QUIETSEAS - Assisting (sub) regional cooperation for the practical implementation of the MSFD second cycle by providing methods and tools for D11 (underwater noise)

D5.2 Proposal of a methodology to establish thresholds values for D11C2 in the Mediterranean and Black Sea regions.

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3	Service hydrographique et océanographique de la marine	Shom	France
4	Politecnico di Milano-Department of Civil and Environmental Engineering	POLIMI-DICA	Italy
5	Hellenic Centre for Marine Research	HCMR	Greece
6	Inštitut za vode Republike Slovenije/Institute for water of the Republic of Slovenia	IZVRS	Slovenia
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Abstract

This document is the Deliverable "D5.2 Proposal of a methodology to establish thresholds values for D11C2 in the Mediterranean and Black Sea regions" of the QUIETSEAS project funded by the DG Environment of the European Commission within the call "DG ENV/MSFD 2020 call". This call funds projects to support the implementation of the second cycle of the Marine Strategy Framework Directive (2008/56/EC) (hereinafter referred to as MSFD), in particular to implement the new GES Decision (Commission Decision (EU) 2017/848 of 17 May 2017) laying down criteria and methodological standards on Good Environmental Status (GES) of marine waters and specifications and standardised methods for monitoring and assessment, and repealing Decision 2010/477/EU) and Programmes of Measures according Article 13 of the MSFD. QUIETSEAS aims to support the practical development of the second implementation cycle under the MSFD for D11 (underwater noise).

The object of this document is to develop a joint proposal of a methodology for the establishment of thresholds to implement the GES decision regarding the D11C2 in the Mediterranean and Black Sea Region.

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List of Abbreviations

CTN	Centro Tecnológico Naval y del Mar
ACCOBAMS	Permanent Secretariat of the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area
DFMR	Department of Fisheries and Marine Research
IZVRS	Inštitut za vode Republike Slovenije/Institute for water of the Republic of Slovenia
HCMR	Hellenic Centre for Marine Research
UM	University of Malta -The Conservation Biology Research Group
POLIMI-DICA	Politecnico di Milano-Department of Civil and Environmental Engineering
SPA/RAC	Specially Protected Areas Regional Activity Centre
ICES	International Council for the Exploration of the Sea
Shom	Service hydrographique et océanographique de la marine
MHD	Maritime Hydrographic Directorate
MSFD	Marine Strategy Framework Directive
GES	Good Environmental Status
MS	Member States
MED	Mediterranean Sea
BS	Black Sea
CA	Competent Authority
NR	National representative
SO	Specific Objective
TB	Thematic Block

Introduction

The QUIETSEAS Project is funded by DG Environment of the European Commission within the call “DG ENV/MSFD 2020”. This call funds MSFD development, in particular, the preparation of the next 6-year cycle of implementation.

The QUIETSEAS project aims to enhance cooperation among Member States (MS) in the Mediterranean Sea Region (MED) to implement the third Cycle of the Marine Directive and in particular to support Competent Authorities and strengthen cooperation and collaboration in the Mediterranean Sea and Black Sea regions through the following specific objectives:

- Specific objective 1 (SO1): To identify relevant indicators for criterion D11C2 (Anthropogenic continuous low-frequency sound in water).
- Specific objective 2 (SO2): To promote the consolidation of relevant indicators for D11 and support the operationalisation of indicators on the state, pressure and impacts of underwater noise in close coordination with TG Noise.
- Specific objective 3 (SO3): To promote harmonisation of regional work on threshold values with TG Noise recommendations.
- Specific objective 4 (SO4): To develop effective and efficient mechanisms for GES assessment and regional coordination by providing management tools for harmonization, reporting and assessment of D11.
- Specific objective 5 (SO5). To demonstrate the potential effectiveness of coordinated mitigation measures to reduce shipping noise.
- Specific objective 6 (SO6): To promote (sub)regional cooperation to ensure i) coordination across the region/ subregions ii) the involvement of Competent Authorities iii) long-term dissemination of the results.

To achieve its objectives, the project is divided in 4 work packages (thematic blocks) and 9 activities whose relationships are shown in Figure 1.

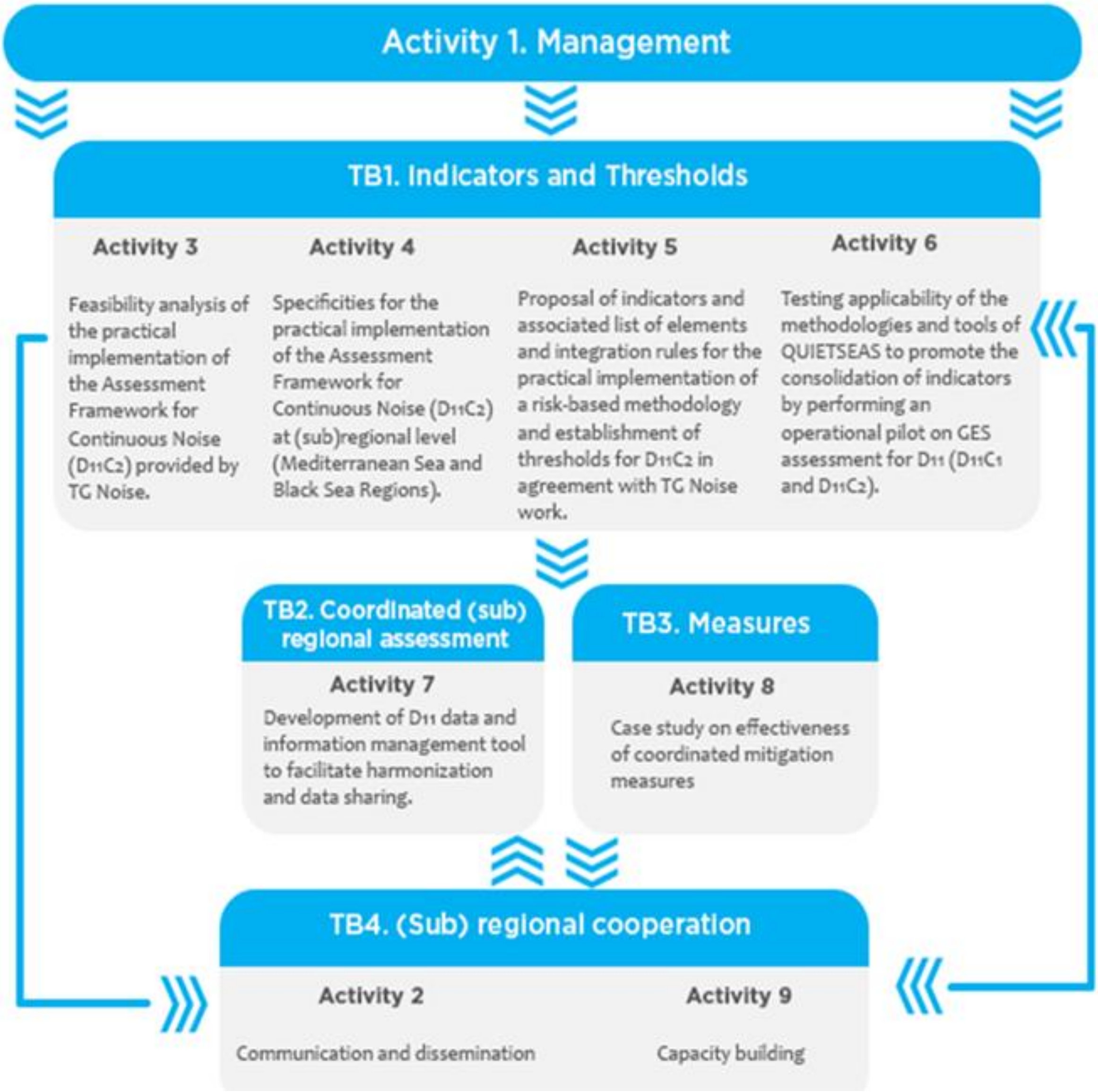

Figure 1. Work plan structure

The project is developed by a consortium made up of 10 entities coordinated by CTN and it has a duration of 28 months starting on 1st February 2021.

