and sound levels. Frequencies spanned 80-1000 Hz and sound levels included 85–188 dB re 1 μ Pa rms (sound pressure) and particle accelerations of 10-3 to 17.1 m.s⁻². Secondary escape responses (inking, jetting) were observed between 80-300 Hz in both species, although cuttlefish responses occurred across a slightly broader range and to lower sound levels. Coloration changes and fin movements were observed at all frequencies and sound levels. Squid response latencies for inking and color change were variable but generally rapid, most often occurring at speeds of 0.1 to 0.01 s. Response occurrence rates decreased after repeated exposures but each species habituated at different rates. Total response inhibition occurred for squid but was not reached for cuttlefish and a basal “startle” response remained present in these animals. Overall, response intensity and occurrence rates were dependent upon stimulus amplitude and frequency. The graded responses associate with levels of predator threat suggest that cephalopods possess loudness perception with a maximum sensitivity around 150-200 Hz. These responses, typical of anti-predator secondary defenses, suggest an ecological function for sound use in cephalopods.

MID- AND HIGH-FREQUENCY NOISES OF SMALL FAST-SPEED BOATS IN SHALLOW WATER AND THEIR POTENTIAL IMPACTS ON THE INDO-PACIFIC HUMPBACED DOLPHINS (*SOUSA CHINENSIS*)

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Vessel noise impacts on marine animals are increasingly concerned. However, most vessel noise measurements have only focused on low frequency components. For mid- and high-frequency cetaceans, such as the Indo-Pacific humpbacked dolphins (*Sousa chinensis*), mid- to high-frequency noise components may be more of a concern in terms of their potential impacts on the animals. In this study, noises of a small shuttle fast-speed boat in a dolphin watching area focusing on the humpbacked dolphins in Sanniang Bay, Guangxi, China, were recorded using a broadband recording system. The fast-speed boat produced substantial mid- and high-frequency noise components with frequency up to over 100 kHz in three measured speeds: approximately 40, 30, and 15 km/h. The boat noise elevated ambient noise levels of 10 to 50 dB re 1 μ Pa rms across frequency band from 1 to 125 kHz at ranges between 20 and 85 m with louder levels at higher speed and closer distance. It is concluded that the noises produced by the investigated small fast-speed boat could be well heard by the *Sousa chinensis* and potentially affect the dolphins in diversified forms.

SHIP-ORIGINATED NOISE IN NARROW STRAITS USED FOR INTERNATIONAL NAVIGATION

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Narrow straits used for International navigation, such as the Istanbul Strait (Bosphorus), are heavy traffic corridors and ship-originated noise is a major threat for marine life as well as for human population mostly at night where they live on the shore of the straits. The Istanbul Strait or Turkish Straits System (Istanbul Strait - Marmara Sea – Canakkale Strait) is a unique corridor between the Black and Mediterranean Seas and yearly over 50,000 ships pass through the straits. There are also constant trips by commuter boats between the Asian and European sides of the straits. The amount of underwater noise created by such traffic may be impediment for migration and spawning for both the migratory and local fish communities. Besides, cetaceans are also adversely impacted from the noise pollution in the straits. A global monitoring is needed for such narrow straits used for international navigation. All precautionary approaches should be taken to mitigate or minimize noise pollution by using more eco-friendly ship engines, speed limitation and changing navigation routes during the migration period of cetaceans and the migration and spawning period of fish. One of the descriptors of Marine Strategy Framework Directive of the European Union is marine noise and this can be one of the instruments to reduce or control ship-originated noise in narrow international straits.

UNDERWATER SOUNDSCAPE ALONG WEST COAST OF TAIWAN

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Recent years, due to the development of offshore wind farms in Taiwan, many underwater ambient noise measurements were made in the west coastal shallow water zone. In 2013 and 2014, more than 20 experiments were made with underwater acoustic recorders (SM2M), and over 600 days data were collected at 10 sites. The goal of this study is to understand the acoustical characteristics of ambient noise and sound sources for the shallow water soundscape in Taiwan. According to results of spectrograms and Auditory recognition, various sound sources are found and diversely distributed in different locations. The sound made by croakers is the one of the most significant characteristics in Taiwan coastal zone. The strong croakers' sounds even exceed 120 dB re 1 μ Pa at 1 to 2 kHz from spring, and usually appear at 21:00 to 03:00 with few hours shifting depending on the locations and seasons. Besides, a continuous 60-Hz signal is measured by the recorder deployed near Tung-Hsiao Power Plant. The unique sound source may be produced by the power plant. Shipping and wind-driven wave noises are shown as the baseline of ambient noise. These materials are based upon works supported by Ministry of Science and Technology, Council of Agriculture Executive Yuan Forestry Bureau, Taiwan Generations Corp. and SWancor Ind. Co., Ltd.

