Noise issues for offshore windfarms

Basic acoustics: what needs to be measured and why

Stephen Robinson
National Physical Laboratory

12th December 2012

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Contents

- Background and drivers
  - Regulatory drivers
- Some basic underwater acoustics
  - Difficulties of measuring underwater noise in shallow water
- Noise measurements
  - Piling noise
  - Operational noise
- Moves toward standardisation

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Underwater sound: anthropogenic sound

- Applications
  - sonar, positioning and navigation, geophysical exploration, hydrographic surveying, echosounders, mine hunting, weapons guidance, oceanography, tomography, etc …
- Radiated noise
  - shipping, construction noise, explosive decommissioning, oil and gas platforms, etc …
- Influence on marine fauna
  - Marine animals use sound for echolocation and communication
  - Many are protected species
  - Effects can range from physical injury and hearing impairment (PTS and TTS) through to masking, disturbance, displacement …
  - Fish species sensitive to low frequency sound and vibration (particle velocity)

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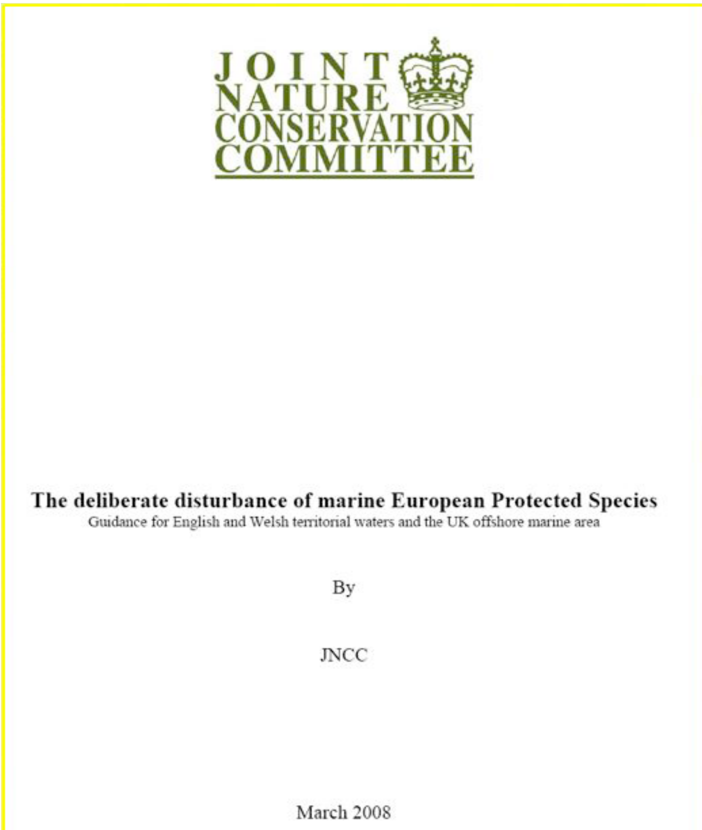
UK regulatory drivers


JOINT NATURE CONSERVATION COMMITTEE

The deliberate disturbance of marine European Protected Species

Guidance for English and Welsh territorial waters and the UK offshore marine area

By

JNCC

March 2008

- Increasing legal requirements for EIA:
  - Conservation (Natural Habitats &c.) Regulations 1994 (i.e. the Habitats Regulations, HR)
  - Offshore Marine Conservation (Natural Habitats) Regulations 2007 (the Offshore Marine Regulations, OMR) 2007
  - Prohibits “deliberate disturbance”
  - Includes “anthropogenic noise”
- JNCC Guidelines (UK)
  - “The deliberate disturbance of marine European protected species”
  - JNCC advise Government
  - Licences issued by: DEFRA, DECC, etc

EU Regulation

- European Marine Strategy Framework Directive
- Working Group 3, Descriptor 11:
  - “Introduction of energy, **including underwater noise**, is at levels that do not adversely affect the marine environment.”
- Pollution*: “… the introduction of substances or energy, including human-induced **underwater noise**, which results or is likely to result in deleterious effects”

Working group 3 : Habitats

Descriptor 6 : Sea-floor and benthic ecosystem	
INFOMAR	
Thomas FUREY, *Marine Institute, Ireland*	Slides
Natural and anthropogenic impacts on sea-floor	
Jean-François BOURILLET, *Ifremer, France*	Slides
Defining 'good environmental status' of seafloor ecosystems: experiences from the Baltic Sea	
Alf NORKKO, *Finnish Institute of Marine Research, Finland*	Slides
Descriptor 7 : Hydrographical conditions and ecosystems	
Luis VALDES, *Centre oceanographique de Gijon, Spain*	Slides
Descriptor 11 : Energy	
Good environmental status for noise in the oceans: challenges in setting standards	
Mark TASKER, *JNCC, UK*	Slides
Climate impacts and descriptors of good environmental status	
Keith BRANDER, *ICES/GLOBEC Coordinator, Denmark*	Slides