1. Definition of threshold value in Commission Decision 2017/848/EU

The Marine Strategy Framework Directive (2008/56/EC) (hereafter MSFD) requires that Good Environmental Status (GES) to be achieved and maintained in European waters by the Member States (MS) of the European Union. The European Commission (Commission Decision 2010/477/EU) stipulated that the achievement and maintenance of GES should take place by 2020. This is defined in the qualitative description of the GES in relation to 11 descriptors, together with a set of related criteria and indicators to be applied for the quantitative assessment. After the evaluation of a first cycle, the European Commission, to improve the implementation of a second evaluation cycle, amended the 2008 MSFD and repealed the 2010 decision (Decision 2010/477/EU) with a new Decision referred to as 2017/848/EU. This provides methodological standards and criteria to help MS determine GES using standardised methods for monitoring and evaluation.

The 'threshold value' is defined in Article 2(5) of Decision 2017/848/EU as a value or range of values that allows assessment of the extent to which good environmental status has been achieved for a particular criterion.

The defined threshold values should ensure that anthropogenic noise does not exceed levels that adversely affect marine animal populations and that the "extent of the assessment area over which the threshold values have been reached" is reported (Decision 2017/848).

According to Article 4 of the Decision, threshold values should be established by the MS through cooperation considering the required consistency in the establishment of threshold values with EU legislation as well as the different biotic and abiotic characteristics of the regions, sub-regions and subdivisions of the EU (Article 13 2017/848).

The threshold values should help determine the characteristics for GES by the MS and assess to what extent the GES has been achieved (items 6 and 8 2017/848).

2. Revision of the TG Noise methodological proposal

In 2010, a Technical Group on Underwater Noise (TG Noise), together with the Working Group on Good Environmental Status (WG GES), was mandated by the MSCG in its work programme 2020-2022 to contribute to the harmonised implementation of the MSFD in addition to a common strategy in defining EU threshold values for descriptor 11 (D11C1, D11C2).

The new European Commission Decision (2017) stipulates that the risk-based approach (point 6) with a flexible and open assessment framework (allowing for regional differences?) should be applied to both the threshold value assessment framework and the definition of the GES.

The methodology proposed by the TG Noise (TG NOISE, DL3, 2021) provides a sequential approach to define threshold values and quantify the area impacted by continuous noise. This type of approach is based on the one followed for impulsive noise (D11C1) (Dekeling et al., 2020; Heinis et al., 2015; Merchant et al., 2018; OSPAR, 2017;).

2.1. Steps in the proposed methodological framework

The methodological framework proposed by TG Noise is based on 9 gradual steps as follows:

Step 1. Define Indicator Species and their Habitats

Indicator (or representative) species should be chosen based on their conservation status, or in consideration of the risks caused by noise pollution.

Indicator species can be selected either because they are considered to respond to noise in a representative manner, because they are of concern regarding underwater noise or conservation status or simply because data are available.

It is also advisable to consider the IUCN classifications of species, so that not only endangered species can be taken into account, but also those with deficient data. However, knowledge about species and their habitats is often scarce or unavailable, which therefore may limit the usefulness of the? methodology.

In addition, the assessment area needs to be considered. If the assessment is sub-regional or it concerns a subdivision, the species selected as representative of this area may be different from the species which are representative at the regional level, e.g., the common dolphin (*Delphinus delphis*) for the Aegean-Levantine Sea sub-region or the Black Sea porpoise (*Phocoena phocoena relicta*) for the Northern Aegean area.

The factors to be taken into account for the species selection are therefore:

- sensitivity to continuous noise

- conventions/agreements: if the species is listed as protected in any of the

international convention/agreement or legal instruments (IUCN conservation status)

- species or habitats on RAC lists with relevance to the Marine Strategy Framework Directive (Palialexis et al., 2018)

- threat status of the species to other anthropogenic pressures

- species that support or provide vital ecosystem services (e.g., nutrient availability)

- species characteristics requiring special considerations

Step 2. Define the Level of Onset of Biologically Adverse Effects (LOBE)

The definition of LOBE (Level of Onset of Biologically adverse Effects) is critical to determine for D11C2. Initially, in the DL3 document (TG NOISE, DL3, 2021) it was defined as LOSE (level of onset of biologically significant adverse effects) but in this document it has been changed to LOBE (cfr. TG Noise DL2 and DL4). This point is used to define the noise level at which animals begin to experience adverse effects. Above this level, it is expected that there is a risk of effects that may affect the animals' reproduction, welfare, and survival. The effects analysed here are divided into 3 categories:

-masking of acoustic communication that may impact mating or mother-offspring communication, group communication, decreased feeding, effects on orientation and navigation.

-behavioural disturbances of foraging and lactation time of the offspring, which can affect survival and reproduction.

-physiological effects, e.g., increased stress hormone levels and cardiovascular effects due to long-term exposure.

Step 3. Determine Time Periods for Assessment

Three time periods are defined:

- observation period related to monitoring (seconds or minutes, up to 1 day or 1 month);
- analysis period related to the analysis time window determining the thresholds (recommended one month);
- assessment period related to the MSFD report (monthly, seasonal, or annual).

Step 4. Assess the Acoustic Status by Monitoring

It can be done by direct measurements or by modelling, which has to reflect shipping activity or other relevant continuous sound sources. Assessing the acoustic status of a marine area using modelling requires information a) on the environmental parameters of the area affecting the acoustic propagation, and b) on vessel traffic. The model, however, must be validated by direct measurements to ensure credibility.

Step 5. Establish Reference Condition

Regardless of anthropogenic noise in the oceans, natural environmental sounds will always be present, so the natural state contains sounds that result from meteorological, geological and biological activities. This assessment can either be done by modelling or by direct measurements. In practice, only wind is considered for establishing the Reference Condition.

Step 6. Establish Current Condition

The current condition depends on natural ambient sound and anthropogenic noise and can be assessed by modelling or through measurements that must be representative for the entire habitat.

Step 7. Evaluate Grid Cells Condition

The grid cell is the basic element of the evaluation methodology. Cell size within a grid may vary depending on the geographical system used, which is decided at the regional or sub-regional level.

"The condition of a grid cell is determined by evaluating the proportion of time that the current condition is above LOBE" (TG NOISE, DL3, 2021).

The assessment can be done in two ways:

- by using a fixed value of LOBE with the arithmetic mean or monthly median of the current and reference condition (more appropriate for behavioural or physiological disturbance);
- by instantaneously subtracting the current condition from the reference condition where LOBE is expressed as a fixed ratio between the two conditions (more appropriate for masking). This is the excess noise level.

The result is a proportion of time for each grid cell. If this proportion is not greater than the time threshold value, the grid cell is considered non-significantly affected (or in acceptable condition).

Step 8. Determine Habitat Status

Habitat status is assessed by evaluating the proportion of habitat grid cells that are significantly affected (or their condition is not acceptable). This number is compared with the spatial threshold value, which sets an upper limit to how large a fraction of the habitat may be at non-tolerable (or non-acceptable) status.

Thus, a habitat status is considered as tolerable (or acceptable) if the fraction of the habitat and fraction of the time where the grid cell condition is not impacted is less than the tolerable impacted area and tolerable duration, respectively.

Step 9. Assess the Marine Reporting Unit (MRU) Status as being at GES or not at GES

If the MRUs are equal to habitats, then an MRU is considered to be in GES if the fraction of habitat at non-tolerable status does not exceed the spatial threshold value. If the MRUs are not identical to habitats, the GES in an MRU is assessed by combining the statuses of habitats that together constitute the MRU. Notice that there may be more than one habitat within an MRU.

2.2. Main TG Noise recommendations

Commission decision (2017) demands that D11 descriptor thresholds (impulsive D11C1 and continuous D11C2) must ensure that anthropogenic noise levels do not exceed levels that adversely affect marine animal species. The TG Noise recommends that MS continue to carry out sound monitoring programmes to ensure not only a higher data availability but also higher data quality. In addition, it is advisable to fill existing knowledge gaps on indicator species as well as on the entire marine ecosystem by continuing to cooperate in providing options for threshold setting.

