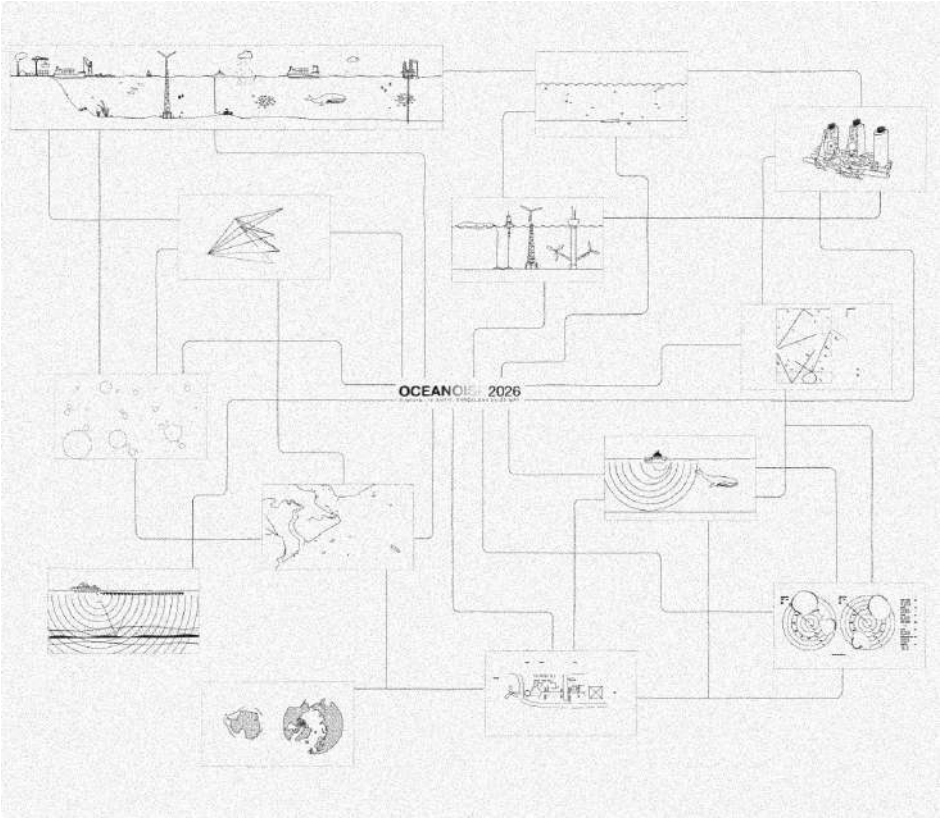
OCEANOISE 2026

Vilanova i la Geltrú, BARCELONA 25-29 MAY

An International Conference and Exhibition on Ocean Noise



Programme & Abstract Book

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UPC UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

SONSETC.COM
Making Sense of Sounds

THE SENSE OF SILENCE

WITH THE SUPPORT OF

JASCO APPLIED SCIENCES

AJUNTAMENT DE Vilanova i la Geltrú

CTN CENTRO TECNOLÓGICO NAVAL Y DEL MAR

OceanInstruments NZ

RTsys UNDERWATER TECHNOLOGIES

ARAEX Grands
Spanish Fine Wines

AUDITORI EDUARD TOLDRÀ
VILANOVA I LA GELTRÚ

PROGRAMME

Date: Monday 25 - 09:00-09:30

OPENING SESSION

Michel André
Laboratory of Applied Bioacoustics, Universitat Politècnica de Catalunya (BarcelonaTech, UPC), Spain

Date: Monday 25 - 09:30-11:00

RENEWABLE ENERGY

Chairs

Sonia Mendes
JNCC, UK

Jonas von Pein
Novicos GmbH, Germany

Update of the 2020 field report (ERa) on impact pile-driving noise and application of noise mitigation technologies from 2020 to today

Michael A. Bellmann
Institut für technische und angewandte Physik GmbH (ITAP), Germany

Pile Driving Noise Perspectives: from Acoustic Predictions to Risk Assessments

Jonas von Pein
Novicos GmbH | Offshore Noise Engineering and Consulting, Germany

Pile driving sound impacts hearing abilities, respiration rates and behavior in a particle-motion sensitive fish: summer flounder (Paralichthys dentatus)

T. Aran Mooney
Woods Hole Oceanographic Institution (WHOI), USA

PURE WIND: Understanding the impact of sound from offshore wind energy generation on marine ecosystems

Ana Širović
Norwegian University of Science and Technology (NTNU), Norway

Assessing Impacts of Operational Underwater Noise from Floating Offshore Wind to Marine Mammals

Denise Risch
Scottish Association for Marine Science (SAMS), UK

Underwater noise and vibration from an offshore wind turbine

Emilia Lalander
Swedish Defence Research Agency (FOI), Sweden

Date: Monday 25 - 11:30-13:00

EMERGING TOPICS

Chairs

Federica Pace
JASCO Applied Sciences, the Netherlands

Klaus Lucke
BSH, Germany

Emerging Topics for the Oil and Gas Industry
Zack Lawrence
ExxonMobil and the Sound and Marine Life JIP, USA

What Are the Potential Underwater Sound Emissions from Offshore Decommissioning Projects?
Roberto Yubero
JASCO Applied Sciences, Netherlands

Characterising and regulating intermittent sound sources
Federica Pace
JASCO Applied Sciences, Netherlands

Acoustical effects of deep-sea mining on marine fauna - a real threat?
Klaus Lucke
Federal Maritime and Hydrographic Agency (BSH), Germany

Shipping Noise: Emerging Topics Shaping Coherent Action
Samy Djavidnia
European Maritime Safety Agency (EMSA), Portugal

Measurements of noise emissions from ultrasonic antifouling and assessment of potential risks for marine mammals
Matthias Ram
DHI Group, Germany

Date: Monday 25 - 13:00-13:30

KEYNOTE

Lindy Weilgart
OceanCare, Canada

The Scientist-Environmentalist: A View from the "Trenches" of the Science/Policy Intersect

Lindy Weilgart
OceanCare, Canada

Date: Monday 25 - 15:00-16:30

MAPPING AND MODELLING

Chairs

Thomas Folegot
Quiet-Oceans, France

Sergio Jesús
University of Algarve, Portugal

Advanced Source Formulation and Seabed Modelling Effects in Shallow-Water Sound Mapping

Ines Addeo
University of Trieste, Italy

FSI Modeling of the AquaVib System for Controlled Particle Motion in Underwater Noise Experiments

Bassel Tabaja
Universitat Politècnica de Catalunya, BarcelonaTech (UPC), Spain

Mapping noise from deep-sea exploitation activities

Luciano de Oliveira Júnior
SiPLab - CINTAL, University of Algarve, Portugal

Advancing Global Assessment: Comparing Large Scale Acoustic Exposure Mapping Against Hypothesis Driven Impact Expectations

Corey Morris
Fisheries and Oceans Canada, Canada

Mapping the Underwater Noise of Recreational Boats

Carl Andersson
IVL Swedish Environmental Research Institute, Sweden

Indexing Underwater Noise in Ecosystem Based Marine Spatial Planning

Thomas Folegot
Quiet-Oceans, France

Date: Monday 25 - 16:30-18:00

SHORT TALKS AND POSTERS

CAB Technology: Near Real-Time Passive Acoustic Monitoring for Mitigation and Noise Measurement

Chloe Malinka
SMRU Consulting, UK

Experimental Evaluation of the Pulcea High Performance Bubble Curtain

Simon Stephenson
Seiche Ltd, UK

Windfarm-associated sounds variably influence the behavior and physiology of the American Lobster (Homarus americanus)

Andria Salas
Woods Hole Oceanographic Institution, USA

The Menck MNRU - Primary noise mitigation for impact pile driving

Thomas Kohlsche
Menck Marine Foundations, Germany

Physiological responses of coastal plankton when exposed to offshore windfarm noise

Justine Courboules
Norwegian University of Science and Technology (NTNU), Norway

Aquatic Pollution from Light and Anthropogenic Noise: Assessment of potential mitigation options

Rosalyn Seddon
Centre for Environment, Fisheries and Aquaculture Science (CEFAS), UK

The Casablanca-DAS seafloor observatory: A new fibre-optic platform for continuous, multi-layer ocean monitoring

German Ocampo Botero
Repsol, Spain

The Fourth State of Water: A Potential New Frontier for Underwater Acoustics and Bioacoustics

Maja Nimak-Wood
Natural England, UK

Advancing DAS-Based Cetacean Localization Monitoring: Dual-Cable Strategy in the Campos Basin, Brazil

Divna Djokic
Aqualie Institute / Laboratório de Ecologia Comportamental e Bioacústica (LABEC), UFJF, Brazil

BioDCASE: Towards standardised data challenges supporting robust development of ML models for underwater acoustic event detection

Clea Parcerisas
Flanders Marine Institute (VLIZ) / Ghent University, Belgium

Uncertainty Assessment of Simplified Models for Underwater Acoustic Propagation

Pablo Martínez
Marine Technology Center (CTN), Spain

Theoretical and Experimental Characterization of Acoustic Transmission Loss in Underwater Bubble Curtains

Iván Felis Enguix
Marine Technology Center (CTN), Spain

Application of Underwater Acoustic Modeling to Prospective Offshore Scenarios in the Santos Basin Pre-Salt.

Fabiano Marcos de Lima
Brazilian Navy Research Institute (IPqM), Brazil

From Decibels to Distance - Why Small Acoustic Errors Can Matter for Marine Mammal Injury Ranges

Simon Stephenson
Seiche Ltd, UK

Predicting the Performance of Near-Pile Noise Mitigation Systems: Sensitivity Analysis and Realistic Upper Bounds

Rens van Leijden
Delft Cymatics and AdBm Corp, Netherlands

Challenges in Cross Project Comparison of European Underwater Sound Maps

Özkan Sertlek
JASCO Applied Sciences, Germany

TUNE: a nimble Tool for Underwater Noise Evaluation

Valentina Caradonna
University of Campania "Luigi Vanvitelli", Italy

Date: Tuesday 26 - 09:00-10:00

POLAR

Chairs

Philippe Blondel
University of Bath, UK

Heidi Ahonen
Norwegian Polar Institute, Norway

Sound-Cruising: Investigating acoustic output characteristics and noise budgets of cruise operations in Svalbard

Heidi Ahonen
Norwegian Polar Institute, Norway

Marine soundscapes of the Arctic and human impacts - From monitoring to regulating

Philippe Blondel
Norwegian Polar Institute, Norway

Acoustic monitoring of ice and animals in one of the ocean's noisiest places, a glacial fjord

Evgeny Podolskiy
Arctic Research Center, Hokkaido University, Japan

Long-term acoustic monitoring of odontocetes in Inuit Nunangat through collaborative research

Eva Hidalgo Pla
Scripps Institution of Oceanography, UC San Diego, USA

Date: Tuesday 26 - 10:00-10:30

KEYNOTE

Dorian Houser
National Marine Mammal Foundation, USA

A need for interdisciplinary action on the issue of baleen whale hearing

Dorian Houser
National Marine Mammal Foundation, USA

Date: Tuesday 26 - 10:30-11:00

SHORT TALKS AND POSTERS

Validating numerical predictions of sound generated from underwater explosions in shallow waters

Gonçalo Peixoto Dourado
Netherlands Organisation for Applied Scientific Research (TNO), Netherlands

Characterisation of underwater noise generated by fireworks events

Pedro Poveda-Martínez
University of Alicante, Spain

Detecting underwater explosions: results from the Philippines

Roee Diamant
University of Haifa / University of Zagreb, Israel

The "noisome": understanding the genetic response to marine noise using the zooplanktonic Oikopleura dioica as a model system

Eva R. Quintana
Universitat de Barcelona, Spain

Effects of noise on Pacific sand lance with implications for their avian predators

Francis Juanes
University of Victoria, Canada

Date: Tuesday 26 - 11:30-13:30

SENSITIVITY AND PATHOLOGY

Chairs

Aran Mooney
WHOI, USA

Raquel Vasconcelos
MARE-UL, Portugal

Auditory dynamics during echolocation in freely swimming trained and wild toothed whales

Adam Smith
University of Southern Denmark, Denmark

Retracting to sound: the first behavioral audiogram of reef-building corals and sensitivity to vessel noise

Carolin Nieder
Woods Hole Oceanographic Institution (WHOI), USA

The potentially disturbing effects of seismic surveys on free-swimming fish and shrimp populations

Dennis Higgs
University of Windsor, Canada

The aquatic tympanic ear

Jakob Christensen-Dalsgaard
University of Southern Denmark, Denmark

Effect of hatchery noise conditions on development and survival of Chinook salmon and considerations for future mechanistic studies

Allison Coffin
Creighton University, USA

MALDI Imaging of Proteins and Lipids in Sepia officinalis Larvae Following AquaVib Sound Exposure

Marta Solé
Universitat Politècnica de Catalunya (UPC), Spain

Soundscapes of seahorse habitats: a sensory ecology perspective on vulnerability to anthropogenic pressures

Raquel Vasconcelos
MARE-UL, Universidade de Lisboa, Portugal

Investigating substrate-borne vibrational sensitivity in marine gastropods

Ambrosine Clark
University of Liverpool, UK

Stress, Sound, and Sanctuary: How Marine Reserve Age Shapes the Physiological Resilience of Australasian Snapper

Craig Radford
University of Auckland, New Zealand

Date: Tuesday 26 - 15:00-16:30

BEHAVIOUR

Chairs

Ana Širović
NTNU, Norway

Chloe Malinka
SMRU Consulting, UK

BOOMIN: Using Acoustic Tags on Whales to Study Impulsive Sound Exposure near a US Military Training Range

Erin Falcone
Marine Ecology and Telemetry Research, USA

Movement decisions in a busy seascape: harbour seals, offshore wind farms, and vessels

Joseph Schnitzler
Institute for Terrestrial and Aquatic Wildlife Research (ITAW), University of Veterinary Medicine Hannover, Germany

Effects of boat noise and warming on the reproductive behaviour of a coastal marine fish

M. Clara P. Amorim
Universidade de Lisboa, Portugal

Atlantic salmon exposed to boat noise: acute responses during sexual maturation but habituation under chronic exposure

Emilie Rojas
Norwegian University of Science and Technology (NTNU), Norway

Reactions of harbour porpoises to underwater noise: Level of onset of biological adverse effects (LOBE)

Jakob Tougaard
Aarhus University, Denmark

The combined effects of anthropogenic noise and Artificial Light at Night (ALAN) from shipping on an offshore predator and prey

Lise Sivle
Institute of Marine Research, Norway

Date: Tuesday 26 - 16:30-18:00

SHORT TALKS AND POSTERS

Fin Whale (Balaenoptera physalus) Behavioral Response to Vessel Approaches in Shallow Coastal Western North Atlantic United States Habitat

Dana Adcock
Syracuse University, USA

Blue Whales Decrease Foraging Rates During Close-Range Vessel Encounters

Laia Rojano-Doñate
Aarhus University / Stanford University, Denmark

Interactions between substrate-borne vibration from offshore wind farms on the hermit crab (Pagurus bernhardus): assessing the effects of simulated continuous vibration on feeding behaviour

Zoe Bainbridge
University of Hull, UK

Chronic Noise Effects on the Development and Hunting Success in Sepia officinalis

Catherine Golinvaux
Research and Technology Centre West Coast, Kiel University, Germany

Passive Acoustic Monitoring of Baleen Whales in a Brazilian Offshore Oil Field

Gabrieli Rodrigues
Aqualie Institute / Laboratório de Ecologia Comportamental e Bioacústica (LABEC), UFJF, Brazil

Analysis of underwater soundscape of Nice harbor, France: Calculation of SL from human activity and mapping of the area of adverse noise effect

Sidonie Brault
SENSEA groupe SAS, France

Is the high occurrence of loud, broadband, cavitation transients from ship propellers a prob-lem for toothed whales?

Cristina Marcolin
Aarhus University, Denmark

Impacts to cetaceans within the St. Lawrence Estuary from underwater radiated noise produced by commercial vessel within the global fleet

Charlotte Rose Findlay
Heriot-Watt University, UK

Underwater radiated noise database of vessels - Description of the data collection method used in Finland

Reijo Alakoivu
Turku University of Applied Sciences, Finland

Underwater noise from ferry in a vital humpback whale area - Tahiti-Moorea case study

Cedric Gervaise
SENSEA groupe SAS, France

Did we forget about recreational vessels? analysis of shipping underwater radiated noise from the Hearmyship database

Roee Diamant
University of Haifa / University of Zagreb, Israel

Transfer Learning for Distance Classification of Marine Vessels Using Underwater Sound

Wout Decrop
Flanders Marine Institute (VLIZ), Belgium

The Noisy Few: Similar Vessels vary by up to 20 dB in Radiated Noise Levels

Fabienne Mannherz
Aarhus University, Denmark

Date: Wednesday 27 - 09:00-10:30

RIVERINE AND COASTAL

Chairs

Tomonari Akamatsu
Sasakawa Peace Foundation, Japan

Songhai Li
Chinese Academy of Sciences, China

Large-scale monitoring of coastal odontocetes using multiple static acoustic sensors

Songhai Li
Institute of Deep-sea Science and Engineering, Chinese Academy of Sciences, China

Long-term Passive Acoustic Monitoring of Odontocetes in the Istanbul Strait (Bosphorus)

Ayaka Amaha Ozturk
Turkish Marine Research Foundation (TÜDAV), Turkey

Decadal co-occurrence of finless porpoise presence and high-frequency vessel noise in a coastal area of central Japan

Tomonari Akamatsu
Waseda University, Japan

Long-term Variation Characteristics of Underwater Ambient Noise in the Coastal Waters of the Yellow Sea, Korea

Young Geul Yoon
Korea Institute of Ocean Science & Technology (KIOST), South Korea

Manatee and pink dolphin automatic classification as a management tool to assess human disturbance, including noise

Mike van der Schaar
Universitat Politècnica de Catalunya, BarcelonaTech (UPC), Spain

Influence of Offshore Wind Farm Development on the Critically Endangered Taiwanese White Dolphin: Long-Term Acoustic and Visual Evidence with Explainable AI

Shashidhar Siddagangaiah
National Taiwan Ocean University, Taiwan

Date: Wednesday 27 - 10:30-11:00

SHORT TALKS AND POSTERS

The OSPAR Regional Action Plan for Underwater Noise

Rosalyn Seddon
Centre for Environment, Fisheries and Aquaculture Science (CEFAS), UK

From monitoring to conservation: linking acoustic biodiversity data with soundscape data

Ellen Jacobs
Aarhus University, Denmark

A decade of noisy activities in a harbour porpoise protected area

Sónia Mendes
Joint Nature Conservation Committee (JNCC), UK

Using monitoring data collected during offshore construction to inform future mitigation advice

Hannah Elms
Joint Nature Conservation Committee (JNCC), UK

Date: Wednesday 27 - 11:30-13:00

MANAGEMENT AND POLICY

Chairs

Erica Staaterman
BOEM, USA

Carina Juretzek
BSH, Germany

Leveraging complementarity of large-scale projects for effective management of underwater noise in the Eastern Mediterranean: The Greek case

Aristides Prospathopoulos
Hellenic Centre for Marine Research (HCMR), Greece

New developments and learnings on URN gained from German offshore wind projects and research activities

Carina Juretzek
Federal Maritime and Hydrographic Agency (BSH), Germany

A Spatio-Temporal Management Framework for Identifying Sensitive Sea Areas for Ship Underwater Radiated Noise Using Biologically Weighted Sound Maps

Masahiro Sakai
The University of Osaka, Japan

Categorizing Alternative Seismic Sources Based on Their Potential to Affect Marine Mammals

Erica Staaterman
Bureau of Ocean Energy Management (BOEM), USA

Advancing an ecosystem-based approach to underwater noise management by implementing a trait-based framework

Arienne Calonge
Flanders Marine Institute (VLIZ), Belgium

DEMASK: policy options for underwater noise

Karen de Jong
Rijkswaterstaat, Netherlands

Date: Wednesday 27 - 13:00-13:30

KEYNOTE

Douglas Nowacek
Duke University Marine Laboratory, USA

Multi-sector partnerships for monitoring and managing ocean noise with an emphasis on offshore renewable energy development

Douglas Nowacek
Duke University Marine Laboratory, USA

Date: Wednesday 27 - 15:00-16:30

SEISMIC

Chairs

David Hedgeland
BP, UK

Michael Jenkerson
ExxonMobil, USA

Marine Vibroseis as an Alternative to Air Guns: Development and Field Validation of the MVJIP Source

Vladimir Nechayuk
ExxonMobil, USA

Advancements in Marine Vibrator Technology for Offshore Seismic Acquisition with Reduced Acoustic Impact

Alysa Evensen & Ricardo Guimarães
Petrobras / Shearwater, Brazil / Norway

Sustainable Seismic source trial, a lean-crew robotic ship and non-impulsive marine vibrator source.

Ted Manning
BP, UK

Controlled Exposure Experiments with An Operational Marine Vibrator and Very-Low Frequency Whales

Brandon Southall
Southall Environmental Associates (SEA), USA

Project COSIMMAS: A review of non-impulsive sound impacts on marine mammals and their mitigation, with a focus on geophysical exploration sounds

Chloe Malinka
SMRU Consulting, UK

Reducing the Environmental Impact of Seismic Surveys: A Review of Impulsive Source Technologies and Monitoring Solutions

Jeremy Aznar
Sercel, France

Date: Wednesday 27 - 16:30-18:00

SHORT TALKS AND POSTERS

Underwater noise impact assessment in the Pelagos Sanctuary: a focus on four species

Noelia Ortega
Centro Tecnológico Naval y del Mar (CTN), Spain

The Marine SoundLib: An open Infrastructure for exploring and understanding Marine Soundscapes

Elisabeth Debusschere
Flanders Marine Institute (VLIZ), Belgium

The importance and challenges of an ecosystem-based, multi-taxa approach to underwater noise risk assessment and management

Anna-Sara Krång
IVL Swedish Environmental Research Institute, Sweden

Towards an ecosystem-based Underwater Noise Limit Value for the North Sea: A Functional and Risk-Based Framework

Helena Eicher
University of Veterinary Medicine Hannover, Germany

Quantitative Assessment of Coastal Dolphin Exposure to Small Vessel Noise

Changsoo Kim
Jeju National University, South Korea

Experimental exposure of free-ranging fish to airguns: investigating behavioural responses with acoustic telemetry

Lise Doksæter Sivle
Institute of Marine Research, Norway

Individual-based approaches can bridge disciplinary gaps to assess the effects of seismic surveys on cetacean behavior, physiology and health

Alexandre Machado
Instituto Baleia Jubarte, Brazil

Adoption of a new generation of reduced impact seismic sources

Xander Campman
Shell Global Solutions International BV, Netherlands

Reducing fauna habitat exposure to marine seismic surveys through source-less acquisition

Alice Affatati
National Institute of Oceanography and Applied Geophysics (OGS), Italy

Influence of offshore seismic surveying on the acoustic detectability of the Antarctic minke whale (Balaenoptera bonaerensis) on the Brazilian Equatorial Margin

Julia Sarmanho
Federal University of Rio Grande do Norte, Brazil

Cambridge Bay, Nunavut - important gateway for ship traffic passing through the Northwest Passaged during the Arctic summer

Annika Heimrich
University of Victoria, Canada

Assessing ringed seal exposure to vessel noise in the Canadian Arctic using a novel perception-based approach

Deborah Sharpe
University of Victoria, Canada

Acoustic and temporal comparison of grunts produced by Arctic and Pacific gadids

Kelsie Murchy
University of Victoria, Canada

Development and Experimental Validation of Acoustic Metamaterials for Sonar Signature Reduction

Ivan Felis Enguix
Marine Technology Center (CTN), Spain

Date: Thursday 28 - 09:00-10:30

SOUNDSCAPES

Chairs

Jennifer Miksis-Olds
University of New Hampshire, USA

Brandon Southall
Southall Environmental Associates, USA

A path towards adding biological noise to the modelled ocean soundscape.
Kevin Heaney
Applied Ocean Sciences, USA

Can Distributed Acoustic Sensing help monitor underwater soundscapes?
John Potter
Norwegian University of Science and Technology (NTNU), Norway

Soundscape analysis of the multi-diverse marine environment of eastern Mediterranean: The Greek case
Vasilis Trygonis
University of the Aegean, Greece

On the vertical distribution of ambient acoustic energy in the Fram Strait.
Giacomo Giorli
NATO Centre for Maritime Research and Experimentation (CMRE), Italy

Evolving from Soundscapes to Acoustic Scenes in Ocean Acoustics
Jennifer Miksis-Olds
University of New Hampshire, USA

Connecting ocean soundscapes to societal needs for our changing ocean
Megan McKenna
Middlebury Institute of International Studies, USA

Date: Thursday 28 - 10:30-11:00

SHORT TALKS AND POSTERS

Interpretable Acoustic Classification for Monitoring Marine Mammals in Shipping-Influenced Polar Waters: A Bearded Seal Case Study

Siddharth Prashant Khopkar
Korea Polar Research Institute, South Korea

Synthesising underwater acoustic datasets for noise robust sound event detection

Bram Cuyx
Flanders Marine Institute (VLIZ) / KU Leuven, Belgium

Next-Generation Soundscape Monitoring with Distributed Acoustic Sensing: Insights from the Western Ionian Sea

Flavia Grenga
Università degli Studi di Palermo, Italy

Characterising coastal soundscapes and cetacean presence in Shisiwani National Park (Anjouan, Comoros) using passive acoustic monitoring

Sara Ferri
University of Turin, Italy

Coastal soundscape of the Desertas Islands MPA (Madeira Archipelago): a long-term passive acoustic monitoring assessment

Laura Redaelli
ARDITI / MARE, Madeira, Portugal

Scottish Passive Acoustic Network - First insights into North East Atlantic soundscapes in Scottish waters

Monika Kosecka
Marine Directorate, Scottish Government, UK

Date: Thursday 28 - 11:30-13:00

SHIPPING

Chairs

Eric Baudin
Bureau Veritas, France

Christ de Jong
TNO, the Netherlands

InciteShip - Open Source Measurement And Incentive System For Mitigation Of Ship Underwater Noise

Torbjorn Johansson
IVL Swedish Environmental Research Institute, Sweden

Measuring Underwater Noise from transiting Crew Transfer Vessels in the German Bight

Fritjof Basan
Federal Maritime and Hydrographic Agency (BSH), Germany

Co-benefits and trade-offs between URN reduction and energy efficiency of ships

Frans Hendrik Lafeber
Maritime Research Institute Netherlands (MARIN), Netherlands

LOWNOISER contributions to Underwater Radiated Noise (URN) mitigation

Santiago Molins Riera
Técnicas y Servicios de Ingeniería (TSI), Spain

Benefits of using VFD for Diesel-Electric Ferries

Chanwoo Bae
BC Ferries, Canada

PONANT cruise line management of underwater noise

Wassim Daoud
PONANT, France

Date: Thursday 28 - 13:00-13:30

SHORT TALKS AND POSTERS

Characterization of the Sound Levels at the PLOCAN Test Site

José Antonio Díaz
PLOCAN, Spain

Listening Beneath the Waves: southern elephant seal drift dives reveal the Southern Ocean soundscape

Nicole El Haddad
Aarhus University, Denmark

Assessment of underwater noise levels generated by natural acoustic sources

Daida Cristina Almeida Navarro
DC Servicios Ambientales, SL, Spain

Spatio-temporal analysis of underwater soundscapes in French Polynesia: Integration of Biosound software and Artificial Intelligence

Séréna Laurent
SENSEA groupe SAS, France

Acoustic Characteristics of Sciaenid Fish Choruses and the Influence of Water Temperature in Korean Coastal Waters

Young Geul Yoon
Korea Institute of Ocean Science & Technology (KIOST), South Korea

Tidal Forcing of Underwater Noise: Insights from Ieodo Ocean Research Station

Seong Hyeon Kim
Korea Institute of Ocean Science & Technology (KIOST), South Korea

Date: Thursday 28 - 15:00-16:00

EXPLOSIVE SOURCES

Chairs

Roberto Racca
JASCO Applied Sciences, Canada

Paul Lepper
Loughborough University / National Physical Laboratory (NPL), UK
(standing in for **Stephen Robinson**)

Evaluation of technologies for mitigation of the acoustic impacts from underwater unexploded ordnance clearance operations

Paul Lepper
Loughborough University / National Physical Laboratory (NPL), UK

Assessment and remediation of UXO impacts on marine mammals in the Southern North Sea

Sander von Benda-Beckmann
Netherlands Organisation for Applied Scientific Research (TNO), Netherlands

Underwater Noise Reduction from Explosive Sources Using Tunable Acoustic Resonators: Laboratory and Field Measurements

Mark Wochner
AdBm Technologies, USA

SALIENT - Investigating alternative UXO Clearance methods in the Netherlands

Frans-Peter Lam
Netherlands Organisation for Applied Scientific Research (TNO), Netherlands

Date: Thursday 28 - 16:00-17:30

SONAR

Chairs

Frans-Peter Lam
TNO, the Netherlands

Dorian Houser
National Marine Mammal Foundation, USA

Introducing the Sonar session with some examples of the 3S project (Sea mammals and Sonar Safety)

Frans-Peter Lam
Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Germany

The Atlantic Behavioral Response Study (BRS): An interdisciplinary research program to measure the behavioral responses of deep-diving cetaceans to military sonar

Brandon Southall
Southall Environmental Associates (SEA), USA

Estimating the exposure levels of goose-beaked whales to sonar using multiple modeling modes in a behavioral response study

Douglas Nowacek
Duke University, USA

Modelling the masking potential of continuous active sonar on killer whale communication

Sander von Benda-Beckmann
Netherlands Organisation for Applied Scientific Research (TNO), Netherlands

A Comparative Study of Cumulative Impact Assessments of Naval Sonar

Cecile Mariëtte van der Stappen
Netherlands Organisation for Applied Scientific Research (TNO), Netherlands

Les leçons de Ziphia, A Case Study to Better Protect Marine Mammals from Anthropogenic Noise in the French Exclusive Economic Zone

Eric Baudin
Netherlands Organisation for Applied Scientific Research (TNO), Netherlands

Date: Thursday 28 - 17:30-18:00

SHORT TALKS AND POSTERS

Underwater noise depth dependency in high tidal environment (Gran Canaria, Atlantic Ocean)

Aliaksandr Lisimenka
Gdynia Maritime University, Poland

How Sampling Strategy Shapes Marine Soundscape Characterization: Insights from Dual Hydrophone Monitoring at the W1M3A Observatory

Sara Pensieri
Consiglio Nazionale delle Ricerche (CNR), Italy

Time-frequency object-based analysis for dolphin vocalizations detection

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

Soundscape monitoring in the Salish Sea, describing changes relevant to southern resident killer whale (SRKW, Orcinus orca) and objectives to lessen acoustic impact

Rianna Burnham
Fisheries and Oceans Canada, Canada

Feasibility of Deep Learning-Based Detection of Delphinidae Sounds with Limited Training Data in Marine Soundscape Analysis

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

Disturbing the sanctuary: Anthropogenic noise disrupts humpback whale (Megaptera novaeangliae) song and alters dive behavior

Lizzy Glazer
Duke University, USA

Learning from the past to protect our future: Quantifying ship noise from the Gulf of Mexico to the Arctic

Katrina Johnson
Scripps Institution of Oceanography, UC San Diego, USA

Date: Friday 29 - 11:30-13:30

INTER-SESSION DISCUSSION

Open discussion across all sessions, moderated by Michel André and Roberto Racca

ABSTRACTS

Update of the 2020 field report (ERa) on impact pile-driving noise and application of noise mitigation technologies from 2020 to today

Remmers P; Klug J; and Gerlach S

Michael A. Bellmann
bellmann@itap.de
Institut für technische und angewandte Physik GmbH (ITAP), Germany

Most offshore foundations are installed by using impact pile-driving, which causes impulsive noise with high sound levels in the vicinity of the piling activity. In order to avoid (temporary or permanent) threshold shifts in marine life multiple noise mitigation values were defined world-wide. In 2020, the experience with impact pile-driving noise and application of noise abatement/mitigation systems from German Offshore Wind Farms (OWF) was summarized in an experience report (ERa) by Bellmann et al. (2020) with pile diameters of up to 8 m in water depth of up to 40 m. Based on deeper waters, more challenging soil conditions and larger wind turbine generator sizes the diameter of the foundation structures were increased and will increase. Thus, it results in larger impact hammers so that the pile-driving noise levels will increase too which partly requires higher overall noise reductions to comply with noise mitigation values. Based on that, new hammer technologies such as PULSE, MNRU or EQ piling have been developed and partly tested offshore as noise mitigation systems to reduce the source level of impact pile-driving. Furthermore, some enhancements for existing state-of-the-art noise abatement systems like the enhanced Big Bubble Curtain have been successfully tested and new systems are currently under development or will be tested offshore soonest. This study provides an update on the latest experience with these new and improved mitigation technologies. A major finding from the application of new hammer technologies is that the emitted pile-driving noise will not only reduce the level, but also significantly change the spectrum, mostly towards lower frequencies. This frequency shift might have an influence on the effectiveness of additionally applied noise abatement systems like the Big Bubble Curtain. Therefore, the overall achievable noise reduction by single and combined application of different mitigation technologies will be presented. Moreover, possible impacts and limitations for future OWF projects will also be discussed based on the new key findings.

