

European Marine Strategy Framework Directive

MONITORING GUIDANCE FOR UNDERWATER NOISE IN EUROPEAN SEAS

PART II - Monitoring Guidance Specifications

**2nd Report of the Technical Subgroup on Underwater Noise and
other forms of energy (TSG-Noise)**

INTERIM GUIDANCE REPORT

May 2013

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Authors:

Dekeling, R.P.A., Tasker, M.L., Ainslie, M.A., Andersson, M., André, M., Castellote, M., Borsani, J.F., Dalen, J., Folegot, T., Leaper, R., Liebschner, A., Pajala, J., Robinson, S.P., Sigraay, P., Sutton, G., Thomsen, F., Van der Graaf, A.J., Werner, S., Wittekind, D., Young, J.V.

TSG Noise acknowledges valuable contributions and comments received from:

Mark Prior, Mike van der Schaar, Özkan Sertlek, John Campbell, Michael Dittrich, Foort de Roo, Geert Aarts, Jeroen Janmaat, Bill Pramik, Sander von Benda-Beckmann and Leo de Vrees (EC).

Interim Guidance Report:

TSG Noise was tasked to deliver guidance so that European Member States could initiate programmes for underwater noise monitoring. As monitoring must be operational by 2014, first guidance was required by spring 2013. The Interim Guidance report provides the basis for the noise monitoring programme however since new information continues to be compiled TSG Noise can review and update the guidance later in 2013. In addition, the results and feedback that may arise at the training workshop (preliminary planned now for Autumn 2013) can be incorporated. This also means the inclusion of new findings into the design of the register for impulsive noise generating activities, and from currently running initiatives around the Baltic Sea, The Netherlands, Germany and Ireland, for ambient noise. For this reason this report has been designated as an interim guidance until Autumn 2013.

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Final editing was done by René Dekeling, Mark Tasker, Sandra van der Graaf and Maria Ferreira.

TSG Noise details:

Contact person: Sandra van der Graaf, Rijkswaterstaat Centre for Water Management, Postbox 17, 8200 AA Lelystad, The Netherlands; tel: 31 320 298 085 / 31 6 1152 6484; email: sandra.van.der.graaf@rws.nl

Chairs: Mark Tasker, email: mark.tasker@jncc.gov.uk and René Dekeling, email: rene.dekeling@minienm.nl

Disclaimer: This interim guidance report has been prepared by a group of experts nominated by EU Member States and Stakeholders. It provides technical advice and options for the operational implementation of monitoring MSFD Descriptor 11 on Underwater Noise. It does not constitute an official opinion of the European Commission, nor of the participating Institutions and EU Member States.

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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 reaching good environmental status, MS should establish **monitoring programmes for assessment**, enabling the state of the marine waters concerned to be evaluated on a regular basis.

In 2010, in Commission Decision 2010/477/EU, criteria and methodological standards on GES of marine waters were published. 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) under the Working Group on Good Environmental Status (WG GES) 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. In February 2012, TSG Noise delivered its first report [Van der Graaf *et al.*, 2012]¹. For both the impulsive and the ambient noise indicators significant progress was made to their practical implementation of the indicators, and most ambiguities had been 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 the view to considering indicators of noise effects.

The present document is **Part II** of the **Monitoring Guidance for Underwater Noise in European Seas** (Interim Guidance Report) and provides MS with the information needed to commence the monitoring required to implement this aspect of MSFD. TSG Noise has focussed on ambiguities, uncertainties and other shortcomings that may hinder monitoring initiatives and has provided solutions, and describes methodology for monitoring both impulsive and ambient noise in such a way that information needed for management and policy can be collected in a cost-effective way. TSG Noise has no doubt that further issues will arise once monitoring starts, but hopes 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 results 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, that provides the specifications for the monitoring of underwater noise, with a dedicated section on impulsive noise (Criterion 11.1 of the Commission Decision) and ambient noise (Criterion 11.2 of the Commission Decision). It provides a detailed guide to those who will implement the monitoring/modelling, and noise registration technical specifications.

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

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

1. Introduction

1.1 Introduction to Underwater Noise

In the EC Decision 2010/477/EU on criteria and methodological standards on GES of marine waters, two indicators were published for Descriptor 11 (Noise/Energy) of the MSFD 2008/56/EC. 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 in 2010 agreed to establish a TSG under the WG GES for further development of Descriptor 10 Marine Litter and Descriptor 11 Noise/Energy. For practical reasons Directorate-General Environment (DG ENV) decided that the work would be carried out by two separate groups. 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 μ Pa 2 .s) or as peak sound pressure level (in dB re 1 μ Pa 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 1 μ Pa 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 Types of underwater noise

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 kind of energy is underwater sound. It is likely that sound levels, and 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 such a change. 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].

Energy input can occur on many scales in both space and time. Anthropogenic sounds may be of short duration (e.g. impulsive) or be long lasting (e.g. 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 the nature of, and transmission of, sound in the marine environment.

Marine organisms that 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. worst case, death). These adverse effects can be widespread (as opposed to local for other forms of energy) and, following the recommendations of Tasker *et al.*, (2010), the EC decided in September 2010 that the two indicators for underwater noise listed in Text Box 1 should be used in describing GES (EC Decision 2010/477/EU on criteria and methodological standards on GES). This interim guidance report therefore focuses largely on providing guidance for monitoring these indicators of underwater sound rather than on other sources of energy.

The International Standard [ISO 2003] distinguishes between “**continuous sound**” and “**impulsive sound**”. Specifically, according to [ISO 2003]:

“The sound pressure level of the sound from a continuous sound source can be constant, fluctuating or slowly varying over a time interval. Continuous sound is preferably described by the [weighted] equivalent continuous sound pressure level over a specified time interval. For fluctuating and intermittent sounds, the [weighted] maximum sound pressure level with a specified time weighting may also be used.”

Further, [ISO 2003] defines “impulsive sound” as “sound characterised by brief bursts of sound pressure”, with the clarifying note: The duration of a single impulsive sound is usually less than 1 s.

TSG Noise defined “impulsive sound” as *a sound for which the effective time duration of individual sound pulses is less than ten seconds and whose repetition time exceeds four times this effective time duration. In this interpretation, it is proposed that all sounds of duration less than 10 s that are not repeated are also impulsive* [Van der Graaf *et al.*, 2012].

