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D9

Underwater noise studies in the Gulf of Lions region.

Anthropogenic contributions to underwater noise due to maritime traffic and offshore windfarm operation

Co-funded by the European
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Acronyms

AIS	Automated Identification Data
CEA	Cumulative Effect Assessment
CIA	Cumulative Impact Assessment
EIA	Environmental Impact Assessment
EU	European Union
GES	Good Environmental Status
IEO	Instituto Español de Oceanografía (Spanish Institute of Oceanography)
IMP	Integrated Marine Policy
MMSI	Maritime Mobile Service Identity
MSP	Maritime/Marine Spatial Planning
MSPD	Maritime Spatial Planning Directive
MSFD	Marine Strategy Framework Directive
OWF	Offshore Wind Farm(s)
RANDI	Research Ambient Noise Directionality
SCI	Site of Community Importance
SHOM	Service Hydrographique et Océanographique de la Marine Française (French Naval Hydrographic and Oceanographic Service)
SPL	Sound Pressure Level

1. Introduction

1.1. Underwater noise generated by maritime activities. The approach of MSF and MSP policies.

Sound is a dominant feature of the underwater marine environment as a result of natural (biological sources, underwater earthquakes, wind) and human-made (anthropogenic) sound sources (Richardson et al. 1995, NRC 2003, Popper and Hastings 2009 in Tasker et al, 2010). Underwater noise generated by maritime activities (i.e. maritime traffic) is proven to adversely affect the marine environment producing different types of effects on the pelagic component, especially on cetaceans. During last decades, the effects of noise on marine organisms such as mortality, hearing impairment, communication masking and behavior disturbance has been increasing. In this sense, underwater noise has become a hot topic for environmental managers and regulators in Europe and beyond (Thomsen et al, 2021).

The Marine Strategy Framework Directive[1] (MSFD) includes as one of the qualitative descriptors (Descriptor 11) for determining Good Environmental Status (GES), the introduction of energy, including underwater noise, at levels that do not adversely affect the marine environment.

For this purpose, the Commission Decision (EU) 2017/848, of 17 May 2017, laying down criteria and methodological standards on good environmental status of marine waters and specifications and standardized methods for monitoring and assessment, and repealing Decision 2010/477/EU[2], defined two criteria to assess underwater noise GES:

- Anthropogenic impulsive sound in water (Impulsive sound described as monopole energy source level in units of dB re 1 μPa2 s or zero to peak monopole source level in units of dB re 1μPa m, both over the frequency band 10 Hz to 10 kHz).
- Anthropogenic continuous low-frequency sound in water (Annual average, or other suitable metric agreed at regional or subregional level, of the squared sound pressure in each of two ‘1/3-octave bands’, one centered at 63 Hz and the other at 125 Hz, expressed as a level in decibels in units of dB re 1 μPa, at a suitable spatial resolution in relation to the pressure. This may be measured directly, or inferred from a model used to interpolate between, or extrapolated from, measurements).

Underwater energy inputs with a potential impact on marine ecosystems can occur at many scales of both space and time, and are very varied, coming from natural or/and anthropogenic sources. These sources could include thermal energy, electromagnetic fields, light, and

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[1] Directive 2008/56/EC of the European Parliament and of the council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive).

[2] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017D0848&from=es

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radioactive energy. Of all these energy sources, the most widespread and invasive is underwater noise, and its assessment and monitoring is therefore a priority[3].

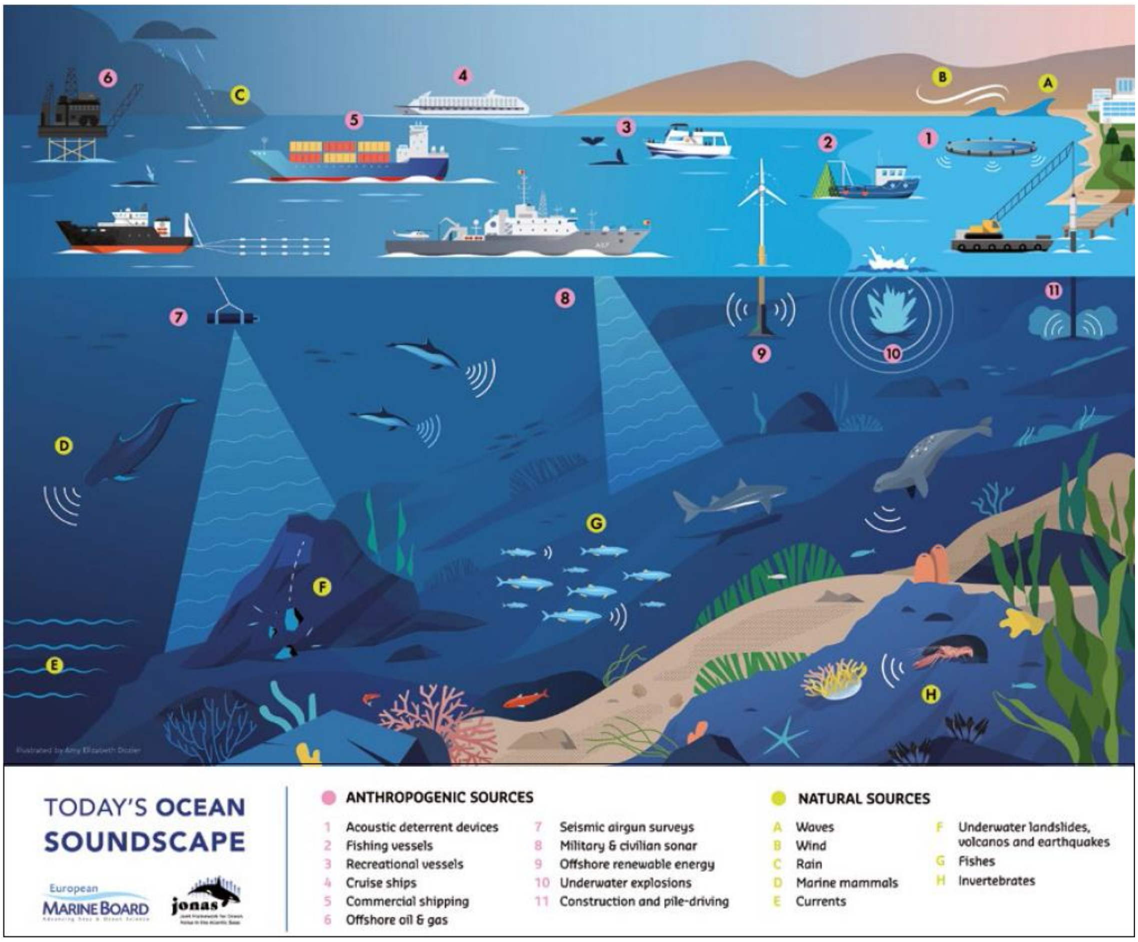

Figure 1: Anthropogenic and natural sources of underwater noise. Credits: European Marine Board and Jonas project. Source: Thomsen et al, 2021.

Underwater noise anthropogenic sources are commonly related to maritime transport, deep-sea mining, fishing, and construction. Some of them are introduced into the environment incidentally by the activity; others could be introduced intentionally for a particular purpose (i.e. seismic sources). Anthropogenic sound sources have a broad range of characteristics, including source level (sound level 1 meter from the source), frequency content (expressed in Hertz [Hz] or Kilohertz [kHz]), duty cycle (pattern of occurrence) and movement (i.e., stationary, or mobile) (Tasker et al,2010).

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[3] Marine Strategies: Initial Assessment, Good Environmental Status and Environmental Objectives, 2012. Ministry for the Ecological Transition and the Demographic challenge: https://www.miteco.gob.es/es/costas/temas/proteccion-medio-marino/0_Documento%20marco%20estrategias%20marinas_tcm30-130950.pdf

An important aspect of the underwater noise is that is generated (among others) by mobile activities (i.e. Marine transport) and its “travels” along the space. Added to this, receptors of this pressure are mainly mobile across borders (i.e. cetaceans) which highlights the importance of the transboundary approach to this topic.

Furthermore, there are static infrastructures related to the development of new activities in the marine environment, such as Offshore Wind Farms (OWF), that also generate underwater noise.

In this sense, one of the main challenges that are facing Member States currently is to carry out a coherent and effective distribution of human activities in the marine environment, which also allows assessing the possible impacts and pressures that may affect species and habitats, in order to ensure a responsible use of marine resources. For this purpose, the EC approved in 2014, the Directive 2014/89/EU establishing a framework for maritime spatial planning, which “considers the economic, social and environmental aspects to support sustainable development and growth in the maritime sector, applying an ecosystem-based approach, and to promote the coexistence of relevant activities and uses”, accordingly to its article 5. Furthermore, MSP was already included in the Integrated Maritime Policy (IMP) of the European Union, which already indicated that "...*the increasing human impacts on the oceans, together with the fast-growing demand and competition for maritime space for different purposes, such as fishing activities, offshore renewable energy installations and ecosystem conservation, have highlighted the urgent need for integrated ocean management*...".

One of the activities with future prospects is offshore wind energy. It is already considered in the IMP and in the objectives of the European Green Deal, as one of the sectors that foresees a big development in the coming years. However, it is an emerging sector in various parts of Europe, with the exception of some northern European countries that have more experience in this kind of development. This leads to a lack information and studies related to the aspects needed for the specific characteristics of the Mediterranean, for instance, different from those of northern European seas. Therefore, the effects of these activities on the marine environment still need to be studied and analyzed, including underwater noise pressures that may have a negative impact on the species present in the areas where these OWF are planned to be deployed.

To evaluate cumulative effects in the ecosystem, the effects of noise pollution caused by human activities need to be assessed and considered in the corresponding Cumulative Impact Assessment (CIA) and eventually in the Environmental Impact Assessment (EIA). Consideration of all effects generated by an activity is essential for an effective and realistic CIA to inform MSP.

Moreover, it needs to be highlighted that Environmental Impact Assessment (EIA) is a mandatory procedure in the EU for each new activity to be developed in the marine environment. The growing demand of maritime activities and uses needs a good understanding of how human and ecological components of the systems interact, including the interaction between maritime uses (conflicts or synergies) and between uses and environment (pressures and impacts) (Casimiro et al, 2021). Accordingly to this argument, much progress has been made during the last decade in EIA and mitigation, but to optimally use mitigation and management measures we need to gain

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better knowledge on their effectiveness (Thomsen et al., 2021), which needs to be supported by the characterization of noise source; the use of numerical noise propagation modelling to estimate sound levels at various distances away from the source; and some form of exposure assessment using knowledge on species sensitivity to sounds of different frequencies, their risk of hearing damage and their distribution and abundance (Faulkner et al., 2018 in Thomsen et al, 2021).

MSP is a policy with a clear connection to CEA (IOC-UNESCO and European Union, 2017). Since the ecosystem-based approach is a pillar of MSP, dealing with cumulative effects is one of the key elements supporting the development of MSP itself (Ardron et al., 2008; Depellegrin et al., 2017; Douvere, 2008; Kidd et al., 2019 in Gimard et al., 2018). In turn, CEA/CIA assessments in MSP provide a way to ensure that MSP considers all pressures (Fernandes et al., 2021) identifying areas of great concentration of pressures and high impacted ecological components, therefore proposing measures to reduce these impacts, reallocating activities and/or proposing specific management measures. Most European countries now have regulatory frameworks to manage noise and the tools to integrate underwater noise into Marine Spatial Planning. However, more is needed to put some of these into practice and to fully test their effectiveness (Thomsen et al., 2021).

For this purpose, EU MSP transboundary projects are the best opportunity to create a first link between countries at technical level, which in the long term may lead to real cooperation at joint decision levels and integrate results (coming from case studies) as recommendations into MSP national processes. The importance of these pilot projects lies in their usefulness as laboratories dedicated to building the technical capacities necessary to ensure the proper implementation of the MSPD; the results obtained should support and can be implemented in the MSP national process. In general, national MSP processes can benefit from transboundary projects in different aspects, including the analysis of different variables to have better scientific knowledge about conflicts between human activities and the marine environment through the development of methodologies and capacities for cumulative impact analysis, which are essential tools for applying an ecosystem approach, supporting the compatibility of economic development with the achievement and maintenance of the good environmental status of the marine environment, its conservation, protection and improvement, to ensure that vulnerable and/or protected habitats and species are not affected by the location of human activities that require the use of marine space (Gómez-Ballesteros et al., 2021).

In this sense, there is intrinsically a link between MSFD and MSPD in addressing environmental, economic and social stakes to establish coherence between both Directive's purposes and their implementation (i.e. objectives, indicators and monitoring programs).

1.2 Proposed case study area.

The Gulf of Lion is a cross-border area between France and Spain that extends from Cap de Creus in Spain to Toulon in France (Louis, 1914, Russell, 1942, Ulses et al., 2008 in Dalleau et al, 2018). It has an unusually large continental shelf which is well defined at 100-200 m depth and a complex network of submarine canyons reaching depths of 2.000 m. Some submarine canyons are located close to the shore, such as the Cap de Creus Canyon (Dalleau et al, 2018).

The case study considers the area comprising from the city of Marseille to Barcelona in its broader definition. It is an outstanding area concerning marine biodiversity (i.e. marine birds, marine mammals, pelagic ecosystems), being the most productive zone in the Mediterranean, with particular climatic and oceanographic conditions. The high productivity of the marine waters and the aforementioned specific conditions, make this area an important area for economic development (i.e. artisanal fisheries, maritime traffic, offshore wind energy).

