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METHODOLOGY RISK ASSESSMENT FOR NOISE AREAS

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Issue: Development of a methodology for acoustic risk mapping implemented in NETCCOBAMS

1. Action requested

The Scientific Committee is invited to:

a. **note** the methodology for acoustic risk mapping implemented in NETCCOBAMS;
b. **advise** on the development of acoustic risk maps.

2. Background

In the framework of the ACCOBAMS Working Programme 2016-2019, ACCOBAMS Parties expressed the willingness to start trials of best available science and new technologies in order to collect, analyse, and model data on cetaceans, as well as on impacting human activities, so to support the threat-based management approach and the identification of Cetacean Critical Habitat.
The objective was to update the NETCCOBAMS platform.

Thanks to a voluntary contribution from Italy, SINAY experts were selected to undertake the work focusing first on anthropogenic noise.

The attached document reflects the methodology developed to identify, plot and quantify areas where cetaceans may suffer from adverse effects caused by shipping noise, through the following iterative process:

i) the first draft was proposed by SINAY experts on environmental assessments and underwater noise;
ii) an online workshop was held with members of the ACCOBAMS Scientific Committee and the co-Chair of the TG-Noise (also member of the JNWG);
iii) improvements and modifications of the original draft were integrated in the second draft methodology which is presented in the attached document.

Methodology for acoustic risk mapping implemented in NETCCOBAMS

Accobams

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SINAY
MARITIME DATA SOLUTION

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1 INTRODUCTION

1.1 Context and Objectives

In the framework of the ACCOBAMS Working Programme 2016-2019, the ACCOBAMS Secretariat expressed the willing to start experimentation of best available science and new technologies to collect, analyse, and model data on cetaceans as well as on impacting human activities, in order to support the threat-based management approach and the identification of Cetacean Critical Habitat. The focus of the whole experimentation was on three items of the triennal Working Programme: Anthropogenic noise (item CA2b), Climate Change (CA2g), Chemical and biological pollution (CA2f).

SINAY was entrusted address such experimentation through the development of a platform that would replace the existing NETCCOBAMS tool with a new platform available online. The new NETCCOBAMS platform is meant to include both the already existing features and the new elements addressing the anthropogenic noise, climate change and chemical and biological pollution. Given the extremely large extent of the scope of such experimentation, it was decided by ACCOBAMS to focus on anthropogenic noise first. This choice is based on the fact that noise has been addressed since a long time by ACCOBAMS and that scientific litterature is available on adverse effects on cetaceans and monitoring methodologies (CBD, 2012; Erbe et al., 2019). However, to address anthropogenic noise, not only novel technologies are necessary, but also new scientific methods such as for the quantitative assessment of the risk of underwater noise on cetacean populations and habitats.

This paper describes the development of the methodology implemented in NETCCOBAMS to identify, plot and quantifiy areas where cetaceans may suffer from adverse effects caused by shipping noise. The methodology has been developed thanks to an iterative process: i) the first draft was proposed by SINAY experts on environmental assessments and underwater noise; ii) then, an online workshop was held with members of the ACCOBAMS Scientific Committee and the co-Chair of the TG-Noise (also member of the JNWG); iii) furthermore, improvements and modifications of the original draft were integrated into the second draft methodology which is presented in this document to the present meeting of the Scientific Committee of ACCOBAMS (SC14).

1.2 Methodological approach

The approach taken for the new NETCCOBAMS platform is based on common Risk Management, a standardized process under ISO31000:2018[1]. With the terminology used in the ISO 31000 standard, Risk is defined as the ‘effect of uncertainty on objectives’, where the ‘objectives’ may be referred to the conservation goals of the ACCOBAMS Agreement. Following the ISO standard, Risk is expressed in terms of risk sources, potential events, their consequences and their likelihood. When it comes to environment, the likelihood of something happening (for example negative effects on cetaceans such as auditory impairment or avoidance of portions of habitats) can be studied through techniques that focus on how much a hazard (noise) comes in contact with an ecological endpoint (cetaceans), including spatial and temporal quantifications. This is usually referred to as the ‘Exposure Assessment’ or ‘Exposure Analysis’ by the US Environmental Protection Agency (EPA)[2]. In this regard, the likelihood of occurrence of adverse effects depends on the presence of the species which are vulnerable to loud noise levels, where ‘presence’ can be expressed in several ways, including habitat suitability and estimated abundance.