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

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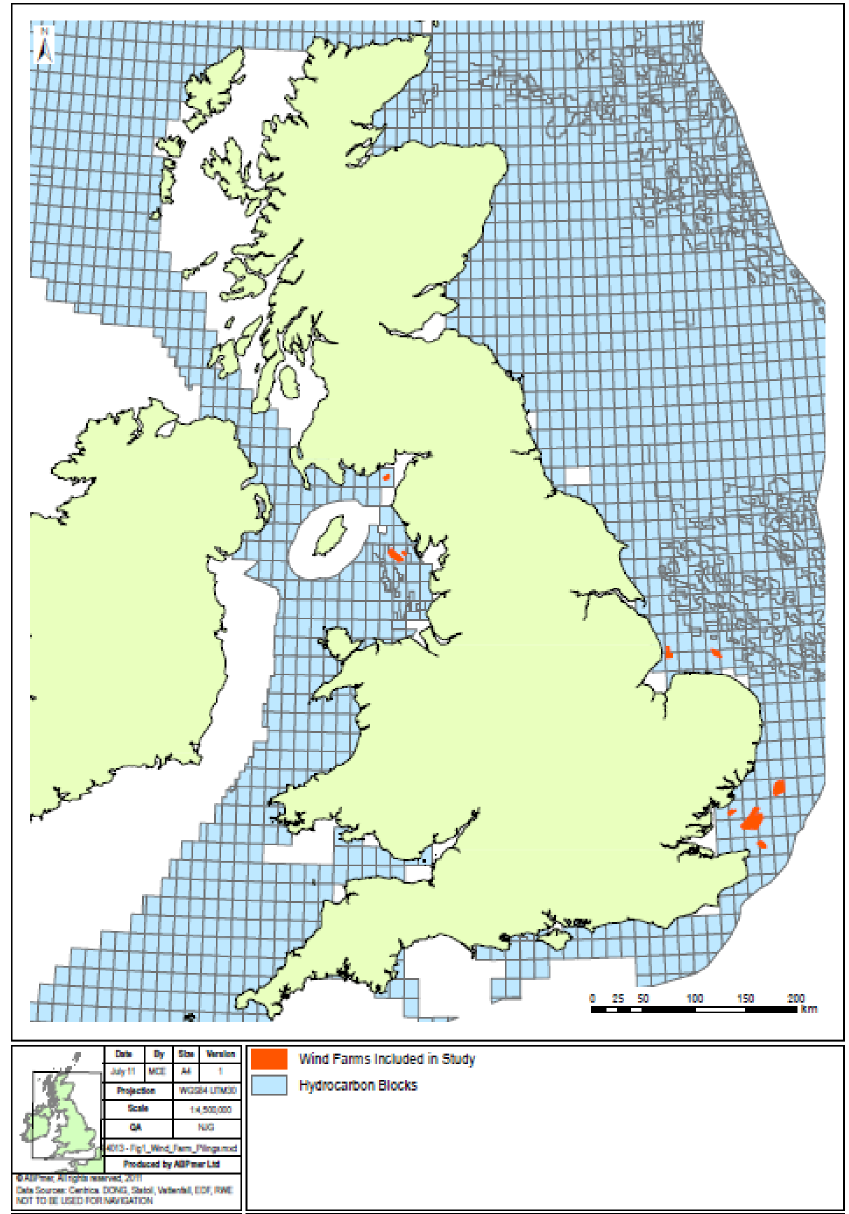
* Directive 2008/56/EC of the European Parliament, 17 June 2008

Response of members states: UK

Indicator 11.1 loud, low and mid frequency impulsive sounds

- Known effects:
- “Holes” in populations
  - displacement of animals fleeing the sound
- Lack of knowledge of how many loud impulsive noises are generated by activities
- Establish **noise register**
- Count number of impulsive sounds in specific areas (blocks)