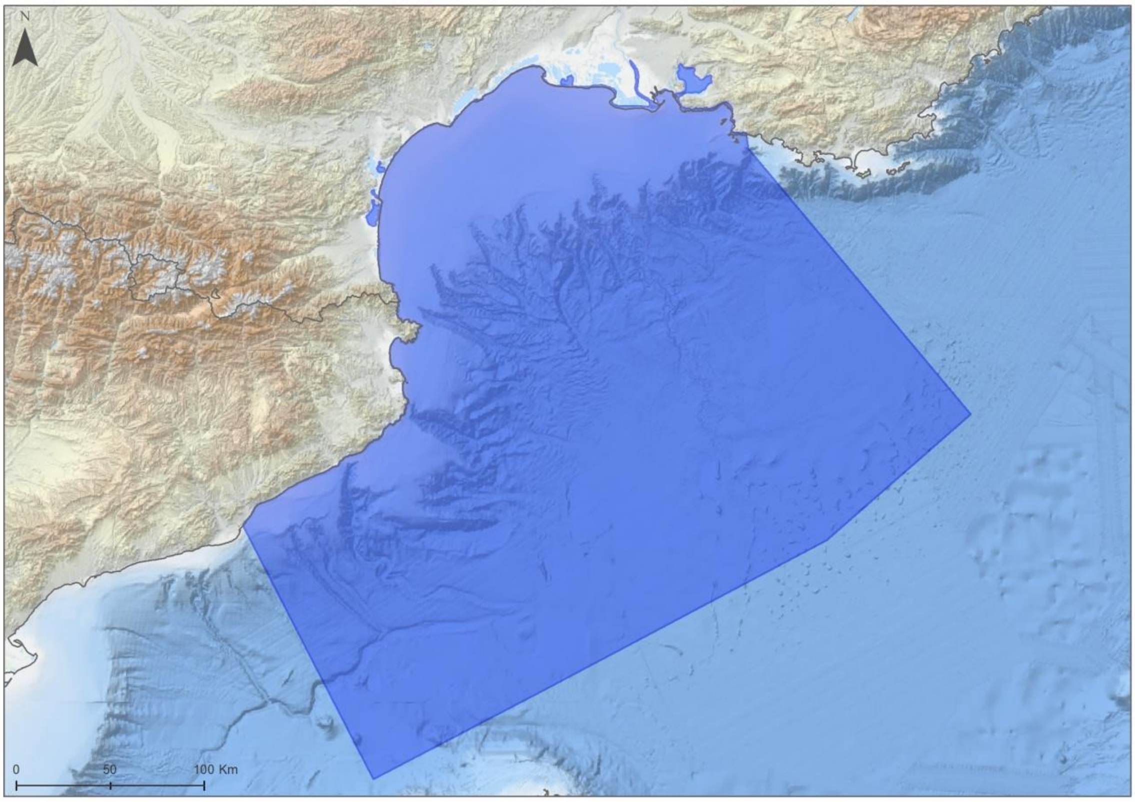

Figure 2: Case Study area in the Gulf of Lion. Credits: Spanish Institute of Oceanography.

The Gulf of Lion has been studied for different purposes by some projects, such as SIMWESTMED (*Supporting Implementation of Maritime Spatial Planning in the Western Mediterranean region*) through cross-border cooperation between Spain and France to conduct a mapping exposure risk of marine megafauna to concomitant pressures.

Other project of interest was LIFE+ INDEMARES (*Inventory and designation of marine Natura 2000 areas in the Spanish sea*) where the marine area “South-West Gulf of Lions canyons system” was declared as a Site of Community Importance (SCI) due to the habitats and species included in the zone.

Despite these initiatives, the Gulf of Lion still suffers from a strong lack of knowledge on species and habitats, as well as the interactions between these and the human activities. For this reason, the assessment of the interactions between the marine environment and maritime uses of interests in the area is still at an exploratory stage, as it could be the impact of underwater noise produced by maritime traffic and OWF in the pelagic component.

Maritime traffic in Gulf of Lion

In the area of the Gulf of Lion, the density of marine traffic is not very high around the cape of Creus, since it is not located near commercial routes neither in the proximity of large ports (Dominguez-Carrió et al, 2014). For the case study area, maritime transport is composed by goods and passengers’ vessels, where main ports are Barcelona and Marseille. In Spain, Barcelona port is ranked in the 3rd position in Spain regarding total transported goods in volume. For France, 85,7% of this goods traffic happens in the port of Marseilles (GPMM). This port is the first French one and the 6th European one in terms of volume. In 2014, goods traffic was up to 78,52 million tons, 55,6% of it was petroleum products. Regarding containerized goods, 1.18 million of TEUs (twenty-foot equivalent) transited (Moirano, 2018).

Offshore Windfarms in Gulf of Lion

Currently there are not OWF located in the case study area. In Spain, the draft MSP plan of the Balearic-Levantine marine demarcation, considered a Priority Use Area for offshore wind energy development located at the southeast of Cap the Creus (called LEBA 2) however, after the public consultation this may be different in the eventually approved plans. In France, there are 3 pilot projects for OWF in the Gulf of Lion, which will test from 3 to 4 turbines from 2023. In addition, there are 2 offshore windfarms projects, comprising around 25 turbines each, which were in public debate during the end of 2021.

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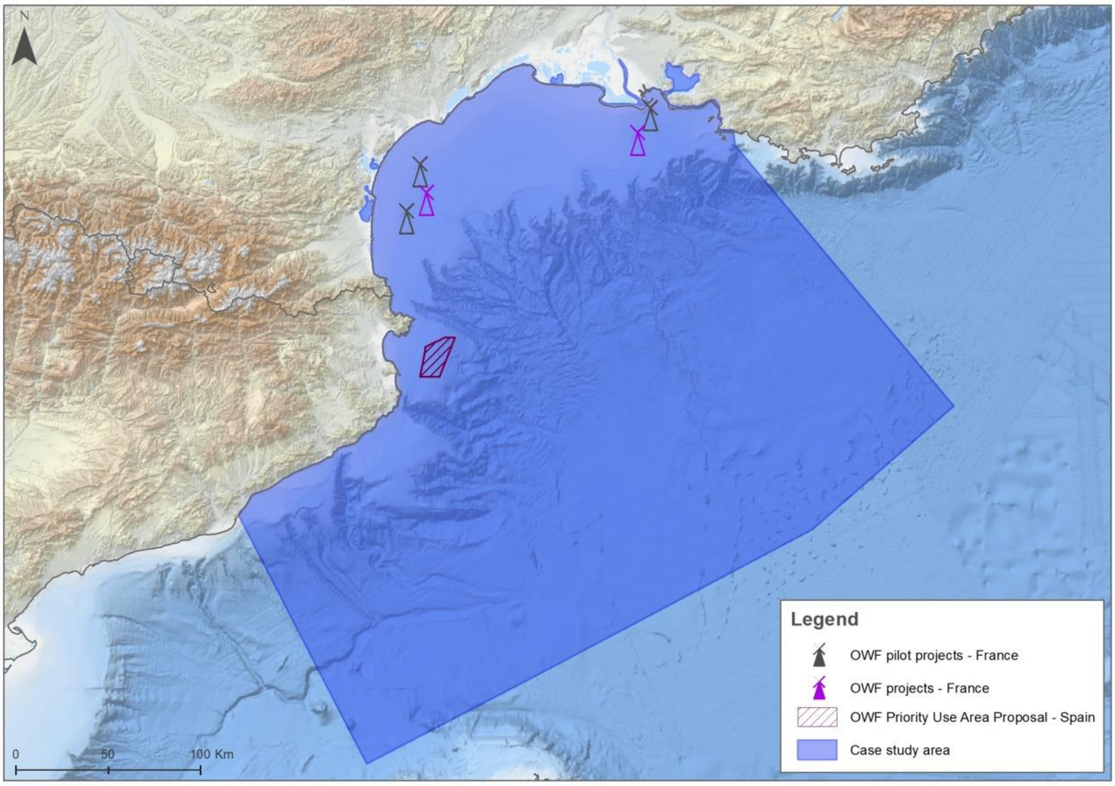

Figure 3: OWF proposals in the Case Study area in the Gulf of Lion[4]. Credits: Spanish Institute of Oceanography*.

The presented case study pretends to illustrate a methodology to evaluate the underwater continuous noise present in the area due to marine traffic and how the operation of OWF can play a relevant role with respect to the total soundscape and the influence of underwater noise on marine ecosystems and species (especially to cetaceans). The temporal and spatial analysis of noise will be implemented following the sections defined by means of next sections.

**Note: The analysis at first just considered the area which comprise the Gulf of Lions from Barcelona to Marseille. The decision to use the SIMWESTMED case study area was made after the AIS data request and the underwater noise modelling, thus the data analysis does not cover the whole case study area.*

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[4] OWF priority use area proposal for the Spanish area at the time of elaboration of this report was being reviewed and modified after the public consultation of the MSP plans.

2. Methodology

2.1 Underwater noise generated by marine traffic

Underwater noise represents an invisible pollutant since is not perceptible at naked eye as other types of hazardous waste. Nevertheless, the impact of noise is directly related with adverse impacts addressed to anthropogenic activities carried out in the sea. Depending on the temporal properties of the acoustic deposition of energy on the sea, underwater noise has been categorized as continuous noise or impulsive noise. Impulsive noise sources are related with activities localized in time and space and normally with moderate to high source level. Typically, impulsive noise is produced by activities involving detonations, seismic surveys, use of sonars or pile driving activities during the construction phase of windfarms among other activities. Regarding the continuous low frequency noise, is known that the activity that most importantly contributes to increase this type of sound is marine traffic. The shipping routes are well defined in the marine environment and the mean level of noise radiated to the medium remains constant or is increasing depending on the considered area. In fact, according to the results published by the American Geophysical Union (Tournadre, 14) the maritime traffic has increased over 300% over the past 20 years. In addition, nowadays the 90% of traded goods are transported by ship. So, marine spatial planning is linked directly with the underwater noise present in the marine environment, especially regarding the low frequency continuous noise produced by marine traffic. The assessment of the adverse impact of underwater noise is difficult and sometimes tentative due to the lack of information on aspects of the marine environment (i.e. population of sensitive species together with the underwater noise present in the studied area). For this reason, the MSFD plans to monitor the underwater continuous noise by means of experimental measurements and theoretical simulations to evaluate the noise generated by ships and radiated to the medium. The monitoring of continuous noise brings the possibility to infer trends in the source pressure level (hereafter Sound Pressure Level (SPL)) by means of the calculation of descriptor 11.2 (*The spatial distribution, temporal extent and levels of anthropogenic continuous low-frequency sound do not exceed levels that adversely affect populations of marine animals*) that pretends to measure the spatial and temporal extension of the sound pressure level related to the ship traffic.

The methodology followed to carry out the assessment consists in:

- Compute the Automated Identification Data (AIS) in the region of interest and evaluate the noise radiated to the medium by each navigating ship.

- Apply a suitable sound propagation method considering a specific bandwidth, the characteristics of the speed of sound in the water column and the properties of the sea bottom.

- Establish a temporary framework of the assessment considering a time windowing regarding the marine traffic snapshots considered.

- Obtain a statistical metrics regarding the sound pressure level able to be compared with the results offered by experimental data.

- Perform experimental measurements at a given locations with the aim to validate global results of noise by means of local experimental measurements.

In this framework, to achieve a better knowledge about the low frequency noise present in a given area a specific methodology is going to be illustrated through the assessment of underwater noise in the Gulf of Lion from January to May 2021.

It is important to remark that underwater noise is a pollutant that propagates efficiently through the water, summing up to the mobile character of its main source, maritime transport. In this sense, it is important to highlight those neighboring countries should implement plans and actions regarding the standardization of the assessment procedures trying to improve the cooperation to make methodologies and used metrics, comparable.

Considering vessel as a source of sound is a complex subject since there are diverse mechanisms associated to its operation that contributes to its acoustic signature. The spectrum of emitted signal is mainly dominant at the range [5 Hz - 400 Hz] (Hildebrand, 2009) but others frequency components are also present. As can be observed in the figure 4, the contribution to the acoustic signal emitted by operating vessel is composed by two main mechanisms: working machinery and hydrodynamics.

In turn, each category is composed by several aspects that emits in a frequency band overlapping with other contribution mechanisms.

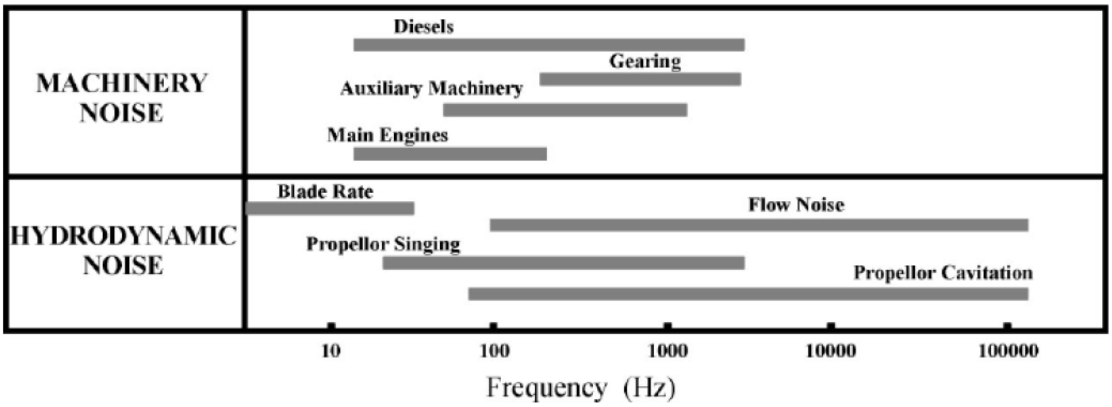


Figure 4. Bandwidth associated to the different types of systems able to radiate noise in a ship. Credits: MEPC 59/19, IMO 2009.

