European Marine Strategy Framework Directive

Monitoring Guidance for Underwater Noise in European Seas

PART III - Background Information and Annexes

MSFD Technical Subgroup on Underwater Noise

November 2013

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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 in 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. 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] 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 III** of the **Monitoring Guidance for Underwater Noise in European Seas** and provides MS with the background information, examples and references 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 detailed 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 Specification, 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. 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 (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

This document Part III presents the background information, examples, the annexes, including references and glossary and is added for additional information, examples and references that supported the Monitoring Guidance.

In the following chapters, contributions from various authors in the form of short articles are presented. These deal with various relevant topics and examples of scientific substantiation and project-related information that provide additional insight that support the recommendations of TSG Noise provided in the Monitoring Guidance.

2. Background information and further substantiation

2.1 Guidance on underwater sound sources to be included in the Register of Low and Medium Frequency Sources of Impulsive Sound

(Authors: M.A. Ainslie & R.P.A. Dekeling)

Summary

The purpose of this section is to substantiate the advice of TSG Noise to MS on the choice of thresholds of source level and proxies for inclusion in the Noise Register associated with the implementation of Indicator 11.1.1. Our first step is to choose a relevant metric for «significant impact». The value of source level then follows from the choice of distance for potentially significant impact and of propagation model used to convert from that distance to a source level. Conversion to a suitable proxy is necessary for those sources for which source level is not an appropriate measure.

For the most relevant sources of low and mid-frequency impulsive noise minimum thresholds for uptake in the register are derived. Technical Sub-group Underwater Noise (TSG Noise) concludes that for pile-drivers no minimum threshold should be used and that all pile-driving activities should be registered. For sonars, airguns, acoustic deterrents[1] and explosions, minimum thresholds can be used and values for these minimum thresholds are recommended.

TSG Noise concludes that it is useful to distinguish between sources of different level. To register detailed information on levels will be too complicated or may hamper information gathering. A compromise is offered, suggesting source level data collection in 10 dB bins.

2.1.1 Introduction

The Commission Decision of September 2010 requires EU Member States (MS) to address anthropogenic sound sources that may result in significant impact, via Indicator 11.1.1 of GES (henceforth abbreviated as "Indicator 1"). MS will need to collect data on loud low- and mid-frequency impulsive sound sources, and the first TSG Noise report, in line with the earlier TG11 report [Tasker *et al*., 2010], proposes to achieve this by establishing a register of the occurrence of these sources. The next work item for TSG Noise was to establish a monitoring guidance, giving concrete guidance which sources should be taken up in the register and how the data should be collected. While working on its first report, TSG Noise attempted to distinguish between sound sources that may entail significant impact and sources that were not, as a selection criterion to decide whether sources should be taken up in the register, but this could not be completed in the time available in 2011.

At the TSG Noise meeting of April 2012 in Spain, this issue was discussed and TSG Noise concluded that some adaptation to the earlier approach (which was based on the text of the Commission Decision) was needed. In the Spain meeting TSG Noise concluded that:

- Given uncertain knowledge of which sources cause significant impact, it is helpful to distinguish between a threshold for inclusion in the source register (henceforth, "the Register") and the threshold that may cause significant impact, i.e. uptake in the Register does not necessarily need

[1] The term "acoustic deterrents" is a general term to indicate acoustic sources use primary purpose is to deter an animal from approaching an area, regardless of the reason for doing so, and regardless of source level. It includes devices commonly known as "acoustic harassment devices" (abbreviated "AHD") as well as "acoustic deterrent devices" (abbreviated "ADD").

to mean that the source is actually causing 'significant' impact; we do not yet fully know when a loud source causes 'significant' impact.

- We propose to adopt a lower threshold for the Register than for Indicator 1. Doing so enables us to deal with this uncertainty by choosing a deliberately low threshold for the Register; thus, the Register would only exclude sources unlikely to have significant impact, resulting in a lower threshold for inclusion than including those that are likely to have significant impact.
- The Register will include quantitative information about the sources; TSG Noise will advise what extra information (e.g., source level, frequency of use, directivity index) is needed in the register.
- Registration in decibel bins (e.g., 10 dB (equivalent)).

The initial purpose of this indicator is to assess the pressures on the marine environment, i.e. an overview of all loud impulsive low and mid-frequency sound sources, through the year and through areas. 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 the 1st TSG report [Van der Graaf et al., 2012].).

To achieve this target, we should make sure that we register all relevant sources to assess the pressure on the environment. At the same time, it should be ensured that registration efforts are not wasted on low energy sources that are probably insignificant. Because we cannot at this time determine when sources are significant, we will register all sources that have the potential for significant impact from an ecological perspective (population or local population level). We are not saying that no animals are adversely affected by omitted sources; only that any effect is not considered significant at the population or local population level. This means that at this stage we will only exclude the sources that are less likely to have significant impact from this ecological perspective. For the sources that we will register the data will be collected in bins to be able to differentiate between very loud sources and sources that might only have limited impact.

In this chapter the rationale to decide whether a sound source needs to be taken up in the register is explained:

- The register should be workable, and preferably based on information already available.
- The register needs to ensure that all relevant sound sources of concern will be included.
- Registering of sound sources that are less likely to be of relevance should be avoided.

This chapter addresses the last issue, and describes a methodology for determining which sources are less likely to result in significant impact and that may be excluded from registration. It does so by first describing "significant impact" and the relation between received levels and effect. By first making a precautionary choice for the relevant parameters (received levels) and describing received levels and propagation loss, we can get insight into the source levels needed for a likely effect, depending on the type of source and how the source is used. As a final step, for cases where the source level is difficult to obtain, the source level is converted to a more convenient proxy.

TERMINOLOGY AND DECIBEL REFERENCE VALUES

The terminology in this document follows the recommendations from the international workshop on acoustic standards that was held in Delft, The Netherlands, in February 2011, as described in a consensus report for the Dutch government [Ainslie (Ed.), 2011]; in this meeting consensus was reached on the definitions contained in that document making a suitable starting point from which to construct an international standard.

The consensus report provides for a choice between three alternative conventions for reference values associated with levels cited in decibels:

- The '10lgP rule', by which the reference values are proportional to power (1 μPa^2 for SPL and 1 μPa^2 s for SEL).
- The '20lgA rule', by which the reference values are proportional to the square root of power (1 μPa and 1 μPa $s^{1/2}$); and,
- A third, mixed rule, by which a choice is made between power and root power on a case by case basis, according to the perceived convention.

This report follows the mixed rule, with the 20lgA convention for some quantities (e.g., 1 μPa for SPL and 1 μPa m for source level[2]) and the 10lgP convention for others (e.g., 1 μPa^2 s for SEL and 1 μPa^2 m^2 s for energy source level).

WHAT IS MEANT BY 'SIGNIFICANT IMPACT'?

In the first report of TSG Noise [Van der Graaf *et al.,* 2012] it was explained that the indicator for impulsive noise would address 'displacement', i.e. 'severe and/or sustained and/or long-term avoidance of an area'. In the methodology described below thresholds at which this effect was found in marine animals are used. Most of the available data about effects of sound on the marine environment describes effects on marine mammals; these animals are dependent on using sound, and many species of marine mammals are known to be sensitive to sound. Therefore, for determination of thresholds, TSG Noise used data on the response thresholds of marine mammals, but this does not exclude the possibility that species from another group/family would show responses at lower levels. TSG Noise also realises that there are also observations of impact on fish from airguns and pile driving where the fish has undertaken both severe and/or sustained displacements and that displacement can include vertical migrations.

SOUND PRESSURE LEVEL OR SOUND EXPOSURE LEVEL?

An evaluation of possible metrics that is most appropriate for assessment of behavioural effect can be found in [Southall *et al*., 2007]. In this landmark publication it was suggested that sound pressure levels were the best available metric for assessing behavioural effects:

> *Considering all of these limitations and the nature of the available data, as a practical matter, we use [sound pressure level (SPL)] as the acoustic metric for the behavioral analyses given below. Where necessary and appropriate, simple assumptions regarding transmission loss were applied to predict [received levels]. This was done only for studies that provided sufficient information on source and environmental characteristics.*
> *Our approach does not presume that SPL is necessarily the acoustic metric best correlated with behavioral changes (significant or otherwise). In particular, SPL fails to account for the duration of exposure whereas this is captured using [sound exposure level]. SPL is the metric that has most often been measured or estimated during disturbance studies, however. Thus, it is currently the best metric with which to assess the available behavioral response data.*

For the scope of this document (excluding the insignificant sources) we adopt this approach, although TSG Noise notes that SPL may not be the applicable metric for assessing/ understanding behavioural effects in fish. When using SPL we do not consider the accumulated received SEL over the animal's full duration of exposure but only the actual, often highest, experienced level of sounds. For some types of sound the SPL is not the most practical metric. For these cases, we will use a different approach and prefer single pulse SEL (as opposed to cumulative SEL) to SPL. This approach applies for sounds with an explicitly impulsive character, these sounds were called 'pulses' by Southall *et al*. [2007] (brief, broadband, atonal, transients which are characterized by a relatively rapid rise-time to maximum sound pressure amplitude followed by a decay that may include a period of diminishing and oscillating maximal compressional and rarefactional pressures). Examples of pulses are sounds from explosions, gunshots, sonic booms, seismic airgun pulses, and pile driving strikes; see Southall *et al*. [2007]. Furthermore, single pulse SEL is proposed by Southall as a metric for behavioural response to single pulses.

The reason for this approach is that for short pulses, changes in the shape of the pulse can occur over time (e.g., due to multipath propagation) so that care is needed in the interpretation of reported SPL or zero to peak sound pressure values. For this reason, the (single pulse) source energy (characterized by the energy source level SL_E; [Ainslie, 2010]), which is not affected by changes in pulse shape, is a more robust

[2] The reference value "1 μPa @ 1 m", though widely used, is avoided here because 1 μPa @ 1 m is not an SI unit. The intended meaning is the same.

measure than zero to peak, peak to peak or RMS sound pressure for the characterization of short pulses and *single-pulse* SEL is a more practical measure for reporting the received levels. (See Ainslie, 2010, ch 10, page 525).

WEIGHTED OR UNWEIGHTED?

For the purpose of a criterion for inclusion in the Register, unweighted levels are preferred to weighted ones. This is done for simplicity, avoiding the complication of which weighting to use. Weighting can be applied in a later process and might require different weighting functions based on which functional hearing group of animals is considered. Therefore, including unweighted levels in the Register allows for different types of analysis on a later phase.

SOURCE LEVEL OR OTHER SOURCE PARAMETERS?

Until now the TSG has worked towards source level (SL) and this report continues in this direction. For some types of sources, SL is unsuitable either because the source cannot be characterised in terms of SL or because it is not usual to do so, and for such sources TSG Noise advises converting the appropriate source level threshold into a threshold for a suitable proxy. One example is for a pile driver, for which the report of the February 2011 international workshop concludes that no definition is available [Ainslie (Ed.), 2011]. For other sources (e.g., explosives) even though an (energy) source level is sometimes used (and well defined in deep water at least, at long distances from the source), we advise use of a proxy in terms of equivalent TNT charge mass in order to eliminate the need for the conversion of this charge mass to a source level. Specific proxies advised are the equivalent TNT charges mass of explosives, the hammer energy of an impact pile driver and the source level of an airgun array.

2.1.2 Choice of SEL or SPL threshold for inclusion in the Register

MULTIPLE EXPLICITLY IMPULSIVE SOUNDS (SEL THRESHOLD FOR "SOUTHALL *ET AL*. PULSES")

We have made a brief summary of the scarce information currently available concerning displacement, this was also described in the 1st TSG Noise report.

Danish work [Tougaard *et al.*, 2012] mentions 'received levels of sound were, on average, 140 dB re 1μPa (peak-peak) at' the distance within which harbour porpoises[3] were observed to avoid impulsive sounds from a pile driver. This is expressed in terms of peak-to-peak sound pressure, which makes it difficult to use within the present framework.

Some work has been done in Germany at the "alpha ventus" wind park. Some of this has been published in a report by Wittekind *et al.* [2010] (*Auswirkungen des Baus des Offshore-Testfelds „alpha ventus" auf marine Säugetiere*). This publication reports that porpoises react to sound for a single pulse with SEL = 140 dB re 1 μPa^2 s or higher.

Use is made of these values from field data in preference to data available from laboratory work or otherwise artificially constrained situations: e.g. Lucke made TTS-measurements of harbour porpoises after exposure to airgun sounds [Lucke *et al.,* 2009]. In this work consistent "aversive behaviour" was noted when single-pulse SEL-values exceeded 145 dB re 1 μPa^2 s; Kastelein observed behavioural changes at lower values (single pulse SEL of 115 dB re 1 μPa^2 s) [Kastelein *et al.*, 2011], but in an artificial setting with very low background noise levels (see e.g. Ellison *et al,* [2011] for considerations on background noise levels).

[3] The harbour porpoise is known to be one of the most sensitive marine animal species, for both physical and behavioural effects. For this reason this species has been selected in this approach, implying use of a low limit and hence a conservative approach [Southall et al., 2007; Lucke et al., 2009; Kastelein, 2011].

The term 'explicitly impulsive sound' is used in this report as a synonym of a 'pulse' in the sense of Southal et al (2007).

Therefore we propose SEL_0 = 140 dB re 1 μPa² s as a threshold for significant behavioural disturbance due to multiple explicitly impulsive sounds.

SINGLE EXPLICITLY IMPULSIVE SOUNDS (SEL THRESHOLD FOR A SINGLE "SOUTHALL *ET AL*. PULSE", SUCH AS AN EXPLOSION)

For most of the activities generating impulsive sounds considered to have effect on animals (piling, sonar, seismic) the sounds will be transmitted repeatedly for longer durations (e.g. piling for a wind turbine, a sonar exercise or a complete seismic survey) and exposure to these repeated impulsive sounds induces the reaction. Explosions, and certainly most of the large explosions, are often not repeated events: in NW-Europe, the most relevant activity is clearing of unexploded legacy ammunition, demolition of oil extracting constructions and within geological research. Most studies on the effect of explosions focus on physiological damage to marine life, and not on behavioural effects. However, for this specific type of sound, Southall *et al.* [2007] also suggested that these should be treated separately and suggested to use higher thresholds for behavioural effects; Southall *et al.* [2007] proposed the TTS-value as threshold for behavioural impact of marine mammals. It is not known to the present authors whether animal displacement is a relevant effect of these single impulsive sounds. Nevertheless it is considered desirable to keep sources of single "Southall *et al*. pulses" (like explosions associated with the detonation of individual mines) in the Register, and we follow this proposal of Southall *et al.* [2007] which means that the threshold for a single pulse is higher than that for multiple pulses. While for multiple explosions in a short time period (e.g. a military exercise or research campaign) the lower threshold for multiple explicitly impulsive sounds could be used, doing so would only make a difference for multiple explosions of mass less than 8 g, which are infrequent events. For this reason, TSG Noise recommends a threshold for inclusion of that is based on single explosions, irrespective of whether the actual event to be registered involves single or multiple explosions.

For the single pulse event we propose to use the TTS-onset values found by Lucke as threshold SEL_0 = SEL_{TTS} = 164.3 dB re 1 μPa² s from [Lucke et al., 2009] as a threshold for significant behavioural disturbance due to single explicitly impulsive sounds.

NON-PULSE SOUNDS, INCLUDING SONAR (SPL THRESHOLD FOR "SOUTHALL *ET AL*. [2007] NON-PULSES")

There are a number of research programmes addressing the effect of sonar on cetaceans and the knowledge is growing rapidly, and by now there are some (peer-reviewed) publications on the behavioural effects of sonar on cetaceans.

In this approach we decided to make use of the most recent publications available, firstly the study on the effect of sonar on beaked whales [Tyack *et al.,* 2011]. In this publication a value for interruption of echo location behaviour at SPL = 140 dB re 1 μPa for beaked whale exposure to mid-frequency sounds is suggested.[4] However, recently it was suggested that at lower levels, from 120-130 dB re 1 μPa, there was an increased risk of severe behavioural responses, although there are large differences across species - long-finned pilot whales showing little response below 150 dB re 1 μPa, but for killer whales and sperm whales response were noted at the above-mentioned lower levels [Miller *et al.,* 2012]. Even lower response thresholds were found for harbour porpoises in a laboratory setting (Kastelein, 2012). Although this work provides useful information of relative impact of different frequencies and signals, the authors do not consider measurements in a controlled laboratory setting to be representative of the natural environment.

Here we propose SPL_0 = 130 dB re 1 μPa as a threshold for significant behavioural disturbance due to non-pulse sounds of short duration.

[4] From p7, "Our results support a … criterion of about 140 dB SPL for beaked whale exposure to mid-frequency sounds."

2.1.3 Choice of propagation loss model

Our purpose is to identify a source level threshold that is both realistic and conservative. This implies calculation of a reasonable lower limit on propagation loss (PL). Absorption is not relevant[5] at the frequencies of this indicator (low- and medium frequency i.e. below 10 kHz) and ranges (~ 1 km) considered here and therefore not used in the PL model.

SHALLOW WATER

At ranges of interest we expect mode stripping to give a conservative (lower limit) PL value (spherical and cylindrical spreading regions are restricted to distances up to a few water depths). For the sediment we choose medium sand because this results in good low frequency waveguide (by comparison, clay, silt and gravel are poor reflectors of sound [Ainslie 2010]).

Long range shallow water propagation at distances R of interest can be described by mode stripping, i.e. (see Ainslie 2010 chapter 9, pp 452-458)

$$\mathrm{PL}(R) = 15 \log_{10} (R / r_{\mathrm{ref}}) + 5 \log_{10} (\eta H / \pi r_{\mathrm{ref}}) \text{ dB} \quad (1)$$

with:

η = reflection loss gradient = ¼ (representative of sand)
H = water depth = 20 m
r_{ref} = 1 m

This equation, of the form PL = constant + 15 log R, is more realistic than (say) cylindrical spreading, and by taking lowest reasonable values of η and H is a reasonable value for the shallow waters that are of interest; low frequency sound does not propagate well in water of depth less than 20 m. We therefore adopt the criterion

$$\mathrm{SL_E} > \mathrm{SEL_0} + \mathrm{PL}, \quad (2)$$

with PL given by eq (1). The equivalent inequality relating SL to SPL is

$$\mathrm{SL} > \mathrm{SPL_0} + \mathrm{PL}. \quad (3)$$

DEEP WATER

In deep water, we assume spherical spreading at short range, followed by cylindrical spreading (CS). For CS in a surface duct (surface sound speed c, sound speed gradient g and duct thickness D) we use (see Ainslie, 2010, chapter 9):

$$\mathrm{PL} = 10 \log_{10} (R / r_{\mathrm{ref}}) + 5 \log_{10} [c D / (8 g\, r_{\mathrm{ref}}^2)] \text{ dB} \quad (4)$$

where R > $(c D/8g)^{1/2}$.

Calculations with c = 1490 m/s, D = 100 m, g = 0.016 /s show that deep water propagation loss is higher than the shallow water loss in the range 0-5 km. While a higher threshold could be considered for deep waters, for simplicity we advise use of a single threshold for data registration, irrespective of water depth. In subsequent analysis of register data it will be possible to distinguish between the very loud sources and the sources of less relevance.

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5 At 1 kHz, absorption is less than 0.1 dB/km, see http://resource.npl.co.uk/acoustics/techguides/seaabsorp

2.1.4 Choice of distance for potentially significant impact

We have to make a decision about the range or area within which displacement can be considered to be significant. In the reports of studies with harbour porpoises carried out in Germany and Denmark, displacement ranges around wind farm construction sites of magnitude 20 km are mentioned, implying an area of ca. 1250 km². At this stage, there is concern that these kind of disturbance in combination with numbers of other similar events could lead to population level effects.