Pile Driving Noise Perspectives: from Acoustic Predictions to Risk Assessments

von Pein, J

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Pile driving noise is a major source of anthropogenic impulsive underwater noise. In particular, the construction of offshore wind farms involves extended periods of repeated pile installations, resulting in piling noise being a significant stressor to the marine environment. There are several different strategies to manage and mitigate potential impacts of pile driving noise. These measures generally fall into two categories: strict threshold limits that must be complied with at all times, and impact-dependent mitigation approaches that are implemented based on assessed environmental risks. The evaluation of measurement data from past offshore wind farm projects reveals substantial variability in recorded sound levels. This variation can partly be attributed to site-specific soil conditions, which affect the required pile driving energy, sound propagation characteristics, and, if noise abatement measures are applied, tunneling effects that can cause acoustic leakage through the seabed. The project specific noise level distributions provide different perspectives depending on the regulatory metric considered. For strict single-strike sound exposure level (SEL) limits, the upper tail of the distribution is most relevant, as it determines the risk of exceedance. When cumulative sound exposure levels are assessed, variability can be even more pronounced due to the combined effect of level fluctuations and strike counts. Therefore, the author aims for deriving robust cumulative probability curves for future wind farms by combining the variation of the results of the acoustic modelling with the range of the outcome of the pile drivability studies. These cumulative probability curves enable quantitative risk-based assessments and more targeted mitigation planning. The influence of predicted level distributions becomes even more pronounced when effect ranges and impacted areas are considered. Consequently, Environmental Impact Assessments and Population Consequence Assessments can also benefit from this probabilistic perspective, as it captures both worst-case scenarios and the inherent real-world variability in the data.

Pile driving sound impacts hearing abilities, respiration rates and behavior in a particle-motion sensitive fish: summer flounder (Paralichthys dentatus)

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Offshore wind is a growing renewable energy source and key to a sustainable future. Long-term successful co-use and operation is dependent upon understanding how related activities may influence key fisheries taxa. Pile driving, commonly used to install offshore wind turbines, produces high-intensity sounds that propagate through the seafloor and water column. These sounds can affect numerous animals that sense sound, however, little is known about the impacts on species that primarily sense particle motion, and live on the benthos, where sound may travel particularly efficiently. One such species is the summer flounder (Paralichthys dentatus), an ecologically important, benthic flatfish that comprises a valuable fishery that overlaps with numerous planned, or in-construction, wind farms. Here we measured how the hearing abilities, physiology (respiration rates) and behavior of summer flounder may be influenced by actual in situ pile-driving, quantifying pressure, particle acceleration and induced substrate vibrations. From the in situ pile driving exposure experiments, significant noise-induced hearing loss was noted after only 15-min of pile-driving and persisted 24 hrs post-exposure. Diminished hearing abilities recovered but could last up to 3 weeks post-exposure. Behavioral responses varied and included changes in respiration rates. Flight responses were noted for a portion of fish, yet other individuals showed a cryptic staying-still "anti-predator" response, resulting in an actual increase in apparent sound exposure. Results show that temporary hearing loss can be induced in a particle-motion sensitive fish. The data also underscore that noise impacts are often complex, and sensory impairment may be influenced by species-specific behavioral responses. A broader understanding of sensory ecology, and evaluating multiple vital parameters (e.g., physiology, hearing, behavior), is critical to determine the influence of offshore development on key taxa.

PURE WIND: Understanding the impact of sound from offshore wind energy generation on marine ecosystems

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Offshore wind farm (OWF) activities can be important contributors to anthropogenic underwater noise in regions with concentrated OWF development. Substantial effort has been expanded on understanding possible impacts of noise resulting from the development stages of the OWF lifecycle, but despite 30 years of their operation in the EU waters, our understanding of the impacts of the operational phase on marine ecosystems remains limited. At the same time, tenfold expansion is expected by 2050. In this consortium, we have been addressing this gap by expanding our knowledge of the radiating and propagating noise and the biological consequences of OWF operations. We developed source models linking radiated noise to wind speed and turbine characteristics. This was further integrated with 2D/3D propagation models in a virtual research platform for easier use and dissemination. In addition, comprehensive propagation models were developed for both piling and operational wind farm noise. From the biological perspective, we investigated spatial use of operating OWF by harbour and grey seals and studied the impact of OWFs on the foraging behaviour of harbour porpoises. Mesocosm experiments revealed OWF noise effects on plankton community structure and function. These efforts advanced our knowledge of acute and cumulative effects of operational OWF noise across the food web. In addition to investigating physical and biological effects of OWF operational noise, we also set out to place them in appropriate regulatory contexts. We built a knowledge base and integrated it into the Tethys database (tethys.pnnl.gov) for OWF environmental effects. We also developed case studies that synthesised relevant learnings and best practices from experiences with fixed offshore wind development and translated for application in the development of policy, mitigation, and regulation for the floating OWF. With expected substantial expansion in OWF infrastructure globally as part of the green shift, our learned information and approaches will help facilitate this transition while minimizing impacts on the marine ecosystems.

Assessing Impacts of Operational Underwater Noise from Floating Offshore Wind to Marine Mammals

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This study assessed the likely impacts of underwater noise from three hypothetical Floating Offshore Wind (FOW) farms in UK waters. The turbine platforms considered (Hywind Scotland, Hywind Tampen and Kincardine) were placed in one near-shore and one offshore location and animal responses to underwater sound fields were modelled for two different seasons and wind speeds. The modelled impact scenarios indicate that it is unlikely that operational noise from FOW farm arrays of similar specification and in similar environments will cause auditory injury or TTS in those marine mammal species groups investigated here. Similarly, it appears unlikely that fish would be exposed to noise levels above thresholds at which noise impacts are expected. However, behavioural threshold values for marine mammals were exceeded in all modelling scenarios and for all marine mammal functional hearing groups (i.e., low-frequency and very-high frequency cetaceans, as well as pinnipeds in water) investigated. The extent of exposure ranges to behavioural thresholds varied by species, turbine type, location, season and windspeed. However, turbine type and array layout and deployment environment had a bigger effect on exposure distances than season. Hywind Tampen produced considerable smaller areas of exposure across all modelled scenarios. Differences in its mooring design might thus provide effective ways forward for underwater noise mitigation of future FOW systems. Overall, this work underscores the importance of considering the cumulative noise output of large FOW turbine arrays in marine spatial planning of new projects, especially in deep waters and in marine regions where boundaries of several FOW projects overlap with one another or other marine space uses.

Underwater noise and vibration from an offshore wind turbine

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Sweden is facing a historically large expansion of offshore wind power in Swedish waters to ensure future electricity supply. During all phases of an offshore wind farm, which include site surveys, construction, operation, and decommissioning, underwater noise and vibrations is generated into the water column and the seabed which can negatively affect marine organisms. Operational noise, which is continuous in nature, is currently not considered to impact the environment as much as construction noise, despite the long time frame of 20-30 years. However, there are significant knowledge gaps regarding how this chronic noise may affect marine animals communication, behavior and indirect effects such as stress. There is a lack of measurements from wind turbines larger than 8 MW which, especially in terms of seabed vibration, particle motion and sound level in the water at various distances from a wind power plant which can be used for impact studies. The focus of this project is to measure and model the sound and vibration levels from an operational wind farm. Measurements have been undertaken in the Danish Kriegers Flak park owned by Vattenfall with various sensors to determine the source level of an individual turbine and the acoustical footprint of the whole wind farm. Here we present data gathered during September to November 2025 on seabed vibration, particle motion and sound level at different distances from a wind turbine. In addition, measured levels are compared over different wind speeds and output power of the wind turbine.

Emerging Topics for the Oil and Gas Industry

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For over two decades, the Sound and Marine Life Joint Industry Program (JIP) has supported independent, peer reviewed research to ensure that the global oil and gas industry can operate responsibly while maintaining strong environmental safeguards. Identifying and funding underwater acoustics and marine biology research on emerging topics is central to this mission. Topics emerge as important when industry activity interacts with sensitive or protected environments and the science describing the interaction and impacts has evidence gaps. By funding targeted scientific studies to fill these evidence gaps, the JIP advances the understanding of underwater acoustics and the effects of industry activities on marine life in order to enable evidence based regulation. The JIP is focused on supporting research on broader ways of assessing marine life impacts to oil and gas activity and innovative technologies that have the potential to shape the next generation of marine environmental mitigation approaches. Recent investments include research on marine vibroseis as an alternative geophysical sound source. This work spans behavioral response studies and full scale field trials, both of which are being presented at OceanNoise. Other emerging-topic initiatives include improving approaches for assessing cumulative effects, understanding impacts from continuous noise sources, applying population consequence of disturbance methodologies, and investigating new technologies such as distributed acoustic sensing (DAS) and infrared imaging to enhance marine mammal mitigation.

What Are the Potential Underwater Sound Emissions from Offshore Decommissioning Projects?

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Considering that the first large-scale decommissioning projects are expected to take place in Europe in the next few years, it is necessary to understand and evaluate whether sound emissions from these activities may pose a risk to marine life. The underwater noise generated during the decommissioning activities remains poorly understood due to the limited number of such projects conducted to date. In 2025, JASCO contributed to two European offshore decommissioning studies assessing the environmental impact of underwater noise. The first project addressed the cutting and removal of an metocean monitoring station in Danish waters of the North Sea, conducted over two weeks in very shallow water (~13 m), during which underwater sound was recorded across operational phases, sources were characterised, and radiated noise was modeled to evaluate potential impacts on local marine fauna through acoustic impact ranges calculations. A second study examined the decommissioning of oil extraction wells in Spanish waters at three locations in the Atlantic and Mediterranean, where activities from multiple platforms in 70-650 m water depths were analysed to quantify noise from distinct operations. This article summarises both projects and presents some findings to inform methodological development.

Characterising and regulating intermittent sound sources

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Many anthropogenic underwater sound sources are currently unregulated. The ICU-Noise project, commissioned by the German Nature Protection Agency, BfN, sets out to review intermittent sources that do not currently fall in one of the two MSFD criteria of impulsive or continuous sources, such as acoustic deterrent devices, echo-sounders, ultrasonic anti-fouling devices and active sources used in geotechnical surveys. These sources are extremely common and, in some cases, deployed as a method for mitigating the potential impacts of impulsive sources on marine mammals. It is therefore critical to understand their characteristics and the extent of their application to limit potential acoustic impacts on marine life. The 4 year project identifies data poor sources, investigates their characteristics through dedicated acoustic measurements and develops an assessment of their harmfulness to marine life to support the definition of threshold values for relevant sources in the German EEZ. The study presents the outcomes of the literature review, and the monitoring programme will be carried out to characterise sources that have been identified has having non-negligible impacts on marine fauna.

Acoustical effects of deep-sea mining on marine fauna - a real threat?

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Deep-sea mining is an emerging industry with the potential to disrupt and destroy marine life in the pristine and poorly researched and understood abyssal environment. These mining activities will most likely directly affect marine mammals due to the noise they would emit throughout the water column. Noise sources related to deep-sea mining include the mining support vessels at the surface with their dynamic positioning systems and operational activities such as ore cleaning and bunkering, pumps operating to uplift the ore to the vessel and the ore tumbling up the metal riser in mid water, and the mining tool generating noise at the seafloor through its propulsion, collector equipment moving, crushing of ore nodules and pumps and hydraulic jets lifting nodules from the seafloor. In this presentation, first results from ongoing research projects, a synopsis of published literature and the latest policy developments are presented. While empirical data on acoustic emissions from these activities are scarce, expert judgement and predictive modelling suggest that the most relevant acoustic effects on marine fauna will be through masking of important communication signals or displacing animals from important habitat. Indirectly, the sounds emitted may affect marine mammals via impacts on food webs. In the light of current industrial efforts and political developments, dedicated research on this topic is increasingly important, especially with regard to species about which little is known, such as beaked whales, due to their deep-diving behavioral ecology and cryptic nature.

Shipping Noise: Emerging Topics Shaping Coherent Action

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Underwater Radiated Noise (URN) from shipping is rapidly emerging as a priority issue at the interface of science, policy, and maritime operations, and is increasingly recognised as a key topic in ocean environmental governance. While significant progress has been achieved in recent years, the transition from awareness to effective, large-scale mitigation remains a key challenge. Within the European Union, the European Maritime Safety Agency (EMSA) supports the European Commission and Member States in implementing URN-related requirements under the Marine Strategy Framework Directive (MSFD), providing technical and scientific assistance for monitoring, assessment, and policy development. In parallel, global momentum is building through initiatives at the International Maritime Organization (IMO) and the High Ambition Coalition for a Quiet Ocean (HAC), signalling a shift towards more coordinated international action. Looking ahead, the need for coherence between European and global processes is becoming increasingly critical, particularly as expectations grow for robust indicators, harmonised methodologies, and operational solutions. Building on the successful completion of NAVISON Phase 1, EMSA is launching NAVISON Phase 2 to further strengthen the technical and scientific basis for URN mapping, modelling, and assessment in European waters. This talk will reflect on progress to date while focusing on what comes next, with particular emphasis on emerging topics: identifying key scientific and technical challenges, and outlining priorities for future developments to support coherent and effective action on URN at both European and global levels.

Measurements of noise emissions from ultrasonic antifouling and assessment of potential risks for marine mammals

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Biofouling on ship hulls increases drag, fuel consumption, and greenhouse gas emissions, while also facilitating the spread of invasive species and obstructing seawater cooling systems. Ultrasonic antifouling has recently emerged as a non toxic alternative that uses high frequency vibrations to prevent the settlement of fouling organisms. Its growing adoption raises the question of whether these additional high frequency emissions contribute to acoustic stress in marine mammals. While mid- to high-frequency sonars have been extensively studied, continuous ultrasonic emissions from antifouling systems fall outside the focus of most monitoring programmes and impact assessments, which have traditionally emphasised low-frequency commercial shipping noise. This talk presents underwater noise measurements from ultrasonic antifouling transducers installed on a tanker and a diving vessel. Measured source characteristics are combined with numerical propagation modelling to evaluate potential environmental impacts. Results are assessed against established thresholds for behavioural disturbance and for temporary or permanent hearing impairment. Particular attention is given to the classification of the ultrasonic emissions as impulsive or non impulsive, as this distinction directly affects applicable regulatory criteria. Our findings indicate that sensitive species such as harbour porpoises may experience behavioural effects at ranges up to 3 km. These results highlight the need to consider ultrasonic antifouling within broader discussions on underwater noise management.

The Scientist-Environmentalist: A View from the "Trenches" of the Science/Policy Intersect

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Ocean noise pollution has strong policy implications, yet there are pitfalls when scientists venture into the policy arena. In particular, scientists need to recognize that science is only one, though an important, part of determining policy. Other risks include sacrificing their scientific credibility or failing to recognize their limitations in this area. Here, I attempt to help scientists transmit their research results more accurately and effectively to policy makers by summarizing the public, economic, and political implications of their work, after becoming thoroughly informed and experienced in policy fora. Consulting with managers before their research could increase the chance of it changing policy, as well as later shepherding their results to decision-makers. Scientists can advocate for the environment as long as they don't misrepresent the facts or lie, and can preserve their scientific and ethical credibility, so important for maintaining trust in science, by sticking to the facts, not allowing themselves to be used for propaganda, and adhering to the strictest ethical standards for permitting.Science should not be used to delay necessary remedial action for the environment, and non-scientific reasons for policy should be made explicit vs. manipulating the science to fit the policy agenda. Precaution is necessary in uncertainty, is scientifically sound, and in line with environmental law.

Advanced Source Formulation and Seabed Modelling Effects in Shallow-Water Sound Mapping

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In coastal environments, especially under shallow-water conditions and in the presence of complex seabed structures, an accurate representation of both noise sources and wave propagation mechanisms can become crucial for reliable underwater sound assessment. In these settings, strong boundary interactions, fluid-solid coupling, and source directivity effects may significantly influence the resulting acoustic field. The broader objective of this research is to develop a framework for generating high-resolution acoustic maps of selected target areas. The present study represents a first step toward this goal, providing initial results and methodological developments. The reduced spatial extent of the domain enables a more detailed representation of environmental features, as well as the implementation of advanced noise source modeling. The numerical framework, based on the direct solution of the full 3D time-domain wave equation, supports a study developed along two complementary research directions. The first focuses on source characterization, investigating how different source representations affect the resulting propagation pattern. For this purpose, we employ the open-source tool OpenFOAM. Systematic simulations are performed within the Gaussian canyon benchmark geometry by implementing different source models, including rotpoles at varying rotation frequencies, and comparing them with monopoles. Results show that source representation strongly controls the predicted acoustic field, with rotpoles producing patterns significantly different from monopoles. This analysis allows us to quantify discrepancies in the acoustic field introduced by source directivity and to explore more realistic source representations as a function of vessel type and speed. The second research direction addresses wave propagation in complex environments. The open-source software SPECFEM3D, which includes fluid-solid coupling, is adopted. A case study in the Gulf of Trieste, based on a MiniGI experiment, is used to evaluate the sensitivity of the acoustic field to variations in seabed geophysical and geometrical parameters, to assess the impact of modeling the seabed as an elastic solid versus an equivalent fluid, and to validate numerical results against field measurements. Results confirm that elastic seabed representation is crucial for reliable predictions in shallow-water conditions, and validation against field data supports the robustness of the approach.

FSI Modeling of the AquaVib System for Controlled Particle Motion in Underwater Noise Experiments

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The present research examines particle motion amplification in the AquaVib system with the aim of validating and optimizing its control for underwater noise experiments. Impulsive pile-driving signals were first applied in both acoustic pressure (AP) and particle motion (PM) modes, while simultaneously measuring acoustic pressure and particle motion. Under fully water-filled conditions, AP mode behaved as expected, with pressure-dominated responses. However, PM mode also exhibited pressure-dominated behavior, contrary to expectations. To replicate these findings, a fully coupled two-way fluid-structure interaction (FSI) model was developed, which successfully reproduced the experimental results. To improve particle motion performance in PM mode, a multiphase configuration incorporating pressure-release elements (water and air) was introduced. Frequency sweep signals were used to identify system resonances and natural frequencies, while multi-tone excitations centered on each third-octave band were employed to quantify amplification by comparing shaker velocity with water particle velocity. These results demonstrate the critical role of multiphase resonance in controlling particle motion and provide a validated framework for AquaVib optimization.

Mapping noise from deep-sea exploitation activities

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Deep-sea mineral exploitation is likely to become a reality in the near future, despite limited understanding of deep-ocean ecosystems and the potential impacts of such activities. In response, the EU Horizon TRIDENT project aims to develop monitoring methodologies and tools to assess environmental impacts, forecast outcomes, and support informed decision-making. The apparatus associated with deep-sea industrial activities is expected to generate two main impacts: sediment plumes and acoustic noise. This work presents the TRIDENT tool for monitoring and mapping anthropogenic noise from deep-sea exploitation, along with results from preliminary experiments and validation. To cover the large spatial coverage of noise in the open ocean, the tool integrates wind, shipping, and sound propagation models. Baseline soundscapes (without exploitation activity) are simulated using the Hildebrand model for wind noise, while shipping noise is derived from AIS data converted to source levels via the JOMOPANS-ECHO model and propagated using the Bellhop ray-tracing code with GEBCO bathymetry and Copernicus environmental data. Noise from exploitation activities is incorporated using source levels obtained from sensors installed on the machinery. Data from a 12-day sea trial in May 2025 at the Tropic Seamount were used to generate baseline maps and evaluate model performance. Validation against multi-platform observations across depths shows that model captures the main characteristics of median sound pressure levels in the 10 Hz-4 kHz band, with best agreement near 100 Hz and discrepancies up to 10 dB at lower and higher frequencies. A simulated exploitation scenario using three sources at the 6 m, 500 m, and 1000 m indicates that instantaneous sound pressure levels remain below thresholds for temporary auditory effects (>180 dB). However, cumulative sound exposure levels may exceed thresholds within ~10 km of the source. At distances of 100 km, exploitation activities increase median sound pressure levels by 25-65% across the frequency band, potentially reducing habitat suitability for marine species. These results demonstrate the capability of the TRIDENT framework to reliably predict and map noise impacts in deep-sea environments and highlight the importance of predictive acoustic tools to support environmentally responsible deep-sea resource management.

Advancing Global Assessment: Comparing Large Scale Acoustic Exposure Mapping Against Hypothesis Driven Impact Expectations

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Advancing Global Assessment: Comparing Large Scale Acoustic Exposure Mapping Against Hypothesis Driven Impact Expectations We are now able to investigate effects of seismic surveying noise on complete fisheries in a manner not previously possible thanks to advances in open data, modelling and statistical methodologies, fisheries and environmental monitoring, and computing power. Leveraging these capabilities, we developed a large scale soundscape dataset covering 1 million km2 of fisheries management areas at 2 x 2 km spatial resolution, including daily noise exposure estimates for the fishing seasons (May-October) from 2015-2021. We compiled fisheries datasets at the same spatial and temporal resolution, for snow crab, northern shrimp, redfish, and Greenland halibut derived from fishing logbooks and reported landings. Environmental variables including temperature and ocean currents were integrated into the same data structure. A collaborative survey of fish harvesters to document first hand observations on how seismic surveys influence catch rates, in addition to available scientific literature, was used to develop testable hypotheses and guide analytical approaches. This integrative work is ongoing. If a similar and consistent approach could be developed across many other regions, direct comparisons of various noise related impacts could be widely expanded and used to address globally-relevant challenges, such as cumulative effects or whether shifting ocean noise baselines over time might blur impacts on marine life.

Mapping the Underwater Noise of Recreational Boats

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Recreational boating is increasingly popular in many countries, often in sensitive coastal environments. The underwater noise emitted by these recreational vessels can be the dominant source of anthropogenic underwater noise in these areas, since commercial vessels typically do not operate in these sheltered areas (Wilson, Pine & Radford, 2022). Here we describe our efforts to produce underwater noise maps for recreational vessels in the Kosterhavet Marine National Park on the west coast of Sweden. Since small recreational boats typically do not have AIS transmitters, noise mapping cannot be approached in the same way as for commercial traffic. Instead, a boat detection algorithm is used to detect boats in satellite images. These detections are used to compute a boat density map - a statistical measure of the expected number of boats per unit area. A newly developed source level model for recreational boats (Lalander et al., 2025) converts this boat density into a source power density in the entire study area. To handle the propagation of this grid of source powers to the grid of receiver positions, a semi-empirical propagation loss model is used. This model is tuned to several thousand in-situ measurements of propagation loss performed in the area. The study area is acoustically complex with many small islands, generally shallow waters, and a mixture of soft clay and harder rocky surfaces. The measurements were chosen to cover a wide range of circumstances, including open shallow or deep areas, and transmission around islets or promontories. The noise map is validated with measurements from four locations in the area, collected during one summer season of boating. Since the satellite images are taken at noon and are only usable in conditions with clear skies, the resulting noise map also represents these conditions. The model results are therefore compared to the measurements averaged only for the corresponding (daytime and clear weather) conditions. The noise map shows good agreement with the measurements, suggesting that this approach can work at a larger scale to cover greater coastal regions.

Indexing Underwater Noise in Ecosystem Based Marine Spatial Planning

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This study introduces a quantitative framework for integrating Underwater Radiated Noise into Marine Spatial Planning through a Cumulative Effects Assessment approach. The method, aligned with international policy, combines calibrated sound mapping with web based decision support tools to assess acoustic risk. Central to the framework is the ANPIndex, a standardized indicator describing how acoustic intensity varies over time relative to species specific management thresholds. The approach was tested in the Northern Adriatic Sea, revealing seasonal hotspots where continuous AIS derived URN overlaps with key species distributions. Elevated risk areas emerged for European hake and loggerhead turtle in the southern and central basin, and for bottlenose dolphin in the northern sector. Including underwater noise increased cumulative impact scores by about 7%, especially along major shipping routes. While noise pressure is locally high, the CEA effectively highlights where it translates into ecological risk. The framework provides actionable maps to guide measures such as vessel speed reductions or the designation of sensitive areas, supporting scenario evaluation and sustainable maritime planning within a blue economy context

CAB Technology: Near Real-Time Passive Acoustic Monitoring for Mitigation and Noise Measurement

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Near real-time mitigation monitoring using passive acoustics is increasingly required for marine mammals surrounding industrial activities in the ocean, such as offshore wind farm construction and port expansions. It is beneficial to understand both realised source levels of activities, as well as where marine mammals are with respect to a given mitigation zone, as these minimizes potential adverse impacts on species of concern. Doing so is also advantageous as these development activities are costly endeavours, sometimes requiring large exclusion zones over which monitoring is to be conducted, and/or exclusion zones which require monitoring in hours of darkness and poor visibility. In response to these needs, SMRU Consulting developed an autonomous passive acoustic monitoring system which includes three hydrophones: the CAB Guardian (Coastal Acoustic Buoys). Using time of arrival differences, bearing information of marine mammal sounds can be calculated. This information is available alongside noise measurements and automated detections and classifications of clicks/whistles/moans. This is done via an onboard acoustic processing system running PAMGuard in real-time, with real-time information allowing for any resulting regulatory actions to be well-informed. Following on from previous demonstrations of full system CAB field validations, we here highlight examples of where CABs have contributed to both marine conservation and marine developments. Real-time examples detailed include noise measurement during piling construction, and mitigation monitoring during a dredging campaign in an area that partly overlaps with a Special Area of Conservation for bottlenose dolphins. Automated detections were uploaded via cell modem to a virtual computer in the cloud, accessible by PAM operators from anywhere with an internet connection. This allowed for the evaluation, in real-time, of whether mitigative actions were required, based on noise levels and the position of the marine mammals with respect to the mitigation zone. This presentation explores real-world case studies of passive acoustic mitigation monitoring, and provides a discussion on important considerations when customizing technology to best suit the particular opportunities and constraints of a given project and location.

Experimental Evaluation of the Pulcea High Performance Bubble Curtain

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The Pulcea "High Performance Bubble Curtain" is a novel noise abatement system developed to reduce underwater impulsive sound from offshore piling through the in-situ generation of micro to nano scale gas bubbles within an enclosed sleeve. Unlike conventional bubble curtains that rely on buoyant air release from the seabed, the HP-BC produces oxygen bubbles throughout a confined water volume at depth, forming a quasi-stable acoustic barrier around the source. A programme of controlled dock-based trials using seismic airguns as piling proxies has been undertaken to quantify broadband and frequency dependent insertion loss under representative conditions. Results across a range of fluid concentrations and configurations demonstrate that the system can achieve mitigation levels comparable to established noise abatement technologies while offering a fundamentally different deployment concept. This presentation provides an overview of measured acoustic performance, discusses frequency dependence and scaling considerations, and outlines the pathway toward optimisation and future offshore validation.

Windfarm-associated sounds variably influence the behavior and physiology of the American Lobster (Homarus americanus)

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Windfarm installation and other offshore anthropogenic activities generate high levels of noise, fundamentally altering soundscapes of marine habitats over decades-long project lifetimes. The impact of noise on the many invertebrates in affected habitats remains poorly understood, despite the ecological and commercial importance of some species. To address this, we tested the effects of windfarm-associated noise on the American lobster (Homarus americanus), a species that detects and uses low-frequency sounds for predator avoidance and communication. We developed a lobster-borne biologging tag that records acceleration and heart rate, allowing us to assess behavioral and physiological responses to noise. In lab-based testing, tagged lobsters were exposed to repeated 10-min exposures of vessel engine sounds recorded offshore, representing a common source of non-impulsive noise pollution. Cardiac pauses, which can be indicative of a stress response, were observed in some lobsters at the start and/or end of noise events, altering heart rates. There were also cases of sustained heart rate increases that persisted for the duration of sound exposures, with rates typically recovering in inter-noise intervals. The presence and degree of responses to the sound exposures varied by individual, ranging from minimal to strong cardiac responses. We compare lab-based findings to results from a controlled field study, in which tagged lobsters were exposed to four 15-min sequences of actual impact pile-driving strikes, an impulsive noise pollution source. Experimental results and calibrated acoustic treatments (pressure and particle motion) are contextualized using offshore passive acoustic data collected in partnership with commercial fishermen. We used sound pressure measurements collected within lobster traps to calculate particle motion received levels, allowing us to estimate potential responses of wild lobsters exposed to noise pollution. Measuring the effect of both impulsive and continuous anthropogenic noise on physiological stress and behavior is critical for understanding implications for the fitness of exposed populations. This unique combination of eco-physiological experiments and fishery-collaborative, in situ observations provide data key to informing stakeholders on the influence of sound on the culturally- and economically-vital American lobster.

The Menck MNRU - Primary noise mitigation for impact pile driving

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The rapid expansion of offshore wind energy is essential for achieving global decarbonization goals, yet its development must have minimal impact on marine ecosystems. Among the most significant environmental stressors associated with offshore wind construction is underwater noise generated during impact pile driving for turbine foundations. High-amplitude impulsive sound can adversely affect marine mammals, fish, and invertebrates, necessitating effective noise mitigation methods. This contribution discusses the potential of the Menck Noise Reduction Unit (MNRU) as a primary sound damper integrated directly into the hydraulic impact hammer, designed to reduce radiated underwater noise at the source. The system operates by prolonging and reshaping the ram impact impulse through a specially engineered mechanical mechanism, thereby reducing peak sound pressure levels while maintaining sufficient pile-driving efficiency. The physical principle of the MNRU is demonstrated using sophisticated numerical simulations, describing how the impulse stretching modifies the frequency content and amplitude of the radiated wave field. A fully coupled hammer-pile-soil-water model is employed to examine the dynamic response and noise emission characteristics. Recent measurement data from a full-scale commercial project is furthermore shown to discuss the effectiveness of the primary noise mitigation approach under real offshore conditions. The results demonstrate a notable reduction in underwater noise levels compared to conventional impact hammer operation, with measured peak and broadband noise decreases consistent with simulation predictions. The findings confirm that integrating a primary noise mitigation system within the impact hammer itself can significantly reduce environmental noise emissions without compromising installation efficiency. Based on these positive results, an outlook on the next generation of impact hammers with optimized acoustic performance and primary noise mitigation is given. This approach contributes to more sustainable offshore wind development by minimizing acoustic disturbance to marine life during foundation installation.

Physiological responses of coastal plankton when exposed to offshore windfarm noise

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Anthropogenic noise impacts a wide variety of marine organisms, from megafauna to microorganisms. However, the effects of low-frequency noise from offshore windfarms on plankton communities remain largely understudied. To address this gap, two field experiments were conducted in 2023 and 2024 in Hopavågen lagoon (Norway). Natural coastal plankton communities were exposed to offshore windfarm noise using a novel in situ experimental setup. Using an underwater speaker, offshore windfarm recordings were broadcast in the lagoon reaching sound pressure levels of 100-106 dB re: 1 uPa over 50-2000 Hz at the treatment site. Meanwhile a naturally acoustically isolated section of the lagoon served as control, with ambient noise varying between 70-88 dB over that frequency band. We combined short-term incubation experiments with a three-week mesocosm study to evaluate how noise-induced changes in growth and grazing rates could explain community biomass dynamics. Specifically, we measured physiological responses, phytoplankton growth rates and microzooplankton and copepods grazing rates, through incubation experiments. During the mesocosm experiment, we evaluated long-term population dynamics using pigment, flow cytometry, and microscopy analyses to monitor, bacterio-, phyto-, and zooplankton communities. Pigment-based growth rates of larger phytoplankton (notably diatoms and prymnesiophytes) were higher in the noise treatment compared to the control, whereas cytometry-based picoplankton growth rates were lower. Similarly, pigment-based microzooplankton grazing on diatoms and prymnesiophytes was higher in the noise treatment than in the control, while cytometry-based microzooplankton grazing on the picoplankton fraction was lower. Conversely, copepod grazing on nano- and picophytoplankton was also higher under noise exposure. In addition, results from the mesocosm experiment revealed divergent biomass trends. While noise exposure led to higher concentration of 19'hexanoyloxyfucoxanthin (prymnesiophytes), it also resulted in lower fucoxanthin concentrations (diatoms) compared to the control. These findings suggest that the effects of low-frequency noise on plankton physiology are potentially taxon dependant. Furthermore, similar physiological responses did not necessarily result in similar biomass trends demonstrating that anthropogenic noise can decouple physiological rates from community structure by potentially inducing trophic cascades within the plankton food web.

Aquatic Pollution from Light and Anthropogenic Noise: Assessment of potential mitigation options

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AquaPLAN (Aquatic Pollution from Light and Anthropogenic Noise: management of impacts on biodiversity) is a 48 month Horizon Europe research programme that aims to quantify, understand and manage the combined impacts of light and noise pollution (LNP) across freshwater, estuarine and marine ecosystems. The project brings together an international consortium to assess LNP prevalence, develop harmonised monitoring protocols, design long term ecological observation programmes, and provide decision support tools for policymakers and environmental managers. Its overarching challenge is to address critical knowledge gaps and to improve the ability of regulators and stakeholders to prevent and mitigate LNP impacts on biodiversity. At Oceanoise, we will present an overview of one task aiming to deliver a focused technical evaluation of current and emerging mitigation solutions for LNP. Drawing on policy reviews, stakeholder responses, recent scientific literature, and expert guidance from the AquaPLAN Scientific Advisory Board, preventive and corrective measures designed to reduce LNP at source or via operational management are being assessed. Evaluation includes comparing the applicability, technical efficacy and technology readiness of mitigation methods across different aquatic settings, while examining potential co benefits and trade offs where light and noise co-occur. During our AGM in Lisbon (January 2026) there was a stakeholder workshop, where mitigation options were presented, discussed in breakout groups, and scored interactively by participants across the consortium. A summary of the outcomes of this workshop will be presented at Oceanoise. Overall, the goal of D5.2 is to identify scientifically robust, scalable and context appropriate mitigation options that can inform future policy recommendations and support integrated environmental management planning, including those aligned with the Marine Strategy Framework Directive. By clarifying the strengths and limitations of available solutions, this work contributes directly to AquaPLAN's mission to improve evidence based mitigation for LNP impacts on aquatic biodiversity and ecosystem services.

