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A Risk-Based Model Using Communication Distance Reduction for the Assessment of Underwater Continuous Noise: An Application to the Bottlenose Dolphin (*Tursiops truncatus*) Inhabiting the Spanish North Atlantic Marine Demarcation

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Abstract: Over the last decade, national authorities and European administrations have made great efforts to establish methodological standards for the assessment of underwater continuous noise, especially under the requirements set by the Marine Strategy Framework Directive (MSFD). Through the MSFD implementation across EU Member States Marine Reporting Units (MRUs), it is intended to establish the Good Environmental Status (GES) whether it is achieved or not. The evaluation of the Sound Pressure Level (SPL) at the local or regional scale for 1/3 octave band of 63 Hz and 125 Hz and the identification of long temporary trends were considered to be a priority due to the valuable information they can offer in relation to continuous low-frequency noise. Nevertheless, the methodology to determine threshold values from which to evaluate the GES has become difficult to define, and new approaches and considerations are currently being discussed by groups of experts, such as the technical subgroup on underwater acoustics (TGnoise) and regional commissions (e.g., OSPAR). This work presents a methodology to perform the assessment of a given area, providing a risk index that is related to potential appearance of masking effect due to the underwater noise produced by marine traffic. The risk index is hinged on the calculation of area under curves defined by the density of animals and a variable related to underwater noise SPL, defined as percentage of communication distance reduction. At this stage, the methodology presented does not consider physiological or behavioral mechanisms to overcome the masking by animals. The methodology presented has been applied to the bottlenose dolphin *(Tursiops truncatus)* inhabiting the ABIES—NOR marine demarcation to illustrate the possible use of risk-based models to manage marine areas related to human pressures, such as marine traffic, with the potential adverse impact on a given species (e.g., masking effect).

Keywords: underwater noise; marine pollution; cetaceans; risk assessment

1. Introduction

The monitoring of underwater noise and its influence on marine ecosystems has become a high priority for EU countries and institutions since the adoption of the Marine Strategy Framework Directive (Directive (2017/56/EC [1]; hereafter MSFD). In addition, several organizations, such as the IMO (International Maritime Organization [2]) and the World Health Organization (WHO), have stated that underwater noise should be considered as an important pollutant that can produce relevant adverse impacts on marine ecosystems [3]. The MSFD aims to achieve the Good Environmental Status (GES) of the marine waters of the EU, and Member States (MS) are ultimately responsible for the implementation of the Directive in their national waters. The Directive sets out eleven qualitative/quantitative descriptors to define the GES. Descriptor 11 is related to underwater noise and other forms of energy deposed in the marine environment and specifies that GES will be achieved when "Introduction of energy including underwater noise is at levels that do not adversely affect the marine environment". The need to determine whether or not GES is achieved through this descriptor has provided impetus to the work of several groups of experts, research projects, regional commissions, and European and local authorities. As an example, it is worth highlighting the results offered by projects such as JONAS (Joint Framework for Ocean Noise in the Atlantic Seas), QUIETMED, or JOMOPANS (Joint Monitoring Programme for Ambient Noise North Sea), just to name a few. Most of the work carried out in the field focuses on establishing a standardized terminology, defining methodological approaches, and trying to solve the problems and lack of knowledge related to underwater noise measurements and their potential impact on marine life. The proposed guidelines resulting from the work of several dedicated expert groups have demonstrated the need to evaluate continuous low-frequency noise. This evaluation should specifically include the Sound Pressure Level (SPL) at 1/3 of frequency octave band centered at 63 Hz and 125 Hz, reporting long-term trends and mean values of sound, applying proper methodologies. These activities have been included in the scope of Descriptor D11C2 [4]. Under the MSFD, SPL monitoring is a primary criterion and new approaches are also needed to obtain a complete picture about the potential adverse impacts on vulnerable species. The marine habitat is a complex environment [5] and underwater noise can affect it in different ways [6]. One of the most studied species are the cetaceans, because of their known sensitivity to the underwater noise [7]. They use underwater sound to communicate, to find their prey, and to be aware of their surroundings. Adverse impacts on cetaceans caused by underwater noise have been widely studied [8,9] over the years, with findings indicating that the type of disturbance or damage produced depends on the source level and the sound duration. Usually, the underwater sound that is generated by anthropogenic activities is divided into two categories, impulsive and continuous, depending on the temporal characteristics of the radiated noise. Impulsive noise is understood to have a temporary short and high SPL that is locally generated by activities such as pile driving, explosions, sonar, and seismic surveys. These activities present a periodic pattern, ranging from tens to hundreds of wideband pulse train signals depending on the event type or operation conditions. The impact on individuals can range from masking to temporary threshold shift (TTS) (TTS: defined as a temporary or reversible loss in hearing sensitivity; the threshold will return to normal level) [10], permanent threshold shift (PTS) (PTS: defined as a permanent loss in hearing sensitivity; can occur as a consequence of multiple TTS or as a result of single exposure to high SPL), and fatal injuries. Abrupt changes in behavior have also been reported, even resulting in the death of individuals [11]. On the other hand, continuous noise is mainly due to ship traffic, and one of the multiple impacts that this can cause is the masking effect. The concept of masking may be defined as the impossibility to correctly interpret a received acoustic signal by a certain marine mammal [12]. This effect normally occurs due to the existence of a noise level that is high enough to produce a poor Signal-to-Noise Ratio (SNR) (SNR: defined as the comparison between the desired signal amplitude with background noise level). Among the problems that marine mammals can have due to underwater noise, masking is the one that has the biggest impact on the fitness of individuals of some species and could be used as a first indicator of impact due to continuous noise in the marine environment [13–15]. However, measuring the occurrence of the masking effect taking place at sea is difficult because it depends on numerous variables such as the characteristic hearing curves of the species under study, the intensity and frequency of emitted vocalizations, or the critical ratio related to the sound reception associated with each species [16–18]. There are diverse studies in the literature that have reported different effects of individuals subjected to masking [19,20]. For example, some whales exhibited mechanisms to overcome masking, such as adapting its frequency and sound level [21]. Throughout this article is presented a methodology based on a risk model seeking to address the probability of masking effect produced by underwater low-frequency noise, generated by marine traffic, in relation with a given cetacean species. The framework used to structure the risk-based model presented is based on ISO31000—risk management guidelines [22]. The framework proposed in the ISO guidelines establishes five steps to develop a general risk assessment. The stepwise procedure contains different phases that can be summarized as (i) establish the context, (ii) risk identification, (iii) risk analysis, (iv) risk evaluation, and (v) risk treatment. This conceptual design of risk assessment, together with the ecological elements needed to perform studies related to the marine environment, and specifically with underwater noise assessment, have been widely studied in the framework of RAGES project [23]. It is remarkable that the methodology presented through this work is aligned with the type of work also carried out by regional sea conventions (RSCs) such as OSPAR, projects such as JOMOPANS [24], or authors who developed risk indicators [25]. Aligned should be understood as similar to other metrics developed through different case studies and which are based on the temporal measurement of the noise excess level with respect to a certain threshold value. In the case presented through this study, the excess level is calculated with respect to the natural ambient noise due to weather conditions.

The metric presented in this work fits into the following steps:

- Risk identification. The main aim of the risk-based model is to measure, in a quantitative way, the risk of masking for cetacean species due to the radiated low-frequency noise produced by marine traffic.
- Risk analysis. Risk analysis takes into account the human pressure produced on the marine environment due to marine traffic and the density of animals able to be used as a proxy to infer the probability of the masking effect appearance.
- Risk evaluation. The risk evaluation is probably the most controversial issue since usually the data used to feed the models in marine sciences are tentative, qualitative, or just missing, depending on the case. Despite these difficulties, there is a need to forecast the potential adverse impact on marine ecosystems caused by human activities. This is an important aspect to cover by competent authorities with the aim to define better strategies to manage anthropic tasks in the sea. The present methodology seeks to infer the probability of masking effect in relation to communication among individuals. The risk assessment process through the presented model allows detection of the potentially acoustic degraded zones, as well as monitoring the need or the influence of mitigation measurements on the marine traffic activity.

