REPORT

Proposal assessment framework

OSPAR candidate indicator ambient underwater sound

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1 Introduction

The OSPAR region is an important area and habitat for many marine species. Sound is omnipresent in the underwater environment and can be produced by natural (waves, weather, animals) and anthropogenic (shipping, wind farms, oil and gas activities) sources. There are indications that the sound levels have been increasing over recent decades due to increased human activities at sea. Many marine animals, such as whales, fish and even invertebrates, use sound for communication, prey recognition and to detect potential threats. Man-made underwater sound can cause physical injury, disturbance and mask communication and is therefore directly relevant for marine life. But the integrated impact of sound on the marine ecosystem is largely unknown.

1.1 Objectives of this report

OSPAR ICG-Noise is tasked with preparing a Candidate Indicator specification for ambient sound sources, in time for approval at the next EIHA[1] meeting. The concept proposal sheet is available and discussed in the last meeting. However, it contains several subjects to be determined. This report addresses the gaps in the assessment method for ambient sound and suggestions for further refinement or references to other documents or projects. The proposed steps and metrics are defined to be used for two goals:

- OSPAR quality statement report in 2023, and
- EU Marine Strategy Framework Directive (MSFD) progress of Good Environmental Status (GES) of descriptor D11C2 (continuous noise).

The ambient sound indicator is intended to describe or assess the state of the environment. Bear in mind that other metrics may be necessary when used in other type of assessments, e.g. for D11C1 (impulsive noise).

1.2 Definitions underwater sound

Many of the terms related to underwater sound are defined by ISO 18405:2017. Unless indicated otherwise OSPAR adopts ISO 18405:2017 as a starting point. Furthermore, definitions are compatible with those adopted by EU Member States in connection with MSFD (TG Noise; Dekeling *et al*., 2014; update 2019 in prep.).

> ***Sound or noise***
> *For this report the term "noise" is used when discussing sound that has the potential to cause negative impacts on marine life.*
> *The more neutral term "sound" is used to refer to the acoustic energy radiated from a vibrating object, with no particular reference for its function or potential effect.*
> *"Sounds" include both meaningful signals and "noise" which may have either no particular impact or may have a range of adverse effects.*
>
> *From: "Towards thresholds for underwater noise", TG Noise in preparation, 2020*

Underwater sound can be divided into two main categories: natural sound and anthropogenic sound.

- Natural sound arises from physical phenomena, like wind, rain, currents and waves, and from animals living in the sea that produce sound during their normal activities (e.g. feeding) or for communication.

[1] *OSPAR's Environmental Impact of Human Activities Committee (EIHA)*

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- Anthropogenic sound is introduced into the environment by human activities, including shipping, explosions, geophysical exploration, drilling and construction.

Both categories can be further subdivided into impulsive sound and continuous sound.
- Impulsive sound is often transient and intermittent and is characterised by a rapid rise time and short duration. Examples of anthropogenic impulsive sound sources are military sonar, seismic surveying with air guns, pile driving and marine explosions. An example of natural impulsive sound is the sound some marine animals produce for prey detection.
- Continuous sound has only slow variations in level and frequency content. The major anthropogenic source of continuous sound is shipping, where different ship types can be recognised. Natural continuous sounds include wind, rain, waves and currents.

Ambient sound
The term ambient sound is defined as the sound that would be present in the absence of a specified activity (ISO 18405: 2017), like sound measurements. Ambient sound can be anthropogenic or natural, as well as continuous and impulsive. The part of the ambient sound that can cause negative impacts on marine life is called ambient noise.

1.3 Ecological impacts of underwater sound

Anthropogenic activities such as shipping, military activities, construction work and oil and gas exploitation lead to an increase of underwater sound sources in areas where natural sound sources would typically be the only sources available. There is an increasing concern about the possibility of negative effects of anthropogenic underwater sound on the life of marine fauna.

Impacts of underwater sound can be either primary (direct effect) or secondary (delayed impact or when primary disturbance continues to affect an individual). The impacts of sound on marine animals are generally categorised as follows (adapted from Ferreira *et al.,* 2016; Merchant *et al,* 2018a; TG-Noise GES_22-2019-18):
- Behavioural response:
  - Masking occurs when a listener is unable to detect, recognise, or interpret an acoustic signal due to the presence of some other confounding sound source (Clark *et al.*, 2009). It may lead to a loss of the opportunity to feed, nurse or communicate. As a secondary impact it can mask communication essential for successful reproduction.
  - Avoidance of the area in which the sound is present. This can lead to displacement, negative impact on energy levels and possibly reduced food availability or food intake.
  - Mortality is a possible consequence of behavioural response to noise, e.g. stranding or decompression sickness.

- Physical injury:
  - Permanent or temporary auditory impairment also known as TTS (Temporary Threshold Shift) or PTS (Permanent Threshold Shift). This impact mainly occurs with impulsive sounds. Although it can also occur with sustained exposure to high levels of continuous sounds. PTS is the loss of hearing sensitivity at specific frequencies which do not recover over time. This can for example limit the ability to hunt for food.
  - Long term exposure to sound can lead to an increase in cortisol levels (stress hormones), which can lead to a reduced immune response (physiological stress) (Southall *et al.* 2019; Slabbekoorn H. *et al.* 2018).

- Immediate death:
  - Barotrauma can lead to mortality (unlikely for continuous sound).

The primary effect targeted by the criteria for continuous sound (D11C2) is the reduction of listening and communication space of marine organisms, known as masking. So, masking will be the major concern for ambient noise.
Masking is closely related to signal-to-noise ratio. Everything else being equal, increasing the ambient sound in the same frequency band as a biologically relevant signal will affect the signal-to-noise ratio and make this signal harder to be detected.
Animals can respond to masking in different ways to reduce its effects (partially or completely), for example by increasing the intensity and repetition rate of calls, changing frequency, moving away from the noise source (if it is close by) or orienting making use of directionality cues. Fundamentally, however, this does not change the basic relationship: increasing the ambient sound level (i.e. reducing the signal-to-noise ratio) makes it more difficult for animals to hear a biologically relevant signal, whether intended for them or not (TG-Noise GES_22-2019-18).

At present there is still a knowledge gap about the effects of continuous noise, like masking, but this is increasingly being addressed. The progress of scientific knowledge is probably not sufficient to be conclusive about population consequences in the near future, but it is expected that over the coming years new knowledge will lead to different insights about the best way to assess continuous sound.

2 Background and related programmes ambient sound indicator

A lot of governmental bodies and organisations are dealing with the subject of underwater sound. It is good to be aware of the objectives and progressions of each mechanism in order to learn, share knowledge and align methods and metrics. This will facilitate the strategy to decline the negative impacts of underwater sound.

2.1 OSPAR

OSPAR is the treaty by which 15 Governments & the EU cooperate to protect the marine environment of the North-East Atlantic. See Figure 2-1 for the OSPAR protected area.

In 2010 OSPAR adopted the North East Atlantic Environment Strategy which included the implementation of the European North East Atlantic Environment Strategy (MSFD – see paragraph 2.3). Underwater sound is addressed in the thematic section on Biological Diversity and Ecosystems where the aim is to “endeavour to keep the introduction of energy, including underwater noise, at levels that do not adversely affect the marine environment in the OSPAR maritime area”. In 2020 a revised Strategy will be adopted by OSPAR and underwater sound is still being addressed as a pollutant. ICG-Noise[2] is the working group considering underwater noise in practice and reports to the Environmental Impact of Human Activities Committee (EIHA) and Coordination Group (CoG).

Figure 2-1. OSPAR area with five distinctive regions.

[2] *ICG: Intersessional Correspondence Group*

OSPAR adopted an Ambient Noise Monitoring Strategy in 2015 (OSPAR Agreement 2015-05 (15-05ef)). The approach for monitoring of underwater sound uses sound maps, generated from a combination of models and measurements. The North Sea has been chosen as a pilot region to start monitoring. This joint monitoring programme will be established by Jomopans project (see paragraph 2.6).

In 2017, as part of the Intermediate Assessment of the state of the North-East Atlantic, OSPAR undertook its first regional assessment of the pressure from impulsive noise. The assessment framework for continuous noise follows in general the same steps as the impulsive noise assessment framework. Impulsive noises are generally regulated through national marine licencing. An Impulsive Noise Registry was developed to hold the information and produce a regional assessment based on pulse block days[3].

2.1.1 OSPAR indicator impulsive noise

For impulsive noise OSPAR already set up an indicator framework, see Figure 2-2 for an indication of a workflow. This report focuses on ambient sound. However, the assessment framework for impulsive noise acted as a template for the framework for ambient noise and the impulsive noise registry may contribute to the monitoring of ambient sound if impulsive sources contribute significantly to the ambient sound indicator.

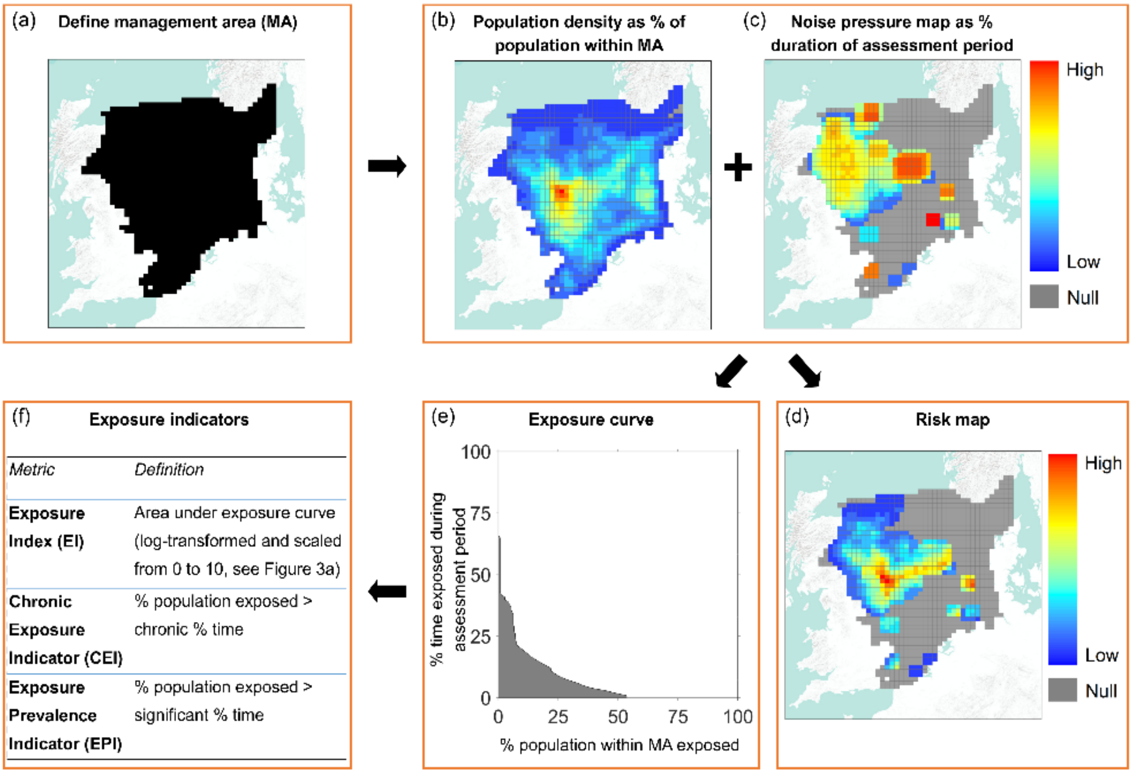

Figure 2-2. Example workflow for mapping risk and calculating exposure indicators of impulsive noise. Example population density (b) is modelled for North Sea harbour porpoise density during autumn (Sep.-Nov.), from Gilles et al. (2016). Noise pressure map (c) is based on impulsive noise data reported for the OSPAR maritime area in Sep.-Nov. 2015. Merchant et al (2018).

