Modelling underwater sound fields from noise events contained in the ACCOBAMS impulsive noise register to address cumulative impact and acoustic pollution assessment

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Summary

The need to monitor and assess marine noise pollution from impulsive signals in European waters has been especially tackled by the European Union through the Marine Strategy Framework Directive, whereby the establishment of a register of impulsive noise sources is recommended. Today, this register is primarily meant at recording data on the location and time of the use of noise sources, with the aim of computing and mapping the number of days with impulsive noise over a year and over a regular spatial grid (Pulse-block days). While this system allows identifying areas with concentrating noise-producing human activities, it leaves many questions unsolved such as those addressing the cumulative acoustic effects on marine wildlife of multiple sources. In the Mediterranean Sea and the Black Sea, the development of a common noise register following the framework described above is led by ACCOBAMS in cooperation with the Barcelona Convention. This work presents an approach for enriching the ACCOBAMS register with sound propagation models based on the following steps: modelling the propagation of sound from noise events contained in the register; applying sound exposure criteria available in the scientific literature to convert estimated sound fields into potential disturbance to marine life; calculating and mapping the area and periods of disturbance. Test results obtained by applying this approach are presented and can be used to feed the discussion on the future development of impact indicators for the Mediterranean and the Black Sea. Further, this approach opens interesting doors by showing the potential of the register to act as a planning tool, and to contribute to processes belonging to different legal frameworks such as the EU regulation on the Environmental Impact Assessments and Strategic Environmental Assessments, and for the implementation of the provisions of different international fora on environmental conservation.

1. Introduction

Human activities produce, as widely acknowledged, several forms of pollution wherein the most widespread one is underwater noise [1], [2]. This noise comes from marine traffic as well as from offshore human activities, especially those producing high-intensity impulsive signals like hydrocarbon-related activities, pile driving, amongst others [3], [4]. As underwater noise is recognised as a threat to marine life [5]–[8], in the European Union the need to monitor and assess marine noise pollution from impulsive signals has been identified and tackled by the European Commission through the Marine Strategy Framework Directive (2008/56/EC, MSFD). The criterion for the monitoring and assessment of impulsive noise is defined by the Commission Decision 2017/848 as follows: the spatial distribution, temporal extent, and levels of anthropogenic impulsive sound sources do not exceed levels that adversely affect populations of marine animals [9]. The metric recommended in the same Decision is: the number of days per quarter (or per month if appropriate) with impulsive sound sources; proportion (percentage) of unit areas or extent in square kilometres (km2) of assessment area with impulsive sound sources per year. To do so, previous work from TG-Nosie recommended to establish a register at the national and regional sea level [10].

Therefore, this register is primarily meant at recording data on the location and time of the use of noise sources, and computing and mapping the number of days with impulsive noise over a year and over a regular spatial grid. As such, this system allows identifying areas with concentrating noise-producing human activities, which appears as a simple way for environmental managers to use information from the register to take decisions. However, underwater acoustics is a complex discipline which is hardly understood by non-specialist, and despite the simple criterion developed in the framework of the MSFD, the establishment of realistic operational and environmental targets to achieve and maintain a good environmental status still appears as a difficult task [11].

This impulsive noise register leaves today many questions unsolved such as those addressing the cumulative acoustic effects on marine wildlife of multiple sources [12]. Loud noise levels can indeed travel hundreds or thousands of km, especially low frequency signals, affecting large areas and potentially causing adverse effects on wildlife populations very far from the noise source.

In the Mediterranean Sea and the Black Sea, the development of a common noise register following the framework described above is led by ACCOBAMS in cooperation with the Barcelona Convention. [13], [14]. However, the ACCOBAMS Agreement has a scope that goes beyond the mere plotting of geographical and temporal distribution of noise sources, as its goal is ensuring a favourable conservation status for cetaceans frequenting the Agreement area. To reach this goal, assessments of threats, including noise, need to be done regularly,

In such a context, we propose here an approach for expanding in the future the scope of the impulsive noise register for the Mediterranean and Black Sea, by enriching the records of noise-producing human activities with propagation models for each type of anthropogenic impulsive noise. Thanks to a modelling step, the propagation of impulsive signals emitted by noise sources is estimated and the actual area affected by noise is modelled; also, this approach is built to account for hearing characteristics of species frequenting the affected area. Therefore, new indicators can be proposed that consider not only the geographical and temporal distribution of noise sources, but also the noise footprint created by impulsive signals and the sensitivity of species.