2. Guidance for registration of impulsive noise

From the Commission Decision 2010/477/EU (CD), Indicator 11.1.1: *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 1µPa 2 .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 of this indicator is not unambiguous and therefore TSG Noise suggests the following less ambiguous description of the indicator. TSG Noise refines its interpretation of indicator 11.1.1 on low and mid-frequency impulsive sounds as follows:

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 1st TSG report [Van der Graaf et al., 2012].

2.1 Main objective and Scope of the indicator

TSG Noise noted earlier that guidance was needed on the main objective of the indicator for impulsive noise. In the First report of TSG Noise of February 2012, the aim of the indicator was therefore further explained. 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 is addressing 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 therefore not covered by this indicator, and this indicator on its own is not intended, nor is it sufficient, to manage singular events. Environmental Impact Assessments (EIA) can be used to assess and where necessary, to limit the environmental impacts of individual projects.

The impact that is addressed by Indicator 11.1.1 is “considerable” displacement. This means displacement of a significant proportion of individuals for a relevant time period and spatial scale. The indicator addresses the cumulative impact of sound generating activities and possible associated displacement, rather than that of individual projects see [Van der Graaf, 2012], par 3.3.1.3).

The initial purpose of this indicator 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, which has not been achieved previously (see First report of TSG Noise, Feb 2012).

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

2.2 Outline of the register (M1-b)

A noise register may be viewed as the data that would underlie a relatively coarse scale map. The amplitude, frequency and other impulsive characteristics of the sounds being mapped are not precisely defined – the frequency range has been defined in the Commission Decision as 10 Hz to 10 kHz. It should be noted that the precise properties of an impulsive sound that cause displacement are not known, and is certain to vary with biological receptor and period of the year. Thus rather than attempt to define these properties, a practical approach is to map those human activities likely to generate “loud” impulsive sounds within the frequency range in the Commission decision.

Seismic survey, pile-driving, explosives, sonars working at relevant frequencies and some acoustic deterrent devices are the most important sound-sources that should be considered for inclusion in the register. Possibly there are additional sources that could be of concern (boomers, sparkers, scientific echo sounders). Since a registry that leaves out part of the sound sources is not useful if the aim is to address cumulative effects of all sources of impulsive noise, and therefore it is recommended that information on all sources should be included in the registry [see Van der Graaf et al., 2012]. TSG Noise therefore suggest that data on explosions and from activities of which the sole purpose is defence or national security should be included in the register, on a voluntary basis, but notes that this is a national policy issue.

The main items in the register needed to derive pulse-block days (the number of days that in an area (block) a certain threshold (pulse) is exceeded) as required in the text of the Commission Decision, are:

- Pulse-generating activity
- Day
- Location
- Source level

Thresholds have been proposed for inclusion of sources in the register (2.3.2) and recommendations for registration of further information to characterise the source (2.4); see also section 2.1 of Part III report for the methodology.

2.2.1 Options for addressing temporal and spatial scale

The temporal scale of the map is one day, while the proposed spatial scale is of blocks of sea similar in size to present offshore licensing blocks (approximately 10 nmi x 5 nmi). There are two spatial units that should be used in the analysis. The first is the blocks or grid size used for registering the data. The second is the assessment areas used for the analysis.

In the first report of the TSG Noise, options for addressing spatial scale were set out. It was recommended that one grid size should be used by all MS. For practical reasons TSG Noise proposes to use standard hydrocarbon licensing blocks for collection of data for seismic surveys, since most MS commonly use these licensing blocks. Use of these blocks may be practicable when collecting data for other relevant sources, but sometimes other approaches may be needed (see Part III of the Monitoring Guidance, chapter 2.2).

2.3 Technical Specifications

2.3.1 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 sonars, airguns, acoustic deterrents and explosions, 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 $\mu\text{Pa}^2 \text{ m}^2 \text{ s}$. For airguns and explosives it is more convenient to convert these to proxies of zero to peak source level (SL_{z-p}) and equivalent TNT charge mass (m_{TNTeq}), respectively. The recommended thresholds for these source levels and proxies are listed below².

² 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.

- | | |
|---------------------------------------|--|
| • Airgun: | $SL_{z-p} > 209 \text{ dB re } 1 \mu\text{Pa m}$ |
| • Low-mid frequency sonar: | $SL > 176 \text{ dB re } 1 \mu\text{Pa m}$ |
| • Low-mid freq. acoustic deterrent: | $SL > 176 \text{ dB re } 1 \mu\text{Pa m}$ |
| • Generic non-impulsive sound source: | $SL > 176 \text{ dB re } 1 \mu\text{Pa m}^3$ |
| • Explosions: | $m_{TNTeq} > 8 \text{ g}$ |
| • Generic impulsive sound source | $SL_E > 186 \text{ dB re } 1 \mu\text{Pa}^2 \text{ m}^2 \text{ s}$ |

2.3.2 Source characterisation (M1-a)

The thresholds that were derived 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 being registered that actually will have a relatively low potential for significant impact. TSG Noise concluded that there is a need for more detail in the register than only the day and location, but also other information, of which the source level is the most important. The likely role of the register is recording activities in order to assess/evaluate the total pressure from impulsive sources. For this role additional information should be recorded if it is available. In a later phase the register may serve as a tool to aid management decision-taking.

If member states wish to improve the quality and usability of the register, TSG Noise recommends that the following additional information should be gathered in the register. This will improve the assessment of the impact of sounds:

Source properties

- Source level or proxy (already registered);
- Source spectra;
- Duty cycle;
- Duration of transmissions;
- Directivity⁴;
- Source depth;
- Platform speed

Of these parameters, the source level (or proxy) is the most important one. Since it is possible that many operators (e.g. navies using sonar, oil and gas companies using airguns) will not cooperate if detailed information of source properties is requested, (e.g. military sonar source level is often considered classified), it is proposed that in such a case the operators will have the option to report source level in 10 dB bins rather than giving a precise figure.

2.4 Interpretation of results (M1-c&d)

This indicator is designed to provide the information to assess the temporal and spatial distribution of impulsive noise sources and the possible impacts of displacement at the population level. The data that will be gathered in the register will enable MS to estimate per day at a course scale the size of area that is affected, e.g. from which animals may be displaced. Many further steps would be needed

³ 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.