3. Proposed application of the methodology for the Mediterranean and Black Sea areas

3.1. Definition of indicator species in the Mediterranean Sea

The Mediterranean has a wide variety of habitats as the bathymetry is extremely variable, ranging from shallow waters with a continental shelf to deeper areas with steep continental slopes. This variability results in the presence of numerous species of marine mammals in the area. Regional authorities are requested to assess the environmental status to account for the specificity of each area. The MS can refer to the appropriate level subdivisions of the Mediterranean region (Figure 2; https://www.eea.europa.eu/data-and-maps/data/msfd-regionsand-subregions-1), so that they are compatible with the marine subregions (Figure 3):

- Western Mediterranean Sea
- Adriatic Sea
- Ionian Sea and the Central Mediterranean Sea
- Aegean-Levantine Sea

Figure 2. The MSFD marine region of interest: the Mediterranean Sea.

Figure 3. The 4 MSFD Mediterranean marine subregions.

Considering the Mediterranean area, there are 9 cetacean species considered regular in this area (Notarbartolo di Sciara et al., 2016), each of which has specific habitat preferences: striped dolphin (*Stenella coeruleoalba),* bottlenose dolphin (*Tursiops truncatus*), common dolphin (*Delphinus delphis*), Risso's dolphin (*Grampus griseus*), Cuvier's beaked whale (*Ziphius cavirostris*), long finned pilot whale (*Globicephala melas*), sperm whale (*Physeter macrocephalus*), harbour porpoise (*Phocoena phocoena relicta*) and fin whale (*Balaenoptera physalus*).

Other species such as killer whale (*Orcinus orca*), false killer whale (Pseudorca crassidens), Indian Ocean humpback dolphin (*Sousa plumbea*) humpback (*Megaptera novaeangliae*) and common minke whale (*Balaenoptera acutorostrata*) are classified as limited and occasional in the Mediterranean Sea (Fontaine, 2016; Esteban et al., 2016; Frantzis, 2019), while for the rough-toothed dolphin (*Steno bredanensis*), mainly sighted in the eastern part of the basin, there are not enough data to establish its distribution (Palialexis et al., 2018).

This high heterogeneity combined with different levels of knowledge about the species present makes the identification of indicator species and habitats difficult. The selection of representative/indicator species and habitat are made at MS level and when they extend to more than one MS they are considered at the regional/sub-regional level. The knowledge on the occurrence and distribution of species in different countries, but also at sub-regional level, within the Mediterranean is very diverse and heterogeneous. This makes the selection of species and habitat difficult, not to mention the implementation of a harmonised methodology for the definition of threshold values and GES assessment.

3.2. Definition of indicator species in the Black Sea

The Black Sea is a closed basin with areas of deep water, steep slopes adjacent to land and submarine canyons (Murray et al., 1989). The Black Sea waters host a great variety of habitats, but despite this, biodiversity is relatively low (Oguz and Ozturz, 2011, Selifonova, 2011). An important peculiarity of the Black Sea is the presence of the surface layer (within 200m) that is well oxygenated, while the deeper layer (between 200 and 2000m) is depleted of oxygen. Approximately 87% of Black Sea waters are therefore anoxic with low salinity levels (Sanchez-Cabanes et al., 2017).

Three cetacean species regularly occur in the Black Sea: the common Black Sea dolphin (*Delphinus delphis ponticus*) (Barabash 1935), the Black Sea bottlenose dolphin (*Tursiops truncatus ponticus*) (Barabash-Nikiforov 1940) and the Black Sea porpoise (*Phocoena phocoena relicta*) (Abel 1905) (Sánchez-Cabanes et al., 2017). These species are distinct subspecies from those of the Mediterranean, being endemic to the Black Sea.

3.3. Vulnerability and sensitivity of species to continuous noise

A key point in setting thresholds is to identify those species vulnerable to noise as well as their habitats. It is therefore necessary to know the vulnerability of each representative species to underwater noise. To better understand the level of vulnerability to noise and the potential impact of continuous noise on Mediterranean cetaceans, it is necessary to learn more about their auditory sensitivity and the characteristics of their bioacoustics. Knowledge about the hearing thresholds of Mediterranean cetacean species is derived from studies conducted in different areas or in captivity and very little is still known about their response to noise at sea.

Table 1 shows the knowledge on hearing thresholds of Mediterranean cetaceans from different studies conducted in different areas and in captivity (Table 1). The table records observed effects on different species such as masking and behavioural disturbance, but also temporary threshold shift (TTS), permanent threshold shift (PTS) and physical damage.

