DELIVERABLE 4.1-4.4
APPLYING THE RAGES RISK-BASED APPROACH TO MSFD DESCRIPTOR 11, UNDERWATER NOISE

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Preface

This document outlines the Risk Based Approach (RBA) developed by the RAGES project and demonstrates its applicability to Descriptor 11 of the Marine Strategy Framework Directive (MSFD), Underwater Noise. A fully detailed account of the RBA, which is adapted from the ISO Risk Management standards (ISO, 2009; 2018) can be found in RAGES Deliverable 2.3. The work in this document covers Deliverables 4.1, 4.2, 4.3 and 4.4 (partially) within Work Package 4, and the work applying to each Deliverable is clearly marked in red throughout the document. Please note that the deliverables do not appear in sequence here, as due the evolution of the work, the order of tasks has slightly changed from what was originally envisaged.

This current document focusses specifically on applying the RBA at two different spatial scales in the North East Atlantic, first at a subregional scale and then at a local scale. It illustrates the applicability of the RBA in these differing scenarios and highlights how it can be adapted to different types of datasets and situations. As such, the document also fulfills the requirements of Deliverable 4.4, (Perform Risk Assessment), by applying the approach at two different spatial scales. The document will also make reference to a case study off the west coast of Ireland illustrating how the method could be applied to an impulsive noise scenario, as well as to a modelling study in the Azores area (thanks to a collaboration between the RAGES and JONAS projects), in which the model outputs was compared to the shipping data in the region. Both of these studies provide additional information about the application of the risk-based approach in a wider context.

The final part of this document provides an appraisal of the RBA and describes how any challenges with its application were overcome, finally making some recommendations as to what is needed to improve the outputs. This analysis should help others in the future when applying the approach and will build the understanding of the broad applicability of the RBA to the MSFD.

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Introduction

There is increasing global awareness about the effects of human sounds on marine biodiversity, the growing anthropogenic sound input to the marine environment and the latent ecological risks of exposure to underwater sound (McQueen et al., 2020; Miksis-Olds et al., 2013; NRC, 2005; UN, 2018). Underwater noise can be impulsive, corresponding to *«loud, intermittent or infrequent noises, such as those generated by piling, seismic surveys, and military sonar»* or continuous, comprised of *«lower-level constant noises, such as those generated by shipping and wind turbines»* and *«characterized by a long duration and (…) commonly defined as background noise»* (EEA, 2020). Literature is mainly focused on the overlap between underwater noise of human origin and the organisms potentially affected, as well as on their hearing extent. There is a relative lack of knowledge on the effects of noise on overall biodiversity, though several studies have identified it as impacting behavior and physiology (Gervaise et al., 2012; Jägerbrand et al., 2019; Nedelec et al., 2015). The MSFD included noise (Descriptor 11) as a new and emerging pressure in the marine environment that is not explicitly tackled by other policies. While this has bolstered the MSFD's central role in a complex marine policy landscape, the lack of knowledge associated with marine noise (and some other) descriptors has meant that defining GES for them is a major challenge. Therefore, approaches such as risk assessments have been proposed as a possible way forward, in particular in areas where the spatial scales required for MSFD implementation are very large and noise data are lacking.

This document summarizes how the risk-based approach presented in RAGES Deliverable 2.3 (see Figure 1 for a summary) was applied to Descriptor 11 (hereafter D11) of the Marine Strategy Framework Directive (MSFD) (European Commission, 2008). The focus of the work and of this document is on the application of the approach for D11C2 (Criterion 2, Continuous noise) at a Sub-Regional and a Local scale, however the methods developed for assessing consequence are equally applicable to Criterion 2, Impulsive Noise (D11C1) and a case study for Impulsive noise is at Annex I. The tasks in the RAGES Gannt Chart are also referenced (in red) throughout this document, to highlight where the work relevant to them is being described.

This document illustrates the steps of the risk-based approach as they may be applied to D11, using a variety of different data sources and proxies. It is not intended to be a prescriptive methodology to address D11, rather it illustrates how the risk management process can be followed at different scales to address the issue, depending on the spatial scale under consideration, the amount of data available and the level of detail required.

A full description of the RAGES risk-based approach, including explanations of the DAPSI(W)R(M) conceptual frame and how the risk process aligns with the steps of the MSFD is provided in RAGES Deliverable 2.3 but some of the major features of the process are summarized here to help explain how this process was applied for D11. Steps one and two of the Risk Based Approach can be partially related back to the MSFD and its annexes and supporting communications. Step 1, **establishing the context** lays out the ecosystem elements and parameters used to measure risk as well as setting the assessment scale. This step is supported by the Commission Decision EC 2017/848 (EC, 2017a), which identifies the specific criteria for each of the 11 MSFD descriptors. Similarly Step 2, **risk identification** can be performed in part by reference to the Activities and Pressures listed in the directive amendment 2017/845 (EC, 2017b) and identification of pathways between these Pressures and particular ecosystem elements.

The **risk analysis** (Step 3) is more involved and makes up the main analytical stage of the process containing a number of sub-steps, including:

- **Preliminary analysis** - the purpose of this is to focus resources on the most significant risks. Data are screened in order to identify the most significant risks, or to exclude less significant risks from further analysis. However, this step may not always be appropriate; it is very important not to screen out low risks which occur frequently and may have a cumulative effect (ISO, 2009 and also see Judd et al., 2015)
- **Analysis of likelihood -** the likelihood that a Pressure will have a particular effect on a receptor
- **Analysis of consequence -** the potential severity of adverse effects from exposure to the Pressure, which relates to the biological sensitivity of a species, population or habitat.

Subsequently (in Step 4) a **risk evaluation** process is performed enabling the analyst to compare the risk between areas and ecosystem elements and to prioritize them.

The final step (Step 5) involves **risk treatment**, the development of specific Measures to address the risks identified in the previous steps.

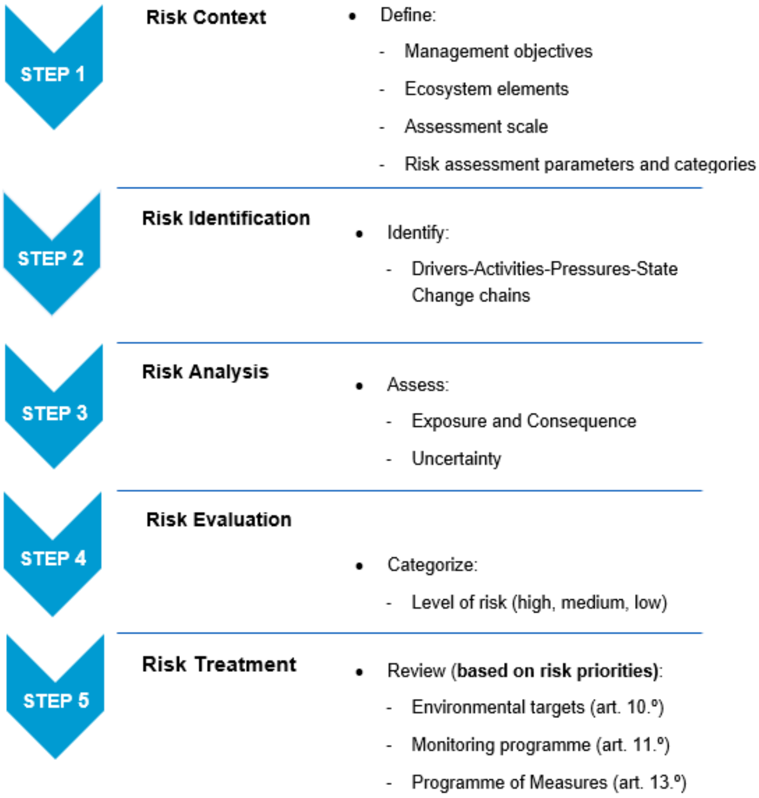


Figure 1. *The Risk-based approach as developed by the RAGES project (taken from RAGES Deliverable 2.3m, where a more detailed description of the risk process can be found)*

Additional Case studies

This document describes in detail the main work of the RAGES project for D11, but references two additional case studies that were undertaken as part of the RAGES project which supported the work of the project and provide some additional information. They reflect developments that arose from consortium discussions during the course of the project which catalyzed further collaboration.

a. Impulsive noise data off the Southwest Coast of Ireland

Whilst the RAGES project has focussed primarily on Criterion 2, Continuous noise, this case study (found in its entirety in Annex 1) focusses on the impact of Criterion 2: Impulsive Noise (the **Pressure**) created by seismic activity (the **Activity**) on cetacean species (the **Ecosystem Element**) off the western coast of Ireland.

b. Azores Noise Modelling Case Study

This work was undertaken as part of the collaborative agreement between the RAGES and JONAS projects (www.jonasproject.eu) and main goal was to compare the results of a spatially explicit risk analysis of continuous anthropogenic noise on cetaceans based on shipping density data (*proxy* of noise in the subregional approach) to those based on acoustic modelling. The work of the Case Study is found in its entirety in RAGES Deliverable 4.6 (Silva et al., 2021).

Step 1. Establishing the Context

(TASK 4.2, DELIVERABLE 4.2-DEFINE RELEVANT CRITERIA ELEMENTS)

Policy Context

In establishing the context for Descriptor 11, information contained within the EC Decision 2017/848 (EC, 2017a) is of key importance. This decision document provides the criteria elements and the criteria (management objectives), as shown in Table 1 below and two different types of noise Pressure are considered, impulsive (D11C1) and continuous (D11C2) noise. The work presented here focusses on D11C2, continuous noise, though it does propose a broad structure for a risk-based approach to impulsive noise also (see Table 3).

Table 1. *The criteria elements and criteria laid out in EC Decision 2017/848 for Descriptor 11. The bulk of the RAGES work focused on Criterion 2, Continuous Noise.*

Criteria elements	Criteria: management objectives	Thresholds
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.	**Thresholds currently in development:** to be established through regional or sub-regional cooperation, but not available at the time of writing this deliverable
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 sub-regional specificities.	

Attempts to address underwater noise within the MSFD have initially focused on the identification of its spatial distribution and sources (for which data are available) to characterise the likely exposure of marine ecosystems to this pressure (EC, 2020a). Although the monitoring of continuous underwater noise has been performed, data analysis and assessment are not fully developed and therefore underwater noise was reported as lacking significant monitoring information and knowledge (EC, 2020a). Culhane et al., 2019 has shown that in the NEA, the trends in the assessment of noise pressure are mainly stable in terms of percentage area affected. However, an understanding of uncertainty around directionality, variability and level of the sound source as well as sound propagation patterns through the ocean from the source is essential for the evaluation of the distribution of underwater noise (Tyack & Thomas, 2019). To support the MSFD, many EU Member States (MS) have contributed to impulsive noise registers to monitor noise-generating activity in their waters (Dekeling et al., 2014). Furthermore, international coordinated approaches are necessary to monitor, assess and manage the noise pollution that propagates across transnational borders, affecting ecosystems and species. For the Northeast Atlantic Region (NEA), OSPAR has appointed the International Council for the Exploration of the Sea (ICES) to produce and uphold an OSPAR impulsive noise register, used to assess the OSPAR Common Indicator of the Distribution of Reported Impulsive Sounds and adopted by HELCOM (Dekeling et al., 2014; Merchant et al., 2020). In addition, the work implemented at the EU and at regional levels through the Technical Group on Noise focuses on monitoring issues and relates to activities undertaken in Regional Seas Conventions (RSC). It has also included the production of monitoring guidance on underwater noise (EC, 2020b). Criteria to monitor and assess the adverse impacts of continuous underwater noise are in progress, under the MSFD and Regional Seas Conventions outlines (EEA, 2020; TG Noise, 2019), but this work is in an earlier stage of development.

Assessment Scale

A map of the RAGES area with the three subregions indicated is shown in Figure 2 below. The nature of the D11 risk-based assessment may vary considerably depending on the spatial scale being examined. To enable a focus on both a subregional-level assessment, which could in turn inform more detailed local modelling, the RAGES project makes use of the best available data to consider two different assessment scales:

1. **The Subregional Scale -** includes three MSFD subregions: The Celtic Seas, The Bay of Biscay and Iberian Coast and Macaronesia. Data have been collected from within the EEZs of the four MS which are partners on the RAGES project (Ireland, France, Spain, Portugal). Descriptor 11 is a particularly appropriate descriptor upon which to test a regional approach, because ocean noise can be considered a 'transboundary pollutant' and low-frequency noise can cross entire ocean basins (Erbe, 2013).
2. **The Local Scale –** A local scale modelling case study involving acoustic monitoring and a noise modelling exercise for the Bay of Biscay.