According to such definitions, for the NETCCOBAMS platform we propose a methodology for computing acoustic risk areas based on the spatial and temporal overlap between ship-radiated noise

[1] https://www.iso.org/obp/ui#iso:std:iso:31000:ed-2:v1:en:term:3.4
[2] https://www.epa.gov/risk/conducting-ecological-risk-assessment

levels having the potential to entail adverse effects and the presence of cetaceans in the ACCOBAMS Agreement area.

1.3 Species

The work focused on 3 cetacean species for which scientific literature is available concerning the effects of ship noise:

- the fin whale (Castellote et al., 2012)
- the Cuvier's beaked whale (Aguilar de Soto et al., 2006)
- the sperm whale; for this species there is more uncertainty concerning the effecs of ship noise and the diverse responses described in different studies (avoidance, no response, and even attraction) highlight the importance of context in assessments of underwater noise (Erbe et al., 2019).

1.4 Study area

The whole ACCOBAMS area is used for computation of risk maps. This area extends to the whole Black Sea and Mediterranean Sea and a portion of the North-eastern Atlantic Ocean spanning from the Gibraltar strait up north to Spanish waters in the Bay of Biscay and through continental Portuguese waters. The area is roughly comprised between longitudes of - 13.8 and 42, and between 30 and 47 degrees latitude north (Fig 1).

Figure 1. Area used for computing acoustic risk maps in the NETCCOBAMS platform.

2 SHIPPING NOISE MAPPING

2.1 Noise Modelling

The general approach is based on the use of the Automatic Identification System (AIS) to gather data on vessels crossing the study area (noise sources), and of environmental parameters as drivers of propagation of sound waves. Input data are used to estimate the propagation of noise radiated by ships and to compute received noise levels across the study area.

To achieve this, we adopted the following plan:

- Select a geographical area of study,
- Identify the input parameters of the propagation model,
- Identify sources of noise (ships navigating in the ACCOBAMS Agreement area in our case),
- Choose a propagation model,
- Calculate the noise level emitted for each source,
- Calibrate the model with in-situ recordings,
- Make a statistical study of the percentiles and mean noise levels for each frequency band considered.

The final goal is the calculation of statistics like the arithmetic mean and different percentiles of noise levels in decibels (dB re 1µPa) relative to the study period, at any point of the study area. For this work, AIS screenshot were taken at random intervals, i.e. 3 random screenshots per day, totalling 180 screenshots during the whole study period (01/07/2019 to 01/09/2019). Each vessel present in each AIS screenshot is used as a noise source for modelling. The noise radiated by each vessel is then summed up to obtain a noise map representing the noise conditions for that AIS screenshot. A noise map is obtained for all AIS screenshots, then the calculation of the noise statistics over the study period is performed. The arithmetic mean and the percentiles are based on this sample size (n = 180).

A diagram summarising the methodology used to carry out the modeling of ship-radiated noise is shown below (Fig 2).

Figure 2. Noise modelling workflow

2.2 Input Data sources

2.2.1 AIS data

The AIS feed (Automated Information System) is a protocol for the automated exchange of messages between vessels by VHF radio and satellite data. This system makes it possible to know the identifier, status, position in near real time, as well as the size, speed, load and route of vessels located in the area. AIS data can be used to enable realistic shipping noise mapping, as they provide parameters required as input for an acoustic modelling system. For the present work, AIS messages sent by both VHF and satellite (S-AIS) were used to guarantee best quality data. We obtained AIS data by the antenna network and satellites images provided by SPIRE which were structured to be directly exploited by underwater noise modeling algorithms.

2.2.2 The Source level Model

Several physical phenomena can generate noise in the displacement of a ship, e.g., the effect of cavitation, vibration tree line, vibration rotary machine transmitted by the hull and bow wave etc. Each of these phenomena generates noise on a different frequency band and with different levels. Further factors affect the noise generated by a navigating ship and especially the speed, the length, the load and the depth of the the propeller.