The methodology developed will be illustrated through a case study considering the marine traffic as a human pressure, the radiated noise associated as a pollutant, and population of bottlenose dolphins inhabiting the shelf waters of the ABIES—NOR Spanish marine demarcation. Results will be presented and discussed in Section 3.

2. Material and Methods

Assessing risk involves the process of identifying the human activities that generate pressure in the marine environment, analyzing the potential adverse impact produced on a certain species/area. Therefore, the aim of the risk-based model is to define metrics that allow evaluation of the likelihood, magnitude, and severity of the identified threat. Developing a risk analysis is challenging, especially on environmental issues, because the data are often sparse and scientific assumptions are sometimes tentative (e.g., it is difficult to establish a threshold from which a certain condition begins to be relevant, on a certain species). In our study, a methodology has been developed relating a variable associated with a pollutant, in our case, underwater continuous noise, with the presence of a sensitive population in order to assess the potential risk of adverse impact. This potential risk will be evaluated by means of the risk index that depends on the population density of animals inhabiting the study area and a variable that links the noise level with the potential masking produced in those animals. This variable is called the percentage of communication distance reduction (hereafter, $CDR_{\%}$) and is based on the concept of the SNR between two scenarios, the one that considers the marine environment without human activity, with respect to the situation in which there are anthropogenic activities, specifically, marine traffic. The final result of the risk-based model is a georeferenced index map calculated from the area under the curves defined by the cumulative probability density functions of the animal population density and the $CDR_{\%}$. The use of the area under curves allows calibration of the georeferenced index with respect to the worst-case scenario, which is a cell unit on the map where the maximum number of animals present in the area is exposed to the maximum communication distance reduction during the entire evaluation period (100% of the assessment time). A detailed explanation of the calculation of the risk index is provided in the following sections.

2.1. Risk Identification

This step must identify the pressure exerted by a given anthropogenic activity on the marine species. Depending on the purpose of the study, the data available, and the characteristics of the man-made activity, the risk-based model may be more qualitative or quantitative. Either way, it should be highlighted that the results could be useful to monitor the status of a given marine area. Therefore, it can serve as a useful tool able to help the authorities to make decisions that balance the use of a marine area, and the man-made activities carried out there with regard to the fitness of a given species. The work presented through this communication is related to the underwater continuous noise produced by marine traffic and the potential adverse impact on bottlenose dolphins, considering the masking effect as a condition. The choice of the bottlenose dolphin species is due to the availability of data in the ABIES—NOR area due to the annual PELACUS survey carried out by the Spanish Institute of Oceanography (IEO). No other consideration was taken into account to select the species (e.g., to be the most endangered species or to be more sensitive to noise with respect to another species). Regarding the condition related to the masking effect, it is a widely studied adverse impact in relation to underwater noise. Nonetheless, it should be noted that the masking effect has not been selected because it is considered by the authors to be more important than other conditions.

2.2. Risk Analysis

The risk analysis process considers the likelihood of the underwater continuous noise during the assessment period and the population density of the receivers that can be impacted negatively. With this information, the calculation of the exposure to noise must be performed, linked to the possible masking produced on the bottlenose dolphin. The data necessary to carry out the risk analysis are the underwater noise, calculated over the evaluation area at frequencies that overlap with the hearing sensitivity of the animals, and their population density. The relationship between marine traffic and potential masking is defined by the $CDR_{\%}$. The following subsections explain in detail the points that make up the risk analysis.

2.2.1. Underwater Noise Modeling

The underwater noise simulation models produced by ships must consider aspects mainly related to the properties of the sources and the propagation medium. The parameters to consider in order to perform the simulations are:

- The characteristics of ships as noise sources (source level, spectral components, and directivity).
- The environmental conditions that determine the seasonal variation of the speed of sound in the water column, because the sound speed profile determines the geometry of noise propagation through the medium.

- The bathymetry and sea-bottom properties.
- The implementation of a propagation model with affordable computational costs and suitable prediction accuracy.

In relation to the presence of ships in the studied marine area, automated identification system (AIS) data from the entirety of 2019 were used. The analysis was carried out considering snapshots (1 h/day) and obtaining a set of specific images of the noise present in the area by which to calculate its mean value. It is important to note that to perform this study the authors had no access to a vessel monitoring system (VMS) related to fishing vessels, so the noise level in fishing areas may be underestimated. Three frequency bands were considered to calculate the noise maps associated with ship traffic (1 kHz, 5 kHz and 10 kHz) and computed to apply the proposed methodology. The reasons to choose these frequency bands are based on the following: (i) the audiogram of bottlenose dolphins is defined by several studies (between 1 kHz to 100 kHz), assuming, therefore, that they can detect sound at least in these frequency ranges [26–28], and (ii) the whistle signature of bottlenose dolphins reported by several authors starts from about 1.8 kHz and ends at 24 kHz (these values may vary slightly depending on the study area), and it is rare to find whistles with minimum frequencies below 3.5 kHz [29–31].

The proposed methodology aims to apply the risk-based model considering those frequencies in which the contribution of noise generated by marine traffic overlaps with the possible whistles emitted by bottlenose dolphins. The 1 kHz case study does not meet this superposition, considering the received sound coming from dolphin whistle emission. However, the 1 kHz case study has been studied with the aim to show the influence of the noise pressure level on the performance of the proposed methodology (ships emit a higher level of noise at lower frequency bands) representing, therefore, the highest level of disturbance due to marine traffic noise. In addition, the hearing curves of bottlenose dolphins are defined from approximately 1 kHz, so this frequency band also may be indicative of potential masking of other types of sounds present in the soundscape (e.g., other delphinid species sounds such as long-finned pilot whale whistles [32] or sounds from another vessel in terms of collision avoidance [33]). Therefore, the 1 kHz case study results should not be interpreted as communication distance reduction between conspecifics; just the 5 kHz and 10 kHz cases should be interpreted that way.

Regarding the process to implement the calculation of sound maps, it can be roughly summarized considering the following three main steps:

1. Quality cuts and snapshot definition. The starting point of sound map estimation is related to the application of quality cuts over the AIS raw data. Quality cuts consist of applying a filtering process to neglect missing and NaN values present in the variables used to calculate the source level emitted by each ship. Once the data are filtered, a snapshot of 1 h is considered for each day. To obtain this temporary segmentation, a second filter is applied to the Maritime Mobile Service Identity (MMSI) variable, ensuring that each ship is counted only once for each date interval. MMSI is a unique nine digit number for identifying a ship.
2. Calculation of source level emitted by the selected ships. The SPL radiated by each of the considered ships was calculated using the Randi model [34]. To apply this model, aspects such as speed over ground, longitude, latitude, and length of the ships must be known. These data were extracted from AIS raw data for the entire year 2019. The Randi model offers the distribution of source-level values for each frequency considered (see Figure 1).
3. Propagation of sound through the medium. Once the source levels associated with the specific frequency for each ship are calculated, the propagation of sound must be computed. There are different types of models and different theories for calculating the transmission loss (TL) (TL: describes the attenuation of sound as it propagates through a medium, $TL = 10log10(I_{received}/I_{emitted})$), and their suitability traditionally depends on the frequency range considered (high, medium, low) and on the depth (deep water or shallow water) [35]. Traditionally, the application of parabolic

equation [36] is accepted for low-frequency and shallow-water environments. In the case presented, the frequencies are equal to or greater than 1 kHz, and a model based on ray theory [37] has been applied. The implemented model is based on the BELLHOP [38] open-source algorithm, applied ship by ship. One of the main benefits of using this method is linked to the computing resources needed. As the frequency increases, the computational costs do not rise. Moreover, ray-based models can offer a good approximation, even at low frequencies, if the source and the receiver are located at least at half-wavelength above the seabed, as some authors have pointed out [39].

It must be underscored that the aim of this work is not to perform a study of different propagation methods but to establish a methodology that combines sound maps related to marine traffic and the population density of marine mammals with the aim to infer the possibility of individuals being affected by masking. The theoretical models of source level and signal propagation applied in this work were validated experimentally in [40].

