seminar in Tallinn, 25.01.2013

GES REG

GOOD ENVIRONMENTAL STATUS THROUGH REGIONAL COORDINATION AND CAPACITY BUILDING

PRINCIPAL UNDERWATER NOISE SOURCES IN BALTIC SEA AND METRICS USED IN NOISE LEVEL ASSESSMENT

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- *background*
- *indicators*
- *noise sources*
- *soundscape*
- *thresholds*
- *sound levels*
- *conclusions*

BIAS

KIK

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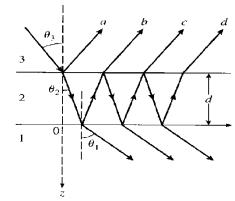
background

- The underwater noise level is increased over the past decades mainly due to the increased anthropogenic use of the seas worldwide
- Underwater noise levels from shipping, marine constructions, *etc.* have raised concerns regarding chronic impacts of anthropogenic noise on marine fauna (Baltic Sea fish, seals and harbour porpoise)
- Baltic Sea is a shallow brackish water basin, which has complex acoustic conditions due to main halocline, shallow coastal areas, heavy fresh water fluxes, *etc.* Sea bed composition is highly variable due to the presence of sand, mud, bedrock, clay, *etc*. Also seasonal variability includes storm surges and ice coverage.
- Systematic information on ambient noise trends is not available for Baltic Sea

sound characteristics

1. SOUND SPEED [*c*] = m/s

The speed of sound depends on the medium the waves pass through (in water 1482 m/s). Sound speed in the sea depends on temperature *T* (°C), salinity *S* (‰) and depth *z* (m), and is estimated by an empirical function:



Brekhovskikh & Lysanov (2003)

$$c_{water} = 1449.2 + 4.6\,T - 0.055\,T^2 + 0.00029\,T^3 + \ldots + (1.34 - 0.010\,T)(S - 35) + 0.016\,z.$$

2. FREQUENCY [*f*] = Hz

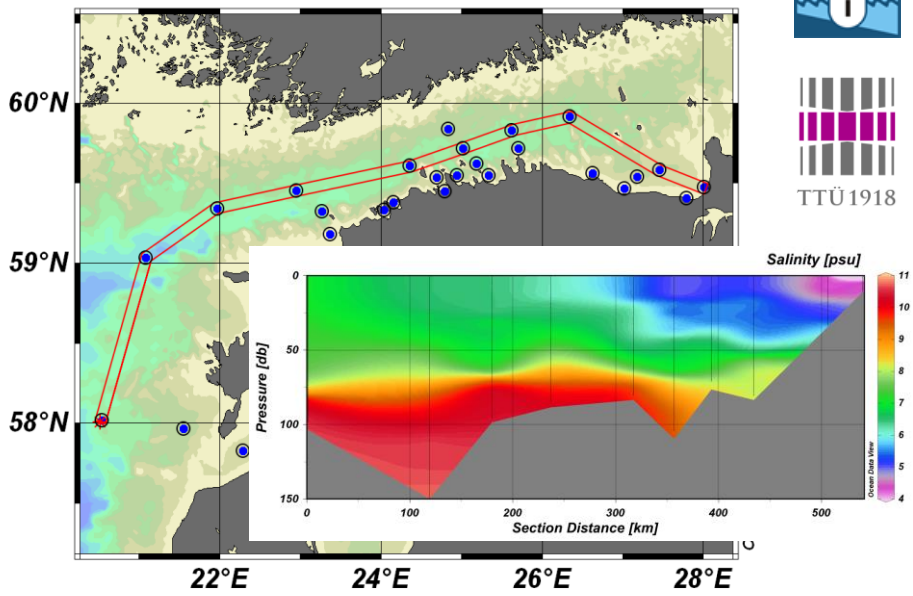
The sound waves have cut off frequency f_0 in the shallow sea (< 200 m deep) :

$$f_0 = \frac{c_{water}}{4h}\sqrt{\frac{1}{1-\left(c_{water}/c_{sediments}\right)^2}}$$

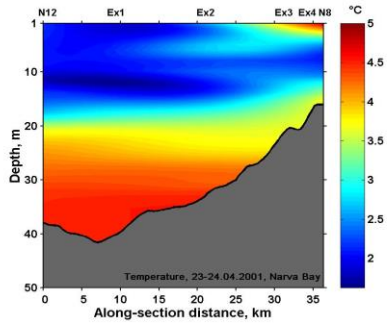
Urick (1983)

Conclusion: sound travels in water about five times faster than in air and absorption is less compared to air. Sound in water is a traveling wave, which can be measured by pressure changes and particle motions (acceleration).