We do not know at what stage cumulative displacement effects will have a significant impact. However, a usable consideration on significance can be found in Southall *et al.* [2007], page 448:

> *The NRC (2005) argued that, although the duration of behaviours likely to affect vital rates is believed to be particularly significant, current scientific knowledge is insufficient to support an analytical treatment of biological significance and ad hoc criteria are needed in the interim. Here, substantive behavioural reactions to noise exposure (such as disruption of critical life functions, displacement, or avoidance of important habitat) are considered more likely to be significant if they last more than one deil period, or recur on subsequent days. Consequently, a reaction lasting less than 24 h and not recurring on subsequent days is not regarded as particularly severe unless it could directly affect survival or reproduction.*

A 24 hour time-period is too long if we want to make sure that we stay in the 'no-effect' range. For instance, important species like harbour porpoises have a high digestive rate and have to forage many times per day (see e.g. [Kastelein *et al.,* 1997]). If evasive movement influences its ability to forage for several hours, a porpoise already starts depleting energy reserves. The Commission Decision of 2010 requires MS to assess the activities per day, but that does not mean that duration of the response must be on the order of one day, exposure of shorter duration can have negative effects. TSG Noise therefore advises to start registering sources that have the potential for displacement. Further, we want to make a translation from 'time' to 'distance'. And for the chosen value for distance to be acceptable, we advise a precautionary value but avoid choosing a value that is unnecessarily low and thereby unworkable.

This was discussed within TSG Noise in the October 2012 meeting in Ireland. For instance, considering the possible effects at zero range would lead to an unworkable situation - we do not use that approach when assessing other forms of pollution. For this particular effect, the minimum for the range of interest would be at a scale less likely to have a significant habitat loss. TSG Noise initially proposes to use the (1000 m) range to take up sources in the register, but this could be reviewed at a later stage (e.g. the foreseen 6-year review of the Commission Decision on the indicators in 2016).

The PL over such a range can easily be calculated using the methodology described above for shallow water. For several possible ranges the PL is shown in Table 1.

Range	PL [dB re 1 m]	SL_E needed[6] [dB re 1 μPa² m² s]
100 m	31.0	171.0
300 m	38.2	178.2
1000 m	46.0	186.0
3000 m	53.2	193.2

Table 1: Propagation loss (PL), evaluated using Eq. (1), for different ranges and energy source level (SL_E) that would lead to the single pulse SEL value of 140 dB re 1 μPa² s for multiple-pulse sources (like piling and airguns) at that range.

[6] The reference value is sometimes written "1 μPa² s @ 1 m" instead of "1 μPa² m² s". The latter is preferred because «1 μPa² s @ 1 m» is not an SI unit. The intended meaning is the same.

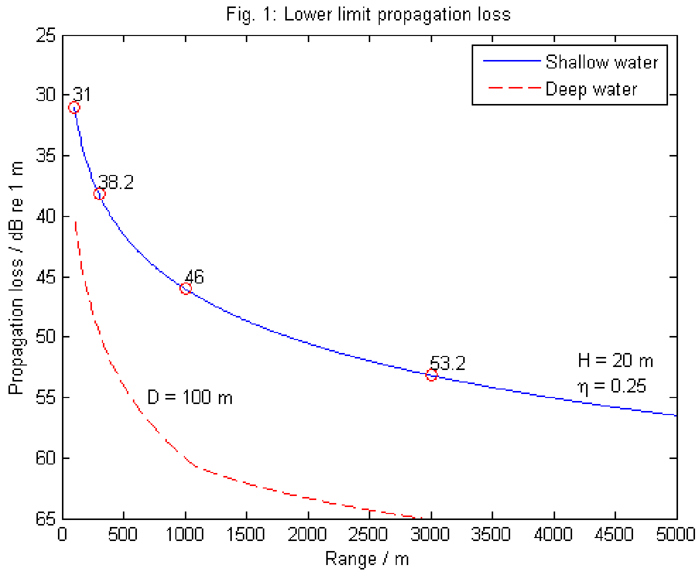

Figure 1: Propagation loss [dB re 1 m] vs range [m].

PL is calculated using eq. (1), which assumes negligible absorption and is consequently independent of frequency. Equation (1) provides a lower limit on PL and is therefore precautionary. The solid blue line in the above figure shows the expected lower limit for propagation loss in shallow water. The estimated lower limit for PL in deep water (dashed red line) is higher than the shallow water lower limit, so the shallow water curve may be used as an overall lower limit for effects up to 5 km.

Since we are interested in effects at distances of order 1000 m range we choose to use the SL_E value obtained for this range as the recommended minimum to take up multiple pulse sources in the register: 186 dB re 1 μPa^2 m^2 s.

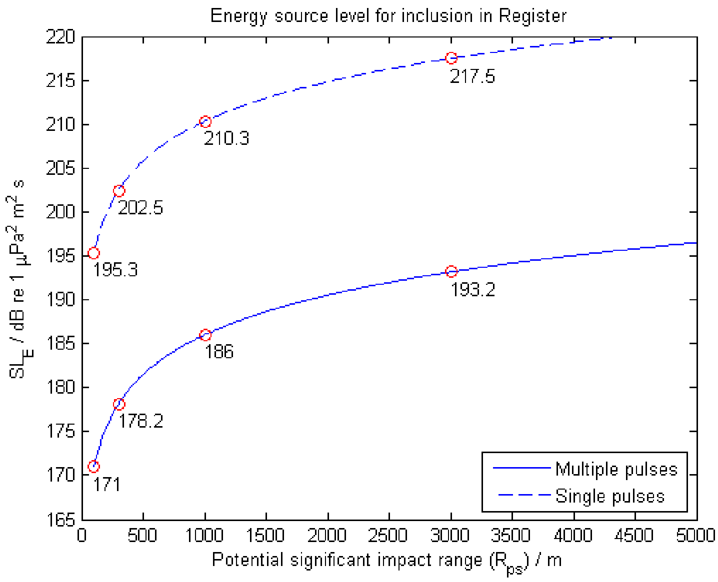

Figure 2: Energy source level threshold [dB re 1 μPa² m² s] vs significant impact range [m].

Since we are interested in effects at distances of order 1000 m we use the SL_E value obtained for this range as the recommended minimum to take up single pulse sources in the register: 210 dB re 1 μPa^2 m^2 s.

Range	PL [dB re 1 m]	SL_E needed [dB re 1 μPa² m² s]
100 m	31.0	195.3
300 m	38.2	202.5
1000 m	46.0	210.3
3000 m	53.2	217.5

Table 2: PL for different ranges and SL_E that would lead to the single-pulse SEL value of 164.3 dB re 1 μPa² s for single pulse sources (explosives) at that range. The conversion from SL_E to TNT charge mass is made in Table 4.

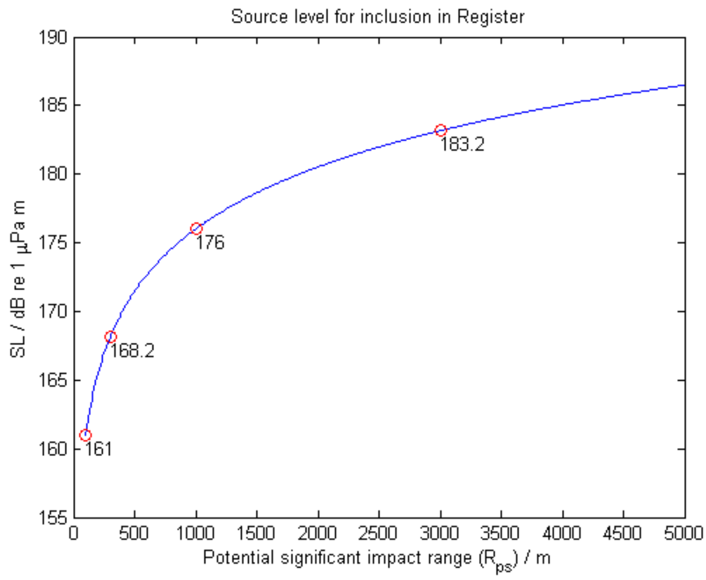

Figure 3: Source level threshold [dB re 1 μPa m] vs significant impact range for sonar [m].

Range	PL [dB re 1 m]	SL needed[7] [dB re 1 μPa m]
100 m	31.0	161.0
300 m	38.2	168.2
1000 m	46.0	176.0
3000 m	53.2	183.2

Table 3: PL for different ranges and SL that would lead to the single-pulse SPL-value of 130 dB re 1 μPa for non-impulsive sources (sonars) at that range.

Since we are interested in effects at distances of order 1000 m we use the SL value obtained for this range as the recommended minimum to take up non-pulse sources in the register: 176 dB re 1 μPa m.

2.1.5 Choice of proxy and implications

Sources other than sonars and acoustic deterrents are rarely characterised by their source level (whether SL or SL_E). For each source it is convenient – and for some sources, essential – to find a proxy that is more widely used and still makes sense.

The acoustic strength of sonars and acoustic deterrents is routinely reported in terms of source level, so no proxy is needed for these. The strength of explosions is widely reported in terms of TNT equivalent charge mass (m_{TNTeq}). The strength of airgun arrays is widely reported in terms of their far-field source

[7] The reference value is sometimes written «1 μPa @ 1 m» instead of «1 μPa m». The latter is preferred because «1 μPa @ 1 m» is not an SI unit, but the intended meaning is the same.

signature (product of distance from the airgun array and far-field sound pressure at that distance, usually in the vertical direction, immediately beneath the array), the maximum magnitude of which is known as "source strength" *A* [Dragoset, 2000]. This quantity is related to the zero to peak source level [Ainslie (2010), p 431] of the dipole formed by airgun array plus surface image according to

$$\mathrm{SL_{zp}} = 10 \log_{10} (A^2/(\mathrm{uPa^2\ m^2}))\ \mathrm{dB} \qquad (5)$$

The quantity $\mathrm{SL_{zp}}$ is referred to by [Ainslie (Ed.)., 2011] as "peak pressure dipole source level"

The strength of impact of pile drivers is sometimes reported in terms of source level, but doing so leads to problems of interpretation [Ainslie *et al.,* 2012, "Aquatic Noise 2012"]. Instead we propose hammer energy (E_{hammer}) as a suitable proxy.

2.1.6 Conversion to proxies

AIRGUN ARRAY

The acoustic strength of an airgun array can be characterised by its zero to peak source level $\mathrm{SL_{zp}}$

If one can characterise the pulse of an airgun array by a single cycle of period τ; then:

$$\mathrm{SL_E} = 10\log_{10}[(1/2)\ \tau/\ \mathrm{s}]\ \mathrm{dB} + \mathrm{SL_{zp}} \qquad (6)$$

Combined with $\mathrm{SL_E}$ = 186.0 dB re 1 μPa² m² s gives $\mathrm{SL_{zp}}$ = 209.0 dB re 1= 209.0

Notes:

- Source level of an airgun array is measured in the direction of its main beam. For the environmental relevance, the source level in the horizontal plane or at a certain angle of relevance from the acoustic axis is preferred and therefore information on directivity should preferably be added. If this is not possible the usually provided value in the vertical direction will be used (acknowledging that this overestimates the amount of energy trapped in water column)
- Because the strength of an airgun array is specified in terms of peak sound pressure and because peak pressure is sensitive to bandwidth, it becomes necessary to specify a frequency band. Based on the Descriptor text, the range 10 Hz to 10 kHz seems appropriate. However, there might be a case for lowering the upper limit of this frequency range to 1 kHz. This is because in reality what matters is $\mathrm{SL_E}$ rather than $\mathrm{SL_{zp}}$, and the integral $\int p(t)^2\,\mathrm{d}t$ is dominated (because of the assumed 10 ms period) by sounds ca. 100 Hz.

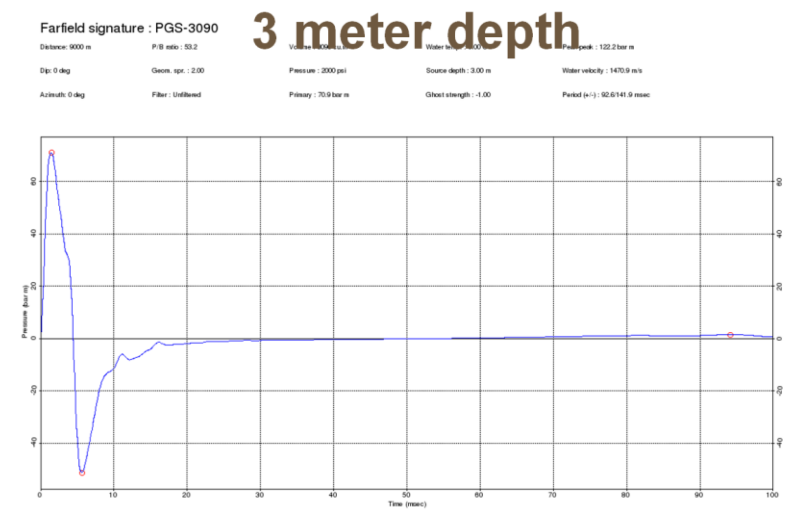

Figure 4: Farfield signature: PGS-3090; 3 m depth: Airgun signature in bar metres (bar m) (supplied by W Pramik, Geokinetics).

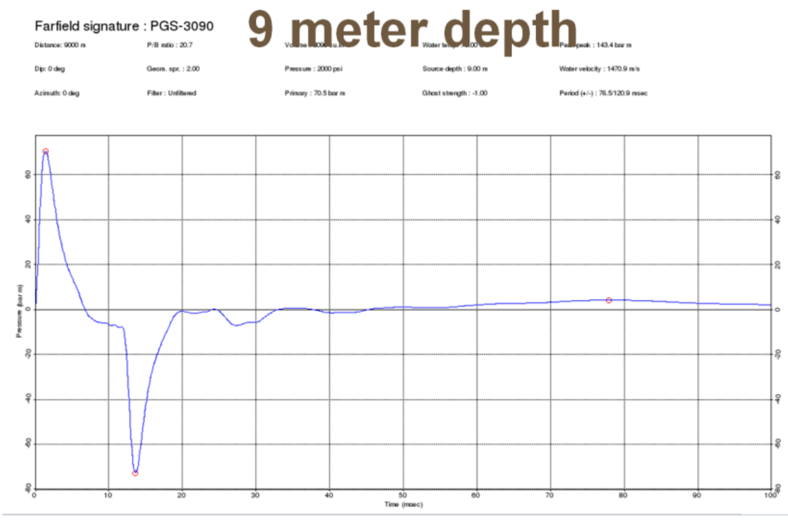

Figure 5: Farfield signature: PGS-3090; 9 m depth: Airgun signature in bar metres (bar m) (supplied by W Pramik, Geokinetics).

The duration of the first full cycle is between 10 ms and 20 ms. In both cases the source strength A is about 67 bar m, corresponding to a zero to peak source level of 257 dB re 1 μPa m.

Explosions

Explosives are usually characterised by means of their “equivalent TNT charge mass”, defined as the mass of TNT that would release the same amount of explosive energy. This mass, denoted “m_{TNTeq}”, is related to $\mathrm{SL_E}$ via [Ainslie, 2010] (excluding bubble pulses):

$$\mathrm{SL_E} = 231\ \mathrm{dB\ re\ 1\ \mu Pa^2\ m^2\ s\ kg^{-1}} + 10\log_{10}(m_{\mathrm{TNTeq}}/\mathrm{kg})\ \mathrm{dB} \tag{7}$$

$$m_{\mathrm{TNTeq}} = 10^{(\mathrm{SL}_E - 231)/10}\ \mathrm{kg} \tag{8}$$

substituting $\mathrm{SL_E}$ = 210.3 dB re 1 μPa² m² s for a single explosion gives m_{TNTeq} = 8 g.

Impact pile driver

The international workshop of February 2011 concluded that a definition of source level for a pile driver is not yet available [Ainslie (ed) 2011]. Instead impact pile drivers are usually characterised by means of their hammer energy (sum of potential and kinetic energy at the moment of impact with the pile), providing a suitable proxy. The energy radiated as sound can be expressed as a proportion of the hammer energy

$$(E_{\mathrm{ac}})_{\mathrm{pile}} = \mu\, E_{\mathrm{hammer}}, \tag{9}$$

where μ is the constant of proportionality.

It is straightforward to convert the energy source level threshold to an energy threshold defined as the acoustic energy that would be radiated from an omnidirectional source of energy source level equal to the $\mathrm{SL_E}$ threshold.

$$(E_{\mathrm{ac}})_{\mathrm{threshold}} = 10^{(\mathrm{SL}_E - 170.7)/10}\ \mathrm{J} \tag{10}$$

Using eq. (5) and (6), one can then compare the energies instead of the source level. Requiring their right hand sides to be equal results in the following expression for E_{hammer}

$$E_{\mathrm{hammer}} = \frac{1}{\mu} 10^{(\mathrm{SL}_E - 170.7)/10} \text{ J} \tag{11}$$

With $\mathrm{SL_E}$ = 186.0 dB re 1 μPa² m² s; putting μ = 0.03 (a realistic value; factor 2 higher than available measurements = 1-2%); [de Jong & Ainslie 2008 (1%); Zampolli *et al.*, 2013 (2%)]. A threshold of 1.13 kJ follows. This is much lower than typical values used for offshore construction (hundreds of kilojoules). It is therefore proposed to include all impact pile driving in the Register.

The above conclusions for impact pile drivers do not depend on the precise choice of R_{ps}. They would follow also from a choice of 100 m or 3000 m for this range.

2.1.7 Conclusions

The source level threshold for a non-pulse (sonar etc), derived from Table 3, is 176 dB re 1 µPa source level threshold for a non-pulse (sonar etc), derived from Table 3, is 176 dB re 1 µPa m.

	Impact pile driving	Seismic survey (airgun array)	Explosions
$\mathrm{SL_E}$ threshold for Register	186 dB re 1 uPa² m² s	186 dB re 1 uPa² m² s	210 dB re 1 uPa² m² s
Proxy	Hammer energy E_{hammer}	Zero to peak source strength $\mathrm{SL_{zp}}$	TNT charge mass m_{TNTeq}
Derived proxy threshold for Register	1.1 kJ	207 dB re 1 Pa m	8 g

Table 4: Derived proxies for multiple pulses and explosions.

Converting to the various proxies, as explained in Sec. 2.1.6, gives the following criteria for inclusion in the Register of low and mid-frequency sources:

Airgun (see sec 2.1.6):	$\mathrm{SL_{zp}}$ > 209 dB re 1 µPa m
Low-mid frequency sonar:	SL > 176 dB re 1 µPa m
Low-mid frequency acoustic deterrent:	SL > 176 dB re 1 µPa m
Explosions (see sec 2.1.6):	m_{TNTeq} > 8 g

The minimum hammer energy needed is very low (compared to the values of this parameter encountered in practice) and a minimum threshold would not be relevant. All licensed pile driving activity associated with offshore construction would be included in the Register.

2.1.8 Further improvements: further details of data collection

The thresholds that were derived will ensure that all sources that have a potential for significant effect will be included in the register. However, these relatively low thresholds imply that sources will be registered that actually will have a relatively low impact, e.g. sonars whose source level is less than 200 dB re 1 µPa m, while there are much stronger sources that may have a much greater impact (e.g. sonar sources that have a source level around 230 dB re 1 µPa m). TSG Noise noted that there is a need for more details in the register than only the pulse-day level suggested by TG11. For example not only the day, but also the number of noise-producing events, and the source level of each might be recorded if they are available to be used at a later stage. Further information would be helpful in both roles of the register to record what has happened and to act as a potential planning tool for future activities.

It is proposed that the following additional information be gathered in the register, which will further enable MS to assess the magnitude of impact of sounds sources:

SOURCE PROPERTIES

1. Source level or proxy;
2. Source spectra;
3. Duty cycle;
4. Directivity;
5. Duration of transmissions;
6. Platform speed.

Of this list, an estimate of the first five would be needed to calculate the free-field energy, a measure of environmental cost proposed by [Ainslie & Dekeling, 2011]. Platform speed also determines size of impacted area so collecting this data may be useful.