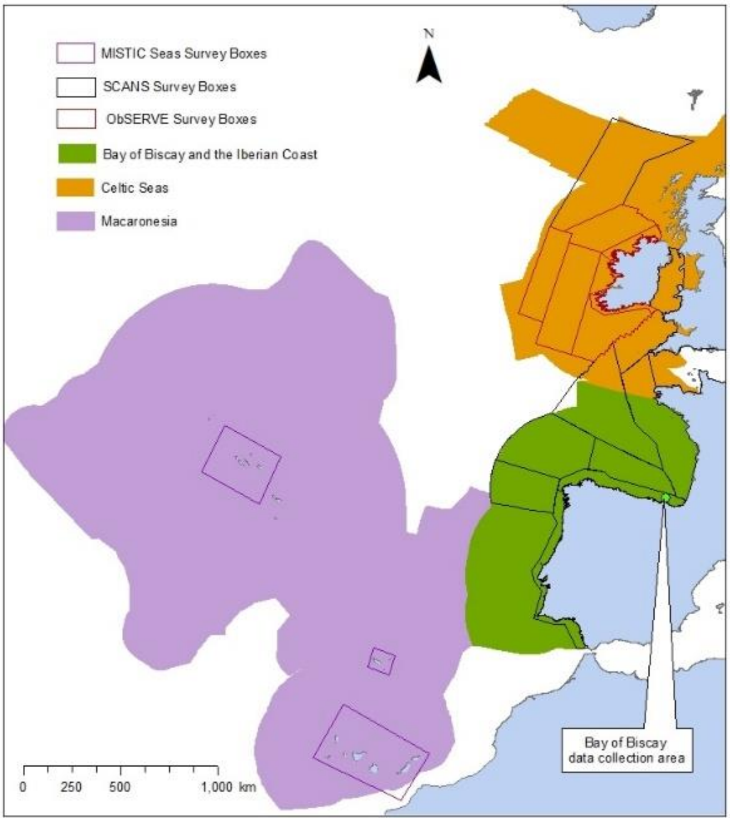


***Figure 2**. Map of the RAGES area showing the subregions and the cetacean survey boxes used for the cetacean data. Details of the SCANS and ObSERVE survey Box names and locations can be found in the reports of those survey campaigns. The site of the Bay of Biscay data collection is also indicated*

Ecosystem elements (receptors)

There are several sources of underwater noise, e.g. vessel noise, dredging, pile driving, seismic activity, acoustic devices and explosives, that may affect marine fauna as a result of mortality, physical injuries, auditory damages, physiological stress, acoustic masking, or behavioural changes (Merchant et al., 2020; Sinclair et al., 2020). In fact, the impact of noise on a number of individual receptor taxa has been well-documented (eg. Tougaard et al., 2009;

Blair et al., 2016; McCauley et al, 2017), but there remains a knowledge gap in terms of the overall impact of underwater noise at the broader ecosystem level (Merchant, 2019).

Marine mammals use sound for numerous reasons and thus are potentially vulnerable to high levels of human noise in their environment (Sinclair et al., 2020). Much work has focused on the impact of noise on cetacean species, with potential Impacts including behavioural changes and displacement due to processes such as acoustic masking and hearing loss (Nowacek et al., 2007; Erbe, 2012). However, despite long-standing research efforts, it has proven very difficult to draw robust statistical conclusions between noise and cetacean behavior. A scale ranking the severity of response for cetaceans has been proposed to overcome this (Southall et al, 2007, 2019; Ellison et al., 2012) but an extensive review of evidence by Gomez et al. (2016) suggests a simpler, binary “behavioural response/no behavioural response” approach may be more appropriate given the lack of evidence and data in many cases. The review by Gomez et al (2016) provides a summary of evidence for response to noise in a large number of cetacean species and a good basis for a broad assessment of cetacean species.

The subregional scale analysis focused on obtaining the best available distribution and density information for cetacean species found in the NEA region. Cetacean density data that had been gathered in surveys of the RAGES area were obtained from the SCANS I, II and III surveys (Hammond et al., 2017), as well as from the ObSERVE report (Rogan et al., 2018) and the MISTIC SEAS reports (Saavedra et al., 2018). The species found in the area are listed in Figure 2, which also illustrates their latitudinal distribution and relative densities across the study area, with the sub-regions indicated. Note that the list is not exhaustive and does not imply that these are the only cetacean species in this area, rather these are the species for which sufficient numbers were observed during the surveys to enable estimates of density. The SCANS, ObSERVE and MISTIC SEAS reports also list a number of less frequently sighted species for which only presence could be assessed.

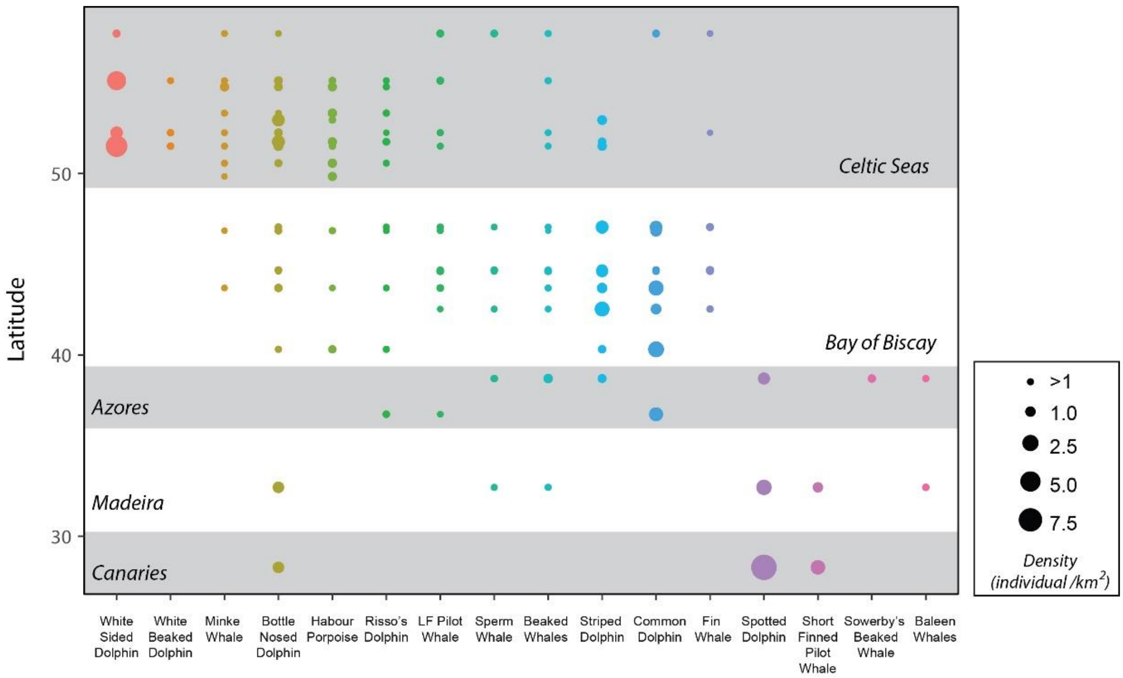


Figure 3. *Showing the latitudinal distribution of the cetacean species in the RAGES area, with the subregions indicated; the circle radius is proportional to the species density*

In order to determine the receptor species or ecosystem elements to be examined in this study, a Priority Index process was developed as a first step towards species selection. The purpose of this process was to identify which species in the RAGES area could be examined further according to a number of simple criteria (see Box 1), ultimately generating a ‘long list’ of species, which can be further refined during the later Risk Analysis step. The resulting species list is shown in Table 2. For the detailed local-scale modelling of the Bay of Biscay, *Tursiops truncatus* density data were obtained from the IEO PELACUS campaign, which were the most appropriate data to use given their coastal focus.

BOX 1. Priority Index, the process to identify the relevant receptor species for D11, C2

For each species under consideration, 5 or 6 questions must be answered. This is a binary, unweighted approach to choosing which species to focus on in the next steps. Fish and invertebrates must fulfil all 6 criteria to be considered, marine mammals must fulfil criteria 1–5.

1. Can the species detect noise?
2. Is the species known to be negatively impacted by noise? The impacts can be
    a. Physical (auditory), e.g., PTS, TTS.
    b. Physical (non-auditory), e.g., decompression sickness, internal haemorrhage, tissue rupture, death.
    c. Perceptual, e.g., masking, vocalisation shifts/changes, inability to interpret environment.
    d. Behavioural, e.g., temporary or permanent displacement, interruption of/less efficient foraging, mating, socialising.
    e. Indirect, e.g., reduced prey availability, riskier behaviour that can increase other hazards (stranding, ship strikes, predation).
    f. Chronic, e.g., increased stress, vulnerability to disease, decreased viability/reproductive success, habituation, PCoD.
3. Are there distribution/density data available for the species?

***Table 2**. Cetacean species and questions used to generate priority index. Impacts include Physical, auditory and non-auditory impacts, impacts on perception, and behaviour indirect impacts and chronic impacts related to stress, disease viability and reproductive success. A species that returned a 'no' result for any question was eliminated from further investigation.*

	Q1 Can the species detect noise	Q2 Is the species impacted by noise?	Q3 Are distribution density data available	Q4 Is the species representative of a species group or taxon?	Q5 is the species abundant or common in the area?
White Beaked Dolphin	Yes	Yes	Yes	Yes	No
White Sided Dolphin	Yes	Yes	Yes	Yes	No
Minke Whale	Yes	Yes	Yes	Yes	Yes
Bottle Nosed Dolphin	Yes	Yes	Yes	Yes	Yes
Harbour Porpoise	Yes	Yes	Yes	Yes	Yes
Risso,s Dolphin	Yes	Yes	Yes	Yes	Yes
Long-finned Pilot Whale	Yes	Yes	Yes	Yes	Yes
Sperm Whale	Yes	Yes	Yes	Yes	Yes
Beaked Whales	Yes	Yes	Yes	Yes	Yes
Striped Dolphin	Yes	Yes	Yes	Yes	Yes
Common Dolphin	Yes	Yes	Yes	Yes	Yes
Fin Whale	Yes	Yes	Yes	Yes	Yes
Spotted Dolphin	Yes	Yes	Yes	Yes	Yes
Short-finned Pilot Whale	Yes	Yes	Yes	Yes	No
Sowerbys Beaked Whale	Yes	Yes	Yes	Yes	Yes
Baleen Whales	Yes	Yes	Yes	Yes	Yes

Step 2. Risk Identification

Risk identification involves identifying a pathway between the risk sources creating the **Pressure** and the sensitive **Receptors** within the study area.

Activities (Drivers)

As mentioned in the previous section, Commission Directive 2017/845 (EC, 2017b) lists a number of Activities, all of which could generate anthropogenic noise to a greater or lesser extent. Examples include:

- Transport - shipping
- Extraction of oil and gas
- Extraction of minerals
- Fish and shellfish harvesting
- Military Operations (eg. low-frequency sonar, mid-frequency sonar)
- Renewable energy generation (wind, wave and tidal power)

Despite the range of activities, the disruption of ambient ocean soundscapes by the continuous low-frequency noise generated by commercial shipping can be considered the most spatially widespread and persistent problem globally, in particular in the northern hemisphere (Hildebrand, 2009; Cominielli, 2018). Therefore, data collection focused on this activity as the most significant generator of continuous noise in the RAGES area.

Pressures

The relevant Pressures for Descriptor 11 have been listed in the Commission Decision 2017/848 (EC, 2017a) as:

- Input of anthropogenic sound;
- Input of other forms of energy.

The work of the RAGES project focused on the first of these and Table 1 shows that the MSFD includes two criteria, one focusing on impulsive (resulting from e.g., drilling and oil and gas activity) and the other on continuous noise (resulting from Activities such as shipping, offshore wind turbines). Regulation of ocean noise has usually tended to focus on the impulsive noise sources, with the MSFD being regarded as one of the first regulatory attempts to tackle continuous noise (Erbe, 2013, Erbe et al., 2014 but see also IMO/MEPC, 2014). Therefore, whilst the RAGES project has placed considerable focus on developing a risk-based approach for continuous noise, we did also address the impulsive noise criterion (see Annex I).

(DELIVERABLE 4.1, TASK 4.1 - DATA COLLECTION ON D11)

Subregional-scale datasets

At a subregional scale, no dataset of continuous noise exists at present for European waters. Active efforts to develop regional models of continuous noise for the North East Atlantic are currently underway as part of a number of EU projects including JONAS, SATURN and private initiatives such as the Quiet Oceans Noise service and these could be incorporated into the RAGES risk process once they become available. In the meantime, in the absence of a noise dataset at the appropriate regional scale, a shipping density dataset based on AIS data is used here as a proxy for continuous noise. The Human Activities Data Portal of The European Marine Observation and Data Network, EMODnet (www.emodnet-humanactivities.eu) has developed a processed shipping dataset from AIS (Automatic Identification System) data for European waters. At present, this represents the only freely available dataset that can provide European-scale shipping information to inform studies of continuous underwater noise. For this study, the data from 2017 only were used by way of illustration, however the EMODnet website now also includes AIS data from 2018 and 2019. These AIS data were originally acquired from and pre-processed by a commercial provider (Collecte Localisation Satellites-CLS). The data were further processed by EMODnet such that density was expressed as ***ship hours per square kilometer per month***. A detailed description of all pre-processing, processing and interpolation routines employed can be found in the EMODnet method statement (Falco et al., 2019).