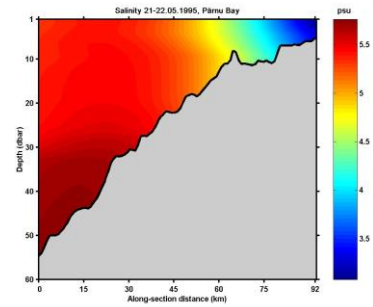
Baltic Sea oceanography



Gulf of Finland



Gulf of Riga



European Commission Decision of 2010 (EC 2010)

- EC MSFD Descriptor 11 on underwater noise and other forms of energy: "Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment"
- At present TSG-11 group (personal communication with Peter SIGRAY) is clarifying the purpose, use and limitation of the indicators and methodological standards. Following division of sounds is proposed:

    1 Multiple impulsive (air guns, piling)

    2 Single impulsive (explosions)

    3 Non-impulsive (sonars)

    4 Continues sound (ships, infrastructures)

noise - is taken to mean sound that has the potential to cause negative impacts on marine life

sound - is used to refer to the acoustic energy radiated from a vibrating object, with no particular reference for its function or potential effect

underwater noise indicators (TSG-11 report February 2012)

EC MSFD Criterion 11.1: Distribution in time and place of loud, low and mid frequency impulsive sounds

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

EC MSFD Criterion 11.2: Continuous low frequency sound

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

TSG-11 - *Technical Subgroup on underwater noise and other forms of energy*

ambient noise

→ Ambient noise is defined as background noise without distinguishable sound sources. It includes natural (biological and physical processes) and anthropogenic sounds.

→ Research has shown increases in ambient noise levels in the past 50 years, mostly due to shipping activity (TSG-11 report 2012).

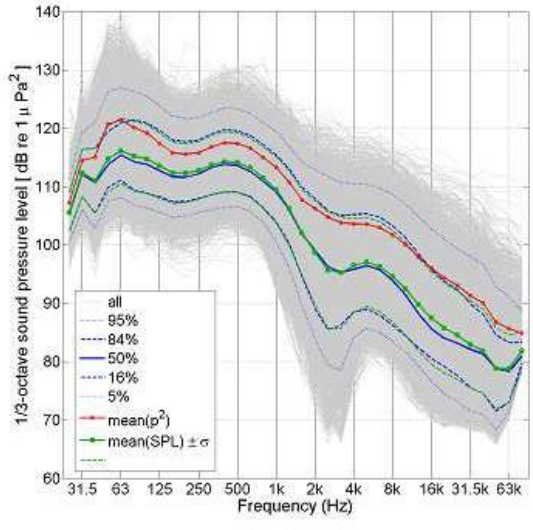
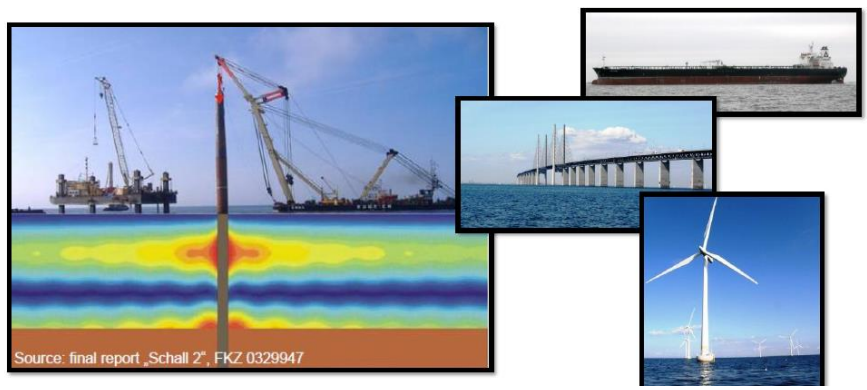


FIGURE: Ambient sound pressure levels (SPL) in 1/3-octave bands. The results of all individual measurements (6 second snapshots, taken once per minute during a one week period in September-October 2009) are represented by the light-grey curves. Measurements were undertaken off from the Dutch Coast in 20 m water depth (Ainslie *et al*. 2011)

man-made underwater noise

Shipping, wind farm construction and operation, pile-driving operations, explosions, seismic surveys, military sonar activities, industrial terminal operation, marine bridge and tunnel traffics, and others.