In order to assess which sources, of those included in the Register contribute to the Indicator 11.1.1, it is necessary to determine whether they have significant impact. To achieve this, TSG Noise considers it necessary that at least the source level (or proxy) and the number of times a source is used per day are registered. In order to give operators, e.g., navies using sonar, oil and gas companies using airguns, the option of not disclosing sensitive detailed information of source properties, e.g. sonar source level is often considered classified. It is proposed that not the specific level is registered but that operators will have the option to report source level as follows:

Sonars 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 μPa^2 m^2 s
- Low: 211-220 dB re 1 μPa^2 m^2 s
- Medium: 221-230 dB re 1 μPa^2 m^2 s
- High: above 230 dB re 1 μPa^2 m^2 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
- 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, 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

2.2 Proposal for establishing national and a common Regional Sea noise registry

(Authors: M.L Tasker, R.P.A. Dekeling, P Redman)

The objective of the noise register is to develop a large scale picture of the occurrence of loud impulsive sounds in national and regional seas, information that is not available in any coherent way at the moment. It is plainly of benefit that national work be compatible across marine boundaries. This is the main underlying reason for the establishment of TSG-Noise. All European MS were asked to supply information on loud impulsive underwater sounds to TSG-noise in order that the group could learn from existing efforts and to determine what information was readily available for use. Information was forthcoming from the UK, the Republic of Ireland and The Netherlands. The following proposal is therefore based on that somewhat limited dataset.

The information provided by the three Member States was basically all that was available arising from the processes used to regulate activities under European (primarily the EIA Directive) or national legislation. TSG-noise notes this pragmatism and considers that such information will cover a very high percentage of all relevant impulsive sound occurring in Europe's seas. Adding other noise sources to registers may not have enough added value in relation to the added cost.

The following notes are based on analysis of data on seismic sources in UK waters. In this case, three main types of information are available:

a) the forms used to apply for consent or to notify authorities of the intention to carry out a seismic survey

b) the "close-out" reports made by many operators after the seismic survey

c) the reports made by marine mammal observers and/or passive acoustic monitoring personnel placed on board all seismic vessels in UK waters under the consent conditions for those surveys.

Type a) differs from types b) and c) because these forms are completed before the survey and no plans are ever followed exactly – weather, ship availability and equipment issues are all factors that affect actual practice. Both type a) "prior to activity" and types b) / c) "after activity" are required; the former is needed should management of activity be required, while the latter gives a truer picture of what happened. This is an important principle in the establishment of a noise register.

In the UK at present the close-out reports are not detailed enough (e.g. pulse-block-days are difficult to derive from them), but this is being addressed. Full reports from marine mammal observers and/or passive acoustic monitoring personnel are generally the most detailed, but certainly not perfect, source; manually plotting the effort data from these reports is currently the only way to determine pulse-days and this is very labour intensive. These reports may also be limited to a pre-firing check or daylight hours/good weather, which means a lot of location data on when the guns were actually firing may be missing.

For seismic activities it may be simpler (and sufficient for some purposes) to provide a monthly overview of noise per block, but for other activities (e.g. piling for wind farms) it may be easier to collect data on actual lat/long positions. Naval operators may prefer to report in operating areas/exercise areas that are of different size and structure than the seismic blocks. Exercising naval units normally use dedicated areas for specific training as in the map shown here, e.g. 'Navy Area Charlie' is the area where helicopter sonar training can be executed; 'Charlie', or 'Charlie South' could be used for reporting.

Text box 1: Variable scale operating areas

- In the **UK**, offshore leases are normally granted in 10X12 minute blocks (or sub-divisions therof), this may be different per MS; in the **Netherlands** no fixed block size is used
- Various military exercise areas and testing range exist but these are not typically of a standard size (although local subdivision may be).

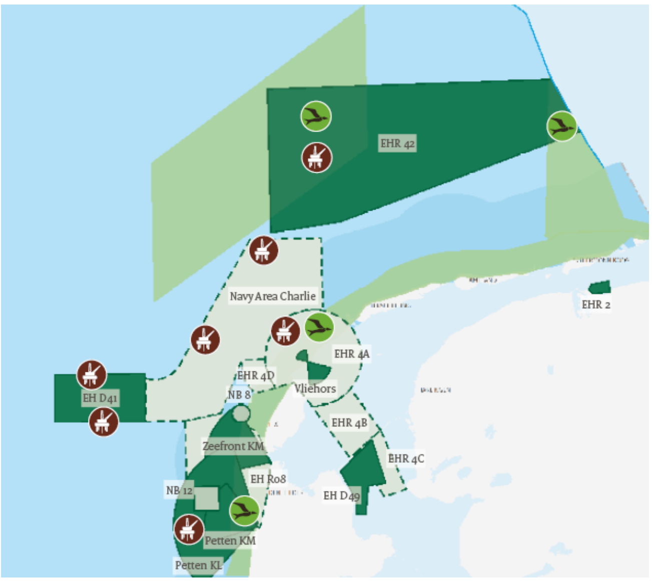

Figure 6: Map of military operating areas in the Netherlands part of the North Sea.

2.2.1 Collation of data

Member States should attempt to ensure that as much relevant data as possible are collated, whilst trying to prevent any duplication. Duplication occurs mostly in "after activity" data as there may be multiple sources. Duplication of data would also need to be considered at boundary areas (e.g. where surveys regularly cross between UK and Norwegian waters) if data from different member states is collated at a later stage.

Standardised filenames, possibly using the consent (legal) reference within the filename, help considerably in sorting information. Where this is not possible (and also to reduce the length of filenames) there should be a set protocol for renaming and saving files so that they are easy to locate and check with the consent data. Data files should be checked for quality assurance as soon as possible after they are received. The minimum check would be:

1) that required files are included in an appropriate format (e.g. excel spread sheet).

2) that consent number and dates agree within files (check each sheet within the excel file) and between the written report and excel spread sheet.

3) That the details of the survey (e.g. location, dates, size of airguns etc) match those with the consent number from the licensing authorities (i.e. the correct consent number has been attached to the report/spread sheets).

In order to ascertain if all data/surveys are being added to the Register, it is important to keep track of all three types of data and cross-check these in order to chase up on missing data; it is also important to receive notification of when surveys get amended, cancelled or extended.

Many errors occur within the submitted reports – obvious errors can sometimes be corrected but it is not always possible to determine what the correct value should be. This highlights the importance of ensuring that files are submitted as soon as possible and checking files soon after they are received to allow errors to be rectified quickly.

2.2.2 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;

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/timeperiod);
- Directivity[8];
- Source depth;
- Platform speed

Of the source properties listed, the source level (or proxy) is the most important one. It is possible that many operators (e.g. navies using sonar, oil and gas companies using airguns) may have concerns about releasing sensitive or commercially valuable 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 (of e.g. 6 dB, or 10 dB) rather than giving a precise figure.

2.2.3 Issues for a common register between Member States

TSG recommends that a common register be set up at least on a Regional Sea level. In setting up the common register the following issues need to be addressed:

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:

- Use of a common language (English)
- Use of a common format for date (DD/MM/YYYY) and lat/long (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 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 effect range for harbour porpoises is 20 km (*reference, Tougaard...)*). A circle with a radius of 20 km has an area of ca. 1250 km^2. TG 11 suggested blocks of 15 minutes by 15 minutes. At a

[8] 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.

latitude of 45 degrees North this would give an area of about 550 km2. For easier interpretation of results in a common register, TSG Noise would recommend one 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 percentage) that 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.

Coastal blocks and Boundary blocks – special considerations for inclusion in a noise register

There are two areas where additional factors for monitoring pulse-block-days may need to be taken into consideration:

1) Coastal areas

- Blocks may be smaller than standard size
- Blocks may contain transitional waters (not directly covered by MSFD)
- Blocks may contain unconnected bodies of water (blocks which are bisected by a landmass)

2) Boundary areas between Member States

- Blocks may be smaller than standard size
- Seismic surveys may cross the boundary line

These blocks can be flagged in a registry to allow additional information to be collected. Member States need to consider whether part-blocks need to be treated differently to complete blocks (this may depend on the amount of water within the block) and ensure that duplication is prevented at boundary areas. Noise in transitional waters has the potential to impact on the MSFD area and should be included in the registry, but a realistic cut-off point needs to be applied e.g. when deciding how far upriver noise should be monitored.

UK example – coastal blocks

A simple set of rules has been suggested for collating additional information for coastal blocks in the UK register. Within the database, any block containing part of the UK coastline will be coded for three attributes:

a) Whether or not the block contains <5% water: yes/no. This 5% rule includes transitional waters, which will be included in the UK register.
b) The type of water in the block:
   i. coastal
   ii. transitional, or
   iii. includes both coastal and transitional waters
c) Whether or not the block is split: yes/no. A block will be considered split if
   i. it contains both coastal and transitional waters,
   ii. land bisects the block such that water bodies within it are completely separated, or
   iii. it contains islands, enclosed bays or other features which make it difficult to judge how noise will propagate through the water in the block.

It is proposed that the UK register is developed so that noise occurring in coastal blocks containing <5% water is allocated to an adjacent block for mapping of data (this 5% rule will also provide a cut-off point for how far upriver data is to be collated) and lat/long are requested for activities in split blocks or for activities in transitional waters. This additional information can be used to exclude data from analyses if required and will provide more accurate information on noise within specific blocks if the register is to be used to regulate activities in the future.

Boundary Blocks:

It is necessary to provide guidance to ensure that information collected by Member States from boundary areas is not duplicated in a common register. It is therefore advisable that data uploaded to the common register contains information at the level of individual days (i.e. it is not uploaded to the common register as 'days per month' per block). In areas where the block sizes are the same, partial blocks will line up with one another along the boundary line and this will allow duplicate data to be readily identified. However, where block sizes are different, partial blocks may be staggered, making it more difficult to determine what constitutes duplicated data. Other issues, e.g. different time zones, variations in the details recorded, etc. can only be addressed when we know the areas to be covered by a common register.

2.3 Noise maps for shipping and explosions in the Dutch North Sea

(Authors: M.A. Ainslie & O. Sertlek)

SUMMARY
The purpose of this section is to illustrate the potential for noise mapping. This purpose is met by providing examples of noise maps for two very different kinds of anthropogenic sound source: shipping and explosions. Maps for both types of source are provided and conclusions are listed.

2.3.1 Introduction

The Marine Strategy Framework Directive defines Good Environmental Status (partly) in terms of Indicator 11.2.1. This Indicator (henceforth "Indicator 2") requires Member States to monitor annually averaged noise in third octave bands centred at 63 Hz and 125 Hz. The purpose of this section is to present annually averaged noise maps in one of these frequency bands for selected anthropogenic noise sources for the Dutch Exclusive Economic Zone in the North Sea (hereafter referred to as the "Dutch North Sea"). See Figure 7 (below).

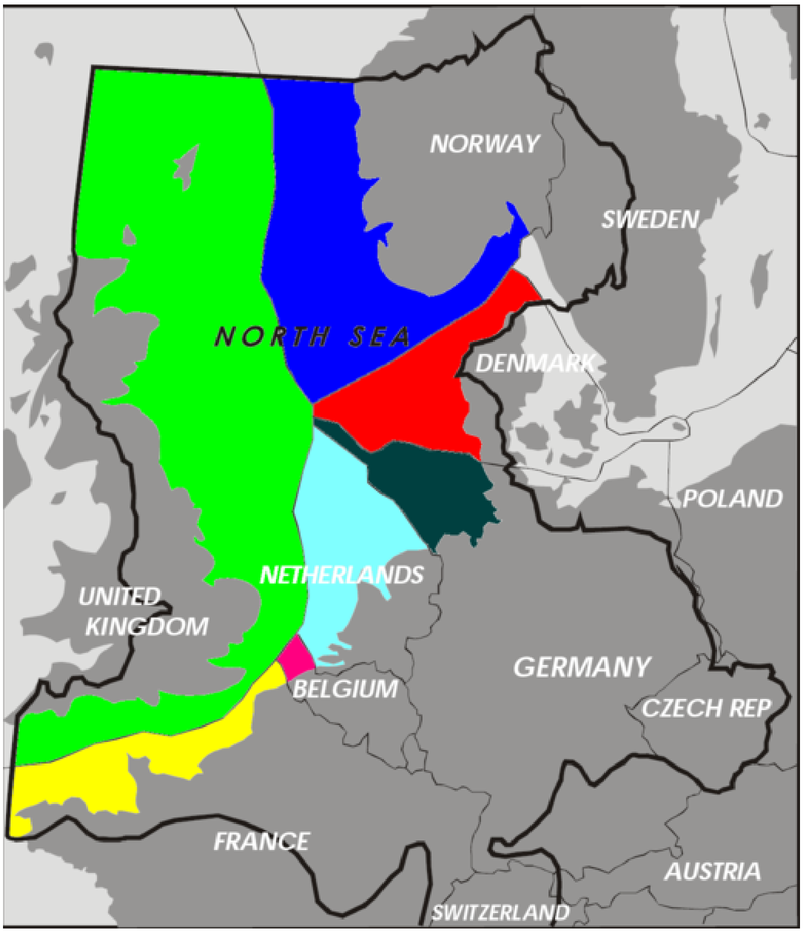

Figure 7: North Sea Exclusive Economic Zones. The region covered by this memo is the cyan region marked "NETHERLANDS".

2.3.2 Sources considered

Anthropogenic sources

The purpose of Indicator 2 is to monitor underwater sound in a frequency band representative of shipping noise (decidecades[9] centred at 63 Hz, 125 Hz). This memo focuses on 125 Hz. In the North Sea, results for 63 Hz are expected to be similar.

Ainslie *et al*. [2009] identifies four main sources of low frequency underwater sound, all of which can be expected to contribute to Indicator 2 in the North Sea: air guns (seismic surveys), shipping, explosions (detonation of unexploded WW2 ordnance) and impact pile driving (mainly associated with wind farm construction). According to Ainslie *et al*. [2009]:

- Seismic surveys carried out in the Dutch North Sea in 2007 involved 3D surveys covering a total area of 1400 km^2 and 2D surveys covering a distance of 150 km;[10] the estimated zero to peak source level of a typical air gun array used in these surveys is 255 dB re 1 μPa m.
- "the average number of ships per year in the Netherlands Exclusive Economic Zone (EEZ) in the years 1999 to 2001 was 336." [11]
- The number of controlled detonations that took place in the Dutch North Sea in 2008 was 136, with an average TNT charge weight per detonation of 78 kg.
- Assuming a wind turbine capacity of 2 MW per turbine, wind farm construction in the Dutch North Sea would result in the installation of 2904 new turbines by 2020 (264 per year on average from 2009 to 2020).

Based on these data, the four activities mentioned were estimated by [Ainslie *et al*, 2009 to contribute 8000 kJ, 3000 kJ, 700 kJ and 500 kJ, respectively, to the annually averaged free-field sound energy [Ainslie & Dekeling 2011] in the Dutch North Sea. These are the only activities whose total predicted free-field energy contributions in the Dutch North Sea exceed 10 kJ.[12] They are given special attention for the present work because the authors consider them the main anthropogenic contributors to low frequency underwater sound.

This memo concentrates on shipping and explosions (see Table 5). Source distributions are shown for shipping in Figure 8 (average distribution for the year 2007) and for explosions in Figure 9 (averaged over the period 2010-2011).

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[9] The term "third octave band" is interpreted as one tenth of a decade (a decidecade).

[10] source: Jaarverslag Staatstoezicht op de Mijnen 2007

[11] this is an error; it should read "number of ships … was 336 in the Netherlands [EEZ]" and not "number of ships per year … was 336 in the Netherlands [EEZ]"

[12] In fifth place, at 2 kJ, was expected future sonar use, two orders of magnitude smaller than the fourth place (wind farm construction).

Type of source	Source distribution from	Start date	End date	Duration	Source level	Source depth
shipping	AIS	Jan 2007	Dec 2007	1 year	[Wales & Heitmeyer 2002]	4 m
explosions	RNLN	Jan 2010	Dec 2011	2 years	[Weston 1960]	equal to water depth

Table 5: Overview of data used for calculation of noise maps for shipping and explosions.

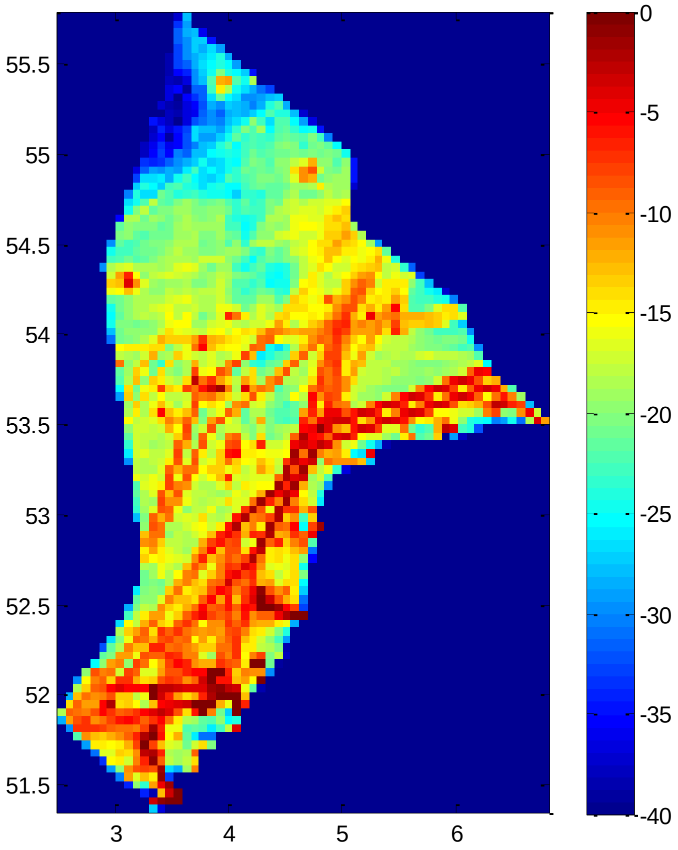


Figure 8: Distribution of shipping density $10\log_{10}(25\ N/\mathrm{km}^2)$ where N is the average areic shipping density in 2007 (data obtained from IMARES).

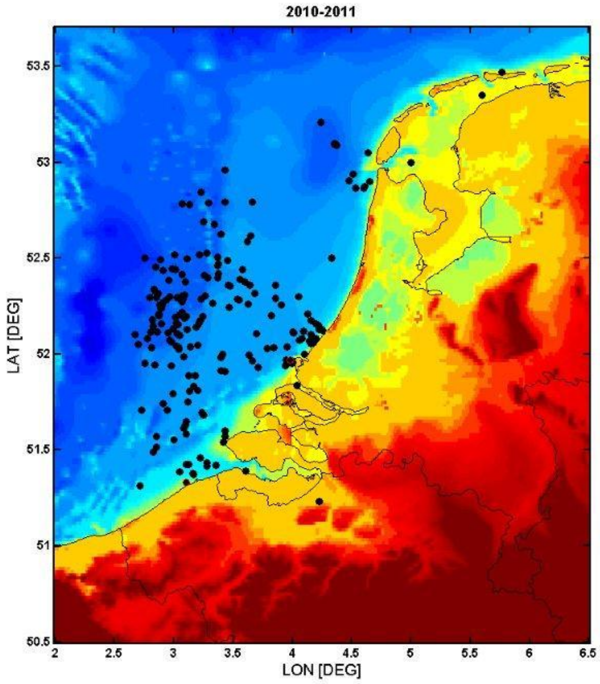


Figure 9: Distribution of explosions in 2010 and 2011 (data from RNLN).

Natural sources

Although noise maps for natural sources are not included here, it is useful to consider the range of likely levels of natural noise, as this helps in the interpretation of the maps of anthropogenic sound. For wind speed see Figure 10.