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[3] *www.ospar.org*

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2.1.2 OSPAR indicator ambient sound

ICG-Noise set up a framework (see Textbox 1) for an indicator to assess the impact of ambient sound on the marine environment. This framework is discussed and approved in last EIHA meeting of April 2019 (0718_candidate_indicator_ambient_noise, EIHA 2019). The framework now needs further refinement to set up an indicator for ambient sound. This is done in the next chapter. It is the purpose the indicator is applicable for the whole OSPAR region.

Textbox 1. Framework of indicator ambient sound based on the candidate indicator of ambient noise (EIHA 2019) with minor changes. Note that in this report only steps 0 to 6 (pressure indicator) will be elaborated on. The step 7 to 9 (risk-of-impact indicator) are added for completeness, these steps need more research and will be detailed in the future.

0. Set spatial and temporal resolution
The spatial and temporal parameters are to be set by specifying time (e.g. season) and space (e.g. geographic area). This will help determine the spatial and temporal resolution for the input and output data. The temporal and spatial resolution of the maps can be dependent on the region.

1. Collect information on human activities
The human activities that generate low-frequency continuous sound need to be evaluated. Sources of this information are (AIS) for shipping intensities, Vessel Monitoring System (VMS) for fishery activities and the OSPAR impulsive noise register for other sources of noise. These data need to be obtained with a temporal resolution of 1 hour
maximum.

2. Collect acoustical properties of the sources
Acoustical properties of most of the sources are not available in a sufficient detail. Literature can provide statistical proxies for these properties. Jomopans has developed in co-operation with JASCO and the ECHO project (Port of Vancouver) a model for ship noise source levels, RANDI3.1c[4]. It is important to continuously improve the knowledge of the source properties. These models can be verified using field measurements where required.

3. Collect physical properties of the environment
Bathymetry and properties of the sea bottom (composition) are important for the numerical modelling of sound propagation. These parameters can be considered static. (Meteo) parameters, like wind, rain, current, temperature, isoclines, salinity are dynamic.

4. Calculate sound scape and excess level maps
Through acoustical propagation modelling sound scape maps (sound pressure level as well as background level) will be calculated as defined in the indicator metric.
Acoustical models for sound from natural sources are available and being evaluated. Propagation models for sound propagation of various sound sources can be chosen.
From these excess level maps and dominance maps can be derived.

5. Measure long term acoustical parameters at a number of stations
At a number of measurement stations the soundscape is monitored on an ongoing basis. From these measurements statistical parameters of the SPL can be derived.

6. Evaluate the sound scape maps and produce confidence maps
Using the sound scape maps and the measurements a validation is performed, and confidence maps will be produced which indicate where there is greater or lesser confidence in the model predictions.

7. Specify estimated animal density or habitat area of indicator species
Use density estimation data if available and appropriate, otherwise use areas (e.g. habitat quality mapping, MPA, Spawning grounds, etc.).

8. Compute exposure/risk map by combining 6 and 7
Including quantitative assessment of confidence in the risk values derived.

9. Compute exposure/risk indicator(s)
A risk indicator must be computed for each relevant region, that can be assessed against a GES criterion.

[4] *To be published.*

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2.2 HELCOM

HELCOM is the governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area, known as the Helsinki Convention. The Contracting Parties are Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia, Sweden and the European Union. HELCOM was established about four decades ago to protect the marine environment of the Baltic Sea from all sources of pollution through intergovernmental cooperation. One of the subjects HELCOM is working on to achieve a good ecological status and a healthy Baltic Sea environment is underwater noise. In 2013, HELCOM Copenhagen Ministerial Declaration agreed that the level of ambient sound and distribution of impulsive sounds in the Baltic Sea should not have negative impact on marine life and that human activities that are assessed to result in negative impacts on marine life should only be carried out if relevant mitigation measures are in place. The HELCOM Experts Network on Underwater Noise (EN-Noise) was established to prepare and facilitate the implementation of a roadmap to building a knowledge base on underwater noise in a short term (2015-2017).[5] It supported the BIAS project and a regionally organized registry of impulsive events in the Baltic Sea region has been launched. This is the same Impulsive Noise Register where OSPAR submits its data.

2.3 European Commission / MSFD

In 2008 the European Commission approved the Marine Strategy Framework Directive (MSFD: 2008/56/EC), requiring all EU Member States, to reach or maintain a Good Environmental Status (GES) by 2020.

> "Marine strategies shall apply an ecosystem-based approach to the management of human activities, ensuring that the collective pressure of such activities is kept within levels compatible with the achievement of good environmental status and that the capacity of marine ecosystems to respond to human-induced changes is not compromised, while enabling the sustainable use of marine goods and services by present and future generations." Article 3, MSFD

This ecosystem approach means that the effects on the whole ecosystem should be assessed and not the effects on individuals. In practice, the effects of underwater noise will be assessed on the population of key species or on the habitat for those species.

GES is described by eleven descriptors and all the Member States must set criteria and methodological standards for each descriptor in their marine waters. Member States are required to define the GES they use. Descriptor 11 focuses on the energy in the marine environment, including underwater noise and describes two types of underwater sound, divided into two indicators:

- loud, low and mid frequency impulsive sounds (D11C1) and
- continuous low frequency sound (D11C2).

Measures should be taken by member states and the progress must be monitored.

The EU/MSFD Technical Group on Underwater Noise (TG Noise) is commissioned to further develop the two indicators of underwater sound. Currently TG Noise is working on the development of a common methodology to assess potential effects of underwater noise, as a first step towards development of Threshold Values for D11C1 and D11C2.

[5] *Information from http://www.helcom.fi/*

2.4 United Nations

In 1999, the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea was established in order to facilitate the developments in ocean affairs and the law of the sea. It focusses on identifying areas where coordination and cooperation at the intergovernmental and inter-agency levels should be enhanced (resolution 54/33). There is a yearly meeting to discuss these topics.
The United Nations have declared the years 2021-2030 as the Decade of the Oceans. This will generate more attention to the different threats to the ocean, like underwater noise.

2.5 IMO

In 2014, the International Maritime Organization (IMO) approved guidelines prepared by the Marine Environment Protection Committee (MEPC) on reducing underwater sound from commercial shipping, to address adverse impacts on marine life. Given the complexities associated with ship design and construction, the Guidelines focus on primary sources of underwater sound, namely propellers, hull form, on-board machinery, and various operational and maintenance recommendations such as hull cleaning[6]. This non-mandatory instrument entitled Guidelines for the Reduction of Underwater Noise from Commercial Shipping to Address Adverse Impacts on Marine Life (MEPC.1/Circ.833) is intended to provide general advice on the matter to designers, shipbuilders and ship operators.

2.6 Projects

There are several projects in which more knowledge is gathered around underwater sound. Below some relevant projects on the monitoring of underwater sound are described. There is an increasing demand for underwater sound projects in the artic. But this is not yet addressed.

BIAS
The Life+ project Baltic Sea Information on the Acoustic Soundscape (BIAS project) was established in 2012 and ran to 2017. The goal of the project is to support a regional assessment of the underwater sound in the Baltic Sea. The output of the project included soundscape maps, showing the underwater sound generated by commercial vessels, the major source of human-induced underwater sound in the Baltic Sea. Seasonal soundscape maps were produced for the demersal, pelagic and surface zones. These soundscape maps will serve as a baseline for the development of monitoring and assessment of ambient sound in the Baltic Sea. In total 9 partners from countries around the Baltic Sea participated in the project.[7]

Jomopans
On 1 January 2018 the Jomopans project (Joint Monitoring of Ambient Noise North Sea) has started and it will run until December 2020. It aims at establishing a joint infrastructure for monitoring ambient sound in the North Sea. This will be based on two tracks: modelling and measurements. The result will be maps which show a total of the average sound levels for a certain period (monthly, yearly or seasonal). Measurements of underwater sound (at selected locations) are used to validate the modelling results and to determine the source levels of shipping. These results will be made available in a web-based tool for the management of GES for underwater sound. In total 11 institutions from countries around the North Sea participate in the project. Rijkswaterstaat from The Netherlands is the lead partner.[8]

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[6] Information from www.imo.org
[7] https://biasproject.wordpress.com/
[8] https://northsearegion.eu/jomopans/

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JONAS

JONAS (Joint Framework for Ocean Noise in the Atlantic Seas) is an Atlantic Area funded project addressing threats to biodiversity from underwater sound which started in May 2019 and will run until 2021. The aim is to streamline ocean sound monitoring and risk management on a transnational basis. JONAS will produce monthly sound and risk atlases based on spatial modelling of sound characteristics and the distribution statistics of key bio-indicators for sensitive species in the north east Atlantic Ocean. In total nine different partners from Ireland, UK, France, Portugal, and Spain participate in the project.[9]