Taxon	Marine Mammal Hearing Group	Auditory Weighting Function	Audiometry	Ear Type	Auditory Modeling	Sound Production	Click Type	References
Fin Whale (*Balaenoptera physalus*)	Low-frequency cetaceans	LF	--	Mysticete middle ear, Type M cochlea	0.02 to 20 kHz	0.01 (rumble, thud, 20-Hz signal) to 1 kHz (slam)	--	Audiometry: No data Anatomical modeling: Cranford & Krysl, 2015 Acoustic: Watkins et al., 1987; Edds, 1988; Thompson et al., 1992; McDonald et al., 1995a; Charif et al., 2002; Širović et al., 2007, 2013; Weirathmueller et al., 2013
Sperm Whale (*Physeter macrocephalus*)	High-frequency cetaceans	HF	--	Physeteroid middle ear, Type I cochlea	--	SOC: 0.4 (squeal) to 9 kHz (coda) ECH: 3 to 26 kHz+	MP	Audiometry: No data Anatomical models: No data Acoustic: Backus & Schevill, 1966; Levenson, 1974; Watkins & Schevill, 1977, 1980; Watkins, 1980; Weilgart & Whitehead, 1988; Goold & Jones, 1995; Madsen et al., 2002a, 2002b; Møhl et al., 2003; Weir et al., 2007
Cuvier's Beaked Whale (*Ziphius cavirostris*)	High-frequency cetaceans	HF	--	Physeteroid middle ear	--	ECH: 28 to 47 kHz+	FM	Audiometry: No data Anatomical models: No data Acoustic: Frantzis et al., 2002; Zimmer et al., 2005; Baumann-Pickering et al., 2013b
Short Beaked Common Dolphin (*Delphinus delphis*)	High-frequency cetaceans	HF	--	Odontocete middle ear	--	SOC: 0.3 (whistle) to 44 kHz (whistles) ECH: 25 to 35 kHz+	BBHF	Audiometry: No data Anatomical models: No data Acoustic: Busnel & Dziedzic, 1966; Fish & Turl, 1976; Moore & Ridgway, 1995; Oswald et al., 2003; Ansmann et al., 2007; Petrella et al., 2012; Azzolin et al., 2014
Long Finned Pilot whale (*Globicephala melas*)	High-frequency cetaceans	HF	AEP: < 4 to 89 kHz	Odontocete middle ear	--	SOC: 0.1 (chirp, squeal) to 24 kHz (whistle)	BBHF	Audiometry: AEP: Pacini et al., 2010— n = 1 Anatomical models: No data Acoustic: Steiner, 1981; Rendell et al., 1999; Nemiroff, 2009; Azzolin et al., 2014
Risso's Dolphin (*Grampus griseus*)	High-frequency cetaceans	HF	BEH: < 1.6 to 100 kHz AEP: < 4 to 142 kHz	Odontocete middle ear, Type II cochlea	--	SOC: 0.1 (grunt) to 29 kHz (whistle) ECH: 24 to 131 kHz+	BBHF	Audiometry: BEH: Nachtigall et al., 1995—n = 1; AEP: Nachtigall et al., 2005— n = 1 Anatomical models: Wartzok & Ketten, 1999; Nummela, 2008 Acoustic: Au, 1993; Rendell et al., 1999; Corkeron et al., 2001; Philips et al., 2003; Madsen, 2004; Soldevilla et al., 2008; Smith et al., 2016
Striped Dolphin (*Stenella coeruleoalba*)	High-frequency cetaceans	HF	BEH: 2 to 154 kHz	Odontocete middle ear	--	SOC: 1 (whistle) to 34 kHz (whistles)	--	Audiometry: BEH: Kastelein et al., 2003—n = 1 Anatomical models: No data Acoustic: Oswald et al., 2003; Azzolin et al., 2013; Papale et al., 2013
Common Bottlenose Dolphin (*Tursiops truncatus*)	High-frequency cetaceans	HF	BEH: < 0.4 to 146 kHz AEP: < 5 to 169 kHz	Odontocete middle ear, Type II cochlea	0.15 to 163 kHz	SOC: 0.1 (thunk) to 165 kHz (creak) ECH: 23 to 102 kHz+	BBHF	Audiometry: BEH: Johnson, 1967; Ljungblad et al., 1982; Lemonds, 1999; Brill et al., 2001; Schlundt et al., 2008; Finneran et al., 2010—n = 6; exclude Finneran et al., 2005a, 2007; AEP: Popov & Supin, 1990; Houser & Finneran, 2006; Popov et al., 2007; Finneran et al., 2008, 2011; Houser et al., 2008; Mann et al., 2010— n > 39 Anatomical models: Ketten, 1994b; Tubelli et al., 2012f; Ketten et al., 2014a, b; Racicot et al., 2016a Acoustic: Lilly & Miller, 1961; Evans & Prescott, 1962; Lilly, 1963; Caldwell & Caldwell, 1968, 1979; Diercks et al., 1971; Evans, 1973; Au et al., 1974; Fish & Turl, 1976; Kamminga, 1979; Au & Penner, 1981; Steiner, 1981; Au et al., 1982; Wiersma, 1982; dos Santos et al., 1990; Au, 1993, 2004; Jacobs et al., 1993; Ding et al., 1995; McCowan & Reiss, 1995; Schultz et al., 1995; Connor & Smolker, 1996; Blomqvist & Amundin, 2004; Boisseau, 2005; Azevedo et al., 2007; van der Woude, 2009; Hawkins, 2010; Simard et al., 2011; Wahlberg et al., 2011b; Branstetter et al., 2012; Azzolin et al., 2014; Frankel et al., 2014; Buscaino et al., 2015; Gridley et al., 2015
Killer Whale (*Orcinus orca*)	High-frequency cetaceans	HF	BEH: < 0.2 to 140 kHz AEP: < 1 to 90 kHz	Odontocete middle ear	--	SOC: 0.1 (click burst) to 75 kHz (ultrasonic whistles) ECH: 22 to 80 kHz+	BBHF	Audiometry: BEH: Szymanski et al., 1999—n = 2; exclude Hall, 1972; AEP: Szymanski et al., 1999—n = 2; see also recent paper from Branstetter et al., 2017—n = 6, with individuals "A" and "B" excluded 90 kHz whistles) Anatomical models: No data Acoustic: Schevill & Watkins, 1966; Diercks et al., 1971; Steiner et al., 1979; Dahlheim & Awbrey, 1982; Ford & Fisher, 1983; Hoelzel & Osborne, 1986; Morton et al., 1986; Moore et al., 1988; Ford, 1989; Barrett-Lennard et al., 1996; Thomsen et al., 2001; Au et al., 2004; Van Opzeeland et al., 2005; Miller, 2006; Riesch et al., 2006, 2008; Simon & Ugarte, 2006; Simon et al., 2007; Samarra et al., 2010; Riesch & Deecke, 2011; Simonis et al., 2012
Rough-Toothed Dolphin (*Steno bredanensis*)	High-frequency cetaceans	HF	AEP: < 10 to 120 kHz	Odontocete middle ear	--	SOC: 3 (whistle) to 29 kHz (whistle) ECH: 16 to 29 kHz+	BBHF	Audiometry: AEP: Mann et al., 2010—n = 1 Anatomical models: No data Acoustic: Norris & Evans, 1967; Oswald et al., 2003; Seabra de Lima et al., 2012; Rankin et al., 2015
Harbour Porpoise (*Phocoena phocoena*)	Very high-frequency cetaceans	VHF	BEH: < 0.3 to 160 kHz AEP: < 10 to 160 kHz	Odontocete middle ear, Type I cochlea	0.25 to 220 kHz	SOC: endnote [1]ECH: 125 to 200 kHz+	NBHF	Audiometry: BEH: Kastelein et al., 2002, as updated by Kastelein, 2010; Kastelein et al., 2010, 2015—n = 3; exclude Andersen, 1970; AEP: Popov et al., 1986; Popov & Supin, 1990; Ruser et al., 2016—n = 28 Anatomical models: Ketten, 1994a; Ketten et al., 2014b; Racicot et al., 2016a Acoustic: Busnel & Dziedzic, 1966; Schevill et al., 1969; Dubrovskii et al., 1971; Møhl & Andersen, 1973; Kamminga & Wiersma, 1981; Wiersma, 1982; Verboom & Kastelein, 1995; Au et al., 1999; Kastelein et al., 1999; Teilmann et al., 2002; Villadsgaard et al., 2007; Hansen et al., 2008; Madsen et al., 2010; Clausen et al., 2011; Kyhn et al., 2013

Table 1. Subdivision into marine mammal hearing groups for the Mediterranean, their applicable auditory weighting functions (LF, HF, VHF) and sound production (Southall et al., 2019).

Noise is capable of causing an impact on cetaceans (Southall et al., 2007, 2019; Weilgart, 2007; Slabbekoorn et al., 2018; Gordon, 2018; Erbe et al, 2018, 2019) through different mechanisms. Several studies have shown that noise exposure can cause damage at the anatomical and physiological level (auditory receptors, cardiovascular or hormonal effects), at the level of communication and masking but also at the behavioural level.

Furthermore, it is crucial to consider the areas where animals perform functional activities such as feeding, reproduction and migration and to assess what the impact is on these more sensitive areas (Southall et al., 2007, 2019). The negative effects may vary depending on the location and period under consideration, making the definition of thresholds more complicated. Hence, this becomes a complicated point as knowledge on masking or behavioural disturbances caused by continuous noise is limited. Some studies, such as that of Southall et al. (2007, 2019), explore the dose-responses of marine mammals to noise by classifying behavioural changes into a severity scale (based on 9 categories) ranging from mild and brief reactions to stronger and more important responses.

This severity scale was also used in the review by Gomez et al. (2016), revisited and adapted. At present, however, there is no consensus either on the scale or on the levels to be considered.

Current scientific knowledge acknowledges the fact that the sound source characteristics, the auditory sensitivity of marine mammals as well as the exposure context must all be taken into account to predict the likelihood and the severity of the potential biological effects. Especially with marine mammals and behaviour, such predictions are challenging.

Also, with regard to masking, there are still uncertainties in defining levels of onset of adverse biological effects since such levels are difficult to predict for any combination of source, receiver, and environment. To date, in fact, we have no complete masking models for any species (Erbe et al., 2016).

3.4. Definition of The Level of Onset of Biologically Adverse Effects (LOBE)

LOBE is the sound level above which biologically adverse effects on indicator species are expected. Using this level, areas of low effect and areas of significant effect are determined. The definition of LOBE must be based on evidence from studies on indicator or related species (TG Noise, DL3, 2021).

Considering behavioural disturbance for the definition of LOBE, there are many studies proving that noise can interrupt essential actions such as feeding or vocalizations resulting in the modification of these or in the abandonment of habitat (Erbe et al., 2019; Perry, 1998; Prideaux, 2017; Richardson et al., 1995; Slabbekoorn et al., 2018; Southall et al., 2007, 2019a, 2019b; Weilgart, 2007; Würsig and Richardson, 2002).