The Casablanca-DAS seafloor observatory: A new fibre-optic platform for continuous, multi-layer ocean monitoring

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Offshore monitoring is becoming critical as marine environments host growing industrial activity, dense maritime traffic, and increasing environmental monitoring demands. Reliable monitoring of offshore geohazards and environmental processes remains challenging because conventional instrumentation is sparse, expensive to deploy, and difficult to maintain in marine environments. From 2022 to 2025 we deployed the Casablanca-DAS Seafloor Observatory, a dedicated fibre-optic cable instrumented using distributed acoustic sensing (DAS) offshore the Ebro Delta, near the continental shelf break in the north-western Mediterranean Sea. The system operates in association with the Repsol Casablanca offshore platform (Tarragona, Spain) at a water depth of about 161 m. The work was carried out under the European Union NextGenerationEU/PRTR programme through project REMO (CPP2021-008869), in collaboration between Repsol, ICM-CSIC, the University of Alcalá, and Aragón Photonics. DAS transforms the submarine fibre into a dense array of synchronized virtual sensors with metre-scale spacing, enabling continuous monitoring of seafloor strain over large spatial scales. We present the deployment and architecture of the observatory together with a data-processing workflow designed to manage large DAS datasets and detect seismic signals in near real time. During its operational period, the system recorded several low-magnitude earthquakes, demonstrating the capability of DAS to complement coastal seismic networks and reduce the observational gap caused by sparse offshore instrumentation. The observatory also reveals the potential of fibre-optic sensing to capture signals generated across multiple Earth-system layers. The DAS system records strain signatures associated with atmospheric forcing (storms and surface-wave loading), marine acoustic sources (ships and whales), and lithospheric processes such as earthquakes. This multi-layer sensitivity highlights the potential of submarine fibre infrastructures as next-generation ocean observatories. The Casablanca site provides an exceptional natural laboratory for assessing the potential of DAS-based observatories for ocean monitoring and marine-noise research in a setting characterized by intense maritime traffic, recurrent storms, and marine-mammal migration corridors. The site combines geophysical relevance, ecological sensitivity, and strong anthropogenic forcing within an operationally accessible offshore environment.

The Fourth State of Water: A Potential New Frontier for Underwater Acoustics and Bioacoustics

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Water is generally described as existing in three phases-solid, liquid, and gas. However, over the last decade, research in biophysics has described a fourth, interfacial phase of water, often termed Exclusion Zone (EZ) water or structured water. This phase forms adjacent to hydrophilic surfaces and exhibits a markedly higher molecular order, altered density and viscosity, and distinct electrical properties compared to bulk liquid water. Although the phenomenon is well documented in laboratory settings, its implications for underwater acoustics have remained largely unexplored. The intention here is to introduce the fourth phase of water to the Oceanoise community by examining how the presence of structured water at interfaces may influence sound propagation, scattering, and coupling in marine environment. EZ water forms thin, stable layers at biological membranes, sediments, minerals, and organic surfaces, hence it has the potential to act as a micro scale acoustic modifier-locally altering acoustic impedance, affecting reflection and refraction, and subtly influencing attenuation at mid to high frequencies. There are several emerging hypotheses relevant to ocean noise research: * Propagation: EZ layers may create micro boundaries that scatter or shape sound fields, particularly in biologically rich or surface active habitats. * Sensing: Structured water adjacent to biological tissues could influence how marine animals receive sound, potentially modulating impedance at the water-tissue interface. * Vocalisation: The acoustic efficiency of organs involved in sound production-such as phonic lips in odontocetes-may depend in part on near surface water structuring. * Noise pollution: EZ rich environments, such as kelp forests, reefs, and biofilm coated substrates, may act as natural acoustic filters or shields. While speculative, these ideas could potentially open a promising line of inquiry linking microscale water physics to macroscale acoustic phenomena. Thus, this is the invitation to contemplate and preferably test whether structured water may represent an unrecognised variable in underwater sound modelling, marine mammal communication, and environmental noise impact.

Advancing DAS-Based Cetacean Localization Monitoring: Dual-Cable Strategy in the Campos Basin, Brazil

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Distributed Acoustic Sensing (DAS) enables high-resolution underwater acoustic monitoring with strong potential for cetacean vocalization studies. A central limitation of single-cable DAS deployments is source localization, as time-of-arrival analysis reconstructs only radial distance in the transverse plane, leaving angular ambiguity unresolved. To address this, we employed two DAS interrogators simultaneously monitoring nearby submarine cables in the Campos Basin, offshore Brazil, Petrobras' Imbetiba telecommunications station in Macaé. Both systems detected identical vocalization events, allowing independent radial reconstructions that were combined to estimate source position from the intersection of the two reconstruction planes. Comparative spectrogram analysis further demonstrated complementary sensitivity profiles arising from differing acoustic wave projections, mitigating directivity-related blind spots inherent to single-cable geometries. These results highlight the importance of cable selection and deployment geometry in DAS-based monitoring, offering practical guidance for improving localization accuracy and reducing directivity ambiguity through multi-cable or variable-geometry strategies. The project was developed jointly by Instituto Aqualie, Immer Messen start-up, and Petrobras.

BioDCASE: Towards standardised data challenges supporting robust development of ML models for underwater acoustic event detection

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With the current rise of the application of Machine Learning (ML) models to detect specific sound events in underwater passive acoustics monitoring recordings, the need for standardised and scalable comparison between developed models emerges. For this reason Task 2 in the bioDCASE (2025) data challenge was proposed, with the objectives of (1) bringing together ML, marine science, and bioacoustics communities (2) improving rigour and fairness in comparing performance of proposed solutions (3) helping to bridge the gap between the requirements of operational monitoring projects and existing ML evaluation protocols (4) engaging entry-level researchers into model development, and (5) providing an open-source benchmark for further developments. The designed data challenge asked participants to develop automatic multilabel detectors using strongly labelled events. The dataset selected for the task was the Miller et al. (2020) dataset, comprising recordings from 11 location-year pairs. The annotation effort focused on calls from Antarctic blue whales (Balaenoptera musculus) and fin whales (Balaenoptera physalus), split into seven labels, which were grouped into three final labels for the task. A curated version of the dataset was made available on Zenodo. The task proposed a fixed training, validation and evaluation split where the ground truth of the evaluation set remained unknown for participants. The splitting was designed to evaluate the model's ability to generalise across unseen locations and years using a hold-out dataset approach. In the selected split, the validation set and the evaluation set included site-year combinations which were not included in the training set regarding year, location or both. The evaluation metric was based on one-dimensional intersection over union along the temporal axis and penalised models that generate multiple detections for a single ground-truth event to support applications such as density estimation. Considering the imbalance of occurrences between classes, the comparison metric was chosen to be macro-averaged. In the 2025 bioDCASE edition, two baselines were provided by the organising team using YOLOv11 and ResNet, respectively, and the task had 12 submissions from 6 different teams. The best performing model achieved an F-score of 0.5, with only one model beating the baseline YOLOv11 performance, showcasing the difficulty of the task. The same task will be released in 2026 with a supplementary evaluation dataset.

Uncertainty Assessment of Simplified Models for Underwater Acoustic Propagation

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Accurate prediction of underwater sound propagation is essential for assessing the environmental impact of anthropogenic activities, including maritime traffic characterized through AIS data, offshore infrastructure development, and the acoustic effects of underwater explosions. However, the complexity of propagation models varies considerably, ranging from rapid analytical approximations to high-fidelity numerical models that require substantial computational resources. This study investigates the uncertainty associated with simplified acoustic propagation models through a systematic comparison with more physically comprehensive approaches. The analysis evaluates the performance of simple models, including the image method, the Colossus model, and spherical spreading approximations, under a range of environmental conditions. These models are compared with reference solutions obtained from advanced numerical models such as MMPE and BELLHOP, which provide a more accurate representation of the underlying acoustic propagation processes. The comparative framework considers key environmental variables, including water depth, acoustic frequency, seabed composition, and, critically, variability in the sound speed profile. The results demonstrate how the accuracy of simplified models strongly depends on environmental parameters, quantifying their deviations from reference models across scenarios of increasing environmental complexity. Based on these findings, the study proposes guidelines for selecting the most appropriate propagation model according to the characteristics of the acoustic scenario and the acceptable level of uncertainty. This work provides a practical methodology for balancing computational efficiency and predictive accuracy in underwater acoustic impact assessments.

Theoretical and Experimental Characterization of Acoustic Transmission Loss in Underwater Bubble Curtains

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Bubble curtains are being used as a mitigation technique to reduce the propagation of underwater noise generated by activities such as offshore construction, pile driving, and underwater blasting. Their effectiveness relies on the strong acoustic impedance contrast between water and air, which leads to scattering, reflection, and absorption of incident acoustic waves. However, the acoustic performance of bubble curtains strongly depends on parameters such as bubble size distribution, air flow rate, curtain thickness, and environmental conditions, making accurate prediction of their transmission loss challenging. This study presents a combined theoretical and experimental investigation of the transmission loss produced by bubble curtains in controlled underwater conditions. A theoretical framework based on effective medium theory and multiple scattering models is developed to estimate the acoustic attenuation produced by a bubble layer as a function of bubble radius distribution, void fraction, and frequency. The model accounts for the resonant behavior of bubbles and its influence on sound propagation across the curtain. To validate the theoretical predictions, a series of laboratory-scale experiments were conducted in a freshwater tank using a controlled bubble generation system. Bubble curtains were produced using perforated diffuser lines with adjustable air flow, allowing the formation of different bubble densities and curtain thicknesses. Acoustic measurements were performed using calibrated hydrophones placed upstream and downstream of the curtain, and transmission loss was evaluated across the frequency range from 500 Hz to 20 kHz. The results show good agreement between theoretical predictions and experimental measurements within the frequency bands dominated by bubble resonance effects. The experiments confirm that transmission loss increases with air flow rate and bubble density, while the frequency response is strongly influenced by the characteristic bubble size. The proposed model provides useful insight into the mechanisms governing acoustic attenuation in bubble curtains and can serve as a practical tool for predicting their performance in noise mitigation applications. These findings contribute to improving the design and optimization of bubble curtain systems for underwater noise control in offshore and

Application of Underwater Acoustic Modeling to Prospective Offshore Scenarios in the Santos Basin Pre-Salt.

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The Santos Basin Underwater Soundscape Monitoring Project (PMPAS-BS) was developed in response to a request from the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA) to PETROBRAS as a condition for environmental licensing of offshore exploration and production (E&P) projects in the Santos Basin. The project aims to characterize the underwater soundscape and monitor potential impacts associated with the increase in industrial activities in the region. A key component of the project was the implementation of the Underwater Acoustic Modeling System (SIMAS, in the Portuguese acronym), a computational tool that uses numerical models to estimate acoustic noise in the water column. SIMAS employs a normal-mode-based acoustic propagation model, incorporating inputs from the Automatic Identification System (AIS), representative acoustic signatures of ships and platforms, as well as oceanographic and geophysical data. This paper presents an application of SIMAS for analyzing underwater noise generated by future scenarios from 2025 to 2033, which simulate the expansion of activities planned for Phase 4 of the Pre-Salt cluster, involving the installation of ten new offshore production platforms by PETROBRAS. The results indicate that the projected noise increments do not produce significant effects on the regional soundscape of the Santos Basin. These effects remain spatially localized and are more evident in regions with lower current intensity of E&P and navigation activities. The largest average annual increases are observed near specific platforms, particularly in the immediate vicinity of the Aram field, located in an area at an early stage of E&P activity development when compared to the established Pre-Salt production cluster.

From Decibels to Distance - Why Small Acoustic Errors Can Matter for Marine Mammal Injury Ranges

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Acoustic propagation models are widely used to predict marine mammal auditory injury zones and their uncertainty is usually reported as plus or minus a few decibels, yet regulators and biologists make decisions in metres rather than decibels. The link between a level error and a change in predicted injury range is rarely made explicit, so a model described as accurate to within +/-3 dB may sound reassuring but gives little sense of what that means for mitigation zones or risk. This study explores how decibel uncertainty translates into distance uncertainty under both peak pressure and cumulative sound exposure level criteria. For peak thresholds governed by geometric spreading, simple relationships show that a 6 dB difference can approximately double or halve predicted injury range under spherical spreading, while a 3 dB difference can have a similar effect under cylindrical spreading. For cumulative SEL criteria the relationship is more complex because sound decays logarithmically with range while animal movement and piling duration change linearly in space and time, so the impact of a fixed decibel error depends on starting range and exposure assumptions. Using simplified piling scenarios, this work compares propagation uncertainty expressed as decibels with uncertainty in movement and threshold assumptions. The aim is to make acoustic modelling uncertainty more transparent in terms of predicted injury range and to support clearer communication and proportionate mitigation design. This presentation represents work in progress toward practical guidance for interpreting modelling error in distance terms.

Predicting the Performance of Near-Pile Noise Mitigation Systems: Sensitivity Analysis and Realistic Upper Bounds

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Monopiles are the dominant foundation type for offshore wind turbines and are typically installed using impact hammers, generating high levels of underwater sound which may affect marine life. In many cases, both near-field and far-field mitigation systems are therefore applied. While far-field systems such as bubble curtains are relatively well understood, near-field systems placed around the pile are less well documented. Publicly-available data on the performance of these systems are limited and often difficult to interpret, as the environmental and installation conditions and the acoustic metric used are not always specified. Predicting mitigation performance is therefore challenging, as insertion loss depends strongly on soil properties, water depth, and pile design. These uncertainties become increasingly important as offshore wind projects move toward larger monopiles and deeper waters, where XXL monopiles radiate more low-frequency energy, which is more difficult to mitigate. The purpose of this study is to provide insight into both the sensitivity of predicted noise mitigation performance to these external parameters, and what constitutes realistic performance expectations for near-pile noise mitigation systems. First, we investigate the sensitivity of predicted insertion losses of an AdBm Noise Mitigation System to variations in environmental parameters, including those which can change during the installation process of a single pile. The near-field response is modeled using finite-element software representing the monopile, surrounding fluid, soil layers, and the AdBm system. The computed near-field response is propagated to the far field using a semi-analytical model, insertion losses are evaluated at 750 m, and the results are presented as 1/3-octave band and broadband sound exposure levels. The results demonstrate that even minor changes in the model inputs (system size, pile size, water depth, soil properties) can lead to significant changes in the predicted sound exposure levels. These levels are then compared with two 'ideal' near-pile noise mitigation cases: a fully-blocked fluid path around the pile, and an idealized 'perfect absorbing' case in which all acoustic energy in the fluid path is absorbed. These comparisons help provide estimates of the upper bounds for realistically achievable insertion losses from near-field mitigation systems.

Challenges in Cross Project Comparison of European Underwater Sound Maps

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Sound maps are practical tools to quantify the contribution of ships across time, space, and frequency, with the 63 Hz and 125 Hz decidecade bands being particularly important for assessing Good Environmental Status (GES) under the EU Marine Strategy Framework Directive (MSFD). Although such maps have been calculated for various European regions across multiple projects, combining or comparing their results is not straightforward. Differences in the sound level metrics used, such as percentiles, medians, or arithmetic means, complicates direct comparison. Further discrepancies arise from differences in modelling approaches taken for source characterisation, propagation modelling, and overall sound mapping, as well as the data quality of inputs used in these models. These factors can only be systematically assessed once a common metric is adopted. This work reflects on the lessons learned from the NAVISON project, funded by the European Maritime Safety Agency, with particular focus on the challenges faced when comparing NAVISON sound maps for the North Sea with those produced by the EU Interreg projects DEMASK and JOMOPANS. Examples are presented to illustrate the differences between the sound maps generated by these projects, each of which includes shipping sound mapping for the North Sea. These insights highlight the need to harmonise metrics and standardise methodologies. Achieving such alignment is essential to enable meaningful comparison across projects and to ensure that sound maps can reliably support marine environmental monitoring and policy development.

TUNE: a nimble Tool for Underwater Noise Evaluation

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Descriptor 11 of the Marine Strategy Framework Directive (2008/56/EC; MFSD) requires the assessment of energy inputs into the marine environment, including underwater sound. Criterion D11C2 specifically addresses continuous sound, such as low-frequency noise originated by ships. A variety of commercially available software exists to compute acoustic metrics, including sound pressure levels and power spectral densities. Certain software programs charge a fee, while others may not perform accurately with low-frequency data. This work introduces TUNE (Tool for Underwater Noise Evaluation), a standalone application designed in MATLAB. TUNE is freely accessible to the scientific community. It is designed to meet MSFD requirements. TUNE processes audio files of any length and in .wav format allowing users to upload calibration files specific to each recording chain. Considering these key-properties, TUNE proves a useful tool for obtaining reliable as well as absolute measurements. Among other, both root-mean-square as well as zero-to-peak sound pressure levels (dB re 1 uPa) can be assessed. Outputs are .jpeg files as well as .txt files, that are easily stored and imported into other applications e.g. for advanced statistical analysis. We demonstrate TUNE workflow and prove its ease of use. We present output metrics and parameters to be set. Stay TUNEd!

Sound-Cruising: Investigating acoustic output characteristics and noise budgets of cruise operations in Svalbard

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The Svalbard Archipelago and its surrounding waters provide important habitats for many Arctic endemic marine mammals, as well as seasonal migratory species. Historically, this region has had soundscapes with little anthropogenic noise. However, shipping and expedition tourism have increased across the Arctic and have done so exponentially in Svalbard. Globally, shipping noise is considered to be the most pervasive types of marine pollution with recognised negative impacts for marine mammals. Most studies on shipping noise focus on transient types of ship movement patterns and the resulting continuous, low-frequency noise emissions. But the operational patterns of Arctic expedition vessels differ significantly from conventional types of shipping because they venture away from port and coastal infrastructure on flexible itineraries and spend prolonged periods of time exploring special areas of interest. In Svalbard, these areas tend to be the fjords and sea-ice edges, which overlap with key habitats for marine mammals. Findings from a pilot study that we conducted in Svalbard in June 2023 indicate that noise emissions from cruise expedition-related operational procedures, such as dynamic positioning during guest activities, may lead to prolonged noise emissions for up to five hours within a particular area. Noise from these operations spreads over a broad range of frequency bands, overlapping with many marine mammals' communication and hearing ranges. The Sound-Cruising project assesses underwater noise patterns from cruise expedition activities in three remote Arctic fjords in Svalbard (Smeerenburgfjorden, Burgerbukta and Adventfjorden) by analysing continuous acoustic data sets obtained from three autonomous recording stations over the peak tourist season in summer 2025. Utilising the data from these acoustic recordings and Automatic Identification System to map vessels to the recordings, we can investigate the noise budgets (the surplus in noise above the natural ambient sound generated by human impact) associated with local cruise activities. This study's results will provide a baseline that can be used to provide advice regarding operational and technical changes to reduce underwater noise from cruise operations and similar activities in the fjords around Svalbard. Insights might also guide technical and regulatory measures to reduce the impacts of vessel noise from similar operations in other polar regions and beyond.

Marine soundscapes of the Arctic and human impacts - From monitoring to regulating

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The Arctic regions are much quieter acoustically than other oceans, and they act as a refuge for many animals, some of which are critically endangered. But climate change happens three times faster in the Arctic, decreasing sea ice seasons and covers and changing ecosystems, against a background of ocean temperatures increasing in the upper 2,000 m. This affects its natural soundscapes, as easier and increasing access to the Arctic waters introduces additional sounds which can be heard hundreds of kilometres away. What kind of anthropogenic sounds should one expect? What frequency ranges should be used for monitoring? Because of the challenging and remote environment, sound measurements are still very sparse: can models or proxies supplement them? How do the answers vary with regions and contexts of human activities? How do they vary with Arctic seasons and the ice cover? How can we use them to define guidelines of how loud sounds should be and for how long? Can we use the examples of successful actions around the world, for example the European Marine Strategy Framework Directive or the Canadian ECHO programme? To start addressing these questions, we have analysed 10 years of data at a community observatory in the coastal Arctic, 6 years of acoustic measurements near a continental break and several years of measurements in deep seas. Ships and airguns used in seismic exploration are key contributors to Arctic soundscapes, as expected. Activities on ice, from snowmobiles to machinery and low-flying aircraft, vary with areas and seasons. Comparing times of full ice cover (when no ships should be expected) and open water, we show the "shipping bands" set by the MSFD at 63 Hz and 125 Hz are not enough to quantify the human impacts of these different sources. Human impacts should be quantified using frequency bands up to 1 kHz, a threshold dependent on the amount of ice cover. Satellite tracking of ships (using AIS) is not enough to identify and follow ships when the transponders stop being used or ships are too small to require them. Defining adequate baselines is particularly pressing as climate change and geopolitical challenges are bound to greatly increase access to the Arctic and its marine (and terrestrial) resources. As demonstrated at lower latitudes, underestimating current impacts and their developments will lead to inadequate policies, management and mitigation efforts. It is therefore increasingly urgent to define Arctic guidelines.

Acoustic monitoring of ice and animals in one of the ocean's noisiest places, a glacial fjord

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Since 2019, we have been working with Inuit hunters in Greenland and installing passive and active acoustic equipment in some of the least-explored ocean areas near the calving fronts of maritime glaciers. These regions are changing quickly due to ice loss and ecosystem shifts, but they are known as foraging hotspots for animals such as seabirds and seals, and appear to attract whales, including narwhals, on which the local community depends. However, due to iceberg calving, icebergs drifting with keels over 100 meters, and dense ice cover, accessing and retrieving stations is difficult and not always successful. Here, we share our ongoing work in Inglefield Bredning, Northwest Greenland, using passive and active acoustic seabed moorings, supported by video and oceanographic sensors. The data show seasonal changes in noise levels influenced by ice, the presence of animals such as narwhals, seals, fishes, and zooplankton, and highlight some controversial topics, such as the unusual repeated physical interactions of narwhals with our seabed instruments or narwhal presence near our active sonar, which are important to discuss with the community aiming to expand polar acoustic networks and establish best practices.

Long-term acoustic monitoring of odontocetes in Inuit Nunangat through collaborative research

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Rapid environmental change and rising shipping in the Arctic are reshaping underwater soundscapes. The changes also affect marine mammals that are important ecologically and to Inuit culture and food systems across Inuit Nunangat (Inuit regions in Canada). We present results of long-term passive acoustic monitoring in the Canadian Arctic co-developed through partnerships with community-based Hunters and Trappers Organizations in Nunavut and the Nunatsiavut Government (Canada). Multi-year recordings from fixed High-frequency Acoustic Recording Packages (HARPs; 200 kHz) were analyzed for echolocation clicks using a semi-automated detection and classification pipeline. Signals were clustered by spectral characteristics, inter-click intervals, and duration, and a deep neural network-based classifier was trained to assign detections to dominant classes. In Nunavut, acoustic records from Eclipse Sound (2016-2025) document narwhal (Monodon monoceros) seasonal presence in an important summering region with increasing industrial vessel traffic, with detections overlapping the period of greatest vessel activity and supporting ongoing work to estimate their responses to underwater noise. In Nunatsiavut's Torngat Area of Interest (2021-2025), the same workflow identifies multiple odontocete species and describes their multi-year seasonal patterns in the region for the first time. Outputs are being used by the Nunatsiavut Government to inform development of the Imappivut Marine Plan as part of the implementation of an Inuit Protected Area in northern Labrador, and to describe the underwater soundscape in the region as a baseline to better understand potential impacts of underwater noise on marine mammals.

A need for interdisciplinary action on the issue of baleen whale hearing

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The hearing of baleen whales has been inferred from behavioral responses to acoustic exposures, predicted from anatomical models, and recently, estimated through the recording of auditory evoked potentials (AEPs), which are small voltages produced by the brain when a sound is heard. Each of these approaches has its strengths, but none is sufficient to produce a baleen whale audiogram. Anatomical models can predict hearing ability, but they have been impossible to validate against empirical measures of baleen whale hearing. Behavioral responses to noise can be used to assess if an animal heard a sound in the absence of other potential causes of a response. However, the approach is plagued by the potential that an animal may not respond even though a sound is heard. Measuring AEPs directly assesses auditory system function, but AEP thresholds are typically much higher than behavioral hearing thresholds. Recent hearing studies on humpback (Megaptera novaeangliae) and common minke (Balaenoptera acutorostrata) creatively addressed some historical methodological shortcomings, but also demonstrated a continuing need for interdisciplinary approaches to assessing baleen whale hearing. Using a modified form of behavioral observation audiometry (BOA), a minimum response level (MRL) to various frequency sweeps was obtained from a population of migrating humpback whales. Results suggested that some MRLs were unmasked by ambient noise and provided estimates of the hearing threshold. However, other frequencies were masked, making it impossible to create an audiogram from the data. In the minke whale, the upper frequency limit of hearing and region of best hearing sensitivity were identified with AEP methods. However, because AEP thresholds overestimate hearing thresholds, a behaviorally-equivalent audiogram could not be created. Both studies suggested that predictions from anatomical models underestimated the upper frequency limit of hearing, yet overall anatomical model predictions were close to empirical results. This suggests that empirical measures can be used to validate anatomical models and provide insight into model improvement needs. Conversely, as anatomic models are validated, they may better guide future AEP and BOA studies by bounding expectations regarding frequency range and thresholds of hearing. Collectively, the strengths of each approach can accommodate the weaknesses of the other approaches to improve our knowledge of baleen whale hearing.

Validating numerical predictions of sound generated from underwater explosions in shallow waters

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Underwater unexploded ordnance (UXO) that are present in the North Sea are commonly cleared in a controlled way by means of high-order detonations. This is to mitigate the safety risk these UXO pose to humans, equipment, and infrastructure at sea, but it comes at the cost of producing high-amplitude shock waves which may be harmful for marine life. In previous research it was shown that the use of a linear propagation model leads to significant overestimation of the far field sound of detonated UXO's for large charge masses (with hundreds of kilograms of TNT) in shallow water, and required an empirical correction factor to match measured spectra at distances up to 2 km. To better understand the sound radiated from high-order detonations in shallow waters over long distances, we developed a hybrid numerical model that couples nonlinear sound generation from the underwater explosion and nonlinear propagation close to the source with linear-acoustics effects for sound propagation to larger ranges. The pressure-time signals and sound levels generated by detonating large UXO (with hundreds of kilograms of TNT) in a shallow-water scenario were estimated using this hybrid model for a range of up to 10 km and an upper frequency of 7.5 kHz. These results were compared to existing datasets obtained from measurements at sea up to a range of 2 km, which showed that the coupled model matched measurements well for frequencies up to 1 kHz without the need of an empirical correction factor. Although the model leads to a significant improvement in the predicted radiated noise over a wide frequency range, the upper frequency of the numerical model needs to be extended upper frequency of this numerical model needs to be extended to predict the effect that detonating UXO has on very-high frequency (VHF) cetaceans, such as the harbour porpoise. In addition, the range where the transition from nonlinear to linear propagation occurs in the model needs to be further studied.

Characterisation of underwater noise generated by fireworks events

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According to the Marine Strategy Framework Directive, anthropogenic noise can be classified into two groups: continuous and impulsive. The first group refers to sources whose radiation persists over a prolonged period and is primarily caused by maritime traffic. The second group consists of short-duration (milliseconds) and high-energy sounds. The main human activities responsible for this type of disturbance include maritime construction (pile driving), oil exploration, and sonar operations. However, certain sound sources are not explicitly mentioned in current regulations, despite their potential to significantly impact the marine ecosystem. These sources originate outside the water and are transmitted to the seabed through the air. A clear example of this type of source is fireworks, which are used worldwide as an audiovisual element in celebrations and entertainment events. This study analyses the impact of fireworks on the underwater soundscape. It is based on sound recordings obtained during a celebration in a village on the Mediterranean coast. The signals are characterised in terms of time and frequency to determine the noise immission level, the duration of the detonations, and their bandwidth. Both continuous and impulsive noise patterns are produced by the configuration of the detonations and the duration of the event, which lasts between 20 and 30 minutes. The results reveal sound pressure level increases above 160 dB for frequencies within the auditory range of fish, potentially posing a threat to certain marine species

Detecting underwater explosions: results from the Philippines

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Illegal fishing using explosives is a major source of damage to the marine environment, destroying reef habitats and killing all types of biofauna within ranges that can extend kilometers from the explosion source. Enforcement authorities conduct regular inspections, but especially in developing countries, detecting fishing operations that use explosives is challenging. Fishermen are careful not to use explosions from the vessel collecting the fish, and these operations are performed before dawn. Passive acoustic monitoring (PAM) offers a possible solution for detecting and estimating the direction of blast sounds. The blast signal is not an impulse but rather appears as a momentary increase in intensity in the low-frequency region. Current PAM approaches rely on a template for blast signals consisting of three pulses with varying bandwidth content. However, in shallow areas, these methods produce high false alarm rates, and at low signal-to-noise ratios, it is difficult to separate the blast pulses. We propose a blast detection algorithm that, instead of using templates, is based on the statistical relationship between blast-related samples for greater robustness. Our method searches for a region of interest with low entropy compared to its surroundings (3-sigma threshold) to identify non-random patterns in the signal, and whose auto-correlation is narrow (large third moment) to reflect a stationary signal. We implemented our method on a floater that autonomously maintains depth while detecting blast signals in real time. Upon detection, the floater ascends and reports the blast event via satellite communications. Being submerged, there is a reduced chance of damage or theft compared to existing buoy-based solutions. The system achieved a 60% detection rate of 150 recorded blast signals, with no false alarms during a continuous one-month recording period - a performance considerably better than benchmarks. We demonstrated the effectiveness of our system in a series of deployments in Palawan, Philippines. The system successfully detected two low-intensity blast signals produced during controlled operations, with zero false alarms over three days of varying sea conditions and noise sources.

The "noisome": understanding the genetic response to marine noise using the zooplanktonic Oikopleura dioica as a model system

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Noise pollution from human activities is an increasing concern for marine ecosystem health. While its effects on vertebrates such as cetaceans and fish have been extensively studied, impacts on marine invertebrates remain poorly understood despite their central ecological roles in trophic webs and biogeochemical cycling. Within the DeuteroNoise JPI-Oceans consortium, we investigated the effects of underwater noise on marine food webs using the appendicularian tunicate Oikopleura dioica as a zooplanktonic mesopelagic model species. O. dioica's key phylogenetic position as an early-branching chordate and combines ecological relevance with simple morphology and stereotypic embryonic development. We examined noise effects across all life stages, from embryo to mature adult, integrating morphological assessments with transcriptomic profiling. RNA-seq analyses focused on defining the "noisesome," the set of genes whose expression is altered in response to noise exposure. Animals were exposed to different noise intensities and frequency profiles, including pure tones, an EU high-impact reference noise, and ecologically representative ship noise recordings. Gross morphological analyses revealed high resilience of early embryos to noise exposure. However, transcriptomic analyses uncovered pronounced and stage-specific genetic responses. High-impact noise was characterized by downregulation of developmental and structural programs together with upregulation of metabolic and stress-response pathways, whereas ecologically relevant ship noise elicited weaker but directionally consistent transcriptional changes. Our results provide the first genome-wide characterization of the genetic response to marine noise in a zooplanktonic invertebrate, linking transcriptomic changes with molecular, developmental, morphological, and behavioural alterations. These findings address a major knowledge gap regarding invertebrate susceptibility to anthropogenic noise and position transcriptomic responses as powerful tools for ecological impact assessment on marine ecosystems and oceans' health.

Effects of noise on Pacific sand lance with implications for their avian predators

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As anthropogenic noise continues to grow throughout the world's oceans, its effects on fish have increasingly become an area of concern, as they are both economically and ecologically important. Forage fish, as they often play a central role in transferring energy from lower to higher trophic levels in the marine food web, are a critical resource for many predatory species. However, although noise is known to have negative effects on many fish species, information about how noise affects forage fish condition and behavior remains scarce. Research suggests that noise may affect both the behavior (availability) and condition (quality) of forage fish like Pacific sand lance, Ammodytes personatus. Pacific sand lance are unique as they bury in the sand both short-term (hours in summer) and long-term (months in winter) making them inaccessible to predators. To understand how noise affects Pacific sand lance quality and availability as prey in summer, and if winter dormancy buffers them against potential effects, we captured Pacific sand lance and exposed them to anthropogenic noise in summer and winter. We found that fish in control conditions were higher quality and that fish in all treatments varied in their accessibility compared to controls in summer. During winter dormancy fish showed fewer negative effects of noise on quality, though some differences still remained. These results suggest that noise may indirectly affect the seabirds that rely on these fish by lowering Pacific sand lance quality and altering their availability in the summer when they are most important to breeding seabirds.

Auditory dynamics during echolocation in freely swimming trained and wild toothed whales

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Echolocating animals rely on hearing to forage and navigate while moving through complex acoustic scenes. However, most auditory data from toothed whales come from stationary animals, limiting our understanding of how they receive and process sound during natural biosonar behavior. Here, we used suction-cup biologging tags with skin-surface electrodes to record auditory brainstem responses (ABRs) from four freely swimming, trained bottlenose dolphins and a wild harbor porpoise during prey capture. ABRs were measured in response to each individual's outgoing clicks and returning echoes during target approach. We found that biosonar adjustments reduced ABR amplitudes for outgoing clicks, while amplitudes for returning echoes remained generally constant. Notably, faint echoes elicited response amplitudes similar to those for higher-level self-produced clicks, and individuals showed progressively reduced response amplitudes to their own clicks as click rate increased. These findings indicate that auditory responsivity dynamically changes during target approach and suggest toothed whales possess an additional gain control mechanism for minimizing sensations of self-generated clicks. This study provides the first baseline measurement of auditory dynamics in free-swimming odontocetes, and the first empirical sensory measurements from any non-human animal during natural behavior in the wild. Tag-based ABRs close a major gap between stationary lab studies and natural behavior by offering direct insight into sensory reception within real-world conditions. The method may thus provide the means to (i) explore in-situ effects of anthropogenic noise on the auditory system of wild cetaceans, and (ii) collect auditory measurements across a larger diversity of wild species that are data deficient and not readily available for established, stationary experimental paradigms under direct human care.

