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Monitoring Guidance for Underwater Noise in European Seas

Part II: Monitoring Guidance Specifications

A guidance document within the Common Implementation Strategy for the Marine Strategy Framework Directive

MSFD Technical Subgroup on Underwater Noise

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TABLE OF CONTENTS

FOREWORD

The Marine Directors of the European Union (EU), Acceding Countries, Candidate Countries and EFTA Countries have jointly developed a common strategy for supporting the implementation of the Directive 2008/56/EC, "the Marine Strategy Framework Directive" (MSFD). The main aim of this strategy is to allow a coherent and harmonious implementation of the Directive. Focus is on methodological questions related to a common understanding of the technical and scientific implications of the Marine Strategy Framework Directive. In particular, one of the objectives of the strategy is the development of non-legally binding and practical documents, such as this recommendation, on various technical issues of the Directive. These documents are targeted to those experts who are directly or indirectly implementing the MSFD in the marine regions.

This document has been prepared by the Technical Sub-Group on Underwater Noise and other forms of Energy (TSG Noise), established in 2010 by the Marine Directors. In December 2011, EU Marine Directors requested the TSG Noise to provide monitoring guidance that could be used by MS in establishing monitoring schemes to meet the needs of the MSFD indicators for underwater noise in their marine waters.

The Marine Strategy Coordination Group has agreed (in accordance with Article 6 of its Rules of Procedures) to publish this document as technical guidance developed in the MSFD Common Implementation Strategy. The participants of the Marine Strategy Coordination Group concluded:

"We would like to thank the experts who have prepared this high quality document. We strongly believe that this and other documents developed under the Common Implementation Strategy will play a key role in the process of implementing the Marine Strategy Framework Directive. This document is a living document that will need continuous input and improvements as application and experience build up in all countries of the European Union and beyond. We agree, however, that this document will be made publicly available in its current form in order to present it to a wider public as a basis for carrying forward on-going implementation work."

The Marine Strategy Coordination Group will assess and decide upon the necessity for reviewing this document in the light of scientific and technical progress and experiences gained in implementing the Marine Strategy Framework Directive.

Disclaimer:

This document has been developed through a collaborative programme involving the European Commission, all EU Member States, the Accession Countries, and Norway, international organisations, including the Regional Sea Conventions and other stakeholders and Non-Governmental Organisations. The document should be regarded as presenting an informal consensus position on best practice agreed by all partners. However, the document does not necessarily represent the official, formal position of any of the partners. Hence, the views expressed in the document do not necessarily represent the views of the European Commission.

SUMMARY

The Marine Strategy Framework Directive (MSFD) requires European Member States (MS) to develop strategies for their marine waters that should lead to programmes of measures that achieve or maintain Good Environmental Status (GES) in European Seas. As an essential step in reaching good environmental status, MS should establish monitoring programmes, enabling the state of the marine waters concerned to be assessed on a regular basis. Criteria and methodological standards on GES of marine waters were published in 2010 (Commission Decision 2010/477/EU). Two indicators were described for Descriptor 11 (Noise/Energy): Indicator 11.1.1 on low and mid frequency impulsive sounds and Indicator 11.2.1 on continuous low frequency sound (ambient noise).

As a follow up to the Commission Decision, the Marine Directors in 2010 agreed to establish a Technical Subgroup (TSG) for further development of Descriptor 11 Noise/Energy. TSG (Underwater) Noise in 2011 focused on clarifying the purpose, use and limitation of the indicators and described methodology that would be unambiguous, effective and practicable; the first report [Van der Graaf *et al.*, 2012][1] was delivered in February 2012. Significant progress was made in the interpretation and practical implementation of the two indicators, and most ambiguities were solved.

In December 2011, EU Marine Directors requested the continuation of TSG Noise, and the group was tasked with recommending how MS might best make the indicators of the Commission Decision operational. TSG Noise was asked first to provide monitoring guidance that could be used by MS in establishing monitoring schemes for underwater noise in their marine waters. Further work includes providing suggestions for (future) target setting; for addressing the biological impacts of anthropogenic underwater noise and to evaluate new information on the effects of sound on marine biota with a view to considering indicators of noise effects.

The present document is **Part II** of the **Monitoring Guidance for Underwater Noise in European Seas** and provides MS with the information needed to commence the monitoring required to implement this aspect of MSFD. TSG Noise has identified ambiguities, uncertainties and other shortcomings that may hinder monitoring initiatives and has provided solutions. Methodology is described for monitoring both impulsive and ambient noise to ensure the information required for management and policy is collected in a cost-effective way. Further issues will certainly arise once monitoring starts, but the principles laid out in this guidance will help resolve these.

The Monitoring Guidance for Underwater Noise is structured, as follows:

- Part I: Executive Summary & Recommendations,
- **Part II: Monitoring Guidance Specifications,** and
- Part III: Background Information and Annexes.

Part I of the Monitoring Guidance is the executive summary for policy and decision makers responsible for the adoption and implementation of MSFD at national level. It provides the key conclusions and recommendations presented in Part II that support the practical guidance for MS and will, enable assessment of the current level of underwater noise.

Part II, is the main report of the Monitoring Guidance, is the main report of the Monitoring Guidance. It provides specifications for the monitoring of underwater noise, with dedicated sections on impulsive noise (Criterion 11.1 of the Commission Decision) and ambient noise

[1] The 1st TSG Noise Report (27 February 2012) available online: http://ec.europa.eu/environment/marine/pdf/MSFD_reportTSG_Noise.pdf

(Criterion 11.2 of the Commission Decision) designed for those responsible for implementation of noise monitoring/modelling, and noise registration.

Part III, the background information and annexes, is not part of the guidance, but is added for additional information, examples and references that support the Monitoring Guidance specifications.

1. INTRODUCTION

1.1 Introduction to Underwater Noise

Two indicators were published for Descriptor 11 (Noise/Energy) of the MSFD 2008/56/EC in the EC Decision 2010/477/EU on criteria and methodological standards on GES of marine waters. These are: Indicator 11.1.1 on "low and mid frequency impulsive sounds" and Indicator 11.2.1 on "Continuous low frequency sound" (ambient noise). As a follow up to the EC Decision, the Marine Directors agreed to establish a technical sub-group (TSG) for further development of Descriptor 11 Noise/Energy. This report compiles the recommendations of TSG Noise. Text box 1 shows the extract of the EC Decision specifically for the indicators of Descriptor 11.

Text Box 1: Extract of the indicators for Descriptor 11 (Noise/Energy) from EC Decision 2010/477/EU

Descriptor 11: Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment.

Together with underwater noise, which is highlighted throughout Directive 2008/56/EC, other forms of energy input have the potential to impact on components of marine ecosystems, such as thermal energy, electromagnetic fields and light. Additional scientific and technical progress is still required to support the further development of criteria related to this descriptor, including in relation to impacts of introduction of energy on marine life, relevant noise and frequency levels (which may need to be adapted, where appropriate, subject to the requirement of regional cooperation). At the current stage, the main orientations for the measurement of underwater noise have been identified as a first priority in relation to assessment and monitoring, subject to further development, including in relation to mapping. Anthropogenic sounds may be of short duration (e.g. impulsive such as from seismic surveys and piling for wind farms and platforms, as well as explosions) or be long lasting (e.g. continuous such as dredging, shipping and energy installations) affecting organisms in different ways. Most commercial activities entailing high-level noise levels affecting relatively broad areas are executed under regulated conditions subject to a license. This creates the opportunity for coordinating coherent requirements for measuring such loud impulsive sounds.

11.1. Distribution in time and place of loud, low and mid frequency impulsive sounds

- Proportion of days and their distribution within a calendar year over areas of a determined surface, as well as their spatial distribution, in which anthropogenic sound sources exceed levels that are likely to entail significant impact on marine animals measured as Sound Exposure Level (in dB re 1 μPa 2 .s) or as peak sound pressure level (in dB re 1 μPa peak) at one metre, measured over the frequency band 10 Hz to 10 kHz (11.1.1)

11.2. Continuous low frequency sound

- Trends in the ambient noise level within the 1/3 octave bands 63 and 125 Hz (centre frequency) (re 1μPa RMS; average noise level in these octave bands over a year) measured by observation stations and/or with the use of models if appropriate (11.2.1).

1.2 Importance of noise versus other forms of energy

There are many kinds of anthropogenic energy that human activities introduce into the marine environment including sound, light and other electromagnetic fields, heat and radioactive energy. Among these, the most widespread and pervasive is underwater sound. It is likely that the amount of underwater sound, and therefore associated effects on the marine ecosystem have been increasing since the advent of steam-driven ships, although there have been very few studies that have quantified these changes. The numbers of anthropogenic electromagnetic fields are increasing due to the increasing number of power cables crossing our seas but these emissions are relatively localised to the cables. Light and heat emissions are also relatively localised, but may have significant local effects (Tasker *et al*. 2010).

Sound energy input can occur on many scales in both space and time. Anthropogenic sounds may be of short duration (*i.e.* impulsive) or be long lasting (*i.e.*. continuous); impulsive sounds may however be repeated at intervals (duty cycle) and such repetition may become diffuse with distance and reverberation and become indistinguishable from continuous noise. Higher frequency sounds transmit less well in the marine environment whereas lower frequency sounds can travel far. In summary, there is great variability in transmission of sound in the marine environment.

Marine organisms which are exposed to noise can be adversely affected both on a short timescale (acute effect) and on a long timescale (permanent or chronic effects). Adverse effects can be subtle (e.g. temporary reduction in hearing sensitivity, behavioural effects) or obvious (e.g. injury, death). These adverse effects can be widespread (as opposed to localised for other forms of energy) and, following the recommendations of Tasker et al (2010), in September 2010 the European Commission identified the main orientations for monitoring of underwater noise that should be used to describe Good Environmental Status (GES) [EC Decision 2010/477/EU on criteria and methodological standards on GES].

This report provides guidance to Member States for establishing monitoring programmes for these indicators of underwater sound.

2. GUIDANCE FOR REGISTRATION OF IMPULSIVE NOISE

Indicator 11.1.1 is described in the Commission Decision 2010/477/EU (CD) as: *Proportion of days and their distribution within a calendar year over areas of a determined surface, as well as their spatial distribution, in which anthropogenic sound sources exceed levels that are likely to entail significant impact on marine animals measured as Sound Exposure Level (in dB re 1µPa² .s) or as peak sound pressure level (in dB re 1µPa peak) at one metre, measured over the frequency band 10 Hz to 10 kHz.*

This description is not unambiguous and therefore TSG Noise recommends the following revision of the indicator 11.1.1 on low and mid-frequency impulsive sounds:

The proportion of days and their distribution within a calendar year, over geographical locations whose shape and area are to be determined, and their spatial distribution in which source level or suitable proxy of anthropogenic sound sources, measured over the frequency band 10 Hz to 10 kHz, exceeds a value that is likely to entail significant impact on marine animals (11.1.1).

For further considerations and explanation, see the first TSG report [Van der Graaf *et al.*, 2012].

2.1 Main objective and scope of the indicator

TSG Noise has noted that guidance is needed for the main objective of the impulsive noise indicator and the aim of the indicator was further explained in the first report by TSG Noise in February 2012. A basic principle of the MSFD is that it addresses the ecosystem rather than individual animals or species (consideration 5: the development and implementation of the thematic strategy should be aimed at the conservation of the marine ecosystems). This indicator addresses the cumulative impact of activities, rather than that of individual projects or programme (those are addressed by other EU legislation); effects of local/singular activities are not covered. This indicator alone is not intended, nor is it sufficient, to manage singular events, but Environmental Impact Assessments (EIA) can be used to assess, and where necessary, to limit the environmental impacts of individual projects.

TSG Noise suggested that "considerable" displacement is the most relevant effect of loud low and mid-frequency sounds that can practicably be measured - this may lead to population effects and thus should be addressed by Indicator 11.1.1. "Considerable" displacement means displacement of a significant proportion of individuals for a relevant time period and at a relevant spatial scale. The indicator addresses the cumulative impact of sound generating activities and possible associated displacement, where effects may occur at the ecosystem level; for further clarification see the first report of TSG Noise [Van der Graaf, 2012], par 3.3.1.3).

The purpose of this indicator is to quantify the pressure on the environment, by making available an overview of all loud impulsive low and mid-frequency sound sources, throughout the year, in regional seas. This will enable MS to get a complete overview of the occurrence of all the activities that produce the relevant sounds that place pressure on the environment, which has not previously been achieved. It will also make it easier to assess cumulative effects of the pressure on the environment (see the first report of TSG Noise [Van der Graaf, 2012]).

The initial step is to establish the current level and trend of these impulsive sounds. This may be done by setting up a register of these impulsive sounds.

2.2 Impulsive sound and most relevant sources

The Commission Decision uses the term "impulsive" sounds. TSG Noise realised that the term "impulsive" is reserved for specific sounds that are often transient, and which are characterised by a rapid rise time and high peak pressures. The term "pulse" is sometimes also used for these sounds including in widely accepted publications [Southall *et al*., 2007]. The original intention of the indicator was that also other loud short-duration sounds were probably of relevance, e.g. sonar sounds [Tasker *et al*., 2010]. These sounds would not be included in the definition of "impulsive" (or "pulse") as used in some communities [Southall *et al*., 2007]. Therefore TSG Noise concluded some clarification on the (use of) the term "impulsive" is needed.

