

Book of Abstracts

The Effects of Noise on Aquatic Life

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INTERNATIONAL STANDARDIZATION IN UNDERWATER BIOACOUSTICS

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Standards are helpful in all walks of life, from buying a plug that fits that socket at home to synchronizing a docking operation at the International Space Station at 15:58:22 UTC. Standardization in air acoustics began as an initiative of the American Standards Association (now ANSI) in the 1930s, and the International Organization for Standardization (ISO) established its technical committee Acoustics (TC 43) in 1947. Seventy years later we can buy a standardized sound level meter knowing that it applies an appropriate auditory filter, tuned to the perception of human hearing.

In underwater acoustics the process of international standardization is in its infancy. For example, as of 2019 there exists no standard hearing filter for a single species of aquatic animal, no international standard for measuring sound pressure or particle motion, or hearing thresholds, source levels or scattering strengths of aquatic biota. ISO TC 43's first step towards standardization in underwater acoustics was made in 2011 when it established the sub-committee Underwater Acoustics (TC 43/SC 3). Since then, reference values (ISO 1683:2015) and terminology (ISO 18405:2017) in underwater acoustics have been standardized, SC 3 has published two measurement standards (ISO 17208-1:2016; ISO 18406:2017), and the International Electrotechnical Commission (IEC) has updated its hydrophone specification (IEC 60500:2017). As part of a major revision of the International System of Quantities, ISO 80000-8 'Quantities and units -- Part 8: Acoustics' is being updated to include underwater acoustics, with the revised standard scheduled for publication in 2019. The Working Group on Standardization for the International Quiet Ocean Experiment has published an inventory of existing standards for observations of sound in the ocean (<https://iqoe.org/groups/standardization>). Example applications include the standardization project of the E&P Sound and Marine Life Joint Industry Programme, and several underwater sound monitoring projects, including ADEON (<https://adeon.unh.edu/>), JOMOPANS (<https://northsearegion.eu/jomopans/>), and QUIETMED (<http://www.quietmed-project.eu/>).

The development and application of international standards in underwater acoustics since 2015, and new international standards currently under development, are described, with special attention to their application to the protection of aquatic life. Areas where international standards are lacking are described. Such standards are needed to facilitate inter-laboratory, inter-disciplinary and international compatibility, and to avoid costly mistakes. Without them scientific progress is hindered by the lack of inter-project compatibility, resulting in effort wasted by repeatedly re-inventing the wheel.

IEC (2017). IEC 60500:2017 "Underwater acoustics – Hydrophones – Properties of hydrophones in the frequency range 1 Hz to 500 kHz," International Electrotechnical Commission (Geneva).

ISO (2016). ISO 17208-1:2016 "Underwater acoustics -- Quantities and procedures for description and measurement of underwater sound from ships -- Part 1: Requirements for precision measurements in deep water used for comparison purposes," International Organization for Standardization (Geneva).

ISO (2017a). ISO 18405:2017 "Underwater acoustics -- Terminology," International Organization for Standardization (Geneva).

ISO (2017b). ISO 18406:2017 "Underwater acoustics -- Measurement of radiated underwater sound from percussive pile driving," International Organization for Standardization (Geneva).

APPLICATION OF DAMPED CYLINDRICAL SPREADING TO IMPACT PILE DRIVING RISK ASSESSMENT

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Environmental risk assessment for impact pile driving requires characterization of the radiated sound field. A widely used method to estimate the field at range is to measure the sound exposure level (SEL) at (say) r_1 and extrapolate from r_1 to r using an empirical formula for transmission loss (TL) of the form $15\log(r/r_1)$ dB, or similar. A recently developed alternative to this “15logR” approach is a theoretical model called damped cylindrical spreading (DCS) (Lippert et al., 2018). DCS describes sound propagation of the Mach cone generated by the interaction of the hammer with the pile (Reinhall and Dahl, 2011) and further associates the TL with the Mach cone, which naturally follows cylindrical spreading combined with exponential decay caused by multiple seabed reflections (Zampolli et al., 2013).

For impact assessment it is conventional to also use criteria involving peak sound pressure level (Lpk) and root-mean-square sound pressure level (Lrms). Lpk and Lrms can be estimated from SEL using empirical correlations based on (Lippert et al., 2015). A regression analysis was carried out on measurements for four wind farm construction sites to produce correlations representative of the southern North Sea, thus facilitating predictions using the DCS approach of SEL, Lpk and Lrms.

The traditional 15logR and alternative DCS model methods were compared with measurements made during the construction of Borkum Riffgrund I. In this validation test, the 15logR approach overestimated the initial slope of the TL curve, and consequently underestimated SEL for distances between 30 m and 3 km, whereas the DCS prediction showed a better agreement with the measurements. This improved accuracy is explained by the use by DCS of basic physical principles, leading to cylindrical spreading of sound trapped by the shallow water waveguide, from which it follows that if is chosen close to the pile the 15logR approach necessarily underestimates the impact. We illustrate this point by applying both methods to estimate impact on fish and harbour porpoise of the construction of a generic pile. When estimating the impact area associated with recoverable injury in fish, the 15logR approach predicted an impact distance of 0.19 km (area $A = 0.11$ km²), while DCS predicted 0.50 km ($A = 0.79$ km²). The 15logR approach therefore underestimated the impact area by a factor 7. For a similar calculation for the harbour porpoise, the 15logR approach underestimated the impact area for TTS in the harbour porpoise by a factor 4.

Lippert, T., Ainslie, M. A., & von Estorff, O. (2018). "Pile driving acoustics made simple: Damped cylindrical spreading model," *J. Acoust. Soc. Am.* 143, 310-317.

Lippert, T., Galindo-Romero, M., Gavrilov, A. N., & von Estorff, O. (2015). "Empirical estimation of peak pressure level from sound exposure level. Part II: Offshore impact pile driving noise," *J. Acoust. Soc. Am.* 138, EL287-EL292.

Reinhall, P. G., & Dahl, P. H. (2011). "Underwater Mach wave radiation from impact pile driving: Theory and observation," *J. Acoust. Soc. Am.* 130, 1209-1216.

Zampolli, M., Nijhof, M. J., de Jong, C. A., Ainslie, M. A., Jansen, E. H., & Quesson, B. A. (2013). "Validation of finite element computations for the quantitative prediction of underwater noise from impact pile driving," *J. Acoust. Soc. Am.* 133, 72-81.

CETACEAN RESPONSE TO BROADBAND EXPLOSIVE NOISE IN KAUAI

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Passive acoustic monitoring of marine mammals occurs regularly on the Pacific Missile Range Facility (PMRF) in Kauai, Hawaii. Disturbance analyses have been performed for some species in response to Navy training events, such as the biannual Submarine Command Course event and other periods of active sonar (e.g. Martin et al. 2015, Henderson et al. 2016, Manzano-Roth et al. 2016). Explosions have been opportunistically recorded in some datasets and contain enough acoustic energy to propagate large distances to be heard on multiple hydrophones across the ~1,100 km² area of the PMRF instrumented range. Automated tracks were generated for minke whales (*Balaenoptera acutorostrata*), low-frequency baleen whales (including fin whales (*Balaenoptera physalus*) and Bryde's whales (*Balaenoptera edeni*)), and humpback whales (*Megaptera novaeangliae*). These tracks form the basis to assess presence and, in some cases, derive call rate, heading, and swim speed before, during, and after explosions. Propagation modeling was used to estimate received levels for each tracked animal at the closest point of approach to the explosive events. The results of this preliminary study can help guide further analysis of explosive sound sources at PMRF, complement future research, such as comparing responses to other types of acoustic disturbance (e.g. sonar, boat noise), and inform environmental compliance behavioral response criteria for noise resulting from the use of explosives by the military and the fishing industry (e.g. seal bombs).

Henderson, E. E., Martin, S. W., Manzano-Roth, R., & Matsuyama, B. M. (2016). Occurrence and habitat use of foraging Blainville's beaked whales (*Mesoplodon densirostris*) on a US Navy range in Hawaii. *Aquatic Mammals*, 42(4), 549.

Manzano-Roth, R., Henderson, E. E., Martin, S. W., Martin, C., & Matsuyama, B. M. (2016). Impacts of US Navy training events on Blainville's beaked whale (*Mesoplodon densirostris*) foraging dives in Hawaiian waters. *Aquatic Mammals*, 42(4), 507.

Martin, S. W., Martin, C. R., Matsuyama, B. M., & Henderson, E. E. (2015). Minke whales (*Balaenoptera acutorostrata*) respond to navy training. *The Journal of the Acoustical Society of America*, 137(5), 2533-2541.

CHARACTERIZATION OF AN IMPULSIVE PILE DRIVING SIGNAL WITH RANGE DURING INSTALLATION OF OFFSHORE WIND TURBINES

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The Block Island Wind Farm is the first offshore wind farm in the U.S. It consists of five 6-MW turbines located three miles southeast of Block Island, Rhode Island in water depths of approximately 30 metres. Pile driving was performed to secure the lattice-jacket foundation support structure for each wind turbine to the seabed. Acoustic sensors, including a passive towed array, two moored vertical line arrays, and a tetrahedral array were deployed during the construction of the wind farm to record the pile driving acoustics at ranges from 500m to 15km from the foundations.

Impact pile driving creates intense sound that radiates into the environment and propagates through the air, water, and sediment. The acoustic signals generated from impact pile driving are described as impulsive and are characterized as broadband signals that consist of high peak sound pressure and a rapid rise time. The impulsiveness of a signal can be described by kurtosis, which is a statistical measure of the probability distribution that is often applied to describe the shape of sound pressure amplitudes. Impulsive signals with high kurtosis and high instantaneous peak pressure may be more injurious to some marine mammals (Southall et al., 2007). The kurtosis and signal duration were calculated for pile driving events recorded on all of the acoustic sensors at varying ranges to understand how the acoustic signal is changing with distance from the pile driving location.

The U.S. National Marine Fisheries Service (NMFS) has released acoustic thresholds to provide guidance on how to assess potential impacts to marine mammals from both impulsive and non-impulsive underwater sounds (National Marine Fisheries Service, 2018). A signal is defined as impulsive based on the physical characteristics of the sound at the source, but as sound propagates out in range the characteristics that make a signal impulsive (i.e. rapid rise time and high peak pressure) will change and dissipate due to the time dispersion effects of propagation. A sound that is classified as impulsive could be perceived as more non-impulsive at range and therefore less injurious to marine mammals. The kurtosis and signal duration measured at varying ranges from the pile driving location will provide insight into the transition of the signal from impulsive at close ranges to more non-impulsive at farther ranges. [Work supported by Bureau of Ocean Energy Management (BOEM)]

National Marine Fisheries Service (2018). 2018 Revision to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0).

Southall, B. L., Bowles, A. E., Ellison, W. T., Finneran, J. J., Gentry, R. L., Greene Jr, C. R., Kastak, D., et al. (2007).

“Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations,” *Aquat. Mamm.*, 33, 411-521.

CORAL CHORUS: REEF SOUNDSCAPE CONDITIONS INFLUENCE CORALS OF DIVERSE LIFE STAGES

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Coral provide the foundation of reef ecosystems, supporting some of the highest biodiversity on Earth. While coral reefs are under substantial stress little is known the role of sound in coral ecology. Early evidence suggests that coral larvae orient towards sound suggesting sensitivity, yet it is unclear if or how sound cues may induce settlement or impact coral health.

We conducted two experiments that addressed sound-sensitivity across two key coral life stages. First, to examine how larvae may use sound to find appropriate habitat, larvae of the coral *Porites astreoides* were placed *in situ* in chambers on reefs differing in habitat quality (coral and fish abundance), and the soundscape was recorded. Larval settlement was significantly higher in an acoustic environment with greater levels of low-frequency sounds, typical of a high-quality, healthy reef. This enhancement of coral settlement by healthy reef soundscapes suggests fish abundance and fish sounds may facilitate coral recruitment. Second, we addressed effects of noise on adult colonies. Colonies of the widespread temperate calcifying coral *Astrangia poculata* were exposed to impact pile-driving playbacks, a potential stressor these animals face as windfarm and other construction proliferates. Sound pressure and particle motion were quantified. Polyp (individuals) numbers fully extended, partially retracted, and fully retracted were enumerated. Corals colonies exposed to 15-min of pile-driving noise showed greater proportions of retracted polyps compared to no-sound controls. Retraction typically occurred within the first minute of playback. While the proportion of polyps re-extending gradually returned to near-baseline, some polyps did not re-extended. Additionally, some animals showed greater noise sensitivity, as evidenced by increased polyp retraction in trials later that day or subsequent days.

These data shed new light on how a foundational invertebrate uses and is impacted by sound. We demonstrate that increased coral settlement occurs in the presence of a low-frequency, fish-chorus dominated soundscape, often representative of a healthier, more diverse reef. This suggests a positive feedback loop where reefs of higher coral cover and fish abundance generate soundscapes best suited to attract coral larvae, which in turn sustain the healthy habitat for fish. Perhaps more alarming is that adult coral are clearly affected by anthropogenic noise, with responses likely to impact ecologically vital feeding rates and water filtration. As multiple coral species are threatened and face many stressors, these ecologically-relevant responses clearly underscore the need to further evaluate coral sound use and mitigate noise impacts on these key invertebrates.

COMPARATIVE STUDY ON THE ANTHROPOGENIC NOISE MASKING EFFECT ON THE VOCAL REPERTOIRE OF *Delphinus delphis* AND *Stenella coeruleoalba* IN THE EASTERN AEGEAN SEA, GREECE

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The social communication repertoire of odontocetes comprises of whistles and narrowband tonal calls, with a frequency range between 5 and 20 kHz, which last a few seconds (Ansmann et al., 2007). The anthropogenic noise produced by marine vessels dominates the range of frequencies between 100 Hz to 10 kHz and affect the marine environment (Frisk 2007; Boyd et al., 2011). These sounds tend to mask dolphin whistles as their frequencies overlap (Morisaka et al., 2005).

This study aims to distinguish the Sea Ambient Noise (SAN) levels in the waters surrounding Samos Island in the Eastern Aegean Sea, Greece, in accordance to the EU Marine Strategy Directive (2008/56/EC). For the assessment of the impact of maritime traffic noise on the whistle repertoire of the Striped dolphin (*Stenella coeruleoalba*) and the Short-beaked Common dolphin (*Delphinus delphis*), acoustic data was collected using a stationary Passive Acoustic Monitoring (PAM) system between August 2017 and September 2018. Raven Pro v1.5 was used to analyse high Signal-to-Noise ratio overlapping whistles with the parameters: begin time (s), end time (s), beginning frequency (Hz), final frequency (Hz), peak power (dB), peak frequency (Hz), duration (s), central frequency (Hz), number of inflection points, number of harmonics and shape of whistle. The equivalent continuous sound pressure level (Leq) and the instantaneous sound pressure level were calculated for every 30 seconds of each acoustic data sample for the 1/3 octave band frequencies (63 Hz, 125 Hz, 63 – 2 kHz, 2 -20 kHz).

Data distribution was assessed using a Shapiro-Wilk (significance < 0.05) test for normality and descriptive statistics (range, minimum, maximum, mean, standard error, and coefficient of variation) were used for the whistle parameters. Non-parametric tests (Kruskal Wallis, Wilcoxon Mann Whitney) and correlation index were used to determine the variations of the whistle parameters in comparison to the median ranks (0 or 1) of the four bands of interest. In the case of the *S. coeruleoalba*, the 63 Hz and 125 Hz 1/3rd octave band whistle frequencies significantly increased compared to the remaining bands of interest. In SAN conditions of elevated low-frequency (below 2 kHz), this species significantly shifts its whistles to higher frequencies, whereas within a higher SAN range (2-20 kHz), there was a reduction in the peak frequency. This combination of changes highlights how *S. coeruleoalba* may change their whistle parameters in areas of high maritime traffic, compared with *D. delphis*.

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Boyd, I.L., G. Frisk, E. Urban, P. Tyack, J. Ausubel, S. Seeyave, D. Cato, B. Southall, M. Weise, R. Andrew, T. Akamatsu, R. Dekeling, C. Erbe, D. Farmer, R. Gentry, T. Gross, A. Hawkins, F. Li, K. Metcalf, J.H. Miller, D. Moretti, C. Rodrigo, and T. Shinke. (2011). "An International Quiet Ocean Experiment. Oceanography" 24(2):174–181, doi:10.5670/oceanog.2011.37.

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Morisaka, T., Shinohara, M., Nakahara, F. & Akamatsu, T., (2005b). "Effects of ambient noise on the whistles of Indo-Pacific bottlenose dolphin populations". Journal of Mammalogy, 86, 541–546.

HEARING ABILITIES IN PENGUINS (*Spheniscidae*): 3D-VISUALIZATION OF THE EAR MORPHOLOGY

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Underwater noise by man activity and ships may have a serious impact on the hearing abilities of aquatic species, particularly in the Antarctic region. To evaluate the potential influence of man-made noise on the marine fauna, the ability of underwater hearing in Spheniscidae is analyzed in a co-operative project by the German Meeresmuseum Stralsund, Museum für Naturkunde Berlin, University of Rostock, and the Danish Syddansk University.

In combination with the psychoacoustical studies of the project, the morphology of the inner and middle ear of penguins is visualized. The main sources of study material are the collections of the Museum für Naturkunde in Berlin. For three model species (*Aptenodytes forsteri*, *Pygoscelis papua*, and *Spheniscus demersus*) the bony and soft tissues of the ear region are studied based on CT images. In order to increase the contrast between soft tissues and bone in the CT images, heads preserved in alcohol are stained with Lugol's iodine. For *Aptenodytes forsteri* and *Spheniscus demersus* key structures of the penguin ear such as the bony and the membranous labyrinth, the middle ear cavity with the columella and the tympanic membrane, associated nerves, vessels, and muscles are segmented using the software Volume Graphics. This approach enables a detailed description as well as various measurements on physiological important structures in the otic region. Moreover, it is possible to follow the outer ear canal and the Eustachian tube including their accompanying structures to get an impression of potential opening and closure mechanisms for the purpose of pressure compensation during diving. Nonetheless, in some cases the success of standard fixation and staining protocols for CT analysis of museum material can be limited as well. Especially the soft tissues in the inner ear of the formaldehyde fixated specimens do not always react well to the staining agent.

The results of the visualization will be used to produce video sequences demonstrating the digitized structures in 3D. Within the framework of the interpretation of the physiological results of the entire project, the visualizations help to understand the processes of underwater hearing. Furthermore, they support the project's overall aim to explain the impact of under-water noise on the hearing abilities of aquatic species and to address its influence on the fauna to a broader public.

QUANTIFYING HARBOUR PORPOISE FORAGING BEHAVIOUR IN CPOD DATA

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Harbour porpoises (*Phocoena phocoena*) are regularly monitored to assess how they are impacted by the construction and operation of offshore wind farms. A suitable method to do this is passive acoustic monitoring (PAM), and in particular using specific stationary hydrophones called CPODs. These devices provide information on click activity, which can then be analysed to investigate habitat use over time, differences between areas and the impact of human activities.

Prey occurrence is considered one of the main drivers in porpoise distribution and successful feeding is vital to the fitness and survival of individual porpoises. Information on foraging behavior, however, is difficult to obtain in the field, in particular as animals feed under water.

Harbour porpoise use narrow band high frequency signals in a sequence of clicks (i.e. click trains) for echolocation, communication and foraging. The different behaviors are characterised by the modulation in time lag between clicks (i.e. inter-click interval). For foraging behavior, the click train sequence is noticeably characterised by low inter-click intervals and a final increase in inter-click intervals. While such a train sequence can be resolved by hydrophones mounted on tags (Sørensen et al., 2018), the detection of foraging events is more challenging for stationary hydrophones such as CPOD devices.

Using CPOD data collected in Dutch water during and after the construction of the Gemini wind farm (June 2015 to February 2016), the present study first investigates different data processing methods for the quantification of foraging behavior. The results indicate that a click based classification (as opposed to click trains) as in Pirotta et al. (2014) provides the best results. This analytical tool is then applied to the entire data set to explore the potential applications of this method. The results show that foraging events could be determined in sufficient numbers to detect patterns over time, such as correlation with pile driving activities, as well as to compare differences between CPOD stations.

Pirotta, E., Brookes, K. L., Graham, I. M., & Thompson, P. M. (2014). “*Variation in harbour porpoise activity in response to seismic survey noise*”. *Biology Letters*, 10(5), 20131090.

Sørensen PM, Wisniewska DM, Jensen FH, Johnson M, Teilmann J and Madsen P (2018) “*Click communication in wild harbour porpoises (Phocoena phocoena)*”. *Scientific Reports* Volume 8, Article number: 9702.

USE OF UPWARD ACTIVE ACOUSTIC DEVICES TO INVESTIGATE PELAGIC COMMUNITIES IN OFFSHORE WIND FARMS DURING SOUND EXPOSURE TO SEISMIC SURVEY AND PILE DRIVING

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There is a steady progress in the number of operational Offshore Wind Farms (OWF) in the Netherlands, Belgium, Europe and worldwide. There are many ecological changes associated with the installation and operation of OWFs, such as altered substrate and current conditions and an increase of anthropogenic noise. The latter concerns high level pulsed sounds from seismic survey activities and pile driving, but also more moderate and more or less continuous sounds from construction, maintenance and vessel activities. Some of these ecological changes will attract species and some of them will deter species, and all together, they will certainly lead to changes in local animal communities. Most work to date has focused on alterations in the benthic community, while effects on the pelagic community remain relatively unexplored.

Along the Dutch coast, a lot of knowledge has been gathered through research projects conducted within the framework of Wind at Sea Ecological Program (WOZEP). In Belgium, much has been learned from studies in the context of the WINMON program. Data is needed on the density and diversity of pelagic fish and zooplankton as well as their tendency to respond to anthropogenic noise pollution within and around OWFs to complement current insights. In 2018, two ASL Acoustic Zooplankton Fish Profilers (AZFP) were deployed off the Dutch and Belgian coast. These were deployed sequentially in three different OWFs (1 month monitoring period each), consisting of: (1) a baseline deployment, (2) a deployment coinciding with high level of piling noise (OWF construction), and (3) a deployment coinciding with an experimental, full scale seismic survey (PCAD4Cod JIP-project). In the current study, we investigated the potential use of acoustic profilers in shallow turbid water to monitor the pelagic animal community for presence and responsiveness to anthropogenic noise

BIOPHONICAL CHARACTERIZATION OF A MEDITERRANEAN SUBMARINE CANYON USING STATIC ACOUSTIC MONITORING AND GLIDERS, A PRELIMINARY INVESTIGATION

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Underwater soundscapes play an important role in the ecology of organisms at several life stages and provide high-resolution information about ecosystem process, status, dynamics and human impacts (Lillis et al., 2014). Fish calls are major contributors of coastal marine soundscapes between 100 Hz to 2 kHz, where Passive Acoustic Monitoring (PAM) has been used for investigating their presence, distribution and cycles of activity (Rountree et al., 2006; Lindseth & Lobel, 2018). Less than a dozen studies worldwide have focused on deep-sea fish; in the Mediterranean Sea, PAM of fish populations has been carried out up to a maximum depth of -40 m (Kéver et al., 2016).

Submarine canyons are key structures for ecosystem functioning in the Mediterranean Sea. This study was conducted in the canyon of Calvi (North-West Corsica, France) by using a combination of Static Acoustic Monitoring (SAM) and hydrophone integrated gliders (Seaexplorer, Alseamar). During summer 2016 and 2017, three SAM campaigns (-125 m to -150 m, 3 kilometers from coastline) and one gliders mission (-900 m to -60 m, 6 kilometers to 3 kilometers from coastline) were here conducted. A total of 194 hours of recordings were analysed for fish sound diversity (i.e. number of sound types) and for fish sound abundance (number of sounds per sound type and per unit of time).

Biological sounds were detected in 37% of the recorded audio files. Besides for the presence of marine mammals clicks and whistles, at least 8 sound types (for a total of more than 8.000 sounds) with characteristics similar to those emitted by known vocal fish species were characterised; for one of these, emitter identity could be inferred at the genus level (*Ophidion* sp.). Furthermore, an increase in Sea Ambient Noise between 10 and 15 dB re 1 µPa was observed during daytime hours due to boat traffic.

The vastness of the deep-sea and, in particular, the heterogeneity of submarine canyons, their high biodiversity and level of fauna specificity, together with the very localized character of observations carried out to date fully justify the use of an holistic monitoring approach such as PAM, especially when a combination of methods is used (e.g. SAM and gliders). Our study demonstrate that PAM can provide novel information about the ecoacoustics and the distribution of vocal fish species in these pivotal Mediterranean environments and can assess the contribution of anthropogenic sound and their adverse effects (such as masking) on fishes.

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EFFECTS OF ACUTE AND CHRONIC SHIP NOISE PLAYBACKS ON THE EARLY LIFE STAGES OF THE NORWAY LOBSTER, *Nephrops norvegicus*

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The effects of anthropogenic noise on marine invertebrate larvae, often sensitive and regarded as population bottlenecks, are unknown for most species, despite their ecological and commercial importance.

In a controlled laboratory experiment we investigated whether and how ship noise, played back throughout zoea stages I, II and III of the commercially important Norway Lobster *Nephrops norvegicus* affects its development. Three treatment groups (n = 82 each), emulating different levels of shipping activity were compared:

- * T1 ‘Busy’ treatment: frequent ship noise playback with regular timings
- * T2 ‘Occasional’ treatment: less frequent ship noise playback at randomized intervals
- * T3 ‘Ambient’ treatment: constant ambient sound exclusive of any ship noise (control)

At ZI, neither T1 nor T2 affected development time to the next stage in comparison to the control. However, the duration of ZII was significantly longer ($p < 0.05$) in the ‘Busy’ treatment than the other two treatments. The duration of ZIII was significantly longer in the ‘Occasional’ group than in the other two treatments ($p < 0.01$). We also observed carry-over effects of noise impacted larvae: first stage juveniles of ‘Busy’ and ‘Occasional’ treatment groups showed significant reductions in escape response stamina compared to the control (33% and 46% reduced tail flicking stamina respectively, $p < 0.05$). Molecular carbon and nitrogen content of first stage juveniles did not vary across treatment groups.

We also assessed the effects of acute ship noise playbacks on the oxygen consumption rate of naïve and pre-exposed ZI, ZII and ZIII larvae. Averaged across all stages (n = 30 per group), naïve larvae consumed 25.9% more oxygen when subjected to noise compared to the control treatment without noise ($p < 0.001$). In contrast, pre-exposed larvae consumed 13.1% less oxygen when subjected to a further acute ship noise exposure ($p = 0.038$) compared to the control. Pre-exposed larvae consumed 17.3% more oxygen than naïve larvae under control conditions ($p = 0.014$).

If the observed developmental delays and escape-response stamina reductions are replicated in the wild, this would likely increase the risk of predation and could lead to reduced recruitment to the commercially important adult population. Our oxygen consumption results demonstrate that rather than causing habituation, repeated exposure to noise causes a change in response strategy. This can be summarized as a transition from a ‘startle’ response to a ‘shut-down’ response following repeated exposures. To our knowledge, this is a novel finding with regard to marine invertebrates.

BEHAVIORAL RESPONSES AND SOUND SOURCE AVOIDANCE OF BOTTLENOSE DOLPHINS DURING MULTIPLE EXPOSURES TO VIBRATORY PILE DRIVING SOUND

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Anthropogenic activities that produce noise, such as pile driving, often occur in coastal and estuarine waters commonly inhabited by dolphins and porpoises. There is growing concern over the impacts of pile driving sound on these and other marine mammal species. Exposure to anthropogenic noise may lead to behavioral reactions, which, if severe, could result in fitness costs to the exposed animals (e.g. reduced foraging opportunities). Even noise at relatively low sound pressure levels (SPLs) has the potential to distract an individual from a fitness-related task. To investigate potential behavioral impacts to bottlenose dolphins (*Tursiops truncatus*) exposed to vibratory pile driving noise (VPN), a controlled exposure study was conducted with five bottlenose dolphins performing an echolocation target detection task to determine the relationship between the SPL of VPN and changes in the dolphins' overall behavior. The dolphin's task was to produce echolocation clicks and report the presence of randomly occurring "phantom" echoes that simulated the presence of physical targets at various azimuthal angles around the dolphin's netted enclosure located in San Diego Bay. Upon detection of a "phantom" echo, the dolphin touched a response paddle and received a fish reward. The experiment used a pre-exposure, exposure, and post-exposure design, each period lasting 30min in duration and performed consecutively. No VPN playback occurred during the pre-exposure and post-exposure periods. During the exposure period, recordings of VPN were played back to each animal at four different source levels (broadband SPL of 110, 120, 130 and 140 dB re 1 μ Pa at 1 m) or no sound was played (i.e., a control condition). Ethograms were created by observers blind to the treatment using recorded video (i.e., no audio was available to identify trials). Initial exposures at the highest SPLs resulted in behavioral reactions (e.g., tail slapping, fast swimming, refusal to participate) and sound source avoidance in the majority of the dolphins. Reactions decreased in frequency of occurrence and severity, or extinguished, with repeated exposures. The results suggest that animal's naïve to a sound, even at relatively low received SPLs, may change their behavior, but can rapidly habituate in order to continue important tasks. Overall, behavioral reactions may be highly dependent on the individual or context of the exposure.

IMPULSIVE NOISE PRESSURE IN UK MARINE WATERS: A 4 YEAR TIME SERIES 2015–2018

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A ‘Good Environmental Status’ (GES) must be achieved in European seas by 2020 according to the EU Marine Strategy Framework Directive. One of the descriptors of GES is that the ‘Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment’.

To inform the definition and assessment of GES, the UK has established a ‘noise registry’ (Dekeling et al., 2014, UK Marine Strategy, 2012) to record the occurrence of activities that produce loud, low to mid frequency underwater noise. Activities include seismic surveys, impact pile driving and explosives detonation. The UK Marine Noise Registry (MNR) has been collating data since 2015 and is currently the largest database of impulsive noise events for an individual country.

Here we present data, in the form of a series of maps, to illustrate the distribution of impulsive noise in UK marine waters over the past 4 years (2015–2018). The pressure is presented in pulse block days (PBD) which are defined as the number of days in a calendar year in which impulsive sound activity occurred within a defined area, such as a UK Oil and Gas licensing block (O&G block). Seismic and sub bottom profiler surveys account for the majority of PBDs in all years and are more widespread than pile driving and Ministry of Defence activities, which contributed to high number of PBDs in more localised areas. A general downward trend has been observed in the total number of PBDs from a high baseline level in 2015 of over 6000 PBDs out of a theoretical maximum of 1,608,555 PBDs (4407 O&G blocks x 365days). Most blocks in all years experienced between 0 and less than 5 days of noise events but go up to 101 days in one block reported in 2017.

The data in the MNR is allowing the UK to assess pressure from impulsive noise both spatially and temporally, highlighting patterns and the contribution of different human activities that produce noise. Data in the registry has the potential to be used to inform the management of noise and to be used as a planning or advisory tool aiding in cumulative impacts assessments on marine species.

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UNRAVELING THE AUDITORY FUNCTION OF ZEBRAFISH OTOLITHIC END ORGANS USING NOISE

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Teleost fish represent the largest group of extant vertebrates that have developed a remarkable diversity of inner ear structures to enhance hearing sense in a variety of underwater soundscapes. Many species rely on their auditory system to interpret crucial biotic and abiotic information from the acoustic environment; however, the contribution of each inner ear otolithic endorgan (sacculle, utricle and lagena) for sound detection within a species is still not clear. While the sacculle has often been assumed to be the main auditory endorgan in teleosts, the utricle and lagena have also been implicated in auditory processing in different species. Some authors suggest that all three endorgans may serve mixed auditory-vestibular functions and they might have different sensitivities to extend the dynamic range when one reaches the saturation level at high sound amplitudes.

In this study we investigated the auditory roles of the different otolithic endorgans by analyzing the impact of noise exposure on the sensory receptors of the sacculle, utricle and lagena in the zebrafish (*Danio rerio*), a widely used model organism in hearing research. Adult specimens were exposed for 24 hours to continuous pure tones (100, 200 and 2000 Hz) at 150 dB re 1 μ Pa versus quiet laboratory conditions (c. 105 dB). The hair cell bundle density was determined for several locations of the sensory macula of the different endorgans. In order to relate morphological damage with functional changes, auditory sensitivity of subjects under the same acoustic treatment was measured using the auditory evoked potential recording (AEP) technique.

Preliminary results revealed noise frequency dependent hair cell loss in the sacculle and lagena, while the utricle did not show evidence of damage. While hair cell loss in the sacculle could be observed in specimens from all noise treatments but in different locations of the sensory macula, the lagena showed higher hair cell damage only when exposed to the lower frequency tones. Inner ear morphological damage was accompanied by changes in hearing sensitivity with significant auditory threshold shifts at different frequencies depending on the noise treatments. Current work focuses on quantifying the synapses with primary auditory neurons (ribbons) at the various endorgans under the same noise treatments.

STRATEGIC ENVIRONMENTAL ASSESSMENT AS A TOOL TO SHAPE THE POLICY OF OFFSHORE SEISMIC SURVEYS IN ISRAEL

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In 2014, the Israel Ministry of Energy (MoE) launched an offshore oil & gas exploration and production Strategic Environmental Assessment (SEA) in Israel's Mediterranean Sea. The SEA weighs in environmental considerations in sustainable development of offshore oil and natural gas resources, and minimize potential harm to the ecosystem while evaluating other benefits of environmental, social, and economic value. The SEA formed a knowledge base and acts as a decision-making tool for the Petroleum Commissioner in granting petroleum rights offshore Israel.

The offshore SEA is the first of its kind in Israel and is setting new standards in the way Israel administer its' natural resources. The content of the SEA complies with international practice, the OECD requirements and European Union EC/42/2001 directive. Its preparation was accompanied by a steering committee comprising representatives of government ministries, the public, NGOs, industry and other relevant stakeholders.

Data collection was performed by the Israel Oceanographic and Limnological Research (IOLR) and the Geological Survey of Israel (GSI). Habitats were defined based on their community homogeneity and per physical characteristics. Over 60 benthic habitats within Israel's territorial waters and EEZ were defined. Whereas the water column was divided into five three-dimensional and layered habitats.

The potential environmental impacts of offshore oil and gas exploration and production were analyzed for all habitats, and the ecological vulnerability of the various habitats has been determined.

In 2017 the MoE issued environmental guidelines for seismic surveys. The guidelines were based on current guidelines like those of ACCOBAMS, JNCC and BOEM. The guidelines' purpose is to minimize potential effects on cetaceans and marine turtles. The guidelines were created in conjunction with Israel Nature and Parks Authority (INPA) and The Israel Ministry of Environmental Protection.

The guidelines consider the vulnerability of the different pelagic habitats defined in the SEA and spatially limit seismic activities in habitats having a very high vulnerability level, temporally limit surveys between March and October in medium sensitive habitats and also require to consult with the INPA prior to conducting a survey at water depths of 0–120 m.

To further minimize the risk to marine mammals, the MoE is funding research to identify additional cetaceans-rich habitats. The ministry is also looking for better methods of identifying marine fauna under low visibility conditions during seismic surveys.

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CAPTURING VARIABILITY MARINE SOUNDSCAPES: ELEPHANT ISLAND, ANTARTICA – A CASE STUDY

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Here we present a comprehensive description of the acoustic environment approximately 31 km west-northwest of Minstrel Point, Elephant Island, Antarctica at 210 m water depth based on three years (Jan 2013 – Feb 2016) of subsampled (5 min per hour) passive acoustic recordings. Long-term spectrograms reveal a notable recurrence of acoustic environments between years.

Fin and Antarctic blue whale calls dominate the low (< 100 Hz) part of the biophonic spectrum energetically from end of January to late July/early August. November through early January are dominated by leopard seal vocalizations at around 300 Hz. Concurrently, the geophonic spectrum exhibits strong fluctuations between days, both due to storm and tidal influences, causing flow and shackle noise from the instrumentation itself.

Manual analysis of every second day of the subsampled data by visual and aural screening (employing short term spectrograms) was used to examine the data in greater detail for additional acoustic contributions and to assign the various acoustic signatures to their sources. Six cetacean and two pinniped species were identified based on their acoustic signatures and analysed for seasonal and diel patterns in occurrence. Anthroponic signatures were attributed to air guns on 3 % of the analysed days. Vessel noise was noted between 10 and 12 % of days on annual averages, occurring mainly in austral summer and fall with sporadic events throughout the remainder of the year. This work illustrates the value of soundscape studies and provides a first step towards understanding the actual contribution of sound sources in their respective acoustic context and overall local noise budget.

EFFECTS OF WATER GUN ON ECHINODERMS: BIOCHEMICAL CHANGES ON SEA URCHIN (*Arbacia lixula*) AND SEA CUCUMBER (*Holothuria tubulosa*)

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Sources Airguns and Waterguns are used in seismic exploration the marine seafloor for different purposes such as oil and gas search, or geological-geodynamic reconstruction. In this technique a bubble of compressed air is produced with a consequently production of loud sound wave penetrating the ocean floor.

The impact of seismic Airguns was assessed in some cetaceans (Kyhn et al. 2019), fish species and invertebrate (Carroll et al. 2017), but we need to know more.

In this study we evaluate the biochemical changes in sea urchin (*Arbacia lixula*) and sea cucumber (*Holothuria tubulosa*) exposed to a 20 minutes of watergun noise (1 pulse each 10 s) at a distance of 50 m. For each species 40 individuals were captured and caged in the sea in groups of 10. After four days of acclimation we started the experimental test that previewed these 4 samplings phases: T0-control group before the Watergun sound exposition; T1-post group soon after the end of sound exposition; T2-post group after 3 hour of exposition; T3-post group after 24 hour of exposition.

Watergun pulse was characterized by measuring pressure (SM2U, Wildlife Acoustics) and particle speed (M20-105, Geospectrum) in the three dimensions at the same position of the caged animals. Watergun pulses Power Spectral Density for pressure and particle speed showed respectively a peak of 122 dB re $1\mu\text{Pa}^2/\text{Hz}$ at 850 Hz and a peak of 207 dB re $(1\text{nm/s})^2$ at 550 Hz for x component (direction parallel to the sea surface and forward the caged animals).

The coelomatic fluid was extracted by each animal for the following successive analysis: total volume withdrawn, Total Hemocytes Counts (THC), total protein, phosphatase, esterase and peroxidase activity.

In the sea urchin we observed significant differences in esterase (T0 < T2 and T3), and peroxidase (T0 < T2 and T3). Concerning sea cucumber we found significant differences for THC (T0<T1), and total protein (T0 > T2; T1 < T2). This is the first attempt to study the effects of a short loud low frequencies sound exposition in echinoderms species and results show that these animals reacted to the noise with an alteration of some coelomic fluid parameters indicators of stress.

Carroll AG, Przeslawski R, Duncan A, Gunning M & Bruce B (2017) A critical review of the potential impacts of marine seismic surveys on fish & invertebrates. *Mar Pollut Bull* 114:9–24.

Kyhn LA, Wisniewska DM, Beedholm K, Tougaard J, Simon M, Mosbech A & Madsen PT (2019) Basin-wide contributions to the underwater soundscape by multiple seismic surveys with implications for marine mammals in Baffin Bay, Greenland. *Mar Pollut Bull* 138:474–490.

UNDERWATER SOUNDSCAPE PATTERN DURING HIGH SEASON OF NAUTICAL TOURISM IN CABO FRIO ISLAND, BRAZIL

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The underwater sounds are related to abiotic, biotic and human activities. All these activities compose the underwater soundscape that may change in time and/or space (Pijanowski et al., 2011). Several ecological relationships are associated to information generated through soundscape patterns. However, anthropogenic sounds have been recently regarded as underwater noise pollution (Williams et al., 2015).

This study aims to characterize the underwater soundscape of Cabo Frio island, a marine protected area in Arraial do Cabo, Rio de Janeiro, Brazil, evaluating biological and anthropogenic acoustic patterns. Signals were recorded from December 2016 to January 2017. The duty cycle was established as a one-minute recording every five minutes, totalizing 20% of day. Three frequency ranges were selected (“A” 0.1–22 kHz, “B” 0.1–2 kHz and “C” 2–22 kHz) and the following acoustic measurements were taken: average power, average entropy and maximum frequency.

Biological patterns were observed in all three frequency ranges, mainly during twilight and nighttime. Based on the association among the acoustic measurements, the presence of touristic and fishery boats was recorded in the region mainly at frequencies approximately 200 Hz range during the daytime. Average power peaks were observed in frequency range B. These power peaks were louder than biological power peaks during daytime and can be related to the highest traffic of touristic boats. Also, average power peaks associated to biological sounds were recorded during twilight. The results suggest that the constant disturbance caused by boats can impaired the establishment of the natural underwater soundscape of the region during the touristic activities. The association among the acoustic measurements can be a potential tool for boat traffic management in marine protected areas.

Pijanowski, B.C., Farina, A., Gage, S.H., Dumyahn, S.L., and Krause, B.L. (2011). “What is soundscape ecology? An introduction and overview of an emerging new science,” *Landscape ecol.* 26, 1213-1232.

Williams, R., Erbe, C., Ashe, E., and Clark, C.W. (2015). “Quiet (er) marine protected areas,” *Mar. Pollut. Bull.* 100, 154-161.

UNEXPLODED ORDINANCE CLEARANCE – CHALLENGES WHEN ADVISING ON RISK ASSESMENT AND MITIGATION

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In the UK, statutory nature conservation bodies (SNCBs) advise on marine permits and work with regulators and industry to improve standards of risk assessment and mitigation. Our understanding of noise characteristics from offshore activities and their impacts to marine mammals has much improved in recent years, however challenges remain as to how to assess the risk of hearing damage and disturbance and how to mitigate effectively.

There has been an increased need in recent years to clear offshore areas of unexploded ordnance (UXO) in readiness for wind farm and cable developments. Detonation of UXOs can produce some of the loudest man-made underwater sounds and can cause fatal injury, auditory damage and behavioural responses in marine mammals. Updates to marine mammal injury thresholds used in assessments (NMFS, 2018, Southall et al 2019), combined with the size of potential ordnance that may be encountered, has resulted in a range of predicted injury zones of up to 15km. Furthermore, in areas of forthcoming development in the North Sea it is still unclear how many UXOs are present and need to be detonated.

A review of noise assessment outputs from past and current projects in UK waters will be presented alongside data reported in the UK Marine Noise Registry. In addition, a review of mitigation measures employed to protect marine mammals during UXO clearance will be provided. The challenges faced by Regulators, SNCBs and industry when considering the risk of injury and mitigation options will be discussed, including issues regarding mitigating impacts at large distances from a source and uncertainty around sound at source and noise propagation modelling. A need for field recordings, particularly at distance, to validate noise models will be highlighted, as well as a need to use more realistic parameters in noise modelling.

NMFS. (2018). “2018 Revision to Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing”. National Marine Fisheries Service, U.S. Dept. of Commerce, NOAA Technical Memorandum NMFS-OPR-59, 167 p.

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THE IMPORTANCE OF SOUND SCIENCE FOR EVIDENCE BASED DECISION-MAKING

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There appears to be a growing concern from the public and potentially affected stakeholders about the impacts of seismic surveys on marine ecosystems. When concerned stakeholders review environmental impact assessments for seismic surveys, it is a commonly expressed view that the assessments are poorly supported and further scientific evidence is necessary. This scientific uncertainty often results in additional precaution being applied by regulators during decision making. This in turn results in requirements for additional or more stringent control measures and can cause delays in the environmental approvals process or reduce operational flexibility for seismic data acquisition. It is expected that this problem will only be heightened as transparency of environmental management decision making increases for the offshore petroleum industry and survey operators attempt to access more sensitive areas.

At present, this problem persists because scientific uncertainty is only being acknowledged and addressed in an ad hoc manner, i.e. when it presents a challenge in the environmental approvals process for an individual seismic survey. Even then, the operator's response is typically to apply more precautionary control measures and not to address information gaps. A relatively recent and positive development in Australia is the implementation of scientific studies to test the accuracy of predictions and inform environmental management of seismic surveys.

Australian examples of scientific studies to address predictive uncertainty in environmental impact assessment will be used as case studies to demonstrate the benefit of a more strategic scientific response to EIA challenges. The case studies will highlight challenges encountered when predicting impacts of sound on lesser studied animals, the scientific measures proposed to address the challenges and how these benefitted the environmental approvals process.

The case studies will provide examples of where science has successfully addressed key information gaps to provide assurance that impacts from a particular seismic survey were managed appropriately. However, these studies required significant investment of time, money and resources from individual companies and the scientific questions and outputs were specific to an individual activity's circumstances and may have limitations to broader application. The return on science investment could be increased substantially if the scientific questions were developed and validated at a global level and addressed collaboratively to ensure the scientific response is well funded and governed and provides outputs that have broad application to EIA.

AN ARRAY OF ACOUSTIC PLATFORMS TO INVESTIGATE INDO-PACIFIC HUMPBACK DOLPHIN (*Sousa chinensis*) DISTRIBUTION IN A COASTAL CONSTRUCTION ZONE OF CHINA, HAINAN ISLAND

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Passive Acoustic Monitoring (PAM) offers a non-invasive and reliable method to survey acoustically marine mammals and provide information on their distribution and activities at high spatiotemporal resolution (Zimmer, 2011). Indo-Pacific Humpback dolphin (*Sousa chinensis*) is a species inhabiting the tropical and warm-temperate waters of the eastern Indian Ocean and Southeast Asia and a new record was logged in 2014 (Li et al, 2016; Dong et al., 2017) in the coastal waters southwest of Hainan Island (South China Sea). The significant recent increase in coastal development in this area, related to economic growth linked with touristic business, has resulted in several activities (e.g. seashore construction, coastal urbanization, artificial islands) that could impact the dolphin habitat.

We are investigating the long-term distribution of this population using an array of underwater platforms installed in shallow waters (10-20 m depth). In each PAM site, an acoustic stationary recorder (Soundtrap) is installed periodically from Feb 2018. A sampling frequency of 288 kHz with 16-bit quantization was chosen. We established a recording sampling protocol of 5 min every 30 min, with about two months of data acquisition with no-battery recharge. The PAM survey that we are applying with multiple platforms encouraged us to use automatic analyses methods (Caruso et al., 2017).

Here, preliminary results on species distribution are presented across multiple temporal and spatial scales. A detection algorithm was developed in MATLAB to identify echolocation signals (clicks) of Indo-Pacific humpback dolphin. Moreover, the accuracy of click detection process was examined through the different locations and an acoustic data logger (A-tag) was also installed in each platform. The acoustic presence of dolphins was checked via manual approach (spectrogram visualization and listening, Raven Lite software) and other signals of interest (natural, biological and anthropogenic sources) were identified in correspondence with dolphin vocalizations.

Caruso, F., Alonge, G., et al. (2017). "Long-Term monitoring of dolphin biosonar activity in deep pelagic waters of the Mediterranean Sea". Scientific Report, 7: 4321, DOI: 10.1038/s41598-017-04608-6.

Dong, L., Liu, M., Dong, J., and Li, S. (2017). "Acoustic occurrence detection of a newly recorded Indo-Pacific humpback dolphin population in waters southwest of Hainan Island, China". The Journal of the Acoustical Society of America, 142(5), 3198–3204. doi:10.1121/1.5011170

Li, S., Lin, M., Xu, X., Xing, L., Zhang, P., Gozlan, R.E., Huang, S. and Wang, D. (2016). "First record of the Indo-Pacific humpback dolphins (*Sousa chinensis*) southwest of Hainan Island, China". Marine Biodiversity Records, 9:3.

Zimmer, W.M.X. (2011). "Passive acoustic monitoring of cetaceans" (Cambridge University Press, United Kingdom

CHARACTERIZATION OF THE PERFORMANCE OF A FISH AND HUMAN TORSO PHYSICAL MODEL TO UNDERWATER IMPULSE ACOUSTICS

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The Naval Submarine Medical Research Laboratory (NSMRL) is the United States Navy's lead on the bioeffects of underwater sound and blast on swimmers and divers. To provide more accurate injury predictions due to underwater blast, NSMRL has developed the Quantitative Instrumented Torso (QUINT). This physical model is geometrically representative of a 50th percentile human male with inflatable lungs, rib cage, intestines, and integrated sensors for measuring the internal structures' responses to blast exposure. While QUINT is valuable for measuring response to underwater blast, it is limited in its ability to be correlated with actual human injury response.

NSMRL has also developed a fish physical model. This model is geometrically representative of a 260 mm (total length) trout-like fish with inflatable swim bladder, skeletal structure, integrated blast sensors, and a three-dimensional accelerometer approximately where the ears would be located. Unlike QUINT, the fish model can be tested alongside live fishes to correlate the internal sensor measurements with actual fish injury response. As we evaluate the response of the fish physical model to live fish, we can use this information to characterize the fish model's performance and thus obtain critical information about the potential capabilities of both the fish and QUINT physical models to provide injury predictions for their respective biological counterparts.

NSMRL has conducted experiments with the fish and QUINT physical models as well as live fishes in response to seismic air gun exposures. In addition, studies are underway characterizing the physical models' responses to small charge explosives, with the long term goals of testing these models in locations where fishes are being impacted by explosives or other active acoustics. The development and testing of these physical models will be discussed as well as how the models could be used for injury prediction and mitigation by the diving and environmental communities.

BOAT NOISE AND BLACK DRUM COMMUNICATION IN MAR CHIQUITA COASTAL LAGOON (BUENOS AIRES, ARGENTINA)

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The Mar Chiquita coastal lagoon (Buenos Aires, Argentina) has an important conservation value for its unique ecosystem. It is classified as a Man and the Biosphere Reserve (MAB, UNESCO, Iribarne 2001) and it is an important area of tourism and local fishing. From September 1st to December 1st, during the week days, a partial ban of fishing activities is imposed in order to protect the reproductive period of silversides *Odontesthes* spp.. However, the black drum, *Pogonias cromis*, is also an important fish species presents in the lagoon (Cousseau and Perrotta, 2004). During the reproductive period, males produce drumming sounds as advertisement calls characterized by frequency at approximately 150 Hz (Locascio et al 2011). Boat noise may overlap *P. cromis* sounds causing a potential masking effect (Smott et al. 2018), but it is not known if communication is altered.

Aims of our study are to: 1) evaluate the effects of different boat noises on *P.cromis* acoustic communication 2) analyse the effectiveness of fishing ban activity from an acoustic point of view.

Acoustic data were collected during November 2017 by using an autonomous recorder equipped with a Benthowave BII 7016 T6 hydrophone. The sample frequency was 192 kHz at 16 bit, alternating 2 minutes of recordings and 8 minutes of pause.

All the dataset was visually inspected. *P. cromis* sounds were identified and counted combining pulse train analysis of Avisoft SASlab pro. The number of files where boat noise passages were recorded was counted. To quantify the potential impact of the boat noise, they were categorized relating to their frequency extension: 1) Class A, when the noise extension was below 700 Hz; 2) Class B, when the noise extension was only over 700 Hz; 3) Class C, when the noise extension covered below and over 700 Hz.

We recorded boat noise during fish signal emission on 12,8 % of data. We found that the presence of boat noise significantly affected the number of fish signals (Welch's Test $p < 0.001$); boat noise that overlap the fish signals frequency (Class A and C) significantly reduced the number of fish signals (Tamhane post-hoc, $p < 0.001$). The ban of *Odontesthes* spp. fishing determined the reduction of boat noise class C (U-Mann Whitney test: $Z = -3,025$, $p > 0.01$) but it doesn't affect the other kind of noises. The results show the degree of noise impact on *P. cromis* communication and underline the importance to adapt the current management of human impacts.

Cousseau, M. B., Perrotta, R. G. (2004). "Peces marinos de Argentina. Biología, distribución, pesca," edited by Instituto Nacional de Investigacion y Desarrollo Pesquero (INIDEP), Mar del Plata, Argentina.

Mok, H. K., and Gilmore, R. G. (1983). "Analysis of sound production in estuarine aggregations of *Pogonias cromis*, *Bairdiella chrysoura*, and *Cynoscion nebulosus* (Sciaenidae)," Bull. Inst. Zool. Acad. Sin. 22,157–186.

Iribarne, O. (2001). "Reserva de Biosfera Mar Chiquita. Características físicas, biológicas y ecológicas," edited by O. Iribarne (Martín-Argentina)

Smott, S., Monczak, A., Miller, M. E., and Montie, E. W. (2018). "Boat noise in an estuarine soundscape—A potential risk on the acoustic communication and reproduction of soniferous fish in the May River, South Carolina," Mar. Poll. Bull. 133, 246-260.

STUDY OF TAIWAN INTEGRATED MARINE MAMMAL MONITORING NETWORK (TIMMAMN)

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Sousa chinensis (aka Chinese white dolphin), a critically endangered species, resides in the coastal waters of western Taiwan. The coastal development close to their major habitat has seriously challenged their survival. This study proposes an integrated monitoring network to be installed in their protection zones which occupy a thin strip expanding 20 km in the east-west direction, and 200 km in the north-south direction along the west coast of Taiwan. The integrated monitoring network comprises of visual and audio components, namely marine mammal observers (MMO) and passive acoustic monitoring (PAM) units. These two components can co-exist in a mobile or fixed platform or are conducted separately.

The TIMMAMN comprises seventy to one hundred fixed PAM stations to form 10 sparse arrays (similar to interception lines) perpendicular to the coast and cover 200 km coastline which can track the crossings of the dolphins. Mobile platforms with visual units (high-definition video cameras served as MMOs) and audio units (dipped hydrophones or tow hydrophone array) can be used to track their whereabouts.

The main purpose of the monitoring network is to provide important baseline information about marine mammals for the government in environmental impact assessment when coastal development plans coincide with the dolphins' protection zones. Effectiveness of the network will be presented with simulations and feasibility test results.

Brunoldi, M., Bozzini, G., Casale, A., Corvisiero, P., Grosso, D., Magnoli, N., & Povero, P. (2016). "A permanent automated real-time passive acoustic monitoring system for bottlenose dolphin conservation in the Mediterranean sea," *PloS one*, 11(1), e0145362.

Lin, T. H., Chou, L. S., Akamatsu, T., Chan, H. C., & Chen, C. F. (2013). "An automatic detection algorithm for extracting the representative frequency of cetacean tonal sounds," *The Journal of the Acoustical Society of America*, 134(3), 2477-2485.