One of the studies considered to decide the level of LOBE is the review by Gomez et al., (2016), cited above, in which 370 articles were reviewed and 79 studies analysed. In this review, behavioural responses were classified on a severity scale (9 categories) and cetaceans were divided into 3 auditory groups following those previously proposed by Southall et al, 2007:

- LF low frequency hearing (e.g., whales)
- MF med- frequency hearing (e.g., toothed cetaceans, other than HF)
- HF high frequency hearing (e.g., odontocete cetaceans)

More severe responses were not always associated with higher received noise levels (RL), and that happens because the exposure context may sometimes be a stronger driver than RL (e.g., traveling animals may tolerate much higher RL than foraging/resting animals). From the review by Gomez et al. (2016), the results appear to show that 110 dB re 1 µPa could be considered as the received level at which behavioural responses can begin to occur for both MF (hearing range: 150 Hz to 160 kHz) and LF (hearing range: 7 Hz to 30 kHz) cetaceans (Figure 4).

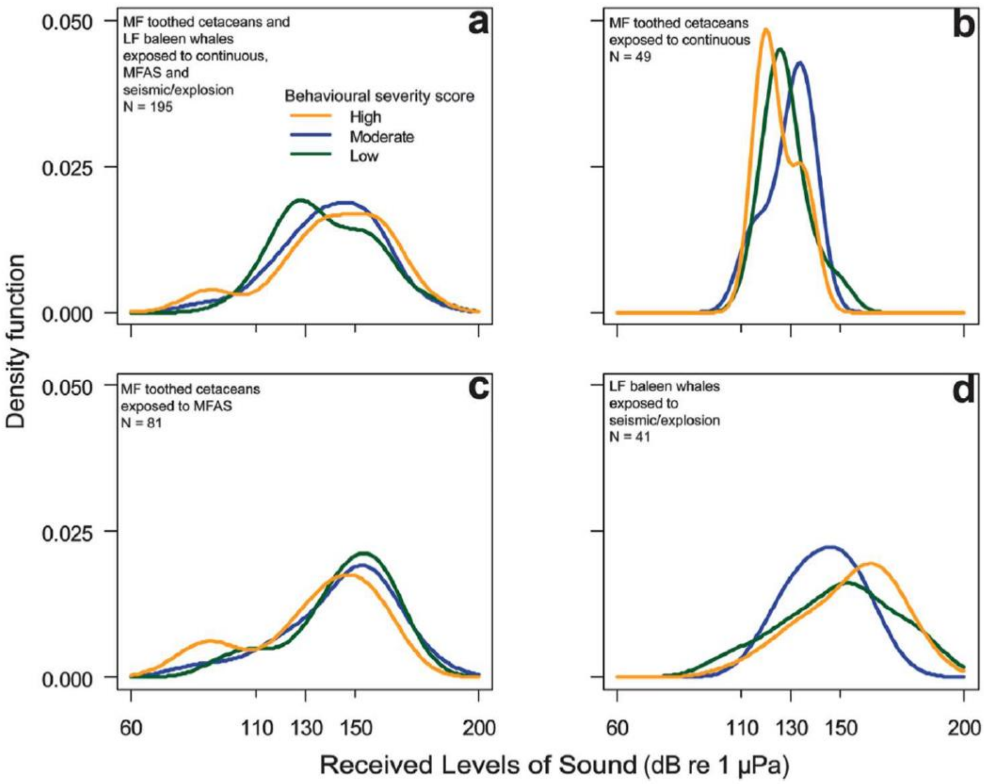

Figure 4. Severity score in behavioural response (low, moderate, high) in low-frequency (LF) baleen whales (a, d) and mid-frequency (MF) toothed whales (a, b, c) in relation to received levels (RL) of seismic/explosion, continuous and mid-frequency active sonar (MFAS) sound sources (Gomez at al., 2016).

As far as masking and stress responses are concerned, Tougaard et al. (2021) indicate a threshold of 20 dB above the natural condition. Specifically, the excess noise was quantified, which expresses the deterioration of the signal-to-noise ratio caused by the ship noise and hence the reduction in maximum communication range. Several tools are available to quantify the loss of communication space due to noise (Clark et al., 2009; Erbe, 2015; Erbe et al., 2015; Hatch et al., 2012; Moore et al., 2012).

Furthermore, to establish LOBE values there must be a relationship between the chosen noise metric and the magnitude of this negative effect. The value defined for LOBE can then be used to determine whether the habitat is at a tolerable status, or not, if it is below or above the LOBE level, respectively, in the chosen time period. The choice of metrics concerns the observation window and time analysis.

Recommendations are to use observation periods of 1-60s for masking and 1 to 2 hours for behavioural responses, but those could also last from 1 day up to 1 month (TG Noise, DL4, 2021). While the analysis period to determine thresholds is instead recommended at 1 month, the assessment periods must be chosen by MS and should be chosen to be biologically representative of the habitat, reflecting any seasonal variation.

3.5. Assessment of the acoustic state with modelling and establishment of the current condition

Vessel traffic is by far the dominant source of continuous noise. Information on the marine acoustic environment, on the sources (vessels) and the vessel traffic generating the continuous noise is needed to assess acoustic status. Data for ships obtained from the Automated Identification System (AIS) and data for fishing vessels from the Vessel Monitoring System (VMS) can be used to obtain information on vessels such as location, routes, speed, vessel type, activity, cargo, and size.

Different models, based on size, speed and category of vessels, can be used to predict a SL (Source Level) at different depths (e.g., RANDI 3.1 model (Breeding et al., 1996), which is used in QUIETSEAS case studies). In addition, the spatial resolution of the grid, the time period of the analysis and the investigated frequency bands must be decided according to the auditory sensitivity of all chosen species. In QUIETSEAS case studies, modelling of acoustic state is based on a 10' x 10' grid, and on a monthly average traffic density, and the investigated frequency bands are the 1/3 octave bands at 63 Hz and 125 Hz.

AIS data together with environmental data (e.g., bathymetry, seabed type, salinity, temperature), are used as input in noise propagation models to produce noise maps and, thus, assess the acoustic state.

Figure 5 shows the median noise map (SPL) for the month of August in the year 2019, over a 10' x 10' grid, concerning the third octave band centred at 63 Hz.

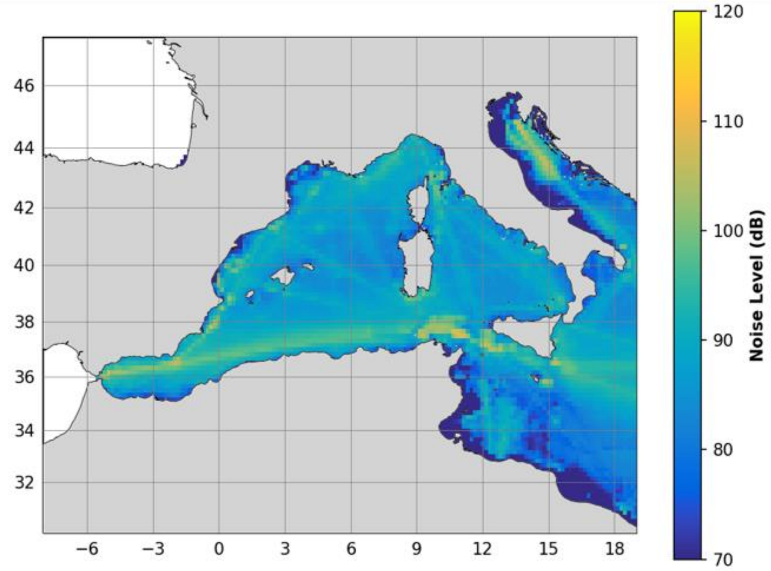

Figure 5. Shipping noise for the one third octave band centred at 63 Hz for August of 2019 at XX m depth in a part of the Mediterranean Sea region; colour scale represents grid cell monthly average SPL.

The reference condition represents the acoustic state which is determined only by natural noise-generating sources affecting the marine environment. The reference condition is therefore a baseline that specifies an environmental state in which anthropogenic noise is at low levels, so that the state would be considered similar to the one in the absence of anthropogenic noise sources. Logically, as observed in several projects (BIAS, JOMOPANS, JONAS and QUIETMED2, Sigray et al., 2019), actual sound levels are higher than those in absence of anthropogenic activities.

The reference condition must be statistically defined and be representative of the actual acoustic state of the habitat, i.e., when the habitat is affected by meteorological, geological and biological activities. The ceiling of the reference condition is an upper bound estimate of the reference condition and thereby a measure of the upper range of sound levels that can be expected to occur naturally. Levels below this upper limit are within the range that chosen indicator species might naturally experience.