Regarding environmental conditions, seasonal variations in salinity and temperature versus depth have been incorporated into the model since they are known to affect the propagation of sound. Information available on the Emodnet (https://www.emodnet.eu/en, accessed on 16 February 2022) site has been used, specifically data from the apex profiling float located at Lat/Lon 46.237/5.44 operated by BSH—Bundesamt Seeschifffahrt und Hydrographie of Germany. The speed of sound in the water column has been calculated using the Mckenzie equation [41] (see Figure 2). The bathymetry was obtained from the GEBCO portal (https://www.gebco.net/, accessed on 13 January 2022) [42].

The propagation of sound performed for each temporal snapshot considers the sound speed profile at the same temporal window. An example of SPL values obtained at 1 kHz frequency band are shown using a sound map representation in Figure 3.

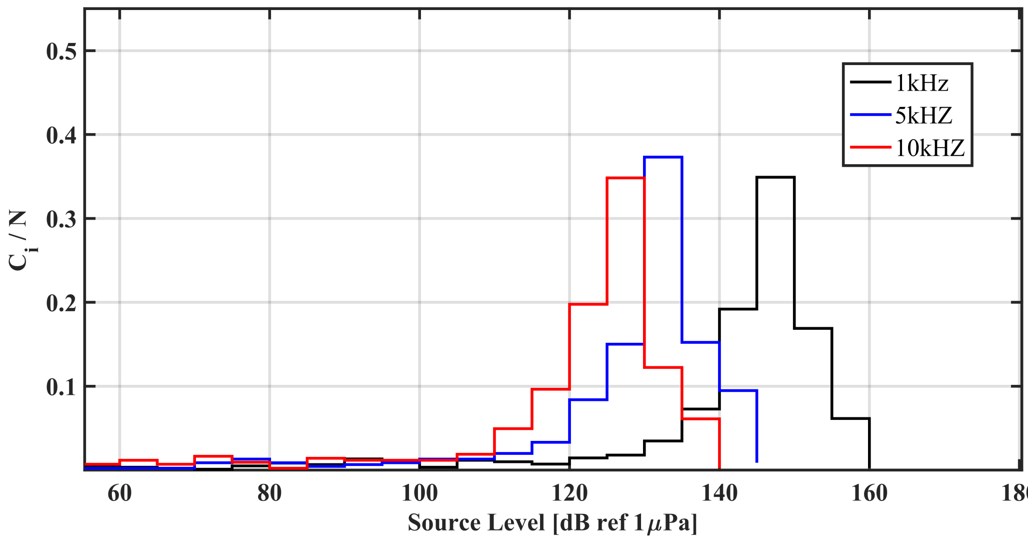


Figure 1. Distribution of the source level values associated with the ships accounted for in the assessment. Randi model has been applied on the 2019 AIS data. C_i represents the samples included in a frequency bin, and N is the total number of cases.

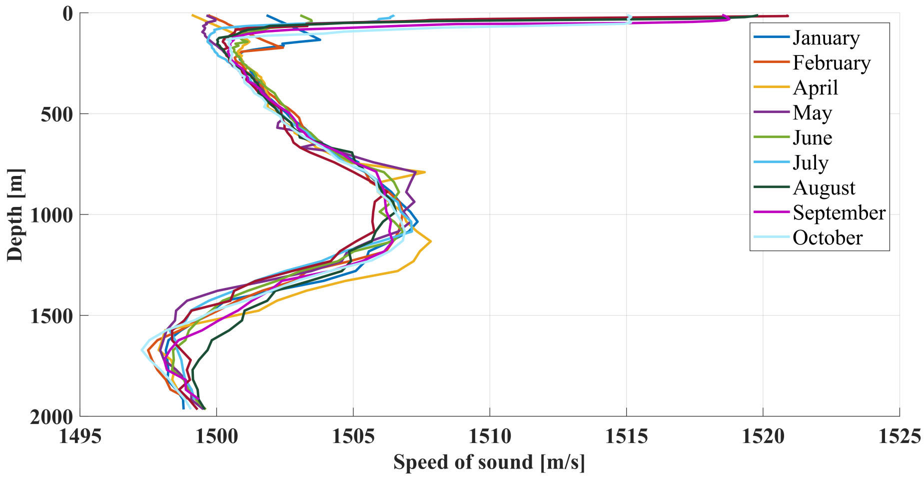


Figure 2. Seasonal variation of the speed of sound in column water. The vertical sound speed profile has been considered in the propagation of noise through the sea water. Data of salinity and temperature are missing for March, November, and December.

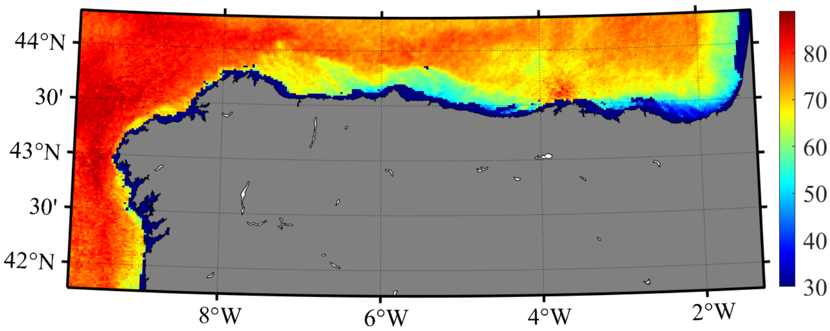


Figure 3. Shipping noise map calculated at 1 kHz frequency band for 2019. The color bar represents the Sound Pressure Level (SPL) dB ref 1 μPa.

2.2.2. Density of Dolphins

Bottlenose dolphin sightings were collected following distance sampling methodology [43] during the PELACUS multidisciplinary surveys. These surveys were carried out on the north and the northwest Spanish continental Atlantic shelf waters in the spring (March and April) between 2007 and 2017. It is remarkable that this species exhibits a resident behavior in the studied area, so despite the fact that the survey period comprises 2 months against the year considered for the noise assessment, its use is considered representative. Habitat use by populations of botttlenose dolphins in the ABIES-NOR marine demarcation has been reported in [44], pointing out that "animal distribution is homogeneous throughout the waters of the northern peninsula, there is a clear gradient in density, this being higher in eastern areas of the Bay of Biscay where the largest groups have been recorded". In addition, "along the Galician coast and using photo-identification technique a resident population was identified and movement of some individuals were recorded between Galicia and Euskadi".

Details of the methodology applied to perform the dolphin density calculation are provided in [45]. The sightings were modeled using the density surface technique (DSM) as described in [46], in which counts per segment are calculated as a sum of smooth functions of environmental covariates using generalized additive models (GAM). Once the best model was selected, bottlenose dolphin density was predicted across the entire study area, obtaining the mean density surface and its associated uncertainty during the 2007–2017 period. The results of the density of dolphins are shown in Figure 4.

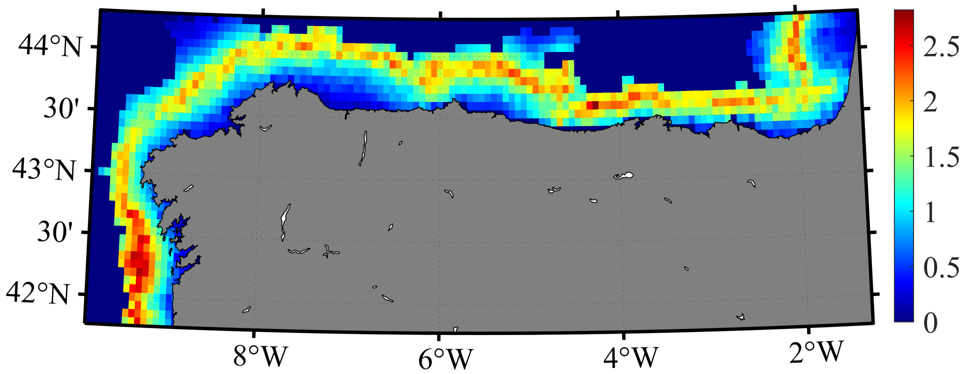


Figure 4. Density of bottlenose dolphins calculated from PELACUS—IEO survey (2007–2017). The color bar represents density of dolphins in a cell grid of (5.5 × 7.7) km^2.