Port of Vancouver. (2018). *Underwater listening station- ECHO Program Year 1 Report*. (JASCO Applied Sciences) The Cornell Lab of Ornithology. "Right Whale Listening Network," Bioacoustics Research Program.

<http://www.listenforwhales.org/page.aspx?pid=430>

CAN BELUGA EXPOSURE TO SHIPPING NOISE BE REDUCED DESPITE A TRAFFIC INCREASE? AN INDIVIDUAL-BASED MODEL TO INFORM A NOISE ABATEMENT PROCESS IN THE ST. LAWRENCE ESTUARY AND THE SAGUENAY RIVER

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In the context of the Quebec Maritime Strategy, several port-industrial complexes could be developed nearby or within the critical summer habitat of the St. Lawrence Estuary (SLE) beluga population. In the absence of efficient noise abatement measures, the traffic increase associated with the planned development projects would increase belugas' cumulative exposure to shipping noise. The SLE beluga population is listed as *Endangered* under the Canadian Species at Risk Act, and *Threatened* under Quebec Act Respecting Threatened or Vulnerable Species. A chronic exposure to noise is a recognized stressor, that might play a role in the current decline of the population. Any increase of anthropogenic pressure could lower even more their chance of recovery. In this context, the Government of Quebec funded a 5-year research program led by Université du Québec en Outaouais to assess the potential impacts of port-industrial development projects and explore and recommend noise reduction options in collaboration with multiple stakeholders.

This inherently interdisciplinary research program first focuses on improving a prototype of an individual-based simulation model for beluga and vessel movements coupled with models of underwater sound sources and propagation (Chion et al., 2017). This simulation model will be used to assess and compare realistic scenarios of navigation noise abatement co-developed by a multi-stakeholder working group (Chion et al., 2018). To do so, the research program is tied in with other scientific efforts including some conducted under the Canadian Ocean Protection Plan. In parallel, the research program will propose an economic framework of the noise abatement options for the maritime industry based on their costs and benefits. This study aims at providing stakeholders, including the Government and the maritime industry, with tools for decision-making and ways of reducing the acoustic footprint of shipping.

First, we will present the global approach to 1) cumulative noise impact assessment of navigation on SLE beluga and 2) noise abatement option co-development and recommendation process. We will then describe the main modules of the spatiotemporal simulation model with a focus on describing the vessel and whale movement model, and acoustic model. The simulation plan to assess beluga noise exposure and noise abatement options will also be discussed.

Chion, C., Lagrois, D., Dupras, J., Turgeon, S., McQuinn, I. H., Michaud, R., Ménard, N., et al. (2017). "Underwater acoustic impacts of shipping management measures: Results from a social-ecological model of boat and whale movements in the St Lawrence River Estuary (Canada)," *Ecological Modelling*, 354, 72–87.

Chion, C., Turgeon, S., Cantin, G., Michaud, R., Ménard, N., Lesage, V., Parrott, L., et al. (2018). "A voluntary conservation agreement reduces the risks of lethal collisions between ships and whales in the St Lawrence Estuary (Québec, Canada): From co-construction to monitoring compliance and assessing effectiveness," *PLoS ONE*, 13, e0202560.

TRENDS AND DEVELOPMENTS IN THE REGULATION OF IMPACTS OF NOISE ON AQUATIC HABITATS

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The underwater acoustic environment provides important biologically relevant information to animals, allowing them to perceive the auditory scene—detecting predators and prey, locating conspecifics, and orienting themselves within their environment (Fay & Popper, 2000). While most regulations worldwide focus on the acute effects of noise on individuals, usually cetaceans, the quality of the acoustic habitat has also started to come to the forefront of interest. Governments and multinational organizations have increasingly noted that a regulatory focus simply on injury or behavioral disturbance of cetaceans likely allows for underestimating impacts on the animals in question and disregards impacts on fishes and invertebrates.

Globally, regulatory agencies have approached the issue of the impact of underwater anthropogenic sound in different ways. While in the United States laws like the Marine Mammal Protection Act and the Endangered Species Act generally treat sound as an acute stressor that impacts animals rather than their habitats, approaches over the past decade have started to consider regulating sound as an impact to the habitat rather than just to the animal. Sound as a potential barrier to movement and migration is specifically mentioned in critical habitat designations under the ‘Endangered Species Act’ for sea turtles and sturgeon, and in 2018, sound level was listed as component of the critical habitat of a population segment of false killer whales inhabiting the waters surrounding the Hawaiian Islands.

Moreover, the European Union has established ambient sound as an indicator of Good Environmental Status under the Marine Strategy Framework Directive (2008/56/EC), with the goal that member states attain noise levels which do not inhibit “clean, healthy, and productive” oceans by 2020, a deadline fast approaching with discussion on measuring impacts still ongoing. The Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas has taken a different approach from the EU or other regulators and rather than establishing thresholds or criteria, has established a framework for analyzing the impacts of underwater noise (Prideaux, 2016). Clearly, agencies which oversee aquatic resources are implementing new mechanisms to regulate and control underwater noise.

This presentation will review existing national and international regulations to assess how noise as an impact to acoustic habitat is regulated. Special attention will be provided to developments in policy or regulation over the past three years, since the 2016 Aquatic Noise Conference.

Fay, R. R., and Popper, A.N. (2000). “Evolution of Hearing: the inner ears and processing.” *Hearing Research*. 149, 1–10.
Prideaux G, (2016), *CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities*, Convention on Migratory Species of Wild Animals, Bonn.

DIFFERENCES IN THE POTENTIAL EXPOSURE OF MARINE MAMMALS IN THE CALIFORNIA CURRENT: TOWARDS AN UNDERSTANDING OF THE POPULATION CONSEQUENCES OF DISTURBANCE

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While many studies have examined the sensitivity of marine animals to underwater noise, an essential component of assessing risk is to determine the proportion of the population exposed to a disturbance. Given the differences in the movement patterns of marine mammals, some species are likely to be more at risk than others are. For example, individuals of resident species are likely to receive greater exposure than highly migratory species. While differences in the probability of exposure has been examined within a species in a variety of habitats, none has compared the differences in exposure of a group of marine mammals within the same habitat. Here we compare the probability of exposure for blue, humpback and beaked whales, California sea lions and northern elephant seals existing within the California Current System. Using satellite telemetry data, we modeled the potential exposure of individuals to an acoustic disturbance by estimating how many individuals would be exposed and for how long. We used switching state space models to identify foraging and transit regions along the tracks, and calculated the time spent in each foraging region and the time spent in transiting between foraging sites. A series of 100 mobile sound sources were modeled within the foraging habitat of each of these species. We then used the tracking data to estimate the amount of time the animals would be exposed to a sound, assuming exposure is sufficient to cause a change in behavior. As in earlier models, this will be the worst-case scenario and would overestimate the potential impact of a sound source. Individuals of the resident species, beaked whales and California sea lions had a greater probability of exposure than the highly migratory species. Of these, individual northern elephant seals were least exposed followed by blue whales and then humpback whales. Following previous work¹ on population consequences of disturbance, these analyses are a necessary first step to estimate the population impact of a disturbance as they provide an estimate of the proportion of the population that would be exposed. These results can then be used to estimate the energetic costs of that disturbance on a female's energetic budget in terms of energy expended but not acquired, followed by an estimate of the additional time a female would have to spend foraging to offset this lost foraging time, and finally estimating the subsequent effects on offspring growth and survival.

¹Pirotta, E., C. G. Booth, D. P. Costa, E. Fleishman, S. D. Kraus, D. Lusseau, D. Moretti, L. F. New, R. S. Schick, L. K. Schwarz, S. E. Simmons, L. Thomas, P. L. Tyack, M. J. Weise, R. S. Wells, and J. Harwood. 2018. Understanding the population consequences of disturbance. *Ecology and Evolution* 8:9934-9946.

THE EFFECTS OF SEISMIC EXPLORATION ON SNOW CRAB MOVEMENT OBSERVED WITH POSITIONING TELEMETRY ON THE CONTINENTAL SLOPE OF ATLANTIC CANADA

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Sound is an environmental feature that is used by marine animals for a variety of life activities. Consequently, alterations to the soundscape have the potential to alter an individual's behaviour, physiology and ultimately fitness. Furthermore, such responses have potential to negatively influence commercial fishing interests.

In Atlantic Canada, snow crab fishing and hydrocarbon extraction are billion dollar industries. Harvesters contend that seismic noise has strong negative effects on catch rates; an issue that will become more acute given that the species is in decline.

As part of a collaborative, multi-disciplinary study (Morris et al. 2018), positioning telemetry was used to assess the behavioral responses of snow crab to exposure from industry seismic vessels. While effects of seismic exposure on snow crab movement could not be ruled out completely, effects were at most quite small relative to natural variation. Environmental conditions related to water temperature, time of day and water velocities affected snow crab movements but also explained relatively little of the observed variation.

In concert with other study components (Catch-per-unit-effort, physiological, genomic, and chronic exposure studies), telemetry results indicate that seismic effects on snow crab behaviour are subtle and are perhaps less severe than observed for other taxa (e.g. marine mammals and fish).

Moriss, C.J., Cote, D. Martin, B., and Kehler, D. (2018). Effects of 2D seismic on the snow crab fishery. *Fish Res* 197, 67-77.

THE PERIPHERAL AUDITORY SYSTEM OF MYSTICETES: SENSITIVITY AND DIRECTIONALITY

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The frequency sensitivity and directional characteristics of the peripheral auditory system are important factors for survival in marine vertebrates. We developed a set of tools, the Vibroacoustic Toolkit (VATk), that provides a means to simulate and visualize the biomechanical processes of mysticete sound reception, particularly for low-frequency (LF) sounds. The VATk combines CT scan data with elastic tissue properties and finite element modeling (FEM) techniques. X-ray computed tomography (CT) scanning gathered density maps for three mysticetes, an entire minke whale (*Balaenoptera acutorostrata*) and intact heads from a fin whale (*Balaenoptera physalus*) and a gray whale (*Eschrichtius robustus*).

These investigations implemented various finite element modeling tools and techniques, including the VATk, to generate three significant discoveries: (1) the first computational audiograms for two mysticetes, a fin whale and a minke whale; (2) evidence that mysticete skulls are integral to the primary bone conduction mechanism for LF sound reception; and (3) LF sound reception in mysticetes is directional, but the underlying mechanism(s) are currently unclear.

Minke whales produce pulsed sounds between 50 and 300 Hz, while the "boing" sounds occur between 1-2 kHz. The computational audiogram for the minke covers both ranges, but also includes a prediction of sensitivity between 10–40 kHz. This "high-frequency" sensitivity may offer some protection against killer whale predation.

The tools and techniques we developed provide an innovative computational platform that simulates the intricate biomechanical processes of baleen whale sound reception (Cranford and Krysl, 2015), as well as biosonar signal generation, beam formation, and sound reception in toothed whales (Cranford *et al.*, 2014; Cranford *et al.*, 2015).

Our current hypothesis is that *all* cetacean heads function like acoustic antennas (Cranford and Krysl, 2017). Inputs to the ears are integrated over the entire surface of the head. Some surface areas contribute more than others, but there is no specific "window" or bilateral channel for sound reception.

Cranford, T., and Krysl, P. (2017). "Sound Paths, Cetaceans," in *Encyclopedia of Marine Mammals*, edited by B. Würsig, J. G. M. Thewissen, and K. Kovacs (Academic Press, San Diego), pp. 963-966.

Cranford, T. W., Amundin, M., and Krysl, P. (2015). "Sound production and sound reception in delphinoids," in *Dolphin Communication and Cognition: Past, Present, and Future*, edited by D. L. Herzing, and C. M. Johnson (MIT Press, Cambridge), pp. 19-48.

Cranford, T. W., and Krysl, P. (2015). "Fin Whale Sound Reception Mechanisms: Skull vibration enables low-frequency hearing," *PLoS ONE* 10, e116222.

Cranford, T. W., Trijoulet, V., Smith, C. R., and Krysl, P. (2014). "Validation of a vibroacoustic finite element model using bottlenose dolphin simulations: The dolphin biosonar beam is focused in stages," *Bioacoustics* 23, 161-194.

GROUP BEHAVIOURAL RESPONSES OF JUVENILE COMMON CARP (*Cyprinus carpio*) TO PULSED TONAL STIMULI IN THE PRESENCE OF MASKING NOISE

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In the aquatic environment, migratory freshwater fish species encounter many threats from human activity in the form of hydropower turbines and water abstraction pumps. Traditionally, these have been mitigated using mesh screens. Physical screens, however, incur high maintenance and installation costs, and cause high mortality rates at higher water velocities. As such, behavioural barriers and interest in the use of sound as a freshwater fisheries management tool has taken off in recent years.

The majority of studies investigating fish response to sound are conducted under relatively quiet ambient background noise conditions. These scenarios are a far step removed from real life situations. Noise conditions at anthropogenic barriers act as a crucial constraint to the signal transmission of deployed acoustic deterrents, and subsequent behavioural responses of targeted species (Wiley, 1994). Secondly, our understanding of hearing thresholds, acoustic masking, signal to noise ratio and critical bands, is mostly obtained through experiments investigating auditory sensitivity (e.g. ABR, AEP). This may be problematic given that the capability of an individual to detect a stimulus does not directly predict a behavioural response (Kemp et al., 2012).

Group behavioural responses of juvenile common carp (*Cyprinus carpio*) to a pulsed tonal acoustic stimuli (170 Hz; critical band ~ 151-190 Hz; Kojima et al., 2005) either in the presence or absence of a known broadband background masking noise (120-3000 Hz; @ 110 dB re 1 μ Pa (RMS)) was investigated. Carp were chosen for their excellent hearing, and importance within fisheries management from both a conservational (e.g. Asia) and highly invasive (e.g. U.S.A., Australia) perspective. Three differing signal to noise ratios were investigated (low, medium, high). Experiments were performed in an experimental arena (86 x 30.6 x 30.2 cm), within an acoustically isolated chamber. Underwater speakers, placed outside of the experimental area, generated the sound field. A hydrophone was moved around a matrix system to map the sound field (SPL (RMS)) of both tonal and broadband noise (1/3 octave band). Fish were recorded using a webcam, and behaviour tracked and quantified using a custom written MATLAB script.

Preliminary investigation of results suggest a significant impact of masking on fish group behavioural response to tonal stimuli. This presentation will discuss these results within the context of using sound to conserve or control fish species.

Kemp, P.S., Anderson, J.J., and Vowles, A.S. (2012). "Quantifying behaviour of migratory fish: Application of signal detection theory to fisheries engineering," *Ecol. Eng.* 41, pp. 22-31.

Kojima, T., Ito, H., Komada, T., Taniuchi, T., and Akamatsu, T. (2005). "Measurements of auditory sensitivity in common carp *Cyprinus carpio* by the auditory brainstem response technique and cardiac conditioning method," *Fisheries Sci.* 71, pp. 95-100.

Wiley, R.H. (1994). "Errors, exaggeration, and deception in animal communication," in: *Behavioural mechanisms in evolutionary ecology*, edited by Leslie A. Real (University of Chicago Press) pp. 157-189.

PHYSICAL EFFECTS OF UNDERWATER BLAST EXPOSURE ON FISHES

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There is long interest in effects of exposure to explosions on fishes, but few scientifically rigorous data (e.g., Popper *et al.*, 2014). While it is likely that fishes close to an explosion will die, the larger concern is determining the distance from a blast where fishes are no longer at risk of physical injury or other impact. Thus, the goal of this study is to develop a dose-response curve for effects of exposure of fishes from an explosive charge. We describe our approach to the study and the first preliminary data collected in 2018.

The experimental protocol was similar to that used in earlier studies of exposure to seismic airguns (Popper *et al.*, 2016). In each of five experimental treatments, Pacific sardines (*Sardinops sagax caerulea*) were placed in five cages (0.35 m³) from 18 to 250 m from the source and exposed to a single detonation at depth 10 m of C4 explosive (equivalent to 4.7 kg TNT). Water depth along the whole range was 20 m and the cages were at about 10 m depth. Non-exposed fish (controls) were treated identically. Following exposure, fish were euthanized and necropsied using established methods (Halvorsen *et al.*, 2012).

Each cage was instrumented with blast sensors to measure the approximate acoustic field experienced by the fish. Several acoustic metrics were calculated as function of range and depth, including peak pressure, sound exposure level, and pressure impulse to explore potential correlations between blast acoustics and injury response. An important feature of the study is the limit in negative pressure observed owing to acoustic cavitation; this effect, and other sound field properties observed along the experimental range will be discussed.

Results from the initial study showed no immediate mortality, even to fish only 18 m to the explosion. A variety of different physical effects were observed during necropsy, including damage to the swim bladder, kidney, and blood vessels. However, the effects were not consistent between fishes, even within any one cage. Effects were seen as far as 200 m from the source, but preliminary analysis suggests few, if any effects, at 250 m. Studies in 2019 will incorporate different species to address different swim bladder and hearing anatomy. (Work supported by U. S. Navy Living Marine Program.)

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ACOUSTIC MONITORING DURING A PIPELINE INSTALLATION PROJECT IN COOK INLET, ALASKA

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In 2018, NOAA's National Marine Fisheries Service (NMFS) issued an incidental harassment authorization (IHA) to Harvest Alaska pursuant to section 101(a)(5)(D) of the Marine Mammal Protection Act (MMPA). The IHA authorized the take of marine mammals, by Level B harassment, incidental to installing two subsea oil and gas pipelines in Cook Inlet, Alaska. Primary work included the use of multiple vessels in a concentrated area, pulling pipelines from a barge, and barge anchor handling. Harvest conducted long-term acoustic and marine mammal monitoring to gauge the acoustic footprint of the project and potential beluga whale (*Delphinapterus leucas*) impacts.

A passive acoustic mooring package containing a Loggerhead Instruments DSG-ST recorder and Chelonia C-POD echolocation logger was deployed 1 km north of the pipeline corridor for 128 days during construction. A Matlab script calculated broadband sound pressure level (SPL in dB rms re 1 μ Pa for 20 Hz – 24 kHz). Pamguard v2.0 automated beluga whale whistle and calls. Matlab based Triton version 1.93 generated long-term spectrograms to identify and log anthropogenic noise events. C-POD software version 2.044 was used to process echolocation and identify beluga detections.

Results demonstrate broadband vessel noise was the primary source of acoustic energy and vessels were generally equally distributed in time and space. During the IHA process, NMFS estimated noise levels of 120 dB would extend 2.7 km from the pipeline corridor. RLs at the mooring ranged from 86 to 137 dB SPL (median = 113.1 dB; mean = 114.8 dB). RLs at the mooring exceeded 120 dB for 31.1% of the sampled time. Assuming practical spreading (a conservative transmission loss rate for Cook Inlet), RLs would have to be 126.5 dB to equate to the 2.7 km 120 dB isopleth. RLs exceeded 126.5 dB 14.8% of sampled time. These results demonstrate the IHA analysis was conservative the majority, but not all, of the time and potential harassment was adequately characterized. Minimizing and clustering vessel movement would likely reduce the project's acoustic footprint.

When concurrent acoustic and visual efforts were compared (n=128 days), all days with sightings included acoustic detections except 3 (2.3 %), while 28 days (21.3%) with acoustic detections did not include sightings. Maximum acoustic detection range from the mooring was estimated at 6.7 km for vocalizations and 2.4 km for echolocation. Visual detection range was 7–10 km approximately 85% of the time and less than 4 km approximately 6% of the time (Sitkiewicz et al., 2018).

EFFECTS OF SOUND EXPOSURE FROM A SEISMIC AIRGUN ON HEART RATE, ACCELERATION AND DEPTH USE IN FREE-SWIMMING ATLANTIC COD AND SAITHE

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Airguns used for offshore seismic exploration by the oil and gas industry contribute to globally increasing anthropogenic noise levels in the marine environment. There is concern that the omnidirectional, high intensity sound pulses created by airguns may alter fish physiology and behaviour. A controlled short-term field experiment was performed to investigate the effects of sound exposure from a seismic airgun on the physiology and behaviour of two socio-economically and ecologically important marine fishes; the Atlantic cod (*Gadus morhua*) and saithe (*Pollachius virens*). Biologgers recording heart rate and body temperature and acoustic transmitters recording locomotory activity (i.e., acceleration) and depth were used to monitor free-swimming individuals during experimental sound exposures (18 to 60 dB above ambient).

Fish were held in a large sea cage (50 m diameter; 25 m depth) and exposed to sound exposure trials over a three-day period. Sound levels, both in terms of pressure and particle motion was continuously recorded in the sea cage. Concurrently, the behaviour of untagged cod and saithe was monitored using video recording. The cod exhibited reduced heart rate (bradycardia) in response to the particle motion component of the sound from the airgun, indicative of an initial flight response. No behavioural startle response to the airgun was observed, both cod and saithe changed both swimming depth and horizontal position more frequently during sound production. The saithe became more dispersed in response to the elevated sound levels. The fish seemed to habituate both physiologically and behaviourally with repeated exposure. In conclusion, the sound exposures induced over the time frames used in this study appear unlikely to be associated with long-term alterations in physiology or behaviour. However, additional research is needed to fully understand the ecological consequences of airgun use in marine ecosystems.

EXPOSURE TO SEISMIC AIR GUN SIGNALS ALTERS BEHAVIOR AND PHYSIOLOGY IN THE SCALLOP *Pecten fumatus*

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Little is known regarding how invertebrates, including economically and ecologically important bivalves, are affected by exposure to seismic signals. In a series of field-based experiments, we investigate the impact of exposure to seismic surveys on scallops, using measurements of physiological and behavioral parameters to determine whether exposure may cause mass mortality or result in other sublethal effects. Exposure to seismic signals was found to significantly increase mortality when compared with control samples, particularly over a chronic (months post-exposure) time scale. Exposure did not elicit energetically expensive behaviors, but scallops showed significant changes in behavioral patterns during exposure, through a reduction in classic behaviors and demonstration of a non-classic “flinch” response to air gun signals.

Furthermore, scallops showed persistent alterations in recessing reflex behavior following exposure, with the rate of recessing increasing with repeated exposure. Hemolymph (blood analog) physiology showed a compromised capacity for homeostasis and potential immunodeficiency, as a range of hemolymph biochemistry parameters were altered and the density of circulating hemocytes (blood cell analog) was significantly reduced, with effects observed over acute (hours to days) and chronic (months) scales. The size of the air gun had no effect, but repeated exposure intensified responses. We postulate that the observed impacts resulted from high seabed ground accelerations driven by the air gun signal. Given the scope of physiological disruption, we conclude that seismic exposure can impact scallops.

THE EFFECTS OF SEISMIC AIR GUN SIGNALS ON THE STATOCYST AND RIGHTING REFLEX OF SOUTHERN ROCK LOBSTER (*Jasus edwardsii*)

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The statocyst is the invertebrate mechanosensory organ responsible for the detection of gravity and the sense of body positioning. Statocysts are generally comprised of a fluid filled capsule in which a dense body is associated with a field of sensory hairs. Gravity or movement causes the body to act on the hairs, creating a sensory signal.

In this study, the impact of seismic surveys on the statocyst of the Southern Rock Lobster (*Jasus edwardsii*) was investigated. Lobsters rely on input from the statocyst to control swimming and body posture during their escape response, which involves a series of powerful tail flips to propel the lobster away from danger (Newland & Neil 1987; 1990). To evaluate whether the statocyst of the lobster is affected by exposure to seismic air gun signals, a series of field-based experiments were performed using an air gun fitted with either a 45 in³ or 150 in³ chamber, which generated cumulative sound exposure levels of 192-195 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$, equivalent to exposure to a modelled 3065 in³ source at a range of 100-200 m. In these experiments, 120 exposed lobsters were compared to 119 unexposed controls at days 0, 2, 14, 120 and 365 post-exposure for two factors: damage to the statocyst sensory hairs, quantified using scanning electron microscopic analysis, and righting reflex, assessed by measuring the time taken for lobsters to return to a dorsum-up position after being placed ventrum-up in a bin of seawater.

Lobsters exposed to seismic signals were found to have significantly more damaged hairs than control lobsters these experiments, with the damage apparent as the severing of the hairs from the hair cell body. Damage was centralised in the area in contact with the statoconia, the dense particles associated with the hair cells upon which gravity acts. The damage was persistent in lobsters that had moulted, raising the possibility that the damage could be long-term to permanent. Exposure also resulted in impaired righting, with exposed lobsters taking 80-157% longer to right themselves. Again, this difference was persistent to the end of the experiment at 365 days post-exposure.

These results indicate that exposure to air gun signals caused morphological damage to the statocyst of rock lobsters, which can in turn impair complex reflexes. These findings add further evidence that anthropogenic aquatic noise has the potential to harm invertebrates, necessitating a better understanding of possible ecological and economic impacts.

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EFFECTS OF NOISE ON THE ACOUSTIC BEHAVIOUR OF KILLER WHALES, *Orcinus orca*, IN ICELAND

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Some killer whales (*Orcinus orca*) in Iceland are believed to be specialized in feeding on herring (*Clupea harengus*). Only in Icelandic waters killer whales have been observed using a unique call type known as the ‘herding call’ (i.e. relatively long, lower-frequency vocalisations associated with feeding events) that is typically used by the whales before the fish is debilitated with a tail slap. Use of sound is not only important for killer whales during fitness-enhancing behaviour, but also during other activities such as social interactions.

The Vestmannaeyjar archipelago in the south of Iceland is a known herring-spawning ground where killer whales come in summer to feed on spawning herring. However, the area also has relatively high vessel presence. With the increase in shipping, and anthropogenic activities in the oceans in general, both worldwide and locally, questions arise regarding impacts of noise on killer whales. Vocalisation may be masked, potentially resulting in reduced foraging efficiency and hampered communication, and noise may directly disturb behaviour. Anthropogenic noise may thus have direct and indirect impacts on individuals, and possibly on the overall population.

The aim of this study was to assess the effects of anthropogenic noise on the acoustic behaviour of killer whales in Vestmannaeyjar. Acoustic data were gathered continuously during June to August 2018 using two bottom-moored acoustic recorders. Land-based observations of vessels and killer whale groups in the area were collected during the same period, whenever weather conditions allowed, using a theodolite. Individual killer whale whistles and calls were identified using an automatic detection algorithm and then characterised in Raven Pro. Ambient noise levels just prior to the vocalisations were measured in third octave bands in PAMGuard. We quantified the effects of noise on the acoustic behaviour of the whales by modelling the relevant signal parameters as functions of vessel presence, type, and noise levels.

HOW COULD WE PREDICT EFFECTS OF NOISE ON FISH REPRODUCTION

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Impacts of anthropogenic noise on aquatic animals range from short-term avoidance to long-term changes in life-history traits. One thing we know little about is how noise affects fish reproductive behavior and reproductive success, even though noise may affect spawning success and offspring survival in some species. However, fish species vary widely in reproductive traits and behavior and this may affect their sensitivity to noise-disturbance. In addition, human sound-sources vary in their characteristics as well, with for example long-drawn and relatively continuous sounds or brief and repeated pulsed sounds. Here, we propose a method to identify which reproductive traits are most likely to be sensitive to the different types of anthropogenic noise.

Despite sparse data on the effects of anthropogenic noise on reproduction, it is well-investigated how stress and the disruption of communication can affect fish reproduction. We combined this knowledge with meta-analyses that test the effects of different anthropogenic sound types on fish behavior and physiology to formulate predictions about how noise could impact fish reproduction. Documented effects of noise were grouped into three mechanistic categories: stress, masking and hearing-loss. For each category, we performed a meta-analysis to test which type of anthropogenic noise was most likely to produce a significant response. Continuous sounds with irregular amplitude and/or frequency-content were most likely to cause stress, and continuous sounds may also be most likely to induce masking and hearing-loss. Thus, irregular continuous sound may be most harmful noise pollution in the context of fish reproduction.

UNDERWATER SOUND MAPPING: STATISTICS AND UNCERTAINTY

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The aim of the Joint Monitoring Programme for Ambient Noise in the North Sea (EU Interreg North Region Programme ‘JOMOPANS’ (<https://northsearegion.eu/jomopans/>)) is to develop a framework for operational monitoring, based on a combination of acoustic modelling and measurements. Output will be the management tools necessary to incorporate the effects of ambient noise in assessment of the environmental status of the North Sea, and to evaluate measures to improve the environment.

JOMOPANS has specified frequency spectra in the 10 Hz to 20 kHz one-third octave (base-10) bands of the monthly percentiles of the distribution of one second snapshots of the depth-averaged sound pressure level (SPL), as acoustic metrics for continuous noise in the North Sea. The main objective of the acoustic modelling is to develop and demonstrate verified and validated modelling methods applicable for generating North Sea maps of this acoustic metric. All partners in the JOMOPANS acoustic modelling work package have prior experience with underwater sound mapping (see e.g. Erbe et al, 2012; Colin et al, 2015; Sertlek et al, 2019). To counter the current lack of standardization in underwater sound measurement and modelling, the partners are comparing results and exchanging lessons learned, with the aim to draw conclusions about the validity and effectiveness of the various models and sources of model input data.

The initial focus in JOMOPANS is on modelling underwater sound from ships and wind. Semi-empirical source models for ships and wind are combined with propagation models to calculate the geographical distribution of the acoustic metrics in the North Sea. Direct numerical calculation of the SPL for all 1 s snapshots in each month for a receiver grid covering the complete North Sea area is not feasible in practice. Moreover, the calculations are subject to several uncertainties associated with the selected modelling approach and available input data. A probabilistic modelling approach reduces the computing efforts and includes modelling uncertainties in maps of sound level percentiles.

An inventory is made of the various uncertainties in the acoustic modelling and input data. Uncertainties in the propagation loss models are quantified by comparison of the results of various models for well-defined benchmark scenarios. The uncertainty in the ship source level model is quantified through comparison with data sets from the ECHO (<https://www.portvancouver.com/environment/water-land-wildlife/echo-program/>) and SHEBA (<https://www.sheba-project.eu/>) projects. Preparations are being made for validation of the modelling against data from JOMOPANS North Sea monitoring stations.

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BEHAVIOURAL CHANGES IN SMALL-SPOTTED CATSHARK (*Scyliorhinus canicula*) EXPOSED TO SHIPPING AND BIOLOGICAL SOUNDS IN AQUARIUM

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Despite in recent years the interest about the human-made noise effects on marine animals have received notably increasing (Abdulla, 2008; Popper and Hawkins, 2012), at date few studies have investigated the potential role of acoustic masking on animal's bio-ecological relationship (Clark et al., 2009). In this study, we exposed twelve specimens of small-spotted catshark (*Scyliorhinus canicula*, Linnaeus 1758) to biological and anthropogenic sounds in order to assess their behavioural changes potentially referable to prey presence and masking effect due to the shipping noise.

Specifically, the sharks held individually in aquarium were exposed to three acoustic experimental conditions differentiated in their spectral (Hz) components (biological and anthropogenic mixed sources) and intensity (dB re 1 μ Pa) levels. Swimming behaviour and spatial distribution of the specimens were recorded. The results highlighted significant differences in time spent in swimming and in spatial use of the aquarium among the experimental conditions. The sharks concentrated their swimming behaviour in the aquarium's lower sections when the intensity levels of the biological acoustic sources were higher than the anthropogenic ones. Conversely, when the intensity levels of the anthropogenic sources were higher than the biological, the specimens showed the highest values of time spent in swimming, and changed their spatial distribution highlighting an aquarium occupancy in favour of the less noisy sections.

In conclusion, this study hypothesised that the environmental soundscape could play an important role in the small-spotted catshark prey-predator relationship and that the impact of masking effect can strictly depends on the acoustic intensity levels.

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COMPARATIVE MORPHOLOGY OF THE EXTERNAL EAR CANAL IN SEVERAL SPECIES OF ODONTOCETES

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The external ear canal in cetaceans has long been considered to be vestigial, an evolutionary remnant that has lost its function with the development of alternative acoustic pathways, such as the mandibular fat bodies. Recent research indicates this is a misconception, as the ear canal proved a well-innervated, well-vascularized complex structure with many active components such as glands, striated musculature, and an abundance of sensory nerve formations (De Vreese et al., 2014). However, the function of the external ear canal in cetaceans is still under debate and the knowledge on its morphology is largely incomplete.

We applied macroscopic dissection and a variety of microscopic analysis, including electron microscopic and immunohistochemical techniques on the ear canals of several species of odontocetes and terrestrial Cetartiodactyla. In this presentation, we highlight the intense innervation of the external ear canal of odontocetes with the abundant presence of lamellar corpuscles over its entire course, and the absence of sensory nerve formations in all studied terrestrial mammals. For the characterization of the corpuscles, we used four different antibodies: anti-S100, anti-NSE, anti-NF, and anti-PGP 9.5. Each corpuscle consisted of a central axon, which stained positive for anti-NF, anti-PGP 9.5, and anti-NSE, and was surrounded by several lamellae of Schwann receptor cells, positive for anti-S100. The periphery comprised a thin cellular layer that stained positive for anti-PGP 9.5 and anti-NSE. These findings show that the corpuscles are mechanoreceptors with a morphological resemblance to the inner core of Pacinian corpuscles and without any capsule or outer core. Based on morphological data, these corpuscles were labeled as simple lamellar corpuscles. Such a sensory innervation may represent a unique phylogenetic feature of cetaceans, and an evolutionary adaptation to life in the marine environment.

We also provide an essential understanding of the comparative morphology of the ear canal in several species of odontocetes, including striped dolphin, bottlenose dolphin, harbor porpoise, long-finned pilot whale, and Cuvier's beaked whale. We give detailed descriptions of the intra- and interspecific differences and similarities in the presence, shape, and characteristics of soft tissues, their interrelations and the association with the middle ear components, and the differences in sensory innervation.

Although the exact function of the ear canal is still not well understood, we provide a basic understanding, essential for further research of the functional morphology of the ear canal of cetaceans, as well as a preliminary hypothetical deviation on its function as a unique sensory organ.

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ECO-ACOUSTIC SCORES OF BIODIVERSITY AT THE LEVEL OF THE WESTERN MEDITERRANEAN BASIN AND THEIR IMPLICATIONS FOR LARGE-SCALE ECOSYSTEM MONITORING

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Marine organisms invertebrate are known to produce an important and diverse biophony composed of sounds emitted while foraging, moving, for reproduction, territorial defense etc. These sounds, in particular those emitted by benthic invertebrates and fish, often represent a major component of coastal soundscapes and have the potential to provide information on the habitat, on organism–environment relationships and biodiversity, relevant for ecosystem monitoring issues. Using early summer recordings from 2015 until 2018 from over 100 temporary recording sites of the CALME network, an acoustic observatory of the Western Mediterranean basin, we established eco-acoustic diversity maps along more than 100 km coastline. These maps were built using eco-acoustic scores of benthic invertebrate and fish sounds. They are based on community ecology principles and are a combination of acoustic sound diversity (in terms of sound repertoire), acoustic richness and abundance (number of sounds or sound density). Acoustic diversity and richness were estimated for benthic invertebrates using 129 400 000 transient sounds characterized by 28 acoustic features. For fish, diversity metrics were obtained from a few thousand sounds classified in types based on acoustic properties only. These eco-acoustic scores of invertebrate and fish assemblages were then tested for natural environmental drivers such as habitat type, habitat characteristics, biocenosis, etc. We hereby provide a first and exhaustive ocean basin-wide picture of coastal marine biophonic diversity using eco-acoustic scores and discuss its implications as environmental proxies for ecosystem monitoring programs.

PASSIVE ACOUSTIC MONITORING OF A SEISMIC SURVEY IN THE BRAZILIAN EQUATORIAL MARGIN

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The present study analyzed data from six lagrangian profilers and four shallow water moorings deployed in the Brazilian Equatorial Margin to monitor the noise contribution of a seismic survey in the basin's soundscape. The operation took place from November 2015 to September 2016 in the deep waters ($z > 1000\text{m}$) of Barreirinhas Basin. The lagrangian profilers were deployed offshore and aimed to provide broad spatial coverage of the survey area while the shallow water moorings were installed in the continental shelf—on water columns near 30m and distant from the activity—to investigate the seismic pulse arrival nearshore.

Each profiler performed up to five 1-minute acoustic windows per day in preset depths down to 1000 metres. Broadband and 1/3 octave pressure levels statistics of the acoustic windows were transmitted via satellite after each dive. The autonomous acoustic recorders in the moorings were configured to continuous recordings and serviced every month for raw data recovery. During the seismic survey period, the profilers accomplished 399 dives with a total of 1693 acoustic windows recorded. The minimum distance from a profiler to the seismic source was 1.3 km where a Peak-to-Peak sound pressure level of 164.86 dB is observed. A sharp decay in the pressure levels is present in the first 50 km, but a difference of 16 dB is still perceived in peak-to-peak levels at 100 km from the seismic source.

Pulse signals with similar characteristics of the seismic source were identified in the shallow water moorings, but further investigation is needed to quantify and correlate their occurrence statistics to the seismic activity.

THE OCEAN SOUNDSCAPE OF THE ANTHROPOCENE

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The ocean of the Anthropocene presents a soundscape that is dramatically distinct from that of the pristine ocean. It continues to change with rapidly expanding ocean industries and human activities and concurrent changes in ocean physics and biology. Widespread removal of sound-producing animals (e.g. whales and fishes) over the past few centuries, dramatic increase in human-generated noise in the past century and recent sea-ice loss, have all led to profound changes in the ocean soundscape, an essential component of the marine ecosystem. While impacts of human-made noise on marine organisms are well recognized, the effect of human activities on ocean soundscapes has not yet received the same attention as for terrestrial soundscapes. Further, changes in marine soundscapes have thus far been overlooked in assessments of cumulative stressors on marine fauna (Young et al. 2016, Lotze et al. 2018) and reviews of global change in the ocean (McCauley et al. 2015, Ingeman et al. 2019). Here, we present the findings of a working group reviewing marine soundscape research to generate greater awareness among policy makers and stimulate research into causes of soundscape-level change in the Anthropocene. We provide an overview of current understanding of ocean soundscapes, their components and ecological relevance, and their link with ocean health. First, we describe the putative traits of soundscapes of the pristine ocean, emphasizing recent discoveries and knowledge gaps. We then summarize how human activity has, directly and indirectly, reshaped the soundscape of the Anthropocene ocean across all components (biophony, geophony and anthrophony). We conclude by exploring alternative trajectories for the soundscape of the future ocean, and identify managerial actions and interventions needed to restore a positive ocean soundscape in the Anthropocene.

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UNDERWATER NOISE LEVELS AROUND THE PORT OF SAINT JOHN

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The Bay of Fundy is a rich environment with its biological diversity and highly productive ecosystems. The area is a hot spot for several species of whales, dolphins, seals, porpoise and shorebirds (Buzeta et al., 2003). Shipping contribution to ambient noise levels have increased as much as 12 dB over the past decades (Hildebrand, 2009). With increased shipping in the Bay of Fundy and resulting increased noise levels from vessel traffic it becomes more important to monitor underwater noise especially in areas frequented by at-risk species such as the North Atlantic Right Whale (*Eubalaena glacialis*). The noise monitoring can provide a baseline sound profile and data on how an area changes acoustically over time. For these reasons, an underwater noise monitoring project was created to monitor noise levels in the Bay of Fundy, around the Port of Saint John.

The Port of Saint John is Canada's third busiest port (by tonnage) and the fourth busiest cruise ship destination (Port Saint John, 2018). Industry is important to the area as many livelihoods rely on the traffic in and out of the bay and the port. For this reason, the underwater soundscape was studied focusing on vessel traffic as it entered the port. Acoustic data was collected by hydrophones at multiple sites deployed outside the harbour over three years from 2015-2017 creating a long-term acoustic profile of the area. The ambient noise measurements of the areas were compared over time. Emphasis was placed on 1/3-octave bands 63 & 125 Hz, associated with shipping activity by the Marine Strategy Framework Directive (Tasker et al., 2010).

Results will be interpreted to provide information on the baseline ambient noise measurements and noise pollution levels around the port. Results will also include detected marine mammals and vessel noise measurements. The results will provide data not only for researchers, but for regulators, as well as baseline noise measurements for future environmental assessments of the area.

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A POPULATION CONSEQUENCES OF DISTURBANCE MODEL FOR HUMPBACK WHALES MIGRATING THROUGH A COMMERCIAL SEISMIC SURVEY

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Managing the non-lethal effects of disturbance on marine mammal populations, though a requirement for most impact assessments, is challenging due to the lack of empirical data. The Population Consequences of Disturbance (PCoD) model has been put forward as a conceptual framework with which to summarize the potential for population-level consequences following exposure of animals to an anthropogenic noise source. The PCoD framework is a simple four-step process, moving from changes in individual behavior and/or physiology, to a change in individual health, vital rates, and finally to population-level effects. This study presents a PCoD model for migrating humpback whales exposed to a commercial seismic survey and is comprised of five analytical stages. The first stage used measured behavioral responses of migrating humpback whales to seismic air guns (BRAHSS experiment) to parameterize an agent based model (ABM). Next, the ABM was used to simulate a full commercial seismic survey, estimating the probability of response of a migrating group and the cost of the response in terms of a delay in migration to the feeding grounds. Thirdly, this step was repeated using a simpler simulation. Here, parameters such as exposure probability and time spent within the survey zone were manipulated to estimate an exposure history per individual. This was used to estimate the mean number of hours of disturbance per migrating cohort, and quantify changes in this parameter due to different exposure probabilities and exposure duration. The fourth step estimated the energetic consequences of this response (migratory delay due to disturbance) using an individual-based model parameterizing the energetic cost of migration to lactating females. These breeding females were considered to be the most vulnerable (in terms of energetic costs) and they were the ones most likely to influence any change in population growth. A migratory delay in lactating females was hypothesized, at some point, to reduce their future breeding success. The fifth and final step modelled potential changes in population growth (using survey data for this population) due to any reduction in the breeding rate of females. Results suggest a low potential for population consequences of seismic surveys on migrating humpbacks in this population but the model framework can be easily integrated for different scenarios and more vulnerable populations.

BROAD-SCALE ACOUSTIC MONITORING FOR CETACEANS AND UNDERWATER NOISE IN RELATION TO OFFSHORE WIND FARM CONSTRUCTION IN SCOTLAND

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Marine construction projects, such as offshore wind farms and port developments often use techniques that produce significant levels of noise underwater, which could have effects on marine wildlife. Marine Scotland is the government body responsible for regulating these activities in Scottish waters and for ensuring that wildlife populations are protected in line with legislation.

Large scale offshore wind farm construction started off the Scottish east coast in 2017, using piled foundations. To monitor for potential broad scale changes in distribution of protected cetacean species during construction activities, Marine Scotland deployed an array of 30 click detectors and 10 broadband acoustic recorders across the Scottish east coast each summer since 2013. Since 2018, underwater ambient noise measurements from the east coast array have been incorporated into an EU INTERREG funded project, Jomopans, which aims to produce noise maps at the scale of the North Sea acoustic basin. Here we present baseline distributions for dolphins and harbour porpoises, along with ambient noise levels recorded concurrently. We also introduce how Marine Scotland is contributing to the generation of tools for policy makers to assess Good Environmental Status, through the Jomopans project, and will discuss how the east coast monitoring is being supplemented with additional stations adjacent to proposed wind farm projects from 2019.

Dolphin detections across the monitored area are highly variable, with some locations that are clearly favoured where dolphins are detected on most days. Harbour porpoise are ubiquitous across the study, and in more than 60 % of locations they are detected on 100 % of monitored days. This is likely to mean that there is more power to detect changes in porpoise distribution in relation to offshore wind farm pile driving than for dolphins. Seasonal variability is clearly apparent, and rates of detection of harbour porpoise are at their highest during the winter, when visual surveys are less likely to be useful.

THE FULL LINE OF MITIGATION: VAN OORD'S UNDERWATER NOISE MITIGATION PHILOSOPHY

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Van Oord is a leading marine contractor in the construction of Offshore Wind Parks (OWP). Whilst the transition to renewable energies has countless environmental benefits, the negative aspects pertaining to underwater noise generated during wind park construction are under increased public and regulatory scrutiny. Van Oord approaches the mitigation and knowledge development of the underwater noise generated by its construction activities according to the hierarchy of mitigation. This approach consists of in-house systems, as well as strategic partnerships with start-ups and established companies within the field of underwater noise mitigation.

The hierarchical mitigation approach starts at the full avoidance of potential impact towards a sensitive receiver. Avoidance of impact piling noise is being field tested through the installation of mono-bucket foundations aimed at eliminating impact piling entirely. The next step in the hierarchy of mitigation entails the minimisation of impact. Through its FaunaGuard system Van Oord aims to combine full avoidance and minimisation of potential underwater noise impact. The in-house FaunaGuard system produces safe specialised acoustic signals designed to deter specific animal groups from marine construction sites. The FaunaGuard is developed through a three phased approach: a literature study, a laboratory test, and then field tests verifying its effect on its target receiver. After the implementation of deterrence devices to keep sensitive receivers from the construction site, Van Oord practices further impact minimisation by making use of innovative piling methodologies such the Blue Piling water combustion hammer and a pioneering hammer noise reduction unit to lower the noise dispersal at the source. The final step in hierarchical mitigation is the execution of mitigation measures. With two full-scale field tests Van Oord has introduced the innovative, frequency specific near-to-pile AdBm system into full-scale operation in order to substantially reduce the noise travelling from the pile foundation into the surroundings.

Through a combination between in-house initiatives and collaboration with partners Van Oord takes a proactive approach to innovation and a multi-tiered methodology in the field of underwater noise mitigation during the construction of offshore wind farms.

AN OPPORTUNISTIC QUIET OCEAN EXPERIMENT

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The concept of a “quiet ocean experiment” has generated interest for well over a decade (Boyd *et al.*, 2011). We took advantage of the Balinese Day of Silence (Nyepi) to observe changes in the marine soundscape. During the 24-h period of Nyepi, Balinese as well as visitors observe the cultural tradition of silence, meditation, and introspection; businesses are closed and all traffic (road-borne, air-borne, and water-borne) ceases.

We deployed six underwater sound recorders off southern Bali for one week around Nyepi. The soundscapes consisted of the sounds of wind, rain, fishes, boats, and airplanes (Williams *et al.*, 2018). Due to a series of unfortunate events, the three deep-water recorders were never recovered and so the effects of the cessation of large shipping in the otherwise busy shipping routes around Bali could not be determined.

We did, however, document a statistically significant drop in the noise levels in shallow water, due to the cessation of all boat and airplane passes (Erbe *et al.*, 2018). Given the frequency of these transient sources (e.g., one airplane overflight every 7 minutes on average, with each overflight audible for 10 s), the associated masking of fish choruses was eliminated. Boats had a much more broadband sound signature underwater than did airplanes and their cessation therefore avoids the masking of snapping shrimp choruses and dolphin whistles.

Previous megafauna surveys have indicated cetacean presence in the deeper-water regions, where all recorders were unfortunately lost. Based on our shallow-water findings and the series of lessons learned, it would be very useful to redo the deep-water study in order to quantify the drop in commercial shipping noise and to document potential changes in marine fauna behavior. Bali’s Day of Silence provides a unique opportunity for a local quiet ocean experiment.

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SHIP NOISE MAPPING IN UK WATERS

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Maps of underwater noise levels are needed to assess the risk of impact to marine fauna and inform management measures (Erbe et al., 2014). Noise maps are based on modelled source levels and the acoustic propagation characteristics of the environment. However, for shipping noise, modelling the large numbers of sources using numerical models is computationally intensive, and current sound mapping approaches have not been rigorously validated with experimental data.

Here, we present a computationally efficient approach for producing instantaneous shipping noise maps of large spatial areas at high temporal resolution, and assess the predictions against field measurements. Satellite Automated Identification System (sAIS) ship-tracking data were used to produce noise maps based on the position of each tracked vessel at 10-minute intervals. The propagation losses were pre-computed using an energy flux method, taking into account bathymetry, seabed properties, and variations in the water column properties for each calendar month. An ensemble model for ship source level (Wales and Heitmeyer, 2002) was combined with the propagation loss matrices to produce maps of the shipping noise component. Additionally, the contribution of wind-driven noise was computed, allowing the exceedance of shipping noise above this natural background to be assessed. Combined noise maps of UK shelf waters were produced covering the year 2017 at 10-minute intervals. The results were validated against measurements taken at monitoring stations along the east coast of Scotland during 2017 (see Merchant et al., 2016), as part of the Marine Scotland East Coast Marine Mammal Acoustic Study (ECOMMAS). Overall, the model predictions of the median sound level were within ± 3 dB for 89% of the data for frequency bands in the range 125 Hz – 2 kHz, indicating significant confidence in the model predictions.

The risk of impact on particular species can be understood by producing risk maps which combine noise mapping with density or habitat data for target species (e.g. Erbe et al., 2014; Merchant et al., 2018). We demonstrate this concept for North Sea harbour porpoise using modelled density data based on field surveys. The amount of shipping noise exceeding natural background was filtered to reflect the noise audible to harbour porpoise, using audiogram data. Risk maps were then produced which show the areas of greatest cooccurrence of harbour porpoise and audible shipping noise above natural background. The results show clear seasonal changes in risk and highlight where management of shipping noise could be most effective for this species.

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RECENT ADVANCES AND CHALLENGES IN UNDERWATER NOISE IMPACT ASSESSMENT

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Growth in the blue economy is driving increases in noise-generating activity, notably the construction of offshore wind farms and other marine infrastructure, seismic surveying of oil and gas deposits, and shipping. Policymakers and regulatory bodies are increasingly aware of the impacts of underwater noise on marine life, and require clear scientific guidance to assess the risk of proposed activities, particularly in relation to species and habitats with statutory protections (e.g. EU Habitats Directive, US Marine Mammal Protection Act). As scientific understanding of the impacts of underwater noise improves, it is critical that such guidance keeps pace with the current state of knowledge.

Here, we review recent developments in risk assessment of underwater noise pollution which we have encountered through our roles as scientific advisors to UK Government and regulatory bodies in England and Wales, and as technical consultants producing environmental impact assessments (EIAs) for developers in other jurisdictions.

In particular, we use case studies to assess the implications for EIA of updated noise exposure criteria for hearing impairment in marine mammals (National Marine Fisheries Service, 2018; Southall et al., 2019) in relation to previous guidance. Since both auditory frequency weightings and noise exposure thresholds determine the extent of effect zones produced for permanent and temporary threshold shift (PTS and TTS), it is necessary to run modelling scenarios to understand the interaction of these frequency-dependent factors with source spectrum and sound propagation characteristics. Based on typical EIA scenarios, we use noise modelling techniques to demonstrate the relative differences in risk assessment yielded by the updated guidance for each of the five marine mammal functional hearing groups.

Assumptions of animal behaviour are also instrumental in determining PTS/TTS effect zones, and the parameters used to describe fleeing responses strongly affect the outcome of assessments (Faulkner et al., 2018). Similarly, the application of noise abatement technologies can greatly influence the assessment of risk (Merchant, 2019), although their use is often not included in assessments, meaning regulators may be unaware of the potential for risk reduction should such technologies be required as a licence condition (Faulkner et al., 2018). Using further case studies, we explore the influence of these factors on EIA for noise-generating activities, and review the scope for future advances and developments in risk assessment as our scientific understanding evolves.

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PREDICTING POTENTIAL IMPACTS TO MARINE MAMMALS FROM ACOUSTIC DETERRENT DEVICES (ADDs) USED IN AQUACULTURE

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Acoustic deterrent devices (ADDs) are used to mitigate seal depredation on finfish aquaculture sites through the emission of loud and aversive acoustic signals (Götz and Janik, 2013). On the west coast of Scotland, detections of ADD noise have increased substantially over the last decade, and are considered to be a significant and chronic source of underwater noise pollution in this area (Findlay et al., 2018). Given the frequency ranges (2-40 kHz) and source levels (≤ 185 dB re 1 μ Pa [RMS]) reported for these devices, there is a risk that ADDs could adversely impact the behavior and physiology of target (seals) and non-target (cetacean) species (Lepper et al., 2014), with potential impacts on individual fitness and population level consequences.

This study predicts the extent of ADD noise from aquaculture sites across the west coast of Scotland, to understand the potential risk of auditory damage for harbor porpoise and seals. An energy flux model was used to calculate transmission loss from all aquaculture sites known to be using ADDs in the region (Weston, 1971). Results were used to predict the potential for auditory damage in marine mammals, based on the 2018 NOAA criteria for non-impulsive noise sources. The maps of ADD noise highlight areas of potential injury for species commonly found along this coastline, as well as overlaps with associated current or planned Marine Protected Areas.

Model results suggest that received levels of ADD noise remain high (>100 dB) even at considerable distances (>20 km). Results predicted a risk for seals and cetaceans to incur temporary (TTS) and permanent threshold shifts (PTS) at ADD peak frequencies. For example, an ADD operating at 10.3 kHz with a source level of 192 dB re 1 μ Pa (RMS) could cause PTS in harbor porpoise if they remained within 5 km of the source for 24 hours. Maps of ADD noise highlighted several areas of particular concern for auditory damage to both porpoise and seals. This work indicates the potential for auditory damage from aquaculture sites using ADDs on the west coast of Scotland, and implies that behavioral changes to avoid auditory damage may lead to exclusion from biologically important habitats. Future work will (1) validate the sound propagation model with empirical data, (2) use telemetry data to assess the potential for auditory damage in seals, and (3) use long-term towed array data to assess whether ADDs may cause larger scale habitat displacement in harbor porpoises.

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DOLPHIN SELF-MITIGATION OF NOISE

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Previous studies have shown that some species of marine mammals are capable of voluntarily adjusting their hearing sensitivity (a conditioned hearing change) as a way of “self-mitigating” noise exposure (reviewed by Nachtigall et al., 2018); however, the underlying mechanisms and their spectral and temporal properties remain poorly understood.

In the present study, the ability of dolphins to self-mitigate noise exposures was investigated by tracking changes in hearing when dolphins were warned of an impending intense noise. Hearing was assessed by measuring auditory brainstem responses (ABRs) to tone bursts presented before/after a warning sound and intense tone. In (binaural) underwater testing with two dolphins, tone burst frequency and level, and intense tone frequency were systematically varied. Results showed frequency-specific attenuation of ABRs after pairing the warning and more intense tones, with increases in ABR threshold (reduction in hearing sensitivity) as large as 40 dB. Suppression of ABRs could be maintained for at least 31 s. Once the warning sound was no longer paired with the intense tone, ABRs returned towards baseline values. During monaural testing in air with two additional dolphins, ABRs originating in each ear were attenuated when the warning/intense sounds were presented via a contact transducer located on the lower jaw. The data indicate a neural mechanism originating at the level of the cochlea or auditory nerve, which suggests the involvement of the olivocochlear system of efferent nerve projections to the cochlea.