principal underwater noise sources
(frequency band 10 Hz - 10 kHz)

1. Shipping noise

Representatives are

→ *large ship such as tanker*

→ *small ship such as motor boat*

2. Construction noise

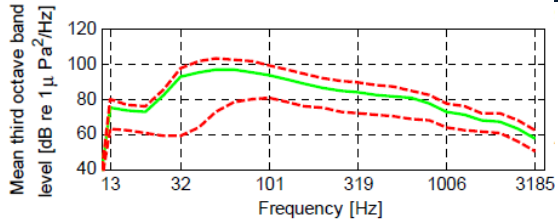
Representative is

→ *blow sound of hammering* (strike < 1 second)
during pile-driving operation (till 7000 strikes per pile)

large ship such as tanker

Noise from large ships is pervasive throughout the marine environment, especially at low frequencies (< 500 Hz), and is therefore a key concern regarding the effects of chronic noise exposure on marine species.
The spectral maximum occurs usually in the range 50 Hz – 300 Hz.

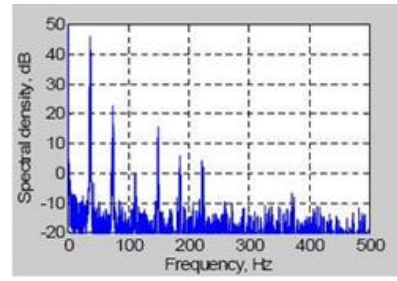
PSD



small ship such as motor boat

Boats can emit significant levels of underwater noise above 1 kHz, particularly small vessels with outboard motors. Noise from motor yachts, cruisers, cargo ships, fishing boats, *etc*. is pervasive throughout the marine environment, the sound characteristics of which are not well documented. These underwater noise sources represent also a concern regarding the effects of chronic noise exposure on marine species.

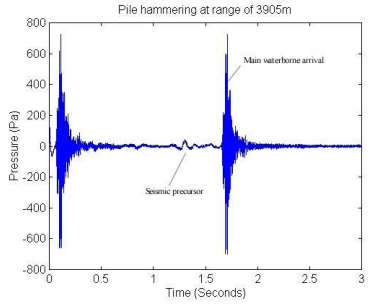

Photo: Courtesy of Baltic Workboats

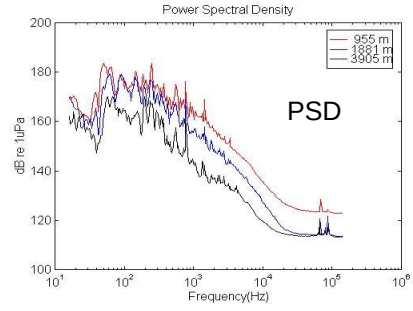


pile-driving strikes

Impulse noise from pile-driving operations is well pervasive in the marine environment up to 80 km, within frequencies < 10 kHz. The spectral maximum occurs usually in the range of 80 Hz – 200 Hz.

Photo: Mathias Andersson





soundscape information

1. There is very little information about the background noise levels trends in Baltic Sea. Underwater acoustics information originates mainly from the measurements of wind-farms constriction noise.
2. Natural sounds due to wind, waves, rain, *etc.* can contribute much to the variability of background noise levels. For instance, wind speeds from 1.0 - 8.7 m/s are usually associated with the noise variations up to 20 dB in the shallow waters.
3. Pile hammering peaks sound level can reach over 200 dB re 1μPa^2 at 100 meters distance from the source. Around at 80 km away the received peak sound pressure levels are usually no longer distinguishable above background noise.
4. Underwater noise contribution from shipping is apparently increased in Baltic Sea during last decades. The assessment of shipping noise in coastal waters is complicated by the presence of both intermittent noise from local vessels and the ambient noise from background that includes distant shipping (in the range around 50 km).

sound thresholds (TG11 report April 2010)

1. Underwater noise - Low and mid-frequency impulsive sound

The proportion of days within a calendar year, over areas of 15'N x 15'E/W in which anthropogenic sound sources exceed either of two levels, 183 dB re 1μPa^2 s (i.e. measured as sound exposure level) or 224 dB re 1μPa peak (i.e. measured as peak sound pressure level) when extrapolated to one metre, measured over the frequency band 10 Hz to 10 kHz.