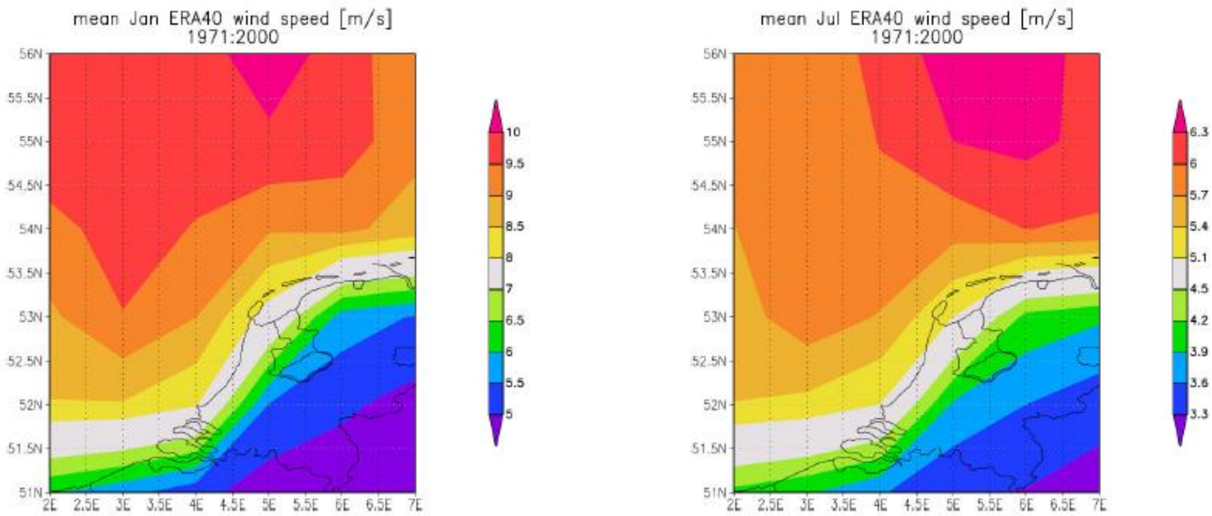


Figure 10: Map of mean wind speed in January (left) and July (right). Figure from Ainslie et al. [2009].

For the range of wind speed 5 m/s to 10 m/s, the areic spectral density dipole source level at 125 Hz is in the range 55 dB to 62 dB re 1 μPa²/Hz (Figure 10). The noise level in deep water can be estimated by adding 5 dB to this value [Ainslie 2010], giving a wind noise spectral density level of 60 dB to 67 dB re 1 μPa^2/Hz, corresponding to sound pressure level (SPL) between 75 dB and 82 dB re 1 μPa in the decidecade centred at this frequency. In shallow water, additional contributions can be expected from seabed reflections, with resulting noise levels in coastal water "5 to 10 dB higher than in deep water far from shore at frequencies greater than about 500 Hz" [Urick, p. 213]. For example, a difference of 7 dB would result in a range of 82 dB to 89 dB re 1 μPa in shallow water. This seems consistent with the predicted maxima of 91 dB and 96 dB re 1 μPa (for July and January, respectively) for the frequency band 10 Hz to 1 kHz, from [Ainslie *et al*, 2009].

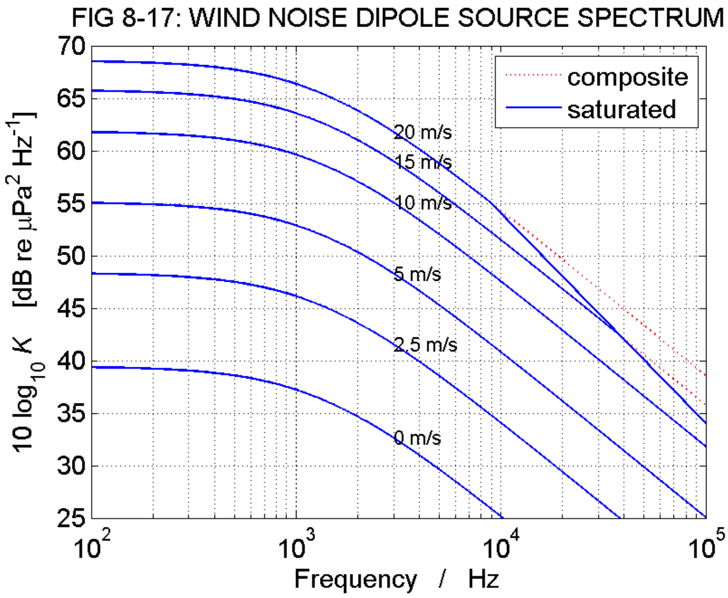


Figure 11: Areic spectral density dipole source level due to wind (from [Ainslie (2010)] © Springer).

2.3.3 Noise maps

Two noise maps are presented in this section, one for shipping and one for explosions. Both are for annually averaged squared pressure in the decidecade centred at 125 Hz, expressed as a level in decibels and for a receiver placed at depth 1 m from the sea surface.

Input parameters used for both maps are:

Wind speed = 0

Sediment = medium sand [Ainslie 2010]

Bathymetry = ETOPO1 (interpolated with 5 km resolution)

Sound speed profile = isovelocity

Shipping

The left graph of Figure 12 shows predicted sound pressure level in the decidecade band centred at 125 Hz associated with the shipping distribution of Figure 8. According to this distribution, the average number of ships in the Dutch North Sea in 2007 was 259, of which 248 are taken into account in the present calculations. The shipping distribution and therefore the resulting noise map are averaged over one year (January to December 2007). Shipping noise so calculated is between 50 dB and 100 dB re 1 μPa on most of the Dutch North Sea. The bright spots near the coastline centred at approximately 50 km E, 450 km N are probably artefacts and should be disregarded.

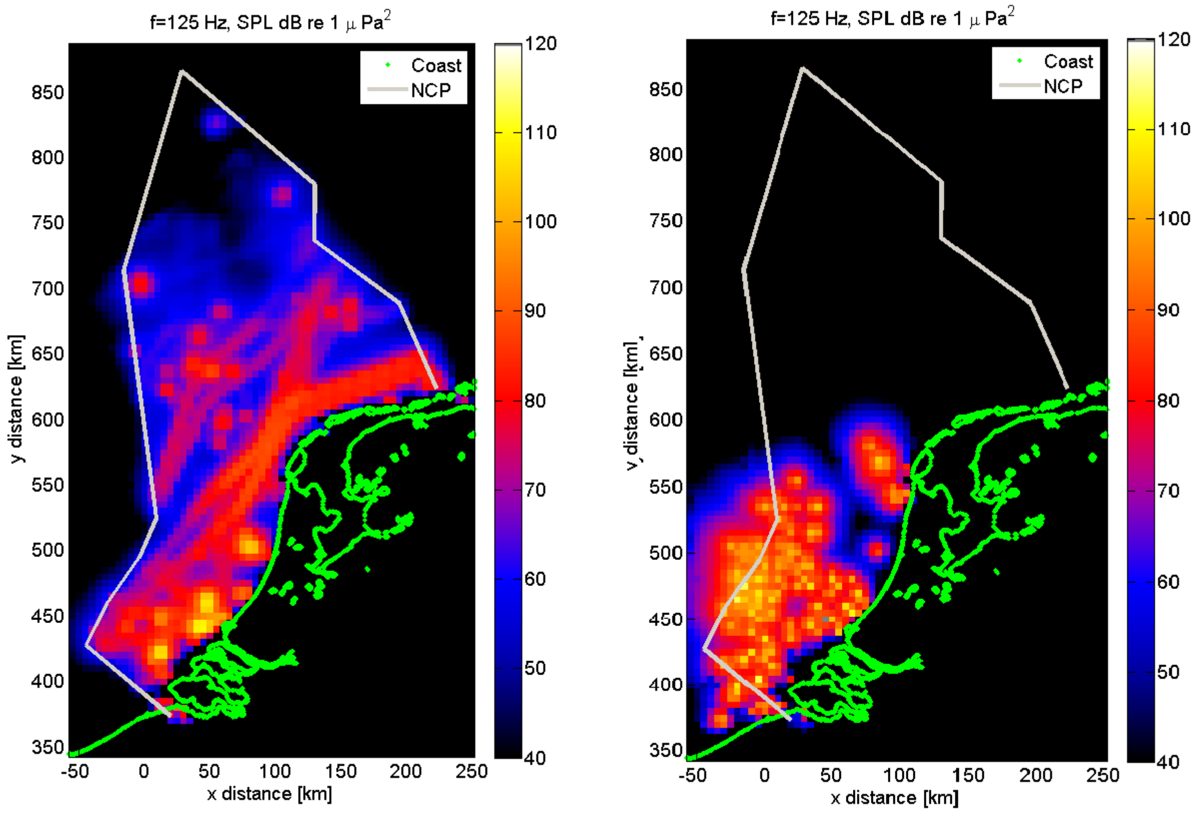


Figure 12: Annually averaged noise predictions for the Dutch North Sea: SPL in the decidecade centred at 125 Hz. Left: shipping noise for 2007; right: noise from explosions, averaged over two years (2010 and 2011). Receiver depth is 1 m. (provided by Özkan Sertlek (University of Leiden) and TNO, © Özkan Sertlek).

Explosions

Approximately 230 underwater explosions took place in the Dutch North Sea in the period 1 Jan 2010 to 31 Dec 2011 (see Figure 9).

Explosions are concentrated in the southwest corner of the Dutch North Sea, where the predicted annual average contribution from explosions to the 125 Hz band is mostly between 70 dB and 110 dB re 1 μPa, compared to mostly 60 to 90 dB re 1 μPa from shipping in the same frequency band. If the predicted contribution at a given location is dominated by a single detonation, a one second average at that location will be 75 dB higher than this during the explosion (i.e., up to ca. 185 dB re 1 μPa in the same frequency band). The maximum SPL will depend on both the bandwidth and duration of the received pulse. A system designed to record such events in combination with the background noise would require a dynamic range of at least 110 dB. Conversely, a system designed to omit these high amplitude events would neglect the single largest contribution to Indicator 2 in the south-western part of the Dutch North Sea. This shows the need to store the complete distribution for the purpose of analysis.

2.3.4 Conclusions and way ahead

Noise maps similar to those presented can give a clear indication of the main anthropogenic sources that contribute to sound at each location. The two chosen activities take place mainly in the south and southwest of the Dutch North Sea, close to the coastline. Such maps can be used to identify:

- locations for which the soundscape is dominated by a single (and identifiable) anthropogenic source.
- locations at which the soundscape is dominated by multiple (identifiable) anthropogenic sources.
- locations where soundscape is dominated by natural sounds.

Applications include:

- choice of suitable locations for monitoring by measurement.
- choice of suitable locations for monitoring by modelling.
- design of suitable measurement and data acquisition equipment (e.g., the need for high dynamic range in areas with a high likelihood of explosions).

Important sound producing anthropogenic activities sources not included in the present maps are seismic surveys and offshore construction (mainly of wind farms).

One could use similar maps to calculate statistics of the spatial distribution, such as:

- arithmetic mean of squared sound pressure.
- a measure of spatial variability.
- the annually averaged total sound energy in the Dutch North Sea. By taking account of the propagation conditions, doing so would provide a ranking of sound sources in the Dutch North Sea of higher fidelity than that obtained by Ainslie *et al.* [2009] using the concept of free field energy [Ainslie & Dekeling, 2011]

2.4 Noise modelling and mapping in Irish waters

(Author: T. Folegot)

Summary
The research programme STRIVE Noise, conducted by Quiet-Oceans (France) and CMRC (Ireland) and funded by the Irish EPA aims to provide a preliminary seasonal ambient noise atlas based on available environmental and anthropogenic data. Among this atlas of noise, specific sound maps associated with shipping has been produced based on an annual collection of Automated Identification System (AIS) data. While there was excellent agreement between modeled outputs and local in-situ acoustic validation data, uncertainty and variability of the environmental and anthropogenic parameters is taken into account by a Monté-Carlo approach. This enables the production of seasonal and statistical noise maps which describe, for each geographical location in the map, the probability to measure a given noise level in the form of percentiles.

2.4.1 Method

The proprietary Quonops© ocean noise monitoring and prediction system (Folegot 2010) has been used to model soundscapes in Irish waters. The model domain ran from 3°–25° W longitude, and 46°-59° N latitude, utilizing a 0.5°x0.5° grid over the shelf and nearshore waters and 1°x1° in offshore waters. Quonops© uses a Monté-Carlo approach to determine the seasonal statistics of the sound fields, and describe the spatio-temporal distribution of noise levels generated by human activities across the Irish EEZ in terms of probability. The noise level distribution in the water column and sediments depends largely on the noise sources present, bathymetry, and environmental conditions including temperature, salinity, sea state, and sediment type. Therefore, these variables are included in the Quonops© modeling framework. Bathymetry data come from the freely available GEneral bathymetric Chart of the Oceans (GEBCO) database. Seabed sediment distribution data was sourced from the MESH Atlantic project (www.meshatlantic.eu) and matched with APL equivalents (APL 1994) for which specific sound absorption figures are available, based on expert knowledge. Sediment data was lacking for a proportion of cells, and these were allocated a nominal "sand" classification on the grounds that this sediment type dominated the offshore sediment types in the area for which data was available. Modeled data for temperature/salinity profiles were obtained from the Irish Marine Institute using the NE Atlantic oceanographic forecast model, which provides temperature/salinity profiles at 2km grid resolution. Seasonal wave heights across the model domain were computed from the HIPPOCAS hindcast data (Vijaykumar et al. 2004), with the mean value for each season used in unpopulated grid cells. In order to represent the spatial and temporal distribution of shipping traffic for noise modeling purposes, Automatic Identification System (AIS) data were obtained from the Department of Transport, Tourism and Sport, and processed to give ship density per km^2 for each season. For ships, sound sources were modeled as point sources near the surface using the Wales & Heitmeyer model.
An autonomous underwater sound recording device was deployed for 16 days outside Cork bay on the south coast of Ireland to accurately characterize the sound field and locally ground-truth the predictive sound maps produced by the model.

2.4.2 Shipping activities in Irish waters

The AIS network was able to report a semi-coastal description of vessel positions under the current year which requires AIS to be fitted aboard all ships of gross tonnage exceeding 300 engaged on international voyages, cargo ships of gross tonnage exceeding 500 not engaged in international voyages and all passenger ships irrespective of size. The AIS based data set is therefore not exhaustive, but gives a reasonable description of large shipping. A seasonal density map has been derived from the annual AIS dataset, and Figure 13 is an illustration of the shipping density corresponding to July-September 2012.

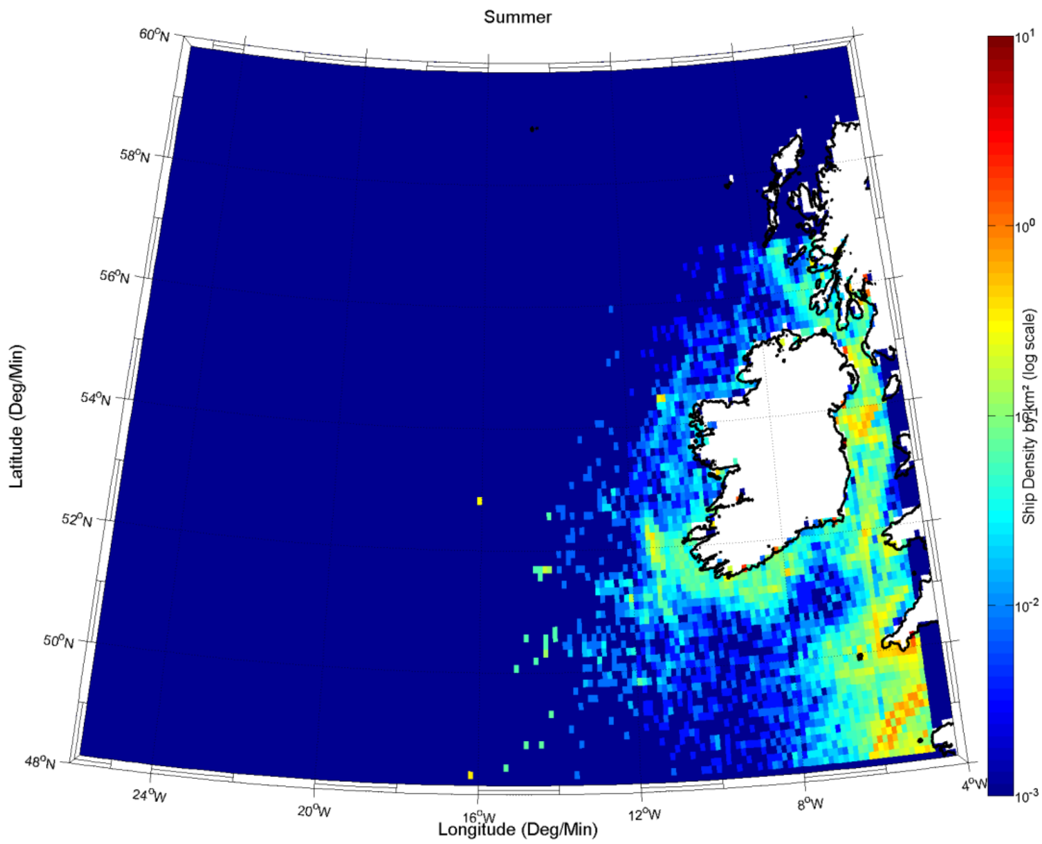


Figure 13: Ship density map corresponding to the period July-September 2012, and based on the coastal AIS network. The colour scale unit is the average number of vessel present per square kilometre and is expressed in a logarithmic scale between 10^{-3} km^{-2} (deep blue) and 10 km^{-2} (deep red).

2.4.3 Shipping noise mapping

The stochastic nature of noise is related to the fact that the sources of anthropogenic noise and, to a lesser extent, environmental conditions, are difficult to predict or to anticipate. It is difficult to predict number, type and position of ships in the area, although AIS gives a fair description of the spatial and temporal distribution over the year. Environmental uncertainty, such as weak or sparse data describing bottom properties, or variability such as fluctuating sea-state also usually leads to difficulties when it comes to characterization of the anthropogenic noise at the scale of a basin and a season.

To overcome these two difficulties, an approach based on Monte-Carlo has been proposed in order to build a statistical map of the anthropogenic noise, and to provide to the stakeholders a representative description of the seasonal and spatial variability at the scale of an oceanographic basin. The Monte-Carlo approach applied in this project consists of a number of releases of anthropogenic situations that are consistent with the statistical description given by the AIS data.

Based on the statistical environmental description of the Irish EEZ (oceanography, bathymetry, bottom properties, etc.), Quonops, Quiet-Oceans' ocean noise prediction system was able to calculate the noise field associated with each individual anthropogenic situations. From this set of "instantaneous" three-dimensional sound predictions, the noise statistics representative of the seasonal environment and the shipping variability has been derived in the form of percentiles. A percentile is describing, for each latitude and longitude of the map, the proportion of time and depth where the ambient noise is larger than a given value, and these are expressed according to the International Standard [ISO 1996-1:2003] as "N% exceedance levels". The 50% exceedance level is exactly the definition of the median.

The resulting noise maps for the Irish EEZ and representative of the summer are represented in Figure 8 for 1% (rare occurrence), 10% (significant occurrence), 50% (median occurrence) and 90% (most occurrences) exceedance levels. The 1% exceedance level represents the highest noise levels that are expected, whereas the 90% exceedance level is close to the distribution of the lowest level of anthropogenic noise. It is interesting to note that the shipping route in the north-west corner of France contributes more to underwater sound levels than the routes that go to some harbours in the south coast of Ireland and the multiple routes in the Irish channel. It is also interesting to note the resurgence zone of ambient noise in the shallow waters in the north-west of Irish EEZ. Although this has to be confirmed by in-situ measurement, it could be explained by propagation effects linked to the bathymetric and oceanographic features of the area.