The Source Level (SL) is the noise level emitted by a noise source, in our case a ship, which is generally referred to the level that could be measured at 1 m from the source. A SL model is described by a level in dB re 1 µtPa m associated to the main factors affecting the emission level of a ship. To perform effective propagation modelling, general source level models available in litterature can be used and each method presents strenghts and weaknesses depending on sea state, available vessel information, water depth, distance of measurements and more. Therefore, the choice of the model for NETCCOBAMS was made empirically using the calibration data gathered during the QUIETMED project. We found that the model closest to the data recorded is the **Randi model** in the low frequency (Breeding et al., 1996).

2.2.3 Environmental variables

For the estimation of the propagation of sound waves, environmental drivers are to be quantified through several coefficients:

- ✓ Water column data: sound speed profile (calculated from temperature and salinity, in 3D);
- ✓ Geo-acoustic model of the bottom:
    - o number of layers (sediment layers, sub-bottom, etc.) and thickness (in meters)
    - o velocity profile (m/s)
    - o density (g/cm^3)
    - o attenuation of compressional waves and shear waves (dB/λ)

The selection of the coefficients depends on the availability and on the resolution of environmental data, and therefore on the assumptions made whenever necessary to overcome data gaps.

Bathymetry

The acoustic wave propagation in the ocean can be defined into two main phases: free propagation and interactions with frontiers and obstacles. When an acoustic wave encounters the bottom, a part of the wave is transmitted into the sediment, while the other part is reflected. That’s why the energy losses in the shallow waters are much greater than in the deep sea.

The shape of the bottom is also important. Many phenomena occur during the contact of the acoustic wave with the seabed as the diffusion of waves, transmission and reflection. For this reason, the angle of incidence of the wave that arrives at the interface (water / seabed) affect the amount of energy transmitted and reflected. Therefore, the resolution of the bathymetry data is a crucial parameter in the choice of the database. In our case over a large area a resolution of **130 m** between two successive points is considered adequate. Bathymetry was obtained from the EMODnet Digital Terrain Model with a resolution of **0.01°**.

Sound speed profile
Due to the limitation of the propagation medium by the surface and the sea floor, the acoustic wave undergo successive reflections on the interfaces. Moreover, variations in the speed of the medium can cause deformations of the sound wave paths. The speed of sound depends both on temperature, salinity and depth, and varies in the same direction as these three magnitudes.

The temperature and the salinity of the area are two key parameters for calculating the velocity profile of sound in water which changes with depth. For this task, we collected the data from from **Copernicus Marine Environment Monitoring Service (CMEMS)**. Means for July and August 2019 were calculated from the daily means obtained from the service.

Sediment type and sediment thickness database
The shape and nature of the sediments have a major impact on the level of ambient noise and especially in the shallow bottom where reflections are multiple. The sedimentation process leads naturally to vertical stratification in most cases. The geometry of the studied environment varies slowly in the horizontal plan but quickly in the vertical plan. The influence of the seabed is much more complex than that of the surface; many phenomena are present simultaneously: diffusion by the relief of the water-bottom interface; penetration of the sediment incident wave, sediment damping, sediment refractions and reflections, and attenuation of the P (longitudinal) and S (shear) waves.

Given the absence of samples on the study area or calibration measure with active emissions that allows us to identify the geoacoustic parameters accurately, our choices are based on the **SHOM** database. These maps allow us to identify the type of sediment to know approximately the values of the density and the coefficient of attenuation in this medium.

2.3 Model computing

2.3.1 The choice of the most suitable propagation model

Several mathematical methods exist to calculate the transmission loss and to consider the physical phenomena of the propagation of the acoustic wave. In our case study, the choice of the propagation model at the studied frequency bands (1/3 octave bands centred at 63 Hz and 125 Hz) is directly related to the nature of seafloor and to the bathymetry « Range dependent (RD) » or « Range independent (RI) » in shallow and deep water. An appropriate modelling method for this study is therefore the range-dependent parabolic equation (**RAM**).

2.3.2 Model outputs

Outputs of the models are matrices where each cell of the grid are assigned sound levels in dB re 1µPa. To be coherent with the ongoing work done on underwater noise monitoring and assessment by EU Member-States under the MSFD, two 1/3 octave bands are used: one centred at 63 Hz and the other at 125 Hz. Such choice is also consistent with IMAP guidance developed by UNEP/MAP for the Mediterranean Sea basin. With regards to noise indicators, we calculated the arithmetic mean, the 50th and the 95th percentile: the arithmetic mean to adopt the recommendation of TG-Noise (Dekeling et al. 2014); the 50th percentile because it represents the median value of underwater noise and is widely acknowledged as an appropriate indicator for describing ambient noise levels of an area; and the 95th percentile because this indicators points up the highest levels. In summary, model outputs shown in NETCCOBAMS are the following:

- Arithmetic mean, 50th percentile (median level), and 95th percentile of the sound level distribution at the 1/3 octave frequency band centred at 63 Hz
- Arithmetic mean, 50th percentile (median level), and 95th percentile of the sound level distribution at the 1/3 octave frequency band centred at 125 Hz

Figure 2 and 3 show examples of noise maps shown in NETCCOBAMS.