2. Underwater noise – High frequency impulsive sounds

The total number of vessels that are equipped with sonar systems generating sonar pulses below 200 kHz should be decreased. (*The vessels that are equipped with sonar systems (civilian) may be restricted.*)

3. Underwater noise – low frequency continuous sound

The ambient noise level measured by a statistical representative sets of observation stations in Regional Seas where noise within the 1/3 octave bands 63 and 125 Hz (centre frequency) should not exceed the baseline values of *reference year* or 100 dB (re 1μPa rms; average noise level in these octave bands over a year).

TG11 - *Task Group on underwater noise and other forms of energy*

Briefly about BIAS (LIFE+) project in Estonia

BIAS will work towards a goal to bridge the gap between the indicators of Marine Strategy Framework Directive (MSFD) descriptor 11 and actual management of human-induced underwater noise.

Project main activities are

- B1 Establishment of noise measurements standards
- B2 Establishment of signal processing standards
- B3-B9 Field survey
- B10 Data analysis and quality assurance
- B11 Modelling of soundscape
- B12 Design of GIS-based planning tool
- E2-E7 National management
- *and more*

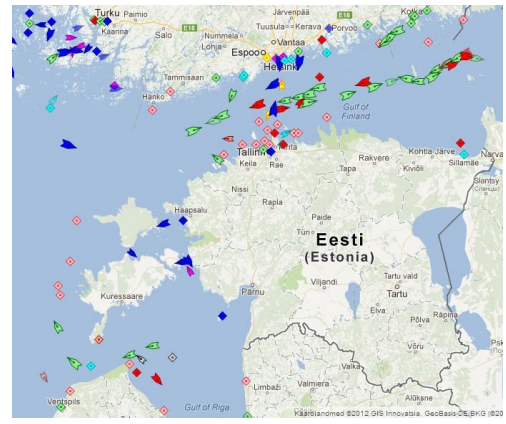


FIGURE: Ship traffic in Baltic Sea by Automatic Identification System (AIS)

underwater sound exposure

→ An objective of the BIAS project is implementation of a planning tool for straight-forward management of intermittent underwater noise sources.

→ BIAS has decided not use TG11 (2010) suggested areal size of 15'N x 15'E/W where anthropogenic sound sources exceed threshold levels during the proportion of days within a calendar year.

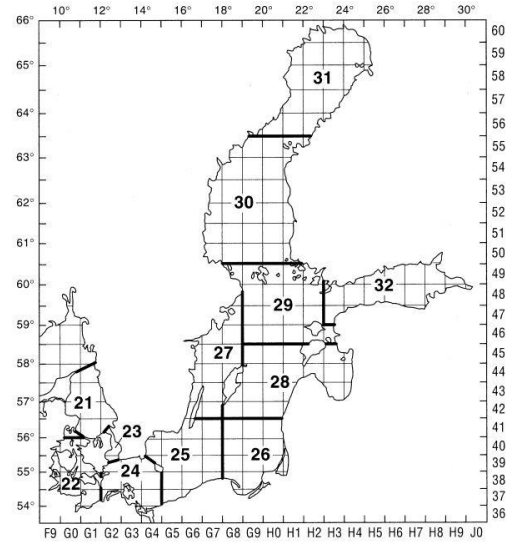


FIGURE: Baltic Sea subdivisions of the International Council for the Exploration of the Sea (ICES)

metrics used in sound level assessment

- MSP – Mean Square Pressure
- RMS – Root Mean Square
- SPL – Sound Pressure Level (L_{eq})
- SEL – Sound Exposure Level (L_E)
- PSL – Peak Sound pressure Level (L_{peak})
- SNR – Signal to Noise Ratio
- PSD – Power Spectra Density
- PDF – Probability Density Function
- dB – deciBels

sound pressure level

SPL is the *mean square pressure* (MSP) expressed in deciBels (dB) relative to a reference pressure (p_{ref}).

mean square pressure:

$$\mathrm{MSP} = p_{rms}^2 = \frac{1}{T}\int_0^T p(t)^2\,dt$$

$$\mathrm{SPL} = 10\log_{10}\left(\frac{p_{rms}^2}{p_{ref}^2}\right) \qquad [\mathrm{SPL}] = \mathrm{dB} \quad \mathrm{re} \quad 1\mu\mathrm{Pa}^2$$