SPATIAL AND TEMPORAL VARIATIONS OF BIOLOGICAL SOUND IN A SHALLOW MARINE ENVIRONMENT

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The shallow marine environment exhibits different soundscape characteristics compared to that from the deep ocean. In the shallow waters, biological sound plays an important role in local soundscape. Biological sounds such as fish calls and cetacean whistles are used for communication and finding mates. In addition, odontocetes also use high-frequency biosonar to search their prey. Thus, study the spatial and temporal variations of biological sounds can help us examine the behavior and habitat use of soniferous marine animals. In shallow waters of western Taiwan, most of the biological sounds are produced by snapping shrimps, croakers, and Indo-Pacific humpback dolphins. Shallow and coastal waters are highly influenced by tidal currents, seasonal change of river runoff, and temperature. Due to the difficulty of marine ecological research using visual-based surveys in turbid waters, the temporal and spatial variations of biological activities remain unclear. In this study, underwater sound recorders, SM2M and SM2+, were used to collect long-term acoustic data. Among biological sounds, croaker chorus was identified according to the daily change of sound pressure levels within the 0.5-2.5 kHz frequency band, and whistles and echolocation clicks of humpback dolphins were detected using the local-max detector and high frequency click detector, respectively. Croaker choruses and dolphin vocalizations were frequently detected at inshore and estuarine stations during wet seasons (from April to September). Croaker choruses were evident during the nighttime, especially after sunset. Humpback dolphins were primary detected after the midnight until the next morning. During dry seasons (from October to March), the durations of croaker chorus were reduced. There were no evident differences among inshore and offshore stations. The detection rates of humpback dolphins in the estuarine station were lower compared the detection rates in wet seasons. The temporal and spatial variations of croaker chorus and dolphin vocalizations indicate that the distribution and behavior of croakers and humpback dolphins changed between wet and dry seasons. Several offshore wind farms have been planned to be built in western Taiwan waters. The construction and operation noise of these wind farms may alter the acoustic environment and influence the behavior and habitat use of marine animals. Current results can be used to evaluate the potential impacts of offshore wind farms on the local ecosystem.

ACOUSTIC SPECIES IDENTIFICATION AND MONITORING TO ASSESS THE EFFECT OF MARINE DEVELOPMENT ON MARINE MAMMALS

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THE DISTRIBUTION OF AN ISOLATED POPULATION OF FINLESS PORPOISES IN RELATION TO NOISE, SHIP TRAFFIC AND FISH DENSITY IN ISE AND MIKAWA BAYS, JAPAN

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Finless porpoises are endemic to Asian coastal waters, their distributions extending from the Red Sea to Japanese waters but are usually restricted to a depth less than 50 m. They are therefore particularly susceptible to anthropogenic impacts and need to be monitored regularly. One of the three subspecies, the narrow-ridged finless porpoise (*Neophocaena asiaeorientalis sunameri*) is distributed along the East Asian coasts from the South China Sea to Sendai Bay, northeast Japan. There are five isolated populations of this animal found in Japanese water. To study the ecology of an isolated finless porpoise population in Ise and Mikawa bays, Japan (N34.2-35.0, E136.5-137.5), we conducted passive acoustic line transect surveys for the porpoise. A stereo event recording device, called A-tag was towed 100 m behind the survey ship to detect echolocation signals of finless porpoises, which are produced every six seconds on average, both day and night. An echo sounder was also used to detect their prey items. The zigzag lines were designed to cover Ise-bay (1465km²), Mikawa-bay (533 km²) and an oceanic region (933km²), respectively. The three areas were investigated repeatedly in spring, summer and winter from 2012 to 2014. Passive acoustic monitoring was successfully applied to observe population dynamics of the finless porpoises within a two dimensional area. In a total of seven surveys, the lines of 4014 km were surveyed and 849 finless porpoises were detected. The porpoises were found mostly in the area with a depth shallower than 30 m. Encounter rates were much higher inside the bays than the oceanic regions (on average 0.21 and 0.07 individuals/km, respectively). The distribution showed clear seasonal change. The porpoises move out from the shallow Mikawa-bay to Ise-bay in winter and go into Mikawa-bay from spring to summer. The lower density are of the porpoises occurred where fish were also absent. However, porpoises were found to occupy channels for big ship lanes, fishing and noisy areas. The distribution patterns associated with prey density are similar to that observed in Yangtze finless porpoises.

MAPPING & MODELING

FINE-SCALE MAPPING OF PILE DRIVING NOISE IN THE CROMARTY FIRTH

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Assessments of the effects of underwater noise on marine fauna often rely on simplistic assumptions of sound propagation. Much offshore development occurs in shallow coastal waters, often with complex bathymetric features and seabed properties, which confound the predictions of models based on geometrical spreading. Nevertheless, such models routinely form the basis of environmental impact assessments for offshore operations. Here, we consider the application of more sophisticated models with greater predictive capability to the assessment of noise generated by pile driving in a coastal inlet. During 2014, the dock at the fabrication yard in Nigg, Scotland, was extended, with foundations installed using both impact and vibrational piling. The yard lies at the mouth of the Cromarty Firth, within a Special Area of Conservation for marine mammals, including bottlenose dolphins. Three autonomous recorders were deployed during the construction period, measuring underwater sound synchronously throughout the site. Additionally, an array of C-PODs monitored the presence of small cetaceans in the area. An N-by-2D parabolic equation model (RAM) was used to map levels of piling noise throughout the site, using input data from the recorders and environmental parameters. This enabled assessment of fine-scale variability in noise exposure, particularly in relation to the locations of the C-POD cetacean detectors. Our results demonstrate that sound propagation substantially deviated from spreading-based predictions, and that counterintuitive increases in noise level with increasing range were accurately represented in the noise maps produced using RAM. These findings highlight the need for more detailed consideration of sound propagation in the assessment of noise exposure in coastal regions.