2.4.4 Discussion

Underwater sound propagates very rapidly (approx. 1500m per second), and over large distances at low frequencies (1000's of km's). Sound propagation in the ocean is largely dependent on the topography of the ocean floor, and the nature of the sediments (Guiesse & Sabathié 1964). The modeled area of the Irish EEZ is bathymetrically complex, with strong contrasts between the relatively flat coastal shelf area, and large offshore features such as the Rockall trough, Porcupine Seabight and Hatton bank, all of which exert a significant influence on the resulting propagation patterns.

Although consistent with the scientific and technical state-of-the-art, the results are of a predictive nature and have only been calibrated against ocean acoustic field surveys in one part of the model domain (off Cork bay). While there was excellent agreement between modeled outputs and validation data, uncertainty in model parameters is taken into account by the Monté-Carlo approach. This enables parameters to be varied within a range of uncertainty. Whilst our approach also provides a reasonable description of shipping activities, it should not be regarded as a fully comprehensive description of all vessel traffic. The coastal AIS network cannot capture signals from vessels that are far from shore, resulting in offshore vessel movements being underrepresented, and the contribution from fishing vessels is likely to be underrepresented, as a (unknown) proportion may not operate AIS. However, model outputs represent a viable and feasible assessment of the propagation of underwater noise in the framework of the MSFD.

2.4.5 Acknowledgements

This research was undertaken in partnership with the Coastal and Marine Research Centre, University College Cork, Ireland, and financed through the Environmental Protection Agency Science, Technology, Research and Innovation for the Environment (STRIVE) Programme 2007-2013, funded by the Irish Government under the National Development Plan 2007-2013.

2.5 BIAS - Baltic Sea Information on the Acoustic Soundscape

(Authors: P. Sigray & M. Andersson)

The Baltic Sea is a semi-enclosed ocean with nine states bordering the sea. It consists of eight sub-catchment areas (basins) and a numerous of harbours. The density of ships is one of the highest in Europe. It is estimated that about 2000 sizeable ships are at sea at any time. Further, several large wind farms are planned to be erected adding noise to the marine environment. Undoubtedly, due to the unbound character of noise it has to be dealt with and preferable on a regional scale.

In September 2012 the EU supported BIAS project was started (LIFE+ programme). The project has three main objectives. The first is to establish a regional implementation of Descriptor 11, which includes development of user-friendly tools for management of the Descriptor and to obtain sound levels. The second objective is to establish regional standards and methodologies that will allow for cross-border handling of data and results, which is necessary for an efficient joint management. The third objective is to model the soundscape and thereby expand the measurements to the entire Baltic Sea. Not at least, a regional handling will decrease the over-all costs to individual Member States.

The BIAS project is aimed at solving the major challenges when implementing Descriptor 11 in the Baltic Sea. One year of measurements will be performed covering the whole Baltic Sea. In total 40 sensors will be deployed. The measurements will be performed by adhering to the standards that will be established in the project. Likewise will the data be analysed using standardized signal processing routines. Results will be subjected to a quality control and finally stored in a common data-sharing platform.

The project has faced many of the challenges that arise when the Descriptor is to be transformed into daily practice. Consequently the BIAS project has gained valuable experience that can be shared with all Member States. For more details visit BIAS website where contact information can be found (www.bias-project.eu).

2.6 Noise modelling and mapping in German waters

(Author: S. Werner)

2.6.1 Objective

Acoustic mapping of noise levels arising from offshore human activities over scales relevant to long-term, regional-scale decision making would also allow a holistic assessment for D 11 MSFD.

A German research & development project (at the Federal Environment Agency (UBA)) is recently educing 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 for modelling of the underwater sound fields in the EEZs of the German Baltic and North Sea and imaging species-related impacts on organisms.

Software requirements were given beforehand, e.g.:

- 50 Hz to 20 kHz, 1/3 octave, 500 m resolution
- 3-D, sound speed profile and bottom variability
- SEL for impulse, SPL for continuous noise, several propagation models optional
- Digital bathymetrics
- List of target species, their audiograms (hearing threshold as a function of frequency), and regulator thresholds (e.g. for behavioral disturbance, temporary threshold shift)
- Evaluation against receiving properties of animals (audiograms)
- Supported by long time (abt. 3 month) monitoring in dedicated areas
- With input from other projects validation of propagation loss
- Determination of noise variability
- Proposal of recorder placement (5 in North Sea, 3 in Baltic Sea) preferably at existing stations

A first version of the SEANAT Software (Subsea Environmental Acoustic Noise Assessment Tool) is now available running on a JavaScript-enabled web browser to be accessed through a SEANAT user account.

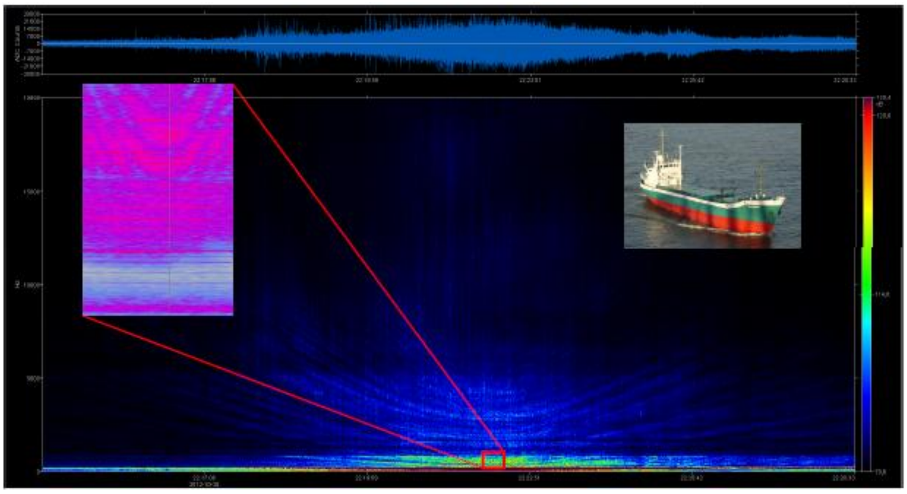
The SEANAT system includes the following main components:

- Web-based graphical interface
- User-specific configuration and results files
- Databases of source spectra, environmental data, and model parameters
- A high-perfomance computing environment on which sound propagation models are run

In the following a short overview is given about the working packages carried out within this project.

2.6.2 Measurement standards, sound profiles, recordings of background noise

Sources and their signatures, align with respective measurement standards, are collected or measured if not available with the aim of producing a catalogue of relevant source signatures of those acoustic sources that are supposed to be incorporated in the mapping. Those include shipping, pile driving and seismic activities including predictions for their typical propagation loss. Information is collected on distribution, density and acoustic characteristics of human activities in European waters for multiple depths and frequencies (as part of a sound register). In addition features which lead to substantial variation of propagation loss are identified.



Picture 1: Spectrogram of passing ship, CPA at 0.3 nm (@DW ShipConsult)

2.6.3 Definition of area-specific propagation models

Existing validated propagation models for the different marine regions as well as information on validated environmental data for European Seas (bathymetry, constitution of sediment, in situ-measurements of hydro-acoustic parameters etc.) were collected and factored for the definition of area-specific propagation models. SEANAT uses a modelling approach, where the transmission loss (TL) is calculated as a function of range, depth and frequency along radials from the source. TL is combined with the source spectrum to obtain received level as a function of range, depth and frequency along each radial. The results can be combined in a number of ways to obtain a variety of received level plots.

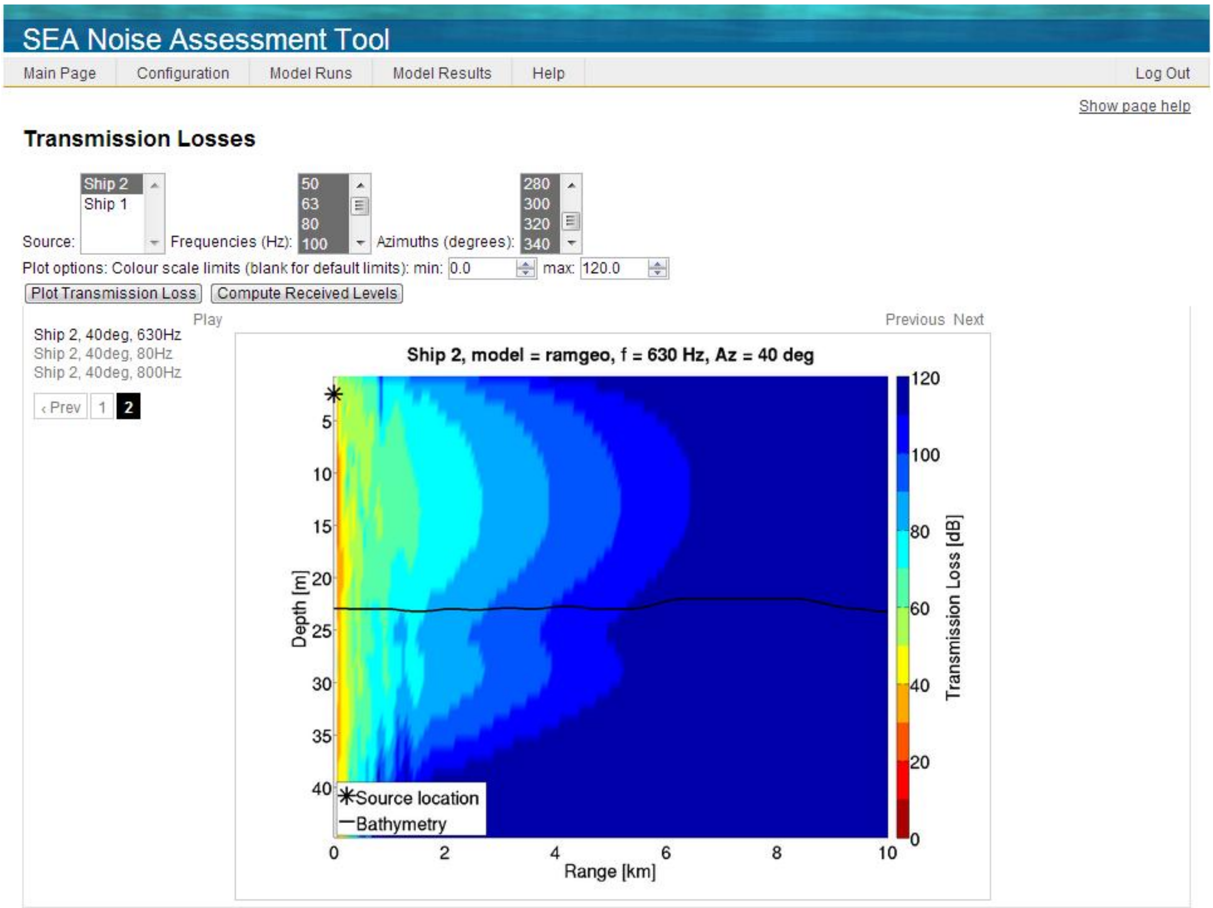
Following underlying propagation models were chosen for SEANAT and tested by evaluating passing ships:

For frequencies up to and including 2kHz:

- RAMGeo
- Parabolic equation model by Michael Collins, US Navy Research Laboratory
- Captures full wave acoustics
- Too slow at higher frequencies

For frequencies above 2kHz:

- BELLHOP
- Gaussian beam tracing model by Michael Porter, HLS Research
- Ignores wave diffraction effects so not accurate at low frequencies



Picture 2: Example of plotted transmission loss results for computing received levels

2.6.4 Status of work

Recorder with acoustic releaser were procured, placed in the Baltic and North Sea and recovered. AIS data for the Baltic Sea is already procured, the same will be done for the North Sea. Source spectra for pile driving and ships were generated and implemented in SEANAT. Water column sound speed profiled were procured, selected and implemented in SEANAT as well as bottom acoustic data which was derived from pile driving signal characteristics.

A first version of the software is available, tests are ongoing. First species-specific sound levels for harbour porpoises to illustrate different zones of impacts (TTS, disturbance) are already incorporated in SEANAT. Other species including the possibility to compare their audiograms with received sound levels will be added.

Discussions have taken place with national experts and political decision-maker to meet their requirement and to ensure wide usage of the software once available for regular usage.

2.7 European experience with the use of mapping

(Author: Michael Dittrich)

The use of mapping has some history and in the process of implementing the MSFD we should make use of earlier European experience. Noise monitoring in air has been carried out for decades and has resulted in a body of work on noise maps. The relevant EU regulation is described in Part II, *Text Box 1*, and provides some useful background within Europe that can assist in implementing the MSFD.

European Directive 2002/49/EC [2002/49/EC], also known as the Environmental Noise Directive (END), regulates the assessment and management of environmental noise from large infrastructures including major agglomerations (>250 000 inhabitants), roads (> 6 million vehicle passages per year), railways(> 60 000 train passages per year) and major airports. The END is one of the instruments of Community policy to achieve a high level of health and environmental protection, in particular against noise. It requires these infrastructures to be assessed by producing revised noise maps every five years. In addition, action plans for noise mitigation must be compiled, aimed at reducing noise levels that exceed national limits set by individual MS. Both the noise maps and action plans are submitted to the European Commission (EC), which collects these in a database for evaluation purposes. The action plans must also be updated every five years and must take into account major changes affecting noise levels. The noise maps and action plans are publicly disseminated.

The noise indicators used for noise mapping are the day-evening-night level (Lden) and the night level (Lnight), both determined for a whole year. The noise levels may be determined by measurement or by calculation. The harmful effects of noise are determined by dose-effect relationships for annoyance and for sleep disturbance. By combining topographical data on location and numbers of inhabitants per dwelling, numbers of annoyed and sleep disturbed people can be estimated. The END does not set noise limits at the receiver locations, which is at the discretion of member states.

The END prescribes the following in its annexes:

a. The definition of the noise indicators;
b. The assessment methods for the indicators, both measurement and calculation;
c. Assessment methods for harmful effects;
d. Minimum requirements for strategic noise mapping and action plans
e. Data to be sent to the Commission.

values of Lden and Lnight can be determined either by computation or by measurement (at the assessment position). Measurement methods must be adapted in accordance with the principles governing long-term average measurements stated in [ISO 1996-2] and [ISO 1996-1].

Recommended assessment methods are listed for member states that have no methods or wish to change their methods. Currently, the Commission is introducing new assessment methods into legislation known as CNOSSOS-EU. The assessment methods predict average noise levels at receiver positions based on noise source data and propagation models. The source data are typically derived from average sound emission data for characteristic vehicle groups (road or rail), their average speeds and operating conditions, the infrastructure (road type or track type for railways) and the flow rate of each vehicle group. For sound propagation, the basic geometry, ground absorption, reflections and noise barriers are taken into account. For noise mapping, generally total broadband Lden levels are used. But for more accurate assessment in relation to action plans, noise levels in octave bands are used.

The END was evaluated in 2010 [Rev 2002/49/EC 2010], to review the implementation of the key provisions of the Directive, to review measures employed to manage environmental noise from key sources, and to develop an Action Plan outlining further implementation strategies and Community action on environmental noise.

2.8 Comparison of averaging methods for Indicator 11.2.1

(Authors: M. A. Ainslie, M. van der Schaar, M. André, S. P. Robinson & M. K. Prior[13])

Summary

The purpose of section 2.8 is to substantiate the advice of TSG Noise to MS on the choice of annual averaging method for implementation of Indicator 11.2.1 (henceforth abbreviated as «Indicator 2»). Because no suitable data are available in European waters, it was decided to compare different averaging methods on a data from the International Monitoring System of the Comprehensive Test Ban Treaty Organization (CTBTO), made available to TSG Noise via LIDO. The definition of «ambient noise» is discussed in sec 2.7.2, followed by a description of the CTBTO data set (2.7.3) and a comparison of different averages (2.7.4). The advantages and disadvantages of each averaging method are listed in sec 2.7.5 and discussed in 2.7.6. The conclusions (2.7.7) depend on one's chosen definition of «ambient noise». TSG Noise recommends (see sec 2.7.8) use of the arithmetic mean (AM).

2.8.1 Introduction

The MSFD defines GES (partly) in terms of Indicator 11.2.1. This Indicator (henceforth "Indicator 2") requires a measure of annually averaged noise. The purpose of this memo is to consider pros and cons of different kinds of averaging. 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 is interpreted by the TSG Noise report of February 2012 as: "Trends in the annual average of the squared sound pressure associated with ambient noise … expressed as a level in decibels".

The purpose of this memo is to reconsider this definition. It does so by comparing the annual average (arithmetic mean) of the squared sound pressure with other possible metrics. Specifically, we consider processing by which the mean square sound pressure is determined in successive samples ("snapshots") of duration *T*. A distribution of snapshots with fixed *T* is then obtained by collecting them over one or more consecutive years. The following three averages of this distribution are considered:

- Arithmetic mean (AM - the TSG interpretation);
- Geometric mean (GM - equivalent to the average of individual SPL values in decibels);
- Median.

The possible benefits of a fourth type of average, the mode, are considered in sections 5.6.5 to 5.6.7.

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. There might also be locations at which shipping noise is not the largest contributor to Indicator 2.

The choice of averaging method needs to be:

I. robust to minor changes or differences in implementation;
II. physically meaningful and representative of a large enough region to justify its use as an indicator of GES;
III. practical (simple to implement);
IV. compatible with comparable regulations or procedures (desirable property but not essential).

It seems likely that Indicator 2 will be monitored by different Member States (MS) with different equipment and different analysis protocols, and that the selection of equipment and protocol is unlikely to be fixed for all time. We therefore seek an average that is robust to small differences and changes in equipment and processing protocols. We used CTBTO data, which were analysed with a software package from the LIDO-project (Listening to the Deep Ocean Environment) [André *et al.,* 2011].

[13] The views expressed in this paper are those of the author and do not necessarily reflect those of the CTBTO Preparatory Commission.

The remainder of this chapter concentrates mainly on requirement (I), the invariance with the choice of snapshot duration. The other two requirements are addressed in the discussion section. The LIDO data that were used for this memo had been analysed in time segments of 65.5 seconds. The minimum snapshot duration used here is therefore 65.5 seconds. Noise measurements were provided as sound pressure levels over the data segment. Longer snapshots were made by combining the SPL measurements of multiple consecutive data segments. This means that the averages other than the AM were influenced by the AM that is already part of the SPL computation. The use of a 65.5 second snapshot time in this document is not intended as a recommendation from the authors; it was chosen with a different application in mind, namely the detection of certain cetaceans. A similar analysis on the same recordings, using a smaller snapshot time (10 seconds) is provided in van der Schaar *et al.* [2013].

2.8.2 Definitions of "ambient noise"

Indicator 2 is defined as a trend in annually averaged ambient noise, so it is important to have definitions for the terms "trend" and "ambient noise".

The term "ambient noise" is defined by TSG [Van der Graaf *et al.*, 2012, Annex 3 (Glossary)] as "*For a specified signal, all sound in the absence of that signal except that resulting from the deployment, operation or recovery of the recording equipment and its associated platform*."

This definition is accompanied by the note: "*If no signal is specified, all sound except that resulting from the deployment, operation or recovery of the recording equipment and its associated platform.*

See part II chapter 2 where the definition of [ambient noise] *is explained*."

The opening paragraph of Van der Graaf *et al.* [2012] Sec. 4.1 reads:

> "*Ambient noise is commonly defined as background noise without distinguishable sources* (*see:* [*Wenz, 1962, Urick, 1984, Dahl et al., 2007, Cato, 2008*]*). However, this poses the problem how to deal with identifiable sources that contribute to the local soundscape and that add to pressures. TSGN therefore discussed a more operational definition of sound relevant to indicator 11.2.1 that is more in line with the term 'soundscape' (see* [IQOE] *Science Plan). Following this line of thinking sounds from identifiable sources should be included in recording and analysis in addition to non-identifiable sources. Self-noise, including platform noise and non-acoustic contributions such as electrical self-noise, flow noise and cable strum may contribute to the recorded signals, but these should be minimized during measurement and should not be considered in the analysis of trends*."

With this definition, "ambient noise" is all sound except self-noise, including infrequent transients, consistent with the definition ANSI 1994; ('all sound' includes both natural and anthropogenic sounds).

