Gulf of Lion case study – France and Spain: Planning the offshore Gulf of Lion in regards with ecosystems

D10 - Underwater noise studies in the Gulf of Lion region

Knowledge synthesis and scenario testing about interaction between noise-causing uses and Mediterranean biodiversity (species)

IEO (CSIC)

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Acronyms

ACCOBAMS	Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic area
AIS	Automatic Identification System
ASI	ACCOBAMS Survey Initiative project
CDR	Communication Distance Reduction
CNPDF	Cumulative Normalized Probability Density Function
IEO(CSIC)	Instituto Español de Oceanografía (Spanish Institute of Oceanography)
EL	Excess Level
EMODnet	European Marine Observation and Data Network
GEBCO	General Bathymetric Chart of the Oceans
GES	Good Environmental Status
IF	Impact Factor
JOMOPANS	Joint Monitoring Programme for Ambient Noise North Sea
JONAS	Joint Framework for Ocean Noise in the Atlantic Seas
LOSE	Level of Onset of biologically Significant Effects
MMSI	Marine Mobile Service Identity
MPA	Marine Protected Area
MSFD	Marine Strategy Framework Directive
MSP	Marine/Maritime Spatial Planning
MSPMED	Towards the operational implementation of MSP in our common Mediterranean Sea project
OFB	Office Français de la Biodiversité (French Biodiversity Office)
OWF	Offshore Wind Farm
PAM	Passive Acoustic Monitoring

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RAGES	Risk-based Approaches to Good Environmental Status
RANDI	Research Ambient Noise DIrectionality
RI	Risk Index
SIMWESTMED	Supporting Maritime Spatial Planning in the Western Mediterranean region project
SPAMI	Specially Protected Areas of Mediterranean Importance
SPL	Sound Pressure Level
TG Noise	MSFD Technical Group on Underwater Noise

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1. Context

In the framework of the MSPMED project, a transboundary pilot case study (task 2.2) was developed by the Spanish and French partners, Instituto Español de Oceanografía (IEO(CSIC)) and Office Français de la Biodiversité (OFB), respectively, in the Gulf of Lion area with respect to the ecosystems in the context of MSP.

1.1. Case study

The main objective of the case study was to provide a common and updated knowledge on ecological stakes in the Gulf of Lion and their interactions with human activities, specifically Offshore Wind Farms (OWFs). In line with the importance of carrying out coordinated and coherent Maritime Spatial Planning (MSP) processes in both countries, the Gulf of Lions case study has been developed through 3 main sub-tasks:

- Sub-task 2.2.1: To build and promote a global view of ecological stakes and their evaluation in the Gulf of Lions, especially related to cetaceans, sea turtles, seabirds and deep habitats (Deliverable 7);

- Sub-task 2.2.2: To provide knowledge about interactions between Mediterranean ecosystems and maritime uses, with a specific focus on windfarm development in the Gulf of Lions area (Deliverable 8);

- **Sub-task 2.2.3: To assess the effects of noise pollution caused by intense activities, such as maritime transport and offshore windfarms, on the pelagic component and especially cetacean species (Deliverables 9 and 10). In addition, a workshop regarding underwater noise was held in the framework of this task, which results can be found in the Deliverable 11.**

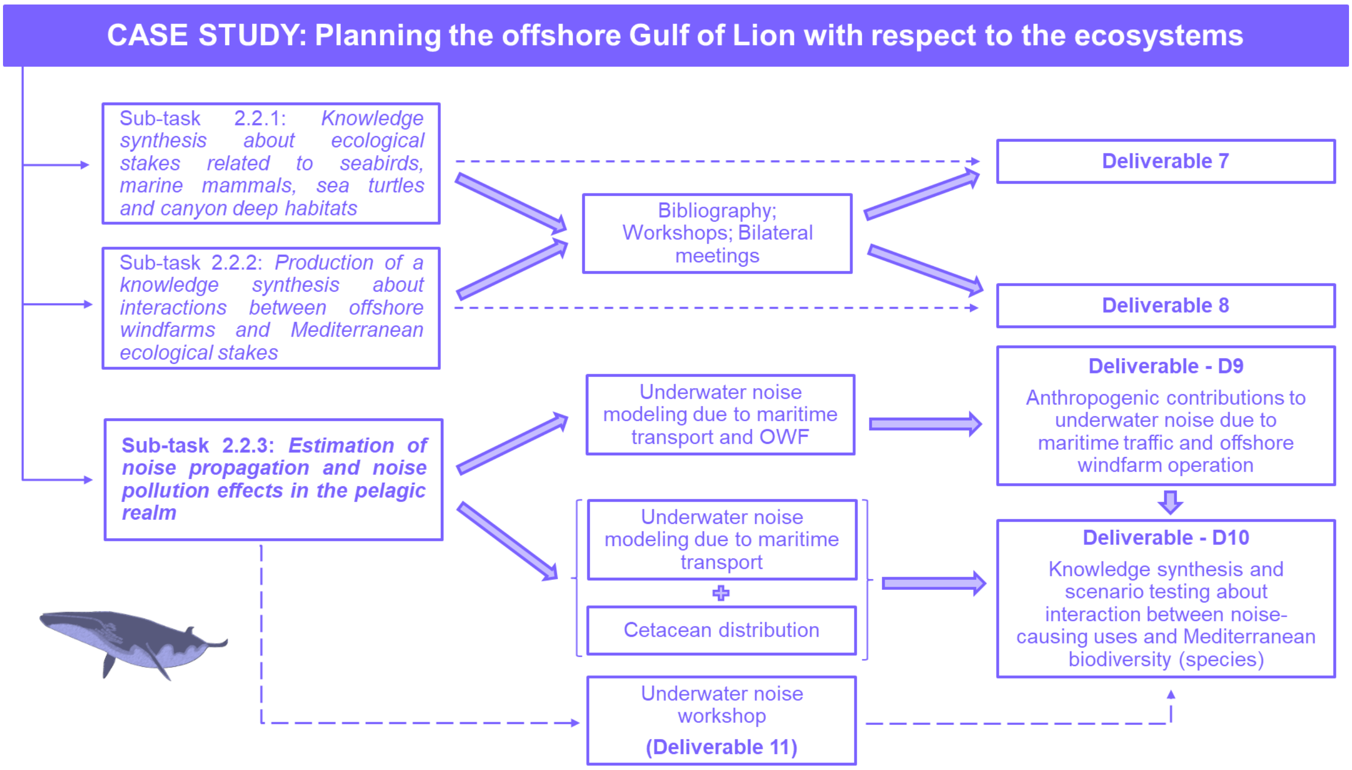

Figure 1. Developed subtasks for the case study of the Gulf of Lions. Source: Own elaboration, IEO(CSIC).

The present report details the work carried out in the sub-task 2.2.3 that has analysed underwater noise generated by marine traffic, which is proven to adversely affect the marine environment producing different types of effects on the pelagic component, especially on cetaceans. With this regard, this work has been elaborated in two steps. In the first step, which resulted in the deliverable 9 (D9 - Underwater noise studies in the Gulf of Lions region: Anthropogenic contributions to underwater noise due to maritime traffic and offshore windfarm operation), underwater noise was analysed using Automatic Identification System (AIS) data from maritime traffic to generate underwater noise propagation models in the Gulf of Lion from January to May 2021. In addition, a tentative assessment on a hypothetical pilot offshore windfarm was modelled to evaluate how underwater noise from OWF could also have an effect on the marine environment, in addition to the noise produced by maritime traffic.

Second step of this sub-task 2.2.3 was focused on, including in the underwater continuous noise assessment, sensitive to noise cetacean species population data. The main aim was to overlap the anthropogenic pressure (maritime traffic) and therefore the underwater continuous sound radiated by ships as a pollutant, with respect to the cetacean species trying to study the potential adverse impact caused by the underwater noise.

The results obtained from the analysis of both deliverables and their final conclusions could be translated into recommendations or lessons learnt that could be used by the MSP competent authorities of both countries, in order to be applied in the maritime spatial plans of each country, as well as to establish a detailed planning of the maritime sectors (in this case, maritime traffic and OWF development) in a transboundary context considering the protection of the marine biodiversity in the Gulf of Lion. Additionally, a workshop regarding underwater noise was held in the context of this subtask.

The Gulf of Lion is located in the north-western Mediterranean Sea, with coast from Cap de Creus in Spain to Toulon in France (Germain, 1914; Russell, 1942; Ulses et al. 2008 cited in Dalleau et al., 2018). It covers a total area of 20400 km2 (Bănaru et al., 2013) which contains a large continental shelf that reaches 100-200 m depth with a complex network of submarine canyons of up to 2000 m depth. Its continental slope is an open boundary along which there is a strong geostrophic current (Bănaru et al., 2013), and its abyssal plain, which extends to the southeast, reaches depths of around 2.500 m. Furthermore, the Gulf of Lion, together with the Ligurian Sea, is the coldest part of the western Mediterranean Sea (Bianchi et al., 2012), and it is possible to find cold temperate species, not common in the south (Bianchi and Morri, 1994). The seafloor substrate is characterized by the presence of sand near the shore, sandy mud at intermediate depths with isolated areas of sand and coarse and mixed sediment, and fine mud at deeper bottom (data obtained from EMODnet (European Marine Observation and Data Network) website).

The Gulf of Lion is a highlighted area in terms of marine biodiversity (i.e. marine mammals, marine turtles, seabirds, fishes, etc.). Its high productivity makes it an area of great interest for economic development, indeed, its coastal area is one of the points of the Mediterranean Sea where it is concentrated the interaction between high biodiversity areas and threats (Coll et al., 2012).

In relation to the case study area, in the Deliverable 9 the analysis at first just considered the area which comprise the Gulf of Lion from Barcelona to Marseille. The decision to use the SIMWESTMED case study area was made after the AIS data was requested and the underwater noise modelling processed, thus the data analysis did not cover the whole case study area. For the analysis and modelling of this Deliverable 10, the case study area comprises the whole SIMWESTMED case study area, as shown in the following map.

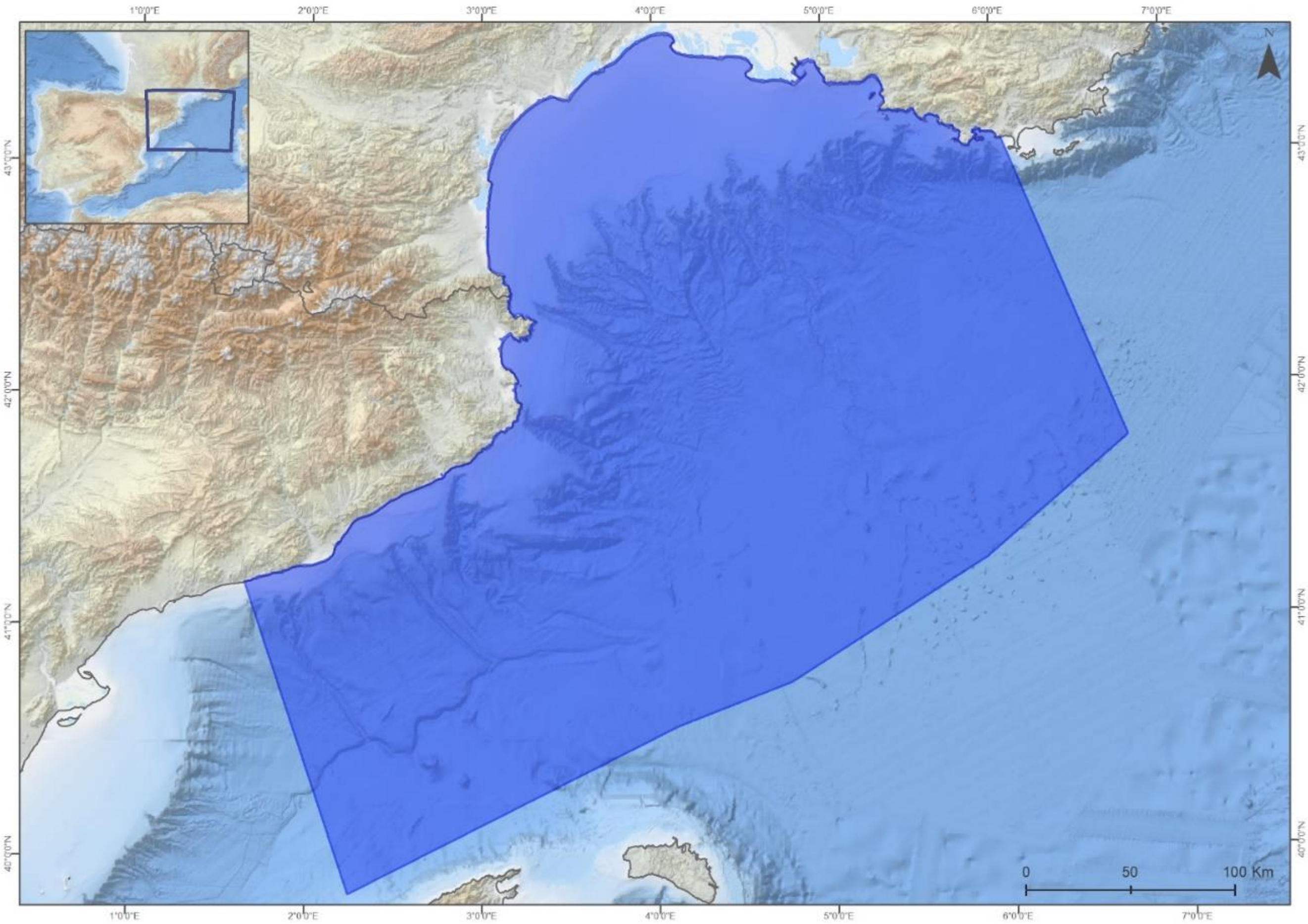

Figure 2. Case study area of the Gulf of Lions. Source: Own elaboration, IEO(CSIC).

The main anthropogenic activity contributing to the low frequency underwater continuous noise in the marine environment is the maritime traffic. Barcelona harbour is the first Spanish port in terms of international traffic and the 3rd one regarding the total transported goods in volume and Marseille port is the first in France and the 6th in Europe. It has activities related to commerce, freight and cruises. Annually, 100 million tons of freight, 60 of them petroleum, pass through Marseille port (Nazirova & Lavrova, 2018).

The Gulf of Lion has been studied over the years through different projects and/or initiatives in relation to very different objectives, such as the analysis of the existing deep habitats in Spanish waters (*LIFE INDEMARES project - Inventory and designation of the Natura 2000 network in marine areas of the Spanish State*), the analysis of cetacean or sea turtle populations through projects financed by different European or national funds (*Photo-identification within AHAB project* (SUBMON); TURSMED I and II projects (OFB and MIRACETI); among others, which can be consulted in the Deliverable 7 of MSPMED).

However, it was not studied in the context of maritime spatial planning until the SIMWESTMED project (*Supporting Implementation of Maritime Spatial Planning in the Western Mediterranean region*) started in 2016, where a specific analysis was carried out in the Gulf of Lion case study.

The objectives of this case study were (i) to assess the policy development and regulatory frameworks, (ii) to evaluate past and present projects regarding sector compatibility, (iii) the co-development and conflict resolution in the marine space of both countries, (iv) to assess future trends of economic sectors and marine conservation and protection, and related spatial demands (including data and information requirements for MSP), (v) to support stakeholder engagement in a transboundary context of working and elaborate guidance on best practices/ experiences, and (vi) to evaluate and exchange applied methods and experience for cumulative effect assessment in the area between Spain and France. The results of this assessment could be consulted in the document *Mapping exposure risk of marine megafauna to concomitant pressures*.

The present deliverable applies different methodologies to consider together the underwater continuous noise and sensitive to noise cetacean species (considering its distribution), with the aim to propose a framework able to be used by authorities performing marine spatial plans to monitor the potential harmful effects produced by underwater noise. It is important to remark that the different approaches follow the recommendations of the Marine Strategy Framework Directive (MSFD) Technical group on underwater noise (TG Noise) and the calculation has been performed using the current condition and reference condition paradigm. Lastly, it has not been the intention of this deliverable to achieve results regarding whether the Good Environmental Status (GES)[1] is reached or not. For this reason, no specific threshold values related to adverse impact like masking or disturbance has been considered. This topic requires deeper knowledge and considerations about animals inhabiting the studied area, nevertheless the different approaches followed would allow the calculation of indexes applying biological based threshold values.

1.2. Deliverable 9: main results.

As previously indicated, the main objective of Deliverable 9 was to develop underwater noise models using AIS data from January to May 2021, in order to evaluate how underwater noise is propagated by maritime traffic. In addition to this work, the analysis of underwater noise produced by a hypothetical offshore windfarm located in the case study area, and the sum with the effect of traffic noise, was also performed.

[1] "Good Environmental Status means the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for uses and activities by current and future generations" extracted from DIRECTIVE 2008/56/EC.

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After the analysis performed and the drafting of the deliverable, the main conclusions obtained were as follows:

- The modelling of maritime traffic using AIS data indicated that the noise sound pressure levels for 125 Hz were lower in comparison with the values obtained at 63 Hz.

- The highest noise values were located in the areas close to the ports of Barcelona and Marseille, and, as could be intuited from the noise maps obtained, the maritime "highways" were visualized where there was a higher underwater noise than in the surrounding areas.

- The establishment of cooperation among research institutes (IEO(CSIC) and SHOM), was valuable as it facilitated the sharing of results, methodologies and metrics regarding the underwater noise evaluation for the same study area.

- The maximum sound pressure level value due to the location of a hypothetical offshore wind farm, in addition to maritime traffic, indicated a significant increase regarding the spatial and temporal extent of sound pressure level in the study area.

More information on the results obtained from the underwater noise analysis in Deliverable 9, can be found in the following link: https://mspmed.eu/wp-content/uploads/2022/08/D9-1.pdf.

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2. Introduction

2.1. Cetacean species and their distribution in the Gulf of Lion

The high productivity that occurs in the Gulf of Lion due to oceanographic phenomena, generates habitats propitious for the existence of a high density of cetaceans. The distribution of cetaceans has been analysed by different studies and initiatives carried out in the Gulf of Lion, indicating that in the area there is a presence of certain species permanently or during migratory season. One of the major initiatives developed in the Mediterranean Spanish waters, which resulted in the declaration of the Cetacean migration corridor in the Mediterranean Sea Marine Protected Area (MPA) and Specially Protected Areas of Mediterranean Importance (SPAMI), was the *Identification of Areas of Special Interest for the Conservation of Cetaceans in the Spanish Mediterranean (Mediterranean project)* whose overall objective was the identification of areas of special interest to be designated as marine protected areas, contemplated both by the Barcelona Convention (SPAMI) and by other treaties or agreements signed by Spain on nature conservation that concern the creation of marine areas that affect the Mediterranean and give cetaceans a special relevance (Bern Convention, ACCOBAMS) and especially the Habitat Directive 92/49/EEC, designating SCIs (Sites of Community Importance) that become part of the European Natura 2000 Network, ACCOBAMS) and especially the Habitat Directive 92/43/EEC, designating SCI (Sites of Community Importance) that become part of the European Natura 2000 Network. The analysis indicated the presence of 8 species in the northern sector, where the Gulf of Lion is included. North area of this Cetacean migration corridor in the Mediterranean Sea protected area overlaps with the present case study area.