⁴ 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.

to assess whether or not such displacement might affect species at the population level. This will require considerable further research for even the most studied species at present and the consequences will vary with species. Some modelling approaches, such as the Population Consequences of Acoustic Disturbance (PCAD) model project [National Research Council, 2005] may aid understanding. Plainly the ecological consequences of displacement will not only depend on its temporary and spatial nature but also on whether or not alternative suitable habitat is available.

Baseline

According to EC guidance⁵ 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.*

For impulsive noise the reference state (type a) baseline) is a state where there is negligible population level displacement impacts from anthropogenic noise. This is a zero-line, e.g. no significant displacement (where 'no significant displacement' means 'no significant displacement caused by man-made sound').

Once a register is set up, it should be possible to determine the spatial and temporal distribution of impulsive noise sources. This quantified assessment of impulsive noise sources can then be used to determine policy targets and to establish type b) baseline.

For the analysis of the data, the use of these blocks may be practical, but MS should realise that the actual size of the area affected by a source may vary (most notably depending on source level and sound propagation characteristics). In addition, various marine organisms may be affected by different received sound characteristics. Making use of standard blocks to describe the affected area may not be sufficient to evaluate whether GES is achieved. This can be better evaluated in the future using actual monitoring data.

Thresholds and targets

There is presently insufficient knowledge to determine the amount of disturbance that would compromise Good Environmental Status. There are several options for target setting, each of which needs further consideration that might best occur once example registers are in place. These might include:

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

TSG Noise stresses that setting a realistic target is only possible once a baseline (i.e. a quantified assessment) is known and when more information is available on the impacts of noise. TSG Noise will

⁵ 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.

work in 2013 and 2014 towards advice on thresholds and targets. This advice will be on the type of target MS could consider. Setting the threshold level is, of course, a responsibility of the MS themselves.

Practical uses of the noise register

The register can initially be used for estimating 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 is known and targets have been set the register can be used for management purposes (e.g. by regulators in the process of 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 the monitoring of ambient noise as covered by 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 starts with a brief introduction and recapitulation of the scope of the indicator. What follows are the definitions – as recommended by TSG Noise – for the most essential terms of Indicator 11.2.1. Next, the report will outline some 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 cornerstones of the organisation of the monitoring / modelling, the technical specifications of equipment and averaging method will be provided. The chapter ends with initial suggestions for the interpretation of the results.

3.1 Main objective and Scope of the indicator

Tasker *et al.*, (2010) and Van der Graaf *et al.*, (2012) provide the background for the understanding of the concept behind Indicator 11.2.1. This indicator focuses on the issue of chronic exposure of marine life to low frequency ambient noise with the main contributor, at least in many regions, being sounds from commercial shipping, hence the initial choice of the two frequency bands most relevant to shipping noise. Literature suggests that exposure to these types of sounds could lead to masking of biological important signals and in the long term could also induce stress in receivers, which in turn may lead to physiological impacts (see review by OSPAR, 2009).

TSG Noise provides advice on scope and optimal approach, and further provides some clarifications and more detailed definitions of some essential terms to make Indicator 11.2.1 operational.

In addition to the advice needed to operationalize the indicator, TSG Noise discussed to what extent monitoring trends is sufficient to reach the overarching aim of the MSFD to ensure that Good Environmental Status is reached. Within TSG Noise it was suggested that *trends only* are not sufficient to describe GES: trends indicate whether the actual pressure on the environment (e.g., shipping noise) is rising or falling. To describe actual GES actual levels, based on a wider overview of the area, a combination of modelling/ mapping will be needed.

This reasoning was compared with the approach chosen by the Working Group on Good Environmental Status (WG GES) and described in the 'Common Understanding' document [EC WG GES, 2011⁶]. WG GES 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".

A similar trend-based target can be used for underwater noise. If it were known that existing levels were too high, but not yet what levels are safe, it would make sense to adopt a downward trend as 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 do, and there is also some evidence [Rolland *et al.*, 2012] that noise increases stress, in the opinion of TSG Noise there is still insufficient knowledge on the effects of (increased) ambient noise levels in the ocean to determine whether existing levels are too high or where GES is being achieved with respect to ambient noise. However, if

⁶ 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

a Member State suspects that noise levels are too high (or might soon be too high if they continue to rise), then that Member State might still choose to adopt a downward (or non-increasing) trend as target, in line with the use of the precautionary principle as described in the MSFD.

An indicator can be used by MS for target setting and in programmes of measures, if there is a reasonable expectation that determining the value of the indicator is achievable, and where needed adopt programmes of measures, on a timescale relevant to the adaptive management process as required by article 3 of the MSFD. At present, there is no knowledge of longer-term trends of ambient noise in European waters, but there is some information 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 series presented in Van der Schaar *et al.*, (2013) showed 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 to have occurred in deep water in other parts of the industrialised world, this cannot be confirmed by measurements in European waters since no suitable historical measurements are available and even with a validated hind cast model it will be difficult to verify the accuracy of the data. In shallow water, trends of ambient noise are likely to be different, due to different categories of vessels using these waters and differing sound propagation conditions. Whether the changes in trends in shallow water are likely to be greater or less than in deep water is not known. This is further complicated by spatial variation of trends, which is likely to be greater than in deep water, partly because the distance to the sources is typically smaller (increasing the likelihood of high amplitude transient sounds), and partly because of the variable propagation conditions typically encountered in shallow water. Spatial variation will probably be much larger than the yearly trends, because some waters (e.g. harbour channels) are used to a far greater extent than other areas.

Thus, it will probably take decades rather than years (much later than 2020) to establish a statistically significant trend of ambient noise for EU waters. From a practical point of view it therefore makes sense to measure levels, not trends. Levels can be measured on a timescale relevant to MSFD, and can be compared with a target.

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

In conclusion, it was decided that it is within the remit of TSG Noise not only to describe how MS can monitor trends, but alongside to advise MS about the best approach to measure actual levels (including a wider overview of the area, created by combination of modelling/ mapping), and this will provide the option for MS to choose the most appropriate approach when setting up monitoring; this guidance therefore also addresses how MS in a cost-effective way can monitor actual levels (and thereby monitor trends).

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 μ Pa, 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 the monitoring concept, it is important to note explanations for some of the terms 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 year-to-year (or longer) changes in a specific quantity.

Annual averaged squared sound pressure level. TSG Noise recommends that the averaging method for 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 also required, corresponding to percentage exceedance levels. The 50 % exceedance level is also the median. For the establishment of the statistical significance of the trend, 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 of received levels. See fig. 1 (below) for clarification.