The RAGES project is facilitating subregional cooperation to develop a risk-based approach and to do this, products that are freely available at a broad scale were being used. However, the flexibility of the approach means that it can be followed with any dataset, for example, if in the future broadscale noise models are available, the process can again be followed in the same way. Although shipping density is being used as a proxy layer in this study, it is *not* assumed that it replaces quantitative noise models. Further modelling work is needed to establish the true impact of shipping and its relation to overall noise in a given area and therefore, there are a number of important caveats associated with using shipping density, which are detailed below:

- Many factors are known to affect the propagation of sound underwater, such as bathymetry, seafloor composition and oceanographic factors. As a result, shallower ocean basins (eg. North Sea) will have very different noise profiles to very deep ones (eg. North East Atlantic) and animals in each of these areas would perceive the same noise in very different ways.
- The EMODnet data currently has a coastal bias and under-represents data far from shore. This should be borne in mind when interpreting the results of the analysis, especially when comparing coastal and offshore regions.
- A recent noise model study in the North Sea and Celtic Sea (Farcas et al., 2020) indicates that while the association between sAIS (satellite AIS) and overall noise is weaker in deeper water and at lower frequencies, sAIS shipping data can dominate noisescapes and closely follow the patterns of underwater noise at higher frequencies. In the Azores case study undertaken as part of this work (See RAGES Deliverable 4.6), the noisiest locations in the study area corresponded reasonably well to locations with higher density of ships, but modelling results showed that noise propagated over areas beyond shipping routes. This should be taken into account when interpreting the data shown here.
- It is known that exposure should be calculated separately for varying ship types (for example as shown by McKenna, 2012), because the noise generated differs between them. However although the data within EMODnet is divided into ship types, these types cannot easily be equated with a particular noise profile. Therefore, for this initial analysis, data for all ship types were considered together.

Data collection for The Bay of Biscay noise model

The approach to risk assessment at a local scale was the same as that used at a subregional scale with continuous noise emitted by ship traffic also being the focus. However, in this case a true pressure map (as opposed to a proxy layer) reflecting ship noise was created. Considering GES in relation to noise is complicated because some areas can have high noise levels but may not have species sensitive to noise, and some species can be more vulnerable to noise than others. Therefore, risk-based models in this study use Sound Pressure Level (SPL ref 1microPa) to measure exposure for a single highly sensitive species, *Tursiops truncatus* (the bottlenose dolphin). The type of exposure considered was based on the Communication Distance Reduction (CDR) for this species. At present, the Commission Decision EC 2017/848 indicates that 1/3 octave band of 63Hz and 125Hz should be reported but for this work, which considered the effect of acoustic masking for a selected species, the frequencies 1kHz, 5kHz and 10kHz were considered. These specific frequency bands were selected due to their overlapping with the sound repertoire of the *Tursiops truncatus,* which ranges from 0.8kHz to 24kHz (Lilly and Miller, 1961; Caldwell et al., 1990; Wang et al., 1995).

In order to assess the noise linked to ship traffic at the Gulf of Biscay, an annual AIS ship traffic dataset was used. The AIS database contained information on speed over ground, length and tonnage of each ship. Ships were treated as acoustic sources by applying a Randi Model (Breeding et al., 1996) for 10kHz frequency. In addition, seasonal variations of speed of sound in water column were considered using Argo data (www.emodnet.eu) and using the MacKenzie equation (Mackenzie, 1981) to combine sound velocity with temperature, salinity and depth. Using all of these information sources, a noise model was created of the area that was later validated with data from a passive acoustic monitoring campaign in the Bay of Biscay (N43º36,682; W02º39,419) carried out from June 20th, 2019 until September 20th, 2019, during which 25 days of acoustic data were collected. Ambient noise indicators of 1/3 octave at different frequencies (63Hz, 125 Hz, 2 kHz and 5 kHz) were obtained (Lara et al., 2019) to assess the accuracy of the model.

Step 3: Risk Analysis (for Continuous Noise)

Subregional-Scale Risk Analysis

In order to define ecological values relevant to assessing noise at a subregional level, both the consequence (sensitivity) of the receptor and the extent of exposure need to be understood. Although identifying a spatial overlap of underwater noise (or proxy thereof) and a particular cetacean species does not necessarily imply that an Impact will result, it is a necessary first step and therefore a good starting point to test the risk-based approach.

Preliminary analysis

The **preliminary analysis** as defined within the ISO 31010 Standard (ISO, 2009; 2018) can be carried out to exclude areas or situations where risk is very low or non-existent. This was carried out for the subregional scale work only and 'low' shipping density was defined as those areas with **fewer than 1 ship hour per month**. The EMODnet shipping dataset for 2017 clipped to the study area totalled 3,064,473 square km, representing the EEZs of Ireland, France, Spain and Portugal. 145,485 square kms of the total area were found to have greater than one ship hour per month. Figure 4(a) shows that the majority of the grid cells with greater than 1 ship hour were located close to the coast and analysis showed that 74% were within 50km of the coast. Although Macaronesia was the largest region by area, it had the smallest area (7,910 square km) with a shipping density of greater than one ship hour By contrast, the Bay of Biscay had the highest area (107,790 square km) in which there was greater than one ship hour (see Figure 4 (b)). Following the preliminary analysis, 2,918,988 square kms with fewer than one ship hour were excluded from further analysis and only the area with greater than one ship hour per month was analysed further.

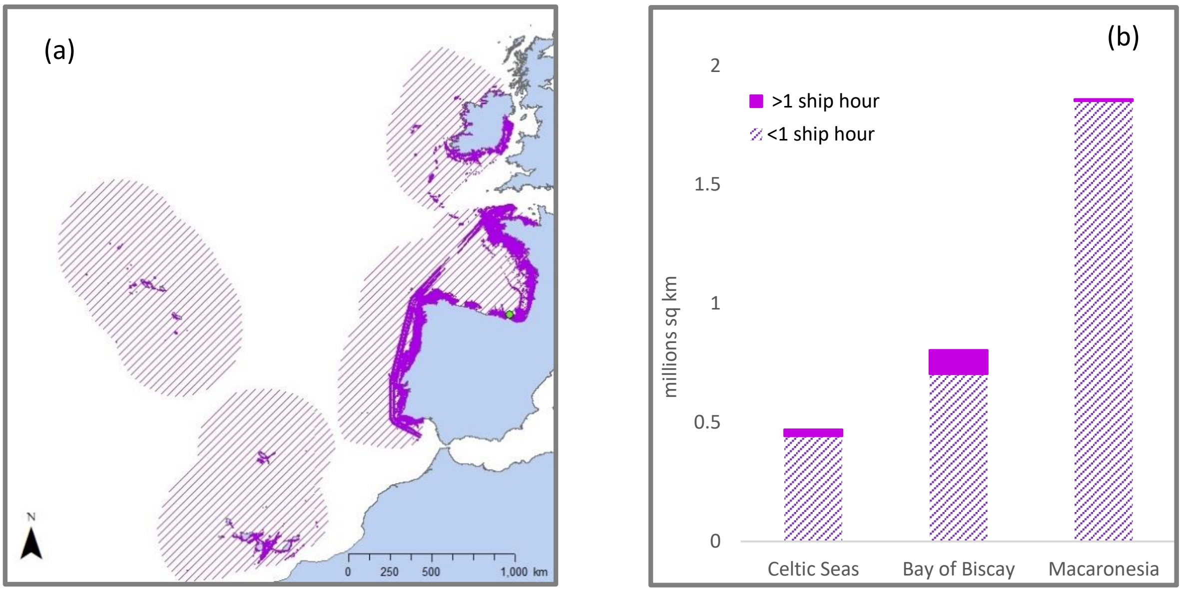


***Figure 4.** Preliminary analysis of EMODnet shipping density data in the RAGES area, showing **(a)** where the number of ship hours per month was < 1 (hatched area) and > 1 (purple area) and **(b)** each subregion represented graphically, showing the relative number of square kilometers where the number of ship hour was <1 (hatched) and > 1 (purple). Only the purple areas were taken forward for further analysis.*

Consequence Analysis

For the consequence analysis sensitivity – State Change), a similar approach to sensitivity was taken for the subregional and local scale analyses. The environmental pressure caused by continuous noise may result in the deterioration of the State of a particular population and the aim of the consequence analysis is to look in more detail at the species (or species groups, habitats) affected by noise in each of the two 1/3 octave bands indicated within the EC 2017/848 (EU, 2017a). Due to the lack of data about the true environmental consequence of the pressure, the sensitivity of the species is essentially used as a proxy for consequence. The species to be taken through this process would ideally be all of those identified from the Step 1 (see Table 2 and Box 1 above). However, despite decades of research, as well as increasing concern about underwater noise impacts on cetaceans, it is accepted that quantitative data describing cetacean's sensitivity to ship noise remains inconclusive (see Erbe et al., 2013 and Southall et al., 2019). Therefore the sensitivity process was conducted by performing a qualitative expert judgement-based scoring process, designed to identify the species likely to be most affected by exposure. The method used is described in Box 2 below and eight of the species emerging from Step 1 were taken through this process: Beaked Whales, Bottlenose Dolphins, Bottlenose Dolphins, Sperm Whales, Common Dolphins, Minke Whales, Risso's Dolphin and Fin Whales. The number of species represents the extent of expert evidence that was available at the time of this work. At least one expert completed the process for each of the eight species, and where more than one expert completed the process, the mean of their scores was used. The results are illustrated in Table 3 (b). These species were chosen to illustrate how the process could be applied to a range of species with differing ecologies and geographical distributions. Ideally all of the species on the long list from Step 1 should be taken through this process, but further input from experts would be required to achieve this (see comments on page 25 for further details).

Box 2: Sensitivity Analysis to identify the most relevant receptor species

The consequence of the noise pressure for each population was quantified by adding up a list of scaled (from 0-4) criteria, so that a higher total value indicated more severe consequences of noise disturbance. The criteria used were:

1. **Conservation status.** This was based on the IUCN Red List classification, but also took into account regional directives (e.g., the EU Habitats Directive Annex II/IV) and local population assessments. **CR/EN=4, DD/VU=3, NT=2, LC=0, Under EU protection=3, Locally threatened=4**
2. **Critical/important habitats affected.** These included areas such as foraging hotspots, breeding/nursing grounds, and migration corridors, as well as areas that encompassed all or most of a species' known range. **None=0, ~one third of breeding grounds=3, More than half the feeding grounds=4**
3. **Sensitive life stage affected.** This took into account that impacts on reproduction and survival of juveniles to reproductive age will negatively affect a population's ability to recover from disturbance, thus lowering its resilience. **None=0, Neonates/Pregnant females=4**
4. **Type and severity of sensitivity to acoustic disturbance**This criteria weighted impact by the **probability** of occurrence and the **severity** of the outcome, i.e., how commonly is that effect observed and how damaging are the consequences. **.** Both severity and probability are given a score between 0 and 1. Due to data deficiencies, these scores were given as 0, 0.25, 0.5, 0.75, 1 which reduced the possibility of false accuracy. The two values were then multiplied to give the overall sensitivity for that species between 0 and 1.. The following table illustrates this:

Type of impact	**Probability**	**Severity**	**Sensitivity (Prob*Severity)**
Physical (auditory)	0-1	0-1	0-1
Physical (non-auditory)	0-1	0-1	0-1
Perceptual	0-1	0-1	0-1
Behavioural	0-1	0-1	0-1
Overall sensitivity			**0-4**

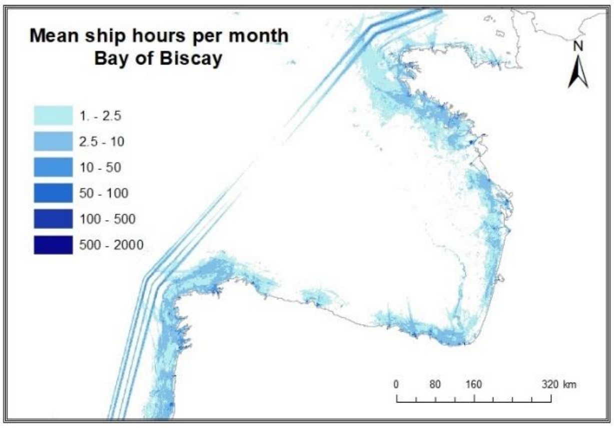
Table 3. *Sensitivity Scores for eight priority cetacean species calculated according to Box 2 (note that sensitivity calculations were not undertaken for eight species only)*