It is important to note that the noise maps should consider the particularities in the use of the habitat of the studied species. This means calculating noise maps at depths where the animals live most of the time. In our case, the bottlenose dolphin has been chosen as the species to study, knowing that normally it does not dive very deep, spending most of its time in the photic layer [47,48]. Due to the use of habitat exposed before, noise maps were calculated in our study at 50 m depth. If more accuracy is desired, several noise maps could be calculated over a depth range taking into account those higher values in the water column, assuming therefore the worst scenario to perform the risk assessment. Regarding the area studied, it is remarkable that the region is characterized by its high productivity and high biodiversity, reflected in a relevant fishing ground. Many cetacean species are present in the area, among which is the bottlenose dolphin [49]. Standings of the species have been reported in the area and it accounts for 11% of the records between 1990–1999 [50].

2.2.3. Communication Distance Reduction

The acoustic masking effect is related to the difficulty to properly interpret an acoustic signal due to the poor SNR. This effect can play an important role, for example, in communication between conspecific dolphins when they use whistles. Several authors have studied the masking effect in relation to different cetacean species. Aspects such as hearing functions [12], frequency tuning as a response to masking, and critical ratios are known for some species. However, this is an open research field that is in continuous evolution and advances are slow, mainly due to the challenge associated with performing experimental measurements, especially on wild populations. Therefore, the results are sometimes tentative or limited to experimental conditions. In addition, it has been proven that marine mammals can adapt their vocalizations and behavior to underwater noise stimulus [19,51]. It is important to remark that the implemented model does not consider specifically the adaptation of the animals to underwater noise in terms of increasing the intensity or frequency modulation in its vocalization. The use of the Sound Exposure Level (SEL)(SEL is a measure of energy that takes into account both the level received and the duration of exposure; calculated taking into account $SEL = 10log10(E/E_0)$, where $E_0 = 1\mu Pa^2 s$ and $E = \int_{t_1}^{t_2} p(t)^2\,dt$) is commonly accepted to evaluate the possible impacts caused by transient noise because it gives an accurate idea about the cumulative effects. The SEL can be used to set threshold values for specific adverse impacts such as TTS or PTS [52]. Dealing with continuous noise adds extra difficulty because it is not trivial to know for how long the medium exceeds a certain threshold level, considering huge areas by means of theoretical simulations or how to compute the cumulative effect of the continuous noise. For the reasons stated above, setting threshold values based on the SEL for continuous noise is a non-trivial problem. In order to overcome this problem, we define a variable related to noise called communication distance reduction (CDR), which can be used to calculate a scaled range of masking severity. The communication distance reduction percentage ($CDR_{\%}$) is defined as the percentage of reduction in distance communication that a certain species of cetaceans could be affected by, due to the presence of noise in the environment with respect to pristine conditions. The paradigm applied to address the problem is depicted in Figure 5.

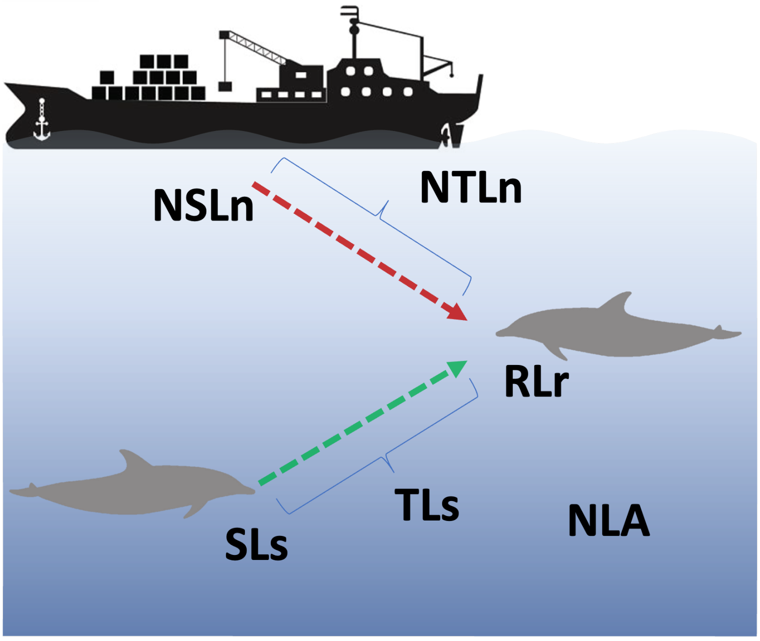


Figure 5. Conceptual scheme that represents the communication process between individuals, taking into account all the variables involved in the distance reduction calculation. The variables considered are noise level radiated by the n-th source NSL_n, transmission loss calculated from the n-th source NTL_n, ambient noise level NL_A, source level emitted SL_s, transmission loss from the emitter or source to the receiver TL_s, and received signal level RL_r.

With the aim to define and calculate the communication distance reduction, some assumptions are made using the sonar equation [53] applied to a specific emitter–receiver system. Given a hypothetical listener, SNR can be defined as:

$$SNR_r = RL_r - NL_r, \tag{1}$$

where RL_r represents the received level and NL_r represents the noise level, both of which are at the receiver position. At the same time, the received level and the noise level can be defined as:

$$RL_r = SL_s - TL_s \tag{2}$$

$$NL_r = NL_A + \sum_{1}^{N} NL_n \tag{3}$$

$$NL_n = NSL_n - NTL_n \tag{4}$$

where SL_s = source kevel emitted by the ideal conspecific, TL_s = transmission loss from the emitter to the receiver, NL_r = noise level present in the medium, NL_A = ambient noise level, NL_n = noise level generated by the N anthropogenic sources, NSL_n = N-th source level, and NTL_n = transmission loss calculated from n-th source (all quantities referred to dB ref 1 µPa).

The calculation of the range distance at which communication is assumed to be possible takes into account the sound excess (SE), ref. [54] defined by:

$$SE = SNR_r - DT \tag{5}$$

where DT is the detection threshold of the receiver system. Analogous to the sonar equation, in the calculation it is implicitly assumed that $SE = 0$, which implies that the listener has a 50% probability of detecting the received signal. We will use this assumption to generate the conditions of a hypothetical receiver system. In addition, it is also assumed that $DT = 0$, which implies that the listener could detect a signal at the level of SNR without the need for excess decibels. The literature related to bottlenose dolphin points out that DT could be approximately 4 dB [55], but some of these calculations are based on experiments performed with individuals in captivity. Since the DT value is expected to be different in wild individuals, DT is set to 0 in this study. We have calculated that the influence of considering a value of $DT = 0$ dB or $DT = 4$ dB represents an increase of 3.7% in distance reduction. The transmission loss applied between two average bottlenose dolphins was calculated using the equation presented in [56], using the Marsh and Shulkin coefficients, following the Beaufort scale. A key aspect in the development of the proposed methodology, and on which the calculation of the $CDR_{\%}$ depends, is the knowledge of the noise present in the marine environment associated with natural causes. It is assumed that the weather conditions are the most important factors contributing to the natural ambient noise level at the frequencies defined by the interval [100 Hz—10 kHz]. This is mainly by the bubbles and spray produced on the sea surface due to wind and rain. The relationship between weather conditions and natural ambient SPL is established by means of the Beaufort scale following the Wenz curves which were adapted (after National Research Council, 2003) from Wenz (1962) [57]. In turn, the Beaufort scale establishes a relationship between wind speed and the severity of the observed weather conditions, in a scale ranging from 0 to 12. The relationship between wind speed and Beaufort index follows

$$Wind\ Speed = 0.836 \cdot B^{3/2} \quad (6)$$

where B is the Beaufort index, ranging from 0 to 12. The authors are aware that measuring the natural ambient noise is an assessment process itself and should be composed of several steps, such as

- Performing an experimental measurement of ambient noise in a location where ship traffic influence is minimized as much as possible.
- Developing a theoretical framework to infer the value of natural environmental noise based on meteorological conditions for the same period for which experimental measurements are available.
- Validating the theoretical values for natural ambient noise by means of the experimental data.

Regarding the case study implemented, the natural ambient SPL was calculated using the annual data of wind speed using the "Puertos del estado" meteorological drifting buoys placed along the North Atlantic Spanish marine demarcation (see Figure 6).