The ability of marine mammals to self-mitigate an impending noise exposure may offer the potential to reduce noise impacts by warning animals of impending high-intensity noise; for example, by ramping up the exposure level. The potential for self-mitigation should also be considered when interpreting marine mammal temporary threshold shift data.

Nachtigall, P.E., Supin, A.Y., Pacini, A.F., and Kastelein, R.A. (2018). “Four odontocete species change hearing levels when warned of impending loud sound,” *Integr. Zool.* 13, 2-20.

AGESCIC: ACHIEVE GOOD ENVIRONMENTAL STATUS FOR COASTAL INFRASTRUCTURES CONSTRUCTION

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With more than 400 projects per year in the EU, coastal constructions are an important source of water pollution with turbidity and underwater noise. These cause severe damage on biodiversity, especially benthic fauna, fish, mammals, cephalopod, microalgae and seagrass.

The AGESCIC project, an EU Life funded project, aims at bringing new technology solutions to reduce the marine environmental impacts of coastal works, especially for the underwater noise and turbidity impacts, on marine fauna and ecosystems. AGESCIC is related to the new European ocean protection strategy through the Marine Strategy Framework Directive (MSFD) 2008/56 / CE (descriptors 6 and 7 for turbidity and 11 for underwater noise) to reach Good Environmental Status for oceans.

In practice, AGESCIC's innovation is made of a suite of three complementary technology solutions dedicated for coastal infrastructure construction that will mitigate the pressure, monitor pressure and receptors, and restore the ecosystem. The first stone of the complete solution is the SubSea Quieter® (SSQ), an innovative underwater noise and turbidity containment system made of an air-filled membrane. To report on the efficiency of the SSQ and to continuously ensure compliance with the regulation during operations, the solution is also made of SmartPAM+, a smart connected buoy jointly developed by Quiet-Oceans and UPC, that monitors in real time the levels of turbidity, the levels of underwater noise and the presence of marine mammals. Finally, the AVOREST system, based on sound attraction device and an artificial habitat for fish and larvae is added to reduce the impact on fish and recover the ecological functions of the work area.

A pilot real-scale demonstration of the solution is planned for 12 months on a coastal construction project in France in 2020. The physical resistance of the SSQ® system in real condition will be validated, as well as the procedures for deployment, maintenance and recovery. The data transmitted by SmartPAM+ will be validated using independent calibrated sensors but also serve to validate the efficiency of the SSQ on both the reduction of the environmental perturbation and the benefits for the ecosystem and especially the noise and turbidity species present in the area. Finally, the performance of the ecological restoration system AVOREST systems will be evaluated using the bio-acoustic data collected near the artificial habitat.

BOAT NOISE EFFECTS ON MEAGRE (*Argyrosomus regius*): MASKING AND VOCAL BEHAVIOUR

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Aquatic noise has increased in the last decades, especially along the routes of freighter liners and in harbours areas, likely augmenting the pressure on aquatic animals' acoustic communication and causing enhanced stress on populations inhabiting such regions. One of such areas, the Tagus estuary, holds important maritime harbours and a network of ferryboat connections, and is used as breeding grounds for several fish species, namely the meagre. This valuable marine species enters the estuary for breeding. During the breeding season the adults form loud choruses likely allowing fish aggregations, and anthropogenic noise, has the potential to interfere with this behaviour since its acoustic energy encompasses the frequency spectrum of the meagre sounds.

We used Auditory Evoked Potentials (AEP) to measure meagre hearing in 10–12 cm long juveniles. By playing back stimuli where decreasing meagre call levels were embedded in boat noise we were able to assess the level of masking caused by different boats (we used 4 different meagre calls and 4 different boat sounds, 2 ferry boats and two outboard engine boats). We also assessed the effects of ferry boat passages on meagre choruses in the Tagus estuary, where we have long-lasting continuous recordings, by measuring and comparing choruses' energy before and after boat passages.

The AEP's show that meagre juveniles can encode the conspecific calls even when the amplitude of the call is 12 dB below the boat sound level, a surprising indication that masking by boat noise is not very strong. The effect of boat passages on adult meagre choruses is variable, which suggests that noise is probably accompanied by other disturbances affecting chorusing behaviour such as waves generated by the boat or visual stimuli like the silhouette or shadow of the boat. Nevertheless there is usually a reduction in the chorus energy related to ferryboat passages.

ACOUSTIC DETECTION AND CLASSIFICATION USING DEEP NEURAL NETWORKS

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In current years, large numbers of hydrophones are being deployed worldwide, generating vast amounts of acoustic data that easily exceed our capacity for manual analysis and require automated methods for detection and classification. Taking advantage of state-of-the-art Deep Learning techniques, which have proven highly successful in the context of computer vision and natural language processing, MERIDIAN (Marine Environmental Research Infrastructure for Data Integration and Application Network) is developing novel software to meet the needs for automated detection tools. Current projects include the development of neural networks for detecting “grunts” produced by Arctic cod and “rasps” produced by sablefish (see contribution of A. Riera *et al.*), and neural networks capable of differentiating between the songs of three species of whales (right whale, fin whale, and sei whale).

Our detectors and classifiers are based on Convolutional and Recurrent Neural Networks. We are evaluating different network architectures and the most successful will be made available as part of an open-source library named Ketos, which aims to facilitate the adaptation of Deep Learning techniques by the ocean science community. Pre-trained models for the detection and classification of several marine species will also be released under open-source licences. Finally, we are developing an application that will allow the human expert to interact with the neural network during the training process. In this way, scientists will be able to transfer some of their expertise to the network and interactively improve its performance. For example, a whale detector trained in a region with shipping noise could be adapted to perform well in a new region, where seismic background noise is prevalent. In this contribution, the first preliminary results from this work will be presented.

UNDERSTANDING THE NOISE EXPOSURE PROFILE BY MARINE MAMMALS IN THE MEDITERRANEAN SEA: MODELLING AND MEASUREMENT WITH A GLIDER AT A BASSIN SCALE

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In response to concerns about the impact of manmade noise on marine ecosystems, research and regulatory communities are currently collecting *in situ* measurements of oceanic noise levels and developing models that map the levels of underwater noise at large scales, forecasting the impact of shipping noise on marine fauna.

The objectives of *in situ* measurements are twofold. First, they provide necessary inputs, i.e. the acoustic signatures of individual ships to feed the models. Second, they are used to calibrate the model and adjust its parameters. The usefulness of the data collected depends on the duration of acquisition and measurement diversity (e.g., shipping density, water depth). Gliders are ideal candidates to collect noise level data across oceanic basins, over long time periods and because they can sample on the potential trajectories of marine mammals, particularly during diving, they can be used to estimate the real received levels in the sea column.

Here we show results from a SeaExplorer glider equipped with a high-quality acoustics payload travelling for 30 days along a 1000km-long transect of the Western French Mediterranean Sea. The trajectory of the glider was chosen to sample the highest and lowest shipping densities. We first characterized the self-noise of the SeaExplorer and removed it from the recordings thanks to an exact timing indicating its occurrence. The flow noise that may exist for frequencies below 100 Hz, can be removed by reducing the glider's speed or by running a drift. To calibrate the acoustic chain of the SeaExplorer, recordings were compared with a fixed bottom-moored acoustic recorder placed in the glider's trajectory.

Here we report on i) the statistical distribution of oceanic noise levels in the bandwidths assessed by the European Marine Framework Strategy Directive, ii) the anthropogenic contribution of shipping to the global noise budget and the acoustic footprint of main shipping lanes, thanks to a refined propagation model, iii) comparisons of the lowest Mediterranean ambient noise levels to the ones of a pristine area with regard to shipping noise and finally iv) what could be the potential impacts of this anthropogenic noise on marine mammals with a diving behavior similar to the one of the glider.

THE FINAL CALL: EVIDENCE FOR SIGNATURE WHISTLE OF DYING COMMON DOLPHIN IN ARGENTINA (SOUTH AMERICA)

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Signature whistles are stereotyped and individually distinctive acoustic signals emitted by *T.truncatus* in isolated captive conditions. They are used as individual recognition signals, for maintaining group cohesion and during stressful situations (Janik and Sayigh, 2010). However, little information was reported for other species (reviewed in Janik and Sayigh, 2013). Here, we tested the hypothesis of the occurrence of signature whistles in an isolated short-beaked common dolphin (*Delphinus delphis*) kept in a rehab circular tank (13m diameter, 1.35m deep) at Mundo Marino Aquarium (San Clemente del Tuyú). The dolphin, an adult female, was found ashore in Villa Gesell, Argentina, on 19th January 2019. During its maintaining, a hydrophone (model Benthowave BII-7017) with a flat sensitivity response of -174.5 (\pm 2) dB re V/ μ Pa from 0.1 to 100 kHz connected to digital analogical converter C5535 DSP (TMS320C5535), was deployed in the tank. Twenty-three hours of continuous recordings were collected, starting after 12 hours from the beginning of the dolphin's rehab until their death for hepatitis. Data were visually screened and the number of whistles was noted. Six parameters (peak, maximum and minimum frequencies, duration, frequency contour and the number of harmonics) were measured from the recorded whistles by using Raven Pro (Cornell University). A total of 59 whistles were analyzed and only one type of frequency contour was detected (ascending-descending). They showed an averaged peak frequency of 9.04 \pm 2.33kHz; an averaged maximum frequency value of 13.28 \pm 1.81 and a minimum of kHz; a 5.99 \pm 1.58; the average duration was 0.72 \pm 0.29 seconds and harmonic's number ranging from 1 to 4. The CV values of all parameters were lower than 0.4.

The low variability of whistles parameters and the only whistle contour found in an isolated and stressed dolphin support the hypothesis that they produce signature whistles. It is the first evidence of the use of this signal in *D.delphis* in Southwester Ocean. Dolphins produce many non-stereotyped whistles but detecting the presence of signature whistles can provide us new info on socio-behavioral aspects and on the use of vocalizations. Our work is the first step to understanding Latin American common dolphin sound production, which the majority of the ecological aspects are unknown.

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LONG-TERM SOUNDSCAPE MONITORING IN THE ROSS SEA AND ITS MARINE PROTECTED AREA

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The Ross Sea region of the Southern Ocean is one of the most isolated and pristine environments on the planet but is also home to an international commercial fishery for Antarctic toothfish. In 2017, the world's largest marine protected area (MPA) was established, covering some 1.55 million km² of water. As part of a New Zealand program that aims to establish the conservation value of the Ross Sea region MPA, we deployed three passive acoustics recorders (one near Iselin Bank; one near Scott Seamount; one in proximity of the Pacific-Antarctic Ridge) to: 1) provide baseline information on the seasonal occurrence of sperm whales in the region; and 2) understand ecological connectivity between toothfish and sperm whales to investigate potential effects of commercial toothfish fisheries on sperm whales in the Ross Sea region.

Our study also presents an opportunity to more broadly study the soundscape of the Ross Sea region, in terms of geophony, anthrophony, and biophony (Erbe et al., 2015) and its changes under climate variability and change.

The moorings were deployed in February 2018, and two of them recovered and redeployed in February 2019. We are planning on recovering and redeploying all three moorings in 2021. Data were collected using a recording duty cycle that would allow the instruments to record for an entire year, from summer 2018 to summer 2019 when the recorders were refurbished. The recorders were set up to record for 342 seconds at a sampling rate of 48 kHz, then 64 seconds at a sampling rate of 125 kHz, and then to turn off for 12 minutes. Power Spectral Density analysis was used to investigate the variation in the soundscape levels throughout the year and among locations. Preliminary data show the presence of baleen and sperm whales, as well as odontocetes and leopard seals. We outline plans for using the acoustic information collected in the next five years of this project to understand how climate variability and change affect the soundscape of the region and provide information on key predators in the region. We are also looking to develop international collaboration on this project.

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BEHAVIORAL EFFECTS OF SOUND FROM MARINE GEOPHYSICAL SURVEYS ON MARINE MAMMALS: A LITERATURE REVIEW

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We evaluated more than 200 original peer-reviewed publications, technical reports and unpublished source materials to span the full breadth of available information on behavioral effects of anthropogenic sound on marine mammals, with an emphasis on sound sources used in geophysical surveys.

Due to limits in time and resources, the 114 references that scored highest among five independent reviewers for impact and relevance were selected for in-depth examination, while the remaining references were given a less thorough evaluation by two or more independent reviewers. Review assignments were made using a pseudo-random process (modified Gellerman series), so that the number of reviews by each reviewer and every combination of three reviewers was equal (Fellows, 1967). The individual who generated the review assignments did not participate in the analysis of review results, and the individual analyzing the results was blind to who reviewed which references (double-blind control).

After the initial review a subset of references was subjected to a second review, using the same pseudo-random balanced design of review assignments and double blind control protocols. The subset selected for re-review included references for which there was disagreement between reviewers during initial scoring, but also included control references for which agreement had been unanimous in the first review round. The mix of reviewers for the re-review included a balanced combination of the first reviewers and new reviewers who had not seen the reference during initial review. This design provides a particularly robust statistical basis for quantifying inter- and intra- reviewer variability, an inevitable part of any literature review which is seldom addressed.

While there are recent reviews of behavioral responses to sound (e.g., Gomez et al., 2016), we have used techniques to quantify inconsistency and bias, both in the literature and in the subsequent review of the literature. Our methodological approach, while more labor-intensive and methodologically rigorous, provides for greater weight and statistical power of the review than for more conventional reviews by one or a few reviewers working collaboratively. Among the most useful discoveries of our review were disparities between actual and reported sound sources; contrasts between observed and interpreted data; and emergent robust trends in response behavior across sound sources, species, and contexts.

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Gomez, C., Lawson, J. W., Wright, A. J., Buren, A. D., Tollit, D., and Lesage, V. (2016). "A systematic review of the behavioural responses of wild marine mammals to noise: the disparity between science and policy." *Can. J. Zool.* 94, 801-819.

ECOACOUSTICS AS TOOL FOR ENVIRONMENTAL AWARENESS: THE OCEAN SOUNDSCAPES

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At the present time our planet is undergoing one of the most challenging epochs of history: the Anthropocene. This era is marked by serious impacts of anthropogenic pressure on the environment, leading to “unpredictability of earth-systems conditions” (Vidas 2018:236). In the last and present years, rapid innovation in technology has granted a massive exploration of the deep ocean, revealing that the ocean environment faces an extremely increasing stress caused by human impact.

The importance of sound as a component of an environment is studied by the field of ecoacoustics. Ecoacoustics is a combination of studies in ecology and in (bio) acoustics that “investigates natural and anthropogenic sounds and their relationships with the environment over multiple scales of time and space” (Farina and Gage 2017:1). Sound contributors in ocean soundscapes can either be natural, or human (anthropogenic). Understanding these soundscapes can be a powerful tool to predict the evolution of the environments through the time (Farina and Gage 2017:236).

Today, we are assisting an increase in researchers, scientists and artists that rely on sound or soundscapes to study and understand environments, as well as a growing interest of musicians and composers to include natural sounds in their compositions (Monacchi and Krause, 2017). Therefore, ecoacoustics approaches can be considered an interesting field to improve the link between sciences and art, providing the setting for artistic exploration of sound material. Moreover, by combining ecoacoustics with artistic practice, one can reveal the power of sound (and all their counterparts such as vibration or particle motion) as an immersive medium for soundscape composition, reviewing concepts such as aurality, presence, immersion or synesthetic perception in the context of interdisciplinary sonic experiences. Furthermore, through artistic practice one can have the opportunity to share information to broader audiences, communicating environmental issues to the general public, thus creating awareness for the preservation of environments as well as for the problematic of noise pollution (Bianchi & Manzo, 2016).

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Farina, A., and Gage, S. H. (2017). *Ecoacoustics the ecological role of sounds*. UK: John Wiley and Sons.

Monacchi, D., and Krause, B. (2017). Ecoacoustics and its Expression through the Voice of the Arts: an Essay. In *Ecoacoustics the ecological role of sounds* (pp. 297–312).

Vidas, D. (2018). The Law of the Sea for a New Epoch? In S. Hessler (Ed.), *Tidalectics: Imagining an Oceanic worldview through art and science* (pp. 231–240). Cambridge, Massachusetts: The MIT Press.

PARTICLE MOTION FROM SHIPPING NOISE IN RELATION TO THE AUDITORY SENSITIVITY OF FISH

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Boat noise is ubiquitous in the marine environment and their dominating frequencies overlap those where fish have demonstrated sensitivity to sound. This suggests that boat noise could interfere with important environmental cues for fish. At low frequencies fish respond to the particle motion component of the sound field with a sensitivity of about 0.1mm/s² and reaction thresholds at 10 mm/s². There is a lack of data on particle motion generated by boats to assess at what distances boat noise may be audible to fish and cause avoidance reactions.

Particle motion from large vessels were measured in the Great Belt, Denmark using four hydrophones suspended from a drifting platform.

Larger vessels produced higher total accelerations, even at greater distances. A ship of 17,400 GT transiting at a range of 750 m from the array produced maximum accelerations of 43 mm/s², whereas 7 mm/s² were registered from a 1200 GT vessel at 400 m range across the frequency range of 10-500 Hz. Filtering the recordings at 50-250 Hz and 5-30 Hz gave acceleration values of 0.4-37 mm/s² and 0.3 – 12 mm/s² respectively, within a 1000 m range from the ship.

The results indicate that particle acceleration generated by large ships is detectable by fish and could also cause avoidance reactions at considerable ranges.

It further underlines the urgency for research into how and why particle motion is important to fish. Acknowledging the distance at which vessel's acoustic accelerations are reaching, fish may be restricted by ship noise in their access to critical habitats and their resources across the fish' life history stages.

CAN WHISTLES BE A TOOL TO DISCOVER TEMPORAL TRENDS OF DOLPHINS' POPULATION?

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Passive acoustics allows long-term and cost-efficient monitoring of the activity and trends of marine mammals (Zimmer, 2011). Knowledge on circadian and seasonal rhythms in the vocalizations of a species is crucial for improving conservation by understanding the temporal occurrence of signals and potentially behavioral activity. For dolphins, several studies of temporal trends were based on impulsive sounds, while whistles were rarely used (Caruso et al., 2017). The aim of this work was to evaluate if dolphins' whistles can be used as a tool to investigate their acoustic presence and temporal trends in the waters between Capo Feto and Capo San Marco (South-Western Sicily, Italy).

A preamplified hydrophone (Reson TC 4014, Denmark), installed onboard of an elastic seamount and located 3 miles away from the coast (37°31.052' N 12°39.187' E) was used for data collection. Data were recorded in continuum for 14 months with a sampling frequency of 50 kHz, and stored in 5 minutes files. The number of whistles along the recordings was estimated combining automatic (through Silbido software - Roch et al., 2011) and visual (through spectrogram screening by an expert operator) methods.

Over a total of 84057 files, 14048 whistles were counted. Whistles were present along all the year. Considering presence/absence of tonal acoustic detections, a significant difference between daily hours was found for all the months (Kruskal Wallis test $P < 0.01$). For whistle detection rate (number of whistles/minutes, per each hour) a seasonal rhythm was identified, with a peak in autumn and winter and a lower detection rate during spring and summer (Kruskal Wallis test $P < 0.001$). The higher whistles detection rate was found during night hours compared to daytime (Mann-Whitney test $P < 0.001$).

While diel trend is comparable with the one identified for clicks recorded within the same population in the same area (Papale et al., 2018), the seasonal rhythm showed a difference with an opposite trend for wintertime where the click rate recorded is low.

Results demonstrated that whistles can be used as a tool for detecting temporal trends for dolphins' populations, even if their number is usually lower compared to the impulsive signals due to their different functional use. These outcomes can provide additional information to data regarding impulsive signals since whistles are commonly used with communication and identification purposes.

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MODELLING THE ACOUSTIC REPERTOIRE OF CUVIER'S BEAKED WHALE CLICKS

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Cuvier's Beaked whales (CBW) are known to produce echolocation clicks which distinguish them in passive acoustic recordings. The use of Digital Acoustic Tags allowed to describe the click properties which are used in acoustic identification of CBW. The clicks are typically assumed to be upsweep-type chirps (with the duration of $\sim 200 \mu\text{s}$ and central frequency around 42 kHz (Zimmer et al., 2005)). However, the spectral and temporal properties can vary considerably in recordings, especially because of the directivity effects of CBW clicks.

This study proposes to use the flat circular piston model (Au, 1993) to simulate the effects of directivity on temporal and spectral properties of CBW clicks. The simulation is then compared to the real 2015 and 2017 data from the Gulf of Mexico.

The results show that the upsweep property of the CBW clicks is not prominent and can be turned into down-sweep calls when the angle between the acoustic axis of the whale and the ray that reaches the receiving hydrophone is larger than 13° . This better understanding of the different time-frequency patterns associated with CBW clicks is a necessary step to obtain high quality ground truth datasets, currently lacking in the bioacoustics community. These datasets are of critical importance for benchmarking the algorithms for detection, classification, localization, and density estimation of CBW.

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AUDITORY THRESHOLDS IN FISHES: TOWARDS INTERNATIONAL STANDARD MEASUREMENT PROCEDURES

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Fishes rely on their auditory system to detect and interpret sounds in their surroundings, including those originating from predators, prey, and conspecifics. Fish auditory sensitivity can be impaired, for example, by masking or temporary threshold shifts. To understand and quantify impacts of underwater noise on fishes, a quantitative and comparable understanding of normal and impaired auditory sensitivities to sound pressure and particle motion is needed. Audiograms are available for individuals representing a few species. Crucially, differences between measurement procedures leave existing audiograms mostly incomparable between laboratories (Ladich and Fay, 2013). For example, the goldfish (*Carassius auratus*), has had many audiograms measured by different laboratories, with the spread in reported auditory thresholds exceeding 40 dB. These differences are largely attributed to divergence in methodologies rather than in auditory sensitivity, leading to calls for increased standardization (Hill, 2005; Ladich and Fay, 2013; Maruska and Sisneros, 2016; Halvorsen and Ainslie, 2018). This large uncertainty means that the communication space for fishes is largely undetermined. Thus, standardization of auditory sensitivity measurements is essential to achieve environmental management goals worldwide. To meet these needs, the formation of a standards working group (WG) is underway. A proposal has been submitted to an international ocean bioacoustics program to create a bioacoustical standards WG. The purpose of the proposed WG is to promote international bioacoustical standardization by identifying existing standards and data gaps; demonstrating where new standards are needed and where existing standards need improvement. Participants in the bioacoustical WG would include multidisciplinary subject matter experts and end-users of the standard. In anticipation of the formation of an ISO or ANSI WG, an ad-hoc fish auditory WG has been formed, comprising the present authors, to initiate the process towards the development of scope, structure, and content for a fish auditory measurement standard. In 2018, an ANSI audiogram standard for toothed whales was completed, which provides a basic framework for the bioacoustical WG. However, the content will differ, starting with the animals of interest, including the measurement geometry and environment, auditory sensitivity to pressure and/or particle motion, and psychophysical protocols. This paper summarizes the need for, and steps made toward a standard psychophysical protocol for fishes. We invite participation and sponsor involvement in the development of this necessary standard.

Halvorsen, M.B., and Ainslie, M.A. (2018). Auditory threshold in fishes: Towards international standard measurement procedures. *The Journal of the Acoustical Society of America*, 144(3), 1662-1662.

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LISTENING SPACE REDUCTION: A MEASURE OF THE RELATIVE REDUCTION OF SPACE OVER WHICH SOUNDS CAN BE DETECTED AND RECOGNIZED IN THE PRESENCE OF INCREASED MASKING NOISE

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A simple but powerful approach for quantifying masking of biologically-important sounds by anthropogenic noise is presented. A new metric, referred to as Listening Space Reduction (LSR), is defined as the percentage reduction of original listening space caused by an increase in masking noise, where listening space is the volume of ocean within which a listener can detect and recognize biologically-relevant sound sources. While absolute listening space depends on several parameters, including the important sound's source level and other parameters that are often poorly known, the relative listening space is less sensitive to most parameters and can often be estimated quite accurately from the change in masking noise level.

The LSR method generalizes the Listening Area approach (Barber et al., 2009), originally developed and applied to estimate reductions of spatial areas that birds could effectively hear important sounds when masking noise was added to their natural soundscape. LSR expands Barber et al.'s method to consider also directional masking noise, source and listener directivity, listener hearing sensitivity, listener cognitive signal processing gain, non-uniform acoustic propagation loss and temporal distributions of masking noise levels.

A calling animal's active space represents the volume of ocean within which other animals of the same species can detect its sounds in the presence of noise. LSR instead considers the acoustic space important to a listener. It is less sensitive to most of the poorly-known parameters that directly influence active space, including the source levels of the biologically-important sounds, absolute acoustic propagation loss, absolute processing gain, and detection threshold. LSR is sensitive to the rate of acoustic propagation loss (i.e. dB per logarithm of distance) which must be estimated. It is applicable to all biologically-relevant sounds that decay uniformly with distance between source and the listener, including sounds from prey and predators.

A modified version of LSR is defined for echolocation sounds and a corresponding Echolocation Space Reduction (ESR) is defined. Although LSR and ESR predict only relative spatial volumes, they are much less sensitive than active space to several uncertain and variable parameters. LSR and ESR are therefore more stable and can be estimated with higher confidence. LSR is discussed here mainly for marine applications but it is also suited to airborne noise masking assessments.

The presentation will derive LSR from the sonar equation and will provide examples of its application to a real-world anthropogenic noise scenario.

Barber J.R., Crooks, K.R., and Fristrup, K.M (2010) "The costs of chronic noise exposure for terrestrial organisms," Trends in Ecology and Evolution Vol.25 No.3, 2010

USING PASSIVE ACOUSTIC MONITORING TO MEASURE NOISE IMPACTS: THE IMPORTANCE OF QUANTIFYING ANIMAL DETECTION PROBABILITY

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Passive acoustic monitoring (PAM) is an effective tool for monitoring aquatic life and can be used to assess potential impacts of noise. PAM data can be used to estimate a range of metrics including animal occurrence, distribution and density (e.g. Mellinger et al., 2007; Marques et al., 2013; Carlén et al., 2018), and how these metrics change as a function of increasing noise. However, in order to use these PAM-derived measures to effectively monitor animal populations, a key step is to quantify the areas over which PAM systems monitor. The size of a monitored area may also change over time due to changing environmental or noise conditions, which will also need to be considered when interpreting results. The fundamental question in understanding noise impacts to animals is whether the behavior or ecology of an animal changed as a function of noise, or whether animals were simply less detectable due to increased noise. For example, the number of acoustic encounters of a given species may decrease if the acoustically-monitored area decreases due to an increase in ambient noise. Such patterns in acoustic encounters may be misinterpreted unless changes in the monitoring conditions have been accounted for in the analysis. Fortunately, methods can be borrowed from animal density estimation approaches to estimate the size of monitored areas. Animal density estimation methods require a key parameter, detection probability, to be estimated, which is linked to the size of the monitored area. There are a suite of approaches available to estimate detection probability for a range of PAM scenarios, where number of instruments and their configuration may differ. In this presentation, we will give examples of recent cetacean PAM studies, where detection probability and the size of the monitored area have been quantified. Further, we will demonstrate how variables such as instrument depth, ambient noise and variable bathymetry can fundamentally impact detection probability/size of the acoustically monitored area, even for the same species. These examples will therefore highlight the importance of quantifying these parameters when using PAM to assess potential impacts of noise on aquatic populations.

Carlén, I., L. Thomas, J. Carlström, M. Amundin, J. Teilmann, N. Tregenza, J. Tougaard, J. C. Koblitz, S. Sveegaard, D. Wennerberg, O. Loisa, M. Dähne, K. Brundiers, M. Kosecka, L. A. Kyhn, C. T. Ljungqvist, I. Pawliczka, R. Koza, B. Arciszewski, A. Galatius, M. Jabbusch, J. Laaksonlaita, J. Niemi, S. Lyytinen, A. Gallus, H. Benke, P. Blankett, K. E. Skóra, and A. Acevedo-Gutiérrez. (2018). "Basin-scale distribution of harbour porpoises in the Baltic Sea provides basis for effective conservation actions," *Biol. Conserv.* 226: 42–53.

Marques, T.A., L. Thomas, S. Martin, D. Mellinger, J. Ward, D. Moretti, D. Harris and P. Tyack. (2013). "Estimating animal population density using passive acoustics," *Biol. Rev.* 88: 287-309

Mellinger, D.K., Stafford K.M., Moore S.E., Dziak R.P. & Matsumoto H. (2007) "An overview of fixed passive acoustic observation methods for cetaceans," *Oceanography* 20(4): 36-45.

A DECISION FRAMEWORK TO IDENTIFY POPULATIONS THAT MAY BE VULNERABLE TO THE POPULATION LEVEL EFFECTS OF DISTURBANCE

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The chronic effects of disturbance have been the focus of much attention, but quantifying the links between individual disturbance-induced behavioral and physiological responses and their population-level effects is not straightforward. In part, this is because an individual's response is likely to be affected by the context of the disturbance and the individual's motivation, experience and conditioning, but it is also a consequence of a lack of basic data. As a result, a full assessment of the population-level risks for all species whose range overlaps with an area that is likely to be affected by a disturbance-inducing activity is likely to be time-consuming and costly. In addition, it may be unnecessary if the most vulnerable components of the population are unlikely to be exposed to the activity as a result of the species' life history and patterns of residency in the affected area. Here, we present a decision framework that uses triage principles to identify species for which detailed population-level assessments are required in order to understand the potential impacts of a particular disturbance activity. The framework was developed to assess the potential effects of disturbance on marine mammal populations, but it can be applied to other taxonomic groups. It uses a series of five questions which concern: the spatio-temporal overlap between the activities which are being assessed and the populations that are exposed to these activities, the proportion of each population that is exposed to the activities, the probability of repeated disturbance, the reproductive strategy of each species and the life stages of the individuals that are most likely to be disturbed. Through application of the decision framework, populations of low risk can be excluded from subsequent assessment processes, and priority can be given to those populations that are considered to be at the highest risk. Some of the questions require the application of thresholds to decide whether populations should or shouldn't be included in subsequent assessment. We used elements of the Interim Population Consequences of Disturbance (iPCoD) approach (King et al., 2015) and the outputs from an expert elicitation described in Donovan et al. (2016) to provide some guidance on these thresholds. We present the framework in the context of a worked case study using marine mammals and a U.S. Navy training activity in the Gulf of Alaska.

Donovan, C., Harwood, J., King, S., Booth, C., Caneco, B., and Walker, C. (2016). "Expert elicitation methods in quantifying the consequences of acoustic disturbance from offshore renewable energy developments." in *Effects of Noise on Aquatic Life, II*, edited by A. N. Popper and A. D. Hawkins (Springer Science+Business Media, LLC, New York), pp. 231-237

King, S. L., Schick, R. S., Donovan, C., Booth, C. G., Burgman, M., Thomas, L. and Harwood, J. (2015). "An interim framework for assessing the population consequences of disturbance." *Methods Ecol Evol* 6 , 1150–1158

NOAA AND NAVY SOUND MONITORING IN SANCTUARIES

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As part of a settlement agreement, the U.S. National Oceanographic and Atmospheric Administration (NOAA) and the U.S. Navy are engaged in a multi-year effort to monitor underwater sound within the U.S. National Marine Sanctuary System. The agencies are working with numerous scientific partners to study sound within seven national marine sanctuaries and one marine national monument, which includes waters off the east coast region of the United States (Stellwagen Bank, Gray's Reef and Florida Keys National Marine Sanctuaries), the west coast region (Olympic Coast, Monterey Bay and Channel Islands National Marine Sanctuaries) and the Pacific region (Hawaiian Islands Humpback Whale National Marine Sanctuary and Papahānaumokuākea Marine National Monument). The project is designed to provide standardized baseline information important for contextualizing both how much sound is introduced within these protected areas by specific sources and the potential for each type of source to impact the areas' marine taxa and habitats.

NOAA's Office of National Marine Sanctuaries (ONMS) and the Navy worked collaboratively to select approximately 30 recording locations where sound conditions and acoustically sensitive species were of management interest and where the Navy has environmental compliance interests. Beginning in fall 2018, regional teams began deployment rotations using identical, temporary bottom-mounted sensors within the eight protected areas. Recording efforts will continue for 3 to 4 years. Collaboration with partners will make use of other technologies and existing acoustic recordings at locations where further time series or comparisons are of interest.

To inform the project's development, the agencies sponsored an expert workshop in May 2018 to discuss and compare analytical approaches and support dialog among colleagues working internationally (<https://sanctuaries.noaa.gov/science/monitoring/sound>). The meeting sought to match existing or in-development soundscape description and interpretation methods with the project's highest priority information needs. Workshop participants emphasized standardized approaches to facilitate comparison in soundscape attributes among projects with longer-term and larger-scale monitoring focus. Participants also emphasized the need for defining ecologically meaningful measures and producing visualization methods that can support both management processes and public communication. These recommendations have guided the project's priorities and work to develop analysis techniques for characterizing both the overall sound levels and specific contributions from marine animals, physical processes and human activities. Unprocessed data will be archived and made publicly available through NOAA's National Center for Environmental Information (NCEI). A web portal for further access and exploration of products is under development.

THE IMPORTANCE OF UNDERWATER SOUNDS TO GADOID FISHES

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It is often assumed that fishes are simple, unfeeling and primitive, because their behavior is more difficult to observe than that of most terrestrial animals. As Balcome (2016) has pointed out, however, fishes are sentient, aware and social animals, that are capable of interacting with one another. Many fishes recognise and communicate with one another using underwater sounds (Hawkins and Myrberg, 1983). In particular, the codfishes (the Gadidae) include a number of species that produce sounds. The calls of gadoid fishes are especially important during spawning.

The codfishes produce sounds, or calls, by means of a specialised vocal apparatus, consisting of rapidly contracting striated muscles (the drumming muscles) attached to the gas-filled swim bladder (Hawkins and Amorim, 2000). Calls have been recorded from seven species, including the commercially important Atlantic cod and haddock. Several other species possess drumming muscles (Hawkins and Rasmussen, 1978), although their sounds have yet to be recorded.

Gadoids like the cod and haddock can vary greatly in their abundance and they exhibit high recruitment variability in areas like the North Sea. They gather at particular locations to spawn, and if their calls are interfered with by the presence of anthropogenic noise, it may affect the reproductive behaviour of the fishes adversely, perhaps with significant effects upon recruitment. This paper discusses the potential of anthropogenic noise to mask, disrupt or reduce acoustic communication in gadoid fishes, and considers the possible adverse effects upon their populations.

Balcombe, J. (2016). *What a fish knows: The inner lives of our underwater cousins*. (Scientific American/Farrar, Straus and Giroux).

Hawkins, A. D., and Myrberg, A. A., Jr. (1983). "Hearing and sound communication underwater", in *Bioacoustics: A Comparative Approach*, edited by B. Lewis (London: Academic Press), pp. 347-405.

Hawkins, A. D., and Rasmussen, K. J. (1978). "The sounds of gadoid fish," *J. Mar. Biol. Assoc. U.K.* 58, 891-911.

Hawkins, A. D., and Amorim, M. P. C. (2000). "Spawning sounds of the male haddock," *Environmental Biology of Fishes* 2 59, 29-41.

OFFSHORE DRILLING SOUND CHARACTERISATION

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Modelling studies are increasingly used to help understand underwater sound levels and propagation characteristics associated with E&P activities such as marine seismic surveys and offshore drilling. For deep water drilling facilities, the most prominent source of underwater sound is typically associated with the use of propulsion systems (multiple thruster units) that are controlled by dynamic positioning to enable a mobile offshore drilling unit (MODU) to maintain position over extended periods of time.

Modelling methods to predict sound source levels from such facilities are commonly based on historical empirical data and derived relationships between sound output and thruster power (Erbe 2013). However, what data is available is typically vessel based and outdated relative to modern generation installations being used offshore today.

Also, assumptions made to determine source sound levels, result in over estimation of sound levels in close proximity to a facility, which are not physically realised due to the distributed nature of sound output associated with large mobile offshore facilities and/or vessels.

An acoustic monitoring study was conducted using a combination of drift-buoy and autonomous surface vehicle technology to collect acoustic data to characterise and quantify the sound field within the immediate proximity of the MODU out to several kilometres to provide a validation dataset for existing and future modelling studies for deep water MODU activities.

An offshore drilling facility is typically accompanied by one, perhaps two support and/or supply vessels, which operate within the immediate area. As well as posing a data analysis challenge, coordinating deployment/recovery and movement of multiple acoustic data recording platforms within a busy traffic area presents both operational and logistics challenges. The presentation will focus on these aspects. Outcomes of the data analysis will be discussed separately.

Erbe, C. et al (2013). "Underwater noise from offshore oil production vessels" JASA Express Letters.

INTEGRATED MODELLING OF ATLANTIC MACKEREL DISTRIBUTION, MOVEMENT PATTERNS AND RESPONSE TO UNDERWATER NOISE: A TEMPLATE FOR DYNAMIC RISK ASSESSMENTS

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To manage the consequences of anthropogenic underwater noise on changes in animal behaviour and ultimately on population dynamics, it is essential to analyse and predict distributions and movements of animals in response to environmental variables and pressures such as noise. Predictive modelling is often the only available approach for quantifying complex large-scale distribution and movement patterns to inform on environmental impact and risk assessments. Models are particularly useful when dealing with complex dynamic systems (as pelagic ecosystems) where data are limited and if various ‘what if’ scenarios should be tested.

The aim of this study was to implement an integrated modelling approach, linking high resolution hydrodynamic models (HDM) of the marine environment with correlative species distribution models (SDM) and agent-based models (ABM), for describing the spatio-temporal distribution and movements of Atlantic mackerel (*Scorpaenopsis scorpaenoides*) in the Norwegian Sea. Using this setup, the potential of the model for assessing the impact of a single seismic survey (mimicking a real survey) was evaluated.

The SDM was fitted with scientific mackerel trawl data as response variables and temperature (from the HDM), water depth and time period as predictors of spatial distributions. The SDM was able to produce dynamic predictions of a similar order of magnitude as observed catch per unit effort (CPUE) as well as realistic large-scale distribution patterns when tested on independent data (not included in the modelling). The ABM was calibrated, with normalized SDM predictions (habitat suitability as a proxy for food availability) and hydrodynamics as input and simulated on a single year (2013) for the period May–October, when the migratory mackerel is present in the study area. A pattern-oriented modelling (POM) approach was used to verify if the model reproduced multiple observed real-world patterns. The ABM produced similar patterns as observed regarding migration timing, growth and large-scale geographic distribution.

We estimated the number of affected fish (within 50 km from the sound source) and potential changes in local migrations, with the specific assumed minimum sound pressure thresholds (resulting in a fleeing reaction by the mackerel) set to 165 dB re 1 μ Pa. The model framework was shown to be useful by allowing simulations of impact scenarios in a realistic and dynamic environment. The model can be further updated when data on fine scale movements of mackerel and most importantly when improved data on response behaviour to impacts of sound become available.

ASSESSING THE CUMULATIVE EFFECTS OF DUTCH OFFSHORE WINDFARM DEVELOPMENT ON THE HARBOUR PORPOISE POPULATION OF THE NORTH SEA AND RESULTING LIMITS FOR PILE DRIVING SOUND – AN UPDATE

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The Netherlands have set ambitious goals for the reduction of CO₂-emissions and therefore for the production of renewable energy. In achieving these goals, offshore wind energy plays an important role. In 2013, agreement was reached on the development of wind farms in three wind energy areas, covering the period 2016–2023 (Energy Agreement). In 2018, the Roadmap for wind energy at sea 2030 was published, presenting plans for the further realization of offshore windfarms for the period 2024 to 2030, including the planning and choice of three new wind energy areas.

In the Netherlands, plot decisions for wind energy at sea must be based on an ‘Ecology and Cumulation Framework’ (KEC, <https://www.noordzeeloket.nl/en/functions-and-use/offshore-wind-energy/ecology/>) that was developed in 2014. For the construction of offshore windfarms, the emphasis is on the cumulative impact of disturbance by impulsive underwater sound on the harbour porpoise population. This impact should be limited to a maximum reduction of the harbour porpoise population on the Dutch Continental Shelf after construction of all offshore wind farms by 5%. In order to ensure this, the government sets sound limits that cannot be exceeded during the piling for wind turbine foundations. As the original KEC did not yet take into account the construction of wind farms in the period 2024–2030, a new KEC was required.

Cumulative effects of the construction of wind farms at sea in the period 2016-2030 were investigated, both for national and international scenarios. The most recent knowledge and insights on piling sound modelling and impact assessment were incorporated in the KEC framework. Effects of the realization of offshore wind energy on the porpoise population were calculated by using an updated version of the Interim PCoD model (<http://www.smruconsulting.com/products-tools/pcod/ipcod/>; King et al., 2015) which included the results of an expert elicitation workshop held in June 2018. With this update, a 3 – 6 times smaller population reduction due to disturbance by piling sound was calculated than with the earlier 2014 version. The updated KEC assessment suggests that with the use of a piling sound limit of SEL_{ss} (750 m) = 168 dB re 1 mPa²s for all the Dutch wind farms after 2023, the probability is more than 95% that the construction of Dutch offshore wind farms over the entire period 2016–2030 will result in a maximum reduction of the harbour porpoise population on the Dutch Continental Shelf by 1.7%.

King, S.L., Schick, R.S., Donovan, C., Booth, C.G., Burgman, M., Thomas, L., and Harwood, J. (2015). “An interim framework for assessing the population consequences of disturbance,” *Methods in Ecology and Evolution* 6, 1150-1158.

MINKE WHALES EXHIBIT LOMBARD EFFECT DURING NATURAL CHANGES IN OCEAN NOISES CONDITIONS

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Data from passive acoustic monitoring (PAM) of navy training ranges can be used to test predictions of marine mammal responsiveness to changes in background noise, both from anthropogenic sources and naturally occurring events (Martin et al., 2015). Minke whale (*Balaenoptera acutorostrata*) vocalizations were detected, classified, localized, and associated into individual tracks using data collected from bottom mounted hydrophones at the U.S. Navy's Pacific Missile Range Facility located off Kauai, Hawaii (Helble et al., 2015). Data were analyzed over a variety of naturally occurring noise conditions, spanning multiple seasons and years. The source level of each minke whale vocalization was estimated by calculating the estimated transmission loss using the Range-dependent Acoustic Model (RAM) [CM5] and adding the transmission loss to the measured vocalization received level. Automated methods were developed to assign source level, using received levels independently measured on 5 hydrophones. To date, source level estimates have been calculated for a subset of minke calls occurring in the fall, winter, and spring from 2013 to 2017. We plan to present results from the entire dataset, which represents hundreds [SWM6] [TH7] [CM8] [EH9] of individual minke whale tracks, containing over 10,000 vocalizations.

Minke whales seemed to increase their call source level with increasing background noise. For [RG10] example, in January 2017, the average root-mean squared (RMS) source level was estimated to be approximately 167 dB re [EH11] 1 μ Pa at 1m, but this level varied considerably with changing background noise conditions. In low-noise scenarios, the average source level was approximately 163 dB re 1 μ Pa at 1m, and in high-noise scenarios the average source level increased to nearly 170 dB re 1 μ Pa at 1m. Overall, the source level increased by approximately 0.4 dB per 1 dB increase in background noise level (measured in the 1250–1600 Hz band). This trend can be seen with relatively short-term changes in ocean noise (in this case, the background noise fluctuated with the arrival of a storm), but the Lombard effect can also be seen when aggregating the data over multiple seasons and years.

The apparent Lombard effect observed in minke whales has important implications for marine mammal ecology, as the Lombard effect demonstrates the whales' limited ability to adapt to changing ocean noise conditions. Results from this study will also assist in improving methods for passive acoustic marine mammal density estimation, as it is often assumed the average animal source level is fixed.

Helble, T. A., Ierley, G. R., D'Spain, G.L. & Martin, S.W. (2015). "Automated acoustic localization and call association for vocalizing humpback whales on the Navy's Pacific Missile Range Facility," J. Acoust. Soc. Am. 137(1), 11-21.

Martin, S.W., Martin, C.R., Matsuyama, B.M. & Henderson, E.E. (2015). "Minke whales (*Balaenoptera acutorostrata*) respond to navy training," J. Acoust. Soc. Am. 137(5), 2533-2541.

BLAINVILLE'S BEAKED WHALES REDUCE FORAGING DIVES PRIOR TO THE ONSET OF HULL-MOUNTED SONAR DURING NAVY TRAINING EVENTS

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Passive acoustic data were recorded before, during, and after a biannual Submarine Command Course (SCC) training event conducted at the Pacific Missile Range Facility (PMRF) in Hawaii from 2011 through 2018, for a total of 16 events. Blainville's beaked whale (*Mesoplodon densirostris*) group foraging dives have been detected throughout these periods of recording effort; as has been shown previously on this and other Navy ranges, there is a decrease in foraging dives detected on the range and a change in the spatial distribution of foraging dives during periods of mid-frequency sonar (MFAS) activity (e.g. McCarthy et al., 2011; Manzano-Roth et al. 2016). Additionally, there is an initial decrease in dives associated with the portion of training activity that does not include hull-mounted MFAS. Over the 16 training events, there were an average of 2.2 group foraging dives per hour (DPH) on the range in the 0.9 – 9.5 days before the SCC, which decreased to 1.4 group foraging DPH in the first 2 – 2.5 days of training activity without hull-mounted MFAS (called Phase A), and then decreased further to 0.6 group foraging DPH during periods of MFAS (called Phase B). This was followed in the 0.3 – 5.6 days after the SCC by some recovery to an average of 1.6 group foraging DPH (values based on a total of 7519 dives over 4836.4 hours of recording effort during these 16 events).

This analysis focuses on the initial decrease in group foraging dives associated with increased training activity on PMRF. Broadband received levels across three frequency bands (10-1000 Hz, 1-10 kHz, 20-48 kHz) at the start of each dive during Phase A as well as at randomly sampled times (bootstrapped using the probability of a dive occurring on a hydrophone in the before period) without dives during Phase A to determine if there were differences in soundscape when dives did and did not occur. In addition, the probability of a dive onset was examined before the SCC and during Phase A using a change point analysis to determine when the dives began to decrease. Finally, the locations of dives that occurred on the range before, during Phase A, during Phase B, and after the SCC were assessed using a spatial analysis to determine if animals were remaining on the range during the SCC, or if they were actually leaving the range or moving away from the center of activity.

Manzano-Roth, R., Henderson, E. E., Martin, S. W., Martin, C., & Matsuyama, B. M. (2016). Impacts of US Navy training events on Blainville's beaked whale (*Mesoplodon densirostris*) foraging dives in Hawaiian waters. *Aquatic Mammals*, 42(4), 507.

McCarthy, E., Moretti, D., Thomas, L., DiMarzio, N., Morrissey, R., Jarvis, S., ... & Dilley, A. (2011). Changes in spatial and temporal distribution and vocal behavior of Blainville's beaked whales (*Mesoplodon densirostris*) during multiship exercises with mid - frequency sonar. *Marine Mammal Science*, 27(3), E206-E226.

THE MARINE MAMMAL STRESS RESPONSE AND ITS RELATIONSHIP TO NOISE EXPOSURE

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Models of the consequence of acoustic disturbance to marine mammals (e.g. the Population Consequences of Disturbance model) seek to link physiological and behavioral responses to sound exposure to vital rates, and ultimately, population dynamics. The stress response is a physiological response that mitigates the impact of a stressor (e.g. noise, food deprivation) on an animal, but which can be deleterious to health and reproduction if prolonged or too great in magnitude. Numerous papers have speculated that noise-induced stress might be a concern for marine mammals, highlighting the need to understand the physiological consequences of the stress response and its relationship to noise exposure. The marine mammal stress response is potentially different from that of terrestrial mammals due to adaptations enabling an obligate aquatic or amphibious existence. However, few studies have characterized the stress response in marine mammals, and far fewer have characterized the stress response due to noise exposure. This talk reviews current knowledge of the marine mammal stress response, how it differs from that of terrestrial mammals, and the few available papers that characterize the stress response of odontocetes exposed to noise. Two yet to be published studies are presented—1) determination of the stress response following vibratory pile driving noise (VPN) exposure, and 2) determination of the stress response following high-level mid-frequency sonar exposure. Both studies were conducted in bottlenose dolphins. Received sound pressure levels (SPLs) ranged from 110-140 dB re 1 μ Pa in the VPN study, and from 115-185 dB re 1 μ Pa in the sonar study. Voluntary blood samples, which are necessary to prevent stress due to forced blood draws, were obtained from all dolphins pre- and post-exposure. Samples were processed for the stress hormones cortisol, aldosterone, epinephrine and norepinephrine. Dolphins generally showed changes in behavior as a function of received SPL but without significant differences in hormone levels between pre-exposure and post-exposure conditions. Variability in hormone levels was high suggesting possible differences in individual noise tolerance. However, neither cortisol nor aldosterone increased to levels observed under acute out-of-water stress tests performed in dolphins wherein levels increased 2–3 times and up to 13 times, respectively, within 15–30 minutes of the beginning of the stress test. Evidence to date suggests demonstrative noise-induced behavioral responses do not necessarily equate to elevations in stress hormones in dolphins, which is important to interpret behavioral responses of toothed whales exposed to noise in the wild.

EFFECTS OF SEISMIC AIRGUN PLAYBACKS ON ATLANTIC COD EQUIPPED WITH ACOUSTIC TAG AND ACCELEROMETER

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Seismic surveys are explorations of the geological structure beneath the seafloor using airguns. Airguns produce high intensity, low-frequency impulsive sounds at regular intervals. This sound is audible to most—if not all—fishes and, because of the high intensity, can propagate for tens to hundreds of kilometres. Little is known about the effects of such sounds on fish behaviour. We especially lack understanding of behavioural responsiveness at relatively large ranges from the source, whereas high numbers of fish will be exposed at these ranges. For this experiment, we studied the effect of seismic airgun sound on swimming and foraging activity patterns of Atlantic cod (*Gadus morhua*). We equipped the cod with an acoustic tag and acceleration logger to acquire their swimming patterns, VeDBA (vector of dynamic body acceleration, a proxy for energy expenditure) and to identify activities. Trials were performed with individual cod (n = 20) in a net pen in a shallow (3-5 m), but acoustically sheltered and well-characterized, harbour. The aim of this study was not to assess absolute response thresholds to fully realistic seismic pulses, but to study variation in behavioural patterns, as reflected by telemetric triangulation and logged accelerometer data, in ambient conditions and when exposed to seismic pulse like sounds. After release in the pen and about 20 hours of baseline data collection, we exposed the cod to one hour of playback of airgun shots. Preliminary plots of spatial data and VeDBA indicate that some individuals show abrupt changes in their behavioural patterns, while others do not. We will report on more detailed statistical analysis of the data using animal movement models.

COMPARISON OF POTENTIAL ACOUSTIC IMPACTS FROM MARINE VIBRATOR TECHNOLOGY AND AIR GUNS

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Marine seismic surveys are conducted to study the geologic structure of the earth's crust under bodies of water. Compressed air sources, commonly referred to as seismic air guns, are the most widely-used sound sources for these surveys; however, alternative technologies are being explored, including marine vibroseis (MV). Relative to air gun arrays, MV sources generally produce lower acoustic pressures and frequency spectral content, but to generate the required geophysical data, they are programmed to produce longer duration signals with short inter-pulse periods. This desktop study involved modeling of source signals, sound propagation, and animal movements to quantitatively assess several MV and air gun array configurations and signal types in multiple realistic operating scenarios. Several established criteria for injury and behavioral exposure were used to allow comparisons between criteria.

Modeled air gun and idealized MV signals produced similar broadband acoustic energy in this study, but MV arrays emitted less high-frequency energy. Since the same frequency weighting was applied to both sounds, and L_E thresholds are higher for the non-impulsive MV sounds, the modeled distances to L_E thresholds were generally shorter for MV arrays. However, for both air gun and MV arrays, modelled distances to injury thresholds were short and animal exposure modeling predicted very few marine mammals would be exposed to such levels.

Differences between the two source types in their potential behavioral impacts on marine mammals varied greatly depending on which criteria and related frequency weighting were applied. The single-step unweighted L_p thresholds currently used by some regulatory agencies resulted in higher estimates of behavioral impacts from MV arrays, primarily as a result of the very low threshold for non-impulsive sounds (L_p 120 dB re 1 μ Pa). When frequency-weighted, multiple-step function criteria were used, the result was reversed, and air gun arrays were predicted to cause more behavioral responses.

The longer duration of MV array sounds relative to air gun array pulses means there is less opportunity for "dip-listening" between MV sounds (between 1/3 and 2/3 less time in a given period). However, the lower source levels of MV arrays means the distances within which masking may occur may be 2 to more than 5 times less than for air guns. Additionally, if the harmonic content of MV array sounds above 100 Hz is kept low, then potential masking of mid- and high-frequency cetaceans will be almost entirely eliminated and greatly reduced for low-frequency cetaceans.

STARTLE AND AVOIDANCE REACTIONS OF CUVIER'S BEAKED WHALES TO SUDDEN ONSET SOUNDS

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The Cuvier's beaked whale (*Ziphius cavirostris*) is a species that has repeatedly been found stranded in association with naval sonar operations (Harris et al., 2018). Controlled exposure experiments have found a clear response to sonar sounds played from scaled sources (e.g. DeRuiter et al., 2013). Yet, experimental approaches have not revealed responses that would ultimately lead to strandings unless a noise source were to follow a whale.

Apart from received level, the sudden onset of sonar sounds has been identified as a potentially aversive feature that could contribute to strong avoidance responses (Harris et al., 2018). In all tested mammal species, sounds with rapid onset times elicit a startle reflex (a rapid contraction of flexor muscles) which can lead to a sensitization of avoidance responses with repeated exposure (Götz & Janik 2011). In this study we tested the reactions of Cuvier's beaked whales at the surface to repeated startle sounds to investigate whether animals show evidence of sensitization to such stimuli.

