NATURAL AND ANTHROPOGENIC SOURCES OF SOUND IN THE NORTH SEA

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Abstract: *This paper summarises the progress made by TNO on describing the most significant natural and anthropogenic sound sources in the North Sea (Dutch sector). An assessment of their relative importance is made by estimating an annual energy budget, not neglecting that details of the sound distribution in frequency, time and space might be equally important. Our approach to propagation modelling of the noise sources in the shallow waters near the Dutch coast is explained. Example noise maps are presented. Validation of the noise predictions requires a capability for long-term noise monitoring. Suitable monitoring solutions are discussed.*

Keywords: *Underwater sound sources, North Sea, energy budget, noise maps*

1. INTRODUCTION

For a proper (national) implementation of the European Union's ambitious Marine Strategy Framework Directive, it is required that the impact of anthropogenic activities on the North Sea environment be assessed thoroughly. One of the effects of the use of the North Sea by humans is the generation of underwater sound. Sound propagates over longer distances in water than in air. The impact of anthropogenic underwater sound sources could therefore be serious.

At this time, there is insufficient information on the underwater sound environment in the North Sea to make an impact assessment. Once this information becomes available, the next challenge is to predict correctly how the sound propagates in the shallow water of the North Sea, i.e. to find out the sound footprint of individual anthropogenic or natural sources of sound. The research reported on here assesses the existing knowledge on the underwater sound environment and identifies the gaps.

The first step is an inventory of all relevant natural and anthropogenic sources of sound, similar to Ref. [1], with specific information on source levels, frequency bands, etc. Sound sources in the air (e.g. aircraft) are excluded from the study. The study is limited to the Netherlands Continental Shelf (NCP), which covers an area of approximately 57,000 km^2.

2. NATURAL SOUND SOURCES

Ubiquitous natural underwater sound sources are wind and rain. Lightning is also subject to scrutiny because of the large amount of energy available in each individual strike. Compared to the sound levels due to these causes, the levels due to underwater fauna – marine mammals, fish, crustaceans and other biota – are small. As such, the animals do not substantially contribute to the total (time-averaged) sound levels in the North Sea. Other natural sources in the North Sea include precipitation other than rain, breaking gravity (surf) waves, wave-wave interactions and gravel noise.

For the main natural sources wind, rain and lightning, the total acoustic energy produced on an annual basis in the NCP has been estimated by Ref. [2]. Based on formulas from Ref. [3] for the spectral density of the wind's dipole strength, the total radiated acoustic power on the NCP is estimated to first order. For wind speeds of 5-10 m/s at 10 m above the sea surface, the underwater acoustic power due to wind equals 2-9 GJ/y (gigajoules per year). Similarly, again using formulas from Ref. [3], the total radiated acoustic power of rain is estimated. In these simple formulas, the influence of drop size is neglected. For an annual rainfall of 800 mm, uniformly spread over the NCP area, the underwater acoustic power due to wind is estimated to be 0.3-1 GJ/y.

Only little has been published on underwater acoustics of lightning strikes. Ref. [4] estimates a source level of 260.5 dB re 1 $\mu Pa^2 m^2$, which for a typical strike duration of 30 μs converts to a source energy of 30 kJ. Assuming 2 strikes per km^2 per year [5], this gives $114{,}000 \times 30$ kJ/y $\approx$ 3.4 GJ/y for the underwater acoustic power due to lightning. Assuming further a total discharge energy of 500 MJ [5] (http://en.wikipedia.org/wiki/Lightning), this implies a 0.006% efficiency for conversion of electrical energy of the discharge to acoustic energy in the water. In practice, the estimation of source level, and the associated conversion efficiency, is speculative and subject to high uncertainty (several orders of magnitude).

3. ANTHROPOGENIC SOURCES

The anthropogenic sources are divided in two categories: intentional sound sources and unintentional ones. The latter are undesirable by-products, e.g. shipping noise, while for the former the production of sound is essential, e.g. sonar.

Relevant intentional sources are airgun arrays for seismic explorations, sonar equipment (single- and multi-beam echo sounders, sub-bottom profilers, side-scan, fish-finding, research and military search sonar) and acoustic deterrent devices. Other minor or unknown intentional sources are obstacle avoidance sonar, minesweeping equipment, Doppler current profilers, acoustic communications equipment, acoustic transponders and acoustic cameras.

Important unintentional sources include shipping (merchants, ferries, super/tankers, leisure craft, fishing vessels), pile driving for offshore construction, dredging, underwater explosions (mine & bomb clearance), operational oil & gas platforms and wind farms.