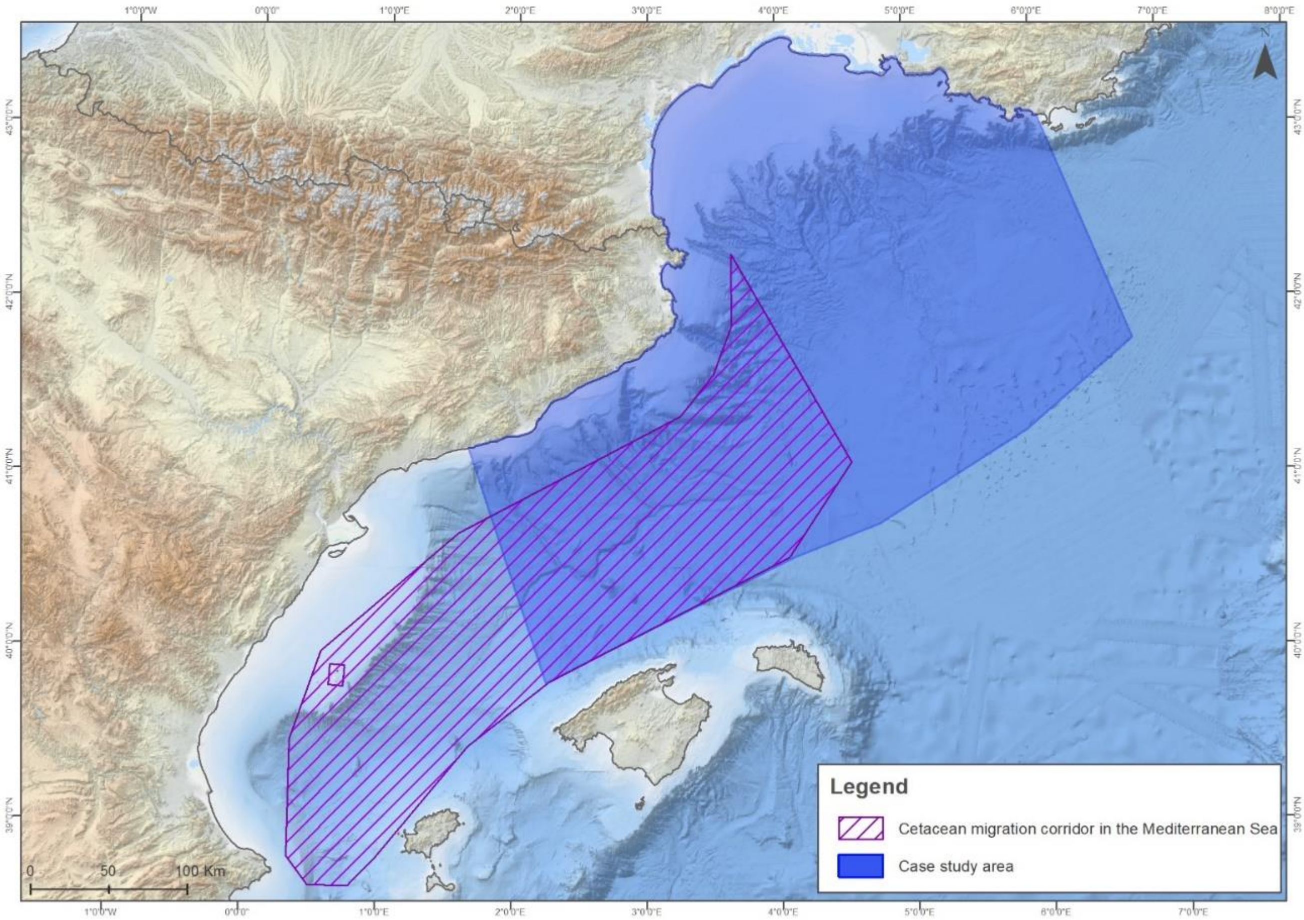

Figure 3. Case study area of the Gulf of Lion and the Cetacean migration corridor in the Mediterranean Sea. Source: Own elaboration, IEO(CSIC).

The importance of this protected area relies on the fact that these waters have a high ecological value and constitute a migration corridor of vital importance for the survival of cetaceans in the Western Mediterranean. The presence of species such as the fin whale (*Balaenoptera physalus*) has been confirmed in this area, which maintains migratory patterns towards the waters of the Gulf of Lion from March to June, where they migrate mainly to feed due to the high productivity of the waters during the spring months. In addition, other cetaceans that do not follow defined migratory patterns are present in both, the protected area and in the case study area, such as the bottlenose dolphin (*Tursiops truncatus*), striped dolphin (*Stenella coeruleoalba*), common dolphin (*Delphinus delphis*), pilot whale (*Globicephala melas*), the Risso's dolphin (*Grampus griseus*), the sperm whale (*Physeter macrocephalus*) and Cuvier's beaked whale *(Ziphius cavirostris*).

Numerous projects developed in the study area have provided a better knowledge of how these species are distributed in the Gulf of Lion. In the first sub-task elaborated in this case study (*sub-task 2.2.1 - To build and promote a global view of ecological stakes and their evaluation in the Gulf of Lion, especially related to cetaceans, sea turtles, seabirds and deep habitats*), a large search was conducted for information on projects, publications and scientific reports, or online databases on the presence of cetaceans in the Gulf of Lions, especially projects with

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geolocated sighting data (aerial or ship-based). It included scientific literature, grey literature (technical/expertise/evaluation reports), websites referencing maritime scientific surveys in French and Spanish waters, and online or referenced databases. This list of projects and initiatives can be found in Deliverable 7. In addition to this work, there were direct exchanges with scientific experts during technical meetings regarding cetaceans in the Gulf of Lion.

After the bibliographic analysis and the meetings held with cetacean experts, it was concluded that the cetacean species present in the Gulf of Lion are:

- Cuvier's beaked whale (*Ziphius cavirostris*)
- Long-finned pilot whale (*Globicephala melas*)
- Risso's dolphin (*Grampus griseus*)
- Fin whale (*Balaenoptera physalus*)
- Sperm whale (*Physeter macrocephalus*)
- Common bottlenose dolphin (*Tursiops truncatus*)
- Striped dolphin (*Stenella coeruleoalba*)
- Short-beaked common dolphin (*Delphinus delphis*)

However, it was not easy to obtain detailed mapping of the distribution of all the species mentioned above. For this reason, the cartographic data of the ACCOBAMS Survey Initiative project (ASI project) was used. The ASI project is an integrated, collaborative and coordinated monitoring system for the status of cetacean populations at the whole ACCOBAMS area level, with the final aim to strengthen the conservation efforts and governance for cetacean species (ACCOBAMS, 2021). This project is implemented by the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic area (ACCOBAMS) Permanent Secretariat, and includes the data collected by boat and aerial surveys conducted during 2018 and 2019 and the analysis of the distribution made for cetacean species in the ACCOBAMS area. To address the proposed activity and study the potential adverse effect of continuous noise, cartographic data of 4 odontecetes and 1 mysticete species have been used as an indicator species:

- Common bottlenose dolphin (*Tursiops truncatus*)
- Striped dolphin (*Stenella coeruleoalba*)
- Short-beaked common dolphin (*Delphinus delphis*)
- Risso's dolphin (*Grampus griseus*)
- Fin whale (*Balaenoptera physalus*)
- Striped dolphin (*Stenella coeruleoalba*) or Short-beaked common dolphin (*Delphinus delphis*)

A small description of each of these species and their distribution in the Mediterranean Sea, according to the ASI data submitted by ACCOBAMS and the results of the assessment (*Estimates of abundance and distribution of cetaceans, marine mega-fauna and marine litter in the Mediterranean Sea from 2018-2019 surveys*), is given in Annex I.

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It must be pointed out that these five-indicator species are present in the Red Book of the vertebrates of Spain (Blanco and González, 1992). *Balaenoptera physalus* and the Mediterranean populations of *Tursiops truncatus* and *Delphinus delphis* are listed as vulnerable, *Grampus griseus* as not threatened and *Stenella coeruleoalba* as insufficiently known.

2.2. Underwater noise assessment under MSFD framework

Sound is one of the predominant types of energy in the marine environment. Due to its physical characteristics, it can propagate efficiently through marine environment. The increasing human activities in the marine environment (specially the marine traffic) together with the sensitivity of aquatic animals and particularly cetaceans to sound, have turn out the attention of scientific community and authorities to consider the anthropogenic noise as an important pollutant to be aware of (Williams et al., 2015).

The focus on underwater sound as a possible pollutant is relatively recent and its first approach was in terms of affecting long-range communication among mysticetes (Payne and Webb, 1971 cited in Williams et al., 2015). Nowadays the efforts of many projects and programmes are focused on studying the effects of anthropogenic underwater sound and developing strategies related with marine areas management.

With the aim to create a framework for the sustainable use of European's marine water the MSFD was designed. The MSFD contains a qualitative descriptor (D11) to reach the knowledge about the GES in relation to underwater noise levels. This can be roughly summarized as: the sound pressure levels have no adverse effects on the marine environment.

To meet this objective, the EU approved the Commission Decision (EU) 2017/848 of 17 May 2017 laying down criteria and methodological standards on good environmental status of marine waters together with specifications and standardized methods for monitoring and assessment.

Table 1: Criteria elements and methodological standards collected in the 2017/848 Commission decision.

Criteria elements	Criteria	Methodological standards
Anthropogenic impulsive sound in water.	D11C1 — Primary: The spatial distribution, temporal extent, and levels of anthropogenic impulsive sound sources do not exceed levels that adversely affect populations of marine animals. Member States shall establish threshold values for these levels through cooperation at Union level, taking into account regional or subregional specificities.	*Scale of assessment:* Region, subregion or subdivisions. *Use of criteria:* The extent to which good environmental status has been achieved shall be expressed for each area assessed as follows: (a) for D11C1, the duration per calendar year of impulsive sound sources, their distribution within the year and spatially within the assessment area, and whether the threshold values set have been achieved; (b) for D11C2, the annual average of the sound level, or other suitable temporal metric agreed at regional or subregional level, per unit area and its spatial distribution within the assessment area, and the extent (%, km^2) of the assessment area over which the threshold values set have been achieved. The use of criteria D11C1 and D11C2 in the assessment of good environmental status for Descriptor 11 shall be agreed at Union level. The outcomes of these criteria shall also contribute to assessments under Descriptor 1.
Anthropogenic continuous low-frequency sound in water.	D11C2 — Primary: The spatial distribution, temporal extent and levels of anthropogenic continuous low-frequency sound do not exceed levels that adversely affect populations of marine animals. Member States shall establish threshold values for these levels through cooperation at Union level, taking into account regional or subregional specificities.	

In relation to the specifications and standardized methods to monitor and evaluate the continuous noise is important to remark that the D11.C2 should address the 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. Member States may also decide at regional or subregional level to monitor for additional frequency bands.

The foregoing serves to contextualize the need to have methodologies that allow evaluating the temporal and spatial extension of underwater continuous noise present in the marine environment, linking it with the potential adverse impact produced on marine ecosystems.

In the framework of the MSFD implementation, several programs are focused on the anthropogenic sound management, as the Joint Framework for Ocean Noise in the Atlantic Seas (JONAS), the Joint Monitoring Programme for Ambient Noise North Sea (JOMOPANS) or Risk-based Approaches to Good Environmental Status (RAGES). Most of the work is focused on establishing methodological standards that allow undertaking the necessary studies to evaluate the environmental status related to underwater sound in an efficient and comparative way.

The MSFD implementation regarding the descriptor 11 must be considered as a common approach by European member states ensuring the achievement of comparable and reliable results. This is an ambitious goal due to the specificities and different scenarios considered from a global point of view. It is therefore clear that the MSFD Technical Group on Underwater Noise made a huge advance during last decade defining standards and methodologies offering a scientific advice regarding the underwater noise assessment.

In 2021, TG Noise developed a guidance on an assessment Framework for EU Threshold Values for continuous underwater sound (Sigray P et al. Assessment Framework for EU Threshold Values for continuous underwater sound, TG Noise Recommendations).

Under its recommendations, the starting points are the definition of habitat, considered as "where the indicator species or a community of indicator species lives" together with the estimation of the reference and current condition. The reference condition is the acoustic baseline minimizing as much as possible the influence of anthropogenic activities and the current condition is the present acoustic state of a given grid cell in a habitat during an evaluation period, considering both natural and anthropogenic sources of sound. The degree of deviation from the reference condition could be used to quantify the degradation of a habitat because of anthropogenic sound. With respect to the adverse impact two conditions are pointed as a mechanism to measure the acoustic degradation of a habitat, masking and disturbance. It is noteworthy, regarding the biological data about species able to be considered as indicator species, that aspects like hearing sensibility, vulnerability or its threat status among other factors must be considered.

Sometimes biological data is tentative, linked to specific seasons and the effort of sighting surveys is uneven between different areas. During the execution of this work no particular species has been prioritized and, taking the advantage of ASI results, the whole available data has been used.

In the case that concerns the study developed in this document, both reference and current conditions can be determined by monitoring or modelling.

Taking as a starting point the indications coming from the framework of the MSFD on the evaluation of the impact of sound on the marine environment, the aim of this deliverable is to develop a methodology to determine the extent to which the underwater continuous sound from maritime traffic has adverse effects on habitat and indicator species in the Gulf of Lion. The approaches followed to face off the problem are divided in two main strategies, one based on the evaluation of the risk of acoustic masking of intraspecific communication signals for a given species and the other one based on quantifying the spatial and temporal extent of sound pressure level above a given threshold value.

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According to the explanation above, the five cetacean species analysed in the present study as mentioned in the previous section, are considered indicator species. These species produce and use different frequencies to be aware about its surroundings, feed, mate etc., for example, mysticetes vocalize at low frequencies, and odontocetes uses sound at higher frequencies, reaching tens or even hundreds of kHz (Parks et al., 2007; Cranford & Krysl, 2015, Arverson & Vendittis; 2000, Hermannsen et al., 2014; and Veirs et al., 2016 cited in Erbe et al., 2019).

To summarize the frequency properties of the vocalizations of the considered species, the following is noted:

- *Balaenoptera physalus* emits two main types of vocalizations, both with downsweep frequency characteristic, high amplitude and short duration. One of them is centered at 20 Hz and has a narrow frequency band and the other presents higher frequencies, named 40 Hz calls, sweeping from 75 Hz to 40 Hz (Wiggins & Hildebrand, 2020). Rogamosa et al. (2021) associated 40 Hz calls with feeding contexts. Several authors have reported source levels of 189 dB re 1 µPa for 20 Hz calls (Sirovic et al., 2007), which is the range of the source level reported by Wiggins and Hildebrand (2020) for 40 Hz calls with mean frequencies from close to 34 Hz to close to 63 Hz.

- *Tursiops truncatus* produces broadband echolocation clicks at frequencies from 40 to 130 kHz (Greco et al., 2003) and whistles with the mean peak of frequency of about 13 kHz (Díaz, 2011), ranging from 1.8 kHz to 24 kHz, rarely under 3.5 kHz, (Wang et al., 1995; Díaz, 2011; Caldwell & Caldwell, 1979 cited in Bou-Cabo et al. 2022). Frankel et al. (2014) indicated a source level ranging from 114 dB to 163 dB.

- *Delphinus delphis* emits whistles ranging from 1.6 to 33.2 kHz (Panova et al., 2021; Gannier et al., 2010). Echolocation clicks are emitted from 23 and 67 kHz and have source levels of at least 160-170 dB re 1 µPa (Evans, 1973; Fish & Turl, 1976; Dziedzic, 1978 cited in Richardson et al., 1995 and in Todd et al., 2015).

- Whistles from *Stenella coeruleoalba* range from 3.5 to 28.5 kHz with source levels of 170 dB re 1 µPa and clicks have a broad range from 0.3 to 100 kHz (Zanardelli et al., 1990 cited in Kastelein et al., 2003 and in Todd et al., 2015).

- *Grampus griseus* emits whistles between 4 and 22 kHz (Todd et al., 2015) and echolocation clicks with peak frequency at 48 kHz, reaching 105 kHz (Philips et al., 2003).

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3. Methodology

As was introduced before, the proposed methodologies evaluate, through two approaches, the potential adverse effect of the sound introduced into the marine environment by maritime traffic.

- The approach based on the calculation of the temporal and spatial extent of underwater sound considers the percentage of area (habitat approach) or number of individuals (species approach) that are above a certain threshold level a certain percentage of time. This methodology implements an index called impact factor that computes the area under curve defined by % of area vs % of time or % of individuals vs % of time. Defining a biological-based threshold level, the proposed methodology brings the opportunity to quantify the amount of area or animals that are exposed to sound levels that could produce for example disturbance on individuals, considering the evolution of sound levels through the evaluation period.

- The masking approach consist in the measurement of the deviation among current condition and reference condition. This quantity is related with the reduction of the communication distance among conspecifics considering that animals could experience acoustic impairment when the hypothetical bio-acoustic signal has the same sound level or less than the current condition.

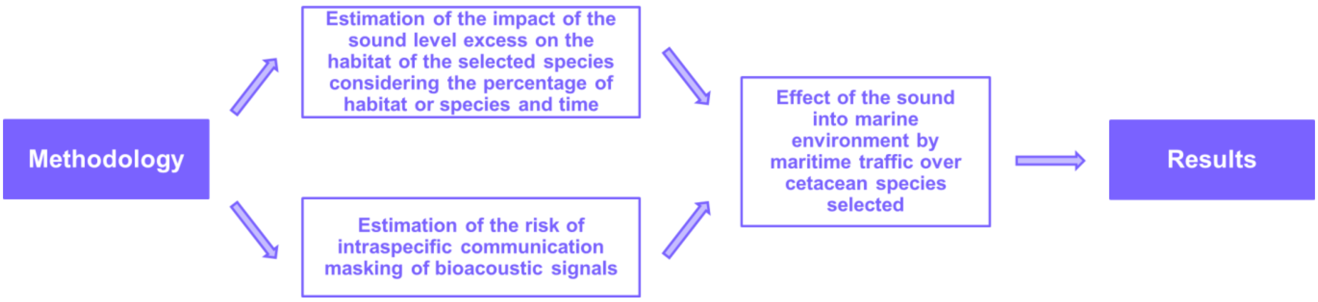

Figure 4. Methodology used for the underwater noise analysis in the case study. Source: Own elaboration, IEO(CSIC).

Within the necessary steps to follow with the aim to implement both approaches, some of them are common between the methodologies. Aspects such as computation of navigation AIS data, calculation of routes density, achievement of theoretical sound maps based on ship traffic or the cartography of the cetacean populations must be considered as inputs with respect to the developed models.

Throughout the section 3 it will be presented first, the common aspects used in the developed methodologies and then, the details about the specificities of each approach will be shown. Section 4 collects the results obtained following the different procedures applied over the case study area, and finally in section 5 the main conclusions inferred from the work carried out through this deliverable are pointed.

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3.1. Common inputs to underwater continuous sound assessment.

3.1.1. Ship route density map

One of the main aspects needed to develop the underwater sound assessment is the consideration of the acoustic sources radiating a certain sound pressure level to the marine environment. Therefore, the first step is to study the marine traffic present in the case study area during the evaluation period. This has been done by means of the AIS navigation data of the first semester of 2022. The procedure consisted of grouping the navigation raw data by the Marine Mobile Service Identities (MMSI) identifier to calculate the ship routes. To avoid the possibility to obtain ambiguous or fictitious routes, a time window of 1h was considered in the ship routes calculation, ensuring that only AIS data trajectories are present in the analysis. The navigation routes were in a GeoPackage file with line geometry. Then a QGIS line density algorithm was applied assuming grid cells of 0.05° side (approximately 23 km^2) considering the lines within a neighbourhood with a radius of 0.05°. Results obtained are depicted at figure 5.