TREND

TSG Noise defines "trend", as that by Van der Graaf *et al.* [2012]:

"*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*"

2.8.3 CTBTO data set

Data are available from CTBTO over several years (see Figure 15 for the location of the hydrophone stations and Table 6 for start and end date of data used from each station). One channel of each station was analysed for a period of at least three years. The analysis was done in data segments[14] of duration

[14] A single CTBTO data segment contains 16384 samples at a sampling rate of 250 Hz.

~65.5 seconds. For each segment the mean square pressure was computed in the third octave band centred at 63 Hz. In the following this quantity, expressed as a level in decibels, is denoted SPL_{63}. The digitisation sensitivity in the last column is defined as the ratio of the digital representation of a sound pressure sample, as recorded by CTBTO, to the acoustic pressure giving rise to that sample.

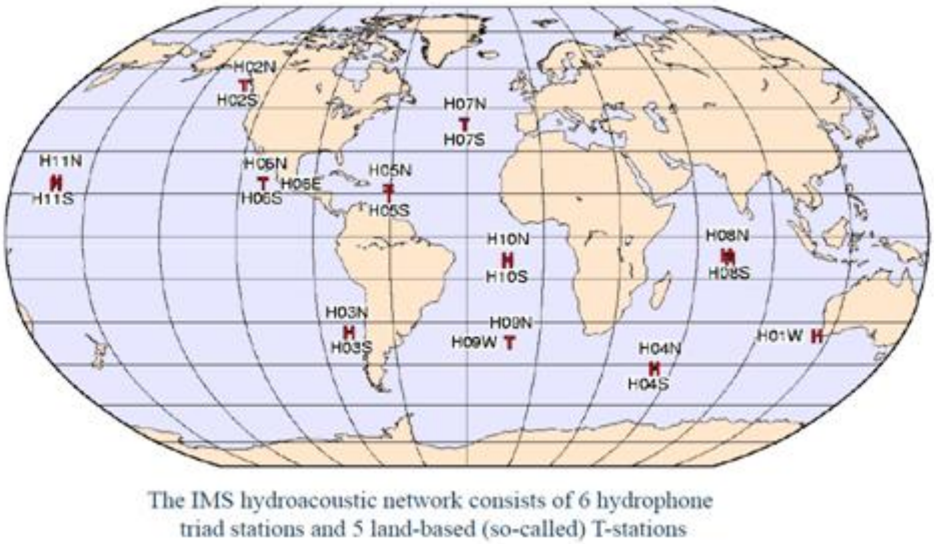


Figure 14: Location of CTBTO stations.

Platform	Hydrophone station #	Time start	Time end	# Segments (duration 65.5 s)	# Days	Digitisation sensitivity [counts per millipascal]
Cape Leeuwin	H01	Jan 2008	Jun 2011	1580682	1189	1.83918
Juan Fernández Islands	H03	Jan 2007	Feb 2010	1459911	1098	1.77996
Ascension Island	H10	Jan 2008	Jun 2011	1650629	1242	1.82815
Wake Island	H11	Jan 2008	Jun 2011	1650603	1242	1.82715

Table 6: Summary of CTBTO data set.

Measured values of SPL_{63} exceeding 180 dB re 1 µPa were removed from the data set on the assumption that they are probable acquisition artefacts. Measurements from each station are described below.

ASCENSION ISLAND

At Ascension Island (16) the distribution of the level stayed mostly the same throughout the years (Figure 17).

Figure 15: Location of Ascension Island (hydrophone station H10).

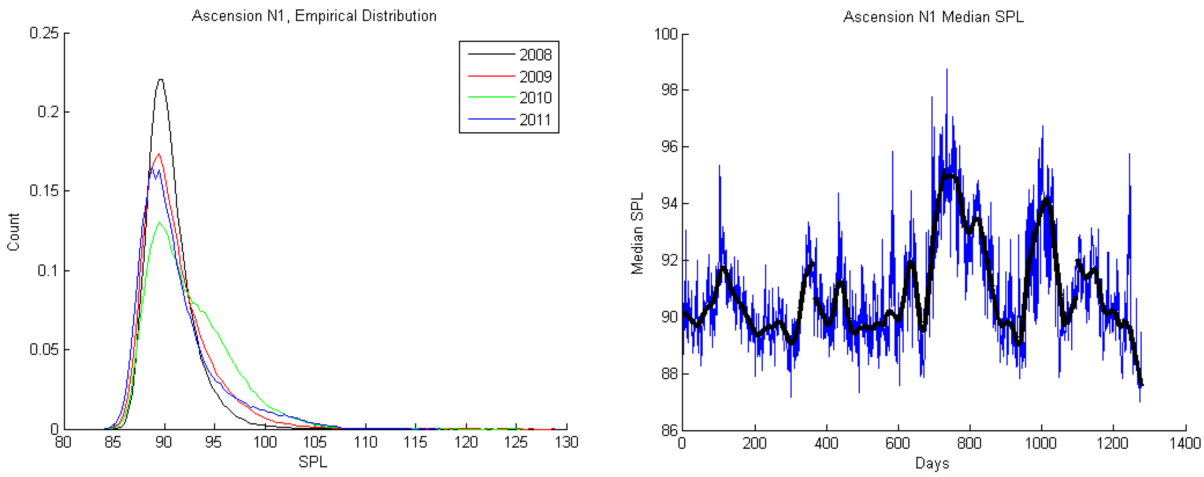


Figure 16: Left graph: Histogram of SPL_{63} distribution for Ascension Island (T = 65.5 s); right graph: daily median of SPL_{63} vs time.

In 2010 data for Ascension Island, around day 750, a temporal increase in noise can be seen. The station had a characteristic noise pattern from a seismic survey (Figure 18).

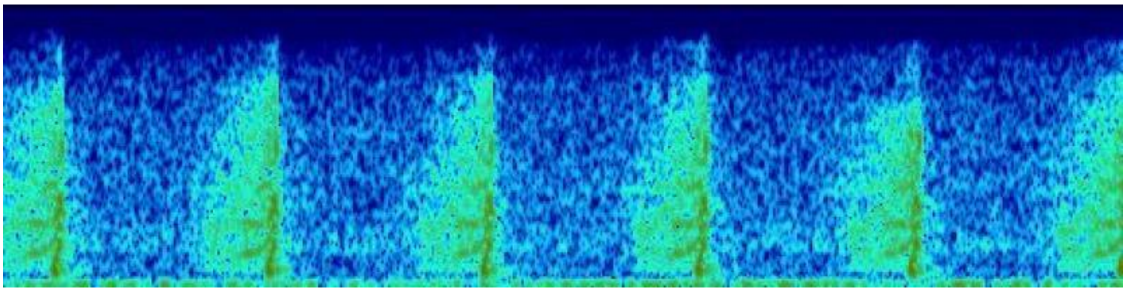


Figure 17: Spectrogram recorded on June 30 2010, from 15:39.55 to 15:41:00 (UTC) for Ascension Island; this is one sample of 65.5 s duration.

CAPE LEEUWIN

At Cape Leeuwin (Figure 19) a change in noise levels could be measured (Figure 20). But from 2011 only the first half of the year was available which seems to be the noisiest season and will offset the distribution.

Figure 18: Location of St Alouarn Islands, close to Cape Leeuwin (hydrophone station H01). Well placed for ice noise from Antarctica.

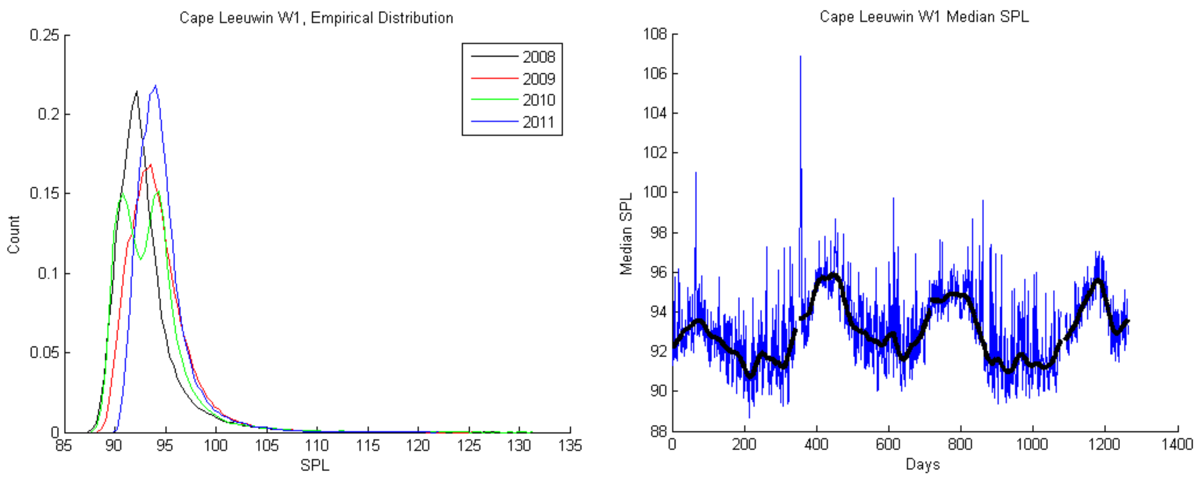


Figure 19: Left graph: Histogram of SPL_{63} distribution for Cape Leeuwin (T = 65.5 s); right graph: daily median of SPL_{63} vs time.

Figure 21 shows evidence of ice noise at ca. 21:00 on 14 May 2011 (although the highest amplitude events on that day seem to be those of 14:40 and 23:05).

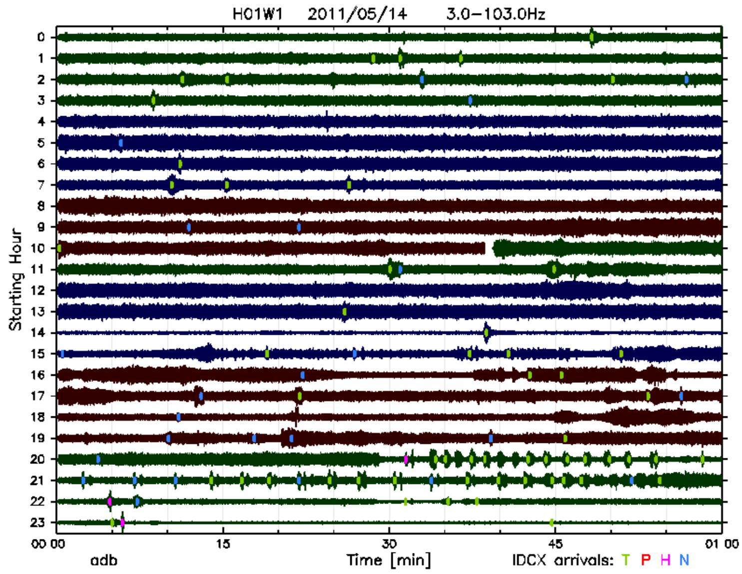


Figure 20: Broadband (3 Hz to 103 Hz) pressure time series (24 h) for Cape Leeuwin.

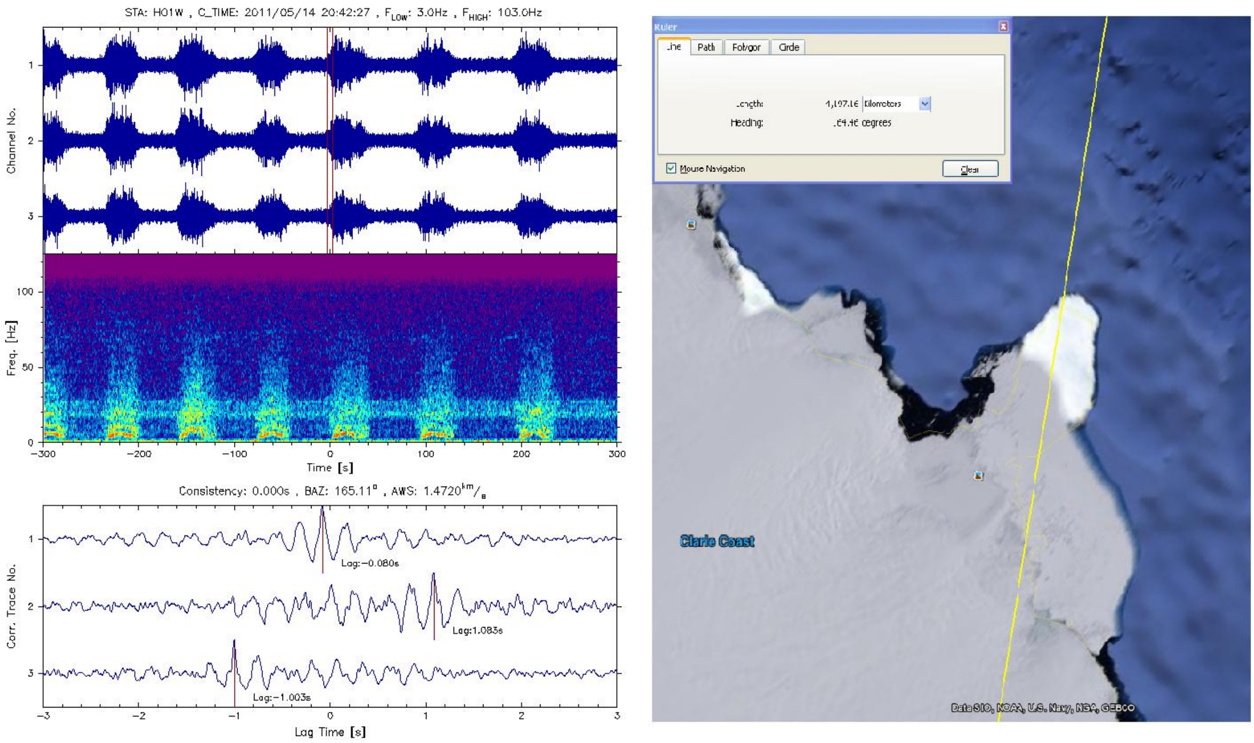


Figure 21: Left: Close-up of broadband (3 Hz to 103 Hz) pressure time series and spectrogram at 20:42:27 ± 300 s on 14 May 2011 for Cape Leeuwin; lower graph shows time lag plot indicating sound originates from bearing 165 deg. Right: Ice tongue on Antarctica at bearing 165.

JUAN FERNÁNDEZ ISLANDS

The noise levels at Juan Fernández (Figure 23) were measured to be more or less the same throughout the year (Figure 24).

Figure 22: Location of Juan Fernández Islands (hydrophone station H03).

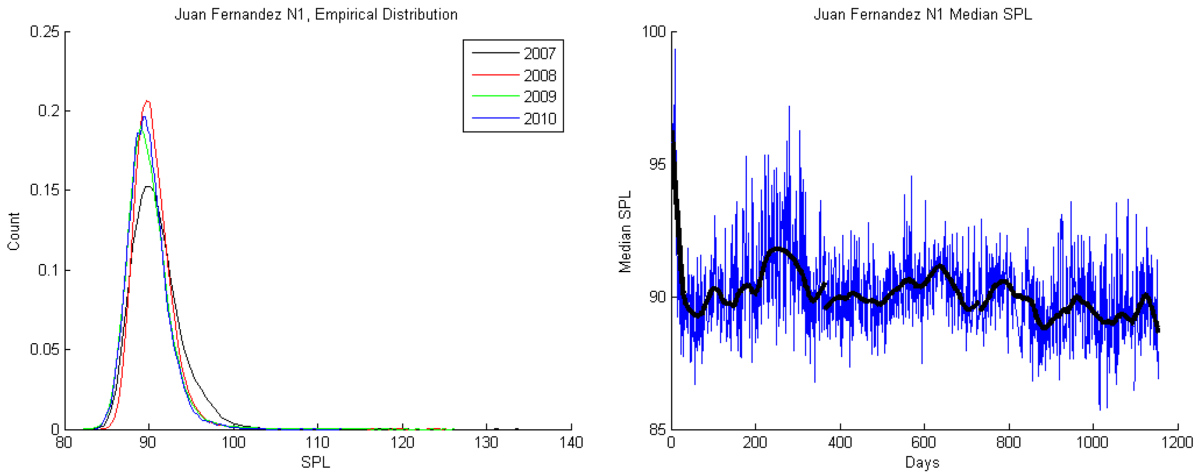


Figure 23: Left graph: Histogram of SPL_{63} distribution for Juan Fernández Islands (T = 65.5 s); daily median of SPL_{63} vs time.

WAKE ISLAND

As with Cape Leeuwin, a strong seasonal cycle at Wake Island (Figure 25) gives rise to an almost bimodal distribution of the sound levels. Since only the first six months of 2011 were available its distribution was more unimodal.

Figure 24: Location of Wake Island (hydrophone station H11), well placed for the Tohoku earthquake.

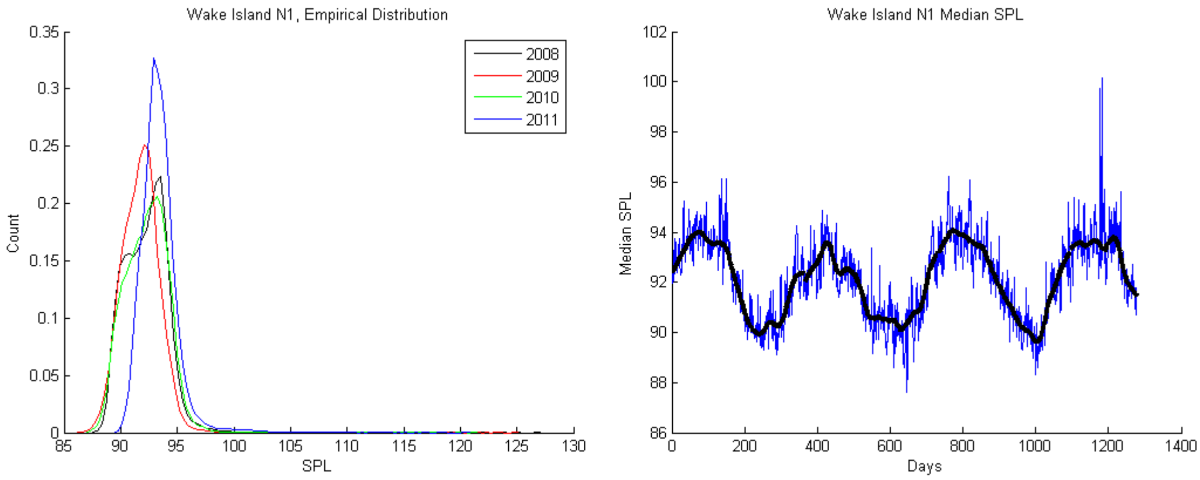


Figure 25: Left graph: Histogram of SPL_{63} distribution for Wake Island (*T* = 65.5 s); daily median of SPL_{63} vs time.

The sharp peak ca. day 1200 (Fig. 27 and 28) corresponds to an earthquake of 11 March 2011 at Tohoku and its aftershocks. Figure 29 shows the time series recorded by the Wake Island hydrophone (H11) two days after the earthquake illustrating these aftershocks. The purpose of Figs 27-29, and later figures examining the possible causes of individual events, is to provide insights that would help assess the possible relevance of such events to masking.