In order to obtain the natural ambient noise map, the study area was segmented into four zones relative to each buoy. The measurement areas of each sensor have been segmented considering the mean distance between each buoy and its consecutive. Temporal segmentation was also performed to overlap natural ambient noise with sound maps related to "snapshots" of maritime traffic for 2019. Finally, a whistle source level of 150 dB (ref 1 μPa) for an average bottlenose dolphin was considered. This value is located within the range of the data reported by several authors that point out a source level ranging from 114 dB to 163 dB [58]. The distance at which the SNR = 0 is obtained considering the intersection of the noise level present in the area with the attenuation of sound between animals (see Figure 7).

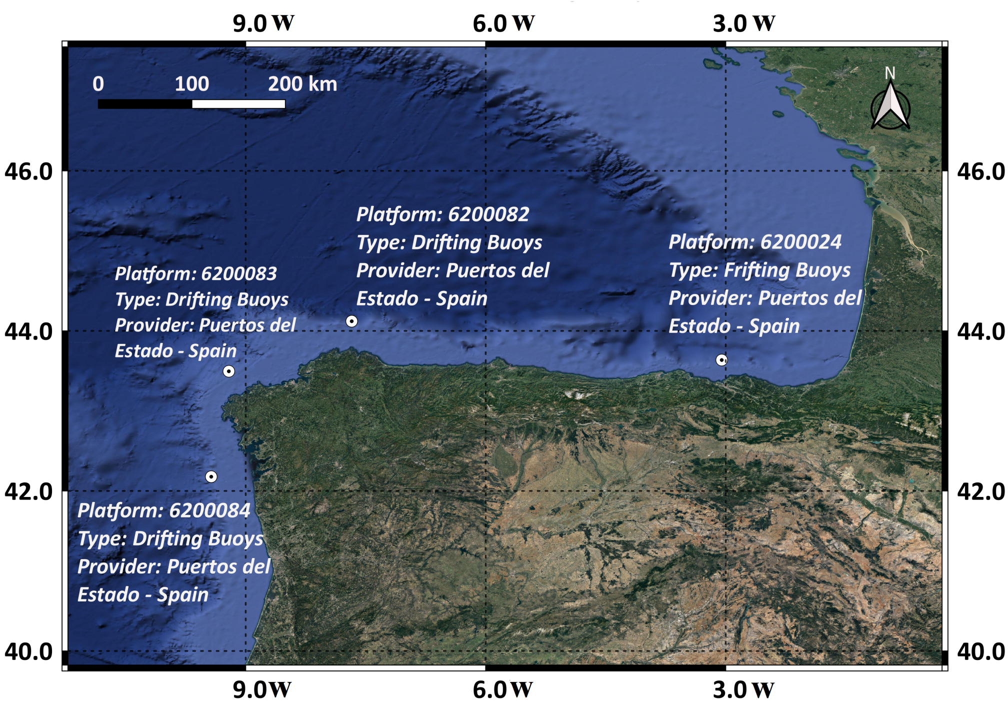


Figure 6. Position and identification code of the drifting buoys platforms used to extract data from EMODNET web portal.

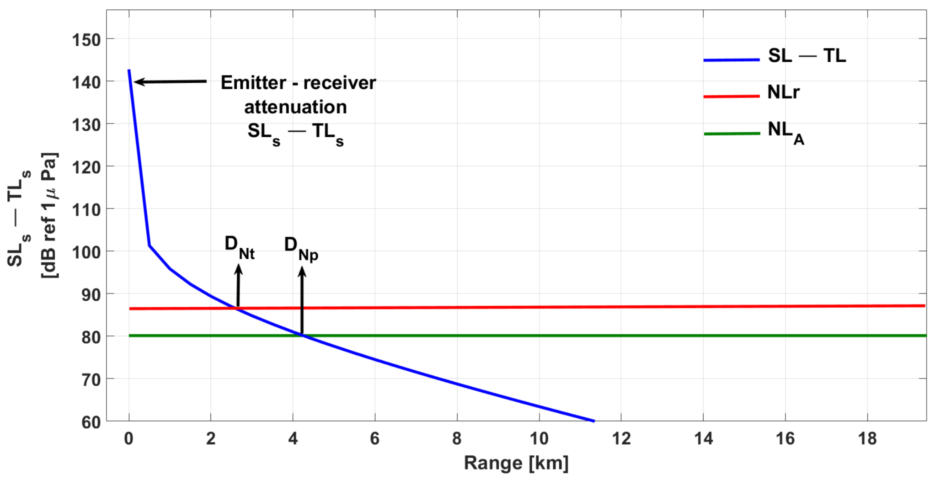


Figure 7. The intersection between the decay curve of the sound level between emitter–receiver and the noise level present in the marine area determines the maximum distance in which SNR = 0. The distances calculated considering the natural ambient noise and natural plus anthropogenic noise will determine the reduction of the communication distance due to marine traffic activity.

The definition of $CDR_{\%}$, due to noise generated by marine traffic, is based on the distance calculation at which SNR = 0, for both noise scenarios considered. The $CDR_{\%}$ is defined by means of Equation (7):

$$CDR_{\%} = (1 - D_{Nt}/D_{Np}) \cdot 100 \tag{7}$$

where D_{Nt} represents the distance, considering the anthropogenic plus natural ambient noise contribution, and D_{Np} represents the "pristine" ambient noise due to weather conditions. The $CDR_{\%}$ provides the opportunity to directly relate the pressure produced by a human activity to an adverse effect on cetaceans. Establishing a link between cause and effect is not easy, especially when several types of variables can play an important role in the life of marine mammals (e.g., food availability in specific areas, water temperature, or other environmental conditions influencing their distribution). Nevertheless, it is clear that the inability to establish proper communication among individuals can be considered as a potential threat, which is directly related to the pressure studied here.

2.2.4. Risk-Based Variable

The main objective of this work is to define a variable based on the risk of masking appearance due to the underwater noise generated by maritime traffic. The methodology for creating such a risk variable must consider the spatial and temporal distribution of CDR and density of dolphins. Another important aspect to consider is the possibility to scale the higher value of the normalized index with respect to the most adverse situation with the aim to establish a scale from low to high risk. The developed methodology fulfills the requirements pointed out above and is based on the calculation of the coincident area under the curves that defines the evolution of each variable during the assessment period (see Figure 8). With the aim to dispose of comparable normalized variables to calculate the coincident area under the curves, data related to the density of dolphins were normalized between [0—1], applying the cumulative normalized probability function (hereafter $CNPDF$) of the population distribution to the value of each map cell.

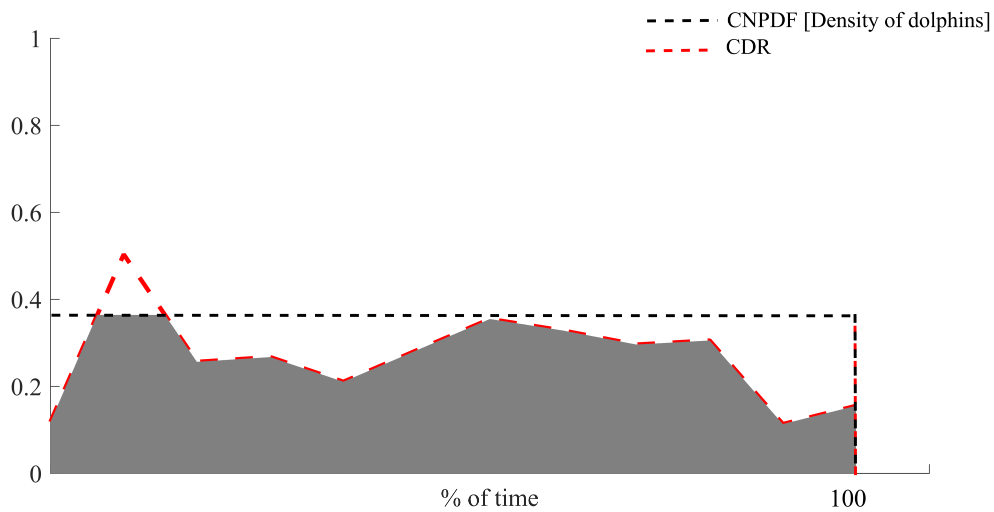


Figure 8. Example of the coincident area between the intersection of the evolution curves of the variables $CNPDF$ (black dashed line) and CDR (red dashed line) during the evaluation period in a specific map cell. Both variables defined between [0–1] are represented in the y-axis during the assessment period in percentage of time (x-axis).