Retracting to sound: the first behavioral audiogram of reef-building corals and sensitivity to vessel noise

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Recent research suggests that marine invertebrates, including coral larvae, use natural soundscapes for habitat selection. However, the auditory sensitivity of reef-building corals remains unknown. Establishing sound detection thresholds is a necessary first step towards understanding potential vulnerability to anthropogenic noise, and increasingly pervasive sounds such as shipping and small vessel noise. Here, we determined behavioral sound thresholds in five species of adult reef-building corals by exposing coral fragments to pure tones ranging from 80 to 2000 Hz under controlled laboratory conditions. Sounds were calibrated in sound pressure and particle acceleration. All species responded by retracting their polyp tentacles in a dose-dependent manner, ranging from mild (only a few polyps partially retract their tentacles), medium, strong to very strong (all polyps fully retract their tentacles), as sound level increased. Sensitivity was greatest at the lowest test frequency (80 Hz) and declined with increasing frequency; no responses occurred at 2000 Hz. These findings provide the first behavioral audiogram for adult corals. We then exposed corals to boat noise playbacks to assess responses to ecologically relevant anthropogenic sound. Similar dose-dependent retraction behavior was observed, underscoring sensitivity to low-frequency noise (<500 Hz), a dominant component of vessel traffic. As experiments were conducted in the acoustic nearfield, further in situ studies are needed to assess ecological relevance under natural soundscape conditions. Given the global rise in underwater noise and the ecological importance of reef-building corals, these findings highlight the need for in situ studies to evaluate ecological consequences under natural soundscape conditions. Yet, given that corals provide the foundation for ecologically vital and biodiverse reefs, the responses to tones and noise observed here for multiple species underscores the need for understanding the ecological implications of this sound-sensitivity.

The potentially disturbing effects of seismic surveys on free-swimming fish and shrimp populations

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While concern over the effects of anthropogenic sound inputs into freshwater and marine systems is increasing, there remains a dearth of field studies on the effects of some common types of sound sources on free-swimming fish and invertebrate populations. There is a large body of data suggesting sounds from recreational and commercial vessels can impact fishes and invertebrates, however, we are lacking data concerning the possible effects of sounds from resource exploration. Seismic surveys are frequently employed for resource exploration and have been a focus for effects on marine mammals, yet little is known about their possible effects on the far more diverse fish and invertebrate populations. The purpose of the current study was to estimate population effects on free swimming Atlantic cod (Gadus morhua), Acadian redfish (Sebastes fasciatus), and northern shrimp (Pandalus spp.). Baited remote underwater videos were taken to quantify animal numbers before, during, and after towing a seismic airgun off the coast of Newfoundland, Canada. There were small decreases in the numbers of cod and redfish seen at each camera during the one-hour airgun deployment period, but their numbers quickly rebounded once the airgun was turned off. Shrimp, however, showed large decreases in number during deployment and their numbers did not recover after deployment ended. At a finer-scale, there were also decreases in fish and shrimp numbers in between each 5-minute deployment, suggesting animals were initially disturbed with airgun firing. Overall, our results suggest that while seismic airgun may cause fish to move away from the sound source, or at least quit feeding, these effects seem short-lived, although effects on shrimp may be longer lasting.

The aquatic tympanic ear

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All groups of tetrapods have members that adopt aquatic lifestyles with adaptations also of their auditory system. Water is a high pressure, low particle motion medium, and the consequence is that an efficient underwater ear is sensitive to sound pressure. It is often stated that underwater hearing can work efficiently without a middle ear apparatus by bone conduction, but the sensitivity of such an ear is limited by the very low particle motion in water. A comparison of tetrapods ranging from totally aquatic (the clawed frog Xenopus laevis) and mostly aquatic (the red-eared slider Trachemys scripta) to mostly terrestrial (the cormorant Phalacrocorax carbo sinensis) show similar features. All have tympanic middle ears with an air-filled middle ear cavity. The eardrum vibration peaks at the resonance frequency of the middle ear cavity air volume and the eardrum is modified (plate-like). In all three species, the lowest threshold to underwater sound is at this peak frequency and is around 80 dB re 1 uPa. Sensitivity to sound pressure is slightly lower in water than in air, making underwater hearing much more efficient in terms of sound energy. Consequently, the slightly modified tympanic ears of these species are efficient aquatic sound receivers.

Effect of hatchery noise conditions on development and survival of Chinook salmon and considerations for future mechanistic studies

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Anthropogenic noise in aquatic environments poses a substantial risk to fish populations. Close contact with extreme noise events such as underwater construction can cause outright mortality, while exposure to lower noise levels in both natural and aquaculture environments can negatively impact fish growth and sensory function, ultimately reducing fitness. The negative effects of hatchery noise exposure are a particular concern for salmonids (genus Oncorhynchus) reared in the Pacific Northwest of North America. U.S. hatcheries rear and release over 100 million Pacific salmon each year to supplement wild populations for commercial and recreational fisheries. Given the anadromous life cycle of Oncorhynchus spp., post-release fitness is critical to long-term hatchery success. We therefore asked how hatchery noise conditions affected development, swimming behavior, and post-release survival of Chinook salmon Oncorhynchus tshawytscha. Chinook fry were reared for four months in one of three noise conditions: quiet (noise abated), ambient hatchery noise, and continuous white noise treatment (150 dB re 1 uPa). Fish reared in continuous white noise were smaller in April, shortly before release, but showed normal sensory morphology and swimming behavior compared to fish reared in ambient or quiet conditions. Strikingly, white noise-treated fish were significantly less likely to return to the hatchery as adults, suggesting that hatchery noise conditions impact post-release fitness. However, mechanisms by which hatchery noise altered fitness remain unknown. Lab experiments using a tractable genetic fish model, the zebrafish, can help address these questions by allowing for precise manipulation of noise conditions simultaneous with measures of cellular activity. This talk will highlight the importance of both hatchery- and lab-based studies to better understand how aquatic noise affects fishes and suggest strategies to mitigate these impacts.

MALDI Imaging of Proteins and Lipids in Sepia officinalis Larvae Following AquaVib Sound Exposure

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Under the SATURN EU-funded interdisciplinary research project, an experimental laboratory system, AquaVib, was developed. AquaVib is a transparent acoustic chamber equipped with sensors for sound pressure, particle acceleration, dissolved oxygen, and temperature, and enclosed by a pair of 1 kN electrodynamic shakers. This system is capable of reproducing low-frequency sounds with characteristics similar to underwater radiated noise (URN), providing a multimodal platform to investigate physiological, pathological, and ultrastructural effects on invertebrate species across different life stages. In this study, we evaluate the effect in Sepia officinalis larvae following controlled sound exposure in AquaVib at the proteomic and lipidomic level using a novel spatial MALDI-MSI-based approach integrated with ion mobility of Experiments were conducted within the SATURN project using shipping-related URN, and within the DIAPHONIA project using pile-driving noise exposure. Results revealed significant changes in protein expression after sound exposure, particularly involving stress-related proteins and cytoskeletal components, suggesting alterations in cellular integrity and stress response pathways. Lipidomic analysis indicated modifications primarily associated with membrane structure and energy metabolism, highlighting potential impacts on cellular function and homeostasis. The application high-resolution spatial proteomics and lipidomics to S. officinalis larvae represents a novel and powerful approach, enabling spatially resolved visualization of proteins and lipids alterations. This technique provides new insights into the molecular effects of underwater sound, including both particle motion and pressure components, on marine invertebrates.

Soundscapes of seahorse habitats: a sensory ecology perspective on vulnerability to anthropogenic pressures

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Anthropogenic noise is increasingly altering coastal soundscapes, particularly in areas exposed to intense maritime activity. Seahorses are especially sensitive to such disturbance due to their limited mobility, small home ranges, and strong association with structured habitats. In Portuguese coastal ecosystems, two species occur: the long-snouted seahorse (Hippocampus guttulatus) and the short-snouted seahorse (Hippocampus hippocampus). This study investigates the acoustic characteristics of three seahorse habitats in Portugal-the Tagus estuary, the Sado estuary, and the Ria Formosa lagoon, focusing on the contribution of anthropogenic noise. Auditory sensitivity in both species will also be assessed to explore potential masking effects and estimate the active acoustic space of seahorse click signals under contrasting soundscapes. Preliminary analyses reveal clear differences among sites, with the Tagus estuary showing the highest anthropogenic noise levels associated with intense shipping activity. These findings highlight the importance of considering acoustic habitat quality in the conservation and management of seahorse populations worldwide.

Investigating substrate-borne vibrational sensitivity in marine gastropods

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Substrate-borne vibration (vibrational noise) is a biologically relevant but poorly understood component of underwater noise. Substrate-borne vibrations play an important role in how animals detect predators and prey, forage, and interact with their environment. Anthropogenic activities in direct contact with the seabed, such as pile driving, produce acoustic waves in water but also generate sediment-borne waves. While sensitivity to vibration has been demonstrated in crustaceans and bivalve molluscs, comparatively little is known about gastropods, despite their close association with hard substrates and sediments, via a muscular foot, and their ecological importance. Here, we present a controlled laboratory study investigating the behavioural responsiveness of marine gastropods to substrate-borne vibration. Experiments were conducted with two intertidal species, the common periwinkle (Littorina littorea) and the dog whelk (Nucella lapillus), using an identical experimental framework to allow direct comparison between species with differing ecological roles. Vibrational stimuli spanning a range of frequencies (< 1kHz) and amplitudes (< 5m/s^2) were delivered to the tank base, with acceleration levels monitored throughout. Behavioural indices were used to determine detection thresholds following approaches previously established for other marine invertebrates. Data indicate that these species are responsive to substrate-borne vibrations, with a greater sensitivity at lower frequencies (< 200 Hz) and that sensitivities fall within measured levels of vibrational noise in aquatic environments (i.e. pile driving, drilling, offshore wind farms). This work emphasises the necessity of extending underwater noise management to include vibrational noise, in tandem with acoustic.

Stress, Sound, and Sanctuary: How Marine Reserve Age Shapes the Physiological Resilience of Australasian Snapper

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The Hauraki Gulf Marine Park (HGMP) is a uniquely managed seascape that includes several Marine Protection Areas (MPAs) established between 1975 and 2003. MPAs are intended to shield ecosystems from human driven pressures, especially fishing, and to conserve biodiversity. While reduced fishing pressure is well known to boost fish abundance and protect species diversity, far less is understood about how long term protection shapes the physiological stress responses of fish. Work in the HGMP has already shown striking behavioural differences in the Australasian snapper (Chrysophrys auratus): individuals inside the world's oldest no take MPA were attracted to boat sound, whereas snapper in fished areas respond aversively. This contrast suggests that protection may influence not only population structure but also how fish perceive and respond to disturbance. To explore this further, the overarching goal of our study was to quantify molecular stress responses in snapper across MPAs of different ages and compare them with responses in fished populations. Because traditional physiological sampling can be invasive, and often restricted in protected areas, we first evaluated whether gill swabs could serve as a minimally invasive alternative to gill or fin tissue sampling. Our results show that gill swabs reliably capture molecular indicators of stress, offering a practical tool for monitoring fish physiology in sensitive or regulated environments. With this validated method, we then measured transcription of key stress related genes in snapper from three MPAs spanning different establishment ages, alongside a non reserve site. Sampling across this gradient allows us to test whether the duration of protection influences baseline stress physiology and whether long protected populations show evidence of reduced chronic stress. The forthcoming results from this main experiment will help clarify whether older reserves provide benefits that extend beyond rebuilding fish stocks, potentially buffering species from broader environmental stressors and highlighting the deeper ecological value of long term marine protection.

BOOMIN: Using Acoustic Tags on Whales to Study Impulsive Sound Exposure near a US Military Training Range

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The Southern California Anti-submarine Warfare Range (SOAR) has been a study site for the effects of Mid-Frequency Active Sonar (MFAS) on goose-beaked whales (Ziphius cavirostris) since 2006. MFAS is not the only potential source of anthropogenic disturbance for whales in this region, however. Impulsive sounds, including those from in-water and near-surface explosions, the launch and impact of live and inert rounds in munitions training, and the use of seal bombs as deterrents in commercial fisheries, are not uncommon on and around SOAR. This has prompted the Behavioral Observations of Marine mammals around Impulsive Noise (BOOMIN) project, in which methods used to study MFAS effects are expanded to impulsive sounds (IMP). We used acoustic data from Sound and Motion Recording and Telemetry tags deployed on 16 Ziphius, 3 fin whales, and 2 blue whales at SOAR from 2019-2025, yielding 119.5 days of recordings (2-12.4 days per tag). Nineteen of 21 tags recorded a total of 2,540 IMP (1-525 per tag), at rates from 0.1-4.5 detections per hour. Their median peak-to-peak sound pressure level (SPL) was 145.6 dB re 1microPa (range 138.5-175.3). Median sound exposure level (SEL) was 111.1 dB re 1microPa*2s (range 100.7-152.8), measured over 95% energy durations (median 0.74 s, range 0.01-6.4 s). IMP were prevalent on and near SOAR, absent outside the Southern California Bight, and were about 3 times more common at night. Ziphius forage in regular cycles, 26% of which included IMP, (3-56% per tag with IMP). This means exposure to IMP may at times be more common than to MFAS, underscoring the importance of understanding the effects of impulsive sounds at this busy training range. Preliminary review of the data suggests that exposure to impulsive sounds, especially at higher levels, may elicit behavioral changes similar to MFAS, including more variable dive durations, truncated foraging effort, and prolonged inter-foraging intervals.

Movement decisions in a busy seascape: harbour seals, offshore wind farms, and vessels

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The number of offshore wind farms (OWFs) is rapidly increasing to meet the growing demand for renewable energy in the European Union. Harbour seals (Phoca vitulina), one of the most abundant top predators in the North Sea, occupy diverse coastal habitats ranging from the rocky coasts of the United Kingdom to the tidal mudflats of the Wadden Sea. From their haulout sites, seals regularly undertake offshore foraging trips, raising the question of whether OWFs may act as attractive foraging habitats due to their reef-building potential or whether seals avoid them because of associated anthropogenic disturbances such as vessel traffic and turbine noise. Despite the rapid expansion of OWFs, their ecological effects on marine predators remain poorly understood. To address this gap, we tracked 26 harbour seals from the German Wadden Sea using SMRU GPS Phone Tags deployed between 2015 and 2024. Tracking data were screened for events of seals entering OWFs, and the frequency and characteristics of these visits were analysed. To evaluate attraction or avoidance patterns more broadly, we applied step selection functions (SSFs) to quantify movement decisions relative to OWFs and habitat features. The models incorporated variables such as geomorphology, distance to haulout sites, vessel presence, and distance to OWF turbines. Harbour seals spent less than 8% of their at-sea time within OWFs, questioning their importance as foraging habitats for this marine predator. The SSF analysis revealed no attraction to wind turbines or their vicinity. Instead, seals showed clear avoidance of vessel presence: while animals displayed strong directional movement, the probability of selecting a movement step decreased with increasing numbers of vessels in the direction of travel. In addition, we observed substantial inter-individual variability in movement behaviour, suggesting heterogeneous responses to environmental conditions and anthropogenic activity. Ongoing analyses examine the ecological implications of persistent vessel traffic associated with OWF areas. Continuous vessel presence alters the local soundscape and may offset potential habitat benefits created by turbine structures. Overall, this study highlights the importance of integrating movement ecology with assessments of anthropogenic disturbance to better understand the ecological consequences of offshore wind farm expansion for marine predators.

Effects of boat noise and warming on the reproductive behaviour of a coastal marine fish

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Marine species are increasingly exposed to multiple environmental stressors with detrimental effects across taxa. While numerous studies have investigated the individual impacts of anthropogenic noise and ocean warming on marine fishes, their combined effects remain largely unexplored. Because behavioural responses are often the earliest indicators of environmental disturbance, the study of animal behaviour provides a powerful tool for understanding how anthropogenic stressors affect organisms and for predicting and mitigating potential population-level consequences. Therefore, elucidating how these stressors interact to affect behaviour is essential for anticipating ecological responses and informing effective conservation strategies. Here, we investigated how anthropogenic noise and elevated temperature jointly affect the reproductive behaviour of the painted goby (Pomatoschistus pictus), a highly visual and vocal marine fish species with paternal care. Male painted gobies perform conspicuous acoustic and visual courtship displays to attract females to the nest for spawning, and their acoustic signalling is closely linked to reproductive success. We conducted laboratory-controlled experiments using a fully factorial design with two temperature levels (16degC and 20degC) and three sound treatments: control (no added sound), added sound (boat noise playback), and a control for the speaker's electromagnetic field. The latter was implemented by feeding copper coils with the same sound files used in the noise treatment, following established methodology. Noise playback simulated the passage of 10 ferryboats and 4 small boats per hour. We quantified visual and acoustic courtship behaviours as well as spawning success. Neither temperature, sound treatment, nor their interaction had a statistically significant effect on the probability of males courting, producing sounds, attracting females to the nest, or receiving eggs. However, both noise and temperature treatments, as well as their interaction, significantly affected the pulse period of courtship sounds (drums), with the interaction term also showing a significant influence on drum pulse period. Although the present results are limited by a low sample size and high behavioural variability, this study highlights the importance of multi-stressor experimental approaches for understanding how concurrent environmental pressures may shape the behaviour and reproductive dynamics of marine fishes.

Atlantic salmon exposed to boat noise: acute responses during sexual maturation but habituation under chronic exposure

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Underwater sound levels in coastal environments are increasing due to expanding maritime traffic. These habitats are dominated by low-frequency ship and boat noise (<1kHz) that propagates efficiently over long distances and overlaps the hearing sensitivity of many fish species. During the spawning season, Atlantic salmon (Salmo salar) are exposed to this anthropogenic noise whether they are migrating in the wild or are being held in coastal waters. We experimentally investigated behavioural and physiological responses of pre-spawn Atlantic salmon of wild genetic lineage exposed to synthesized boat noise using two complementary temporal scales. An acute experiment (Sep.2023) consisted of a 1-h continuous exposure across a gradient of sound levels to determine the onset of responses and to investigate links between behavioural and physiological indicators. A chronic experiment (Sep.-Oct. 2024) involved fish being exposed for 31 days to the minimum response level identified in the acute trial (130 dB re 1 uPa over 100-1000 Hz band, played back intermittently) to evaluate long-term effects on behaviour and gonadal maturation. During acute exposure, fish under control condition displayed active and disorganized swimming, whereas salmon exposed to noise reduced mobility, increased group cohesion and exhibited freezing behaviour that intensified with sound level, suggesting an anti-predatory strategy. Contrary to expectation, plasma cortisol concentrations were higher in control fish, indicating that behavioural inhibition was not directly associated with a physiological stress response. Under chronic exposure, control fish maintained higher activity levels (e.g., swimming). Noise-exposed individuals initially showed behavioural suppression but returned to control-like activity by the end of the experiment, indicating habituation. Physiological markers did not indicate an effect from noise exposure, but they were strongly structured by sex. Females showed higher oxidative stress while males exhibited a more energetic metabolic profile consistent with the known sexual maturation of the species. Overall, behaviour was more sensitive than physiological metrics for detecting disturbance, and prolonged exposure led to acclimation rather than persistent impairment. Our findings suggest that boat noise primarily affects short-term behavioural processes during the spawning period, while long-term physiological disruption may be limited at these lower noise levels.

Reactions of harbour porpoises to underwater noise: Level of onset of biological adverse effects (LOBE)

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The EU Marine Strategy Framework Directive is a significant driver for management and regulation of off-shore activities generating underwater noise. Underwater noise is specifically addressed through criteria D11C1 and D11C2, related to negative impact of impulsive and continuous underwater noise, respectively. Monitoring and assessment by both criteria starts by quantifying the noise in the environment. For this quantification to be compliant with most recent advice from the European Commission (TG-Noise) it must be done in a spatially explicit way and with a temporal resolution of one month. The spatio-temporal mapping of the noise allows an overlay with the abundance and sensitivity of selected biological indicator species. The degree of overlap between noise and noise-sensitive species is then evaluated through application of the so-called "Level of Onset of Biological adverse Effect" (LOBE). LOBE is a species-specific sound pressure level, defined for continuous noise (D11C2) as "The noise level at which individual animals start to have adverse effects that could affect their fitness". Different species are very likely to have different LOBE values, due to differences in their hearing physiology and behavioural responses and LOBE values must there-fore be estimated species by species, in most cases based on very little empirical data. However, a single species, the harbour porpoise (Phocoena phocoena), stands out - being likely the best studied marine mammal when it comes to auditory physiology, susceptibility to acoustic injury and behavioural responses to underwater noise from a wide range of sources. Based on literature reviews and recent results from individual, free-swimming porpoises, it was thus possible to converge on a first estimate of a LOBE threshold for harbour porpoises. This estimate is based on results from the EU Horizon project SATURN, where it was demonstrated that exposures of porpoises to underwater noise from individual ship passages with received levels above 97 dB re 1uPa (frequency weighted with the VHF weighting function) had quantifiable negative effects on the animal's energy budget. A review of the substantial literature on behavioural responses of porpoises to underwater noise resulted in a similar range of levels for onset of responses of 95-115 dB re 1uPa (VHF-weighted), supporting the generality of the results and lead to proposal for LOBE for porpoises of 95 dB re 1uPa (VHF-weighted).

The combined effects of anthropogenic noise and Artificial Light at Night (ALAN) from shipping on an offshore predator and prey

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In recent decades substantial research has increased our understanding of how sound from human activities and artificial light at night (ALAN) can impact aquatic biodiversity. However, their combined effects have not been investigated. Offshore anthropogenic activities such as ship traffic, offshore wind farms, oil and gas and aquaculture are increasing hence with the level of both pollutants. Here, we have investigated the combined effect of ship light and noise exposure both in isolation and combination through cross manipulation exposure experiments with two key species representing a prey and a predator; herring and humpback whales. The exposure was noise playback of a large tank ship, while ALAN was all deck lights turned on. The experiments were conducted as a randomized block design with noise/no ALAN, no noise/ALAN, noise/ALAN. Herring behavior were monitored by the ships echosounders while whales were tagged with depth/accelerometer/acoustic tags and visual monitoring of behavior. All experiments were conducted under natural darkness. Herring responded to the sudden onset of vessel noise and/or deck lights by horizonal and vertical avoidance. Light exposure had a stronger effect than noise in isolation, while exposure to both simultaneously seem to cause a stronger and longer effect. Tag results are yet to be analyzed, but visual observations indicate that whales resting at the surface aborted their rest and swam off at high speed in response to all stimuli. These results show that studying stressors in isolation may underestimate the behavioral effects of disturbances such as shipping, and that future studies would benefit from adding multiple stressors in exposure experiments.

Fin Whale (Balaenoptera physalus) Behavioral Response to Vessel Approaches in Shallow Coastal Western North Atlantic United States Habitat

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The number of vessel noise sources are increasing globally, particularly near major shipping ports. Knowledge is limited on whether this noise changes the behavior of some large baleen whales, such as the fin whale, in shallow coastal areas. To address this gap, 29 acoustic biologging tags were deployed on fin whales using unmanned aerial systems (UAS) near the Port of New York and New Jersey in the United States. Vessel approaches were identified in the acoustic data. Kinematic data were processed from the magnetometer, accelerometer, and pressure sensors and classified into 5 different behavioral states (feeding, exploratory foraging, travel, rest, and unknown). 40 in-situ vessel approaches were recorded on tags deployed on 13 fin whales (12 males, 1 female). Exposures ranged in duration (30 s to 54.5 min, mean 10 min), maximum received level (100.6 to 142.3 dB RMS re 1 uPa, mean 126.5 dB RMS), and maximum SNR (6.0 to 40.3 dB). A change point analysis using four kinematic inputs (heading change, mean roll, maximum pitch, and fluke count) and standardized Mahalanobis distances detected movement outliers above baseline thresholds during these vessel exposures. A Generalized Estimating Equation (GEE) model clustered by individual showed the probability of outlier presence increased with higher received levels in the preceding interval. In an additional GEE model, resting behavior significantly increased (34%) and traveling significantly decreased (19%) only during the approach phase of these exposures. This can increase risk of vessel collisions since resting is their shallowest and least active state. These results increase knowledge of how an endangered baleen whale responds to anthropogenic stimuli during midsummer in this foraging habitat.

Blue Whales Decrease Foraging Rates During Close-Range Vessel Encounters

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Commercial vessel traffic is a pervasive feature of modern oceans, especially within productive coastal habitats that support dense aggregations of marine predators. This spatial overlap results in frequent close-range encounters and increases the risk of behavioural disruption and other fitness relevant impacts. Baleen whales have long been considered particularly vulnerable to vessel exposures because their communication overlaps with low-frequency ship noise. Although behavioural responses to vessels have been documented across several species, there is limited quantitative evidence linking vessel exposure to changes in a key fitness-related function: foraging. Here, we used high-resolution biologging data from 42 blue whales (Balaenoptera musculus) tagged off California to test whether close-range vessel exposures are associated with changes in lunge-feeding rate, a direct proxy for energy intake. Across 280 days of on-animal recordings, deployments had a median duration of 4 days (95% range: 1 - 18 days), where we identified a total of 485 close-range vessel approaches (~12 per deployment). Results show that blue whales reduce lunge-feeding rate by approximately 6% during vessel encounters, providing the first mechanistic evidence that close vessel exposures can decrease baleen whale foraging performance. While the effect of a single encounter may be modest, many of the most productive foraging areas for blue whales overlap with some of the busiest shipping corridors, creating conditions for repeated disturbance. Accumulated across multiple encounters, such reductions in feeding have the potential to lower seasonal energy intake and impose long-term energetic costs that ultimately compromise the fitness and survival of exposed populations. By demonstrating a quantifiable energetic burden from close vessel exposures, these findings address a critical gap in how vessel disturbance affects large marine megafauna. Integrating these results with spatially explicit encounter probability maps provides a powerful framework for estimating changes in energy budgets across habitats and seasons, and for guiding targeted mitigation strategies in heavily trafficked feeding grounds.

Interactions between substrate-borne vibration from offshore wind farms on the hermit crab (Pagurus bernhardus): assessing the effects of simulated continuous vibration on feeding behaviour

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Offshore wind farms are essential for the UK to achieve its global climate targets, yet the ecological impacts of continuous substrate-borne vibrations remain poorly understood. Although current research has focused on the impact of construction activities, such as pile driving, there is limited understanding of how vibrations from operating turbines affect benthic invertebrates that may reside on or near turbine foundations. As key contributors to ecosystem processes, such as nutrient cycling, bioturbation, and sediment mixing, these organisms are fundamental in marine ecosystem functioning. Understanding how continuous vibration affects their behaviour is therefore essential for predicting ecosystem-level impacts. This study investigated the effects of simulated continuous sinusoidal vibration on the feeding behaviour of hermit crabs (Pagurus bernhardus). Hermit crabs were exposed to 7 hours and 45 minutes of simulated continuous sinusoidal vibration (control, 0.1, 0.2 and 0.3 ms-2 at 114 Hz) per day for 5 days. Individuals were fed pre-weighed cooked mussels for 5 hours, at the same time each day, corresponding to peak activity at dusk. The remaining food was removed, dried, and post-weights were compared against a standard wet-to-dry weight calibration curve to determine the consumption rate. Results indicate that hermit crabs exposed to vibration at any amplitude consumed significantly less food than those in the control group ($p<0.001$). However, there was no significant difference between vibrational treatments. The observed reduction in feeding indicates that continuous vibrations likely associated with operational wind turbines may influence behavioural processes important for individual fitness. Such changes could have broader ecological consequences if reduced feeding influences growth, reproductive output, or ecosystem processes such as nutrient cycling. These findings may also have implications for commercially important crustaceans, highlighting the need to monitor both vibration levels and biological responses in offshore wind development.

Chronic Noise Effects on the Development and Hunting Success in Sepia officinalis

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Over the past century, anthropogenic noise has increased in marine environments, with well-documented effects on marine mammals and fish, but limited research on invertebrates, particularly cephalopods. This study investigates the impacts of chronic, moderate-level low-frequency noise on the embryonic development, hatching success, and early feeding behavior of S. officinalis. We found that noise exposure at 130 dB re 1 uPa2 and 170 Hz during embryonic development resulted in subtle developmental differences. Juveniles exposed to noise displayed improved feeding performance, with shorter attack latencies and higher success for all prey, declining in performance when prey difficulty increased. Three potential mechanisms explain feeding enhancements: cross-modal sensory enhancement, reliance on visual cues, and optimal arousal state. Overall, this study shows that moderate levels of low-frequency noise exhibit complex, context-dependent effects on cephalopods, indicating that noise may incur energetic costs during development and improve feeding performance dependent on task complexity, with further investigation needed to understand the long-term consequences of chronic noise exposure on marine life.

Passive Acoustic Monitoring of Baleen Whales in a Brazilian Offshore Oil Field

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Anthropogenic underwater noise has increased globally over recent decades, particularly in areas dedicated to oil and gas exploration and production. The Campos Basin, located in the southwestern Atlantic Ocean, stands out as one of Brazil's main sedimentary basins for petroleum exploration, accounting for approximately 60% of the national production. In this region, intense vessel traffic and continuous offshore platform operations are associated with environmental pressures that may affect the behavior, acoustic communication, and even migratory routes of cetaceans that use the area as a corridor to breeding grounds. In this context, understanding species occurrence patterns and acoustic behavior is essential to support more effective conservation actions and environmental impact assessments. A Permanent Reservoir Monitoring (PRM) system was installed in 2012 in the northern portion of the Campos Basin, offshore Brazil, at the Jubarte Field. Although not primarily intended for monitoring mysticetes, this system records low-frequency signals (up to 250 Hz), encompassing the acoustic niche of large whale species. In this study, geophysical data acquired by the PRM system were converted into audio files (.wav) and analyzed for passive acoustic monitoring purposes. The dataset, comprising 63 days between June and August 2013 (1,434 hours), was randomly subsampled, totaling 274 hours of manual inspection. At least nine types of acoustic signals were detected and attributed to different whale species. Among these were 20-Hz calls of Balaenoptera physalus, downsweeps of Balaenoptera borealis, and partial songs of Megaptera novaeangliae. The results demonstrate the potential of leveraging existing geophysical infrastructures, such as PRM systems, to support offshore acoustic monitoring in Brazil. Data collected in areas of intense oil and gas activity can also contribute to understanding the occurrence and acoustic repertoire of baleen whales, providing information relevant to conservation assessments and impact evaluation. The data analyzed in this study were collected and provided by Petrobras through the MAPC Project, in partnership with Instituto Aqualie.

Analysis of underwater soundscape of Nice harbor, France: Calculation of SL from human activity and mapping of the area of adverse noise effect

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Nice harbor is the only commercial harbor in the French part of PELAGOS sanctuary in the Mediterranean Sea. This harbor hosts various human activities such as regular harbor works, cruise ships, cement carriers and ferry traffic. Nice harbor is part of Pelagos sanctuary and cetaceans' presence is known for a long time. Fin whale (Balaenoptera physalus), sperm whale (Physeter macrocephalus), pilot whales (Globicephala melas) and delphinids such as striped dolphin (Stenella coeruleoalba), Risso's dolphins (Grampus griseus) and bottlenose dolphin (Tursiops truncatus) are usually seen in the vicinity of the harbor. This study provides an analysis of human activity through real data collection and analysis and the impact on local marine fauna with noise modelling. Our dataset is based on continuous recordings at 196kHz sampling frequency from three acoustic sensors deployed from October 31 to November 26, 2025. The stations were positioned inside, at the exit (opening acoustic window toward offshore) and outside the harbor (behind the dikes). These three strategic positions covered the main activities around the harbor. The acoustic data were processed using the homemade SENSEA Biosound software, which provides qualitative analysis through the creation of spectrograms across all time scales. Sound pressure levels were extracted for different frequency ranges to characterize anthropophony, especially the source level of harbor work (hydroblasting) and radiated underwater noise and source level of ferry. RAMDAM, a homemade SENSEA modelling software relying upon Parabolic equation (RAMGEO), wave number equation (SCOOTER) and ray launching (BELLHOP), was used to propagate the source level and map the received level for each activity in the area and to deduct the impact on marine fauna. Results highlight behavioral disturbance and communication masking for fin whale, sperm whale, and the different species of dolphin caused by ship noise. However, no physical and auditive injuries caused by ship noise were established for these species. This work shows the possibility of evaluating the impact of harbor noise on local marine fauna, focusing primarily on the impact of maritime traffic.

Is the high occurrence of loud, broadband, cavitation transients from ship propellers a prob-lem for toothed whales?

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Vessel noise is the overwhelmingly dominant source of anthropogenic underwater noise, and it is most prominent several decidecades below the range of best hearing in echolocating toothed whales. Accordingly, toothed whales have historically been considered a low-impact group for vessel noise, even though noise from cavitating propellers extends into the ultrasonic range. Here we provide evidence that fast propellers commonly produce such loud, ultrasonic, cavitation pulses. To quantify the source parameters of these transients, we deployed an 8 m linear steel 4-channel array between November and December 2024 in the middle of Great Belt, Denmark, a highly trafficked route for commercial vessels. Combining the AIS tracking data and the decidecade levels from the recordings, we were able to track and identify more than 200 vessel passages in a 100 m radius around the array, of which 14 could be used for localization and quantification of cavitation transients source parameters. From these passages, source parameters were quantified from >400 localized cavitation transients. We find that cavitation transients have centroid frequencies (fc) of 32 kHz [IQR 28.4-34.5], and durations of 0.036 ms [0.030-0.044], Very High Frequency (VHF) weighted source levels (SLpp) of 198 dB re. 1uPa [196-202] (1 m) and sound exposure source levels (SEL10dB) of 144 dB re. 1uPa2*s [140-149] (1 m). The cumulative sound exposure level (cSEL) of all transients in the vessel passages was 161 dB re. 1uPa2*s [158-165]. Based on available thresholds for HF and VHF toothed whales, we argue cavitation noise is likely to induce behavioral disruptions in toothed whales up to hundreds of meters from a cavitating propeller, but masking and hearing threshold shifts are unlikely to occur.