We exposed three individuals to sequences of bandwidth-limited startle sounds with a 20 dB bandwidth from 3.5 to 9 kHz. We monitored the animals' muscle contractions using 3D accelerometry recorded with DTAGs and analysed their avoidance behavior focusing on swim speed, vocalization behaviour and distance covered after exposures. We found that Cuvier's beaked whales have a clear startle response that is consistent with descriptions for other terrestrial and marine mammals. All whales ceased vocalizing, increased swim speed and left the playback site when hearing startle stimuli with a rms received level between 135 and 160 dB re 1 μ Pa. In a second exposure bout, one animal showed avoidance to a received level of only 104 dB re 1 μ Pa rms, suggesting conditioned sensitization may be taking place. We conclude that rise time is a significant component of a noise stimulus that has the potential to amplify avoidance reactions shown by beaked whales.

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ON THE CONVERSION BETWEEN SOUND PRESSURE AND PARTICLE MOTION

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The measurement of underwater sound for the purpose of environmental impact studies often involves the measurement of sound pressure by means of hydrophones. Measurements of the particle motion induced by sound waves are less often carried out. This is justified for marine mammals which are sensitive to sound pressure in water like land mammals are for sound pressure in air. However, some species of fish and invertebrates are also sensitive and responsive to particle motion (Hawkins et al., 2017). Therefore there is a potential need for direct measurements of the particle motion in addition to pressure.

One way to obtain particle acceleration is to measure it by a dedicated particle motion sensor, which measures the particle acceleration in multiple directions (Martin et al., 2015). In the absence of such sensors, particle motion could be estimated from sound pressure data using relationships for freely propagating plane waves. However, free-field propagation conditions are not always present and this estimation may be subject to significant error (Gray et al., 2016). This paper compares experimental and modelled particle motion and pressure data to determine to what extent and with what accuracy sound pressure data can be used to estimate particle motion data.

Measurements are reported for different types of vector sensors. These sensors house three orthogonal accelerometers able to measure particle motion of the water directly. The presence of a collocated hydrophone inside the sensors also allows for the measurement of the acoustic impedance, i.e. the complex ratio of the sound pressure and particle velocity, both of which vary with frequency. Experiments were carried out in a laboratory basin and a field test in shallow Dutch waters, using a scaled seismic airgun as a source. It is shown that the conversion between sound-pressure and particle-motion can be assessed using the concept of scaled impedance, which is the ratio of measured impedance over free-field impedance. This ratio is shown to become small for low frequencies and to stabilize for higher frequencies, where the source-receiver distance represents a larger number of acoustic wavelengths. The transition frequency depends on the receiver distance from water surface and seabed. Experimental results of scaled impedance are compared to numerical calculations performed with the OASES seismo-acoustic model.

The scaled impedance metric is proposed as a convenient way to quantify the sound pressure – particle motion conversion as a function of range, frequency and depth, resulting in recommendations for bioacoustic studies.

Gray, M.G., (2016). “*Acoustic particle motion measurement for bioacousticians: principles and pitfalls*“, J. Acoust. Soc. Am, Proceedings of Meetings on Acoustics, 27, 010022.

Hawkins, A.D., Popper, A.N., (2017). “*A sound approach to assessing the impact of underwater noise on marine fishes and invertebrates*“, ICES Journal of Marine Science 3, 635-651.

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ACOUSTIC PARTICLE VELOCITY MEASUREMENTS NEAR A ROCKY SHORE OFF CABO FRIO ISLAND

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The Island of Cabo Frio is at the tip of the Cabo Frio cape, a landmark of the Brazilian coast situated 23 degrees south, between the tropical ocean and the southern temperate region. This cape is subject to, often strong, NE winds developing a significant upwelling phenomenon on its southward. Between the island and the mainland there is bay relatively protected from the southern ocean by a rocky shore that has only a narrow entrance, through which extremely cold water enters when upwelling occurs. For more than one year continuous sound recording has been performed near the rock shore (Xavier et al., 2018). From January 14 to 18, 2019, an experiment named BIOCUM19, involving acoustic transmissions across the bay was carried out. Together with other instrumentation an acoustic vector sensor was also installed near the shore with the objective of recording particle velocity. It is now well known that a large number of organisms are sensitive to particle motion, which differentiates itself from sound pressure, specially near acoustically hard surfaces or at close distance from acoustic sources. The recorder itself is based on a dual tri-axial accelerometer combined with an hydrophone (Mantouka et al., 2017) and was primarily developed for seismic imaging from on board autonomous vehicles (Santos et al., 2017 and Felisberto et al., 2019). During BIOCUM19 the recorder was attached to a rectangular pod positioned at about 8 m from the rock wall and at 7 m depth. The recorded data covers two full days and includes additional acoustic data along the water column and other environmental information such as temperature profiles both at the receiver site and along the transmission path across the bay. The data processed so far shows that together with sound pressure particle velocity is clearly sensitive to the biological signature identifiable in the area. A daily pattern can be observed between 1.5 and 5 kHz, during the periods without acoustic transmissions, as coming from the rocky wall. Particle motion is extremely difficult to interpret but seems to show a similar pattern, at least for the accelerometer that is placed towards the shore. This study supports the development of tools to identify and classify several bioacoustic signatures from benthic community.

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Mantouka A., Felisberto P., Santos P, Zabel F. Saleiro M, Jesus S.M. and Sebastião L., (2017) "Development and testing of a Dual Accelerometer Vector Sensor for AUV acoustic surveys", *Sensors*, vol 17(6), pp.1328.

Santos, P., Felisberto P., Zabel F., Jesus S.M. and Sebastião L., (2017) "Dual Accelerometer Vector Sensor mounted on an AUV – Experimental Results", *Proc. of Meetings on Acoustics (POMA)*, Acoustical Society of America.

Xavier F.C., Silveira N.G., Netto E.B., Simões M.V. and Jesus S.M., (2018) "Soundscape of benthic fauna off Cabo Frio Island under upwelling regime", *2nd Oceanoise Asia Conference*, Hakodate (Japan).

SOUND LEVEL ANALYSIS FOR AN OFFSHORE OIL & GAS DRILLING ACTIVITY

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The typical approach used to predict the acoustic output of a mobile offshore drilling facility, dominated by the azimuthal thrusters used for station-keeping, is based on the empirical formulas from Ross (1976) and Brown (1977). Both methods provide a way of calculating the source level associated with the thrusters of surface vessels but have limited accuracy at low frequencies, where the acoustic energy varies considerably between different vessels. Modern vessels are not included in the empirical data used by Ross and Brown. An acoustic characterisation study was conducted to improve understanding of the variability of sound levels within several kilometres of a facility and compare with a conventional modelling approach.

A sound field mapping survey was carried out in December 2017, during normal operation of a 6th generation Mobile Offshore Drilling Unit (MODU). The study was commissioned to produce an acoustic dataset for future verification of sound propagation modelling for modern semi-submersible facilities.

The presentation will focus on the technical aspects of the study, in particular data processing and sound characterisation. The measurement-based source level spectrum for the MODU will be discussed, along with the limitations of a conventional sound propagation modelling. The data acquisition and operational aspects of the study will be discussed separately.

Ross D. (1976). Propeller Cavitation Noise. In *Mechanics of Underwater Noise* (pp. 253-287). Pasadena, CA: Pergamon Press.

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THE LINK BETWEEN SONAR AND MASS STRANDINGS OF CETACEANS

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Notably, the Canary Islands have witnessed many mass strandings of cetaceans, but since 2004, mass strandings have nearly subsided. Why? Military sonar activity was banned by the Spanish Parliament. This reduction in incidents reported in the Canary Islands suggests that sonar is a major factor in the mass strandings of cetaceans. In 2000, the United States government, for the first time, announced a correlation between mass strandings and sonar activity within the ocean. However, a stranding coinciding with sonar activity was first recorded by researchers thirty years earlier.

Early studies (E.C.M. Parsons, 2017) suggested beaked whale species were the only cetaceans effected by mid-frequency sonar, but more recent studies have shown other whale and dolphin species are also impacted by the noise output of vessels that release sonar into the ocean (n.d). After September 11, 2001, it was documented that the decrease in ocean traffic eliminated stress hormones found in the feces of right whales (Rolland et al, 2012). Most research conducted on mass strandings has shown deep diving cetaceans to be more susceptible to N₂ intake when exposed to sonar activity, which can cause the development of gas bubbles in the tissues of cetacean species similar to decompression sickness in people.

Unfortunately, many mass strandings have been ruled as “coincidental” when sonar is present. This presentation will review mass strandings “coincidental” with sonar activity and summarize studies on this topic to conclude that sonar activity is undeniably a contributing factor to mass strandings of cetaceans in the ocean.

Marine Mammal Strandings U.S. Navy Sonar Activities. (n.d.). Retrieved from [https:// www.hstteis.com/portals/hstteis/files/reports/Marine_Mammal_Strandings_Associated_with_U.S._Navy_Sonar_Activities_June2017.pdf](https://www.hstteis.com/portals/hstteis/files/reports/Marine_Mammal_Strandings_Associated_with_U.S._Navy_Sonar_Activities_June2017.pdf)

Parsons, E. C. (2017). Impacts of Navy Sonar on Whales and Dolphins: Now beyond a Smoking Gun? *Front Mar Sci*, 4. doi:10.3389/fmars.2017.00295.

Rolland, Rosalind M. , Susan E. Parks, Kathleen E. Hunt, Manuel Castellote, Peter J. Corkeron, Douglas P. Nowacek, Samuel K. Wasser, and Scott D. Kraus (2012). Evidence that ship noise increases stress in right whales. *Proc R Soc [Biol]: Biological Sciences*, 279(1737), 2363-2368. doi: 10:1098/rspb.2011.2429.

DEVELOPING MARINE ENVIRONMENTAL QUALITY MEASURES TO MANAGE UNDERWATER OCEAN NOISE AND OTHER PRESSING MARINE ECOSYSTEM STRESSORS

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As human development and activities in marine ecosystems continue to increase (Cox, 2018), intensifying pressure on marine biodiversity, there is a need for a suite of approaches and evidence-based management tools to address impacts. Under the *Oceans Act*, the Minister of Fisheries and Oceans has the authority, in collaboration with partners and stakeholders, to establish marine environmental quality objectives, guidelines, and standards. The Marine Environmental Quality program, in the Aquatic Ecosystems sector of Fisheries and Oceans Canada, has a long history which began with a focus on pollution and has evolved to a broader view focused on research, monitoring and the development of tools and approaches to protect and maintain the health and quality of marine ecosystems.

As part of the Government of Canada's Oceans Protection Plan, the Marine Environmental Quality program works collaboratively with other federal departments and agencies, provinces, territories and Indigenous groups, to increase understanding and address pressing issues affecting the quality of marine environment, including the health of marine mammals. Concurrently, Fisheries and Oceans Canada research is being undertaken to collect and analyze underwater noise data for areas of highest concern and for at-risk species to inform the development of potential management measures for noise in specific marine ecosystems.

An overview of the national Marine Environmental Quality program will be provided, with a focus on current coordination and measure development work on underwater ocean noise and proposed next steps to address pressing ecological stressors under the *Oceans Act*. Existing tools, key challenges and opportunities in the development of underwater noise measures, and the ongoing need for international collaboration will be highlighted.

Cox, K., Brennan, L.P., Gerwing, T.G., Dudas, S.E., Juanes, F. (2018). Sound the alarm: A meta-analysis on the effect of aquatic noise on fish behavior and physiology," *Glob Change Biol.* 2018;00, 1–12.

INFLUENCES OF PILE DRIVING NOISE EXPOSURE ON FEEDING AND REPRODUCTIVE BEHAVIORS OF LONGFIN INSHORE SQUID (*Doryteuthis pealeii*)

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Marine pile driving noise will increase in occurrence with rapid expansion of offshore wind energy in the Northeast U.S, and this noise can have a myriad of adverse behavioral impacts across animal taxa. Pile driving produces far-propagating, low-frequency, and high-intensity noise. Yet little is known regarding how this noise impacts ecologically important marine invertebrates such as squid. Cephalopods, and squid in particular, play a central role in trophic webs as a key link between top predators and small prey, thus their behavioral responses to noise may have widespread consequences.

In a controlled laboratory setting we initially characterized squids' alarm responses to impact pile driving sounds and then examined how this noise influenced feeding and reproductive behaviors of an important fishery species, the longfin squid (*Doryteuthis pealeii*). We used playbacks of pile driving noise recorded during offshore wind farm construction. Sound pressure and particle acceleration were fully calibrated in experimental tanks in 3D. Separate squid were used as controls during silent playbacks. Initial experiments (n=27 noise-exposed squid) assessing baseline alarm responses (e.g. inking, jetting, body patterning) revealed responses were nearly always elicited at the onset of pile driving noise and squid habituated quickly within the first minute of playback. After a 24-h rest period, similar proportions of noise-exposed squid exhibited alarm response rates suggesting habituation was only short-term. Feeding experiments utilized individual squid and live minnow prey, with experiments assessing both daytime and nighttime feeding (n=39 and 22 respectively). There were significant increases in proportions of squid with failed attacks and no attack attempts on the prey in noise-exposed trials compared to control trials. Another series of experiments addressed noise impacts on reproductive behaviors, including changes in occurrence rate and duration of squid courtship (e.g. visual signaling, chasing), fighting, and copulatory behaviors. Reproductive behaviors that began prior to noise playback did not cease during playback.

Results suggest that responses may be context specific. Noise impacts alarm and feeding behaviors, potentially making squid more vulnerable to predation, and potentially reducing foraging, a key behavior in these squids' maintenance of a limited energy budget. Yet effects on reproduction may be limited. Investigations of noise exposure impacts on these behaviors are novel for cephalopods. By analyzing a suite of ecologically relevant behaviors in a controlled environment, this work will improve understanding of how behavioral alterations during noise exposure may influence survival and reproductive success in squid.

KILLER WHALE NOISE EXPOSURE MODEL

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Underwater noise from commercial shipping and whale watch boats may be impacting recovery of endangered Southern Resident killer whales (SRKW). The most likely acoustic effects from these vessel noise sources are behavioral responses (BR) and masking, both of which are driven by short term noise levels. A spatially explicit probabilistic noise exposure model was therefore developed to estimate BR and echolocation click masking at 5-minute increments in 200 m grid cells within our study area (130 x 150 km).

This noise exposure model relies on 1) spatiotemporal probabilities of SRKW density, 2) broadband (20 Hz – 96 kHz) SPL and 50 kHz PSD levels, 3) low and moderate severity (Southall et al. 2007) dose-response curves (developed from three relevant killer whale datasets) and a click masking model (Au et al. 2004). The SRKW densities were calculated by effort correcting voluntary sightings (Olson et al. 2018). The SPL and PSD levels were calculated separately for the two vessel noise categories. Ship noise levels were modeled using AIS data, ship source levels modified for ship speed and a transmission loss model. As whale watch spatiotemporal movement is dependent on SRKW, boat noise levels were back-calculated and added to the ship noise levels after SRKW were placed in the model space. SPL levels triggered low or moderate BRs. If a BR was not triggered, masking was estimated.

The noise exposure model can be run over a season or year and iterated multiple times to estimate BR and masking on a per whale basis with confidence intervals. By assuming a BR resulted in a switch from foraging to non-foraging behavior and that masking reduced foraging time, the exposure model outputs were combined into a cumulative effect metric “potential lost foraging time” and compared across scenarios. This exposure model estimated a 21% reduction in “potential lost foraging time” as a result of a voluntary ship slowdown led by the Vancouver Fraser Port Authority in 2017. The noise exposure model also estimated that ~2/3 of “potential lost foraging time” under current conditions is due to ship noise (largely BR-related) and the remaining ~1/3 is due to echolocation click masking loss related to whale watch noise (and associated inherent assumptions). This killer whale focused model can be used to estimate priority noise stressors, the effectiveness of mitigation strategies and help prioritize area-based protective management options such as sanctuaries or refuges.

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CHARACTERIZATION OF THE ACOUSTIC ACTIVITY OF BIVALVE *Perna perna* (LINNAEUS, 1758)

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In coastal regions, bivalves have great social, economic and ecological importance (Di Iorio et al., 2012). *Perna perna* is a Mytilidae that presents a wide distribution in the Brazilian coast, being much used in the mussel farming (Resgalla et al., 2007). Although widely studied, there is no previous research using the acoustic approach for the specie.

This study aims to characterize, in the laboratory, the sound emitted by the mussel *Perna perna* and analyze the variation of its acoustic activity rate regarding the sample densities of the population. Six treatments were defined, divided in two groups of three, containing 10, 40 and 80 individuals each. In the first group the mussel signals were recorded with the fully submerged individuals and in the second the mussels were kept partially submerged, simulating intertidal zone. The acquisition time of the signal was 10 minutes per treatment, and each treatment was recorded eight times, totaling eight hours of recordings. The recordings occurred in a tank with acoustic insulation, built for this study.

In the end of the recordings, after identification of the signals, 4.344 selections of bivalve acoustic activities were performed. The sounds were related to valve movements and identified as impulsive events. The mussel's peak frequency ranged from 0.14 to 23.90 kHz ($= 8 \pm 6$ kHz). The highest activity concentration occurred in the 4 - 6 kHz band ($N = 1.665$). The peak power ranged from 43 to 105 dB re 1 μ Pa ($= 63 \pm 7$ dB re 1 μ Pa). Regarding signal duration, the data showed that up to 95% of activities had a duration of up to 0.03 seconds ($= 0.02 \pm 0.01$ s / $N = 4.115$), with a higher concentration in the class of 0.01 - 0.02 s ($N = 2.121$). According to kruskal Wallis test, the acoustic activity rate is dependent on the sample densities of the population. The results provided subsidies for population density estimation of the mussel from its acoustic activity. In addition, can be an important step for its monitoring over a spatial and temporal scale.

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HARBOR PORPOISE FISH-CATCHING ABILITY IN RELATION TO OFFSHORE PILE DRIVING

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The foundations of offshore wind turbine parks are often constructed by means of percussion pile driving. Broadband impulsive sounds generated by pile driving may disturb and distract marine mammals such as harbor porpoises (*Phocoena phocoena*); their concentration may be reduced, affecting the skills they need for foraging (e.g. timing, precision), and thus reducing their ability to catch prey and their foraging efficiency. The resulting reduction in fitness may eventually lead to population declines. It is therefore important to understand the effects of these anthropogenic sounds on the ability of harbor porpoises to catch fish.

Two captive harbor porpoises (F05 and M06) performed a fish-catching task while they were exposed to low ambient noise (quiet conditions) and impulsive pile-driving playback sounds at three (M06) or four (F05) mean received single-strike sound exposure levels (SELs) between 125 and 143 dB re 1 $\mu\text{Pa}^2\text{s}$. The two study animals differed in their fish-catching success rate at all noise levels, including under quiet conditions: F05 was less likely to catch fish than M06. They also responded differently to increasing SELs: only F05 was significantly more likely to terminate trials and less likely to catch fish as SELs increased above 134 dB, but her trial failure rate (which was ~20%) remained unaffected by increasing SELs. The time taken to catch a fish did not vary with SELs, but was slightly longer for F05 than for M06. Results suggest that loud pile-driving sounds are likely to affect foraging negatively in some harbor porpoises, by decreasing their catch success rate and increasing the termination rate of their fish-catching attempts; the severity of the effects is likely to increase with increasing pile-driving SELs. However, individual differences in responses to sound, termination rates, and fish-catching success (even in ambient conditions) may complicate the quantification of the impacts of pile-driving sounds on harbor porpoise populations.

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SIGNAL DETECTION BY HARBOR SEALS AND HARBOR PORPOISES IN AMPLITUDE-MODULATED NOISE

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Masking occurs when one sound (the noise) interferes with the detection by an animal of another sound (the signal). The degree of interference depends upon the relative amplitudes of the sounds and on the degree of difference between the frequencies of the signal and noise: masking is greatest when the two sounds overlap in spectrum. The lowest signal-to-noise ratio at which an animal can detect a tonal signal in a broadband continuous Gaussian masking noise is defined as the critical signal-to-noise ratio (or critical ratio, CR).

So far, mainly only masking due to continuous random Gaussian white noise has been studied in harbor seals (*Phoca vitulina*) and harbor porpoises (*Phocoena phocoena*). The CRs derived in these studies, when used in environmental impact assessment models, result in overestimation of the masking effect of natural and anthropogenic noise, because most noise fluctuates in amplitude (e.g. noise produced by waves, wind, propellers, and wind turbine blades). In order to assess masking more realistically, information is needed about the masking effect of noise that varies over time, both in amplitude and spectrum.

The goal was to determine the masking effect of Gaussian white noise that was modulated in amplitude at various frequencies (0.125, 0.250, 0.5, 1, 2, 5, 10, 20, 40, 80, and 90 Hz) and of constant-amplitude Gaussian white noise; the noise also varied in modulation depth, noise bandwidth and sound pressure level (SPL). Two harbor seals and two harbor porpoises were asked to detect signals of 0.5, 1 and 2 s duration in the masking noises. Two hearing signal frequencies were tested: a 4 kHz tone in a one-third octave noise band around that frequency, and a 32 kHz tone in a one-third octave noise band around that frequency. The hearing thresholds of both animals of each species were almost identical for each masking condition. Masking was less with amplitude-modulated noise than with constant-amplitude noise, and varied between modulation frequencies. The amplitude-modulation frequency range fell into three distinct bands as follows: <1 Hz (the timing of the signal relative to the sinusoidal amplitude-modulating noise affected the hearing threshold), 2-20 Hz (hearing thresholds increased with increasing modulation frequency), and 40-90 Hz (hearing threshold increased less as modulation frequency increased). For certain noise amplitude modulations, masking release is substantial relative to constant amplitude noise

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TEMPORARY HEARING THRESHOLD SHIFTS IN HARBOR PORPOISES AND HARBOR SEALS

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Safety criteria for anthropogenic underwater sounds are needed in order to protect the hearing of wild harbor porpoises (*Phocoena phocoena*). So far, susceptibility to temporary hearing threshold shifts (TTS) in harbor porpoises has been tested only for sounds in the 1-7 kHz range; data are needed for the species' entire hearing range (0.125-150 kHz). Therefore, TTSs were quantified in two harbor porpoises that were exposed for one hour to continuous one-sixth octave noise bands centered at 0.5, 16, 32, 63 and 88.4 kHz. TTS onset and TTS increase with increasing sound exposure level (SEL) were measured. Hearing was measured at the center frequency of the fatiguing sounds, and half an octave and one octave higher. Hearing was quantified until the hearing thresholds had returned to pre-exposure levels, in order to assess recovery. Once susceptibility has been quantified for the entire hearing range, it will be possible to generate weighting curves for cetaceans that echolocate at high frequencies.

Similar data on susceptibility to TTS caused by underwater sounds are needed for phocid seals. For the harbor seal (*Phoca vitulina*), TTS data have been collected for 2.5 and 4 kHz; data are needed for the species' entire hearing range (0.125-60 kHz). Therefore, TTSs were quantified in two harbor seals that were exposed for one hour to continuous one-sixth octave noise bands centered at 0.125, 0.250, 0.5, 1, 2, 6.5, 16, 32, and 40 kHz. TTS onset and TTS increase with increasing sound exposure level (SEL) were measured. Hearing was measured at the center frequency of the fatiguing sounds, and half an octave and one octave higher. Hearing was quantified until the hearing thresholds had returned to pre-exposure levels, in order to assess recovery. Once susceptibility has been quantified for the entire hearing range, it will be possible to generate weighting curves for phocid seals.

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FUNCTIONAL ANATOMY OF EXTREME HEARING FROM BATS AND ELEPHANTS TO BELUGAS AND BOWHEADS: COMMONALITIES, DIFFERENCES, AND DATA GAPS

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During the explosive period of mammalian radiation, three taxa, Chiroptera (bats), Proboscidea (elephants), and Cetacea (whales and dolphins), emerged with highly evolved adaptations for infrasonic to ultrasonic hearing in radically different media. In the last 50 million years, these groups have proliferated into diverse species, all of which possess highly sophisticated auditory structures. This paper addresses media related functional differences of auditory systems of these groups; i.e., structural variations in the outer, middle, and inner ears, highlighting convergences in the cytoarchitecture and morphometry of their inner ear, middle and outer ear structures related to their specializations for perceiving infra vs ultrasonic signals. Data presented are taken from behavioural, electrophysiologic, microscopic, ultrahigh resolution imaging, and FEM simulation studies.

Inner ear anatomy is fundamentally similar across the groups although differences exist in both neural densities and distributions as well as basilar membrane dimensions and cochlear spiral configurations. Specialist ears are present in both groups, suggesting at least one odontocete has cochlear specializations consistent with CF-CM bats, including specialized basilar membrane regions and high frequency neural foci whereas cochlear configurations in the elephants and baleen whales are geared to the enhancement of infrasonic response in the inner ear. Cochlear specializations in all groups are linked primarily to peak spectra of their vocalizations, expanded frequency representation in the inner ear, and in some cases, possibly enhanced tuning in adjacent ear segments derived from standing wave phenomena. Differences that are consistent with processing of aerial vs aquatic borne sound, such as the fatty tissues associated with the ear in cetaceans, are found primarily in the outer and middle ear elements. Other differences among species within each group are correlated with signal type, prey, and/or habitat features.

Current work on modeling based on the ear anatomy for some of these species will also be presented, specifically for the low frequency specialists that are expected to be most liable to impacts from underwater anthropogenic sound sources. We employed micro CT, dissection, and histology to calculate inner ear frequency maps (FPMs) of total hearing ranges and frequencies of greatest liability for NIHL (notch) for each species. Anatomically derived maps were compared with nanoindentation measures of basilar membrane

The study was supported by the Joint Industry Programme on Sound and Marine Life, the Hanse Wissenschaftskolleg ICBM Fellowship, and the Helmholtz International Fellow research programs.

JOINT MONITORING PROGRAMME FOR AMBIENT NOISE IN THE NORTH SEA

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In 2018, the three-year project “Joint Monitoring Programme for Ambient Noise in the North Sea” (EU Interreg North Region Programme ‘Jomopans’ (<https://northsearegion.eu/jomopans/>)) started. Jomopans will develop a framework for a fully operational joint monitoring programme for ambient noise for the North Sea region. The project will deliver the tools necessary for managers, planners and other stakeholders to incorporate the effects of ambient noise into their assessments of the environmental status of the North Sea, and to evaluate measures to improve the environment.

International concern increasingly focusses on the potential negative effects of anthropogenic underwater noise on sensitive marine fauna. Questions regarding sound sources, sound transmission, and the distributions of vulnerable species in the North Sea must all be tackled transnationally, as specifically required by the EU Marine Strategy Framework Directive and by the OSPAR Convention.

The project’s approach

The Jomopans project follows the guidelines for monitoring continuous underwater sound set by the European Technical Group on Noise (Dekeling et al, 2013). The project develops soundscape maps for the North Sea. The relative importance to the soundscape of different sound sources (such as ships and wind) will be determined, together with the variation in continuous sound pressure levels and sources in different parts of the North Sea. A paper on underwater sound mapping has been submitted to Aquatic Noise 2019 (De Jong et al, 2019).

In total, 14 measurement stations around the North Sea are now employed and gather long-term sound data. These data will be combined with modelling to obtain validated soundscape maps of the North Sea.

Project results

A management tool will be developed which combines distribution maps of sensitive species with the soundscape maps. Marine policy makers can use this information to evaluate Good Environmental Status in relation to underwater sound. Also, the aim is that they can use the tool in the future to design and assess appropriate measures to reduce the risk of environmental impacts of underwater sound.

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AN ATLAS OF CANADA'S CHANGING OCEAN SOUNDSCAPE

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Underwater noise generated by human activities such as shipping raises concerns about its potential impact on marine life, for instance, by affecting their ability to navigate, communicate, feed, and reproduce. With increased shipping activity along traditional routes and the opening of new shipping lanes, changes in noise distribution in Canadian waters are expected. The Canadian Species at Risk Act imposes to protect the habitats of endangered species from degradation. It is therefore imperative to better understand and quantify the impacts of shipping noise on marine life, so that adequate and efficient protective measures can be implemented where necessary.

To aid these efforts, MERIDIAN (Marine Environmental Research Infrastructure for Data Integration and Application Network) and collaborators are developing a web-based, interactive Ocean Soundscape Atlas that will enable users to visualize and explore modeled noise levels in a multitude of dimensions including latitude, longitude, depth, time, frequency, and source type, and obtain impact risk estimates in areas of interest. The Ocean Soundscape Atlas uses validated physical models to determine the levels of noise in Canadian waters due to shipping activity and geophysical environmental noise sources such as wind and waves. The Atlas will provide a novel interface between two communities whose effective communication is crucial for responsible and efficient management of the ocean: the researchers, managers, policy makers on the one hand, and the general public, on the other hand. The Atlas will facilitate the transfer of scientific information from researchers to the public, and more generally will contribute to an increased ocean literacy. The Atlas will allow managers and policy makers to monitor trends in the state of the ocean acoustic environment, and hence ensure more timely, effective, and efficient marine environmental conservation and management of the valued and especially protected marine species.

PERCEPTION AND ACOUSTIC ECOLOGY

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Three factors affect the ecology of acoustic communication: (1) efficient signaling by the sender, (2) the characteristics of the transmission channel, and (3) the perceptual abilities of the receiver. All three interrelated factors must be taken into account when evaluating adaptation of acoustic signaling. Efficient signaling involves producing sounds in an energy efficient way, and with little distortion and variation of the signal characteristics on which the receiver relies in analysis. The transmission channel will modify and mask these features as can be exemplified by the effect of background noise and the physical characteristics of the medium through which the acoustic signal is transmitted. Receivers have evolved a number of mechanisms that serve to overcome or even exploit the constraints imposed by the first two factors. The presentation will focus on the receiver side of communication.

Spectral analysis of the signals by the receivers’ sensory system will improve the signal-to-noise ratio and, thus, help increase communication distance. Temporal analysis of the incoming signals not only serves revealing perceptually important signal structures. It also improves the receiver’s ability to focus on brief instances in time in which the level of background noise is low and the signal-to-noise ratio is high. Comodulation masking release is an effect that relies on such a temporal analysis and may improve the signal-to-noise ratio for perception by up to 20 dB, thus, lowering perceptual thresholds.

Monaural and binaural processing mechanisms combine to allow segregating the sounds produced by different sources in a complex acoustic scene. Such sound-source segregation is described as auditory streaming. Auditory streaming considerably improves the receiver’s ability to analyze specific features of the signals broadcast by a sender in a complex acoustic background produced by other sources. Auditory streaming is supported by differences of the spatial location of sources, by differences in the temporal characteristics between signals broadcast from different sources, and by differences of spectral features of the signals originating from different sources. Auditory streaming not only will improve detection thresholds in noisy environments, it also supports the analysis of signals far above threshold as is evident in the phenomenon of informational masking.

EFFECTS OF SEISMIC SOUND ON THE MOVEMENT AND BEHAVIOUR OF ATLANTIC COD (*Gadus morhua*) IN THE BELGIAN PART OF THE NORTH SEA

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Seismic surveys are acoustic explorations of the seabed in search for offshore resources like oil and gas or in preparation for construction of, for example, wind farms. These surveys are performed by seismic vessels equipped with air guns that repeatedly emit a broadband but low frequency acoustic pulse towards the sea bottom. Due to the high power, required to penetrate the sea bottom, these pulses also propagate horizontally and thus create a potential threat to marine life. The hearing range of most fish falls within this low frequency range (100-500 Hz), but the effects of such surveys on fish behaviour are unclear. The current study, funded by the Joint Industry Program (JIP), investigated the effects of an experimental seismic survey on the movement and behaviour of free-ranging Atlantic Cod (*Gadus morhua*) in the Belgian part of the North Sea. 56 individual cod were tagged with acoustic transmitters to track their movement, depth and average vector of the dynamic body acceleration before, during and after a three day seismic survey with a closest approach of approximately 2 km from the tagging site (Belwind offshore Windpark). The fish exhibited individual movement patterns with indications of behavioural changes at the onset of the seismic period. Here we present preliminary results describing home ranges, movement and behaviour of individual cod in response to a seismic survey.

DOES LOCAL VARIATION IN ACOUSTIC EXPERIENCE AFFECT NOISE IMPACT ON ANTI-PREDATOR BEHAVIOUR IN SAND GOBIES?

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Noisy conditions can undermine anti-predator behaviour of both terrestrial and aquatic animals. In fish, experiments on the effects of anthropogenic noise have shown a variety of responses, ranging from heightened vigilance, at the expense of foraging or reproductive activities, to increased mortality by distraction. However, long-term experience with potentially disturbing sounds might alter the influence of short-term exposures, which has received little attention up till now. We studied the effects of boat noise on anti-predator behaviour in sand gobies (*Pomatoschistus minutus*) from more or less acoustically disturbed areas. Free-ranging gobies were exposed to a simulated predator during playback of boat sound or ambient sound, while their behaviour was recorded on camera. Our results provide more insight into the potential for habituation to acoustic disturbance and into changing vulnerability to predation risk due to noise pollution. Knowing how long-term acoustic exposure to potentially disturbing sounds influences the effects of short-term sound exposure on fish will help us understand vulnerability and resilience to acoustic disturbance and aid in targeting conservation efforts of marine areas that are under pressure from anthropogenic noise levels.

AN OVERVIEW OF THE STATUS OF THE BUREAU OF OCEAN ENERGY MANAGEMENT'S (BOEM) PROJECTS TO CHARACTERIZE THE SOUNDFIELDS OF OCEANOGRAPHIC AND HIGH RESOLUTION GEOPHYSICAL (HRG) SURVEY SOURCES IN SHALLOW WATER

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In 2014, The Bureau of Ocean Energy Management (BOEM) and the U.S. Geological Survey (USGS) identified a common need to reliably predict the extent and characteristics of the sound fields surrounding common oceanographic and High Resolution Geophysics (HRG) Survey sources in shallow water for environmental compliance purposes. These sonar systems include representative systems for each of the following general types: boomers; sparkers; chirp sub-bottom profilers; bubbleguns; side-scan sonar; and single, swath, and multi-beam bathymetric fathometers. These systems encompassed a broad frequency range (approximately 0.05 to 200 kHz) and a wide variety of pulse types and source levels. In addition, the operational depths of interest were 10 - 200 m.

A series of three tests or projects were identified and funded to accomplish this goal. In the first test, the U.S. Navy's Naval Undersea Warfare Center Division New Port (NUWC-NPT) was contracted to complete the calibrated measurements of 18 different sources. This characterization included quantifying the source level, beam patterns, frequency content, and transmitted signal characteristics of each of these sources for many of their operational modes (Crocker and Fratantonio, 2016). This testing was completed at NUWC facilities in Rhode Island and Florida. The second test was conducted in June 2016 off Maryland and Virginia and included all of the first test's sources, plus several hull-mounted sources that were available on the test vessel and a small airgun. This test consisted of the in situ measurement of the sound field in three water depths (10, 30, and 50-100 m) and two distinct bottom types (sand and mud) (Halvorsen and Heaney, 2018). The final project in this series utilizes the data collect in the first two tests to examine which acoustic propagation models best predict sound field for each source and each depth and bottom type combination. This effort is currently underway. The author will review the results thus far and identify the products and expected timelines for the completion of this project.

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EFFECTS OF CONTINUOUS ACTIVE SONAR – STATUS UPDATE OF THE 3S3-BRS PROJECT

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The 3S project (Sea Mammals, Sonar, Safety) has conducted behavioral response studies (BRS) since 2006, and started its third phase (3S3) in 2016. This paper will provide a brief overview of the project and focus on its latest results on the effects of continuous active sonar (CAS).

Worldwide there is a trend to exploit new technology to extend the duration of sonar transmissions up to (almost) continuous transmission schedules. The performance of CAS as a sonar tool is promising, with the capacity to achieve similar or better sonar performance than the traditional sonar PAS (Pulsed Active Sonar) with reduced source level, see e.g. Van Vossen et al. (2011). However, the environmental impact of CAS on marine mammals is unknown, because experimental and monitoring studies of effects of sonar have focused on traditional PAS transmission schedules.

As part of the 3S3 project we have been contrasting the responses of sperm whales to CAS and PAS exposures in Norwegian waters. These BRS experiments were executed in 2016 and 2017 (Lam et al., 2018a,b), with 16 different animals exposed to CAS and PAS transmissions of 1 to 2 kHz as well as to a no-sonar control consisting of the same protocol as for sonar exposures but without any sonar transmission (in total 54 exposure sessions). By analysis of time-and-energy budgets of the whales, we found that the cumulative sound exposure level (SELcum; measured over the exposure period of 40 minutes) was the best predictor of the response. We did not find a statistical difference in the responses to CAS and PAS for similar SELcum levels. We also found that changes in time-and-energy budgets of sperm whales were smaller than previously observed in 2008 and 2009 experiments for which whales were exposed to PAS (Isojunno et al., 2016).

In the final stage of the 3S3 project we will investigate possible masking effects of CAS, with CAS exposure experiments conducted on delphinid species that produce communication signals in the 1-2 kHz CAS band. In addition, we plan to study the effects of distance of the sonar source by including a Norwegian frigate with operational source (PAS only).

Isojunno, Curé, Kvadsheim, Lam, Tyack, Wensveen, Miller (2016) Sperm whales reduce foraging effort during exposure to 1-2 kHz sonar and killer whale sounds *Ecol.Appl.* 26(1), 77-93.

Lam, FP, PH Kvadsheim, S Isojunno, PJO Miller, *et al.* (2018). Behavioral response study on the effects of continuous sonar and the effects of source proximity on sperm whales in Norwegian waters - The 3S-2017 Cruise report. TNO report *TNO2018 R10958* (<http://publications.tno.nl/publication/34627071/pohdo8/TNO-2018-R10958.pdf>).

Lam, FP, PH Kvadsheim, S Isojunno, PJO Miller *et al.* (2018). Behavioural response study on the effects of continuous sonar on sperm whales in Norwegian waters - The 3S-2016-CAS cruise report. TNO report *TNO2018 R10802* (<http://publications.tno.nl/publication/34627070/Q3bPWP/TNO-2018-R10802.pdf>)

Van Vossen, R., S.P.Beerens, E. Van der Spek (2011) Anti-Submarine Warfare with Continuously Active Sonar. *Sea-Technology*, Nov-issue, 33-35.

CHANGES IN THE USE OF A WINTER BREEDING AREA REVEALED BY MALE HUMPBACK WHALE CHORUSING

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North Pacific humpback whales (*Megaptera novaeangliae*) migrate from high latitude feeding grounds each winter to breed in coastal tropical waters around Hawaii, Mexico, Central America, Japan and the Philippines. Population estimates indicate that approximately half of the north Pacific stock breeds in Hawaiian waters (Calambokidis et al, 2008). During the breeding season, males produce an elaborate acoustic display known as song, which becomes the dominant source of ambient noise in Hawaiian waters between December and April (Au et al, 2000). Beginning in 2015, commercial operators, researchers, and citizen-science counts in Hawaii began reporting unusually low numbers of whales compared to previous years. To further examine this reported trend, data from bottom-moored acoustic recorders were analyzed for the period between 2014 and 2018 at five monitoring sites off the island of Maui. Male chorusing was used as a proxy for relative whale presence and activity both within and between years. Root-mean-square sound pressure levels (RMS SPLs) in the 20 Hz-1.5 kHz band were used to compare the acoustic energy produced by singing whales among recording locations, over the breeding season, and among seasons. Results show that despite a similar overall temporal trend reflecting the migratory pattern of humpback whales, average monthly SPLs trended down more than 6 dB re 1 uPa over the monitoring period. This suggests that the number of singing males or the amount of time males spent singing decreased substantially over the four-year period. Further, the timing of the chorusing peak within the seasons shifted, suggesting that whales left the breeding area earlier than in past years. It remains unclear whether our observations reflect a decrease in population size or a behavioral response to an environmental stressor. However, the trend is consistent with a concurrent decline reported among mother-calf groups in the same area that has been linked with climatic anomalies in the eastern north Pacific (Cartwright et al, 2019). Continued monitoring efforts, including examining previously unsurveyed whale breeding areas, are needed to resolve the uncertainties associated with the observed changes.

Au, W. W. L., Mobley, J. Jr., Burgess, W. C., Lammers, M. O. and Nachtigall, P. E. (2000). "Seasonal and diurnal trends of chorusing humpback whales wintering in waters off western Maui," *Mar. Mamm. Sci.* 16, 530–544.

Calambokidis, J., Falcone, E. A., Quinn, T. J., Burdin, A. M., Clapham, P. J., Ford, J. K. B., Gabriele, C. M., LeDuc, R., Mattila, D., Rojas-Bracho, L., Straley, J. M., Taylor, B. L., Urb'an, R. J., Weller, D., Witteveen, B. H., et al. (2008). "SPLASH: Structure of Populations, Levels of Abundance and Status of Humpback Whales in the North Pacific," Final report for contract AB133F-03-RP-00078. U.S. Department of Commerce, Western Administrative Center, Seattle.

Cartwright, R., Venema, A., Hernandez, V., Wyels, C., Cesere, J., Cesere, D. (2019) "Fluctuating reproductive rates in Hawaii's humpback whales, *Megaptera novaeangliae*, reflect recent climate anomalies in the North Pacific," *R. Soc. Open Sci.* 6: 181463. <http://dx.doi.org/10.1098/rsos.181463>

UNDERWATER SOUND STUDY INDUCED BY A SEISMIC MARINE VIBRATOR SOURCE; FIELD TEST IN THE NORTH SEA

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Impulsive acoustic sources are the most commonly used sound sources for marine geophysical surveys. Concern about the potential impact of these sources on marine fauna prompted CGG to invest in the research and development of Marine Vibratory (MV) technology. While marine seismic impulsive source signals concentrate the sound energy in time and have high amplitudes spread over a broadband spectrum, MV signals are typically limited in frequency content, but have lower amplitudes and are of longer duration.

Recently, the industry improved the understanding of the effects of underwater sound on marine life by the means of sound propagation modeling techniques. CGG took the opportunity of a MV geophysical field test it conducted in the North Sea in 2017 to record the far-field radiation in the water column, using a tailor-made autonomous acoustic recording system. Towed by a vessel, one MV source unit was band-limited from 20Hz to 75Hz. Different types of MV signals were used and repeated several times along a source line. We performed different kinds of analysis of the received signals at the recording station during the acquisition lines, by having the MV source activated, but also outside the source acquisition window to characterize the background noise.

Sound Pressure Level (SPL) peak values fluctuated within a 46dB range between the average level of background noise and the active MV source at its closest point of approach. Analysis of Power Spectral Density (PSD) made it possible to separate the energy generated by MV signals from the vessel noise. In addition, by using upswep MV signals covering the bandwidth from 20Hz to 75Hz, broadband spectral analysis of the observed radiated sound pressure, performed up to 150kHz, showed reduced impact in the frequency domain. Harmonic distortion detection above the intended frequency band in the recorded data shows a Total Harmonic Distortion (THD) of less than 5%. A comparative study was performed between simulated and measured data of the observed sound pressure at the recording station for several single events and cumulative exposure metrics. Furthermore, an environmental impact assessment using NOAA 2016 cumulative Sound Exposure Level (SEL) criteria (LF cetaceans) was performed over a selected 24-hour period. PTS (Permanent Threshold Shift) and TTS (Temporary Threshold Shift) thresholds were not exceeded with the MV source, while an equivalent simulated impulsive source exceeded the thresholds. This implies a significant reduction in the seismic activity's acoustic footprint when using the MV source.

NOAA. (2016). Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing. National Oceanic and Atmospheric Administration, U.S. Department of Commerce. NOAA Technical Memorandum NMFS-OPR-55

IMPACT OF NOISE EXPOSURE ON DEVELOPMENT AND PHYSIOLOGICAL STRESS IN LARVAL ZEBRAFISH

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Although noise pollution is now widely present in most aquatic soundscapes, very limited information is known on how this environmental stressor impacts fish populations especially in early ontogeny.

Zebrafish (*Danio rerio*) has become an important vertebrate model for high-throughput screening of ototoxic chemical agents and to investigate genetic modulators of embryonic development.

In this study, we performed a split-brood experiment to test the effects of increasing ambient noise levels (c. 105/control, 130 and 150 dB re 1 μ Pa, white noise playback) and temporal patterns (continuous and random intermittent) on survivability, development, and physiological stress in larval zebrafish (at 3 and 5 days post fertilization). Recently laid eggs from multiple zebrafish breeding tanks were randomly chosen and split into custom-made net-boxes that were suspended above underwater speakers placed in the bottom of several acoustic treatment tanks.

We found that exposure to increased levels of continuous noise exposure led to a significant increase in cardiac rate and a significant decrease in the size of the yolk sac in both 3 and 5 days post fertilization, which are indicators of physiological stress.

These results were complemented by whole body cortisol quantification ELISA tests, which revealed significant increase in the glucocorticoid hormone in noise-exposed groups.

Variation in the temporal patterns did not elicit clear differences in development and physiological stress responses, with the continuous noise treatment causing the highest changes.

Our work provides first evidence of higher physiological stress in larval zebrafish due to increasing noise amplitude at moderate noise levels (140-150 dB), and not by changing the temporal patterns of noise exposure. Current work focuses on using behavioural paradigm tests to evaluate noise-induced anxiety levels in larval zebrafish.

CAVITATION-INDUCED HEARING LOSS IN LARVAL ZEBRAFISH: A LABORATORY MODEL FOR UNDERWATER NOISE DAMAGE

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Hearing loss from excessive noise negatively affects a wide variety of marine organisms, including fish and marine mammals. Underwater noise comes from multiple sources in a wide range of frequencies, with some of the major contributors including boats, underwater industrial machinery, and military operations (Hawkins & Popper, 2018). Cavitation from high frequency vibration sources, such as boat propellers, may further contribute to damage by creating intense broadband acoustic energy (Wittekind & Schuster, 2016). It is important to understand the impact of noise on marine life because it can have detrimental effects on hearing, behavior, and overall fitness of the affected organisms.

To complement field-based research, we developed zebrafish as a laboratory model to study the effects of underwater noise on hair cells. The zebrafish is a popular research model and is easily reared in captivity. We utilize this organism to understand the mechanisms of noise-induced hearing loss, via an acoustic trauma system developed in our lab that utilizes ultrasound to induce cavitation and deliver a broadband underwater acoustic stimulus that targets lateral line hair cells (Uribe *et al.*, 2018).

Using our cavitation system, we characterized the timing and extent of noise-induced hair cell damage. Larval fish were exposed to noise parameters that induced partial hair cell loss in both the anterior and posterior lateral line. After 24 hours, hair cell survival was comparable to controls, but by 48 hours, noise-exposed fish showed a significant reduction in hair cell number. In mammals, noise-induced auditory damage is also known to occur at the level of the synapse between hair cells and their afferent neurons, even in the absence of hair cell death (Kujawa & Liberman, 2009). We therefore explored if this synaptic damage also occurs in the zebrafish lateral line. After assessment of synaptic integrity between hair cells and their afferents following noise exposure, we found an increase in hair cells lacking their post-synaptic partner, indicating a disrupted synaptic connection. This research can inform how noise induces damage at the level of the peripheral auditory system in larval fish *in vivo*. This system has the potential for translation of knowledge to other aquatic systems, including marine mammals, and modification for use with other developmental stages.

Hawkins, A. D., and Popper, A. N. (2018). "Effects of Man-Made Sound on Fishes". In: *Effects of Anthropogenic Noise on Animals*, edited by H. Slabbekoorn, R. J. Dooling, A. N. Popper, and R. R. Fay (Springer Science+Business Media, LLC, New York).

Kujawa, S. G., and Liberman, M. C. (2009). "Adding insult to injury: cochlear nerve degeneration after "temporary" noise-induced hearing loss", *J Neurosci.* 29(45):14077-85.

Uribe, P. M., Villalpando B. K., Lawton, K. J., Fang, Z., Gritsenko, D., Bhandiwad, A., Sisneros, J. A., Xu, J., Coffin, A. B. (2018). "Larval Zebrafish Lateral Line as a Model for Acoustic Trauma", *eNeuro*, 5(4).

Wittekind, D., and Schuster, M. (2016). "Propeller cavitation noise and background noise in the sea", *Ocean Engineering*. 120:116-121.

"THE SEA WAS ANGRY THAT MONTH": MASS STRANDING OF SEA TURTLES ON THE COAST OF ISRAEL

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During the month of January 2019, 96 sea turtles were stranded along Israel's Mediterranean coastline. 69 loggerheads (*Caretta caretta*), 16 green sea turtles (*Chelonia mydas*) and 11 unidentified sea turtles were located. Only 30% (29) of the turtles were still alive when located, all suffering from serious injuries, and were brought to the Israel Nature & Park Authority (INPA) Sea Turtle Rescue Center for medical treatment. This represents an alarming nearly ten-fold increase in the number of stranded turtles located yearly in the month of January.

CT scans of live injured sea turtles revealed that 83% (19 of 23 examined) showed symptoms of soft tissue trauma: pulmonary hemorrhage and accumulation of fluids in the middle ear. Such symptoms are consistent with shock-wave trauma, suggesting a fatal exposure to a yet undetermined strong impulsive sound source, such as underwater explosions, on a significant level.

Similar stranding events, with identical clinical symptoms (Aizenberg et al., 2013), were previously documented by the INPA on a smaller scale in 2012 and 2015. Both in 2012 and during the current event (but not in 2015), seismic surveys for gas exploration were carried out in the territorial waters off the Israeli coast (2012) or within Israel's Exclusive Economic Zone (EEZ, 2019). The temporal overlap between the current stranding events and seismic surveys has raised alarm by the INPA and prompted a joint investigation headed by the Ministry of Energy together with environmental experts from the Ministry of Environment, INPA, Israel Oceanographic and Limnological Research Institute and leading academic professionals.

Such a large-scale mortality event of sea turtles may negatively impact endangered populations of the two turtle species within the entire eastern Mediterranean, both which are already threatened by human activities. Thus, there is an urgency to ascertain the possible cause (natural or anthropogenic) leading to this incident and determine where in the Mediterranean it had occurred in order to establish the necessary national and regional guidelines (Popper et al., 2014), so as to mitigate future negative effects of various levels of man-made underwater acoustic activity on sea turtles.

Aizenberg, I., King, R., Grundland, Y., Levy, Y. (2013). "Blast injury and sea turtles". Proceedings of the International conference on diseases of zoo and wild animals 2013: May 8th - 11th, 2013, Vienna, Austria. Leibniz Institute for Zoo and Wildlife Research.

Popper, A.N., Hawkins, A.D., Fay, R.R., Mann, D., Bartol, S., Carlson, T., Coombs, S., Ellison, W.T., Gentry, R., Halvorsen, M.B., Løkkeborg, S., Rogers, P., Southall, B.L., Zeddis, D., Tavolga, W.N. (2014). "Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI. ASA S3/SC1.4 TR-2014". Springer and ASA Press, Cham, Switzerland.

NEW MARINE SEISMIC ENERGY SOURCES FOR OIL EXPLORATION: TUNED PULSE SOURCE, MARINE VIBROSEIS, AND WOLFSPAR

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Seismic airgun surveys have come under more scrutiny because of their potential impact on marine mammals and other marine life. This has led to intensive research for sound source alternatives to traditional airguns, such as: Tuned Pulse Source (TPS), Low Impact Seismic Source (LISS), Marine Vibroseis (MV), and BP's ultra-low frequency marine energy source Wolfspar. In general, these new seismic sources appear to provide solutions that are more environmental friendly than the traditional airgun array(s), and deliver the seismic resolution and seismic imaging needed for hydrocarbon exploration. This presentation will discuss the technical merit of each of these new marine energy sources and their design for reduction of potential environmental impacts.

In brief, the three new marine seismic energy sources can be summarized as follows:

Tuned Pulse Source (TPS): is a pneumatic source designed to operate using low-pressure air. Compared to airguns, the TPS has a much stronger low frequency content (down to 1 Hz), and reduced high frequency content (Ronen & Chelminski, 2017).

Marine Vibroseis (MV): provides a controllable frequency bandwidth for seismic surveys. The modified MV array can provide about 20 dB lower broadband (to 100Hz) peak-to-peak sound level (SPL p-p) in comparison to an airgun array (Tenghamn et al., 2018).

Wolfspar: is an ultra-low frequency seismic source designed by BP. The Wolfspar seismic source provides increased 3D seismic data in the 1.4 to 2.4 Hz range. It enhances the bandwidth of the data significantly, thus improving FWI while reducing any potential environmental impact to marine mammals (Pool et al., 2018).

Pool, R., Kanu C., Brenders, A., and Dellinger, J. (2018). "The Wolfspar Field Trial: Design & Execution of a Low-Frequency Seismic Survey in the Gulf of Mexico," in SEG Extended Abstract, pp. 91-96

Ronen, S. and, and Chelminski, S. (2017). "Tuned Pulse Source – a new low frequency seismic source," in SEG Extended Abstract, pp. 6085-6088

Tenghamn, R., Long, A., Strand, C., and Beitz (2018). "Improved operational efficiency using spread sweeps for marine vibrators," in SEG Extended Abstract, pp. 81-85

ULTRASOUND IMPACTS ON HUMANS IN THE CONTEXT OF AQUATIC NOISE

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In assessing the impact of unwanted noise on aquatic life, or the potential of sound to act as a deterrent to steer fauna away from hazards (or as an attractor to steer towards safety), there is considerable reliance on decades of experience with human audiology. When seeking ways to deal with the response of fauna to aquatic noise, researchers have reached back to human audiology to adapt techniques such as behavioral audiograms and Auditory Evoked Potentials.

However, the ease with which human audiology has translated over decades from the research lab to the high-street hearing-aid dispenser, sometimes belies the underlying challenges that human audiology overcame, and which face its aquatic analogue because it is still in its infancy. If we need a hearing-aid, we expect it to be based upon our personal audiogram. However, if we visit a noisy factory (which will usually not have access to the personal audiograms of visitors), we can expect our hearing to be protected by regulations that, rather than being based on the susceptibility of the ‘average’ human, instead take into account that a visitor might be particularly susceptible (NIOSH, 1998). This requires data based on many relevant individuals, perhaps separated into important cohorts (e.g. by age), and the objective is to protect every individual even though we do not have data on their personal susceptibility.