The title of the indicator is "11.1. Distribution in time and place of loud, low and mid frequency impulsive sounds". This text suggests that one needs to distinguish between impulsive sounds and non-impulsive ones, and a definition of "impulsive sound" was proposed in [Van der Graaf *et al*., 2012]. A more careful reading of the indicator text:

"[anthropogenic sounds may be of short duration (e.g. impulsive such as from seismic surveys and piling for wind farms and platforms, as well as explosions) or be long lasting (e.g. continuous such as dredging, shipping and energy installations) affecting organisms in different ways"

makes clear that the emphasis is not on "impulsive sounds" as such, but on sound of "short duration", of which impulsive sounds are mentioned as an example.

For Indicator 11.1.1, the TSG Noise proposal is to monitor loud sounds of short duration that are likely to cause disturbance. Impact pile driving has been shown to result in an evasive response in harbour porpoises [Dähne *et al*., 2013] and airguns have been shown to result in evasive reaction in many cetaceans [Stone and Tasker, 2006], and disturbance on fish may also occur [Dalen and Knudsen, 1986; Engås et al., 1996; Slotte et al., 2012]. Sonar transmissions have also been shown to cause a strong aversive reaction in beaked whales [Tyack *et al*., 2011, DeRuiter *et al*., 2013]. Therefore airguns, impact pile driving and sonar should be included in the scope of this Indicator. Most available data for explosions focuses on physical harm [e.g. Danil & St. Leger, 2011] rather than on disturbance, but these should also be included as sound levels produced by explosions are much higher than that of the above mentioned sources.

Whereas sounds produced by piling, airguns and explosions typically are short (less than one second), sonar sounds may be of longer duration, i.e. several seconds. To cover all sources of concern, TSG Noise proposes that all loud sounds of duration less than 10 seconds should be included.

2.3 Outline of the register (M1-b)

The main aim of the register is to record activities in order to enable assessment of the total pressure from impulsive sources. In addition to serving as an assessment tool, it is possible that the register may also serve as a tool to aid management decision-making in the future, once a baseline level has been determined and/or there are targets for the management of sound.

A noise register will provide data that could be used to map the occurrence of activities generating loud sounds. The amplitude, frequency and other impulsive characteristics of the sounds are not precisely defined in the Commission Decision, although the frequency range has been defined as 10 Hz to 10 kHz. The precise properties of an impulsive sound that cause displacement are not yet known, and are certain to vary with biological receptor and the time of year. An essential first step towards cumulative impact assessment is to map those human activities which are likely to generate "loud" impulsive sounds within this frequency range.

The most important sound-sources that should be considered for inclusion in the register are airguns, pile-driving, explosives, sonar working at relevant frequencies and some acoustic deterrent devices. Additional sources that could also be of concern include boomers, sparkers and scientific echo sounders. TSG Noise proposes to use thresholds for inclusion in the register. Thresholds were derived that will ensure that all sources that have a potential for significant population level effect will be included in the register (see part III, chapter 2.1 for substantiation of the chosen thresholds). However, the use of these (relatively low) thresholds will result in sources with a relatively low potential for significant impact also being registered. TSG Noise concluded that there is a need for more detail in the register than just the day and location; of this additional information, the source level is the most important.

The main aim of the registry is to provide an overview of all loud sounds. If certain sound sources are left out, the aim of addressing the cumulative effects of impulsive noise would not be fully met, and therefore it is recommended that information on all sources should be included [see Van der Graaf *et al*., 2012]. TSG Noise suggest that data on explosives and military activities (of which the sole purpose is defence or national security) should also be included in the register, but notes that this should be on a voluntary basis as this is a national policy issue.

2.3.1 Information to be included in the register

For the future register, the following data should be collected:

- ✓ Position data (geographic position (lat/long), licensing block/area)
- ✓ Date of operation
- ✓ Source properties:

  Essential (minimum)

  - Source level or proxy of source level;

Additional data will be beneficial for improved assessment - where available the following may also be recorded:

- Source spectra;
- Duty cycle;
- Duration of transmissions (and actual time/time period);
- Directivity [2];
- Source depth;
- Platform speed

It is possible that many operators (e.g. navies using sonar) may have concerns about releasing sensitive information. Where detailed information of source properties is requested it is proposed that certain operators be given the option to report source level in bins (for example, in intervals of 10 dB) rather than giving a precise figure.

[2] Much of the energy from airguns is directed downwards, and therefore directivity data are needed to assess their significance. Directivity plots are routinely produced by seismic survey companies in advance of carrying out their surveys. If this information is made available (if possible in digital form), MS can include this information when assessing possible effect ranges and thereby improve the assessment. If for other sources the producer of the sound wants the directionality to be taken into account, that producer should provide the necessary information.

2.3.2 Issues for a common register between Member States

TSG Noise recommends the setting up of a joint register of the occurrence of impulsive sounds at least on a Regional Sea level.

The final format for the common register needs to be established to ensure future compatibility. This cannot be conclusively decided until the register location and management are decided, but some factors could be implemented now, such as:

- ✓ Use of a common language (English)
- ✓ Use of a common format for date in accordance with the appropriate standard (ISO 8601) (YYYY-MM-DD or YYYYMMDD)
- ✓ Use of a common format for position (latitude and longitude, decimal degrees)
- ✓ Use of a common map projection (unprojected data – WGS84)
- ✓ Use of a common template (i.e. setting out the order in which information is recorded)

2.3.3 The use of grids, grid definition and size

As mentioned above, for some of the data (e.g. seismic survey data) the use of a grid (based on standard licensing blocks) may be practicable to collect (part of) the data on impulsive noise. Member States may choose to use such a grid to organise data (for instance, use the above-mentioned blocks to store data instead of the actual positions of a piling activity). Member States may also choose to use such a grid for other purposes e.g. presenting data, assessment purposes and for future management action.

In such cases, the actual choice of grid definition, and the size of the grid cells, is a choice that should be made by Member States and this can be based on practical considerations, e.g. in the UK, data are registered in standard hydrocarbon licensing blocks that are 10 minutes latitude by 12 minutes longitude. If the grid is to be used for assessment purposes, a possible option is to base the grid on estimated impact (e.g. the reported range of displacement effects for harbour porpoises from pile driving has been of the order of 20 km [Tougaard *et al*, 2012*]*. A circle with a radius of 20 km has an area of ca. 1250 km^2. TG 11 suggested blocks of 15 minutes of latitude by 15 minutes of longitude, which at a latitude of 45 degrees North, would give an area of about 550 km^2. For easier interpretation of results in a common register, TSG Noise would recommend one standard grid size to be used by Member States.

If the grid chosen by Member States is to be used for assessment purposes, it should be noted that it may not be of the same spatial scale as the area actually affected by the noise source. The number of days (or proportion/percentage of a longer period) over which activities occur should not be interpreted as a direct measure of habitat loss (holes in distribution). This may not be a problem - a correction factor could be applied when comparing results that are generated using different grid sizes, or if the grid sizes are not appropriate for definitions of targets. This correction factor could, in principle, be based on the ratio of expected impact size to registry grid size. (see Van der Graaf *et al.*, 2012).

There may also be issues for grid cells in coastal areas or at boundaries between Member States. For these blocks some additional considerations may apply. See Part III of the guidance for more detailed information on these coastal and boundary blocks.

2.4 Technical Specifications

2.4.1 Thresholds (M1-a)

Minimum noise thresholds have been defined for low and mid-frequency sources as a basis for including sources in the register. For background and explanation of these values see Part III of the Monitoring Guidance (chapter 2.1)

For impact pile-drivers no minimum threshold should be used and all pile-driving activities should be registered.

For sonar, airguns, acoustic deterrents and explosives, minimum thresholds should be used for uptake in the registers. The generic source level (SL) threshold for inclusion in the register for non-impulsive sources is 176 dB re 1 μPa m, whereas the threshold for inclusion of impulsive sources is an energy source level (SL_E) of 186 dB re 1 μPa² m² s. For airguns and explosives it is more convenient to convert these to proxies of zero to peak source level ($SL_{z\text{-}p}$) and equivalent TNT charge mass (m_{TNTeq}), respectively.

The recommended thresholds for these source levels and proxies of short duration sound sources are listed below[3].

- Explosive: $m_{\mathrm{TNTeq}} > 8$ g
- Airgun: $SL_{z\text{-}p} > 209$ dB re 1 μPa m
- Other pulse sound source $SL_E > 186$ dB re 1 μPa² m² s
- Low-mid frequency sonar: [4] SL > 176 dB re 1 μPa m
- Low-mid freq. acoustic deterrent: SL > 176 dB re 1 μPa m
- Other nonpulse sound source: [5] SL > 176 dB re 1 μPa m

Where operators are given the option to report in bins instead of the specific level, the proposal is that they report source level as follows:

Sonar or acoustic deterrents (source level, rounded to nearest decibel):
- Very low: 176-200 dB re 1 μPa m
- Low: 201-210 dB re 1 μPa m
- Medium: 211-220 dB re 1 μPa m
- High: above 220 dB re 1 μPa m

Generic explicitly impulsive source (energy source level, rounded to nearest decibel):
- Very low: 186-210 dB re 1 μPa² m² s
- Low: 211-220 dB re 1 μPa² m² s
- Medium: 221-230 dB re 1 μPa² m² s
- High: above 230 dB re 1 μPa² m² s

Airgun arrays (zero to peak source level, rounded to nearest decibel):
- Very low: 209-233 dB re 1 μPa m
- Low: 234-243 dB re 1 μPa m

[3] This list of thresholds need to be updated regularly as techniques evolve. An example is marine vibroseis that may soon be used to replace airguns in shallow water and transition zone surveys.
[4] This threshold implies that all military search sonars would need to be included in the register (if MS opt to do so).
[5] For sources with a tonal character (sonars, deterrents and the generic non-impulsive source) the SL in the frequency band below 10 kHz is relevant.

- Medium: 244-253 dB re 1 µPa m
- High: above 253 dB re 1 µPa m

Explosions (equivalent TNT charge mass, rounded to nearest 10 g if less than 10 kg and to nearest 1 kg otherwise)

- Very low: 8 g to 210 g
- Low: 220 g to 2.1 kg
- medium: 2.11-21 kg
- high: 22-210 kg
- Very high: above 210 kg

Impact pile driver (hammer energy[6], rounded to nearest 10 kJ)

- Very low: less than 280 kJ
- Low: 290 kJ-2.80 MJ
- Medium: 2.81-28 MJ
- High: above 28 MJ

2.5 Interpretation of results (M1-c&d)

The monitoring of indicator 11.1.1 will enable Member States to quantify the pressure on the environment from loud impulsive low and mid-frequency sound sources. Pressure indicators and pressure-based targets may be used in management if a clear understanding of the relationship between pressure, state and impact exists [Claussen et al., 2011; Borja et al,. 2013].

More specifically, this indicator is designed to provide information describing temporal and spatial distribution of impulsive noise sources, through the year and throughout regional seas, to enable assessment of possible cumulative impacts of displacement on marine species at the population level. Current data on bio-acoustic impacts are mostly limited to short-term individual responses. Cumulative exposures from multiple noise sources over large geographic scales and long durations can be modelled, but not much is known about impacts of cumulative acoustic exposure. The data gathered in the register will enable MS to estimate the size of the area affected by anthropogenic impulsive noise sources. Using information on response thresholds in received levels for particular species, the area of displacement can be estimated. Further steps are needed to assess how displacement affects a species at the population level. This requires considerable research, even for well-studied species, and results are likely to vary between species. Some modelling approaches, such as the Population Consequences of Acoustic Disturbance (PCAD) and Population Consequences of Disturbance (PCOD) models (National Research Council, 2005) try to link noise characteristics to population effects and may aid understanding. The ecological consequences of displacement will depend on the duration and extent to which animals are displaced and also on whether alternative suitable habitat is available.

Baseline

[6] Mitigation technologies currently being developed (e.g. bubble curtains) may result in hammer energy on its own not being sufficient to describe the level, and this advice may need adaptation in the future

According to EC guidance[7] the baseline can either be defined as:

a) *reference state or background levels: a state of the environment considered largely free from the adverse effects of anthropogenic activities (i.e. negligible impacts from pressures on the environment). This can be defined in relation to aspects of environment state (physical, chemical and/or biological characteristics), or to levels of pressure on the environment or impact (e.g. an absence of contaminants or certain impacts). This type of baseline is typically used to allow an acceptable deviation in state to be defined which acts as the target threshold value to be achieved. Or;*

b) *A specified/known state (of the environment, or the pressures on the environment and impacts acting upon it) usually implying, due to the methods used to derive it, that it may not be a reference state. This type of baseline is typically used to define the state at a specified time, often with an aim that there should be no further deterioration in environmental quality or levels of pressures on the environment and their impacts and/or that there should be improvements in quality from that date. Targets are consequently set towards improvement in quality or to ensure no further deterioration.*

The impulsive noise reference state (type a) baseline) would be a state with negligible impacts from anthropogenic noise. Given the historic use of impulsive noise sources, which may have affected the population dynamics and distribution of sensitive species, there will be few areas where this type of baseline could be determined.

The register will describe the spatial and temporal distribution of impulsive noise sources. This quantified assessment can then be used to help decide policy targets and to establish type b) baseline for the current situation.

The use of discrete spatial blocks within the register may be practical for data analysis, but MS should realise that the actual size of the area affected by a source may vary depending on source level, background noise level and sound propagation characteristics. In addition, various marine organisms may be affected by different sound characteristics.