Impacts to cetaceans within the St. Lawrence Estuary from underwater radiated noise produced by commercial vessel within the global fleet

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Global reductions in underwater radiated noise (URN) from commercial vessels are needed to reduce impacts on marine wildlife. Cetaceans have been found to be negatively impacted by vessel noise, which can alter their behaviour and mask important acoustic cues. Concern for the widespread impacts from vessel noise have led regulators to take increasing measures to reduce URN. However, due to a lack of measurements from individual vessels operating within the global fleet, quantifying URN impact metrics relevant to cetaceans (e.g., maximum received levels and the duration of time that vessel noise elevates ambient soundscapes) and how this varies across vessels and operational conditions, has been limited, complicating impact assessments and efforts to mitigate vessel noise. The St. Lawrence Estuary (SLE) falls within a vital shipping route connecting the Atlantic Ocean with several major ports in North America. Annually, 4,000 commercial vessels transit this route delivering 37,000,000 tonnes of freight demonstrating its economic importance. Nonetheless, this estuary is a key habitat for cetaceans, including a resident population of endangered beluga whales, and many species of migratory baleen whales. Consequently, this overlap in the SLE is expected to result in greater risks of impact from vessel URN to cetaceans with implications for populations. To characterise URN from vessels operating in the SLE and to support mitigation approaches, the Marine Acoustics Research Station (MARS) project has utilised an optimised setup of vertical hydrophone arrays deployed near to the shipping lanes to strategically measure individual vessel URN. Utilising measurements of 1266 vessels collected at the MARS station (2021-2023), we quantified impact metrics relevant to cetaceans from vessels operating within the global fleet, including cetacean auditory frequency weighted maximum received levels (dB re 1 uPa RMS), exposure duration and distance (time and distance over which vessel received levels exceed wind noise), and the percentage listening space reduction. Further, we assessed how impacts varied by vessel class, length, draught and operational speed. Our work highlights the importance of considering variations in URN from the perspective of marine mammals and how this can differ between vessels to better inform mitigation approaches.

Underwater radiated noise database of vessels - Description of the data collection method used in Finland

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It is probable that target values for the underwater radiated noise level (URNL) caused by vessels will be increasingly published in the future. Therefore, marine sector should prepare themselves by measuring the current ships so that suitable noise control can be assessed if target values are exceeded. URNLs have not been measured in Finland before 2024. Our purpose is to describe the data collection method developed by TUAS. Data collection aims to the creation of database, which would contain a large share of vessels sailing in Finland. The method is based on random access of ships along a specified shipping lane. URNL is determined using DNV method designed for shallow water, where the transducer is located against the seabed. Measurement station is founded on a shipping lane in such position, where the requirements of the test method are fulfilled and probability of successful pass-by is high. Signal is collected using hydrophone loggers which can record signal up to 4 months. Pass-by of the vessel is successful if the distance to the logger is 50-200 m. The location of the vessel is obtained afterwards from Automatic Identification System AIS, which updates ship locations every six seconds. The method is demonstrated for one shipping lane. Database collected from two shipping lanes is also demonstrated. The method will be applied in 2025-2026 to eight more shipping lanes in Finland. The outcoming database will give a good picture of the URNLs of ships sailing in Finland. Based on that, it is possible to assess the need of noise control for each vessel if target values will appear. The database may also enable some systematic analysis, how the URNL depends on vessel properties and driving parameters.

Underwater noise from ferry in a vital humpback whale area - Tahiti-Moorea case study

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Serving as a vital economic lifeline, the maritime corridor between Tahiti and Moorea is the busiest strategic shipping route in French Polynesia. Major operatorsrun dozens of daily crossings starting at dawn.High-speed vessels such as the Terevau and Aremiti 6, measuring approximately 45 to 50 meters, operate at speeds exceeding 30 knots to reach the sister island in just half an hour.While larger mixed ferries such as the Vaeara'i andTauati Ferry, which are close to 80 meters long, navigate at 15 to 20 knots to maximize their capacity for vehicles and heavy freight. At the same time, the waters between Tahiti and Moorea constitute a vital sanctuary for humpback whales migrating from Antarctica to breed and calve in warm tropical waters . Individuals occurring in Polynesian waters belong to the Oceanian subpopulation, which is still considered endangered by the IUCN. This channel provides sheltered conditions that serve as a nursery for mothers and calves. It is also a critical social arena where adult whales engage in complex courtship rituals and males perform their haunting songs. As part of OCEAN WATCH project, five acoustics datalogger were deployed between july 2025 and novembre 2025 to measure long-term underwater noise time series and study humpback whales song activity in the channel. Before this deployment the data logger were assembled into a vertical linear hydrophone array and deployed for two days along the main shipping axis. This configuration complied with ISO 17208-1 and 17208-2 standards and enabled the measurement of Underwater Radiated Noise (URN) and monopole Source Levels (SL) of passing ferries. Estimated URN and Source level were compared with reference envelopes from the Canadian fleet. These SL were then integrated into a home-made RAMDAM modeling software relying upon parabolic equation, wave number equation and ray launching was used to map the spatial and temporal footprint of ferry noise throughout the whale season. Model outputs were validated through comparison with long-term in situ acoustic measurements. Simulations of single-ferry transits were used to characterize the noise exposure experienced by a whale along a transect, with particular attention to collision-risk scenarios and the acoustic shadow zones formed in the wake of vessels. Finally, cumulative daily traffic scenarios were modeled to assess the risks of behavioral disturbance according to the severity scale proposed by Southall 2021.

Did we forget about recreational vessels? analysis of shipping underwater radiated noise from the Hearmyship database

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With the increasing expansion of human marine exploration and excavation, our seas have become noisier than ever, driven by more than a 50% increase in commercial vessels (measured by deadweight). Broadband noise in the 50 Hz - 10 kHz range, with source levels from 150 - 180 dB, makes it clear that rising shipping activity and nautical tourism have implications for the health of marine fauna due to high levels of Underwater Radiated Noise (URN) from vessels. Shipping-related URN is now recognized as a form of pollution. As a result, standards have been established to limit transmitted acoustic power per exposure time, and regulatory organizations such as CMS, CBD, ASCOBANS, and ACCOBAMS have passed resolutions to reduce underwater noise from ships and other man-made sources. The EU's Marine Strategy Framework Directive (MSFD) requires EU members to take action to reduce the impact of underwater noise on marine life, and the International Maritime Organization (IMO) has issued guidelines for measuring URN levels. These regulatory and monitoring efforts are primarily focused on large ships such as cargo vessels, auxiliary vessels, and ferries. However, this is not the case for small vessels, such as yachts, motorboats, or fishing vessels, even though small vessels are much more abundant in coastal waters and their URN levels may be comparable to those of large commercial vessels. There is a gap in the quantification of URN from small vessels and in the methodology for measuring such noise. To address this, we created a dataset with a web interface named "HearMyShip", consisting of acoustic and optical data from approximately 1,200 vessels under 55 meters in length, collected in situ in the coastal area of Šibenik, Croatia. Analyzing this data, we describe the statistical relationship between a vessel's URN and its speed, size, and type, as well as frequency characteristics, compared to current commercial notations (Lloyd's Transit and Lloyd's Silent). Our conclusions regarding the frequency and level characteristics of URN emitted by small vessels under various operating conditions highlight the need for improved monitoring methodologies and regulations specifically for small vessels. These findings can support URN mitigation efforts in coastal waters.

Transfer Learning for Distance Classification of Marine Vessels Using Underwater Sound

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This study investigates the use of underwater acoustics to classify the distances of marine vessels in ecologically sensitive areas, including Marine Protected Areas (MPAs) and offshore wind farms. By employing a convolutional neural network (CNN) model, we classified vessel proximity based on passive acoustic recordings collected from the Belgian part of the North Sea. The dataset consists of over 116 days of acoustic recordings, integrated with Automatic Identification System (AIS) data, offering a comprehensive representation of varying seasonal and environmental conditions. To enhance model performance, we applied transfer learning to the BioLingual CLAP model, comparing two approaches, fine-tuning the network and using it as a feature extractor, to classify vessel distances into 1 km bins up to 10 km, with an additional category for distances beyond 10 km. This approach produced robust results, achieving accurate predictions with a root-mean-square error of 1.587 km. Our model demonstrates significant potential for passive acoustic monitoring, particularly for identifying vessels in MPAs, including those that do not broadcast AIS signals (dark vessels). This research contributes to the EU-funded AXOLOTL project (exploring model adaptions for Cyprus) and contributes to the Marine SoundLib. The associated training dataset and code are publicly available ensuring accessibility for further development and reproducibility. Ultimately, this research seeks to advance monitoring capabilities and support enforcement actions aimed at safeguarding marine ecosystems.

The Noisy Few: Similar Vessels vary by up to 20 dB in Radiated Noise Levels

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Vessel-generated underwater noise is a dominant component of the ocean soundscape and has been repeatedly linked to adverse effects on marine wildlife. As noisier vessels ensonify a disproportionately larger area and therefore affect substantially more individuals, identifying the noisiest vessels within the global fleet is critical for effective noise reduction. Because larger, faster, and older vessels generally produce higher underwater radiated noise, mitigation strategies have primarily focused on managing vessel size, speed, and age. However, these approaches implicitly assume that vessels of similar size radiate comparable noise levels at similar speeds. Emerging evidence shows that noise emissions are strongly influenced by vessel-specific drive-line characteristics, yet the extent to which these differences translate into variability in noise levels among otherwise similar vessels remains poorly quantified. Here, we test the hypothesis that if radiated noise levels vary substantially among similar vessels, then a relatively small proportion of the fleet, namely the noisiest vessels, is responsible for a disproportionately large acoustic load on the marine environment. To evaluate this, we quantify the unexplained variability in radiated noise levels after accounting for known drivers such as speed, size, age and vessel type. Our analysis uses a large, representative dataset of opportunistic in-situ recordings comprising 5,000 unique vessel passages collected along one of the world's most heavily trafficked maritime routes into the Baltic Sea. We found approximately 20 dB variability in radiated noise levels across nominally similar vessels. Roughly 30% of this variation was explained by speed, size, age, and type. The high unexplained variability implies that the noisiest vessels cannot be effectively targeted by regulatory measures based on speed, size, age or vessel type. This comprehensive assessment demonstrates that maximum noise-level limits, analogous to emission limits used in air and road traffic, represent an effective and targeted regulatory mechanism applicable beyond the study area. By focusing on the noisiest vessels rather than the fleet as a whole, such limits could deliver substantial reductions in underwater noise exposure with minimal burden to maritime operators.

Large-scale monitoring of coastal odontocetes using multiple static acoustic sensors

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Passive acoustic monitoring (PAM) is increasingly being adopted as a non-invasive method for the assessment of ocean ecological dynamics. PAM is an important sampling approach for acquiring critical information about marine mammals, especially in areas where data are lacking and where evaluations of threats for vulnerable populations are required. The Indo-Pacific humpback dolphin (IPHD, Sousa chinensis) and finless porpoise (IPFP, Neophocaena phocaenoides) are coastal odontocetes which inhabit tropical and warm-temperate waters from the eastern Indian Ocean throughout Southeast Asia to central China. The distribution pattern of these animals around the Hainan Island (China) is unclear, but evidences for a resident population of both the species have recently emerged. An array of passive acoustic platforms was deployed at depths of 10-20 m (the preferred habitat of humpback dolphins, and potential habitat of finless porpoises), across sites covering more than 100 km of coastline. In this study, we explored the spatiotemporal patterns of distribution, acoustic behavior, and potential noise effect of these species by using the PAM data through supervised machine learning algorithms. Our work demonstrates that the distribution and habitat use of the coastal and resident odontocetes can be monitored over a large spatiotemporal scale, using an array of passive acoustic platforms and a data analysis protocol that includes both machine learning techniques and spectrogram inspection, and potential noise effect was evaluated.

Long-term Passive Acoustic Monitoring of Odontocetes in the Istanbul Strait (Bosphorus)

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The Istanbul Strait (Bosphorus) is one of the busiest water ways in the world, connecting the Aegean Sea and Black Sea. There are three cetacean species found in the Strait, namely the Black Sea harbour porpoise (Phocoena phocoena relicta), the common dolphin (Delphinus delphis), and the bottlenose dolphin (Tursiops truncatus). The Istanbul Strait is a front line where maritime activity and wildlife collide. However, whether anthropogenic activities and odontocetes result in conflict or coexistence remains an unresolved question. To monitor the presence of the odontocetes, a fixed stereo passive acoustic monitoring system (A-tag) was deployed in the middle of the Strait from July 2009 to present, for over 16 years. Remarkable seasonal differences on number of click train detections were observed. Maximum number of click trains in a day is always detected in April; eg. 2172 CT/day on 22 April 2022. Within a day, more click trains were detected during the night time than daytime, but it was prominent specially in March and April. Short range sonar (inter-click intervals, ICIs, less than 50 ms) was commonly detected in spring. These facts suggest that the odontocetes could capture prey in springtime. During the rest of the year, ICIs could reach up to 160-200 ms, which is long range sensing, implying that dolphins and porpoises could just pass through the Strait. The long-term monitoring results also showed that some historical events can influence the movement of the cetaceans in the Strait. During the COVID pandemic in 2020-2021, although local marine traffic was much lighter than the regular times, the acoustic detection did not increase, implying that cetaceans do not only avoid traffic in the Strait. It is also noted that there was extremely high number of CTs in April-May 2022, shortly after the Russian-Ukrainian war started. The cetaceans might have moved away from the northern Black Sea and even entered the Strait.

Decadal co-occurrence of finless porpoise presence and high-frequency vessel noise in a coastal area of central Japan

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Many Asian coastal waters experience intense vessel traffic and also support resident small cetaceans. However, long-term empirical studies evaluating how these animals persist under chronic vessel-noise exposure remain limited. We conducted passive acoustic monitoring over a decade at multiple nearby sites in Mikawa Bay, a coastal embayment in central Japan. Mikawa Bay is a highly congested coastal area used by fishing vessels, recreational fishing boats, ferries, and large commercial ships. Our aim was to examine relationships between the acoustic occurrence of finless porpoises (Neophocaena asiaeorientalis) and high-frequency vessel sounds. Finless porpoise echolocation click trains and high-frequency vessel sounds were quantified as presence/absence within 1-h and 1-min time bins. Their co-occurrence was then evaluated across temporal scales. Finless porpoise clicks were detected on 99.3% of monitoring days. This result indicates near-continuous habitat use throughout the 10-year study period and highlights the study area as important habitat for this species. At the hourly scale, porpoise acoustic presence did not decline with increasing vessel activity. This suggests no clear long-term reduction in site use despite chronic exposure to vessel noise. In contrast, minute-scale analyses showed that porpoise detection probability was sometimes higher when high-frequency vessel noise was present. This pattern suggests short-term responses associated with vessel passage. These results show that the apparent relationship between porpoises and vessel noise depends strongly on temporal scale. They also indicate that long-term persistence in high-traffic coastal waters does not exclude fine-scale behavioral responses. Our findings provide rare decadal evidence from a resident small cetacean inhabiting chronically noisy coastal habitat. They also contribute to understanding the ecological implications of long-term vessel noise exposure.

Long-term Variation Characteristics of Underwater Ambient Noise in the Coastal Waters of the Yellow Sea, Korea

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As the development and utilization of marine spaces continually increase, underwater noise has rapidly emerged as a significant pollutant threatening marine ecosystems. To establish effective underwater noise management strategies and implement practical reduction policies, it is essential to accurately determine the natural baseline levels of ambient noise and to comprehensively understand the spatiotemporal variation characteristics of diverse acoustic sources. In this study to carefully assess the underwater acoustic environment at the Socheongcho Ocean Research Station, Korea, Passive Acoustic Monitoring (PAM) was conducted for about one year, from June 2018 to August 2019. To capture the long-term acoustic trends while effectively managing data storage, acoustic data were recorded using a duty cycle of 1-minute recordings at 30-minute intervals. The acquired raw acoustic signals were systematically processed and converted into Power Spectral Density (PSD) and one-third octave band levels to evaluate both their detailed frequency characteristics and broadband time-series variations. The results revealed that flow noise driven by tidal currents was a dominant acoustic feature in the region. Furthermore, through the analysis of long-term acoustic data, the study area showed clear seasonal differences in underwater noise levels, with a continuous fluctuation pattern in the overall ambient noise baseline throughout the monitoring period. The results of this study provide a reliable seasonal baseline for ambient noise in the region, serving as valuable foundational data to evaluate the environmental impacts of future coastal developments and human activities.

Manatee and pink dolphin automatic classification as a management tool to assess human disturbance, including noise

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Freshwater mammals such as river dolphins and manatees inhabit acoustically complex environments that are increasingly affected by human-generated noise, particularly from boat traffic. Assessing the ecological impact of this noise remains challenging due to the difficulty of continuously monitoring both animal presence and anthropogenic sound sources. Here we present a framework to evaluate human-induced acoustic disturbance on freshwater mammals by integrating passive acoustic monitoring with deep learning-based event detection. The framework uses convolutional neural networks (CNNs) trained to automatically detect and classify key acoustic events within long-term recordings: echolocation clicks as indicators of river dolphin presence, tonal calls associated with manatees, and boat engine noise representing anthropogenic disturbance. Acoustic recordings were processed into spectrograms and analysed using CNN architectures optimised for bioacoustic detection. Model outputs were aggregated to estimate event occurrence rates and level of overlap between mammal signals and boat engines at multiple temporal scales. By detecting these events simultaneously, the system quantifies temporal co-occurrence patterns between mammal acoustic activity and boat noise, providing a proxy for potential disturbance or habitat displacement. We applied this approach to passive acoustic datasets collected in Amazonian floodplains across two contrasting habitat types: confluence and floodplain lake. These habitats differ in hydrological connectivity, boat traffic intensity, and acoustic propagation conditions, offering an opportunity to test how environmental context mediates noise exposure. The proposed framework enables scalable, automated assessment of acoustic interactions between freshwater mammals and human activities. By identifying periods and locations where boat noise overlaps with animal acoustic behaviour, it provides a quantitative basis for evaluating disturbance risk and informing conservation strategies in highly dynamic floodplain systems. This approach demonstrates how deep learning combined with passive acoustics can support long-term monitoring and management of threatened freshwater megafauna in increasingly noisy aquatic environments.

Influence of Offshore Wind Farm Development on the Critically Endangered Taiwanese White Dolphin: Long-Term Acoustic and Visual Evidence with Explainable AI

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Taiwan's only endemic cetacean, the critically endangered Taiwanese white dolphin (Sousa chinensis taiwanensis), occupies a narrow coastal habitat in the Eastern Taiwan Strait that overlaps rapidly expanding offshore wind farms. We combined eight years of visual surveys (2016-2023) with five years of passive acoustic monitoring (2017-2022) at Taiwan's foremost wind-farm site to evaluate long-term responses to underwater noise. During this period, low-frequency sound pressure levels in the 10-250 Hz band increased by ~15 dB as turbine construction and operation intensified. Over the same interval, whistle detections declined by >95%, from >3,000 calls per year in 2017-2019 to <100 by 2022, while visual indicators showed parallel declines in dolphin density per unit effort and sightings per unit effort after 2018. Acoustic and visual metrics were strongly correlated, indicating that reduced vocal detections reflected a real decline in occurrence rather than a monitoring artefact. To identify the factors underlying this change, we applied a novel explainable artificial intelligence framework combining XGBoost with SHAP (Shapley Additive Explanations). The model showed that interannual progression of development and increasing low-frequency sound levels were the dominant predictors of whistle occurrence, whereas temperature, season, diel period, and tide had weaker secondary effects. SHAP dependence plots further revealed nonlinear thresholds, with very high noise levels contributing strongly negative effects on dolphin acoustic presence. Together, these results provide the first integrated long-term acoustic and visual evidence that offshore wind-farm development is reshaping habitat use and acoustic occurrence of this range-restricted population. The findings highlight the need for precautionary siting, cumulative-noise limits, and continuous acoustic-plus-visual monitoring to reconcile renewable-energy expansion with conservation of one of the world's most endangered coastal dolphins.

The OSPAR Regional Action Plan for Underwater Noise

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OSPAR's 2025 Regional Action Plan for Underwater Noise (RAP Noise) marks a major step towards reducing anthropogenic noise across the North East Atlantic by 2030, responding to growing evidence that underwater noise disrupts communication, navigation, feeding, and survival of marine species. Building on long standing monitoring and assessment under OSPAR's Quality Status Report and the EU Marine Strategy Framework Directive, the RAP was shaped through extensive stakeholder engagement and technical work by OSPAR's ICG NOISE. The Action Plan establishes eight actions that combine cross cutting measures-such as setting regional noise targets and thresholds compatible with MSFD Descriptor 11 and integrating noise into marine spatial planning-with targeted interventions addressing major noise sources. These include promoting uptake of IMO guidelines on reducing underwater radiated noise from ships, advancing quieter technologies and best practices for geophysical surveys, improving noise abatement in offshore infrastructure construction, and reducing impacts from disposal of unexploded ordnance. Additional actions focus on emerging noise sources and strengthening outreach to industry, scientific bodies, and civil society. Implementation from 2025-2035 will rely on collective action by Contracting Parties, scientific bodies, industry, and NGOs, with a 2030 mid term review to assess progress. By shifting from assessment to concrete mitigation, the RAP represents a significant advance in regional effects to project marine ecosystems from underwater noise. Here, we will outline the scientific and policy foundations of the RAP, and provide an overview of the eight actions, highlighting expected outcomes, challenges and opportunities across the OSPAR maritime area.

From monitoring to conservation: linking acoustic biodiversity data with soundscape data

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In compliance with the Marine Strategy Framework Directive, EU countries are required to monitor and report on 11 descriptors and assess the degree to which Good Environmental Status (GES) has been achieved. Monitoring for descriptor 11 is primarily about quantifying a physical pressure factor (underwater sound) but ultimately about mapping and quantifying impact on marine organisms. Organisms are themselves monitored for descriptor 1 (biodiversity), which in turn requires close coordination of monitoring and assessment of the two descriptors. Large amounts of broadband passive acoustic monitoring (PAM) data are collected and analyzed specifically for descriptor 11, then typically discarded or stored indefinitely, effectively rendering data "single use." However, broadband acoustic recordings taken over long periods in consistent locations can, if analyzed using automated species detectors, create a singularly valuable dataset of animal detections in an area over time, directly applicable to descriptor 1. With the introduction of automated species detectors into the workflow of large-scale noise monitoring projects and storage of such detections in a centralized database, soniferous species could be monitored in an efficient and cost-effective manner. Large-scale PAM data allows for remote observation of species on biologically relevant scales, supporting analysis of spatiotemporal patterns of abundance, movement patterns over entire habitats, and changes in acoustic behavior linked to environmental drivers. As part of the EU Horizon project, Digital Twin Ocean, we present a use case for previously collected PAM data from diverse contributors. We use existing architecture of the European Tracking Network to create a large-scale database of harbor porpoise detection data, starting with pure detection data from C & F-PODs and expanding later to store full-spectrum acoustic data, such as that collected through descriptor 11 monitoring. Through collaboration between VLIZ and AU, the initial dataset focuses on the North Sea with plans to expand across European waters. This aggregation of standardized, quality-assured data allows us to model harbor porpoise (Phocoena phocoena) distribution, movement and behavior. This spatial information is itself valuable for descriptor 1 monitoring, but also available for overlaying with soundscape data from descriptor 11 to conduct assessment of GES according to recommendations from the European Commission.

A decade of noisy activities in a harbour porpoise protected area

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In 2015, the UK Marine Noise Registry started collating data on certain noisy activities in UK seas, obtained through the licensing process. Data on the activity such as noise source, date and location have allowed retrospective monitoring of noise events from sources such as geophysical surveys, pile-driving, and explosives. This has been particularly useful in harbour porpoise Special Areas of Conservation (SACs), where spatio-temporal limits are used to manage the amount of noise disturbance allowed each day (affecting a maximum of 20% of the area of the site) and each season (10% of the area on average). The monitoring allows regulators to check for compliance with those limits. To estimate the area disturbed within the SAC, default disturbance ranges are used, based on empirical evidence associated with the different noise sources. The noisiest of the SACs is the Southern North Sea SAC given the extensive oil and gas exploration in the area, the many constructed and planned offshore windfarms, and the need for UXO clearance. With a decade of data now acquired from this site, this project investigated whether noise disturbance was kept within limits, at the relative contribution of each activity type to the disturbance footprint, accounting for any seasonal or distributional patterns in noise events. The results showed that most noise disturbance footprints have remained below the set limits. The results also identified that the largest disturbance footprints were a result of seismic surveys, sub-bottom profiler surveys and pile-driving. Compliance, particularly in recent years, has been possible due to the tight collaboration between developers and regulators. Both stakeholder groups regularly discuss planned noisy activities affecting the site via a Development Coordination Forum which enables projects to be scheduled accordingly. Retrospective monitoring via the UK Marine Noise Registry helps assess whether the noise management framework is effective while also providing information on where to focus further management efforts. To understand whether harbour porpoise continue to use the SAC and its important habitats despite the allowed disturbance, regular surveys of harbour porpoise are now required.

Using monitoring data collected during offshore construction to inform future mitigation advice

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Offshore developments will have environmental monitoring requirements stipulated within project consents. As a minimum, the purpose of this monitoring is to validate predictions made at the application stage informing potential environmental impacts. Additionally, monitoring provides an opportunity for statutory advisors to investigate the data with the aim to improve mitigation advice for future projects. Noise monitoring data collected during unexploded ordnance (UXO) clearance campaigns in the UK have been collated and reviewed as part of this project. The aim of this review was to increase understanding of potential injury ranges from low order deflagration methods to inform and strengthen advise relating to the use of acoustic deterrent devices (ADDs). Predicted injury ranges for low order deflagration using NMFS 2024 injury thresholds can range between 900m -1500m, depending on marine mammal hearing group, model method and location. Detecting marine mammals at these distances can be challenging. Visual and acoustic surveys ahead of detonation are often supplemented with ADD use to deter animals from the area within which they could experience auditory injury. However, these deterrents can cause additional disturbance above the clearance activity itself, particularly if activated for a prolonged duration. A balance is required between reducing the risk of injury and unnecessary disturbance of marine mammals. This project will present the results of noise monitoring and discuss in the context of ADD use, and if so, how long should they be active to deter animals for the required range. It will also consider these real-world results in the context of injury ranges predicted at the application stage, to reflect on how much precaution is built into modelling with the aim to inform future advice given by statutory advisors to regulators and industry.

Leveraging complementarity of large-scale projects for effective management of underwater noise in the Eastern Mediterranean: The Greek case

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Threshold values for underwater noise developed by the Technical Group on Underwater Noise (TG Noise) under the European Commission's Marine Strategy Framework Directive (MSFD) represent the first-ever European Union (EU)-wide limits and the first of their kind globally, contributing to the EU zero pollution vision for 2050. The implementation of the MSFD, supported by TG Noise's work in addressing emerging challenges and providing guidance to EU Member States, has strengthened the integration of underwater noise considerations into regional and national assessment, mitigation processes and associated measures. This is particularly important for countries like Greece, which hosts some of the most ecologically valuable marine areas in Europe, while simultaneously emerging as a major energy and transport hub in the Eastern Mediterranean. A substantial portion of its marine waters is recognized as being of high ecological importance and in need of enhanced protection; however, at present, formal protection measures are in place for only a very small percentage. At the same time, Greek seas are subject to significant and increasing pressures from noise-generating anthropogenic activities, such as seismic surveys for hydrocarbon exploration and exploitation, the planned installation of offshore wind farms, major shipping corridors with intense commercial traffic, heavy recreational and fishing activity for extended periods each year, as well as industrial operations near ports. This presentation highlights key scientific and policy challenges related to underwater noise management as identified by TG Noise, outlines the objectives and targets of four long-term, large-scale projects in Greek marine waters, and demonstrates how their complementarity and interconnection contribute to addressing these challenges, advancing harmonised assessment methodologies, and supporting coherent policy and management decisions in a marine region where the remarkable complexity of its insular geography, the high proportion of deep marine waters, and the differentiated extent of territorial waters further complicate policy measures, marine spatial planning, and management.

New developments and learnings on URN gained from German offshore wind projects and research activities

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New technical developments in various URN generating activities require that knowledge gaps in regard of new or changing types of underwater noise emissions, their acoustic properties and corresponding noise reduction options be identified and adressed through research and development activities. Currently, various research projects aim to provide scientifically sound findings and practical solutions for noise reduction, which are to be proposed for incorporation into existing URN management strategies or for the establishment of new strategies. Here, we outline some of the current opportunities and challenges in reducing underwater noise emissions, as well as in monitoring and compliance with limit values. Furthermore, we present results and key findings from recent research and development projects based on the latest monitoring data available in the German National Noise Register and the MarinEARS expert information system at BSH.

A Spatio-Temporal Management Framework for Identifying Sensitive Sea Areas for Ship Underwater Radiated Noise Using Biologically Weighted Sound Maps

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Underwater radiated noise (URN) from ships has been recognized as a potential source of disturbance to marine ecosystems, particularly to marine mammals. At the same time, the maritime sector is required to improve energy efficiency (EE) in order to reduce greenhouse gas emissions, and measures for URN reduction may sometimes conflict with EE improvements. This study proposes a spatio-temporal management framework for identifying sensitive sea areas for ship URN based on biologically weighted sound maps. This framework may contribute to the development of operational strategies that reconcile URN reduction with improvements in EE. The proposed framework integrates background noise, ship-generated noise, and the auditory characteristics of marine species through biologically weighted sound maps. The evaluation metric is the 24-hour weighted sound exposure level derived from the concept of temporary threshold shift (TTS) presented in the NOAA technical guidance, which reflects the hearing sensitivity of marine mammals. Received sound levels are estimated by combining source level estimation methods with an acoustic propagation model, and biologically weighted sound maps are generated. By overlaying the resulting sound maps with information on marine species habitats, areas where acoustic exposure may exceed biological thresholds can be extracted and identified as sensitive sea areas. A case study conducted in waters around Japan demonstrates the applicability of the proposed framework. The results show that relatively high exposure levels are distributed along major shipping lanes, while no areas exceeding the TTS threshold for large whale species were observed during the analyzed period. These findings indicate that the proposed framework provides a useful basis for identifying areas where biological impacts of ship URN may occur and for supporting underwater noise management strategies that consider both spatial and temporal variability in the marine environment.

Categorizing Alternative Seismic Sources Based on Their Potential to Affect Marine Mammals

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Seismic airguns generate high-intensity noise that can affect marine life. We evaluated four recently developed alternative seismic sources to assess their relative impacts on marine mammals and classify them within the tiered framework of the Operational National Mitigation Protocol (ONMP) in the 2025 National Marine Fisheries Service (NMFS) Biological Opinion under the Endangered Species Act. The analysis included three ultra low-frequency (ULF) pneumatic sources (Tuned Pulse SourceTM, Gemini SourceTM, and HarmonyTM) and a representative marine vibroseis (MV) system. Although these technologies are increasingly proposed as lower-impact alternatives to conventional airgun arrays, their regulatory integration requires quantitative evaluation of acoustic characteristics and potential biological effects. Using NMFS auditory injury and behavioral disturbance thresholds, along with a new broad-audibility metric (60-s M-weighted SEL), we found that all evaluated alternative sources produce smaller auditory injury zones and reduced detectability across marine mammal hearing groups. We provisionally place the alternative sources into lower tiers, which means surveys using these sources will require fewer mitigations than Tier 1 sources. Overall, this analysis provides a quantitative foundation for integrating alternative seismic technologies into regulatory processes and supports adaptive, impact-proportional mitigation as new data emerge.

Advancing an ecosystem-based approach to underwater noise management by implementing a trait-based framework

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Managing the ecological threats of underwater radiated noise (URN) demands a scientifically valid and biologically relevant Underwater Noise Limit Value (UNLV). Moving beyond a primarily pressure-based approach focused on quantifying sound pressure levels, an ecosystem-oriented, risk-based framework to manage URN was proposed. To support this risk-based framework, a trait-based vulnerability scoring system was developed for marine mammals, fishes and invertebrates, which allows the selection of indicator species from multiple taxa in setting regional UNLVs. The scoring system quantifies intrinsic vulnerability through evaluating multiple attributes such as the species' capacity to produce and sense sound, documented impacts from URN and general vulnerability related to life-history traits and socio-ecological status. In conjunction, the scoring system evaluates the quality of the data used for the assessment, highlighting species with a robust evidence base of vulnerability to URN. The vulnerability scoring system offers an adaptable framework that can be applied across different regions and refined as bioacoustics research evolves. Seasonal distribution maps of indicator species overlaid with sound level maps, generated under current and future policy scenarios, provide full transparency on the extent of habitats exposed to the stressor and the subsequent ecological implications of selecting different regulatory UNLVs. By linking URN to habitat loss and its consequent impacts on vulnerable populations, a holistic and ecosystem-based URN assessment can be achieved, delivering essential information that will support marine spatial planning and compliance to the Marine Strategy Framework Directive.