Several authors have studied the contribution and relevance of the different aspects that play a role in the total noise emitted by a vessel. For instance, Southall, 2005, pointed that the dominant source of noise in a vessel is produced by the operation of the propeller that emits sound due to cavitation phenomena produced in the blades. Other studies (Wright, 2008) suggest that the main contributors to the total noise radiated related to the machinery mechanisms are propulsion engines and ship service generators. Independently of the source of noise considered within the different parts of the ship, the speed of the vessel contributes not only in relation to the amplitude of sound pressure level but also with the range of frequencies radiated. For this reason, it is accepted that the noise emitted by machinery is dominant at low-speed regimes and as speed increases the noise radiated by propellers turn in to be the most influential.

The characteristics of ships, such as length or tonnage, also play a role in the characteristics of radiated noise. The relationship among the characteristics of emitted noise and the performance and characteristics of the vessel have been addressed during the last decades by the development of different types of empirical based models. A huge effort has been done by several authors and initiatives to characterize experimentally the acoustic signature of different types of ships (McKenna, 2012) (Espérandieu, 1990). The majority of the models are based on experimental measurements of acoustic signatures of ships attending to its characteristics and its speed over ground. To point out a few of them, Urick and Ross models are based on acoustic signature of ships collected during World War II. The Urick method mainly considers the radiation of noise due to the propellers being usable for frequencies from a 1 kHz. Ross model considers the speed over ground dependence of ship and the tonnage but does not implement the dependence of the size of the ship. In addition, the source level is calculated integrating over frequency range.

In the case study carried out through the Gulf of Lion, for the first five months of 2021, the Randi model has been used to parametrize the source level at a given frequencies for each vessel considered. The RANDI (Research Ambient Noise DIrectionality) model (Wagstaff,73) and the update of the RANDI model (Breeding, 1994) considers the dependence of source level radiated for a given frequency range establishing a categorization of the ships attending to its length and tonnage. The main categories are fishing, merchant, tanker, large tanker and super tanker. The application frequency range covers from 10 Hz to 10 kHz and it is considered the speed over ground of each ship attending to its category. The updated Randi model is one of the most complete models because it considers several characteristics of ships. By this reason, it has been applied to calculate the source level of each vessel present around the case study area. The applied equation to compute the source level for a frequency regime < 500Hz is shown below:

$$SL\,(f,V,L) = SL_0(f) + 60 \cdot \log\left(\frac{V}{Vref}\right) + 20 \cdot \log\left(\frac{L}{Lref}\right) + df \cdot dL + 3dB$$

where V represent the speed over ground of the vessel and L its length and SL_0 can be calculated following the expression depicted below.

$$SL_0(f) = -10 \cdot \log\left(10^{-1.06 \cdot \log(f) - 14.34} + 10^{3.32 \cdot \log(f) - 21.425}\right), for\ f < 500Hz$$

Following the MSFD guidelines for the assessment of continuous noise, frequency bands of 63 Hz and 125 Hz have been considered.

Once the methodology of source level calculation associated to each ship attending to its category and operation characteristics is developed, the next step is to collect and compute the Automated Identification System data (hereafter AIS data). The AIS data is an automatic track system based on the transceiver emitter located in each ship. Through the AIS data information about the position, Maritime Mobile Service Identity (MMSI identification number), speed over ground, course or date among other information can be retrieved by each vessel. It is remarkable that not all the ships present in the sea are monitored by AIS transponder. It is only mandatory in those vessels with tonnage exceeds 300T (2002/59/CE). One important aspect regarding the underwater noise model implementation based on AIS data is the spatial coverage and data quality. There are roughly two types of AIS data: the terrestrial and satellite based. The coverage of terrestrial data fails beyond coastal waters approximately at distances greater than 46 mi. This aspect must be considered if sound maps with different AIS data suppliers must be compared.

The case study implemented has analyzed AIS data covering the period from 1st of January to 31st of May 2021. A necessary segmentation of data is needed to obtain the static ‘snapshots’ of maritime traffic from which develop the statistical trends over the assessment period. The temporary resolution of the snapshots was 6h. Figures 5 and 6 shows the density of routes calculated with the available AIS data used to model underwater noise considering different cell size.

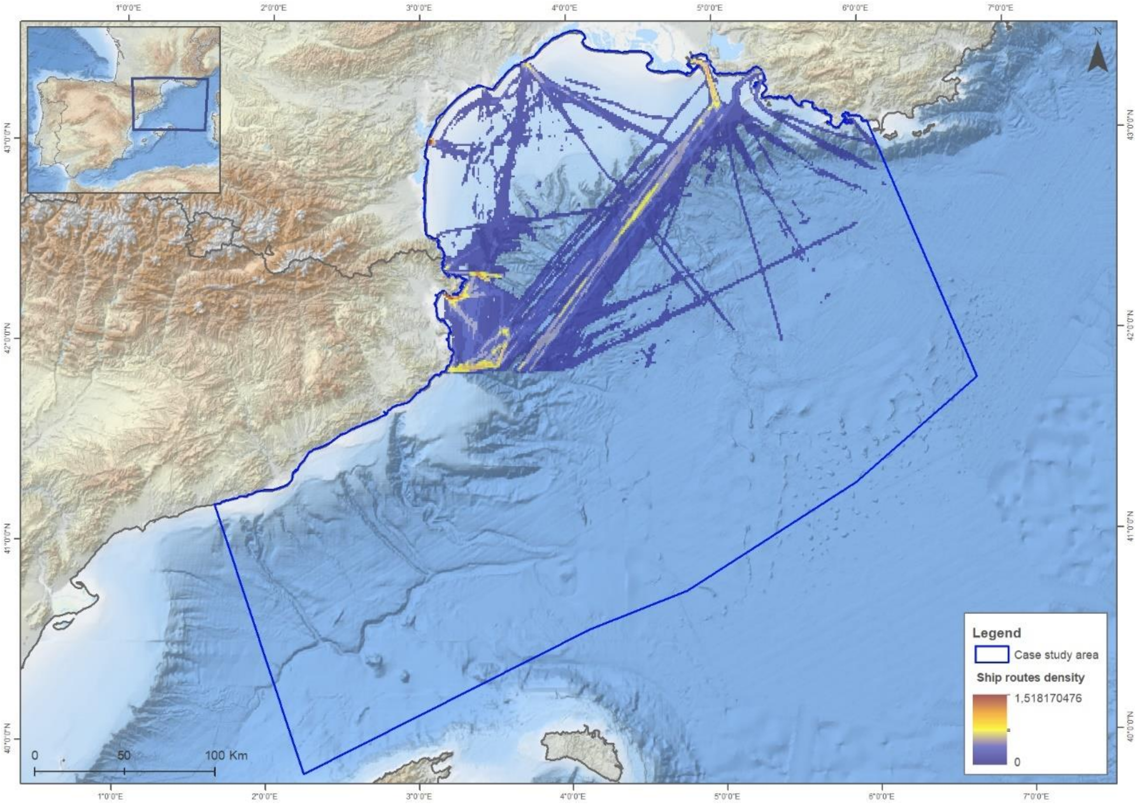


Figure 5. Route density calculated over a cell grid array of MxN km^2 cell blocks for the AIS first five months of 2021 period. Credits: Spanish Institute of Oceanography.

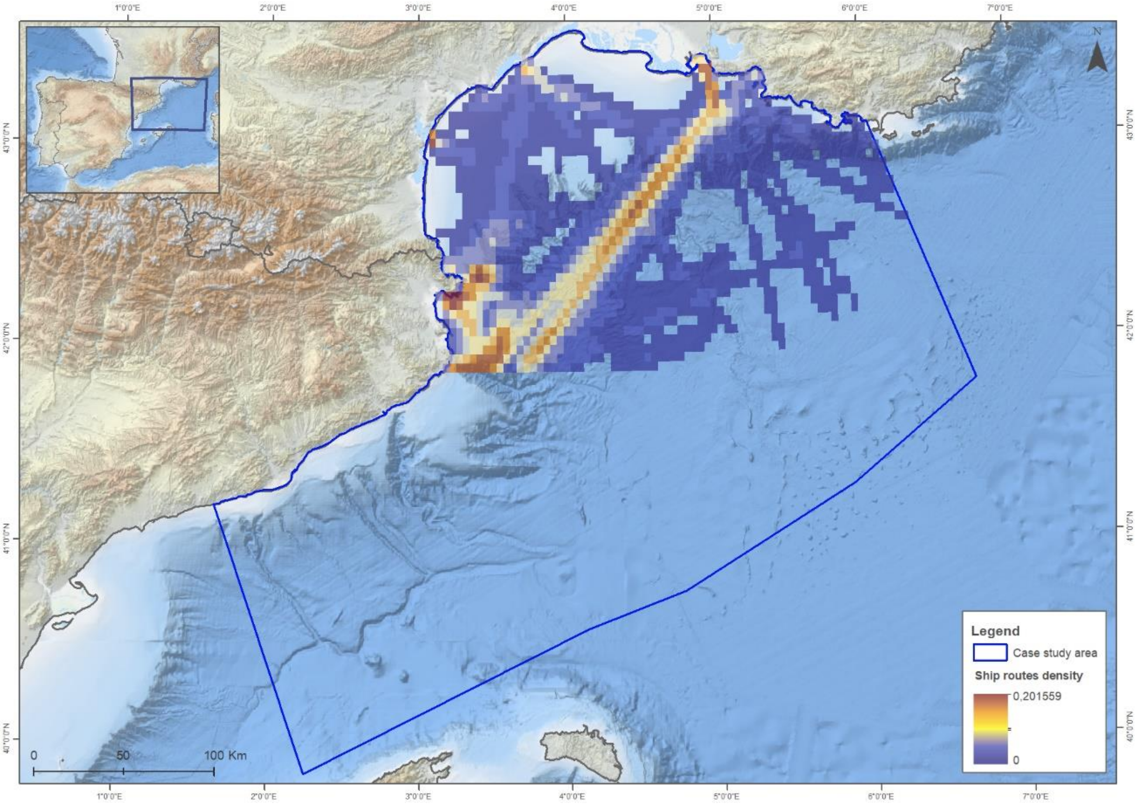
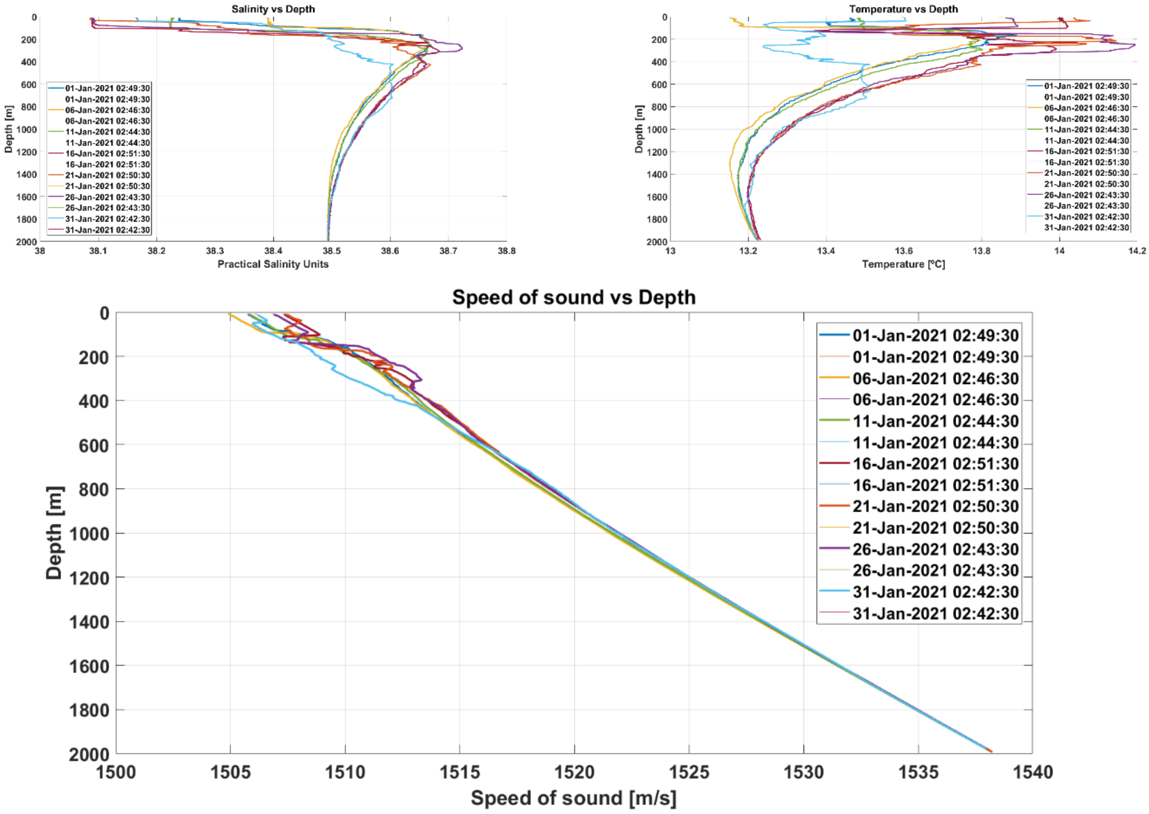


Figure 6. Density of routes calculated over a MxN cells grid spatial array for the first five months of 2021 period. Credits: Spanish Institute of Oceanography.

Each ship is considered as a noise source radiating to the medium, so it is necessary to apply a proper technique to propagate the sound through the marine environment. There are a variety of wave equation solutions depending on the considered solver function applied.