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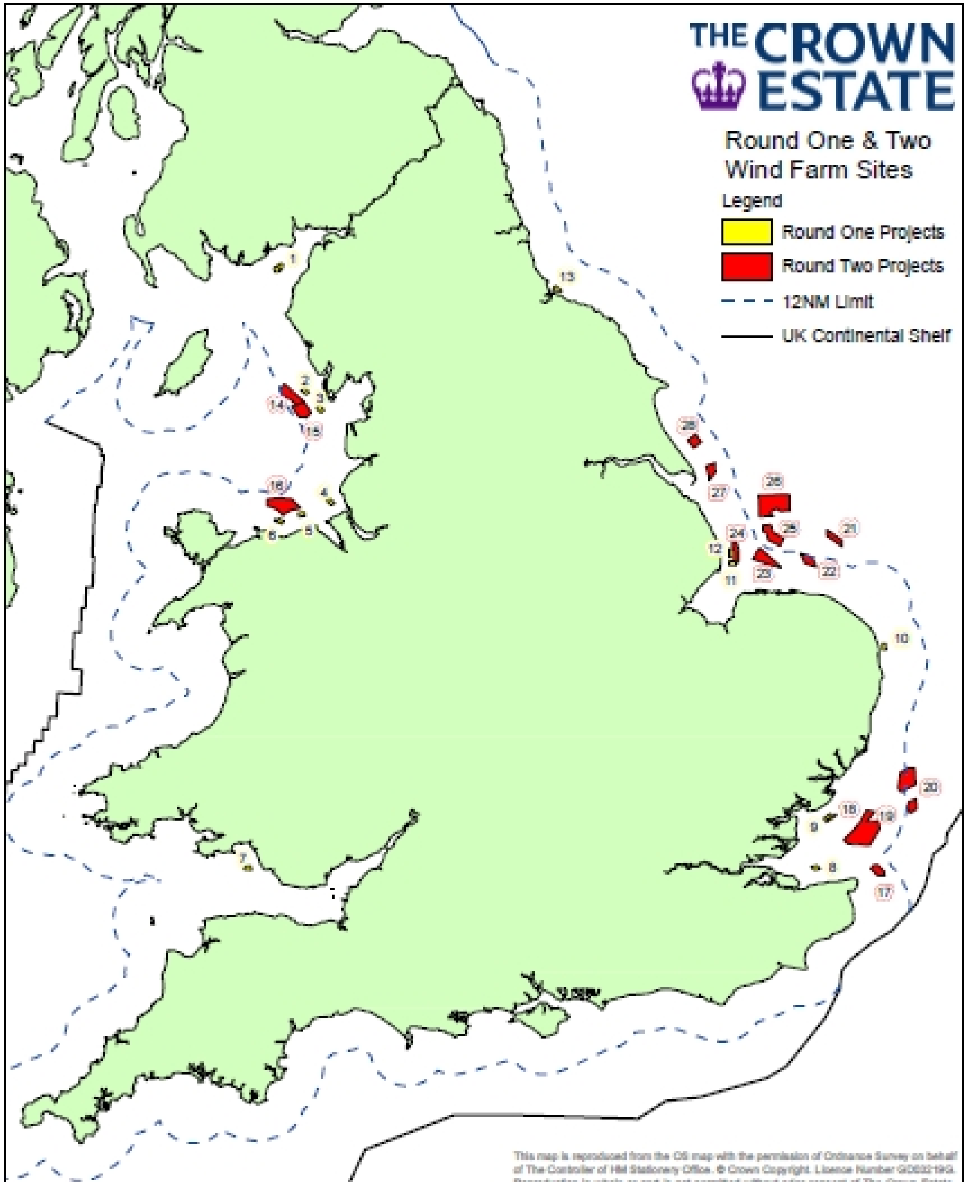
Response of members states: UK
Indicator 11.1 loud, low and mid frequency impulsive sounds

Seismic surveys	2008	2009	2010
2D block pulse days	18374	14132	2099
3D block pulse days	1296	2596	12207
4D block pulse days	113	85	3130
Total block pulse days	19783	16813	17437