Thresholds and targets

Noise indicators must be considered as part of a general process to evaluate the GES of the marine environment. The MSFD requires a holistic assessment of the impacts of different pressures on the different components of the marine ecosystem. Ultimately, the status (relative to GES) of a population or system will be determined by the cumulative impacts of all environmental pressures. For example, displacement may result in a loss of available habitat - this can be included in a cumulative effects model alongside direct human induced mortality to assess the population status relative to an undisturbed state. Whether the status of the ecosystem is “Good” relative to its undisturbed state will be a societal decision. Some such decisions have been made in existing legislation. For example, protected species under the Habitat’s Directive need to be maintained at favourable conservation status and an example of a societal decision for small cetacean by-catch is that populations should be restored or maintained at a certain level relative to carrying capacity (ASCOBANS, 1997)[8]. Work is ongoing to extend this approach to include other impacts such as noise.

There are several options for the setting of reduction targets, each of which needs further consideration once example registers are in place. The targets might include:

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[7] European Commission. 2012. Guidance for 2012 reporting under the Marine Strategy Framework Directive, using the MSFD database tool. Version 1.0. DG Environment, Brussels. pp164.

[8] ASCOBANS. 1997. MOP 2: Resolution on Incidental Take of Small Cetaceans. Bonn, Germany.

a. A target on the maximum permitted number of pulse-block days in an assessment area
b. A no-deterioration (i.e. stable or negative trends) target on the number of pulse-block days in an assessment area
c. A percentage target on the assessment area affected due to noise disturbance -*i.e*. on any given day less than x% of the assessment area is lost due to noise disturbance

The possible targets fall into two basic types – those that relate to limits on noise producing activities (e.g. examples a and c) or those that relate to trends (e.g. example b). Although limits will have more biological significance and relevance to GES, there is currently insufficient information to set such limits. By contrast, a trend towards a reduction in noise producing activities would be certain to be moving towards GES in situations where the system was assessed not to be at GES due to noise. One approach to setting targets would be to start with a trend and then move towards limits as more data become available.

Article 10 of the MSFD, establishment of environmental targets, provides for environmental targets that will guide progress towards GES. Annex IV of the directive outlines characteristics to be taken into account in the setting of these environmental targets including 2(c) "*operational targets relating to concrete implementation measures to support their achievement*".

Specific operational targets can help in terms of reduction of the levels of impulsive sound by tackling the sources. They can also be set to assess the effectiveness of measures implemented to reduce input from specific sources. Operational targets cannot substitute environmental targets, but will be helpful in terms of defining measures. Once measures are implemented, their success must be evaluated.

Examples for possible operational targets are:

- A target to minimize impact to acceptable levels by reducing noise output from certain sound sources
- [XX%]reduction in the number of piles which have pile driven foundations to encourage development of alternative foundation methods
- A restriction of pile diameters to xx meters in order to limit the noise generated.

Practical uses of the noise register

The register can be used to estimate the spatial and temporal impact on the environment (the total period and total habitat loss by impulsive noise sources) and for determining the baseline level. Once a baseline and targets have been set, the register can be used for management purposes (e.g. regulating planning and licensing activities) and assist in marine spatial planning, incorporating displacement mitigation guidelines and reducing the potential for cumulative impacts.

3. MONITORING GUIDANCE FOR AMBIENT NOISE

This chapter provides a guide for monitoring ambient noise as covered in the EU MSFD indicator 11.2.1. This indicator is described in the Commission Decision:

- Trends in the ambient noise level within the 1/3 octave bands 63 and 125 Hz (centre frequency) (re 1µPa RMS; average noise level in these octave bands over a year) measured by observation stations and/or with the use of models if appropriate (11.2.1).

The chapter begins with a brief introduction describing the indicator's scope. What follows are the definitions, as recommended by TSG Noise, for the essential terms of Indicator 11.2.1. Next, the report outlines key concepts of a monitoring programme for this indicator. It is beyond the remit of TSG Noise to provide a detailed guide for all European (sub) regions, but the cornerstone principles for monitoring/modelling, the technical specifications of equipment, and guidance on the use of averaging methods, will be provided. The chapter concludes with suggestions for the interpretation of the results.

There are no international standards for monitoring underwater ambient noise. Monitoring requires a combination of measurements and modelling, which means that standards are required to cover both aspects. Existing standards under development by the International Organization for Standardization (ISO) include a terminology standard[9] and several measurement standards[10]. The measurement standards, once complete, will facilitate the collection of valuable information about the sources of ambient noise (shipping and pile driving are being addressed); seismic surveys and explosions are also important sources of ambient noise, at least in the North Sea [Ainslie *et al*., 2009]. The measurement standards do not address is long term ambient noise monitoring as required for the MSFD. TSG Noise therefore advises MS to follow some basic guidelines described in Sec. 3.3. TSG Noise also points out the need for International Standards for the measurement of underwater sound generally and for ambient noise in particular. In this regard, the U.S. National Oceanic and Atmospheric Administration (NOAA) has begun developing a forward looking Ocean Noise Strategy to provide long term direction to NOAA's management of Ocean Noise. Initial discussions have focused on conserving the quality of marine acoustic habitat in addition to minimizing more direct adverse physical and behavioural impacts on specific species. As part of the Ocean Noise Strategy initiative, NOAA has recently established a Soundscape Characterization Group. This group is in the initial phase of developing a framework for ocean noise monitoring in U.S. waters in which methods and techniques for characterizing and monitoring marine soundscapes will be outlined. Developing international standards for the measurement of underwater ambient noise would be of mutual benefit for both EU Member States and NOAA.

3.1 Main objective and Scope of the indicator

Tasker *et al.*, (2010) and Van der Graaf *et al*., (2012) provide the background on the concept behind Indicator 11.2.1. This indicator focuses on chronic exposure of marine life to low frequency, anthropogenic ambient noise. The main contributor, in many regions, is noise from commercial shipping, hence the initial choice of two frequency bands where the contribution of noise from shipping (relative to other sources, including natural) is likely to be greatest. Data suggests that exposure to elevated ambient noise from human activities could lead to the masking of biologically important signals. In the long term this could also induce stress in receivers which, in turn, may lead to physiological impacts (see review by OSPAR, 2009).

[9] Working Group 2 of ISO/TC 43/SC 3 – Underwater Acoustics
[10] Working Groups 1 and 3 of ISO/TC 43/SC 3 – Underwater Acoustics and ISO/TC 8/SC 2-TC 43/SC 3/JWG 1

TSG Noise provides advice on scope and optimal approach, in making Indicator 11.2.1 operational. TSG Noise also provides clarification and detailed definitions of essential terms.

In addition to the advice relating to the indicator, TSG Noise discussed to what extent the monitoring of trends would be sufficient to reach the overarching aim of the MSFD, i.e. to ensure that Good Environmental Status is maintained. Within TSG Noise it was suggested that *trends only* are not sufficient to describe GES. To describe GES *levels*, based on a wider overview of the area, a combination of modelling / measurements and possible mapping will be needed.

The Working Group on Good Environmental Status (WG GES), in the "Common Understanding" document [Claussen et al., 2011[11]], advocates the use of a trend as an interim target "to ascertain whether progress is being made towards achieving GES … until the evidence base supports the establishment of more quantitative environmental targets". For example, the proposed target for anthropogenic nutrients: "A decreasing trend in dissolved organic nitrogen and phosphorous concentration, resulting from anthropogenic nutrient input over a 10 year period".

Similar trend-based targets can be used for underwater noise. In a situation where GES was not achieved due to underwater noise then it would make sense to adopt a downward trend as an interim target. Although there is some evidence that cetaceans adjust their vocalisations according to noise conditions in much the same way as birds are known to, there is also evidence [Rolland *et al*., 2012] that noise increases stress. It is therefore the opinion of TSG Noise that there is insufficient knowledge on the effects of increasing levels of human-induced ambient noise to determine whether existing levels are too high, or if GES is being achieved. However, if a Member State suspects noise levels are too high or on the increase, then that Member State may choose to target a downward (or non-increasing) trend in line with the precautionary principle described in the MSFD.

An indicator may be used by MS for target setting and programme of measures, where there is reasonable expectation of determining the indicator value, and where programmes of measures are required, on a timescale relevant to the adaptive management process, by Article 3 of the MSFD. At present, there are no data on longer-term trends of ambient noise in European waters, but some information is available that may make clear what MS can expect if they attempt to determine trends in European waters.

Long term (decadal) measurements in the north-east Pacific Ocean show an increase in the 63 Hz band of 5 dB in 35 years (between 1965 and 2000), which amounts to 1.4 dB per decade on average [Andrew *et al.,* 2011]. The 3.5-year time span series presented in Van der Schaar *et al.,* (2013) shows large fluctuations in measurements, with four hydrophone stations placed in three different oceans (also see chapters 2.8 for a description of this data set in Part III).

Although similar trends can be expected in deep water in other parts of the industrialised world, this cannot be confirmed by measurements in European waters, since no results or data are available. Even with a hindcast model it is difficult to verify the accuracy of the data. In shallow water, trends of ambient noise are likely to be different due to the different types of vessels in these waters and differing sound propagation conditions. It is not known whether the trends in shallow water are greater or lesser than in deep water, and this is further complicated by spatial variation, which is likely to be greater in shallower water. This variation is due, in part, to shorter distances to noise sources (increasing the likelihood of high amplitude transient sounds), although the variable propagation conditions typically encountered in shallow water is another factor. Spatial variation is expected to be much larger than yearly trends because some waters, such as harbour channels, are used to a far greater extent than in others.

Thus, it could take decades rather than years (and so much later than 2020) to establish statistically significant ambient noise trends for EU waters. From a practical point of view it is

[11] EC Working Group on Good Environmental Status, Common Understanding of (Initial) Assessment, Determination of Good Environmental Status (GES) and Establishment of Environmental Targets (Art. 8, 9 & 10 MSFD), Version 6 – 22 November 2011, endorsed as living document at the meeting of the EU Marine Directors on 8-9 December 2011

preferable to measure levels, not trends, as levels can be measured on a timescale relevant to MSFD and compared with a target.

Consequently, to describe GES and to determine trends regarding sound levels, actual levels are needed, and understanding of the spatial and temporal variations is needed to identify an underlying trend.

In conclusion, it has been agreed that it is within the remit of TSG Noise, not only to describe how MS will monitor trends, but to advise MS on the best approach to determining actual levels (including a wider overview of the area, created with a combination of modelling and mapping). This will provide the option for MS to choose the most suitable approach when setting up monitoring. This guidance also addresses how MS can monitor actual levels (and thereby monitor trends) in a cost-effective way.

3.2 Definitions for ambient noise

TSG Noise has suggested a more precise definition of the original Indicator 11.2.1:

Trends in the annual average of the squared sound pressure associated with ambient noise in each of two third octave bands, one centred at 63 Hz and the other at 125 Hz, expressed as a level in decibels, in units of dB re 1 µPa, either measured directly at observation stations, or inferred from a model used to interpolate between or extrapolate from measurements at observation stations [Van der Graaf *et al*., 2012].

For monitoring it is important to clarify the terminology included in the above definition [see Van der Graaf *et al*., 2012]:

Trend should be defined as the general direction in which something is developing or changing. In the context of monitoring, “trend” refers to changes in a specific quantity, over periods of a year or longer.

Annual averaged squared sound pressure level. TSG Noise recommends that the averaging method for calculating annually averaged noise level is the arithmetic mean of the squared sound pressure samples. In order to establish the statistical significance of any trend, the distribution, in the form of percentiles, of the cumulative probability density function is required. This corresponds to percentage exceedance levels; the 50 % exceedance level is the median. For establishing the statistical significance of trends, the distribution in the form of exceedance levels is required (see also chapter 3.3.) The difference between the arithmetic mean and median is a measure of variability and skewness (i.e., lack of symmetry) of received levels.

The measured signal as displayed by Figure 1 has a typical structure for background noise and emerging ship noise when ships pass close to the hydrophone. Three types of averaging are displayed: the arithmetic mean, which reflects the presence of high amplitude transients; the geometric mean; and the median.

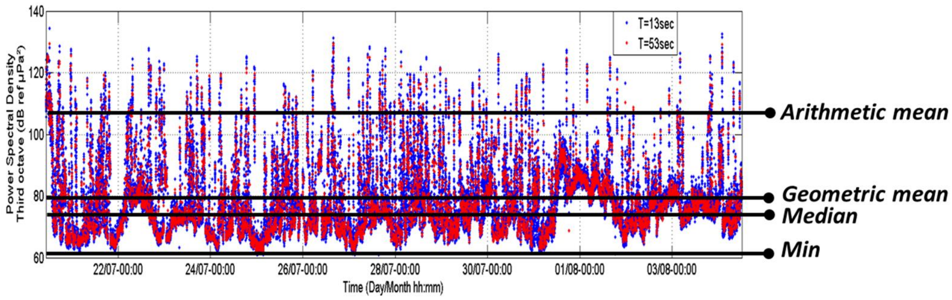

Figure 1: Example of approx. 14 days of continuous measurement in the 125 Hz third octave band made off Cork harbour (Ireland) entrance made during the STRIVE project (source: Quiet-Oceans).