(b)	**Q1. Conservation status**		**Q2. Critical/ important habitats affected**		**Q3. Sensitive life stage affected**		**Q4. Overall Sensitivity**		**Final Score**
Species	**Score**	**Comments**	**Score**	**Comments**	**Score**	**Comments**	**Score**	**Comments**	
Minke Whale	0	Least Concern	2	Important habitats found over the entire RAGES area	4	Resident species, so calves, females and juveniles all present	0.5	Hearing range (audiogram):.01-34kHz	6.5
Bottlenose Dolphin	0	Least Concern	4	There are several resident coastal populations in RAGES area + uncertain range of offshore populations	3	Evidence that females are affected more than males (Gomez et al., 2017)	1.75		8.75
Risso's Dolphin	1.5	Globally "Least Concern", "Data Deficient" in Europe, arguably at low/medium risk. Annex IV in EU Hab Dir demands strict protection	3.25	Important calving/nursing grounds in the Azores, foraging hotspots near continental shelf edge & English Channel, generally high site fidelity to small areas	0	Scenario sound at much lower frequency than this species' threshold, so unlikely to be affected at any stage	0	Can't find evidence that Risso's are affected in any way at such low frequencies, so the probability is 0 and it doesn't really matter what the severity is.	4.75
Long-finned Pilot Whale	0.5	Globally "Least Concern", Annex IV in EU Hab Dir demands strict protection	1.25	Some seasonal movement inshore (i.e., more within RAGES area) following food sources	2.13	Evidence of female philopatry, meaning same female individuals could be repeatedly exposed to a specific area's noise, or displaced from their preferred range if disturbance is too high	0.56	Similar to Risso's, generally react to higher frequency and sound pressure levels than this scenario	4.44
Sperm Whale	3	Vulnerable	3	Important habitats found over the entire RAGES area; Critical habitat in Azores (breeding) and to and from (migration)	2.75	Resident species, so calves, females and juveniles all present; Sexual segregation outside breeding grounds may cause disproportionate impacts between the two	0.73	potential masking of echolocation, so reduced foraging success; some evidence of going silent and behavioural changes in vessel presence	9.48
Beaked Whale	4	Most spp. are data deficient and therefore a precautionary approach taken	3	Some of the RAGES area contains critical habitat (eg. shelf area where they feed)	4	Unknown, therefore precautionary approach taken	2.5		13.5
Fin Whale	3	Vulnerable	3	Some of the RAGES area contains critical habitat during migration	2	Juveniles may be more at-risk during migration	1.75		9.75
Common Dolphin	0	Least Concern	2	Identified over the entire RAGES area	4	Resident species, so pregnant females, calves and juveniles present	0.5	Hearing Range 5-150kHz	6.5

Likelihood Analysis (Exposure)

The purpose of the **likelihood** analysis is to undertake an analysis of the overlap between the Pressure under assessment and the ecosystem elements selected (i.e. the exposure). Likelihood analysis should consider both temporal and spatial exposure and the candidate indicator currently being developed via the OSPAR ICG-Noise group could be applied once it is in a more advanced stage of development. To consider the issue of underwater noise at a subregional level, the RAGES project used AIS data processed by EMODnet to create an activity layer as a *proxy* Pressure layer to identify areas where continuous noise Pressure is likely to be high. A full description of the data and the processing undertaken can be found on the EMODnet website

The shipping density data for the RAGES area was first analysed to consider differences between sub-regions, this involves a more detailed consideration of the regional dataset used in the Preliminary Analysis above. Figure 4a illustrates the shipping density data for one sub-region by way of example and Figure 4b illustrates how certain sub-regions have a higher density of shipping than either of the other regions, with Macaronesia having particularly low shipping densities.



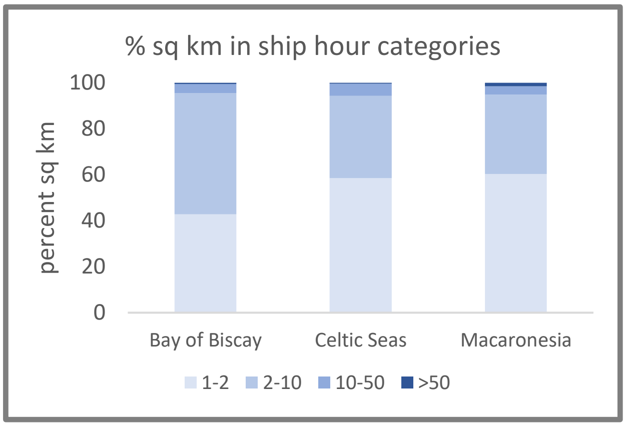


***Figure* 5**. *(a)*

*An example of the EMODnet shipping density data from the Bay of Biscay (showing only data where shipping density was greater than one ship hour per month) and **(b)** the percent area within each of four density categories per region*

Although Figure 5 provides a useful comparison between sub-regions, further analysis is required in order to identify areas where risk is highest and to do this for the RAGES area, the cetacean density data and the shipping were considered together. The average density per cetacean species (those listed in Table 2) was obtained for each SCANS and ObSERVE survey box, as well as for the MISTIC Seas survey boxes (these boxes were created based on the extent of the survey data received by the RAGES project). These survey boxes are all illustrated in Figure 2. The data were imported into ArcGIS and the average shipping density (number of ship hours per month) was also calculated for these boxes using the Zonal Statistics function. The average cetacean densities were then overlain with the average shipping densities for each survey box and the result of this exercise is illustrated in Figure 6. This figure allows areas of high density of individual species of interest to be identified and also allows particular survey boxes exposed to a higher shipping density to be identified. For example, the figure shows that high densities of Spotted Dolphins were recorded around Madeira, but they are exposed to relatively low levels of noise, compared with Striped Dolphins in SCANS Survey Box AC (located along the northern coast of Spain), which are exposed to higher levels of noise but were recorded in relatively low densities.

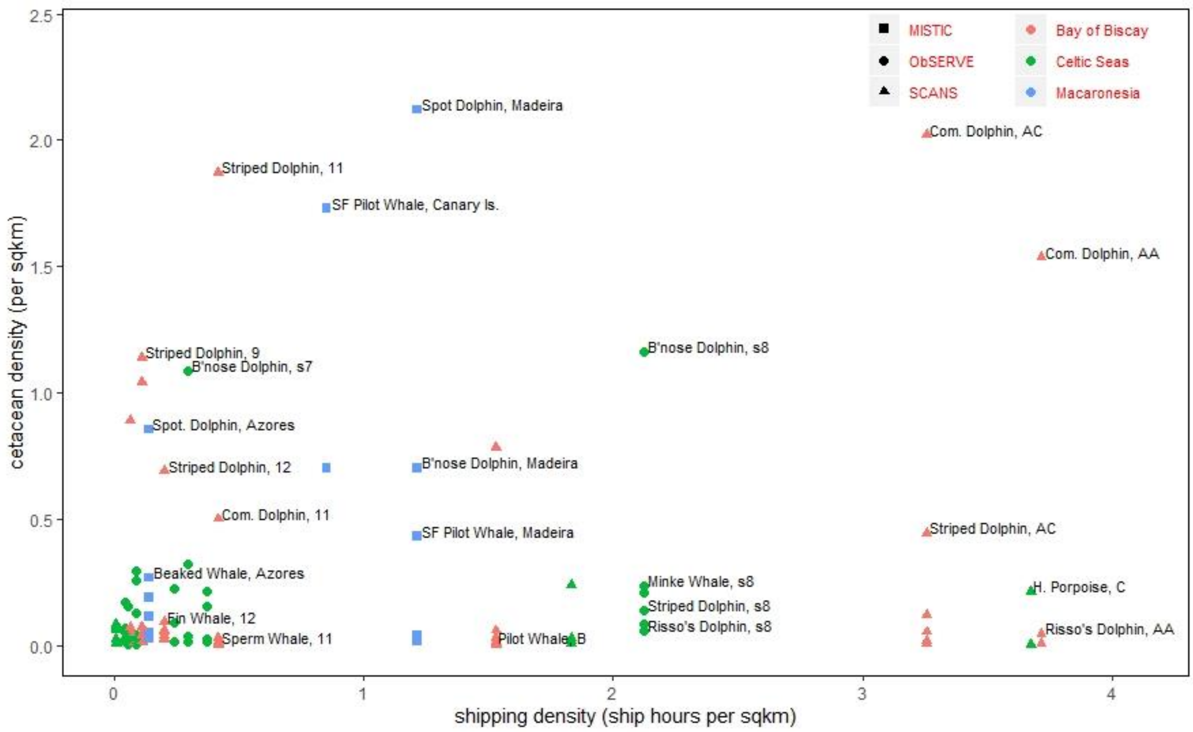


Figure 6. *Exposure to continuous noise for Cetacean Species in the North East Atlantic. For each survey box, cetacean densities (per sq km) were overlain with the average shipping density (ship hours per sq km). The codes refer to survey boxes shown in Figure 2.*

A likelihood score per cetacean species per survey box was then calculated per species per survey box. This was done by obtaining a proportional density per species per survey box (relative to the whole study area) and multiplying this by the shipping density for that survey box as follows:

$$\textbf{Likelihood} = (D^{sb}/D^{t}) * SD^{sb}$$

Where:

$\mathbf{D^{sb}}$ = Density of Species X within Survey Box Y

$\mathbf{D^{t}}$ = Total density of Species X in RAGES area

SD = Shipping Density for Survey Box Y

For example, for the Common Dolphin in Survey Box AA:

$\mathbf{D^{sb}}$ = 1.536
$\mathbf{D^{t}}$ = 8.431

SD = 3.715

Likelihood Score for Common Dolphin in Survey Box AA = (1.536/8.431) * 3.715 = 0.677

This likelihood score can be used in the risk evaluation step along with the score for consequence, and together these will be used to establish risk level.

Local-Scale Risk Analysis (Bay of Biscay modelling work)

Consequence Analysis

The results of the consequence analysis at the subregional scale were also relevant for local scale work and in this case, the Bottlenose Dolphin (*Tursiops truncatus*) was considered a suitable species for the development and application of a risk-based model. This is because data are readily available for this species and in addition, the frequency range of their whistles goes from 0.8kHz to 24kHz (Lilly and Miller, 1961; Wang et al., 1995) and their hearing sensitivity is 1-180kHz (Finneran et al., 2010; Houser et al., 2008). It is known that acoustic attenuation during propagation depends on frequency and that higher frequencies are strongly attenuated. Considering also that the acoustic emission of ships is stronger at lower frequency values, the lower frequency limit on *T. truncatus* whistles makes them likely to be affected by ship noise.

Likelihood Analysis

Coming up with a measure of likelihood (or 'exposure') at the local scale involved a consideration of the noise maps produced using AIS data. This analysis considered the masking effect of noise on the receptor, defined as the rise of the hearing threshold for a given frequency band due to a presence of noise overlapping in time and space (Erbe et al., 2016). Analysis of masking is not trivial and depending on the acoustic variable used, the information retrieved can have different interpretations. The most direct way to try to evaluate the potential threat of acoustic masking would be to consider the noise map and Sound Pressure Level (SPL) at each cell of the simulated area. However, the absence of thresholds makes it difficult to establish a direct relationship between cause (ship traffic noise) and effect (in our case acoustic masking). Moreover, it is not easy to apply other metrics like Sound Exposure Level (SEL) to continuous noise because the time exposure is different from that of impulsive noise. For this reason, a Communication Distance Reduction (CDR) from pristine ambient has been considered as an acoustic related variable to perform this analysis (see Figure 7 for an illustration).

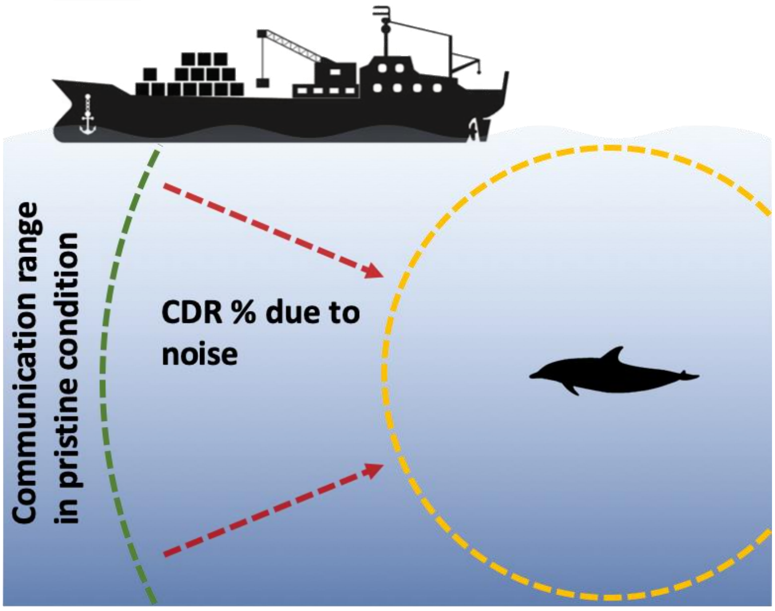


***Figure 7**. Conceptual diagram of distance reduction due to noise.*

Following this approach, it is assumed that whatever the noise level is, a masking effect of some kind will be generated, depending on the distance between emitter and receiver. Applying sonar equations, it is possible to calculate the distance the emitter and receiver must be from each other to receive at least the same SPL from social calls (whistles etc). Obviously, this distance will be reduced by the presence of maritime traffic compared with pristine ambient. Therefore, the method can first assess how degraded the medium is with respect to noise (using CDR) and second it can correlate CDR with species density. In this sense the method is used to determine risk by correlating density of animals with noise present in the area, but it will not detect high risk areas where animals are not present. The analysis performed does not consider the detection threshold or auditory weighting function. This simplifies the calculation and circumvents the lack of knowledge or agreement between experts about values of these variables for different species as such it represents a logical and defensible risk-based approach.