Pile driving 2010	North Sea	Celtic Seas
Pulse-block-days	150	171

Total pulse-block-days likely to rise to ~**2500** in next decade

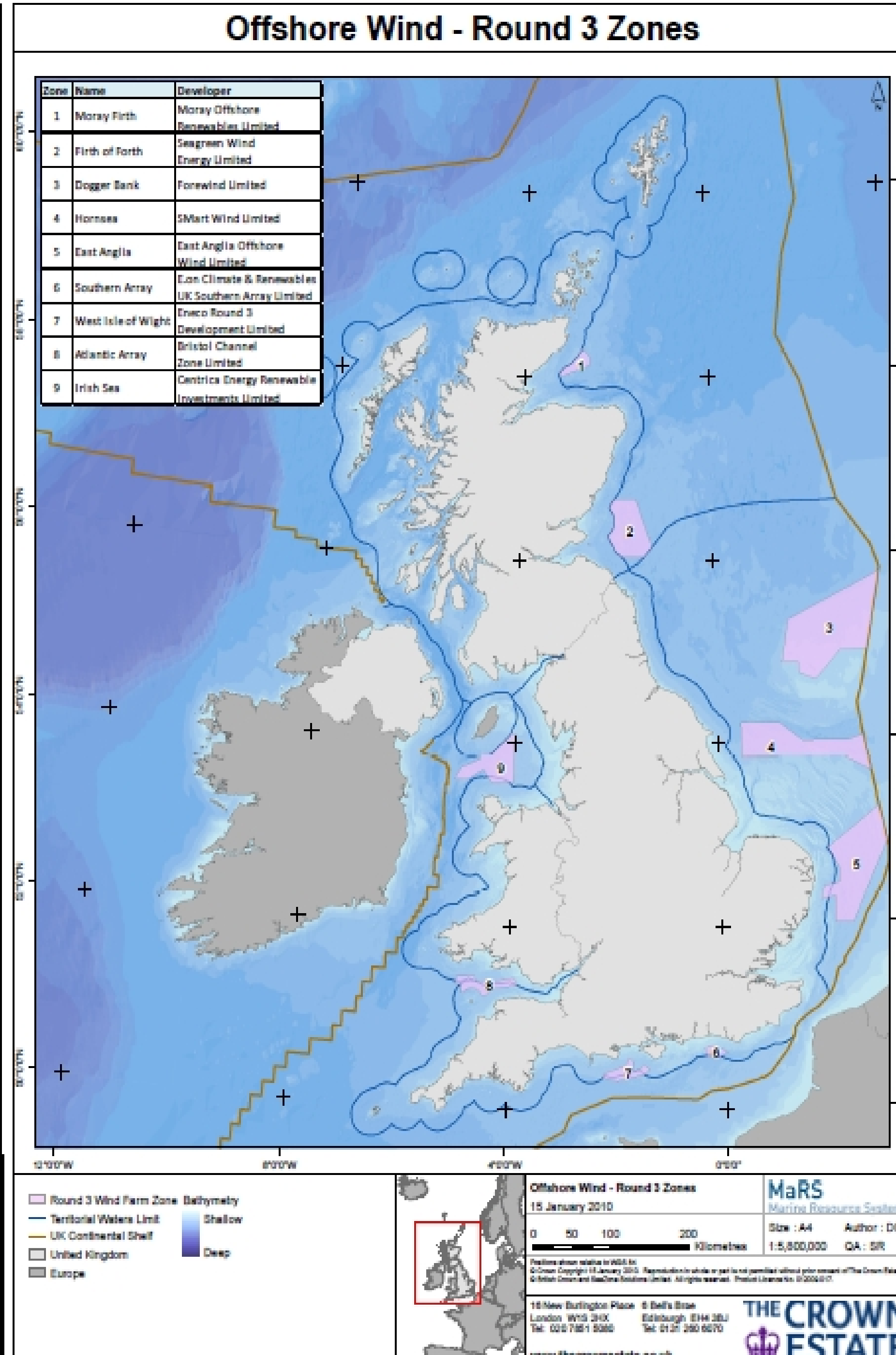


Round One Projects:

1 Robin Rigg
2 Ormonde
3 Barrow
4 Burbo Bank
5 North Hoyle
6 Rhyl Flats
7 Scarweather Sands
8 Kentish Flats
9 Gunfleet Sands I
10 Scroby Sands
11 Lynn
12 Inner Dowsing
13 Teeside

Round Two Projects:

14 Walney
15 West Duddon
16 Gwynt Y Mor
17 Thanet
18 Gunfleet Sands II
19 London Array
20 Greater Gabbard
21 Dudgeon
22 Sheringham Shoal
23 Race Bank
24 Lincs
25 Docking Shoal
26 Triton Knoll
27 Humber Gateway
28 Westermost Rough



Zone	Name	Developer
1	Moray Firth	Moray Offshore Renewables Limited
2	Firth of Forth	Seagreen Wind Energy Limited
3	Dogger Bank	Forewind Limited
4	Hornsea	SMart Wind Limited
5	East Anglia	East Anglia Offshore Wind Limited
6	Southern Array	E.on Climate & Renewables UK Southern Array Limited
7	West Isle of Wight	Eneco Round 3 Development Limited
8	Atlantic Array	Bristol Channel Zone Limited
9	Irish Sea	Centrica Energy Renewable Investments Limited

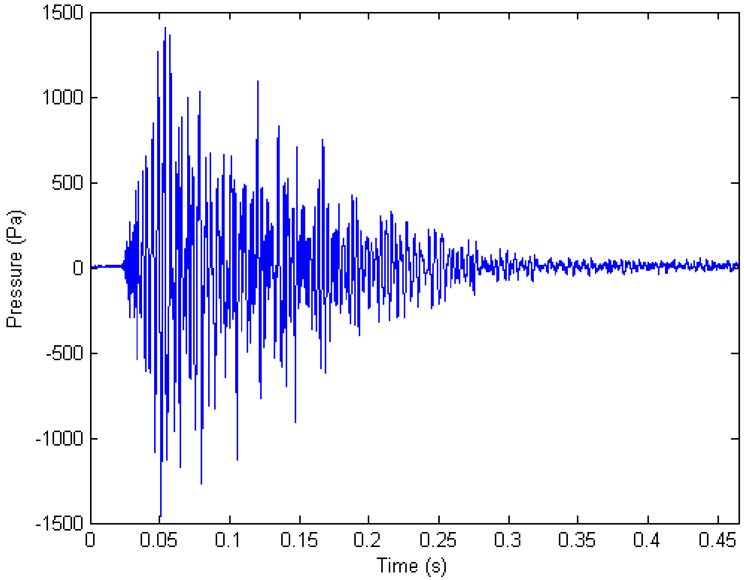
Basic principles: Measures of sound

Measures of sound:

- peak pressure: $p_{\text{peak}} \equiv \max|p(t)|$

- sound exposure: $E \equiv \int_0^T p^2(t)\,\mathrm{d}t$

- Root mean square (RMS) pressure: $p_{\text{RMS}} \equiv \sqrt{\frac{1}{T}\int_0^T p^2(t)\,\mathrm{d}t} = \sqrt{\frac{E}{T}}$