DEMASK: policy options for underwater noise

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The North Sea is one of the busiest shipping areas in the world, which leads to almost continuously increased noise levels along certain shipping routes. At the same time, the pressures from other human activities such as fishing, tourism and ambitious plans for a tenfold increase in the production of offshore renewable energy are increasing. Marine ecosystem health is already impacted by these cumulative human activities, in addition to the effects of climate change, highlighting the urgency of more sustainable ocean management. The last decades have seen many projects to monitor underwater noise and increase the knowledge on its impact on underwater life. Now policy makers want to effectively manage the impact of underwater noise on the environment. Underwater noise is recognised as a pollutant in the Marine Strategy Framework Directive (MSFD) and EU member states are mandated to monitor and mitigate noise pollution as part of their efforts to maintain or achieve Good Environmental Status. To do this, policy options are needed that effectively reduce this pollutant in the marine environment. By building capacities to define and assess scenarios for development, DEMASK supports policy makers, NGOs and the maritime industry in the management of the underwater North Sea soundscape to take measures that contribute to a well-managed soundscape and environmental protection of the North Sea. DEMASK stands for: Development and evaluation of noise management strategies to keep the North Sea healthy. DEMASK is currently developing scenarios for noise management in close collaboration with a wide range of stakeholders. These consider commercial shipping, OWF support traffic, OWF operational noise and recreational boating. Different scenarios for the mitigation of underwater noise, such as speed limits, re-routing or technical measures will be tested against base scenarios and the effect on noise pollution in the North Sea will be evaluated and discussed with the stakeholders. Sound energy budgets are calculated prior to the detailed analysis. Specific case studies will be chosen to illustrate noise for different regions and sound sources. Indicator species will be identified and soundscape maps produced and combined with knowledge on the effects of noise on marine species to quantify the impact of these scenarios. DEMASK thus aims to propose a knowledge-based approach for quantifying the effectiveness of management options.

Multi-sector partnerships for monitoring and managing ocean noise with an emphasis on offshore renewable energy development

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Multi-sector partnerships can have significant benefits in the management of ocean noise; having researchers, regulators, industry, and NGO representatives working together can and has resulted in practical, effective mitigation and management of ocean noise. Several large partnerships and projects have emerged to address ocean noise generally and offshore energy generated noise specifically. The Global Alliance for Managing Ocean Noise (GAMeON), for example, is an international partnership of action-minded scientists, managers, policy experts, and industry representatives fostering inclusive dialogues to fuel creative, workable solutions that will transform ocean noise management. The development of offshore energy sources is not a new contributor to ocean noise, and we have examples of partnerships developed to reduce the risk of exposure to marine life from, for example, offshore oil/gas development. The rapid and large-scale development of offshore renewable energy, particularly wind, introduces relatively new ocean noise sources, particularly in their presentation and timing. There are research projects that are working with scientists, regulators, and industry to quantify inter alia effects of the offshore wind development noise in Europe/ UK (e.g., EcoWind, PrePARED) and North America (e.g., Wildlife and Offshore Wind, WOW). The WOW Project has, for example, worked with offshore wind developers to align research and construction activities to sample cetaceans in what we have termed an 'opportunistic BRS', i.e., to sample animals being exposed to actual construction activities without introducing additional noise for research. While there can be challenges to assembling and working within these multi-sector partnerships, often in first organizing them, the potential and realized benefits are tangible and important. Using the WOW partnerships as an example, we have tagged multiple species of baleen whales (fin, humpback, minke) in/around offshore wind construction and operation activities, including having whales carrying satellite tags at the onset of pile driving in the first OSW facility in the New York bight. Additionally, data from whales carrying high-resolution multi-sensor acoustic tags include pile driving exposure allowing at least initial insights into baleen whale behaviour in these realistic exposure scenarios.

Marine Vibroseis as an Alternative to Air Guns: Development and Field Validation of the MVJIP Source

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The Marine Vibrator Joint Industry Project (MVJIP) was initiated in 2013 to develop a marine vibroseis source as an alternative to the industry-standard air gun. The objective was to design a seismic source with lower peak amplitude and a frequency output restricted to the bandwidth required for geophysical imaging, thereby reducing environmental impact while meeting geophysical performance requirements. In addition to environmental considerations, the marine vibrator was expected to provide increased operational flexibility and potential improvements in data quality. A full-scale prototype marine vibrator has undergone progressive validation, including a real-world pilot test conducted in 2022 and a dedicated Behavioral Response Study completed in 2024. Results from these studies demonstrate the operational viability and reliability of the marine vibrator source. Ongoing analysis of the acquired data aims to quantify its geophysical performance and provide evidence of reduced environmental impact relative to conventional air-gun sources.

Advancements in Marine Vibrator Technology for Offshore Seismic Acquisition with Reduced Acoustic Impact

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Recent development efforts have focused on advancing marine vibrator technology into a fully integrated seismic source, using controlled sweeps that can be matched to the specific geophysical targets of interest. By operating within tailored frequency bands, the source concentrates energy where it is needed for imaging while limiting output in frequencies we do not intend to emit. This targeted use of the spectrum helps reduce noise that does not contribute to the seismic image and provides a cleaner, more predictable input to processing. This control translates directly into geophysical value. Tailored sweeps improve repeatability and signal fidelity, reduce residual sweep noise, and support efficient sampling. These capabilities enable surveys to be completed more quickly while maintaining high data quality, and they enhance the ability to focus energy within the seismic band of interest. The sweeps may also be designed to avoid certain frequencies, e.g. if the geographical area of the survey has special concerns or requirements around sound emission in certain frequency bands. The vibrator design combines a hydraulically actuated acoustic projector with integrated sensing. Accelerometers and near-field hydrophones are used to calculate the emitted source signature in real time, ensuring the wavefield remains aligned with the designed sweep. With earlier prototype work completed, the technology is now progressing through system-level qualification, showing consistent acoustic and operational performance and reducing technical risk as it moves toward field deployment and broader operational readiness. This technology which enhances seismic acquisition efficiency through enabling simultaneous-shot separation, improving wavefield reconstruction, increasing low-frequency output, and higher source repeatability are important advances in the Brazilian context of seismic offshore acquisition. The marine noise impact is expected to be reduced by concentrating energy on the most useful frequencies for seismic processing, limiting the effects on marine communication and behavior. To understand the behavioral responses of cetaceans to the vibratory source, a specific monitoring plan is being developed for the first test of this equipment in Brazilian waters. This monitoring will focus on passive acoustic monitoring, using data collected with hydrophones towed by an independent vessel, nodes and DAS interrogation from a PRM installation in the field.

Sustainable Seismic source trial, a lean-crew robotic ship and non-impulsive marine vibrator source.

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Traditional surveys use energetic impulsive pneumatic sources deployed from large, crew-intensive vessels, producing high peak sound pressure levels (SPLs) and broadband emissions that partially overlap sensitive marine fauna hearing ranges. bp has undertaken a multi-year sustainable seismic programme integrating marine autonomy and robotics, lean or uncrewed operations, and a non-impulsive electric marine vibrator source. This paper summarises results from bp's Sustainable Seismic Source Field Trial (SSSFT), one of the first end-to-end demonstrations of a remotely operated marine seismic source designed to reduce ocean noise, vessel emissions, and human safety exposure. The trial integrated an over-the-horizon (OTH) controlled robotic vessel, a frequency-controlled marine vibrator, passive acoustic monitoring, remote protected species observers (PSOs), and seismic recording using in-well distributed acoustic sensing (DAS). The source comprised eight disc-shaped electrodynamic projectors mounted in a single tow body and operated at ~12 m depth, with no bubble signal. It emitted controlled frequency sweeps over 8 s followed by 8 s quiet periods (50% duty cycle), with energy limited to 10-50 Hz. The source exhibits gradual onset and decay, avoids high peak pressures, and is ~15-25 dB lower in energy than pneumatic sources. Source, float, and rigging weighed <13 t in air. Permitting was issued by BOEM with NOAA/NMFS authorisation. Deployment used a lean-crewed vessel with automated launch, recovery, navigation, and source control conducted from a UK remote operations centre ~7,000 km away, with no specialist source engineers offshore. A remotely operated, DNV-certified LARS reduced offshore safety exposure by ~70%. The deep-water Gulf of America trial acquired ~876 km of source lines with no safety or environmental incidents. Seismic responses were recorded on DAS-instrumented wells, with calibrated seabed acoustic recorders validating sound models. The 160 dB SPL behavioural threshold occurred only within tens of metres; for sea turtles, the 175 dB SPL threshold was reached at ~10 m. Marine mammal behavioural exposure was ~1% of a large airgun array (sea turtles ~6%), with effectively zero injury exposure. Fuel consumption was reduced by up to 80%. The trial demonstrates a viable pathway to lower-impact, lower-risk seismic acquisition, with further work required to optimise bandwidth, scale to multi-vessel operations, and mature remote PSO capability.

Controlled Exposure Experiments with An Operational Marine Vibrator and Very-Low Frequency Whales

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Marine geophysical surveys use acoustic imaging sources including airguns that generate intense impulsive broad-band noise, though only <200 Hz is practically useful. Marine vibrators (MV) have been developed as reduced-impact alternatives to concentrate energy in this band with lower rise time and peak pressure. These parameters almost certainly reduce impacts on species that communicate using higher frequencies but key questions remain for species that utilize very low frequencies, including large whales. We conducted controlled exposure experiments (CEE) to obtain baseline and novel experimental behavioral response data for very low-frequency whales to a full-scale, realistic, operational MV. We focused on blue and fin whales using multi-scale tags, including longer duration (weeks) dart-attached and shorter (days) suction-cup attached high-resolution depth, movement, and acoustic tags. The MV source produced repeated 5-s, 5-100 Hz linear sweeps at 50% duty cycle and 190 dB re:1mPa (broadband RMS). 33 tags yielded ~2500 h of data in eight 90-min CEEs (6 MV; 2 no-noise 'control'). Pilot CEEs with simulated MVs indicated mild, temporary avoidance responses by traveling whales or those feeding in lower prey densities. Initial data from operational MVs did not indicate broad-scale avoidance or strong behavioral changes for blue whales feeding intensely on concentrated prey.

Project COSIMMAS: A review of non-impulsive sound impacts on marine mammals and their mitigation, with a focus on geophysical exploration sounds

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Evidence-based decision-making is at the core of environmental impact assessment, conservation and management. The integration of best available science into this decision-making is a key pillar for effective policy development, implementation, and risk mitigation. Here, we focus on sound impacts on marine mammals, with particular attention on evaluating legacy threshold-based approaches and bridging knowledge gaps in evaluating non-impulsive (or 'continuous') sources, including those developed with the goal of mitigating impacts of intensive impulsive noise. These gaps have resulted in critical and timely international management needs in developing effective, science-based mitigation strategies and appropriate interpretations of noise exposure criteria. Project COSIMMAS is presently underway and reviewing impacts of continuous sound on marine mammals to inform these interpretations in different jurisdictions and identifying strategic research to address knowledge gaps. A variety of non-impulsive sound sources have been reviewed within the project. This includes both data-poor emerging topics of regulatory interest and sources that have been developed as presumably reduced-noise alternatives to more established, impulsive techniques (e.g. marine vibroseis as an alternative to airgun arrays). Information that contributed to this review was drawn via an extensive literature review, as well as via direct engagement with industries (e.g. including oil and gas exploration) and regulatory bodies from around the world. This review process culminated in a recently held week-long international workshop with subject matter experts on both the impacts of sound on marine mammals, as well as those at the forefront of designing, implementing, or using emerging technologies designed for noise mitigation, alongside three webinars with agencies from many nations, industries, and relevant stakeholders. Within this talk, we focus on geophysical exploration sounds, considering both exploration techniques that serve as an alternative to the use of airgun arrays (e.g. marine vibroseis), or methodologies which focus on using only the frequencies needed (e.g. low-frequency rich and bandwidth-controlled methods). This presentation will synthesize the geophysical component of the COSIMMAS expert elicitation evaluation of existing knowledge, data gaps, and outline a roadmap for mitigating impacts of non-impulsive sounds from alternative geophysical sources on marine mammals.

Reducing the Environmental Impact of Seismic Surveys: A Review of Impulsive Source Technologies and Monitoring Solutions

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Active marine seismic surveys are essential for offshore subsurface imaging but can have significant environmental impact, particularly on marine mammals. New source and monitoring technologies are therefore being developed to reduce acoustic impact while maintaining data quality and operational efficiency. We present two lower impact seismic sources, and an integrated passive acoustic monitoring solution, with their application to environmentally sensitive regions such as offshore Brazil and Australia. Bluepulse is a new generation impulsive source designed to minimise high frequency components that overlap with the hearing sensitivity of numerous marine mammal species, while preserving the low frequency bandwidth needed for exploration. Field trials indicate substantial reductions in radiated noise compared with conventional Airgun arrays, enabling at least a threefold reduction in marine mammal exclusion zones for equivalent geophysical objectives. TPS is a large volume, low frequency tuned source that delivers broadband seismic energy with a smoother temporal signature and reduced sound exposure levels. Tests in the U.S. Gulf of Mexico show at least a threefold reduction in exposure distance for low frequency cetaceans, and up to 25 fold reductions in distance, for high and very high frequency species relative to traditional Airguns. The improved source efficiency and data quality can also reduce the need for repeat surveys, decreasing both operational footprint and associated greenhouse gas emissions. To complement the environmentally friendly sources, QuietSea provides real time passive acoustic monitoring and noise measurement. It automatically detects and classifies low, mid and very high frequency cetaceans and issues alerts to support dynamic mitigation during surveys. It can be deployed as streamer integrated sensors near the source and as autonomous buoys around critical habitats, providing a spatially distributed monitoring network. Together, Bluepulse, new source and monitoring solutions represent an integrated approach to environmentally responsible seismic exploration, offering substantial reductions in acoustic exposure for marine mammals and supporting stringent regulatory frameworks while preserving high resolution subsurface imaging.

Underwater noise impact assessment in the Pelagos Sanctuary: a focus on four species

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The Pelagos Sanctuary, a cetacean Marine Protected Area in the north-western Mediterranean Sea, represents a key region for studying species distribution and evaluating the pressures acting on their habitat. Although numerous studies have examined noise, few have applied the Marine Strategy Framework Directive's methodology or verified its thresholds for continuous underwater noise, which stipulates that no more than 20% of the target species' habitat should exceed the Level of Onset of Biologically Adverse Effects (LOBE) in any month of the assessment year. This study used established habitat-preference models to assess whether these criteria are verified within the Pelagos Sanctuary. By integrating habitat suitability predictions with 2019 shipping noise maps generated by SHOM for the QuietSEAS project, the proportion of the suitable habitat exposed to noise levels potentially relevant to LOBE has been estimated. The analysis identified Bottlenose dolphins, Striped dolphins, Sperm whales, and Cuvier's beaked whales as the Pelagos Sanctuary species most at risk from shipping noise due to their distribution. Models predict that over 80% of suitable habitat for some species could experience noise above LOBE, indicating a substantial loss of usable area. Seasonal analyses further allowed the evaluation of how noise-related impacts vary throughout the year, highlighting periods when a larger proportion of optimal habitat is exposed to higher acoustic pressure. The study enhances our understanding of how noise affects cetaceans and offers valuable guidance on considering habitat vulnerability to shipping noise when setting conservation and management goals. These findings are crucial for creating strategies that reduce noise pollution and protect cetacean populations within the Pelagos Sanctuary.

The Marine SoundLib: An open Infrastructure for exploring and understanding Marine Soundscapes

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The Marine SoundLib (https://marinesoundlib.org) is an open FAIR and comprehensive digital infrastructure designed to advance research, policy making, monitoring and public engagement in underwater acoustics. The platform provides a curated and continuously growing repository to explore soundscapes across temporal and spatial scales. The Marine SoundLib represents the sound level trends in time and space, based on hybrid millidecade bands per minute. Hidden within these trends are distinct sound events, from known and unknown sound sources (e.g. anthropophony, geophony, biophony). Currently, knowledge regarding potential sources of sound events in dynamic seas is very limited. The curated annotated sound events are stored and listed in a database on the platform, and their similarity is shown based on their acoustic characteristics projected in a 2D space using UMAP. This approach can be key in identifying events that may belong to the same source. The sound events are machine ready for detection and classifying algorithms to effectively process large and heterogenous datasets in order to unravel the acoustic complexity and biodiversity patterns. Registered users can access the Marine SoundLib via the Application Programming Interface (API) and a Python-based Software Development Kit (SDK). This allows for querying the recordings, its metadata and annotations of sound events as well as contributions to the Marine SoundLib. The platform is specifically designed to support machine learning workflows, aiming to provide training datasets and tools for automated detection and classification of biotic, abiotic or anthropogenic sounds. Next steps on the roadmap are connecting to European data infrastructures such as European Marine Observation and Data Network (EmodNet) and the European Digital twin of the Ocean (EDITO). By facilitating open access to standardized acoustic data, Marine SoundLib contributes to improved assessment of marine ecosystem health, supports policy frameworks addressing underwater noise, and fosters collaboration among researchers, industry stakeholders, and citizen scientists. The platform supports more efficient, comprehensive and scalable interpretation of complex marine soundscapes. The initiative aspires to position the platform as the European node in an emerging international network for marine bioacoustics.

The importance and challenges of an ecosystem-based, multi-taxa approach to underwater noise risk assessment and management

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Without regulatory measures, underwater radiated noise (URN) from human activities poses risks to marine life. To mitigate these hazards, a shift towards an ecosystem-oriented, risk-based URN assessment and management is essential. Fundamental steps for this approach include selecting indicator species across various taxa and establishing ecologically relevant underwater noise limit values (UNLV). Previous URN risk assessments focused primarily on marine mammals, while ecologically vital taxa like fishes and invertebrates are often overlooked. A multi-taxa approach was adopted for assessment of URN impacts at ecosystem level. For this, a trait-based vulnerability scoring system was developed to select indicator species for marine mammals, fishes and invertebrates, estimating the relative URN vulnerability across species by quantifying sound production and detection abilities, documented URN impacts, general susceptibility related to intrinsic life-history traits and socio-ecological status, while also accounting for data quality. The assessment identified a set of multi-taxa indicator species backed by robust evidence. It also highlighted potentially vulnerable species that currently lack sufficient data for selection. A primary limitation is the system's reliance on existing data; high vulnerability scores often correlate with how well a species has been studied. Especially for invertebrates and fishes, the species studied only represent a small fraction of those potentially vulnerable to URN, and data gaps regarding bioacoustics and noise impacts - including effects of particle motion - remain substantial. Other challenges include only a few sound sources tested, a general lack of dose-effect relationships, inconsistent methodologies and metrics that impede comparative analyses, and unknown mechanisms behind demonstrated effects and their impact on populations. Despite these challenges, the establishment of regional UNLVs to protect vulnerable species should not be delayed. Identifying data gaps helps prioritise future research in the emerging field of bioacoustics, allowing the vulnerability assessment framework to be refined iteratively as research progresses. By integrating indicator species' distribution and key habitats with regional UNLV and the spatiotemporal overlap of URN exposure from sound maps for current and future policy scenarios, this multi-taxa approach facilitates an ecosystem-based URN management applicable across different regions.

Towards an ecosystem-based Underwater Noise Limit Value for the North Sea: A Functional and Risk-Based Framework

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Under the Marine Strategy Framework Directive (MSFD), EU Member States must manage continuous underwater noise to achieve or maintain Good Environmental Status, requiring definition of a Level of Onset of Biologically Adverse Effects (LOBE). Current assessments often rely on a single indicator species, missing ecosystem-wide vulnerability. We present a framework from the Interreg North Sea project DEMASK that aims to derive a precautionary, ecologically representative Underwater Noise Limit Value (UNLV) informed by the LOBE concept by integrating evidence across marine mammals, fish and invertebrates, selected via a trait-based vulnerability scoring system. The framework translates fragmented, single-species impact studies, typically reporting responses relative to sound pressure levels (SPL), into a cross-taxa management framework. Rather than aggregating responses by taxonomy, indicator species are grouped by functional hearing characteristics reflecting frequency-dependent vulnerability. SPL values reported across studies are harmonized to a comparative scale and classified along an ordinal severity gradient, ranging from onset of hearing through behavioural and physiological responses to hearing impairment and injury. Knowledge gaps are identified, particularly for masking, effects of particle motion, and limited data. Initial synthesis of harmonized SPL values reveals a consistent severity-prevalence relationship: as SPL increases, both impact severity and the proportion of affected species increase. This relationship is operationalized using cumulative distribution functions, which describe for any SPL the fraction of species expected to experience at least a given impact level. The approach is analogous to Species Sensitivity Distributions used in ecotoxicology, where interspecies variability in sensitivity is statistically represented to derive environmental thresholds. A precautionary UNLV could be derived from a conservative quantile of this distribution, e.g. the SPL at which 10-20% of indicator species are expected to experience at least a given impact level. While this intentionally simplified approach remains under development, it provides a transparent way to integrate heterogeneous evidence across taxa and defines UNLVs near the lower bound of biologically relevant effects. It complements species-specific assessments by supporting ecosystem-based management and provides a reproducible pathway toward UNLV implementation under the MSFD.

Quantitative Assessment of Coastal Dolphin Exposure to Small Vessel Noise

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The global expansion of coastal dolphin tourism utilizing small vessels has raised concerns regarding the acoustic impact of engine noise on marine mammals. To evaluate this impact accurately, quantitative monitoring that correlates underwater noise levels with the precise spatial proximity of dolphins and vessels is essential. However, a significant methodological challenge exists: small tourism vessels frequently operate without Automatic Identification System (AIS) transponders, making it difficult to acquire accurate, real-time positioning data in the field. To address this gap, this study proposes a novel monitoring framework utilizing unmanned aerial vehicles (UAVs) and passive acoustic monitoring. We conducted aerial surveys to film dolphin pods and tourism vessels simultaneously. By integrating the pixel data from the aerial imagery with the drone's onboard GPS logs, we georeferenced the footage to derive the absolute longitude and latitude coordinates of both the dolphins and the vessels. Synchronously, underwater hydrophones were deployed to measure real-time vessel noise levels. Based on data collected over a one-month monitoring period in the target habitat, this paper quantitatively reports the extent to which dolphins were exposed to vessel noise. We analyze the dolphin-centric noise exposure by the vessels. This methodology provides a viable solution for assessing acoustic stressors in coastal environments where standard vessel tracking data is unavailable, offering critical data for the management of sustainable dolphin tourism.

Experimental exposure of free-ranging fish to airguns: investigating behavioural responses with acoustic telemetry

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Seismic surveys contribute to anthropogenic noise in the sea, potentially causing behavioural responses of fish over large areas. Research into the types of responses and sound levels at which animals respond is crucial for providing scientific advice for managing underwater noise. In a series of controlled exposure experiments conducted in a bay in western Norway, acoustic telemetry has been used to track the behavioural responses of Atlantic cod (Gadus morhua) to real seismic sources used in geophysical surveys. Experiments using small airguns revealed that behavioural responses of cod to sound levels mimicking a distant seismic survey were subtle, and fish were not displaced from the area. However, the sound levels at which more pronounced behavioural responses would occur are unknown. Furthermore, these previous experiments have focused only on cod, and the results may not be applicable to other fish species that could be more responsive. The aim of the current study was to expose fish to higher sound exposure levels than used in previous experiments at the same site, aiming for levels that are representative of those experienced at closer range to a typical site survey using airguns. The exposure was conducted with a real seismic survey vessel, and the shot interval was typical for such surveys. The experimental design allows testing for effects of both the seismic airgun sound and the sound of the vessel itself. An experimental exposure was conducted with tagged cod in April 2025, and a repeat of the exposure will be conducted in April 2026. This year, we also aim to tag and expose other fish species, both gadoids and flatfish, to examine whether the results for cod can be generalized, or not, to other species. Sound exposure levels (SEL integrated over 10 s and 5 - 1000 Hz) at the closest range measured from the source (170-350 m) were around 150 dB re 1uPa2 s, hence higher than previously published experiments using airguns at this site. Despite higher SEL, a preliminary review of the fish telemetry data suggests that the tagged cod were not displaced from the study site. Further analysis will be conducted to investigate changes in other movement behaviours such as swimming depth, activity levels, and horizontal movements. The results from these experiments will contribute to scientific advice for management of seismic surveys, by providing sound limits that are considered safe to use without disturbing important behaviours.

Individual-based approaches can bridge disciplinary gaps to assess the effects of seismic surveys on cetacean behavior, physiology and health

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Seismic surveys are sources of intense anthropogenic noise in the ocean. Yet, understanding the responses of seismic air guns on cetaceans and the underlying mechanisms, as well as population-level effects, remains a challenge. Nonetheless, the integration of multi-platform, multi-method individual-based sampling in a quasi-experimental strategy can expand knowledge and bridge disciplinary gaps. The MARESIS Project (Individual Responses of Cetaceans to Seismic - PETROBRAS/CENPES) implemented such integrative approach in Brazil, where the oil industry is thriving and numerous seismic surveys are planned. The project joins experts in animal behavior, bioacoustics, physiology and health to investigate cetaceans around active seismic surveys in the Santos and Campos basins, sampling at a gradient of distances from the noise source, and in the Abrolhos Bank-a key breeding ground of humpback whales not subject to oil exploration, including marine protected areas. Since 2024, this observational approach to quantify cetacean responses to seismic surveys involved data collection on focal-individuals using multiple platforms in a preferred sequence: deployment of biologging devices, blow samples for hormones and health, drone-based photogrammetry to estimate body size and condition, and remote biopsy sampling for genetics, health and hormones assessment. Over 91 days of effort resulted in sampling of 199 individuals (63% were humpback whales) with at least one platform (149 with one, 22 with two, 14 with three, 10 with four, and 4 with all five platforms). Skin and blubber biopsies were most frequently sampled (n=143). Aerial photogrammetry (n=70), tagging (n=28), and blow samples for hormones (n=28) and health (n=22) were more challenging. By integrating biologging, biological samples and aerial photogrammetry, it is possible to assess behavioral responses and measure individual-level data that could modulate responses, such as sex, health status (microbiome, pathogens and body condition) and stress levels (cortisol and corticosterone hormones), supporting a comprehensive investigation of behavioral and physiological responses to noise. Although the proposed integrative approach is feasible, many challenges and opportunities remain. The use and development of emerging technologies, such as autonomous drone systems, can increase the efficiency of sampling and further enhance the capacity to assess the impact of anthropogenic noise on marine megafauna.

Adoption of a new generation of reduced impact seismic sources

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In recent years, several lower-impact seismic source technologies have been developed, tested, and commercialized, marking an important step toward more sustainable marine seismic acquisition. Among these, novel airgun designs seek to substantially reduce acoustic emissions while maintaining geophysical performance. Although these technologies are now commercially available, adoption across the industry remains limited. This presentation reviews the current status of reduced-impact sources and examines the factors constraining wider implementation. The barriers to adoption are not purely technical; they also arise from the complex interactions between operators, contractors, and regulators, whose priorities and decision-making frameworks are often insufficiently transparent, while available flexibilities and implementation options are not always well understood. As a result, commercially available solutions have yet to transition into routine operational use. It is argued that progress will require a more coordinated, multi-stakeholder approach. In particular, an open dialogue modelled on the Dutch 'Noordzeeakkoord' could provide a practical framework for clarifying expectations, addressing trade-offs, and aligning stakeholder objectives. Given the global nature of the seismic industry, such an approach should also be considered in an international context. This process may help resolve the current impasse and support broader adoption of lower-impact seismic source technologies in marine acquisition.

Reducing fauna habitat exposure to marine seismic surveys through source-less acquisition

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Marine seismic surveying typically relies on high-amplitude active acoustic sources to image the sub-seafloor, potentially impacting marine fauna. We developed a novel "source-less" seismic acquisition method that uses continuous vessel-generated noise instead of an active seismic source. This study assesses whether this approach reduces marine fauna exposure during research-scale surveys in shallow coastal waters. Fieldwork was conducted in ~20 m water depth in the Gulf of Trieste, Italy, using a small passenger vessel towing a 24-channel hydrophone streamer. Recordings of the vessel-generated wavefield were processed to produce seismic images with sub-seafloor penetration comparable to those obtained from a conventional active "boomer" survey. Acoustic modeling was used to estimate received sound levels as a function of distance. Behavioral response thresholds were applied to key regional species: bottlenose dolphins (Tursiops truncatus), brown meagre (Sciaena umbra), loggerhead sea turtles (Caretta caretta), and benthic invertebrates. Modeled impact radii and associated habitat exposure percentages were computed along a 100 m trackline using a capsule-based buffer consistent with the TG Noise areal exposure framework. Results were evaluated against a conventional boomer survey acquired at the same site. Source-less acquisition, characterized by a source level of 175 dB re 1 uPa at 1 m, produced substantially smaller modeled impact distances (140-644 m) and habitat exposure (0.9-11.1%), all below recommended screening thresholds. In contrast, the boomer source (210 dB re 1 uPa at 1 m) generated impact distances of 1,193-2,021 m and habitat exposure of 47-208%, exceeding reference thresholds. Values above 100% reflect the modeled noise footprint extending beyond the defined habitat area rather than ecological overexposure. Source-less acquisition reduced the spatial footprint of potential behavioral disturbance by approximately an order of magnitude. Within the framework of the MSFD, the TG Noise recommends that no more than 20% of a habitat be exposed above levels associated with adverse biological effects on a daily basis, or 10% annually. Consistent with these guidelines, source-less seismic acquisition offers a lower-impact alternative to conventional active sources, particularly in ecologically sensitive shallow coastal environments. These results emphasize the role of source selection in reconciling environmental protection with imaging objectives.

Influence of offshore seismic surveying on the acoustic detectability of the Antarctic minke whale (Balaenoptera bonaerensis) on the Brazilian Equatorial Margin

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Seismic oil and gas exploration constitutes a source of high-intensity impulsive noise potentially capable of altering the underwater soundscape, which is why its operation is regulated by environmental mitigation protocols. However, the magnitude of its effects on marine mammals remains unknown. In this study, we investigated the existence of immediate behavioral responses of these animals to exposure to the sound of airgun shots at distances of 65 to 325km from the source. Mysticetes, which use low-frequency vocalizations for communication and reproduction, may experience interference. The objective of this work was to evaluate whether seismic activity is associated with immediate changes in the occurrence or acoustic detection of the Antarctic minke whale (Balaenoptera bonaerensis), a species that produces stereotyped bioduck-type vocalizations, which are easily identifiable in acoustic records. Understanding the presence and activity of these animals in areas of energy interest, such as the Brazilian Equatorial Margin, is relevant to support environmental assessments related to offshore developments. We used recordings from fixed passive acoustic monitoring conducted in the Foz do Amazonas Basin, using autonomous hydrophones moored at approximately 1,000 m depth. The equipment operated with a sampling rate of 128 kHz and a 24-bit resolution. To evaluate potential short-term responses, we calculated, in 30 minute intervals, the mean distance between the seismic source and the hydrophone, the number of emitted shots, and the number of detected bioduck pulse trains, taking into account diel variation. In total, 348 hours of recordings were analyzed. Statistical analysis was conducted using a Generalized Additive Model (GAM) with a Tweedie distribution. The model explained 35.3% of the variation in bioduck detections. Individually, the time of day parameter was significant ($p = 0.035$), with a reduction in detections during the night. In addition, a significant interaction was observed between distance and the number of shots ($p < 0.001$). The effect of distance on the response variable is conditional, depending directly on the intensity of simultaneous shots in the environment. Although the results do not allow inferring a direct impact on the animals, they suggest that seismic activity may influence the detectability or vocal behavior of the Antarctic minke whale in the studied area.

Cambridge Bay, Nunavut - important gateway for ship traffic passing through the Northwest Passaged during the Arctic summer

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Compared to other marine areas, the Arctic Ocean has had historically less noise disturbance from anthropogenic activities given the dampening effect and physical barrier sea ice provides to ship traffic. However, as climate change is causing longer ice-free periods during the Arctic summer, elevated underwater noise levels as well as increased anthropogenic activities such as shipping are consequently a result. By providing important habitat for numerous marine species, many of which represent important subsistence species for Inuit communities, the Arctic Ocean is experiencing rapid changes. Thus, monitoring the underwater soundscape, a crucial habitat feature for marine organisms, is important to understand and further mitigate the effects shipping can have on Arctic marine species. This study presents a collaborative effort between the Ekaluktutiak Hunters and Trapper Organization (EHTO) of Cambridge Bay, the Wildlife Conservation Society (WCS) Canada, the University of Victoria in Canada and Transport Canada, resulting in the first long-term soundscape analysis of PAM data collected in the Kitikmeot Region of Nunavut, Canada during multiple shipping seasons between 2017 and 2024. Acoustic data were analysed for marine mammal and fish vocal presence, examining particularly the temporal overlap between these species and ships. While ringed seal (Pusa hispida) and fish vocalizations were present consistently throughout the shipping season, bearded seal (Erignathus barbatus) vocalizations showed clear peaks during the species' breeding season (April to June); however, less vocal presence during the shipping season. Beluga (Delphinapterus leucas) and Bowhead whale (Baleana mysticetus) vocalizations were detected on a few single days, with visual sightings confirmed by Inuit communities. Underwater sound levels were strongly driven by natural sound sources such as wind speed and rain, as well as ship noise as anthropogenic sound source. Our findings suggest that ringed seals in particular are exposed to high levels of ship noise, raising concern as the species is listed as of Special Concern in Canada (COSEWIC 2019). This study presents the first long-term passive acoustic measurements in the Kitikmeot Region and provides important baseline measurements for future studies on underwater noise within this region.