The solution proposed in this paper aims to explore how the noise register can be used to model the noise level generated by different noise events contained therein, and to identify the necessary improvements and future developments of the register that will enable a robust implementation of this solution, with the ultimate goal of delivering useful meaningful impact indicators. To illustrate the underlying concept, we basically present test sound maps highlighting the potential extent of degradation of the acoustic habitat due to insonification caused by human activities.

In this paper, we first outline the implementation status of the impulsive noise register in the European Union. Then, we explain the modelling method and the desirable input parameters. Finally, test results are shown for a selected test area in order to show the area affected by noise events;

finally, the principles proposed for impact indicators are explained.

2. The Noise Register

The Noise Register is a database recording data on the temporal and spatial distribution of human activities generating loud impulsive acoustic signals in the low to mid-frequency range [10]. According to the MSFD, Regional Sea Conventions around Europe ensure regional consistency for the monitoring and assessment, and for the achievement and maintenance of the good environmental status (GES). In the North-east Atlantic, the North Sea and the Baltic Sea, a regional impulsive noise register is developed and maintained by the International Council for the Exploration of the Sea (ICES, http://underwaternoise.ices.dk/). This register is aimed at ensuring consistent regional assessments under the Oslo/Paris Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), and the Baltic Marine Environment Protection Commission - Helsinki Commission (HELCOM). In the Mediterranean Sea and Black Sea, the Agreement on the Conservation of Cetaceans of the Mediterranean, the Black Sea and the adjacent Atlantic waters (ACCOBAMS) has taken the lead for the development of the regional register for the two areas (both covered by the Agreement). Concerning the implementation of the regional register for the Mediterranean Sea, a Memorandum of Understanding define since 2016 the cooperation between ACCOBAMS and the Barcelona Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean. A demonstration platform is available for the Mediterranean area at http://accobams.noiseregister.org (Figure 1).

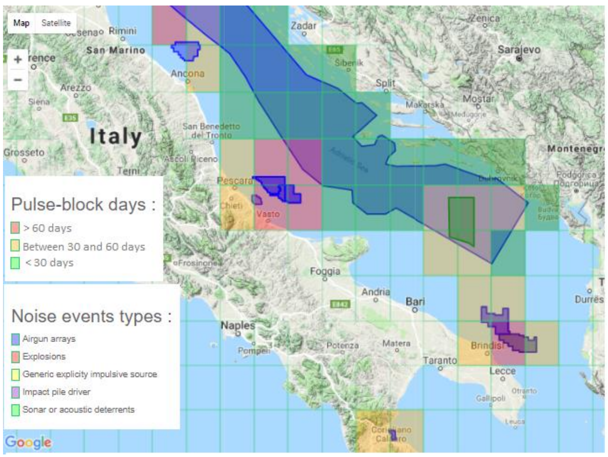

Figure 1. Focus on the current Noise Regsiter demonstrator platform in the Mediterranean.

Following the guidance from TG-Noise, noise sources considered for the Noise Register database are airgun arrays, underwater explosions, pile driving, sonar. Also, the register allows for recording generic explicitly impulsive sources. A spatial grid, with cell size equal to 30 minutes in latitude and longitude, is used for data reporting. The metric is calculated as the number of days over a year and by grid cell where noise source levels exceed a defined threshold (pulse-block days). Threshold on source levels, as a condition for inclusion in the register, are given by noise source type [10].

3. Proposed approach

To experiment the register as a tool to evaluate disturbance and/or impact on marine wildlife, we propose a methodology in four steps:

1- The noise propagation generated from each noise event contained in the register is computed; to do so, we need to know the time, the position and the depth of the emission. While the date and position are among mandatory data to be reported in the register, the depth is not. Also, noise events may be represented as polygons, while propagation of noise is always calculated from a point source. For these reasons, several assumptions are needed to implement our approach. Therefore, literature data are used to build plausible scenarios for each modelled noise event;

2- Cumulative sound exposure levels (received SEL) resulting from different noise events are estimated in the whole study area, by summing up all the contribution from single noise events occurring in the same day;

3- Hearing characteristics of key species present in the area are included to weight received noise levels and sound exposure criteria (thresholds) available in the literature are applied. This allows obtaining daily acoustic risk maps consistently with key species present in the studied areas;

4- The number of days over a year and by grid cell with weighted received cumulated SEL exceeding sound exposure criteria is calculated;

This novel value can be seen as an impact indicator, and the resulting map is an impact map. This approach is similar to the one implemented by [12]. In this paper, we illustrate points 1 and 2 more in details in the following sections.