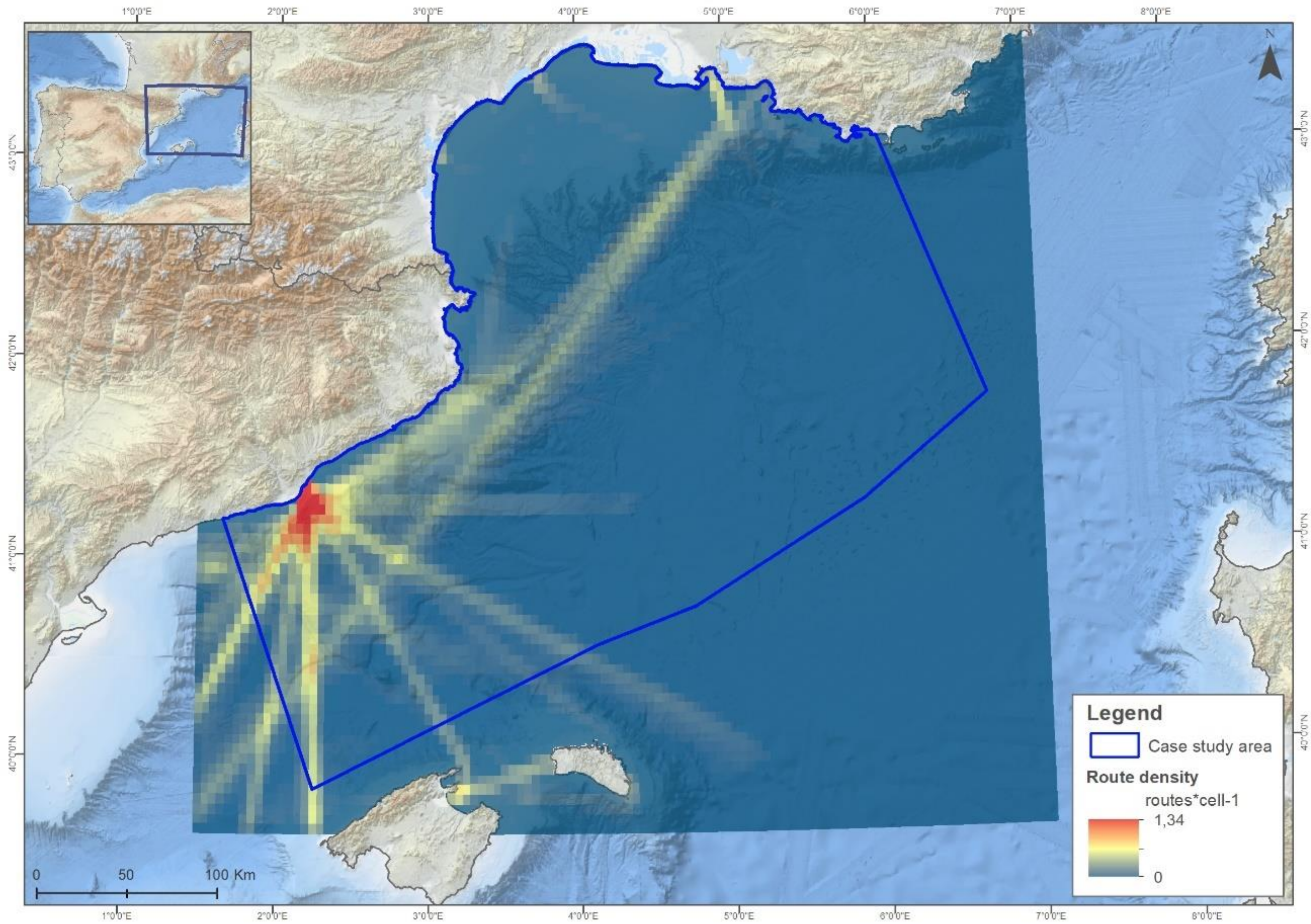

Figure 5. Route density calculated over a cell grid of 0.05° side from the AIS data of the first four-month period of 2022 in the Gulf of Lion. Source: Own elaboration, IEO(CSIC).

As it can be seen, the highest density occurs in the vicinity of the Barcelona port and the most travelled routes are those that arrive or depart from it, followed by the ones related to Marseille port and the routes between the islands of Mallorca and Menorca. On the contrary, the northeast and southwest of the Gulf of Lion appear with a considerably lower density of routes.

3.1.2. Underwater sound maps

Considering the route density, calculated underwater sound propagation models have been applied for two frequency bands associated with ship traffic, ⅓-octave bands of 63 Hz and 5 kHz. The first band is indicated under the low-frequency continuous sound descriptor (D11.C2) of the MSFD to monitor the low-frequency ambient sound, mainly produced by maritime traffic, as it is mentioned in the 2.2 section. Furthermore, 63 Hz is included in the frequency range of the vocalizations of *Balaenoptera physalus* (Wiggins and Hildebrand, 2020), as mentioned above. The frequency band of 5 kHz was chosen because is included in the whistles signature of *T. truncatus*, *D. delphis*, *S. coeruleoalba* and *G. griseus* (Panova et al., 2021; Gannier et al., 2010; Todd et al., 2015).

The propagation model of underwater sound has been applied considering the source and propagation medium properties. The parameters considered to carry out the simulations were the characteristics of the ships as a sound source, the environmental conditions that determine the profile of the speed of sound through the water column, the bathymetry and the seabed properties in the case study area.

The sound pressure level radiated by ships in navigation mode was calculated using the Research Ambient Noise Directionality model (RANDI Model) (Audoly & Rizzuto, 2015). This model takes into account the ship speed over ground, their lengths and their location in the evaluated area. The propagation of the emitted sound through the medium undergoes transmission losses that have to be considered. A model based on ray theory (Clay & Medwin, 1997) has been applied through BELLHOP (Porter & Liu, 1994) open-source algorithm in order to compute the propagation of sound through the medium.

Since the salinity and temperature of the water and the bottom depth affect the sound propagation, these have been included in the model. Data on seasonal variations in temperature and salinity have been provided by the European Marine Observation and Data Network (EDMODnet). Salinity and temperature were used to calculate the speed of sound in the medium using the Mackenzie equation (Mackenzie, 1982). The bathymetry has been obtained from the General Bathymetric Chart of the Oceans (GEBCO) portal.

The sound pressure level was simulated for three different depths, 20, 100 and 500 m. Finally, the maps of the sound pressure level for each frequency for every day were built using the maximum level in water column. For the following methodological steps, this maximum level has been used in order to consider the worst-case situation.

Figures 6 and 7 show the sound pressure level maps for 63 Hz and 5 kHz, respectively, corresponding to the median value of the first four-month period of 2022. As it was expected, in general, the sound pressure level values for 63 Hz were higher than 5 kHz, since large ships emit more efficiently at low frequencies. In both frequencies, the highest values of sound pressure level appear in the vicinity of the port of Barcelona and extend towards the area of the port of Marseille and towards the two islands of Mallorca and Menorca. The latter is more noticeable in the case of 63 Hz, where the sound pressure level values between islands reach higher values compared to the surrounding ones. These sound maps are consistent with the route density map (Figure 5).

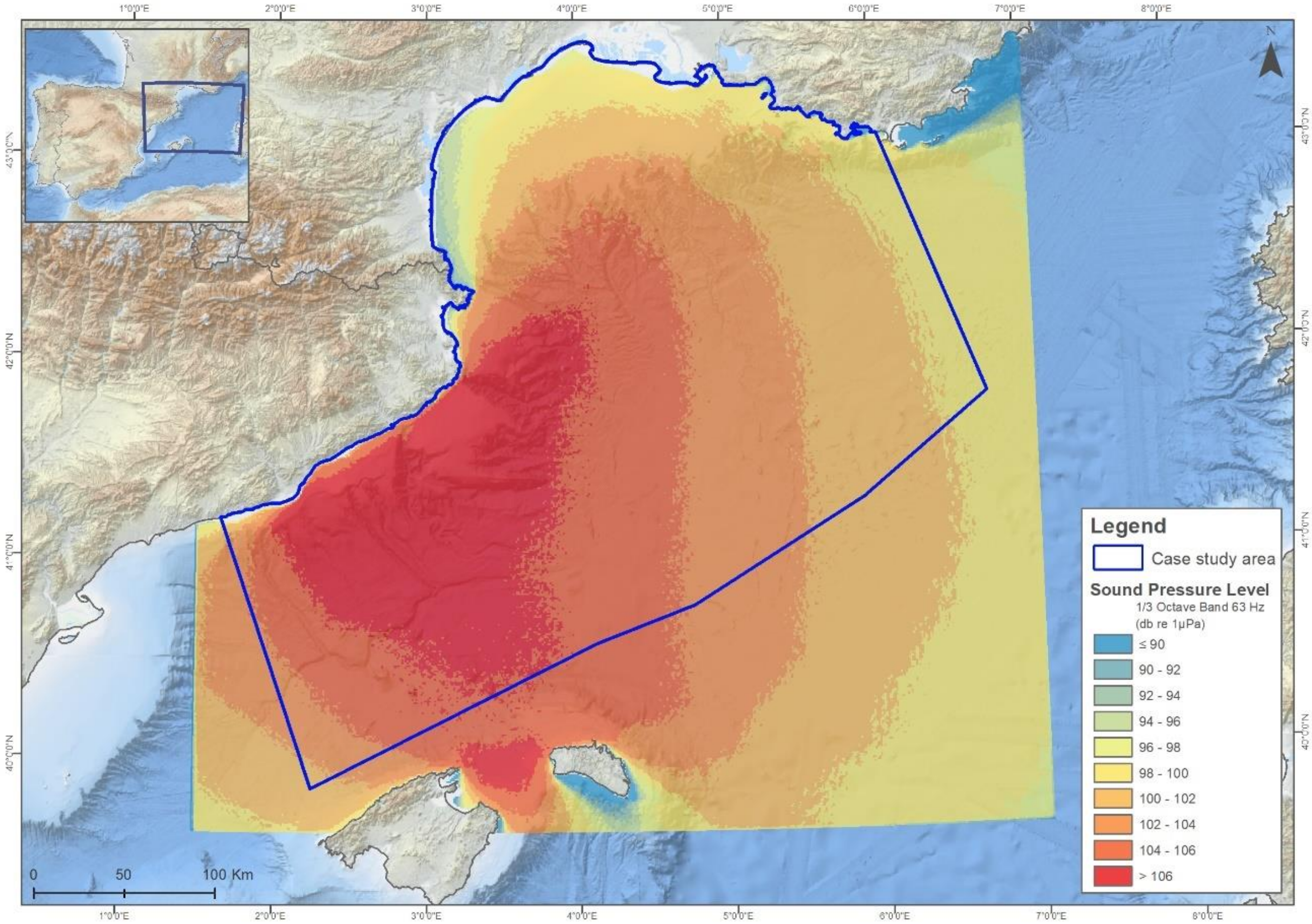

Figure 6. Map of the median of maximum sound pressure level in ⅓ octave band of 63Hz in case study area in the first four-month period of 2022. Source: Own elaboration, IEO(CSIC).

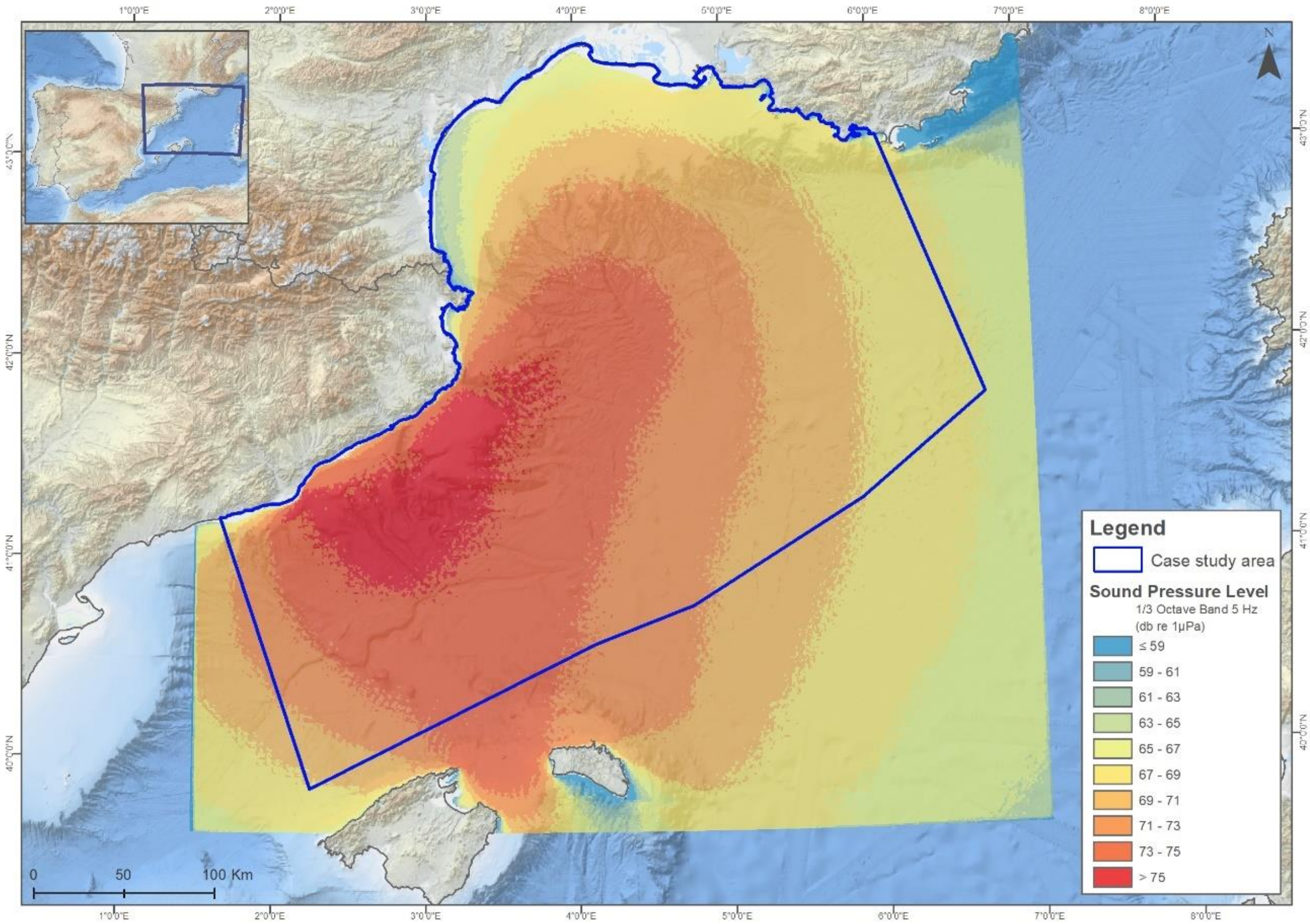

Figure 7. Map of the median of maximum sound pressure level in ⅓ octave band of 5 kHz in case study area in the first four-month period of 2022. Source: Own elaboration, IEO(CSIC).

3.1.3. Cetacean distribution data

Regarding the cetacean distribution data used to perform this study, the estimation of the number of different species individuals have been considered thanks to the ASI project results (as mentioned in 2.1 section).

The projected number of individuals for each cell of 0.2° side (approximately 370 km^2) for *B. physalus*, *T. truncatus*, *S. coeruleoalba* and *D. delphis* and *G. griseus* are shown in Figures 8, 9, 10 and 11, respectively. The cartography of the estimated number of individuals has been performed using the Geographic Information System QGIS. Data for *S. coeruleoalba* and *D. delphis* are presented together on the same map.

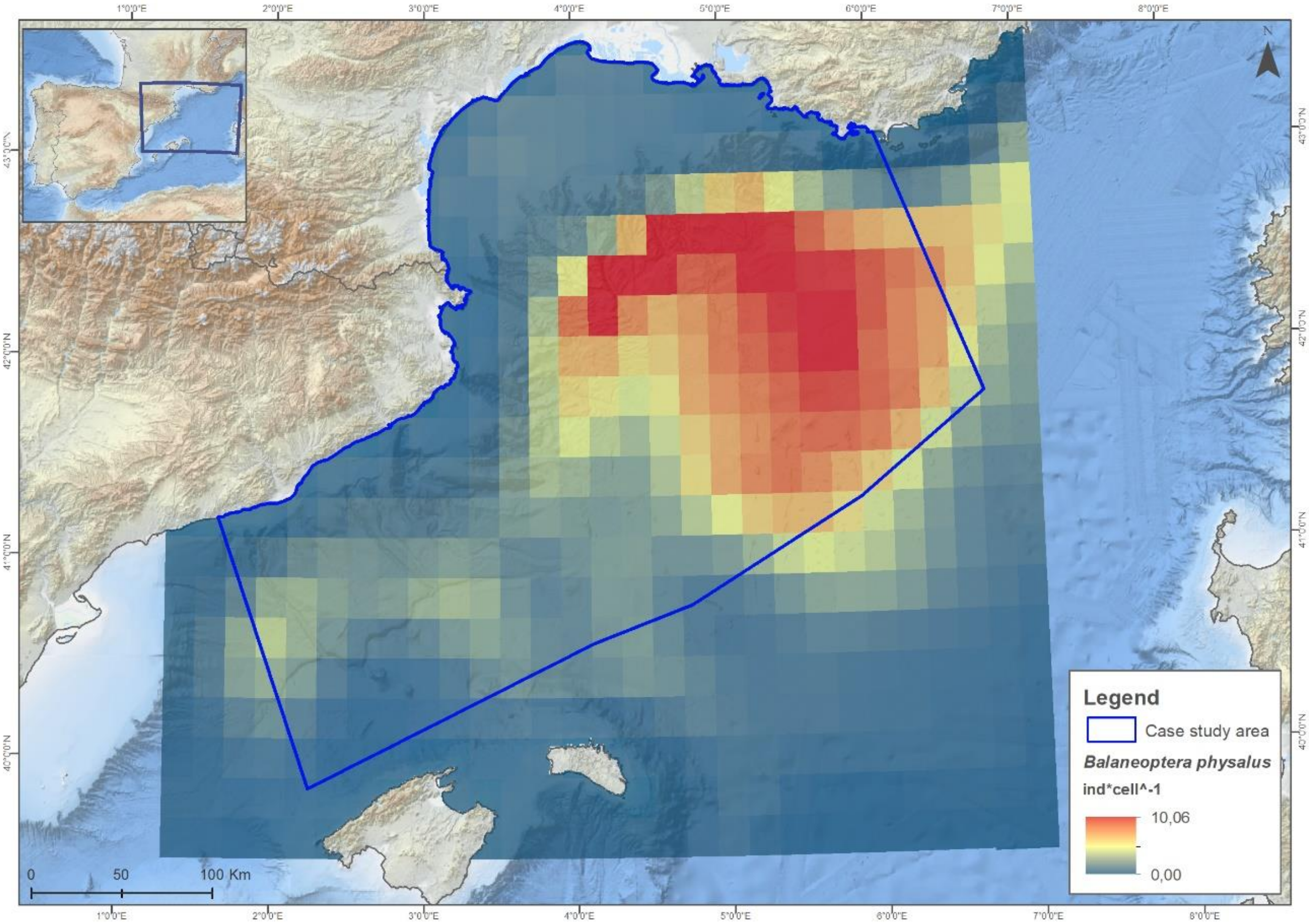

Figure 8. Number of individuals of B. physalus per map cell calculated from the ASI Project Survey (2018). Every cell has 0.2° side. Source: Own elaboration, IEO(CSIC).