THE PSSEL MODEL FOR RAPIDLY MAPPING THE PROBABILITY OF SHIPPING SOUND EXPOSURE LEVEL FROM TRAFFIC DENSITY

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The effects of the long-term increasing trend in cumulative level of manmade noise on aquatic ecosystems are sources of concerns for several national and international regulation agencies, research groups, and the general public. Since shipping is the most prevalent contributor, addressing the shipping noise problem and its impact on marine life is among present research priorities. This includes series of measurements of mid- to long-term underwater noise at various locations in the 3D environments affected by different shipping activity and the assessment of the actual source levels (SLs) of the present fleets. This information can be combined with traffic density and transmission loss (TL) models to feed shipping noise mapping models generalizing the measurements to broader temporal and spatial scales of the studied parcel of ocean of interest for marine life.

Mapping vessel noise from shipping traffic density, vessel SLs and TL models is therefore emerging as one method of identifying areas where sound exposure level (SEL) due to shipping noise could have negative impacts on aquatic ecosystems. Mean shipping sound exposure levels (SSEL) over a given time integration period (T) is an important metric for identifying areas of relative high noise level. However, this metric is unable to provide information on how often the SSEL is exceeding thresholds of concern for its impact on aquatic life. For instance, a heavy traffic of silent ships can have the same mean SSEL than a low traffic of very noisy ships but the impacts on aquatic life will be different.

To identify areas of actual concerns as well as areas of negligible effects on the basis of the recurrence of levels exceeding critical thresholds, the probability distribution function (pdf) of SSEL is needed. The pdf of SSEL can be obtained from repeated short-time SSEL mapping and Monte-Carlo simulations assuming valid pdf for inputs variables, but at the cost of excessively large computing efforts. The PSSEL model is a new method to rapidly compute the pdf of SSEL by using actual pdfs of ship traffic density on seaways, SLs, and TLs. The method relies on the sonar equation and classical statistical relations linking the pdfs of random variables to their sums and products.

The PSSEL model is illustrated here with applications to marine mammal habitats crossed by seaways in Arctic and temperate Canadian waters. The SSEL-pdfs are computed for synthetic or real shipping density data in a single step with a high resolution. The percentage of time the SSEL is above or below threshold values is mapped and areas of concern or negligibly affected on the basis of management based threshold levels and degree of recurrence can be delineated.

SONIC: MODEL GENERATED SOUND MAPS AND FOOTPRINTS OF SHIPS

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“The SONIC (Suppression Of underwater Noise Induced by Cavitation) project was awarded within the European Seventh Framework Programme to develop tools to investigate and mitigate the effects of underwater sound generated by shipping activities on marine life. Model generated sound maps were identified by the European Commission as a monitoring tool to complement measurements.

Sound mapping tools are being developed to provide a representation of shipping sound that is both meaningful to policy makers without a background in acoustics and sufficiently representative of the phenomena relevant to environmental impact. The accuracy of the end result depends on the fidelity of the source description and of the propagation model used to compute the sources' combined contributions.

A shipping sound map can cover a large geographic area, including a large quantity of sources radiating sound over a broad spectrum of frequencies. The corresponding computational load is too large to generate a solution in an acceptable time using off-the-shelf acoustic propagation models, and the band of frequencies to be computed is wider than the domain of application of most available individual models. A solution to these limitations has been found in the form of an efficient hybrid propagation modelling approach.

In this presentation, the sound map and footprint tool developed within the SONIC project is presented. Both the numerical and data driven validation of the model are discussed through a variety of examples. Finally it is shown how the tool can be used to display the results that are calculated in five dimensions (latitude, longitude, depth, frequency and time) in meaningful two-dimensional sound maps for assessing environmental impact and studying measures to mitigate potential adverse effects on marine life.

MAPPING RISK AND OPPORTUNITY AREAS FOR THE MANAGEMENT OF SHIP NOISE IN THE HABITATS OF 10 MARINE MAMMAL SPECIES OFF WESTERN CANADA

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In our study, we mapped the zones of risk and the zones of opportunity for the interaction of ship noise with 10 species of marine mammals in British Columbia, Canada. Based on previously published ship tracks for the summer of 2008, we modelled the propagation of ship noise throughout British Columbia on a 5 km x 5 km grid. Received spectra were weighted using estimated mean audiograms for Pacific white-sided dolphins, killer whales, porpoises (one audiogram for both harbor and Dall's porpoise), harbor seals, elephant seals, Steller sea lions, and baleen whales. In the absence of a baleen whale audiogram, we selected the ambient noise limited audiogram derived by Clark and Ellison (2004) for fin whales, humpback whales and minke whales. Integrating mean square pressure yielded maps of ship noise relevant to each of the 10 species. We correlated these audiogram-weighted noise maps with density maps for each species to highlight the risk areas, where high animal density and high ship noise overlap. We further correlated the density maps with the inverse of the noise maps to show regions of opportunity, where animals occur in large numbers, and ship noise is low. For all species, one such opportunity area was east of Haida Gwaii. We discuss how both the risk and the opportunity areas can be used in marine spatial planning.

MAPPING ANTHROPOGENIC NOISE IN EUROPEAN WATERS: EXAMPLES FROM THE AQUO AND BIAS EUROPEAN PROJECTS

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“The European AQUO project started in October 2012, in the scope of the FP7 European Research Framework, for three years duration. The final goal is to provide policy makers with practical guidelines and solutions, in order to mitigate underwater noise footprint due to noise radiation from ships.