all may be expressed in **decibels**

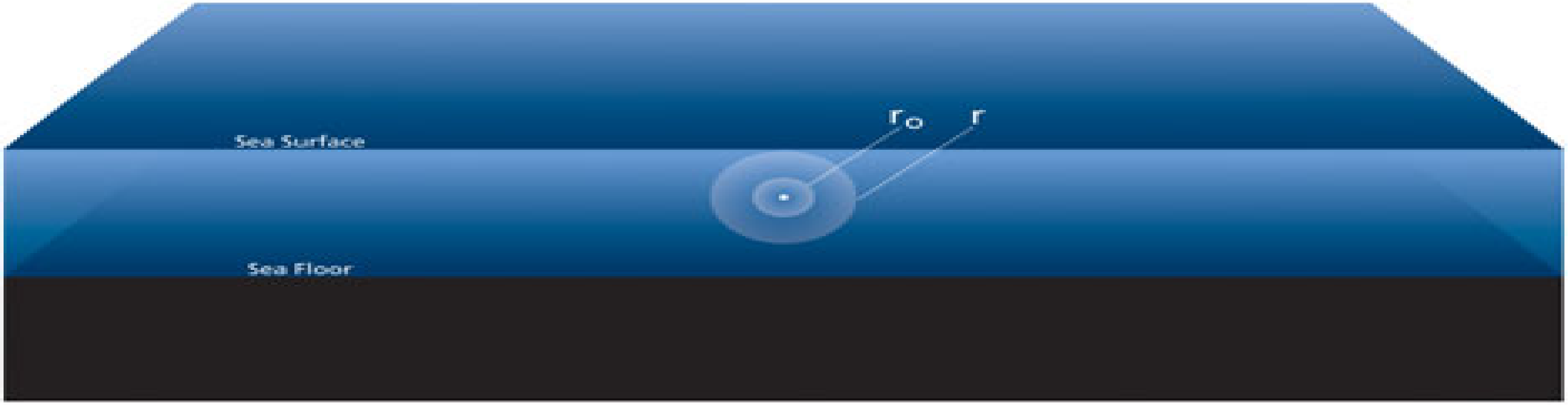
For above pulse:	
Pk-pk:	**189.5 dB** re 1 μPa
Pk:	**183.5 dB** re 1 μPa
SPL:	**172.5 dB** re 1 μPa
SEL:	**164.1 dB** re 1 μPa^2·s

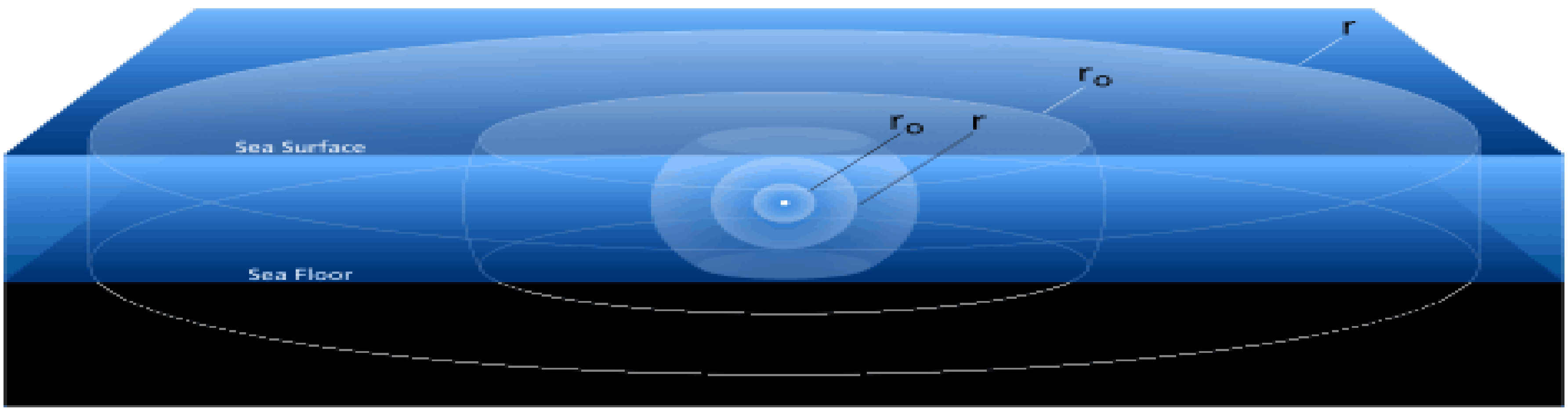
SEL is particularly useful for pulses as it considers the energy in the signal

- can be used cumulatively to calculate total exposure

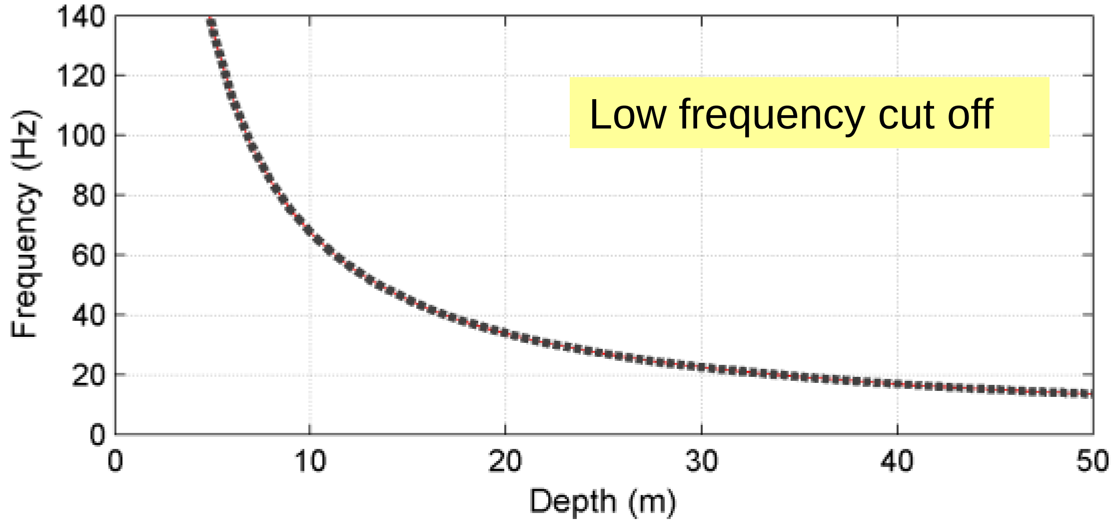
Peak and peak-peak metrics difficult to model/propagate