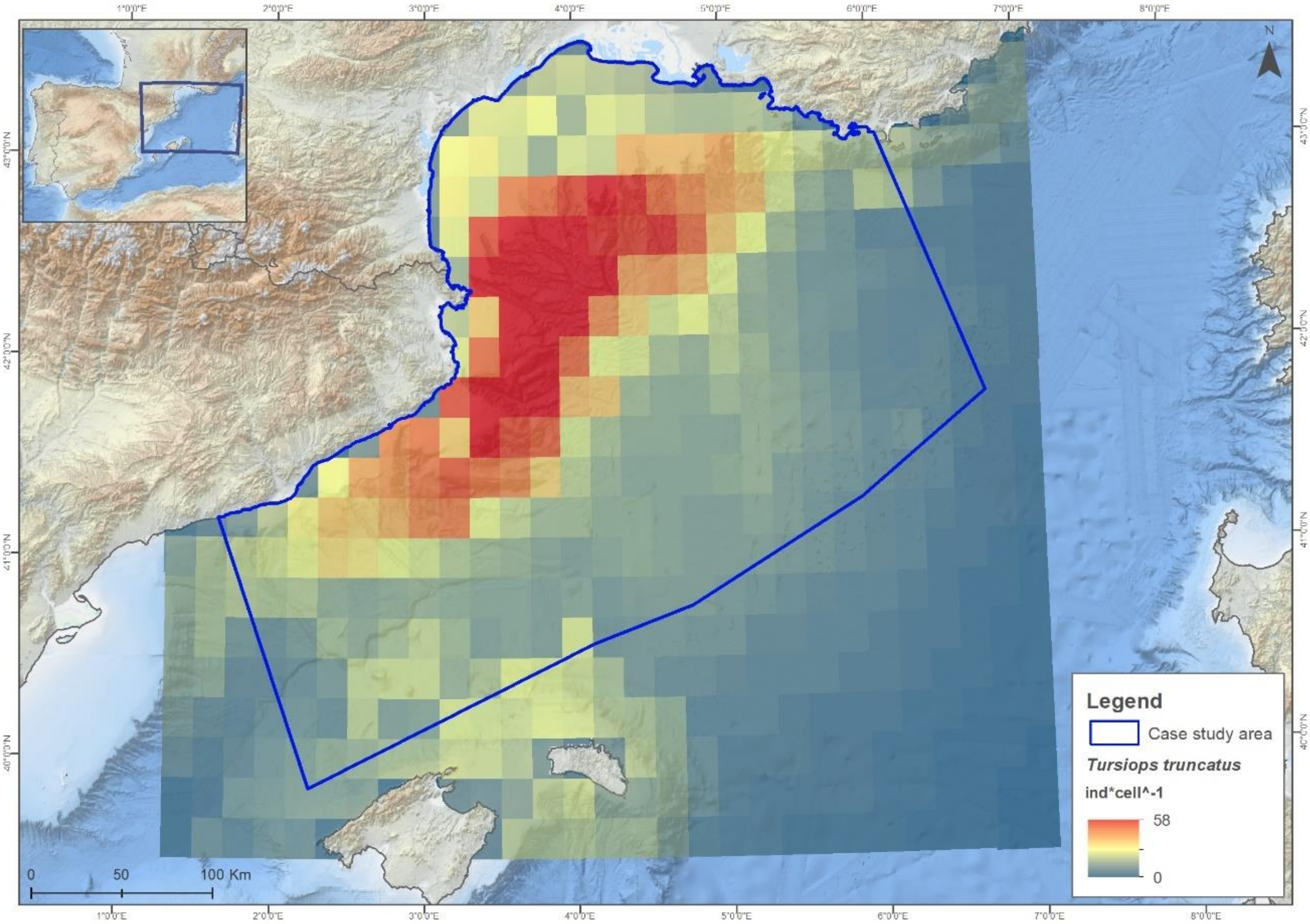

Figure 9. Number of individuals of T. truncatus per map cell calculated from the ASI Project Survey (2018). Every cell has 0.2° side. Source: Own elaboration, IEO(CSIC).

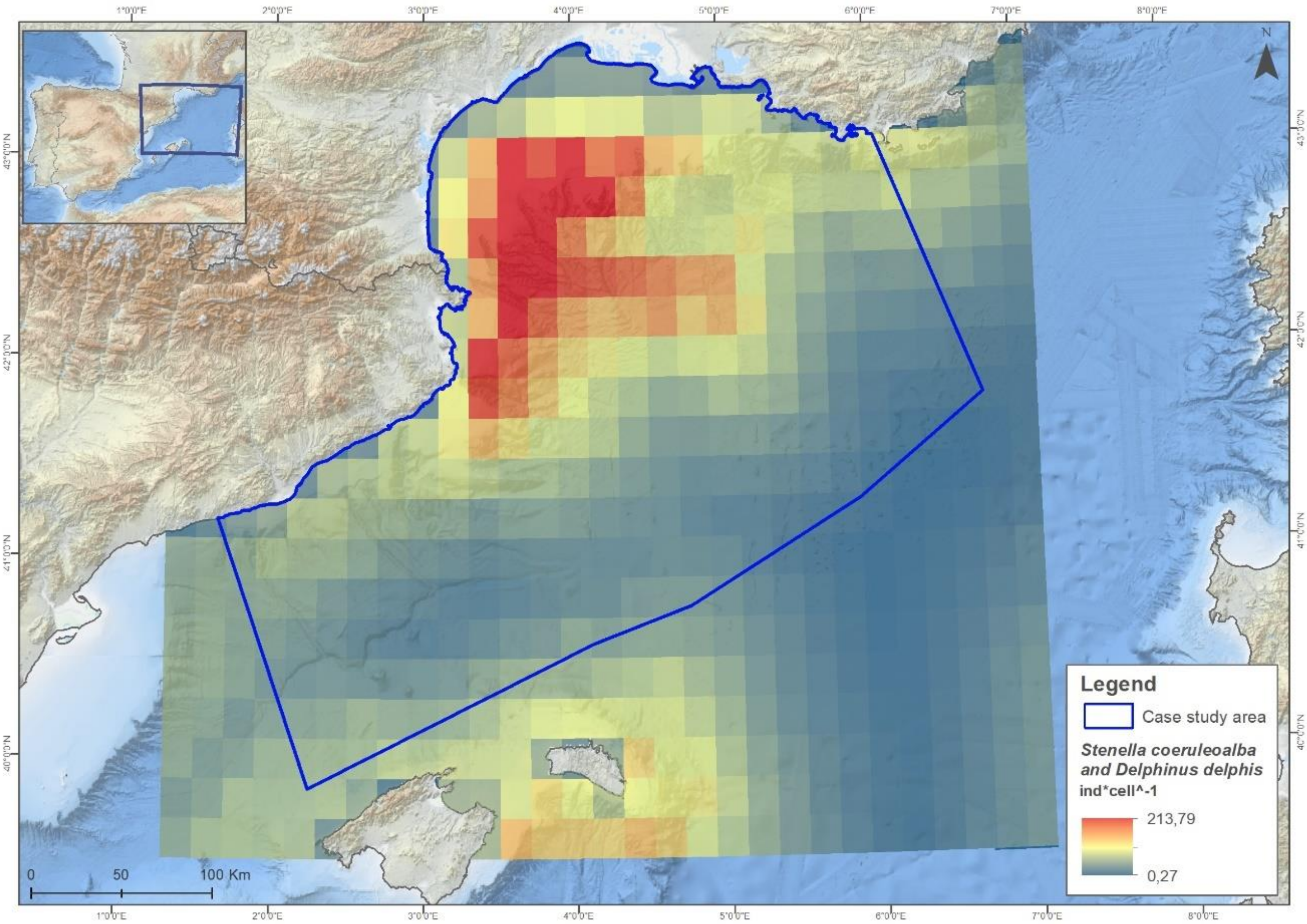

Figure 10. Number of individuals of S. coeruleoalba and D. delphis per map cell calculated from the ASI Project Survey (2018). Every cell has 0.2° side. Source: Own elaboration, IEO(CSIC).

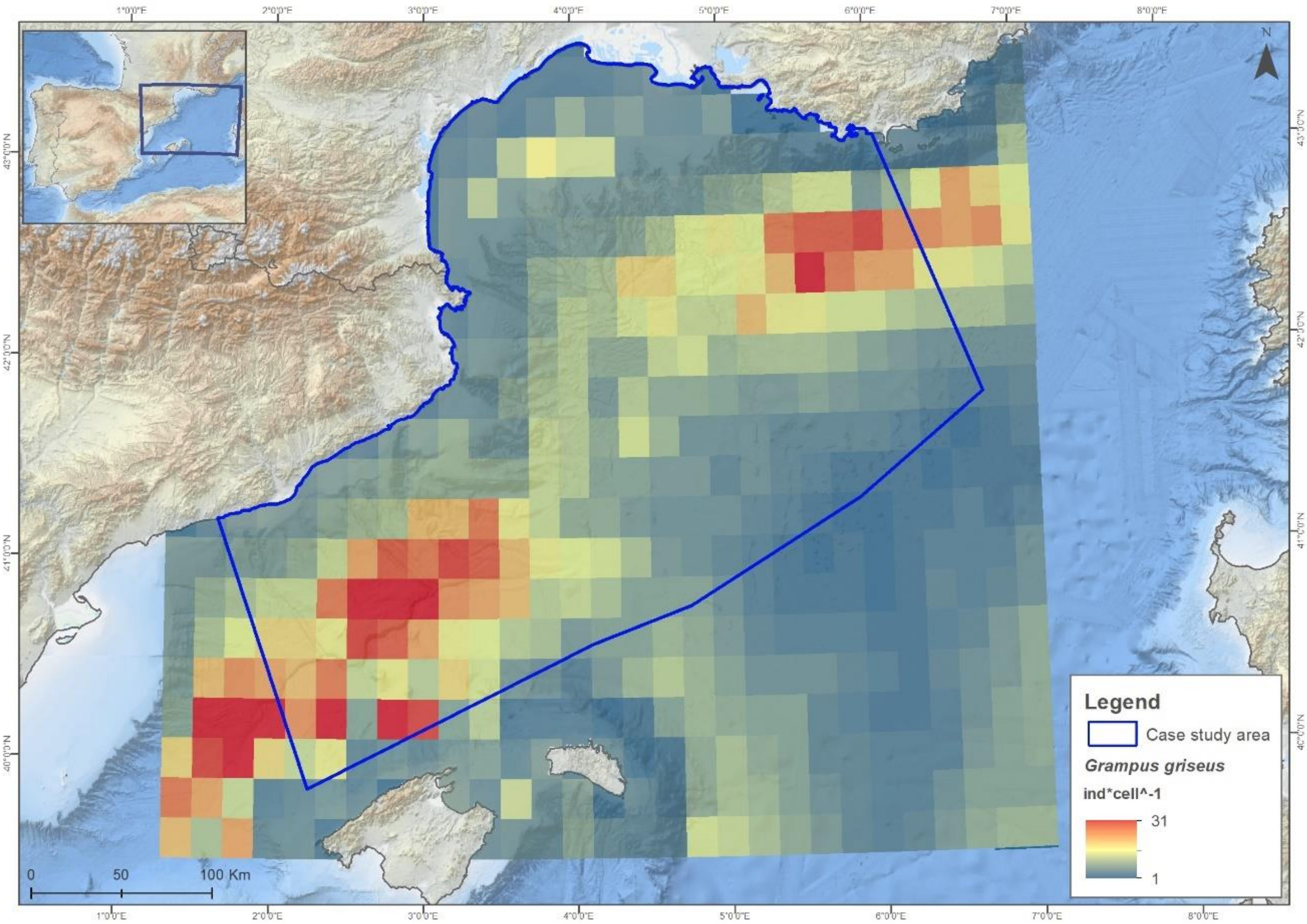

Figure 11. Number of individuals of G. griseus per map cell calculated from the ASI Project Survey (2018). Every cell has 0.2° side. Source: Own elaboration, IEO(CSIC).

3.2. Habitat/species approach based on the sound pressure level excess

The methodology presented in this section aims to address the criteria stablished by the Commission Decision of 2017 defined by underwater continuous noise: "*D11.C2 - Primary: The spatial distribution, temporal extent and levels of anthropogenic continuous low-frequency sound do not exceed levels that adversely impact populations of marine animals*."

It is implied in the previous paragraph that certain threshold values are needed to evaluate if in the studied area during the evaluation period GES is reached or not. These threshold values would be stablished by member states considering regional and subregional specificities.

Regardless of the adoption of threshold values related to a specific adverse impact such as disturbance or masking seems clear that the methodology should rely on the calculation of excess sound pressure level with respect to a given reference condition and the evaluation of its spatial and temporal extents.

The methodology carried out using the Impact Factor (IF) proposed in this section computes the percentage of area or individuals that are exposed to excess level values above a given reference condition considering the temporal evolution during the evaluation period. The threshold values used to calculate the impact factor are statistically based and no considerations about negative condition induced by noise were done. Nevertheless, the choice of threshold values based on biological evidence related to induced adverse impact on selected species would not change the methodological proposal developed.

With respect to the estimation of the reference condition it is important to remark that it represents a complex task either calculated through theoretical models that consider the sound pressure level in the area due to weather conditions or by means of experimental measurements obtained in locations with low anthropogenic activity.

In the presented case study, the reference condition was defined considering the experimental data collected from the Passive Acoustic Monitoring (PAM) performed at 90 m depth in the Cabrera Archipelago Maritime-Terrestrial National Park (Spain) in 2018. Specifically, the 50th percentile of the 63 Hz data from each sampling event was calculated and considered as the best available approach to the sound pressure level in the absence of anthropogenic activity. The sound pressure level of the reference condition was 79.09 dB re 1 µPa for 63Hz frequency. The relative frequencies of the sound pressure level values obtained from the monitoring and the resulting percentiles are shown in Figure 12.

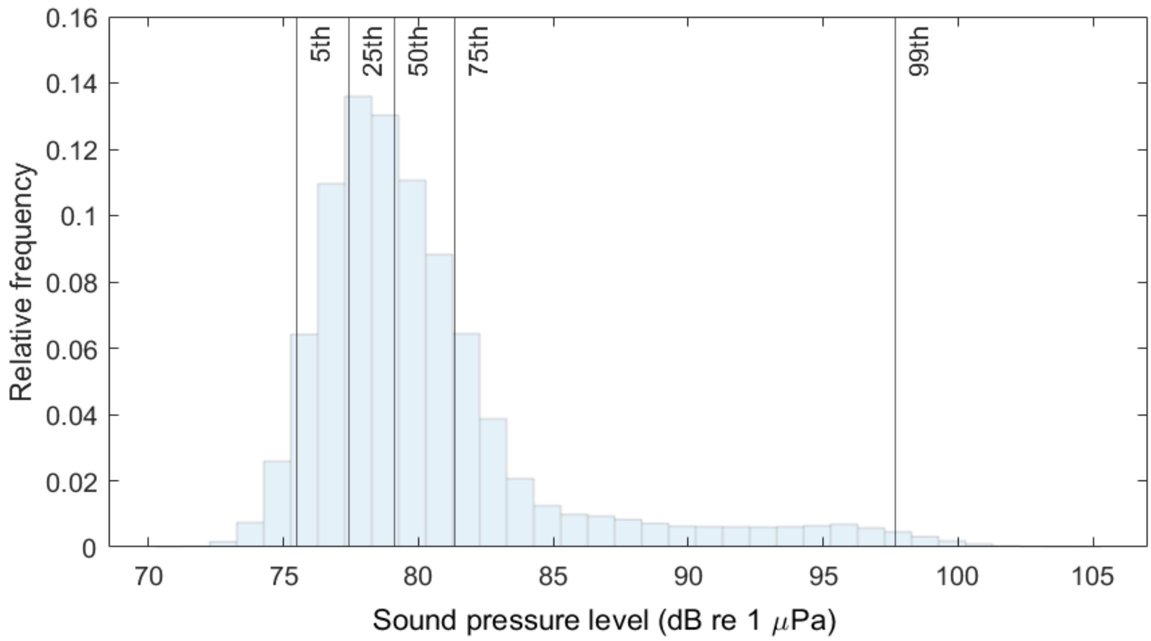

Figure 12. Relative frequency histograms of sound pressure level values in ⅓ octave band of 63 Hz from passive acoustic monitoring performed at 90 m depth in the Cabrera Archipelago Maritime-Terrestrial National Park (Spain) in 2018. Source: Own elaboration, IEO(CSIC).

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Once reference condition is assumed and the sound pressure level derived by the theoretical model applied over AIS data is taken as a current condition, the next steps require the calculation of the excess level, the study of the percentage of time that each grid cell is above the threshold level, and finally, the establishment of the relationship among the temporal extent of the excess level with the percentage of animals/area exposed to excess level values. This relationship is achieved by the Impact Factor defined by the area under curve defined by the percentage of time vs percentage of individuals (or area). The procedure can be summarized as a stepwise as follows:

1. Considering the area defined by the species presence, the excess level is calculated over a daily time window for the whole assessment period.

2. Four threshold values were defined to exemplify the performance of the methodology. These values [10, 20, 25 and 30 dB] were based on the statistical distribution of the excess level.

3. Considering the daily excess level, the percentage of time that each cell of the studied area is above a given threshold value was calculated.

4. Assuming the same spatial scaling among biological data and excess level data, the %area-%time or %number of individuals-%time exposure curves can be inferred for the entire evaluation period.

5. The Impact Factor can be calculated as the area under the exposure curves. The meaning of the Impact Factor is different depending on whether area or number of individuals is considered. In the case of Impact Factor related to habitat, it is a single value that represents the percentage of area and time exposed to an excess level with respect to a threshold level. In the case of Impact Factor related to species, it represents the percentage of the estimated number of individuals and time exposed to an excess level with respect to a threshold level.

In figure 13 are depicted the results obtained in relation to the percentage of time that each cell of the studied area is above a given threshold value (step 3). The results related to the Impact Factor will be shown in next section because they are considered the main output of the model and therefore what defines the results of the underwater sound assessment both considering habitat and species approach.