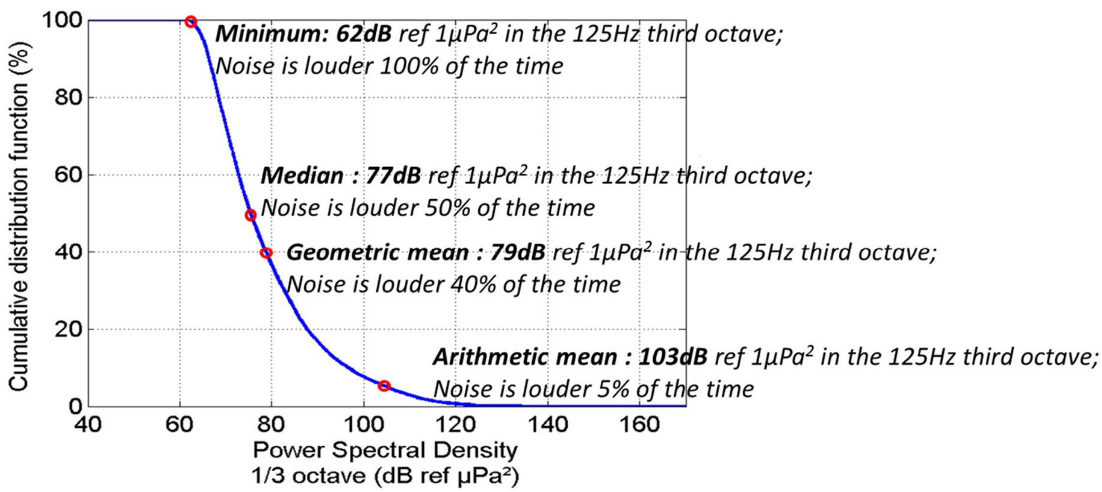

Figure 2: Statistical representation of the measured sound pressure level in the 125 Hz third octave band off Cork harbour as a cumulative distribution function, the exceedance[12].

The curve shows the proportion of time where a given minimum level is reached. For example, it shows that 50% of the time, the measured level exceeds 77 dB re 1 µPa, and that the level exceeds the arithmetic mean only 5% of the time.

***N* percent exceedance level:** Level that is exceeded *N* times out of 100

[12] The term 'exceedance level' is preferred to 'percentile' because '10th percentile' can mean either the value exceeded 10% of the time (10% exceedance level) or the value not exceeded 10% of the time (90% exceedance level). See [ISO 2003] ISO 1996-1:2003, INTERNATIONAL STANDARD ISO 1996-1, Second edition, 2003-08-01, Acoustics — Description, measurement and assessment of environmental noise —, Part 1: Basic quantities and assessment procedures

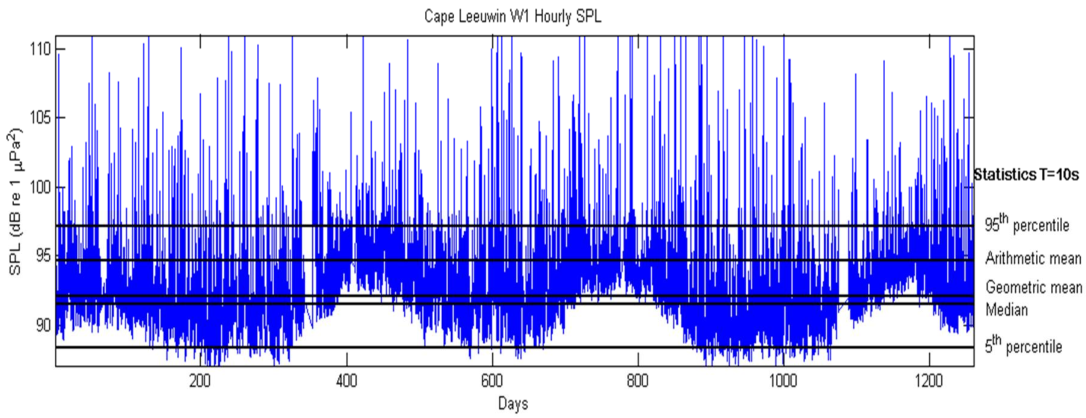

Figure 3: Example of 3 years of measurements in the 63 Hz third octave band made at the CTBTO Cape Leeuwin station.

The graphic of Figure 3 shows hourly summarised SPL measurements. The five statistics indicated on the right were computed over 10 second SPL measurements.

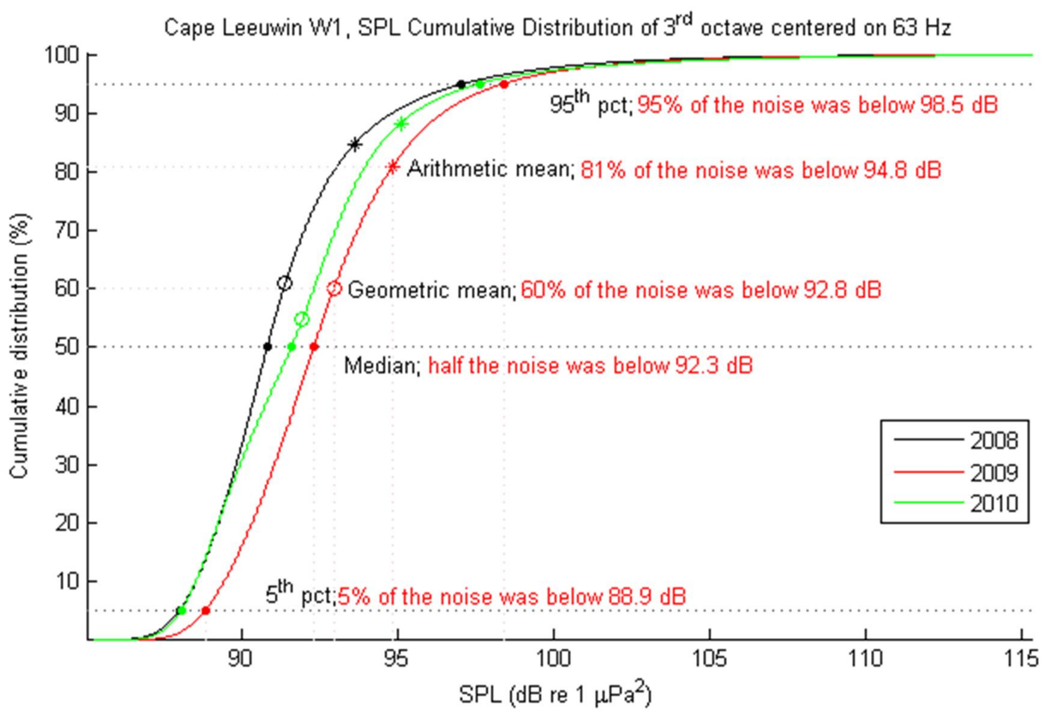

Figure 4: Cumulative distribution of the noise levels (SPL over a 10 second window) measured at the CTBTO Cape Leeuwin station during three consecutive years.

The curve of Figure 4 shows the proportion of measurements that were below a certain sound level. The five statistics on the right are interpreted for the year 2009 (red).

Ambient noise All sound except that resulting from the deployment, operation or recovery of the recording equipment, and its associated platform, where "all sound" includes both natural and anthropogenic sounds.

Third octave bands A frequency band whose width is one tenth of a decade and whose centre frequency is one of the preferred frequencies listed in *IEC 61260:1995 Electro-acoustics – octave band and fractional-octave-band filters*. TSG Noise recommends that including third octave bands covering the frequency range up to 20 kHz be considered by Member States for recording and possibly in the analysis. The additional range specified will add relatively little to the operational cost but will provide potentially valuable extra data, which will contribute to the knowledge base, and may assist with the evaluation of the monitoring regime at the six-year revision.

3.3 Measurements and modelling

TSG Noise notes that the Commission Decision does not require Member States to describe the complete noise field in their waters. In theory, a limited number of monitoring stations (measurement locations) would be sufficient to fulfil the requirements of the indicator. TSG Noise has evaluated the advantages and disadvantages of different monitoring approaches.

TSG Noise considers measurements to be essential to ground truth the models, but results are sensitive to bias introduced by known changes in the spatial distribution of human activities, e.g. changes in ferry routes, or bias introduced by environmental and climatic variables. Measurements are logistically challenging at sea, therefore TSG Noise has researched whether modelling can be used to design a more comprehensive and cost-effective monitoring strategy. Modelling is a supplement to measurements and a properly validated model will increase utility of the measurement results.

3.3.1 Models

Several kinds of models can be applied for data processing and predictive acoustic modelling. For an acoustic model for sound field simulation, the following parameters are needed:

- ✓ Model for the sources (possibly requiring different source spectra for different classes of vessel)
- ✓ AIS for location and class of vessel
- ✓ Environmental characteristics relevant to acoustic propagation (seabed characteristics, etc)
- ✓ Prediction of temporal variation to enable calculation of statistical distributions of noise

Validation of the model by comparison to measured data is required and, preferably, it should be benchmarked against standard test cases. Models maybe classified into a number categories (see Jensen *et al.,* 1994, Weston, 1959 and Weston, 1976):

- ✓ solution of Helmholtz equations
    - o parabolic equation
    - o normal mode approximation
    - o wave number integration
    - o ray tracing
- ✓ Energy flux model
- ✓ Boundary finite element and finite difference

3.3.2 The use of modelling

The use of modelling for indicators and noise statistics, and possibly the creation of noise maps, ensures that trend estimation is more reliable and cost-effective, for the following reasons:

i. Use of models reduces the time required to establish a trend, with a fixed number of measurement stations (the expected trend in shipping noise, based on observations in deep water, is of the order of 0.1 dB/year; and therefore it takes many years, possibly decades, to reveal such small trends without the help of *spatial averaging*)

ii. Use of models reduces the number of stations required to establish a trend over a fixed amount of time (similar reasoning), therefore reducing the cost of monitoring

iii. Modelling helps with the choice of monitoring positions and equipment (selecting locations where the shipping noise is dominant as opposed to explosions or seismic surveys being dominant).

The use of models enables individual identification of trends for different sources, thus identifying the cause of any fluctuations, which could facilitate mitigation. Furthermore, models allow the removal of selected sources if these are not considered to cause a departure from GES (such as natural sound sources, both biotic and abiotic (e.g. lightning)).

The use of models provides MS with an overview of actual levels and their distribution across the sea area, thereby enabling identification of a departure from GES.

In addition, there are advantages of using modelling that could contribute to a greater understanding of potential impacts of noise, such as:

- ✓ Use of models enables forecast of changes and their effects (e.g. what is the expected effect of certain percentage increases in shipping traffic in the eastern Baltic over the coming years?) as well as construction of a past history (hindcast). New ships may have different noise signatures to their earlier equivalents which may further affect results.
- ✓ Use of models enables compilation of an ex ante estimate of the efficacy of alternative mitigation actions.

TSG Noise concludes that the combined use of measurements and models (and possibly sound maps) is the best way for Member States to ascertain levels and trends of ambient noise in the relevant frequency bands. Member States should be careful to balance modelling with measurements.

3.3.3 Available knowledge on noise mapping and possible applications

Noise mapping is a form of spatial modelling, and is explored here as it provides a convenient and accessible way to visualise such models. A noise map can be used, in management and in the evaluation of measurements. Several Member States have produced noise maps. These are listed below and are described in more detail in part III:

- Noise maps of shipping and explosions in the Dutch North Sea. This provides an overview for the potential of such maps, and how they can be used to identify locations where the soundscape is dominated by specific sources. In addition the study demonstrates how noise maps may help in choosing suitable locations for measurement stations.
- Noise modelling and mapping in Irish waters demonstrates how sound maps, relating to shipping, can be produced using data from an Automated Identification System (AIS). Using this data, the noise prediction system can calculate the noise field associated with

specific anthropogenic activities, including noise statistics which depend on seasonal variations of environmental factors, as well as shipping variability

- The Baltic Sea Information on the Acoustic Soundscape (BIAS)[13] project aims to establish a regional implementation of noise monitoring, which includes the development of tools to manage and describe of sound levels. In order to enable efficient, joint management, the project also aims to establish regional standards and methodologies for handling data and results. Measurements will be done at 37 locations in the Baltic Sea. The measurements will be used in models to produce soundscape maps.
- Work on noise modelling and mapping in German waters has been funded by the Federal Environment Agency (UBA) and recently concluded a mapping software SEANAT (Subsea Environmental Acoustic Noise Assessment Tool). A modelling approach is used which is based on measurements of ambient noise and relevant sound sources. The software is created to allow modelling of the underwater sound fields in the EEZs of the German Baltic and North Sea and imaging species-related impacts on organisms (more information available in part III chapter 2.6).

Member States have decades of experience of airborne noise monitoring and mapping. This earlier European experience should be used in developing underwater noise monitoring. Further information is available on noise mapping in air in part III chapter 2.7, including the relevant EU regulation (the Noise Directive), including useful background information that can assist in implementing the MSFD.

3.4 Outline of the monitoring programme

TSG Noise advises MS, within a sub region, to work together in setting up ambient noise monitoring systems. Without knowing how MS will work together, TSG Noise cannot define exact locations for monitoring, but suggest an initial set of considerations for the placement of devices based upon Tasker *et al.*, [2010], Van der Graaf *et al*., [2012] and further discussions within TSG Noise.

This indicator is designed to monitor ambient noise at specific frequencies. The frequency bands were chosen to focus monitoring of ambient noise on the contribution of shipping. For MS, it makes sense to design monitoring programmes based on shipping for this very reason. In addition, patterns of shipping tend to remain consistent over many years compared to other noise sources, such as seismic surveys, which may contribute more noise energy but display varied noise distribution patterns.