Considering each cell of the map as a spatial unit, the evolution of each variable through the assessment period defines the curves. The intersection of areas under both curves will then be used to create a normalized risk-based variable (hereafter RBV). The RBV is defined at each grid cell (indexed as i, j) as:

$$RBV_{i,j} = \frac{\int_{t_1}^{t_2} (CDR_{i,j}(t) \cap CNPDF_{i,j}(t)) \cdot dt}{Maximum\ Exposure} \tag{8}$$

The worst scenario (maximum exposure) corresponds to the maximum number of animals suffering the maximum degree of masking during the whole assessment period. This most adverse case defines an area under curves that can be used as a normalizing factor to calibrate the RBV as shown in the diagram of Figure 9.

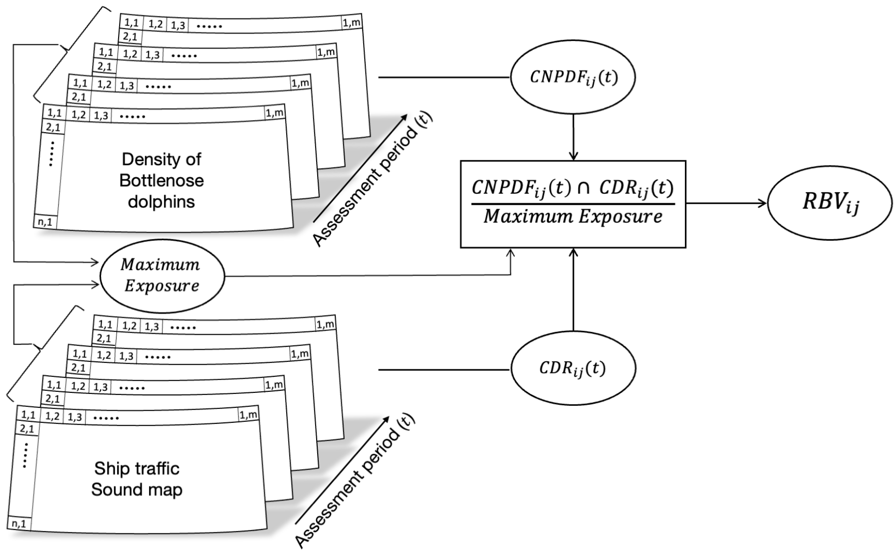


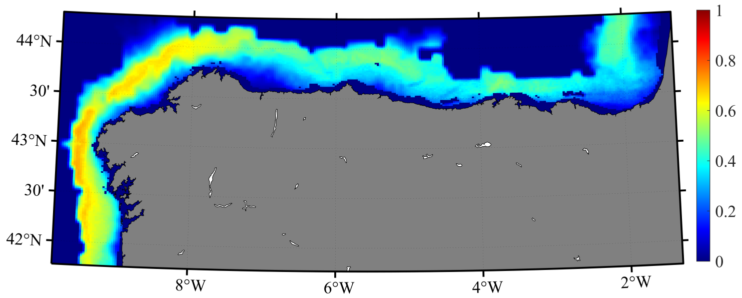
Figure 9. Diagram block that summarizes the methodology applied to obtain the risk-based variable.

An implementation of the developed method will be presented through Section 3 by means of the case study carried out across the ABIES—NOR marine demarcation. Results will reveal the potential use of this methodology in terms of proper management of marine area in relation to continuous noise generated by marine traffic and dolphin population inhabiting the area.

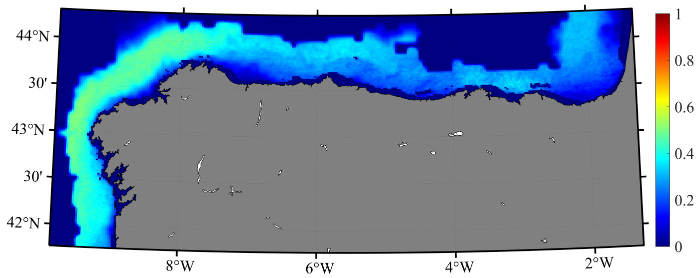
3. Results and Discussion (Risk Evaluation)

This section shows the results obtained after applying the developed risk-based methodology on the ABIES—NOR shelf waters. Marine traffic has been considered as a human pressure on the marine environment, the population density of bottlenose dolphins as a potential impact receptor, and underwater continuous noise as a pollutant. The $CDR_{\%}$ variable is linked to natural and anthropogenic noise sources, and the frequency bands chosen at which the assessment is carried out can play a relevant role due to its dependence on the source level. The addressed case study does not consider the hearing function or detection threshold characteristics of the bottlenose dolphin species, but authors are aware that these aspects may be relevant when assessing the masking effect. In addition, compensatory measures to overcome masking by animals (e.g., increase of emitted level or frequency modulation) have not been considered in this model, assuming that masking appears when the acoustic signal arrives to a hypothetical listener with the same level as noise present in the area. The results of applying the risk-based model presented are summarized in Figure 10 for the different frequency bands selected.

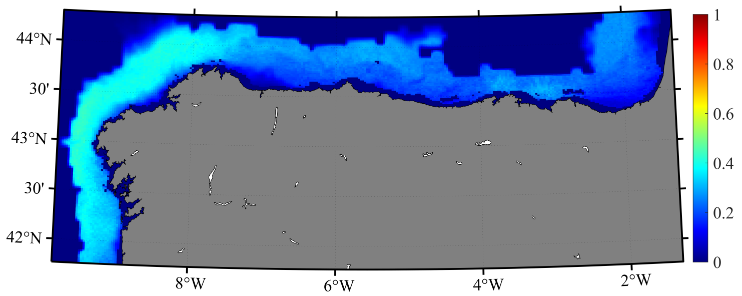
It is possible to observe that the greatest risk of masking is located in those areas where both the presence of animals and the SPL are higher. The Galician coast presents the highest risk index of masking for bottlenose dolphins during the evaluation period. This is mainly due to the superposition of a high marine traffic activity and a relevant value of the dolphin population density. The area located in front of the Cantabria region also presents important values of dolphin density, but the risk index indicates that masking could be lower in comparison with respect to the Galician coast. In addition, on the Galician coast there is an important fishing sector that does not carry AIS but does carry VMS, so it is estimated that even the $CDR_{\%}$ is underestimated. In fact, the entire north Spanish coast from the north coast of Galicia to the inner part of the Bay of Biscay present very similar values for the maximum values of the RBV. It is important to mention that similar results regarding the spatial extension of RBV are obtained for the different frequency bands, which is expected since hearing function of animals was not considered. In terms of the RBV amplitude, the risk is found greater for lower frequency values. This is because as the frequency value increases, the emitted noise level decreases (see Figure 1). It is known that the largest ships are more efficient in terms of low-frequency noise emission. Further detailed studies should be carried out, taking into account the specific characteristics of the auditory sensitivity function of the animals. This opens the opportunity to consider the lowest frequencies where dolphins can communicate by whistling as proxy frequencies through which to assess the masking risk, since these are the frequencies at which the value of noise radiated by ships will be higher.



(**a**)



(**b**)



(**c**)

Figure 10. Risk-based variable results for each frequency band studied. (**a**) Corresponds to the 1 kHz case studied. This frequency should not be interpreted in terms of communication distance reduction between conspecifics, since the species of dolphin considered do not emit whistles at this frequency. However, it is included because it may be representative of the masking of other types of sounds present in the soundscape. The case of 5 kHz (**b**) and 10 kHz (**c**) can be interpreted in terms of communication distance reduction because at these frequencies bottlenose dolphins establish communication among them by means of whistles. It is possible to observe how the RBV is greater at 5 kHz due to the greater emission of noise from ships at this frequency.