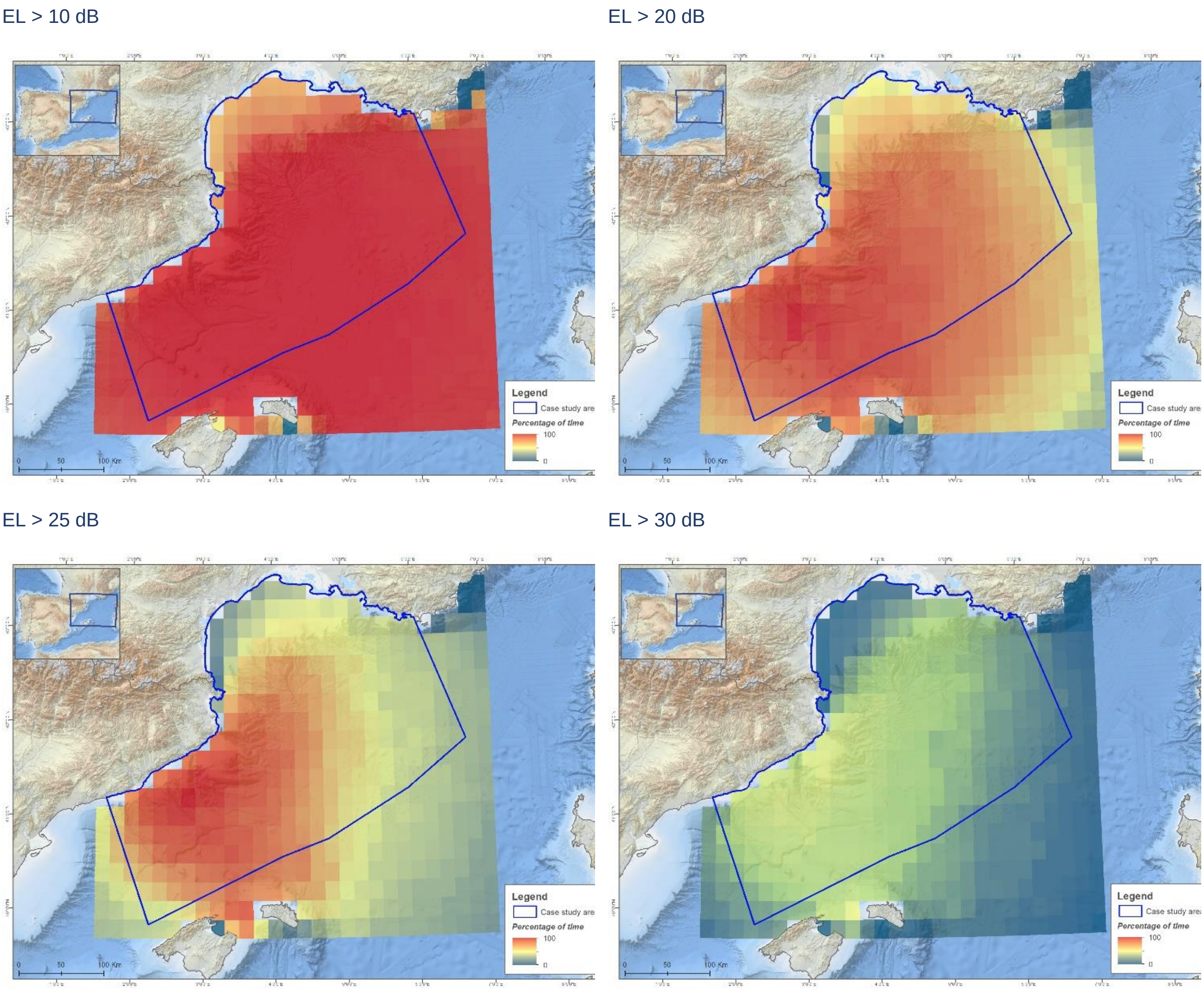

Figure 13. Example maps of the percentage of time that each cell of the evaluated area presents an excess level over the percentile 25 (left) and the percentile 75 (right) of the set of excess levels. Source: Own elaboration, IEO(CSIC).

3.3. Underwater sound assessment based on masking effect

The acoustic masking effect is related to the ability to optimally interpret an acoustic signal due to a low signal-to-noise ratio. The proposed methodology evaluated the risk of acoustic masking of intraspecific communication signals due to the introduction of anthropogenic sound pressure level in the marine environment.

Some cetaceans have certain capacity for adaptation to noise, for example, by changing vocal behaviour (Weilgart, 2007). It should be noted that the applied model did not consider the possibility that individuals adapt their vocalizations in order to overcome the underwater noise level either modulating the frequency or increasing the emitted intensity.

A methodology to evaluate the risk of acoustic masking effect was developed by Bou-Cabo et al. (2022) in the framework of the RAGES project and follows the steps defined in the ISO31000-Risk Management Plans in relation to environmental impact of anthropogenic pressures in the sea. It is based on the percentage of Communication Distance Reduction (CDR%) that certain cetacean species can suffer due to the presence of anthropogenic noise in the marine environment. The main idea is to assume that animals can communicate over a greater distance the lower the sound pressure level is present in the medium.

The evaluation of the CDR% is based on the ratio between the distances at which animals can interpret properly the bio-acoustic signals linked to the reference condition and current condition. The hypothesis is that the maximum range of communication is determined by the signal to noise ratio among received level of bio-acoustic signal and the sound pressure level present in the medium. Figure 14 summarizes the concept of the communication distance reduction, defined by equation (1).

$$CDR_{\%} = (1 - D_{CC} / D_{RC}) \cdot 100 \qquad (1)$$

where D_{RC} and D_{CC} are the distance of the intersections between the decay of the source level due to transmission loss and the sound pressure levels of the reference and current conditions, respectively.

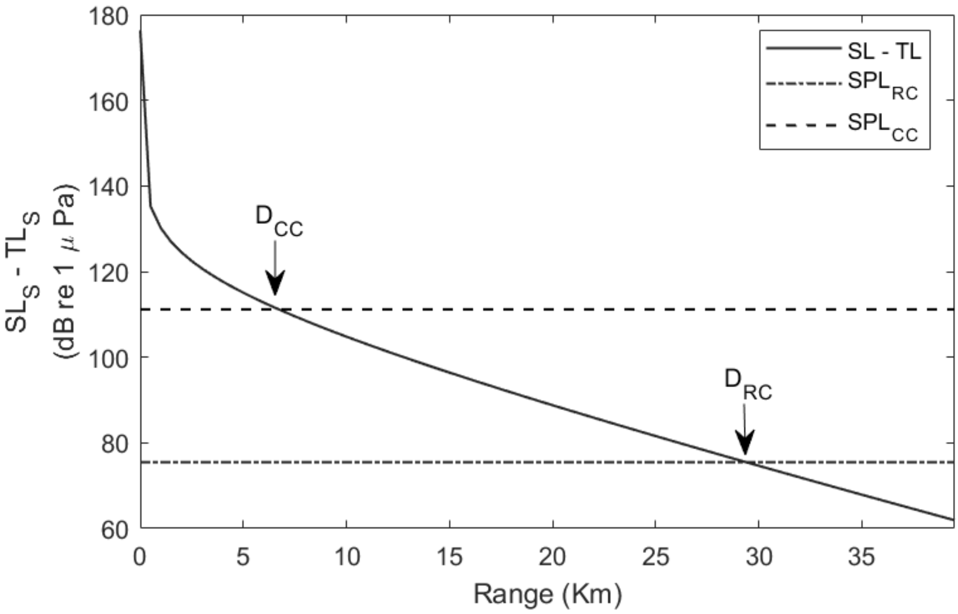

Figure 14. Detail of the D_{RC} and D_{CC} calculation representing the maximum communication range among individuals assuming pristine and current condition scenarios respectively. The solid black line is the sound attenuation among individuals while dotted and dashed black lines are the sound pressure level of pristine ambient and current condition. Source: Own elaboration, IEO(CSIC).

Therefore, higher levels of anthropogenic noise with respect to a “pristine” scenario will produce poor signal to noise ratio and the distance where animals can stablish communication would be reduced.

It is important to note that the CDR% calculation depends on the frequency band studied, and this choice depends on selected species.

Once the CDR% is evaluated for each timestamp, the next step in the methodology consists in relating it with the animal distribution in the case study area. The main goal is to find where there is more risk of masking and this depends on how many animals are potentially impacted by this effect. This is achieved by the definition of a risk-based variable as follows (equation (2)):

$$Risk\ Index_{i,j} = \frac{\int_{t_1}^{t_2}\left(CDR_{\%\ i,j}(t) \cap CNPDF_{i,j}(t)\right) \cdot dt}{Maximum\ exposure} \quad (2)$$

Being the CDR% the percentage of communication distance reduction, the CNPDF the cumulative normalized probability density function of the animal distribution and the maximum exposure, a normalization factor that depends on the assessment period. The indexes i,j refer to the each cell grid composing the total area.

The Risk Index variable must be understood as the coincident area under curves defined by the CDR (normalized) and CNPDF vs percentage of the assessment period. Figure 15 shows graphically the concept of the Risk Index.

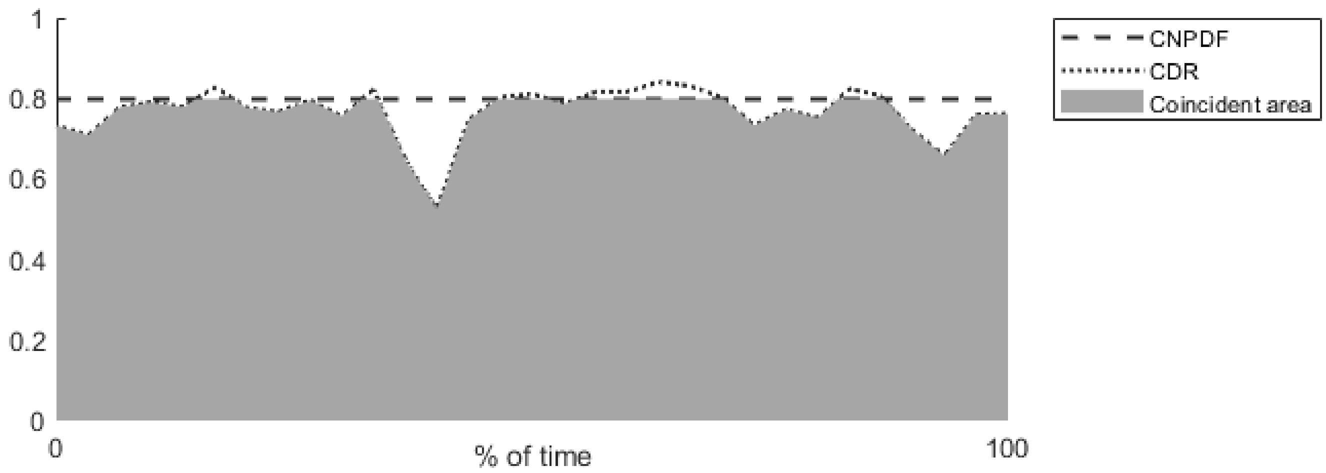

Figure 15. Example of the coincident area under the curves defined by the evolution of the normalized values of the CDR and the CNPDF, both between 0 and 1, throughout the 100 % assessment period. Source: Own elaboration, IEO(CSIC).

Once the methodology has been presented, its application over the case study area and the selected species can be summarized as:

1. Selection of species, the bandwidth and source level associated to its vocalizations:

   - 63 Hz communication signals for *B. physalus*.
   - 5 kHz communication signals for *T. truncates*.
   - 5 kHz communication signals for *D. delphis* and *S. coeruleoalba*.
   - Source level values of the communication signals emitted from each species in the frequency of interest. The source level considered for *B. physalus* is 189 dB re 1 µPa. A whistle source level of 150 dB re 1 µPa of an average individual of *T. truncatus* was taken. A source level of 170 dB re 1 µPa has been used in the case of *D. delphis* and *S. coeruleoalba* since they are computed together, and this source level is the value reported for the whistles of *S. coeruleoalba*.

2. Establishment of current condition and reference condition.

   - The current condition is defined by the calculation of sound maps during the assessment period considering daily time windowing. Figures 6 and 7 represents the median value of sound pressure level in the third octave band for the 63Hz and 5kHz for the entire evaluation period.
   - The reference condition has been calculated at both frequency bands considered, figure 12 shows the results for 63Hz and figure 16 depicts the results regarding 5kHz. As it was described, the sound pressure level of the reference condition was the 50th percentile of the data, 79.09 dB re 1µPa for 63 Hz and 71.16 dB re 1 µPa for 5 kHz.

3. Calculation of the CDR%, and CNPDF related to cetacean distribution. See Figure 17 to observe the CDR% calculated over the entire assessment period at frequency band of 63kHz.

4. In each cell of the evaluated area, the Risk Index is calculated from the coincident area under the curves defined by the evolution of the normalized values of the CDR and the CNPDF of the species throughout the assessment period. The Risk Index is a normalized variable that expresses the relation between the coincident area under the curves CDR and CNPDF for a specific cell. The worst situation is used to normalize the index and corresponds to the maximum exposure. This is defined by a hypothetical cell where the maximum density of individuals and the maximum CDR occur during the entire evaluation period.

The results regarding the Risk Index will be shown in the next section for each species considered.

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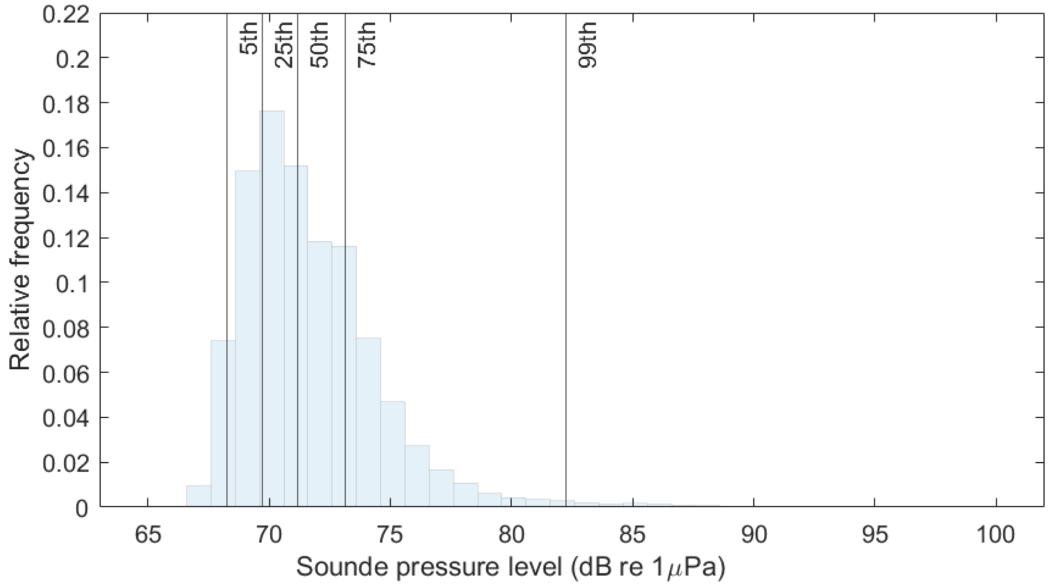

Figure 16. Relative frequency histograms of sound pressure level values in ⅓ octave band of 5 kHz from passive acoustic monitoring performed at 90 m depth in the Cabrera Archipelago Maritime-Terrestrial National Park (Spain) in 2018. Source: Own elaboration, IEO(CSIC).

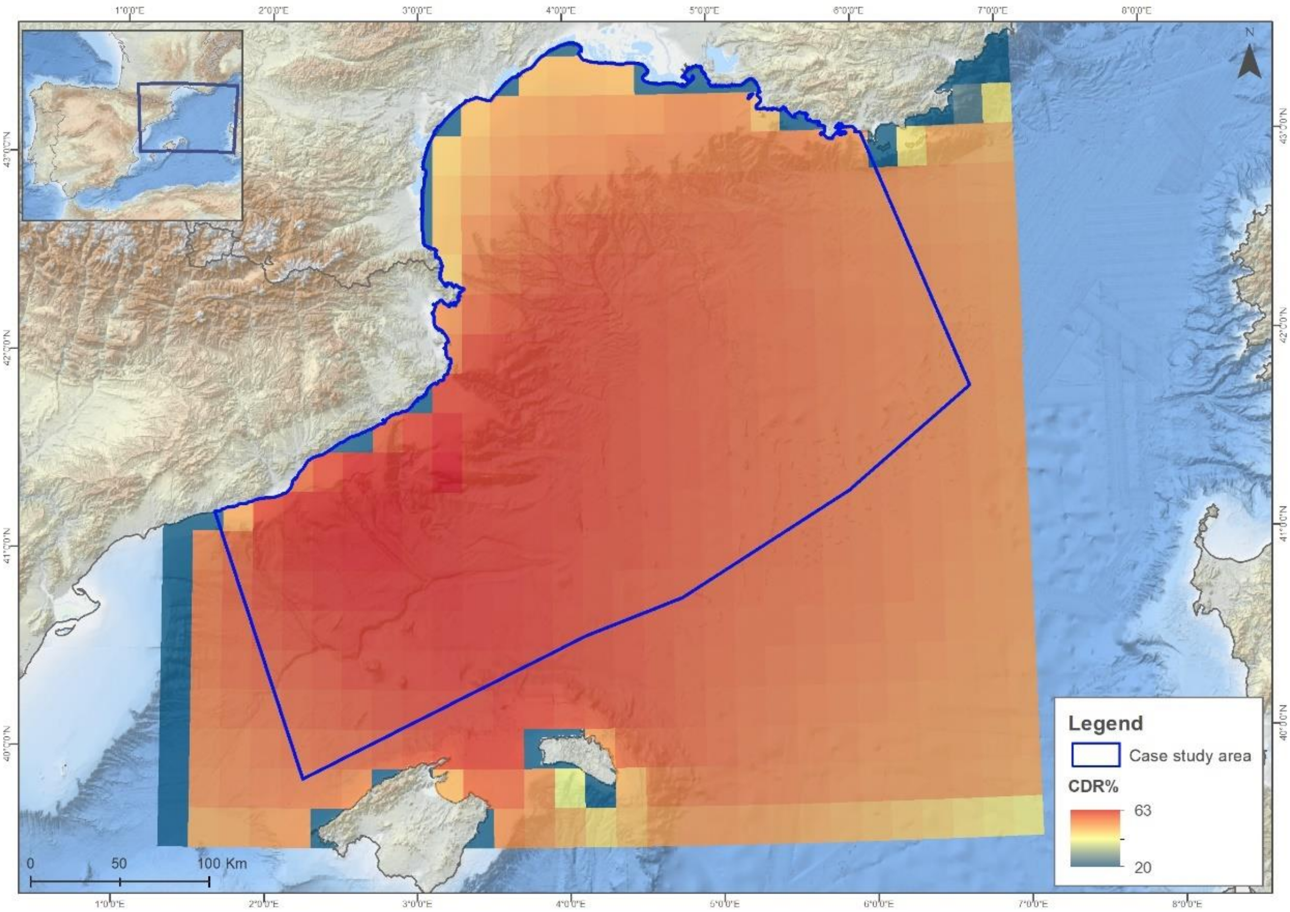

Figure 17. Example of the CDR% related to 63kHz 1/3 frequency band. Source: Own elaboration, IEO(CSIC).

4. Results

In this section the results obtained after applying the presented methodologies over the case study area and chosen species are presented.

4.1. Results of habitat/species approach based on the sound pressure level excess

With respect to the results considering the habitat approach, an exposure curve has been calculated considering different excess levels of sound in 1/3-octave band of 63 Hz with respect to threshold values defined by 10dB, 20dB, 25dB and 30dB for the first four-month period of 2022.

Figure 18 shows the area-time exposure curves and the Impact Factor inferred from each threshold value.

From these curves it is possible to observe that, for example, around 100% of the area is 70% of the time with a level excess above 10 dB, resulting in an Impact Factor close to 95%. As it was expected, the Impact Factor decreases as the excess level threshold value increases. In order to illustrate the spatial and temporal extent of the excess level reporting a numerical result, Table 2 shows the values of percentage of time that certain percentage of area presents an excess above the different thresholds.