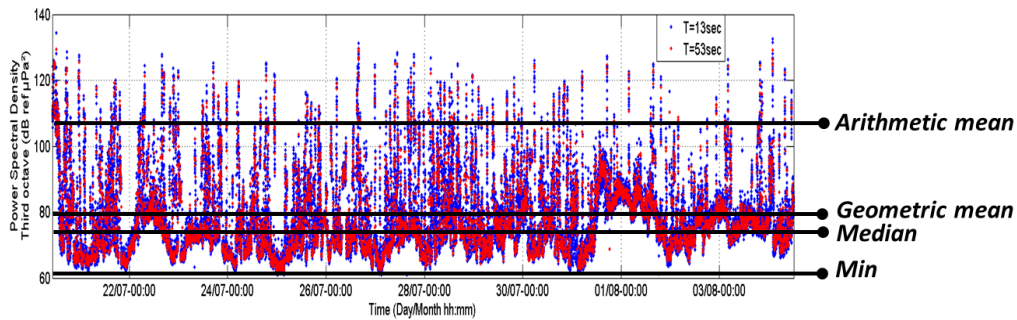


Figure 1: Example of approx. 14 days of continuous measurement in the 125 Hz third octave band made off Cork harbour (Ireland) entrance made during the STRIVE project (source: Quiet-Oceans). The measured signal has a typical structure of background noise and emerging ship noise when ships are passing 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.

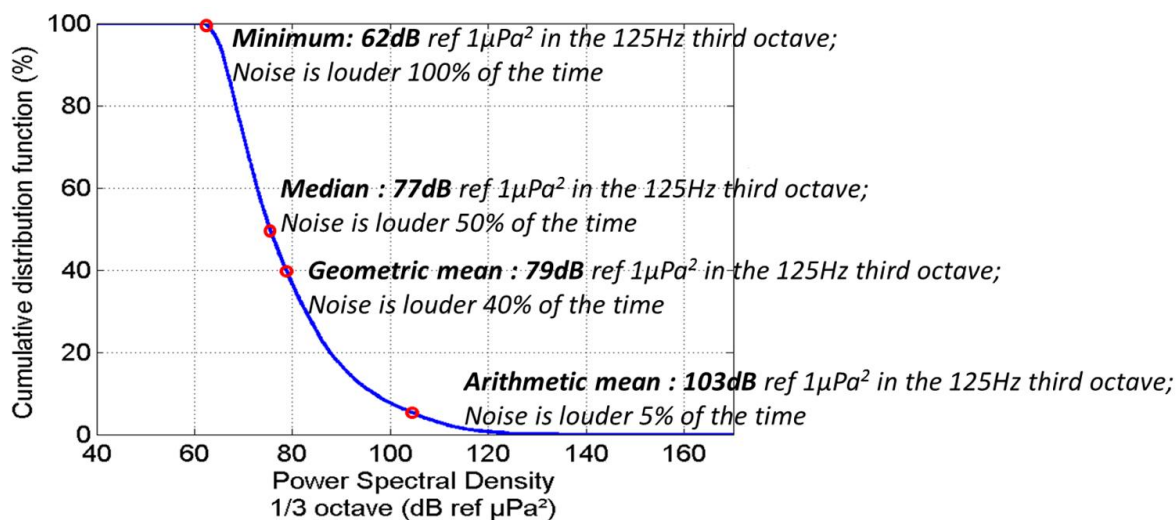


Figure 2: Statistical representation of the measured sound pressure level in the 125 Hz third octave band off Cork harbour as a cumulative distribution function, the exceedance⁷. The curve shows the proportion of time where a given minimum level is reached. For example, it shows that 50% of the time, the measured level exceeds 77 dB re 1 μPa , and that only 5% of the time the level than exceeds the arithmetic mean.

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

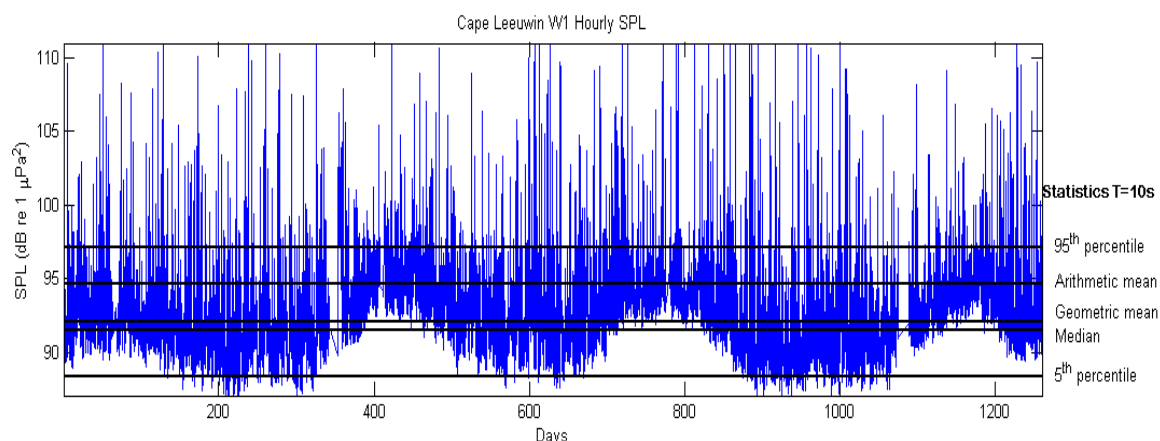


Figure 3: Example of 3 years of measurements in the 63 Hz third octave band made at the CTBTO Cape Leeuwin station. The graphic shows hourly summarised SPL measurements in blue to avoid a very dense graphic and leading to a somewhat smoothed curve. The five statistics indicated on the right were computed over 10 second SPL measurements.