ECHO

The ECHO Program (the Enhancing Cetacean Habitat and Observation Program), is a Port of Vancouver-led initiative aimed at better understanding and managing the impact of shipping activities on whales along the southern coast of Canada (British Columbia). This program was established in 2014. The long-term goal is developing voluntary measures that will lead to quantifiable reduction in threats to at-risk whales in the region. One of the outputs will be a real-time notification system to alert ship operators when whales are in the area. In 2017 a voluntary vessel slowdown trial occurred within an important summer feeding area for whales, where the level of sound reduction was measured when ships reduced their speed. The program is a collaboration between industry, marine advocates and scientists.[10]

BONUS-SHEBA

From 2015 to 2018, the BONUS-SHEBA project (Sustainable sHipping and Environment of the BAltic Sea region) measured ship sound in the Baltic Sea to provide an integrated assessment of policy options to mitigate pressures linked to shipping, quantifying as far as possible anticipated changes in ecosystem services (compared to an established baseline). An advanced emission model based on AIS ship movement data was used to produce calculations of emissions to water, to air and of underwater noise. This project is a collaboration between 11 different partners from Sweden, Germany, Finland, Estonia, Poland and Denmark.[11]

QUIETMED2

The QUIETMED2 project aims to enhance cooperation among EU Member States in the Mediterranean Sea Region to implement the Second Cycle of the Marine Directive and in particular to assist them in the preparation of their MSFD reports focussing on the GES assessment on D11-noise:

- A joint proposal of a candidate for an impulsive noise indicator in the Mediterranean Region.
- A common methodology for Competent Authorities to establish threshold values, together with associated lists of elements and integration rules.
- A data and information tool to support the implementation of the monitoring programmes of impact of impulsive noise based on the current ACCOBAMS joint register which will be demonstrated on.
- An operational pilot of the tool.
- Several activities to boost current regional cooperation efforts of the Barcelona Convention developing new Mediterranean Region cooperation measures.

This project builds on work done and results of QUIETMED project that has been developed by most of the partners of this project and other projects funded by Directorate-General for Environment, European Commission (DG Environment). The project has a duration of 24 months starting on February 2019.[12]

SOUNDSCAPE

In 2019 the Soundscape project started focussing on soundscapes in the North Adriatic Sea and their impact on marine biological resources. The main objective of the project is to create a cross-border technical, scientific and institutional cooperation between Italy and Croatia in the Northern Adriatic Sea to face together

[9] *https://www.jonasproject.eu/*
[10] *https://www.portvancouver.com/2017-echo-program/*
[11] *https://www.sheba-project.eu/*
[12] *https://quietmed2.eu/*

the challenge of assessing the impact of underwater environmental noise on the marine fauna and in general on the ecosystem on a basin scale. The project addresses maritime traffic and recreational vessels (tourism) in particular.[13]

RAGES
RAGES (Risk-based Approaches to Good Environmental Status) will develop a conceptual frame for incorporation of risk-based approaches into the MSFD. It is a three-year project (January 2019 – December 2021) which focuses on the Exclusive Economic Zones (EEZs) of Ireland, Portugal and the Atlantic parts of the French and Spanish EEZs. Noise (descriptor 11) is chosen as one of the example topics. The findings and best practices will be used to recommend targets for the descriptors as well as to develop a transferrable Standard Operating Procedure[14]. The RAGES project will work closely with the OSPAR Commission. In total 13 different partners from the countries mentioned above will collaborate in this project.

COMPASS
In 2017 the 5-year project COMPASS (Collaborative Oceanography and Monitoring for Protected Areas and Species) started. The aim is to deliver a clearer understanding of what changes in the oceanographic climate have on underwater habitats, fauna and flora across the region of Northern Ireland, the Border Region of Ireland and Western. A network of oceanographic and acoustic moorings was established within and adjacent to cross-border marine protected areas (MPAs) which will produce new monitoring data and aid in the development of effective future monitoring programmes for MPAs. This project is a collaboration between four partners.[15]

MarPAMM
MarPAMM is an environment project, which will run until 31 March 2022, to develop tools for monitoring and managing a number of protected coastal marine environments in Ireland, Northern Ireland and Western Scotland. One of the outputs will be a seal foraging and underwater noise model. The aim of the project is the development of six comprehensive MPA management plans. It is a collaboration between seven partners including statutory organisations, academic institutions and a Non-Governmental Organisation.[16]

[13] *http://www.ismar.cnr.it/projects/international-projects/project-001/soundscape-project?set_language=en&cl=en*
[14] *https://www.msfd.eu/rages/*
[15] *https://www.sams.ac.uk/science/projects/compass/*
[16] *http://www.mpa-management.eu/*

3 Proposal assessment framework ambient sound indicator

As mentioned in paragraph 2.1.2 a stepwise approach of the ambient sound assessment framework is already agreed on. In the picture below (Figure 3-1) the relation between the different steps of the framework is expressed. It indicates that different steps can be progressed at the same time or are dependent on each other. The steps are further refined in this chapter.

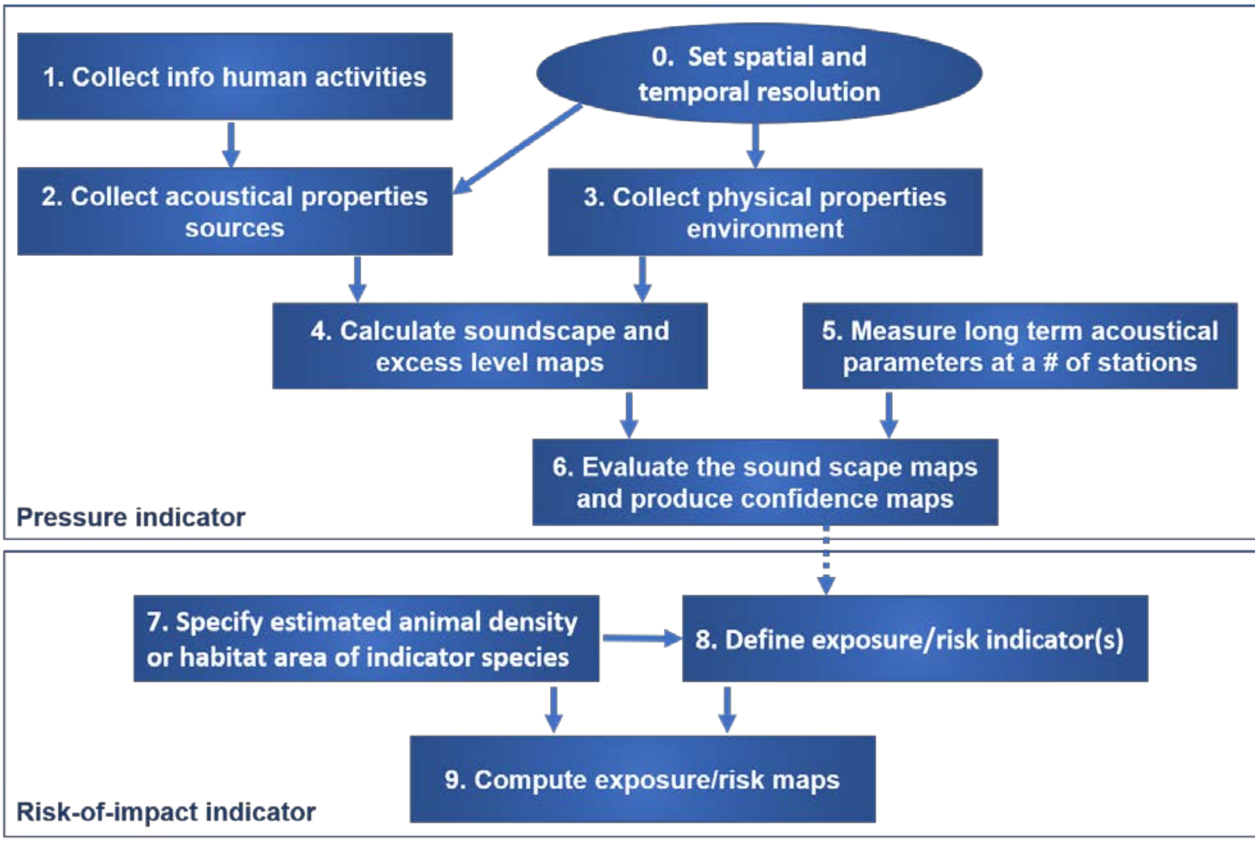

Figure 3-1. Framework ambient sound indicators.

At various points in the steps below (numerical) models are referenced. The method does not explicitly advice certain models. They are mentioned as examples.

3.1 Step 0. Set spatial and temporal resolution

The marine environments across the North-East Atlantic differ in physical properties and the ability to obtain data over space and time. Therefore, it is important to determine the geographic area and season in order to set the spatial and temporal resolution for the input as well as the output data. It is possible that different settings will be used for different regions for the input as well as the output. The basics are stated below.

Determine input resolution (time/space)

- Preferable input for shipping data is a 1-hour resolution and 1 km^2 (based on Jomopans experience);
- Impulsive sound from OSPAR register has temporal resolution of 1 day. Spatial resolution differs between countries;
- For other sound sources the resolution needs to be determined, depending on available information;
- Seasonal variation. Biological information of seasonal variation is limiting: a better resolution than 1 month can be difficult. Collecting information of human activities for 1 month is therefore sufficient.

Determine output resolution (time/space)

- The temporal and spatial resolution of the maps can be dependent on the region.
- Output resolution in terms of time percentiles.
- Jomopans makes monthly maps with a resolution of 5 km. AIS input data per complete month are used.
- Mapping ambient sound levels should preferably be carried out within sea regions, as sound can impact large areas underwater.

3.2 Step 1. Collect information on human activities

In this step all human activities that generate low-frequency continuous sound are evaluated. Sources of this information are for example AIS (for shipping intensities), VMS (for fishery activities) and the OSPAR impulsive noise register (for other sources of sound). It is important to do a quality control on the input data. AIS and VMS often prove to be incomplete, but also a mutual overlap can exist for ships with both AIS and VMS. Consistency across a larger area should be observed. Below an overview is given of the possible activities, where information can be obtained and the knowledge gaps and limitations of data collection. The data is preferably obtained with a temporal resolution of 1 hour maximum.

Specify sound producing activities

- Preferably, information is collected of all human activities producing (continuous) sound at sea, see Table 3-1. At least information of activities with the greatest contribution to low continuous sound should be collected, like shipping. Make clear which activities are included and which are not.
  - For this report the focus was on shipping as this is the most important continuous sound source.