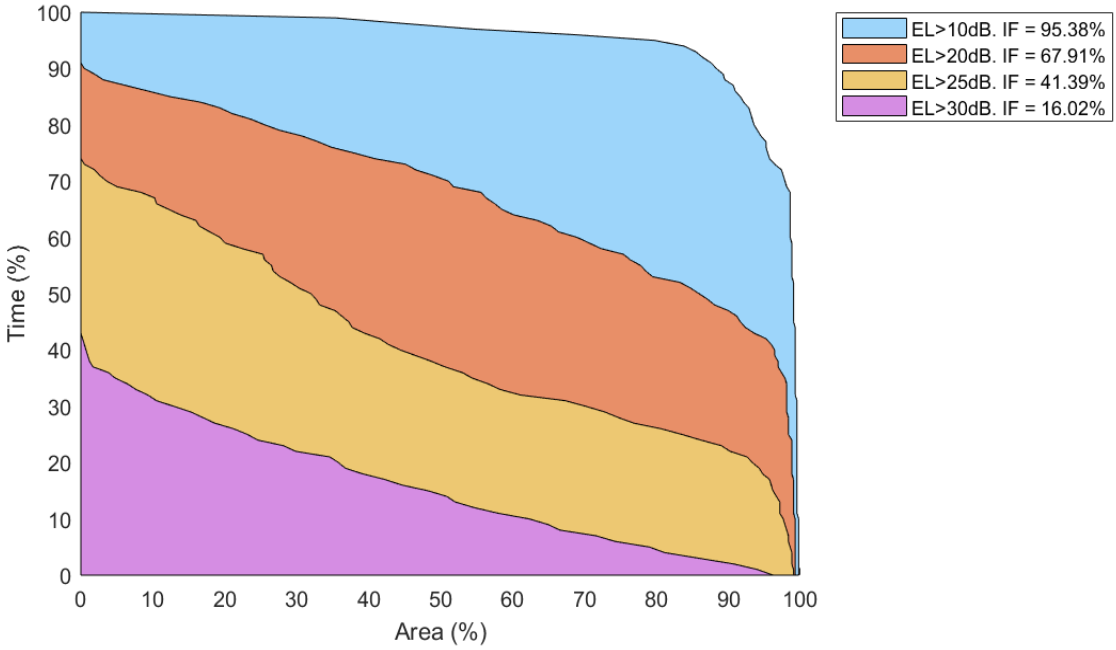

Figure 18. Area-time exposure curves and the resulting Impact Factor (IF) relative to thresholds of excess level at 63 Hz (EL>10, 20, 25 and 30 dB) evaluated for the shared habitat of the indicator species and the first four-month period of 2022. Source: Own elaboration, IEO(CSIC).

Table 2. Percentage of time during which the 25, 50 and 75 % of the area presents an excess level above the thresholds (EL>10, 20, 25 and 30 dB).

	Percentage of area		
	25 %	50 %	75 %
EL > 10 dB	99.29	97.48	95.43
EL > 20 dB	80.28	70.50	57.13
EL > 25 dB	57.10	37.31	27.86
EL > 30 dB	23.88	14.32	5.34

It is noted that through the obtained area-time exposure curve is possible to monitor the quantity of area exposed to an excess level during a given period. If the threshold level used is based on biological value that evidence through results obtained by the literature an adverse effect such as disturbance for specific species, a possible quantitative assessment on GES could be determined. If the threshold levels are just a given value of excess level, the methodology can be used to monitor if the area exposed to a given excess level during a certain period of time increases or decreases for long periods of monitoring.

Regarding the species approach (considering the number of animals at each cell map), the number of individuals-time exposure curves and the Impact Factor calculated related to *B. physalus*, *T. truncatus*, *S. coeruleoalba* and *D. delphis* and *G. griseus* are depicted in Figures 19, 20, 21 and 22.

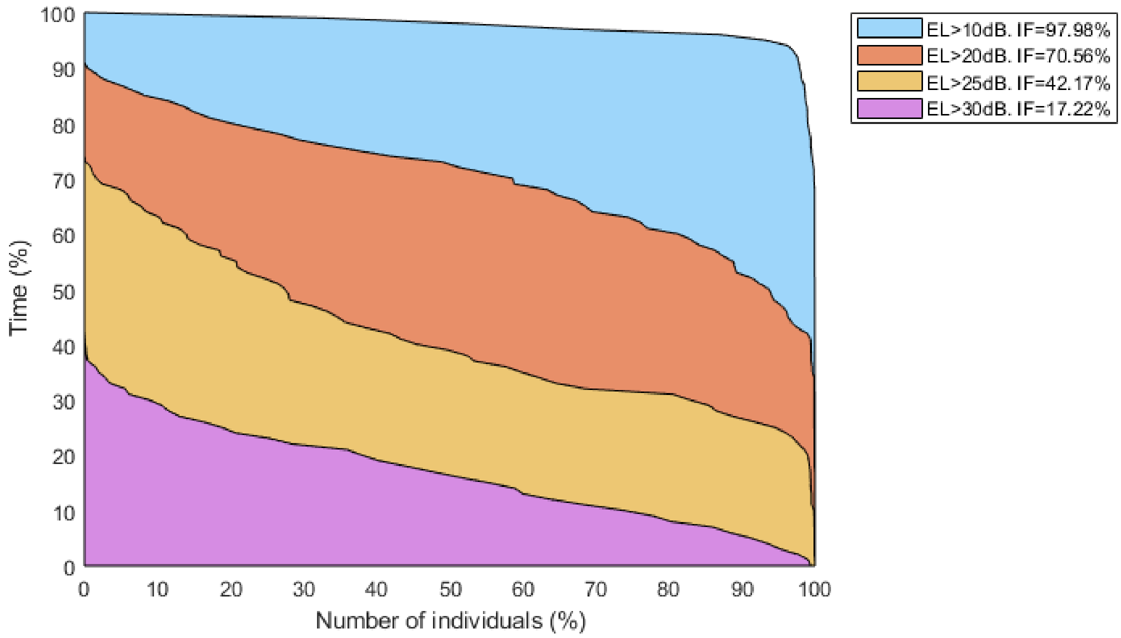

Figure 19. Number of individuals-time exposure curves and the resulting Impact Factor (IF) relative to thresholds of excess level at 63 Hz (EL>10, 20, 25 and 30 dB) evaluated for B. physalus and the first four-month period of 2022. Source: Own elaboration, IEO(CSIC).

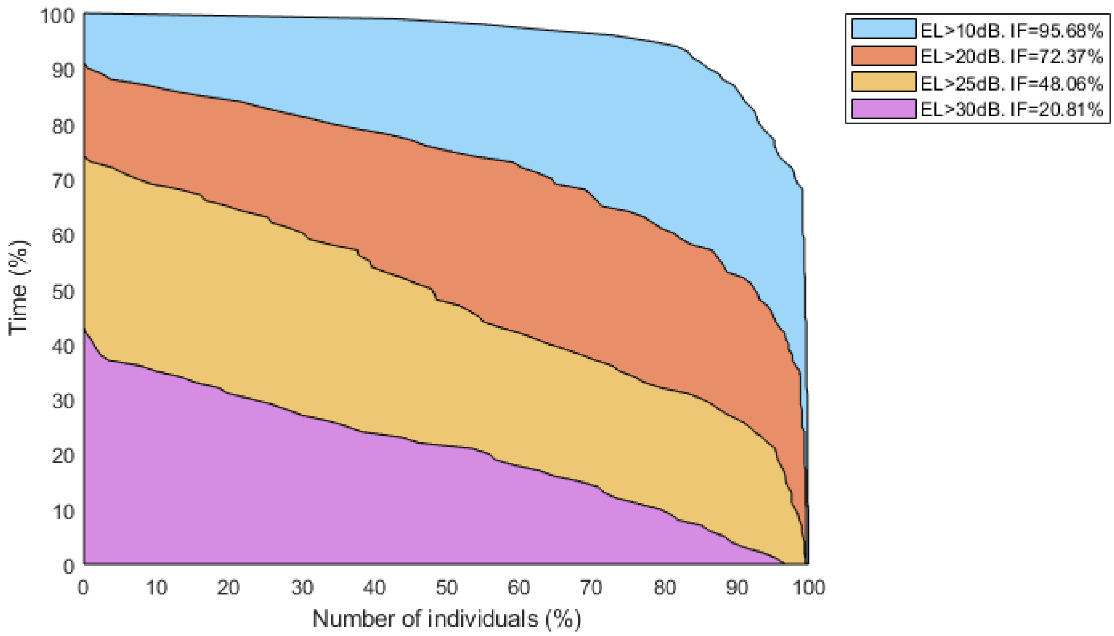

Figure 20. Number of individuals-time exposure curves and the resulting Impact Factor (IF) relative to thresholds of excess level at 63 Hz (EL>10, 20, 25 and 30 dB) evaluated for T. truncatus and the first four-month period of 2022. Source: Own elaboration, IEO(CSIC).

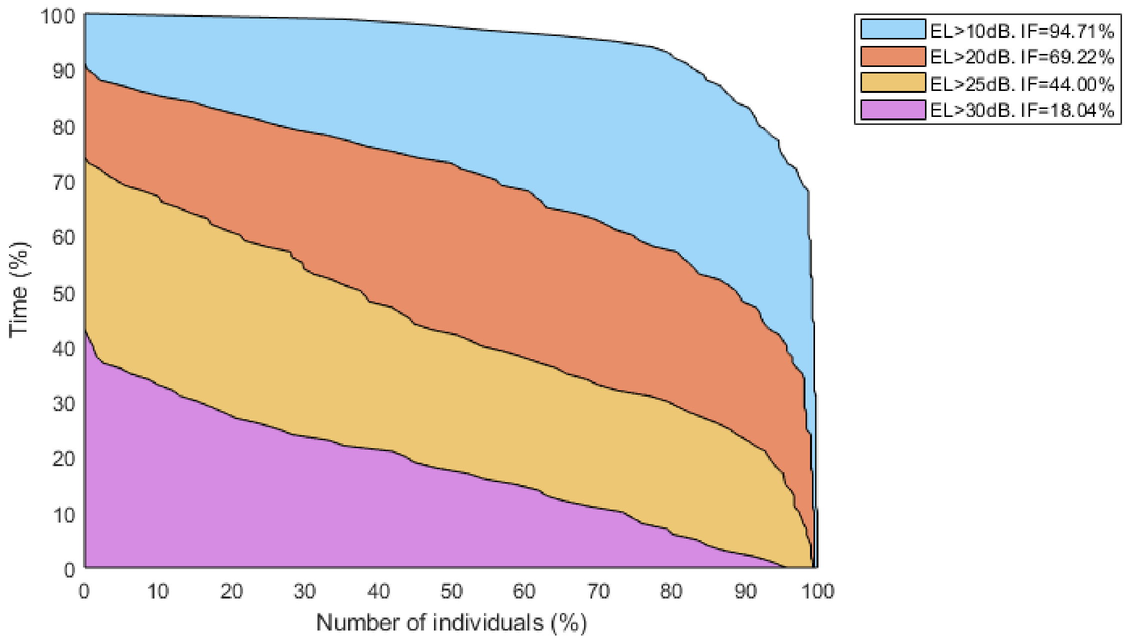

Figure 21. Number of individuals-time exposure curves and the resulting Impact Factor (IF) relative to thresholds of excess level at 63 Hz (EL>10, 20, 25 and 30 dB) evaluated for D. delphis and S. coeruleoalba and the first four-month period of 2022. Source: Own elaboration, IEO(CSIC).

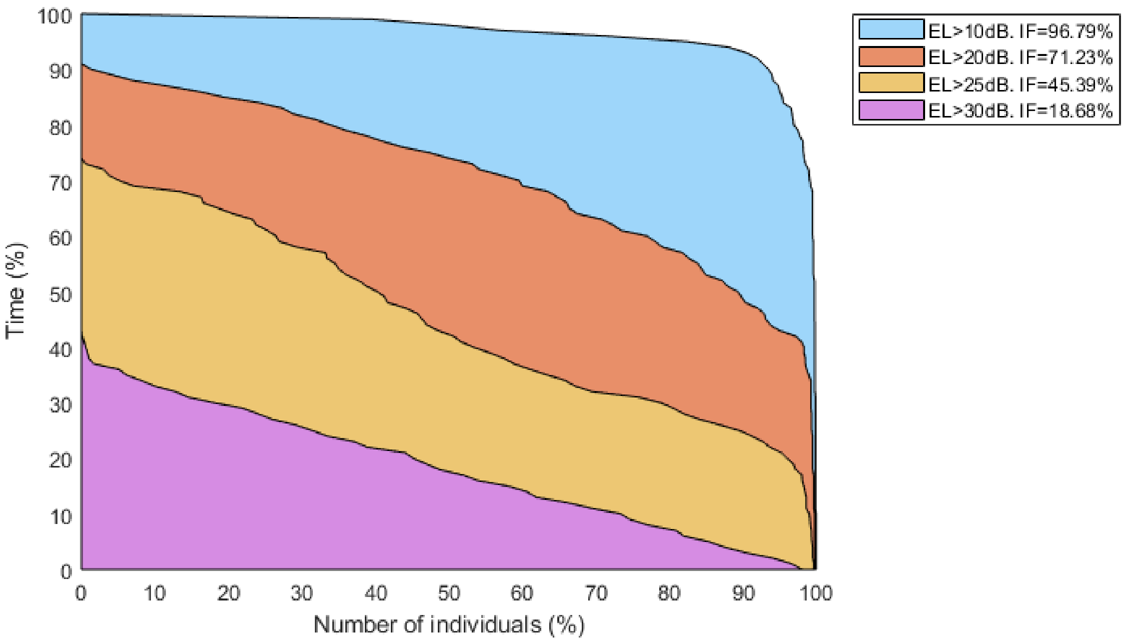

Figure 22. Number of individuals-time exposure curves and the resulting Impact Factor (IF) relative to thresholds of excess level at 63 Hz (EL>10, 20, 25 and 30 dB) evaluated for G. griseus and the first four-month period of 2022. Source: Own elaboration, IEO(CSIC).

Concerning the Impact Factor in relation to the number of individuals, it must be highlighted that data was provided by a two-month survey in the framework of ASI project, so these data have not been updated and compose a static image that does not consider seasonal variations or other variability sources. The relevance of the absence of temporality depends on the species, but it is essential to know its scope during the implementation of the methodology.

It is possible to see that the methodology allows to compare the influence of underwater noise with respect to the different species attending their distribution and the number of animals.

For example, the highest values for the number of individuals of *T. truncatus* are distributed in areas where the sound pressure level from maritime traffic is greater than areas inhabited by *B. physalus*. This produces that the Impact Factor related to the excess levels above 30 dB for *B. physalus* is 3.5 points lower than the corresponding to *T. truncatus*. This type of considerations can be observed in Table 3, where the percentage of time under excess levels above 20, 25 and 30 dB is higher for *T. truncatus* than *B. physalus*.

Table 3. Percentage of time during which the 25, 50 and 75 % of the population of every indicator species subjected to an excess level above the thresholds (EL>10, 20, 25 and 30 dB).

		Percentage of population		
Species		**25 %**	**50 %**	**75 %**
Balaenoptera physalus	**EL > 10 dB**	98.24	98.11	96.59
	EL > 20 dB	78.51	72.54	62.68
	EL > 25 dB	51.75	38.90	31.46
	EL > 30 dB	23.09	16.35	9.71
Tursiops truncatus	**EL > 10 dB**	99.42	98.41	95.56
	EL > 20 dB	82.77	75.08	64.04
	EL > 25 dB	63.09	47.54	34.43
	EL > 30 dB	29.30	21.48	11.45
Delphinus delphis* and *Stenella coeruleoalba	**EL > 10 dB**	99.29	97.58	94.44
	EL > 20 dB	80.31	73.01	59.68
	EL > 25 dB	57.89	42.20	34.44
	EL > 30 dB	25.55	17.50	8.75
Grampus griseus	**EL > 10 dB**	99.37	97.89	95.67
	EL > 20 dB	83.71	73.99	60.54
	EL > 25 dB	61.17	42.28	31.12
	EL > 30 dB	27.50	17.58	8.83

In the guidance developed by TG Noise (Sigray et al., 2022), three states of current condition are defined according to its deviation from reference condition and threshold values able to produce adverse impact (e.g disturbance). Below the reference condition, animals are exposed to sound levels mainly due to weather conditions; above reference condition but below threshold level based on biological evidence of adverse impact, pressure level may have effect on animals, but probably it does not threaten their fitness; and above the threshold level, the indicator species may be adversely influenced by the selected condition.

In this case study, the threshold values based on biological evidence of adverse impact for a given condition was not selected. Thresholds values were defined by an excess level (10dB, 20dB, 25dB and 30 dB) to illustrate the methodology based on Impact Factor assessment. In the same way as in the habitat approach the Impact Factor calculated over a non-biological based threshold value, can be used to monitor if a given percentage of individuals is exposed to a certain level of excess sound during a given period of time and infer the increase, decrease or maintenance of a given acoustic scenario.

4.2. Results of underwater sound assessment based on masking effect

The Risk Index (RI) for each scenario has been calculated for the first four-month period of 2022. The resulting RI maps for 63 Hz communication signals of *B. physalus* and 5 kHz communication signals of *T. truncatus*, *D. delphis* and *S. coeruleoalba* are presented in Figures 23, 24 and 25, respectively. It should be noted that the range of Risk Index is from 0 to 1, however, the colour scales range from 0 to the highest values obtained in order to highlight the variations within the habitat.

In all scenarios, the distribution of the masking risk maps appears to be consistent with the distribution of the sound pressure level, with high values in the environment of the routes connected to the port of Barcelona.

In the case of the masking of *B. physalus* communication signals by 63 Hz sound, the Risk Index values are higher and more evenly distributed because the higher population densities are not in the same region than the elevated sound pressure levels. This is caused by the dominance of $CDR_{\%}$ values in determining the Risk Index in areas where the estimated number of individuals is high, since the $CDR_{\%}$ ranged from 0 to 1 can be lower than the CNPDF during most of the evaluation period and the Risk Index of a cell reflects the coincident area under the curves of $CDR_{\%}$ and CNPDF (Figure 21), and, likewise, the CNPDF values dominate in areas where the CDR% is lower.

For 5 kHz sound masking on dolphin species, the Risk Index values are lower, and their higher values are more concentrated close to the Barcelona port and between the islands. $CDR_{\%}$ presents low values, below the CNPDF in a large part of the habitat and during a large part of the evaluation period. Consequently, the distribution of the Risk Index maps are similar to the sound pressure level map in 5 kHz.