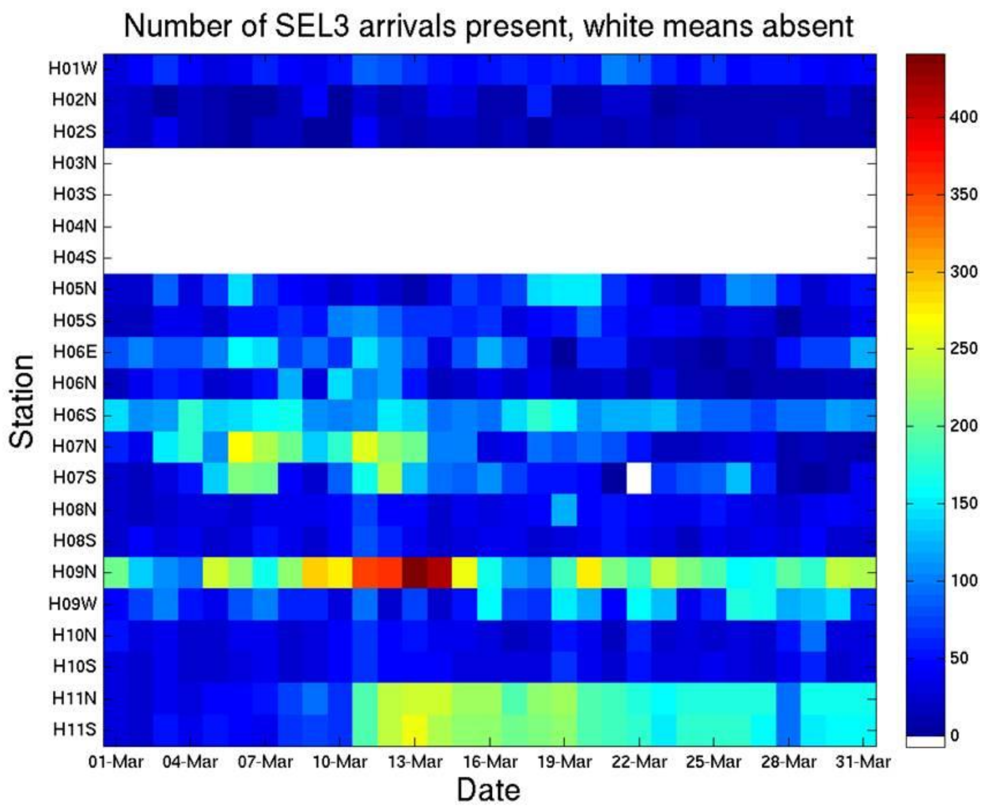


Figure 26: T: The abrupt increase of activity at H11 (Wake Island) on 11 March 2011, caused by the Tohoku earthquake.

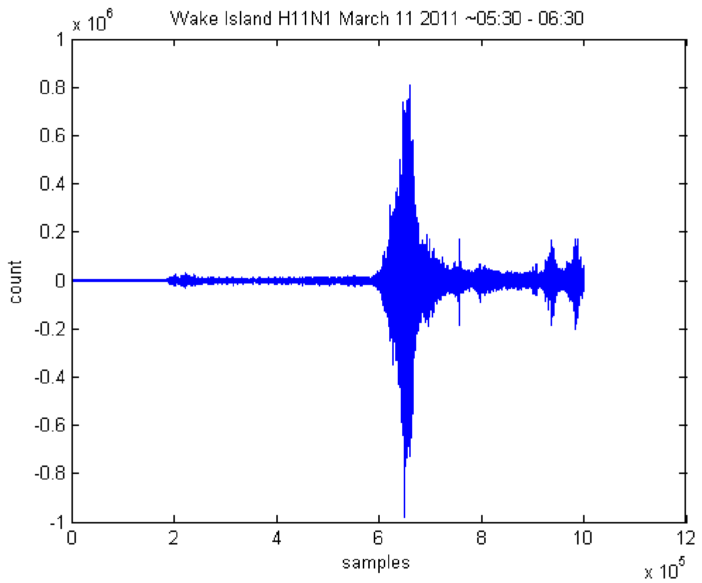


Figure 27: Broadband pressure signature on H11 (Wake Island) caused by Tohoku earthquake on 11 March 2011.The maximum sound pressure magnitude corresponds to a sound pressure of -550 Pa (-10^6 counts, with a sensitivity of 1.83 counts per millipascal).

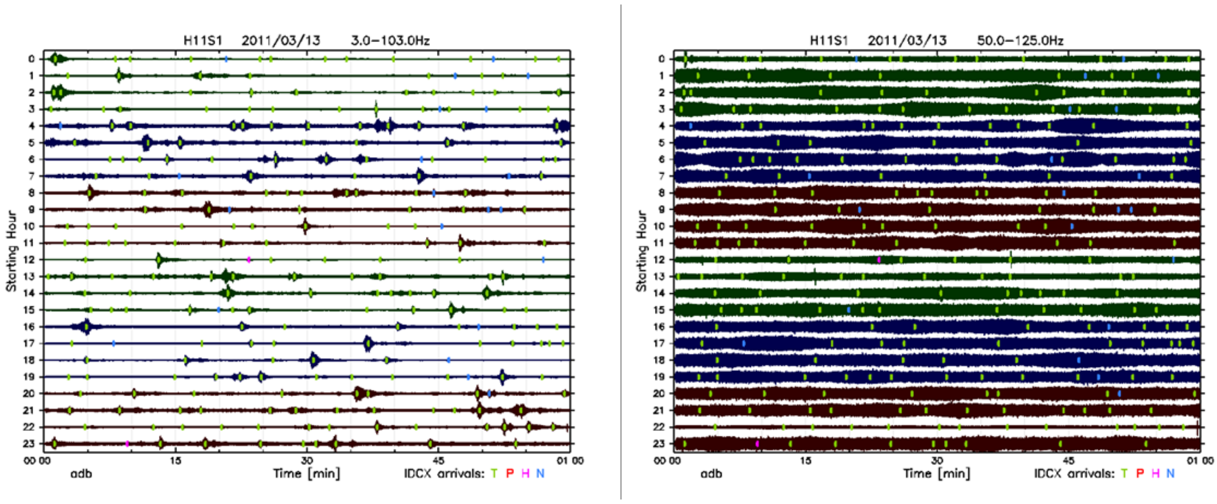


Figure 28: Pressure time series (24 h) for Wake Island on 13 March 2011. Left: broadband (3 Hz to 103 Hz); right: filtered in the frequency band 50 Hz to 125 Hz.

2.8.4 Annual averages

Different systems are likely to use different segment durations, so it is important to look at the effect of changing the averaging time. The term “snapshot” is adopted to mean a collection of one or more segments combined together for the purpose of evaluating the mean square pressure. The snapshot duration (T) is an integer multiple of the segment duration (in this case 65.5 s). For each snapshot duration, the number of snapshots in a year is approximately 365.25 days/T.

Four types of annual average are considered, arithmetic mean, geometric mean, median and mode. The median, denoted $L_M(T)$, is the median of all SPL_{63} snapshots of averaging time T. The mode is the value that appears most often in a set of data. The arithmetic and geometric means are defined as follows.

First the arithmetic mean $A(T)$ is

$$A(T) \equiv \frac{1}{N(T)} \sum_{n=1}^{N(T)} P_n(T)$$

where $N(T)$ is the number of snapshots of duration T in one year (on the assumption that the data are continuous, containing no gaps for an entire year).

$$N(T) = \frac{1\ \text{year}}{T}$$

and $P_n(T)$ is the mean square sound pressure (in 63 Hz band) of the nth snapshot of duration T.

The arithmetic mean is expressed as SPL in dB re 1 µPa (the level of the mean square sound pressure) using

$$L_A(T) \equiv 10\log_{10}\frac{A(T)}{p_{\mathrm{ref}}^{\;2}},$$

where p_{ref} = 1 μPa

The geometric mean $G(T)$ is

$$G(T) \equiv \left(\prod_{n=1}^{N(T)} P_n(T)\right)^{1/N(T)}.$$

The geometric mean is expressed as the average SPL value in dB re 1 μPa using (mean of individual SPL values)

$$L_G(T) \equiv 10\log_{10}\frac{G(T)}{p_{\mathrm{ref}}^{\;2}}.$$

To examine how sensitive these averages are to the snapshot duration T, each of the averages vs sample duration is plotted in Figure 24. It can be seen that that L_A is independent of snapshot duration (as it theoretically should), while the other two averages vary with sample duration by up to 1.7 dB (L_M) and 0.8 dB (L_G). This variation can be examined in more detail by looking at differences relative to L_A and this is done in Figure 25 all averages tend to L_A for long sample duration. Snapshot durations < 65.5 s, not considered here, would lead to larger differences.

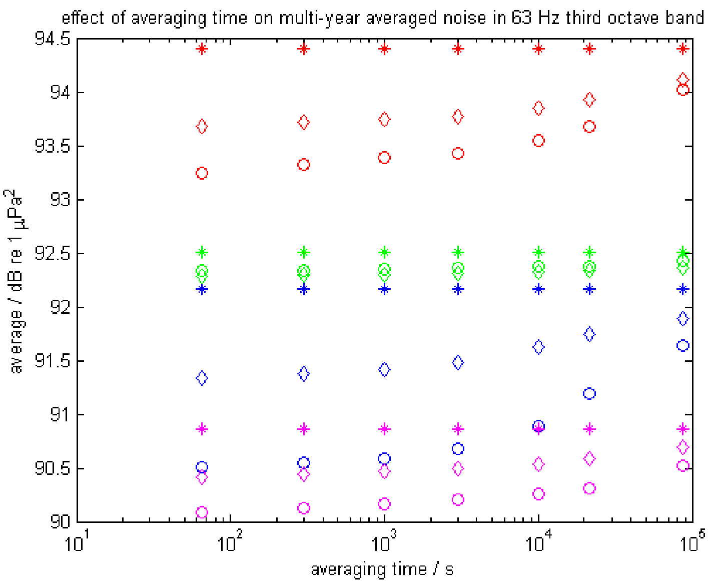


Figure 29: Arithmetic mean (asterisks), geometric mean (diamonds) and median (circles) plotted vs snapshot duration for four CTBTO sites; colours: Ascension Island, Cape Leeuwin, Wake Island, Juan Fernández. The averaging times (snapshot durations) are 65 s, 300 s, 1000 s, 3000 s, 10000 s, 21600 s and 86400 s.

Next we plot the levels relative to the arithmetic mean.

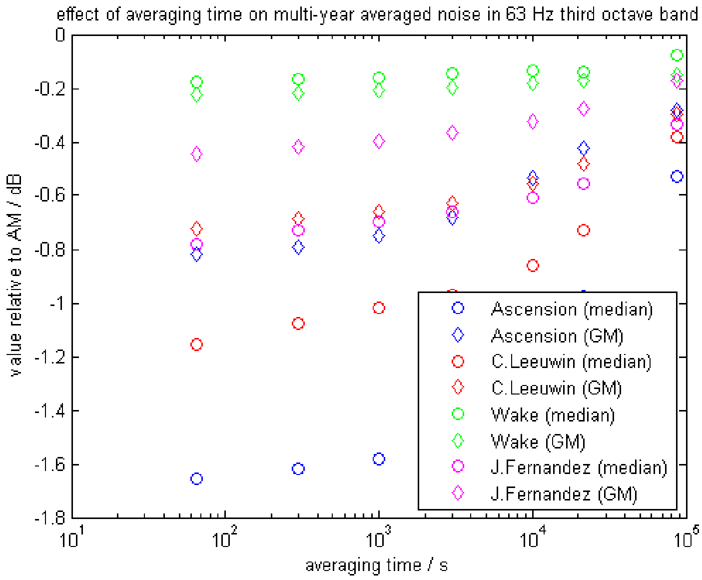


Figure 30: Differences $L_G - L_A$ and $L_M - L_A$ vs snapshot duration for four CTBTO sites; change seems to accelerate (increase in slope) for T > 1 hour; at least for Cape Leeuwin and Ascension Is. colours: Ascension Island, Cape Leeuwin, Wake Island, Juan Fernández.

2.8.5 Pros and cons

	PROS	CONS
Median	Representative of "background noise" if one wishes to exclude infrequent excursions from an otherwise stable background. Moderate dynamic range requirement	Sensitive to changes or differences in sample duration. Excludes high amplitude excursions that might contribute to total noise Incompatible with Leq metric of air acoustics Cannot be predicted using annually averaged properties of sound sources Uncertainty calculations for the median are less straight-forward and tend to lead to larger values than for the mean (for the same population) making the median less discriminating in detection of trends
Arithmetic mean	Robust to changes or differences in sample duration Can be predicted using annually averaged properties of sound sources Compatible with Leq metric of air acoustics Representative of mean acoustic power	Sensitive to outliers (extreme high values) caused by probable acquisition or processing artefacts Well-established metrics calculating uncertainty (variance, etc), although these tend to work better for a Gaussian distribution, which is not expected Requires high dynamic range to capture extreme (high) values
Geometric mean	Representative of "background noise" if one wishes to exclude infrequent (high) excursions from stable background	Sensitive to changes or differences in sample duration. Cannot be predicted using annually averaged properties of sound sources. Incompatible with Leq metric of air acoustics Sensitive to outliers (extreme low values) caused by measurement error. Requires high dynamic range to capture extreme (low) values
Mode	Representative of "background noise" if one wishes to exclude infrequent excursions from a stable background. Represents the most likely level	Sensitive to changes or differences in sample duration, and to the choice of bin size. Cannot be predicted using annually averaged properties of sound sources. Incompatible with Leq metric of air acoustics. Unstable if the distribution contains two or more peaks (e.g. for a bimodal distribution with two different values that are equally probable)

Table 7: Summary of pros and cons.

2.8.6 Discussion

The four requirements for an averaging method are addressed below:

Robust to minor changes or differences in implementation

For the measurements from CTBTO stations presented in this memo, dependence on snapshot duration of L_M is up to 1.7 dB and of L_G up to 0.8 dB (the largest values both occurring for Ascension Island). Variations depend on site, with the smallest variation occurring for Wake Island (up to about 0.2 dB).

Measurements reported by [Merchant *et al.,* 2012] show greater sensitivity in an area close to a heavy shipping lane (and therefore more relevant to Indicator 2), with a dependence of L_M on snapshot duration up to 15 dB and of L_G up to 14 dB.

More important than the magnitude of the difference between L_A and L_M is the year to year variability in this difference. The measurements reported in [Van der Schaar *et al.,* 2013] demonstrate year to year changes between 0.9 dB (Wake Island) and 3.8 dB (Ascension Island).

The value of L_A is always independent of snapshot duration. To obtain an average that is independent of snapshot duration using a geometric mean (GM) or median requires a snapshot duration exceeding 10^5 s (ca. 1 day). Such a long averaging time is not considered practical. An arithmetic mean (AM) is the only kind of average that is robust to the choice of snapshot duration for short snapshots. An additional advantage of AM is that it can be predicted using annually averaged properties of the main sound sources. Use of AM would also permit comparison with other data sets (e.g., CTBTO or US data), likely to use a different snapshot duration than EU MS. The main disadvantages of AM are its sensitivity to high outliers caused by measurement error or equipment failure and the requirement for a high dynamic range to capture high amplitude events. While this is a disadvantage requiring high end recorders, it is an advantage from the biological point of view. High amplitude events, even if very short, are very meaningful from an acoustic ecology perspective and their potential for negative effects in marine life. Correctly quantifying the energy contribution of such events must be an important condition for the correct implementation of Indicator 11.2.1.

Physically meaningful and representative of a large enough region to justify its use as an indicator of GES

It can be argued that infrequent sounds are less likely to affect GES than frequent ones. By infrequent we mean sounds that from an animal's perspective appear as individual events i.e. the response to one sound is not influenced by the response to the previous occurrence of sound of that type. For example, an infrequent sound is unlikely to cause a displacement response because although it may cause startle or injury, a consistent flight response is only likely to occur if the sound is repeated within a certain time period. For example, animals do not generally flee from a single explosion but may be displaced by a seismic survey. For Indicator 2 our interest is in masking, for which it might be appropriate to discard some infrequent sounds.

For example, if one wished to exclude rare events similar to the Tohoku earthquake (see Figure 22), partial or complete exclusion of infrequent sounds can be achieved by means of the GM or median. The risk of doing so is that one might unwittingly exclude sounds of direct relevance to GES (the passage of one ferry per hour might be the only source of anthropogenic sound in an otherwise quiet background; a 3-month long seismic survey that raises the background by 30 dB during that period would be excluded).Overall, the monitoring should aim to distinguish natural and anthropogenic sounds to the extent possible but where this is not possible it is important not to bias ambient noise measurements with infrequent events (as defined above). This requires an averaging method that does not give undue influence to infrequent events but still needs to provide sufficient data to identify that these have occurred (e.g. comparing AM to median).

One can also argue that the physically meaningful quantity is mean square sound pressure if we are interested in the average acoustic power. This would be in line with common practice in air acoustics ISO 1966, where the concept of "Leq" is used for long-term averages of a sound pressure time series, with the values transformed into decibels only after averaging. If the data are available in decibel form (as might be the case if measured using a sound level meter), these must first be converted to pascals squared before averaging and then transformed back to dB afterward [ISO 1996-1:2003]. Essentially, use of an arithmetic mean would be equivalent to an Leq approach, as adopted also, as an interim measure, by CetSound [Gisiner 2012] "The physics and biology of underwater sound make it difficult to come up with a universal metric; [received sound pressure level, sound exposure level], band-averaged weighting or other metrics all fall short under certain contexts. It is sufficient for now that Leq can serve as a kind of 'straw man [proposal]' for weighting the pros and cons of alternatives".[15]

The requirement for Indicator 2 to be representative of a "large region" leads potentially to a need for multiple monitoring locations.

A complete description of the acoustic conditions would need to include both the (yet to be defined) general background level and the contribution of higher intensity events that are significant to the GES regardless of their frequency of occurrence. Loud, impulsive noises can have severe impacts on marine life but - if infrequent enough - might make a negligible contribution to the averaged sound field. Different averages will be more or less sensitive to occasional loud signals but any over-arching description of the acoustic conditions in an area should be sensitive to such signals because they form an important part of those conditions. Conversely, if the sounds are infrequent but still influence the mean, they would have been high intensity events. Therefore, the difference between the AM and the median might be a way of determining the potential for occasional acute effects.

While it is not obvious how this should be done, if the masking background can be represented by one of the higher exceedance levels, a possible way ahead is suggested by [ISO 1996-1:2003], which defines "residual sound", one of three "sound designations", as (emphasis added).

Residual sound: **total sound** remaining at a given position in a given situation when the **specific sounds** under consideration are suppressed

The other two sound designations are:

Specific sound: component of the **total sound** that can be specifically identified and which is associated with a specific source,

and

total sound: totally encompassing in a given situation at a given time, usually composed of sound from many sources near and far

A similar definition of "residual sound" is provided by [ANSI 1988], including the following clarifying note: "Residual sound may be approximated by the percentile sound level exceeded during 90-95 percent of the measurement period."

Also defined by [ISO 1996-1:2003] is the ***N* percent exceedance level**: "time-weighted and frequency-weighted sound pressure level that is exceeded for N % of the time interval considered"

[Miksis-Olds *et al*., 2013] presents a statistical analysis of changes in ambient sound in the frequency range 10-105 Hz at Diego Garcia, in the Indian Ocean between 2002 and 2012. Using a 1 minute snapshot duration, the authors of that paper calculate ten-year trends in the 1 %, 10 %, 50 %, 90 % and 99 % exceedance levels. There are two hydrophones at Diego Garcia, one north of the island and one south. At the southern hydrophone (right-hand graphs, Figure 32), Miksis-Olds *et al* find a consistent increasing trend of order 1.5 dB per decade, except at the 1 % exceedance level (1 % highest intensity), for which no significant trend is visible. At the northern hydrophone (left-hand graphs, Figure 32), there are also clear trends, but the direction (increasing or decreasing) depends on the chosen percentile. The higher

[15] A "straw man proposal" is a simple draft proposal intended to generate discussion of its disadvantages and to provoke the generation of new and better proposals. For more explanation and examples, see http://en.wikipedia.org/wiki/Straw_man_proposal

exceedance levels (99 % and 90 %, corresponding to P1 and P10 in the graph, close to the noise floor) tend to increase with increasing time, while the lower exceedance levels (1 % and 10 %, corresponding to P99 and P90 in the graph, close to the noise ceiling) tend to decrease, with no visible trend in the median (50 % exceedance level). This figure demonstrates the importance of standardising on the statistical processing as well as on equipment and measurements.