⁷ 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

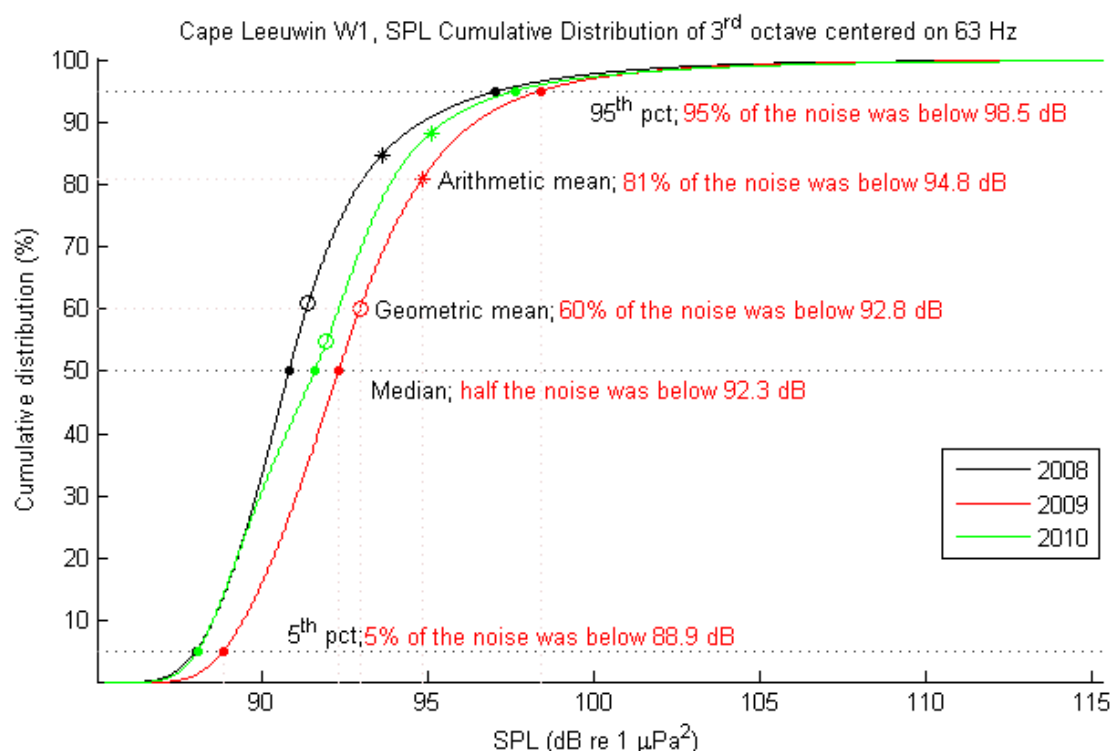


Figure 4: Cumulative distribution of the noise levels (SPL over a 10 second window) measured at the CTBTO Cape Leeuwin station during three consecutive years. The curve shows the proportion of measurements that were below a certain sound level. The five statistics on the right are interpreted for the 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 also recommends 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 that will contribute to the knowledge base and may assist with evaluation of the monitoring regime at the six-year revision.

3.3 Measurements and modelling

TSG Noise notes that the CD does not require that MS describe the complete noise field in their waters, and in theory a limited number of monitoring stations (measurement locations) could suffice to fulfil the requirements of the indicator. TSG Noise has also evaluated the advantages and disadvantages of different monitoring approaches.

TSG Noise considers measurements to be essential to provide ground truth at specific locations, but results are sensitive to bias introduced by known changes in the spatial distribution of human activities, e.g. changes in a ferry route and bias introduced by the natural variability of the environment (climatic, seasonal change, change in vertical stratification of the ocean and other factors). At sea measurements are also logistically challenging. TSG Noise therefore has evaluated whether modelling can be used to design a more comprehensive and cost-effective monitoring strategy.

3.3.1 The use of modelling

1. First and foremost, the use of modelling within indicators and noise statistics, and possibly eventually to create noise maps, ensures that trend estimation is more reliable and cost-effective, for a number of 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 order 0.1 dB/year; it will take many years, possibly decades, to reveal such a small trend without the help of spatial averaging)
 - ii. Use of models reduces the number of stations required to establish a trend in a fixed amount of time (similar reasoning) and thus reduce the cost of monitoring
 - iii. Modelling will also help with the choice of monitoring positions and monitoring equipment (to select locations where the noise is expected to be dominated by shipping as opposed to explosions or seismic surveys).
2. Further, use of models would enable the identification of trends for different types of source separately, directly identifying the cause of any increase (or decrease) and thus facilitating mitigation action. Furthermore, models would permit the removal of selected sources if considered not to cause a departure from GES (such as natural sources of sound, both biotic and abiotic (e.g. lightning)).
3. Use of models would provide a member state with an overview of actual levels and distribution of levels across its sea area, and thereby enable identification of departures from GES.

In addition, there are a number of advantages of using modelling approaches that could contribute to a greater understanding of the likely impacts of noise in the future.

4. Use of models enables one to possibly predict the effect of future changes (forecast- e.g. what is the expected effect of a certain percentage increase in shipping traffic (assuming no noise mitigation) in the eastern Baltic over the next years?) and to re-construct a history of the past (hind cast). There would be limitations to such work as new ships may have other noise signatures than their earlier equivalents and the relationship between amount of traffic and sound is not straightforward.
5. Use of models enables one to make 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 appropriate measurements.

The first TSG Noise report [Van der Graaf *et al.*, 2012] describes standards that measurement equipment should comply with, along with comments about possible shortcomings of commercially available equipment. Models also require standards and definitions which are needed to clarify what is an appropriate model and what is not. This chapter provides advice on the standards to which models should comply with and will describe modelling approaches that can be used by Member States.

3.3.2 Available knowledge on noise mapping and possible applications

Next to modelling, the use of noise mapping has been suggested and the terms of reference require TSG Noise to address the use of mapping.

Acoustic modelling of the noise can be done in such a way that the output is delivered in the form of noise maps. Noise maps can be seen as a form of model output that is relatively easy to understand. It creates opportunities for other uses, for instance for management and evaluation of measurements. Therefore, several initiatives using mapping have started in a number of Member States. These are described in more detail in part III. These include:

- Noise maps for shipping and explosions in the Dutch North Sea- this provides an overview of the potential of such maps, and how they can be used to identify locations for where the soundscape is dominated by specific sources, but also how noise maps may help choosing suitable locations for measurement stations.
- Noise modelling and mapping in Irish waters describes how sound maps associated with 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 depending on seasonal variations of environmental factors and shipping variability
- The Baltic Sea Information on the Acoustic Soundscape (BIAS) project that aims to establish regional implementation noise monitoring, including development of tools for management description of sound levels. The project further aims to establish regional standards and methodologies for handling of data and results, to enable efficient joint management. Further aim is to model the soundscape and thereby expand the measurements to the entire Baltic Sea.
- Noise modelling and mapping in German waters describes the initiative to develop mapping software but also the possible link to habitat modelling and impact assessment.