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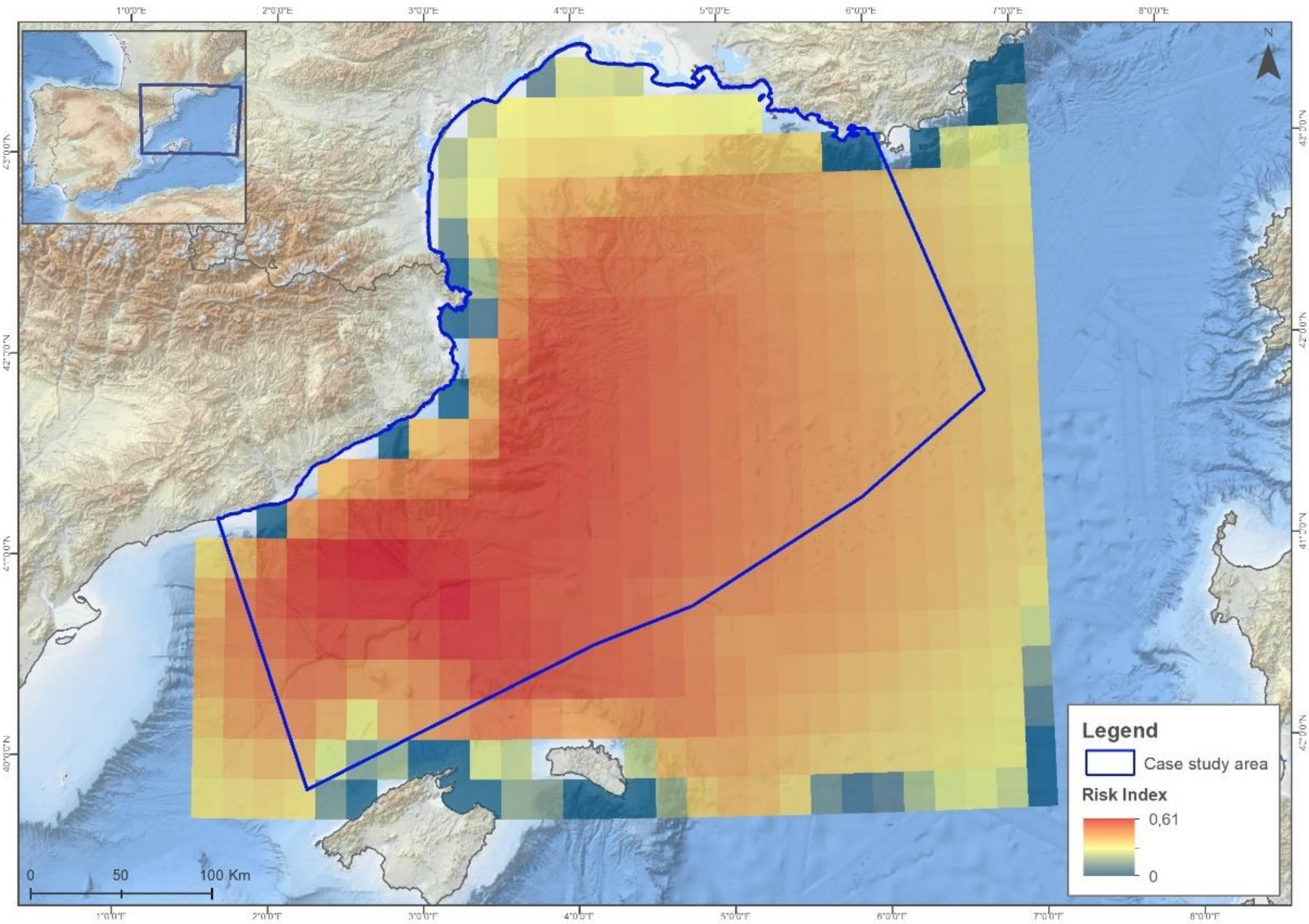

Figure 23. Risk Index map based on masking effect assessment for B. physalus 63 Hz communication signals. Map obtained across study area for the first four-month period of 2022. Source: Own elaboration, IEO(CSIC).

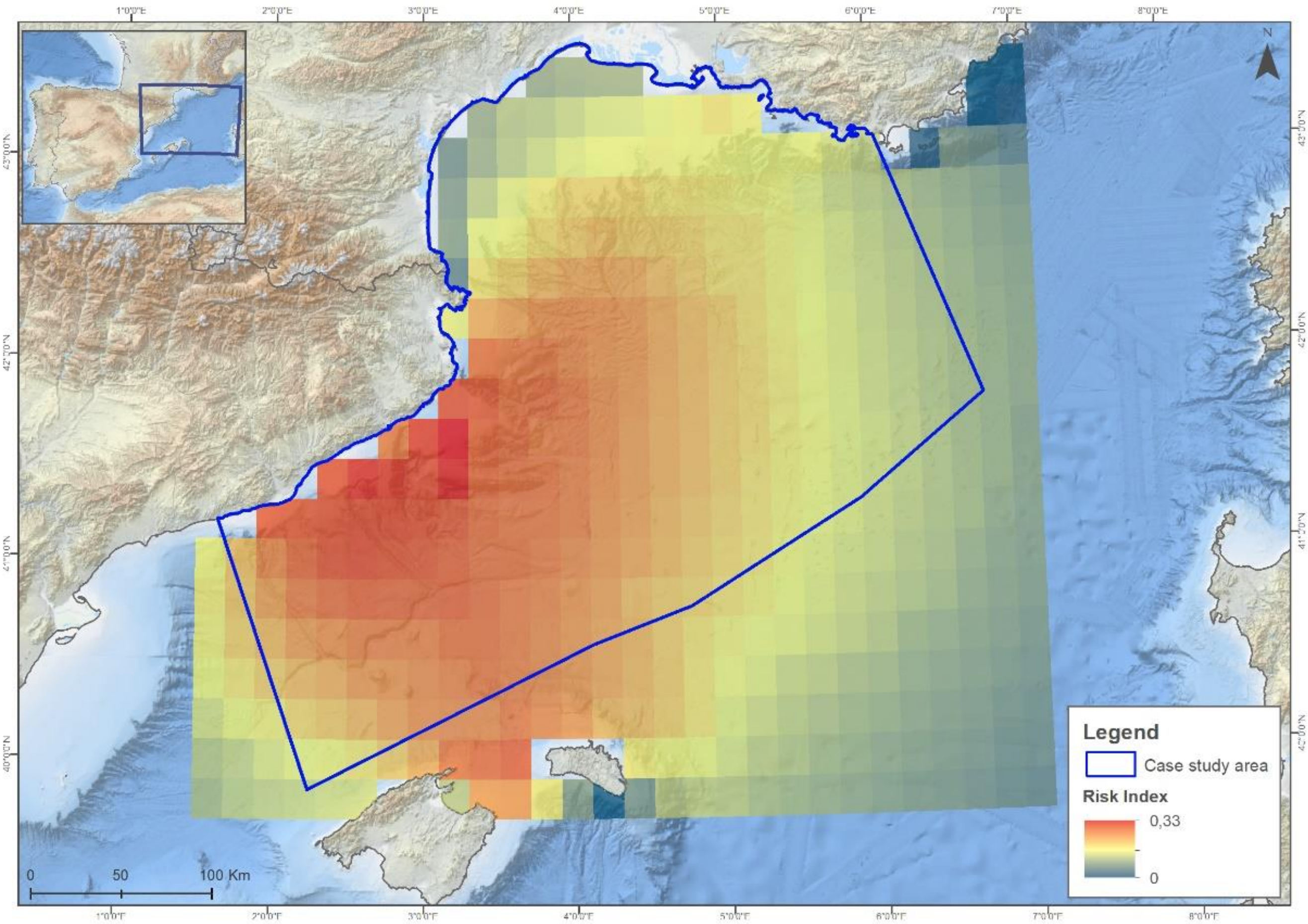

Figure 241. Risk Index map based on masking effect assessment for T. truncatus 5 kHz communication signals. Map obtained across study area for the first four-month period of 2022. Source: Own elaboration, IEO(CSIC).

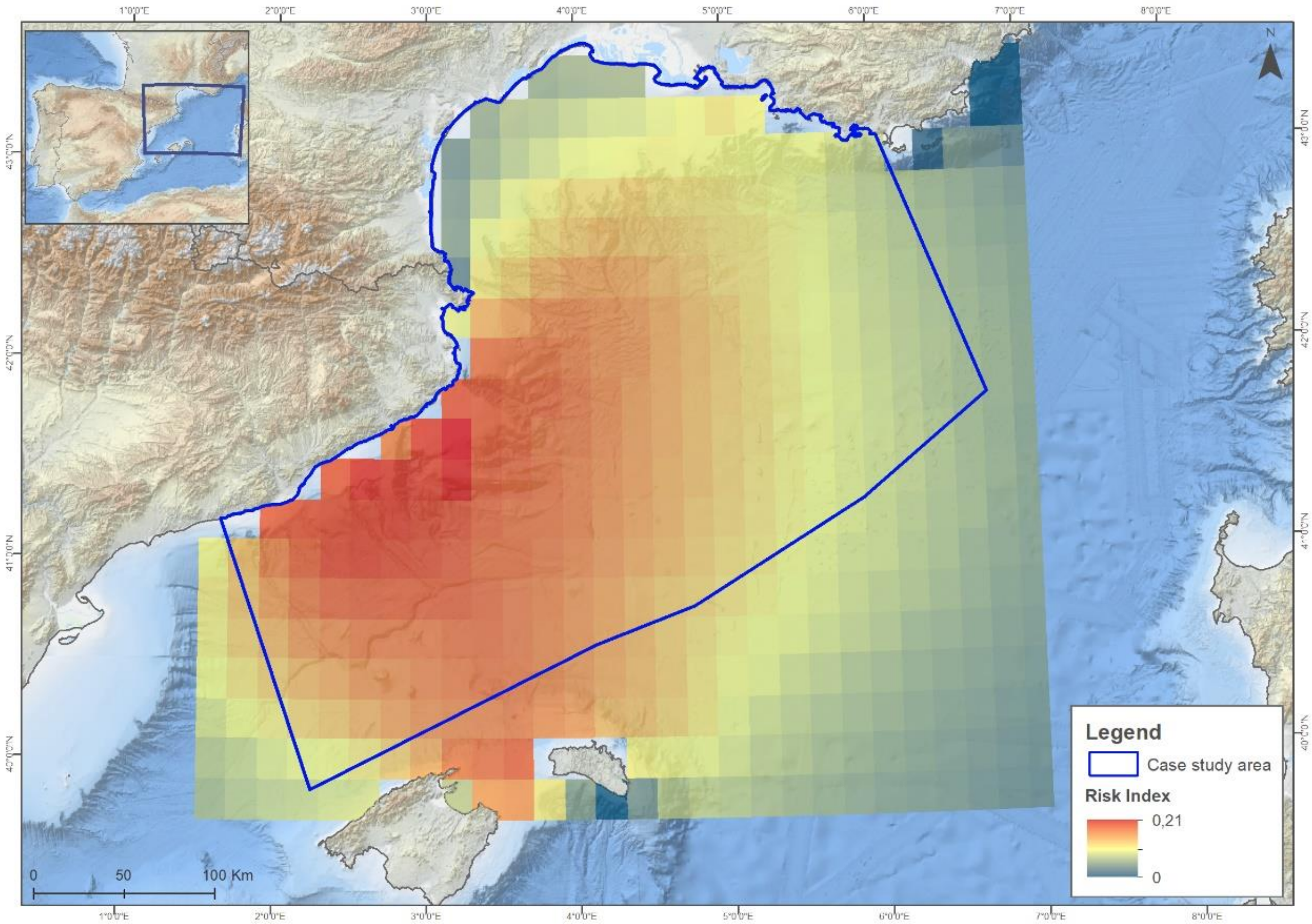

Figure 25. Risk Index map based on masking effect assessment for D. delphis and S. coeruleoalba 5 kHz communication signals. Map obtained across study area for the first four-month period of 2022. Source: Own elaboration, IEO(CSIC).

The proposed methodology allows to assess the risk of masking considering the spatial and temporal extension of sound together with the distribution of animals. This could be revealed as a useful tool to detect problematic regions due to the presence of high sound pressure levels produced by maritime traffic and significant population of vulnerable species.

It is important to conclude by pointing out that in this implementation of the presented methodology the hearing function and the detection threshold of the indicator species have not been considered, it has been assumed that the individuals can detect bioacoustics-signals with sound pressure level greater than sound present in the marine environment. Moreover, data on estimated number of individuals come from a single survey, so seasonal variations are not considered. In the case of implementing the proposed methodology, it is necessary to be aware of these aspects.

5. Conclusions

Following the MSFD framework and with the aim to stablish procedures that bring the opportunity to perform the assessment of adverse impact produced by underwater continuous noise, two methodologies have been defined. Despite no biological threshold values have been considered at this moment, the methodologies can be used to study the two main adverse impacts pointed out by expert groups like TG Noise, such as masking effect or disturbance. Both methodologies consider the spatial and temporal extent of sound pressure level as criteria of D11.C2 suggest. Nevertheless, the establishment of the GES linked to a given area depends on the proper selection of threshold values and, at this moment, this topic represents an open field of research that needs to cover the gaps and lacks of knowledge with respect to some vulnerable species. In addition, the implementation of the specific hearing function of selected species and their detection thresholds must be implemented with the aim to increase the accuracy of the obtained results implementing the proposed models.

These kinds of models bring the possibility to policy makers and management authorities to implement the most suitable marine spatial plans finding a balance between the man-made activities and the health of marine ecosystems. Cetacean species are especially vulnerable to underwater sound and the development of these kind of methodologies can be applied to protect them, establishing a scientific basis to develop, maintain or increase marine protected areas. In addition, even without a biological threshold level, the models can be revealed as a useful tool to monitor and detect the trend of underwater sound and its temporary evolution at long periods of monitoring in relation to vulnerable habitats or species.

Finally, it is relevant to mention that the MSPMED project develops pilot case studies in different areas of the Mediterranean Sea whose results could help to feed MSP national process. In this specific case with regards to the subtask 2.2.3., assessing the effects of noise pollution caused by intense activities, such as maritime transport and offshore windfarms on the pelagic component and especially cetacean species, showed how a specific analysis of a specific subject (underwater noise) created a first link between countries at the technical level, i.e. applying methodologies coming from a European working group (TG Noise) and sharing impressions in the specific workshop of underwater noise held in this subtask. Eventually, in the long term, this may lead to real cooperation at joint decision levels, and the integration of results (coming from case studies) as recommendations into MSP national processes, which could bring 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. Therefore, it can serve as a useful tool to help the authorities to take 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.

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Finally, it should be highlighted that underwater noise is an issue that has scarcely been incorporated into the MSP plans of European countries. The results of the continuous noise analysis exercise in the framework of an MSP project has also demonstrated the need for further analysis and to obtain better knowledge in order to incorporate the results in the plans. This would allow, on one hand, a better planning of the maritime space and on the other hand, an approach for the monitoring phase of the plans, whose results could be included in the next MSP cycle. It is therefore a working path that must be continued in the future.

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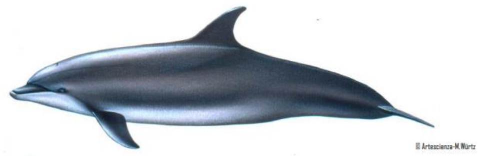
Annex I:

Description of the species analysed and their distribution in the Mediterranean Sea according to the report of *Estimates of abundance and distribution of cetaceans, marine mega-fauna and marine litter in the Mediterranean Sea from 2018-2019 surveys* of ACCOBAMS.

Common bottlenose dolphin (*Tursiops truncatus*)



Cosmopolitan, widely distributed in all oceans. Common on the continental shelf of the Mediterranean where its distribution now seems scattered and fragmented into smaller units, probably due to anthropogenic degradation of their habitats. Found mostly inland, coastal waters and offshore near the continental slope. In the Mediterranean, it lives in groups usually smaller than 20 individuals, although greater aggregations have been observed.

Bottlenose dolphins were the second most abundant species (n=75,885; 95% CI=50,116-114,903) observed during the aerial component of the ASI. Mostly observed in coastal areas, confirming existing knowledge on the coast habits and preferences of this species (Bearzi et al., 2009), the species distribution appeared strongly fragmented and discontinued with areas of higher abundance found in particular in the Strait of Gibraltar and Alborán Sea, the Balearic Sea and the Gulf of Lion, the waters surrounding the Island of Corsica and north of Tyrrhenian Sea.

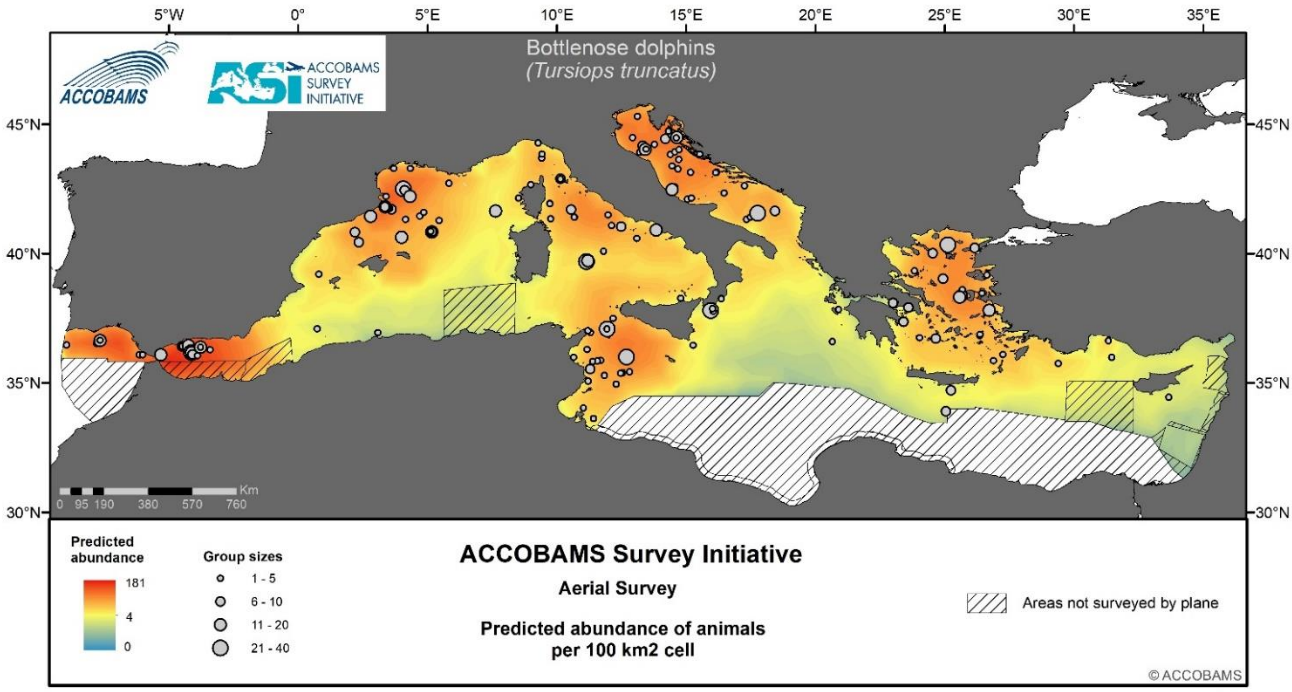


Figure 26. Common bottlenose dolphin (Tursiops truncatus) description and predicted abundance in the Mediterranean. Source: ACCOBAMS.

Striped dolphin (*Stenella coeruleoalba*)

In temperate and subtropical waters of all oceans. The most common cetaceans in the Mediterranean ocean, present in the offshore waters of Gibraltar to the Aegean Sea in the Levant basin. However, movements across the Strait of Gibraltar have been observed. Found from Gibraltar tothe Levant basin and the Aegean Sea. The abundance of striped dolphin appears to decrease toward the eastern part of the Mediterranean basin, which probably reflects a decreasing gradient of marine productivity. A gregarious species usually living in groups from 10-100 individuals. Often in mixed groups of common dolphins, Risso's dolphins, and fin whales.