4. Study area and period

For illustration purposes, we select the Adriatic Sea as a test area, as it is a limited and know area, with available environmental parameters useful for propagation modelling. Also, it appears as an interesting example of the need for transboundary management concerning marine noise pollution.

Concerning the period, the MSFD needs to assess Descriptor 11 (D11) yearly and therefore the approach should be applied over 1 calendar year. In this work, we select to show the propagation of two noise events occurring in the same day in the study area. In practice, we selected a day with at least two noise events occurring at the same time. However, as currently the Noise Register Demonstrator does not record any official data, the exact day we are focussing on is not important for the objectives of our study. Instead, the choice of the day is important for the selection of relevant environmental covariables which are necessary for propagation modelling. The selected day corresponds to typical Spring values for such changing parameters as temperature and salinity.

5. Implementation

The following plan was defined to illustrate the first two phases of the approach:

1. Select the source level input data from noise events reported in the register demonstrator;
2. Select an adequate propagation model according to the following parameters: frequency range of impulsive signal being modelled, bathymetry, and propagation environment;
3. Define the input parameters of the propagation model. These data are presented in section 5.2
4. Calculate the transmission loss from each source to obtain noise footprint maps of single sources.
5. Calculate cumulated noise levels over a day.

5.1. Sources of impulsive noise

In order to account for multiple pulses at different moments of the same day, we used the accumulated Sound Exposure Level (SEL_{cum}) as metric, which is computed as follows:

$$SEL_{cum} = SEL + 10\,Log_{10}(T) \qquad (1)$$

Where T is the sum of the duration in seconds of all pulses in a day.

Two noise events were selected based on data available from the ACCOBAMS Noise Register in 2015 for the Adriatic Sea (Figure 2). To keep the exercise simple, we selected the same noise source type, i.e. an airgun array. As said above, many assumptions were needed, summarised hereafter:

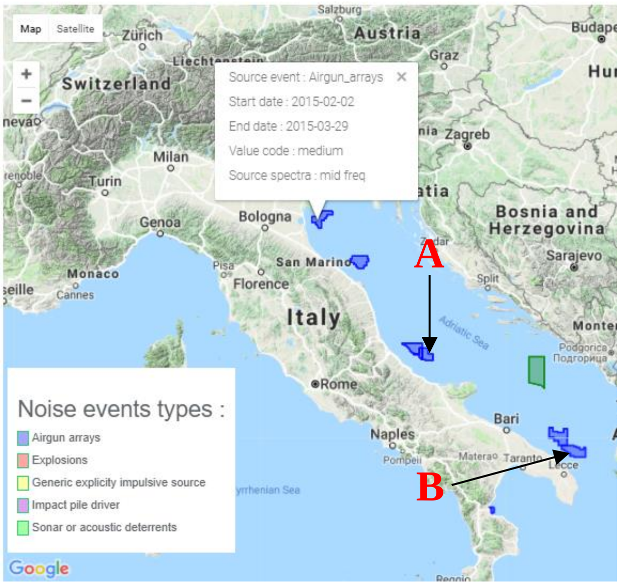

Figure 2: Spatio-temporal distribution of noise events (A and B) in 2015 as available in the ACCOBAMS NR Demonstrator

The location of the two noise sources need to be a points source to be modelled. As selected noise events correspond to airgun arrays, they are represented as polygon. Therefore, the centroid of the polygon was taken as point noise source, in decimal degrees of latitude and longitude:

Noise Event A = 42.33, 4.92

Noise Event B = 41.05, 18.13

Other input parameters based on assumptions are the following;

- Source level (with unit of measure) = 226 dB re 1µ Pa²s (source A), 236 dB re µ1 Pa²s (source B)
- Source depth = 1 m
- Receiver depth = 1 m
- Frequency = 1/3 octave band centred at 125 Hz
- Pulse duration: 10 milliseconds

Further, we consider that emissions occurs every 10 seconds [15] and that the distribution of the source in the polygon is uniform.

5.2. Propagation model

There are several mathematical methods to calculate the transmission losses and to take into account the physical phenomena of the propagation of the acoustic wave [16]. In our case study, the choice of the propagation model at the studied frequency band (1/3 octave band centred at 125 Hz) is directly related to the nature of seafloor and to the bathymetry. The most appropriate modelling methods for this study is the Range dependent parabolic equation (RAM). Beyond noise source data described in 5.1, the following parameters are needed to carry out the noise modelling exercise:

* Water column data: sound speed profile (calculated from temperature and salinity, in 3D);

* Geo-acoustic model of the bottom: number of layers, velocity profile, density and attenuation of compressional waves and shear waves;

* Properties of the source: source level, emission frequency spectrum, source depth and position (latitude and longitude).