In the aquatic world, the audiometric data upon which we base our decisions may be built on too few individuals, not separated into relevant cohorts, and rather than ‘protect all individuals’ the success criteria might be based on the less comprehensive response rates to which the animal behavior community are accustomed. In the first two respects (sparse data and cohorts), this aquatic problem resembles that which has remained unresolved in protecting humans from very high frequency (VHF: 14.1-17.8 kHz) and ultrasonic (>17.8 kHz) acoustic signals in air (Leighton, 2017). Here, the audiological data is based on fewer individuals than is needed to produce an appropriate representative audiogram that can protect all humans; yet the approach has been to produce guidelines based on too little information (Leighton, 2016). This has led to a range of unfortunate consequences, both in discussing the protection of humans from VHF sound and ultrasound, and in discussing when such frequencies might be used deliberately to induce adverse effects (from verified cases of ‘teenager deterrents’, to unverified claims of sonic attacks on US Embassy staff in Cuba and China) (Leighton, 2018).

Leighton, T. G. (2016). “Are some people suffering as a result of increasing mass exposure of the public to ultrasound in air?” *Proc. Royal Society A*, 472(2185), 20150624 (57 pages) (doi:10.1098/rspa.2015.0624) <https://royalsocietypublishing.org/doi/full/10.1098/rspa.2015.0624>.

Leighton T.G. (2017) “Comment on ‘Are some people suffering as a result of increasing mass exposure of the public to ultrasound in air?’” *Proc. Royal Society A*, 473(2199), 20160828 (13 pages) (doi: 10.1098/rspa.2016.0828). <https://royalsocietypublishing.org/doi/10.1098/rspa.2016.0828>.

Leighton, T.G. (2018) “Ultrasound in air-Guidelines, applications, public exposures, and claims of attacks in Cuba and China,” *J. Acoust. Soc. Am.* 144(4) 2473-2489 (doi: 10.1121/1.5063351) <https://asa.scitation.org/doi/10.1121/1.5063351>.

NIOSH (1998) “Criteria for a recommended standard; Occupational Noise Exposure; Revised Criteria,” Cincinnati, OH: U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 98-126.

SHELTER PREFERENCE AND ANTIPREDATOR RESPONSES OF EUROPEAN LOBSTER JUVENILE (*Homarus gammarus*) UNDER NOISE AND PREDATION EXPOSURE

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European lobsters (*Homarus gammarus*) juvenile life-stage is highly dependent on finding a suitable shelter for protection and survival. However, due to their cryptic lifestyle, the shelter preferences of juvenile lobster and the different stressors that may influence their choice remain largely unknown. Of all the parameters that may have a major influence on shelter occupancy, one that remains largely unaccounted for is noise. Is it already acknowledged that anthropogenic noise in the ocean has an impact on lobster's locomotor activity and immunological responses (Filiciotto et al., 2014). On the community level, juvenile lobsters also compete with aggressive predators, such as green crab *Carcinus maenas* for shelter and resources (Rayner and McGaw, 2019).

In this full factorial study, we investigated the effect of noise and predation on shelter preference (n= 96) between rocks and European oyster shells *Ostrea edulis* and the antipredator responses (n= 48) of juvenile lobster (14.0 ± 1.7 mm carapace length or CL) with four treatments: control, predator presence, added noise and the combination of both stressors. The predator presence consisted of a green crab (62 ± 1 mm CL) enclosed in a 5 mm mesh-box and maintained at 10 cm from the bottom. The added noise was a constant low frequency multi-tone of around 100 Hz produced by a “noise egg” device consisting of an electromotor in a waterproof container (de Jong et al., 2017) attached to the mesh-box top. An empty mesh-box and “noise egg” was used for the control treatment. Shelter preference was assessed after three hours of each treatment. There was no effect on the final choice of shelter among treatments: 67% of the lobsters selected rocks, and 33% oyster shells. Video recordings of 40 min allowed the analysis of their behaviour, initial shelter preference and mobility among shelters. We identified six key behavioural units: peeking, shelter excavation, exploring, fleeing, burrowing and hiding. First results show that lobsters in control treatments spend more time excavating their shelters (10.6%) than other treatments (5%>). Burrowing was only observed in treatments under predation and noise and not in control treatment. Noise and predation alone had both an effect on the time hiding (93.8% and 85.3%, respectively) compared to control and combined treatments which spent less time hiding (79%). The results of our study suggest that noise interferes significantly with antipredator responses, potentially affecting the likelihood of juvenile lobsters reaching sexual maturity.

De Jong, K., Schulte G., and Heubel, K.U. (2017). “The noise egg: a cheap and simple device to produce low-frequency underwater noise for laboratory and field experiments,” *Met. Ecol. & Evol.* 8, 268-274.

Filiciotto, F., Vazzana, M., Celi, M., Maccarrone, V., Ceraulo, M., Buffa, G., Di Stefano, V., Mazzola, S., Buscaino, G. (2014). “Behavioural and biochemical stress responses of *Palinurus elephas* after exposure to boat noise pollution in tank.” *Mar. Poll. Bull.* 84 (1-2), 104–14.

Rayner, G., McGaw, I.J. (2019). “Effects of the invasive green crab (*Carcinus maenas*) on American lobster (*Homarus americanus*): Food Acquisition and Trapping Behaviour,” *J. Sea. Res.* 144, 95–104.

HARMONY AND DISCORD IN INTERNATIONAL REGULATION OF UNDERWATER NOISE

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Like many major environmental issues of our time, underwater noise and its potential impacts on marine life is characterized by scientific uncertainty, diversified values across many stakeholders, political and regulatory complexities, and a continually-evolving ecological and social environment. It involves many essential human ocean activities, including energy development, mining, shipping, military preparedness exercises, scientific research, underwater telecommunications and commercial fishing. It sparks not only public controversy when human-generated noise is seen as harmful to marine life, but it has also fueled the growth of research and academic programs to help better understand the issue.

Underwater noise now sits squarely on the international stage and is even being addressed by high-level international bodies, such as the United Nations. At last count, there were at least 15 multi-organization management bodies working to regulate underwater noise at regional scales. This is in addition to the many governments of individual coastal nations that work under their own national laws and requirements. Sometimes these collective actions operate in harmony but at other times in discord.

So, how do we manage a seemingly intractable global scale issue? We start by looking for connections, where the integration of science and policy has led to common approaches. This presentation will provide an overview of themes in managing underwater noise around the world and address the question of where harmony might exist.

BROADBAND SHIP NOISE AND ITS POTENTIAL IMPACTS ON INDO-PACIFIC HUMPBAC DOLPHINS

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Ship noise pollution has raised considerable concerns among regulatory agencies and cetacean researchers worldwide. There is an urgent need to quantify ship noise in coastal areas and assess its potential biological impacts. In this study, underwater broadband noise from commercial ships in a critical habitat of Indo-Pacific humpback dolphins was recorded and analyzed. Data analysis indicated that the ship noise caused by the investigated commercial ships with an average length of 134 ± 81 m, traveling at 18.8 ± 2.5 km/h [mean \pm standard deviation (SD), n=21] comprises mid-to-high components with frequencies approaching and exceeding 100 kHz, and the ship noise could be sensed auditorily by Indo-Pacific humpback dolphins within most of their sensitive frequency range. The contributions of ship noise to ambient noise were highest in two third-octave bands with center frequencies of 8 and 50 kHz, which are within the sensitive hearing range of Indo-Pacific humpback dolphins and overlap the frequency of sounds that are biologically significant to the dolphins. It is estimated that ship noise in these third-octave bands can be auditorily sensed by and potentially affect the dolphins within 2290 ± 1172 m and 848 ± 358 m (mean \pm SD, n=21), respectively.

ECOSYSTEM EFFECTS OF AN OFFSHORE WIND FARM IN THE TAIWAN COASTAL ZONE

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Under the threat of climate change, offshore wind energy is one of the potential renewable and sustainable energy sources currently considered. However, offshore wind farms may have negative impacts on coastal ecosystems. In order to explore the impacts of offshore wind farms on coastal ecosystems, we constructed and compared two trophic (Ecopath) models by integrating all the community data obtained by field investigations in two wind farms in the Taiwan subtropical zone from 2017 to 2018 before the operation of wind turbines. One was located in the near-shore region with a wind tower (herein referred as FS20) and the other was located in the far-shore region without a wind tower (herein referred as FS40). The results show that both trophic models are composed of four integer trophic levels from primary producers (trophic level=1.00) to top predators (trophic level=3.70~3.99). The total system throughput (TST) was higher in the near-shore FS20 (460.11 g WW m⁻² yr⁻¹) than in the far-shore FS40 (264.87 g WW m⁻² yr⁻¹). Average transfer efficiency (TE) was also higher in the FS20 (12.68%) than in the FS40 (9.28%). The ecosystem parameters of trophic models showed that the FS20 system was more mature relative to the FS40 system, though there was a one-year-old wind tower in the center of the FS20 system. Our results showed that the spatial effect was more important than the tower effect on the structure and functioning of coastal ecosystems, suggesting the construction of wind tower had minor impacts on the coastal ecosystem. However, our preliminary results showed only short-term ecosystem effects after the construction of a wind tower for a year. In the long term, the development of periphyton on the wind tower might change the pelagic ecosystem due to the artificial reef effect due to the introduction of wind tower by enhancing the biomasses of the benthic and fish communities in the wind farm.

Keywords: Average transfer efficiency, Ecopath, food web, Offshore wind farm, Total system throughput

POLAR COASTAL SOUNDSCAPES: MAPPING BENTIC BIOPHONY, TRACKING OF DRIFTING ICEBERG SOUNDS & SIMULATION OF LONG-RANGE CRACKING GLACIERS USING A COMPACT SENSOR ARRAY

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Polar areas show fast changes linked to global warming. The reduction of the ice pack and the melting of the ice sheet modify the conditions of living of marine fauna. Simultaneous monitoring of melting ice and fauna is therefore critical to assess abiotic and biotic dynamics and their links. Here, we propose a method that allows to characterize, monitor and track both, drifting icebergs and glacier activity as well as benthic invertebrates using the respective sounds emitted. Benthic invertebrates produced high energetic pulses with peak frequencies ranging from 1.5 to 60 kHz, most of them below 15 kHz. The geophony showed two components: 1) punctual distant loud cracking sounds, which account for "major" events such as detachments of icebergs during the calving of a glacier or sea ice cracks and 2) Broadband Transient Sounds (BTS). These BTS have two main origins: 1) The ice sheet, located several kilometers or tens of kilometers away, that creates a stable spatial distribution of low energetic pulses (representing the majority of pulses of the soundscape) modulated by the temporal variability, and 2) the movements of isolated icebergs or pack ice that produce localized acoustic events identifiable by the high sound levels and the stable peak frequencies of the emitted pulses.

A compact sensor array of 4 hydrophones (2m*2m*2m) was used to detect, localize and map these biophonic and geophonic contributions in three dimensions ({azimuth, elevation} or {x, y, z}). Simultaneous tridimensional maps of benthic biophony and iceberg geophony of Antarctic and Arctic 3 days-long recording sessions (2015, 2016) were built and analyzed over a surface of the order of 1 km². Drifting icebergs could be tracked over time and in a 7000m² area. The source level of these icebergs was estimated at 148,6 +/- 4,6 dB re 1µPa at 1m that represent a propagation range of 300m. The source level of distant cracking sounds from glaciers was between 160 and 180 dB re 1µPa at 1m. These cracking sound source levels have been used to estimate the acoustic footprint area of a glacier's activity based on acoustic propagation simulations with a refined model. This study show that with the same compact hydrophone array it is possible to characterize, monitor and track benthic activity as well as different close and distant geophonic events related to ice melting.

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QUANTITATIVE COMPARISON OF NOISE EXPOSURE CRITERIA FOR CETACEANS

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Noise exposure criteria have been developed by various researchers and regulatory bodies to reduce the risk of physiological effects of exposure to intense underwater sound on the auditory system of marine fauna. Special emphasis has been given to marine mammals due their high sensitivity to and reliance on underwater sound. The integral parts of these criteria are the thresholds for the onset of TTS and PTS and the auditory frequency weighting functions, which reflect differences in a species' auditory sensitivity over their range of hearing. Criteria differ in both the metrics and threshold levels used and the weighting functions adopted. To inform the discussion and definition of most appropriate threshold levels and weighting functions, a quantitative comparison the most commonly used/referenced noise exposure criteria for marine mammals was conducted in the present study.

Three methods are used to compare the selected exposure criteria. First, a dataset acquired during an experiment that induced temporary threshold shift (TTS) in a porpoise exposed to single seismic impulses (Lucke et al. 2009) was re-analysed using the various criteria to see if they would in fact predict the observed onset of TTS. Second, numerical sound propagation modelling of a seismic airgun array in deep and shallow water and for summer and winter sound speed profiles was performed to estimate the ranges at which the different criteria predicted the onset of TTS and PTS. Third, several examples of 'real-world' data were analysed using the different criteria. The example data were from seismic surveys in deep and shallow water, impact pile driving, low- and mid-frequency naval sonar, and a vessel with fisheries echosounders passing over the measurement hydrophone.

Comparing the noise exposure criteria using these three approaches shows substantial disagreement in the resulting estimates of onset distance for auditory effects such as TTS. The strongest contributing factor to the inconsistency are the weighting functions. Applying the more recently proposed sets of weighting functions results in closer agreement between predicted results and those measured during the referenced TTS study. The closest match for all functional cetacean hearing groups is achieved by the latest U.S. criteria (NMFS 2018). The (unpublished) New Zealand (NZDOC, New Zealand Department of Conservation 2017) criteria yield a similarly good match for high-frequency cetaceans. The outcome of the comparison of the modelled and measured results can be used to inform recommendations on the definition of exposure criteria.

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MONITORING FISH SPAWNING LOCATIONS AND MARINE MAMMAL SOUNDS WITH PASSIVE ACOUSTIC RECORDER ON A WAVE GLIDER

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Remote observations of marine animal behavior have one distinct advantage over direct observations: the observer is not present to disturb the animals. There are no vessel noises, no diver's bubbles, no people present that could alter the behavior of the animals being observed. Because fishes and marine mammals are known sound producers, these animals' location while producing sounds during a mobile survey can be recorded, and their species identity determined; in some cases, their behavior can be associated with specific sounds. We used *Blackbeard* the Acoustic Wave Glider (AWG) to conduct affordable, mobile, long-term passive acoustic monitoring of marine animals and the coastal ocean acoustic environment off North Carolina. (Luczkovich et al., in press). Passive acoustic methods from fixed recording platforms have been used previously to document spawning locations of weakfish, *Cynoscion regalis*, and other fishes in the drum family Sciaenidae in estuarine environments (Luczkovich et al. 2008). Others have demonstrated that sciaenid fishes make spawning "drumming" calls outside the inlets on the continental shelf (Conaughton and Taylor, 1995; Holt, 2008). However, "chattering" sounds that were reported offshore by Conaughton and Taylor (1995) were actually later shown to be due to striped cusk-eels, *Ophidion marginatum*. Here we report that choruses and individual calls of many fish (weakfish, striped cusk-eels, red drum, *Sciaenops ocellatus*, spotted sea trout, *Cynoscion nebulosus*, sea robins *Prionotus* sp., oyster toadfish *Opsanus tau* and an unknown grouper *Epinephelus* sp.) were recorded during wave glider transects running along the 20 and 30 m depth isobaths along the continental shelf of North Carolina coast. Marine mammal sounds (humpback whales *Megaptera novaeangliae* and bottlenose dolphins *Tursiops truncatus*) were also recorded during these excursions. The estuarine-dependent weakfish, spotted seatrout, and red drum fishes (Sciaenidae) were more common in shallow areas (~20 m) near inlets and by artificial reefs, whereas the grouper calls were recorded in deeper water (~30 m) on live bottom reefs. These fishes' sounds are likely to be associated with spawning, suggesting spatial separation of their spawning areas, and extending the known spawning habitats for these species beyond estuaries. The AWG can be used to map critical spawning habitat in offshore areas where anthropogenic vessel noises occur, and where energy development has been planned.

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HABITUATION OF COMMON DOLPHINS TO A SEISMIC SOURCE

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There have been few detailed studies of common dolphins (*Delphinus delphis*) in relation to seismic surveys, yet they are some of the most commonly sighted cetaceans during seismic surveys worldwide.

Goold (1996) noted in studies of common dolphins during a seismic survey off the Welsh coast that they avoided the area of seismic operations and showed high detection numbers both immediately before and to a lesser extent after the seismic survey.

Sightings of common dolphin while airguns were firing on full power during four seismic surveys off Ireland are examined here. Data was divided into 12 weeks from the start of seismic activities. A Kruskal Wallis test demonstrated a statistically significant difference in closest approach to the airguns over time during firing ($P = 0.012$). This demonstrated a possible habituation to sound over time. The mean average distance of closest approach for each week was calculated, it ranged from over 1500m for the first three weeks of a survey to less than 900m for all remaining weeks, with the exception of week 12 which was anomalous.

The variation in closest distance showed that the animals decreased their distance to the active seismic source as the survey continued. Habituation to a sound will normally increase with increased exposure over time unless cetaceans become sensitized to the sound and avoid the area (Richardson, 1995). This habituation could be due to gradual deafening of animals, but auditory damage is virtually impossible to detect in free ranging animals and the current implications of habituation to noise have yet to be measured or understood (Parsons and Dolman, 2004).

Whatever the reason cetaceans become habituated or physiologically acclimatized, this can lead to animals being non-responsive to sound stimuli until exposures reach injurious levels (Wright et al 2007). It is suggested here that continuous acquisition of seismic in Ireland increases noise exposure and soft start standards worldwide serve to promote habituation. Seismic data was collected along straight sail lines and 1146 such lines were acquired and at the end of each line the ship must turn and typically stops the source, starting the next line with a soft start. Only 154 soft starts occurred due to continuous acquisition on line turns. Soft starts were not described, but it is reasonable to assume these were industry standard soft starts, adding one gun at a time, involving sound pressure increases less than would be detected by dolphins.

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OBSERVATIONS ON BOWHEAD WHALE (*Balaena mysticetus*) MOVEMENTS AND BEHAVIOUR IN RELATION TO OIL AND GAS EXPLORATION ACTIVITIES

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From 2006 to 2015, a multi-faceted monitoring program consisting of vessel-based observations, aerial observations, and passive acoustic recording was conducted in the U.S. Arctic Chukchi and Beaufort seas in relation to oil and gas exploration activities, including both seismic data acquisition and drilling. Among a number of regulatory and stakeholder-related monitoring goals, assessing the interaction of industry activities and bowhead whale behaviour was a specific focus. Of particular interest was the effect of exploration activities on the distribution and movement of bowheads during fall migration and their potential availability for subsistence hunting.

The character and intensity of sounds generated by industry activities, including air guns, vessels, drilling, and ice management operations were measured by dedicated hydrophones deployed in relatively close proximity to known activities. In addition, broad area acoustic arrays were deployed throughout the region to assess acoustic effects as well as marine mammal vocalizations. Data on the distribution and behaviours of bowheads were collected by the broad area acoustics arrays, observers on all project vessels, and by aerial surveys conducted over areas encompassing activities.

Results from all three data sources indicate that bowhead whales exhibit significantly reduced densities in close proximity to industry activities, including those that produce both pulsed and continuous sounds. Areas where broadband sound levels of greater than 160 dB re 1 μ Pa SPL were present typically had very low observed presence of bowheads, while areas where sound levels were between 100 and 160 dB re 1 μ Pa SPL showed somewhat graded densities depending upon the behavioural mode at the time of exposure, i.e. higher sound levels were tolerated by foraging or socializing individuals compared to migrating individuals. Apparent avoidance, as indicated by reduced densities, may also be a function of perceived proximity to an activity somewhat independent of received sound levels.

Reduced animal density, as indication of avoidance behaviour, appears to be a local phenomenon with overall migratory and foraging patterns continuing outside of these areas of impact. The general footprint and timing of the migration pattern were not noticeably impacted.

MONITORING OF A COASTAL ENVIRONMENT: FROM THE CREATION OF MARITIME TRAFFIC MAP IN A BY IMAGE PROCESSING TO THE AMBIENT NOISE ANALYSIS AND THE CORRESPONDENCE WITH THE DISTRIBUTION OF BOATS.

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The location of maritime traffic has become a major issue in terms of maritime traffic regulation, safety and environmental monitoring. This consideration is mainly aimed at deep-sea shipping as evidenced by the requirement to equip large offshore vessels with AIS. Maritime traffic in the coastal environment remains poorly known because of the absence of AIS data: only 3.7 % of the 550 boats crossing the bay of Calvi are equipped with the AIS system. To remedy this lack of information, a specific visual monitoring protocol for the bay has been set up on a photographic observatory positioned at a height of 99 m above sea level. A wide-angle camera GoPro® takes photographs of the bay every 5 seconds. The detection and the localisation of boats were carried by two image processing algorithms based on: motion detection, a semi-local modelling of the background (Rittscher et al., 2000), detection thresholds with Constant False Alarm Rate and empirical functions providing the modelling of the deformation due to the Fish eyes effect (Bräuer-Burchardt et al., 2001).

The noise is composed of a set of sound sources that can be studied on two different scales (NRC, 1995) : the individual scale called ocean noise and the global scale background noise. This duality is found during the study of noise radiated by boats. Concerning the global scale, several studies have shown that since the 1960s, increased maritime traffic creates an increase in ocean noise that may exceed 10 dB in some areas. In an offshore context, the MFSD advocates the acoustic monitoring of certain levels. The case of the coastal environment is not yet mentioned, whereas these environments are the providers of 41.7% of the ecosystem services produced by the oceans (Costanza et al., 2014). To answer this duality of analysis, two acoustic descriptors are considered. In one hand, the SPL, being a RMS measurement of the RL characterizing the individualizable sources, informs on the distance of the nearest ship. In the other hand, the ANL, which characterizes the ambient level present by erasing all individualizable sources, informs on the number of boats present in an area described by a disc around the listening point. The spatio-temporal monitoring of these descriptors allows observing the influence of maritime traffic on coastal noise, which is strongly influenced by biological life.

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EFFECTS OF HUMAN ACTIVITIES ON THE ACOUSTIC HABITATS AND BEHAVIOUR OF BOTTLENOSE DOLPHINS

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Underwater noise environments are increasingly being considered in marine spatial planning and habitat-quality assessments, particularly with regard to acoustically-specialized fauna. Coastal species are especially vulnerable to noise pollution as a result of their high degree of habitat overlap with anthropogenic activities. The Swan River in Western Australia flows through the state capital of Perth and consequently experiences a range of anthropogenic activities. However, the river is also extensively used by a resident community of bottlenose dolphins (*Tursiops aduncus*). This study aimed to describe underwater sound sources within the Swan River, examine spatial and temporal soundscape variability, and determine dolphin responses to noisy environments. A combination of visual and acoustic monitoring techniques were employed during data collection. Land-based theodolite tracking at two sites within the Swan River provided information on vessel traffic and dolphin behavior. Acoustic data were collected using autonomous underwater recorders deployed at five sites. In total, approximately 450 h of visual data and 12,200 h of acoustic data were collected. These were assessed using a combination of generalized linear models, generalized additive models, Markov chains, and comparative statistics. Acoustic datasets collected from 2005 to 2015 indicated that the Swan River was comprised of multiple acoustic habitats, each with its own characteristic soundscape and temporal patterns in underwater noise (Marley et al. 2016; Marley et al. 2017a). The anthropogenically “noisiest” site was the Fremantle Inner Harbor (mean broadband noise level: 106 dB re 1 μ Pa rms [10 Hz – 11 kHz]; Marley et al. 2017a). Yet dolphins remained present in this area even at high vessel densities (Marley et al. 2017b). However, fine-scale analyses indicated significant subtle behavioral and acoustical changes. At high vessel densities, dolphin movement speeds, activity states and behavioral budgets altered (Marley et al. 2017c). Additionally, during noisy periods dolphin whistles typically became shorter, with a wider frequency range and multiple inflection points (Marley et al. 2017c). However, whistles also varied naturally according to activity state, group size, and calf presence. These results highlight the need to consider spatial and temporal patterns when assessing the composition of underwater soundscapes. They also illustrate the complexity of disturbance responses in this species, confirming the need for consideration of both surface and acoustic behavior alongside appropriate contextual data.

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UNDERSTANDING THE IMPACTS OF ANTHROPOGENIC NOISE ON THE BEHAVIOUR OF FISHING CAT IN THE GODAVARI MANGROVES

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Fishing cat (*Prionailurus viverrinus*) is a highly threatened felid species which inhabits mangroves, swamps, wetlands, highlands, and riverine habitats in most of its range countries in South and South-East Asia. At present, the Fishing cat is categorized as ‘Vulnerable’ by *The IUCN Red List of Threatened Species*. Much of the Fishing cat ecology related to its ecology and behaviour from the wild is rare (Nowell & Jackson 1996; Sunquist & Sunquist 2002). Wildlife Institute of India has done extensive systematic camera trapping and acoustic surveys from 2014-2017, in the Godavari delta and it revealed a viable population of Fishing cats. The camera trap surveys revealed an estimated >90 individuals of the Fishing Cats and generated significant information on this elusive species’ habitat usage, behaviour (Malla 2016). In this paper we discuss our study aimed to investigate different vocal repertoire and anthropogenic noise disturbances to these threatened small cat species.

From November 2016 to March 2017, we deployed 3 acoustic recorders running from, in one of the main rivers “Coringa” in the Godavari mangroves. A total of 43 different exemplars of calls recorded in the wild, emitted in different behavioural contexts and are classified into different call types like Chuckling, Growling, Screaming, Meow, Hissing. Of all these call types screaming and hissing were mostly recorded which shows that territorial fighting’s are more frequent in fishing cats. This study also found out that there is a heavy anthropogenic noise impact on fishing cat communications from the motorised boats which are used by local fisherman of the nearby mangrove’s dependent villages. Since these cats are more active during the low tide time and vocalisations were recorded mostly during these hours, they had a direct conflict with the local fisherman who are also active during those hours.

Boat engine noise during the low tide fishing activities were found to be mostly influencing the behaviour of the fishing cats, followed by timber extraction and crab collection. So, with this project we were able to understand the vocal behaviour of the fishing cat and how different anthropogenic noise are influencing its behaviour in this dynamic mangrove ecosystem.

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REDUCING UNCERTAINTY IN PASSIVE ACOUSTIC RECORDINGS: EFFECT OF PASSING SHIPS ON VOCAL BEHAVIOR OF FIN WHALES

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Acoustic impact on marine mammals at depth from passing local ships can be significant and abrupt as the animals transit from a shadow zone into a region of reliable acoustic paths, which is facilitated by the ocean acoustic environment. Passive acoustic data provide unique information on how such interactions may affect the vocal behavior of whales. Here, the dataset obtained with the near-bottom High-frequency Acoustic Recording Package (HARP) deployed off the Central California coast at the depth of about 800 m, between 2006 and 2010, is analyzed for fin whale vocalizations and ship passages. Preliminary analysis of the HARP data collected at about the same depth at Thirtymile Bank, 25 nm west of Point Loma in January-March 2013, revealed diverse vocal reactions to passing local ships, including nearly instantaneous ceasing or intensifying of sound production. Two types of potential responses of fin whales to ship passages dominate. In about half of the cases of simultaneously recorded fin whale 20 Hz calls and large ships' acoustic signatures, a statistically significant increase in the fin whale received level is observed to grow abruptly as a ship passes. The rest of the cases demonstrate a gradual decrease in the fin whale received level, which may be explained by an avoidance behavior.

The interpretation of passive acoustic data can be ambiguous because of their spatial uncertainty, which requires some assumptions to be made about relative positioning of the sound source (a ship), sound receiver (a whale) and the acoustic recorder. To verify these assumptions and reduce the uncertainty in interpretation of overlapping acoustic signatures, which may have come from spatially separated sources, we combine passive acoustic data with acoustic propagation modeling and shipping traffic information based on the Automatic Identification System (AIS) reports. The sound propagation within the wide frequency band specific for the shipping-induced noise is estimated using Navy and NOAA acoustic propagation models and environmental databases. The range-dependent sound speed profiles are calculated using daily outputs of temperature and salinity from the HYCOM model, to reduce uncertainty caused by the modeling of the ocean environment.

FISHING FOR SPECTROGRAMS: ACOUSTIC MONITORING IN COASTAL NOVA SCOTIA, CANADA

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Fisheries and Oceans Canada (DFO) has initiated an acoustic monitoring project in Nova Scotia, Canada to identify coastal areas regularly used by baleen whales and to help assess potential noise impacts of vessel traffic on marine life. Several coastal areas in the region have historical, whale-watch or anecdotal cetacean sightings that indicate potential regular seasonal use by certain species (Hastings et al., 2014). Previous acoustic monitoring efforts in the region have focused on offshore areas and made use of larger and heavier recording systems, requiring the use of large vessels. This project uses an innovative approach, partnering with local fishing organizations, tourism operators, and community groups to deploy small acoustic monitors. Lightweight, self-contained passive acoustic monitoring devices are deployed in small, modified lobster traps tethered to subsurface buoys that reduce the risk of entanglement to marine life. The mooring design is intended to allow deployment from small vessels such as coastal fishing or whale watch boats. To date, these acoustic monitoring devices have been deployed at three coastal sites and coverage will be expanded to other locations in the summer and fall of 2019. Thus far, community partners have been able to successfully deploy and retrieve the devices. Preliminary data analysis of the recordings indicates whale presence in some areas; however, the traps themselves may be introducing some level of additional noise.

DFO has a long history of partnering with fishing groups to carry out research related to fish stocks (e.g., Cox et al., 2018); other groups have successfully implemented citizen science projects for monitoring marine mammals (e.g., Tonachella et al., 2012). This project represents an expansion of DFO's community science partnership efforts. Working with community groups has enhanced project effectiveness in multiple ways: partners' local knowledge has informed both the design of a simpler, more streamlined mooring system and the identification of deployment sites that are best-suited to capturing sounds of interest while avoiding local hazards. Additionally, as the project expands, it has the potential to raise awareness of the issue of underwater noise and foster stewardship in coastal areas.

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Hastings, K., King, M., and Allard, K. (2014). "Ecologically and biologically significant areas in the Atlantic coastal region of Nova Scotia," Can. Tech. Rep. Fish. Aquat. Sci. 3107, xii + 174 p.

Tonachella, N., Nastasi, A., Kaufman, G., Maldini, D., and Rankin, R. W. (2012). "Predicting trends in humpback whale (*Megaptera novaeangliae*) abundance using citizen science," Pac. Conserv. Biol. 18, 297-309.

THE NOISY COASTAL AREAS OF THE TRANSBOUNDARY NORTHERN ADRIATIC SEA

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The Northern Adriatic Sea (NAS) represents a transboundary area that encompasses coastal zones of three different nations (Italy, Slovenia and Croatia). This shallow, semi-enclosed sub-basin of the Adriatic Sea extends as far North as 45°47'N and it is west and east bounded by the Italian peninsula and the Balkan region, respectively. The northern and western coasts are generally sandy and shallow, merging into the marshes and lagoons. In contrast, the eastern coast is mountainous, including numerous islands, rocky shores, bays and coves. Both coasts are characterized by a high concentration of harbours (ports of Venice, Trieste, Koper and Rijeka) and by many anthropic activities including mussel and fish cultures and fisheries as well as industrial and commercial activities and urban and tourist development. On the other hand, NAS shows high biodiversity located in many protected areas.

The present paper reviews the sea ambient noise data collected by the authors along the NAS coasts (ie. not exceeding 4 miles from the coastline) in three main study areas, each one including many different recording locations, ie. (i) the Gulf of Trieste (ii) the Venice Lagoon (Italy) and (10) the Cres and Losinj Archipelago (Croatia). The recordings have been done in a period ranging from 2006 to 2015 and in total 1162 10-minute samples have been made. Results on the collected data have been partly published along the last 10 years contributing to about 10 different papers on the local ecosystems.

SPL wideband values range from a minimum of 88 dB re 1 uPa to a maximum of 154 dB re 1 uPa (recorded in the Losinj area); average value is equal to 125 ± 11 dB re 1 uPa. For 63 Hz and 125 Hz 1/3 octave bands SPL levels do not exceed 142 and 136 dB re 1 uPa, respectively.

Statistical differences have been found between SPLs wideband values as well as 63 Hz and 125 Hz 1/3 octave bands SPL levels recorded in the three areas (Kruskal–Wallis test, $p < 0.001$).

The aim of this review is to define a comprehensive state of art knowledge on the underwater noise in the NAS area. This is particularly relevant in the light of the incoming “SOUNDSCAPE” project funded through the European Union Interreg Italy-Croatia Programme that focuses on the underwater noise assessment in order to identify effective protection measures for the sensitive marine species to be included in maritime spatial plans.

USING KURTOSIS AND EFFECTIVE QUIET TO CLASSIFY HUMAN MARINE SOUNDS AS IMPULSIVE OR CONTINUOUS

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Regulations designed to mitigate the effects of human sound on marine life set thresholds on the maximum daily sound exposure levels. Lower thresholds are proscribed for impulsive sounds compared to continuous sounds, but no quantitative metric for identifying impulsive sounds are provided in the regulations. Four metrics of impulsiveness are considered: skewness, kurtosis, the crest factor and the difference between the impulse- and slow- time-weighted sound pressure levels. Biologically relevant values for the metrics were computed by first applying an auditory frequency weighting filter. Applying these metrics to statistical noise distributions and real-world ocean sounds shows that kurtosis is the most effective metric for identifying impulses. Only sounds above the sound pressure level threshold called effective quiet are considered loud enough to accumulate over time and cause a hearing effect. A functional definition for effective quiet is proposed: the level for temporary threshold shift from continuous noise, less 50 dB. Using kurtosis and effective quiet, new classifications of human sources as impulsive or continuous are proposed that depend on functional hearing groups. Under the proposed changes vibratory pile driving and echosounders are impulsive sources. Naval sonar and vessels may be impulsive or continuous depending on the functional hearing group.

KEY FACTORS OF INFLUENCE IN ESTIMATING IMPACT RANGES FOR SEISMIC SURVEYS

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There is a pressing need for guidance in conducting underwater sound risk assessments to increase efficiency in the permitting process for seismic surveys across the UK Continental Shelf. Towards developing such guidance, a comprehensive modelling study was undertaken to identify and quantify the relative influence of some of the many factors that are involved when estimating potential impact ranges on the basis of available sound exposure threshold criteria for marine mammals. Among the factors considered were those related to survey type (air gun source array configuration, operating parameters, survey pattern and duration), to location (environmental conditions e.g. water depth, sound speed profile, sediment type) and to the likely species encountered (marine mammal hearing group and assumptions of animal movement). In recognition of uncertainties and assumptions inherent in models, additional factors related to the choice of survey sound source and propagation models and how models are applied were also investigated.

To evaluate the relative influence of these factors, range estimates to the exposure criteria for the onset of permanent threshold shift (PTS) have been compared using as reference point the standard radius (500m) of the mitigation zone referred to in the JNCC guidelines (JNCC, 2017). For most functional hearing groups, PTS onset range estimates were within 500m with a relatively limited degree of variation. For low frequency cetaceans, however, large differences in range estimates were predicted, in many cases well beyond the 500m mitigation zone.

These results help to identify those factors which alone or in combination exert the greatest relative influence on estimated impact ranges. Examples will be presented to show how this comparative modelling exercise has helped in identifying the issues that need to be addressed through guidance in order to improve the efficiency and accuracy of future noise risk assessments.

JNCC. (2017). "JNCC guidelines for minimising the risk of injury to marine mammals from geophysical surveys" August 2017. http://jncc.defra.gov.uk/pdf/jncc_guidelines_seismicsurvey_aug2017.pdf

LOW FREQUENCIES NOISE EFFECTS ON BEHAVIOUR OF *Sparus aurata* JUVENILES.

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Human activities in the oceans, such as marine traffic and Deep Sea Mining (DSM), are increasing in the last years (Ross 2005; Calvo et al 2016). Underwater noise in the oceans, especially at lower frequencies, is mainly produced by marine traffic and DSM could increase this noise in the next future. Marine Strategy Framework Directive promotes the achievement of a good quality environmental status and aims to monitor “continuous low frequency sound” trend in the ambient noise level within the 1/3 octave bands centred at 63 and 125 Hz.

The aim of this study is to evaluate the behavioural changes of *Sparus aurata* juveniles exposed to a four different acoustic signals in a tank. The emitted signal was white noise filtered at 1/3 octave band centred respectively at 63 Hz, 125 Hz, 500 Hz, and 1 kHz (SPL: 140-150 re 1µPa). For each frequency we tested three independent groups of 6 specimens and video monitored them for a total of 7:30 hours (15 min before, one hour during and 6 hours after the sound exposition) using two cameras located above the tank and in the water column. Moreover, three control group (no acoustic emission) tests were performed (no sounds were dispensed). Behavioural data (cohesion, motility, swimming height) were collected from the 15 minutes of each hour except in during sound exposition, where we considered the entire hour. The bottom of the tank was divided into squares. Cohesion was evaluated counting the number of squares occupied by the group; motility counting the number of squares crossed by each fish; swimming height counting the fish presence in three zones (deepest, intermediate, and highest). Using Kruskal-Wallis tests and multiple comparisons post-hoc we assessed that the cohesion was significantly affected at 63, 125 and 500 Hz. At 63 and 125 Hz, significant increase in cohesion was observed during and up to the third and sixth hour of exposition respectively; at 500 Hz cohesion increased only during the exposition. Significant increase in motility was observed during the 63 and 125 Hz stimuli. For swimming height, all frequencies significantly increase the number of fish in the deepest zone and decrease in the intermediate zone. The juvenile of *S. aurata* exhibit different behaviours depending on the acoustic frequencies. This study evidences an impact at short and medium time on juvenile. This could determine an effect on budget energy and, consequently, a potential threat for their recruitment in a noise-polluted environment.

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THE EFFECT OF IMPULSE NOISE PRODUCED BY AIR GUNS ON ZOOPLANKTON

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Marine petroleum exploration or seismic, involves the repetitive use of intense, low-frequency, acoustic impulse signals to image subsea geology. Prior 2017 the general belief was that seismic signals only impacted zooplankton out to perhaps 10 m, although there was scant information to back this up. In 2007 McCauley repeatedly ran a sonar across the path of a 2055 cui seismic array in an experimental situation and observed a drop in non-fish sonar backscatter, which was consistent in several seismic passes. This work was indicative only, and suggested an impact range of several hundred m on larger zooplankton. In collaboration with the University of Tasmania, replicated experiments in Storm Bay using a 150 cui seismic 'air-gun' showed impacts on zooplankton out to approximately one km range. After passage of the air-gun a 'hole' opened in sonar backscatter which stayed symmetric about the drifting mass of water impacted by the air gun and which increased in radius through time, zooplankton abundance dropped significantly out to 1 km from the air gun line and the number of dead zooplankton found in plankton nets increased by 2-3 times compared with controls, out to the maximum sampling range of 1.2 km. For this experiment, while arguments can be put forward as to why one of these features may have occurred by chance, the odds of all occurring simultaneously are extremely small. Given the spatial and temporal scale of 3D seismic surveys then the implications are considerable. Zooplankton underpin secondary productivity in the ocean plus many larval forms of commercial or keystone species, which have a once per year recruitment cycle, may spend a considerable period of time in the planktonic phase. This talk will highlight experimental results and discuss: implications; possible mechanics of impact; the possible use of similar scaled down signals by marine planktivorous fauna; further research required; and potential techniques and technologies required to understand or minimize such impacts (respectively).

ASSESSING THE ECOLOGICAL IMPACT OF ANTHROPOGENIC NOISE FROM FUNCTIONAL RESPONSE ANALYSIS: A CASE STUDY WITH FRESHWATER FISH

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Alterations in trophic interactions, which are the main drivers of energy flow throughout the community, can influence species coexistence, community stability and food-web structure.

There is growing evidence that anthropogenic noise has potential to modify trophic interactions, changing the behaviour and/or abundances of predators, prey or both, but consequences beyond the individual level remain fairly unknown (Shannon et al. 2016).

One way to quantify predation is to derive the functional response (FR), which is the relationship between resource use and resource density. FR analyses are commonly used in the fields of community ecology, food-web theory, and more recently invasion biology, but are still largely ignored by people interested in the ecological impact of anthropogenic noise (but see Hanache et al., 2019). Compared to snapshot predation tests with single densities, this approach is more informative as the shape and magnitude of FR curves are powerful indicators of how a predator exploits its prey population (Médoc and Spataro, 2015).

We derived the FR of various fish species with or without habituation to noise and under two noise conditions: ambient noise or ambient noise supplemented with boat noise. We also recorded their behaviour during the predation tests. Our results confirm the negative effect of boat noise on predation but also suggest that the strength of this effect depends on prey density. Species differ in their tolerance to noise and stressed fish behave as they would do under predation risk.

Hanache, P., Spataro, T., Firmat, C., Boyer, N., Fonseca, P., and Médoc, V. (2019). Noise-induced reduction in the attack rate of a planktivorous freshwater fish revealed by functional response analysis. *Freshwater Biol.*, In press.

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EXPOSING PEARL OYSTERS (*Pinctada maximus*) TO A SEISMIC AIR-GUN ARRAY SOURCE

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Underwater anthropogenic noise, such as the operation of air-guns during oil and gas geophysical exploration surveys, can induce a range of responses from marine fauna. With its partners, AIMS' Northwest Shoals to Shore research program is investigating responses of pearl oysters (*Pinctada maximus*) to as-near-as-real-world-as-possible operation of a full-size seismic survey source.

Six parallel (500 m separation), 20 km-long seismic sail lines were operated, approximately 36 km west of Broome, Western Australia. In August, 2018, 10,880 pearl oysters were collected from ≈10 m-deep waters off Eighty Mile Beach and transported approximately 40 km north, to the exposure site. Lines of pearl oysters were laid on the seafloor, to acclimate, at ranges of approximately 0, 300, 500, 1000, 2000, 6000 and -1000 m from, and running approximately parallel to, the first seismic sail line. These distances ensured a range of sound exposure levels were experienced for a dose-response test. During the trial, passive acoustic monitoring sensors (pressure, particle velocity and ground motion), were positioned at various ranges to validate estimates of the sound exposure levels across the site.

On Day 1 (September, 2018), seismic Line 1 was conducted with air-guns deployed, but not operated, providing a 'Vessel Control' sample (0 m oyster line) and a 'Control' sample (6000 m). On Day 2, repeat of seismic Line 1 was operated with air-guns active. On Day 3, seismic Line 2 was operated, -500 m from the first line. On the fourth and fifth days, two seismic lines were conducted on each (-1000/-1500 and -2000/-2500m, respectively). A selection of oyster panels were retrieved from each pearl oyster line each day, after seismic operations. Oyster panels were (blind) tagged and transferred back to Broome. A selection of oysters were transferred directly to the laboratory for testing (mortality rates, physiology, histology, pathology, gene expression), another selection was relocated to the local pearl oyster Farm to await sacrificial testing at a later date, and remaining oysters were seeded to produce pearls in a 'grow-out' phase of the study. Multiple sacrificial testing periods (immediate, 30, 90, 180 and potentially 360 days after exposure) were conducted to identify onset and duration of any response. In the final audit of 'grow-out' oysters (2020), the size, shape, color and quality of any pearls produced will be evaluated, as indicators of their response.

This presentation will provide background and the development of the experiment, and highlight some initial results from the study.

PHYSIOLOGICAL RESPONSES IN NEOTROPICAL FISH, PRODUCED BY CHANGES IN THE SOUND PRESSURE LEVEL

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The anthropogenic activities have increased over the bodies of water (seas and rivers) in the last years due to change the sound landscape of the aquatic environment; studies are focused on investigating the effects of these agents on the subaquatic animal life (Slabberkorn and Popper, 2010). For some vertebrates there are studies that focus on vocalization, regardless of there is still little research that investigates physical and behavioral effects in fish (Smith, Kane and Popper, 2003), and even less its effects on neotropical fish.

The expansion of the subaquatic acoustic area and its effects on the Brazilian ichthyofauna is a real problematic due to the growth of the construction of hydroelectric plants and other projects that affect aquatic fauna. Our proposal is evaluate physiological responses to young fish induced stress (sounds) in the laboratory using blood parameters, such as the level of cortisol, glucose, hemoglobin and hematocrit found in two moments: 1. after isolation by 01 hour bucket (control treatment) with one step without experimental sound induction control and; 2 with a sound noise of characteristic frequency of 1 kHz using the capacity of the computer.

All steps of experiments were realized in Laboratório de Biodiversidade of Universidade Federal do Tocantins, Brazil. The specimens of *Pseudoplatystoma corruncans* were acclimatized inside the Acclimation Tank (AT) by one month. After were place in a bucket, always starting at 08:00 p.m; each fish was isolated for one hour with the presence of an oxygen pump and the hydrophone inside, which allowed the same handling for all and the physiological response the this isolation (Barreto and Volpato, 2006), together with blood parameters obtained in the bucket, we analyzed the sound landscape through the hydrophone following Menchant *et al.*, 2015. It was observed the stress generated due to the short noise exposure time of 10 minutes in the bucket and to the 60 minutes period in the isolation. On our partial results with 10 minutes exposition to sound, we used three fish and more three to the control, all the individuals were submitted to noise presented behavioral changes when inserted in the anesthetic solution; in the specimens exposed to the sound were observed an increase in glucose concentrations of 0.634 mg dl⁻¹ in comparison to the control specimens; the percentages of hematocrit were 15% difference between these treatments (exposed sound vs. control). This allowed us to improve our experimental protocols.

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ACOUSTIC LANDSCAPE DOWNSTREAM OF HYDROELECTRIC DAMS: THE CASE OF LUIS EDUARDO MAGALHÃES POWER PLANT

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The underwater environment consists of biotic and abiotic sounds, many of which are important for fish survival (Popper and Carlson, 1998). The growing demand for electric power has provided government actions for the expansion of the energy sector. In Brazil, about 68.1% of electricity is supported by hydroelectric plants. In this scenario, the fish fauna suffers great anthropogenic interference by the interruption of the migratory routes, access to the spawning areas and the mortality downstream of the dams. The mortality of fish in downstream from hydroelectric power is due to the passage of the fish through the turbines, spillway, or the attraction and confinement in the suction pipe during the turbine stops for its maintenance (Agostinho, Gomes and Pelicice, 2007).

We sought to understand how the underwater acoustic landscape changes according to the operating activities of the Luis Eduardo Magalhães hydroelectric power plant (UHE Lajeado) located on the Tocantins river to interfere with the behavior of fish fauna (mortality). We monitored the acoustic landscape with the use of a hydrophone and the underwater recordings were obtained downstream from the dam in a calm water location near the entrance of the fish ladder. This transposition mechanism for migratory fish is very important, however, studies contest their ecologic efficiency (Agostinho et al., 2007). The sound pressure level (SPL) was characterized by the contents of the recordings using sound analyses tools (Merchant et al., 2015). Different protocols were used, including experiments with fish ladder opening and variation of the downstream level to verify the occurrence of the change in SPL level.

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ASSESSING THE CONTRIBUTION OF AN OCEAN MAPPING SONAR TO THE LOCAL SOUNDSCAPE

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Ocean mapping multibeam echosounders (MBES) are operated in a variety of modes and frequencies that are tightly linked to the water depth and survey objective. Each operational mode utilizes a different set of signals to optimize seafloor bathymetry and backscatter or midwater imaging. Consequently, MBES systems signals do not fit cleanly into either the impulsive or continuous sound source categories described in Southall et al. (2007) and U.S. National Marine Fisheries Service (NMFS 2016). Operational modes using frequency-modulated pulses as opposed to single-frequency gated pulses are most closely related to the U.S. Department of the Navy (DoN 2012) source criteria for non-impulsive Low Frequency Active Sonar.

The soundscape of the Southern California Antisubmarine Warfare Range was characterized and compared across baseline, ship-only, and multiple MBES operational modes at select hydrophones during a MBES survey. A Kongsberg EM 122, 12 kHz deep water MBES with a listed source level of 242 dB re 1 mPa, was operated in a variety of modes including single and dual swath mode, single-frequency gated pulses, and a combination of single-frequency gated and frequency-modulated pulses. The effective pulse length varied from 2 ms at the center-most sectors to 100 ms for outer sectors. The time between signal transmissions was on average every 6-7 seconds. One minute averages of the sound level were calculated over the data collection period. Sound level percentiles (P1, P10, P50, P90 and P99) were calculated for the full spectrum of the recording system (1 Hz- 48 kHz) and select frequency bands, and spectral probability density plots were generated for each MBES mode and compared to baseline conditions. Frequency correlation matrices for each MBES mode were produced and compared using difference matrices to identify changes in the soundscape. The results are placed in the context of the auditory scene of Cuvier's beaked whales resident on the range by applying a mid-frequency marine mammal weighting function. The MBES contribution to the soundscape is also assessed in association with effects criteria for impulsive, non-impulsive, and continuous sources from Southall et al. (2007), NMFS (2016), and DoN (2012) [Work supported by NOAA, ONR, and Scripps Institute of Oceanography].

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[NMFS] National Marine Fisheries Service. (2016). *“Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts,”* U.S. Department of Commerce, NOAA. NOAA Technical Memorandum NMFS-OPR-55. 178 pp.

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BIRDS OF A FEATHER: HEARING AND BEHAVIORAL RESPONSES TO SONAR AND WHITE NOISE IN ALCID SEABIRDS

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Seabirds are perhaps the most imperiled group of birds, with at least 25% of species listed as threatened and near 50% of species' in decline. Seabirds readily transit between air and water and enact key behaviors in both habitats. With this amphibious lifestyle, they are likely faced with unique auditory constraints; unfortunately, like many other birds, anthropogenic noise seems to be a stressor, yet we have few data on seabird hearing abilities and noise impacts.

Here we examined the hearing, anatomy and noise induced behavioral responses to sound in two species of two Alcid seabirds: common murre, *Uria aalge*, and Atlantic puffin, *Fratercula arctica* (n=11). These are deep diving species for which sound-mediated underwater behaviors have been suggested. This family is also a conservation concern with most species listed as endangered, threatened or vulnerable. Hearing tests were conducted in-air in a portable semi-anechoic crate using physiological, auditory evoked potential (AEP) methods with temporarily wild-caught, sedated birds. Hearing data were quite clear and provided an auditory curve that was not unlike AEP hearing thresholds in other birds. Lowest measured thresholds were found at 1-2 kHz with a gradual increase in AEP-thresholds at lower frequencies and a steeper increase at higher frequencies. Responses were measurable from 0.5 to 6 kHz. Responses to underwater noise were measured with two foraging murrens in a quiet pool using white noise, mid-frequency sonar signals and control conditions. The birds were exposed to signals ranging in intensity from 110 - 137 dB re 1 μ Pa. In repeated trials, the animals showed a level-dependent graded reaction to sound with cessation of foraging occurring even at the lowest levels (110 dB) but greater response rates at higher received levels and the strongest responses coming from the white noise signals.

Obtaining auditory data for seabirds is particularly valuable considering their conservation status, general population-level declines and a minimal understanding of how they may use or be influenced by their acoustic habitat. These data show both sensitive in-air hearing, thus a concern for coastal noise, and sound-sensitivity to multiple underwater noise stressors which could have clear ecologically relevant consequences. With humans increasingly utilizing the coastal and pelagic habitats of seabirds, the soundscape of these areas are changing and seabirds progressively face acoustic degradation. These results are novel and vital for Alcids and provides needed empirical support for concerns regarding noise impacts on seabirds.

SOUND PRODUCTION MECHANISM IN THE SEMITERRESTRIAL CRAB *Neohelice granulata* (BRACHYURA, VARUNIDAE)

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Neohelice granulata sound production was previously characterized (Filiciotto et al., 2016). However, no studies were conducted to recognize which sex and structures are involved in sound production. Our aim was to identify the sound production mechanism and the sex of the individual producing it in *N. granulata* in a reproductive context. Crabs were collected at Mar Chiquita Coastal Lagoon (37°45'S, 57°19'W, Buenos Aires, Argentina) and transported to the laboratory. Experimental trials consisted in locating (1) a receptive female (RF) + a male (M), (2) a non-receptive female (NRF) + a male, (3) a RF + two M, (4) an NRF + two M. Nine replicates per trial were conducted. Experimental PVC tank was circular (1.2m diameter, 1.5m depth) covered with rubber to avoid sound signals of crabs when walking. A hydrophone (Reson TC4013, 1Hz-170kHz, -211dB) was in the center of the tank at 20cm depth. A GoPro camera was in the central surface to include all the tank bottom superficies. Experiments begun after locating the crabs in the center of the tank and finished 1h after. We analyzed jointly the video and the acoustic signals emission to identify the individual/type of movement/structures making sound. The number of agonistic encounters (each time two males contacted with their cheliped) was quantified. The body structures involved in making sound were dissected and processed to its observation by scanning electron microscopy. Sounds signals were produced by males by moving one cheliped in an up-down movement by rubbing the merus against the lateral cephalothorax, below the eyes. The number of acoustic signals and up-down cheliped movements was different among trials (Kruskal-Wallis: $tH=9.21$, $p<0.05$; $H=14.30$, $p<0.01$, respectively). A posterior Multiple Comparisons test showed that trial (3) differed from (4) the rest with higher number of acoustic signals ($Z=2.82$, $p<0.05$) and up-down cheliped movements ($Z=3.57$, $p<0.01$). In all trials (3) the number of up-down cheliped movements was linearly related correlated to the number of acoustic signals ($R^2=0.721$, $F=125.021.707$, $p<0.001$). The number of agonistic encounters was higher in trial (3) (Mann-Whitney: $Z=1.99$, $p<0.05$). The analyses of the micro-structures making sound showed the merus has serrate setae, which rub against tubercles and pinnate setae of the lateral cephalothorax. *Neohelice granulata* males produce sound signals in a mating context through a top-down movement of the cheliped, probably to advert other males of their presence since they occurred mostly in the presence of two M and a RF, when agonistic encounters were also greater.

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APPLICATION OF KURTOSIS TO UNDERWATER SOUND EXPOSURE

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There is concern about the risk of noise-induced effects on marine life exposed to high-intensity anthropogenic sound. Regulations exist for impulsive as well as continuous underwater noise. These regulations are typically formulated in terms of peak sound pressure, rms sound pressure, and weighted or unweighted sound exposure ($E_{p,\tau_{int}}$).