The use of mapping, which is now being explored for underwater noise monitoring and management has some history and in the process of implementing the MSFD Member States should make use of earlier European experience with air acoustics. Noise monitoring in air has been carried out for decades and has resulted in a body of work on noise maps. In part III chapter 2.8 more information is available on noise mapping in air, including relevant EU regulation (the Noise Directive) and other 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 to set up ambient noise monitoring systems. Without knowing how MS will work together, TSG Noise cannot define exact locations for monitoring. Based on Tasker *et al.*, (2010), and Van der Graaf *et al.*, (2012), and discussions within TSG Noise, we suggest an initial set of rules for the placement of devices.

This indicator is designed to monitor ambient noise, and since the main contribution is made by shipping, the frequency bands were chosen where shipping contributes the most to anthropogenic sound. For MS designing monitoring programme(s) it makes sense to design the monitoring programme based on the presence of one of the biggest contributors, shipping and its sounds. In addition to being a major contributor, patterns of shipping tend to remain consistent over many years compared to other noise sources such as seismic surveys that may contribute more noise energy but distribution patterns of noise production change between years.

A set of measurements from a point at an appropriate distance from a shipping lane can be combined with data on individual vessels (from a vessel monitoring system such as AIS) to provide data on source levels of vessels. Estimates of the source levels for the assemblages of vessels within an area could then be used as input to models

The monitoring programme should aim to pursue two linked objectives:

1. to provide input to the models,
2. to ground truth models. with a representative value for a region

If this approach is taken to ambient noise monitoring then only a limited set of measuring stations per region / basin would be needed to satisfy the requirements of the indicator. However, it would also be necessary to have good information on spatial distribution of activities in each region, and region-wide sound propagation characteristics.

Since low-frequency sound propagates over long distances the sounds in the relevant frequency bands will likely be dominated by shipping lanes throughout many of Europe's seas. Therefore,

remotely placed hydrophones would be able to capture the diversity of noise contributions in a more balanced way sound. Such a monitoring strategy is likely to be suitable for meaningful monitoring at a regional scale.

The positioning of the measurement stations regarding distance to shipping lanes, ferry routes, busy areas (e.g. lease blocks, ports) is therefore critical. Overall received levels from different sources will vary greatly depending on the location of measurement stations. The value found for an average will depend strongly on location, but it may be feasible to detect trends at carefully chosen locations that are representative of a wider area. As noted above, spatial averaging is essential in order to interpret the measured values.

One option might be to contrast measurements made close to e.g. shipping lanes, wind farms or other noise sources, with measurements made at long range.

Text box 3: Deep water and shallow water

In deep water regions, a single measurement point (at low frequencies) may be representative of a wide region because low frequency sound propagates well in deep water. This is not the case in shallow water. However, in deep water, there is still a need to understand environmental factors affecting propagation characteristics. For instance, “sound channels” and discontinuities from simple spreading loss models can occur. These propagation effects may lead, for example, to the sound measured in the Atlantic Ocean in winter at 15 km from a sound source being almost zero in the upper layers of the ocean, whereas at 50 km from that source, the received level may be dominated by the sound from the source. In shallow waters, the vertical distribution of the sound is likely more homogeneous, but geographical changes can occur due to rapid change in bathymetry, coast line geometry, islands, etc. This means that extreme care is required when interpreting measurements from a single hydrophone and spatial averaging is required before attempting to infer trends.

Following these points, TSG Noise recommends an initial set of rules for the placement of measurement devices (in order of importance):

- 1- If there are only few measurement stations per basin, these should be at suitable locations for validating the model prediction used for interpolation and extrapolation. Monitoring may be more cost effective if existing stations are used for monitoring other oceanographic features.
- 2- In deep water, place the devices in areas of low shipping density. The range at which to shipping lanes result in elevated noise levels may be greater in deep water as low frequency sound can propagate long distances.
- 3- Place one hydrophone close to the bottom (a priori subject to the lower variability of noise levels). If budgets allow for a second hydrophone, it should be placed at the depth where the lowest value for the yearly averaged sound speed is expected (if that information is available), and in deep water that depth should be preferred over the seabed or the sea surface.
- 4- Consider special topography and bathymetry effects- e.g. when there are pronounced coastal landscapes or islands/archipelagos it may be considered to place hydrophones on opposite sides,
- 5- In waters subjected 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);
- 6- Consider, and if possible avoid being close to, the possible presence of other sound producing activities that might interfere with measurements e.g. offshore activities like oil- and gas exploration or construction activities. Areas of particularly high tidal currents may also have elevated noise levels.
- 7- Any mooring has to have been designed for noise measurements to avoid self-noise from mooring tackle.

3.4.1 Example of planning sensor locations with ship traffic density

There are several factors that will come into play when choosing the positions in a pre-specified region, such as shipping density, convergence/divergence of shipping lanes, water depths, fishing activities, seismic surveys and areas of special interest. A starting point in the decision process is to make use of available information related to sound activities. The first step is to map actual shipping data, identifying annual ships passages at specified sections and the average annual shipping density over the whole region of interest. These maps can then be used to identify potential locations for monitoring stations and quantify the density of shipping within a specified radius. The characteristics of each potential location can then be examined for other noise generating influences (such as off-shore construction, planned seismic surveys or intense seasonal fisheries). To be consistent with the general principle of monitoring in locations which minimise variability, locations close to loud, but short-term, noise sources would be avoided. At finer spatial scales the detailed characteristics of possible locations can be examined for rates of tidal current, bottom type, and the risks to the monitoring station from fishing activities. In addition, there may be special areas designated for vulnerable marine life where monitoring is considered particularly important.

Step one: establishing the shipping density

The annual density maps of shipping (including AIS and Vessel monitoring system, VMS data) are essential for the decision on preliminary positions. First the shipping lanes, which will constitute candidates for the final sensor positions, are identified. An example is shown in figure 5 where the number of ship passages (not including fishing vessels) over transects are presented for the Baltic Sea. It should be stressed that the density can change due to lanes diverging or converging.

Shipping density can be expressed in a number of ways, transits across an area, total distance travelled within an area or the numbers of vessels within an area. The annual average density surface of ships per unit area is probably most relevant in terms of noise. If such density surfaces 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 6 shows an example of data by 10 blocks. Data at this spatial resolution are readily available, however for most monitoring placements it may be necessary to obtain data at a rather finer spatial scale which can also be obtained from s-AIS.