4. Conclusions and Future Work

The methodology presented has implemented the steps defined in the ISO31000—Risk Management Plans in relation to environmental impact of anthropogenic activities in the sea. The methodology specifically addresses the risk assessment of masking due to underwater continuous noise generated by marine traffic, bringing the opportunity to policymakers and management authorities to localize problematic areas with relevant presence of marine traffic and high density of vulnerable species of cetaceans. The masking effect is not the only or the most important impact that marine mammals can suffer from the presence of continuous noise, but it should be considered as a relevant adverse impact because it is able to modify the SNR compared to a pristine ambient. This provides the possibility to use the masking-based risk indicator to implicitly assess whether the trend in the level of underwater noise produced by maritime traffic increases, decreases, or remains constant as a function of time. The proposed model can be applied to study this effect in any marine mammal species that uses the sound to be aware of their surrounding. The choice of the species to study can be chosen based on criteria such as:

- A specific ecological interest (e.g., endangered species).
- Its use as a global indicator because it represents a group of species very sensitive to noise.
- The data availability.

The results of the risk-based index offer the possibility of studying the risk of masking linked to some species, offering a temporal and spatial extension of the impact, being qualitatively categorized as low, medium, or high risk if an umbralization is applied. Nevertheless, during the implementation process of the present study case difficulties arose, mainly related to the lack or partial knowledge of some variables that play an important role in the risk analysis process. As explained before, the model is based on the population density of noise-sensitive species and the communication distance reduction due to the marine traffic contribution to underwater noise. Concerning the density population data, usually the sighting surveys are performed with a given frequency (e.g., once a year). This means that the image about population is biased since it is linked to a given period of time. As a consequence, the whole process of assessment should be considered as a static view of the animals. Depending on the species, this could be more or less relevant (migrant vs. resident populations or species). Another relevant aspect regarding the communication distance reduction calculation is that it is based on the excess noise level considering anthropogenic and natural sources, compared to the pristine environment. This is a tricky subject because the measurement of noise in the absence of the influence of marine traffic is difficult from an experimental and theoretical point of view. Theoretical models must be adapted to the precise historical meteorological conditions, including wind and rain over extensive marine areas, which are not easy to obtain. The installation of passive acoustic monitoring devices in a specific location, minimizing the influence of underwater noise produced by marine traffic, is challenging because seawater efficiently propagates sound from afar, especially if considering low frequencies. In conclusion, the implementation of risk-based models can be revealed as a relevant tool for authorities in order to establish management plans with respect to marine areas, allowing a balance between human activities and the fitness of marine mammals. However, the implementation of this methodology also points out the need to have a holistic knowledge of the marine environment, encouraging the consideration of marine scientific campaigns and long-term monitoring periods as important tools to assess the GES of the sea with the best possible accuracy.

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References

1. *2017/848*; Laying down Criteria and Methodological Standards on Good Environmental Status of Marine Waters and Specifications and Standardised Methods for Monitoring and Assessment, and Repealing Decision 2010/477/EU. Commission Decision (EU), Publications Office of the European Union: Luxembourg, 17 May 2017.
2. Protecting Marine Life from Ship Noise. 2018. Available online: https://www.imo.org/en/MediaCentre/Pages/WhatsNew-1105.aspx (accessed on 1 February 2022).
3. Kunc, H.P.; McLaughlin, K.E.; Schmidt, R. Aquatic noise pollution: implications for individuals, populations, and ecosystems. *Proc. R. Soc.* **2015**, *B*, 12304–12323. [CrossRef] [PubMed]
4. Dekeling, R.; Tasker, M.; Van Der Graaf, S.; Ainslie, M.; Andersson, M.; André, M.; Borsani, J.; Brensing, K.; Castellote, M.; Cronin, D.; et al. Monitoring Guidance for Underwater noise in European Seas: Monitoring Guidance specifications, Part II: Monitoring Guidance Specifications. In *JRC Scientific and Policy Report EUR 26555*; Publications Office of the European Union: Luxembourg 2015; pp. 1–49.
5. Medwin, C.C.H. *Fundamentals of Acoustical Oceanography*; Academic Press: Cambridge, MA, USA, 1997.
6. Peng, C.; Zhao, X.; Liu, G. Noise in the sea and its impacts on marine organisms. *J. Environ. Res. Public Health* **2015**, *12*, 12304–12323. [CrossRef] [PubMed]
7. Williams, R. Impacts of anthropogenic noise on marine life: Publication patterns, new discoveries, and future directions in research and management. *Ocean. Coast. Manag.* **2015**, *115*, 17–24. [CrossRef]
8. Richardson, W.J. *Marine Mammals and Noise*; Academic Press: Cambridge, MA, USA, 1995. [CrossRef]
9. National Research Council. *Ocean Noise and Marine Mammals*; The National Academies Press: Washington, DC, USA, 2003; Volume 12. [CrossRef]
10. Finneran, J.J. Noise-induced hearing loss in marine mammals: A review of temporary threshold shift studies from 1996 to 2015. *J. Acoust. Soc. Am.* **2015**, *138*, 1702–1726. [CrossRef] [PubMed]
11. Jepson, P.D.; Arbelo, M.; Deaville, R.; Patterson, I.A.; Castro, P. Gas-bubble lesions in stranded cetaceans. *Nature* **2003**, *425*, 575–576. [CrossRef] [PubMed]
12. Erbe, C. Communication masking in marine mammals: A review and research strategy. *Mar. Pollut. Bull.* **2016**, *103*, 15–38. [CrossRef]
13. Wright, A.J.; Soto, N.A.; Baldwin, A.L.; Bateson, M.; Beale, C.M.; Clark, C.; Deak, T.; Edwards, E.F.; Fernández, A.; Godinho, A.; et al. Do Marine Mammals Experience Stress Related to Anthropogenic Noise? *Int. Soc. Comp. Psychol.* **2007**, *20*, 274–316.
14. Weilgart, L.S. The impacts of anthropogenic ocean noise on cetaceans and implications for management. *Can. J. Zool.* **2007**, *85*, 1091–1116. [CrossRef]
15. Rey-Baquero, M.P.; Huertas-Amaya, L.V.; Seger, K.D.; Botero-Acosta, N.; Luna-Acosta, A.; Perazio, C.E.; Boyle, J.K.; Rosenthal, S.; Vallejo, A.C. Understanding Effects of Whale-Watching Vessel Noise on Humpback Whale Song in the North Pacific Coast of Colombia With Propagation Models of Masking and Acoustic Data Observations. *Front. Mar. Sci.* **2021**, *8*, 623724. [CrossRef]
16. Whitlow, W.; Au, L.; Patrick W.; Moore, B. Critical ratio and critical bandwidth for the Atlantic bottlenose dolphin. *J. Acoust. Soc. Am.* **1990**, *88*, 1635–1638. [CrossRef]
17. Erbe, C. Critical ratios of beluga whales (*Delphinapterus leucas*) and masked signal duration. *J. Acoust. Soc. Am.* **2008**, *124*, 2216–2223. [CrossRef] [PubMed]
18. Kastelein, R.A. Critical ratios in harbor porpoises (*Phocoena phocoena*) for tonal signals between 0.315 and 150 kHz in random Gaussian white noise. *J. Acoust. Soc. Am.* **2009**, *126*, 1588–1597. [CrossRef] [PubMed]
19. Fouda, L.; Wingfield, J.E.; Bailey, H. Dolphins simplify their vocal calls in response to increased ambient noise. *Biol. Lett.* **2018**, *14*, 20180484. [CrossRef]
20. Popov, A.Y.; Supin, V.O.K. Frequency tuning of the dolphin's hearing as revealed by auditory brain-stem response with notch-noise masking. *J. Acoust. Soc. Am.* **1997**, *102*, 795–801. [CrossRef] [PubMed]
21. Castellote, M.; Clark, C.W.; Lammers, M.O. Acoustic and behavioural changes by fin whales (*Balaenoptera physalus*) in response to shipping and airgun noise. *Biol. Conserv.* **2012**, *147*, 115–122. [CrossRef]