In underwater acoustics at 1 metre distance the reference pressure is:

$$p_{ref} = 1\ \mu\mathrm{Pa}$$

$(1\ \mu\mathrm{Pa} = 1\times10^{-6}\ \mathrm{Pa})$

sound exposure level

SEL is a measure of acoustic energy level which characterize the sound events of different durations.

$$\mathrm{SEL} = 10\log_{10}\left(\frac{\int \mathrm{MSP}(t')dt'}{p_{ref}^2}\right) \qquad [\mathrm{SEL}] = \mathrm{dB} \quad \mathrm{re} \quad 1\mu\mathrm{Pa}^2 \quad \mathrm{s}$$

MSP is measured over time period (T_1, T_2) and T_0 = 1 second:

$$\int \mathrm{MSP}(t')dt' = \frac{1}{T_0}\int_{T_1}^{T_2} p^2(t)dt$$

Cumulative sound exposure level:

$$\mathrm{SEL}_{cumulative} = \mathrm{SEL} + 10\log_{10}(n)$$

SEL increases by 10 dB with every tenfold increase of the number (n) of "equal" events (*e.g.* strikes in the pile driving).

peak sound pressure level

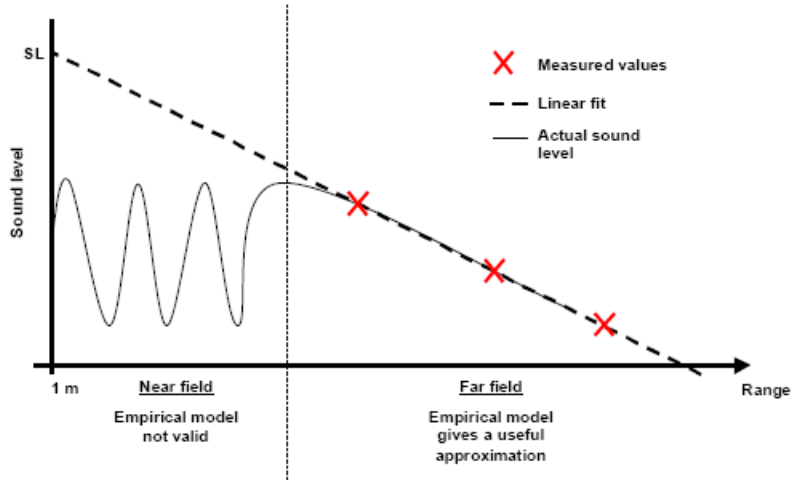
Impulsive sounds can have moderate SPL or SEL values, but very high instantaneous pressure peak though. PSL is used to estimate of sound peak energy.

$$\mathrm{PSL} = 10\log_{10}\left(\frac{p_{peak}^{\ 2}}{p_{ref}^{\ 2}}\right) = 20\log_{10}\left(\frac{|p_{peak}|}{p_{ref}}\right)$$

where p_{peak} is the highest observed instantenous sound pressure amplitude. Absolut value of p_{peak} is only used.

$$[\mathrm{PSL}] = \mathrm{dB} \quad \mathrm{re} \quad 1\mu\mathrm{Pa}$$

empirical modelling



source level: http://www.underwaternoise.org.uk

statistical assessment of sound level

Linear-space mean:

$$\mathrm{SPL}_{\mathrm{linear}} = 10\log_{10}\left(\frac{1}{N}\sum_{i=1}^{N} p_{msp,i}^2 \Big/ p_{ref}^2\right)$$

dB-domain mean:

$$\mathrm{SPL}_{\mathrm{dB}} = \frac{1}{N}\sum_{i=1}^{N} 10\log_{10}\left(\frac{p_{rms,i}^2}{p_{ref}^2}\right)$$

SEL:

$$\mathrm{SEL} = \mathrm{SPL}_{\mathrm{linear}} + 10\log_{10} T$$

T is the exposure period in seconds.

some conclusions

1. Ambient noise levels in shallow waters exhibit high spatiotemporal variability due to the strong dependence of acoustic propagation on local environmental factors such as sound speed profile, seabed composition and water depth
2. *In situ* measurements of long- and short-term exposure of anthropogenic noise both in absolute and relative to background levels are needed
3. Absolute and relative levels of intermittent ship noise contributions to the 24-hours sound exposure level are needed in respect of an adaptive threshold
4. Implementation of AIS vessels tracking data enables analysis of the relationships between vessel movements (sound exposure due to shipping noise) and changes in ambient noise levels
5. Advances in PAM technology and data processing capabilities are making measurement and analysis of continuous, long-term deployments feasible