Figure 3. Median shipping noise level during July-August 2018, corresponding to the levels exceeded during 50% of the assessment period. This indicator may be also referred to as the 50th percentile of the shipping noise level distribution during July-August 2018.

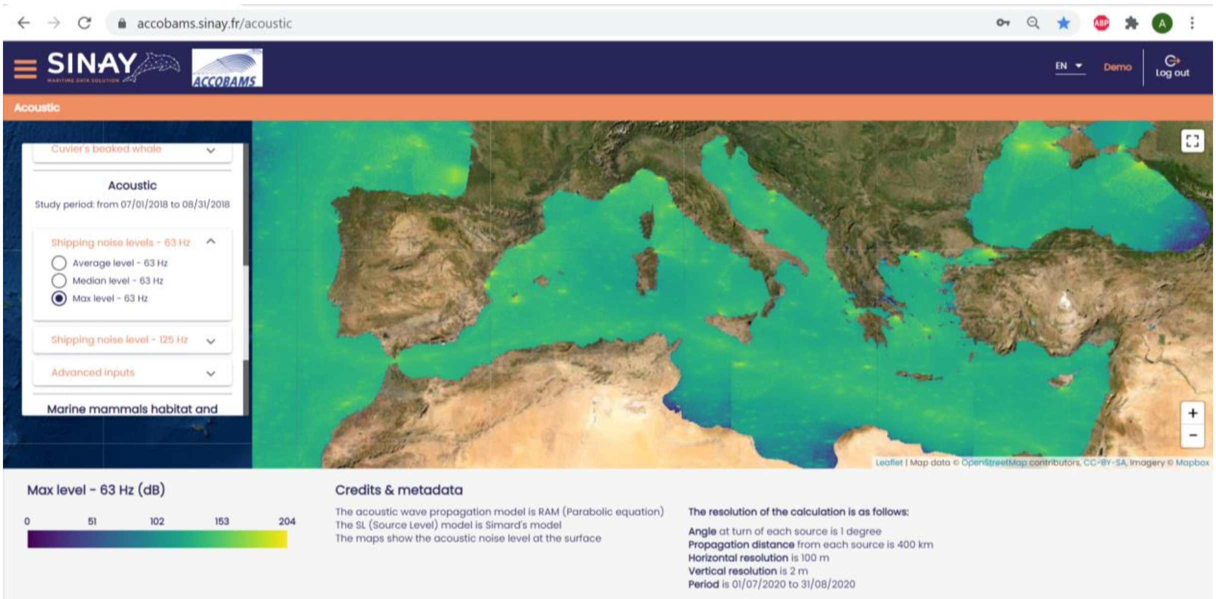

Figure 4. 95th percentile of shipping noise level distribution during July-August 2018, corresponding to the levels exceeded during 5% of the assessment period.

3 CETACEAN DISTRIBUTION MAPPING

Three kinds of maps are used and displayed in NETCCOBAMS:

Maps obtained from results of the Accobams Survey Initiative (ASI[3]): a wide aerial survey of the Mediterranean Sea basin carried out in 2018. ASI maps present the predictions of animal absolute abundance in the Mediterranean. Such results are available single species:

- fin whale, Risso's dolphin, bottlenose dolphin, striped dolphin.

and for groups of species:

- "striped or common dolphins", meaning that the map refers to the abundance of either striped or common dolphin. This map was produced by using sightings for which observers could not distinguish between the two species.
- "small dolphins", including striped dophins, common dolphins, bottlenose dolphins as well as other delphinds frequenting the ACCOBAMS area such as rough-toothed dolphins. This map was produced by using sightings that observers did without distinguishing between all possible small-sized dolphin species.