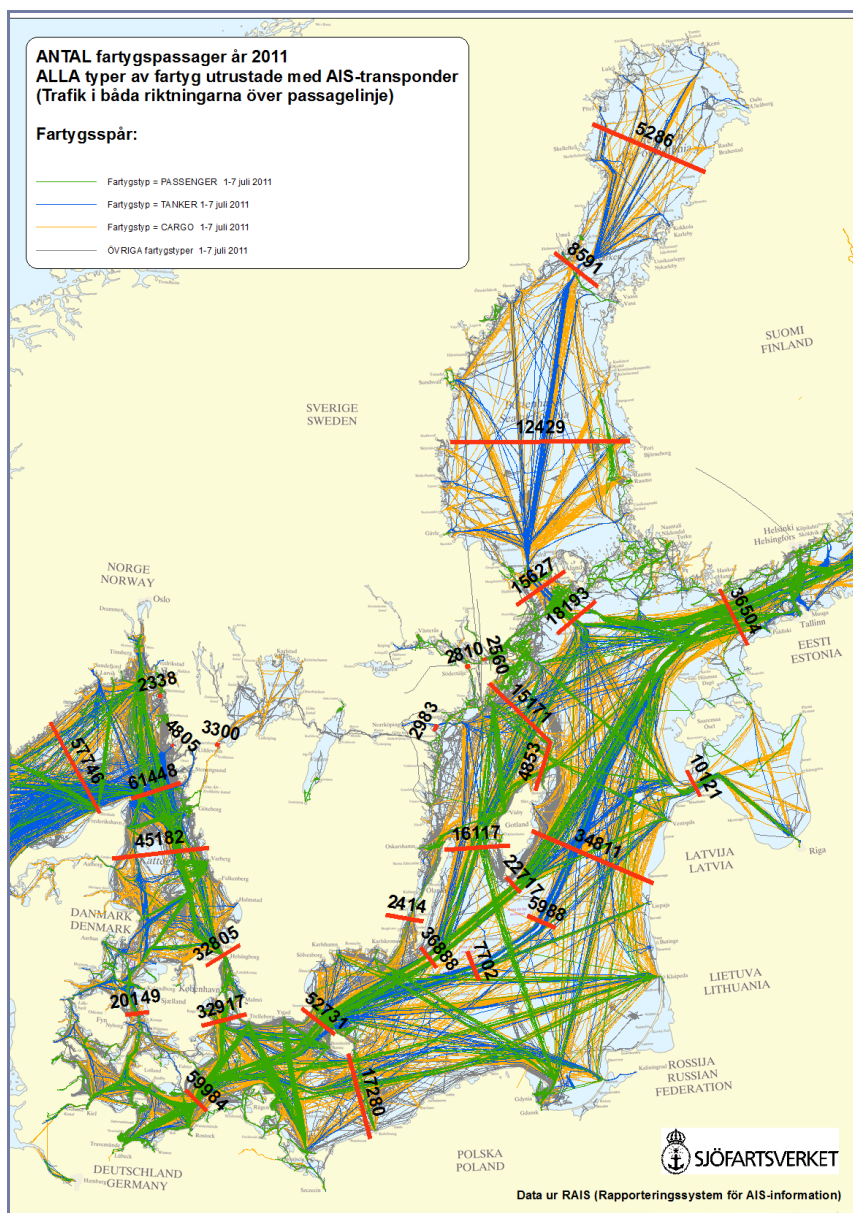


Figure 5. Ship traffic 2011 at the major transects in the Baltic Sea. Black numbers indicate the overall ship passages in both directions over the red line during 2011. Green: passenger ships; blue: tankers; orange: cargo ships; grey, other ships (source Swedish Maritime Administration).

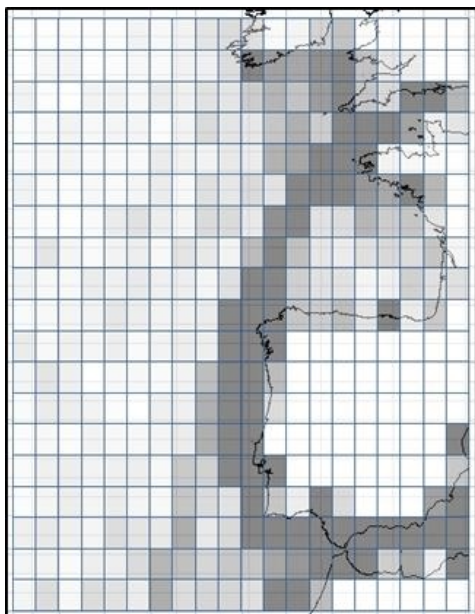


Figure 6. Example plot of density of shipping (vessels km⁻²) by 10 blocks from S-AIS data for the gridded area west of Europe (Lat 35°N to 53°N, Long 0° to 20°W).
Data from Eiden and Martinsen (2010).

Step two: including special areas

Depending on the number of locations that will be employed, Member States may consider that measurements in special areas will be included in a monitoring programme. Marine reserves, Nature 2000 areas and dedicated areas with little or no industrial activity “potential silent areas” are examples of special areas where it could be of interest to obtain measurements. The final decision of their inclusion in the observational programme depends on the number of sensors and the importance of the areas. The recommendation is to initially consider shipping lanes before these areas are included.

Step three: fine scale considerations

When the final positions are established special concern should be given to the nearby area of these positions. Information on fishing activities might be used to avoid loss of sensors due to unwanted trawling events, which are normally done at low speeds (less than 5 knots). By establishing the trawling activities in the region, for example by using VMS data, the areas to be avoided can be identified. If necessary the position can be adjusted to an area with lower fishing frequency, thereby minimising the probability of loss due to trawling. Further, information on shipwrecks can be used to avoid fishing activities as well. If possible the final position can be adjusted to a position nearby a shipwreck, which is normally avoided by fishers.

It should be underlined that sediment properties (related to attenuation of sound) in an area can vary as well as the vertical properties (sound profile). If possible the adjusted position should be in a place, in which the sediment and the depth are representative for the area.

3.4.2 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. 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)]. If the ambient noise includes loud transient sounds (air gun pulses, passing ships, etc.), the potential for masking of these sounds is limited to some extent by the duration of the relatively quiet periods between these transients. For this reason, TSG Noise considers that information about time dependence is needed in addition to an amplitude distribution. Therefore, TSG Noise recommends that the complete distribution be retained in the form of sound pressure level 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.