Sound propagation in shallow water





Sound propagation in shallow water



Sound amplitude dies away at greater range because of Transmission Loss due to:

- Spreading
- Absorption (frequency dependent)
- Interaction with boundaries (seafloor, seabed)

$$RL = SL - TL$$

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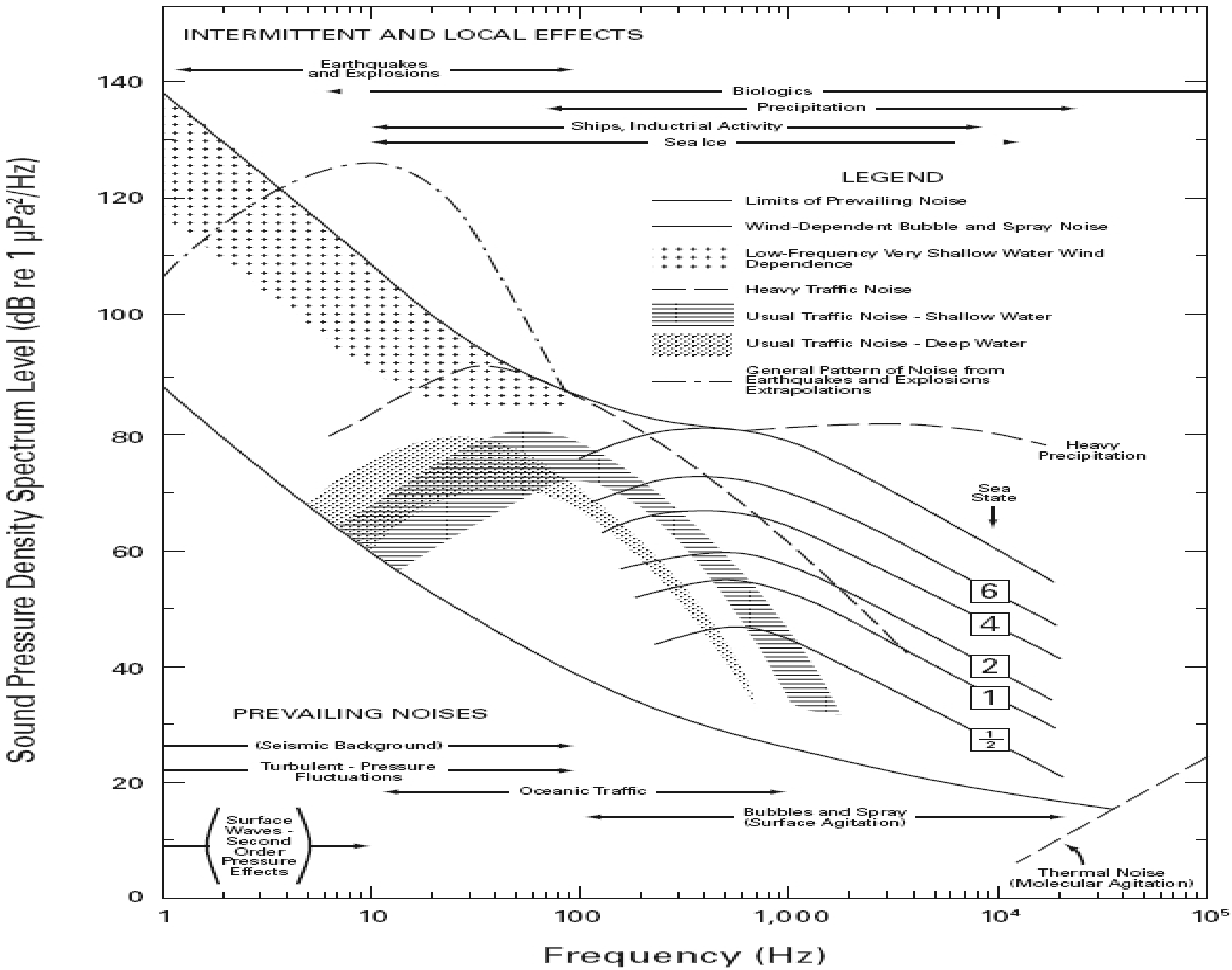
Air versus water