Studies of the effects of sound on humans and other terrestrial mammals suggest that in addition to the metrics mentioned before, the impulsiveness of sound should be considered in order to better predict the risk of hearing loss or other adverse effects. The additional risk is often quantified in terms of the kurtosis (β) (Hamernik & Qiu, 2001; Goley et al. 2011; Liu et al., 2014).

Kurtosis describes the temporal distribution of a (sound) signal ('peakiness') so that it can be used to differentiate between different kinds of white noise (e.g., uniform, gaussian, binary), and it is also influenced by intermittency of the signal. This paper addresses how the concept of kurtosis can be used to improve characterization of impulsive sounds, such as those from airguns, pile driving and explosions.

The kurtosis of a single impulse depends on the evaluation interval duration τ_{int} . For an interval containing a given single pulse, the ratio τ_{int}/β , is shown experimentally and theoretically to be independent of τ_{int} , providing a more robust metric for the pulse. For a sequence of pulses with a known ratio, τ_{int}/β per pulse, the kurtosis for the sequence is proportional to the pulse repetition rate.

This paper shows that τ_{int}/β can be interpreted as a weighted measure for the signal duration, closely related to the effective signal duration, τ_{eff} according to ISO 18405:2017(en). To quantify this relationship between kurtosis and signal duration, a correlation was examined between τ_{int}/β and other definitions of signal duration (τ_{eff} , $\tau_{90\%}$), for airgun sounds, pile driving sounds, explosions, including pile driving sounds that have been played back for impact-assessment studies on fish (Halvorsen et al., 2011). We discuss whether it is possible to predict the signal kurtosis based on measured signal duration. Overall, the paper provides a methodology to measure and apply alternative metrics (β, τ_{eff}). This can aid in quantifying the risk of impact from impulsive sound on marine life.

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Hamernik, R. P. & Qiu, W. (2001). "Energy-independent factors influencing noise-induced hearing loss in the chinchilla model", *J. Acoust. Soc. Am.* 110, 3163-3168.

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IMPACTS OF NOISE ON THE BEHAVIOR AND PHYSIOLOGY OF MARINE INVERTEBRATES: A META-ANALYSIS

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The rise in human-generated noise over the last 60 years has increased concerns regarding the implications for marine species. Many species have been documented to display behavioral and physiological responses to increased noise pollution in our oceans, but the majority of this research has focused on higher trophic organisms, primarily marine mammals and fishes. In contrast, little is known about the effects of noise on invertebrate communities. This knowledge gap is particularly critical as much recent work is beginning to assess the impacts of changing soundscapes on entire aquatic ecosystems. To better understand the impacts of underwater noise on invertebrate communities, a meta-analysis was conducted on the behavioral and physiological impacts of noise on invertebrates. A systematic review of the literature revealed 1,092 potential studies on the topic, 17 of which were extracted for data analysis. The studies used in this analysis resulted in 364 data points that evaluated the impacts of a plethora of acoustic stimuli on a wide range of marine invertebrate taxa. Presented results will discuss the effect size and corresponding variance for each study considered and explore the cumulative effect that exists across a range of experimental conditions. The implications for invertebrate behavior and physiology will be discussed at the species level. Additionally, variation across taxon-specific responses to the array of stimuli considered illustrate the wide range of processes, including reproduction, predation, and distribution, that may be impacted by changes to the prevailing soundscape. This meta-analysis reveals the implications that elevated underwater noise levels may have on marine invertebrate communities.

BEHAVIOURAL RESPONSES OF HARBOUR SEALS TO VESSEL NOISE IN THE NORTH SEA

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Due to intense global ship traffic, vessel noise is one of the most dominant noise sources in the world's oceans. Vessel noise is known to impact marine species, such as cetaceans, on various levels—from masking of communication to distinct behavioural changes, e.g. disrupting foraging activities (Blair et al., 2016; Wisniewska et al., 2018). However, effects of vessel noise on free-ranging pinnipeds are much less studied. Hence, the aim of the present study was to test for behavioural responses of wild harbour seals (*Phoca vitulina*) to vessel noise in the highly trafficked North Sea.

In this context, 10 harbour seals were instrumented with long-term sound and movement tags (DTAG-4), in the Wadden Sea, in the frame of a project funded by the German Federal Agency of Nature Conservation (BfN). These tags consist of a triaxial accelerometer, a triaxial magnetometer, a pressure sensor, a Fastloc GPS and a hydrophone (100 Hz-27 kHz recording bandwidth) and are able to record continuous data for four weeks (Mikkelsen et al., 2019). DTAG sound recordings were screened for passing vessels. As vessel noise is partially masked by low-frequency flow noise from acceleration of the seal, we chose an octave band (1 kHz), whose energy is largely unaffected by the animals' activity and could hence be used to identify vessel passes (Mikkelsen et al., 2019; Wisniewska et al., 2018). To further avoid sound transients from water splashing, bubbles, etc. at the surface, only sound recorded below 1 m water depth was analysed.

Tests of behavioral reactions focused on immediate changes in dive and activity parameters (e.g. descent/ascent rate, dive depth, dive frequency, heading, ODBA) between prior to and after the ship encounter, centered on the time of maximum received octave band levels. Preliminary data analysis indicate immediate responses to high level vessel noise, e.g. avoiding the surface and diving to the sea floor. Larger scale behavioural patterns also changed, e.g. switching from resting to actively swimming after a vessel passage, compared to random subsets of the data. These findings are relevant for the development of appropriate measures for achieving a “good environmental status” as defined by the Marine Strategy Framework Directive.

Blair, H. B., Merchant, N. D., Friedlaender, A. S., Wiley, D. N., and Parks, S. E. (2016). “Evidence for ship noise impacts on humpback whale foraging behaviour,” *Biol. Lett.*, 12, 20160005. doi:10.1098/rsbl.2016.0005

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SEISMIC AIR GUNS CAN REDUCE HUMPBACK WHALE SINGING EFFORT

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Seismic air guns produce high-level, impulsive, repetitive sounds during surveys for oil and gas deposits beneath the sea floor. These sounds may cause a range of impacts on marine mammals including changing their vocal behavior. Reports of changes to mysticete vocal behavior are mixed, however, with both increases and decreases in vocal rates. In the current study, we used a series of experiments on migrating humpback whales to measure the impacts of air gun noise on singing behavior. Whales were exposed to arrays of air guns, ranging from a single 20 in³ air gun to a full commercial 3130 in³ array ('actives'). A second set of experiments exposed whales to the source vessel towing air guns that were not operating ('controls'). Baseline observations of behavior were also made when no seismic vessel was in the area. Singing whales were tracked acoustically using a fixed hydrophone array. The numbers of singers within the study area (generally within 10 km of the source vessel) were counted every 10 mins between 0700 and 1700 daily during September and October 2010, 2011, 2014 and 2015. Additionally, the number of times whales started or stopped singing during a treatment ('transition rate') was also noted. To test whether air gun noise reduced singing activity, baseline singing activity and transition rate (n=94) were compared with singing activity and transition rate during active (n=38) and control (n=30) treatments. Baseline singing activity was greatest mid-season and significantly reduced towards the end of the season. There was no significant effect of time during the day. Singing activity was reduced in the active trials later in the migration, but the overall reduction was small. There was no evidence of any change in transition rate. These results suggest that motivation may moderate the impact of air gun noise. In the mid-season, if whales are highly motivated to sing, they may be less affected by disruptions from noise than late in the migration when their underlying motivation is waning. This study indicates that nearby air gun activity has the potential to reduce singing activity in humpback whales, but the impacts of air guns may be tempered by underlying biological factors which need to be understood.

CHARACTERIZING THE ANTHROPOGENIC SOUNDSCAPES OF FISHERIES CLOSURE AREAS TO INFORM THE RECOVERY OF AT-RISK FISH STOCKS

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Fish make up a vast proportion of the ocean biomass and are ecologically and economically important, yet little is understood about how anthropogenic noise affects fish in the wild. Pacific rockfish (*Sebastes* spp.) are a commercially and culturally important food fish on Canada's west coast. Many species of rockfish produce low source-level, low-frequency vocalizations; however, the vocal repertoire and behavioural context of their vocalizations is unclear (Širović and Demer 2009). Stocks of many rockfish species have declined over the last century due to overharvesting and mismanagement of these long-lived, ovoviviparous fishes. The current recovery plan in Canada includes Rockfish Conservation Areas (RCAs), which are areas of rockfish habitat within which the take of rockfish is prohibited. Monitoring of RCAs over the decade since their implementation has shown little quantifiable recovery, and in some cases, further decline (Haggarty et al. 2016). Investigation into this lack of recovery has focused on education and enforcement (Lancaster et al. 2017), as well as physical habitat quality assessment (Haggarty et al. 2016); acoustic habitat quality has not yet been assessed.

The dominant source of anthropogenic noise in the inshore waters of Canada's southwest coast (the Salish Sea) is motorized vessels engaged in shipping, tourism, fishing, recreation, and transportation. Projected increases in shipping and tanker traffic will increase noise exposure in critical habitat for several at-risk species, including rockfish. Most RCAs in the Salish Sea are situated in or near shipping lanes, marinas, ferry routes, and recreational vessel thoroughfares, with no restrictions on vessels transiting nearby or inside RCAs. In this study we investigated the potential impacts of vessel noise on rockfish recovery by comparing the levels of anthropogenic noise experienced in three Salish Sea RCAs to three adjacent unprotected areas. We characterized noise soundscapes during three six-week periods from August 2018 to June 2019. Our results show that RCA boundaries do not provide any protection from noise pollution, and that the RCAs we surveyed experience noise in low-frequency octave bands which may be detrimental to rockfish communication. We hope that these results will help to inform the adaptive management of rockfish stocks, and add to our understanding of the broad impacts of vessel noise on nearshore marine ecosystems.

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**THE 3-D-V ARRAY: A VOLUMETRIC, DIGITAL, TOWED HYDROPHONE
ARRAY SYSTEM CAPABLE OF SOUND SOURCE BEARING AND
LOCATION ESTIMATION IN 3-D SPACE**

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We are developing and testing a new, three-dimensional towed hydrophone array system called the 3-D-V array that will be capable of using both time-of-arrival-differences (TOAD) and angle of arrival (e.g. beamforming) methods to estimate bearings to biological sound sources for the ultimate goal of localizing marine mammals in three-dimensional space. Real-time passive acoustic monitoring of marine mammals for mitigation and research (e.g. line-transect surveys) is typically conducted using a linear towed hydrophone array system. However, most linear towed array systems have limitations, due to their linear spatial design, which preclude them from determining the vertical component of bearings (i.e. slant angles) to marine mammal sound sources. The main objectives of this project were to design, develop and test a new digital, volumetric, towed hydrophone array system that is capable of real-time monitoring of marine mammals for mitigation purposes during seismic surveys. This tetrahedral shaped towed array system uses automated beamforming, TOAD, auto-detection and localization algorithms some of which that were specifically developed for this project and are fully integrated into PAMGuard. We present information on the hardware and software developed, as well as results of bench and field test of this new system for monitoring marine mammals from research and industry vessels. A final at-sea field test is planned later this year on a large seismic research vessel.

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DO HUMPBACK WHALES HAVE A STARTLE REFLEX?

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The startle reflex is an oligosynaptic reflex which is triggered by short-onset-time stimuli (Yeomans et al., 2002) and leads to a sudden contraction of muscles which is often visible as a flinch. This reflex appears to be universal and conserved among mammals with similar startle thresholds, including rats, mice, humans, seals and dolphins (Götz & Janik, 2011). The startle reflex is elicited when the received level of a stimulus reaches approximately 80-90 dB above an animal's hearing threshold within a short time from the onset. It is most pronounced with stimuli that have a rise time of less than 50 ms. In grey seals (*Halichoerus grypus*), repeated elicitation of the startle reflex led to sensitization of avoidance responses, interruption of foraging behaviour and flight responses (Götz & Janik, 2011). This is in contrast to rapid habituation to other non-startling sounds found in grey seals (Götz & Janik, 2010). Thus, this reflex may explain some exaggerated avoidance behavior to sudden onset sounds observed in marine mammals.

In our study, we investigated whether humpback whales (*Megaptera novaeangliae*) show an acoustic startle response. We exposed 13 whales to series of sudden-onset, limited bandwidth noise pulses with a peak frequency of 700 Hz and received levels between 140 and 160 dB re 1 μ Pa. To identify flinches, we measured their muscle contractions using 3D accelerometry recorded with DTAGs. Two out of 13 whales showed one flinch each at the beginning of a pulse sequence at received levels of 146.8 and 153.9 dB re 1 μ Pa rms respectively. One animal startled in response to the first stimulus in a sequence but did not startle to a subsequent stimulus of a higher received level.

The fact that only two startle responses were observed suggests that humpback whales either have a modified startle response that makes them unique amongst mammals studied so far, or that they are able to adjust their hearing thresholds in the presence of aversive acoustic stimuli, similar to what has been reported for toothed whales (Nachtigall & Supin, 2015). Alternatively, but perhaps less likely, humpback whales may have on average a comparatively poor hearing threshold of > 70 dB re 1 μ Pa at 700 Hz.

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THE SOUNDSCAPE OF GREEN TURTLE FORAGING GROUNDS: ACOUSTIC CUE FOR LOCAL ECOLOGICAL CONDITION?

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The soundscape features of the marine environment provide crucial information about the ecosystems health for many species, and are defined by the local biological, geological and anthropogenic components (Lillis et al., 2016). In this study, we investigated the soundscape of two green turtles foraging grounds in Fiji, central South Pacific, with the aims of characterizing the contribution of each component and of comparing the levels of acoustic pressure between embayments with different turtles occurrence.

Four hydrophones were deployed around two islands in the central channel of the archipelago. Significant correlations were detected among Sound Pressure Levels (SPLs) at very low frequencies (25-40 Hz) and tide height, while Generalized Additive Models highlighted that SPLs at low frequencies (125-250 Hz) were especially affected by wind conditions, and SPLs at medium-high frequencies (above 500 Hz) were mostly influenced by crustacean acoustic activity. Even if significant differences were found among the eight embayments, higher biological activity (especially at low and medium-high frequencies) and higher water turbulence characterize the sites where green turtles were more abundant.

These results suggest that the soundscape could indicate the ecological and biological status at fine scale. Even if little is still known about the actual use of underwater sounds in orientation and searching for food by marine turtles, these outcomes are a base for investigating how the soundscape could be relevant for the biology and conservation of the species.

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EXTENDED DURATION ACOUSTIC TAGS PROVIDE INSIGHT INTO VARIATION IN BEHAVIORAL RESPONSE TO NOISE BY MARINE MAMMALS

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Current estimates of the population level effects of noise exposure rely on model predictions linking exposure and behavioral or physiological changes to health and vital rates (Pirota et al. 2018). While exposure levels can be accurately modelled for intentional signal production (i.e. sonar, seismic signals, construction activities) it is more challenging to estimate the effects of cumulative noise exposure experienced by marine mammals from multiple sources in their environment (Merchant et al. 2018). Controlled exposure experiments to study the impacts of a particular sound type often investigate short-term (< 1 day) behavioral responses of individuals to exposure of a particular sound source (Tyack et al. 2003). These studies produce dose-response curves that, combined with estimated exposure, are used to predict population level effects. In the wild, variation in background noise levels and in the motivational state of individual animals will impact their responsiveness to specific noise sources. The rate of behavioral disruption from sounds likely also plays an important role as to whether acute noise exposures result in negative health consequences. Data collected over longer, more biologically relevant time scales of weeks to months would improve our understanding of actual noise exposures experienced by free-ranging marine mammals (Mikkelsen et al. 2019) and the variability of behavioral responsiveness through time. Our group is working to extend the duration of fine-scale acoustic and movement tag data to explore these questions. Using data from pilot deployments on humpback whales (*Megaptera novaengliae*) and manatees (*Trichechus manatus latirostris*), we will highlight individual variability in behavior through time scaling from short-term tag deployments on the order of 12 hours during the day, spanning 2-3 day tags highlighting diel trends in behavior and exposure, out to 40+ day datasets that show diel and spatial variability in exposure and behavioral responsiveness along with quantification of close vessel encounters experienced by individual animals. This conceptual presentation highlights the value of longer-term fine-scale data to better inform model predictions for disturbance, and offers a path forward for addressing challenging questions related to the cumulative impact of noise-induced responses on individual health.

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EXPOSING FISH TO A SEISMIC AIR-GUN ARRAY SOURCE

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Intense impulsive signals, such as those used in marine geophysical exploration surveys, have the potential to impact the behavior and distribution of fishes. In 2018, Theme 1 of the Australian Institute of Marine Science's NorthWest Shoals to Shore research program investigated the level of displacement of fishes after exposure to eight, 15 km-long seismic lines, operating a full-size (2600 cui) air-gun array.

The study, 90 km off the coast of northwest Australia, in 60 m water depth, comprised a multiple before-after-control-impact (MBACI) and dose-response (DR) design to detect fish responses to exposure and, if present, at what ranges this might occur. A 'racetrack' design was conducted, where the vessel operated one inactive line (guns deployed, but not operational) in a 'Vessel Control' (VC) area before travelling 36 km to conduct an active line in a 'High Exposure' (HE) area. It then circled back the 36 km and commenced another set of active and inactive lines (≈ 14 hours between the start of successive cycles), 500 m west of the previous respective line type. This cycle was repeated until eight active and inactive lines had been conducted

The MBACI design comprised three sampling periods before (July, August, September) and two sampling periods after (October, December) exposure in the HE, VC and Control areas with the DR sampling also including sites at distance that experience 'Medium' and 'Low' exposure. Observations of fish were conducted with an acoustic telemetry study, stereo Baited Remote Underwater Videos (stereo-BRUVs), and echosounder transects (Biosonics DTX, 38 and 410 kHz transducers). A total of 387 red emperor (*Lutjanus sebae*) were tagged (300 and 87 tagged in June and August, respectively) within two ≈ 31 km² telemetry receiver arrays. These arrays, one in each of HE and VC areas, provided near-continuous data on tags in the area, until the arrays were removed in December, 2018. Passive acoustic monitoring sensors (pressure, particle velocity and ground motion) recorded the seismic air-gun signal at various ranges to validate modelling of the sound exposure levels.

With analysis underway, this presentation will highlight the development of the survey design, some considerations for designing a full-scale seismic survey study and some of the initial findings for this experiment.

IMPACT OF TAICHUNG HARBOR NOISE ON CHINESE WHITE DOLPHINS

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This study aims to investigate the underwater noise near the port area and the sounds of the Chinese White Dolphins before the expansion construction for the Taichung Port Area. The survey site is between the north bank of Dajia river in the north and the south bank of Dadu river in the south. It's about 15 km long where is covered the entire Taichung port. The choosing of deployment positions of the underwater recorders which are consider the water depth of the white dolphin's interest, avoid the area of navigation channel, anchorage, port facilities, and as evenly as possible in space. Both of the underwater background noise of Taichung Port and the underwater sound of the Chinese White Dolphins was obtained by underwater acoustic instruments, which can be compared/analysis and understand the influence of the port noise on Chinese White Dolphins.

The experiment was carried out twice in June – August 2018, including six Seabed deployment instruments each time, all for continuously 14 days. The recorder has broadband frequency response can record low-frequency wave noise, ship noise, wind and rain noise, fish, and dolphin sounds. Dolphin sounds include whistle which is use for communication and socialization, and clicks as a navigation and Foraging. We develop our own application algorithms by using Matlab Program to detect the whistles and clicks of dolphins to be analysis.

This is the first study on the underwater noise and dolphin sound in Taichung Port. Analyze the dolphin Whistles and clicks records 24 hours a day, we found those sound are recorded much more often in the early morning and before sunset. According to the records of semi-diurnal tide, the dolphins often appeared before/after the high tide. The dolphin's activities seem to be related to not only the noise of the port, but also the nearby environment and the complex behavior of the dolphins themselves. It is worthwhile to do more measurement and research in this area. In follow-up expansion project of the port, it need to assess the possible impact on the dolphins first.

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COMPARING THE COMMUNICATION AND LISTENING SPACE METHODS TO CHARACTERISE AUDITORY MASKING FOR MANAGEMENT

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Auditory masking is an important non-lethal effect of anthropogenic noise on marine life. The extent and severity of auditory masking is often assessed using either sonar equations to quantify changes in an animal's communication space (the volume of ocean within which a communication signal may be perceived) or by quantifying the frequency-dependent changes to a soundscape that may impair an animal's ability to perceive any biologically-important signal (i.e. its listening space). However, our limited knowledge of the hearing biology of many fishes and their vocalisations impedes our ability to model changes to communication space through sonar equations. Communication space implies a source-receiver calling relationship that neglects that fish also respond to heterospecific vocalisations and abiotically-derived sounds (e.g. bubbles and sediment movement) that combine to create an 'acoustic scene'. An alternative to communication space is the relatively new method of calculating the reduction in listening space (LSR; Hannay et al. 2016; Pine et al. 2018) as the result of noise. The LSR method does not assume that conspecific vocalisations are the only signal of interest to the listener, which may make it more broadly applicable for management. Modelling LSR does not require knowledge of an animal's vocalisations but rather the listener's frequency-dependent hearing thresholds. In this study, we compare the reduction in communication space with the reduction in listening space for Atlantic cod (*Gadus morhua*) as a vessel operating a seismic air gun passes by on the Grand Banks, Newfoundland, Canada. We compare the results of these two models with respect to current management thresholds, and discuss the ecological implications of the inputs and results of each model. This comparison will help managers to use the model best suited to their taxa, noise source, and environment of interest.

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AN ATTEMPT TO INVESTIGATE THE NOISE IMMUNITY OF THE SPATIAL HEARING MECHANISMS IN A BOTTLENOSE DOLPHIN

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Tolerance of spatial hearing mechanisms to noise was studied in a bottlenose dolphin (*Tursiops truncatus*). Auditory evoked potentials (specifically, the rate following responses, RFR) produced by short rhythmic tone pips (carrier frequency 64 kHz, pip rate 1 kHz) were recorded at different sound-source positions in the presence of noise and in quiet. Sound pressure level (SPL) of the noise was 105 dB re 1 μ Pa. The azimuth positions of the signal source varied within a range of $\pm 120^\circ$ from the longitudinal head axis, by steps of 15° . The noise source was located in one of the following positions: $\pm 90^\circ$, $\pm 60^\circ$, $\pm 30^\circ$, and 0° . RFRs were non-invasively recorded from the head vertex, i.e. binaurally. Based on the dependence of the auditory sensitivity on the noise source position, the receiving beam width was plotted. A decrease in the dolphin's hearing sensitivity was noted as the noise source shifted of the frontal positions. The width of the receiving pattern remained unchanged compared to the control in quiet.

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MEASUREMENTS OF PARTICLE MOTION NEAR THE SEAFLOOR DURING CONSTRUCTION AND OPERATION OF THE BLOCK ISLAND WIND FARM

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Noise radiation and particle motion from pile driving activities were monitored using multiple sensors during the construction of the first offshore wind farm off Block Island, RI, USA in 2016. The Block Island Wind Farm (BIWF) consists of five turbines in water depths of approximately 30 m. The substructure for these turbines consists of jacket type construction with piles driven to the bottom to pin the structure to the seabed. Pile driving operations generate intense sound, impulsive in nature, which radiates into the surrounding air, water and sediment producing particle motion that may affect marine environment. The particle velocity sensor package consists of a three-axis geophone on the seabed and a tetrahedral array of four low sensitivity hydrophones at 1 m from the bottom. During the construction phase of the BIWF the particle velocity sensor package was deployed at approximately 500 m from the wind farm. The acoustic pressure acquired by the hydrophones will be processed to calculate particle motion. Data from the BIWF site will be compared with model predictions and published data from other locations. Recent measurements from the same wind farm location during the operational phase also will be presented. During the operational phase of the BIWF the particle velocity sensor package was deployed at approximately 50 m from the wind farm. The measurements from the construction and operational phase will be discussed in the context of their impact on fishes.

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DRIVERS OF SOUNDSCAPE VARIABILITY IN ENGLISH AND WELSH WATERS

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Underwater noise monitoring programmes are being established globally to assess levels of noise pollution in marine habitats and to inform management actions to reduce impacts on marine life. Such measurements can also be used to validate modelled predictions of noise levels. To better understand the dominant factors influencing soundscapes at each monitoring site, detailed analysis of soundscape variability and its dependence on sound-generating processes is needed. We set out to explore these drivers at four measurement locations in England and Wales that are used to monitor anthropogenic noise pollution under the UK Marine Strategy.

Using a range of soundscape analysis approaches (principal component analysis, e.g. Keogh and Blondel, 2009; correlation to environmental variables, e.g. Merchant et al., 2014; periodicity, e.g. Staaterman et al., 2014), we assessed the effects of tide, wind speed, wave height, and total precipitation at each site. Where available, we used AIS data to examine the influence of shipping noise. Two sites are located in the North Sea: Dowsing, a fishing ground north of The Wash, and WARP, in the Thames estuary. A further site is located off Rame Head in the western English Channel, and the fourth is off Puffin Island, north of the Menai Strait in Wales. All sites are shallow (depth 17 – 27 m), macrotidal (tidal range >4 m), and close (<5 km) to shipping lanes.

Our results demonstrate that despite physical similarities between the sites, the soundscape at each differs considerably. For example, the influence of shipping relative to natural environmental drivers varied not only as a result of shipping activity, but also as a consequence of environmental drivers: there is a markedly stronger correlation between wind speed and noise levels at the two North Sea sites, where the fetch is much greater, whereas at the Channel and Irish Sea sites rainfall has a greater effect on sound levels. This work also highlights the need to understand the influence of high tidal flow noise—an expected feature in many coastal environments—when reporting low-frequency sound levels. The Dowsing site was particularly affected, and the high tidal flow noise during summer may be masking the acoustic signature of herring aggregations during the spawning season.

These analyses will be used to validate noise maps and will inform decisions on long-term monitoring in UK waters (Merchant et al., 2016) and further research into the effects of noise pollution in these habitats.

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UNDERWATER MONITORING OF PINNIPED VOCALISATIONS IN THE GULF OF RIGA

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The Gulf of Riga region in the Baltic Sea is a known habitat for the semiaquatic pinnipeds the grey seal (*Halichoerus grypus*) and ringed seal (*Pusa hispida*). This ringed seal habitat is one of the southernmost known. The passive acoustic monitoring has been previously used for detecting the presence and assessing the biological activity of marine species in various studies (Calvert et al. 1985, Gallus et al. 2012). The Gulf of Riga has moderate shipping traffic and fishing activity. Anthropogenic sound is known to have a possible detrimental impact to the vocalizing fish and marine mammals due to the potential of masking their communication (Putland et al. 2017). However, the extent of this impact still needs to be properly quantified.

The current study analyses the data from two underwater acoustic monitoring stations deployed at a shallow depth (~10 meters) in the Gulf of Riga for the period of 3 months (June–August 2018). In order to understand the impact of anthropogenic noise, its proportion in the acoustic soundscape should be assessed. Initial step is to evaluate the content of the measured ambient sound. Proportion of the anthropogenic sound was assessed with the help of AIS and VMS data as well as by direct analysis of the recorded data. The most prominent ambient sound source is the wind driven sea surface agitation. Another natural sound sources are the sonorous marine biota. Most of grey seal and ringed seal vocalizations can be identified in the lower frequency range by their specific patterns. Previous studies have indicated seals having different types of vocalization. The acoustic features of each type can vary depending on population, gender of animals, season, and behaviour (Mizuguchi et al., 2015). Visual observation of the spectrograms of monitored sound confirmed distinct acoustic features of the different call types. A call detection for identifiably different types of vocalizations was performed by the use of commercial sound analysis software.

The effect of variation of natural ambient sound level and potential of masking of biological sounds by ship traffic noise are considered. Analysis of the detection rate and diel activity gives an overview the usage of the monitored area by seals. Overlap of the seal vocalizations with anthropogenic noise can help understanding the adverse effects related to human activities.

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EFFECTS OF SOUND AT NAVIGATIONAL LOCKS ON FISH

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The effects of anthropogenic sound on freshwater animals has received considerably less attention than their marine counterparts. Physical barriers such as dams in rivers and lakes, provide flood protection and generate hydroelectric power but can also hinder fish migration. Fish that transit navigational locks adjacent to dams are exposed subsequently to vessel and machinery sound inside the concrete chamber which could have deleterious effects to auditory sensitivity. To understand the effect of navigational lock sound on fishes, passive acoustic monitoring was conducted at Lock and Dam 5 near Winona, MN during ice-free months (November 2017, April – September 2018) to coincide with peak vessel activity. Omnidirectional hydrophones (ST202) were positioned inside and outside the lock chamber to determine the effect of transiting vessels on the soundscape. Commercial vessel (tow boats with up to 12 barges) transits increased sound levels by up to 40 dB [median broadband SPL (200 – 1,000 Hz)], inside the lock chamber while recreational boat transits increased sound by up to 35 dB. There was also a 10 dB gradient of sound inside the lock chamber, with louder sound upstream compared to downstream, therefore any fish swimming upstream are currently faced with ever-increasing sound during their passage. All fish species studied to date have responded to sound (either pressure or particle motion) in their environment, indicating sound detection is an important cue. By comparing the passive acoustic dataset to known auditory thresholds for native and invasive fishes of the Mississippi River, behavioural and physiological effects of sound during lock passage will be discussed before providing future recommendations for management of the local soundscape.

BEHAVIOR OF SPAWNING COD IN RELATION TO MARINE SEISMIC SURVEYS

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Seismic surveys are a major source of noise in the ocean, and can affect fish behavior in terms of avoidance, changed swimming behavior, and reduced feeding at distances of tens of kilometers (Carroll et al., 2017; Engås et al 1996).

For many fish species, such as the Atlantic cod (*Gadus morhua*), sound production is of particular importance during spawning, when it is used in courtship and aggressive interactions (Rowe and Hutchings, 2006). For such fish, manmade noise has the potential to scare spawners away from their spawning ground, as well as disrupt their spawning interactions through masking of important biological sounds (de Jong et al., 2018).

In the SpawnSeis project, we therefore study effects of seismic surveys on the behavior of wild, free ranging, spawning Atlantic cod using acoustic telemetry in Austevoll, Norway. Mature cod are tagged with acoustic telemetry tags prior to the spawning seasons and tracked with acoustic receivers in the area. Within receiver grids the tagged fish will be tracked in 3D using depth sensors in the tags and triangulation of the acoustic signals emitted by the tags. Acceleration sensors in some of the tags will give additional information about fish activity.

In autumn 2018, a total of 36 acoustic receivers were placed in two grids, on two separate spawning grounds. These will constitute one exposure area (30 receivers) and a smaller control area (6 receivers), with and without exposure to seismic sound, respectively. Additionally, three nearby spawning sites are covered with single receivers to study visits to nearby spawning grounds and movements between spawning grounds. Fish movements in the area will be studied during three consecutive spawning seasons. The 2019 spawning season will act as a baseline for both sites, to document activity levels and diel patterns, site preference within the grids, departure rates and return rates, as well as survival rate for tagged fish. The following years; 2020 and 2021 a seismic survey will be conducted at the exposure site with an authentic, single air gun. This will enable us to study changes in behavior, including potential avoidance, in relation to the seismic sound both within and between spawning seasons. In January 2019, 49 cod were caught, tagged, and released in the exposure area. In the smaller control area, 16 cod were tagged. A similar number of fish will be tagged at both sites in 2020 and 2021.

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SEISMIC SURVEYS AND GRAY WHALES NEAR SAKHALIN ISLAND: THE NEXT CHAPTER

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In 2001 Exxon Neftegas Ltd. (ENL) developed a monitoring and mitigation plan (MMP) which used acoustic measurements from sonobuoys to manage a seismic survey near the nearshore feeding grounds of the gray whale (*Eschrichtius robustus*) off the NE coast of Sakhalin Island, Russia. These data were also used for sound exposure estimation for effects assessment analyses. In a seismic survey conducted in the same region in 2010 the approach was enhanced by using measurements-validated acoustic modelling as a key component of the MMP and subsequent sound exposure estimation, as described at the previous two editions of this conference (Racca et al. 2016a,b).

In 2015 multiple seismic surveys took place near the nearshore feeding grounds, two of them in licence areas where seismic was acquired in 2001 and 2010. As in the earlier seasons, acoustic recording stations (some of them capable of telemetering data to shore to enable real-time verification of the received levels at various sites and compensation of pre-season model estimates of exposure) were deployed in the operational region. In this instance, however, the number and spatial distribution of such stations was substantially larger to enable a much better characterization of the acoustic field for post-season analyses. Although the seismic surveys were conducted on a coordinated schedule to avoid as much as possible the temporal overlap of acquisition in adjacent sectors, the interleaved arrival of pulses from different operations posed a considerable challenge post-season in identifying individual pulses received at each recording station and attributing them to the correct source, a critical prerequisite for using the measured pulse levels to compensate and improve the model-based estimates of acoustic exposure.

This presentation, which deals primarily with the MMP implementation and post-season analyses conducted by ENL, first describes the technical advancements in onboard signal processing and satellite telemetry that enabled the centralized real time calibration of acoustic exposure estimates for operations spaced several tens of kilometres along the coastline. It then reviews the post-season processing of acoustic data from 40 recorders to detect, characterize and attribute pulse arrivals from up to four seismic vessels as well as onshore pile installation activities, and the use of these reference levels to yield substantially improved estimates of sound exposure both at the tracked locations of individual whales (for behavioural effects assessment) and on a regular spatial grid covering the entire region of operations (for evaluation of effects on whale density, distribution and bioenergetics).

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RESPIROMETRY AS A TOOL FOR ASSESSING METABOLIC RESPONSES OF FISH TO ANTHROPOGENIC NOISE

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Anthropogenic noise has changed the underwater soundscape of many coastal locations worldwide and has been reported to have several negative effects on marine taxa, from masking of biologically important sounds, stress induced responses to major barotrauma injuries and even death. There have been an increasing number of studies employing the use of respirometry to measure metabolic responses to anthropogenic noise. Here, we use closed intermittent respirometry to assess the response of two species of fish, snapper (*Chrysophrys auratus*) and common triplefin (*Forsterygion lapillum*), with varying hearing abilities to ship noise. Both the snapper and common triplefin showed a similar response to ship noise, where the rate of oxygen consumption was reduced. Also, intraspecific differences in the personality, in the form of risk taking, of common triplefins do not seem to play a crucial role; bold and timid triplefins react with the same magnitude to boat noise, both showing a decrease in oxygen consumption and consistently more time to take risk. These results are different to other studies (Simpson et al., 2015; Simpson et al., 2016; Harding et al 2018), where it was shown that motorboat noise increases the rate of oxygen consumption. There are a number of potential reasons for this but experimental technique is possibly key. Here we employed long recovery times and intermittent flow through respirometry that measures oxygen consumption repeatedly over a prolonged period. In contrast, the other studies used short recovery times and a simple ‘fish in a bottle’ type approach that is limited in the number of oxygen consumption measures and is potentially fraught with fish activity artefacts. As we cannot exclude species-specific differences for the variable results between studies at the current time, we call for a robust standardised method to assess the effects of anthropogenic noise on metabolism.

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CHARACTERIZATION OF NEAR-BED PARTICLE MOTION BY THE NOISESPOTTER: A THREE-DIMENSIONAL VECTOR SENSOR ARRAY

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Understanding the effects of particle motion on fishes and invertebrates is relevant to regulatory concerns: adverse effects due to increased mortality, injury (and reduced survivorship or sensory capabilities), physiological alterations and behavior (including but not exclusively reproductive) would be important to the preparation of any environmental impact assessment (Nedelec et al., 2016). Fishes and many invertebrates use sound, primarily particle motion, to acquire information about their environment (an approaching predator, the presence of a potential mate), but also for communication or navigation (Zeddies et al., 2012). Among the issues raised by Popper & Hawkins (2018) as requiring further investigation—specifically as they relate to regulations—is the need for robust measurements of particle motion under water.

The NoiseSpotter was developed with support from the U.S. Department of Energy (DOE) to characterize and geolocate sounds from marine hydrokinetic energy devices (MHK), and other sounds in the vicinity of MHK installations. The system consists of a three-dimensional array of three particle motion sensors that measure acoustic particle motion in addition to acoustic pressure. By virtue of making particle velocity measurements, the NoiseSpotter is able to identify the location of sounds in the marine environment, and transmit in real-time, key aspects of the acoustic field.

Here, we present particle velocity measurements of ambient noise and passing vessels that include small boats and two commercial shipping vessels in the Strait of Juan de Fuca, Washington, USA. The NoiseSpotter was deployed as a bottom platform in Sequim, Washington in July 2018. Synchronous particle velocity measurements were made between 50 Hz and 3 kHz, with the three sensors located between 50 cm and 1.25 m above the bottom. Variability in particle velocity is characterized as a function of sensor height above the bottom and distance to the passing vessel and compared to ambient particle velocity levels. The analysis allows for insight into particle velocity levels that can be experienced by bottom-dwelling fishes relative to those whose habitats are further above the bottom, as routine boat traffic transits on the sea surface.

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DISCOVERY OF UNEXPECTED HIGH FREQUENCY “RASP” SOUNDS PRODUCED BY SABLEFISH ILLUSTRATES HOW LITTLE IS KNOWN ABOUT THE DEEP-SEA SOUNDSCAPE

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Sablefish (*Anoplopoma fimbria*) are deep-sea demersal fish of economical and ecological importance in the North Pacific Ocean. Although unpublished accounts had previously suggested sablefish could be soniferous, a validated description of their sounds was not available. We collected passive acoustic recordings from sablefish-holding net pens in Kyuquot Sound (British Columbia, Canada) in April 2016 and 2017 and from rearing tanks in Manchester (Washington, US) in June 2018. We recorded high-frequency click-like sounds that we called “rasps” in both locations, positively identifying the sablefish as their source. “Rasps” occurred between 1826 ± 85 KHz (average \pm standard error) and 9412 ± 312 KHz and a peak frequency of 4299 ± 169 KHz. The duration of “rasps” varied between 139 and 11143 ms and averaged 2353 ± 151 ms. This is the first confirmation that sablefish are soniferous and the only detailed description of their sounds. The documentation of sablefish sounds is an important contribution to our understanding of deep-sea ecology as there are only a handful of deep-sea fishes that are known to produce sounds, although many possess sound production organs.

The role of these sounds in sablefish ecology or as components of the deep-sea soundscape is currently poorly known. Knowledge gaps include: the sound production mechanism, the function of the “rasps”, whether sablefish can hear them, and how the sounds contribute to the natural soundscape. We are beginning studies to address these questions. First, to better understand how the sounds contribute to the natural soundscape we are searching for evidence of sablefish sounds in the wild in video and acoustic recordings made at the Ocean Networks Canada (ONC) observatory in Barkley Canyon located at a depth of 639 m. Specifically, a subset of underwater videos collected between November 2010 and July 2011 are being inspected for the presence of sablefish and behaviours that could be linked to sound production and compared to acoustic recordings made at the same time. In addition, a neural network detector and classifier will be trained to look for “rasps” and run through the complete Barkley Canyon acoustic dataset. The positive identification of sablefish sounds in these recordings, and an accurate auto-detector and classifier would constitute a powerful tool for passive acoustic monitoring of sablefish throughout their range.

UNDERWATER NOISE CHARACTERISATION OF A TIDAL STREAM TURBINE

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Due to increasing need and societal demand for clean energy, the marine renewable energy (MRE) sector has grown rapidly in recent years. This development has also raised questions about the potential impacts of this new industry on marine species. Environmental concerns have primarily focused on risk of physical injury to animals as a result of collision with moving subsurface devices, and auditory injury due to underwater noise during construction and operation of devices. Potential impacts might also include habitat exclusion due to physical or acoustic barrier effects. Impact assessments require accurate data on underwater noise levels produced during different phases of a project's lifetime. However, information on underwater noise emitted from newer MRE technologies, such as tidal stream turbines, has so far been lacking since only a few operational turbines have been deployed worldwide (Lossent et al., 2018).

Here we characterise the underwater noise signature and noise levels emitted during the operation of the Atlantis AR1500, a 1.5 MW horizontal axis tidal stream turbine, currently deployed as part of the MeyGen Phase 1A project in the Inner Sound of the Pentland Firth, Scotland. Underwater noise measurements in high flow environments are challenging and any measurements of device noise must take fluctuations in varying natural ambient noise into account. We used drifting hydrophones for data collection to reduce flow noise and other artificial signals such as cable strum (Wilson et al., 2014). We collected pre-installation ambient noise data during a total of 30 drifts, covering flood and ebb tides during similar tidal cycle phases and weather conditions. Operational turbine noise data were collected during 15 drifts covering both flood and ebb tides.

Results showed most turbine noise to be concentrated below 1 kHz, with peak frequencies in the range of 100-250 Hz. A secondary signal component was observed at about 20 kHz. During turbine operation, median received sound pressure levels measured within 30-50 m from the turbine in third-octave bands (125-250 Hz) were 117-120 dB re 1 μ Pa (flood, neap tide: median flow speeds = 1.7 m/s).

We will discuss comparisons between ambient noise with operational turbine noise data in the context of collision risk and potential noise impacts, and further characterise turbine noise at different tidal phases, flow speeds and dependent on distance and turbine rotational speeds. Further, we will attempt to determine the sources of recorded noise signatures, which might also prove helpful in monitoring turbine operation and condition.

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NOISE ALTERS CHEMICAL SEARCH BEHAVIOUR: STUDYING CROSS-MODAL EFFECTS ON BEHAVIOUR

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The sensing of chemical information allows aquatic animals to interpret their surroundings over long distances. If the use and processing of chemosensory information is disrupted, the ability to find key resources such as food or shelter may be impaired. Anthropogenic activities directly contacting the seabed, such as pile-driving, drilling and dredging produce sediment vibrations (Roberts and Elliott, 2017) which have the potential to disrupt the use of not only the vibrational modality but also other modalities such as chemical. Here, in subtidal field conditions, we exposed free-ranging hermit crabs (*Pagurus acadianus*) to an impulsive noise source directly contacting the substrate. We attracted crabs to the area using a specific chemical cue (Valdes and Laidre, 2018), indicative of the availability of a gastropod shell, i.e. a new home. Numbers of crabs arriving at the bait were monitored in noise versus control conditions. We found that significantly fewer crabs were attracted to the chemical cue during noise compared to the control. Furthermore, measurements of shell inadequacy indicated that compared to control crabs, crabs attracted during noise conditions had significantly poorer shells consistent with a higher motivation to find a new home. The results indicate that noise affected a hard-wired shell searching behaviour, most likely by acting as a deterrent or a distractor. While the impacts of anthropogenic sound and associated seabed vibration are poorly studied, these results suggest that noise can alter search behaviour even across modalities.

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ACOUSTIC ECOLOGY OF THE HUMPBACK WHALE IN BRAZIL: WHERE ANTHROPOGENIC SOUNDS OVERLAP COMPLEX WHALE SONGS?

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Marine soundscapes today are being dominated by increased anthropogenic sounds in a global scale (Halpern et al., 2008), and it is suggested that this may influence important aspects of animal ecology such as searching for prey or finding a mate. Cetaceans are ecologically important for marine habitats as natural regulators in their web-chains and the impact on them may result in a major ecological concern (Tyack, 2008). This work attempts to describe and analyze the occurrence of anthropogenic noise along the coast in Bahia State, Brazil, core area for the humpback whale (*Megaptera novaeangliae*) from the known Breeding Stock A.

Two sailing boat expeditions departing from Salvador to the Abrolhos Archipelago, 350 nm apart, were performed in 2016 and 2018, during whales high season, for sound monitoring through recording points at every 3hs intervals, 24hs no interrupted. Utilizing the recording system for humpback song studies (HTI 96min hydrophone connected to a Tascam DR40, frequency response up to 48kHz), it was possible to record anthropogenic sound sources, from artisanal fishing and whale-watching boats to industrial shipping, describing soundscape parameters from spectrograms and spatially locating them along the Bahian coast.

Data gathered during 31 cruising days, covering a spatial extension of 1400 nm, resulted in 88 recording points, being two samples of 42 and 46 (2016, 2018). During diurnal sampling, 59 humpback whale groups were sighted with 134 individuals. Humpback whale songs were recorded in all 88 points along the transects while anthropogenic noise, from artisanal fishing boats to large cargo ships, was registered in 13 points placed in different localities such as the Abrolhos Bank and near Salvador, where is one of the largest ports in Brazil. During all ship noise recordings in this urban area (n= 5), humpback songs could not be listened. A large whale-watching catamaran approached our boat during a singer male recording in the Abrolhos Archipelago area and it was possible to record both, with the boat overlapping the song, so characterizing potential masking in these places (Clark et al., 2009). These results may indicate pristine and disturbed areas inside the core distribution of humpbacks along the Brazilian coast, being important as a conservation policy (Erbe et al., 2014), claiming for a large spatial-temporal approach in the near future. This is the first research effort to cover a large transect line using a sailing boat in Brazilian waters, contributing to enhance quality and eco-efficiency for sound studies.

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Halpern, B.S., Walbridge, S., Selkoe, K.A., Kappel, C.V., Micheli, F., et al. (2008) "A Global Map of Human Impact on Marine Ecosystems". *Science* 319, 948–952.

Tyack, P.L. (2008). "Implications for marine mammals of large-scale changes in the marine acoustic environment". *J. Mammal.* 89 (3), 549–558.

PASSIVE ACOUSTIC MONITORING OF HADDOCK IN THE GULF OF MAINE

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We have conducted several studies of haddock sounds in the Gulf of Maine (GOM) with mixed results. An analysis of an archival recording from captive haddock brood stock made in 1975 found that the “spawning rumble” sound occurred variously at the end of short thump trains, in the middle of thump trains, or in isolation. Haddock were silent while spawning when we attempted to record sounds in the same facility in March 2000, suggesting that sound production may be negatively affected by chronic noise. Haddock sounds were absent in ROV and ship-tethered bottom instrument surveys in the summer and fall of 2001-2002. During 2006-2007, we deployed bottom mounted recorders while conducting long-line surveys of haddock spawning condition. Few haddock sounds were detected and there was no correlation with spawning activity despite recording in highly active spawning areas. Haddock sounds consisted of isolated knocks, which were difficult to distinguish from thumps of unknown origin.

However, haddock sounds were common in over 2000 h of recordings made on the fishing grounds from May – July 2003 (N = 31) and April – July 2004 (N =13). For each deployment, recordings were made continuously at 11 kHz for up to 55 h. Haddock occurred in 67% of the deployments. Evidence for potential masking of haddock sounds by distant seismic blasting was observed at two separate locations on 9 May 2003. Nearly continuous thump trains, including spawning rumbles, were observed in July suggesting a longer spawning period than previously thought. Haddock were by far the most frequently observed fish sounds, followed by an unknown fish sound and suspected cusk (*Brosme brosme*) sounds. Cod sounds were rare. An unidentified sound suspected to be a crustacean was frequently observed on some dates.

Passive acoustic monitoring appears to be a useful tool for locating spawning haddock in the GOM, however, we caution that other haddock-like sounds with similar waveforms were also observed. This required manual processing of the complete data sets. We are now in the process of comparing the results from automatic detection of haddock thumps based on their waveform in all our 2002-2007 data, with the manually processed data in order to develop a reliable autodetector for haddock and other species.

ANTHROPOGENIC NOISE DISRUPTS SEXUAL BEHAVIOR AND OXYGEN CONSUMPTION IN THE ROCK SHRIMP *Rynchocinetes typus* (H. MILNE EDWARDS, 1837)

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Anthropogenic-driven underwater noise have been recently identified as an important pollutant globally, yet, it has not been quantified in the Southeast Pacific coasts (Slabbekoorn et al., 2010; Wale et al., 2013), nor its effects evaluated on aquatic invertebrates, The rock shrimp *Rynchocinetes typus* is a decapod caridean crustacea, widely distributed along the Chilean coasts. This shrimp present three morphotypes of mature males: *typus*, *intermedius* and *robustus* (Correa et al, 2000).

Mature males and females rock shrimps were obtained from the central coast of Chile (Concepción), transfer to the laboratory and acclimated with only the noise of the aerator for 4 weeks. After acclimatization, shrimps were individually placed in a breathalyzer chamber Q-Box AQUA Aquatic Respirometry. Metabolic rate of *typus* and *robustus* males, and females was measured for one hour in the presence of motor noise (artisanal fishermen boat 50hp four strokes) and without background noise. Mating experiments were also performed under the same noise treatments (boat noise and in silence) to evaluate potential changes in sexual behavior.

Typus males decreases their oxygen consumption in the presence of motor noise compared with the silent treatment, a decrease less evident in *robustus* males. On the other hand, *typus* males had more interactions with the female under motor noise treatment than in the silent treatment. The *robustus* males, instead, become less “aggressive” and more quiescent under motor noise treatment.

These results suggest the sexual behavior is affected by motor noise (artisanal fishermen), as *robustus* males become “alert” rather than sexually actives. Otherwise, if sexual behavior is not successful, the birth rate in the shrimp populations will be affected. This will allow determining how anthropogenic noise impacts the biological adequacy of this species in its natural environment.

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Slabbekoorn, H., Bouton, N., van Opzeeland, I., Coers, A., ten Cate, C., & Popper, A. N. (2010). “A noisy spring: The impact of globally rising underwater sound levels on fish”. *Trends in Ecology and Evolution*, 25(7), 419–427. <https://doi.org/10.1016/j.tree.2010.04.005>

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SEAL SCARERS CAN IMPAIR HARBOUR PORPOISE HEARING

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Acoustic harassment devices (AHD) are regularly used to deter marine mammals. These devices are mandatory applied prior to pile-driving activities in German waters to deter harbour porpoises from the vicinity of the construction site. This official regulation has been determined, to deter harbour porpoises from areas, where single sound exposure levels contain sufficient energy to induce temporary hearing shifts (TTS). Hearing shifts are regarded as an injury and have to be prevented therefore. While AHD are applied to prevent a TTS from pile driving noise, these acoustic signals itself have the potential to induce a TTS. Seal scarer signals are in the range of best hearing of harbour porpoises and show high sound pressure levels up 189 dB re 1 μ Pa.

This study investigated the potential of artificial seal scarer signals to induce a TTS in harbour porpoises, by experiments with an animal in human care, funded by the Federal Agency for Nature Conservation (BfN). Baseline hearing thresholds were determined at 20 and 28 kHz, by measuring auditory brainstem responses. The animal was exposed to an artificial seal scarer signal, consisting of a 0.5 s sine tone at 14 kHz and four overtones with decreasing amplitudes at 28, 42, 56 and 70 kHz. Hearing thresholds were determined prior and post exposure to evaluate effects of exposure on hearing. One sound exposure was conducted per day, starting at a low sound energy level which was gradually increased day by day. We found a significant temporary hearing shifts a both tested frequencies. The TTS onset, defined as a hearing shift significant from baseline hearing, was determined at 142 dB re 1 μ Pa²s at 20 kHz and at 137 dB at 28 kHz. We provide evidence, that single pulses of seal scarers, which are currently applied, have the potential to induce a TTS. Potential hazard zones, where a TTS can be induced from a single exposure, depend on sound propagation and can be limited to 50 m (spherical spreading) but are also likely to occur at 1000 m (cylindrical spreading). Effects of multiple exposures are difficult to predict, due to the randomized intervals between signals between 0.6 and 90 s. In order to prevent TTS by seal scarers, we suggest slowly increasing source levels, allowing the harbour porpoise to flee.

MODELLED ONTOGENETIC CHANGE IN ACOUSTIC PRESSURE SENSITIVITY IN LARVAL RED DRUM (*Sciaenops ocellatus*)

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Detection of acoustic pressure in addition to particle motion can improve a fish's survival and fitness through increased sensitivity to environmental sounds. Pressure detection results from interactions between the swim bladder and otoliths, and characteristics of these structures and the distances between them will influence the degree of sensitivity to pressure. In larval fishes, rapid growth and development alter bladder dimensions and otolith-bladder distances, suggesting an ontogenetic change in a larva's ability to detect pressure. This is significant in light of the prediction that some larvae use acoustic cues during the settlement process.

We used computed tomography imagery of lab-reared larval red drum (*Sciaenops ocellatus*) in a finite-element model to assess ontogenetic change in sensitivity to acoustic pressure in response to a plane wave at frequencies within the typical frequency range of hearing by fishes. We compared the acceleration at points on the sagitta, asteriscus, and lapillus when the bladder was air-filled to results from models using a water-filled bladder. For larvae of 8.5 to 18 mm in standard length, the air-filled bladder amplified otolith motion by a factor of 54 to 3485 times that of a water-filled bladder at 100 Hz. There was a relatively flat frequency dependence of these effects in the audible frequency range, but we found a small increase in amplification with increasing excitation frequency. Otolith-bladder distances increased with standard length, which decreased amplification. The concomitant rapid increase in bladder volume partially compensated for the effect of increasing otolith-bladder distances. Resonance frequencies of the bladders were between 8750 Hz and 4250 Hz, and resonance frequency decreased with increasing bladder volume. Using idealized geometry, we found that the vertebrae and ribs have a negligible influence on bladder motion despite pressing into the bladder wall.

Our results help clarify the auditory consequences of ontogenetic changes in swim bladder morphology and otolith-bladder relationships during larval stages. Otolith-bladder distances across the study larvae were similar to distances achieved by morphological adaptations that enable pressure sensitivity in adult fishes. The simulation results support the hypothesis that these distances allow the transmission of bladder-generated particle motion to the otoliths, suggesting that the size of larval fishes alone may enable some degree of pressure sensitivity. This ability to detect the pressure component of sound would significantly enhance the detection distance of acoustic cues and signals. How this sensitivity changes through ontogeny has implications for settlement success and survival.