3.4.3 Guidance for interpreting results and setting a baseline

This indicator can be used by the Member States to assess the extent to which good environmental status is being achieved- specifically it will provide the information about the ambient noise levels and trends in European waters, and may enable MS to set a baseline.

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 a concrete advice on interpretation of the results at this stage. However monitoring indicator 11.2 will enable Member States to quantify the environmental pressure (expressed as ambient noise level) and trends in these ambient noise levels.

As described in the section 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 might be able to set is the second of the two options- it is unlikely that there will be many areas in European Seas that can be seen as a reference state that is free from influence by anthropogenic sound sources. However, if it is possible to distinguish between natural and anthropogenic sources then models could be used to estimate baseline noise levels that would be expected in the absence of anthropogenic inputs.

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 available to address the need for *in situ* measurement of underwater noise. The performance of these systems is a crucial factor governing the quality of the measured data.

A recent survey by the National Physical Laboratory (UK) suggested that the performance of commercially available systems is sometimes not adequate for the task of absolute measurement of underwater noise (see also part III chapter 2.9). The noise recorders coming to market are often converted from systems designed for other tasks where absolute calibration is not required and high quality recordings are not essential, such as detecting marine mammals, or even recording birdsong. The requirements were discussed in detail in the 2012 TSG Noise report [Van der Graaf, 2012]. However, with the advent of cheap commercial systems, TSG Noise again emphasises the importance of these calibration issues to those procuring systems for use in noise monitoring in response to the Directive.

To prevent procurement of inadequate monitoring equipment, users should make specific requirements of suppliers with regard to performance. Key parameters where performance is sometimes lacking include calibration and self-noise. Full details can be found in Part III chapter 2.9.

3.5.2 Averaging method (M2-b)

In Part III chapter 2.8 the pros and cons of different kinds of averaging are explained. 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 report of Feb 2012 as: *“Trends in the annual average of the squared sound pressure associated with ambient noise ... expressed as a level in decibels”*.

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 averages of 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 in 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 case there are no anthropogenic underwater sounds more persistent than shipping, but there might also be some locations at which shipping noise is not the largest contributor to anthropogenic ambient sound in 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.
- Physically meaningful and 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 (a desirable property but not essential).

Based on the analysis of available historical data of the Comprehensive Nuclear-Test-Ban Treaty Organisation (CTBTO), it was concluded that the arithmetic mean initially will 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 established high shipping density areas (such as commercial traffic lanes); the arithmetic mean is likely to be dominated by this contribution.

3.5.3 Standards and definitions for appropriate noise monitoring models

The modelling approach should take into account representative environmental conditions (oceanography, sea state, bottom, etc.). The results provided by the modelling should be consistent with the averaging methods applies for the measurements. Optionally, the modelling could be done in such a way to make percentile calculation of received level possible at the scale of individual points and at the scale of a region or a basin, if 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 modern predictions, modelling output should include an evaluation of its sensitivity to modelling inputs (environmental data, anthropogenic data, etc.) and the inherent uncertainties.

3.5.4 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 1994]. Each set of solutions is generally valid and computationally efficient in a limited frequency and range regime, and may involve other limits as well. Ray theory is more appropriate at short range and high frequency, 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 & 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 [Harrison 2012] to include convergence effects for an arbitrary sound speed profile.

Examples of appropriate modelling approaches can be found on some open access websites such as the Ocean Acoustics library that contains 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 of general use to the international ocean acoustics community (see <http://oalib.hlsresearch.com/>); 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 that is needed as input parameters for modelling are also available; for data about large and many small ship movements the data from 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/aix/>).

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 and TSG Noise advises to continue using this approach. See [de Jong *et al* 2012] for a definition of monopole source level of the equivalent point source. See [Wales & Heitmeyer 2002] for typical (average) values of source level of commercial shipping. Many publications on radiated noise ships, including the ANSI Standard S12.64-2009 [ANSI, 2009] report not the source level but the radiated noise level, while nevertheless referring to this quantity as "source level".

TSG Noise further 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/>). Also some other parameters may be found: global bathymetry (see 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 approximated 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 the **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.

Seismic survey, pile-driving, explosives, sonars working at relevant frequencies and some acoustic deterrent devices are the **most important sound-sources that should be considered for inclusion in the register**. Possibly there are additional sources that could be of concern (boomers, sparkers, scientific echo sounders). Since a registry that leaves out part of the sound sources is not useful if the aim is to address cumulative effects of all sources of impulsive noise, and therefore it is recommended that information on all sources should be included in the registry. TSG Noise therefore suggest that data on explosions and from activities of which the sole purpose is defence or national security should be included in the register, on a voluntary basis, but notes that this is a national policy issue.

The **main items in the register**, needed to derive pulse-block days (the number of days that in an area (block) a certain threshold (pulse) is exceeded) as required in the text of the Commission Decision, are:

- Pulse-generating activity
- Day
- Location
- Source level

Additional information about source properties that could be collected, include source spectra, duty cycle, directivity, duration of transmissions and platform speed. Collection of this information would enable improved assessment of the overall pressure on the environment.

Once a register is established, it will be possible to determine the coarse scale spatial and temporal distribution of impulsive noise sources. This quantified assessment of impulsive noise sources could be used in future to determine policy targets. It should also be possible to establish a baseline of “current condition”.

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. The first TSG Noise report [Van der Graaf *et al.*, 2012] describes standards with which that measurement equipment should comply with, along with comments about possible shortcomings of commercially available equipment. Models also require standards and definitions are needed to clarify what is an appropriate model and what is not. TSG Noise provides advice on the standards that models should comply with and will describe modelling approaches that can be used by Member States.

TSG Noise also recommended **standards that measurement equipment** should comply with. This reports notes additional possible shortcomings of commercially available equipment. TSG Noise recognises that standards and definitions are needed to ensure that appropriate models are used. TSG Noise therefore also gave advice on which the standard models should comply with and a proposal for standard models that can be used.

TSG Noise supports and advises the **use of mapping**. The use of mapping which is now being explored for underwater noise monitoring and management has some history and in the process of implementing the MSFD Member States should make use of earlier European experience on air acoustics

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 will 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. Until better advice becomes available, TSG Noise recommends that the **complete distribution be retained for this purpose in bins of 1 dB**.

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