Maps obtained from results of the CeNoBS project[4] in the Black Sea:

- Bottlenose dolphin

Maps obtained through a habitat model exercise done by the SINAY team based on a machine learning algorithm (gradient boosting model, GBM). Maps based on GBM modelling were produced for species for which ASI data were insufficient or not available: sperm whales, Cuvier's beaked whales.

As mentioned above, the risk mapping exercise was done for 3 species: the fin whale (for which we could use ASI results), the sperm whale and the Cuvier's beaked whale (for which we used GBM model-based maps). With regards to CeNoBS, abundance maps for harbour porpoise and common dolphin are also available but are not shown in NETCCOBAMS for specific reasons: abundance maps of common dolphin is available for the Black Sea but not the Mediterranean Sea, while harbour porpoise is not shown nor used for risk mapping since the focus of this experimentation (Cf chapter 1.1) is the Mediterranean Sea.

3.1 ASI maps

Fin whale abundance maps were produced as the part of the ASI programme by a dedicated team in charge if this task. For the methodology used for the estimation of absolute abundance, the reader may refer to the the final ASI report [ACCOBAMS, 2021].

Figure 5 show the fin whale abundance map before upload to NETCCOBAMS, as reproduced based on ASI results received by the ACCOBAMS Secretariat.

[3] https://accobams.org/main-activites/accobams-survey-initiative-2/accobams-survey-initiative/

[4] https://www.cenobs.eu/

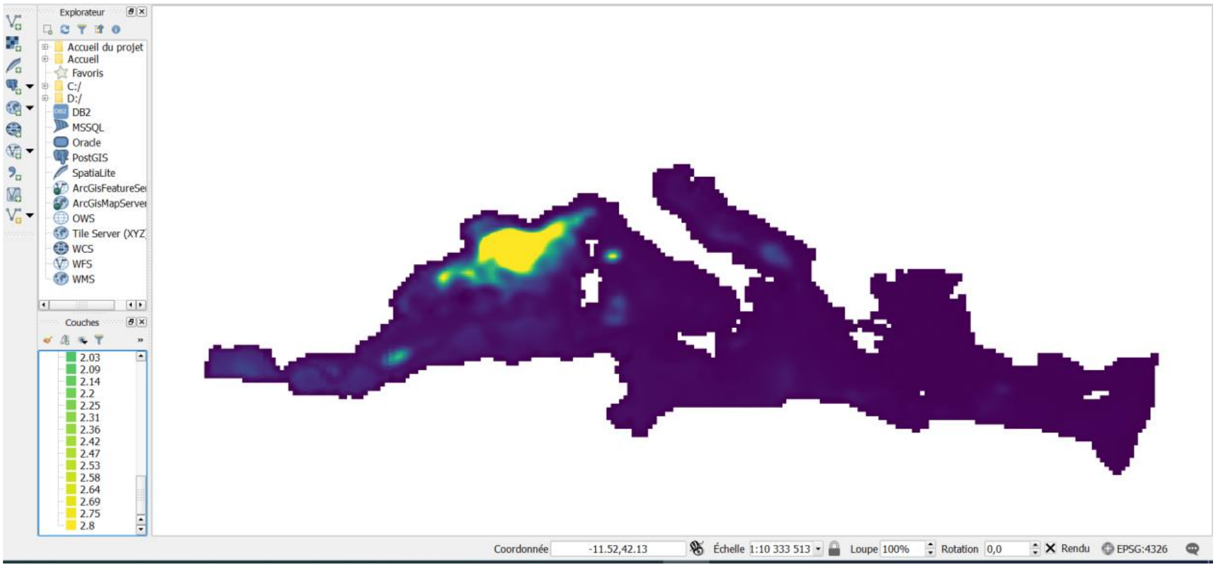

Figure 5. Fin whale abundance map, reproduced fom ASI row results under preparation for NETCCOBAMS.

3.2 GBM-based maps

The GBM modelling was used for sperm whale and Cuvier's beaked whale because abundance maps for these species could not be produced based uniquely on ASI data and no other pre-validated maps were provided by the ACCOBAMS Secretariat for these species.

GBM models need to be fed with presence and absence data. Presence data were obtained from two sources and merged:

1. The Ocean Biodiversity Information System (OBIS, www.obis.org), an open-access database fed by several research projects who are willing to share their data.