It is not intended to describe deeply the technical aspects related to the underwater propagation of sound. This topic is in itself a line of research in the field of physical oceanography. The underwater sound propagation techniques have been widely applied on several topics ranging from active to passive acoustics. Regarding the main topic of this deliverable, the application of underwater sound propagation is related to the forecasting of the noise present in certain area due to maritime traffic. There are several kinds of propagation techniques based on the resolution of wave equations. Some of them consider the temporary information of the emitted signal like finite differences in time domain or finite element method. Usually, the calculation of the sound pressure level due to maritime traffic considers huge areas so the techniques applied to propagate the sound just consider the source level of the emitters and its frequency band. This kind of techniques have been developed during last decades and diverse computing codes are freely available (ref, oalib-web). Despite the availability of techniques to propagate the sound in the sea, its suitability depends on several factors like frequency content of signal able to be propagated, the depth of the site or even computational resources needed. The application of propagation codes brings the opportunity to know the transmission loss between the source and the rest of the medium. So, its characteristics determines the geometric propagation paths of sound through the marine environment. Some authors have categorized the methods of propagation attending to the type of the function used to solve the Helmholtz equation. Usually, these methods are referred in the literature (Jensen, 1994) (Etter.2013) as ray tracing, parabolic equation, normal modes and wave number integration.

Regardless the method used to propagate the acoustic signal through the marine water, the environmental conditions must be considered. Specifically, the geometrical properties of the propagation of sound depends on the surface and bottom characteristics together with the water column speed profile. There are various methods to infer the water column speed profile from the temperature, salinity and the hydrostatic pressure in relation to depth. In the case study presented, the speed of sound was calculated using the Mackenzie nine term equation (Mackenzie, 1981). The choice of the method is based in its suitability for the temperature, salinity and depth values (temperature of between 2ºC and 30ºC, a salinity of 25–40 parts per thousand (PPT) and a depth of between 0 m and 8.000 m). Figure 7 shows the values of temperature and salinity together with the sound speed profile calculated. The experimental values have been obtained from data offered by Argo/profiler system, platform 6902850 operated by IFREMER. Figure 8 corresponds to environmental values of May, where itis possible to see the mixed layer and the formation of the thermocline for the first meters of depth from the surface.


Salinity vs Depth

Temperature vs Depth

Speed of sound vs Depth

Figure 7. The temperature and salinity as a function of depth considered to apply Mackenzie equation to calculate the sound speed profile (January 2021). Credits: Spanish Institute of Oceanography.

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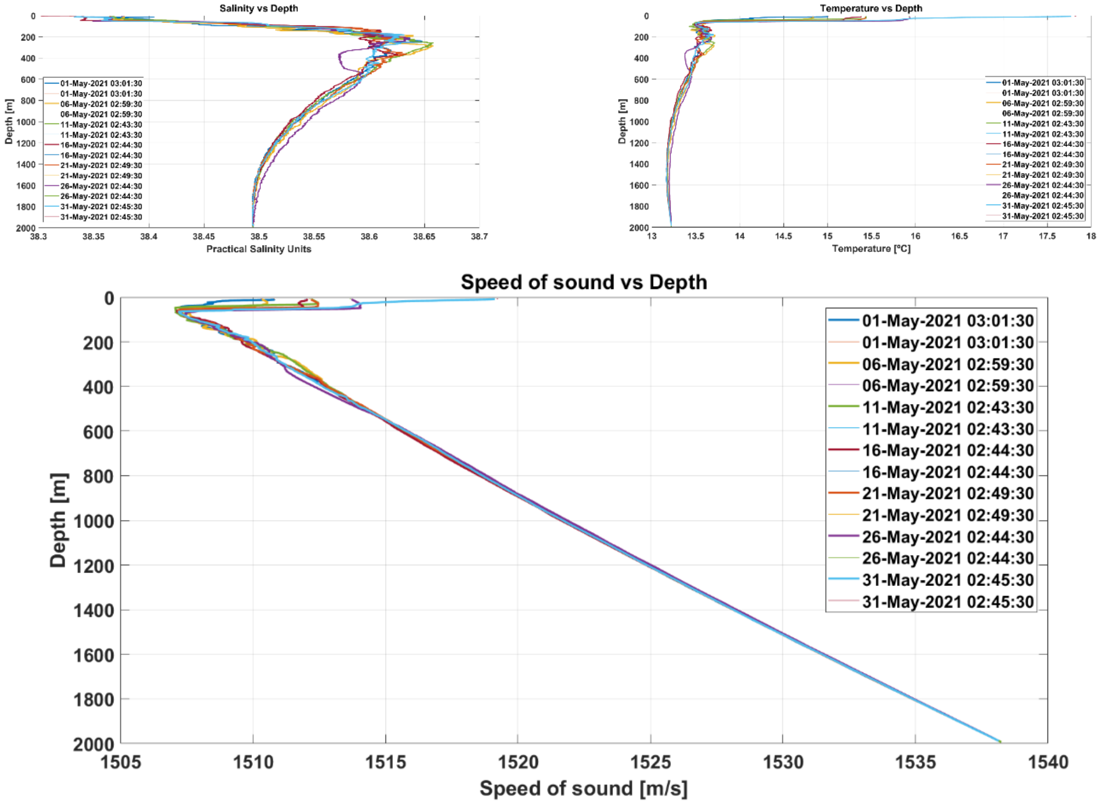

Figure 8. The temperature and salinity as a function of depth considered to apply Mackenzie equation to calculate the sound speed profile (May 2021). Credits: Spanish Institute of Oceanography.

The sound speed profile in the water column and its seasonal variation determines the propagation of sound through the water. The refraction of sound produces that the propagating wave tends to curve towards minimum values of sound velocity gradient. In this sense, each sound map calculated from the AIS data snapshots uses its own velocity profile on a weekly basis. Despite some propagation methods allow to implement range dependent models, it is difficult to dispose of monitored characteristics of the medium in each propagation direction. By this reason, a range independent model was developed to carry out the case study addressed.

The remaining variable that plays a relevant role in the propagation of sound is the bottom characteristics of the studied area. The sea bottom is a complex interface and sound propagating is reflected, scattered and absorbed in different ways regarding the geometry and the type of the bottom. Depending of the complexity of the propagation model considered, the properties of absorption and reflection of the bottom can be implemented. Figure 9 shows the bottom type of the Gulf of Lion (neglecting *Posidonia oceanica* and *Cymodocea* due to their littoral nature).

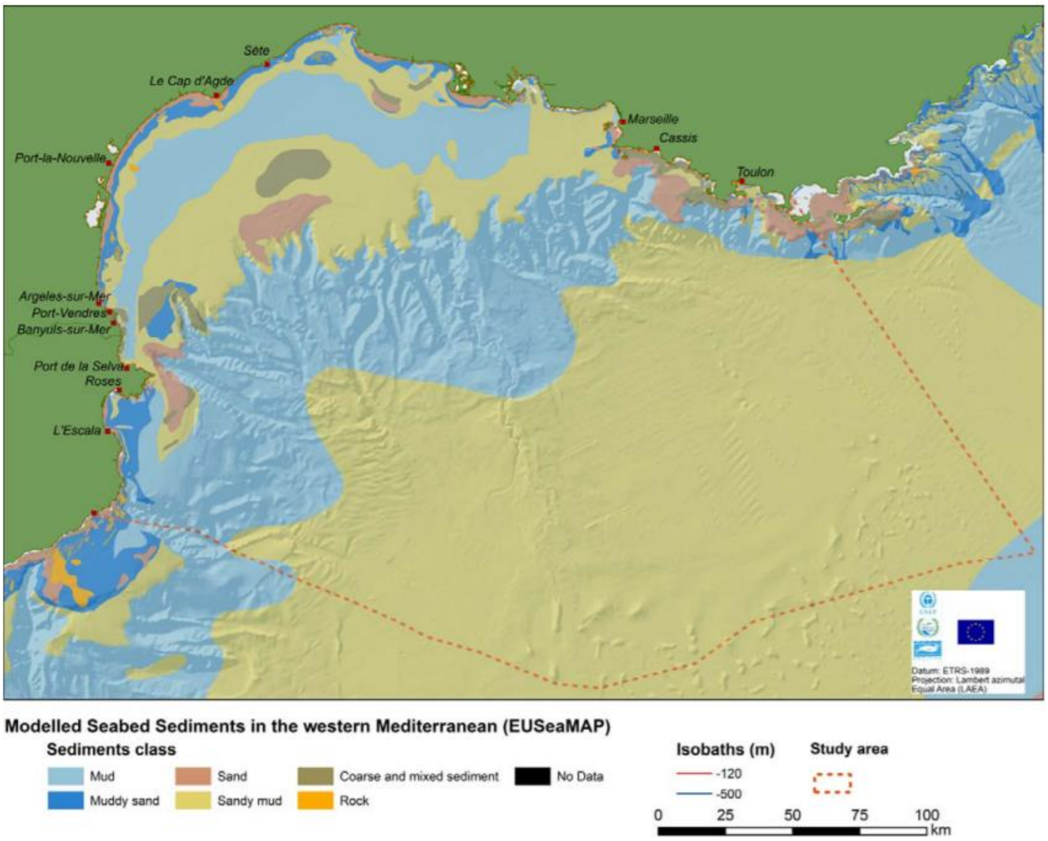

Figure 9. Modelled seabed substrate map from EUSeaMap project. Credits: (EUSeaMap 2011b).

The calculation of the attenuation coefficients of sound in the sea bottom layers is complex and its application on a huge area regarding the sound map modelling is tentative since the spatial coverage is huge and some simplifications are required to make the problem computationally accessible. In the case study a range independent attenuation coefficient has been applied considering mud sediment for the whole area following Wan,2020.

With respect to the sea bottom geometry, bathymetric data was obtained from General Bathymetric Chart of the Oceans (GEBCO, 2021).

The last step in the exposed framework should be the validation of sound maps obtained by means of experimental data offered by a deployment of passive acoustic monitoring devices. Unfortunately, this las step has not been carried out due to aspects unrelated to the project’s implementation so results obtained in the case study must be understood as tentative.

2.2 Temporal and Spatial distribution of noise

The aim of the implemented assessment is studying the temporal and spatial extension of the underwater noise present in the marine environment and produced specifically by maritime traffic. In this sense, statistical procedures must be developed to use metrics that allow to infer patterns and trends that enable the long-term monitoring of noise. Considering the case study implemented, a sound map has been obtained every 6h since 1st of January to 31st of May of 2021. Depending on the sampling rate of the snapshots, the temporary resolution will be more or less accurate. Considering the computational effort needed to decrease the temporary resolution a compromise between the accuracy and temporary window of the snapshots must be achieved.

The results shown in part 3 of this deliverable contains the study of:

(a) mean values of sound pressure level obtained by means of the sound maps obtained by each 6h. A daily time basis for the mean value for the sound pressure level has been implemented. This type of calculation brings the opportunity to study the averaged spatial distribution of noise. The obtained results depend on the snapshots time windowing. This is important when results of the same area are compared. The calculation of the mean value of sound pressure level associated to a given frequency value at each cell of the sound map is calculated by the following equation:

$$\overline{SPL}\,_{i,j}^{Freq} = \left(\sum_{Day=1}^{Day=N} NSPL_{i,j}^{Freq}\right) / \, N$$

being the $NSPL_{i,j}^{Freq}$ the sound pressure level associated to the cellblock i,j defined in the sound map for the frequency Freq for a given day contained in the evaluation period.

(b) associated percentiles to the daily sound maps with the aim to monitor the trend of the sound pressure level calculated through the assessment period.

(c) the temporary extension of noise with respect to some statistical indicator (i.e. defined percentiles). The percentage of time during the evaluation period at which each cell of sound map exceeds a given percentile regarding the sound pressure level has been computed. This metric is exemplified to calculate the time extension of noise related to the anthropogenic activity, following the metrics summarized below.

$$NPcase_{i,j}^{Freq} \rightarrow If\left(NSPL_{i,j}^{Freq} > PCTILE_A\right) == \ 1$$

$$\%Time_{i,j}^{Freq} = 100 \cdot \left(\sum_{Day=1}^{Day=N} NPcase_{i,j}^{Freq}\right)/N$$

where $PCTILE_A$ represents the percentile A calculated over a daily sound map, $NPcase_{i,j}^{Freq}$ the positive cases (normalized to 1) that verifies the cut imposed by $PCTILE_A$ and $\%Time_{i,j}^{Freq}$ the percentage of time that a cell block present values higher than $PCTILE_A$.

Results related with the application of the approaches presented will be presented at part 3 of this deliverable.

2.3 Influence of offshore windfarms operation on the sound pressure level due to marine traffic

The installation of windfarms has grown during the last decade attending to the data published in the 2020 by WindEurope (WindEurope,2020). The countries that have connected more windfarms until 2020 are UK, Germany and Belgium (see Figure 10).