THE EFFECTS OF INCREASED LONG-TERM NOISE AS A STRESS FACTOR FOR WHITEFISH AQUACULTURE

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The study of effects of long-term noise-exposure on fishes is very important due to the recently increasing levels of noise pollution in their natural habitat, and in closed aquaculture tanks (Popper and Hawkins, 2019). Possible consequences include not only impairment of hearing sensitivity in some species but also the increased stress. Stress causes changes in size, shape and structure of the red blood cells (Buscaino et al., 2010). Moreover, adaptation to stress affects telomere biology. The telomere length (TL) determines proliferative potential of cells and serves as a marker of organism physiological state. Unfortunately, such studies have not been conducted yet in fishes. However, TL of some birds is known to decrease under the anthropogenic noise impacts (Meillere et al., 2015). We have carried out a complex comparative analysis of the morphological characteristics of auditory epithelium and otoliths, as well as of primary behavioral and hematological, and secondary telomere stress response in control and sound-exposed groups of different whitefish species, which are the most commonly used in Russia for artificial cultivation. Acoustic impact of tones with a different frequency (up to 500 Hz) at different sound pressure levels of 126-210 dB re 1 μ Pa exposed for 1-18 days included insignificant mechanical damage of the sensory epithelia in its different parts, with full recovery in 37 days, the changes in normal fish behavior and in the structural surface of all types of the otoliths. The formation of otocionial masses, which composed the otolith growth layer, stopped during sound exposure. There were also some stress indicators, such as changes in cytometric parameters of the red blood cells, and some tendencies to changes in relative TL in different tissues (white muscles, medulla oblongata and gonads) during noise exposure and after the recovery for 37 days, but without valid differences between control and experimental groups (Mann-Whitney U Test, $p > 0.05$). In the near future, we plan to investigate acoustic stress response at other levels, including biochemical, microbiological, and molecular ones. We assume that using comprehensive screening of different systems in the artificial rearing of fish under the conditions of intense noise could contribute to indicating the most stress-resistant forms, which are promising for high-tech industrial aquaculture, and developing more gentle approaches to its creation. The work was performed at the Facilities for Ultramicroanalysis, and Freshwater Aquarium (LIN SB RAS) under the support of RFBR, Nos. 17-44-388081 r_a, 17-44-388106 r_a, and the State task No. 0345-2019-0002.

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AN ACOUSTIC TRACKING SYSTEM TO ASSESS POTENTIAL MASKING EFFECT BY SHIP NOISE ON SPERM WHALE ACOUSTIC ACTIVITY IN THE IONIAN SEA

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The Mediterranean sperm whale is listed as Endangered by the IUCN (<2.500 matures). Several factors influenced the high mortality of this population and noise is widely recognized as a significant disturbing factor. Masking effects associated with the increase in ship noise are known to be particularly relevant to baleen whales that use low-frequency sounds (10–200 Hz) to communicate over long distances (Clark et al., 2009). However, the high frequency components (HF) of ship noise typically increase with vessel speed, due to the increase in broadband cavitation noise. HF may also mask the echolocation clicks of odontocetes used for orientation and acoustic communication (Aguilar Soto et al., 2006; Veirs et al., 2016). Yet, the effects of impulsive and diffuse noise generated by ship traffic on the biosonar activity and communication of the sperm whale are still largely unknown (Notarbartolo di Sciara, 2014). Underwater acoustic antennas such as SMO-OnDE, operating since February 2017 in the Gulf of Catania (Ionian Sea) at a depth of 2100, offer a unique opportunity to study whales' movements and behaviour in relation to noise. SMO-OnDE consists of four hydrophones displaced in a tetrahedral configuration. Acoustic signals are continuously digitized in situ at a sampling f of 192 kHz and transmitted to shore through a 28 km long electro-optical cable. All acquisition channels are synchronized and the data stream is labelled offshore with absolute GPS time with a resolution of 25 ns. Custom MATLAB algorithms allow the on-line search and analysis of sperm whales clicks. Triggered signals are recorded together with information on pressure density function of the acoustic noise every 5 min. In this work, we describe the first results on sperm whale acoustic presence in about one year of continuous monitoring. Particularly, an acoustic tracking system was developed to study sperm whale positions and movements in a radio of about 20 km around the observatory. Knowing the approximate position of the animals, the diving profile of recorded sperm whales was studied. Noise produced by close vessels in the monitoring area was studied by modelling sound propagation at different depths and vessel source position was reconstructed by using an AIS antenna. The available deep-sea acoustic recording system together with developed detection and tracking methodologies represent powerful tools to understand the extent of noise effects on sperm whales in the Mediterranean Sea.

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EFFECTS OF MULTIPLE EXPOSURE TO PILE DRIVING NOISE ON HARBOUR PORPOISE HEARING DURING SIMULATED FLIGHTS – A RISK EVALUATION TOOL

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The exploitation of renewable energy from offshore windfarms is substantially increasing in Europa as a promising alternative to fossil fuels and nuclear power. In total, 92 offshore windfarms have been constructed to date in 11 European countries including sites with partial grid connection, accounting for 4,149 connected wind turbines. Although this development represents an important component towards a more environmentally friendly power production, impacts on marine fauna, caused by anthropogenic noise during the construction have to be considered. The majority of wind turbines are bottom mounted, causing high levels of impulsive noise, when piles are driven into the seabed. To prevent temporary threshold shifts (TTS) in harbour porpoise hearing, the single strike sound exposure level (SEL_{SS}) of pile driving strikes, has been limited in Germany by law to a maximum of 160 dB re 1 μ Pa²s at a distance of 750 m. Nevertheless, the reception of multiple pile driving events with single SEL_{SS} below this threshold can still evoke a TTS. Using a simulation approach, we evaluated the potential of multiple pile driving strikes to induce a temporary hearing shift in harbour porpoises either staying at its location or fleeing. We analysed underwater recordings of pile driving strikes, which have been recorded during the construction of the Offshore-Windfarm “Amrumbank West” in the German North Sea. Data was recorded within a project funded by the Federal Agency for Nature Conservation (BfN). We simulated harbour porpoises fleeing from a pile driving site, using literature based swim speeds, a TTS onset and accumulated the received sound exposure levels (SEL_{cum}) for the complete flight track. The here presented analysis tool can be easily adjusted for different sound propagation, acoustic signals or species. Based on our simulation approach only the combination of SEL_{SS} regulation, prior deterrence and soft start allow harbour porpoises to avoid a TTS from multiple exposures. However, deterrence efficiency has to be monitored.

ACCOUNTING FOR POSITIONAL UNCERTAINTY WHEN MODELING RECEIVED LEVELS FOR TAGGED CETACEANS EXPOSED TO SONAR

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Exposure to anthropogenic sound can have various negative behavioral and physical effects on marine species and is of increasing ecological and regulatory concern. In particular, the response of marine mammals, including pilot whales and the Ziphiidae, a family of cryptic deep-diving beaked whales, to military sonar is a pressing and complex issue. To make inference on the response of individual whales to noise, it is critical to know what received levels (RLs) the animal actually experienced.

There exist a variety of tools and techniques to either directly measure or to estimate RLs and associated response(s), each of which has advantages and disadvantages. Most behavioral response studies to date have used relatively short-term, high-resolution acoustic tags that provide direct RL measurements. Because of their short duration these tags do not allow for assessments of longer duration baseline behavior before and following a disturbance that may tell us more about the nature of response. In contrast, most longer-duration tags lack high-resolution kinematic data and the ability to directly measure RL. Here we address these issues and efforts to derive robust statistical characterizations of RLs using animal movement and sound propagation modeling for longer-duration tags in the context of a behavioral response study off Cape Hatteras, NC, USA.

In the autumn of 2017, we tagged 3 short-finned pilot whales and 9 Cuvier's beaked whales and conducted controlled exposure experiments using simulated and operational military mid-frequency active sonar. We used sound propagation modeling methods, modeled positions of individual animals, and available information on diving depths to estimate three-dimensional RLs and statistically describe uncertainty. When properly accounting for positional error, single median RL estimates drastically underestimate the full range of plausible values, with ranges in estimated RL for beaked whales often exceeding 40 dB. Additionally, ancillary data from focal follows can significantly narrow estimated RL ranges. Results suggest that because of the unique deep-diving behavior of beaked whales, fewer positional data points are recorded and estimates of received level can vary broadly. Accounting for this uncertainty using robust statistical modeling is critical when assessing exposure-response relationships.

USING BEHAVIORAL AND AUDITORY BRAINSTEM RESPONSE METHODS TO TEST FREQUENCY-DEPENDENT GROWTH AND RECOVERY OF TTS IN BOTTLENOSE DOLPHINS

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Auditory weighting functions have been used to predict temporary threshold shift (TTS) and permanent threshold shift (PTS) in marine mammals. However, their use for estimating frequency-dependent effects of noise has limitations due to the limited underlying data and questions regarding the applicability of auditory sensitivity to represent weighting function shape. Additionally, methods of estimating noise exposure that do not account for auditory recovery may not be fully appropriate, particularly when exposure intervals are intermittent and some recovery may occur between exposures. The use of electrophysiological [i.e., auditory brainstem response (ABR)] methods in marine mammal auditory research has increased sample size and species representation, but this has not been the case in TTS studies where the relationship between behavioral and electrophysiological methods is still unclear. Direct measurements of TTS across the full range of hearing sensitivity in representative marine mammal species are necessary to better support TTS/PTS thresholds, weighting function derivations, and methodological differences.

The current study examined TTS growth and recovery as a function of exposure frequency in bottlenose dolphins (*Tursiops truncatus*), using both behavioral and ABR methods. Noise exposures consisted of 1/6-octave noise with a duration of 1 h. To assess any changes in hearing following the noise exposure, behavioral hearing tests and ABR measurements were made at the exposure frequency and 1/2-octave above the exposure frequency, before and after each exposure. Data comprised behavioral auditory thresholds based on a staircase procedure, and ABR peak amplitudes and latencies for potentials from the auditory nerve (P1) and midbrain (P4 and N5). Dolphins made alternating dives to an underwater listening station for behavioral and ABR measurements before and after the same exposure. Additionally, control sessions (no exposure) were conducted to define variability in threshold measurements in ambient noise and to maintain subject motivation and cooperation. Preliminary results showed no significant behavioral threshold shifts and no obvious changes observed in ABR peak amplitudes or latencies after 40- and 80-kHz exposures with source levels up to 170–175 dB re 1 μ Pa at 1 m.

WHERE MOTHER-CALF PAIRS GO: RELATIVE DISTRIBUTION OF SOUTHERN RIGHT AND HUMPBACK WHALE MOTHER-CALF PAIRS IN RELATION TO THE SOUNDSCAPE IN ALGOA BAY, EASTERN CAPE, SOUTH AFRICA

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Current studies on marine animal distribution assess the effect of environmental parameters, such as bottom depth, bottom substrate, and sea surface temperature. However, under increasing levels of ambient noise from anthropogenic activities and consequent negative effects on the behaviour of marine species, it is important to include soundscape measurements into the assessment of animal distribution patterns. This is specifically essential for mother-calf pairs of migrating species that are sensitive to disturbance and rely on limited energy reserves for survival (Braithwaite et al., 2015; Villegas-Amtmann et al., 2015).

We deployed two autonomous acoustic recorders (AB1 and AB2) to study the soundscape of Algoa Bay along the Eastern Cape coast, South Africa; a bay that is characterised by two commercial ports. Broadband daily median Sound Pressure Levels (SPLs) ranged from 96 to 120 dB re 1 μ Pa and differed significantly between sites (t-test, $p < 0.001$). Sound levels were highest at AB2 across all full Octave Band Levels (OBLs). Manual inspection of sound files identified a higher frequency of occurrence of large vessels at AB2 as the most prominent difference between sites. A RAM parabolic equation model verified that differences in low-frequency sound were attributable to differences in received ship noise levels. Relative distribution data from boat-based surveys indicates that southern right and humpback whale mother-calf pairs prefer waters of different depths, but that Sightings Per Unit Effort (SPUE) for both species were highest within the area with lowest received ship noise levels.

Our results suggest that both southern right and humpback whale mother-calf pairs prefer areas with lower sound levels. Hence, an increase in sound levels in Algoa Bay could have a negative effect on the presence of both species. Long-term development plans anticipate port expansion plans with a 6-fold increase in the number of berths. These development plans will result in increased shipping activities within the bay and a consequent modelled increase in noise exposure by 8 dB. Minimising effects of port development plans on the presence of southern right and humpback whale mother-calf pairs in Algoa Bay therefore necessitates the use of soundscape analyses as a tool to inform marine spatial planning.

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MAINTAINING MARINE RESOURCES IN A COUNTRY SET TO UNLOCK ITS OCEAN ECONOMY

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In 2014, the South African government launched “Operation Phakisa” as a delivery program to fast-track the implementation of solutions on critical development issues (Zuma, 2014). One aim of Operation Phakisa is to unlock the ocean economy for accelerated alleviation of poverty. This development will likely result in an increased number of large vessels along the South African coast, raising concerns about increased noise levels in the ocean and associated impacts on marine life, such as the southern right and humpback whales that are annually seen in South African coastal waters. Whilst the protection of marine resources and sustainability seems an integral part of Operation Phakisa (Findlay, 2018), the promotion of rapid economic development could distract from the need to maintain ecological ocean integrity; especially when the ecological and socioeconomic roles of marine resources are unknown.

Whales have only recently been recognized to help buffer marine ecosystems from destabilising stresses and to carry ecological value by providing nutrition, assisting in nutrient cycling, and playing a role as sentinel species (Roman et al., 2014). South African waters do not pose an exception in this regard. Hence, the presence of whales contributes to overall ecosystem health, which is essential to support South Africa’s subsistence fisheries, commercial fisheries, and tourism industry. The latter two combined support over 10% of the employment market via direct and indirect jobs, highlighting socioeconomic benefits.

Algoa Bay on the Eastern Cape coast is a location where conflicts between maritime development and marine conservation may arise. As one of the poorest provinces in South Africa, the pressure for socio-economic development in the Eastern Cape is high. In 2009, the commercial Port of Ngqura and associated Industrial Development Zone became operational on the north-western shore within the Nelson Mandela Bay Municipality. This development was considered to host multiple opportunities to enhance the local economy. However, recent soundscape monitoring identified ship noise in important breeding and transit areas for southern right and humpback whale mother-calf pairs. Long-term port development plans anticipate an expansion of berths by a factor of 6, resulting in a 6-fold increase in the risk of ship strike and a modelled increase in noise exposure by 8 dB. This increase in noise could have a negative effect on the occurrence of both species with knock-on effects on ecosystem health and functioning resulting in decreased local socioeconomic benefits from fisheries and tourism.

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SOUTHERN RIGHT WHALE MOTHER-CALF PAIR BEHAVIOUR IN RELATION TO THE LOCAL SOUNDSCAPE IN THE EASTERN CAPE, SOUTH AFRICA

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The population of southern right whales that annually migrate to South African waters is increasing at an average rate of 6.8% per annum (Best, 1990). Maintaining this growth rates to ensure population recovery to pre-whaling limits necessitates the protection of mother-calf pairs to increase reproductive success. However, at present we know little about mother-calf pair behaviour, prohibiting the assessment of potential negative effects related to environmental change, such as increased noise levels.

To study the soundscape of two bays with different levels of anthropophony, we deployed one autonomous acoustic recorder in St. Francis Bay (SF) and two recorders in Algoa Bay (AB1 and AB2), South Africa. Simultaneous boat-based surveys gathered data on southern right whale mother-calf pair behaviour. Broadband daily median Sound Pressure Levels (SPLs) ranged from 91 to 120 dB re 1 μ Pa and differed significantly between sites (Kruskall-Wallis, $\chi^2 = 600$, $p < 0.001$). Overall, sound levels were highest at AB2 and lowest at AB1 (Dunn's test, $p < 0.001$). Inter-site comparisons of daily median Octave Band Levels (OBLs) revealed similar patterns at low frequencies. However, in the 320 and 640 Hz bands, sound levels at AB1 exceeded those at SF (Dunn's test, $p < 0.001$), whereas sound levels at SF exceeded those at both AB1 and AB2 in the 5.12 and 10.24 kHz bands (Dunn's test, $p < 0.001$). Manual inspection of sound files and Power Spectrum Density (PSD) percentile plots suggest that differences at mid and high frequencies are attributable to variations in biophony. The most prominent difference between soundscapes at lower frequencies was seen in the frequency of occurrence as well as type of anthropophony: small vessels dominated at SF and AB1, whereas large vessels dominated at AB2.

A multi-variate analysis of mother-calf pair behaviour showed that, regardless of differences in soundscape, mother-calf pair behaviour was similar across study areas and mostly differed with sea state, with more frequent resting ($\chi^2 = 10.74$, $P = 0.001$) and milling ($\chi^2 = 4.88$, $P = 0.027$) under calm and choppy conditions, respectively. In addition, a significant difference in resting ($\chi^2 = 11.11$, $P < 0.01$), nursing ($\chi^2 = 283$, $P < 0.001$), logging ($\chi^2 = 11.89$, $P < 0.01$), and rate of physical touches ($\chi^2 = 689$, $P < 0.001$) was seen for calves of different age classes, which was consistent across study areas and ambient noise levels.

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PROGRESS SINCE THE 2016 NATIONAL MARINE FISHERIES SERVICE'S MARINE MAMMAL TECHNICAL GUIDANCE

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In July 2016, the National Marine Fisheries Service (NMFS) published Technical Guidance updating acoustic thresholds for assessing the effects of underwater sound on marine mammal hearing (i.e., permanent and temporary threshold shifts) (NMFS, 2016). Additionally, NMFS released an optional User Spreadsheet tool to facilitate the implementation of the Technical Guidance's more complex acoustic thresholds. Since 2016, NMFS continues to work to refine this document, its underlying assumptions, and associated user tools.

On April 28, 2017, Presidential Executive Order (EO) 13795 was issued (The White House, 2017). Section 10 specifically called for the review of the Technical Guidance by the Secretary of Commerce to determine if it was appropriate to rescind or revise this document. To assist the Secretary of Commerce, in 2017, NMFS held a 45-day public comment period and an in-person meeting with Federal agencies to obtain feedback on the Technical Guidance. During the public comment period, NMFS received 62 comments from Federal agencies, oil /gas representatives, Members of Congress, subject matter experts, non-governmental organizations, and the public. Neither the public/stakeholders nor Federal agencies recommended the document be rescinded. Furthermore, 85% of public comments recommended no changes to the Technical Guidance. The remaining 15% of comments suggested additional scientific publications for consideration or provided input to improve implementation of the document.

The EO 13795 review process provided NMFS with the opportunity to acquire valuable feedback from the public/stakeholders and Federal agencies on the Technical Guidance since its finalization. Three key topics were raised: 1) the limited scientific data on mysticete hearing; 2) the appropriate accumulation period for assessing sound exposure on marine mammals; and 3) the need for improvements to the Technical Guidance's user tools. Based this input and per approval of the Secretary of Commerce, in June 2018, NMFS issued a Revised Technical Guidance (NMFS, 2018) and an updated optional User Spreadsheet tool that included a new instruction manual. The Revised Technical Guidance also summarized and evaluated relevant scientific literature published since the 2016 Technical Guidance's finalization. Furthermore, NMFS committed to convening two working groups to address outstanding technical and implementation issues raised: 1) mysticete hearing and 2) the default maximum 24-hour accumulation period. Finally, in late 2018, NMFS conducted an additional 45-day public comment period on the optional User Spreadsheet tool, which resulted in further refinements based on feedback from stakeholders, including the development of a more user-friendly web-based calculator tool.

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NMFS. (2018). "2018 Revision to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0), NOAA Technical Memorandum NMFS-OPR-59," Office of Protected Resources, National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

The White House. (2017). "Implementing an America-First Offshore Energy Strategy," Fed. Reg. 82, 20815-20818.

NOISE VERSUS SPACE-USE CONFLICTS: COMPARING THE RELATIVE IMPACTS OF MARINE SEISMIC SURVEYS TO COMMERCIAL FISHING ACTIVITIES

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Commercial fishing stakeholders frequently oppose marine seismic surveys for a variety of reasons. Marine survey vessels compete with fishing vessels and fishing gear for space, and the noise generated from airguns may negatively affect targeted marine species or the trophic base that supports these species. What is the relative impact from each of these factors in affecting the viability of a local commercial fishing industry? Using the West Coast of the USA as a case study, a review of past research and space-use outcomes suggests that noise from seismic survey operations minimally increased, if at all, direct mortality to harvested species, and that the financial consequences from this factor to the fishing industry was also likely minimal. Any increase in mortality from anthropogenic noise appeared to be swamped by the variability in mortality rates generated by fishing activities or natural causes, (e.g. interannual patterns in large-scale oceanographic conditions). In contrast, space-use conflicts between the two industries frequently occurred and included (1) preclusion from fishing grounds, (2) lost or damaged gear, and (3) competition for port infrastructure. Financial consequences from these types of conflicts could cause considerable impacts to the local fishing industry if not properly managed. Fortunately, after an initial phase of considerable disagreement, a number of mitigation measures were proven to be effective; these included (1) establishing a liaison officer to facilitate communication between industries, (2) designating marine vessel corridors across nearshore fishing grounds, (3) creating a compensation fund for lost or damaged gear, (4) producing a training video for oil industry employees that demonstrated at-sea techniques to reduce or minimize space-use conflicts, and (5) constructing pier facilities solely for oil industry use. One key lesson learned was that the liaison officer played a critical role in soliciting input from commercial fishers to help design a research agenda aimed at understanding potential noise impacts to marine life. Although the research program did not eliminate all the uncertainties and concerns regarding impacts to harvested species, it did shift fishing stakeholder attention and effort towards resolving other conflicts not related to environmental issues.

THE CONCEPT OF SOUNDSCAPE FROM THE HUMAN AND TERRESTRIAL PERSPECTIVE

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Soundscape is a construct of human perception that must be understood as a relationship between human beings, acoustic environments, and society. Soundscape is defined as the “acoustic environment as perceived or experienced and/or understood by people, in context” (ISO 12913-1:2014). Soundscape study calls for a holistic approach; as an increasingly global concept, it proves fruitful to integrate insights from knowledge or values produced by every culture. As a mode of inquiry, Soundscape is directly linked to many disciplines that consider perception, such as acoustics, architecture, ecology, design, human geography, medicine, noise control engineering, social sciences, and even computer simulation and artificial intelligence.

According to the Soundscape concept, the meaning of sound, the composition of diverse sound sources, the listener's attitude, and the listener's expectations towards the acoustic environment are all equally important. The experiences of individuals within the acoustic environment are significant in defining a comprehensive understanding of different perceptions and assessments. Moreover, lifestyle and socio-cultural background both provide important contributions in one's assessment of any acoustic environment. Every situation is different, and the contribution of sound sources will vary (Kang, Schulte-Fortkamp, 2016). Therefore, when considering the built environment and modeling or analyzing dependencies within soundscapes, it may be useful to go beyond sound sources by considering other sensory systems, visual aesthetics, geography, and social, psychological and cultural aspects. Soundscape research represents a timely paradigm shift by considering environmental sounds as a 'resource' rather than a 'waste'; it is more powerful than the classic level-based assessment approach, which is suitable for addressing only major issues such as sleep and hearing protection. Soundscape research proves even more essential when society moves to address higher needs: respect for others, creativity, and spontaneity.

Indeed, Soundscape focuses more on local individual concerns and contexts, giving critical voice to the noise sensitive and other vulnerable groups, but also factoring in cultural aspects and the beauty of natural soundscapes (Lercher et al., 2016). When it comes to noise management and urban planning, Soundscape research has the potential to promote healthy urban environments by integrating diverse fields of knowledge while sharing and incorporating the significant experience of all concerned parties.

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COMBINING MONITORING AND MODELLING FOR POPULATION MANAGEMENT: THE WESTERN GRAY WHALE

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Many studies have shown that marine mammals respond behaviorally to single anthropogenic disturbance events. In addition, exposure to multiple disturbances that cause seemingly minor behavioral changes could lead to reduced reproduction and lower survival of individuals. If enough individuals are affected, population growth declines. Development of methods and models to quantify the links between disturbance and population growth help answer questions about the impacts of cumulative disturbance, which are largely unknown and of great concern.

In particular, changes in foraging behavior directly affect energy input, and individuals may not be able to compensate for lost energy intake, especially if foraging is limited in space or time. State dependent behavioral and life history theory, as implemented by Stochastic Dynamic Programming (SDP) has emerged as a method to model behavioral decisions of animals within a dynamic and disturbed environment. SDP models are an effective way to characterize the end points of natural selection (lifetime reproductive success), linking environment, physiology, and metrics of fitness. The models allow for evolutionarily appropriate behavioral compensation when foraging is reduced and have been effectively used to partially implement the Population Consequences of Disturbance framework for several marine mammal species. However, SDP models require data on bioenergetics, spatial and temporal prey availability, behavioral response to disturbance, and validating metrics.

The endangered western gray whale may be particularly sensitive to cumulative disturbances because their annual foraging period is limited to a few months. Furthermore, their small foraging grounds overlap with oil and gas exploration and production activities which have the potential to interrupt gray whale foraging. ExxonMobil implemented a monitoring program during their 2015 seismic survey activities off the coast of Sakhalin Island that, in addition to assessing impacts and effectiveness of mitigation measures, supported western gray whale SDP modeling efforts. Data collection included detailed nearshore benthic prey sampling during three periods, gray whale distribution and behavior data from 13 shore-based stations, nine photo-ID teams, and acoustic measurements. Along with an existing bioenergetics model, an SDP model for pregnant females was developed using 2015 prey availability and acoustic disturbance data. SDP model results include estimates of habitat use, nearshore and offshore movement, and reproduction, which we can validate with distribution data, photo-ID sighting data, and the number of identified calves the following year. Integration of monitoring programs with modeling efforts support real-world implementation of those models to ultimately aid in species and population management.

D-PORCCA, NEW DETECTOR/CLASSIFIER SYSTEM TO STUDY HARBOUR PORPOISES IN THE WILD

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Recent technological advances enables for continuous sound recordings at sampling rates sufficient for passive acoustic monitoring of odontocetes. The processing of these recordings provides insight into the behaviour of marine mammals and derive abundance estimates, and patterns of distribution and movement (Bittle and Duncan, 2013). As low power consumption of data loggers keep decreasing and memory capacity increases the post-processing of the data in terms of detection and classification becomes increasingly important.

The detection and classification process and performance depend on which device is used as well as background noise and received levels (i.e., signal to noise ratio). We present a novel detection classification system optimized for harbour porpoises. Porpoises produce only narrow-band high-frequency clicks with peak frequency at 130 kHz (Møhl and Andersen, 1973). Monitoring on low-density areas, such as the Baltic Proper (estimated population about 500 porpoises; SAMBAH, 2016) relies exclusively on detecting those clicks. The algorithm specifically focuses on achieving low false positive rates while maintaining a high hit rate and reasonable processing time for long term monitoring data.

The D-PorCCA (Detection and harbour Porpoise Click Classifier Application) was tested using playbacks of synthetic clicks recorded with SoundTraps (Ocean Instruments, NZ) to calculate effective detection ranges. Effective detection ranges depend critically on limitations of the detection-classification-tool. Based on those results, a direct comparison to the C-POD (Chelonia, UK) was performed. Based on randomizing real porpoise click trains recorded in captivity, we will test how different noise levels affect D-PorCCA performance, to provide for controlled estimates of detection thresholds.

Bittle, M. and Duncan, A. (2013). A review of current marine mammal detection and classification algorithms for use in automated passive acoustic monitoring. In *Proceedings of Acoustics 2013*. 17-20 November 2013, Victor Harbor, Australia

Møhl B. and Andersen, S. (1973) Echolocation: high-frequency component in the click of the harbour porpoise (*Phocoena phocoena* L.). *J Acoust Soc Am* 54:1368–1379

SAMBAH (2016) “*Final Report. Covering the project activities from 01/01/2010 to 30/09/2015*”. Static Acoustic Monitoring of the Baltic Sea Harbour Porpoise.

THE CONTRIBUTION OF SHIPPING NOISE TO THE UNDERWATER SOUNDSCAPE: PAST, PRESENT AND FUTURE

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Understanding the individual contribution of different sound sources to the underwater soundscape helps to assess potential effects of underwater noise on marine life. Source specific sound mapping with mathematical methods provides a detailed answer to which sounds are present where, when and how strong. We present sound maps for several sources (ships, seismic airguns, underwater explosives and wind) in the Dutch North Sea, including their spatial, temporal and spectral distributions (Sertlek et al., 2019). In order to compare sources of such disparate nature, we introduce the concept of total sound energy in a specified volume, and averaged over a specified period of time. We choose a long averaging time (two years) to ensure that all sources are present a sufficiently large number of times for the average to be statistically meaningful and to facilitate meaningful comparison between the contributions from each type of source. We find that anthropogenic sources contribute approximately hundred times more sound energy to the sound energy budget in the Dutch North Sea than wind. Of the sources considered, shipping makes the largest contribution to the energy budget (~1800 J), followed by seismic surveys (~300 J), explosions (~20 J) and wind (~20 J) in the frequency band between 100 Hz and 100 kHz. We calculated the acoustic energy of shipping per year to visualize past growth in sound levels due to increases in shipping since the 1940s, and future growth until the 2030s. Our results show that the shipping noise in the Dutch North Sea increased considerably between 1965 and 2000. This increase became steeper after 2000, and an increase of more than 15% for the total acoustic energy contribution from shipping is expected for future years. We also provide examples of how sound maps for shipping can be weighted with auditory frequency functions for marine mammals, to be used alongside seasonal distribution maps, to provide input for marine spatial planners when allocating shipping lanes, considering speed limits, or planning the size of marine protected areas. Similar analyses for a variety of applications are possible for other sound sources and for other species.

Sertlek H.Ö., Slabbekoorn H., ten Cate C., Ainslie M.A., (2019), "Source specific sound mapping: Spatial, temporal and spectral distribution of sound in the Dutch North Sea", *Environmental Pollution*, 247, 1143-1157

THE EFFECTS OF SOUND AND LIGHT ON ZEBRAFISH AND WATER FLEA BEHAVIOUR

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Industrial and recreational activities have increased anthropogenic noise levels in aquatic habitats. Shipping activities, pile driving, seismic surveys, pumping systems, all produce sounds with different temporal patterns and can have detrimental effects on vertebrates and invertebrates. Moreover, light conditions have also changed in aquatic habitats, along the shore line, but also at construction and exploitation platforms and vessels. There are studies that show anthropogenic noise affects animals in different life stages and different contexts. However, there is still a lack of empirical data showing how human-modified conditions in multiple modalities, such as sound and light, affect fish behaviour in captivity or natural habitats.

We study how variation in sound and light levels affect zebrafish and water flea swimming behaviour. We have shown that experimental sound exposure with variable temporal patterns can alter swimming behaviour and detrimentally affect foraging performance. Experimental sound exposure affected zebrafish swimming behaviour and foraging performance, but we found no effects on water flea swimming behaviour. It has also been shown that light condition, independent of sound conditions, can change zebrafish swimming behaviour and spatial preference behaviour in a dual tank set up (Shafiei Sabet et al., 2016).

In a follow-up study, we investigated again whether light conditions may cause changes in water flea swimming behaviour, in terms of swimming speed and depth, and number of swimming jerks, all potentially influencing zebrafish foraging performance. We are using the same temporal exposure patterns in aquaria with the same dimensions as we used before. Our results show that water fleas changed their spatial swimming patterns in response to light, but not to sound. Our experiment reveals the potential for studying fundamental aspects of environmental impact through multiple modalities on fish behaviour, including predator-prey interactions.

Shafiei Sabet, S., Van Dooren, D., and Slabbekoorn, H. (2016). "Son et lumi??re: Sound and light effects on spatial distribution and swimming behavior in captive zebrafish," *Environ. Pollut.*, 212, 480–488.
doi:10.1016/j.envpol.2016.02.046

EVIDENCE OF IMPACT OF ENGINE AND OPERATING WINDFARM NOISE ON THE SINGING EFFORT OF DOHLPINS

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At Eastern Taiwan Strait dolphins are vulnerable for exposure to sustained anthropogenic noise. However, our understanding of the impact of anthropogenic noise responses of these marine organisms are not clearly understood (Board and Council 2003) and there exist no efficient Acoustic Indices (AI) for the detection of their calling in natural habitat (Rice, Soldevilla et al. 2017). Here, in this study we have introduced an AI based on Complexity-Entropy (C-H) method (Rosso, Larrondo et al. 2007, Siddagangaiah 2018). We have shown that C-H index does not require any prior information of the dolphin calling pattern and it is robust to noise from the snapping shrimps occurring in the recordings. Thus, resulting in the probability of detection higher than 90%. Further, the study for the first time showed that the dolphins tend to cease the singing activity, when disrupted by the engine noise and the operation noise originating from the wind farm. This shows that their behavior associated with singing such as feeding, social cohesion and breeding might be affected when exposed to noise. The explored C-H method will enable us to have knowledge on dolphin's density, occurrence and abundance at the monitoring region. Finally, the evidence of behavioral impact caused by noise will facilitate in forming the management of conservation policies of the critically endangered Taiwanese humpbacked dolphin by the Taiwan government.

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Rice, A. N., Soldevilla, M. S., & Quinlan, J. A. (2017). Nocturnal patterns in fish chorusing off the coasts of Georgia and eastern Florida. *Bulletin of Marine Science*, 93(2), 455-474.

Rosso, O. A., Larrondo, H. A., Martin, M. T., Plastino, A., & Fuentes, M. A. (2007). Distinguishing noise from chaos. *Physical review letters*, 99(15), 154102.

Siddagangaiah, S. (2018). Complexity-entropy based approach for detection of fish choruses. *The Journal of the Acoustical Society of America*, 144(3), 1692-1693.

SEISMIC SOURCE CHARACTERIZATION EXPERIMENT

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In 2007 the Sound and Marine Life Joint Industry Programme funded an experiment in the Gulf of Mexico to characterize the far-field 3-dimensional broadband acoustic output from a 4140 cubic inch marine seismic source array. Three vertical moorings, with paired sensitive and less sensitive hydrophones at different depths, were deployed to measure the representative far-field dynamic range and bandwidth of the acoustic field emitted by the array. The designated seismic source vessel shot a specified set of seismic lines to provide broad coverage of received directions and ranges. The distance between the array center and hydrophones varied from about 160 m to 8 km. The representative data statistics was calculated using bins of 3 degrees in polar angle and 10 degrees in azimuthal angle. The array positions were measured in real time using standard techniques. Autonomous positioning systems were deployed to estimate the receiving hydrophones positions. The positions were estimated using Ultra Short Baseline (USBL) acoustics; this was only done during the source vessel line changes to minimize unnecessary acoustic interference. The Environmental Acoustic Recording System (EARS) channels were fully calibrated and provided measurements of absolute pressure values. Desensitized hydrophone measurements were used when clipping occurred on sensitive channels. All recorded direct arrival pulses from the array were processed to calculate a broad range of acoustic field metrics in the time and frequency domains: peak-to-zero, peak-to-peak, and RMS sound pressure levels, sound exposure levels for different temporal windows, power spectral density, and one-third octave band power distribution. The paper will discuss the proper ways to investigate and characterize the array acoustic field and directivity to assess potential seismic survey impact on marine species and to improve mitigation efforts.

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OCEAN AMBIENT SOUND TRENDS ACROSS THE NORTHERN HEMISPHERE

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Main sources of ocean ambient sound at low frequencies include anthropogenic activities such as shipping and seismic explorations (<200 Hz), and physical events such as winds and waves (up to 1 kHz). The contributions to ambient sound from anthropogenic sources have been increasing, although the patterns differ across different spatial scales. We investigated low-frequency (<1 kHz) ambient sound across the North Pacific and Atlantic Oceans as well as the Gulf of Mexico and the Arctic. One site in the eastern North Pacific has been monitored intermittently from 2004, but most other locations had data recorded only during 2010's.

The highest recorded levels of low-frequency ocean ambient sound were in the Gulf of Mexico and lowest in the Arctic. However, there is a large level of variability within each area, as well as between the ocean basins. In the Gulf of Mexico, for example, there was 10 dB of variability in ambient sound at 40 Hz (shipping noise band) across sites, but only about 4 dB at 100 Hz. Most of the difference at 40 Hz was likely resulting from the location of the recorders relative to the main shipping lanes and seismic exploration areas. Sites in Southern California also had large variability in sound at 40 Hz and 100 Hz (up to 20 and 15 dB, respectively) with the variability linked to the local bathymetry and exposure of recorders to different local basins or the open ocean. Generally, southward facing sites in Pacific and Atlantic Oceans had lower sound levels at low frequencies, likely corresponding to lower levels of shipping traffic across those areas. Long-term time series from a site in the eastern North Pacific showed decrease in low frequency ambient sound in 2009-10 relative to 2004, presumably the result of decrease in worldwide shipping during the global recession. However, the trends since then have been variable and harder to interpret in the light of shipping trends.

At most monitored locations there was a strong seasonal contribution to ambient sound from marine mammal calls, most commonly blue and fin whales, but also humpback whales. Understanding of ambient sound trends is important for developing baselines on the levels of noise marine animals may be exposed and used to in their environment. Additionally, it allows placing any increases in noise and experiments on noise impacts into appropriate context of ocean ambient sound.

THE SYMBIOTIC RELATIONSHIP BETWEEN THE RED HERMIT CRAB AND ITS SEA ANEMONE IS CHALLENGED BY SOUND EXPOSURE

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Calliactis parasitica forms a symbiotic relationship with hermit crabs, *Dardanus calidus*, such as the crab can induce the detachment of the anemone's pedal disk from the substrate, allow the transfer of the anemone to the crab's shell, or induce a shell-climbing behaviour by the anemone (Ross, 1979), especially when the crab needs to change the shell when it grows. The association provides protection for the hermit crab, specifically from predation by octopus (Ross and Boletzky, 1979). In return, the anemone gains motility and possibly food scraps from the hermit crab.

Analyses by scanning electron microscopy techniques (SEM) revealed lesions in the statocyst of the red hermit crab, which is found in the East Atlantic (Portugal to Senegal) and Mediterranean Sea, and its symbiotic sea anemone when exposed to low intensity low frequency sounds.

These ultrastructural changes under situations of acoustic stress in partners of a symbiotic relationship that belong to different phyla is a new issue that may limit the survival capacity of the symbionts, thus challenging their role in the oceanic ecosystem. Given that low-frequency noise levels in the ocean are increasing and that reliable bioacoustics data on symbiont invertebrates is scarce, the present study brings an additional contribution to the understanding of the effects of noise on marine ecosystems.

Ross, D.M. (1971). "Protection of hermit crabs (*Dardanus spp.*) from *Octopus* by commensal sea anemones (*Calliactis spp.*)," *Nature*. 9;230, 401-402.

Ross, D.M. and Von Boletzky, S. (1979). "The association between the pagurid *Dardanus arrosor* and the actinian *Calliactis parasitica*. Recovery of activity in "Inactive" *D. arrosor* in the presence of cephalopods," *Mar. Behav. Physiol.* 6(3), 175-184.

PARTICLE MOTION AND SOUND PROPAGATION NEAR BOUNDARIES

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It has been well-established that the inner ears of fishes act as particle motion detectors (Popper and Hawkins, 2018) and that fishes use particle motion to determine the direction of a sound source (Hawkins and Popper, 2018). Many soniferous estuarine fishes live in very shallow water at depths less than 3 m, where sound propagation is complicated by reflection and transmission of waves by and through the substrate and the surface. In these very shallow environments, maxima and minima of sound pressure often occur at different locations than maxima and minima of particle motion, making it difficult to relate hydrophone measurements of sound pressure to the effects of sound on the fishes that perceive particle motion. A recent study (Sprague et. al, 2016) used hydrophones to measure sounds of vessels in nearby channels to determine sound exposure levels at very shallow oyster toadfish *Opsanus tau* nesting sites. In this study we model the propagation of vessel sounds from deeper channels into nearby very shallow regions to determine the relationship between the pressure and particle motion both in the water and in the substrate in these environments and to gain insight into sound propagation in similar situations. Our results indicate that the sound waves in the very shallow regions contain significant particle motion components parallel to the seafloor (horizontal) and a reduced particle motion component perpendicular to the seafloor (vertical).

Hawkins, A. D., and Popper, A. N. (2018). "Directional hearing and sound source localization by fishes," J. Acoust. Soc. Am. 144, 3329–3350.

Popper, A. N., and Hawkins, A. D. (2018). "The importance of particle motion to fishes and invertebrates," J. Acoust. Soc. Am. 143, 470–488.

Sprague, M. W., Krahforst, C. S., and Luczkovich, J. J. (2016). "Noise propagation from vessel channels into nearby fish nesting sites in very shallow water," Proceedings of Meetings on Acoustics 27, 010012.

AUDITORY STUDIES WITH BEARDED SEALS: SOUND SENSITIVITY AND THE EFFECTS OF NOISE

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Bearded seals (*Erignathus barbatus*) have a circumpolar Arctic distribution and are closely associated with moving, broken ice. They spend nearly all of their lives in off-shore, remote habitats; as a result, their biology and behavior remain largely unknown. With respect to sensory biology, bearded seals—like other marine mammals—rely on acoustic cues to support a range of behaviors including orientation, communication, predator avoidance, and prey detection. However, the ability of bearded seals to perceive sound has never been investigated. In this study, a go/no-go behavioral paradigm was applied to determine auditory profiles for two young bearded seals trained to participate in hearing tests. Underwater detection thresholds were measured in quiet conditions for tonal sounds ranging from 0.10 - 61 kHz. The seals displayed sensitive underwater hearing, with peak sensitivity of 50 dB re 1 μ Pa and a broad range of best hearing from 0.35 - 45 kHz. To evaluate their ability to detect signals embedded within background noise, thresholds were then measured in the presence of octave-band masking noise. Like other phocinae seals, the bearded seals performed particularly well at this task compared to other mammals, with critical ratios ranging from 12 dB at 200 Hz to 30 dB at 25.6 kHz. Finally, one bearded seal completed additional testing to evaluate hearing before and immediately following voluntary exposure to single- and multiple-shot impulses from a seismic air gun. Collectively, these psychoacoustic studies describe the hearing capabilities of bearded seals in quiet conditions, in the presence of simultaneous noise, and following seismic noise exposure. Combined with recently reported data for spotted and ringed seals, they inform regulatory guidelines regarding best management practices for marine mammals in a rapidly changing Arctic environment.

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ASSESSING THE EFFECTS OF SHIPPING NOISE ON ST. LAWRENCE ESTUARY BELUGA: A THREE-LAYER, FIVE-YEAR RESEARCH PROGRAM

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St. Lawrence estuary beluga (SLEB) is a threatened small population of ~ 900 individuals whose habitat is crossed by a major continental seaway of Northeastern American economic activity, conveying merchandises between the Atlantic and the Great Lakes. The underwater noise radiated in beluga habitat by this medium-level traffic St. Lawrence Seaway is one of the treats suspected to hinder the recovery of the population. For understanding the effects of this chronic noise on SLEB to minimize this treat, the Canadian Government launched a five-year research project within its Ocean Protection Program initiative in 2017. Using an habitat-based approach, this research will document the three-layer spatial-temporal components of the problem: 1) the 3D probability distribution function (pdf) of the shipping noise over a complete annual cycle, 2) the same 3D pdf information for the belugas, and 3) the interactions of these two 3D pdf layers for addressing the exposure, estimate the noise effects using diverse maps of risk metrics, and explore mitigation scenarios from probabilistic modeling.

An acoustic observatory composed of 10 passive acoustic monitoring (PAM) stations was deployed across SLEB critical habitat. These 2- or 3-hydrophone wideband PAM systems continuously record noise levels as well as beluga communication and echolocation sounds. Dedicated algorithms extract soundscape trend and variability at the scales of interest (Simard *et al.*, 2016) as well as beluga depth and frequentation across their habitat. Validated probabilistic shipping noise modeling, using traffic monitored by acoustic identification system (AIS) (Aulanier *et al.*, 2017), is used to get the exposure level at any 3D (+Time) location of the habitat. Short-term beluga exposure and behavior experiments are conducted with acoustic tags (D-tag) carried by individuals while drifting vertical hydrophone arrays simultaneously measure the soundscape. These data are complemented with systematic aerial surveys and accumulated knowledge on SLEB ecology in the last decades. The combination of all this information with various modeling efforts should bring new insights on how chronic shipping noise affects a marine mammal population, as well as on possibilities to minimize the risk of adverse effects with different mitigation actions.

Aulanier, F., Simard, Y., Roy, N., Gervaise, C., and Bandet, M. (2017). "Effects of shipping on marine acoustic habitats in Canadian Arctic estimated via probabilistic modeling and mapping," *Mar. Poll. Bull.* 125, 115-131.

Simard, Y., Bandet, M., Gervaise, C., Roy, N., and Aulanier, F. (2016). "Soundscape cube: A holistic approach to explore and compare acoustic environments," in *Fourth International Conference on the Effects of Noise on Aquatic Life*, Dublin (Acoust. Soc. Am. Proc. Meetings Acoust. 27, 070012), pp. 1-8.

DAMAGE POTENTIAL INDEX: A SINGLE NUMERIC EXPRESSION FOR NOISE EXPOSURE IMPACTS

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Regulatory noise exposure thresholds are currently based exclusively on exposure amplitude. These thresholds were only recently bracketed in the frequency domain by auditory bands of marine mammals in a set of “M weighting” curves. While these curves are an improvement on understanding and applying regulatory thresholds for “Level B” behavioral disturbance exposures, the suite of regulatory guidelines still falls short of expressing actual damage or disruption potential of any particular noise exposure.

A correlation between signal kurtosis (of amplitude variability over time) and hearing damage has been well established—with overall signal amplitude remaining an important variable. Understanding that regulators prefer single numeric “go/no go” thresholds has likely been a factor in not adopting any more nuanced expressions of exposure damage potential. We are proposing a single numeric that integrates both amplitude and kurtosis in the time/frequency domain as a “damage potential index” which would more accurately express the impacts of a disturbing or damaging sound.

GENTOO PENGUINS (*Pygoscelis papua*) REACT TO UNDERWATER SOUNDS

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Hearing is fundamental for many marine organisms. Some of them may be highly affected by the increasing amount of noise in the oceans caused by human activities (Ketten 2008, Crowell 2016). The impacts from noise pollution on marine mammals and fish currently receive large amounts of attention with several studies assessing the impact on marine mammals and fish (Tyack 2008).

Aquatic birds, however, do not receive much attention in this respect, and very limited data is available on their underwater hearing abilities and possible impacts of noise pollution.

Penguins are considered as being some of the most aquatic adapted of all birds. There is very little known about penguin hearing, and the only study made so far was made in air (Wever, 1969). An earlier study found that African penguins showed avoidance to their preferred foraging areas due to seismic activities, even within a radius of 100 kilometers (Pichegru, Nyengera et al. 2017).

This means we lack entirely information on whether or not penguins make use of underwater sound cues while diving.

To find out if penguins react to underwater sound, we observed the behavioral responses of gentoo penguins (*Pygoscelis papua*) in a zoo, to acoustic playbacks of broadband stimuli with various intensities. Results indicate consistent behavioural reactions to sound at modest sound levels, above some 110 dB re 1 μ Pa rms. This strongly indicates that hearing is an important cue for diving penguins and possibly also other marine birds.

Crowell, S. C. (2016). Measuring In-Air and Underwater Hearing in Seabirds. *The Effects of Noise on Aquatic Life II*, Springer: 1155-1160.

Ketten, D. R. (2008). "Underwater ears and the physiology of impacts: Comparative liability for hearing loss in sea turtles, birds, and mammals." *Bioacoustics* 17(1-3): 312-315.

Pichegru, L., R. Nyengera, A. M. McInnes and P. Pistorius (2017). "Avoidance of seismic survey activities by penguins." *Scientific reports* 7(1): 16305.

Tyack, P. L. (2008). "Implications for marine mammals of large-scale changes in the marine acoustic environment." *Journal of Mammalogy* 89(3): 549-558.

HEARING IN BLACK SEA BASS (*Centropristis striata*) AND THE EFFECTS OF PILE DRIVING SIGNALS ON THEIR BEHAVIOR IN CONTROLLED ENVIRONMENTS

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The effects of exposure to increasing anthropogenic sound levels on marine organisms is the subject of increasing concern and research focus (Hawkins and Popper, 2016). Although there is mounting literature on the topic, relatively little is known about the impacts of such exposures on fish populations (Popper and Hastings, 2009). Black sea bass (*Centropristis striata*) is a commercially, recreationally and ecologically important fish species along the majority of the eastern coast of the United States. Due to intense urbanization along much of this coastline, this species is subject to a wide range of anthropogenic sounds. Moreover, with the large expansion of offshore wind energy infrastructure in these areas, sounds from marine piledriving and construction activities will continue to add to this anthropogenic soundscape. Fisheries and other stakeholder groups have expressed concern that sounds from the construction of such offshore windfarms have already affected black sea bass distribution in the northern part of their range. It is suggested that these sounds may cause the species to vacate affected areas, thereby disturbing the natural distribution, as well as spawning, feeding, and other behaviors required for healthy populations.

The construction of offshore wind farms in the US largely relies on marine pile-driving, which emits impulsive, high intensity and low frequency sounds with peak levels commonly exceeding 200 dB re 1 μ Pa @ 1m underwater (Dahl *et al.*, 2015). Previous studies have found that signals from these activities can trigger behavioural and physiological stress responses in certain fish species, however, it is unknown how these signals may affect black sea bass, and assessing risks is currently difficult as the hearing range/abilities of this species is currently undocumented.

The first phase of this project investigated the potential chronic effects of broadcast pile driving signals on the behavior of black sea bass in controlled environmental settings. Baseline hearing bandwidths were determined through auditory evoked potentials and overlap with anthropogenic sounds evaluated. A number of small and large tank sound trials were performed to characterize the behavioral responses to playbacks of recorded impact pile driving sound. This program is a first step in understanding the potential chronic effects of anthropogenic underwater sound, specifically pile driving, on the behavior and ecology of this important fish species. The next step will ideally be to work from these results to better document and assess *in situ* effects, with the aim to help inform noise mitigation strategies for offshore renewable energy development.

Dahl, P. H., de Jong, C. A. F., and Popper, A. (2015). "The Underwater Sound Field from Impact Pile Driving and Its Potential Effects on Marine Life," *Acoust. Today* 11, 18 - 25.

Hawkins, A. D., and Popper, A. N. (2016). "A sound approach to assessing the impact of underwater noise on marine fishes and invertebrates," *ICES J. Mar. Sci.* 73, 635 - 651.

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EFFECTS OF PILE-DRIVING NOISE AND CADMIUM CO-EXPOSURE ON THE EARLY-LIFE-STAGE DEVELOPMENT OF *THE NORWAY LOBSTER*, *Nephrops norvegicus*

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To date, most studies and environmental risk assessments have assessed pollutants, including noise, using a single-stressor approach. This generally enables confidence in determination of cause-effect relationships, but lacks environmental realism given organisms face pressure from numerous concurrent anthropogenic co-stressors, such as climate change, chemical pollutants, etc. (Gunderson et al., 2016).

To investigate the impacts of anthropogenic noise in a marine-based multi-stressor scenario, we assessed the impacts of pile-driving noise exposure in combination with the heavy metal cadmium. This pair of co-stressors represents an environmentally plausible combination, given construction activities can contribute to re-solubilisation of historically accumulated pollutants from sediments (Hall, 1989). The Norway lobster (*Nephrops norvegicus*) was chosen as a model species as its natural habitat is prone to experience substantial piling noise. Assessment focused on zoea larvae of the species, given early-life-stages are often more susceptible to stress than their adult conspecifics, presenting a potential population bottleneck.

In a laboratory-based multi-stressor experiment, newly hatched larvae were concurrently exposed to underwater playback of field-derived pile-driving recordings (average single-pile zero-peak sound pressure level = 195 dB re: 1 μ Pa, 6:18 hour piling:ambient sound exposure) and one of three nominal cadmium concentrations (low: 1 μ g L⁻¹, medium: 10 μ g L⁻¹, high: 100 μ g L⁻¹) until completion of metamorphosis from planktonic zoea to benthic juvenile stage. Survival was monitored daily.

Piling noise exposure alone did not significantly affect larval mortality at utilised replication (n = 20 per treatment), however significant interaction between piling noise and cadmium exposures occurred ($p < 0.001$). Pile-driving noise was antagonistic to cadmium toxicity at low cadmium concentrations and significantly decreased larval mortality ($p = 0.016$). At high cadmium concentrations however, pile-driving noise exposure significantly increased larval mortality ($p = 0.006$), demonstrating a synergistic relationship between piling noise and cadmium toxicity. Interpretation of statistical analysis suggested a critical cadmium concentration of 15 μ g/L, above which pile-driving noise increases larval mortality. This switch in the interaction is hypothesised to be driven by oxidative stress, and differing stress-response thresholds to noise and cadmium exposure, which will be assessed in follow-up studies. Results evidence that anthropogenic noise exposure can interact with, and modulate the impacts of, other environmental co-stressors. This highlights the need to consider noise exposure in a wider environmental context, and that failure to incorporate more integrative modelling into environmental risk assessments may lead to over- or underestimation of potential risk.

Gunderson, A. R., Armstrong, E. J., and Stillman, J. H. (2016). "Multiple Stressors in a Changing World: The Need for an Improved Perspective on Physiological Responses to the Dynamic Marine Environment," *Ann. Rev. Mar. Sci.*, 8, 357–378.

Hall, L. A. (1989). "The effects of dredging and reclamation on metal levels in water and sediments from an estuarine environment off Trinidad, West Indies," *Environ. Pollut.*, 56, 189–207.

THE IMPACT OF BACKGROUND SOUND SIGNALS ON THE DYNAMIC RANGE OF BELUGA WHALE AUDITORY SYSTEM

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The effects of adaptive background sounds on auditory evoked potentials (AEP) were investigated in a beluga whale. Both test signals and background sounds were trains of cosine-enveloped tone pips of 64 kHz carries followed one another at a rate of 1 kHz. Background sounds lasting 128 ms alternated with test signals lasting 16 ms. The level of the test signals varied from -15 to + 20 dB relative the level of adapting background. AEP (the rate following response, RFR) produced by the test signals were recorded. Increasing of adapting level led to RFR thresholds growth. Background sounds shifted the amplitude-level function upward: then higher the background level was, then bigger was the shift in the amplitude-vs-level function. The 10-dB rise of adapting level led to 7.8 dB rise of the test signal threshold. The form of the amplitude-level function was almost independent on the level of the adapting background. The data demonstrate adjustment of sensitivity of the beluga's hearing of to the background level.