Step 4: Risk Evaluation

(TASK 4.3, DELIVERABLE 4.3 - DEFINE RISK CRITERIA SIGNIFICANCE LEVELS)

Risk Evaluation at a subregional scale

The aim of risk evaluation is to arrive at a measure of **relative risk**, which will in turn inform GES assessments and enable prioritization of Measures. Following the ISO process and building on work carried out in the MISTIC SEAS II project (Saavedra et al., 2018), the likelihood and consequence information were considered together as follows:

CONSEQUENCE x LIKELIHOOD = RISK

For the eight species where a consequence figure was calculated, the likelihood score was graphed against the consequence score (see Figure 8). A graphical representation of these data allows species (or indeed any ecosystem element) more at risk to be identified and thus is a useful tool for assessing relative risk. Once threshold values have been determined and agreed, these can be added to this chart to help to categorise species into different risk groups. A number of points should be noted:

- A **theoretical** simple threshold line has been added to Figure 7 by way of illustration only. Work is ongoing to develop a harmonized approach to the thresholds and once these are in place, those species that are considered high, medium or low risk can be determined. It should also be noted that thresholds might not necessarily form a 'square' as illustrated here.
- This chart should ideally be produced taking temporal considerations into account. For example, since fin whale distribution and critical habitats are very seasonally dependent, their migration or feeding stopovers may overlap more with shipping routes at certain times of year.
- In order for a consequence score to be calculated for **all** species emerging from Step 1 (Establishing the context), further expert input is needed to apply the Priority Index process.

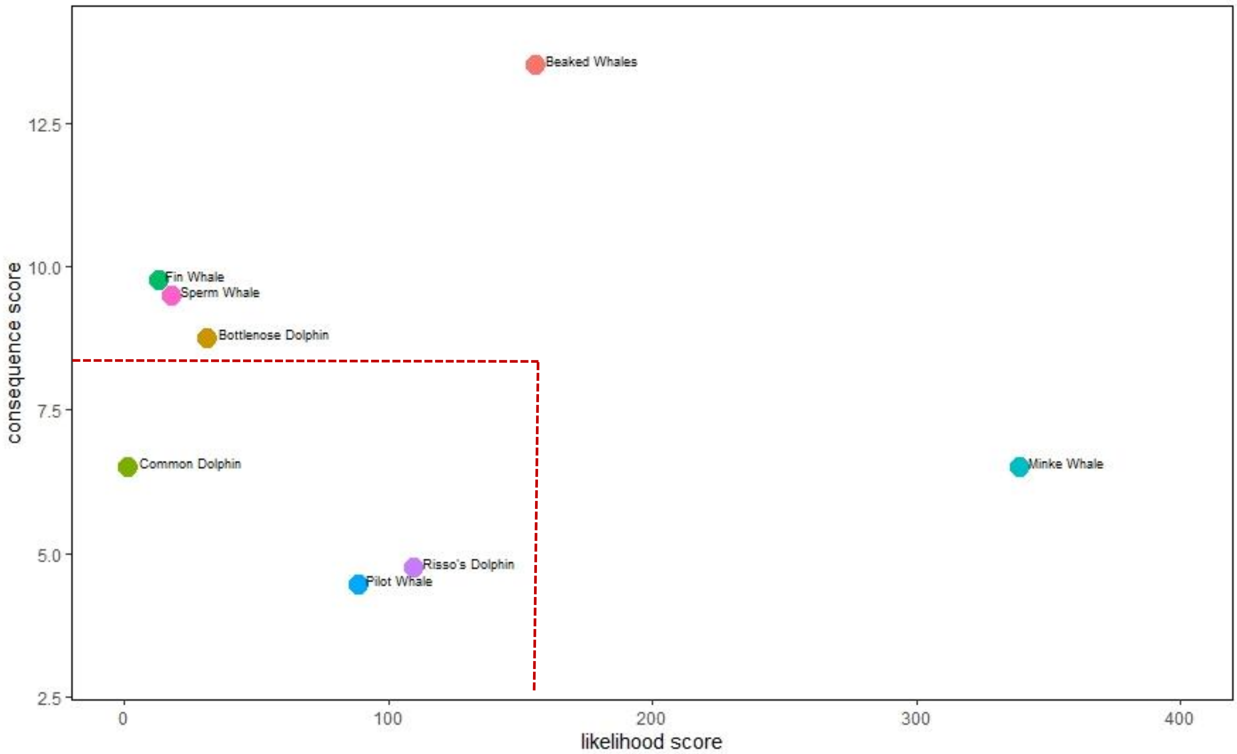


***Figure 8.** Risk Evaluation – **consequence** based on sensitivity analysis and **likelihood** based on average exposure scores (per survey box) for each of eight species. This would allow relative risk to be determined once Threshold Values are in place. Red dashed lines represent **theoretical** likelihood and consequence Threshold Values for illustration purposes only.*

Risk Evaluation at a local scale

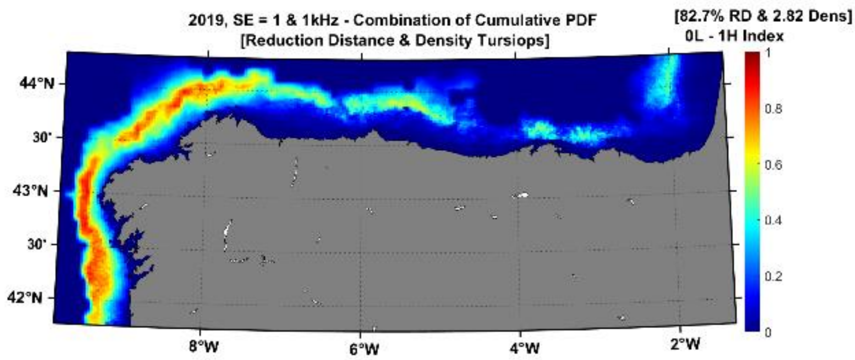
The use of communication distance reduction (CDR) provides the opportunity to study the masking effect over whistles and other social calls at frequencies <= 10kHz. The hypothesis in this case considers that the presence of ship traffic produces a certain signal overlap from the physical point of view, even if noise level is lower than the signal arriving to an ideal receiver from a conspecific. The calculation of CDR depends on the total noise in the area, making it possible to study the percentage CDR in ambient noise with or without ship traffic, which allows a comparison to be made between pristine ambient and the current situation. Cases illustrated in this work were developed assuming ambient noise for 1kHz, 5kHz and 10kHz and sea state 1 (following the Beaufort Scale where wind speed is 1 - 3 knots and wave height is 10cm) and using tabulated values for Wenz curves (Wenz, 1962). As expected, the % CDR with respect to pristine ambient decreased with increasing frequency, due to the level of ship noise present in the area. At 1kHz, maximum values of CDR were 82.7%, at 5kHz, the maximum value of CDR was 64.5%. and for 10kHz, the maximum value of CDR was 55.2%. In all cases, *T. truncatus* density was 2.82 and the Risk Index was 1; see Table 4 for detailed statistics.

The calculation of CDR from pristine ambient due to ship traffic gives an idea of the auditory effect of noise on certain marine species, using as a 'baseline' the distance at which an ideal emitter and receiver can communicate in a no ship traffic situation. Risk evaluation can be based on the possibility of a masking effect occurring in areas where *T. truncates* is present. Both related acoustic variables allow areas with a potential threat of masking to be identified. The resulting risk map is shown in Figure 9 below.

Frequency [kHz]	***Mean % CDR***	***Standard deviation***	***Maximum***	***Minimum***
1	63.6%	10.5%	82.7%	16.6%
5	49.2%	7.7%	64.5%	16.7%
10	42.1%	6.5%	55.2%	17.7%

***Table 4.** Details of statistics for distance reduction percentage at Sea State 1 at different frequencies considered.*

(a)



(b) (c)

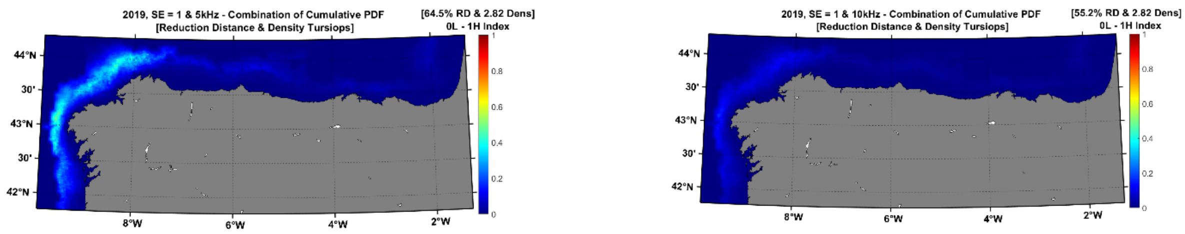


***Figure 9. (a)** Risk map based on density of population and distance reduction from pristine ambient considering sea state 1 at 1kHz. In this case 'Risk index' value 1 is related with maximum values of distance reduction and density of bottlenose dolphins (82.7% & 2.82 respectively). **(b)** In this case, the Risk map is based on calculation of noise at 5kHz. As is expected, the highest value of communication distance reduction is lower than obtained for 1kHz because spectral dependence of noise radiated by ship points that noise deposed in the medium is lower at higher frequencies. 'Risk index' = 1 corresponds in this case, to 64.5% of distance reduction and 2.82 density of population. (c) In this case, Risk map is based on calculation of noise at 10kHz. 'Risk index' = 1 corresponds in this case, to 55.2% of distance reduction and 2.82 density of population.*

Step 5: Risk Treatment

The Risk Treatment step - as defined within the ISO standard (ISO 31000, 2018) – essentially determines the action recommended for areas or situations deemed to be "at risk". This may be taken to refer to the Programmes of Measures (Article 13 of MSFD) and will be examined in more detail in Deliverable 4.5 and in Work Package 5 of the RAGES project.

Lessons learned and Recommendations

The ISO standard methodology provides an ideal framework within which regional and subregional comparisons can be nested, not just for directives like the MSFD, but for marine ecosystems more broadly. It enables regional cooperation even where data availability is patchy or non-existent and it can identify knowledge gaps and steer capacity-building efforts in appropriate directions. For continued progress towards implementation of the MSFD however, future work should explore the applicability of the Risk-based approach to other descriptors, and some of this work is already underway for Descriptor 2 (Non-Indigenous Species), which is quite different in terms of risk typology). For Descriptor 11, further work and development is needed to make best use of the benefits of the risk-based approach. In this document, we have identified and worked through the major steps of the Risk Based Approach for underwater continuous noise (D11 C2). The steps of the ISO standard and the guidance within RAGES Deliverable 2.3 (RAGES, 2021) provide a clear means of structuring the analysis, however some challenges were encountered and the most significant of these are outlined below.

Determining what each risk step entails

There is not always clarity on which specific aspects of the analysis are contained within each risk step. Although this is not a hugely disruptive issue and the approach remains flexible to account for different scenarios it is important that the process is sufficiently clear. While further explicit guidance on the distinction between the steps might be of benefit, the approach must achieve the correct balance between prescriptive instruction and flexibility. It is certain that flexibility is paramount when applying the approach to different descriptors and any areas of difficulty should be acknowledged within risk assessments. For D11, some specific issues include:

- The distinction between **Step 1, Establishing the Context** and **Step 2, Risk Identification** was difficult to define for this descriptor. For example, the Risk-based approach is set up such that parameters (variables to be assessed during Risk Analysis) are defined in Step 1: Establishing the Context. This section does not explore Pressures, which are included in Step 2: Risk Identification. For D11, it was challenging to identify receptors and consider how they are impacted (in Step 1) without also considering the Pressures causing these Impacts.

Mentioning Pressures in Step 1 was unavoidable in this case, but this did seem to somewhat negate the purpose of Step 2, which examined pathways.

- **Step 2, Risk Identification** has been approached such that it is rooted in the Pressures in the geographic area of study. Thus, we have included data collection for the Pressure proxy in Risk Identification. This may not be considered appropriate and others may feel Data collection fits better within Step 3, Risk Analysis.
- At **Step 3, Risk Analysis**, the work at the subregional scale done as part of the Preliminary Analysis could instead have been included in the Likelihood Analysis. It doesn't have a material impact on the work, but in some cases excluding areas prior to a likelihood analysis may not be considered appropriate.