Other minor or unknown unintentional sources are pipe laying, cable laying, flow noise from pipelines, industrial/harbour noise and wind farm/offshore decommissioning.

The total acoustic energy produced on an annual basis on the NCP by the main anthropogenic sources has been estimated by Ref. [2], of which the results are summarised in column 2 of Table 1. From these values, it might seem that echo sounders contribute about 10 times more to the underwater sound than pile driving. However, this would be a misleading interpretation as the two sources have very different frequency ranges. Therefore, the total acoustic energy of the noise sources has been calculated, accounting for frequency-dependent absorption [2], as explained below.

For every source, the free-space energy density has been calculated, assuming a point source of the same power and frequency and assuming spherical spreading with frequency-dependent absorption. Estimates of the total acoustic energy are then obtained by integrating the energy density over all space. The results are given in column 4 of Table 1, which shows that the total sound energy due to pile driving exceeds that due to echo sounders by at least two orders of magnitude.

The table also shows that four of the sources considered, namely airguns, shipping, pile driving and explosions, result in significantly more sound energy than the remaining three. These four are all low-frequency sources, resulting in low absorption, long-range propagation and hence the high estimated values of total sound energy. It does not necessarily follow from this that they have the greatest impact, because some animals are most sensitive to high-frequency sounds that might propagate less effectively, resulting in lower estimates of total energy. A complete impact analysis should consider other aspects as well, such as temporal or spatial variability.

Table 1. Estimation of annual average acoustic power output of anthropogenic sound sources on the NCP (column 2) and order of magnitude estimation of the total (free-space) acoustic energy (column 4).

Type of source	**Estimated annual average of acoustic power output in the North Sea (NCP)** **[GJ/y]**	**Order of magnitude estimation of frequency** **[kHz]**	**Order of magnitude estimation of time-averaged total (free-space) acoustic energy** **[kJ]**
Airgun arrays (3D seismic survey)	30-300	0.01-1	1000-10,000
Shipping	85-850	0.03-3	1000-10,000
Pile driving (wind farm construction)	2-20	0.01-1	100-1000
Explosions (clearance of historic munitions)	< 14	0.01-1	100-1000
Navigation echo sounders	20-200	10-300	< 1
Fish-finding sonar	3-30	10-300	< 1
Military search sonar	< 0.2	1-100	< 1

4. NORTH SEA NOISE MAPS

For estimation of the spatial noise distribution due to sources in the North Sea, a simple and robust underwater sound propagation model has been implemented in a computer code. The applied modelling methodology is based on the work by D.E. Weston [6]. As an example, some noise maps are presented for a selection of cases in Fig. 1. It should be emphasized that these maps are mainly indicative, due to the uncertainties involved (measured source levels, modelling of environment).

For the dredger cases, the source spectrum of the trailing suction hopper dredger *Gerardus Mercator* is used (http://www.sakhalinenergy.com/en/documents/doc_33_cea_tbl4-7.pdf). The wind farm consists of 60 turbines. The source spectrum of each turbine was derived [2] from measurements of a Danish Bonus turbine (*Paludans Flak* [7]). The received noise levels are averaged over depth.

The source levels of wind and rain are computed using the formulas from [3] (and [2]), using 30-year averages for the wind speed distributions (ERA-40 database, accessible via http://climexp.knmi.nl) and a uniform precipitation density. The received noise level is computed at the seabed for these noise maps.

Looking at Fig. 1, the influence of the local water depth is clearly visible for the dredger and rain noise maps. Fig. 2 shows that the dredger noise levels are relatively small in the lower octaves, due to duct cut-off, and in the higher octaves, due to surface scattering and absorption.