The current condition, on the other hand, concerns the acoustic state in a certain habitat over a defined assessment period including natural and anthropogenic sounds. Such an acoustic state is assessed in each grid cell by evaluating the deviation of noise levels between the reference condition and the current condition. This deviation is thus evaluated according to the defined LOBE.

The degree to which this current condition deviates from the reference condition can be quantified as the difference between the arithmetic means or medians of the two noise distributions. The current condition of a grid cell can therefore be in the natural variation zone, in the non-significant effect zone (below LOBE) or in the significant negative effect zone (exceeding LOBE).

3.6. Grid cell evaluation

The grid cell is the basic element of this evaluation methodology. The grid cell size can be variable depending on the geographical system used, which is decided at regional or sub-regional level. The portion of time in which the current condition is above the set LOBE level is evaluated to determine the cell condition: each cell may then be affected non-significantly or significantly if the current condition metric is below or above, respectively, the chosen LOBE.

The acoustic state of the cell is then used to assess the state of habitat by aggregating the states all the grid cells of the habitat. Thus, the cumulative effect of sounds from vessel sources evaluated over the specified time span is used to assess the state of a cell and consequently the state of each habitat.

3.7. Definition of the habitat and its status

The critical point of this methodology is the selection of indicator species used to assess the habitat, at a regional or sub-regional level, in relation to possible noise impacts.

The effects caused by continuous noise can lead to a reduction in quality and degradation of the habitat of sensitive species. Habitats can be degraded through both a decrease in quality or a decrease in size. These factors, taken individually or in combination, can influence the risk of extinction (Johansson & Ehrlen 2003; Franken & Hik 2004; Dennis & Eales 1997; Fleishman et al. 2002). Habitat degradation caused by continuous noise increases proportionally with the portion of exposed habitat and the duration of exposure. Therefore, a relationship can be assumed between habitat degradation caused by noise and the carrying capacity/growth rate of the population that inhabits it, expecting a reduction in population size for long-term exposures.

Habitat thresholds have been created for conservation purposes to ensure species survival (Andrén, 1994; Johnson, 2013; Lindenmayer and Luck, 2005; Mönkkönen and Reunanen, 1999; Pe'er et al., 2014; Swift and Hannon, 2010; Van der Hoek et al., 2015). However, the definition of habitat thresholds or percentages of habitat which must be maintained to allow the population’s survivorship is challenging, since populations respond to a variety of factors which can only partly be represented in the physical habitat. Moreover, the available knowledge for the species may be insufficient to assess the species habitat requirements at the scales needed for modelling.

However, in this framework, the use of simple habitat suitability models, developed based on field observations as a function of physical habitat characteristics, may facilitate this process by enabling an estimation of the potential habitat availability for the species of interest.

3.7.1 Indicator species presence/absence models

The habitat preferences of many species are accessible and documented in literature, as is information about their presence and distribution (Azzellino et al., 2008, 2011, 2012, 2014; Cañadas et al., 2002, 2005, 2008, 2018; Carlucci et al., 2016; Panigada et al., 2008; Pace et al., 2018; Pirotta et al., 2011, 2020).

For instance, in the Pelagos Sanctuary, the relative habitat preferences for each of the different species have been studied (Azzellino et al., 2008, 2011, 2012, 2014). This was made possible through the analysis of a long-term dataset covering an area of approximately 25,000 km^2. Presence/absence models for the different species were developed using covariates as physiographic predictors (e.g., descriptive statistics of bathymetry and slope).

Bathymetry can be obtained from relevant databases (e.g., GEBCO; https://www.gebco.net/data_and_products/gridded_bathymetry_data/), while, by means of GIS tools, it is possible to calculate the sea bed slope that is another robust predictor for determining the probability of species presence/absence. An example of models created for Mediterranean cetacean species is presented in Figure 6 and Table 2 (Azzellino et al., 2012).

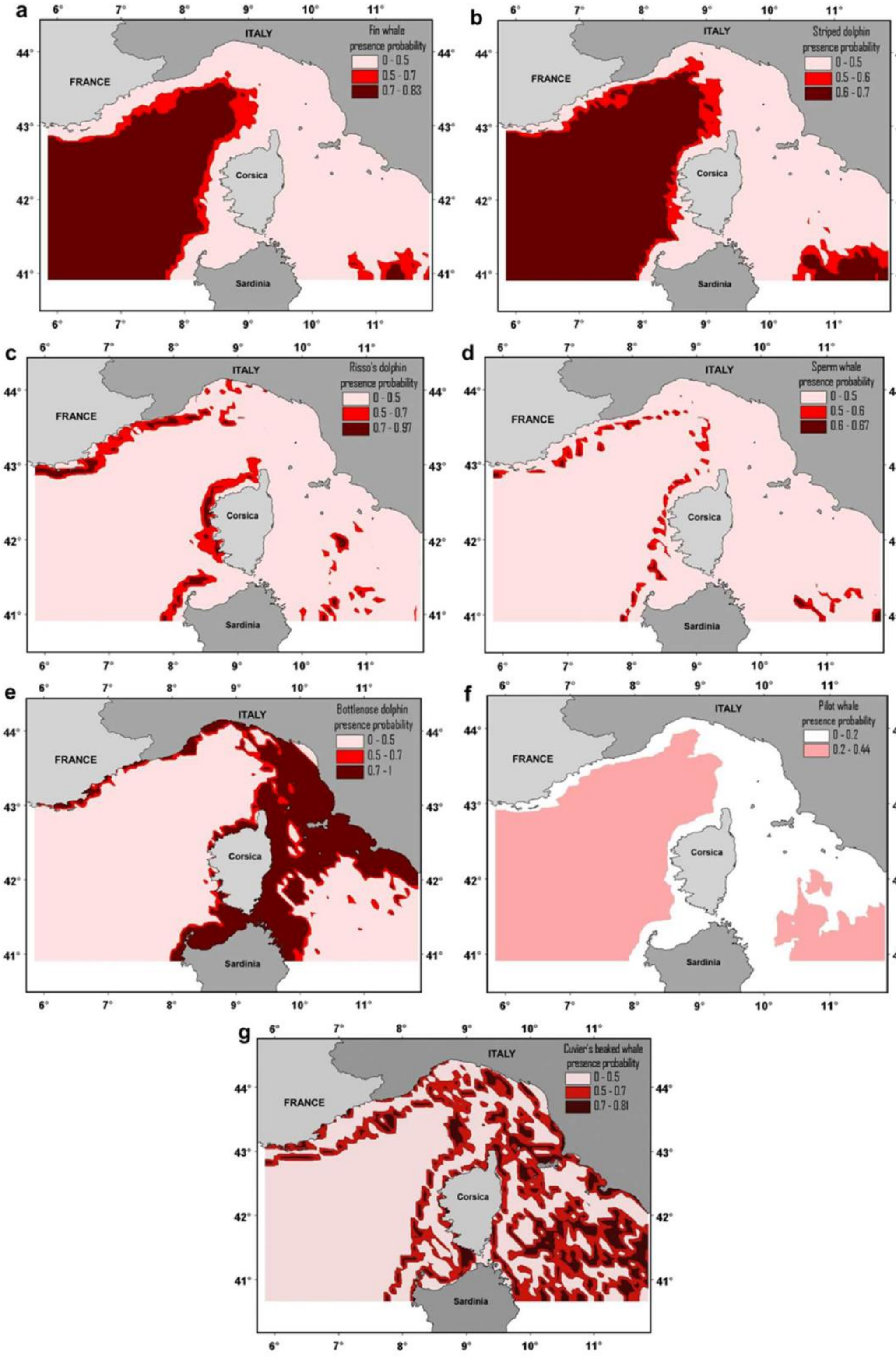

Figure 6. spatial prediction of the presence probability of: fin whale (a); striped dolphin (b); risso's dolphin (c); sperm whale (d); bottlenose dolphin (e); long finned pilot whale (f); Cuvier's beaked whale (g) (Azzellino et al., 2012).