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RELATIONSHIPS BETWEEN BOWHEAD WHALE SOURCE LEVEL, CALLING RATES, AND WIND DRIVEN AMBIENT NOISE LEVELS

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Relationships between calling rates, call source level, and wind-driven continuous ambient noise levels are derived from a few hundred thousand automated and manual acoustic localizations of migrating bowhead whale calls in the Beaufort Sea. Previous work on this dataset, collected between 2008 and 2014, has examined source level distributions, calling depth, and decadal-scale frequency shifts (Thode *et al.*, 2016, 2017). Standard point transect theory (Buckland et al. 2001) is modified to account for an acoustic detector array; this is employed to parameterize call detectability as a function of source level-to-noise ratio (SLNR), which in turn can be applied to correct for call masking effects. At low noise levels the population's call source levels and call density increase with root-mean-square (RMS) noise level. The population adjusts its source level distribution to maintain a consistent functional detection range, which is estimated to be between 18 and 25 km. As noise levels continue to increase, source level increases fail to keep pace, reducing the population's detection range and associated communication space. Call rates, by contrast, monotonically increase with noise level at all noise levels tested. The results provide context for interpreting the effects of industrial noise on bowhead whale acoustic behavior; for example, the presence of distant airgun signals (Blackwell *et al.*, 2015) stimulates an increase in call production rate equivalent to a 15-40 dB increase in wind-driven natural ambient noise, depending on the initial ambient noise level. One unexpected result is that bowhead whales begin to lose their ability to compensate for increases in ambient noise around 75 dB re 1 μ Pa (rms), 20-170 Hz bandwidth, which is only the 10th percentile of the multiyear Beaufort Sea ambient noise distribution. The median background noise level lays several dB higher, at 82 dB re 1 μ Pa (rms). One speculative explanation is that ambient noise levels during the fall migration have increased 5-10 dB over a timescale rapid enough that the population hasn't evolved in response.

Blackwell, S. B., Nations, C. S., McDonald, T. L., Thode, A. M., Mathias, D., Kim, K. H., C.R. Greene, J., and Macrander, A. M. (2015). "The effects of airgun sounds on bowhead whale calling rates: evidence for two behavioral thresholds," *PLoS One* 10, e0125720.

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D.L. and L. Thomas. (2001). *Introduction to Distance Sampling: Estimating Abundance of Biological Populations* (Oxford University Press).

Thode, A. M., Blackwell, S. B., Conrad, A. S., Kim, K. H., and Michael Macrander, A. (2017). "Decadal-scale frequency shift of migrating bowhead whale calls in the shallow Beaufort Sea," *J. Acoust. Soc. Am.* 142, 1482-1502.

Thode, A. M., Blackwell, S. B., Seger, K. D., Conrad, A. S., Kim, K. H., and Macrander, A. M. (2016). "Source level and calling depth distributions of migrating bowhead whale calls in the shallow Beaufort Sea," *J. Acoust. Soc. Am.* 140, 4288-4297.

AIRGUN IMPACT AGENT BASED MODELLING OF HUMPBACK WHALE BEHAVIOUR

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The displacement of marine mammals and fish due to behavioral response to high intensity impulsive sound (e.g. airguns and pile driving) is one of the key issues in the field of Aquatic Noise. We know that behavioral responses can happen at relatively large ranges in some cases but it has been a challenge to understand the population level consequences these effects. Predictive modelling is often the only available approach for quantifying animal movement patterns in response to pressures such as noise to inform population studies. However, the use of models rests on the assumption that they are able to replicate natural conditions, thus allowing for realistic predictions of animal behavior.

In this study, we investigated the ability of Agent Based Models (ABM) to replicate the movement of migrating humpback whales (*Megaptera novaengliae*). Using ABM, the agents were released into a simulated domain, where their decisions were stochastically (i.e. within predefined probabilities) generated based on coded traits (e.g. preferences, memory) and established external forcings (e.g. temperature, wind speed, water depth, noise). The data to parameterize the ABM came from the BRAHSS study (Behavioral Response of Australian Humpback whales to Seismic Surveys; e.g. Dunlop *et al.*, 2017). The agents were then run through a simulated experiment and various output measures (e.g. passage speed etc.) were compared between the BRAHSS data and ABM data. Passage speed (i.e. the speed at which the whales transverse the study area), turning angle, (i.e. course changes of the whales during their movements), and deviation from course south were all simulated in a way that did not show any significant differences to the observations during the BRAHSS experiments. Only for diving time, our model showed differences to reality, which can be explained by the lack of, model calibration for this factor.

Our study shows the potential from an ABM to replicate the movements of migrating humpback whales in both natural and sound impacted circumstances. We found the ABM to successfully replicate key migratory behaviors observed during the BRAHSS experiments as well as changes in these behaviors when agents were exposed to a moving airgun sound source. While the ABM of migrating humpback whales does reflect most humpback behaviors observed in the BRAHSS study, knowledge gaps call for further dedicated research related to ABM modelling.

Dunlop, R. A., Noad, M. J., McCauley, R. D., Scott-Hayward, L., Kniest, E., Slade, R., Paton, D., and Cato, D. H. (2017). "Determining the behavioural dose–response relationship of marine mammals to air gun noise and source proximity," *The Journal of Experimental Biology* 220, 2878.

AGENT BASED MODELS LEAD TO REDUCTION OF TAKES IN IMPACT ASSESSMENTS OF UNDERWATER NOISE

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Assessing impacts related to underwater noise is mandatory for a variety of marine industry activities in Europe, the US and elsewhere. Studies using static assumptions, i.e. non-moving animals can lead to overestimation of impacts leaving regulators with a very high uncertainty about the effects of noise. New methodologies to model animal movement are available; yet, it is not clear how these perform against more conventional approaches. Thus, the application of movement modelling in impact assessments is not well understood.

Here we used Agent Based Models (ABM) and compared the number of North Atlantic right whales (*Eubalaena glacialis*) exposed to pile driving sound with those obtained through a conventional risk assessment. The study area was located off the east coast of the US, where many offshore wind farms are planned. For the simulated impact pile-driving we used a 10 m diameter steel monopile foundation. The noise modelling was performed using a RAMGeo parabolic equation. Impacts were defined based on US regulatory criteria for injury and behavioural disruption. Information on whale abundance and behaviour was derived from literature. Two general states (migration and feeding) were employed. Three movement scenarios were modelled (baseline with no reaction; avoidance, displacement with return to baseline after 1 h or 24 h, respectively).

The results showed that using the ABM approach, the number of takes during migration went down substantially compared to the static approach and depending on scenario. Using displacement, the number of takes was zero. The differences between static and dynamic approach were less pronounced during feeding. Here, takes were reduced slightly using the baseline scenario and more sharply using the avoidance and the displacement scenario.

We show that the ABMs lead to a significant reduction of takes for different scenarios compared to the static approach. It could be premature to use ABM in noise impact assessments, as information on sound impacts is limited. Yet the paradigm is already shifting towards dynamic approaches, and the ABM appear to be the most comprehensive and reliable technology. Furthermore, data on behavioural response of marine mammals to underwater noise exposure are rapidly increasing. We suggest complementing the static approach with the dynamic approach in future studies to allow for comparison and provide regulators with a range of outcomes including uncertainty quantification. Whenever data become available, the static approach can be gradually phased out to make room for more validated animal response models.

STATE-OF-THE-SCIENCE OF METHODS TO MITIGATE IMPACTS OF UNDERWATER NOISE FROM PILE DRIVING

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The construction, operation and decommissioning of offshore wind farms involve activities that generate underwater sound. Most concern has been raised about construction using impact pile-driving (Peak-to-Peak SL= 220-257 dB re 1 μ Pa). Pile driving noise can lead to displacement of marine mammals and marine fish species. Physiological effects such as temporary hearing loss are likely if the acoustic dose at the receiver is exceeding certain thresholds. Here, a review of the methods to mitigate sound during offshore wind farm construction identified three categories: (1) source mitigation comprising methods that reduce the sound directly at the source; (2) channel mitigation comprising methods that reduce the emitted underwater sound in the water column; and, (3) receiver mitigation comprising methods that prevent the receiver from being close to the sound source. Both source and channel mitigation methods are confounded by the need to achieve a certain amount of hammer energy to penetrate the seabed. Source mitigation can involve adjustment of piling energy, pulse prolongation, adjustments to the hammer or alternatives to conventional impact pile-driving, leading to reduction between 9 and 20 dB (broadband). Channel mitigation involves bubble curtains, casings and resonators including hydro-sound dampers. Bubble curtains and casings have proven to be very effective reducing broadband sound levels by 16 dB. Higher frequencies are dampened more effectively compared to lower ones (e.g. 30 dB reduction at 1 kHz). This makes these methods effective in reducing impacts on marine mammals, less so on fish. Receiver mitigation involves devices aimed at deterring animals out of the zone of danger, safety zones, soft-start and temporary piling restrictions. The evidence base regarding the efficacy of seal scarers in deterring seals is still inconclusive, although they can cause aversive behaviour in harbour porpoises to a distance of several kilometres from the source. Safety zones in theory might work during daytime and, if passive acoustic monitoring (PAM) is applied, at other periods. However, PAM can only monitor safety zones if the species of interest produces sound most of the time, which may not be the case for all species of interest. Although widely used across various European countries, it remains unclear how efficient the application of soft-start really is. Several European countries prescribe the combined use of one or several mitigation methods. It is suggested that the selection of the most appropriate mitigation measure(s) in a particular circumstance should be based on a risk-based approach.

EFFECTS OF LOW-FREQUENCY NOISE AND TEMPERATURE ON COPEPOD AND AMPHIPOD PERFORMANCE

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Offshore wind farms (OWF) are often touted for their “green energy” etiquette and their artificial reef-like structures that promote secondary production by benthic invertebrates. As the number of OWF are bound to increase as a mitigation strategy to reduce the emission of greenhouse gases, it is crucial to address all of their potential impacts on key ecosystem components in detail. Especially, the chronic effect of noise created during OWF turbine operations (duration 20-25 years) must be understood.

Negative effects of underwater noise (shipping, airgun, etc.) observed on crustaceans include a reduction of burying and bioirrigation behaviours (Solan et al., 2016), disturbances in feeding behaviours and antipredator responses (Wale et al., 2013), and malformations or delays during larva metamorphosis (Aguilar de Soto et al., 2013; Nedelec et al., 2014). As sensitive receptors cover the whole body of crustaceans to detect their surroundings, those low frequency noises may disrupt basic ecological (prey detection and predator avoidance) and physiological (metabolism) functions.

Here we present an investigation designed to understand the joint effect of noise and other stressors such as an increase in temperature on crustaceans. We carried out experiments with two model key organisms - the pelagic copepod *Acartia tonsa* and the benthic amphipod *Echinogammarus marinus*. The copepod species is commonly used as a proxy for a range of fundamental processes that relate to marine planktonic crustaceans while the amphipod constitutes an important part of fish and shorebirds diets. Given that higher temperatures increase metabolic demands, the experiment was conducted at three different temperature levels (18, 21, 24°C) combined with silent and noise treatments. We assessed the combined effects on energetic balance, mitochondrial capacity and ontogenesis (for copepods only). First results from our work indicate lower respiration rates when copepods were exposed to low-frequency noise coupled with higher temperatures, which could have important consequences for the fitness and the energy available for growth and reproduction. The outputs of the experiment will provide important information on the potential impact of low-frequency noise on marine invertebrate key organisms with implications for secondary production and ecosystem functioning.

Aguilar de Soto, N., Delorme, N., Atkins, J., Howard, S., Williams, J., and Johnson, M. (2013). "Anthropogenic noise causes body malformations and delays development in marine larvae," *Sci. Rep.* 3, 2831.

Nedelec, S. L., Radford, A. N., Simpson, S. D., Nedelec, B., Lecchini, D., and Mills, S. C. (2014). "Anthropogenic noise playback impairs embryonic development and increases mortality in a marine invertebrate," *Sci. Rep.* 4, 5891.

Solan, M., Hauton, C., Godbold, J. A., Wood, C. L., Leighton, T. G., and White, P. (2016). "Anthropogenic sources of underwater sound can modify how sediment-dwelling invertebrates mediate ecosystem properties," *Sci. Rep.* 6, 20540.

Wale, M. A., Simpson, S. D., and Radford, A. N. (2013). "Noise negatively affects foraging and antipredator behaviour in shore crabs," *Anim. Behav.* 86, 111-118.

ESTIMATING CUMULATIVE SOUND EXPOSURE LEVELS FOR DIVING GREY SEALS EXPOSED TO SHIPPING NOISE

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Commercial shipping increasingly generates underwater noise pollution and is associated with a number of negative ecological effects. Predictions of underwater shipping noise for resulting regulatory procedures, primarily take the form of two-dimensional maps. However, marine life utilizes a three-dimensional underwater environment and dynamic ocean properties can cause vertical and horizontal step changes in noise levels. As benthic foragers that dive throughout the water column, this is particularly relevant for seals. Grey seals (*Halichoerus grypus*) exhibit high spatial co-occurrence with shipping and the functional hearing range of this protected species overlaps with shipping noise. Furthermore, seal pups are naïve and must develop foraging strategies alone, potentially making them vulnerable to disturbance. However, there is still very little data about the exposure of grey seals to shipping noise, constraining effective policy decisions. Consequently, this study aims to predict the exposure of seals to shipping noise along their three-dimensional track.

Using AIS data, the RANDI ship source model and the acoustic propagation model RAMSurf, this study estimates m-weighted 24 hour cumulative sound exposure levels (10-1000 Hz) (cSEL). Shipping noise was modelled every 15 minutes along the linearly interpolated GPS/GSM telemetry tracks of 9 adult grey seals in the English Channel (EC) and 9 pups in the Celtic Sea (CS). As a result, noise exposure is linked to at-sea movement, including variation as seals dive throughout the water column. The mean number of ships in a 15 minute period within 120 km was greater for the EC adults (mean = 26.9, SD = 21) than the CS pups (mean = 6.5, SD = 5). However, there was little difference between the mean number of ships within 5 km of the seal (CS = 1.1, EC = 1.3). The closest point of approach for any ship was 161 m. Median predicted cSEL was 143 dB re $1\mu\text{Pa}^2\text{s}$ and 159 dB re $1\mu\text{Pa}^2\text{s}$ for the pups and adults respectively. Median predicted maximum sound pressure level (SPL) was 115 dB re $1\mu\text{Pa}$. When considering only SPL values greater than effective quiet (124 dB re $1\mu\text{Pa}$), cSEL ranged from 141 to 169 dB re $1\mu\text{Pa}^2\text{s}$. Only 9 seals experienced SPL values ≥ 124 dB re $1\mu\text{Pa}$. The predicted exposure of seals to shipping noise did not exceed best evidence thresholds for temporary threshold shift. The results contribute to an understanding of ship noise risk and can inform regulatory planning related to the anthropogenic pressures on seal populations.

THE EFFECTS OF VESSEL SLOWDOWNS ON FORAGING HABITAT OF THE SOUTHERN RESIDENT KILLER WHALES

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The Enhancing Cetacean Habitat and Observation (ECHO) program, led by the Vancouver Fraser Port Authority, is a collaborative initiative aimed at better understanding and managing the effects of commercial vessel activities on at-risk whales off the coast of southern British Columbia, Canada. Vessel-generated underwater noise has been identified by Fisheries and Oceans Canada (2018) as one of the key threats to the recovery of the endangered Southern Resident Killer Whales (SRKW). Much of the coastal waters of southern British Columbia and northern Washington State, U.S.A., are designated as critical habitat for the SRKW, but also support significant marine traffic including ferries, fishing vessels, recreational and ecotourism boating and international shipping channels.

In 2017, the ECHO program, supported by the Government of Canada, led a two-month voluntary slowdown trial of commercial vessels in Haro Strait, a key SRKW foraging area, with a target speed of 11 knots. The goals of the trial were to better understand the relationship between ship speed and underwater noise emissions, how reduced speed may reduce underwater noise in foraging habitat, and implications to the behavior and foraging of the SRKW.

The 2017 voluntary trial reported 61% participation by commercial piloted vessels, and demonstrated a clear reduction in vessel-generated underwater noise, despite longer transit times. Mean reductions in broadband monopole source level were as high 11.5 dB re $\mu\text{Pa m}$ for containerships. Speed-dependence coefficients were calculated in different frequency bands. These data were used to generate a noise field for use in an SRKW noise-exposure simulation model which showed a 21% reduction in “lost foraging time” during the trial, compared to baseline conditions. Using a hydrophone located in core foraging habitat, median broadband ambient noise levels were measured to be 1.2 dB re $1\mu\text{Pa}$ lower during the slowdown as compared to baseline conditions, and 2.5 dB re $1\mu\text{Pa}$ lower when filtered to include only times when large vessels were present, and remove times of high wind and current and small vessel noise.

In 2018, the shipping industry proposed another slowdown, with an aim to increase participation rates by increasing target speeds, thereby lessening the delay for each transit and the associated economic and operational challenges. This presentation will provide the results of the 2017 and 2018 vessel slowdown initiatives in Haro Strait, comparing participation rates, noise reductions and the potential benefits to the behaviour and foraging of the endangered SRKW.

Fisheries and Oceans Canada. (2018). “*Recovery Strategy for the Northern and Southern Resident Killer Whales (Orcinus orca) in Canada.*” Species at Risk Act Recovery Strategy Series, Fisheries & Oceans Canada, Ottawa, x + 84 pp.

CRITICAL ANALYSES OF INPUT PARAMETERS FOR MYSTICETE AND ODONTOCETE MIDDLE EAR MODELS

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Models of middle and inner ear function are a well-established approach for determining hearing abilities of mammals and are practical for species such as baleen whales that are unmeasurable by behavioral and electrophysiological testing. To date, we have published finite element models (FEM) of the middle ear transfer functions and inner ear anatomy that inform us about peak sensitivities and hearing ranges for three baleen whale species: minke (*Balaenoptera acutorostrata*), humpback (*Megaptera novaeangliae*), and right whale (*Eubalaena glacialis*) (Ketten 1994; Parks et al. 2007; Tubelli et al 2012, 2018). We are currently expanding this work to blue whale (*Balaenoptera musculus*) and a middle ear through inner ear model of the right whale (*Eubalaena glacialis*).

One challenge for whale ear models is that physical properties of key structures, such as elasticity and density, have not been measured for most cetaceans. Those that have been measured show significant species differences. Analyses therefore require in the absence of known physical property measurements, that middle ear parameters for cetacean species must be estimated based on known values for structurally appropriate tissues in terrestrial species, which are not necessarily parallel anatomical structures.

In this study, we tested the full physiologically-relevant range for material properties of twenty-one parameters based on structural similarity of known mammalian tissues analogues of middle ear tissues for in order to understand the effects on the model output of varying these parameters. To further test the validity of baleen whale models, we are developing and testing models for bottlenose dolphin (*Tursiops truncatus*) and harbor porpoise (*Phocoena phocoena*), two odontocete species with ample live auditory threshold measurements to serve as controls for model results. Variations in nine parameters were shown to have significant effects on the results, demonstrating that a clear understanding of the anatomy and cellular structure are important elements for choosing tissue input parameters which, like all model inputs, must be documented and verified for model accuracy. Support for this work was provided by the Joint Industry Program for Sound in the Sea.

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LONG-TERM AMBIENT NOISE MONITORING OFF EASTERN SCOTLAND, AND TIDAL INFLUENCE ON MSFD MEASUREMENTS

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Underwater noise is identified as one of the Marine Strategy Framework Directive (MSFD) Descriptors by which the EU monitors Good Environmental Status (GES). Off eastern Scotland, the ECOMMAS array has been recording underwater sound at 10 sites since 2013. However, various sites are affected by tidal flow noise, which influences monitoring measurements. Using a modified version of PAMGuide (Merchant *et al.*, 2015, 2016), this study monitored the spatio-temporal variability in ambient noise, calculated as the averaged RMS levels and percentile statistics for the 1/3 octave band centred at 63 Hz, for the 10 ECOMMAS sites during 2013-2017. To obtain more realistic information on noise conditions, for the top three tidally-affected sites, periods with highest modelled tidal velocity were step-wise excluded until no relationship existed between velocity and the RMS value. Resulting annual RMS values of the ‘tidal-corrected’ dataset were compared to those of the full dataset. Finally, annual averaged RMS levels of both datasets were compared against hypothetical GES noise threshold levels to assess what percentage of time the threshold levels were exceeded for each of the datasets.

A total of 112,071 hours of data were collected. Depending on site and year, annual RMS levels ranged between 86.8-111.0 dB re 1 μ Pa. There was no pattern suggesting that specific years were consistently noisier/quieter across sites. However, for all years, noise levels were substantially higher at one site, whilst for one of the quieter sites in particular, a strong relationship between RMS level and tidal velocity was revealed. For this site, exclusion of periods with highest velocity resulted in 61.0-91.8% data exclusion, and 3.9-11.1 dB reduction in RMS value, depending on year. Consequently, the percentage of acoustically monitored time whereby the measured RMS level exceeded hypothetical GES thresholds were substantially lower for the ‘tidal-corrected’ dataset as compared to the full dataset. Exclusion of data (28.2-86.3%) and subsequent changes in RMS levels (-6.3 to +2.0 dB) for the other two tidally-affected sites resulted in minimal decreases in temporal exceedance of hypothetical GES thresholds.

Original site selection was directed by the primary aim of monitoring coastal bottlenose dolphin movements, and not driven by MSFD reporting. At present, there is no agreed way of handling tidal influence on noise data. Our approach demonstrates that the vast amount of annual data available did allow for data sub-setting, such that sites influenced by tidal periodicity could still provide meaningful data for MSFD ambient noise monitoring.

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UNDERWATER NOISE IN PRACTICE: SEISMIC SURVEYS IN THE NORTH SEA

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Royal HaskoningDHV (RHDHV) would like to give an insight on underwater noise impacts from seismic airguns from a practical experience. As knowledge on the impact of underwater noise is developing rapidly the methodology used to assess the impact of the activity on the marine environment needs to continuously be updated. RHDHV has developed a method to determine the impact on marine mammals in collaboration with the appropriate authorities. When new information becomes available in addition with practical experience from previous seismic surveys the method is updated.

RHDHV is leading company in writing ecological assessments and preparing permitting documents for the Dutch Nature Protection Law (Wet Natuurbescherming) on the Dutch North Sea, specifically for seismic surveys, but also other activities like pile driving. In 2014 RHDHV successfully prepared the first permitting documents on a 3D seismic survey and the seismic survey was successfully conducted in the summer of 2014 (Royal HaskoningDHV, 2014). Since then RHDHV has written several more ecological assessments for different exploration and production companies (Royal HaskoningDHV, 2014).

Here we give an insight what is needed to get a high quality ecological assessment; which scientific information is needed and how to assess the impacts. And secondly, how do impacts and mitigation measure defined on paper work out in the field when conducting the seismic survey.

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THE EFFECT OF MULTIBEAM MAPPING ACTIVITY ON BEAKED WHALE FORAGING IN SOUTHERN CALIFORNIA

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An ocean mapping survey was conducted over the Southern California Antisubmarine Warfare Range (SOAR) hydrophone array to characterize the radiation pattern of the *R/V Sally Ride's* EM 122 (12 kHz) Kongsberg multibeam echosounder. Spanning a 2000 km² area, the 89-hydrophones in the range, combined with the mapping survey, provided the opportunity to study the effect of the multibeam sonar noise on the foraging behavior of Cuvier's beaked whales, resident to the region. The study design and analysis parallel work presented by McCarthy et al. (2011) that examined the effect of Naval sonar on Blainville's beaked whales foraging on the Atlantic Undersea Test and Evaluation Center (AUTEK).

Echolocation clicks are produced by a group of Cuvier's beaked whales as they hunt for prey. This period of vocal activity during a foraging dive is referred to as the group vocal period (GVP). Group vocal periods were automatically detected using software that identified clicks, combining them into click trains based on species-specific characteristics (DiMarzio and Jarvis, 2016). Closely associated click trains were grouped into GVPs on a per hydrophone basis. GVP characteristics were used as a proxy to assess the temporal distribution of foraging activity across six exposure periods with respect to multibeam presence at SOAR. These characteristics included the number of group vocal periods, the number of clicks in a GVP and GVP duration. The exposure periods included 1) before the vessel was on the range (*Before*), 2) the vessel was on the range with mapping sonar off (*Control Survey*), 3) the vessel was on the range and the mapping sonar was on (*EM 122 Survey*), 4) multiple acoustic sources were on (*Other Active Acoustics*), 5) the vessel was mapping off-range (*Immediately After*), and 6) the vessel was off the range and the sonar was off (*After*). A one-way analysis of variance test was conducted to compare each GVP characteristic across the exposure periods.

There were no statistically significant differences between the six exposure periods with respect to the number of clicks per GVP or GVP duration. There were more GVPs *After* the EM 122 survey than there were *Before* or *Immediately After*, but no difference in the number of GVP during the *EM 122 Survey* compared with any other exposure period. This result is in contrast to the findings from AUTEK where fewer GVP events were recorded when Blainville's beaked whales were exposed to Naval sonar as compared to non-exposure periods.

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ZEBRAFISH AS A MODEL SYSTEM IN HEARING RESEARCH: INVESTIGATING THE SPECIES ADAPTATION TO THE NATURAL SOUNDSCAPE AND NOISE-INDUCED HEARING LOSS

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The zebrafish, *Danio rerio*, has become an important model organism to investigate the fundamental mechanisms underlying inner ear development and hair cell regeneration, as well as to test ototoxic environmental agents and drug treatments for auditory impairments. Even though this species has become a well-established model in hearing research, there is no information available on the soundscapes of its natural habitats. Besides, zebrafish are typically reared in large-scale housing systems, although their acoustic properties and potential effects on hearing remain unknown. Although anthropogenic noise is known to cause hearing dysfunction and physiological stress in fish, limited knowledge is available on the mechanisms underlying noise-induced hearing loss in this taxon.

Here, we will focus on two major research lines: 1) characterize the natural soundscape of zebrafish and comparison with captive noise conditions; and 2) evaluate the impact of ecologically-relevant noise levels on the inner ear structure and auditory function in zebrafish.

Our findings from field recordings in Southwest India showed that zebrafish natural soundscapes were quite diverse in amplitude (98-126 dB re 1 μ Pa) and in spectral composition, with quiet noise windows identified in the noisiest habitats matching the species best hearing range (400-2000 Hz). Contrastingly, typical zebrafish housing systems revealed higher amplitude levels (up to 143 dB) and most energy below 1000 Hz, which might cause significant auditory masking.

Experiments in the lab involved the exposure of adult zebrafish for 24 h to white noise at various amplitudes (130, 140 and 150 dB) versus lab silent conditions, and subsequent measurement of auditory sensitivity through the auditory evoked potential (AEP) recording technique. Results revealed noise level-dependent temporary threshold shifts (TTS) up to 33 dB within the best hearing range and gradual increase in response latency. Recovery of hearing function occurred within 3 days for fish exposed to 130 and 140 dB, while thresholds for fish treated with 150 dB noise only returned to baseline levels after 7 days. Hearing impairment was accompanied by significant loss and damage of the inner hair cells, but such effect was only detected at 150 dB.

In summary, our studies established an important ground for future research on the adaptation of zebrafish auditory system to the natural soundscapes; and provided first baseline data of noise-induced hearing loss (NIHL) in this species, which is crucial for future research on the mechanisms underlying noise effects on the structure and function of the vertebrate inner ear.

A REVIEW OF NOISE ABATEMENT SYSTEMS FOR PILING NOISE, AND THE POTENTIAL FOR THEIR APPLICATION IN SCOTTISH WATERS

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The Scottish Government supports plans to develop a large number of offshore wind farms (OWF) in Scottish territorial waters and the exclusive economic zone. The installation of foundations for offshore wind turbines often involves pile driving operations which introduce significant noise into the marine environment and has the potential to impact marine mammals and fish.

The primary objective of this study was to undertake a review of available underwater noise abatement systems (NAS) in relation to their applicability for use at pile-driving operations for OWF construction in Scottish waters. Parameters of interest were the reduction in noise levels that can be achieved and the resulting benefit to marine fauna, as well as the practicality of use, cost, and impact/influence on the construction schedules of projects

The study was based on a review of published peer-reviewed and relevant ‘grey’ literature, combined with a questionnaire-based survey followed up by interviews with system-suppliers and end-users of NAS. The NAS considered were bubble curtains, casings, resonators and alternatives to the conventional impact pile-driver. The environmental conditions at future Scottish OWF sites were characterised to determine the conditions within which the NAS would need to operate.

Based on the information gathered in this review, some of the NAS may potentially be suitable for use in future Scottish OWF sites and could reduce sound exposure levels by 7 to 20 dB and more, although operational experience of OWF construction in depths deeper than 45 m is lacking. The presentation will describe the status of currently commercially available and frequently used NAS and those under development, summarise the experience of NAS-user and NAS-providers with regard to the logistical requirements and limitations for the deployment and operation of these NAS, the environmental limitations that may influence the deployment and operation of NAS, the direct cost implications associated with the use of NAS, and their noise reduction efficacy specifically with reference to the marine species inhabiting Scottish waters. Data gaps will be highlighted which will help to identify future work required for a better understanding of the applicability of the NAS in Scottish waters.

ROLE OF THE LAGENA IN FISH HEARING AND ITS SUSCEPTIBILITY TO ANTHROPOGENIC NOISE

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In recent years, the impact of human generated noise on fish hearing has become a concern. While the saccule is thought to be the primary auditory end organ in many teleost fish species, there is evidence from a small number of studies that the lagena (Lu et al., 2003; Meyer et al., 2010, Vetter et al., 2019) and utricle are capable of detecting and encoding sound, including social acoustic signals (Schulz-Mirbach et al., 2018). These otolithic organs of the teleost inner ear are sensitive to acoustic particle motion, however, some species can also detect sound pressure indirectly via specialized connections between the swim bladder and inner ear. As the lagena is often positioned close to the swim bladder, this end organ may function in sound pressure detection. Furthermore, it is thought that the lagena could play a role in sound source localization, especially when the animal/receiver is close to the sound source, where the stimulus level is relatively high and likely saturating the saccule and its afferents (Lu et al., 2003). Therefore, the lagena could also be susceptible high amplitude anthropogenic sound, especially in fish species that rely on acoustic communication for social behaviors, such as the plainfin midshipman (*Porichthys notatus*) (Vetter et al., 2019). Here, I examine the contribution of the lagena to hearing and its ability to detect both acoustic particle motion and sound pressure to better understand how exposure to high levels of anthropogenic sound may affect fish hearing and auditory-driven behaviors.

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THE EFFECT OF BOAT NOISE ON CALLING ACTIVITY IN THE LUSITANIAN TOADFISH

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Anthropogenic noise has been increasing during the last decades, altering soundscapes throughout most aquatic environments. In estuarine shallow waters one of the most prevalent sources of underwater noise are motorboats and ferries. In this study we compared the effect of boat noise and ambient noise playback on the calling activity of the Lusitanian toadfish males (*Halobatrachus didactylus*), a species that relies on advertisement calls for mate attraction. Two sets of 12 concrete nests that toadfish males occupy spontaneously in the Tagus estuary (Portugal), were exposed to sounds during a fortnight by playing back either ambient noise (control) or boat noise (treatment). Noise treatment mimicked the passage of 10 ferries and of 4 small boats per hour during 18 hours, similar to what fish experience in Tagus estuary. Acoustic activity of each nesting male was monitored during the experimental period. Using an automatic recognition methodology based on the Hidden Markov Model to recognize Lusitanian toadfish vocalizations we found that calling rate significantly decreased in males of the boat noise treatment even at night, when there was no noise exposure. These results suggest that exposure to anthropogenic noise may impact reproduction in vocal fish.

DISCOVERY OF SOUND IN THE SEA: COMMUNICATING UNDERWATER ACOUSTICS RESEARCH TO DECISION MAKERS

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Anthropogenic activities, including the production of underwater sound, are subject to a wide range of environmental regulations. Decision makers must often rapidly synthesize new scientific research results to properly assess potential impacts of proposed projects. To assist this need, the University of Rhode Island Graduate School of Oceanography teamed with Marine Acoustics, Inc. on the *Discovery of Sound in the Sea* (DOSITS) project to provide a central digital resource for accurate scientific information on underwater sound. The project's foundation is a universally available website (dosits.org) that summarizes peer-reviewed scientific findings on underwater sound. The site has over 400 content pages and is updated semiannually with newly published scientific information after a thorough review by a panel of scientific experts. To focus on decision makers' needs, three surveys have been conducted since 2015 to prioritize underwater acoustics content and format options for government employees, federal and state contractors, non-governmental organization employees, and industry representatives.

A current focus of the DOSITS project is the development of resources, including webinars, for the international decision making community. Webinars include presentations by experts followed by interactive, real-time question and answer sessions, all of which is archived on the DOSITS website as a permanent resource. Webinars have been conducted in 2015-2016 and 2018, with modules on the science of underwater sound, sound production and reception by marine mammals, effects of sound on marine mammals, sound production and reception in teleost fishes, and effects of sound on fishes. The 2019 webinar series is focusing on sound sources, including wind turbines, pile driving, seismics, echosounders, sonar, and shipping.

In addition, tutorials, instructional videos, and e-books have been developed to address prioritized content from the decision makers' surveys, such as science of sound fundamentals, hearing sensitivities, and updates on potential effects of underwater sound on marine animals. The tutorials provide a streamlined sequence of webpages to develop knowledge. For example, one tutorial focuses on potential effects on marine animals from increasing background noise and specific sound sources. In contrast to the detailed, hour-long webinars, instructional videos are short clips highlighting key points (3-5 minute). The four currently available videos cover fundamentals of underwater sound, sound reception in marine animals, potential effects on marine life, and mitigation and monitoring methods. Finally, two e-books are available for iOS devices or Macs for offline viewing: "The Importance of Sound in the Sea" and "The Science of Underwater Sound."

CONTROLLED EXPERIMENTS OF NORTHERN BOTTLENOSE WHALES EXPOSED TO CLOSE AND DISTANT NAVY SONAR SIGNALS IN A PRISTINE ENVIRONMENT

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Impact assessments of naval sonar operations typically use received sound levels to predict behavioural disturbance in marine mammals. However, there are indications that cetaceans may learn to associate exposures from distant sound sources with lower perceived risk. To investigate the effect of both source distance and received level on cetacean behavioral response in an area without frequent sonar activity, we conducted multi-scale controlled exposure experiments (n=3) with 12 northern bottlenose whales near Jan Mayen, Norway (Wensveen et al., 2019). Animals were tagged with high-resolution archival tags (n=1 per experiment) or medium-resolution satellite tags (n=9 in total) and subsequently exposed to sonar. We also deployed bottom-moored recorders to acoustically monitor whale presence in the exposed area.

Tagged whales initiated avoidance response over a wide range of distances from the sound source (0.8-28 km), with responses characteristic of beaked whales. Avoidance threshold sound pressure levels (SPLs) estimated for each whale ranged from 117-126 dB re 1 μ Pa, comparable to those of other tagged beaked whales. Limited sampling of the acoustic environment, as well as decreased resolution in satellite tag locations, led to quantifiable uncertainties in the estimated acoustic dose associated with the behavioural response (von Benda-Beckmann et al., 2019).

Both onset and intensity of response were better predicted by received SPL than by source distance (Wensveen et al., 2019). In this pristine underwater acoustic environment, we found no indication that the source distance has an effect on the behavioural response of beaked whales to sonar exposure, as it had been suggested for locations where whales are frequently exposed to sonar.

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METHODOLOGY FOR DETERMINING COCHLEAR POSITION RELATED TO FREQUENCY ENCODING

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The current focus of our work is to formulate audiograms for baleen whales through computational modeling and anatomical and physiological experimentation (Tubelli et al., 2018). Part of this work requires characterizing the material properties of the basilar membrane; a structural component of the cochlea which supports the organ of Corti, which transduces acoustic signals into neural impulses sent to the brain. It is the structural variations along the basilar membrane that dictate how frequency distributions of an incoming sound are encoded. Therefore, it is important to know the exact location of any measurement of basilar membrane stiffness values for accurate interpretation of encoding characteristics.

Here, we present a method for formulating individual-ear specific spiral formulations and calculating the position along the basilar membrane at which stiffness measurements were taken to determine frequency-stiffness correlates. Species-specific models of cochlear geometries (Ketten, 1994; Ketten et al., 1998) and basilar membrane spirals were aligned and fitted to the individual curvature of each specimen membrane and positioned on high resolution photographs of the experimental sites.

This method produces reliable estimates of basilar membrane location with precisions of approximately 0.33%, providing a reliable means of localizing point-stiffness responses for improving audiogram estimation.

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SOUND PROPAGATION IN THE NEAR-FIELD AND FAR-FIELD OF A BROADBAND ECHOLOCATION DOLPHIN AND A NARROWBAND ECHOLOCATION PORPOISE

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Dolphins and porpoises project a relatively narrow and highly directional beam for locating prey, spatial orientation, and detecting other objects at a distance or in conditions where vision is useless in the ocean. The echolocation signals emitted by dolphins and porpoises can be roughly classified into two broad categories: broadband and narrowband high-frequency echolocation signals (Au, 1993; Au and Hastings, 2008). For the bottlenose dolphins (*Tursiops truncatus*), one of the broadband echolocation dolphins, no evidence of focusing was found as the echolocation signals propagated from near-field to far-field in the horizontal plane (Finneran et al., 2016). To further address this topic, we used high-resolution computer tomography (CT) scan data to construct the detecting click signal propagation models of a broadband echolocation dolphin and a narrowband echolocation porpoise in the vertical and horizontal planes. Finite element analysis (FEA) was used to simulate the clicks being emitted from phonic lips, travelling through the forehead in the near-field, and finally transmitting to the target in the far-field. The biosonar beam formation in the near-field and far-field including the amplitude contours for the two species were determined. The FE model was verified by finding the simulated amplitude contour in the horizontal plane and this was consistent with the prior measurement results for *Tursiops* (Finneran et al., 2016). Furthermore, the simulated far-field transmission beam patterns in both vertical and horizontal planes were also qualitatively consistent with the results measured from the actual live animals. This study shows that there is no evidence of convergence for either *Tursiops* or *Phocoena* in the near-field or far-field.

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THE BIOGENIC SOUNDSCAPE: TEMPORAL PATTERNS OF AN ESTUARINE CREEK NEAR SAVANNAH, GEORGIA

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The production and reception of sound is a critical process in organisms across a variety of taxa in aquatic environments. Observations of underwater soundscapes have been used to determine presence and temporal patterns of soniferous fish and snapping shrimp (Ricci et al., 2016).

This study described the relationships of these factors in an intertidal estuarine waterway, Country Club Creek, in Wassaw Sound, Georgia, USA. A hydrophone was deployed in a largely soft-bottomed creek near marsh grass, small oyster reefs and several docks, and sub-sampled 2 min of every 10 min during slack low and slack high tide at sunrise, mid-day, sunset, and mid-night hour long increments during June, July, and September, 2018. Sub-sampling and sound analysis methods of previous studies were reviewed to determine the most apt methods for this study (Monczak et al., 2017; Ricci et al., 2017). The purpose of the present study was to describe effects of month, time of day, or tidal stage and their interactions on biogenic sounds, including an examination of how relative soniferous fish and shrimp (Alpheidae) contributions to the soundscape change with these factors.

Oyster toadfish *Opsanus tau* calls were most strongly associated with diurnal factors, at 33% of all calls occurring during sunset and just 11% during sunrise, and tidal factors, at 73% of all toadfish calls occurring during low tide. Among other fish species, which include silver perch *Bairdiella chrysoura*, black drum *Pogonias cromis* and others, sound production was most associated with month, with at least 7% more calls in June than in July and September, and tidal factors were less pronounced, at 52% of calls occurring during high tide and 48% during low tide. Snapping shrimp were strongly associated with both monthly, at 13% more snaps in July and September than in June, and tidal factors, at 61% of all shrimp snaps occurring during low tide. This characterization of estuarine sounds suggests that not only is the understanding of interacting factors essential, but also the study of changes over time in species' relative contributions to the underwater soundscape critical for the future of bioacoustic research.

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THE IMPACT OF OCEAN NOISE POLLUTION ON FISH AND INVERTEBRATES

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This review of 115 primary studies encompasses various human-produced underwater noise sources, 66 species of fish and 36 species of invertebrates. Noise impacts on development include body malformations, higher egg or immature mortality, developmental delays, delays in metamorphosing and settling, and slower growth rates. Zooplankton suffered high mortality in the presence of noise. Anatomical impacts from noise involve massive internal injuries, cellular damage to statocysts and neurons, causing disorientation and even death, and hearing loss. Damage to hearing structures can worsen over time even after the noise has ceased, sometimes becoming most pronounced after 96 hrs. post-noise exposure. Even temporary hearing loss can last months.

Stress impacts from noise are not uncommon, including higher levels of stress hormones, greater metabolic rate, oxygen uptake, cardiac output, parasites, irritation, distress, and mortality rate, sometimes due to disease and cannibalism; and worse body condition, lower growth, weight, food consumption, immune response, and reproductive rates. DNA integrity was also compromised, as was overall physiology.

Behaviorally, animals showed alarm responses, increased aggression, hiding, and flight reactions; and decreased anti-predator defense, nest digging, nest care, courtship calls, spawning, egg clutches, and feeding. Noise caused more distraction, producing more food-handling errors, decreased foraging efficiency, greater vulnerability to predation, and less feeding. Schooling became uncoordinated, unaggregated, and unstructured due to noise. Masking reduced communication distance and could cause misleading information to be relayed. Some commercial catches dropped by up to 80% due to noise, with larger fish leaving the area. Bycatch rates also could increase, while abundance generally decreased with noise.

Ecological services performed by invertebrates such as water filtration, mixing sediment layers, and bioirrigation, which are key to nutrient cycling on the seabed, were negatively affected by noise. Once the population biology and ecology are impacted, it is clear fisheries and even food security for humans are also affected. Turtles, sharks, and rays were especially underrepresented in noise impact studies. Research on an individual's ability to survive and reproduce, and ultimately on population viability and ecosystem community function, is most vital. More long-term, realistic field studies also considering cumulative and synergistic effects, along with stress indicators, are needed.

BEHAVIOURAL RESPONSES OF SEALS TO PILE DRIVING DURING OFFSHORE WIND FARM CONSTRUCTION

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Offshore wind farm numbers will continue to grow over the coming years, with increased construction and operation of these devices in coastal environments. This has led to concerns about the potential risks to marine mammals. Concerns derive primarily from the high intensity sounds produced during pile driving as part of the foundation installation, potentially leading to a number of impacts including hearing damage, behavioural changes, habitat exclusion, and possible long-term effects on fitness. The at-sea distribution of seals overlaps highly with many of the areas proposed for development; however, our understanding of how seals may respond to these activities remains limited. There is evidence of significant declines in seal abundance near pile driving (Russell et al., 2016), but it is currently unclear if and how individuals change their movement behaviour in response to disturbance.

Using data on the movement and dive behaviour of tagged seals, this study aims to investigate the behavioural responses by individual seals to pile driving activity. Here, we present results from a study of 24 harbour seals (*Phoca vitulina*) fitted with GPS phone tags during construction of a wind farm in The Wash, south-east England. Over a period of four months, we recorded the movement tracks of over 500 encounters between seals and pile driving activity. The total duration of pile driving exposure for each seal ranged from 2.7 to 49.7 hours, with the closest approach distance varying from 3.9 to 40.5 km for each individual. Similar to approaches used to identify behavioural responses of tagged cetaceans to sonar (Antunes et al., 2014; Miller et al., 2014), we developed a Mahalanobis distance-based method to quantify behaviour change over time from seal tag data. For each seal, a randomization test was used to compare movement behaviour observed during pile driving to that observed during non-exposure periods, in order to identify potential behavioural responses. Predicted sound levels at each seal were estimated from an acoustic propagation model of pile driving, and a Bayesian hierarchical model was constructed to estimate the probability of seals responding to pile driving sound at different received levels. Increased understanding of individual response thresholds such as this can reduce uncertainty in impact assessments for future offshore developments and improve our ability to mitigate possible impacts.

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UNRAVELLING THE EFFECT OF VESSEL NOISE ON HARBOUR PORPOISE BEHAVIOUR BASED ON STATIC ACOUSTIC MONITORING DATA

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Vessel noise is the most pervasive anthropogenic input of noise to the marine environment with growing evidence that it constitutes a source of disturbance for coastal cetaceans. So far, the impact of vessel noise on toothed whales has mainly been studied based on visual observations or on tagged individuals. Studies based on tagged individuals can rely on individual-based and detailed behavioural data, but are limited to few individuals and short monitoring periods after a major disturbance event (the tagging). Inferences of tagging based studies are therefore limited to behavioural responses at fine spatiotemporal scales and an influence of the tagging procedure on the measured behavioural responses can often not be ruled out.

Static acoustic monitoring of echolocation clicks allows studying non-captive harbour porpoises in their natural habitat, is not limited to a few study individuals and does not depend on observer vessels with their inherent confounding effect. We use long-term time series of harbour porpoise echolocation clicks from a project funded by the German Federal Agency for Nature Conservation (BfN) to gain insight into harbour porpoise presence and behaviour at fixed monitoring sites around an offshore wind farm in the North Sea. Data on vessel passages and noise is obtained from automatic identification system shipping data and measurements of environmental noise at the monitoring positions.

NOISE DOSAGE REGIMENS: CAN PHYSIOLOGICAL NOISE IMPACTS ON MARINE MAMMALS BE MANAGED TEMPORALLY?

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There is growing recognition that exposure to anthropogenic underwater noise can impact marine mammals in important ways that are sometimes subtle and hard to quantify. Management choices may change the temporal structure of noise production: the noise dosage regimen for exposed animals. For example, limiting seismic survey operations to periods of good visibility extends the overall survey duration, while slowing ships to reduce peak noise levels prolongs transit times. However, we know little about how these trade-offs affect marine mammals. As a first step toward addressing this, we reviewed available literature on physiological effects of noise exposure in model laboratory species (eg., rats) to better understand the consequences of a noise dosage regimen. Several key findings emerged. Firstly, the use of acute or subacute noise exposure, particularly short, high-intensity bursts, in laboratory species to activate stress responses over several hours to days is commonplace. Many generalized aspects of stress responses were noted, including periods of heightened activity of the Sympathetic Nervous System, Hypothalamic-Pituitary-Adrenal axis, and other stress-related neuropeptide signalling systems such as corticotrophin-releasing hormone. Importantly, each of these systems exert broad, immediate influences on behaviour and physiology of the organism (eg., reduced social and sexual behaviour), while also contributing to long-term adverse health consequences (eg., disruptions in cognitive or affective function). Many classic effects of chronic stress were reported following noise exposures imposed over periods of days to weeks, including alterations in hippocampal function (reduced dendritic branching and spines, reduced neurogenesis, etc.) that contribute to cognitive dysfunction such as impaired learning and memory. Behavioural indices of increased anxiety were also noted, as well as metabolic changes that became more profound as the duration of noise exposure escalated from days to weeks. Other effects, such as increased tau phosphorylation in the prefrontal cortex, may contribute to noise-related vulnerability to neurodegenerative processes, whereas effects on inflammatory processes in the Central Nervous System likely contribute to enhanced pain sensitivity (hyperalgesia) in noise-exposed individuals. Thus, a broad spectrum of behavioural and neural alterations were evident in models exposed to noise on an acute, subacute or chronic basis. There was generally a lack of studies examining long-term chronic noise exposure at more moderate sound levels, revealing gaps in the use of lab-based studies with conventional terrestrial species to inform effective management decisions. However, repeated acute and subacute exposures over even relatively brief periods of days have been shown to have enduring physiological and cognitive impacts.

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THE INFLUENCE OF THE UPWELLING REGIME IN ROCKY SHORE BIOACOUSTIC SIGNATURE OFF CABO FRIO ISLAND

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In coastal zones, snaps, clicks, pops and crackles produced by benthic fauna can be quite representative in the soundscape (Butler et al., 2017). These sounds can be caused simply by the movement of these organisms on the substrate, by the stridulation/friction of the hard parts of their bodies or water circulation (Simmonds and MacLennan, 2008). Thus, when many individuals are active in an environment, the sounds merge into a timed sound, producing a Rocky Shore Bioacoustic Signature (RSBS).

This work aims to characterize the RSBS and its upwelling regime relationship. A structure with 4 hydrophones was installed near the Cabo Frio Island, Brazil. The Cabo Frio region is recognized as one of the main points of occurrence of upwelling phenomenon on the Brazilian coast. This phenomenon is characterized by the outcropping of deep, cold (lower than 20°C) and nutrient-rich waters to the surface and increasing of the primary productivity (Calado et al., 2018), especially during spring and summer. This one along with other hydrodynamic features makes the site a unique biological environment (Ferreira, 2003). Temperature data were collected and analyzed together with acoustic data. In addition, was utilized a sound propagation model to evaluate the transmission loss from sources distributed along the rocky shore (simulating RSBS). This simulation was performed for two scenarios, with and without upwelling characteristics.

The results showed the usual daily pattern, which present an increase in biological noise during twilight periods. We can see an interesting relationship between upwelling phenomenon and RSBS, where the RSBS is modulated by the water temperature (decreases in cold waters). This one occurs due to both high transmission loss and low source level caused by upwelling and probably decrease in metabolic rate of benthic organisms, respectively. This relationship between temperature and RSBS can contribute to the understanding of the organisms behavior in relation to the upwelling and to the development of new biotechnological applications.

Butler, J., Butler, M. J., and Gaff, H. (2017). "Snap, crackle, and pop: Acoustic-based model estimation of snapping shrimp populations in healthy and degraded hard-bottom habitats" *Ecological indicators* 77, 377-385.

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A NONLINEAR MODEL FOR ROCKY SHORE BIOACOUSTIC SIGNATURE OFF CABO FRIO ISLAND

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Different marine habitats have distinct acoustic signatures (Radford et al., 2014). These signatures are composed by anthropogenic, natural and biological sounds. In coastal zones, the acoustic signature has a stronger influence of benthic organisms that form the bioacoustic chorus (Butler et al., 2017), that we will term as the Rocky Shore Bioacoustic Signature (RSBS). However, RSBS patterns can be influenced by circadian and lunar cycles, wind, tide, temperature, luminosity and others. Yet, to better understand the influence of abiotic and biotic factors in the RSBS pattern it is very important to model, identify and quantify contributions of each these factors.

This work aims at proposing a nonlinear model for the RSBS, based on data collected off Cabo Frio Island, Brazil. This area sustains a unique environment due to strong upwelling occurrence and other hydrodynamic characteristics (Ferreira, 2003; Calado et al., 2018). A bottom structure with 4 hydrophones and temperature/luminosity sensor was installed near a rocky shore during 82 days. A meteorological dataset (rain, wind, solar radiation) from National Institute of Meteorology (INMET) were utilized for RSBS modelling. The RSBS model was based on a nonlinear least squares multiple regression technique.

Regression analysis revealed that temperature and luminosity explain approximately 50% of the RSBS variance, while other abiotic factors explain just 5%, approximately. Another important result was the nonlinear relationship between luminosity and RSBS. This puts in evidence that the biorhythm can be one of the principal of contributors for RSBS, increasing in twilights. In addition, this model may help to understand RSBS patterns and its variations, and help for developing bioacoustic inversion applications as abiotic data measuring, populational density of benthic organisms and marine health monitoring.

Butler, J., Butler, M. J., and Gaff, H. (2017). "Snap, crackle, and pop: Acoustic-based model estimation of snapping shrimp populations in healthy and degraded hard-bottom habitats" *Ecological indicators* 77, 377-385.

Calado, L., Rodríguez, O. C., Codato, G. and Xavier, F.C. (2018). "Upwelling regime off the Cabo Frio region in Brazil and impact on acoustic propagation" *The Journal of the Acoustical Society of America* 143 (3), EL174-EL180.

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ANTHROPOGENIC SOUND EXPOSURE-INDUCED STRESS IN CAPTIVE DOLPHINS AND IMPLICATIONS FOR CETACEAN HEALTH

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Many cetaceans are exposed to increasing pressure caused by anthropogenic activities in its marine environment. Anthropogenic sound has been recognized as a possible stressor for cetaceans that may have impacts on health. However, the relationship between stress, hormones, and cytokines secretion in cetaceans is quite complexed and not fully understood. Besides, the effects of stress are probably inconsistent because the character, intensity and duration of the stressors are variable. To explore how anthropogenic sounds affect the psychophysiology of cetaceans, the present study compared the changes of cortisol level and cytokine gene transcriptions in blood samples and behaviors of captive bottlenose dolphins (*Tursiops truncatus*) after sound exposures. The sound stimuli were 800 Hz pure-tone multiple impulsive sound for 30 min at different sound levels that likely cause no permanent and temporary threshold shift in dolphins. Six cytokine genes (IL-2R α , IL-4, IL-10, IL-12, TNF- α , and IFN- γ) were selected for analysis. Cortisol levels and IL-10 gene transcription increased significantly and IFN γ /IL-10 ratio was significantly lower after a 30-min high-level sound exposure, indicating the sound stimuli used in this study could be a stressor for cetaceans, although only minor behavioral changes were observed. This study may shed light on the potential impact of pile driving-like sounds on the endocrine and immune systems in cetaceans and provide imperative information regarding sound exposure for free-ranging cetaceans.

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DIFFERENCES IN MEASURED MIDDLE EAR TRANSFER FUNCTIONS BETWEEN CETACEANS AND MYSTICETES

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Knowing how the middle ear shapes the frequency response of sound is critical to estimating what frequencies a species can hear. Odontocetes are often categorized as high frequency listeners while mysticetes are low frequency listeners. We measured the frequency response of 10 odontocete and 3 mysticete middle ears. To measure the transfer function (output velocity relative to input velocity or force) we exposed the stapes footplate through the cochlea and measured its velocity with a laser Doppler velocimeter in response to a velocity or force source over a wide frequency range. The source was placed on a variety of anatomical locations in order to test for the most sensitive region and to measure if there is a frequency dependency on the input location of the stimulus.

The odontocete transfer functions all had results where the frequencies less than a certain point were attenuated and the high frequencies were transferred to the stapes, (a high pass response). The frequency at which this point occurred (corner frequency) varied from 10 kHz to 30 kHz depending on the specimen. The high frequencies extended to the limit of our measurement capability (125 kHz).

The three mysticetes had a bandpass response when stimulated at the glove finger. A bandpass response is characterized by a peak sensitivity in a frequency band and attenuation of frequencies greater and less than the peak. For the mysticetes, the peak was in the 0.5 kHz to 2 kHz region. When the mysticete ears were stimulated on the tympanic bone, the high frequency range of the peak was shifted to higher frequencies.

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