The prime objective for the monitoring programme is to establish the trend. However, since the benefit of using models is acknowledged, the monitoring programme should pursue two linked objectives with separate specific monitoring strategies:

- ✓ **Category A Monitoring -** to establish information on the ambient noise in a location and to ground truth noise prediction,
- ✓ **Category B Monitoring-** to reduce uncertainty on source levels to be used as the input for modelling.

[13] BIAS information: http://www.bias-project.eu

Category A Monitoring - to establish information in a location and ground-truth noise predictions

Low-frequency sound propagates over long distances, and the frequency bands defined by the MSFD are likely to be dominated by shipping lanes throughout Europe's seas. Therefore, for this purpose, it is best to place hydrophones at locations which are remote from shipping lanes in order to monitor the diversity of noise contributions in a more balanced way. Such a strategy is suitable for regional monitoring, and only a limited set of measuring stations per region would be needed to satisfy the requirements of the first objective. Good information on spatial distribution of activities in each region, and region-wide sound propagation characteristics, such as temperature and salinity, surface waves, etc., need to be monitored as well as the noise field. In waters less than 3000 m sensors should be deployed in the interval 30 to 100 times the water depth, measured from the closest edge of a shipping lane. In waters greater than 3000 m sensors should be deployed at a distance of at least 90km from the closest edge of a shipping lane. It should be stressed that, in water depth of 3000 m or greater, convergence zones (strong local maxima due to sound focusing [Urick 1983]) are likely to form at distances of 45-60 km from the sound sources. If the distance to the closest shipping lane is 60 km or less there is a risk that the measurements are sensitive to small shifts in oceanographic conditions or the precise location of the shipping lane. For these reasons a minimum distance of 90 km from the closest shipping lane is recommended. For this form of monitoring, hydrophones should be placed near to the seabed, although the actual design of the rig, and thus the depth of the hydrophone, is site dependent.

Category B Monitoring - to reduce uncertainty in noise models

Noise measurements at an appropriate and relatively close distance to a shipping lane can be combined with data on individual vessels (from a system such as Automated Identification System (AIS)) to provide data on vessel source levels. Estimates of these levels could be used to describe individual sound sources as input for models. It is anticipated that only a limited set of such measuring stations would be needed to fulfil this form of monitoring since, in most regions, a large majority of ships follow the same routes. For a well-defined shipping lane, the measuring station location should be about 100-500 m outside the lane (measured from the edge as specified by the nautical chart); for a less well-defined shipping lane similar positioning should be attempted based on local information. For this type of monitoring the hydrophones should be placed at the closest depth to the minimum of the sound speed.

Following these points, TSG Noise recommends an <u>initial set of guidelines for placement of measurement devices:</u>

1- Where there are few measuring stations per basin, priority should be given to monitoring in order to ground truth predictions (category A), since this monitoring is less sensitive to the influence of individual ships that might bias the averaged sound pressure levels. Monitoring may be more cost effective if existing stations are used for monitoring other oceanographic features;
2- Member States should make sure that they have access to data on the noise characteristics of individual ships
3- In deep water, monitoring devices to ground truth predictions (category A) should be placed in areas of low shipping density. The range at which elevated noise levels may occur is greater in deep water as low frequency sound can propagate long distances;
4- Consider local topography and bathymetry effects e.g. where there are pronounced coastal landscapes or islands/archipelagos it may be appropriate to place hydrophones on both sides of the feature;
5- In waters subject to trawling, use locations that are protected from fishing activities or locations where trawling is avoided due to bottom features (e.g. underwater structures/wrecks) and/or to use trawl safe protection;
6- As far as possible avoid locations close to other sound producing sources that might interfere with measurements e.g. oil and gas exploration or offshore construction

activities. Areas of particularly high tidal currents may also affect the quality of the measurement;

7- In all underwater noise monitoring, the location should be chosen taking into account site-specific properties such as tide, sediment and currents; it is important that the rig is silent and rig design should take account site-specific considerations.
8- Calibrate sensors at the same pressure as encountered at the planned deployment depths (for clarification see part III chapter 2.10)

Planning sensor locations

Factors that need to be taken into account when deciding on the positions for sensor locations include shipping density, convergence/divergence of shipping lanes, water depths, fishing activities, seismic surveys and areas of special interest. The relative importance of these factors will vary depending on region and thus no one "recipe" is possible. In deciding locations MS will have to prioritise among these factors. The numbers of, and location of the sensors will also depend on the characteristics of the area. Sensors can be used to monitor a sea, basin, coast, or even a marine sanctuary. Some of these factors are further explained in this section, but cost will be an important factor in restricting the number of sensors and the area covered.

Maps of shipping density should be consulted when considering potential locations for hydrophones. The characteristics of each potential location can then be examined for other noise generating influences (off-shore construction, planned seismic surveys or intense seasonal fisheries). As mentioned above, locations close to loud, but short-term, noise sources should be avoided. At finer spatial scales the detailed characteristics of possible locations can be examined for rates of tidal current, bottom type, and risks to the monitoring station from fishing activities. In addition, monitoring may be undertaken for other purposes than for the MSFD indicator, for example within an area designated for marine life vulnerable to underwater noise. It may be convenient (and reduce overall cost) if MSFD monitoring is conducted in these areas also.

Establishing the shipping density

Annual and seasonal ship passages at specified sections or areas can be established making use, where available, of Automated Identification System AIS and Vessel Monitoring System (VMS) data. Density maps of shipping are essential for making decisions on sensor positions; an example is given in fig. 5 and fig. 6, where the numbers of ship passages (not including fishing vessels) are presented for the Baltic Sea.

Shipping density can be expressed in a number of ways: transit through an area, total distance travelled within an area or the number of vessels within an area. The annual average surface density of ships per unit area is probably most relevant in terms of noise. If such densities are generated for the region of interest, then the average density for various distances from any location can be estimated. Data from AIS, and particularly satellite AIS (s-AIS), can be used for analysis of shipping density, with appropriate adjustments in high density areas [Eiden and Martensen, 2010].

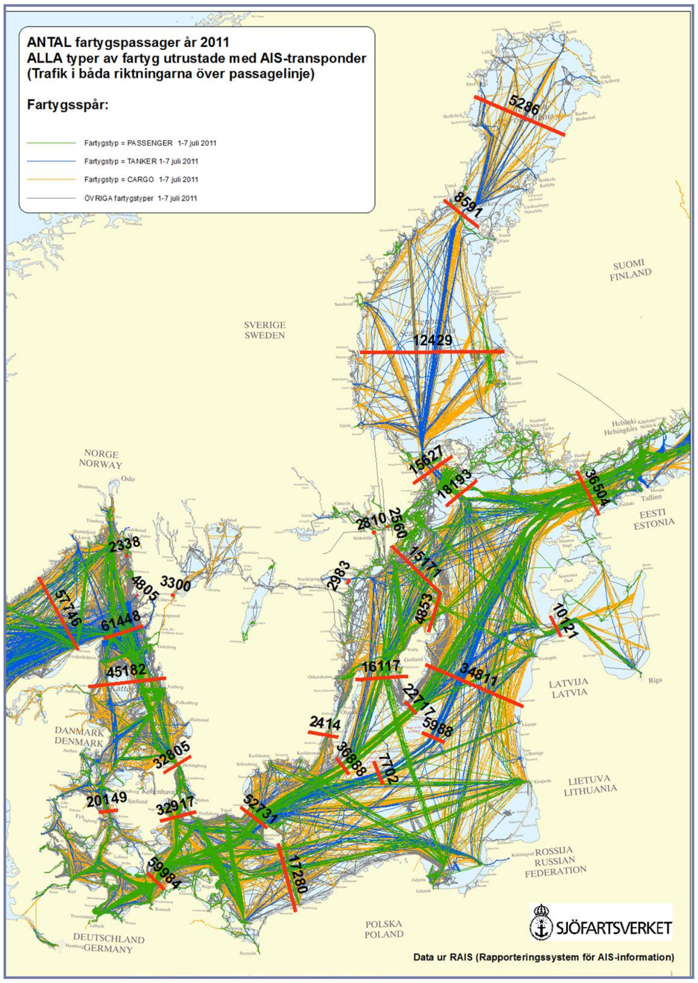

Figure 5. Ship traffic 2011 at the major transects in the Baltic Sea. Numbers in black indicate the overall ship routes in both directions over the red line during 2011. Green: passenger ships; blue: tankers; orange: cargo ships; grey, other ships (source Swedish Maritime Administration).

Inclusion of special areas

Member States may consider including marine protected areas, such as marine reserves or Natura 2000 sites in the monitoring programme. Some protected areas are closed to trawling, which may make them a safer place for the monitoring station, while there may be an interest in establishing noise levels to help in conserving or managing some of the site's features. However, TSG Noise recommends that relationship of the location relative to shipping lanes be considered *before* considering special areas.

Finer scale considerations

When the final positions are established, special concern should be given to the finer scale considerations of these positions. As was pointed out earlier the deployment area should be chosen to avoid short-term noise sources that might potentially affect sound levels. Information on fishing activities might also be used to avoid loss of sensors due to unwanted trawling events. Trawling normally occurs at low speeds (less than 5 knots), and trawling activities in the region can be established, for example, by using Vessel Monitoring Systems (VMS) data, thus indicating areas to be avoided. The sensor position can be adjusted to an area with lower fishing frequency, but only an area without trawling will provide substantially lower risk of loss. Information on shipwrecks, wave buoys or other oceanographic measurement stations can also be used to avoid fishing activities, by adjusting the final position to be nearby one of these structures.

It should be underlined that acoustic properties of an area might vary spatially and temporally. The adjusted position should be as representative as possible of the conditions for the area, such that the data can help relate known sources of noise to the measurements in a way that allows predictions across a wider area from similar noise sources. For example sediment, depths and sound profile of the adjusted location should be representative of the area.

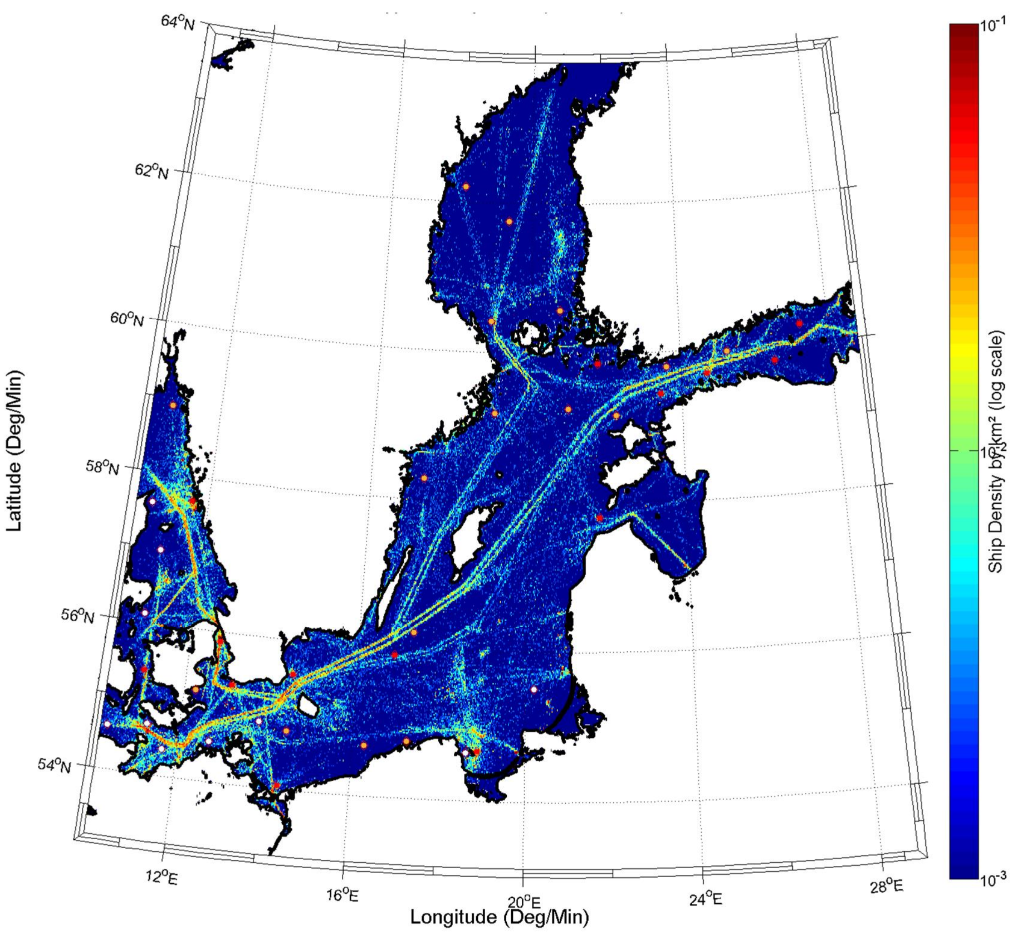

Figure 6: Example of monitoring strategy implemented in the framework of the BIAS project. The background of the image is the ship density for all activities described by AIS data. The dots show the locations of category A and category B monitoring stations.

3.4.1 Guidance for presenting the results

Processing of either the measurement and/or the modelling output can provide local or basin-scale statistics of the annual noise in the form of percentage exceedance levels (see Section 3.2). The rationale that led to Indicator 11.2.1 was associated with a concern that anthropogenic noise might mask important acoustic cues [Tasker *et al*., 2010]. Masking can occur from both continuous and intermittent transient sounds (air gun pulses, passing ships, etc.). The relative potential for masking by continuous and transient sounds is still unclear. For future evaluation of trends (and potentially for setting targets), information on the relative contribution of the various sound sources may be needed. For this reason, TSG Noise considers that information about amplitude distribution versus time is needed. Therefore, TSG Noise recommends that complete distribution be retained in the form of sound pressure levels as a function of time, along with a specified averaging time. If it is not possible to store the full time series, TSG Noise advises the retention of the amplitude distribution for this purpose in bins of 1 dB, and the associated snapshot duration (see also Part III chapter 2.8). TSG Noise advises MS that the snapshot duration should not exceed one minute.