It is not the target of this paper to discuss the parameters used and we will not enter into detailed description. We will simply say that parameters considered in this study are taken from open data platforms (EmodNet and CMEMS platforms).

The main model output is the following:

* Noise footprint maps of received levels at each point of the study area, with a spatial resolution of 1 km (grid cell size)

5.3. Daily noise footprints

Based on the steps described before, daily cumulated SEL is calculated over the study area (1 km resolution) in order to get the noise footprint of impulsive signals of a given day. Illustrative results of the noise propagation modelling step are presented below (Figures 4 and 5). Figure 4 shows the large distance travelled by sound waves of a single source with corresponding SEL values (noise footprint of multiple pulses from a single airgun array). Furthermore, figure 5 show the received SEL cumulated on a day caused by two noise events (two airgun arrays used at different places) occurring in the same day.

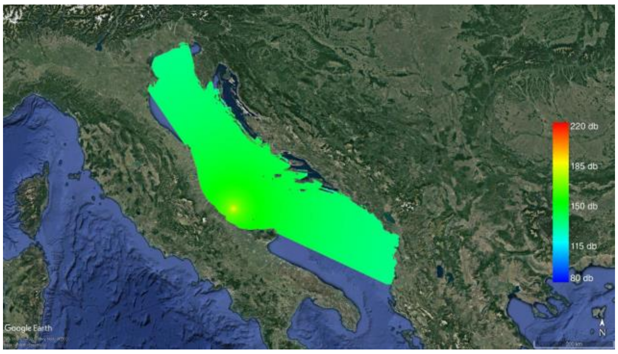

Figure 2. Noise footprint of a single airgun pulse (SEL cumulated over a day)

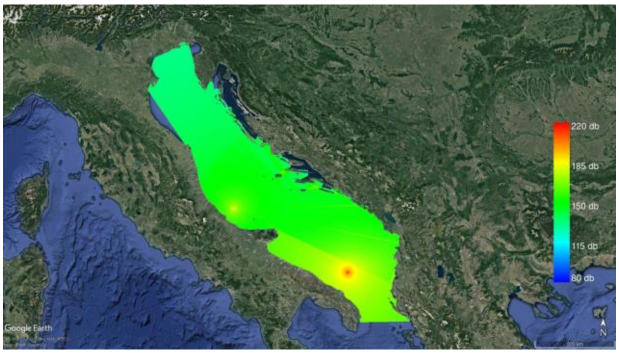

Figure 3. Noise footprint of two noise events occurring in the same day (SEL cuulated over a day)

5.4. Further steps towards yearly disturbance maps

After the modelling step, the approach includes the weighting of results with hearing sensitivity of selected species, and the calculation of daily noise footprints for each day of a calendar year. Afterwards, the daily footprint maps are overlaid on the spatial grid proposed in the ACCOBAMS Noise Register Demonstrator, which has a resolution of 30 minutes in latitude and longitude (against the 1 km resolution of noise footprint maps). Whereas, in a given day, a register grid cell contains estimated cumulated SEL exceeding sound exposure criteria for the selected species, then that grid cell accounts for 1 impact day. Finally, an impact map is obtained for a year summing the number of impact days in each grid cell. Such steps are not shown here but are the object of specific actions undertaken by ACCOBAMS and that will produce soon the first results.

6. Conclusions

Our goal was to illustrate a method to derive indicators of impact from the impulsive noise register in the ACCOBAMS Agreement area, thanks to the use of sound propagation modelling.

In this paper, we carried out an exercise to illustrate the modelling steps of this approach. We could first calculate daily noise footprints. Thanks to this, we highlighted the estimated spatial extent of the disturbance caused by impulsive noise on the marine environment, which appeared to go well beyond the grid cell dimension range used in the international regional impulsive noise register implemented by ACCOBAMS (and by ICES). This represent an important step toward the linking of noise emissions, ecosystem-based impact assessment, and sustainable management measures. However, several assumptions were considered, and input data quality is clearly far from allowing robust outputs. Therefore, improvement is this sense are highly desirable.

7. Perspectives

The most interesting perspectives to improve the work described in this paper deals with the inclusion in the analysis, and in the indicator, of noise-sensitive population parameters such as presence, distribution, abundance and habitat. Sound maps as those shown above could indeed be correlated with presence maps of cetaceans or other noise-sensitive species inhabiting the area. This approach, although technically challenging, will open many interesting doors for addressing unsolved questions such as those of the ecosystem-based impact assessment.

Acknowledgement

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