Striped dolphins are confirmed to be the most abundant species of cetacean in the Mediterranean Sea and the extended ACCOBAMS region. The species has been observed primarily in the offshore waters of the Mediterranean where the largest groups were also observed, indicating a strong preference for deep pelagic waters (e.g. Azzellino et al., 2008). The highest densities were obtained for the Alborán Sea, the Balearic Islands, Gulf of Lion and the waters of the Pelagos Sanctuary.

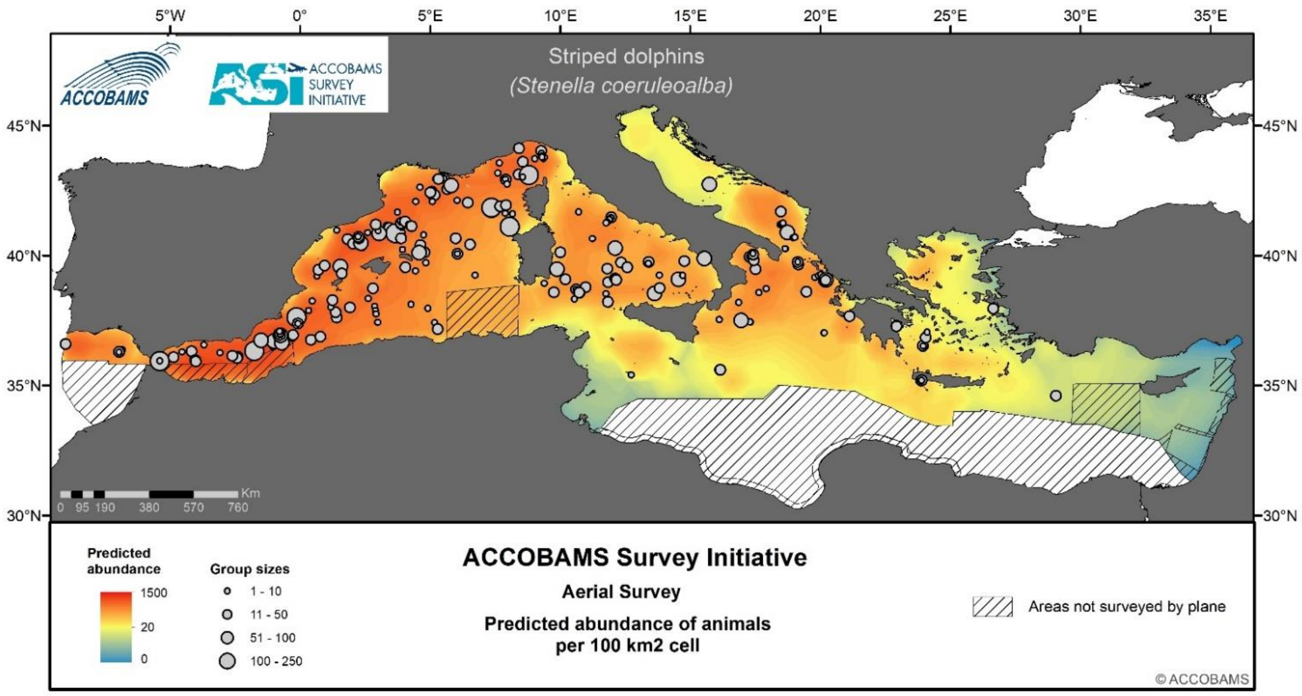
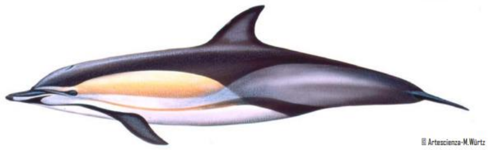


Figure 27. Striped dolphin (Stenella coeruleoalba) description and predicted abundance in the Mediterranean. Source: ACCOBAMS.

Short-beaked common dolphin (*Delphinus delphis*)



The short-beaked common dolphin frequents temperate areas in the tropical waters of the Atlantic, Pacific and probably the Indian Ocean. One of the most common Mediterranean species. At sea level, often found with the striped dolphins. In the neritic region, often seen with bottlenose dolphins. Observations in the eastern Ionian Sea reveal that they are very loyal to one site. Lives in groups of 50- 70 animals, with larger aggregations sometimes occurring.

The Mediterranean sub-population of common dolphin in the Mediterranean has undergone a drastic reduction in the past decades (e.g. Bearzi et al., 2003, 2008; Piroddi et al., 2011; Vella et al., 2021) as a consequence of ever-increasing human pressures on the species range of distribution.

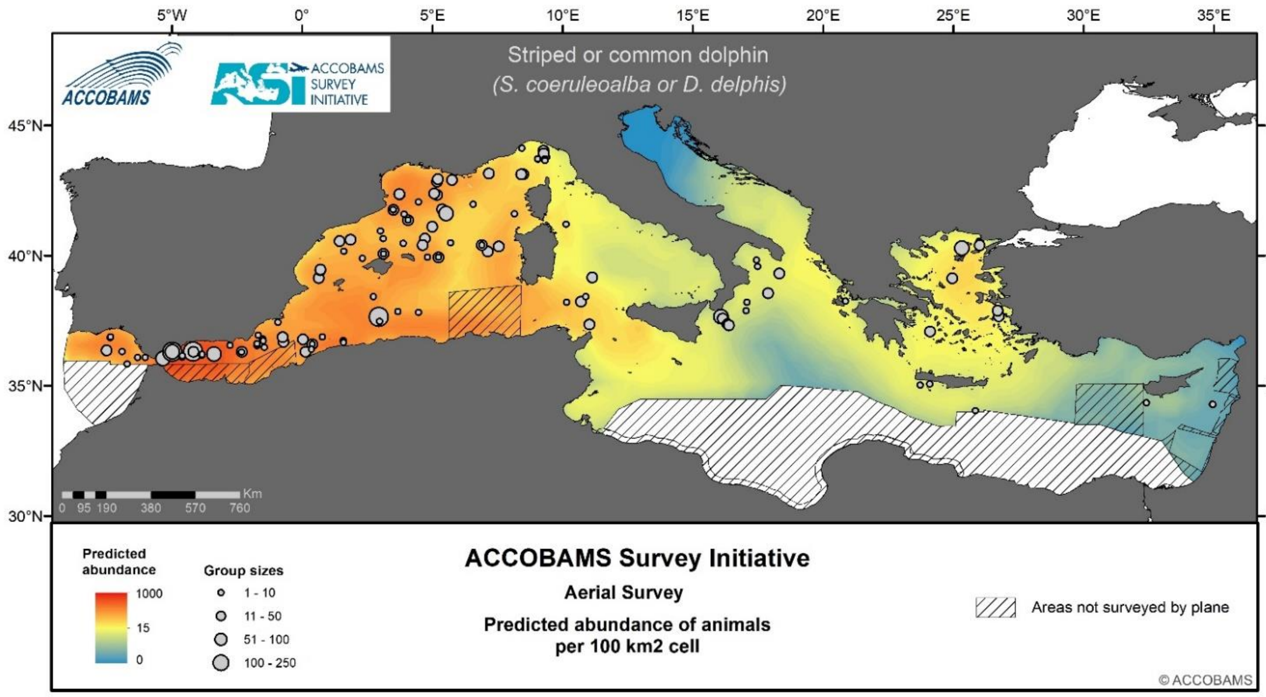


Figure 28. Short-beaked common dolphin (Delphinus delphis) description and predicted abundance in the Mediterranean. Source: ACCOBAMS.

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Risso's dolphin (*Grampus griseus*)

Cosmopolitan in temperate and tropical waters. Common along the northern shores of the Western Mediterranean, the Balearic Islands, the Ionian Sea (including Gulf of Taranto) and west of the Aegean Sea. A gregarious species living in groups of 3 to 20 individuals. Larger aggregations can include up to several hundred individuals. In spite of its robust body, it is a rather agile species.

The Risso's dolphin in the Mediterranean is one of the least-known cetacean species in the region and has been the subject of few dedicated studies. The species is known for its strong habitat preferences where dolphins, usually encountered in relatively small groups, favour continental slope sea areas, primarily in the north-western Basin (Bearzi et al., 2011).

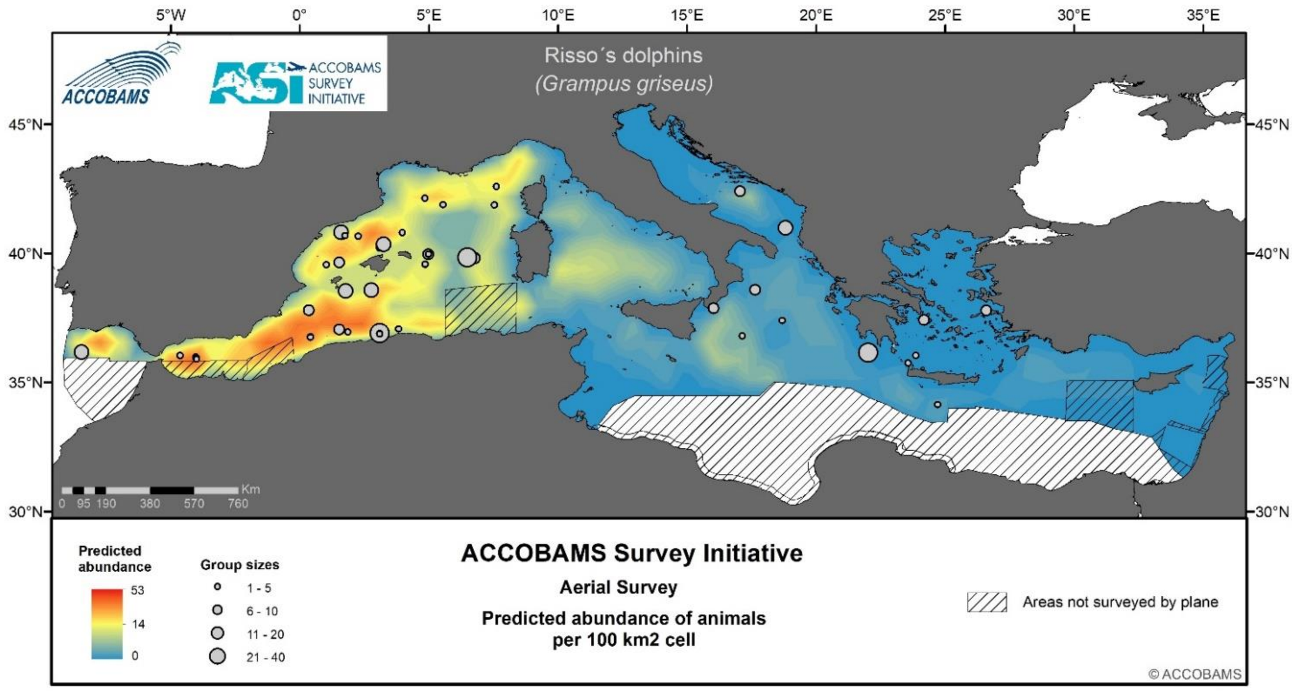
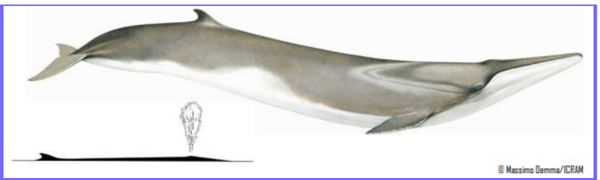


Figure 29. Risso's dolphin (Grampus griseus) description and predicted abundance in the Mediterranean. Source: ACCOBAMS.

Fin whale (*Balaenoptera physalus*)



Pelagic species that lives mostly offshore, above abyssal plains, however it also visits bays and shallow waters. The Corso-Ligurian Basin and the Gulf of Lions are Mediterranean regions with the highest abundance (Notarbartolo di Sciara et al. 2003). Relatively sociable, can be observed alone or in small groups from 3-10 individuals. Inconspicuous, it almost never shows its flukes when it dives. It rarely spyhops, but often breaches, clearing the water completely, to re-enter on its side or belly and less often its back, with a resounding splash. In summer, it feeds in the cold, productive waters, and during winter it migrates to warmer waters to breed.

Fin whales in the Mediterranean have been estimated at 1,684 individuals (95% CI=977-2,904), confirming that the sub-population of the only mysticete regularly occurring in the Region, despite its overall wide distributional range across the area, constitute a rather small unit. As well as previous estimates (e.g. Forcada et al., 1995) and knowledge (e.g. Notarbartolo di Sciara et al., 2003; Notarbartolo di Sciara, 2016), the ASI monitoring has resulted in the highest abundances in the western and north-western Mediterranean, in particular in the Ligurian Sea, Gulf of Lions and Gulf of Cadiz and with overall density of animals decreasing towards the eastern portion of the Basin. The species distribution shows strong preference for pelagic areas, with several groups detected at depths of 2000 meters or more, reinforcing previous knowledge on the species (e.g. Cotté et al., 2009; Panigada et al., 2017b).

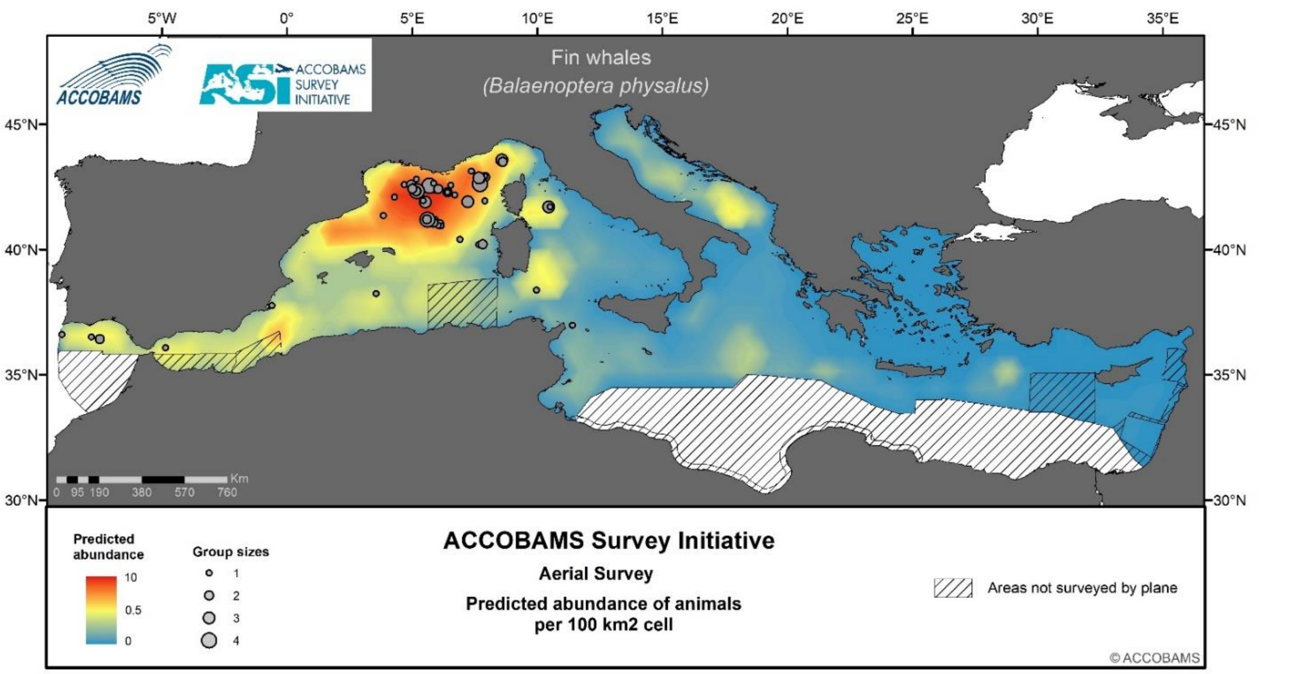


Figure 30. Fin whale (Balaenoptera physalus) description and predicted abundance in the Mediterranean. Source: ACCOBAMS.

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Short-beaked common dolphin (*Delphinus delphis*) and Striped dolphin (*Stenella coeruleoalba*)

During the ASI surveys, these two species which could be misidentified during aerial surveys, were analysed together in order to estimate the distribution. The vast majority of sightings were recorded in the western Mediterranean Sea, in particular in the Alboran Sea and the area of the Strait of Gibraltar, the Balearic Sea, the Gulf of Lion the Ligurian Sea.

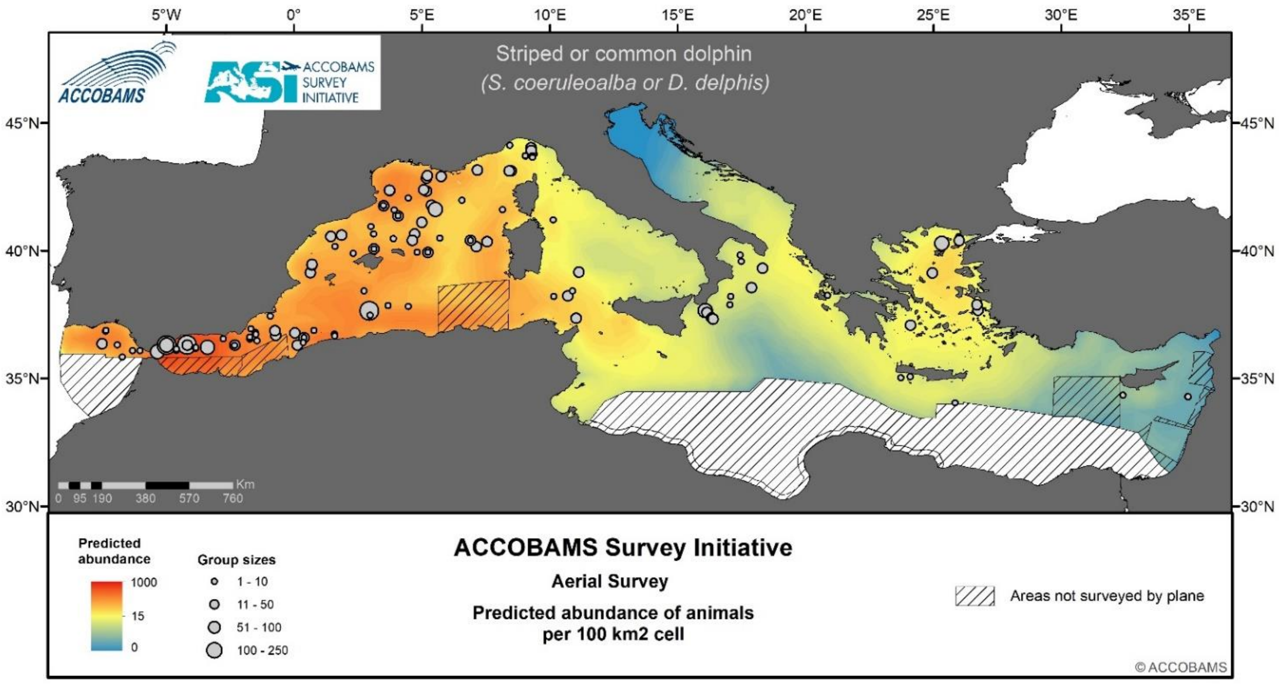

Figure 31. Short-beaked common dolphin (Delphinus delphis) and Striped dolphin (Stenella coeruleoalba) descriptions and predicted abundances in the Mediterranean. Source: ACCOBAMS.