- Comparisons with every day sounds can easily lead to confusion
- *“It is as if the whale is strapped to a Saturn 5 rocket …”* etc

- For the same energy input into the media:
  - Different acoustic impedance: ~36 dB difference in SPL
  - Different reference levels (1μPa versus 20μPa): ~26 dB difference
  - So SPL values are ~62 dB greater in water for same acoustic power or energy input

- However, natural ambient noise levels in the ocean are generally much greater than in air
- Marine creatures have evolved in this (noisier) environment and have evolved appropriate hearing responses



INTERMITTENT AND LOCAL EFFECTS
Earthquakes and Explosions
Biologics
Precipitation
Ships, Inductrial Activity
Sea Ice
LEGEND
Limits of Prevailing Noise
Wind-Dependent Bubble and Spray Noise
Low-Frequency Very Shallow Water Wind Dependence
Heavy Traffic Noise
Usual Traffic Noise - Shallow Water
Usual Traffic Noise - Deep Water
General Pattern of Noise from Earthquakes and Explosions Extrapolations
Heavy Precipitation
Sea State
6
4
2
1
1/2
PREVAILING NOISES
(Seismic Background)
Turbulent - Pressure Fluctuations
Oceanic Traffic
Bubbles and Spray (Surface Agitation)
Surface Waves - Second Order Pressure Effects
Thermal Noise (Molecular Agitation)
Sound Pressure Density Spectrum Level (dB re 1 μPa²/Hz)
0
20
40
60
80
100
120
140
1
10
100
1,000
10⁴
10⁵
Frequency (Hz)

Deep water ambient noise (reasonably) well understood

Less data for coastal water – strong variability

Standard curves not available for shallow coastal water

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Noise radiated from offshore windfarms

- Construction noise
  - Marine impact piling (impulsive noise source)
  - Other installation methods
  - Vessel noise, cable laying, etc
- Operational noise
  - Continuous noise radiated during operation
- (Decommissioning)

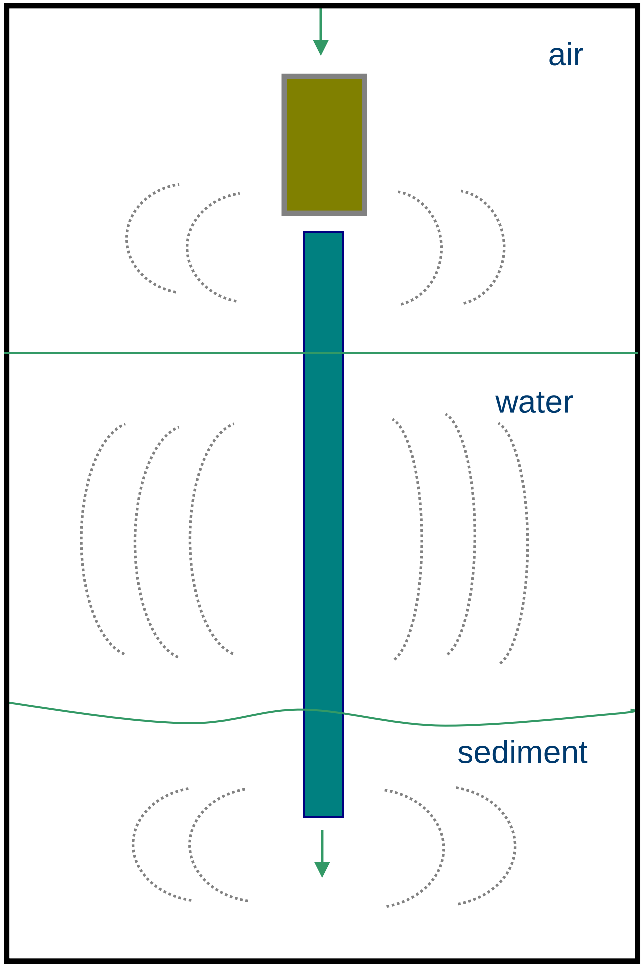
Offshore windfarm nose: Piling noise

Source output depends on:

- hammer energy
  - increases during “soft start”
- sea bed penetration
- sea bed and sediment properties
- pile dimensions
- water depth …

Received level depends on transmission loss variation:

- bathymetry, frequency…
- fluctuations in environmental conditions (sea state …)



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Piling underway: 4.74 m diameter mono-pile