Quality of receptor data for Descriptor 11

Due to the differing spatial resolution of the cetacean datasets made available to the RAGES project, the density information has been analysed at a high level of aggregation (to survey box). Although the data from the MISTIC Seas work was provided at a much more detailed level (per square km), it was not possible to use the data in this way for a regionally harmonized approach as it was necessary to have all datasets at a similar level of detail. Clearly, were SCANS and ObSERVE datasets available at a higher level of spatial resolution, more detailed analyses could be conducted. A harmonised database of cetacean density distribution is needed; one that is spatially standardised, freely available, accompanied by appropriate metadata and crucially, that allows for temporal considerations to be taken into account. The latter is particularly important for migrating cetacean species such as the Fin Whale, for which risk levels will vary at different periods throughout the year. All of these recommendations are supported by the stipulations of the Aarhus Convention on Access to Information, Public Participation and Access to Justice in Environmental Matters (United Nations Economic Commission for Europe, 1998), for which data sharing, data archive centres and freely available environmental data are central pillars. Despite these caveats, the data used here remain the best information available and the most appropriate to use at this scale. As was the case with pressures data, the risk process can be applied to new and improved datasets once they become available.

Quality of pressures data for Descriptor 11

The subregional work in this study used AIS data as a proxy for pressure data, because at present, modelled noise data is simply not available at this scale for European waters. There has been considerable debate within the RAGES project as to the appropriateness of AIS data as a proxy for noise. While qualitatively the latest publications suggest that shipping noise dominates noisescapes in some cases, (Farcas et al., 2020), they also caution that this does not apply in all cases, particularly in deeper water and for lower frequencies. Further modelling work will thus be required to establish how reliable a proxy approach is in identifying areas of risk. Continued developments in the science of noise modelling will increase our understanding of ocean soundscapes but it will also improve the knowledge base for the use of risk-based approaches. Such work continues apace in Europe within initiatives such as the JONAS and SATURN projects, which should be tightly linked to policy needs in order to maximise its application and usefulness. In the meantime, a European-scale map of maritime transport (including offshore shipping) that can be accurately related to noise is required in order to improve the accuracy and utility of risk-based approach at a broadscale level

Although noise models covering the entire RAGES were not available, their use was demonstrated at a local scale in the Bay of Biscay. A series of further noise models like this could also be created in other key areas in order to build up a fuller picture of the overall noise profile within the busy shipping areas of European waters. Passive acoustic monitoring campaigns and measuring stations alongside automatic detection algorithms of cetaceans could also help to validate density models and create sensitivity maps for species. There is also potential for modelling approaches to be harmonised, for example by filling gaps at the regional level and indeed, repeated studies could track areas of increasing or decreasing risk by identifying changes in cetacean population density, migration to other zones as well changes to ship traffic volume. Finally, one of the great benefits of the risk approach is that it has been developed in such a way that it can be applied to any type of dataset and the work undertaken in RAGES will be equally applicable once modelled data does become available.

Consequence analysis for Descriptor 11

Development and refinement of the Priority Index and alignment with current regional initiatives is vital if these are to inform MSFD implementation nationally. While work to understand the impact of noise on cetacean (and other) species will no doubt continue, this will take considerable time and resources, and in the meantime an expert judgement led sensitivity process provides a realistic and effective solution. There is a flexibility to expert judgement processes that lends itself very well to a broad process encompassing different jurisdictions; in the example provided here, some judgements were made by an individual expert but it may be more robust - and transferrable - if completed by a panel of experts who agree on a shared set of scores for use more broadly. Considerable progress could be made by convening a workshop of one or two days to facilitate a discussion and build consensus on the Priority Index and Sensitivity approach outlined here.

Development of agreed qualitative working thresholds should also be a priority, and much work is currently underway on this issue, particularly within the TGNoise group. Although the absence of threshold values is seen as an impediment to progress in policy decisions, the final Risk Evaluation step (Step 5) provides a simple and easily understood graphical representation that nonetheless summarizes a wealth of data and expertise. This graphic has the potential to underpin policy decisions by allowing relative risk of species (or indeed any ecosystem elements) to be visualized.

The most recent work on underwater noise continues to advocate for improved national and international regulation and management of this ocean pressure, even in the face of knowledge gaps and the complexity of filling them (Duarte et al., 2021). To that end, the Risk-based approach is a robust process that can be deployed again and again, even as data are enhanced and understanding increases. It provides a clear, repeatable structure on which the determination of GES can be anchored, supporting continued regional harmonisation and consistency into the future.

Summary Table

Finally, Table 5 summarises the of the Risk Assessment process for continuous noise and impulsive noise being considered in the frame of the project, using an example for each to illustrate the process.

Table 5. *A summary of the approach to Risk Assessment steps 1, 2, 3 and 4 for Continuous Noise (Sub-Regional and Local) and Impulsive Noise*

ISO STEP	PHASE		CONTINUOUS UNDERWATER NOISE – D11, C2	
			Subregional scale	**Local Scale**
1.Establishing the context	**Species selection**		Establishing policy context, assessment scales, priority index development	*Tursiops truncates* prioritised.
2.Risk Identification	**Data Gathering**		Identification of proxy pressure data. Identification of Cetacean data from reports	Passive acoustic monitoring campaign- Bay of Biscay. June to September 2019.
3.Risk Analysis	**Preliminary Analysis**		Data cleaning - elimination of no- and low-risk data	
	Likelihood (exposure)	**Pressure elements**	EMODNet- AIS data 2017 (1km x 1km), ship hours/km^2/month	A Randi model was applied over the AIS data available for 2019 accounting for seasonal variations of speed of sound in water column based on Argo data stored at EMODnet (www.emodnet.eu). These data were validated using the acoustic monitoring campaign.
		State elements	SCANS I, II and III reports for the Celtic Seas and Bay of Biscay (Hammond et al. 2017), the ObSERVE report for part of the Celtic Seas (Rogan et al., 2018) and the MISTIC Seas report for Macaronesia (Saavedra et al., 2018b). Units individuals/km^2	Cetacean data for the Bay of Biscay were obtained thanks to the IEO PELACUS campaign. In this campaign density models for different species of marine mammals were acquired for the period 2007 - 2017.
	Consequence (sensitivity)		Quantitative data for cetacean's sensitivity to noise is absent or inconclusive and therefore a scoring process was designed to identify the most sensitive species, this was applied in all cases (Regional, local, national). Expert judgement was used to complete the scoring process	
4.Risk Evaluation			Likelihood and Consequence of different species graphed to enable relative risk to be established prioritisation of specific management units	Likelihood and Consequence overlaid geographically for a single species to identify areas of highest risk

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ANNEX 1. Impulsive Noise Case Study

APPLYING THE RAGES RISK-BASED APPROACH TO MSFD DESCRIPTOR 11, CRITERIA 1: IMPULSIVE UNDERWATER NOISE

March 2021

rages
risk-based approaches to good environmental status

Work Package	**RAGES Work Package 4** Deliverable 4.4 Perform Risk Assessment (Impulsive Noise Application)
Lead Partner	**UCC**, Ireland: Emma Verling, Tim O'Higgins, Maria Gkaragkouni
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Version	FINAL
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Background and Purpose

This document will outline the process undertaken in trialing the application of the RAGES risk based-approach to impulsive underwater noise on Ireland's continental shelf. Using a case study based on data from 2016 off the southwest coast of Ireland, the aim is to highlight the species most at risk from impulsive noise in this area. This case study makes use of a number of datasets which, although not all collected for this purpose, coincide temporally and spatially to allow them to be considered simultaneously. In the summer of 2016, an acoustic dataset on seismic activity on the Irish continental shelf coincided temporally with the collection of cetacean distribution and density data as part of the ObSERVE project (https://www.gov.ie/en/publication/12374-observe-programme). This document:

1. illustrates the use of the framework provided by the RAGES Risk-based approach with *available* datasets,
2. provides a technical description of how these datasets were examined together to consider the risk to cetacean species from impulsive noise,
3. makes an assessment of the ease of applicability of the Risk-based Approach to impulsive noise and recommendations as to what additional data might be required to refine the results.

The RAGES Risk-based approach

A full description of the RAGES risk-based approach, including explanations of the DAPSI(W)R(M) conceptual frame and how the risk process aligns with the steps of the MSFD is provided in RAGES Deliverable 2.3 (RAGES, 2021) but some of the major features of the process are summarized here (and illustrated in Figure 1) to help explain how the process was applied in this case. Step 1, **establishing the context** lays out the ecosystem elements and parameters used to measure risk as well as setting the assessment scale. This step is supported by the Commission Decision EC 2017/848 (EC, 2017a), which identifies the specific criteria for each of the 11 MSFD descriptors. Similarly Step 2, **risk identification** can be performed in part by reference to the Activities and Pressures listed in the directive amendment 2017/845 (EC, 2017b) and identification of pathways between these Pressures and particular ecosystem elements.

The **risk analysis** step (Step 3) is more involved and makes up the main analytical stage of the process containing a number of sub-steps, including:

- **Preliminary analysis** - the purpose of this is to focus resources on the most significant risks. Data are screened in order to identify the most significant risks, or to exclude less significant risks from further analysis. However, this step may not always be appropriate; it is very important not to screen out low risks which occur frequently and may have a cumulative effect (ISO, 2009 and also see Judd et al., 2015)
- **Analysis of likelihood -** the likelihood that a Pressure will have a particular effect on a receptor
- **Analysis of consequence -** the potential severity of adverse effects from exposure to the Pressure, which relates to the biological sensitivity of a species, population or habitat.

Subsequently (in step 4) a **risk evaluation** process is performed enabling the analyst to compare the risk between areas and ecosystem elements and to prioritize them.

The final step (5) involves **risk treatment**, the development of specific Measures to address the risks identified in the previous steps.0

The reminder of this paper illustrates the application of the Risk-based Approach to Impulsive Noise by closely follows these steps.

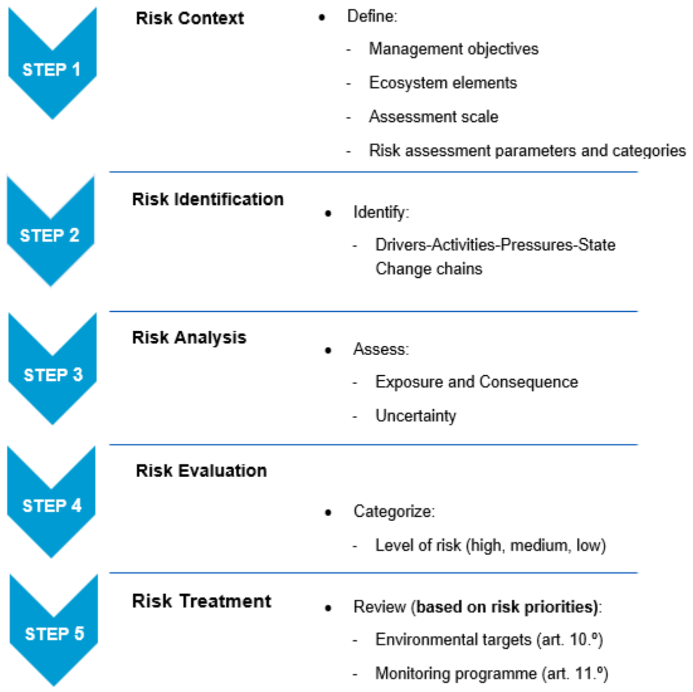

Figure 1. *The Risk-based approach as developed by the RAGES project (taken from RAGES Deliverable 2.3m, where a more detailed description of the risk process can be found)*

Step 1. Establishing the Context

Policy Context

In establishing the context for Descriptor 11, information contained within the EC Decision 2017/848 (EC, 2017a) is of key importance. This decision document provides the criteria elements and the criteria (management objectives), as shown in Table 1 below. The work presented here focusses on D11C1, impulsive noise.

Table 1. *The criteria elements and criteria laid out in EC Decision 2017/848 for Descriptor 11. The relevant criteria is shaded in yellow*

Criteria elements	Criteria: management objectives	Thresholds
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.	**Thresholds currently in development:** to be established through regional or sub-regional cooperation, but not available at the time of writing this deliverable
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	

Criteria elements	Criteria: management objectives	Thresholds
	cooperation at Union level, taking into account regional or sub-regional specificities.	

Local Context

The ObSERVE Programme was established by the Irish government in October 2014 and collects state-of-the-art data to significantly enhance knowledge and understanding of protected offshore species and sensitive habitats in Ireland. **ObSERVE Aerial** consists of a series of high-quality aerial surveys for whales, dolphins, seabirds and other marine life which covered a significant portion of the Irish EEZ and **ObSERVE Acoustic** tapped into the array of underwater sounds made by more than 20 species of whales, dolphins and porpoises, in order to learn more about their occurrence, distribution, abundance and migration habits, particularly those species that are rarely seen. These programmes represent a significant investment in providing state-of-the-art data to feed into the sustainable management of offshore activities and appropriate marine conservation strategies in Ireland. The dynamic "Atlantic Margin", where Ireland's continental shelf merges into deeper oceanic basins, has been a key focus of this work and this is also the area where seismic activity has been underway for a number of years as part of Oil and Gas exploration activities.