2. The Accobams Survey Initiative (ASI)

Sea surface temperature, sea surface salinity, and surface chlorophyll-A concentration (as a proxy of primary productivity) were obtained from the Copernicus Marine Environment Monitoring Service (CMEMS). Means for the year 2018 were calculated from the daily means obtained from the service.

Bathymetry was obtained from the EMODnet Digital Terrain Model with a resolution of 0.01°.

3.2.1 Data processing

All processing steps were performed using R (v. 4.1.0) and specifically the packages: *raster*, *sf*, *dismo*, *mgcv*, as well as the *tidyverse* for general data manipulation.

To create a consistent scaling between all source data and outputs, a grid of 0.02 degrees resolution on both coordinates was established. All predictor variables were resampled to this grid.

All observations of species presence were considered in the analysis, representing 2660 sighting points for *Physeter macrocephalus*, and 316 points for *Ziphius cavirostris*.

Background (absence) data was randomly generated considering only the cells which do not contain a presence point. The number of absence points was fixed at the same number of presence points.

3.2.2 Habitat suitability modelling output

For each species, a GBM model was parameterised to estimate the habitat suitability to the presence of that species. The final model was a Bernoulli-family 950-tree model, with a tree complexity of 10, a learning rate of 0.005, and a bag fraction of 0.5.

Model output is a continuous function ranging from 0 to 1, where suitable habitats are found where model outputs tends to 1.