3.4.2 Guidance for interpreting results and setting a baseline

Monitoring indicator 11.2.1 will enable MS to quantify the environmental pressure (expressed as ambient noise level) as well as trends in ambient noise levels within the two frequency bands. Pressure indicators and pressure-based targets may be used if a clear understanding of the relationship between pressure, state and impact exists [Claussen *et al.*, 2011; Borja *et al,*. 2013]. Since there is very little information available on the effects of increased ambient noise level, and almost no information that describes the effects in a way usable for any quantitative assessment, TSG Noise cannot give concrete advice on interpretation of results at this stage.

As described in the chapter 2.4, a baseline can either be defined as: *a) reference state or background levels, or b) a specified/known state.*

For ambient noise, the baseline that MS should aim to set is the second of the two options. It is unlikely there will be many areas of open sea in European Seas which can be seen as a reference state free from influence from anthropogenic ambient sound in the two frequency bands. Some nearshore sheltered waters may be relatively free of these sounds, but may be atypical in other ways as they will have hydrography typical of nearshore areas and may suffer from reverberation problems. If it is possible to distinguish between natural and anthropogenic sources then models could be used to estimate baseline noise levels which would be expected in the absence of anthropogenic inputs.

Targets could be set based on either limits or trends, but, as for impulsive noise sources, there is currently likely to be insufficient information to set limits. In areas where anthropogenic noise has substantially raised ambient noise levels it may be appropriate to set initial targets based on trends. In these situations a trend towards reduced ambient noise would be more likely to be moving towards GES than if levels increase. An initial target based on trends could be augmented by limit based targets in the future as more quantified information on impacts becomes available.

3.5 Technical Specifications

3.5.1 Specifications for measuring equipment (M2-a)

In recent years, there have been an increasing number of commercially available, autonomous devices to address the need for *in situ* measurement of underwater noise. Their use is motivated by the need to monitor underwater noise, including in response to the requirements of Indicator 11.2 of the EU Marine Strategy Framework Directive. Such systems can provide cost-effective instrumentation for monitoring underwater noise, but the performance of these systems is crucial to the quality of the measured data.

Recent work by the National Physical Laboratory (UK) suggests that the performance of some commercially available systems may limit their usefulness for the absolute measurement of underwater noise. Some noise recorders on the market are converted from systems designed for other purposes, where absolute calibration is not required, and high quality recordings are not essential (detecting marine mammals). These issues were discussed in detail in the 2012 TSG Noise report [Van der Graaf *et al.*, 2012]. However, with the advent of commercial systems, TSG Noise emphasises the importance of calibration and performance issues in procuring systems for use in noise monitoring. Users should ensure that the equipment performance meets the needs of the measurement requirement, and make specific requests of suppliers with regard to certification and performance.

To prevent procurement of inadequate monitoring equipment, and in order to ensure that noise monitoring initiatives by Member States will be done in a cost-effective way and lead to correct data gathering, TSG Noise therefore provides advice on specifications for noise monitoring systems, as well as quality assurance and calibration of the equipment.

3.5.2 Equipment specification, quality assurance and calibration

The principal requirements for ensuring quality of measurements may broadly be categorised as follows:

Methods/procedures

The measurement method chosen must be appropriate for the task, and should be described by a suitable procedure, which may comprise written protocols or instructions.

Staff

The staff undertaking the work should be suitably trained and (ideally) have experience in the technical area.

Equipment

The equipment used must be fit for purpose, with a suitable performance, and must be calibrated traceable to appropriate standards.

This section deals with the requirements of the equipment, but it should be remembered that this is not the only requirement for a high quality measurement to be assured.

Background scientific literature

There are a number of reports in the scientific literature where ocean ambient noise has been measured and reported, and in some cases with descriptions of the recording system used and the analysis methodology adopted [e.g. Wenz 1962, Macdonald *et al*. 2006, Cato 2008, Andrew *et al*. 2011, Dudzinski *et al*. 2011]. Though some of these papers relate to noise measurement in deep water, there are many common considerations when considering measurements in relatively shallow European waters.

Use of autonomous recorders

Commercial autonomous recorders for use in measuring underwater sound are becoming increasingly available. Such recorders consist of a hydrophone connected to an electronics pod containing amplifier, ADC, data storage media and batteries to power the unit. These devices are often highly cost-effective, and have greatly increased the capability for ocean noise measurement without the need for bespoke designs that require great expertise to set up and operate.

When selecting an autonomous recorder, the performance of the recorder must be "fit-for-purpose" for the application. Some designs have been adapted from equipment designed to perform other tasks, and may not be well suited for use in making absolute measurements of sound. Users should ensure that the equipment performance meets the needs of the measurement requirement, and make specific requests of suppliers with regard to certification and performance. The key performance parameters listed in the following sections apply equally to autonomous recorders as they do to systems comprised of separate components.

Hydrophone and recording system performance

<u>Frequency range</u>

The only mandatory frequency ranges required to satisfy the indicator are the two third-octave bands with nominal centre frequencies of 63 Hz and 125 Hz. However, most available systems will record over a wider range of frequencies than these third-octave bands. Therefore, it is desirable that the measurement system used cover at least the frequency range 10 Hz to 20 kHz; the additional range specified above will add little to the operational cost but will provide extra data that will contribute to the knowledge base and may assist with future evaluations of the monitoring regime. Note that where other performance parameters may vary with frequency, these should also be determined over the full frequency range of the recording system.

The requirement for unambiguous representation of the signals within the desired frequency band requires the sampling frequency of any Analogue to Digital Converter (ADC) within the recording system to be greater than two times the maximum acoustic frequency of interest. The maximum frequency of interest will be the upper limit of the maximum third-octave frequency band of interest.

<u>System Self-Noise</u>

The self-noise of the system is an important parameter when measuring ambient noise. Self-noise arises from two sources: (i) noise generated by the hydrophone and recording system; (ii) noise generated by the deployment platform or mooring. Such noise can contaminate the measured acoustic data, so ideally it should be minimised and at least measured and understood.

The system self-noise is normally expressed as a noise-equivalent sound pressure level in dB re 1 μPa2/Hz (IEC 60565, 2006). The self-noise varies with acoustic frequency and as a result is usually presented as a noise spectral density level versus frequency. The noise equivalent pressure may be calculated by measuring the system electrical noise and dividing by the system sensitivity, where the measurement is made without any external acoustic stimulus present. Note that although the system self-noise may be expressed in terms of a noise equivalent sound pressure level, the origin of the noise is purely electrical from the hydrophone, amplifier and electronic components. The self-noise can originate from sub-standard hydrophones and amplifiers, or from pick-up of electrical noise generated by the electronics and data storage system.

It is common to compare values for self-noise with classic empirical curves for ambient noise levels in the ocean, such as those of Wenz [Wenz 1962] and Knudsen [Knudsen 1948]. Fig 7 shows these curves along with measured system self-noise data for a high-quality low-noise hydrophone, and two other recording systems. The low-noise hydrophone has been designed to optimise the noise performance, and the self-noise of such a system can approach Wenz's lowest ocean noise levels. Systems where the self-noise is not one of the key design parameters (recorder systems A and B in Figure 7) are likely to have a higher noise floor.

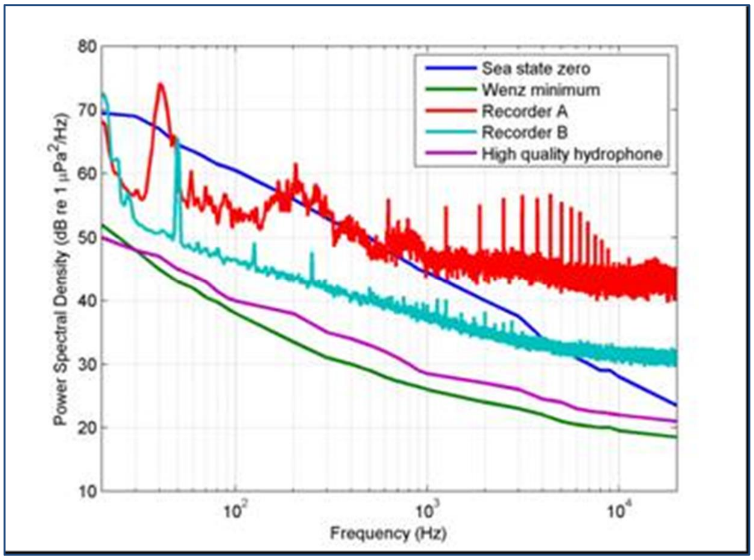

Figure 7: Noise spectral density data showing the performance (self-noise) of two recorder systems and a high quality low noise hydrophone. Also shown are the values for sea state zero and Wenz's minimum noise spectra. [Hayman *et al* 2013]

To achieve an acceptable signal-to-noise ratio when measuring acoustic signals, the self-noise equivalent sound pressure level should be at least 6 dB below the lowest noise level to be measured in the frequency range of interest.

Knudsen sea-state zero values at 63 Hz and 125 Hz, which include distant shipping noise, are approximately 64 dB re 1 μPa^2/Hz and 59 dB re 1 μPa^2/Hz respectively. Without shipping noise, the noise level can be lower still. For example, Reeder *et al* (2011) reports approximately 53 dB re 1 μPa^2/Hz at 63 Hz and 49 dB re 1 μPa^2/Hz at 125 Hz in quiet conditions at the USN Atlantic Undersea Test and Evaluation Center. For a system designed to measure in a very low noise situation, we recommend a maximum self-noise which is 6 dB below these values (i.e., 47 dB re 1 μPa^2/Hz at 63 Hz and 43 dB re 1 μPa^2/Hz at 125 Hz). For measurements of higher noise levels (for example, for deployment close to shipping lanes), these requirements may be relaxed somewhat, but the self-noise should still be at least 6 dB below the lowest noise level of interest.

Dynamic range

The dynamic range of the measuring system is the amplitude range over which the system can accurately measure the sound pressure. This ranges from the noise floor of the system (which defines the lowest measurable signal) to the highest amplitude of signal that may be measured without significant distortion. The system dynamic range should be chosen to be sufficient to enable the highest expected sound pressure to be recorded accurately without distortion or saturation caused by the hydrophone, amplifier and Analogue to Digital Converter (ADC).

When measuring low amplitude signals, care is required to ensure that not only will the signal amplitude exceed the noise floor of the system, but also that the recorded signal is not so low as to suffer from quantisation noise due to the poor resolution of the ADC for very small signals. The resolution of the ADC should be at least 16-bit (some are now available at 24 bits). With the use of modern high-resolution ADCs this is less of a problem than in the past. However, the system settings should be chosen to achieve recorded signals of appropriate resolution.

Some commercial systems may suffer from relatively limited dynamic range so that the large amplitude signals that can be detected at low frequencies can sometimes saturate the recorders. An ideal system would have 24-bit resolution, and be capable of measuring up to 180 dB re 1 μPa to record vessels passing close by. This is challenging, and many systems will not achieve the dynamic range in combination with the self-noise requirements, but in any case the actual dynamic range should be known so that the maximum undistorted signal level can be estimated, and any saturated signals eliminated during analysis of the data.

A method to mitigate problems with dynamic range is to have some flexibility in the sensitivity, often achieved by use of adjustable gains for amplifier stages and scale settings on ADCs. However, where a system has been deployed remotely (for example, an autonomous recording system which is left in-situ for an extended period), there may be no control over the system settings after deployment. Here, some knowledge of the likely range of sound pressure levels is required to optimise the available dynamic range (this knowledge can be obtained from reported levels in the scientific literature or from approximate theoretical calculations). The required dynamic range can vary with acoustic frequency such that the low frequency components may be much higher amplitude than the high frequency components. One method to overcome this problem is to use a measuring system which consists of several channels, each of which is used to measure a specific frequency band [Lammers *et al* 2008]. For each of the frequency bands, the amplifier gain setting, the ADC scale setting and even the hydrophone can be chosen to match the expected sound pressure levels and achieve good quality data that is significantly in excess of the noise floor but without distortion or saturation. A disadvantage is that the system is far more complex, requires more calibration, and requires processing such that the data for each frequency band is integrated to form an overall spectrum; per situation, Member States need to verify that measuring other frequency bands than the two bands described in the indicator does not lead to disproportional cost .

<u>Sensitivity</u>

Ideally, the sensitivity of the hydrophone and measuring system should be chosen to be an appropriate value for the amplitude of the sound being measured. The aim in the choice of the system sensitivity is to:

- avoid poor signal-to-noise ratio for low amplitude signals;
- avoid nonlinearity, clipping and system saturation for high amplitude signals.

The sensitivity of the system must be known in absolute terms from a calibration, which should be the result of a measurement as indicative or nominal values produced at the system design stage may not be reliable. The calibration of the hydrophone and recorder should be done with an overall uncertainty of about 1 dB (expressed at a 95 % confidence level). It is not necessary to specify the required sensitivity to within a narrow tolerance band, as long as it is accurately known. Taking the required noise performance and dynamic range into account, and considering the performance range of available electronic components, the system sensitivity is recommended to be in the range from –165 dB re 1 V/μPa to –185 dB re 1 V/μPa.