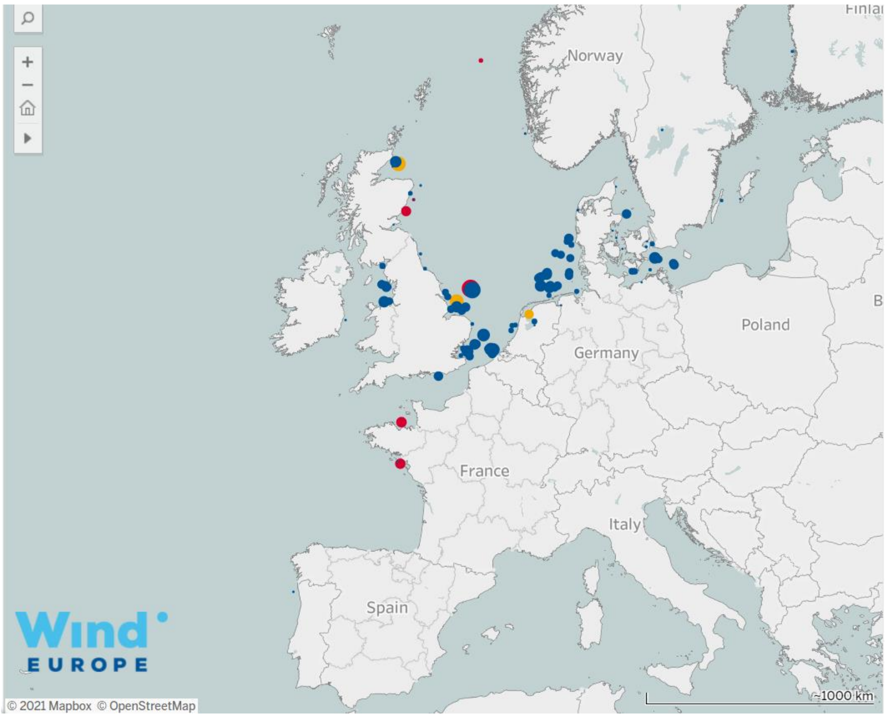

Figure 10. Detail of European windfarm locations. Map accessible in https://windeurope.org/intelligence-platform/product/european-offshore-wind-farms-map-public/

The major part of European windfarm installations is located at Ospar Regions II, III and IV. However, the implementation of this type of technology in the Mediterranean Sea has not yet occurred although it is expected to happen in the short to medium term.

A windfarm installation project represents a source of noise considering the construction and the operation phases. During the construction phase and specially if pile driving activities are planned, impulsive noise must be assessed. This type of noise deposes in the medium a high sound pressure levels (Rodkin, 2004) reaching values of 200 dB (ref 1 µPa RMS). The noise produced by pile driving strongly depends on the type of seafloor and characteristics of hammer used. The construction phase of a windfarm represents a potential huge impact on the noise levels present in the marine environment, but its duration is short in comparison with the operation phase that could arrive to 20 years. This long-time life of operation makes necessary to evaluate the continuous noise emitted by these infrastructures. There are studies in literature performed by some authors, which are specifically focused on the characterization of source level relative to the operation of the windfarms (Tougaard,2020) (Madsen, 2006). The results obtained with respect to the evaluation of the source level of noise or its dominant frequency range are sparse pointing the influence of the noise emitted with the type of turbine and its mechanical characteristics. In addition, also the need to characterize the directivity of the acoustic field radiated to the medium with respect to the wind turbine direction has been suggested. Despite the effort carried out to characterize the offshore windmills there are some lacks of knowledge that need to be addressed.

The influence of the pile driving process during the construction phase is a concern due to the high level of impulsive noise radiated to the medium. For this reason, among others, new foundations technology has been developed considering infrastructures that do not need to be dug on the seafloor. This is the case of floating windfarms. This kind of technology brings the opportunity to place windfarms far away from the coastline, where fixed foundation windmills cannot be installed, stablish better accommodation of shipping lines with respect to windfarm polygon area or increase the number of installed windmills on those countries with small coastlines areas. Despite these advantages the floating windfarms are under development and the characterization of the underwater noise radiated by these infrastructures is not well studied yet.

Regarding the case study performed in the Gulf of Lion through this deliverable and considering that a sound map linked to maritime traffic is available for the period of assessment for the first five months of 2021, the calculation of a floating windfarm influence on the continuous noise sound pressure was carried out. Although the obtained results must be considered as tentative, this type of modeling must be addressed with the aim to detect lacks of information and to have results that must be validated through the experimental measurements.

Considering the installation of the offshore floating *Hywind Tampen Windpark* and taking the advantage of the "*Noise impact assessment Hywind Tampen*" document, a source level value of 150dB for 63Hz and 140dB for 125Hz has been assigned to 8 hypothetical floating windmills located at positions shown in figure 11. This exercise assumed a constant continuous emission

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without dependence of wind since there are no experimental data related to this aspect using floating windfarms. Results regarding the influence on the continuous levels will be presented at part 3 of this deliverable.

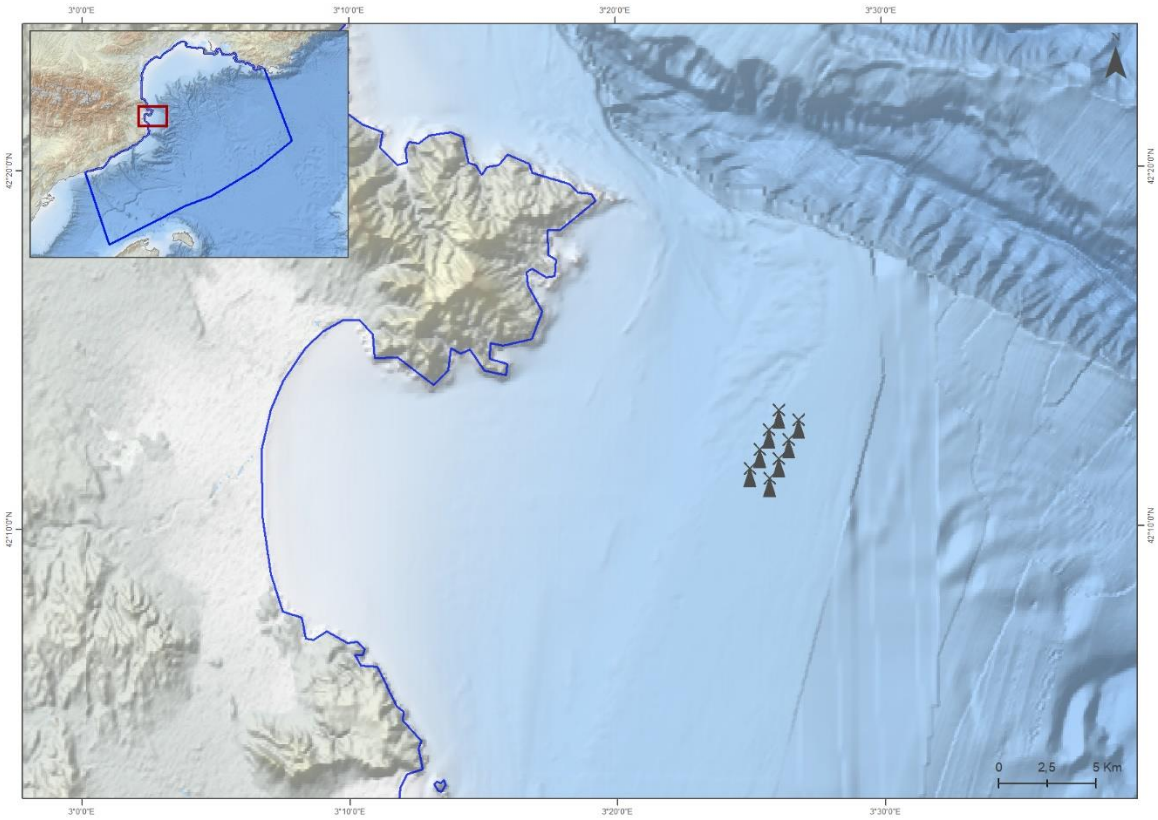

Figure 11. Location of the hypothetical offshore windfarm considered to implement the case study regarding the influence of continuous low frequency noise present in the assessed area. Credits: Spanish Institute of Oceanography.

2.4 Mitigation measurements on marine traffic

As was pointed before, the main anthropic activity contributing to increase the low frequency continuous noise in the marine environment is the maritime traffic. Some authors (Frisk, 2012) have pointed the increasing values of underwater noise sound pressure level relating it with the evolution of maritime traffic. An estimation marks an increment of 3.3 dB (ref 1 µPa) every ten years since 1950 to 2007. With respect to maritime traffic the tonnage and capacity of the merchant ships is expected to increase fivefold in the developing countries. By these reasons, among others, there is a concern about how to manage the economic activities linked with maritime traffic and the possible adverse impact on the marine ecosystem derived by continuous noise deposed in the sea. Regarding the continuous noise emitted to the medium by ocean transport, several variables play a relevant role such as sound propagation characteristics linked to a given area, the characteristics of vessels, their maintenance or quantity and type of ships together with its speed over ground through a shipping, just to mention a few. Mitigation measurements should be understood as those methods aimed to reduce, eliminate or compensate adverse environmental effects. In relation with maritime traffic, mitigation measurements should be applied on variables that reveal influence on the total noise deposed to the aquatic medium. Traditionally the paradigm followed to deal with the implementation of mitigating measures applied on the maritime traffic activities is divided in:

(a) Solutions applied on the design process of the ships. This means reducing the propeller cavitation effects, isolating the vibration of machinery or even replacing the combustion engine by electrical ones.

(b) Implementing the necessary regulation for the better use of marine environment by the application of management plans that include the ordinance regarding the number of ships transiting through a given area, regulating the allowed speed over ground or adapting the navigating lines to the specificity of the sea, especially with respect to marine protected areas.

Is clear that (a) aspects are related to the technological advances together with the interest of commercial companies to invest in the implementation of new designs in their fleets. Therefore, these types of measures respond to the need to reduce the sound pressure level of continuous noise in the sea in the medium long term.

With respect to methodologies to reduce underwater noise based on (b) measures several initiatives have been reported by some authors with the aim to test the real influence of regulations through pilot case studies. Once of the aspects that could represent a relevant reduction of noise radiated by ships is related to speed over ground of the ships. Some results regarding the relationship between speed over ground and noise radiated by a given ship have been reported in the literature (Zobel, 2021) (McKenna, 2021). Despite the spread of the decrease in the broadband noise with respect to the type of ship and its velocity is accepted that a noise reduction ranges from 0.5 dB to 1.5 dB per knot (DFO Can). However, the reduction of ship velocity implies an increasing of noise exposure since vessels spend more time in a certain area. It is therefore necessary to carry out more studies regarding this topic, through the implementation of case studies in real environmental conditions.

3. Results

The results obtained following the previously presented methodology aims to link the anthropic activities related to maritime traffic and the operation of floating windfarm with the underwater low frequency continuous noise expected. The assessment should contain experimental measurements to validate the results offered by theoretical models applied but, unfortunately, no experimental data was available. The results must be understood in terms of:

- spatial assessment of continuous low frequency noise calculated in the frequency bands of 63 Hz and 125 Hz by means of the estimation of the mean value of sound pressure level for the assessment period defined from 1st of January to 31st of May of 2021.
- statistical properties of noise versus time. Trend in the evolution of the daily percentile values.
- study of the temporal extent of noise referenced to percentiles.
- influence of hypothetical floating windfarm to the continuous noise present in the study area.

The mean values of the sound pressure level expected in the medium by means of the maritime traffic contribution are depicted through figures 12 and 13 for 63Hz and 125Hz respectively. In this assessment environmental noise has not been included due to weather conditions. It is possible to observe that the sound pressure level noise values for 125 Hz are lower in comparison with the values obtained at 63 Hz. This is mainly due to the parametrization of source levels following the RANDI model applied. An experimental measurement in a given location of the assessment area would be necessary to validate or achieve more accuracy if needed.

Taking the advantage that sound maps are available every 6h considering the maritime traffic snapshots acquired by means of AIS data, a statistical daily percentile of the sound pressure level in the area can be calculated. Considering that the simulations may have different accuracy depending on the diverse depth values and geometries of the bathymetry, a global [75, 90 & 95] percentile calculation of sound pressure has been computed. The evaluation of the statistical descriptors obtained through the evaluation period enables the possibility to infer trends and patterns of the expected sound pressure level in relation with the anthropic activities, in this case maritime traffic.

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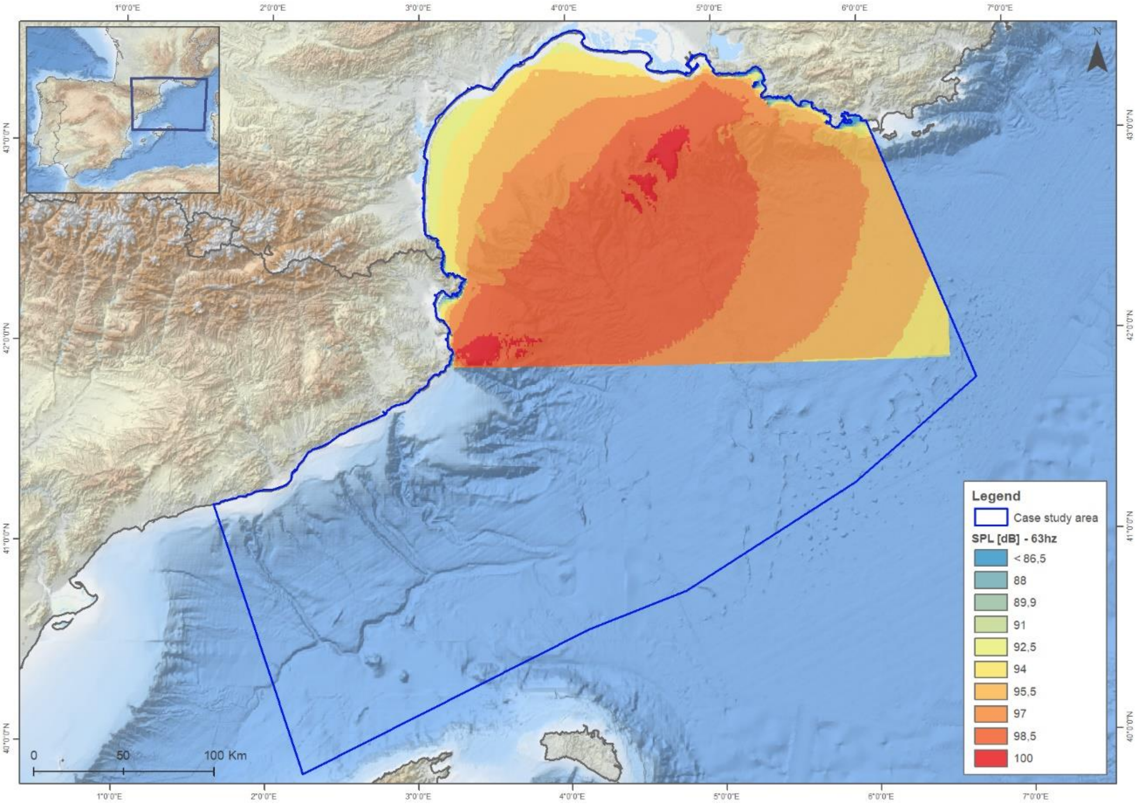

Figure 12. 63Hz Sound map related to mean value of sound pressure level for 63Hz, calculated along the assessment period. Credits: Spanish Institute of Oceanography.