In the framework of the AQUO project, real-time mapping of shipping noise has been implemented in three areas across European waters. The monitoring system is composed of (a) acoustic observatories, deployed permanently, which continuously measure the ambient noise, (b) real-time acoustic embedded processing which continuously estimate noise in third octave bands, (c) real-time modeling which predict three dimensional noise field at large scale, (d) real-time acoustic data assimilation processing which calibrate the modeling output to provide noise map, (e) statistical processing which provide monthly and annual averages in order to evaluate trends of the ambient noise at the scale of a basin.

These services are operational. Results for the AQUO test sites are made available in real-time through a web access which will be demonstrated.”

VARIATION IN AMBIENT NOISE LEVELS AND ACOUSTIC PROPAGATION ACROSS A TIDAL FLOW

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Tidal energy converters will introduce sound into the marine environment by converting water movement into electricity. Propagation of such sound is directly related to local background noise and is of particular interest because of its potential effects on the marine environment. Yet, few measurements of ambient noise or acoustic propagation across tidal flow environments exist. This study measured sound propagation conditions across a tidal stream during different tidal states on the west coast of Scotland. Observed differences in background noise levels were generally higher during high flow (spring ebb tide) as compared to slack periods (neap tide). Sound propagation in this environment was highly frequency dependent. Higher received sound levels were observed during slack flow compared to high flow periods for frequency components between 200 Hz to 6.3 kHz. Below 200 Hz the trend gradually reversed with higher received levels observed during higher flow periods. Likely due to the increase in background noise and reduced propagation of the higher signal frequencies, receivers generally recorded fewer signals during high flow periods and detected signals showed broader variance in these conditions. Similar trends in acoustic propagation were observed on two recorders upstream and downstream relative to the perpendicular axis of the main flow direction, suggesting that propagation conditions were not affected by directional flow components. These observations highlight the variability in natural ambient noise and acoustic propagation conditions in highly energetic environments, which need to be taken into account when predicting the sound field of newly introduced marine structures such as tidal energy converters.

SOUND SOURCE VERIFICATION & MARINE MAMMAL MITIGATION

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Worldwide government agencies and regulators are showing an increasing interest in Sound Source Verification (SSV) techniques, analysis and results in order to assess the impact of sound on marine mammals and the environment. The purpose of the SSV is to monitor, measure and record sound levels generated during man made operations within the seas and oceans. By example, agencies require an SSV to be undertaken for seismic survey source arrays, prior to full operations commencing. Broadband decibel (dB) levels are calculated for 190dB, 180dB, 160dB and increasingly 120dB and empirical distances are identified from the source location. This information is then utilized in order to define marine mammal mitigation zones to be applied to a particular survey and location.

Modelling of the sound propagation is initially undertaken to approximate the sound field expectation. Following this one of two unique solutions are used in order to increase the visibility of the propagation effects across the complete. The first is characterised by the use of drifting buoys, typically six. Utilizing the tidal and other currents an expected trajectory for each buoy is plotted in order to encompass the sound field. The buoys are deployed upstream from the source at the identified launch positions. The buoys are allowed to drift in an autonomous fashion, naturally in the currents gathering data points as they go in a pseudo random fashion. This allows for data to be collected in a very dynamic and realistic manner, typically 1000's of valid data points are recorded for every deployment. The method is particularly effective in fast flowing currents but the drift buoys have also been deployed in areas of low tidal movement with excellent results. As the sensors are travelling with the current the noise normally associated with water flow and drifting debris impacts is eliminated.

Alternatively a seismic source vessel and accompanying support vessel are utilised, a towed hydrophone is permanently deployed from the support vessel and continually records data about the sound levels received as the vessel goes about its normal duties around the source vessel and survey site. The seismic survey vessel operates normally, continually surveying. This gradually builds up a sound field map of the survey in real time accounting for the changing bathymetry and environment at a continually varying distance. Again, as with the drift buoy, this is a pseudo random collection method as there is no pre-determined route or location defined. Both the source and support vessels are GPS and AIS tracked so the exact positions are identified, enabling sound levels to be accurately calculated and the recording location to be pinpointed. Again 1000's of data points are collected from a large number of widely varying locations. This data is then analysed in order to verify the accuracy of the propagation model and enable modelling to be evaluated and improved on an ongoing basis.

FROM LABORATORY TO NOVATIVE IN-SITU CALIBRATION PRACTICES AND SYSTEMS FOR HYDROPHONE LOGGERS AND DIGITIZATION SYSTEMS WITH FOCUS ON PROPAGATION IN-SITU MEASUREMENT.

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- Introduction

In Europe, underwater noise impacts on marine life related to offshore wind farms has been a growing issue. Of which, the main consideration states around installation of monopiles generating very high-level of impulse noises.

- Growing European underwater noise regulations and concerns

In Europe, the Technical Subgroup on Underwater Noise (TSG noise) provided guidance for member states on meeting the requirements of the Marine Strategy Framework Directive (MSFD) with regards to underwater noise, of which measurement of sounds such as pile-driving, and its potential impact on marine life.

Leading the way in the area of noise regulations, Germany, via its Federal Maritime and Hydrographic Agency, BSH, defined a threshold limitation of Sound Exposure Level (SEL) at 160dB at 750 meters from the monopiles for offshore wind farms constructions.

Offshore operators are now to answer both noise mitigation and measurement issues, whereas are to be installed more and more monopiles.