Assessing ringed seal exposure to vessel noise in the Canadian Arctic using a novel perception-based approach

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Ringed seals (Pusa hispida) are an ice-obligate species adapted to quiet underwater soundscapes. Although integral to both Arctic ecosystems and Indigenous communities, the extent to which they are impacted by increasing vessel noise is largely unstudied. A critical first step is to determine where and when seals encounter noise; however, standard methods for describing exposure often involve temporal or spatial averaging that may mask fine-scale patterns. Here, we present the first estimates of ringed seal noise exposure and introduce a novel methodology for evaluating exposure at the level of individual seals and vessels. Predicated on biologging data, this workflow incorporates vessel information from the Automatic Identification System (AIS), ringed seal hearing measurements, and oceanographic context (bathymetry, salinity, subsurface temperatures) to model the range at which vessel noise is perceivable to seals at several frequencies (63, 200, 1000, 3200 Hz). Applying this framework, Argos locations from seven seals tagged in 2012-2013 were fitted with a continuous-time state-space model, producing 5,667 corrected locations with 95% confidence ellipses. Interpolated positions of 73 vessels were matched with seal locations to identify 2,281 potential exposure encounters. Source levels were modeled using vessel attributes and speed, while ambient sound levels were approximated using hourly wind data and a depth-dependent wind noise model. Propagation loss was calculated accounting for bathymetry, bottom substrate, frequency-dependent absorption, and seal depth. Results show that less than 5% of estimated seal locations were exposed to vessel noise at any frequency, with substantial individual variation in exposure rates. Vessel source level estimates had the strongest impact on detection ranges, which were often sizeable even in noisy ambient conditions. The greatest number of exposures occurred at 63 Hz, where seal critical ratios were lowest and vessel source levels were highest. No exposures occurred at 3200 Hz, despite vessel source levels often surpassing ambient levels. This computationally efficient workflow effectively assesses exposure within a meaningful spatial and temporal framework while explicitly considering uncertainty in model-corrected seal locations. It can be easily applied to other datasets and species, providing a means to repurpose telemetry data to enhance our understanding of noise exposure trends in the Arctic and beyond.

Acoustic and temporal comparison of grunts produced by Arctic and Pacific gadids

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Passive acoustic monitoring (PAM) is an emerging field to explore and understand fish species distribution. Arctic cod (Boreogadus saida) are keystone forage fish in the Arctic and are experiencing climate-driven shifts in their abundance and distribution, as well as impacts from elevated underwater noise levels. With warming waters, other gadid species, specifically walleye pollock (Gadus chalcogrammus), are expanding their range potentially into the Arctic Ocean. Both Arctic cod and walleye pollock have been documented to produce a 'grunt' sound during spawning, but comparisons between the species have not been made. Here, we describe the acoustic and temporal characteristics of grunts produced by Arctic cod, Pacific cod (Gadus macrocephalus) and walleye pollock to create a potential method to monitor their distribution and spawning period using PAM. SoundTrap underwater recorders were deployed in tanks containing adult Arctic cod, Pacific cod, and walleye pollock at the Hatfield Marine Science Center in Newport, Oregon. Grunts were examined by analyzing 5-minute subsections every 60 minutes, every other day throughout the peak spawning month for each species. Clear seasonal patterns in grunt production were observed for Arctic cod and walleye pollock, with minimal grunts detected from Pacific cod. Arctic cod and walleye pollock both had increased grunts during their respective spawning months, with differences in acoustic characteristics observed. Lower peak frequency and shorter durations were observed for walleye pollock compared to Arctic cod, as well as significantly higher numbers of grunts per day for walleye pollock. Results from this project demonstrate the potential for using PAM to understand the distribution of gadids during spawning and will aid in monitoring changes in distribution as the climate shifts.

Development and Experimental Validation of Acoustic Metamaterials for Sonar Signature Reduction

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To advance the control of the acoustic signature of naval vessels in general, and submarines in particular, this research focuses on the development of different types of metamaterials suitable for coating pressure hulls. The main objective is to improve acoustic performance, specifically targeting echo reduction and insertion loss. To validate the proposed designs, a series of test specimens were manufactured using square samples of 50 x 50 cm and 150 x 150 cm, with thicknesses ranging from 2 to 4 cm. These samples were used to evaluate performance in the 20-100 kHz and 1-20 kHz frequency ranges, respectively. The results indicate that some specimens present improved designs compared to conventional materials used for these applications, showing promising performance aligned with our objectives of improving the overall acoustic signature, and particularly the echo-sonar signature. This research represents a significant step forward in the development of engineered materials for acoustic applications, providing empirical evidence of the practical feasibility and effectiveness of the proposed metamaterial designs. The systematic approach adopted in this study-combining micro-insertions, multilayer configurations, and controlled distributions of periodic cylindrical structures-contributes to a deeper understanding and optimization of acoustic signature control mechanisms. Furthermore, the implications of this work extend beyond naval applications to other fields, such as noise reduction in offshore industrial environments and maritime transportation in general. The successful validation of our metamaterial designs, manufactured using industrialized techniques and verified through experimental measurements, establishes a solid foundation for further development and optimization, paving the way for practical implementation in real-world scenarios.

A path towards adding biological noise to the modelled ocean soundscape.

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In understanding the ocean soundscape, most modelling efforts have been focused on shipping, wind and other anthropogenic sound sources. In many environments, at particular frequencies, the soundscape can be dominated by vocalizations made by marine animals (mammals and fishes). From the navy perspective these are considered biological noise. In this paper we present a methodology for predicting the marine mammal contribution to the soundscape by combining marine bioacoustics, dynamical oceanographic modelling, ecology and ocean acoustic propagation modelling. Each is a complicated research field in itself. The loose framework is an aggregation of models. Although in its early stages, the model framework can mature as each field advances and can provide a methodology for the merging of measurements through data-assimilation or artificial intelligence. Synthetic soundscapes are generated with wind, ships, fin, minke, sei and sperm whales.

Can Distributed Acoustic Sensing help monitor underwater soundscapes?

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Effective monitoring of underwater soundscapes faces several challenges. Achieving spatial coverage sufficiently extensive to be representative while maintaining the spatial and temporal resolution needed for stable statistical estimates can be costly. Source localisation is also difficult unless multiple hydrophone locations are available, and moored monitoring systems cannot usually provide real-time information. Distributed Acoustic Sensing (DAS) offers a potential solution to several of these challenges by repurposing existing Fibre-Optic (FO) cables to monitor long stretches of seabed with high spatial resolution. Near-field beamforming can be applied along the cable to localise acoustic sources. Because the DAS interrogator is located at the cable end, data can be accessed in near real-time. However, DAS introduces its own set of challenges. In particular, the Signal-to-Noise Ratio (SNR) of DAS virtual sensors is typically significantly lower than that of high-quality ceramic or FO hydrophones. Beamforming can partially mitigate this limitation by providing array gain, but effective beamforming generally requires either computationally intensive searches or prior knowledge of source location, which undermines the goal of detecting unknown sources. Additional complications arise in converting acoustic pressure fluctuations in the water into the strain rate measured along the FO cable. Multiple physical mechanisms contribute to this conversion, and their relative importance increases with frequency, becoming particularly significant above about 1 kHz. Despite these challenges, if DAS performance can be reliably calibrated, an increasingly demanding task at higher frequencies, our results indicate that DAS has strong potential for soundscape monitoring. Its extremely large spatial aperture and dense spatial sampling provide far more data than traditional Passive Acoustic Monitoring (PAM) systems, enabling improved estimation of soundscape statistics and more robust tracking of individual sources. DAS is also excellent at very low frequencies, down to millihertz. DAS offers new opportunities for characterising ship-radiated noise, including frequency and angular dependence, because different segments of a FO cable observe the same source from different angles. Finally, DAS enables acoustic monitoring in environments where hydrophone deployment is difficult, such as beneath sea ice.

Soundscape analysis of the multi-diverse marine environment of eastern Mediterranean: The Greek case

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Greek seas are of prime ecological importance for Mediterranean marine fauna, yet they are also regions where human activities strongly overlap with natural ecosystem components. Across the Hellenic Trench, large sections of the Ionian Sea are designated Important Marine Mammal Areas and Areas of Special Importance for cetaceans within the ACCOBAMS region, while the National Marine Park of Zakynthos is also located in these waters. In 2025, the Ionian National Marine Park was declared by the Hellenic government, covering 17,000 km2 in line with the 30x30 target of the Kunming-Montreal Global Biodiversity Framework. In the Aegean Sea, the National Marine Park of Alonnisos is among the largest marine protected areas in the Mediterranean, alongside the newly declared South Aegean National Marine Park and numerous Natura 2000 sites. Despite their conservation status, these areas face persistent pressures from noise-generating human activities, including shipping, aquaculture, bottom trawling, small-scale fisheries and intense summer leisure traffic, while hydrocarbon exploration and offshore renewable energy are expected to expand, with new seismic surveys planned for late 2026. This diversity of noise sources, operating across different temporal scales and frequency bands, complicates soundscape characterization, further challenged by the lack of historical passive acoustic data in Greece and the complex insular geography featuring very deep waters close to the coast. This presentation brings forward a recent collaborative effort in establishing long-term passive acoustic monitoring (PAM) in Greek waters, showing measurement-based comparisons of multiple coastal and offshore sites that highlight the convoluted soundscape of Greek waters. Case studies from the Ionian, Aegean and Levantine Sea show that near-shore areas are subjected to high levels of anthropogenic noise, originating both from offshore and coastal activities, while new PAM deployments in north Aegean Sea are indicative of under-sampled cetacean hotspots. Within this effort, two important activities have also been undertaken: (a) an unsupervised machine-learning approach that uses pretrained neural networks for clustering and automatic isolation of acoustic signals of biological interest in large PAM datasets, and (b) the design and testing of low-cost hydrophones, contributing to the IQOE initiative of the Low-Cost Hydrophone Project "Global Sounds".

On the vertical distribution of ambient acoustic energy in the Fram Strait.

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The periodic formation of sub-surface acoustic ducts is a well-known oceanographic characteristic of Arctic areas like the Beaufort Sea. On the other side of the Arctic, in the eastern Arctic, the acoustic environment is usually characterized by its upward refracting propagation. In this environment, the vertical distribution of acoustic energy in the Fram Strait reveals the variability of ambient noise as a function of depth and sound frequency. The CMRE Environmental Knowledge and Operational Effectiveness program maintains several oceanographic moorings in this area equipped with oceanographic sensors and acoustic recorders. The moorings are part of the NATO Arctic Climate Observatory (NACO). In this paper, NACO data are used to investigate the vertical distribution of the ambient noise field and revealed the formation of temporary sound energy duct-type areas in the thermocline. We study the influence of sea ice concentrations, sea ice drift and distance to the sea ice edge on the vertical distribution of ambient noise. While sea ice drift and concentration show no correlation with ambient sound levels, we find that the distance from the ice edge is negatively correlated to it. The application of range-dependent sound propagation modeling, coupled with CMRE's Pan Arctic Ocean-sea ice model, provides insights into the possible origins of the sound energy and the circumstances for the formation of the sub-surface sound ducts in Fram Strait that control the vertical distribution of ambient noise.

Evolving from Soundscapes to Acoustic Scenes in Ocean Acoustics

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Over the past few decades, the ocean acoustics community has expanded in its thinking from ambient noise as a single pressure value related to the sonar equation to soundscape - characterization of the ambient sound in terms of its spatial, temporal, and frequency attributes and the types of sources contributing to the sound field (ISO Standard 18405, 2017). Recently, the term auditory scene (or acoustic scene) is appearing in the ocean acoustics literature. Auditory scene and auditory scene analysis (ASA) are not new concepts, as they have been part of the terrestrial and human cognition fields since the mid-twentieth century. ASA was first used to organize complex auditory mixtures into meaningful events and streams associated with auditory perception of both music and speech. Early ASA relied on the human ability to segregate acoustic events into different streams, and to selectively attend to the stream of interest. This methodology and concept of decomposing the acoustic environment into streams or elements starts to align with what the ocean acoustics community is presently considering a soundscape. The goal of this presentation is to catalyze discussion on evolving the use of the term acoustic scene in ocean acoustics distinct from the underwater soundscape. We present the idea that ocean acoustic scenes can be identified by unique combinations of key acoustic metrics that are agnostic to time, geographical location, and species-specific sources. This is demonstrated with examples of coral reef and rain acoustic scenes. Defining the unique combination of acoustic metrics for specific underwater acoustic scenes will enable machine learning algorithms to support real time, autonomous detection or identification of defined acoustic scenes without the need to identify individual sources.

Connecting ocean soundscapes to societal needs for our changing ocean

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The ocean is full of sound offering information and insights on marine life presence and behavior, weather and climate, and human activity. This collection of sounds at any given time tells us about a place, rather than tracking one individual source. From the perspective of monitoring a place, ocean soundscapes have provided insights on the conditions over time and recovery of habitats and places throughout our world's oceans. We showcase the NOAA Ocean Noise Reference Station network to illustrate trends in conditions. Further, we synthesise efforts across the ocean soundscape community into a concise list of insights intended for a broader audience to grasp the potential use of ocean soundscapes. Over the past decades, strategic and collaborative initiatives have applied these insights to advance the field of soundscape ecology and inform natural resource management and noise mitigation. Mobilizing ocean soundscapes into a tool for serving broader societal needs will grow from clear communication with broader audiences to generate informed products. We intend for these communication products to help initiate conversations with initiatives such as monitoring biodiversity benefits associated with blue economies, tracking sustainability targets for maritime business, as well as climate objectives for restoring ocean habitats to meet climate goals. By listening to the ocean with purpose and partnership, ocean soundscapes can move beyond observation to become a cornerstone of evidence-based action in a rapidly changing world.

Interpretable Acoustic Classification for Monitoring Marine Mammals in Shipping-Influenced Polar Waters: A Bearded Seal Case Study

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Increasing vessel activity in polar regions is contributing to more complex underwater acoustic conditions, highlighting the need for monitoring tools capable of reliably identifying marine mammal vocalizations. Passive acoustic monitoring provides continuous observations of biological activity, but classification approaches must remain interpretable and effective when only limited labelled data are available. Here, an interpretable feature-based framework is presented as a monitoring tool for marine mammal vocalizations, demonstrated through a subsampled case study of manually extracted bearded seal calls. A curated subset of vocalizations from Arctic passive acoustic recordings was transformed into smoothed spectrograms and processed using contour-aware Canny edge detection to isolate time-frequency structures. Thirty-seven biologically meaningful acoustic features spanning frequency, time-frequency, modulation, geometric, and time-domain properties were extracted to describe call morphology. The resulting feature space supported both exploratory clustering and supervised classification.U-map projections revealed distinct grouping among several call types, indicating that contour-derived descriptors capture meaningful acoustic variability. Supervised models Bagged Trees, a tri-layer neural network, and a Medium Gaussian SVM achieved strong performance, with the SVM providing the most balanced results across categories. Model interpretability assessed through Shapley value analysis highlighted duration- and contour-related metrics as dominant contributors to classification decisions, reinforcing the biological relevance of the selected features. Applied to a subsampled dataset of bearded seal vocalizations, the framework demonstrates how interpretable acoustic features can function as a transparent monitoring tool supporting future passive acoustic monitoring efforts in polar regions experiencing increasing shipping activity.

Synthesising underwater acoustic datasets for noise robust sound event detection

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Underwater recordings in urbanised marine environments are characterised by the presence of high levels of continuous background noise. This noise can originate from human activity, such as wind farms, shipping, fishing activities, from natural sources like currents over hard structures, wind, waves or rainfall, or can come from the measuring instruments themselves. When analysing these soundscapes for distinct sound events (e.g. biological activity, ...), the noise presence negatively affects the detection ability and range. However, dealing with this noise is not trivial and care needs to be taken in its implementation. Pre-processing methods can shift the input data distribution, if preprocessing is not consistently applied in training and inference, the model may receive inputs outside of its trained data distribution, possibly degrading its performance. If one aims to evaluate the performance of sound event detectors including a pre-processing step, having a synthetic dataset with known event presence and different background noise levels is essential. In this work, we introduce an open toolbox that enables users to synthesise recordings made in different noise scenarios, controlling the noise origin and signal-to-noise ratio (SNR). It allows users to synthesise their own dataset of new recordings mixed from existing events and background noises. Using the toolbox, one has control over the number of events in each generated recording, the SNR range, and the sample rate. To isolate events for mixing, we introduce the use of event presence masks. For every event, a binary two-dimensional mask is first calculated, indicating where the event energy is located in a time-frequency representation of the audio. When generating new files using these isolated events, the masks are aggregated, indicating where event energy is present in the synthesised recording. The generated dataset is accompanied by metadata on aggregated masks, SNR, and events classes for each synthesised recording. Furthermore, evaluations of noise reduction in terms of SNR improvement and probability of misdetection are implemented. This allows one to evaluate the noise reduction separately from the event detector, optimising this step in isolation first.

Next-Generation Soundscape Monitoring with Distributed Acoustic Sensing: Insights from the Western Ionian Sea

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Distributed Acoustic Sensing (DAS) is emerging as a powerful tool for wide-scale underwater soundscape observation, enabling fibre-optic cables to operate as dense acoustic arrays that complement traditional hydrophones. Within the VONGOLA project, funded under the PNRR-NextGenerationEU and led by CSFNSM, a DAS interrogator has been connected to two subsea telecom cables offshore Eastern Sicily and operated continuously since January 2025. These fibres are part of the INFN-LNS marine infrastructure extending from the Port of Catania to 2,000 m depth, and from the port of Portopalo di Capo Passero to 3,500 m depth. Real time monitoring with VONGOLA DAS provides unprecedented spatial and temporal resolution for monitoring the acoustic environment of the Western Ionian Sea. The continuous DAS recordings reveal a complex and dynamic soundscape: persistent airgun activity from late May to early September 2025, intense and ongoing shipping noise, recurrent geophonic signals generated by regional seismicity and volcanic structures, and the presence of a fin whale detected in February 2026. These observations highlight both the biological relevance and the anthropogenic pressure characterising this area of the Mediterranean. The combined use of VONGOLA DAS and of cabled hydrophones installed in the same area thanks to the ITINERIS-PNRR and IPANEMA-ECCSEL projects allows DAS calibration. We also report on the development and first results of a machine-learning framework based on a YOLO convolutional neural network, converting DAS time series into spectrograms for efficient classification of earthquakes, ships, fin-whale vocalisations and unknown events. This AI-driven selection supports scalable data reduction and enables continuous soundscape assessment paving the way for real-time monitoring of biological sources with the VONGOLA observatory.

Characterising coastal soundscapes and cetacean presence in Shisiwani National Park (Anjouan, Comoros) using passive acoustic monitoring

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The Comoros Archipelago, located in the northern Mozambique Channel, represents a marine biodiversity hotspot and key region within the Indian Ocean Sanctuary, although its underwater soundscape is still largely unknown. Here, we present a preliminary comprehensive Passive Acoustic Monitoring (PAM) assessment of the coastal soundscape in Shisiwani National Park (Anjouan, Comoros). An autonomous recorder was deployed at ~20 m depth from April 2024 to March 2025, collecting 15,832 recordings (~1,340 hours; ~1 TB) at 128 kHz with a 16% duty cycle (5 min every 25 min). A MATLAB toolbox and custom algorithms were used to determine frequency-domain metrics, including power spectral density (PSD), 1/3-octave band sound pressure levels (SPLs) and long-term spectrograms, in order to describe the frequency distribution and temporal variability of ambient noise. In addition, a manual analysis was conducted on a representative subset (one file per hour, 3,766 files from April to September 2024) to detect and classify cetacean and anthropogenic sounds. Results revealed a highly dynamic acoustic environment characterised by clear diel and seasonal patterns across different frequency bands. The low-frequency bands were dominated by ship noise and natural sounds from the tides and waves. The mid-to-high frequency bands revealed evidence of persistent fish activity and snapping shrimp. Furthermore, manual detection revealed multiple taxonomic cetacean groups, including delphinids and sperm whales (Physeter macrocephalus), and several mysticetes (i.e. Megaptera novaeangliae, Balaenoptera musculus, B. edeni, B. borealis, B. bonaerensis, and Eubalaena australis). Together, these findings provide a preliminary characterisation of the coastal soundscape of Shisiwani National Park and improve our understanding of cetacean distribution and ambient noise levels in the Comoros Archipelago. In this remote and unexplored region of the western Indian Ocean, passive acoustic monitoring represents a powerful tool for assessing biodiversity and anthropogenic disturbance, providing a key baseline for future research, monitoring, and conservation actions.

Coastal soundscape of the Desertas Islands MPA (Madeira Archipelago): a long-term passive acoustic monitoring assessment

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The Desertas Islands represent an important marine protected area (MPA) of the Madeira Archipelago in the Northeast Atlantic. These islands host a highly diverse assemblage of marine fauna, including vulnerable and endangered species, like the Mediterranean monk seal (Monachus monachus). Here, we present the preliminary results of the first long-term passive acoustic monitoring assessment of the coastal soundscape of this MPA. An autonomous recorder was deployed at a shallow coastal site (12-15 m depth) between the 14th of February 2025 and the 12th of January 2026. A total of 15,872 files were successfully collected at a sampling rate of 256 kHz with a 16% duty cycle (5 min on, 25 min off). Over the 11-month period, annual, seasonal, and diel acoustic dynamics emerged. To thoroughly characterize the frequency distribution and temporal variability of the ambient noise, acoustic metrics were computed across a broad frequency range (20 Hz to 128 kHz). Preliminary results reveal a highly dynamic and biologically rich acoustic environment characterized by distinct spectral patterns. The low-frequency bands exhibit some variability likely driven by a dynamic interplay of geophony, primarily wind and wave action, alongside transient anthropophony such as passing vessel traffic. The mid-frequency bands reveal the persistent presence of fish vocalizations. Finally, the high-frequency bands display high values of sound pressure levels more than 100 dB re 1 uPa, an acoustic signature highly indicative of dominant benthic biophony, likely driven by snapping shrimp activity. Building upon these baseline spectral profiles, systematic manual analyses are currently underway on a representative subset of the data to further detect and classify specific sound sources and acoustic events. Together, these preliminary findings provide the first comprehensive acoustic characterization of the Desertas Islands MPA. In this remote and pristine marine ecosystem, passive acoustic monitoring offers a non-invasive method that provides a critical baseline for assessing habitat quality and guiding long-term conservation and management strategies.

Scottish Passive Acoustic Network - First insights into North East Atlantic soundscapes in Scottish waters

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The Scottish Government has run a long-term passive acoustic monitoring (PAM) project since 2023 (Scottish Passive Acoustic Network; SPAN) consisting of an extensive network of PAM devices at 29 locations. The project aims to address critical knowledge gaps on cetacean distribution required to inform offshore wind development, policy, planning and consenting of marine activities and inform Marine Protected Areas identification and management. In addition, gathered data will serve as a basis for characterisation of acoustic environment, with a primary goal being to monitor the impact of human activities, and fulfil statutory responsibilities of reporting ambient noise levels under UKMS and OSPAR. Here we present preliminary results of underwater sound analysis based on data collected in 2024 from a subset of 6 locations, covering different types of environments varying in depth, sea bottom substrate, intensity of anthropogenic activity, including from offshore wind developments and expected marine mammal presence. Acoustic data were collected using underwater sound recorders on 10 mins on/20 mins off duty cycle and sampling rate of 96 kHz. To investigate site-specific acoustic characteristics, sound pressure level (SPL) at 1/3 octave bands between 10 Hz - 16 kHz were calculated using PAMGuide. Monthly and yearly SPLs were calculated at each site at 63,125, 250 and 500 Hz frequency. Additionally, broadband sound levels for three frequency bands: 20-160 Hz, 0.2 - 1.6 kHz and 2-10 kHz were calculated. To consider the influence of offshore wind development and other natural and anthropogenic sources on the calculated sound levels, current and wind speed data were derived from Copernicus Marine Database, information on impulsive noise emissions in proximity (ca 50 km) to monitored locations were derived from the UK Marine Noise Registry, and monthly average vessel density maps extracted from EMODNet. To account for biological activity and marine mammal presence the click, whistle and moan detectors in PAMGuard software was used. This data analysis enables characterisation of soundscapes at different locations around Scotland, highlighting differences in broadband sound levels and their potential links to variability in underwater environmental and biological activity and anthropogenic contributors, including offshore wind development, to ambient sound levels. It also provides vital analysis to support understanding of underwater noise for UKMS purposes.

InciteShip - Open Source Measurement And Incentive System For Mitigation Of Ship Underwater Noise

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Despite long-standing concern about the environmental impacts of underwater noise from shipping, emissions from individual vessels and the effectiveness of mitigation measures remain insufficiently understood. In recent years, opportunistic measurement stations have been established to collect underwater radiated noise (URN) signatures at scale and link them to noise-reduction incentives, for example through the ECHO, MARS, and PIAQUO initiatives. Building on these efforts, the InciteShip project develops an open-source measurement and incentive system for ship URN. This contribution describes the InciteShip framework and presents results from its first year of data collection. The InciteShip opportunistic measurement approach is inspired by ISO 17208-3 for shallow-water (<40 m) URN measurements. An incentive score is derived from measured noise levels by calculating radiated noise levels and then applying auditory weighting functions representing marine mammals, fish, and invertebrates. The resulting weighted source levels are compared with vessel-class statistics to generate an overall performance score. Such a score can be used to create financial incentives for URN reduction. The technical system is based on affordable, battery- and solar-powered electronics housed in a marine buoy. Three bottom-mounted hydrophones measure ship noise spectra, which are transmitted via 4G to a land-based station where URN signatures are computed and stored in a database. Data are made available to ship owners upon request. Two buoys were deployed from May to September 2025 along the main shipping lanes to the Swedish ports of Gothenburg and Södertälje. Measurement accuracy and repeatability are evaluated through comparisons with dedicated measurements and cross-system assessments. We also present a custom dashboard for data validation and analysis, illustrated using data from more than 3,300 vessel passages recorded in 2025.

Measuring Underwater Noise from transiting Crew Transfer Vessels in the German Bight

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Underwater sound recordings from a monitoring station near Helgoland, Germany, were analyzed to investigate the noise emissions of crew transfer vessels (CTVs) transiting to offshore wind farms. Source levels of 13 individual CTVs were estimated from opportunistic vessel passages using the Smoothed Semi-Coherent Image (SSCI) method, including frequency-dependent absorption. Statistical analysis indicated that most of the observed variability in source levels is attributable to differences between individual vessels. The limited number of observations and the relatively small variation in transit speeds did not allow robust relationships with operational parameters such as speed or vessel length to be established. Nevertheless, the overall spread in source levels was relatively small, suggesting that the derived spectra provide representative average source levels for transiting CTVs that can inform future noise modelling. Despite their comparatively small size, CTVs were found to produce source levels comparable to those of much larger cargo vessels. In addition to presenting the results of this study, the talk will highlight the detection of repeated ultrasonic signals spanning roughly 20-40 kHz observed during several CTV passages. Follow-up investigation suggests that these signals are consistent with acoustic antifouling systems installed on some service vessels. These observations raise questions about the contribution of onboard auxiliary acoustic devices to measured vessel noise spectra and their implications for underwater noise monitoring.

Co-benefits and trade-offs between URN reduction and energy efficiency of ships

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Ships have to comply with regulations concerning the emissions to the air, such as the Energy Efficiency Design Index (EEDI) and the Carbon Intensity Indicator (CII). There are no regulations concerning URN yet, but it is very likely that they will come in the near future. Those will force ship designers, builders, and operators to make shipping quieter. There are several ways to mitigate URN of a ship. Some of them have a positive effect on the energy efficiency of ships, while others lead to a lower energy efficiency. Finding the right balance between these effects is important; the URN should be sufficiently reduced while maintaining the required energy efficiency, economic results, and the transit times of the ship. Various technical and operational approaches will be presented and discussed.

LOWNOISER contributions to Underwater Radiated Noise (URN) mitigation

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Underwater radiated noise (URN) from commercial shipping is a pervasive anthropogenic stressor that disrupts key biological functions in marine species. The EU funded LOWNOISER project addresses this challenge through the development, modelling and evaluation of scalable technologies and methodologies aimed at reducing shipping related URN. Validation activities are supported by six full scale demonstrators, including the Havila Capella and HX Fridtjof Nansen cruise ships and the Montesperanza tanker. This presentation first introduces recent scientific advances in the numerical tools supporting the project. In particular, the PIANO model has been extended to incorporate two major contributors to URN: (i) gearbox induced tonal and broadband noise, represented through enhanced vibro acoustic source modelling, and (ii) air lubrication related modifications to hull-water acoustic interactions through a new specific module. Further, the engine model has been improved for 4-stroke engines and extended to include a response function for the engine mounts according to their physical characteristics. Finally, including the effect of performance degradation and environmental condition has been explored too. These developments improve the predictive capability of PIANO for design and retrofit assessments as well as operational scenario evaluations. The second focus concerns on the hydrodynamic and acoustic behaviour of Air Lubrication Systems (ALS). Results from analytical models and controlled model scale experiments are presented to characterise how bubble layer properties influence noise generation mechanisms, boundary layer dynamics, and acoustic radiation efficiency. The combined approach enables quantitative estimates of ALS induced URN variations across the relevant frequency range and provides guidance on operational and design parameters. Finally, computational evaluations of low noise bevel gear configurations are presented. High fidelity simulations quantify reductions in structure borne excitation transmitted through the propulsion system and demonstrate significant potential for mitigating tonal components associated with gear meshing harmonics, thereby addressing a critical source of machinery induced URN. Together, these results illustrate how LOWNOISER is advancing both scientific understanding and practical solutions to support the maritime industry in meeting future URN performance requirements and in contributing to healthier ocean soundscapes.

Benefits of using VFD for Diesel-Electric Ferries

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This paper analyzes the environmental and operational advantages achieved by integrating Variable Frequency Drives (VFDs) into the main propulsion power of ferry vessels operating in West coast Canada. Conventional fixed-speed AC motor with Controllable Pitch Propeller (CPP) system has a limited optimum operational condition which causes operational difficulties in the off-design conditions, leading to excessive energy consumption, more greenhouse gas (GHG) emissions and cavitation which causes blade erosions and underwater radiated noise (URN). The application of VFD technology allows for optimized propeller loading based on the control of motor speed and propeller pitch throughout the entire operation ranges which bring the environmental and operational benefits. This study analyzes the effects of the new propulsion system on fuel consumption, internal structural vibration and URN levels across various operational profiles. The paper concludes that VFD technology with CPP is a crucial and cost-effective component of modern marine electrification and decarbonization strategies, offering direct environmental benefits and enhancing the reliability of the operation and overall sustainability of ferry operation.

PONANT cruise line management of underwater noise

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PONANT is a leading cruise company committed to minimizing its impact on the marine environment. A key focus of this commitment is the reduction of underwater radiated noise (URN), which can significantly affect marine ecosystems. To address this challenge, PONANT has implemented several concrete measures. The company has invested in advanced propulsion technologies, including electric systems, which substantially reduce noise levels compared to conventional engines. In parallel, onboard underwater noise monitoring systems have been deployed to continuously assess acoustic emissions and adapt operations when necessary. PONANT also collaborates with leading scientific organizations to better understand the impact of underwater noise on marine life. These partnerships have enabled the development of operational guidelines, particularly in sensitive areas, and the implementation of best practices such as reducing engine use during wildlife observation. Reducing URN not only contributes to the protection of marine biodiversity but also enhances the overall guest experience by creating a quieter and more immersive environment. The URN notation awarded to Le Jacques-Cartier by Bureau Veritas highlights PONANT's leadership in this field and its commitment to sustainable tourism. It reflects a broader ambition to reduce the environmental footprint of operations while maintaining high standards of service. Through these initiatives, PONANT sets a benchmark for the cruise industry and demonstrates that environmental responsibility and operational excellence can go hand in hand.

Characterization of the Sound Levels at the PLOCAN Test Site

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In spite of the importance that has been given to ocean sound in recent years, there is still a lot to know about the mechanisms of communication and the use of sound in marine species, and how anthropogenic sound affects them. One of the important contributors to anthropogenic sound is wind farms, which are planned to be deployed in our waters in the coming years. Following the European Union guidelines to measure and understand the effect of ocean sound in the marine environment, this work intends to quantify the baseline of sound level at the PLOCAN test site in the absence of wind generators, and the sound level when a fixed wind generator is in operation, in order to characterize the sound levels of the PLOCAN test site under both conditions. To achieve our goal two datasets of acoustic recordings at the PLOCAN test site were used: 1-With the wind generator turned on from Jul 30 to Aug 19, 2022. 2- With the wind generator turned off from May 8 to June 5, 2024. The two datasets were analyzed with a custom Matlab software developed at PLOCAN for this purpose, which generates the following metrics: Sound pressure Level, (Lp), Equivalent Level (Leq), Peak level (Lpeak), L1 (99th), L5 (95th), L10 (90th), L50 (50th), 90 (10th) and L95 (5th) percentiles, for the original sound signal, the broadband (filtered from 20 Hz to 20 KHz) and one-third-octave band signals from 20 Hz to 20 KHz. Also, the power spectra and Power Spectral Density (PSD) in one-third- octave bands were created and analyzed. The results show that the operation of the wind generator increases the sound level of the full-band, broadband and one-third-octave band signals at 63 Hz and 125 Hz. Also, the power spectral density revealed that the wind generator created a low frequency signature with peaks at 50 Hz, 125 Hz, and 200 Hz which were 12,78, 7,29 and 3,44 dBs respectively above the baseline sound. These three values are statistically significant, and reveal a dominant low frequency source with high ecological relevance below 125 Hz.

Listening Beneath the Waves: southern elephant seal drift dives reveal the Southern Ocean soundscape

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The soundscape defines the acoustic environment animals live in, shaping key aspects of their behavior and communication. Measuring the underwater soundscape is crucial for characterizing these environments, yet current mon-itoring efforts often rely on stationary recorders with limited spatial coverage. The Southern Ocean remains poorly sampled acoustically due to its remote-ness and harsh conditions. Here we explore the use of deep-diving southern elephant seals (Mirounga leonina) as mobile passive acoustic monitors of this environment. To do so, we analyzed acoustic data collected by long term sound recording tags deployed on ten southern elephant seals, focusing spe-cifically on drift dives, periods when the animals are nearly motionless and silent. Our third-octave band analysis of the audio extracted from these drift phases reveals persistent low levels of ambient noise, with occasional distinct acoustic events from biological or environmental sources. These results demonstrate that elephant seals can function as natural, low-cost autonomous underwater vehicles (AUVs), significantly enhancing our ability to moni-tor vast underwater soundscapes in remote oceanic regions.