Collect information of activity and their specifications

- Shipping is the main contributor to low continuous sound. The shipping type, speed and activity affect the sound level, so this information should be collected as a minimum.
  - Professional ships carry AIS on board. Preferably this AIS data is collected via EMODnet[17] (Figure 3-2), but at this moment data has no sufficient detail (no vessel type, speed or activity). Otherwise buy information via commercial platforms, like Quiet-Oceans.
    - Jomopans made an overview of which AIS data is needed (see OSPAR-EIHA, 20190301 memo Jomopans and AIS).

[17] *EMODnet is the European Marine Observation and Data Network. It consists of more than 150 organisations assembling marine data, products and metadata to make these fragmented resources more available to public and private users relying on quality-assured, standardised and harmonised marine data which are interoperable and free of restrictions on use. EMODnet is currently in its third development phase with the target to be fully deployed by 2020 (www.emodnet.eu).*

- o Several fishing and recreational ships carry AIS, but not all. It is difficult to quantify the number of these ships within the AIS data. If AIS is not available:
  - ▪ Commercial fishing vessels carry an AIS and VMS. Up to now the provision of VMS data is problematic in most countries. VMS equipment and data are owned by the fishery companies and the data is supplied to the government for specific purposes. Use for other purposes needs to be confirmed by all data owners. There is no general agreement on this topic yet.
  - ▪ Recreational vessels are monitored sparsely. Mostly monitoring is executed on project basis, for example to gather information at Natura 2000 sites or in the Soundscape project (Adriatic Sea). Data can be collected at harbours or local governments. When difficult to realize make use of research literature, like Hermannsen *et al.* (2019).

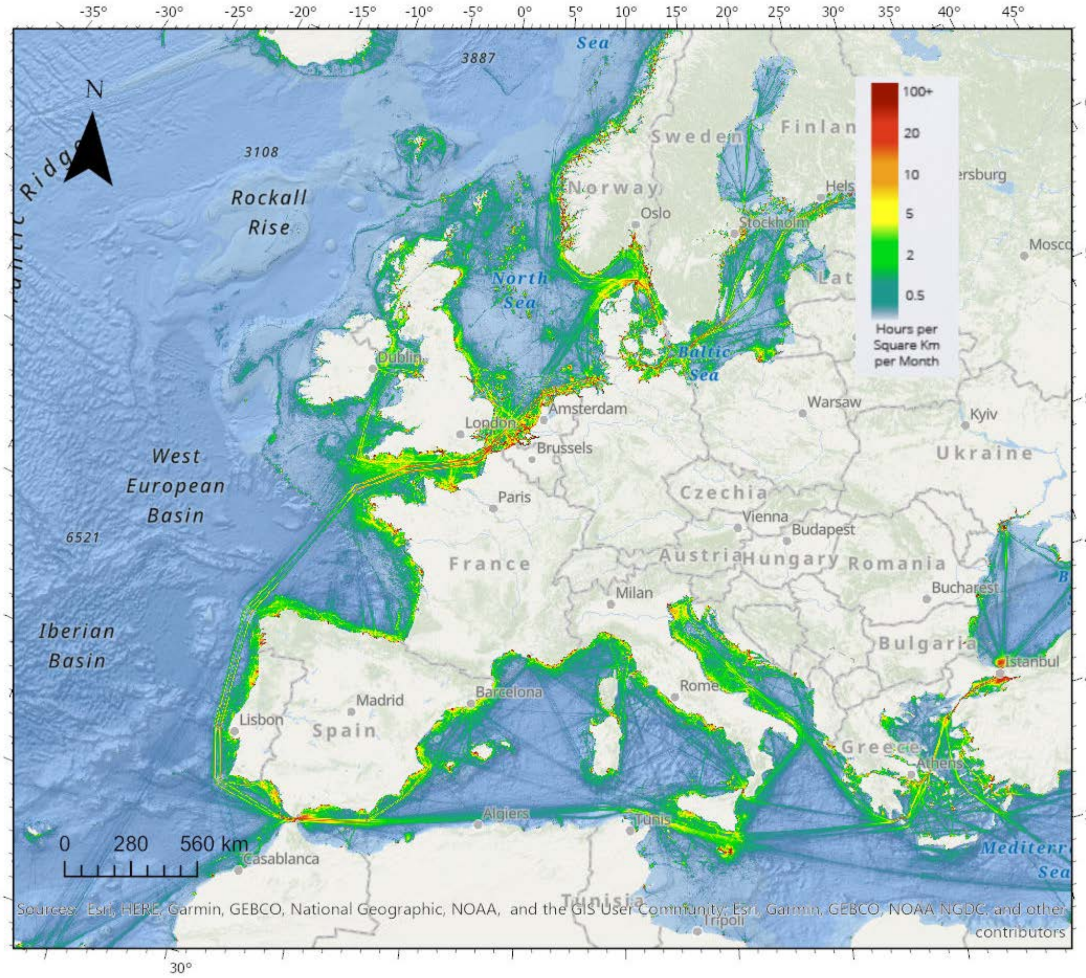

Figure 3-2 AIS vessel density data 2019 (https://www.emodnet-humanactivities.eu/view-data.php)

- <u>Construction</u> activities, like drilling, vibration, dredging and the placement of cables and pipelines can produce low continuous sound during the construction period, lasting several weeks or months.
  - o Information on the number of vessels that execute construction activities can be obtained by AIS data: shipping activity and ship speed is zero or low.
  - o Information on sound levels is difficult to obtain quickly. Information may be available in individual licenses. In some country's licenses are online available, but this is not the standard. Otherwise use generic sound levels from literature.

- Operational wind farms may produce continuous sound, but it is not clear yet to what extent. Until now offshore wind farms are mainly located at the North Sea. Wind farm support vessels are included in AIS data.
    - Knowledge gap: to what extent do operational wind farms produce low continuous sound?

- Tidal energy is also a source of continuous sound. The source level is not known yet and is dependent on the type of tidal energy production. Until to now tidal energy is mainly located in Scottish waters.
    - Knowledge gap: to what extent does tidal energy produce low continuous sound?

- Impulsive sound can contribute to ambient sound at larger distances.
    - Information can be obtained at the OSPAR Impulsive noise register

- Fish farms / aquaculture may have a permanent Acoustic Deterrent Device (ADD) at their devices to scare marine mammals and keep them away.
    - (Permanent) ADD sound does contribute to ambient noise.
      Question is whether this also contributes to the metrics of this indicator?

        - ADD's on aquaculture infrastructure can be an important source of chronic underwater sound in some areas (Findlay *et al*., 2018).
        - The duty cycle of the ADD's is low; they emit an impulsive sound every 10 to 20 secs. This can lead to disturbance of an animal, but not to masking of sounds. Therefore, ADD's on aquaculture infrastructure should be classified under impulsive sound, not under ambient sound. Besides, it is not measurable, because the average sound pressure will quickly drop below the background.

    - Information about ADD's from aquaculture is difficult to obtain quickly. Contact with individual fish farms is necessary. Generic data is available from literature.

All data must be anonymised before processed in this approach. Most data are privacy sensitive. Further refinement with ICG-data on how to organize this is advised.

Table 3-1. Further refinement of information on human activities.

Activity	Specifications activity	Where can info be obtained?	Temporal and spatial resolution	Remarks
Shipping	Vessel type Vessel speed Vessel activity (i.e. transport, fishing, recreation)	• AIS → EMODnet Additional when AIS not available: • VMS (fishery activities) Note: difficult cause individual shipmen are holder of data • Harbours / local governments for information on recreational vessels.	1hr / 1km^2	EMODnet is not yet detailed enough
Construction	Drilling, dredging, vibration, placement of cables/pipelines	Licenses, literature		
Production platforms, pipelines and generators		Licenses, literature		

Operational windfarms		Licenses, literature		Mainly located at North Sea
Tidal energy		Licenses, literature		Mainly located in Scotland
Impulsive sound	Geophysical surveys, explosions, pile driving, sonar, pingers/ADD's	OSPAR impulsive noise register	Temporal resolution is 1 day. Spatial resolution differs between countries.	
Aquaculture	ADD/pinger type Pulse interval and frequency	Fish farms, literature OSPAR impulsive noise register		Fish farms mainly located in Norway & Scotland.

3.3 Step 2. Collect acoustical properties of the sources

In this step the acoustical properties of the relevant sound sources are further detailed. Of several sound sources the acoustical properties are not known or have no sufficient detail. Literature can provide statistical proxies for these properties. It is important to continuously improve the knowledge of the source properties. Although source levels of individual sources can deviate considerably from the average levels used for propagation modelling, the statistical result has a far better accuracy.

Collect information to determine sound propagation and probability distribution

- Source level:
  - For shipping information on depth of source, type of vessel, vessel activity and vessel speed is needed.

Determine acoustical properties of sources

- First focus on shipping and later other sources can be added. Jomopans validates models only for ships and wind.
- Describe where source levels have been obtained, for example from measurements (ECHO or BONUS-SHEBA project) or a model (like RANDI).
- A model for determining source levels of ships is RANDI. Different ship types can be added in this model. Information of the ECHO project is incorporated in new version of this model (RANDI 3.1c), as old data were not scientifically traceable.
- Other ship source level models need more input data. For RANDI 3.1c input of AIS data is enough (length, speed and ship type).
- Note: currently AIS does not directly provide the necessary distinction between container vessels and other cargo vessels. Jomopans will reflect on how to deal with this knowledge gap.

Define how to deal with variation in source levels

- From the ECHO project it is known there is a large variation in source level of a ship type, depending on speed, activity, weather conditions.
- Use all AIS data as input (for a model like RANDI). Do no use an average ship, because there is no average ship.
- RANDI produces a standard deviation of every source level, based on input of 3000 ships.
- Use a model to simulate the effect of measures, like speed limitation.

In earlier stage TG Noise (Dekeling et al, 2014) recommended to use the arithmetic mean (AM), as this is robust and independent metric of time (percentiles are dependent of snapshot duration). However, the use of the AM in a biological manner is doubtful. The disadvantage of the long-term AM is that it is not directly related to the way in which animals perceive the sound and that it does not distinguish between continuous exposure and short periods of high-level exposure with quiet intervals in between.

Set up system to collect and register source levels
For the collection and management of the data concerning source levels, a data model needs to be developed to determine the exact specifics of the data that needs to be collected. Thereafter a data management system needs to be chosen or build to store and view all collected data.

3.4 Step 3. Collect physical properties of the environment

Bathymetry and properties of the seabed (composition) are important for the validated numerical modelling of sound propagation. Most of these parameters are static, except for some meteorological data.