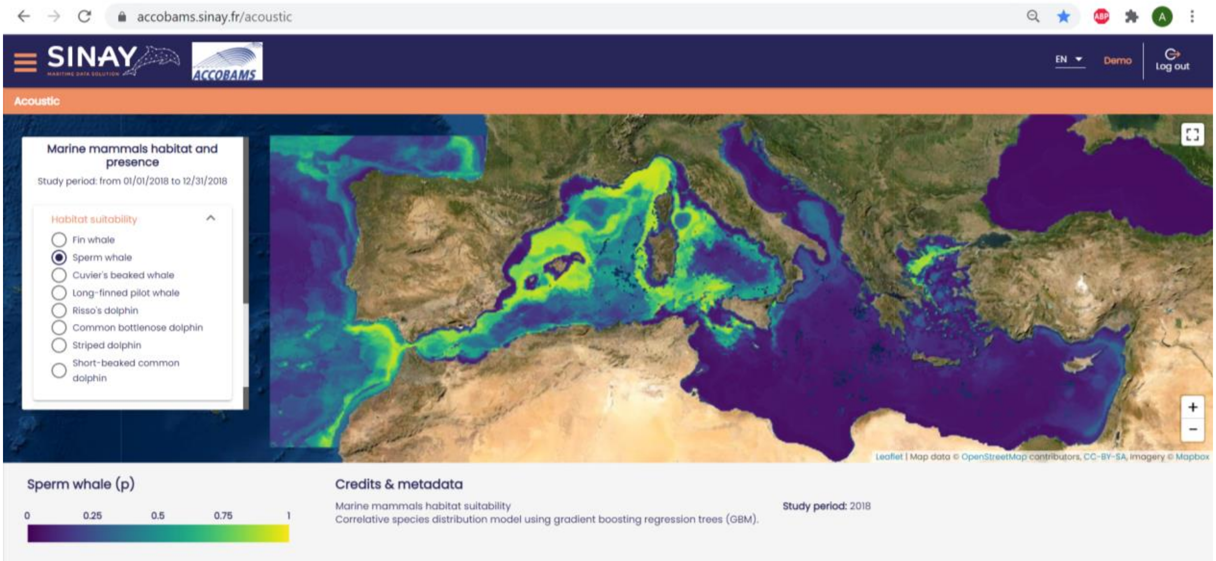

Figure 6. GBM model for habitat suitability for Sperm whales

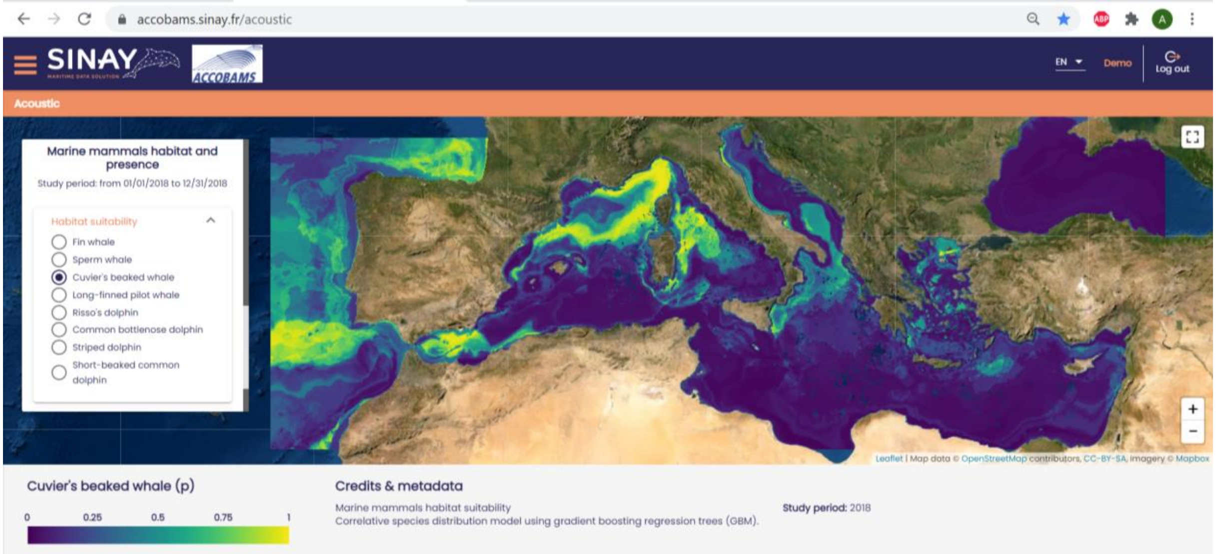

Figure 7. GBM model for habitat suitability for Cuvier's beaked whales

4 ACOUSTIC RISK MAPPING

Following the ISO 31000 definition of risk, we derived a series of acoustic risk maps from the combination of shipping noise maps and species distribution maps. The way noise and cetacean maps are combined together is based on the exposure assessment step of a risk assessment exercise. This step implies studying to what extent cetacean populations are exposed to continuous noise levels high enough to cause negative effects. As we want to support the threat-based management approach implemented by ACCOBAMS, the aim of the exercise is to identify areas presenting highest risks. Therefore, acoustic risk maps are defined here as "**the combination of areas with high probability of cetacean presence and areas with shipping noise over levels of onset of biological adverse effect**".

Based on this definition, two kinds of thresholds were set: a first kind to define "high" probability of cetacean presence; and a second one for the "level of onset of biological adverse effect".

Concerning cetacean presence, the threshold applied was 0.75 based. For sperm whales and Cuvier's beaked whales, habitat suitability scores (ranging from 0 to 1) could be used directly to this end, i.e. only areas where habitat suitability scores exceed 0.75 contribute to the computation of acoustic risk maps. For fin whales, input data were absolute abundance values and hence these values were rescaled to range between 0 and 1 in order to normalize the risk mapping process. The formula used to rescale fin whale abundance data was the following:

$$z_i = \frac{x_i - \min(x)}{\max(x) - \min(x)}$$

Where z_i is the new abundance score ranging from 0 to 1, x_i the original value to be rescaled, and *min(x)* and *max(x)* are the original minimum and maximum abundance values. Therefore, rescaled fin whale data can be read as little estimated abundance where values tends to 0, and high estimated abundance where values tend to 1. After such post-processing, the 0.75 threshold could be applied to fin whales.

With regards to noise, the thresholds for onset of effects indicated in best available litterature (NOAA, 2016) were taken to derive the threshold levels used for this work: 112 dB re 1µPa and 130 dB re 1µPa. These values correspond to the temporal threshold shift (TTS) and permanent threshold shift (PTS) effects, respectively. The units have been transformed from the units used in the NOAA guidelines (2016) in order to fit for the calculation of noise indicators (Cf chapter 2), and hence the values are different from those found in the NOAA guidelines.