22. *ISO 2018-02*; International Standard. Risk Management—Guidelines, 2nd ed.; International Standards Organisation: Geneva, Switzerland, 2018.
23. Verling, E. Application of a risk-based approach to continuous underwater noise at local and subregional scales for the Marine Strategy Framework Directive. *Mar. Policy* **2021**, *134*, 104786. [CrossRef]
24. Kinneging, N.A.; Tougaard, J. *Assessment North Sea*; Report of the EU INTERREG Joint Monitoring Programme for Ambient Noise North Sea (Jomopans); 2021; pp. 1–23. Available online: https://northsearegion.eu/media/17013/jomopans_assessment_eiha2021_1.pdf (accessed on 1 February 2022).
25. Merchant, N.D.; Faulkner, R.C.; Martinez, R. Marine Noise Budgets in Practice. *Conserv. Lett.* **2017**, *11*, 1–8. [CrossRef]
26. Brill, R.L.; Moore, P.W.; Dankiewicz, L.A. Assessment of dolphin (*Tursiops truncatus*) auditory sensitivity and hearing loss using jawphones. *J. Acoust. Soc. Am.* **2001**, *109*, 1717–1722. [CrossRef]
27. Jhonson, C.S. Sound detection thresholds in marine mammals. In *Marine Bioacoustics*; Pergamon Press: Oxford, UK, 1967; pp. 247–260.
28. Lilly, J.C.; Miller, A. Vocal exchanges between dolphins: Bottlenose dolphins "talk" to each other with whistles, clicks and a variety of other noises. *Science* **1961**, *134*, 1873–1876. [CrossRef]
29. Ding, W.; Wursig, B.; Evans, W.E. Whistles of Bottlenose dolphins: Comparison among populations. *Aquat. Mamm.* **1995**, *21*, 65–67.
30. Díaz, B. Whistle characteristics in free-ranging bottlenose dolphins (*Tursiops truncatus*) in the Mediterranean Sea: Influence of behaviour. *Mamm. Biol.* **2011**, *76*, 180–189. [CrossRef]
31. Caldwell, M.C.; Caldwell, D.K. The whistle of the Atlantic bottlenosed dolphin (*Tursions-truncatus*)-ontogeny. *Behav. Mar. Anim.* **1979**, *3*, 369–401.
32. Gannier, A.; Fuchs, S.; Quèbre, P.; Oswald, J. Performance of a contour-based classification method for whistles of *Mediterranean delphinids*. *Appl. Acoust.* **2010**, *71*, 1063–1069. [CrossRef]
33. Schoeman Renée, P.; Patterson-Abrolat Claire, P.S. A Global Review of Vessel Collisions With Marine Animals. *Front. Mar. Sci.* **2020**, *7*, 292. [CrossRef]
34. WP 2: Noise Sources Task T2.1. *AQUO Achieve QUieter Oceans by Shipping Noise Footprint Reduction FP7—Collaborative Project n° 314227*; European Commission: Brussels, Belgium, 2016.
35. Wang, L.; Heaney, K.; Pangerc, T.; Theobald, P.; Robinson, S.; Ainslie, M. *Review of Underwater Acoustic Propagations Models*; NPL Report AC 12; National Physical Laboratory: Teddington, UK, 2014.
36. Tappert, F.D. The parabolic approximation method. In *Wave Propagation and Underwater Acoustics*; Keller, J.B., Papadakis, J.S., Eds.; Springer: Berlin/Heidelberg, Germany, 1977; pp. 224–287. [CrossRef]
37. Clay, C.S.; Medwin, H. *Acoustical Oceanography: Principles and Applications*; John Wiley and Sons: Hoboken, NJ, USA, 1977.
38. Porter, M.B.; Liu, Y. Finite Element Ray Tracing. *Theor. Comput. Acoust.* **1994**, *2*, 947–956.
39. Hovem, J.M. Ray Trace Modeling of Underwater Sound Propagation. In *Modeling and Measurement Methods for Acoustic Waves and for Acoustic Microdevices*; IntechOpen Limited: London, UK, 2013; pp. 573–598. [CrossRef]
40. Lara, G.; Miralles, R.; Bou-Cabo, M.; Esteban, J.A.; Espinosa, V. New Insights into the Design and Application of a Passive Acoustic Monitoring System for the Assessment of the Good Environmental Status in Spanish Marine Waters. *Sensors* **2020**, *20*, 5353. [CrossRef]
41. Mackenzie, K.V. Nine-term equation for the sound speed in the oceans. *J. Acoust. Soc. Am.* **1981**, *70*, 807–812. [CrossRef]
42. Becker, J.J. Global bathymetry and elevation data at 30 Arc seconds resolution: SRTM30 PLUS. *Mar. Geod.* **2009**, *70*, 355–371. [CrossRef]
43. Buckland, S.T.; Anderson, D.R.; Burnham, K.P.; Laake, J.L.; Borchers, D.L.; Thomas, L. *Introduction to Distance Sampling: Estimating Abundance of Biological Populations*; Oxford University Press: Oxford, UK, 2001.
44. 1.6.6.2 OSPAR Request on Indicator Assessment of Coastal Bottlenose Dolphins. Available online: https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2016/Special_Requests/OSPAR_Indicator_assessment_of_coastal_bottlenose_dolphins.pdf (accessed on 10 April 2022).
45. Saavedra, C. Assessing the environmental status of the short-beaked common dolphin (*Delphinus delphis*) in North-western Spanish waters using abundance trends and safe removal limits. *Prog. Oceanogr.* **2017**, *166*, 66–75. [CrossRef]
46. Miller, D.L.; Burt, M.L.; Rexstad, E.A.; Thomas, L. Spatial models for distance sampling data: recent developments and future directions. *Methods Ecol. Evol.* **2013**, *4*, 1001–1010. [CrossRef]
47. Scott, W.R.S. Bottlenose dolphin, Tursiops truncatus, Common bottlenose dolphin. In *Encyclopedia of Marine Mammals*, 3rd ed.; Academic Press: San Diego, CA, USA, 2018; pp. 118–125.
48. Fernández García, R. Ecology of the Bottlenose Dolphin, Tursiops Truncatus (Montagu 1821), in Galician Waters, NW Spain. Ph.D. Thesis, University of Vigo, Vigo, Spain, 2010.
49. Hammond, P.S.; Lacey, C.; Gilles, A.; Viquerat, S.; Börjesson, P.; Herr, H. *Estimates of Cetacean Abundance in European Atlantic Waters in Summer 2016 from the SCANS-III Aerial and Shipboard Surveys*; Sea Mammal Research Unit University of St Andrews: St Andrews, UK, 2017; pp. 1–39.
50. López, A.; Santos, M.B.; Pierce, G.J.; González, Á.F.; Valeiras, X.; Guerra, Á. Trends in strandings and by-catch of marine mammals in north-west Spain during the 1990s. *J. Mar. Biol. Assoc. UK* **2002**, *82*, 513–521. [CrossRef]

51. Papale, E.; Gamba, M.; Perez-Gil, M.; Martin, V.M.; Giacoma, C. Dolphins Adjust Species-Specific Frequency Parameters to Compensate for Increasing Background Noise. *PLoS ONE* **2015**, *10*, e0121711. [CrossRef] [PubMed]
52. NOAA Technical Memorandum NMFS-OPR-55. *Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing: Underwater Acoustic Thresholds for Onset of Permanent and Temporary Threshold Shifts*; United States Department of Commerce: Washington, DC, USA, 2016.
53. Ainslie, M.A. *Principles of Sonar Performance Modelling*; Springer: Berlin/Heidelberg, Germany, 2010.
54. Clark, C.W.; Ellison, W.T.; Southall, B.L.; Hatch, L.; Van Parijs, S.M.; Frankel, A.; Ponirakis, D. Acoustic masking in marine ecosystems. Intuitions, analysis and implications. *Mar. Ecol. Prog. Ser.* **2009**, *395*, 201–222. [CrossRef]
55. Au, W.W.; Snyder, K.J. Long-range target detection in open waters by an echolocating Atlantic Bottlenose dolphin (*Tursiops truncatus*). *J. Acoust. Soc. Am.* **1980**, *68*, 201–222. [CrossRef]
56. Marsh, H.W.; Shulkin, M. Shallow water transmission. *J. Acoust. Soc. Am.* **1962**, *34*, 863–864. [CrossRef]
57. Wenz, G.M. Acoustic Ambient Noise in the Ocean: Spectra and Sources. *J. Acoust. Soc. Am.* **1962**, *34*, 1936–1956. [CrossRef]
58. Frankel, A.S.; Zeddies, D.; Simard, P.; Mann, D. Whistle source levels of free-ranging bottlenose dolphins and Atlantic spotted dolphins in the Gulf of Mexico. *J. Acoust. Soc. Am.* **2014**, *125*, 1624–1631. [CrossRef]