Determine assessment area

- The area should be chosen bearing in mind the following:
  - Distribution of indicator species.

  - Choose a propagation model which is validated for the specific assessment area: deep water, shallow water, coastal zone (sandy beach or cliffs), ice coverage.

    Note:
    - There are good models available for shallow water like the North Sea and deeper waters.
    - Be aware of reflection of ice coverage in arctic waters.
    - The model uncertainty for coastal zones is very large, meaning that shallow areas close to shore are hard to assess. Furthermore, coastal areas can have extra sound sources. For example: the breaking of waves at the beach or shifting of sand will lead towards a higher natural background sound. Cliffs on the other hand will reflect sound.
      → Consider if and why it is necessary to include shallow areas close to shore, taking the uncertainties into account.

  - When relevant: political or national considerations of scoping of area
    For OSPAR an intermediate assessment is not relevant.

Define physical data:

- To be collected from EMODnet
  - Water depth;
  - Seabed: bathymetry and composition (grain size);
    → To improve modelling at low frequencies (<1 kHz), we need information of the acoustical properties of the sediment to greater depth.

  - Temperature and salinity; The sound speed in water is dependent on both temperature and salinity. Especially the sound speed profile determines the propagation over longer distances.

  - Wind (strength and direction); Other (meteo) data like rain, current, and isoclines can be relevant to check assumptions, but are not directly used in current modelling.

Determine way to incorporate meteo information in models

- This has been prepared by Jomopans, see De Jong *et al.* (2018) for details. It is/should be a method which is being updated regularly based on new scientific input.

3.5 Step 4. Calculate sound scape and excess level maps

Through acoustical propagation modelling, sound scape maps will be calculated for the required parameters, Sound Pressure Level (SPL) percentiles (5th, 10th, 25th, 50th, 75th, 90th, and 95th). A sound scape map of natural sound should be made separately. This would enable to produce maps of the excess level. The temporal and spatial resolution of the maps can be dependent on the region. Jomopans makes monthly maps with a resolution of 5 km.

Chosen metrics

Acoustic metric specification for propagation modelling is prepared by Jomopans, see De Jong *et al.* (2018) and Merchant *et al.* (2018) for details. Table 3-2 shows the chosen metrics. This acoustic metric specification is consistent with the definition of MSFD Descriptor 11 Criterion D11C2, as stipulated in the 2017 European Commission decision (European Commission 2017).

Table 3-2 Acoustic metric specification for propagation modelling

Metric	Specification
Physical quantity	SPL: Sound pressure level, dB re 1 µPa
Temporal unit	Percentiles of the SPL distribution measured over one-month periods. Based on individual SPL measurements of 1 second (snapshot duration). Suggested percentiles: 5, 10, 25, 50, 75, 90 and 95.
Frequency	One-third octave bands, with centre frequencies ranging from 10 Hz to 20 kHz, defined according to the base-ten convention (IEC 61260-1:2014; ANSI, 2009).
Space	Depth-averaged value either at the centroid of each grid cell, or as a spatial average of the levels within the grid cell. Geospatial grid referenced using the standardised C-square notation (Rees, 2003).

Metric for assessment pressure indicator

It is proposed to use a broadband excess level from 10Hz to 20kHz as a metric for assessment of the pressure indicator of ambient sound. The parameter for monitoring stays SPL.

- The excess level is the difference between a long-term sound pressure level and the background level.
- This broadband excess level is the appropriate metric for the pressure indicator as we are interested in the masking effects of noise pollution.

Octave bands

Considerations to use broadband frequency spectrum from 10 Hz to 20kHz for the pressure indicator are:

- New insights into the effects of continuous noise show that the frequencies named in MSFD (63 Hz and 125 Hz) are not appropriate.
- A broadband level is commonly used, anything else would be arbitrary.
- It gives you one number, which is clearer for users. When limited bands are used (for example: one for low frequency, one for middle frequencies and one for high frequencies) you get three numbers. For a pressure indicator this is not necessary, it is better to have one shipping noise number. However, for the risk-of-impact assessment, and chosen indicator species, a limited frequency band can be useful depending on sensitiveness of the species.

Background level

The background level is defined as the sound pressure levels without anthropogenic sounds present. It then contains only natural sounds, caused by wind, rain, waves and animals.
A problem occurs in determining the background level in both modelling and measurements.

- In modelling specific models are used to calculate the background levels, based on dynamic environmental conditions. Validation however is difficult.
- In measurements the background sounds cannot be separated from the anthropogenic sounds. Here either modelled background sound levels can be used (see previous remark) or a pragmatic choice can be taken to use the 5% percentile of the SPL as background level. This question has been raised by TG Noise as well.

Sound pressure level (SPL) vs Particle velocity

- Sound consists of two components: sound pressure and particle velocity. In this method sound pressure is chosen as metric.
- Modelling and measurement of particle velocities is in its infancy. It is known that certain fish species are sensitive to particle velocity and not to sound pressure. In the free field sound pressure and particle velocity are coupled through the acoustic impedance, but in practice a free field situation hardly occurs. Particle velocity is important at surfaces (water surface and bottom). The acoustic pressure at the water surface is zero, whereas at a rigid bottom the acoustical pressure is doubled, and particle velocity is zero.
- We want to assess the Sound Pressure Level (SPL; dB re 1 µPa) at a certain depth, not surface, because otherwise measures will not be accurate. With the equation $p = \rho c\, v$ you can calculate pressure into velocity in a plane wave in free space, so not at surfaces. Keep this in mind when dealing with benthic animals.

Excess level and Dominance

From the maps of the Sound Pressure Level and the Background Levels the Excess Levels can be derived. For a given frequency band and averaging time the excess level is the difference in dB between the background sound level and the sum of natural ambient and anthropogenic noise.
Also, Dominance can be derived. Dominance is the percentage of time that the Excess Level exceeds a certain threshold. In the Figure 3-6 and Figure 3-7the Dominance is displayed for an exceedance of 6 dB and 20 dB respectively.

Percentiles

- Monthly percentiles are chosen, because individual snapshots are not useful/reliable. Percentiles are determined from snapshots.
- The spreading in uncertainty of sources at one moment does not affect percentiles of snapshots: Uncertainty spreading of individual source is about 7dB, whereas uncertainty spreading of monthly percentiles is about 1 dB. Currently validation work is done to diminish the uncertainty of percentiles as model results.
- Suggested percentiles are the 5th, 10th, 25th, 50th, 75th, 90th and 95th.
  Most used are the median, 50th and 95th percentiles.
  - Median gives the centroid level overall. It tells the amount of time animals are exposed. It levels up or down, but changes in sound level are slow. You must monitor for at least 30 years to identify a trend (see Merchant *et al*, 2016). So median is not useful for the purpose of this indicator.
  - With percentiles, levels should change more quickly as they are more sensitive for time. This is important for management: it gives an indication where a pressure is coming from and the influence of measures can be followed.
- Levels above 95th percentile are caused by measurements very close to the source and are biologically not relevant for this indicator.

Define type of acoustical model

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- It is important that the used acoustical model is robust and validated for the specific region and for the chosen frequencies, like for:
  - North Sea or
  - Deep sea areas (be aware of thermoclines)
  - Arctic seas (ice cover, thermoclines)
  - Low frequency (normal mode models)
  - High frequencies (ray tracing)

Sound scape maps

- BIAS has made soundscape maps for the Baltic region in 2016, showing the underwater sound generated by commercial vessels, the major source of human-induced underwater sound in the Baltic Sea. Seasonal soundscape maps were produced for the demersal, pelagic and surface zones.
- Jomopans will make soundscape maps of North Sea. Models of ships and wind are validated with measurements. Accordingly, it was verified how often differences occur between model and measurements. This gives an indication about importance of other sources. There will be a soundscape map for every month with the different percentiles (see examples Figure 3-3 through Figure 3-7).
- JONAS will make soundscape maps for the Atlantic Region, focussing on evaluating sound field for this very large sea area.
- A soundscape map of natural sound should be made separately. This would enable to produce maps of the excess level.

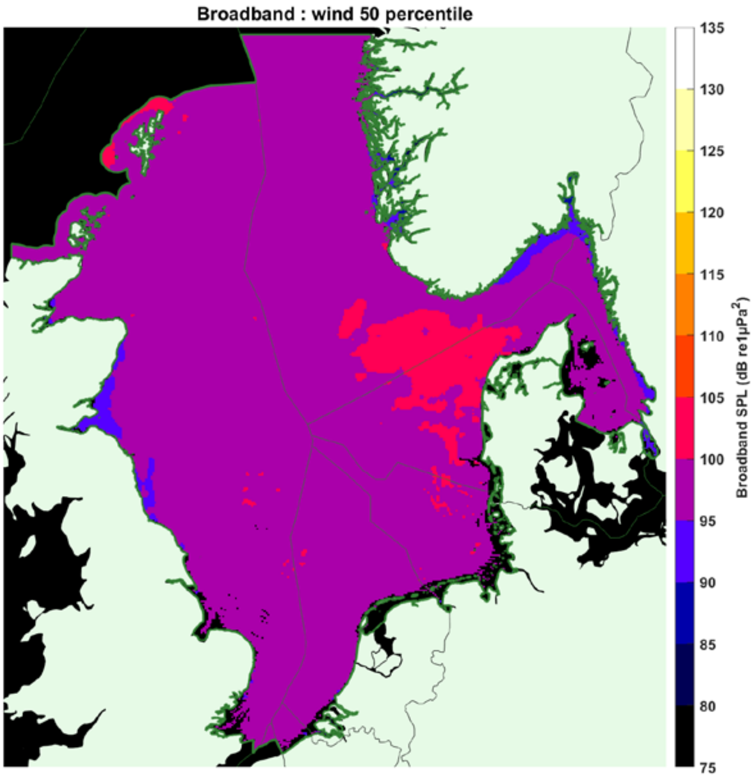

Figure 3-3 Background SPL based on wind (50th percentile) (TNO/Jomopans, 2020)