- Towards in-situ calibrated underwater noise measurements

With a Sound exposure level limitation; a single dB difference in measurement and calculation of the underwater noise level can modify a regulation decision and paralyze construction operation.

It is then crucial for an operator to answer a dual problematic; measure its noise emission level in-field as accurately as possible and validate measurement systems calibration capabilities along the pile driving operations.

REGULATION

MANAGING TERRESTRIAL SOUNDSCAPES AND LESSONS FOR SENSITIVE OR PROTECTED MARINE PLACES.

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Legislative mandates and National Park Service policy demand that park acoustic environments be conserved to leave them unimpaired for the enjoyment of future generations (Organic Act of 1916). NPS funded research and compiled extensive reviews of studies documenting the significance of this physical resource for wildlife and visitor experience. To assess current conditions, NPS developed an acoustical inventory program that captured data from more than 600 sites in a little over 10 years. This measurement program addressed a variety of potential metrics, because acoustic environments are not unidimensional. A geospatial model developed from these data provides predictions of acoustical conditions throughout the US, providing support for park management in the context of large landscape conservation. Interpretation of science and implementation of policy takes place through Director's Orders and other national guidance documents, and park planning. Park acoustic resource management goals are often articulated in the context of managing a specific activity: air tours, snow vehicles, off road vehicles, personal watercraft. The controversy surrounding these activities can complicate the assertion of resource management objectives. Accordingly, some parks have chosen to create Soundscape Management Plans that specify resource management goals that apply to all activities in the park. Effective noise management must transcend park boundaries, and partnerships that span landscape scales are essential. NPS success stories have been distinguished by innovative management options, innovative approaches to partnerships, and innovative communications plans.

APPLICATION OF THE INTERIM PCoD MODEL IN A DUTCH ASSESSMENT OF THE CUMULATIVE IMPACT OF PILE DRIVING SOUND ASSOCIATED WITH NORTH SEA WIND FARM DEVELOPMENT

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Impact pile-driving for offshore wind farms generates loud impulsive underwater sounds. In the past year, a Dutch expert group, supported by the government, has developed an approach for the assessment of the cumulative impact of the long term plans for offshore wind farm development in the North Sea on the harbour porpoise population. The approach combines acoustic modelling for the various wind farm projects with seasonal porpoise abundance data, to estimate the number of porpoises that are potentially disturbed during piling days. Together with various scenarios for the planning of North Sea wind farm projects over the years 2016 to 2022 this provides an estimation of a total sum of 'porpoise disturbance days'.

The Interim PCoD (Population Consequences of Disturbance) tool, developed by scientists at the University of St Andrews and SMRU Marine and made publicly available in the fall of 2014, was used to translate the number of porpoise disturbance days to an effect on the size of the porpoise population. The results for various scenarios show an approximate linear relationship between porpoise disturbance days and porpoise population reduction. The number of piling days alone (EU MSFD indicator 11.1) does not exhibit such a clear relation with the modelled population effect. The assumptions underlying these calculations and the many knowledge gaps that were identified are described in the report of the expert group.

THE NEED FOR INTERNATIONAL COOPERATION ON GENERATING KNOWLEDGE, ASSESSING IMPACTS AND TAKING MITIGATION MEASURES.

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The Dutch government has prepared a framework to assess and evaluate the cumulative effects of offshore windfarms both national and international (in the same biogeographical region) mainly on marine mammals, birds and bats. The framework is meant to be a living document and will be reviewed on a regular bases and updated with the most recent results of research and (international) developments. One of the topics addressed in this framework is the impacts of underwater noise from pile-driving on the harbor porpoise. The framework will eventually address other species and other sources of disturbance as well.

To this end a Dutch expert group was asked to develop an approach to assess the population consequences of windfarm construction on the harbour porpoise over the period in which current Dutch policy is aiming at offshore windfarm development (a five year period for 2018-2023). There are several uncertainties in the assumptions made by the experts and the models used. In the coming years work will continue to substitute the assumptions by results obtained through research. This approach, the assumptions made and the uncertainties due to knowledge gaps will be presented by Christ de Jong of TNO Netherlands in more detail.

Even with the aforementioned uncertainties, it is clear that the impact of the offshore construction of windfarms might have a substantial impact on the marine wildlife of the North Sea. It is also clear that the protection of species like marine mammals, birds and fish that are not bound by national boundaries cannot be accomplished by one country alone. There is a need for the countries bordering the North Sea to cooperate to better understand the impacts of the windfarm construction based on assumptions formulated commonly. And there is a need to work together on deciding the necessary mitigation measures. In 2016 the Dutch government will reach out to neighbouring countries to discuss both the approach developed and the possibilities of cooperation on possible measures to mitigate the consequences of underwater noise on the marine wildlife of the North Sea and to coordinate research effort.

THE CONTRIBUTION OF THE **UK NAVY** TO THE MONITORING PROCESS NEEDED FOR THE **EU MARINE STRATEGY FRAMEWORK DIRECTIVE**

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The UK MOD is committed to taking all reasonable and practical measures when it comes to protecting the marine environment. As part of this commitment they have pledged to report all ASW sonar activity to Joint Nature Conservation Committee (JNCC) who is collating a UK noise activity register. This is seen as the MODs initial input whilst looking at further opportunities to support this initiative.