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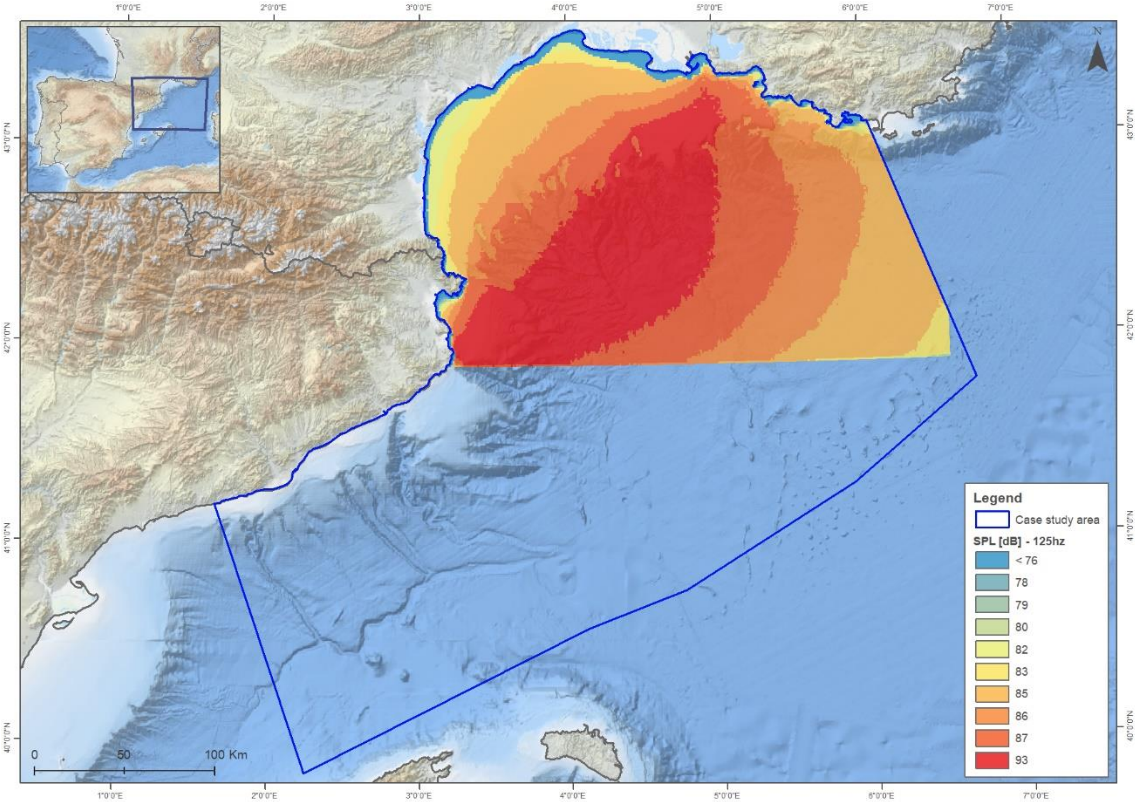

Figure 13. Sound map related to mean value of sound pressure level for 125Hz, calculated along the assessment period. Credits: Spanish Institute of Oceanography.

Figures 14 and 15 shows the daily 75, 90 and 95 percentiles calculated over the 63Hz and 125Hz frequency bands. A linear fit was applied with the aim to infer a possible trend of the statistical values calculated with respect to the assessment period. The slope of the linear fits reveals that 75 percentile describes slightly positive increment with respect to time. This tendency diminishes with respect to higher percentiles. The same pattern is described for the 125Hz values. The coefficients regarding to the linear fits are collected in table 1.

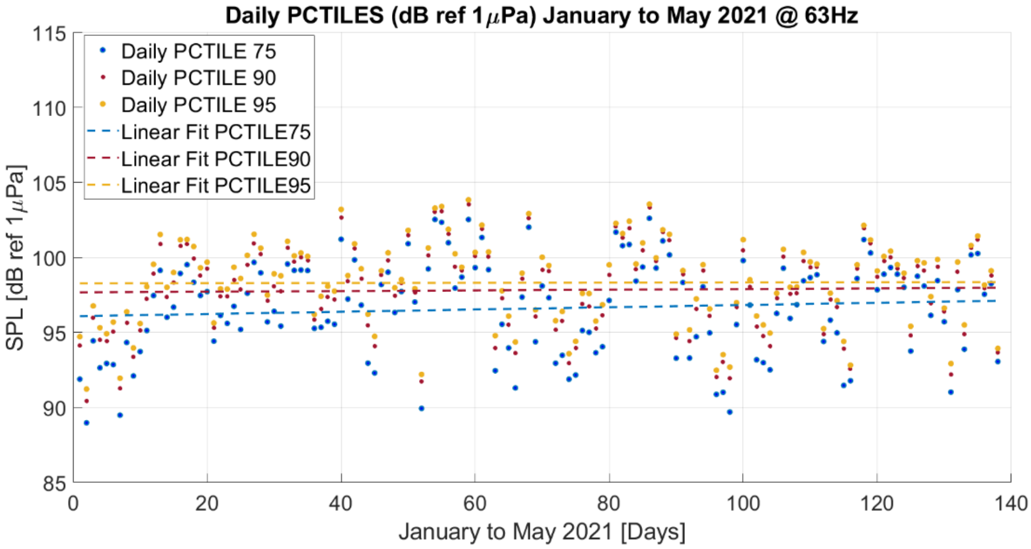

Figure 14. Daily values of percentile 75, 90 & 95 related to the sound maps calculated for a 63Hz frequency band and its corresponding linear fits. Credits: Spanish Institute of Oceanography.

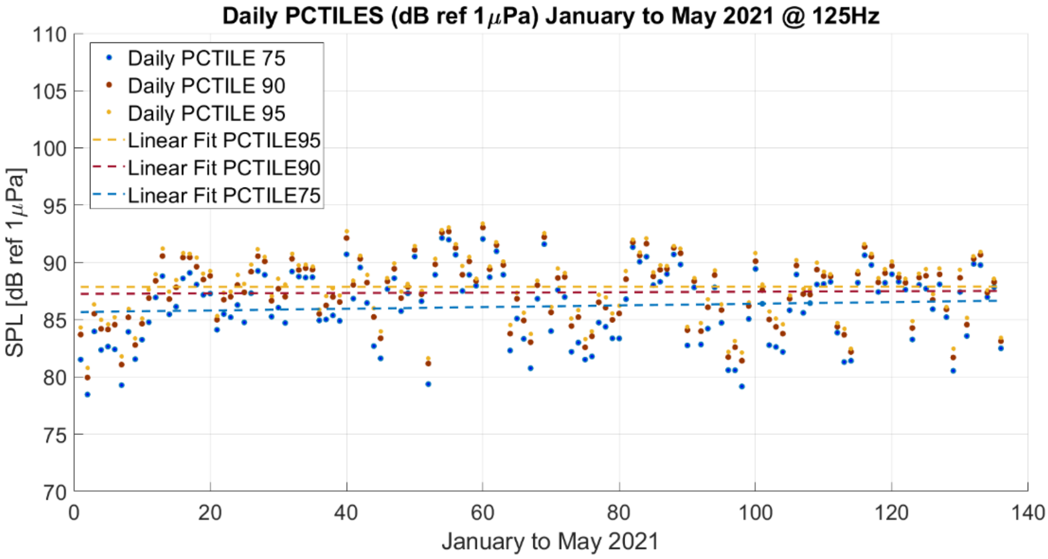

Figure 15. Daily values of percentile 75, 90 & 95 related to the sound maps calculated for a 63Hz frequency band and its corresponding linear fits. Credits: Spanish Institute of Oceanography.

f(x) = p1*x + p2	P1	P2	Adjusted R-square
63 Hz - 75 PCTILE	0.007478	96.09	0.001633
63 Hz - 90 PCTILE	0.002224	97.68	0.006379
63 Hz - 95 PCTILE	0.0005135	98.29	0.007298
125 Hz - 75 PCTILE	0.007287	85.66	0.0008967
125 Hz - 90 PCTILE	0.001893	87.25	0.006775
125 Hz - 95 PCTILE	0.0002792	87.86	0.007447

Table 1 - Coefficients regarding to the linear fits for 75, 90 and 95 percentiles for 63 Hz and 125 Hz. Credits: Spanish Institute of Oceanography.

Regarding the assessment of continuous noise in the Gulf of Lion is remarkable to highlight that is a transboundary area between France and Spain. The establishment of cooperation among research institutes, institutions and competent authorities is valuable sharing the results and the different methodologies and metrics regarding the underwater noise evaluation. Figures 16 and 17 shows the results of underwater continuous noise modelling developed by researchers of the French Naval Hydrographic and Oceanographic Service (SHOM) in the same area reported previously by Spanish Institute of Oceanography (IEO, CSIC). Despite the methodologies used to achieve the sound-maps use different propagation techniques the main difference between results on SPL are due to the frequency band considered. The sound maps depicted in figures 12 and 13, considers a single value of frequency (63Hz or 125Hz) while sound-maps shown in figures 16 and 17 integrate the energy over a 1/3 octave band around 63Hz and 125Hz.

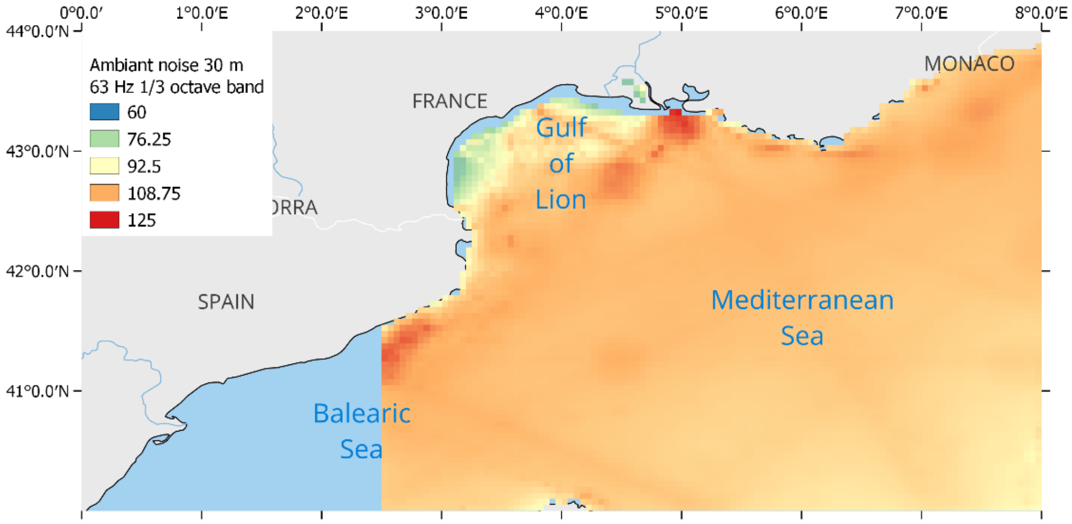

Figure 16. Sound map related to mean value of sound pressure level for 1/3 Octave band of 63Hz corresponding to January 2020 (3' spatial resolution). Credits: SHOM.

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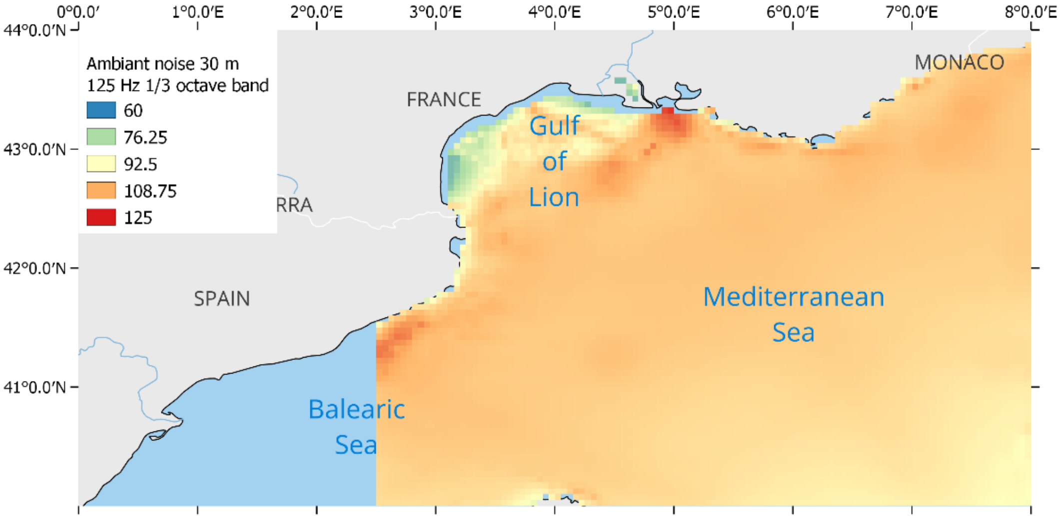

Figure 17. Sound map related to mean value of sound pressure level for 1/3 Octave band of 125 Hz corresponding to January 2020 (3’ spatial resolution). Credits: SHOM.