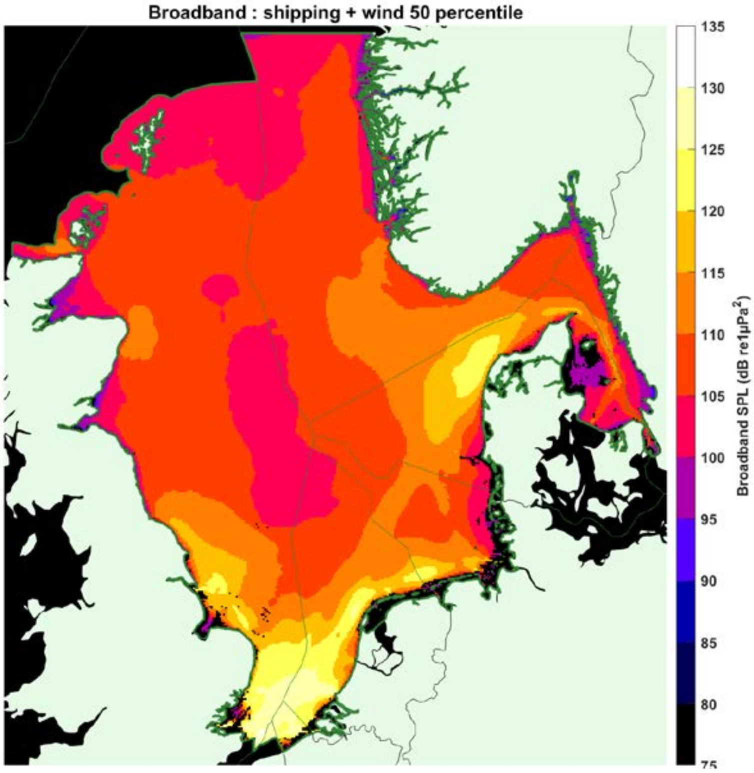

Figure 3-5 Broadband SPL based on shipping and wind (50th percentile) (TNO/Jomopans, 2020)

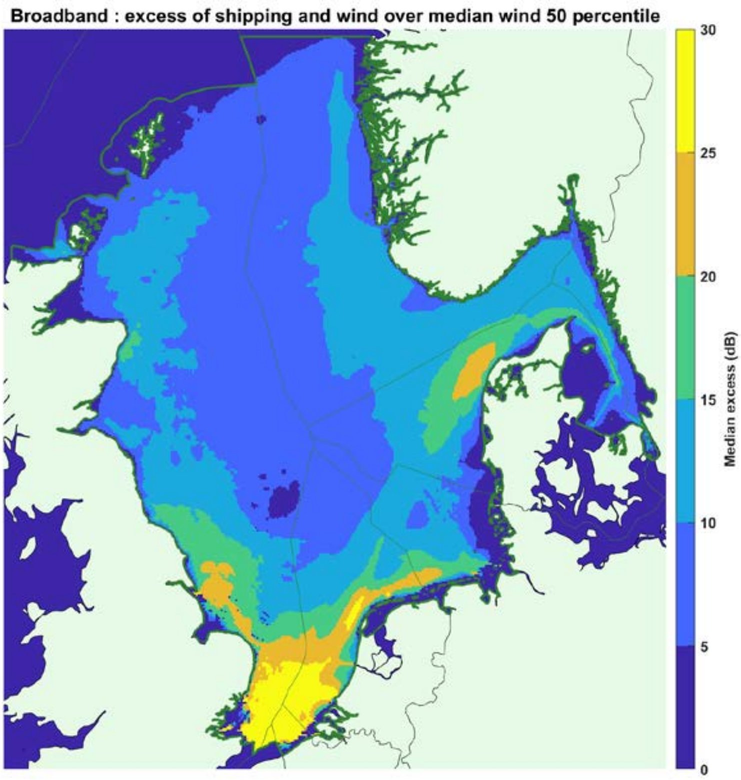

Figure 3-4 Broadband excess level (dB) based on shipping and wind over median wind (50th percentile) (TNO/Jomopans, 2020)

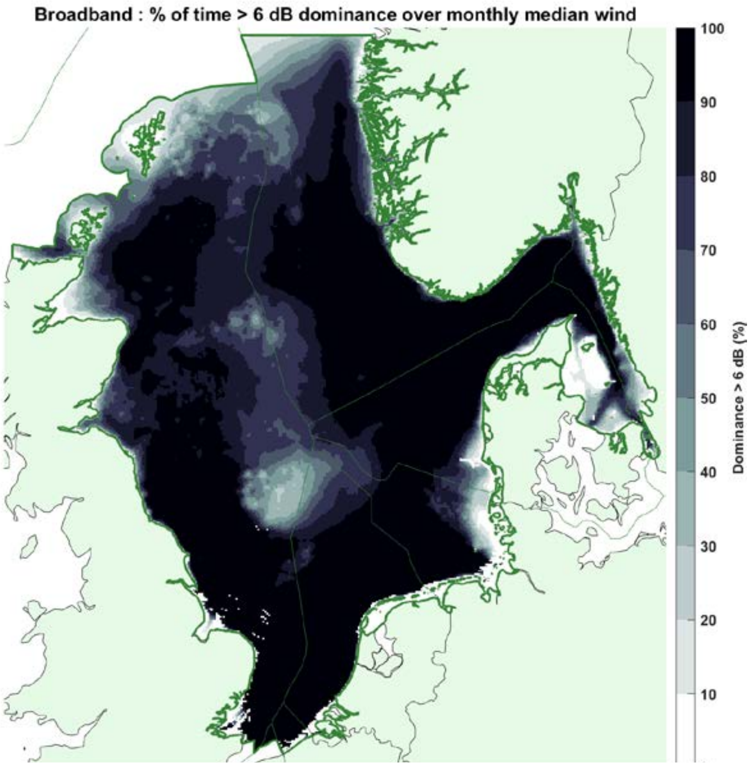

Figure 3-6 Time percentage over which each excess level exceeds a threshold level. This example is based on the monthly median wind and an excess/dominance of >6 dB (TNO/Jomopans, 2020).

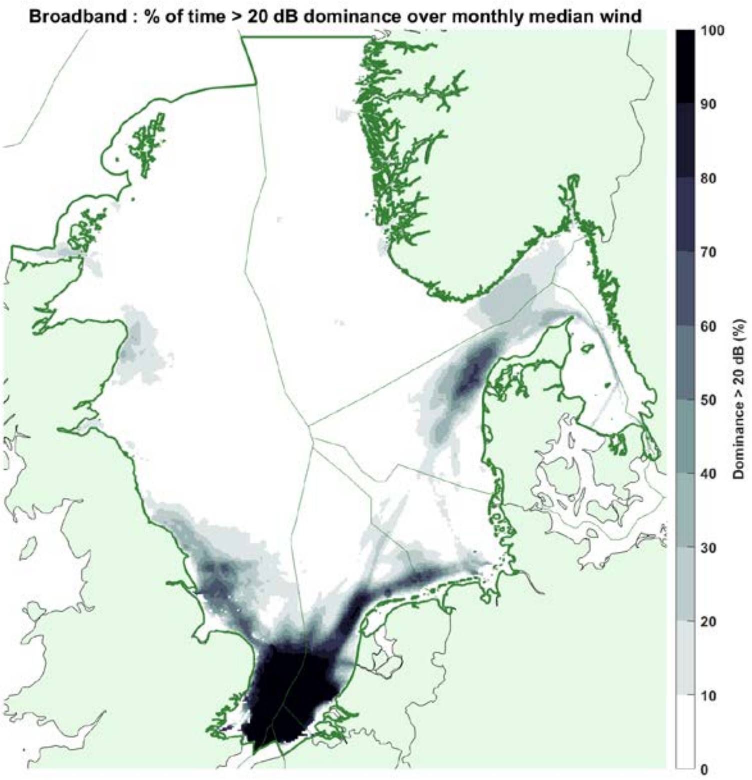

Figure 3-7 Time percentage over which each excess level exceeds a threshold level. This example is based on the monthly median wind and an excess/dominance of >20 dB (TNO/Jomopans, 2020).

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3.6 Step 5. Measure long term acoustical parameters at several stations

At several measurement stations, the Sound Pressure Level (SPL) is measured over a long period. From these measurements statistical parameters of the SPL can be derived.

Importance of measurements

To derive sound maps from measurements alone a vast detailed grid of measurement stations would be necessary. The diversity of the seas and oceans especially closer to shore makes it hard, if not impossible, to interpolate noise measurements from a lesser detailed grid. Noise modelling can take a lot of variables into account and is therefore better equipped for the task at hand. However, calculations and models need to be validated. Noise measurements are the way to do that. In a broader context than this indicator measurements are very useful for real-time monitoring in specific areas to keep track of for example a regulated noise/sound threshold.

Measurement specifications and choose locations

- Measure Sound Pressure Level at several locations.
- Use the following criteria to determine the number of locations and spatial distribution of measurement station locations (for a full overview of the criteria list see Appendix A2) :
  - Physical/environmental properties (depth, bottom type and grain size, geographical position and boundaries.
  - Human and administrative elements: depending on location, one source will be measured more than others. At one spot mainly commercial shipping and at another one mainly production sound will be measured. Critically think about what you want to measure when choosing a location.
  - National considerations (costs, policy considerations)
  - Other applications of the measurements than the assessment of GES (e.g. surveillance).
- Aggregated measurement should preferably (within the legal framework for the responsible countries) made available through a central facility. A database for measurement data is being set up by ICES (commissioned by HELCOM). OSPAR is considering joining this initiative.

Monitoring is executed, following guidance standards. These guidance standards are prepared in the Jomopans project (Snoek et al., 2015), which is a further development from the BIAS standards (Verfuß et al., 2014). Monitoring will result in a sound map.

Function of measurements in assessment of ambient sound

Active noise monitoring is needed because of the following reasons:

- Validation, improvement and keeping up-to-date of models
  - Measurements are needed for the validation and improvement of models.
  - We need continuous measurements to see changes in ambient sound. For example, innovation makes ships quieter. So, we should keep validating source models and update ship noise maps yearly.
  - To understand how the detailed properties of activities (for example new ship design) performs in real world conditions.

    Note that validation of source model / propagation model / overall excess level needs a different measurement set up. Think about this when setting up monitoring system.

- Quality assessment
  - For most oceanic regions there are hardly any measurements/monitoring. We need more monitoring to get better confidence is results. Besides, this is needed for policymakers when they make decisions about measurements.
  - Measurements can help in the discussion and acceptance of the necessary confidence level and the production of confidence maps.
  - We need long time (continuous) monitoring to make time series, so changes can be seen between years. This can help in the understanding of results.
  - In many cases the measurement capacity is limited and a continuous period of time is often not measured (‘duty cycle’). This is usually not affecting the statistical parameters (percentiles) that are needed for this indicator. The duty cycle should be carefully chosen not to compromise the goals of measurements.