Assessment Scale

The study area was located in the western part of Ireland’s continental shelf and also encompassed the continental slope. This region of the North-East Atlantic is known as the Atlantic Margin, contains a series of troughs and canyons and provides a habitat for a range of cetacean species. It is also an area thought to contain reserves of oil and gas and therefore has been subject to some seismic activity. The precise study area was determined by the location of seismic activity (associated with oil and gas exploration) that occurred in the region during Summer 2016. The area crossed two of the ObSERVE survey boxes, s2 and s3 and all of this information is contained within Figure 2.

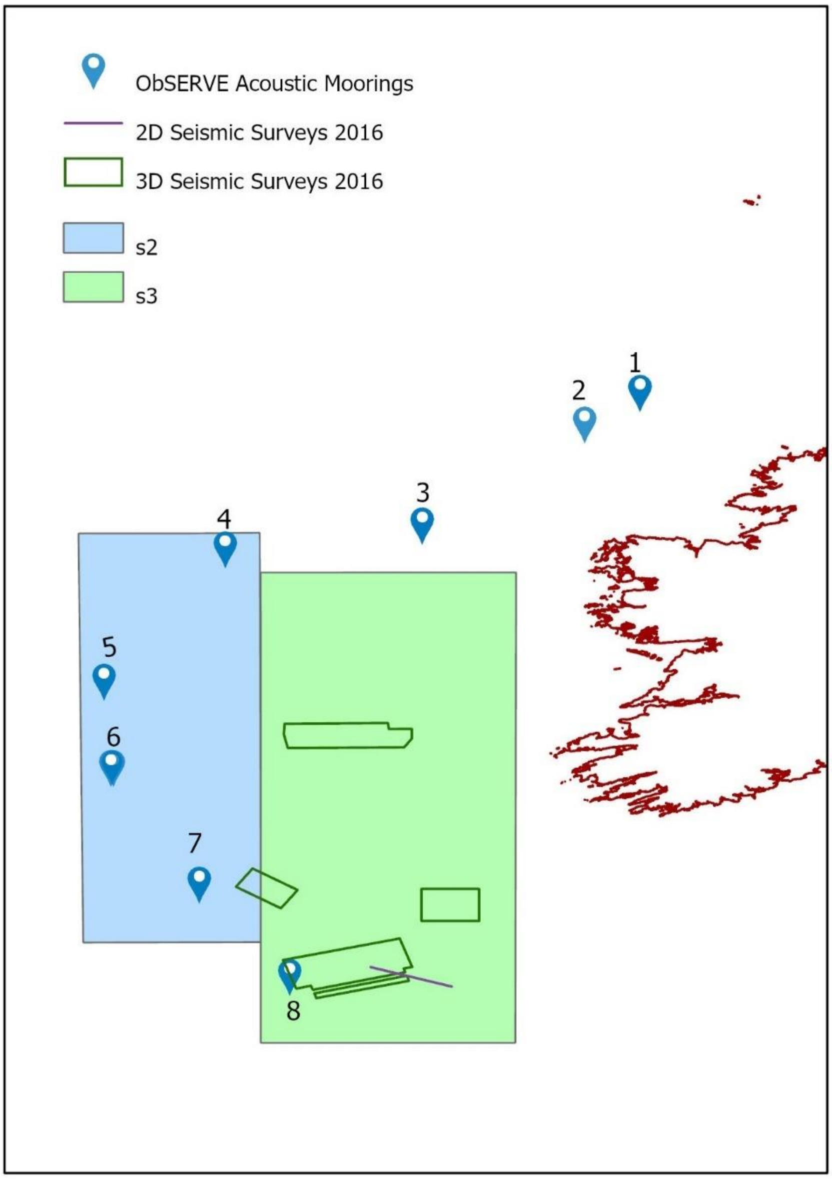

Figure 2. *Showing the location of ObSERVE survey boxes, ObSERVE acoustic moorings and seismic activity during summer 2016*

Ecosystem elements (receptors)

The impact of noise on a number of individual receptor taxa has been well-documented (eg. Tougaard et al., 2009; Blair et al., 2016; McCauley et al, 2017), but there is a knowledge gap in terms of the overall impact of underwater noise at the broader ecosystem level (Merchant, 2019). Much work has focused on the impact of noise on cetacean species, with potential Impacts including behavioural changes and displacement, resulting from processes such as acoustic masking, and hearing loss (Nowacek et al., 2007; Erbe, 2012). However, despite long-standing research efforts, it has proven very difficult to draw robust statistical conclusions between noise and cetacean behavior. A scale ranking the severity of response for cetaceans has been proposed to overcome this (Southall et al, 2007, 2019; Ellison et al., 2012) but an extensive review of evidence by Gomez et al. (2016) suggests a simpler, binary "behavioural response/no behavioural response" approach may be more appropriate given the lack of evidence and data in many cases. The review provides a summary of evidence for response to noise in a large number of cetacean species and a good basis for a broad assessment of cetacean species.

In *order to* determine which of these receptor species should be further examined, a p*rocess was developed* with which to calculate a Priority Index as a first step towards species selection. The first phase in this process was to identify which species could be examined further according to a number of simple criteria; see Box 1 for a description of this phase. This initial process was designed to generate a 'long list' of species, which can be further refined during the later Risk Analysis step. Once the process in Box 1 was applied, eight species were taken forward to the next stage of the process, which are shown in Table 3.

BOX 1. Priority Index, the process to identify the relevant receptor species for D11, C2

For each species under consideration, 5 or 6 questions must be answered. This is a binary, unweighted approach to choosing which species to focus on in the next steps. Fish and invertebrates must fulfil all 6 criteria to be considered, marine mammals must fulfil criteria 1–5.

1. Can the species detect noise?
2. Is the species known to be negatively impacted by noise? The impacts can be
   a. Physical (auditory), e.g., PTS, TTS.
   b. Physical (non-auditory), e.g., decompression sickness, internal haemorrhage, tissue rupture, death.
   c. Perceptual, e.g., masking, vocalisation shifts/changes, inability to interpret environment.
   d. Behavioural, e.g., temporary or permanent displacement, interruption of/less efficient foraging, mating, socialising.
   e. Indirect, e.g., reduced prey availability, riskier behaviour that can increase other hazards (stranding, ship strikes, predation).
   f. Chronic, e.g., increased stress, vulnerability to disease, decreased viability/reproductive success, habituation, PCoD.
3. Are there distribution/density data available for the species?
4. Is the species fairly representative of a species group (broader taxon)?
5. Is the species fairly abundant/commonly occurring within the area of interest?
6. **(For fish and invertebrates only)** Is the species commercially important?

Table 3*. Cetacean species and questions used to generate priority index. Impacts include Physical, auditory and non-auditory impacts, impacts on perception, and behaviour indirect impacts and chronic impacts related to stress, disease viability and reproductive success. A species that returned a 'no' result for any question was eliminated from further investigation.*

Species	Q1	Q2	Q3	Q4	Q5
	Can the species detect noise	Is the species impacted by noise?	Are distribution density data available	Is the species representative of a species group or taxon?	is the species abundant or common in the area?
Minke Whale	Yes	Yes	Yes	Yes	Yes
Beaked Whales	Yes	Yes	Yes	Yes	Yes
Bottle Nosed Dolphin	Yes	Yes	Yes	Yes	Yes
Common Dolphin	Yes	Yes	Yes	Yes	Yes
Fin Whale	Yes	Yes	Yes	Yes	Yes
Harbour Porpoise	Yes	Yes	Yes	Yes	Yes
Risso's Dolphin	Yes	Yes	Yes	Yes	Yes
Short-finned Pilot Whale	Yes	Yes	Yes	Yes	No
Striped Dolphin	Yes	Yes	Yes	Yes	Yes
White Beaked Dolphin	Yes	Yes	Yes	Yes	No
White Sided Dolphin	Yes	Yes	Yes	Yes	No

Step 2: Risk Identification

This study focusses on the impact of impulsive noise (the **Pressure**) created by seismic activity (the **Activity**) on cetacean species (the **Ecosystem Element**) off the western coast of Ireland, and two distinct sources of data were available:

1. **The impulsive noise data submitted by Ireland to the ICES Impulsive Noise Portal (https://www.ices.dk/data/data-portals/Pages/underwater-noise.aspx).** The ICES Impulsive Noise Portal assembles data supplied by contracting parties to OSPAR (North East Atlantic) and HELCOM (Baltic Sea). The data are collated by contracting parties from their registers of licenced events such as pile driving, controlled explosions from naval operations and other activities that release energy. A shapefile containing the locations of the seismic activity in the study area during 2016 was obtained from the Petroleum Affairs Division of the Department of Environment, Climate and Communications. This dataset represents an activity dataset or 'pressure proxy'
2. **Data from ObSERVE Acoustic project.** In the summer of 2016, a number of the acoustic moorings deployed by the ObSERVE Acoustic project picked up the impulsive sounds of seismic surveys in the study area. The location of the eight ObSERVE moorings was obtained from the ObSERVE Acoustic Report (REF) and was converted to a shapefile format (see Figure 2). This represents an ideal opportunity to consider the impact of these sounds on the cetacean species also recorded by the **ObSERVE Aerial** project in the same time period. This dataset represents a true pressure dataset (as opposed to a proxy dataset like the above).

Step 3: Risk Analysis

Although identifying a spatial overlap of underwater noise (or proxy thereof) and a particular cetacean species does not necessarily imply that an Impact will result, it is a necessary first step and therefore a good starting point to test the risk-based approach. In this case study, a likelihood and consequence analysis were carried out using the data identified in the steps above.

Likelihood Analysis

The purpose of the likelihood analysis is to undertake an analysis of the overlap between the Pressure under assessment and the ecosystem elements selected (i.e. the exposure). With regard to the Pressure, the occurrence of the seismic activity detected by the ObSERVE moorings is illustrated in Figure 3 (from Kowarski et al., 2018) below. Seismic pulses were detected by all moorings at some point during 2015 and 2016, at moorings 1-4 in 2015 and at moorings 5-8 in 2016. However, from Figure 3 it can be seen that at moorings 7 and 8, a particularly large number of seismic impulses were recorded during June, July, August and September of 2016, with seismic activity being recorded in 82.8% of the recording days. Less frequent seismic activity was also picked up by Moorings 5 and 6 during this time.

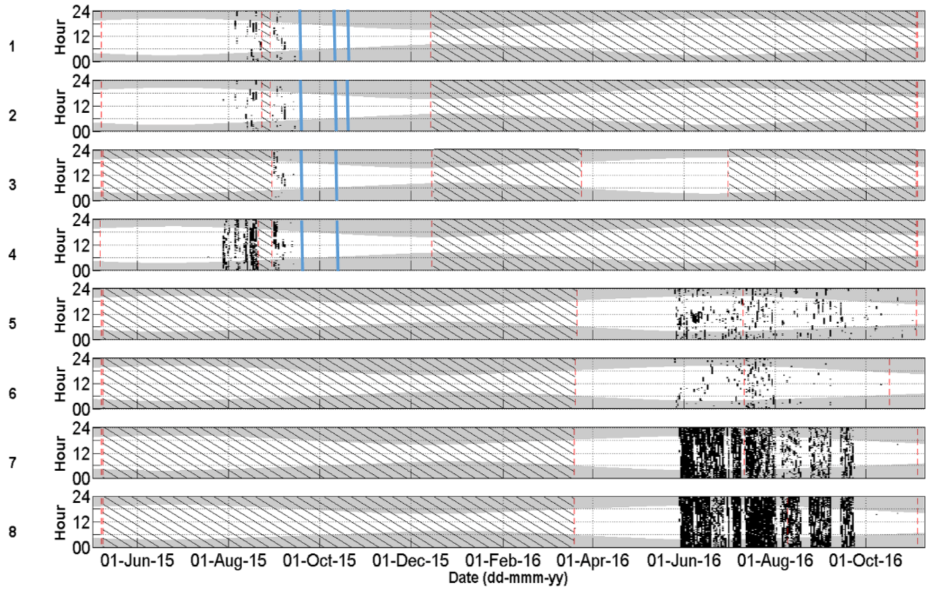

***Figure 3**. Taken from Kowarski et al, 2018 – showing the occurrence of seismic activity at ObSERVE Acoustic Moorings 7 and 8 and (to a lesser extent) Moorings 5 and 6 during summer and early Autumn 2016. Black dots represent seismic impulses.*

As regards the ecosystem elements or Receptors, the eight cetacean species taken forward from Step 1 above were considered and density estimates in the study area existed for all eight species from the ObSERVE surveys (see Table 2 below). However, the Coefficient of Variation (CV) associated with some of these estimates was high (ideally the CV would be 40 or below, but this was not always possible). Therefore, the density measure between 2015 and 2016 with the lowest Coefficient of Variation was selected as the best estimate.