	Observed	Absence	Presence	Overall percentage
Fin whale	Absence	347	217	63.3
	Presence	75	516	87.3
	Overall percentage			**75.3**
Striped dolphin	Absence	1384	501	73.3
	Presence	718	1167	61.9
	Overall percentage			**66.9**
Risso's dolphin	Absence	89	29	75.4
	Presence	30	88	74.6.
	Overall percentage			**75**
Sperm whale	Absence	68	31	68.7
	Presence	29	70	70.7
	Overall percentage			**69.7**
Common bottlenose dolphins	Absence	19	6	76
	Presence	4	21	84
	Overall percentage			**80**
Long finned pilot whales	Absence	8	15	34.8
	Presence	3	20	87
	Overall percentage			**60.9**
Cuvier's beaked whale	Absence	14	4	77.8
	Presence	7	11	61.1
	Overall percentage			**69.4**

Note: The cut value is 0.5.

Table 2. Confusion matrix showing the level of accuracy of the presence/absence logistic models for the species considered (Azzellino et a.l, 2012).

In addition, for the seven Mediterranean species, results from models predicting the potential habitat based on bathymetric characteristics are available in Table 3 (Azzellino et al., 2012).

		B	*S.E.*	*Wald*	*df*	*P*
Fin whale	***Depth Min***	0.002	0	147.659	1	0.000
	Slope Min	0.009	0.003	9.677	1	0.002
	Constant	-3.711	0.394	116.355	1	0.000
Striped dolphin	***Depth Max***	0.001	0	188.988	1	0.000
	Slope Min	0.004	0.001	23.823	1	0.000
	Constant	-1.918	0.169	282.33	1	0.000
Risso's dolphin	***Depth SD***	0.008	0.001	50.709	1	0.000
	Constant	-1.555	0.265	34.45	1	0.000
Sperm whale	***Depth Max***	0.001	0	15.671	1	0.000
	Slope Min	0.009	0.005	3.885	1	0.049
	Slope Mean	0.018	0.006	8.8	1	0.003
	Constant	-4.144	0.888	21.788	1	0.000
Common bottlenose dolphins	***Depth Max***	-0.005	0.002	9.33	1	0.002
	Slope SD	-0.107	0.046	5.367	1	0.021
	Constant	6.921	2.315	8.941	1	0.003
Long finned pilot whales	***Depth Mean***	0.001	0.001	3.635	1	0.057
	Constant	-2.628	1.454	3.269	1	0.071
Cuvier's beaked whale	***Slope Range***	0.019	0.008	5.233	1	0.022
	Constant	-0.694	0.463	2.245	1	0.134

NOTE: The following statistics are shown: **B**: unstandardized regression coefficient; **S.E.**: Standard Error of B; **Wald** statistic for the included parameter; **df**: degrees of freedom; **P**: level of significance.

Table 3. Results of the binary logistic regression analysis model for seven Mediterranean species: presence/absence of cetaceans were correlated with the statistics (i.e., mean, minimum, maximum, and standard deviation) of the physiographic features depth and slope (Azzellino et al., 2012).

This type of approach is deemed appropriate by the relative degree of accuracy derived from it. Moreover, these types of models are also potentially usable for other species and areas of interest, thus being able to predict the most suitable habitat.

3.7.2 Potentially Usable Habitat Area (PUHA) calculation

Habitat acoustic status can be determined by evaluating the tolerable impacted area of the habitat for a defined duration in the assessment period.

The assessment can be done in terms of PUHA (Potentially Usable Habitat Area), which can be calculated for each species based on the species predicted presence probability (i.e., habitat suitability, HS).

Based on the presence probability evaluated for each cell unit of the analysis grid, PUHA can be computed as shown below (Figure 7):

$$PUHA = \sum_{i=1}^{n} HS \times a_i \quad \text{(Eq. 1)}$$

where HS is the Habitat Suitability, i.e., the species presence probability as function of the cell physical characteristics, and a_i is the area of the i_{th} unit cell.

Example: Considering a grid with cell size of 20 km x 20 km, the total physical area of the cell unit is 400 km^2 having various bathymetric characteristics which have different habitat suitabilities for different species (e.g., sp_1, sp_2, sp_3). So, assuming that in that cell unit

- HS_{sp1} = 65%

- HS_{sp2} = 25%

- HS_{sp3} = 75%

then, PUHAs for HS higher than zero will be the following for the three species:

- $PUHA_{sp1}$ = (0.65x400) = 240 km^2

- $PUHA_{sp2}$ = (0.25x400) = 100 km^2

- $PUHA_{sp3}$ = (0.75x400) = 300 km^2

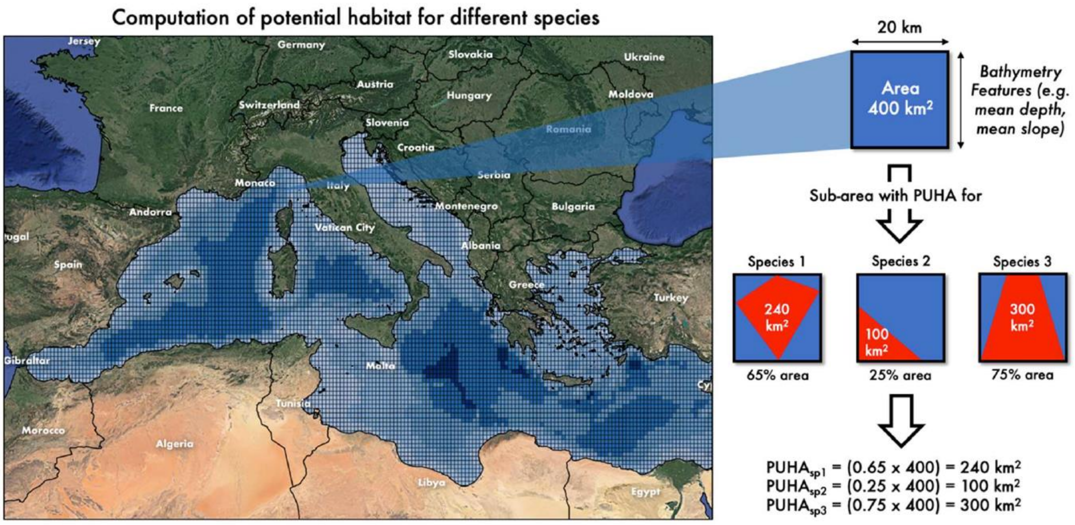

Figure 7. example of PUHA calculation in different cells

Next, the cumulative PUHA is derived, computing the summation of each cell's PUHAwithin the assessment area. Finally, superimposing the noise map onto the PUHA map, the proportion of species' potential habitat that is impacted by noise can be estimated. The habitat status is then assessed by comparing the proportion of habitat impacted by noise levels higher than LOBE against the predefined spatial threshold.

3.7.3 Tolerable exposed area and habitat status assessment

The habitat status is then considered tolerable if the impacted habitat fraction is less than the predefined spatial threshold.

TG Noise DL4, following the same rationale of the study conducted by Tougaard et al. (2013), proposes as conservation target a maximum of 20% reduction in habitat, which under very conservative assumptions may lead to a 20% decline in population size in the long term.

Based on this conservative assumption, a 20% habitat threshold was assumed as an upper limit of tolerable exposed area that should not be exceeded in any month of the year.

Thus, based on the TG Noise proposed threshold: if for all months of the year the habitat area exposed to a noise level higher than LOBE is 20% or less, the environmental status as regards to continuous noise is tolerable.

3.8. Main problems in applying the methodology

It is worthwhile to be reminded here of the caveats regarding the TG Noise proposed methodology. One of the main problems with the proposed methodology is how to use and build sound maps. Indeed, there are different noise mapping methodologies used by MS, and each of them (even if following different approaches) should comply with the suggested guides and recommendations (e.g., Binnerts et al., 2021 or MacGillivray and de Jong, 2021 and QUIETSEAS D4.2 2022 (TG NOISE, DL4, 2021)).

Changing the methodology or the metrics used to assess the noise state can produce very different values and thus affect the results.