- Formulation and evaluation of measures
  - The formulation of management or enforcement measures, and to see the (individual source specific) extremes. Without measurements you lose source specific individual data. Policymakers may want to take measures on individual level. For example, if you want to target ships which do have excessive sound levels (which are within the 10th percentile excess level), it is needed to get back to monitoring data (ship type, ship speed and ship activity). Source models are needed to get statistics right, but you lose individual data; models generate average source levels from ships).
  - May help with real time monitoring to inform, evaluate and possibly enforce management measures.

- Early warning system
  - Measurements can be used to see sudden events. It can be used to monitor, bring to light the need for (future) management measures in sensitive areas and give an adequate response.

- Support (political, public, scientific)
  - Measurements are important for explaining the value and trustworthiness of models towards politics and public and will help getting more trust in the use of models.
  - Continuous learning through new input data as future measurements can give new insights in sound sources and sound specifics of sources, which can subsequently be used to optimise, update or even extend models.

3.7 Step 6. Evaluate the sound scape maps and produce confidence maps

By using the soundscape maps and the measurements a validation is performed and confidence maps will be calculated.

Produce confidence maps to determine error/uncertainty in sound map predictions

- Incorporate measurements in the method to produce confidence maps.

  This is something that needs to be developed.
  JONAS project intends to describe a methodology on sound map models. Below is a first indication:
  - Use measurements at different locations (with different sediment type, water depth, temperature and ocean condition).
  - Comparison of measurements with models must be executed using statistical techniques (to be determined).

- o Identify environmental parameters which are more important than others. For example: sediment grainsize.
- o Make an estimate for the uncertainties, based on measurements we have. Prediction at site level. Do we have enough datapoints to do the statistics? This can be developed when doing it.
- o If we have high confidence in the predictions, it may affect policymakers.

3.8 Risk-of-impact indicator

For the time being the focus of this report is on further refinement of steps 1 to 6. The goal is to determine risk indicator(s) which can be used in assessments, using specific criteria, like the Good Environmental Status (GES). And finally come towards specific measures in case ecological problems occur with ambient noise. In Appendix A2 some ideas are addressed for assessment of the impact and to come towards a risk-of-impact indicator. In the paragraphs below these ideas are briefly introduced.

At this phase only a pressure indicator will be presented to EIHA.

Step 7. Specify estimated animal density or habitat area of indicator species

In this step the biological part is introduced with the selection and data collection of indicator species. This includes the following sub steps: criteria for indicator species, proposal indicator species, determine geographical type of species input and time resolution, determine where to obtain data and determine how to deal with data gaps.

Step 8. Compute exposure/risk indicator(s)

A risk indicator must be computed for each relevant region, that can be assessed using a GES criterion. This includes the following sub steps: determine impact factor and assessment criteria.

Step 9. Compute exposure/risk map

To compute the exposure/risk map step 7 and 8 are combined. This includes a quantitative assessment of confidence in the risk values derived. Step 9 in Appendix A2 shows an example of an exposure index used in the Impulsive Sound Assessment.

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A1 Acronyms

Acronym	Acronym description
ADD	Acoustic Deterrent Device
Ambient sound	Sound that would be present in the absence of a specified activity (ISO 18405: 2017). Ambient sound can be anthropogenic or natural and includes ambient noise.
ASCOBANS	Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas
Continuous sound	Sound which knows only slow variations in level and frequency content. The major anthropogenic source of continuous sound is shipping.
EIA	Environmental Impact Assessment
EEZ	Exclusive Economic Zone
EDR	Effective Disturbance Radius
Impulsive sound	Sound which is often transient and intermittent and is characterised by a rapid rise time and short duration. Examples of impulsive sound sources are military sonar, seismic surveying with air guns, pile driving and marine explosions.
iPCoD	interim Population Consequence of Disturbance. Model for calculating impact of disturbance on sea mammal population.
MPA	Marine Protected Area
MSFD	Marine Strategy Framework Directive
MSP	Marine Spatial Plans
N2000	Natura 2000
NM	Nautical Mile
Noise	Sound that has the potential to cause negative impacts on marine life.
OSPAR	OSPAR is the mechanism by which 15 Governments & the EU cooperate to protect the marine environment of the North-East Atlantic. OSPAR is so named because of the original Oslo and Paris Conventions ("OS" for Oslo and "PAR" for Paris).
PBR	Potential Biological Removal. A measure of the maximum number of individuals of a species that may be removed from the population in addition to natural mortality and emigration without the population undergoing a structural decline.
PTS	Permanent Threshold Shift. An irreversible increase in hearing threshold after exposure to sound.
PVA	Population Viability Assessment
SAC	Special Area of Conservation

SCANS	Small Cetaceans in European Atlantic waters and the North Sea. SCANS-III is a large-scale ship and aerial survey to study the distribution and abundance of cetaceans in European Atlantic waters
TTS	Temporary Threshold Shift. Temporary loss of hearing after exposure to sound as a result of temporary shift of the auditory threshold.

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A2 Criteria list for the choice of the number and location of measurement stations

Interreg
North Sea Region
Jomopans
European Regional Development Fund
EUROPEAN UNION

Memo

Subject: Criteria for choosing measurement stations
Date: Thursday 13 February 2020
From: Niels Kinneging
To: Jomopans project team

Introduction

The most expensive elements of underwater noise monitoring are the measurement stations. In the preparation of the implementation plan it was shown that the reduction of the number measurement stations by working together was key to the cost reduction of the monitoring programme.
In the discussion during the Edinburgh consortium meeting of 3-4 September 2019 it was concluded that criteria were needed on the choice of the number and location of measurement stations. This memo gives some first considerations on these criteria.
The basic role of measurement stations in the monitoring programme is the validation of the modelling and production of sound scape maps. Apart from this also other considerations play a role. It can be policy choice to have more stations or the stations serve other applications.
This memo does not discuss the temporal distribution of measurements.

Physical/environmental properties

Sound propagation is highly dependent on the physical properties of the sea, like bathymetry and the composition of the seafloor. In the North Sea a number of distinct areas can be recognised. Each of these should be sampled sufficitiently.

- Relatively shallow, sandy North Sea with depth ranging from 10 m to 100 m.
- Deep trenches. In the North Sea the Norwegian Trench has a depth from 100 to 700 m.
- Coastal zones with depths up to 10 m
    - now chosen not to include in monitoring
    - only local nose issue
- Non-open sea areas like the Kattegat and river estuaries (Scheldt, Thames, Eems, Elbe)

Since the final aim of the monitoring is to assess Good Environmental Status environmental conditions can also be considered.

- Habitat type.
- Presence of key species.
- Marine protected areas.

Human and administrative elements

Noise sources may vary in strength and character and the monitoring programme should be able to give information on all types of sources. Therefore, measurements stations should be located near major sources of underwater noise as well as on relatively quiet locations for the natural sources.

- Shipping lanes at sea and at the entrance of harbours. Also for types of ships:
  - Trade (bulk carriers, container ships, coastal shipping)
  - Fisheries
  - Recreational
- Wind farms.
- Other human activities (oil and gas, fish farms, …)
- Quiet zones with prohibited or low shipping.

National considerations

Measurement can best be organised through the national programmes of the North Sea countries. Therefore, also a balance must be found in the efforts of the contributing countries.
On the other hand, countries can have other considerations to make choices:

- Costs of the stations
- Policy considerations
- Knowledge position of national institutes
- National security issues (limiting stations in certain areas)

Other applications

Finally, a measurement station can serve multiple applications, like

- Surveillance of ship traffic
- Biological monitoring
- Source measurements
- Science

A3 Risk-of-impact indicator: Steps 7 – 9

Step 7. Specify estimated animal density or habitat area of indicator species

In this step the biological part is introduced with the selection and data collection of indicator species. Collect density estimation data if available and appropriate, otherwise collect information of areas (e.g. habitat quality mapping, MPA, spawning grounds, etc.).

Criteria for indicator species
The selection for indicator species can be done on the following criteria (also based on TG Noise GES_22-2019-18):

- *Hearing sensitivity*: species should be able to detect sound
- *Vulnerable to sound*: species should be known to be negatively impacted by the sound that is considered;
- *Data availability*: enough distribution data must be available about the species;
- *Representative:* species must be representative for its species group;
- *Occurrence:* species must be abundant/commonly occur (in at least one OSPAR region);
- *Commercially importance:* for fish and invertebrates: species must be commercially important. This criterium is of importance for MSFD, not for OSPAR.

When further finetuning is desired and data with sufficient detail is available, the criteria questions proposed by Ferreira *et al.* (2016) can be used, for example:

- Is the indicator relatively easy to understand by non-scientists and those who will decide on their use?
- Does the indicator respond primarily to a particular human pressure, with low responsiveness to other causes of changes?
- Threat status.

Proposal indicator species
Below an example is given of possible indicator species. The selection is carried out on a pragmatic base. Indicator species will vary between regions.

- Marine mammals:
  - Fin whale is a good candidate for the Atlantic.
  - Pilot whale or bottlenose whale are good candidates for deeper Atlantic, as deep diving representatives.
  - Harbour porpoise is most common and most studied/well known cetacean of the North Sea, but not sensitive for LF underwater sound.
  - Minke whale might be better for the North Sea, but less abundant and less studied.
  - Humpback whales and blue whales migrate to OSPAR region.

  - Most of what we know about impact of sound on seals is from harbour seal. If grey seal is chosen as indicator species, then we must assume the hearing is the same as harbour seal.

- Fish:
  - Cod and herring: commercially important, and we know they are acoustical active.
  - Demersal fish: Common sculpin (e.g. *Cottus asper*) is acoustically active, but currently there is limited data of distribution. Sole (*Solea Solea*) is better studied.

- Birds:

- o Cormorant is a diving bird and some studies have been done on impact of sound, but mostly active in coastal zone.
- o Common guillemot is outside breeding season a pelagic species for the North Sea, but less is known about sensitivity to sound.

- Invertebrates:
  - o Some bivalves (Blue mussel) or crustacean (shrimp) are able to detect sound. There is a limited amount of knowledge on the impact of sound on invertebrates. For some crustacean changes in behaviour, like feeding rate, are shown. Some shrimp produce sound itself and it is not yet clear why they produce it and if they are vulnerable for masking. Sessile benthic animals cannot move away from a sound source which makes them potentially very vulnerable.
  - o Zooplankton. No data available yet about sensitivity to sound.