Assessment of underwater noise levels generated by natural acoustic sources

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The ocean's acoustic footprint is a pressure that shapes key ecological processes; therefore, underwater noise has become a core monitoring component of Marine Strategies through Descriptor 11. Within the LIFE IP INTEMARES project, we present an action aimed at establishing reference values for Good Environmental Status in relation to underwater noise in Canary Islands waters. We started from a very specific question: what does a low human-influence area sound like? To address this, baseline ambient noise was characterised by mooring hydrophones in areas with low occurrence of anthropogenic activities. Two moorings were designed and deployed to collect acoustic recordings in two parts of the archipelago: the ZEC ES7020124 Costa de Garafía (La Palma) and the LIC ESZZ15002 Marine Area of eastern and southern Lanzarote-Fuerteventura. In Garafía, a hydrophone was deployed at 35 m depth, yielding continuous recordings representative of spring, summer, autumn and winter 2024. In Lanzarote-Fuerteventura, the hydrophone was deployed at 41 m, and data were collected for spring and autumn. The analysis followed the framework of the MSFD/Spanish Law 41/2010 and the criteria set out in Commission Decision (EU) 2017/848, assessing sound pressure levels (SPL) and their temporal and spectral variability. The results reveal contrasting patterns between areas. At Costa de Garafía, a marked and progressive increase in noise from spring to autumn is observed across all bands, peaking in autumn, when SPL values of 9.8 dB re 1 uPa were recorded. This points to a seasonal intensification of the soundscape, potentially associated with increased maritime activity (fishing and/or recreational) towards the end of the year. In Lanzarote-Fuerteventura, low-frequency bands (63-125 Hz) remain stable with a slight decrease in autumn, whereas high-frequency bands (8-16 kHz) increase in autumn, rising from 96.9 dB re 1 uPa in spring to 104.5 dB re 1 uPa. At both sites, elevated levels were detected in the high-frequency range (8-16 kHz) compared to what would be expected for areas under low anthropogenic pressure, suggesting the need to further investigate source attribution and the role of local conditions. Overall, this work provides seasonal acoustic time series and a first approximation to reference levels for underwater noise, strengthening D11 monitoring and providing a technical basis to design evidence-based management measures.

Spatio-temporal analysis of underwater soundscapes in French Polynesia: Integration of Biosound software and Artificial Intelligence

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French Polynesia, with its vast Exclusive Economic Zone (EEZ), represents a sanctuary of marine biodiversity unique in the world. However, the acoustic characterization of these ecosystems on a regional scale remains fragmentary. As part of a major project (OCEANWATCH) led by the Oceania Association, this study provides a comparative, multi-site analysis of soundscapes across four Polynesian archipelagos, aiming to document the acoustic health of these environments and the presence of marine megafauna. The dataset is based on continuous recordings from six underwater acoustic datalogger deployed from January 17 to July 3, 2025. These stations were strategically positioned around five islands representative of five distinct archipelagos, covering a diversity of habitats including islands with barrier reefs, islands without barrier reefs, and atolls. The processing of this large volume of data relies on a hybrid approach: the Biosound software, which provides qualitative analysis through the creation of spectrograms across all time scales, and a quantitative analysis through the extraction of sound pressure levels and various eco-acoustic indices to characterize ambient noise dynamics (biophony, geophony and anthropophony). Additionally, Artificial Intelligence analysis enables the precise detection and classification of delphinid vocalizations, revealing visitation patterns and the acoustic behaviors of local populations. Initial results highlight a marked heterogeneity in soundscapes across the archipelagos, influenced by reef structure and levels of anthropogenic activity. The combined use of Biosound and AI detectors makes it possible to isolate specific soundscapes and correlate the presence of dolphins with the environmental characteristics of each site. This work demonstrates the effectiveness of automated processing tools for large-scale environmental monitoring. The data collected constitutes an unprecedented acoustic baseline for French Polynesia, which is essential for cetacean conservation and sustainable management of marine resources in the face of growing anthropogenic pressures in the South Pacific.

Acoustic Characteristics of Sciaenid Fish Choruses and the Influence of Water Temperature in Korean Coastal Waters

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The ocean soundscape is an important ecological indicator reflecting complex interactions among geophony, biophony, and anthropophony. Within this framework, fish-produced biological sounds that are recorded using passive acoustic monitoring (PAM) are increasingly used to infer biodiversity, behavior, and ecosystem condition. This study characterizes the acoustic patterns of the Small Yellow Croaker (Larimichthys polyactis) and the Brown Croaker (Miichthys miiuy) in Korean coastal waters. Both species are sciaenid croakers that produce courtship sounds by vibrating their swim bladders. The acoustic characteristics of both species were quantified in terms of frequency band and temporal variability using continuously collected sounds from offshore cage farms during the spawning season. Both species showed distinct diel patterns with predominantly nocturnal activity, whereas chorus duration markedly differed between species. Brown Croaker choruses were mainly concentrated from sunset to pre-midnight, whereas Small Yellow Croaker vocalizations persisted throughout the night. Comparison of water temperature variability with calling metrics further indicated that vocal activity occurred within a limited thermal window and sharply declined outside this range, suggesting that temperature may serve as an important environmental cue for reproductive timing. These results provide baseline acoustic descriptors for ecologically and commercially important sciaenids in Korea and support soundscape-based ecological monitoring.

Tidal Forcing of Underwater Noise: Insights from Ieodo Ocean Research Station

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This study investigates the correlation between sea-level fluctuations and low-frequency underwater noise using long-term acoustic data collected at the Ieodo Ocean Research Station (IORS) from 15 May to 27 August 2013. In dynamic macrotidal environments like the East China Sea, understanding the interaction between physical oceanographic processes and the underwater soundscape is crucial for baseline acoustic monitoring. Our analysis reveals that temporal variations in the overall level of underwater noise are closely synchronized with sea-level changes. A significant contrast in noise levels was observed between tidal cycles: average noise levels below 50 Hz ranged from 99.0-106.6 dB during spring tides, whereas they dropped to 78.4-90.2 dB during neap tides, representing a substantial difference of up to 20.6 dB. When a 6-hour low-pass filter was applied to the absolute values of sea level, a high correlation coefficient of 0.7 was obtained, with the strongest correlation (0.71) occurring around the 16 Hz frequency band. This suggests that the observed acoustic signatures are primarily driven by flow-induced noise from tidal currents. Wavelet transform analysis identified strong periodicities at 0.25, 0.50, and 1.0 days, consistent with major tidal constituents. Specifically, wavelet coherence analysis at the 0.25-day period revealed a 90-degree phase lead (approximately 1.5 hours) of the noise level relative to the sea-level peak. This phase shift demonstrates that the noise level reaches its maximum during periods of peak tidal current velocity rather than at high or low tide, a finding further validated by correlation analysis with various time lags. Furthermore, the noise generated by ebb currents was consistently higher than that of flood currents, likely due to the local asymmetry in tidal flow speed at the station. These results emphasize that tidal dynamics are a dominant factor modulating the low-frequency soundscape at IORS, providing essential insights for distinguishing natural flow noise from anthropogenic sources in high-energy coastal environments.

Evaluation of technologies for mitigation of the acoustic impacts from underwater unexploded ordnance clearance operations

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Unexploded ordnance (UXO) remaining in coastal and offshore regions continues to challenge the expansion of marine infrastructure, particularly in areas historically impacted by military activity. Conventional clearance relies on high order explosive techniques that generate intense shock fronts and extreme underwater sound fields, often strong enough to harm marine fauna and disturb the seabed environment. In response to growing ecological concerns, a range of alternative disposal and noise mitigation approaches has emerged. This contribution presents findings from a combined programme of controlled quarry tests and full scale field trials carried out in the Danish Baltic, examining the performance of traditional high-order and alternate low order deflagration methodologies and physical noise reduction barriers such as bubble curtains. Acoustic measurements and environmental indicators were used to evaluate differences in sound levels, potential impact ranges, and overall disturbance footprints for representative marine species. Results show that low order methods can reduce both peak sound pressure and cumulative sound exposure by roughly 10-20 dB relative to comparable high order detonations, with the possibility of achieving even greater reductions depending on charge mass and site conditions. The outcomes highlight the growing viability of non traditional clearance approaches as effective tools for reducing environmental impact during UXO clearance operations.

Assessment and remediation of UXO impacts on marine mammals in the Southern North Sea

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To support and advise on the management of the environmental impact of clearing unexploded ordnance (UXO) in the Southern North Sea, TNO is carrying out several studies to improve the prediction of the impact of detonations and understand the effectiveness of mitigation measures. Models that predict the effect of detonations on anthropogenic underwater noise are being developed and validated in different environments to improve predictions of noise radiated in shallow water environments for a wide range of explosive types Using data from historical clearance efforts, such models can be used to: (a) estimate the acoustic impact that detonations and alternative clearance methods (e.g. deflagration) have on marine mammal species, and (b) predict the effect of UXO clearance on future offshore wind farm developments. We discuss further steps that can be taken to better understand the acoustic impact of deflagration compared to that of detonation, the effectiveness of potential mitigation measures, as well as current knowledge gaps.

Underwater Noise Reduction from Explosive Sources Using Tunable Acoustic Resonators: Laboratory and Field Measurements

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Controlled detonation of unexploded ordnance (UXO) during offshore wind farm site preparation produces high-amplitude impulsive underwater noise that poses risks to marine life. Effective noise abatement for such events remains an open challenge. This paper presents results from two experimental investigations of a noise abatement system (NAS) based on arrays of tunable acoustic resonators for mitigating noise from underwater explosions and combustions. The NAS consists of modular injection-molded resonator blocks, each containing multiple open-bottom cavities that trap air when submerged. The individual cavity geometry, trapped air volume, and deployment depth determine the resonance frequency of each cavity, allowing the system to be tuned to target specific frequency bands. The collective acoustic behavior of the assembled resonator array is also considered, as it affects the broadband behavior of the system beyond the individual cavity resonance frequency. Two complementary experiments are discussed. First, laboratory measurements were conducted in a large test tank using a combustive sound source (CSS) to simulate UXO-generated noise. The CSS was surrounded by arrays of encapsulated-bubble resonators at varying void fractions, and peak reductions approaching 50 dB were observed near the resonance frequency of the resonators. Second, a field demonstration was conducted during the explosive demolition of piers E9 and E10 of the San Francisco-Oakland Bay Bridge. In this test, the NAS was deployed around a receiver array rather than the source, providing a direct measurement of the system's insertion loss under real-world conditions with actual demolition blasts. The NAS achieved a sound exposure level (SEL) reduction of 14 dB within its 75 Hz to 2 kHz operational band, with maximum one-third-octave band reductions of approximately 30 dB. Together, these results provide strong evidence for the viability of resonator-based systems for mitigating explosive underwater noise. Implications for UXO noise abatement, system design considerations for source-enclosing deployments, applications to other impulsive underwater sound such as air guns, and ongoing development toward operational readiness will be discussed.

SALIENT - Investigating alternative UXO Clearance methods in the Netherlands

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The southern North Sea contains large quantities of unexploded ordnance (UXO), remnants of the First and Second World Wars. In the Netherlands, the Royal Netherlands Navy (RNLN) is responsible for their removal, which is currently carried out primarily through controlled detonation. However, the resulting underwater explosions pose significant risks to marine life, particularly harbour porpoises, which are highly sensitive to underwater noise and are commonly found in the region. Although mitigation measures have been introduced to reduce these impacts, substantial effects on marine ecosystems persist, especially when dealing with large aerial bombs and naval mines. In this talk we introduce the national research program SALIENT (Safe And Low Impact Explosives Neutralization Technology) that is aimed at developing knowledge on alternative underwater explosive clearance methods for the RNLN to reduce the impact of UXO clearance on the environment. The SALIENT program spans four years and focuses on addressing key knowledge gaps while advancing practical solutions for operational deployment by the RNLN. In 2025, the first year of the program, we inventoried existing knowledge, performed a gap analysis, and developed models to analyze how these methods functioned under varying environmental conditions. Experiments, conducted in both controlled bunker settings and harbour environments, examined the performance of selected clearance methods and optimized their effectiveness against different types of explosives.

Introducing the Sonar session with some examples of the 3S project (Sea mammals and Sonar Safety)

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For the sonar session I will demonstrate some developments with the Sea mammals and Sonar Safety (3S) project as an example. 3S is an international research consortium studying how naval sonar affects cetaceans. Since 2006 we have deployed 305 tags to 6 species and conducted 169 controlled sonar exposure experiments and published 80 peer-reviewed papers on effects of sonar on marine life. Initially the focus was to establish dose-response relationships to estimate the number of animals disturbed. Later we addressed specific questions like what is the effect of ramp-up, and what are the main drivers of responses (SPL/SEL or range to the source). The ongoing fourth phase of the project (3S4) started in 2023 and has the aim to investigate whether exposure to Continuous Active Sonar (CAS) leads to different types or severity of behavioral responses than exposure to traditional Pulsed Active Sonar (PAS) signals. We also aim to investigate how well responses from short duration experiments predict responses from longer duration exposures. We collected data during three sea trials off the coast of Norway in October 2023, 2024 and 2025 to address these research questions. The experimental design of the controlled exposure experiments was to use real-time GPS location data of multiple tagged subjects and move the sonar source vessel to achieve repeated dose escalation CAS and PAS exposures to killer and humpback whales over 8 hrs. Ongoing analyses will test for sensitization or habituation during these extended sonar exposures, as well as compare behavioral responses during CAS and PAS, and the potential for CAS signals to mask whale communication. For the introduction of the sonar session some developments in time will be flagged, like the improved tagging technology and changing research questions.

The Atlantic Behavioral Response Study (BRS): An interdisciplinary research program to measure the behavioral responses of deep-diving cetaceans to military sonar

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Cetaceans rely on sound for vital life functions. Human sources of noise can negatively affect these functions, especially in particularly sensitive species, such as beaked whales. This talk will consider the progression and extensive progress made in applied studies designed to address the effects of one specific source of noise, military sonar, including a long-term, adaptive research program conducted off Cape Hatteras, NC. The focal species of our work is the goose-beaked whale (Ziphius cavirostris), given its involvement in past sonar-related stranding events. Initial efforts, supported by the U.S. Navy, began with visual and aerial surveys, passive acoustic monitoring, and tagging to characterize the occurrence, site-fidelity, and baseline behavior in this biologically-important area. More than a dozen publications resulted from this initial work. Following establishment of this baseline, our effort pivoted to a series of behavioral response studies. First, we conducted 13 controlled exposure experimental trials (CEEs) with 53 tagged beaked whales using a simulated mid-frequency active sonar (MFAS) source that produced pulsed MFAS signals similar to those used in operational Navy systems. During these trials tagged whales demonstrated clear but short-lived changes in diving behavior and moved away from the sound source. Next, we coordinated directly with eight U.S. Navy guided missile destroyers to examine the response of an additional 30 tagged Ziphius to real MFAS signals. The behavioral response to these operational sonars was similar in nature and magnitude to the response to simulated signals, although range between the sound source and tagged whales was much greater due the higher power of real MFAS systems. In both experiments, whales resumed normal behavior within 1-2 days of exposure. Finally, we are currently examining the behavioral response of goose-beaked whales to a relatively new MFAS sonar system that uses continuous rather than intermittent signals during transmissions. The objective, using in situ propagation modeling given animal and source locations, is to exposure animals to similar total received sound energy levels accounting for temporal differences between pulsed and continuous MFAS exposures. This final phase of the program is ongoing, and we will compare the results of this work with that of the prior two experiments using both sound pressure and sound energy, providing new insights from these novel studies.

Estimating the exposure levels of goose-beaked whales to sonar using multiple modeling modes in a behavioral response study

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Marine mammals are known to respond to various human noises, including, and, in certain cases strongly, to military active sonar. Responses include small and short-term changes in diving behavior, horizontal avoidance, and mass strandings. Considerable research has been conducted using short-term biologging tags to understand these responses. Yet researchers and managers want a better understanding of responses to sound over longer periods of time in a variety of contexts. The Atlantic Behavioral Response Study examines responses across multiple spatial and temporal scales using vessel-based focal follows, short-term biologging tags, and medium-term satellite transmitting tags. Since the latter do not record sound, we must intersect positions with a sound propagation model to estimate received sound pressure levels (SPL), which is critical to linking exposure to animal responses; to do this we integrate movement modeling with sound propagation models across multiple uncertain data streams. We developed a workflow that assimilates five data sources: Argos positions, focal follow vessel GPS, tag depth bins, ocean bathymetry, and a high-resolution sound propagation model to estimate received SPL for 16 satellite-tagged Ziphius cavirostris during four controlled exposure experiments off Cape Hatteras, NC. Ancillary data from focal follow vessels (goniometer bearings, fluke-print GPS fixes) and a bathymetry-based rejection sampler substantially improved 3D positional estimates, reducing the 95% credible interval of estimated SPL by up to 10 dB compared to using Argos data alone. Modeled SPL estimates agreed well with in situ measurements, i.e., within an average of 3 dB of surface and bottom measurements and all tag-borne measured values fell within the 95% credible intervals of the model estimates. This generalizable workflow enables researchers to rigorously estimate the range of noise exposure conditions experienced by animals carrying non-acoustic satellite tags, improving the precision of exposure-response functions needed for regulatory applications and protected species management. Ongoing and future applications include i) intersecting this workflow with the Kinéis data; ii) using modeled dive data from high resolution tags to improve understanding of baseline behavior; iii) contribute to evaluation of efficacy of different propagation modeling approaches; and iv) application to signals with very different waveforms (e.g., continuous active sonar).

Modelling the masking potential of continuous active sonar on killer whale communication

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Novel naval sonar systems are being introduced that can continuously transmit sonar sound, typically at lower source levels than classical pulsed sonar. Active naval sonar in the 1-10 kHz frequency band overlaps with frequencies that are also commonly used by social marine mammal species, such as killer whales, for communication. The 3S4 study carried out controlled exposure experiments to understand the effects of continuous active sonar on killer whales. To evaluate the masking potential of the sonar signals used during these experiments, a masking model is developed that predicts masking conditions of broadband killer whale communication calls under various sonar exposure conditions. The masking model is derived from masking measurements on trained killer whales exposed to continuous sonar sounds (Branstetter et al. 2024), and accounts for the contributions of spatial masking release. We present the estimated communication distances for killer whale communication masked by continuous and pulsed 1-2 kHz active sonar and highlight knowledge gaps.

A Comparative Study of Cumulative Impact Assessments of Naval Sonar

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Naval use of sonar can disrupt marine mammal behavior, communication, and habitat use, raising concerns about long-term ecological impacts. We compare two approaches to assessing these risks: the OSPAR common indicator method for impulsive sound and a TNO-developed framework to quantify the cumulative sonar footprint of the Royal Netherlands Navy's sonar operations. The comparison highlights differences in data sources, resolution, and biological modeling. The OSPAR method relies on unclassified, aggregated data from the Impulsive Noise Registry (INR) to estimate disturbance risk across broad spatial-temporal scales. It uses coarse spatial units (~20 km ICES grid blocks) and daily counts of noise events (Pulse Block Days), typically focusing on a key indicator species (e.g. harbour porpoise in the North Sea) as a proxy for sensitivity. Disturbance is modeled with simplified criteria, for example, assuming all porpoises within a fixed radius (~20 km for sonar) are disturbed, and produces risk maps and exposure indices, but without explicit acoustic propagation or individual dose-response modeling. In contrast, TNO's framework also includes classified naval sonar data (detailed source logs) and integrates it with high-resolution acoustic propagation modeling. It computes sound exposure fields using tools like BELLHOP, then applies species-specific dose-response functions to estimate the probability of disturbance for marine mammals. This approach yields finer-grained sonar footprint maps of disturbance days, accounting for the spatial-temporal overlap of naval sonar activity with marine mammal distributions. Both methods accumulate disturbance on a daily timescale and overlay results with species density data to quantify affected animals or areas. We discuss differences in the two approaches using detailed information on sonar transmissions during 3S controlled exposures studies in 2025. We discuss how these frameworks could be extended to evaluate longer-duration disturbances, including potential applications of bioenergetic and Population Consequences of Disturbance (PCoD) modeling. While this work is ongoing, such extensions may offer a pathway to better understand how repeated disturbances could influence individual fitness and population dynamics over time. This comparison provides important insights for regulators and naval stakeholders in mitigating the impacts of impulsive noise on marine mammal populations.

Les leçons de Ziphia, A Case Study to Better Protect Marine Mammals from Anthropogenic Noise in the French Exclusive Economic Zone

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On February 2, 2021, a Cuvier's beaked whale (Ziphius cavirostris) stranded on Ile de Ré (Northeast Atlantic, France). Preliminary analyses suggested that the animal's death was likely caused by anthropogenic noise produced by a military vessel conducting tests within a marine protected area. This event marked the beginning of an investigation into the origins of the incident and highlighted the complexity of the relationship between ocean life and human activities. It also served as a foundation for a broader collaborative reflection, integrating various disciplines to rethink ocean knowledge production, the legal frameworks regulating marine space use and protection, and our anthropological relationship with the ocean. Understanding the impact of noise on the ocean requires a holistic approach that embraces its complexity. Anthropogenic noise disrupts organisms at all trophic levels. Its propagation over long distances and the multiplicity of affected habitats make it difficult to document its effects, whether immediate or long-term. When Navy-funded oceanographers developed acoustic tomography techniques, they did not consider their impacts on cetaceans, other organisms and societies: "protecting the environment" was not part of their mission, and the military culture of secrecy prevented any collaboration. Ziphia's death illustrates the current inability of various actors of our society to embrace the complexity of the oceanic environment. By progressively articulating the diversity of approaches to develop new ways to frame problems and discover solutions, our working group moves forward in understanding this complexity. It seems necessary to support the different communities interacting with the Ocean so that the diversity of sensitivities to the oceanic environment evolves into a complementarity of perspectives, knowledge, skills, and resources: this is what the Objectif Océan programme strives to achieve. If we revise our priorities, focusing on the long term and our responsibility to safeguard what sustains life, we will be able to pass on an Ocean that is both alive and sustainable, far beyond the symbol of the whale. Through our interdisciplinary collaborative approach, which actively engaged the primary defense stakeholder, concrete progress has been achieved: testing procedures have been revised to prevent similar consequences from occurring in the future.

Underwater noise depth dependency in high tidal environment (Gran Canaria, Atlantic Ocean)

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Within the PURE WIND project, ambient sea noise measurements were conducted at the PLOCAN test area off the eastern coast of Gran Canaria (Atlantic Ocean). A multichannel autonomous recorder (JASCO AMAR-G4) equipped with omnidirectional calibrated hydrophones was deployed on a 40 m deep sandy seabed under nearly iso-velocity sound propagation conditions. Acoustic data in the 20 Hz-20 kHz band were collected continuously over 37 days (8 May - 13 June 2024), covering multiple semi-diurnal tidal cycles with a tidal range up to 2.3 m. Depth-dependent noise variability was assessed by comparing measurements from a near-bottom hydrophone (5 m above the seabed) and a subsurface hydrophone (15 m below the surface). The most pronounced differences, reaching +10 dB at the bottom relative to the subsurface sensor, occurred during ebb tide and coincided with full-moon conditions. Analysis of archived ADCP dataset shows that current velocities tend to peak during flood tide, with a delay of up to 2 hours for most cases, and reach minima during ebb tide. Enhanced near-bottom shear during specific phases may promote bedload transport of fine sand, increasing noise levels at the deeper hydrophone. Depth-dependent noise sources within the water column may also explain the observed differences. Demersal fish, benthic invertebrates, and other organisms often produce sounds concentrated near the seabed, where their calls experience less geometric spreading and weaker attenuation. The full-moon period may further intensify such biological activity and biomass aggregation near the seabed, contributing additional biophonic noise. Moreover, the vertical structure of the sound field in shallow, well-mixed waters can create pressure maxima close to the bottom due to constructive interference between direct and bottom-reflected paths. These propagation effects, combined with the proximity of the bottom hydrophone to biologically and physically active layers, can enhance recorded levels independently of current speed or sediment motion.

How Sampling Strategy Shapes Marine Soundscape Characterization: Insights from Dual Hydrophone Monitoring at the W1M3A Observatory

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Understanding how different acoustic sampling strategies influence the characterization of marine soundscapes is essential for robust long-term monitoring. Within the PUREWIND and AQUARIUS projects, we analyzed a unique dataset collected at the W1M3A observatory in the Ligurian Sea, where two complementary acoustic streams were recorded: broadband, high-sensitivity measurements from a RESON TC4032 hydrophone sampled for 30 seconds every 10 minutes, and long-duration recordings from an AURAL M3 autonomous recorder acquiring 10-minute segments every hour. This dual-sensor configuration provides an opportunity to evaluate how temporal resolution, duty cycle, and sensor characteristics affect the statistical description of underwater soundscapes. Spectral, temporal, and statistical indicators across the two datasets were examined, focusing on their ability to capture key acoustic processes such as commercial shipping, small-vessel activity, wind-driven noise, rainfall events, and marine mammal vocalizations. Differences in sampling schedules resulted in distinct sensitivities to transient versus persistent sources: the RESON TC4032 stream, with its higher temporal granularity, captured short-lived events and rapid fluctuations in ambient noise, while the AURAL M3 provided more stable estimates of hourly and diel patterns. Despite these differences, both datasets consistently identified major soundscape drivers, though with varying levels of detail and statistical robustness. Results highlight how duty-cycled acoustic monitoring can still provide meaningful ecological and anthropogenic indicators, but also demonstrate the importance of understanding sampling biases when interpreting soundscape metrics. This comparative analysis offers insights for the design of future monitoring programs under MSFD and for the integration of heterogeneous acoustic datasets in large-scale assessments of underwater noise.

Time-frequency object-based analysis for dolphin vocalizations detection

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Underwater acoustic monitoring plays a crucial role in understanding marine ecosystems. In acoustic analysis, bioacoustics, particularly vocalization events are typically annotated by only temporal information within long-term recordings. To avoid labor-intensive manual annotation, automated detection methods based on deep learning have been introduced. Many previous approaches transform acoustic waveforms into spectrogram images and treat vocalization detection as a patch-wise classification task using convolutional neural networks, primarily focusing on temporal event identification. However, these methods do not explicitly provide localization in the frequency domain, making it difficult to detect simultaneous sound sources occurring at different frequency bands. This study evaluates the feasibility of localization in the time-frequency domain for acoustic monitoring. We apply You Only Look Once (YOLO) to detect vocalizations of striped dolphins (Stenella coeruleoalba) in the time-frequency domain using acoustic data recorded by a towed hydrophone in Suruga Bay in April 2019 and 2025. The target species were independently identified by visual observers. The acoustic signals were transformed into time-frequency images using short-time Fourier transform. Band-pass filtering (3-30 kHz) was applied to suppress low-frequency noise and high-frequency components outside the target band. The manually annotated dataset consisted of 324 vocalization events, which was divided into training and a validation sets. Transfer learning was performed using YOLOv8 with an input size of 640x640 pixels. The best validation performance was achieved at epoch 19, with a mean average precision of 0.93, computed using an intersection-over-union threshold of 0.5. The results demonstrate reasonable detection and localization performance of dolphin vocalizations in underwater acoustic recordings. However, object detection requires frequency-domain annotations in addition to temporal boundaries, which increases annotation effort. Despite this additional cost, YOLO provides the ability to localize vocalizations in both time and frequency, which may offer practical advantages compared to classification-based approaches, supporting the application of YOLO for reliable and scalable acoustic analysis.

Soundscape monitoring in the Salish Sea, describing changes relevant to southern resident killer whale (SRKW, Orcinus orca) and objectives to lessen acoustic impact

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Soundscape monitoring and modelling of received anthropogenic noise helps us understand the spatiotemporal patterns of ambient sound levels and identify noise sources. Increases in noise emissions, especially from commercial vessels, have been identified as a key threat against the recovery and survival of several at-risk species. Here, we present both modelled and field data that together helps us understand the soundscape trends and noise sources in the Salish Sea, the collective name for waters around southern Vancouver Island and northern Washington State. This area hosts several marine mammal species, and is designated critical habitat for the endangered southern resident killer whales (SRKW, Orcinus orca). From these data sets, we explore the impact of increases in commercial vessel passages as major projects have come online. As part of this, masking calculations will help determine the impacts to behaviour and habitat use, most notably foraging. Contextual information on changing whale presence, residency, prey size and abundance contributes to the estimate of impact. This all contributes to work trying to understand the levels of noise that do not elicit a detrimental effect to the at-risk species in this area.

Feasibility of Deep Learning-Based Detection of Delphinidae Sounds with Limited Training Data in Marine Soundscape Analysis

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Automated detection of biological sounds is a fundamental component of marine soundscape analysis. However, most deep learning-based detectors require large annotated datasets, limiting their applicability to species with scarce observational records. In this study, we investigate the feasibility of detection of Delphinidae sounds with limited training data under cross-site conditions using a combination of Supervised Contrastive Learning and k-Nearest Neighbors classification (SupCon+kNN). We compare it with a conventional convolutional neural network trained with cross-entropy loss (CE). We analyzed Delphinidae vocalizations recorded in Suruga Bay and the waters off the Izu Peninsula, Japan. Models were trained using only 100 positive examples randomly sampled from Suruga Bay (20 trials), and evaluated on within-site (Suruga Bay) and cross-site (Izu Peninsula) test datasets using precision, recall, and F1-score. More restrictive settings with 25 and 10 positive examples were also examined. Under cross-site conditions, CE showed relatively stable performance with an F1-score of 0.78 +/- 0.11. In contrast, SupCon+kNN exhibited tunable precision-recall trade-offs depending on the ratio of negative samples used during training. When trained with a higher ratio of negative samples, SupCon+kNN achieved high precision (0.99 +/- 0.03), indicating strong suppression of false positives. When the negative ratio was reduced, recall increased to 0.68 +/- 0.15, exceeding that of CE in some experimental settings. These results suggest that SupCon+kNN enables flexible control between low false alarm rate and high recall in soundscape applications. Furthermore, a sequential decision framework combining CE and SupCon+kNN improved overall performance compared to single model approaches, resulting in a 0.05 increase in F1-score. This study quantitatively evaluates detection performance with limited training data under cross-site conditions, and examines the applicability of biological sound detection methods in marine soundscape analysis. Future work will build on these findings to further improve detection accuracy with limited training data under cross-site conditions by optimizing the ratio of negative samples according to operational objectives and by exploring model integration using stacking.

Disturbing the sanctuary: Anthropogenic noise disrupts humpback whale (Megaptera novaeangliae) song and alters dive behavior

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Every winter, the warm, shallow waters of the Hawaiian Islands are home to thousands of humpback whales (Megaptera novaeangliae). During peak season, humpback whales are regularly exposed to noise produced by whale-watching boats, fishing vessels, and other ship traffic. Humpback whales rely heavily on sound, making them particularly vulnerable to acoustic disturbance in the ocean. This project used data from 34 individual whales tagged with suction cup biologging acoustic tags between 2020-2025 to analyze the impacts of vessel noise on humpback dive and acoustic behavior. Spectrograms were generated in Raven Pro to visualize and interpret acoustic tag data. All periods of vessel noise during tag recordings were manually identified and selected, and any interruptions in a whale's song associated with the presence of vessel noise were noted. The tag's recorded tri-axial accelerometer, magnetometer, and pressure data were then used to compare the whale's movement and dive behavior during periods with and without vessel noise. On average, vessel noise was audible during 25% of the recorded tag deployments, suggesting that humpbacks off the coast of Maui are exposed to vessel noise during one quarter of daylight hours. In four cases, singing whales abruptly ended their song in the middle of a song cycle within 10 minutes of being exposed to vessel noise. Additionally, in multiple cases, whales in a stationary behavioral state altered their dive patterns in the presence of vessel noise. Although humpbacks exhibited variable responses across repeated exposures, our results suggest that anthropogenic sound alters acoustic behavior and dive patterns. These findings provide insight into the effects of noise pollution on humpback whales, which can inform adaptive management strategies of vessel traffic during Maui's ecotourism whale season.

Learning from the past to protect our future: Quantifying ship noise from the Gulf of Mexico to the Arctic

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Increasing commercial shipping activity has reshaped low-frequency ocean soundscapes, creating a need for quantitative tools that directly support noise management decisions. This work presents techniques that combine predictive modeling of ship source levels with regional noise mapping to evaluate noise reduction strategies across ocean basins. A neural network-based approach is used to estimate third-octave monopole source levels of commercial vessels from publicly available sources, including AIS-derived ship characteristics and environmental variables, predicting better than current widely used models. These predictive source level models can be used for testing of management options, such as speed reductions, vessel class changes, or adoption of quiet-design standards, by simulating how altered design or operating conditions would change radiated noise without requiring new measurements for every scenario. In parallel, empirically derived ship source levels are incorporated into a propagation-based noise mapping technique for Arctic water that combines AIS traffic reconstructions, wind-driven baseline noise, and parabolic equation modeling at management-relevant frequencies (e.g., 63 and 1,000 Hz). Comparisons with in-situ measurements of wind-driven ambient sound levels identify when and where ship traffic most strongly elevates noise, revealing noise hotspots and conditions where interventions would be most effective. This approach allows direct evaluation of how alternative routing, convoying, or vessel-quieting strategies translate into spatiotemporal changes in underwater noise. Together, the predictive source level models and the data-validated noise mapping framework form a cohesive, transferable toolkit for data-driven ocean noise management across environments ranging from the Gulf of Mexico/Gulf of America, where ship noise is persistent and shaped by economic activity, to the Arctic, where cargo and tourism traffic are rapidly increasing. These linked modeling and mapping approaches connect vessel-scale operating choices to basin-scale soundscape outcomes, providing a basis for designing and assessing practical mitigation measures in regions experiencing rapid growth in ship traffic.