CONSIDERATIONS FOR FUTURE OCEAN NOISE MANAGEMENT

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Management of anthropogenic noise in the oceans has, in the past, largely been limited to singular activities both in space and in time. For example from a regulatory perspective, the management of sounds emanating from a seismic survey has been limited to the survey area itself and the duration of the survey. Further, little to no consideration has been given to the fact that many other concurrent activities could be happening which may contribute to the overall noise levels in the area.

Recently scientists, regulators and concerned stakeholders have petitioned for more consideration to be given to the fact that animals do not necessarily operate on the same spatial and temporal scales as that of anthropogenic activities. For example, animals may use a given ecosystem (potentially large scale areas) to support their life functions. The animals may also depend on time variant ecosystem functions such as changing current patterns or during times that are conducive to productive feeding or breeding. Concerned parties would also like to see consideration be given to the noise contributions resulting from multiple concurrent noise generating activities.

Changing the way in which we think about the scales, both spatial and temporal and the concept of including all sources of noise that could contribute within a given ecosystem presents challenges. Some of these challenges can be of the technical nature such as the need for additional monitoring stations and improved noise modeling techniques to enable a better understanding of ocean noise levels on larger spatial scales.

Although we face formidable technical challenges, non-technical challenges may prove to be greater. For example, the human trait to oppose change or the way various stakeholders view the noise issue are critical hurdles we must overcome for progress to be made.

This presentation will provide the author's view of some of the challenges ahead and present ideas as to how one might begin to solve them.

THE NOAA OCEAN NOISE STRATEGY

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MITIGATION

IS THERE A STATE-OF-THE-ART REGARDING NOISE MITIGATION SYSTEMS TO REDUCE PILE-DRIVING NOISE?

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Underwater noise caused by pile-driving during the installation of offshore foundations is potentially harmful to marine life. In Germany the regulation authority BSH set following limit values: Sound Exposure Level 160 dB and Peak Level 190 dB for marine mammals which must be complied with at a distance of 750 m to the construction site. The experience over the last year's shows that produced underwater sound during pile driving depends on many parameter and measurements show values of up to 180 dBSEL and up to 210 dBPeak. Therefore Noise Mitigation Systems (NMS) are requested to minimize the hydro sound significantly. Since 2011 NMSs have to be applied during all noisy offshore construction work in Germany. The itap measured the hydro sound and evaluated the noise reduction of the used NMS during eleven OWF construction phases (> 700 pile installations without and with different NMS) in accordance to the existing measuring instructions for underwater noise measurements and determination of the insertion loss of NMS after BSH. Additionally, several founded research projects exists dealing with the identification of influencing factors on noise (e. g. "Big Bubble Curtain" (BBC) OFF BW II). In this presentation a general overview of existing and tested NMS including tested system variations is given. Thereafter the main influencing system parameters as well as other potential influencing factors like current or water depth on the effected noise reduction of the BBC based on measured data from research projects and running construction phases will be presented since the BBC is currently the most used NMS system. Additionally combinations of two and more NMS are measured during the construction phase in Germany if monopiles with diameters up to 6 m are installed. It will be demonstrated which effect one and more NMS have on the emitted noise. However it will be shown that it is possible to install monopiles with a diameter of 6 m with noise levels below 160 dBSEL if combinations of suitable NMS are used. Furthermore an overview of all tested NMS systems in Germany will be shown and the measured data will be discussed. The main results are that the noise reduction depends significantly on the NMS system configuration and with only one NMS noise reduction of 10 dB to 15 dB are possible. The question if a State-of-the-Art for reducing pile driving noise exists will be discussed based on measured data and experiences with these NMS under real offshore conditions.

UNDERWATER NOISE MITIGATION USING CUSTOMIZABLE ARRAYS OF ACOUSTIC RESONATORS

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A new type of noise abatement system consisting of a simple collapsible framework containing arrays of air-filled acoustic resonators has been developed to attenuate sound radiated by noise sources such as marine pile driving, offshore energy production, seismic sources, and ships, among others. Modeling and laboratory measurements were used to design individual resonators such that they target specific frequency bands coinciding with the spectrum of a noise source of interest. Demonstrations were performed at two offshore wind farm construction sites in the North Sea in 2014 using a small scale collapsible array to test whether the concept was effective in reducing noise radiated from impact driven piles. In these tests attenuation of nearly 40 dB SPL was measured near the individual resonators' resonance frequency of approximately 100 Hz, and almost 20 dB SEL was measured over all frequencies. The operational advantages of the system, as well as concepts for other applications for other types of noise sources, will also be discussed. Finally, planned validation tests of the noise abatement system will be introduced.