Determine geographical type of species input and time resolution

- Geographical options:
  - o Distribution data (density estimation)
  - o Demarcation of sensitive area (MPA, feeding ground, spawning ground, habitat quality mapping)
  - o Uniform/homogenic distribution of species (if no info available)

- Time resolution:
  - o Make use of available knowledge and information
  - o Make distinction in seasonality if possible and necessary
  - o Use available literature to determine if mean of several years or highest density level of # years is best. Can be species specific. Describe which data have been used.

- Biological information of seasonal variation is limiting: a better resolution than 1 month can be difficult.

Determine where to obtain data

It is important to discuss and record where biological information is obtained at the front of the assessment. Some examples where to obtain data:

- Latest research projects, like SCANS III, literature (i.e. Gilles et al., 2016 for harbour porpoise North Sea or Waggitt et al, 2019 for harbour porpoise (and other marine mammals) for North Sea and Atlantic) or expert judgement.
- Habitat suitability model.
  The distribution of species could already have been affected by ambient noise levels, in which case it could be necessary to look at habitat suitability or persistency over time. Besides, we don't have monitoring data of whole OSPAR area and not at all regional levels, so a habitat model[18] can solve this knowledge gap. Within a habitat model, sensitive areas can be selected to have another weighting factor for impacts
- Population model, like iPCoD or DEPONS.
  Note: DEPONS model, cannot be extended to model sound maps within 2 years.
  These models are often tuned for impulsive noise and much more knowledge is needed to apply such models for continuous noise as well.

Determine how to deal with data gaps

- Address absence of information. If distribution data of a species is important, describe how to deal with the absence of it. Do you use a model, or do you allow expert judgement? Make choices about this and describe them.

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[18] *See JNCC website for recent work done on habitat model for harbour porpoise (or ask Sonia Mendes).*

Table 3-3. Overview of possible indicator species. Species in grey are considered but not appropriate for ambient sound.

Indicator species	Suborder / habitat	Where to obtain info?	Temporal and spatial resolution	Remarks
Marine mammals				
Cetacean: baleen whales	Minke whale (*Balaenoptera acutorostrata*)	SCANS III	Atlantic / low density in North Sea	Very few studies on impact
	Fin whale (*Balaenoptera physalus*)	SCANS III	Atlantic	Very few studies on impact
Cetacean: toothed whales	Pilot whale (*Globicephala melas*) or Bottlenose whale (*Hyperoodon ampullatus*)		Deeper Atlantic	
	Harbour porpoise	SCANS III, Habitat suitability model, Population model (e.g. iPCOD)	North Sea, especially spring and summer	Not sensitive to low frequency sound
Pinnipeds	Harbour seal	Local monitoring data	More coastally distributed, common in North Sea	Present up to 50km off the coast. Lot of impact studies
	Grey seal	Local monitoring data	Widely distributed, common in North Sea	Some impact studies available
Fish				
Herring	Pelagic	Commercial fish monitoring data	North Sea/Atlantic	Limited data on sound impact
Cod	Benthopelagic	Commercial fish monitoring data	North Sea/Atlantic	Extensive data on sound impact available
Sole	Benthic	Commercial fish monitoring data	North Sea/Atlantic	Limited data on sound impact
Birds				
Cormorant	Coastal	Local monitoring data	North Sea	Studies on impact available, but only coastal distribution
Common guillemot	Pelagic	Local monitoring data	North Sea	No knowledge of sensitivity to underwater sound available
Invertebrates				
Blue mussel (*Mytilis edulis*)	Benthic	Local monitoring		Occurs mainly in shallow water
Oyster	Benthic	Local monitoring		
Shrimp	Benthic	Limited		
Zooplankton	Pelagic	Limited	OSPAR region	No sufficient information on the sensory capabilities available

Step 8. Compute exposure/risk indicator(s)

A risk indicator must be computed for each relevant region, that can be assessed using a GES criterion. Furthermore, assessment criteria should be defined.

Determine impact factor

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This requires a definition of exposure and risk based on SPL and habitat data. This is not yet available and needs further elaboration.

- For impulsive sound TTS/PTS is used. For ambient sound this is not an appropriate metric.

- Behaviour reactions to ship sound are not yet known.
  - We are not able to use behaviour reactions in impact assessments yet. We know too little about disturbance of ship sound, but there is work being done on this topic.

- Masking is closely related to a sound signal. Masking can initiate a behaviour reaction. So, the proposal is to use masking as an impact factor.

  The simplest concept is a 'range reduction factor' in a situation where the detection is limited by ambient sound. Then the detection range is reduced when the ambient sound level is increased by anthropogenic sound.
  This requires the selection of a frequency band in which the detection (or communication) is masked.

- We cannot quantity masking. We can detect differences in masking, like elevation to a smaller or larger degree. If the Signal-to-noise ratio goes down, then the maximum mask ratio will go down.

  SNR: Signal-to-noise ratio.
  - Signal that is produced by the animal. Relevant signals must become above background sound. What do we know of this signal?
  - The animal may produce a louder signal, that costs more energy.

Assessment criteria
The following options are currently collected to determine the impact of ambient sound to indicator species.

Proposal
- Use an excess level: try to quantify the exposure in terms of the excess of anthropogenic sound over natural sound.
  - % of signal reduction. So, threshold definition from animal point of view.

  - HELCOM approach:
    Excess level threshold: at what percentile at a specific time is excess level threshold exceeded or not. Exposure curves made based on BIAS trial.

  - Jomopans uses several differences: at what level does anthropogenic sound excess above natural sound. From this a reference level of masking can be determined.
    - % of time the sound exceeds background sound. Look at single moments, no mean or median.
    - Monthly percentiles. Calculate percentiles of excess level per time period (in Jomopans chosen for 1 month).
    - Done for wind and for shipping.
    - In summary: determine the local excess level of ship sound over wind sound per time step, and then determine the percentiles of that excess.

- o Percentage of time and population maybe more useful than a single threshold. Any threshold will be subject to scrutiny. And masking has not so much to do with absolute levels.

- o Work with examples, how does it work in practice. Then you can figure it out in more detail.

- Questions:
→ Can the percentiles be used to quantify excess level?
→ What does it mean if the 5th and 90th percentile are close to each other?
→ When looking at a particular percentile: what is going on 50% of time scale/ how much masking is occurring 50% of the time. Then a range/spectrum of masking can be defined. That would allow discussion makers how much masking is acceptable. (Note: this is studied in JONAS project).
→ What is going on when the median excess level exceeds a specified threshold (e.g. 6dB or 20 dB).

Other options

- One threshold for the whole region.
  - o Difficult to execute; in shipping lanes the threshold is exceeded or is so high, that other parts of is sea are not protected.

- Close sensitive areas.

- Use standard excess level.
  - o Where to draw the line is a political choice, as there is insufficient scientific data.
  - o For explosions 20 dB excess level has been used (TNO, 2014).

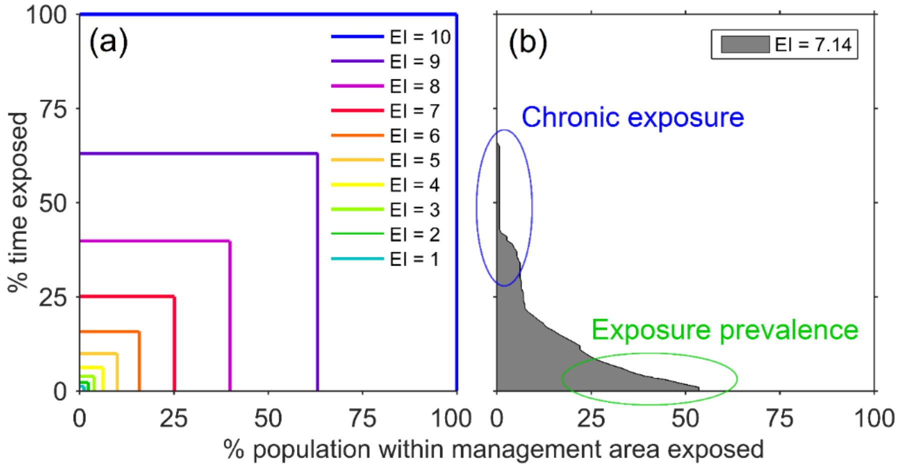
- Combination of spatial + acoustical component: in X% of the area, Y% of the sound must be below level Z dB.
  - o Level can be excess or SPL percentile.
  - o Chose X, Y and Z based on measures and models.
  - o Evaluate after X year to check if goals are achieved.

- Link with impact level: exceeding level or absolute level.
  - o Be aware that variability in seasons can mean that objectives will be realized in winter, but not in summer, depending on chosen impact level. Or make a link with variable measures (seasonal).
  - o It can be biologically relevant to distinguish between seasons. However, we will not have enough seasonal distribution information about species to use this in impact assessments.

Step 9. Compute exposure/risk map

- Combine step 7 and 8.
- Including quantitative assessment of confidence in the risk values derived.
- What is the meaning of a risk?

In the Impulsive sound assessment, the Exposure Index is used (Merchant *et al.*, 2018b). The Exposure Index (EI) expresses the overall exposure of the population based on the area under the exposure curve (see Figure 3-2). This area is log transformed and scaled from 0 to 10. For ambient sound however, it is not ideal to use the Exposure Index. Exposure curves are a better option for shipping sound.



(f) **Exposure indicators**

Metric	*Definition*
Exposure Index (EI)	Area under exposure curve (log-transformed and scaled from 0 to 10, see Figure 3a)
Chronic Exposure Indicator (CEI)	% population exposed > chronic % time
Exposure Prevalence Indicator (EPI)	% population exposed > significant % time

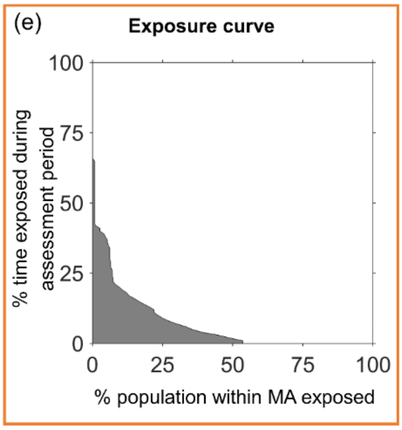


Figure 3-8. Exposure index is used in the Impulsive Sound Assessment (Merchant et al, 2018b).

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