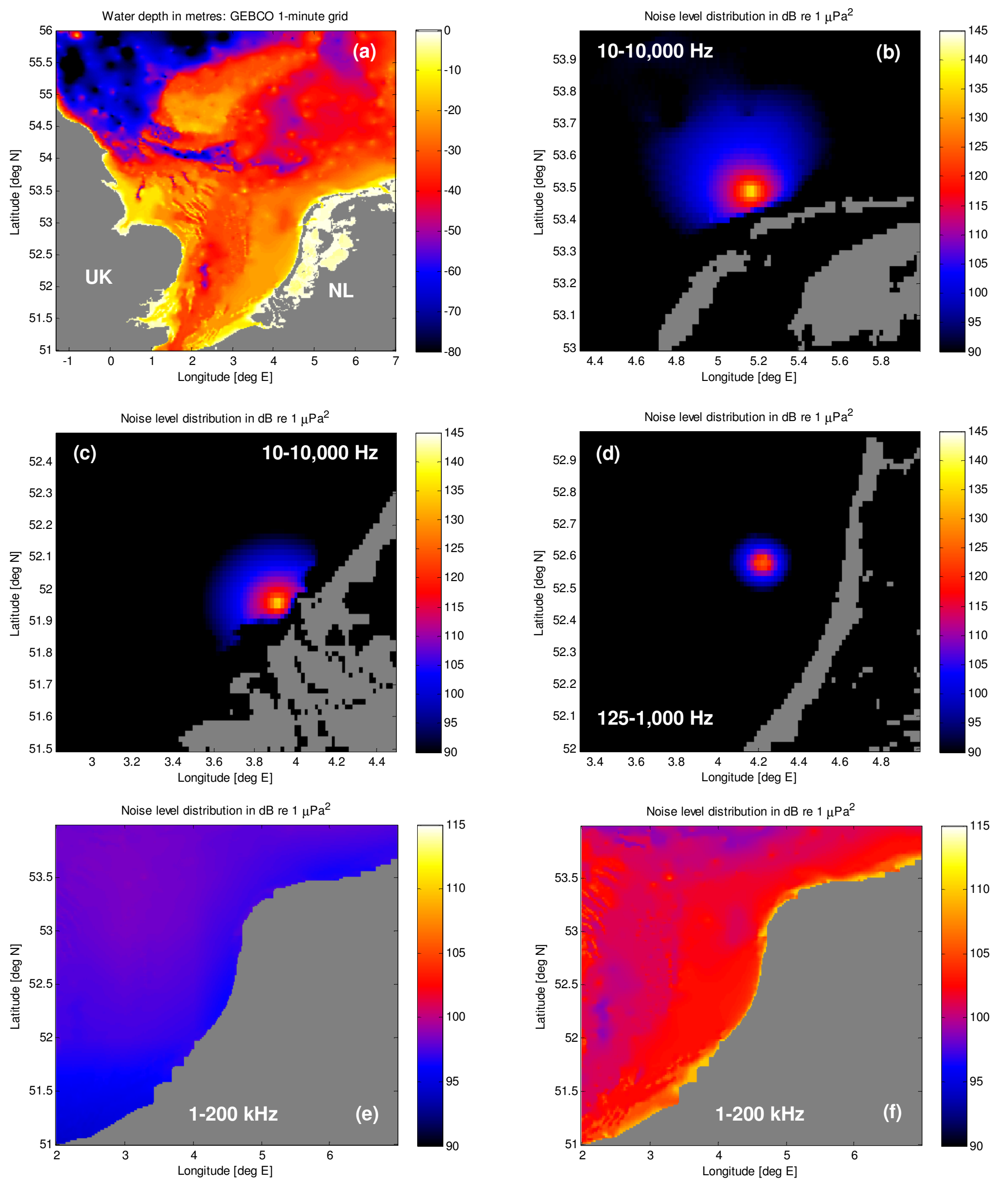

Fig. 1. (a) Bathymetry of the North Sea (GEBCO 1-minute grid). Grey indicates areas above (mean) sea level (a-d). The other panels show simulated broadband noise distributions (received sound pressure level) for (b) a dredger north of the Dutch Wadden Islands, (c) the same dredger near the Rotterdam harbour, (d) a wind farm northwest of Amsterdam, (e) wind noise (at the seabed) in January, and (f) rain noise (at the seabed) for a uniform rain rate of 5 mm/h and an annual wind speed distribution.