<u>Directionality</u>

Ideally, a hydrophone would have an omnidirectional response such that its sensitivity is invariant with the direction of the incoming sound wave. In such cases, the orientation of the hydrophone during measurements would be unimportant. For the two third-octave bands of 63 Hz and 125 Hz required by the indicator, the assumption of an omnidirectional response should be valid.

However, omnidirectionality is only an approximation valid at low frequencies where the hydrophone size is a fraction of the acoustic wavelength. When the hydrophone size is significantly greater than the acoustic wavelength at the frequency of interest, the hydrophone will exhibit a response that shows appreciable directionality. In practice, for typical measuring hydrophones, this becomes a significant issue only at tens of kilohertz. However, one issue that can cause enhanced directionality is where the hydrophone is deployed close to another structure that is capable of reflecting the sound waves. The combination of the direct waves and reflected waves causes interference, the nature of which will change depending on the arrival angle for the sound wave. This effect may be evident at low kilohertz frequencies if the hydrophone is deployed close to a support structure such as a heavy mooring or support. In particular, this effect may occur when using an autonomous recorder where the hydrophone is attached or positioned close to a recorder case that houses electronics and batteries but is mostly air-filled. This configuration should be avoided if an omnidirectional response is required at kilohertz frequencies.

Data storage

To avoid degradation of the data quality, the data format used to store the data should be lossless. Any crucial auxiliary data or metadata which is needed for interpretation of the results (for example, the scale factor or setting of the ADC) should be recorded. It is desirable that such information be included in a file header or log file so that the information is kept with the data. Though a number of suitable data formats exist, there is no standardised format for storing ocean noise data. TSG Noise recommends that issue is addressed in future standards for ambient noise measurements.

3.5.3 Calibration of equipment

System calibration

For an absolute measurement, the sensitivity of the measuring system must be known. This requires that the system be calibrated. A laboratory calibration requires that the system undergo a series of measurements to determine the sensitivity. Indicative or nominal calibration values produced at the system design stage are not reliable and should not be used. The calibration should cover the full frequency range of interest for the specific application at hand. It is possible to calibrate a hydrophone and recording system with an overall uncertainty of better than 1 dB (expressed at a 95 % confidence level). It is recommended that a full laboratory calibration is undertaken before and after every major deployment or sea-trial (IEC 60565 2006, ANSI S1.20 2012).

The system calibration can be undertaken either by full system calibration, or by calibration of individual components. For a full system calibration, the hydrophone is exposed to a known sound pressure field and the recordings produced by the system are analysed. For calibration of individual components, the hydrophone is calibrated separately by an acoustic measurement, but the other components are calibrated using known electrical input signals. The components that require calibration are:

Hydrophone

There are national and international standards describing the calibration of hydrophones such as IEC 60565:2006 – The calibration of hydrophones in the range 0.001 Hz to 1 MHz (available in the UK as BS60565:2007), or ANSI S1.20-2012 - Procedures for calibration of underwater electro-acoustic transducers. The calibration should conform to these procedures and be traceable to national or international standards maintained at a national metrology institute. Hydrophone calibration data is typically expressed in µV/Pa, or in decibels as dB re 1 V/µPa. Typically, it is expressed at a succession of discrete frequencies, or in the form of a calibration curve.

Note that at frequencies well below the resonance frequency, the hydrophone sensitivity should be invariant with frequency. However, as a hydrophone approaches its resonance frequency, the sensitivity cannot be considered to be "flat" and is likely to show variations in response. If the recorded data is already processed into third-octave bands before the correction for hydrophone sensitivity is applied, the required calibration values are the mean sensitivities for each of the frequency bands. Where the hydrophone sensitivity is not flat, a constant value across the band cannot be assumed. Note that if the hydrophone is placed close to a reflective boundary (such as a recorder case), interference from reflected signals will cause further fluctuations in the sensitivity with frequency at kilohertz frequencies.

Note that it is advisable to "wet" a hydrophone before deployment by cleaning the surface with a mild detergent. This will ensure that the surface is free of grease and dirt, and prevent air bubbles from adhering to the surface and causing distortion of the measured signal.

Note also that if extra cable is added to a hydrophone, this will reduce the overall sensitivity. This is the case for hydrophones without an integral preamplifier. For hydrophones that have an integral preamplifier within the hydrophone body, adding extension cable will not affect the sensitivity.

Note that, for some hydrophones, the response may show a dependence on the water temperature and depth of immersion [Beamiss et al 2002]. If the conditions for the calibration are significantly different from those during its use in the field, this may add uncertainty to the measurement. If there is evidence that the hydrophone performance varies significantly with temperature/depth, the calibration should be undertaken as close to the applicable conditions as possible. Alternatively, a hydrophone should be chosen which has a stable performance with temperature/depth (as far as possible).

Advice on choice and use of hydrophones, including the wetting of hydrophones, how to correct for added extension cable, and the performance as a function of depth and temperature, can be found at: http://www.npl.co.uk/acoustics/underwater-acoustics/.

Amplifiers

The performance is typically expressed as a gain factor, either in terms of a linear gain (e.g. x10) or in decibels (e.g. 20 dB). Note that the amplifier gain may not be invariant with frequency, particularly at the extremes of the operating frequency band.

Filters

The filter performance is typically expressed as an insertion loss factor, either as a linear factor or in decibels. By definition, a filter response varies with frequency, and must be characterised over the full operating frequency range of the system. The use of filters may serve a number of purposes: (i) to provide an anti-aliasing function (a low pass filter designed to restrict the frequency content of the signal before digitisation to below the Nyquist frequency of the acquisition system); (ii) to reduce influence of very low frequency parasitic signals (a high pass filter designed to cut out frequencies of less than 10 Hz which may be generated by non-acoustic mechanisms such as surface motion – such filters are commonly incorporated into commercial hydrophones which have integral preamplifiers); (iii) to provide some signal equalisation across the frequency range (usually, this involves a high pass filter with a modest slope which is designed to compensate for the frequency roll-off observed in typical ambient noise spectra, thus avoiding saturation of ADC). If any of the above filters are used in the system, their performance may need to be known to correct the data before analysis.

Analogue to Digital Converter (ADC)

The range setting (full-scale) and the calibration factor of the ADC must be known. Typically, this calibration factor will be invariant with frequency, but could vary depending on the range setting of the ADC. Note that the scale factor used in generating the data files forms part of the ADC calibration factor.

In-situ calibration checks and Quality Assurance

It is advisable to undertake in-situ checks on the system calibration just before and after deployment, and in between any repeated deployments. To do this, it is advisable to make use of a hydrophone-calibrator, which provides the hydrophone with a signal of known amplitude at a single-frequency (commercial devices are available which commonly operate at 250 Hz). The calibrator typically consists of an air-pistonphone that generates a known sound pressure level inside a small coupler into which the hydrophone is inserted. The sound pressure depends on the free-volume inside the coupler when the hydrophone is inserted, and so the coupler must be calibrated for each type of hydrophone that is used with that coupler.

Although the hydrophone calibrator provides a check at only one frequency, it does allow the entire system to be checked using an acoustic stimulus. It is also possible to undertake electrical check calibration of the system components. If the hydrophone in use has an insert voltage capability (many commercial hydrophones with integral preamplifiers have this facility), this may be used to check the electrical integrity and perform a calibration by electrical signal injection. This is a useful technique when deploying long cabled systems from vessels, and can be performed without retrieving the hydrophones. However, the method does not perform an acoustical check on the hydrophone element.

3.5.4 Deployment

Deployment method

The main aims of the deployment configuration are to:

- sample the sound field at an appropriate point in the water column for the duration and range of conditions required for the application;
- minimise parasitic sources of non-acoustic signals caused by the presence of the hydrophone and its platform, which contaminate the measurements and lead to spurious data.

The deployment method will depend on the local requirements of each individual member state. A bottom-mounted deployment is preferable to a surface deployment to minimise parasitic signals (for example from the influence of surface wave action), to keep the hydrophone away from the pressure-release water-air surface, and to minimise disturbance by surface vessels. A number of typical deployment configurations are possible, many of which are presented in the scientific literature (e.g. Cato 2008, Dudzinski *et al*., 2011, Robinson *et al*., 2011, ANSI S12.64: 2009).

An ideal deployment would allow data to be streamed to shore base, either by cable, or through satellite or modem link (though the latter is likely to limit the data bandwidth to be transmitted). Such a deployment has the advantage of near real-time data availability and enables checks of system functionality to be performed (André *et al*., 2011). However, such configurations are expensive and not readily available commercially at this time. Therefore, it is likely that many deployments will be of autonomous recorders with the data only available periodically after recovery (Wiggins *et al*., 2007, Lammers *et al*., 2008). Recovery of such a system will require either an acoustic release system or a surface buoy deployed from a seabed anchor.

Another factor when choosing final positions for deployment is the likely damage or loss of the equipment (and data). This is a problem for long-term deployments using autonomous systems. The main dangers are from (i) extreme weather; and (ii) fishing activity.

Deployment related noise

In addition to the self-noise of the measuring system described in Section 2.10.4.2, the recorded signals may also be contaminated by signals due to "platform self-noise", extraneous signals due to the deployment method for the hydrophone and recording system and its interaction with the surrounding environment (e.g. current, sea-state, etc.). Care needs to be taken in the design of the deployment systems to avoid contamination from noise due to the moorings, or local pressure fluctuations from turbulence due to interaction of the water flow with the measuring system. Often, the presence of contamination cannot readily be detected a priori even though it is present. This makes it very difficult to remove the influence of contaminating signals [Cato 2008, Harland 2008, ANSI S12.64: 2009, Dudzinski *et al*., 2011].

The following list shows some of the more common sources of unwanted signals that contribute to the platform self-noise of the deployed system in addition to the electrical self-noise in the hydrophone and recording system.

Flow noise

Any flow relative to the hydrophone or cable can induce turbulent pressure fluctuations at low frequency that will be sensed by a pressure sensitive hydrophone (typically these generate signals of frequency less than 100 Hz). Methods of reducing flow induced noise include locating the hydrophone close to the seabed where flow is reduced, use of a "sonar-dome", use of drifting buoys, and the use of mechanical fairings, often in spiral or helical form around cables and housings (Urick 1983, Ross 1987, Cato 2008). For autonomous recorders where the hydrophone is protruding from the recorder body, the problem can be exacerbated by turbulent flow around the end of the recorder casing. Strong fluid flow can also cause vibration of moorings and excite resonances in the recorder body. It is not always easy to check for the presence of flow-induced noise, but the recorded signals at low frequencies (<100 Hz) should be checked for correlations with tidal information – the flow noise signal will often show the same cyclic variations as the tides. If measurements have been made at both slack tide and at full tidal flow, it may be possible to quantify the effect of flow noise by comparison of the data.

Hydrophone cable strum

Cable strum occurs when cables are pulled taught by the action of currents, and the cable is caused to vibrate by the action of the water flow, producing parasitic low frequency signals. This is similar to the "aeolian harp" effect, or the singing of telephone wires in the wind. For typical cable diameters and current speeds, signal frequencies are of the order of 10 Hz (1 cm diameter cable in 1 knot of current produces a frequency of 9 Hz). The use of bottom mounted deployments, decoupling of the hydrophone from suspension cables using compliant couplings (e.g. elastic rope), and the use of cable fairings will help to minimise the problem (Urick 1983).

Mechanical noise

This includes (i) debris and/or sediment impacting the hydrophone; (ii) biological abrasion noise; (iii) hydrophone and cables rubbing against each other. Any opportunity for parts of the mooring system to impact against each other will cause noise, which may be audible, especially if it involves metal parts. To minimise the problems:

- avoid metal coming into contact with metal such as with shackles.
- avoid the use of chains in the supports.
- avoid placing hydrophone too close to seabed.

Hydrostatic pressure fluctuations

Any system deployed from the surface will have the potential to be affected by wave action, which will cause low frequency (but high amplitude) pressure fluctuations which may saturate the ADC in the recorder. The best solution to this problem, if the hydrophone is to be deployed close to the seabed, is to mount the hydrophone at the seabed rather than the sea surface, using a bottom-mounted frame or sub-surface buoy arrangement.

3.5.5 Auxiliary measurements

It is beneficial to record any auxiliary data that may be relevant, since these may be correlated with the measured noise levels during analysis. Some of the information may be obtained from other sources (for example, weather data). If measured locally, this may require the deployment of auxiliary equipment. Depending on the availability this may or may not be possible. Relevant auxiliary data may include:

- Sea-state
- Wind speed (and associated measurement height)
- Rate of rainfall and other precipitation, including snow
- Water depth and tidal variations in water depth (this can be measured using an echo sounder)
- Water temperature and air temperature
- Hydrophone depth in the water column
- GPS locations of sources, hydrophones and recording systems
- Seabed type
- Profile of conductivity, temperature and hydrostatic pressure as a function of depth in the water column using a CTD probe - from this information the salinity, density and sound speed profiles can be calculated from standard equations - alternatively, the sound speed profile can be measured directly using a velocimeter
- The pH of the seawater by use of a pH meter - an estimate of pH could be required for calculation of the absorption coefficient
- A monitor of the presence of vessels in the area where measurements are being made using a receiver of ship traffic Automatic Identification System (AIS)
- Nearby ship wrecks
- Nearby military restricted area
- Nearest oceanographic survey station
- Nearest marine reserve area
- Other permanent anthropogenic noise sources (gas pipe line, wind farm, etc.).