It is important to note that PTS and TTS thresholds derived from NOAA guidelines are not used to assess whether animals/populations have actually suffered from PTS and TTS, as this would require a different methodological framework, but rather to highlight the areas where adverse effects due to continuous noise is more likely to occur. Based on this reasoning, we simply consider that areas bounded by TTS or PTS thresholds represent, for animals frequenting those areas, a moderate to high risk of effects, respectively, where 'effects' may include any behaviroual and/or physiological effect. The same threshold values are applied to both third-octave bands used in this work. Further, thresholds for PTS and TTS were used on the maps showing the 95th percentile of shipping noise. This choice implies that the time component is enbedded into the resulting risk maps. The thresholded noise maps can be read indeed as the areas where levels of onset of auditory impairment are exceeded during 5% of time overall in the study period.

Finally, acoustic risk areas are calculated, for both the octave-bands centred at 63 Hz and 125 Hz, as the intersection of areas where a TTS or PTS threshold was exceeded during 5% or the study period and where probability of presence (or proportion of estimated abundance) was over 0.75.

In the figures below, the intersection is shown in red where the PTS threshold is used (higher risk of effects) and orange for the maps based on the TTS threshold (moderate risk of effects).

Figure 8. Areas at higher risk for Cuvier's beaked whale for the octave-band centred at 63 Hz.

Figure 9. Areas at moderate risk for Cuvier's beaked whale for the octave-band centred at 63 Hz

5 DISCUSSION AND CONCLUSIONS

The methodology described in this document represents one of the possible ways to apply the principles of Risk Assessment to underwater noise pollution generated by ships. It was developed with a view to enable meaningful and science-driven conservation measures for cetaceans against the adverse effects of underwater noise. This effort is part of overarching goals of the ACCOBAMS Agreement which are to identifify Cetacean Critical Habitats and to implement a threat-based management approach to cetacean conservation.

The Risk Assessment process was taken as basis to develop the methodology presented here as it is a well established framework, standardised under ISO 31000. To apply it to underwater noise we used best available science on underwater acoustics and cetacean ecology, and the way such two elements are combined to assess acoustic risk for cetaceans is the main step forward addressed in this document.

Several choices are necessary to define such risk-based assessment methodology: what noise indicators (average noise, median, percentiles…), what impact threshold values to consider, what ecological indicator (presence, abundance, group size, etc.) and so on. Within this list, we consider that different choices may be valid thus leaving the door open for different and complementary levels of assessment.

Nonetheless, the topic of impact threshold (PTS, TTS) deserves more attention as the way such threshold values are used in this document may not be self-evident. We know indeed that several factors, beyond the noise levels themselves, play an important role determining whether or not an effect will occurs: the duration of exposure, biological factors like the age of individuals, ecological factors like the period of the year, and more. Also, as the methodology presented here makes use of noise maps in 2D, the time spent by an animal in the depth layer shown in noise maps is highly relevant. Based on this, we may expect that only a portion of the population that overlaps noise levels exceeding some threshold will show the corresponding theoretical reaction; and lastly, it is still unknow to what extent such reactions affect a population in terms of survival, birth rate, and further population parameters.

With this in mind, the reasoning underlying the development of the methodology implemented in NETCCOBAMS contemplates the possibility that exceedance of PTS/TTS thresholds may not necessarily imply an auditory impairment, but rather result in increased probability of any adverse effects related to exposure to noise. That's why PTS and TTS thresholds are not used to assess whether animals have actually suffered from PTS and TTS and/or how much proportion of population has been impaired. Rather, these threshold levels are used to bound the areas where adverse effect due to continuous noise may occur with increased probability.

With regard to the use of information provided in NETCCOBAMS for management and decision-making processes, the extent of acoustic risk areas is calculated and expressed in km^2. This indicator can be monitored along time to assess whether acoustic risk areas get bigger, remain stable, or decrease. In the end, the extent of acoustic risk areas can be used to support a range of decisions about the implementation of adequate conservation measures.

Concerning future efforts, next steps may focus on the use of percentiles of shipping noise levels other than the 95^{th}, for example the 50^{th} and 75^{th} precentile, in order to study how the shape and the extent of acoustic risk maps change compared to the results done with the present methodology, and to evaluate what methodology suits better with relationship to the objectives of cetacean conservation. More broadly, improvement of the current framework will certainly occurr as long as new information becomes availabe on dose-response curves and generally on the effects of continuous noise on cetaceans. Meanwhile, the methodology described here represents the first worked attempt to apply a regional and ecosystem-based framework for the assessment and management of continuous noise and can be already used as a valuable source of information to support conservation of cetaceans in the ACCOBAMS Agreement area.

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