REDUCING CAVITATION BORN NOISE IN SHIP PROPELLER FLOWS

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Propeller cavitation is typically the most dominant noise source of commercial surface ships. Cavitation can rarely be completely avoided since the ship propellers are typically highly loaded. Propeller loading can be decreased by adjusting the main propeller parameters, such as propeller diameter, rate of revolutions, or ship speed. These parameters are usually defined by ship particulars or operational requirements and cannot be affected by the propeller designer. Cavitation enhances tonal and broad band noise emitted from ship propellers. The volume changes in the sheet and tip vortex cavities increase the tonal noise component in the propeller noise spectrum at the blade rate frequency and its harmonics. The broad band cavitation noise forms as a vast amount of cavitation bubbles collapse and rebound in the flow field. The bubbles are formed as the re-entrant jet breaks-off a part of a sheet cavity on the blade and a cloudy cavity formed of bubbles develops from the rear part of the cavity. Bubbles are also originated from mid-chord cavitation and from unsteady tip vortex cavitation. Root cavitation is usually foamy. Minimizing and stabilizing the cavitating region suppress the propeller emitted noise. Although cavitation is driven by pressure changes, the dynamics of cavitation are affected by the viscous effects in the flow field. Numerical methods based on the potential flow assumption and constant pressure inside the cavities are traditionally used in the cavitation analyses of propeller flows. The viscous effects in the flow field are then neglected. Cavitation tests are also used to validate the propeller cavitation performance. There the uncertainties are caused in scaling the results to the full scale and in modelling the ship wake in the test section. The computational fluid dynamics (CFD) based methods take into account the viscous effects in the flow field. The cavitation predictions performed using CFD have matured in the recent years to a point where they can be utilized in propeller cavitation analyses. The most significant benefit of the CFD simulations is that they can be performed directly in full scale. Combining the ship hull and the propeller in the CFD simulations gives the best possible prediction of the working conditions and cavitation behavior of the propeller. This technique helps the propeller designer to modify the propeller geometry so that the cavitation region is as small and stable as possible. The geometry modifications to suppress cavitation are case sensitive and depend also on how much the propeller optimum efficiency can be sacrificed. The presentation shows general principles to suppress cavitation in propeller flows. The effect of turbulence models in Reynolds-averaged Navier-Stokes (RANS) simulations on cavitation dynamics is also demonstrated in propeller flows.

USING OPPORTUNISTIC DATA TO REFINE UNDERWATER NOISE OUTPUT STANDARDS FOR COMMERCIAL SHIPS

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Commercial ships are a dominant source of noise throughout much of the world's oceans, raising profound concern about the degradation of acoustic habitat for marine mammals and other species. To help control the problem, focus has turned increasingly over the last decade to reducing the noise output of individual ships through quiet-ship design and technology. A number of entities have promulgated quantitative performance metrics for commercial vessels. At least two IACS-member ship classification societies (DNV, BV) have published notations for underwater radiated noise that include measurement protocols and noise output standards, and a third society (RIMA) is developing another; at the same time, SILENV, a research program funded by the European Commission, has published its own "green label" recommendations. Yet the metrics set forth in these notations and recommendations differ from one another and are based on limited empirical data. This presentation will show data on noise output derived from opportunistic measurement by the research organization Beam Reach, in the coastal waters of Haro Strait, Washington, off the northwest United States: a data set of approximately 1800 individual transits. It will compare the results from this data set with the performance metrics developed by ship classification societies and other entities, and explore how opportunistic noise measurement might be used to refine those metrics.

LOCALIZATION OF CETACEANS AND ANTHROPOGENIC SOURCES: A DIDACTIC PATTERN RECOGNITION FRAMEWORK USING NEURAL NETWORKS

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In the context of mitigation, passive acoustic monitoring systems able to localize the radiating acoustics sources in real-time and with great accuracy are necessary. Methods for the localization of cetaceans are many and vary in complexity, efficiency, and accuracy or computation time. A computationally efficient way to solve the localization of cetaceans and anthropogenic sources is to restate it as a pattern recognition problem.

This is one of the directions that have been explored at the Laboratory of Applied Bioacoustics (LAB) over the past few years. Such an approach unifies in a clear way methods based on TDOAs and supposedly more complex space-time methods (e.g. beamforming). The pattern recognition frame furthermore has a number of advantages: 1) it connects more tightly the tasks and tools for detection, classification and localization, 2) it applies the latest developments in machine learning and artificial intelligence to the field of cetacean localization, 3) it reaches a competitive accuracy, simplifies online computation and reduces drastically the computation time for real-time passive monitoring.

This presentation will show with concrete maps and situations how the pattern recognition approach works, in particular in the case of neural networks computations, and how it improves in real-time terms the localization and tracking of anthropogenic sources and of various marine mammals species (sperm whales, dolphins, fin whales, blue whales) from deep sea observatories around the globe included in the LIDO* framework.

*Listening to the Deep Ocean Environment : <http://www.listentothedeep.com>

THE MARINE VIBRATOR JOINT INDUSTRY PROJECT: AN UPDATE

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Three major oil and gas producers are working together to develop a commercially and technically viable marine vibrator as an alternative sound source for seismic surveys. ExxonMobil, Shell, and Total are sponsoring a joint industry project managed by Texas A&M University's Global Petroleum Research Institute (GPRI) to design, test, and construct marine vibrator prototypes suitable for use in offshore data acquisition programs. Three vendors have been contracted to each design and build a prototype.

The specifications for the marine vibrator are comparable to the kinds of air gun arrays currently used by industry. The motivation for the project is to mitigate some of the environmental objections to seismic surveying in certain parts of the world and to deliver additional geophysical and operational benefits such as bandwidth control and signal encoding capabilities.

Testing of prototype marine vibrators is currently underway. This presentation will give an update on the status of the project and highlight next steps towards qualifying the systems for use from a technical and environmental point of view.