3.5.6 Averaging method (M2-b)

In Part III, chapter 2.8 the pros and cons of different kinds of averaging are outlined. Indicator 2 is specified by the Commission Decision of Sep 2010 as*: "Trends in the ambient noise level … (… average noise level … over a year)",* which was interpreted by the TSG Noise as*: "Trends in the annual average of the squared sound pressure associated with ambient noise … expressed as a level in decibels"* [Van der Graaf *et al.*, 2012].

In chapter 2.8 the earlier definition was evaluated, by comparing the annual average (arithmetic mean) of the squared sound pressure with other possible metrics. The following four averaging methods for this distribution were considered:

- Arithmetic mean (AM) of snapshots of mean square sound pressure (the TSG Noise interpretation)
- Geometric mean (GM) of the same snapshots (equivalent to arithmetic mean in decibels)
- Median of the same snapshots
- Mode of the same snapshots

> The purpose of Indicator 2 is to quantify noise within a frequency range, likely to be influenced by shipping. Shipping noise has both permanent and intermittent components, and an annual average will automatically include both. Normally, on a year-round basis there are no anthropogenic underwater sounds more persistent than shipping, but there may be some locations at which shipping noise is not the largest contributor to anthropogenic ambient sound, within the frequency bands relevant to Indicator 2.

The different averaging methods were evaluated against the following criteria, where the method needed to be:

- Robust to minor changes or differences in implementation.
- Representative of a large enough region to justify its use as an indicator of GES.
- Practical (simple to implement).
- Compatible with comparable regulations or procedures (desirable but not essential).

Based on analysis of available data the Comprehensive Nuclear-Test-Ban Treaty Organisation (CTBTO), it was concluded that the arithmetic mean will initially be the best option. TSG Noise advises MS to adopt the arithmetic mean. The main considerations in reaching this recommendation are:

a) the arithmetic mean includes all sounds, so there is no risk of neglecting important ones
b) the arithmetic mean is independent of snapshot duration

The trend is the trend in the arithmetic mean. In order to establish the statistical significance of this trend, additional statistical information about the distribution is necessary. For further details, see Part III of the Monitoring Guidance. TSG Noise recommends that the complete distribution be retained for this purpose, in bins of 1 dB.

When an average value for ambient noise is established using the arithmetic mean, the value found for the average will be dominated by the noisiest contribution. Therefore, monitoring in the vicinity of high shipping density areas, the arithmetic mean is likely to be dominated by this contribution.

3.5.7 Standards and definitions for appropriate noise monitoring models

The modelling approach should take into account representative environmental conditions (oceanography, sea state, sea bed, etc.). The results provided by the modelling should be consistent with the averaging methods applied to the measurements. Optionally, the modelling could be done in such a way as to make percentile calculation of received level possible at the scale of individual points and of a region or a basin, should MS require such assessments.

Modelling and input knowledge is likely to improve with the development of new technologies and techniques (operational oceanography, noise from ships, calculation performances, etc.).

If Member States wish to compare calculated historical trends with new predictions, modelling output should include an evaluation of its sensitivity to modelling inputs (environmental data, anthropogenic data, etc.) and inherent uncertainties.

3.5.8 Examples of appropriate modelling approaches

The physics of underwater sound propagation are generally well understood. The propagation of sound through water is described by (the wave) or Helmholtz equation, with appropriate boundary conditions. A number of models have been developed to simplify propagation calculations. These models include "ray theory", normal mode solutions, and parabolic equation simplifications to the wave equation [Jensen *et al*, 1994]. Each set of solutions is valid and computationally efficient within limited frequency and range, and may involve other limits. Ray theory is more appropriate at short range and high frequencies, while the other solutions function better at long range and low frequency. [Harrison 1989]. Modelling appropriate for some specific sounds and conditions is still being developed [Reinhall and Dahl 2011, Zampolli *et al.,* 2013], e.g. the propagation of loud impulsive sounds (from piling, or explosives) in shallow water.

Of the methods described by [Jensen *et al*., 1994], the most practical are parabolic equation, normal modes and ray theory. A practical method, not described in Jensen's book, is Weston's flux integral method [Weston 1959]. This method can be applied to arbitrary seabed bathymetry [Weston 1976] and has recently been extended to include convergence effects for arbitrary sound speed profiles [Harrison, 2013].

Examples of appropriate modelling approaches can be found on open access websites, such as the Ocean Acoustics library, that contain acoustic modelling software and data. It is supported by the U.S. Office of Naval Research (Ocean Acoustics Program) as a means of publishing software for general use to the international ocean acoustics community (see http://oalib.hlsresearch.com/). Also, the AcTUP propagation modelling software is available from the Centre for Marine Science and Technology of Curtin University (see http://cmst.curtin.edu.au/products/actoolbox.cfm).

Examples of basic information needed as input parameters for modelling are also available. For data on large and many small ship movements the Automatic Identification Systems (AIS) can be used, since all large merchant vessels are required to carry an AIS-transponder on board (see http://www.marinetraffic.com/ais/).

In present European noise modelling and mapping projects (as described in part III chapters 2.3-2.6) ships are characterised in terms of the source level of an equivalent monopole, at a specified depth. TSG Noise advises the continued use of this approach. See [de Jong *et al*., 2012] for a definition of monopole source level for the equivalent point source. See [Wales & Heitmeyer 2002] for typical values of commercial shipping source levels. Many publications on radiated noise for ships, including the ANSI Standard S12.64-2009 [ANSI, 2009] do not report the source level, but the radiated noise level, while still referring to this as "source level".

TSG Noise concludes that further investigation into best practice, or even standardised methods, is needed. In addition to data describing the source factors that influence propagation bathymetry, sound velocity profiles are also needed. Of particular importance in deep water is the sound speed profile, available in the World Ocean Atlas 2009, (see http://www.nodc.noaa.gov/OC5/WOA09/pr_woa09.html); and absorption of sound in seawater, described on the website of the National Physical Laboratory (NPL) in the UK (see http://resource.npl.co.uk/acoustics/techguides/seaabsorption/). Some other parameters may be found: global bathymetry (of particular importance in shallow water is the bathymetry http://www.ngdc.noaa.gov/mgg/global/; (1 arc minute), http://www.gebco.net/ ; or http://gcmd.nasa.gov/records/GCMD_DBDBV.html); and sediment composition, often available from geophysical surveys).

For low frequency shipping noise (up to about 100 Hz), the sea surface can be designated as a perfect reflector, with a 180 degree phase change (a so-called "pressure release" surface). For higher frequencies, especially above 1 kHz, a better description is probably needed [Ainslie 2010, Ch 8, pp 362-369]. The NPL website also contains useful information and equations for calculating the speed of sound in sea-water, as a function of temperature, salinity and pressure (or depth) (http://resource.npl.co.uk/acoustics/techguides/soundseawater/).

A recent modelling approach used to make sound maps is described in the Irish STRIVE Noise report, issued in May 2013.

4. MAIN CONCLUSIONS AND RECOMMENDATIONS

4.1 Monitoring impulsive noise

The initial purpose of monitoring impulsive noise is to assess the pressure on the environment, by making available an overview of all loud impulsive low and mid-frequency sound sources, through the year and throughout regional seas. This will enable MS to get an overview of the overall pressure on the environment from these sources.

TSG Noise recommends monitoring of indicator 11.1.1 by **setting up a register of the occurrence of these impulsive sounds**. This is the first step to establish the current level and trend in these impulsive sounds.

Airguns, pile-driving, explosives, and sonar working at relevant frequencies and some acoustic deterrent devices are the **most important sound-sources that should be considered for inclusion in the register**. Additional sources that could also be of concern include boomers, sparkers and scientific echo sounders. TSG Noise proposes to use thresholds for uptake in the register. Thresholds were derived that will ensure that all sources that have a potential for significant population level effect will be included in the register. However, the use of these (relatively low) thresholds will result in sources with a relatively low potential for significant impact also being registered. TSG Noise concluded that there is a need for more detail in the register than just the day and location; of this additional information, the source level is the most important. The initial purpose of monitoring impulsive noise is to assess the pressure on the environment, by making available an overview of all loud impulsive low and mid-frequency sound sources, through the year and throughout regional seas. This will enable MS to get an overview of the overall pressure on the environment from these sources.

The **information required** to derive pulse-block days (the number of days that a certain threshold (pulse) is exceeded in an area (block)), are:

- Position data (geographic position (lat/long), licensing block/area)
- Date of operation
- Source properties:

  Essential (minimum)

  - Source level or proxy;

Additional data about source properties that could be recorded, when available, include source spectra, duty cycle, duration of transmissions (and actual time/time period), directivity, source depth and platform speed. Collection of this data would enable improved assessment of the overall pressure on the environment.

The **main aim of the registry** is to provide an overview of all loud sounds. If the registry leaves out certain sound sources it would not fulfil the aim of addressing cumulative effects of impulsive noise; it is therefore recommended that information on <u>all</u> sources should be included [see Van der Graaf *et al*., 2012]. TSG Noise therefore suggest that data on explosives and military activities (of which the sole purpose is defence or national security) should also be included in the register, but notes that this should be on a voluntary basis as this is a national policy issue.

TSG recommends that **a joint register of the occurrence of these impulsive sounds should be set up at least on a Regional Sea level**, the format of which must ensure future compatibility. This cannot be conclusively decided until the register location and management are decided, but there are some factors that could be agreed upon, such as:

- ✓ Use of a common language (English)
- ✓ Use of a common format for date in accordance with the appropriate standard (ISO 8601) (YYYY-MM-DD or YYYYMMDD)
- ✓ Use of a common format for position (latitude and longitude, decimal degrees)
- ✓ Use of a common map projection (unprojected data – WGS84)
- ✓ Use of a common template (i.e. setting out the order in which information is recorded)

The register can be used to estimate **the spatial and temporal impact on the environment** (the total period and total habitat loss by impulsive noise sources) and for determining the **baseline level**. Pressure indicators and pressure-based targets may be used if a clear understanding of the relationship between pressure, state and impact exists. Once a baseline and targets have been set, the register can be used for management purposes (e.g. regulating planning and licensing activities) and to assist in marine spatial planning, incorporating displacement mitigation guidelines and reducing the potential for cumulative impacts.

4.2 Monitoring ambient noise

TSG Noise concludes that the **combined use of measurements and models** (and possibly sound maps) is the best way for Member States to ascertain levels and trends of ambient noise in the relevant frequency bands. Member States should be careful to balance modelling with appropriate measurements. This report provides concrete advice on specifications for noise monitoring systems, noting that there are no international standards for monitoring underwater ambient noise, for modelling and for data storage. TSG Noise concludes that such standards are needed. **TSG Noise therefore recommends that international standards be developed for the measurement, modelling and data storage of ambient noise** with application to underwater noise monitoring, including the measurement of radiated sound from important sources such as airgun arrays and underwater explosions (standards for the measurement of radiated sound from ships and impact pile driving are already under development by ISO).

Monitoring indicator 11.2.1 will enable MS to quantify the environmental pressure (expressed as ambient noise level) as well as trends in ambient noise levels within the two frequency bands. Pressure indicators and pressure-based targets may be used if a clear understanding of the relationship between pressure, state and impact exists. Since there is very little information available on the effects of increased ambient noise level, TSG Noise cannot give concrete advice on interpretation of results at this stage.

In addition to the advice needed to develop and deploy the systems needed to monitor the indicator, TSG Noise concluded that ***trends* only will not be sufficient to describe GES. To describe GES *levels***, based on a wider overview of the area, a combination of modelling / measurements and possible mapping will be needed. Next to that, much greater **understanding of the relationship between the environmental pressure caused by ambient noise and the state of the ecosystem is needed before GES can be understood**.

There is no requirement for Member States to describe the complete noise field in their waters, a limited number of monitoring stations (measurement locations) would suffice. However TSG Noise concluded that the **use of models can contribute directly to effective ambient noise monitoring and assessment.**

TSG Noise has not defined exact locations for deploying equipment necessary to monitor relevant frequency bands of ambient noise. However, TSG Noise advises **Member States within**

a sub region to work together to establish an ambient noise monitoring system, and TSG Noise has provided a set of rules for the design of a monitoring strategy. Furthermore, TSG has provided **guidance for reporting results**.

The advantages and disadvantages of different averaging methods (arithmetic mean, geometric mean, median and mode) are reviewed, and TSG Noise **recommends that Member States adopt the arithmetic mean**.

In order to establish the statistical significance of the trend, additional statistical information about the distribution is necessary. TSG Noise recommends that **complete distribution be retained in the form of sound pressure levels as a function of time**, **along with a specified averaging time**. TSG Noise advises the retention of the amplitude distribution for this purpose in bins of 1 dB, and the associated snapshot duration. TSG Noise advises MS that the snapshot duration should not exceed one minute.

Additional and background information is provided in **Part III of the Monitoring Guidance** that includes further information, substantiation and detailed references.

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Abstract

This document has been prepared by the Technical Subgroup on Underwater Noise and other forms of Energy (TSG Noise), established in 2010 by the Marine Directors, i.e. the representatives of directorates or units in European Union Member States, Acceding Countries, Candidate Countries and EFTA Member States dealing with or responsible for marine issues. In December 2011, the Marine Directors requested the TSG Noise to provide monitoring guidance that could be used by Member States in establishing monitoring schemes to meet the needs of the Marine Strategy Framework Directive indicators for underwater noise in their marine waters. This document presents the recommendations and information needed to commence the monitoring required for underwater noise.

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