Continuing with IEO´s methodology for this case study area, assuming the percentile values of the mean sound map a study of the temporary behavior of sound pressure levels during the period assessment is shown by means of figures 18 and 19 with respect to 63Hz and 125Hz. These representations show the percentage of time that each sound map cell is above a certain percentile (75, 90 and 95). It is possible to infer that the greater values of percentage are linked to those zones where high density of routes are located (see maps shown in figure 5 and 6).

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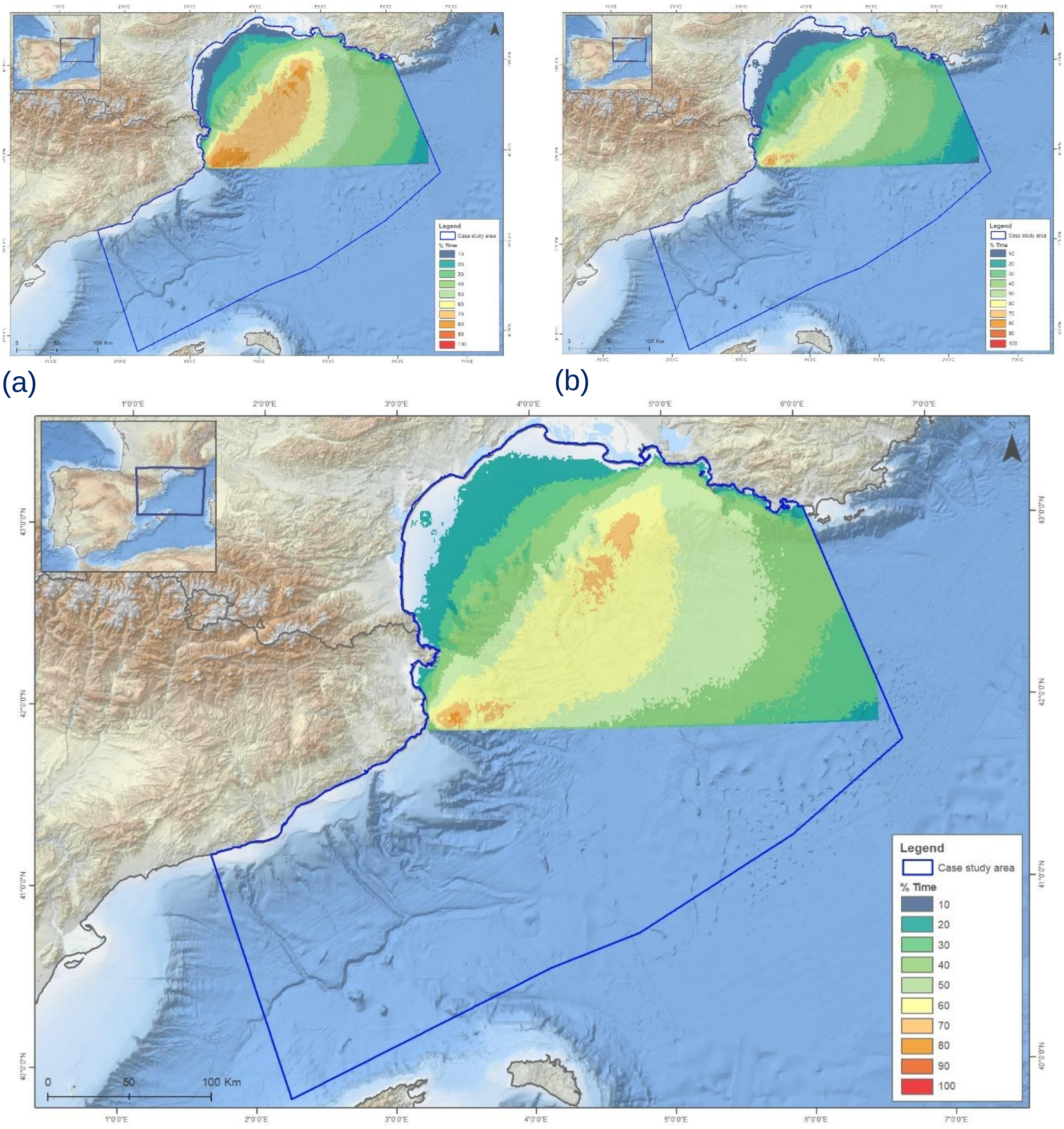

(a)

(b)

(c)

Figure 18. Percentage of time where each cell block is above a given percentile value (a), (b) and (c) corresponds to 75, 90 and 95 percentiles respectively (with respect to 63 Hz). Credits: Spanish Institute of Oceanography.

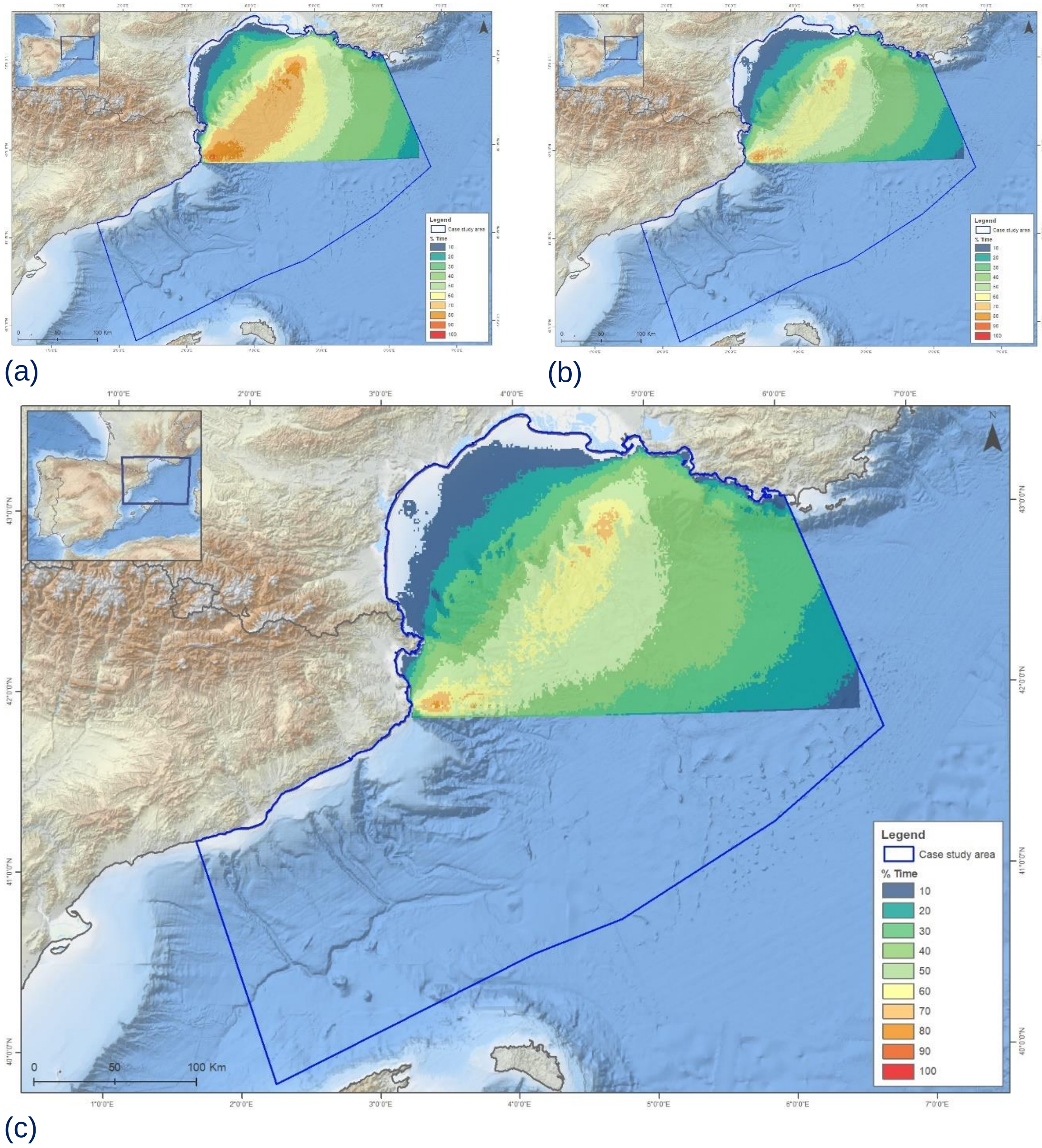

Figure 19. Percentage of time where each cell block is above a given percentile value (a), (b) and (c) corresponds to 75, 90 and 95 percentiles respectively (with respect to 125 Hz). Credits: Spanish Institute of Oceanography.

Once the spatial and temporal assessment of underwater continuous noise related to maritime traffic was carried out, a study of the influence of operating floating windfarm has been simulated. The assumed scenario considered an 8-windmill radiating constantly a certain source level value. It is noteworthy that the source level considered for each frequency band is based on the *Hywind Tampen Windpark* reported values. The followed methodology considers the same analysis

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paradigm but adding the contribution of noise associated to the windfarm. Figures 20 and 21 displays the results related to the mean value of sound pressure level calculated over the 5 months of assessment period. The values of sound pressure levels considering both frequency bands are influenced in the surroundings of the windfarm location by the constantly noise level radiated by the modeled infrastructure.

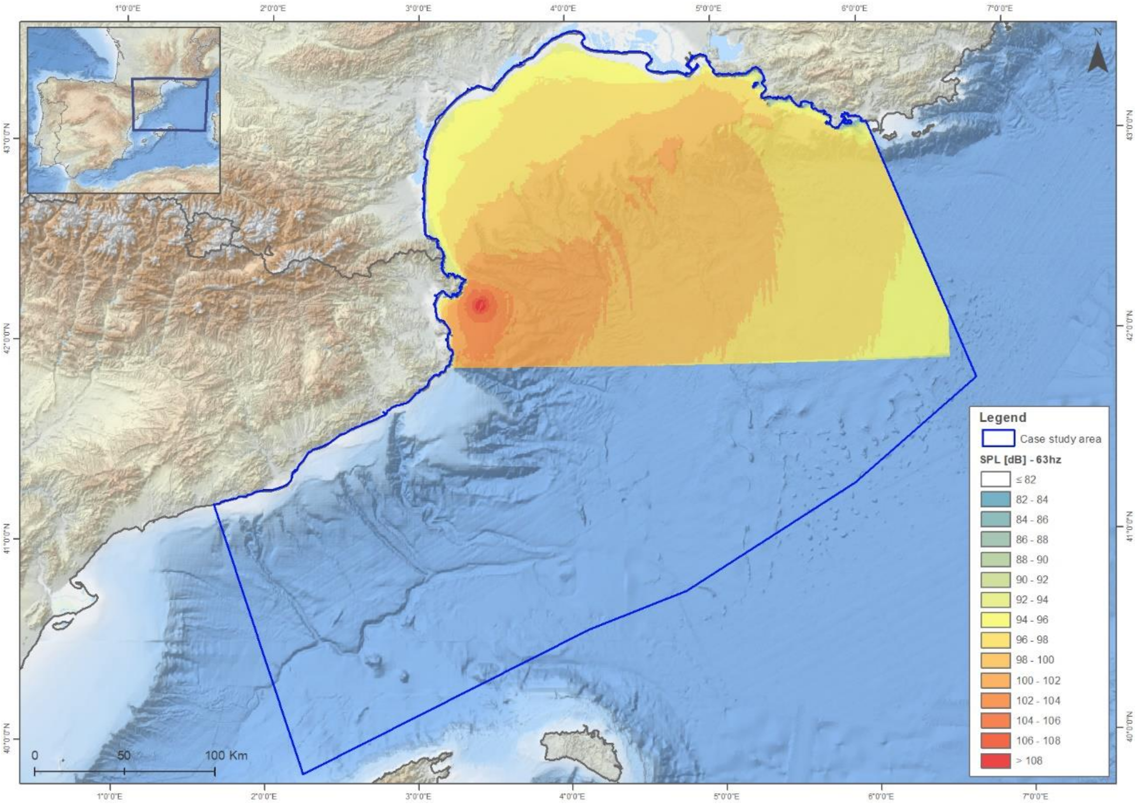

Figure 20. Sound map related to mean value of sound pressure level for 63Hz, calculated along the assessment period. Considering maritime traffic and wind farm operation contribution. Credits: Spanish Institute of Oceanography.

The maximum value of the sound pressure level in both situations has increased with respect to the unique maritime traffic contribution scenario. The experimental measurements would be very valuable to study the influence of the windfarm operation on the total underwater continuous noise present in the assessed area.

The influence of the wind speed with respect to the windfarm acoustic emission was not considered. By this reason, the area where windfarm has been ideally located presents a percentage of 100% time above the 95-percentile value for both frequency values assumed. This is clearly an idealization but shows the potential use of the methodology applied to evaluate the temporary pattern of underwater noise.