ANALYSIS OF THE EFFECTIVENESS OF RAMP-UP DESIGN AS A MITIGATION MEASURE

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Ramp-up or soft start is routinely used at the start of seismic surveys or after shut down. Most environmental regulations specify that ramp-up should start with the smallest air gun in the seismic array and gradually increase the sound output over a period of 20 to 30 min, by adding air guns, although a 6 dB increase in level every 5 min has also been specified. The intention is to give animals time to move out of the way before full power is reached. Although ramp-up is widely used, there is little information to show how effective it is. One of the aims of project BRAHSS (Behavioural Response of Australian Humpback whales to Seismic Surveys) is to test the effectiveness of ramp-up, so a study was initially conducted to determine what ramp-up is typically used by industry. A survey provided by the International Association of Geophysical Contractors ramp-up procedures used in their seismic surveys showed that they followed the requirements, though there was some variation between different air gun arrays, because there is significant variation in the numbers air guns (most are between 20 and 60) and their volumes. As a result, the rate of increase in level per step of ramp-up varies between arrays. Consideration of mammal auditory perception suggests that, for marine mammals, the rate of increase in sound exposure level may generally be too gradual to be noticed as increasing loudness, and thus may not have the desired effect. From the point of view of the perception of ramp-up, the variation in rates of loudness increase means that there is no typical ramp-up. This paper presents an analysis of ramp-up used in seismic surveys and of how the resulting increases in loudness might be perceived by marine mammals. It leads to the view that ramp-up would be more effective, by being more noticeable to marine mammals, if the increases per step were larger than usually used, say about 6 dB. The consequence is that each stage of ramp-up would be larger and have a much longer duration than is currently the case, typically about 5 min per stage.

USING MARINE SEISMIC SOURCE TECHNOLOGY IN A DIFFERENT WAY

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Using marine seismic source technology in a different way R Abma, A Ross (BP America, 501 Westlake Park Blvd. Houston, TX 77079, USA) D Hedgeland, D Ellis (BP Exploration Operating Company Ltd, Chertsey Road, Sunbury-on-Thames, Middlesex TW16 7LN, UK) Introduction The maritime space is used by many industries and stakeholders for activities such as commercial shipping, oil and gas exploration and production, fishing, renewable energy developments, military, recreation and construction; all of which either use sound or introduce sound into the marine environment as a result of activities. Seismic surveys are an important tool for oil and gas exploration. Conventional marine source arrays use multiple airguns or source elements that are activated simultaneously to produce a pulse signal that propagates downwards and is reflected at boundaries between geologic structures beneath the seabed. Reflection data is then recorded and processed to provide images of the subsurface of adequate quality to guide decisions related to the placement of exploration and production drilling infrastructure. For any sound source to become available and widely adopted, it's important to achieve a balance between conducting safe and efficient operations, being able to realise geophysical objectives and understand potential interactions with the marine environment. Airguns currently provide the most efficient, robust and safe sound source that is commercially available for conducting geophysical surveys. The future of seismic exploration is likely to include an increased number of technologies and ways of applying these technologies. For example Popcorn utilises existing airgun technology in a different way, whilst other technologies may offer new or modified alternatives, such as marine vibrator technology or the E-Source. Improved computer technologies continue to enable improved processing and imaging capabilities for geophysical data, which in turn have enabled Popcorn to offer the potential for both geophysical and operational improvements and at the same time an environmental benefit by reducing sound output levels. What is Popcorn? Popcorn is a method that uses data processing routines to reconstruct a recorded signal that has been generated using a source array with individual array elements being activated at different times into a comparable signal that has been generated by a conventional source array where individual array elements are activated simultaneously. This method also offers operational advantages in that it uses existing equipment with minor modifications to distribute the individual element activation times as well as the possibility of reducing the peak amplitude output compared to a conventional airgun sources. The Popcorn method is in very early concept stages of development. Further development, measurement and analysis is required in order to fully assess and compare sound level and characteristics of the output for a moving, full scale/typical

UTILIZING NON-TECHNICAL RISK ASSESSMENTS AND MITIGATION STRATEGIES TO IDENTIFY, ASSESS AND MITIGATE AGAINST RISKS ASSOCIATED WITH MARINE SOUND

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Presenter will demonstrate how non-technical risk assessment can identify, quantify and qualify the risks associated with marine sound from offshore activities and develop an appropriate mitigation strategy to minimize risks and impacts to projects.

THE SAME PROBLEM- DIFFERENT APPROACH

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Worldwide mitigation standards for minimising acoustic disturbance to marine mammals, in particular that coming from seismic acoustic sources, vary greatly. Several countries and regions have their own guidelines and codes of conduct whilst 'industry standard' JNCC or IAGC guidelines are often implemented in those areas with no specific regulations. It is notable that each of these documents approaches the problem of underwater noise in a different way accounting for different noise sources and applying a broad spectre of mitigation measures. Quite often mitigation measures prescribed are arbitrary and not based on any scientific evidence. This is most obvious in regards to the size of mitigation zones and the species affected. Quite often it is forgotten that meaningful mitigation measures need to be tailored for specific habitats and the species within them. Furthermore, standards and experience of marine mammal observers (MMOs) vary greatly too with many operators often forgetting the importance of consistent and good quality data collection especially in areas where dedicated scientific effort is lacking. Currently, only the UK, USA and New Zealand have specific standards for training courses whilst other countries accept MMOs trained under different regulations. The available MMO courses vary in length, concept and resources used, ranging between one day classroom courses to distance learning courses that last several weeks with compulsory practical components. Here we will examine these issues in more detail presenting an overview of the current mitigation measures applied worldwide, the inconsistency among them to address essentially the same issue as well as recommendations on the best approaches and principles based on current scientific knowledge. There is a great need to have more consistency and the same principles which each regional guidelines should apply in order to protect marine mammals from injury and disturbance caused by underwater noise.

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