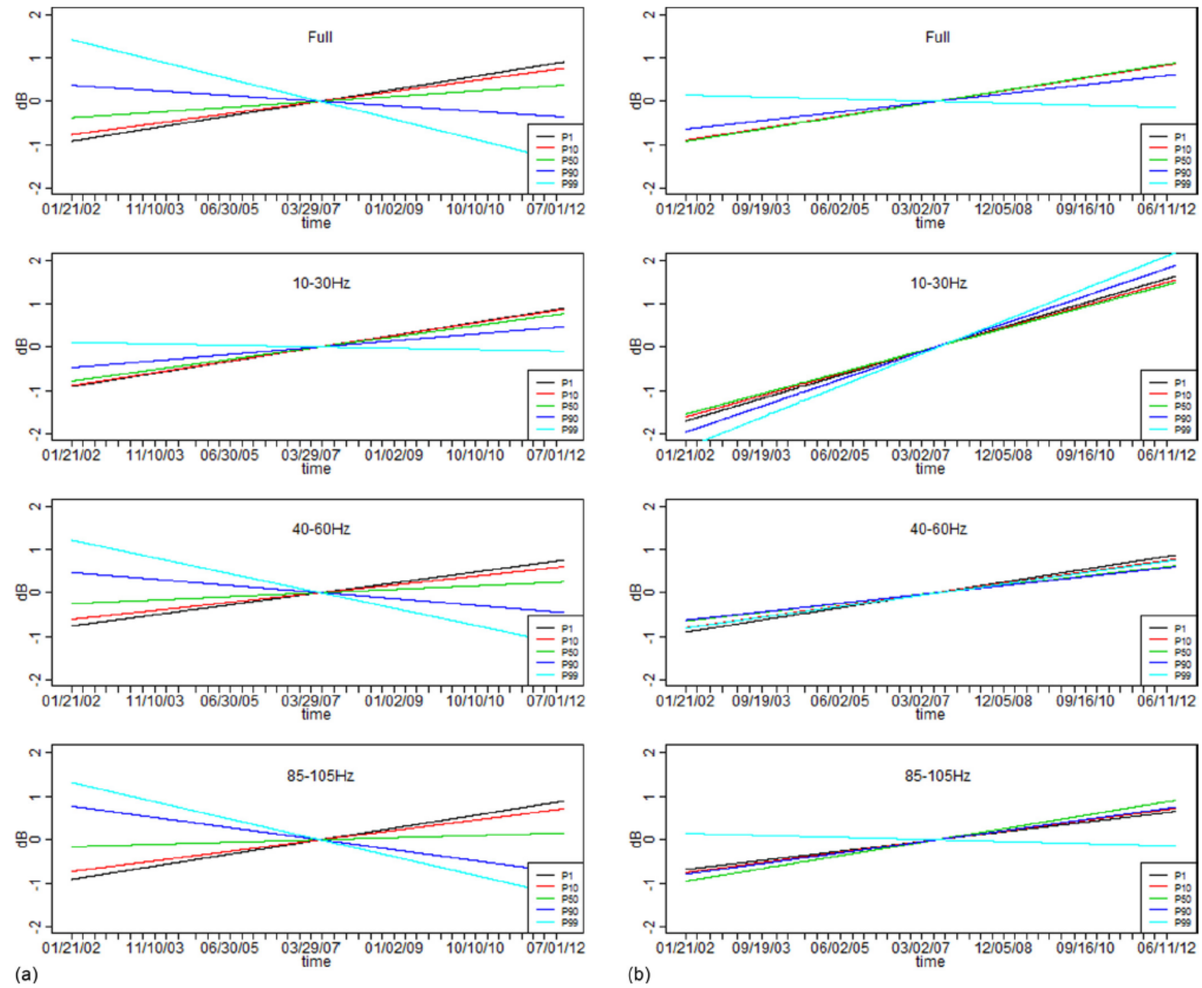


Figure 31 Summary of linear trends for the full spectrum and 20-Hz band analyses from the (A) North (N1) and (B) South (S2) locations. [Miksis-Olds *et al*., 2013]

The duration of the period of (relative) silence between intermittent sounds is an important parameter in determining potential for masking. If we retain only an amplitude distribution we lose this information. Since the main concern with increased ambient noise level is about masking, TSG Noise advises retaining the full sound pressure level distribution vs time for a fixed averaging time to be determined.

Practical (simple to implement)

Any of the four averages considered (AM, GM, median or mode) is simple to implement from the point of view of a single monitoring location, if a data series of SPL snapshots vs time is available at that location. But to claim to monitor GES there is potentially a need for many monitoring stations. We do not expect the number of measurement stations to be large, and the only practical method to extrapolate from a small number of measurements to a large number of monitoring points is through modelling. Any of the averages can be calculated in principle using a computer model of the fluctuating noise field, with which fluctuations due to moving or intermittent sources are then modelled. A sequence in time of the desired duration (for Indicator 2 this would be one year) can be calculated and used to synthesise an annual snapshot distribution, from which the desired statistics can be computed. In practice the large amount of computation required for this approach might cause difficulties. A more practical approach is to average the source distribution over a year and use this average source distribution directly to predict the annually averaged squared sound pressure. Only the AM can be calculated in this way.

Compatibility with comparable regulations or procedures

While compatibility with procedures followed by others is not considered essential, it is at least desirable. Of particular relevance are:

- international standards or agreements for sound in air (e.g. END or ISO 1996/ANSI for residual sound)
- US Cetacean and Sound Mapping 'CetSound' project [NOAA 2012]

The European Noise Directive uses the AM (in the form of an annually averaged Leq) for airborne noise. The US CetSound project has adopted the AM as an interim measure, pending further research.

The ANSI definition of "residual sound" is used by [ref Fristrup *et al.*, pp. 50-53, for sound in air] to justify the 90 percent exceedance level as a measure of "residual or background sound level". For application to underwater noise, a choice of snapshot duration and percent exceedance level would be needed.

2.8.7 Conclusions

The conclusions depend on one's interpretation of "ambient noise" as follows.

Conclusion 1: Use arithmetic mean

AM is the only type of average that for short snapshot durations is compatible with the Feb 2012 TSG definition of ambient noise and robust to differences or changes in snapshot duration. It is also compatible with the annual average noise level required by the Environmental Noise Directive, as well as the "straw man proposal" adopted by Cetsound [Gisiner 2012].

The main disadvantage of AM is its sensitivity to infinities in the data.

Use of the AM follows from the TSG definition. Care is needed to avoid measurement error and equipment failure. This will ensure all sounds are included, both natural and anthropogenic, regardless of their duration, intensity or frequency of occurrence.

Conclusion 2: Use mode

An alternative definition of "ambient noise" as the most likely value leads to the mode. The mode, like the median and GM, depends on the snapshot duration. If one wishes to exclude infrequent sounds from the definition of ambient noise, a possible way of achieving this is by use of the mode. The snapshot duration would need to be chosen carefully to avoid losing the baby with the bathwater. This duration would need to be a constant in order to establish a trend. Infrequent sound events that might be relevant to the GES might be misrepresented.

Conclusion 3: Use a fixed percentile or distribution of percentiles

An example of a fixed percentile is the median. This quantity is sometimes used [Andrew *et al*., 2011, Merchant *et al.,* 2012**Fout! Verwijzingsbron niet gevonden.**, Van der Schaar *et al*., 2013], but the present authors are not aware of a definition of "ambient noise" that would lead to the adoption of median as a metric. The main benefits of the median are its robustness and its low dynamic range requirement.

To the extent that computer modelling is used to monitor ambient noise, use of a fixed percentile (or mode) requires high fidelity predictions of the snapshot distribution resulting from fluctuations in time, which is likely to result in a heavier computational problem, requiring a more complicated computer model, or longer computation time or both.

If one were to define "ambient noise" as "residual noise", then according to ANSI this quantity can be estimated, for sound in air, using the 90 percent exceedance level.

If one requires a metric relevant to chronic effect and wishes to exclude infrequent sounds, the best way to facilitate this is to retain not only the complete probability distribution, but also the time series of SPL snapshots that results in that distribution (because we don't yet know what to calculate, and the separation in time between successive events might be important).

2.8.8 Recommendation

What we seek is a metric of continuous ambient noise that reflects cumulative chronic effects of shipping noise. Research is needed to identify the nature and frequency of occurrence of sounds leading to relevant chronic effects. As an initial measure, TSG Noise advises MS to adopt the arithmetic mean (AM). The main considerations in reaching this recommendation are:

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

The trend is the trend in the AM.

In order to establish the statistical significance of this trend, additional statistical information about the distribution is necessary. 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 (airgun 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, with an averaging time to be specified. If it is not possible to store the full time series, TSG Noise advises to retain the amplitude distribution for this purpose in bins of 1 dB, and the associated snapshot duration (see also chapter 5.6.8). TSG Noise advises MS to use a snapshot duration not exceeding one minute.

2.9 Experience from other projects

(Author: J.F. Borsani)

Ligurian Sea (Mediterranean Sea) long-term low-frequency monitoring (1999-2002).

From 31 August 1999 to 7 September 2002 autonomous recorders (called "Pop-Ups") were deployed in the Ligurian Sea. The deployments were part of a collaborative study between ICRAM – the Italian Central Institute for Marine Research (now ISPRA) and the Bioacoustics Research Project of Cornell University, USA. Eighteen autonomous recorders, sampling in ranges from 1 kHz to 2 kHz were deployed at water depths between a few tens of metres and 1421m. A total of 15 720 hours of sound recordings were extracted. Several lessons with respect to a) deployment techniques and b) analysis methods were learnt. Scientific results are summarized in Clark *et al.* [2002] and Borsani *et al.* [2008].

Recommendations made by [Borsani *et al*., 2008] include:

1) Small hydrophone arrays (e.g. 3-4 elements) perform better than single recording units (noise reduction, range and direction finding up to a certain degree depending on array aperture);
2) The deeper the hydrophones are deployed, the better, although there might be an issue with calibration for deep hydrophones (minimizes surface noise, avoids low-frequency cut off, prevents collisions, minimizes risk of trawling and accidental removal);
3) Free mooring lines of at least 10 m with kit weighing a maximum of 20 kg in air must be provided (prevents kit from banging on sea bottom);
4) Soft anchors (e.g., sandbags) are better than discrete anchors with chains (minimizes self-noise of the mooring, minimizes the risk of drifting and melts with the substrate);
5) "Silent" mooring is mandatory (all metal or hard plastic parts must be embedded in rubber to avoid self-noise and corrosion)
6) Solid state drives are better than hard disk drives (no spin-up noise and low power drain, equals longer duration)
7) At the same cost of deployment, a higher sampling rate is achievable if a statistically robust duty cycle is applied (e.g., for shipping noise 1 hour on – 11 hours off)
8) Continuous recording of at least 60 minutes in a row is desirable; duty cycling may be appropriate (usually 60 minutes comprise a whole ship passage as well as small bits of ambient noise levels).
9) Archival recorders have the draw-back of being at risk of data-loss. In addition, huge data sets produced as a result of long deployments pose a serious challenge to IT resources as well as to staff. The road of real-time or delayed time data transmission is promising and must be explored.
10) If analysis is done manually 1 hour of recordings @ 2 kHz signal recording can take up to 3-5 hours for analysis and reporting; automatic or semi-automatic systems mitigate this but need frequent maintenance and instructions.

2.10 Rate of the increase of 63 Hz band underwater noise in the Pacific Ocean

(Author: M.A. Ainslie)

Summary

The purpose of this section is to quantify the rate of increase of ambient noise based on available measurements since the 1960s. Because no suitable data are available in European waters, the data used are taken from [Andrew et al. 2011], for the north-east Pacific Ocean. Conclusions are listed in the final sub-chapter.

2.10.1 Introduction

The Commission Decision of 2010 [EC, 2010] proposes to determine trends in ambient noise. In this note an estimate is provided of the rate of increase of sound pressure level (SPL) at 63 Hz third-octave band in the northeast Pacific based on the measurements described by [Andrew *et al.*, 2011].

2.10.2 Overview of available data

The following table lists the spectral density levels (SDLs) reported in Table II from Andrew *et al.* [2011] in the 63 Hz third octave band[16] for measurements carried out ca. 1965 (column 2) and ca. 2000 (column 4). The SDL is converted to SPL in columns 3 and 5. The increase (difference between 2000 and 1965 values) is listed in column 6.

	Wenz (ca 1965)		APL UW (ca 2000)		increase
system	**SDL / dB re 1 μPa²/Hz**	**SPL / dB re 1 μPa**	**SDL / dB re 1 μPa²/Hz**	**SPL / dB re 1 μPa**	**total (per decade) / dB**
d (Point Sur)	82.0	93.6	87.0	98.6	5.0 (1.4)
f (San Nicolas Island)	74.4	86.0	80.5	92.1	6.1 (1.7)
g (near northern California)	79.2	90.8	81.8	93.4	2.6 (0.7)
h	82.0	93.6	87.7	99.3	5.7 (1.6)
average	**80.3**	**91.9**	**85.3**	**96.9**	5.0 (1.4)

Table 8: Spectral density levels (SDLs); Andrew et al. [2011] in the 63 Hz third octave band for measurements carried out ca. 1965 (column 2) and ca. 2000 (column 4).

Measurements are reported for four deep water sites in the northeast Pacific Ocean. Spatial averages (across the 4 sites) are calculated using a linear average in mean square pressure "average". For this row the "increase" column shows the increase in the average (and not the average of the 4 separate increases, which is 4.9 dB).

The averaging methods applied by Wenz and APL are not identical. APL calculates a median, which is sensitive to the snapshot duration (163.84 s)[17] , while Wenz calculates a geometric mean after removing outliers. According to Andrew *et al.* [2011], this process is approximately equivalent to the median. The snapshot duration used by Wenz is ca 200 s.

[16] values at 125 Hz are not included in Table II of Andrew *et al.*

[17] Averaging procedure described on p643

Both the median and geometric mean (GM) underestimate the true sound pressure level, which by definition is calculated using an arithmetic mean (AM) of the squared pressure samples. The difference between the median (or GM) and the AM depends on the details of the distribution. For CTBTO sites it is between 1 dB and 6 dB, the averaged difference between the GM and the AM is approximately 2.25 dB [Van der Schaar *et al.,* 2013, Marine Systems (submitted)].

2.10.3 Conclusions

- The difference of 5 dB in 35 years amounts to 1.4 dB per decade on average, in deep water.
- A similar trend can be expected in deep water in other parts of the industrialised world. It is not possible to confirm this expectation by measurements in European waters because it is about the last 35 years of the 20th Century, for which no suitable measurements are known to the authors. It might be possible to do so by means of a hind cast with a validated computer model.
- In shallow water the trend is likely to be different. There is no information available on whether this trend is likely to be greater or less than 1.4 dB/decade in shallow water.
- Spatial variation in SPL at 63 Hz across these deep water sites is ca 8 dB. In shallow water the variation it is likely to be greater than in deep water.

ANNEXES:

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List of Figures

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List of Symbols, Acronyms and Abbreviations

SYMBOLS, ACRONYMS AND ABBREVIATIONS	DESCRIPTION
ADC	Analogue to Digital Converter
ADD	Acoustic Deterrent Device
AHD	Acoustic Harassment Device
AIS	Automatic Identification Systems
AM	Arithmetic mean - the TSG Noise interpretation
ANSI	American National Standards Institute
APL UW	Applied Physics Laboratory, University of Washington (USA)
ASA	Acoustical Society of America
BIAS	Baltic Sea Information on the Acoustic Soundscape
BOEM	Bureau of Ocean Energy Management (USA)
CD	Commission Decision 2010/477/EU
CMRC (Ireland)	Coastal and Marine Research Centre, Ireland
CNOSSOS-EU	Common Noise Assessment Methods of the European Union
CS	cylindrical spreading
CTBTO	Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization / in part 2 as: Comprehensive Nuclear-Test-Ban Treaty Organization
dB	decibel, the most generally used logarithmic scale for describing sound
DECC	Department of Energy and Climate Change (UK)
DG ENV	Directorate General on Environment of the European Commission
EC	European Commission
EEZ	Exclusive Economic Zones
E_{hammer}	Hammer energy
EIA	Environmental Impact Assessment
END	Environmental Noise Directive: European Directive 2002/49/EC [2002/49/EC]
EU	European Union
EUCC	Coastal & Marine Union (EUCC)
GCS European 1950	GCS, GEOGCS (Geographic Coordinate System)
GES	Good Environmental Status as defined in the MSFD
GM	Geometric mean (- equivalent to average in decibels)
h	hours
H#	CTBTO hydrophone station, no. #
Hz	hertz, the SI unit of frequency defined as the number of cycles per second of a periodic phenomenon
ICES	International Council for the Exploration of the Sea
ICRAM	Italian Central Institute for Marine Research (now ISPRA)
IEC	International Electrotechnical Commission
IEC 60565-2006	Norm: Underwater acoustics - Hydrophones - Calibration in the frequency range 0,01 Hz to 1 MHz
IMARES	Institute for Marine Resources & Ecosystem Studies, Wageningen, NL
IQOE	International Quiet Ocean Experiment
Irish EPA	Environmental Protection Agency, Ireland
ISO	International Organization for Standardization
JNCC	Joint Nature Conservation Committee (UK)
LIDO	Listening to the Deep-Ocean Environment
LIFE+ programme	Regulation (EC) No 614/2007 of the European Parliament and of the Council of 23 May 2007 concerning the Financial Instrument for the Environment (LIFE+)
log	logarithm
MPA	Marine Protected Areas
MS	Member State (of the EU)
MSFD	Marine Strategy Framework Directive, 2008/56/EC
m_{TNTeq}	TNT equivalent charge mass
nmi	Nautical mile (1 nmi = 1852 m)

SYMBOLS, ACRONYMS AND ABBREVIATIONS	DESCRIPTION
NOAA	U.S. National Oceanic and Atmospheric Administration
NRC	National Research Center (USA)
NW-Europe	North-West Europe
OSPAR	The OSPAR convention (short for "Oslo-Paris" convention) is the current legal instrument guiding international cooperation on theprotection of the marine environment of the North-East Atlantic.
Pa	pascal, the SI derived unit of pressure (one newton per square metre)
PCAD	Population Consequences of Acoustic Disturbance
PL	propagation loss
Quonops	Ocean Noise Anthropogenic Forecasting Platform
RL	Received Level
RMS	Root mean square
RNLN	Royal Netherlands Navy
R_{ps}	ranges where response is relevant
RWS	Rijkswaterstaat (NL)
SDL	spectral density level
SEL	sound exposure level
SEAMARCO	Sea Mammal Research Company
SI	The International System of Units
SL	source level
SL_E	energy source level
SL_{zp}	zero to peak source level
SPL	sound pressure level
STRIVE Noise	Science, Technology, Research and Innovation for the Environment
T	snapshot duration
TG11	Task Group of Descriptor 11 (Noise/Energy) of the MSFD (EC Decision 2010/477/EU)
TNO	Netherlands Organization for Applied Scientific Research (NL)
TNT	Trinitrotoluene, C6H2(NO2)3CH3
TSG Noise (TSGN)	EU Technical Subgroup on Noise
TTS	temporary hearing threshold shift
UBA	Umweltbundesamt: Federal Environment Agency, Germany
UK	United Kingdom
US CetSound	"As a result, two data and product-driven working groups were convened in January 2011: the Underwater Sound-field Mapping Working Group (SoundMap) and the Cetacean Density and Distribution Mapping Working Group (CetMap). The overarching effort of both Working Groups is referred to as CetSound.
VMS	Vessel monitoring system
WG GES	EU Working Group Good Environmental Status
WGS84	World Geodetic System, the reference coordinate system WGS 84 is used by the Global Positioning System.
µPa	micropascal

Note: The SI units and unit symbols that are used in this report are not listed in this list, these are followed according to BIPM SI brochure (8th edition), available from http://www.bipm.org/en/si/ .