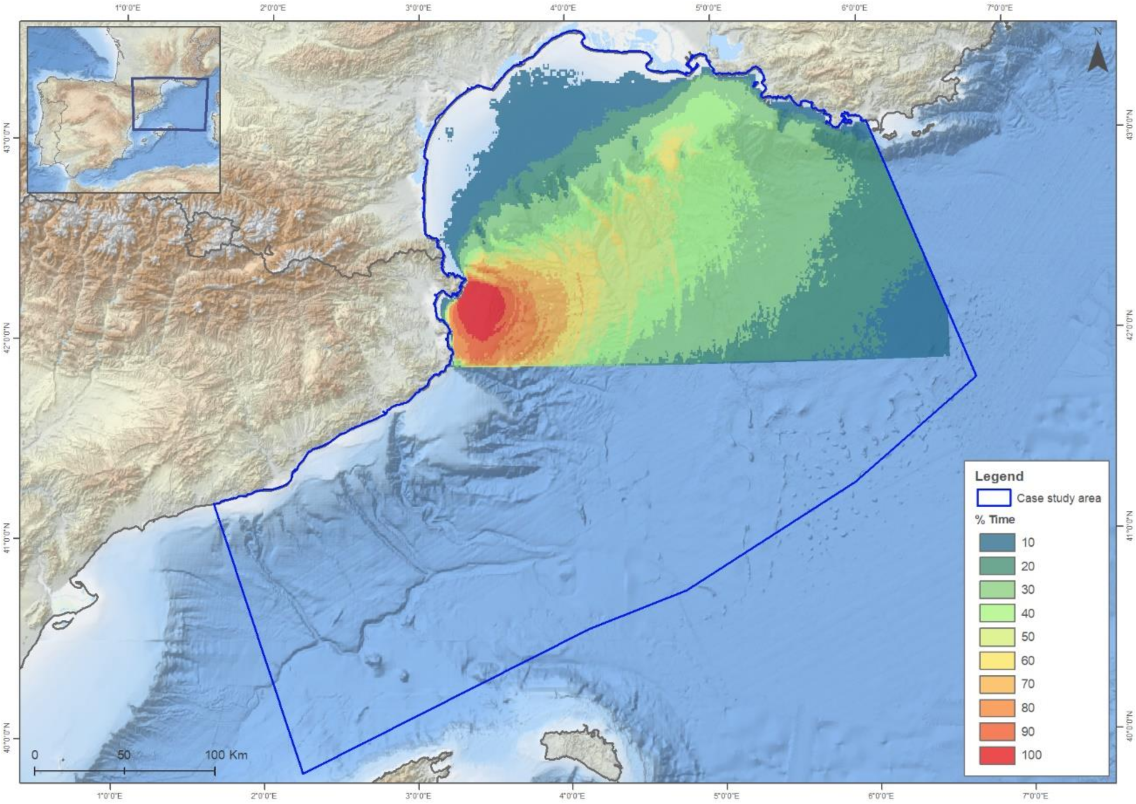

Figure 21. Percentage of time at which each cell block is above the 95 percentile regarding the mean for 5 month sound map for 63 Hz. Credits: Spanish Institute of Oceanography.

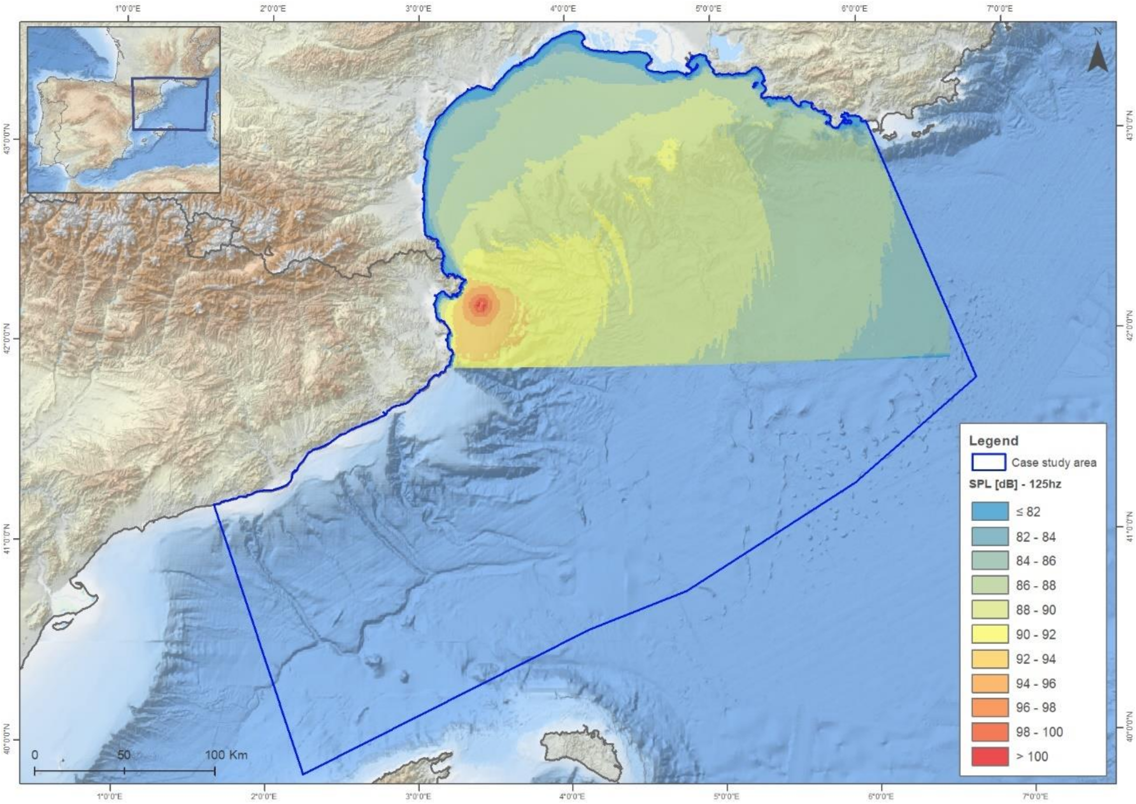

Figure 22. Sound map related to mean value of sound pressure level for 125Hz, calculated along the assessment period. Considering maritime traffic and wind farm operation contribution. Credits: Spanish Institute of Oceanography.

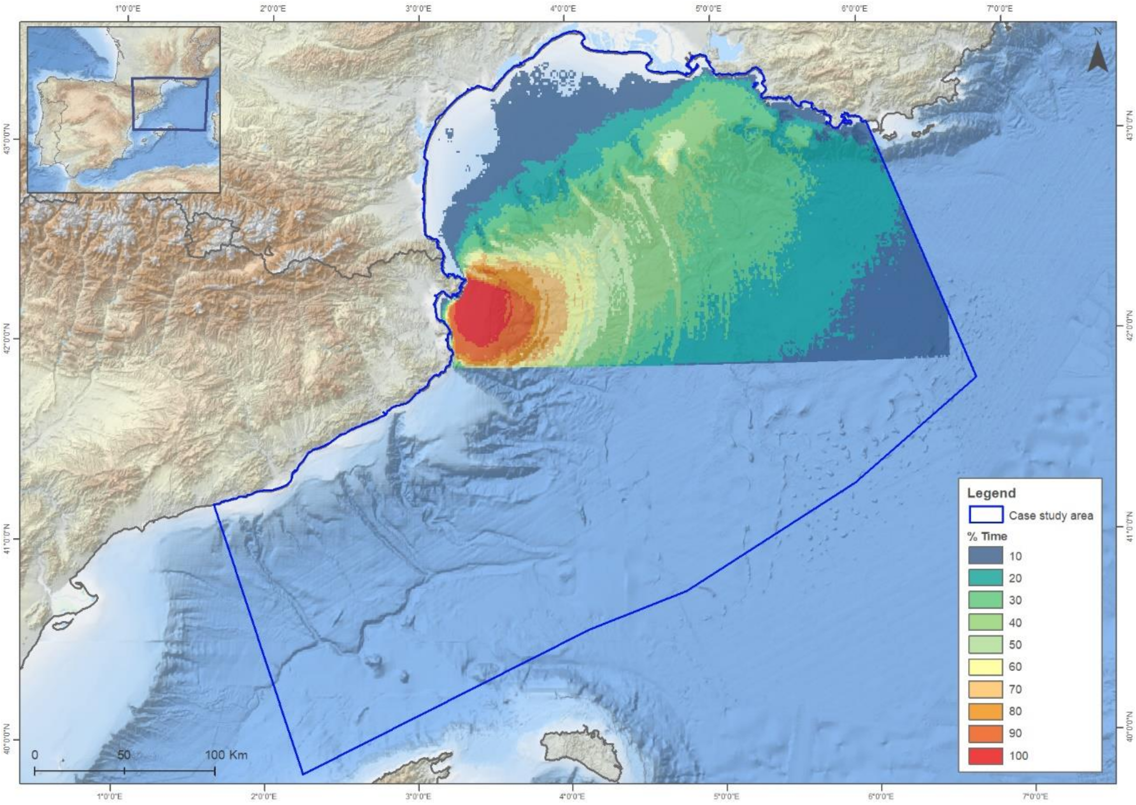

Figure 23. Percentage of time at which each cell block is above the 95 percentile regarding the mean for 5 month sound map for 125 Hz. Credits: Spanish Institute of Oceanography.

Considering both scenarios modelled, a comparison of the distribution of percentile values (shown case in figure 24 corresponds to 95 percentile) can be carried out to evaluate the influence of an ideal operating wind farm.

As expected, it is possible to observe that the lowest values of the sound pressure level distribution for both frequencies increase when windfarm operation is considered. Nevertheless, no significant increment of sound pressure levels has been reported regarding the whole assessment area, despite the increase numbers of cells that reach higher values of pressure.

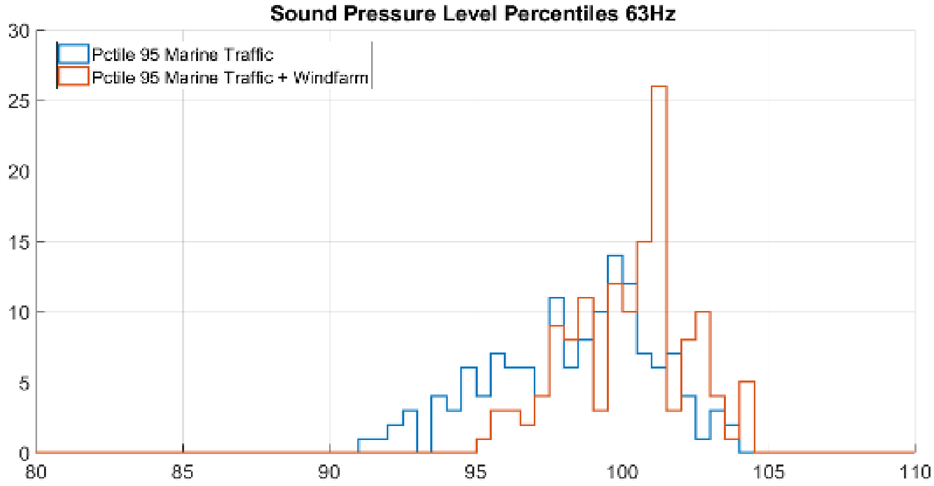

Figure 24. Distribution of 95 percentile values obtained for the daily basis sound maps in both situations simulated, with and without windfarm contribution to maritime traffic noise – 63 Hz. Credits: Spanish Institute of Oceanography.

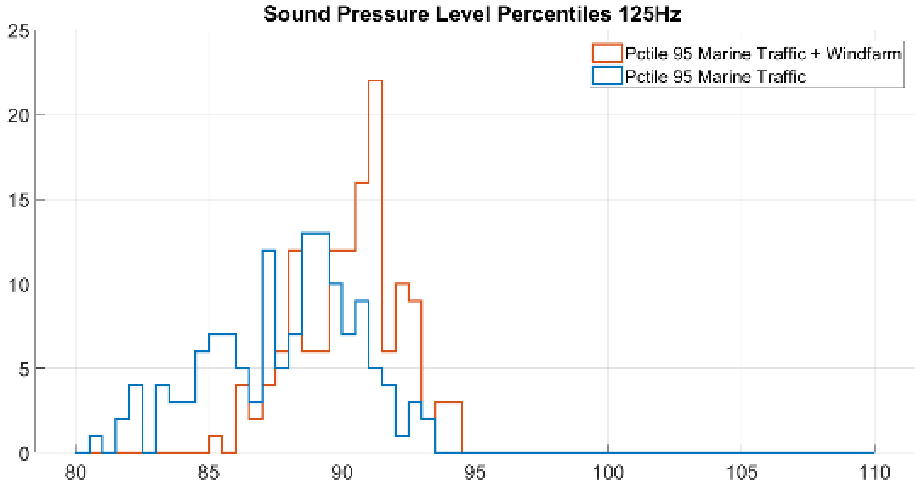

Figure 25. Distribution of 95 percentile values obtained for the daily basis sound maps in both situations simulated, with and without windfarm contribution to maritime traffic noise – 125 Hz. Credits: Spanish Institute of Oceanography.

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4. Next steps

Once the underwater noise models are developed, the next step will be to assess how this pressure will affect the cetacean species present in the case study area. In order to analyse this, data on distribution of cetacean species will be overlapped with the underwater noise modelling developed, considering the different effects that it may produce (i.e. communication masking, behaviour disturbance, etc). This work will be developed in the next deliverable (D10: *Knowledge synthesis and scenario testing about interaction between noise-causing uses and Mediterranean biodiversity (species)*) of this task.

In this case, new underwater noise models will be developed to include the whole study area of SIMWESTMED project which will include the north area of the Migratory Corridor of Cetaceans for the Mediterranean between the Iberian Peninsula and the Balearic Islands, which it is significant to take into consideration due to the presence of migratory cetacean species which use this area to reach the Gulf of Lion. The AIS data that will be used for the elaboration of this new underwater noise modelling will be from January to March 2022.

To end with, and similarly to the hypothetical case of OWF simulated in the study for the Spanish waters, this modelling will be implemented for the OWF projects to be developed in French waters in the coming years to simulate the potential effect that they may have in terms of increment of underwater noise level pressures.

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