In fact, if the choice of metric and LOBE value is not harmonised, different assessments can lead to different results. It would therefore be desirable to adopt an international standard so that assessments can be comparable between regions and the adaptability of the framework ensured. To date, there is still no such standard for measuring and modelling sound pressure in the aquatic environment.

Another crucial element concerning the development of species presence/absence models, is to have enough data to ensure sufficient levels of accuracy. This therefore requires an effort from MS to increase the monitoring activities of the species of interest in assessment areas to expand knowledge and obtain accurate models. The improved knowledge about the sensitivity of species to continuous noise is also necessary to more accurately define LOBE and consequently, the status of the habitats. More effort should be also dedicated by Member States to fill knowledge gaps and in the attempt to include in the assessment species other than cetaceans.

4. Example of the application of the proposed methodology for establishing thresholds in the Western Mediterranean area

This section will show the methodology applied following the steps proposed by TG Noise, giving an example for the Western Mediterranean area.

Step 1: The proposed methodology will be applied for the fin whale in the Western Mediterranean Sea area.

Step 2: Considering behavioural disturbance, LOBE levels are tentatively set at the SPL of 100 dB re 1 µPa for the third octave band centred at 63 Hz.

Step 3: The time observation window of the maritime traffic statistical model is set to 1 month. The temporal analysis window for assessing the habitat state is also set to 1 month.

Step 4*:* The frequency band chosen is 1/3 octave centred at 63Hz, the spatial resolution of the area is 10'x10', and for the time resolution the monthly average scenario is chosen. The current condition is modelled based on the monthly traffic density.

Step 5: The reference condition is 100% of the habitat exposed to sound levels below LOBE.

Step 6: The current condition is established by modelling noise from ships using AIS data and considering monthly average shipping density. Using Randi 3.1 source model, source characteristics for each ship were modelled from ship categories, size, and speed.

Step 7: The grid cell condition is assessed on a monthly average basis by comparing the SPL of the current condition and the defined LOBE (100 dB). If the average SPL for a cell is higher than LOBE, then that cell is defined as significantly affected or impacted (Figure 8).

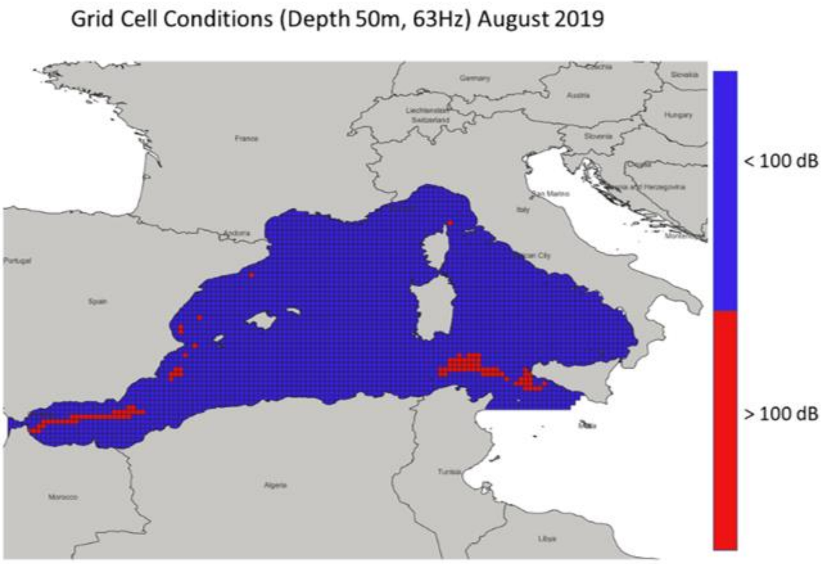

Figure 8. Assessment conditions of individual grid cells: blue cells represent grid cells which are not significantly affected by noise for the set LOBE while the red cells represent grid cells which are significantly affected by noise for the set LOBE. The Temporal Observation Window and The Temporal Assessment Window are set to 1 month.

Step 8: The PUHA calculated for the fin whale is then overlapped with the noise maps, and the habitat status is assessed by calculating the fraction of the investigated area that is significantly affected by noise, and comparing this fraction to the predefined spatial threshold (Figure 9). The spatial threshold refers to the 20% of habitat that is exposed to average noise levels above the set LOBE (Figure 10). In the example given, 3% of the fin whale PUHA is exposed to levels above 100 dB, i.e., the LOBE value. The status of the habitat is therefore considered tolerable.

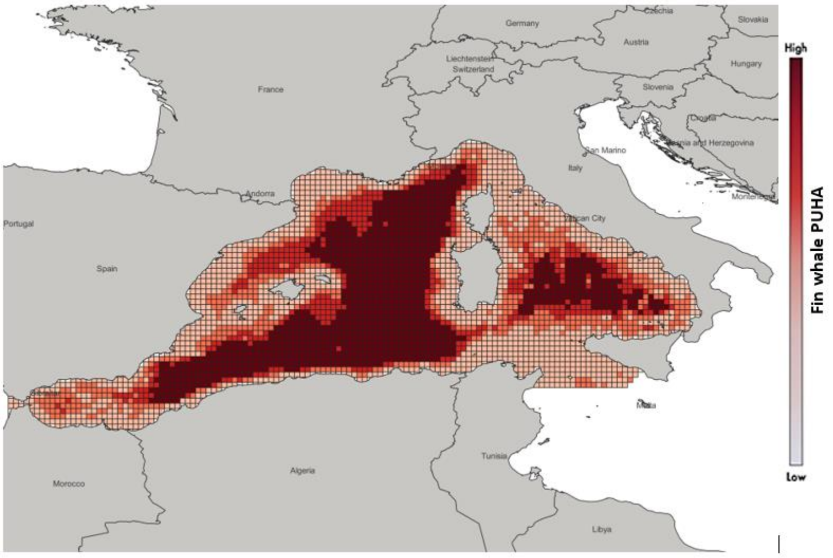

Figure 9. Habitat status assessed in terms of PUHA for fin whale.

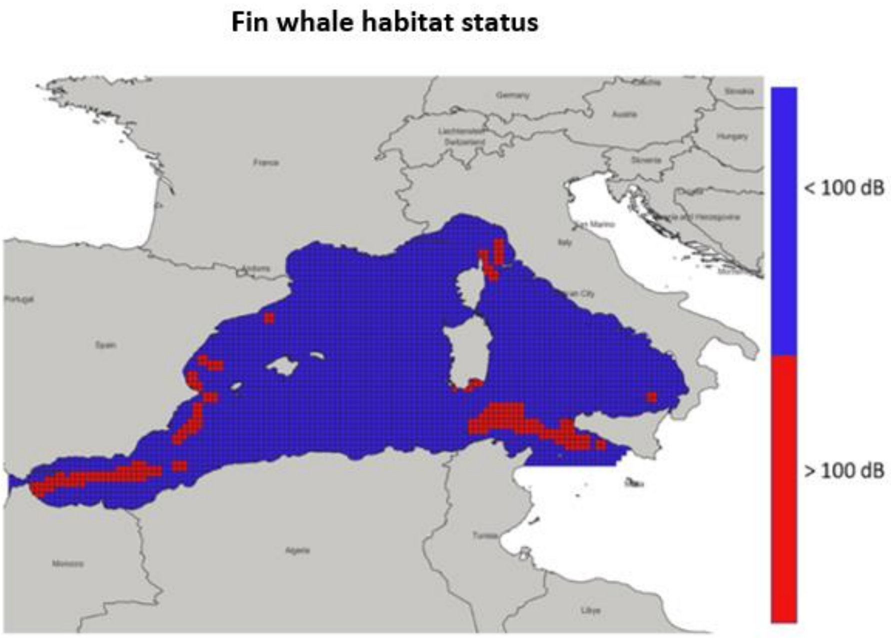

Figure 10. Habitat status assessed by comparing the portion of fin whale habitat in the assessment area significantly affected by noise with the tolerable impacted area. In this example, the tolerable impacted area is set to 20 % of the habitat exposed to average noise levels above the LOBE.

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