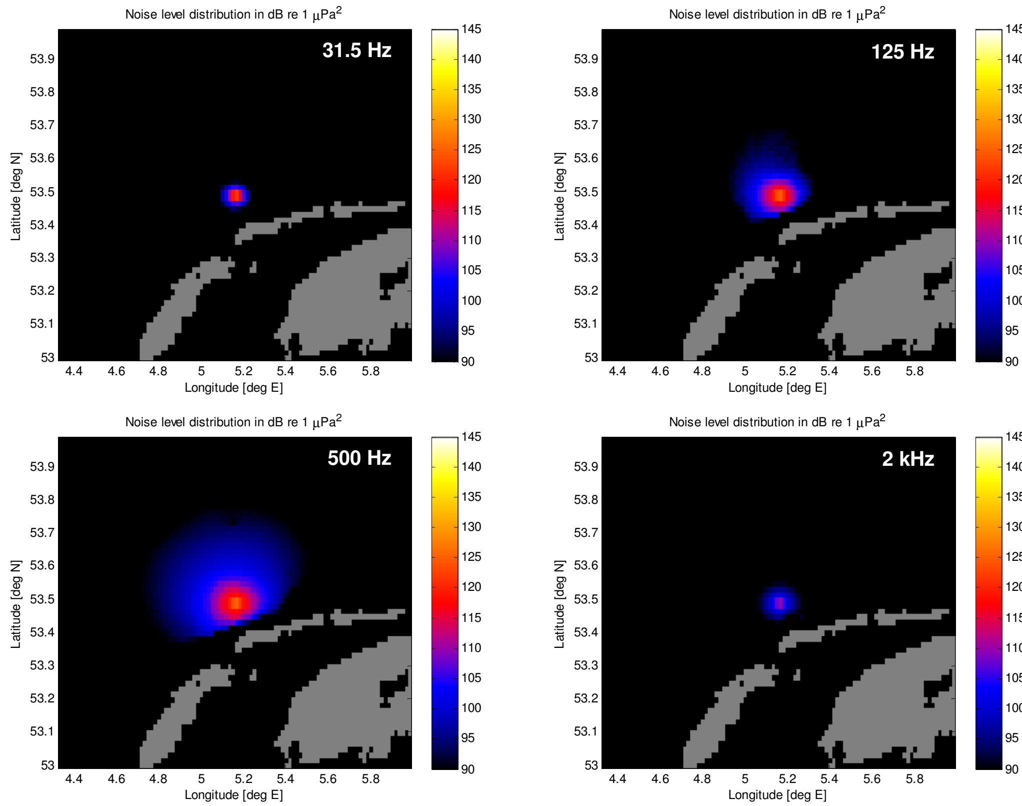

Fig. 2. The noise distribution of Fig. 1b in 4 octave bands with centre freqs. of 31.5, 125, 500 and 2000 Hz.

5. MONITORING SOLUTIONS

The assessment of noise sources in Sections 2 and 3 is based on the scarce data that we have been able to find in publications or acquired through our professional contacts. Also, the demonstrated noise map capability relies on the availability of reliable source level distributions and noise measurements for validation of the modelling assumptions.

What is needed is a (semi) continuous and systematic underwater measurement effort that will reveal the actual noise levels and their variation in time throughout the NCP. This will require an extensive grid of autonomous underwater monitoring stations.

Table 2. Inventory of monitoring systems [8].

Monitoring system	Supplier
PAL	APL-UW (US)
RUDAR	Cetecean Research Technology (US)
WAMS	High Tech (US)
SRB-16	High Tech (US)
IMARES	IMARES (NL)
BANAS	Istanbul Technical University (TU)
OBHS	KUM (GE)
AURAL-M2	Multi Électronique (CA)
RASP MT200	Nauta (IT)
EAR	Oceanwide Science Institute (US)
OptaMarine	OptaSense / QinetiQ (UK)
HARP	Scripps Whale Acoustic Lab (US)

An inventory of long-term monitoring solutions was made recently [8] to be able to judge the present state-of-the-art of commercially available monitoring systems. A total of 12 (potentially) suitable systems has been identified, see Table 2. Which one of them is to be preferred depends strongly on the specific requirements regarding flexibility, technical specifications (energy consumption, storage capacity, dynamic and frequency range, recording scheme, sensitivity, etc.), ease of handling and price.

For most systems, the endurance is limited by storage capacity and not by battery life. The endurance for battery-fed systems is up to one year, when not continuously recording.

6. CONCLUSIONS AND RECOMMENDATIONS

The main contributions to sound energy in the North Sea are estimated to come from shipping, seismic surveys (airguns), underwater explosions and pile driving. This energy estimation takes no account of the hearing sensitivity of individual species.

To find out the sound footprints of these sources, e.g. needed for the development of suitable mitigation measures [2], underwater sound maps are needed. In order to make reliable noise maps, a systematic measuring effort of relevant source level distributions and environmental noise levels should be set up. This requires suitable monitoring solutions and international agreement on guidelines and protocols for the measurement, processing and quantification of underwater sound.

Finally, there is a demand for research on the possible impact of underwater sound on diverse species. This refers to the individual physiology and the short-term dose-response relationship as well as to the long-term impact on the population. It is therefore recommended that experts from various disciplines (acousticians, ecologists, biologists) establish some sort of platform with the aim of improving the collaboration.

7. ACKNOWLEDGEMENTS

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