***Table 2:** The density (per square km) of cetacean species found in Survey Boxes s1 and s2 during the ObSERVE Aerial Survey in Summer 2015 and 2016. Those measures with a lowest CV between the two years were selected for further consideration*

Species	2015				2016			
	s2d	**s2 cv**	**s3 d**	**s3 cv**	**s2 d**	**s2 cv**	**s3d**	**S3 cv**
Bottlenose Dolphin (BND)	0.003	100.56	0.046	51.31	0.153	55.08	0.295	30.72
Beaked Whale (BW)	0		0.0022	64.03	0.012	53.88	0.0086	46.87
Common Dolphin (CD)	0.431	80.25	0.133	70.16	0		0.125	91.24
Fin Whale (FW)	0.002	100.88	0.001	104.68	0.001	99.51	0	
Harbour Porpoise (HP)	**0**		0.049	45.1	0		0.032	52.5
Minke Whale (MW)	0.032	71.46	0.027	53.77	0		0.009	64.03
Risso's Dolphin (RD)	0		0		0.002	101.9	0	
Striped Dolphin (SD)	0.417	67.67	0.189	73.34	0		0.257	50.4

Kowarski et al., 2018 reported that the majority of seismic activity took place between June 1 and October 1 on each of 2015 and 2016 (a period of 122 days) and also provided the percentage of days during this time where seismic data was picked up at each of the moorings (see Table 3). For survey box s2, where there was data from four moorings, and therefore a mean number of days was obtained. A likelihood score was then calculated by multiplying the number of noise days by the density for each species in each survey box. The density value used was a proportional density (density in survey box/total density in all survey boxes)

***Table 3.** Showing noise days between June 1st and October 1st during which seismic activity was detected by the acoustic moorings (from Kowarski et al., 2018), species density and the calculated likelihood score per species per survey box*

	Mooring		Species Density (proportional density per survey box)

Survey Box		% days seismic activity (actual days)	Bottlenose Dolphin	Beaked Whales	Common Dolphin	Fin Whales	Harbour Porpoise	Minke Whale	Risso's Dolphin	Striped Dolphin
S2	4	30.4% (37.1)	0.153 (0.34)	0.012 (0.58)	0.431 (0.76)	0.001 (0.5)	0 (0)	0.032 (0.54)	0.002 (1)	0.417 (0.62)
	5	76.2% (93.0)								
	6	45.9% (56.0)								
	7	82.8% (101.0)								
S2 Mean		58.8% (71.8)								
S3	8	82.8% (101.0)	0.295) (0.65)	0.0086 (0.42)	0.133 (0.24)	0.001 (0.5)	0.049 (1)	0.027 (0.46)	0 (0)	0.257 (0.38)

Consequence analysis

The environmental pressure caused by impulsive noise may result in the deterioration of the State of a particular population and the aim is to look in more detail at the species (or species groups, habitats) affected by noise in each of the two 1/3 octave bands indicated within the EC 2017/848 (EU, 2017a). Due to the lack of data about the true environmental consequence of the pressure, the sensitivity of the species is essentially used as a proxy for consequence. According to the RAGES method (Box 2), the resistance and resilience of relevant species to noise Impacts should be assessed to come to a measure of sensitivity. The RAGES project previously engaged number of experts to undertake this sensitivity exercise for some (but not all) of the species on this list (see Table 3), however the focus of that exercise was on continuous noise and not on impulsive noise. Therefore, whilst part of the results of that process are relevant here (Q1,2,3), some may be inaccurate (Q4). The expert judgement process should be repeated with experts focusing particularly on the impulsive noise scenario presented in this example. The results of the consequence analysis should be viewed in this context and this exercise highlights importance of obtaining appropriate specific expertise to undertake aspects of the risk.

Box 2: Sensitivity Analysis to identify the most relevant receptor species

The consequence of the noise pressure for each population was quantified by adding up a list of scaled (from 0-4) criteria, so that a higher total value indicated more severe consequences of noise disturbance. The criteria used were:

5. **Conservation status.** This was based on the IUCN Red List classification, but also took into account regional directives (e.g., the EU Habitats Directive Annex II/IV) and local population assessments. **CR/EN=4, DD/VU=3, NT=2, LC=0, Under EU protection=3, Locally threatened=4**
6. **Critical/important habitats affected.** These included areas such as foraging hotspots, breeding/nursing grounds, and migration corridors, as well as areas that encompassed all or most of a species' known range. **None=0, ~one third of breeding grounds=3, More than half the feeding grounds=4**
7. **Sensitive life stage affected.** This took into account that impacts on reproduction and survival of juveniles to reproductive age will negatively affect a population's ability to recover from disturbance, thus lowering its resilience. **None=0, Neonates/Pregnant females=4**
8. **Type and severity of sensitivity to acoustic disturbance.** This criteria weighted impact by the **probability** of occurrence and the **severity** of the outcome, i.e., how commonly is that effect observed and how damaging are the consequences. Both severity and probability are given a score between 0 and 1. Due to data deficiencies, these scores were given as 0, 0.25, 0.5, 0.75, 1 which reduced the possibility of false accuracy. The two values were then multiplied to give the overall sensitivity for that species between 0 and 1. The following table illustrates this:

Type of impact	Probability	Severity	Sensitivity
Physical (auditory)	0-1	0-1	0-1
Physical (non-auditory)	0-1	0-1	0-1
Perceptual	0-1	0-1	0-1
Behavioural	0-1	0-1	0-1
Overall sensitivity			**0-4**

Table 3. *Sensitivity Scores obtained via expert judgement for cetacean species, following the method in Box 2 above. Note that these sensitivity scores were not specific to this example and come from*

	Sensitivity Scores				
Species	**Q1**	**Q2**	**Q3**	**Q4**	**Final Score**
Bottlenose Dolphin	0	4	3	1.75	8.75
Beaked Whales	4	3	4	2.56	13.56
Common Dolphin	1	2	4	0.5	6.5
Fin Whale	3	3	2	1.75	9.75
Minke Whale	1	2	4	0.5	6.5
Risso's Dolphin	1.5	3.25	0	0	4.75

Step 4: Risk Evaluation

The aim of risk evaluation is to arrive at a measure of **relative risk**, which will in turn inform GES assessments and enable prioritization of Measures. Following the ISO process and building on work carried out in the MISTIC SEAS II project (Saavedra et al., 2018), the likelihood and consequence information were considered together as follows:

CONSEQUENCE x LIKELIHOOD = RISK

For the species where a consequence figure was available, the likelihood score was graphed against the consequence score (see Figure 7). A graphical representation of these data allows species (or indeed any ecosystem element) more at risk to be identified. Once threshold values have been determined and agreed, these can be added to this chart to help to categorise species into different risk groups. A number of points should be noted:

A **theoretical** threshold line and colour ramp has been added to Figure 7 by way of illustration only. Work is ongoing to develop a harmonized approach to the thresholds (Task Group on Noise, 2019) and once these are in place, those species that are considered high, medium or low risk can be determined.

This chart should ideally be produced taking temporal considerations into account. For example, since fin whale distribution and critical habitats are very seasonally dependent, their migration or feeding stopovers may overlap more with shipping routes at certain times of year.

In order for a consequence score to be calculated for **all** species emerging from Step 1 (Establishing the context), further expert input is needed to apply the Priority Index process.

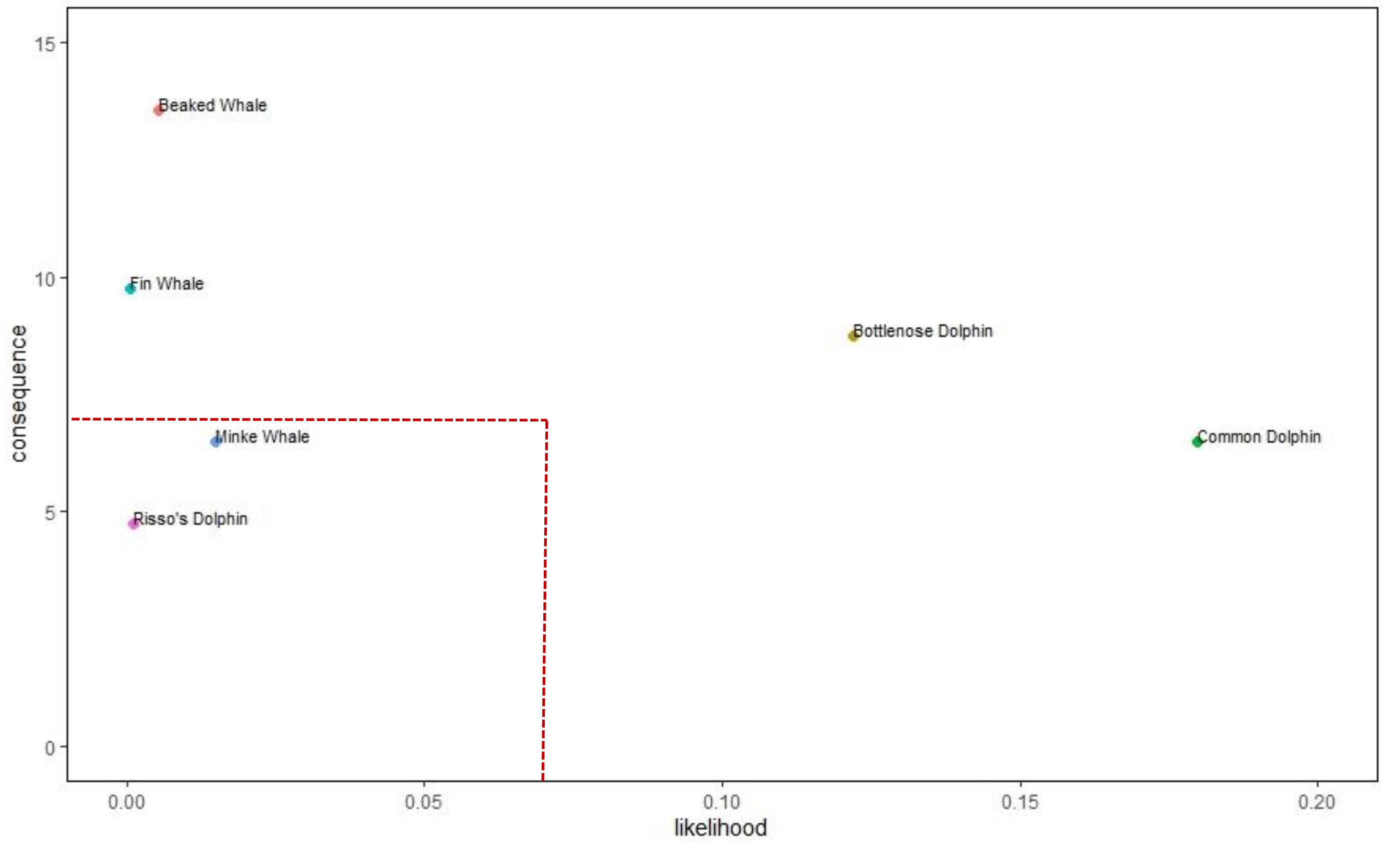

Figure 7. *Risk Evaluation – **consequence** based on sensitivity analysis and **likelihood** based on average exposure scores (per survey box) for each of eight species. This would allow relative risk to be determined once Threshold Values are in place. Red dashed lines represent **theoretical** likelihood and consequence Threshold Values for illustration purposes only.*

Step 5: Risk Treatment

The Risk Treatment step - as defined within the ISO standard (ISO 31000, 2018) – essentially determines the action recommended for areas or situations deemed to be "at risk". This may be taken to refer to the Programmes of Measures (Article 13 of MSFD) and is outside the scope of this case study. However, the issue of Risk Treatment will be examined in more detail in Deliverable 4.5 and in Work Package 5 of the RAGES project.

Summary Table

The table below summarises the application of the risk process in this example.

Table 4. *A summary of the process described in this document RAGES risk process application to impulsive noise*

ISO STEP	PHASE		CONTINUOUS UNDERWATER NOISE – D11, C2
Establishing the context			Establishing policy context, assessment scales, Identification of Cetacean data from reports; priority index development
Risk Identification			Identification of pressure data, including seismic activity in 2015 and 2016, location of Observe acoustic moorings
Risk Analysis	**Likelihood (exposure)**	**Pressure elements**	1. Location of seismic activity in summers of 2015 and 2016. 2. Daily and hourly occurrence of seismic impulses at acoustic moorings stations 1±8 (from Kowarski et al., 2018)
		State elements	ObSERVE report for part of the Celtic Seas (Rogan et al., 2018) containing density of cetacean species from survey boxes s2 and s3. Units individuals/km^2
	Consequence (sensitivity)		Quantitative data for cetacean's sensitivity to noise is absent or inconclusive. The expert judgement results developed by the RAGES project were used, however some of these results were more focussed on continuous noise and therefore should be interpreted in this context. A further expert judgement consultation would be required to ensure the accuracy of the results
Risk Evaluation			Likelihood and Consequence of different species graphed to enable relative risk to be established prioritisation of specific management units

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