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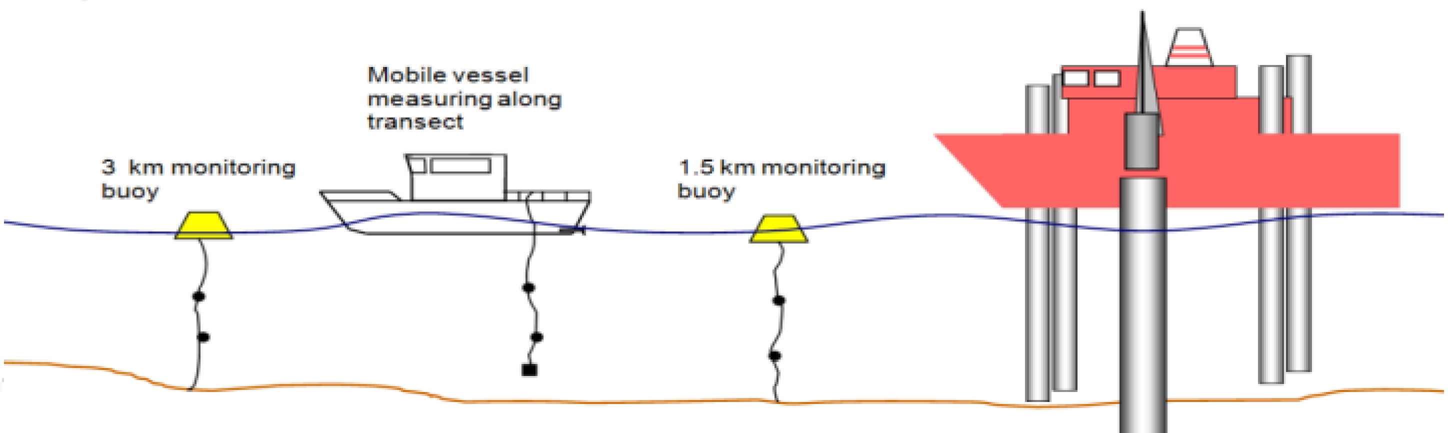
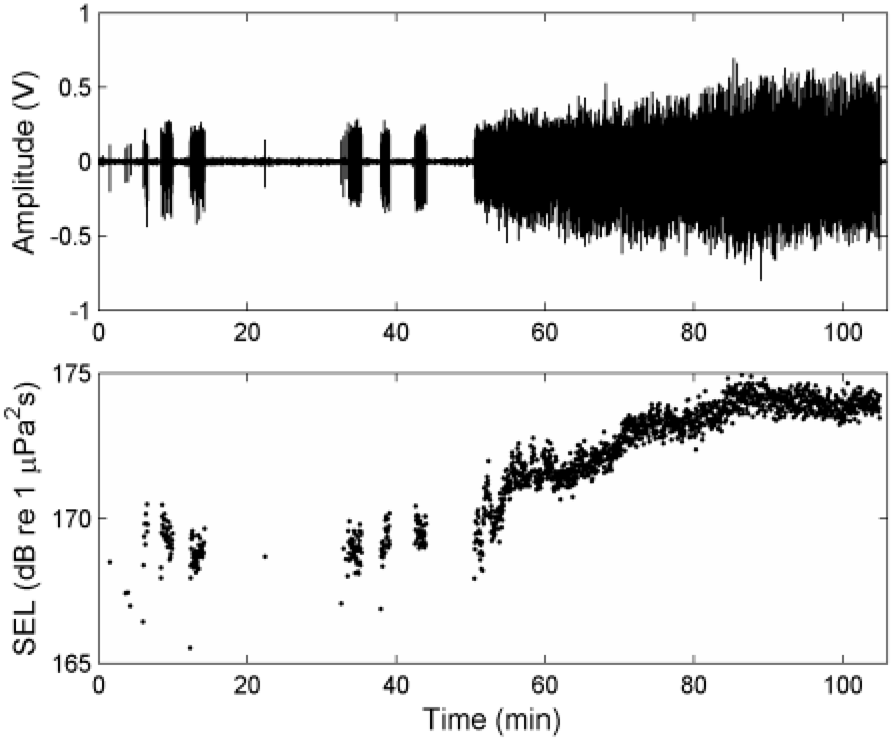
Measurement requirements and methodology

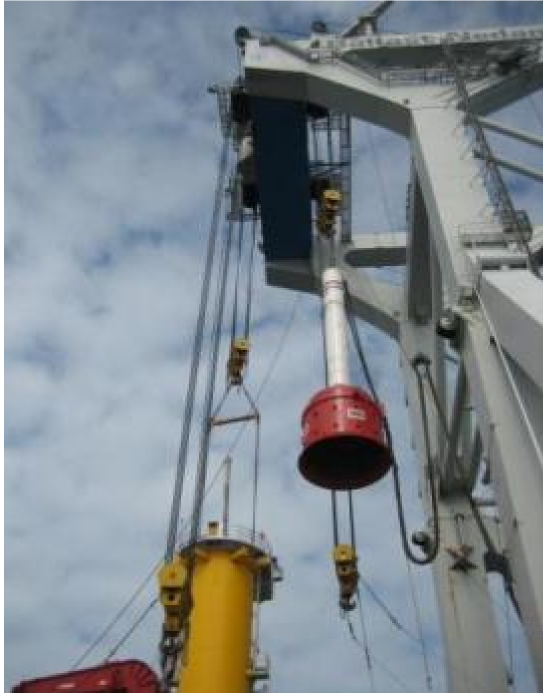
- Measure as a function of range to estimate the 'source level'
  - Start close and move away in a survey vessel
- Fixed noise monitoring buoy measures entire piling sequence
  - provide a range independent measurement – used for 'level calibration'
  - necessary because of soft-start
- Usually have to predict the impact beyond ranges measured
  - Requires outward propagation modelling for which the 'measured' source level is used
- Ambient noise measurements taken from survey vessel during non-piling activity

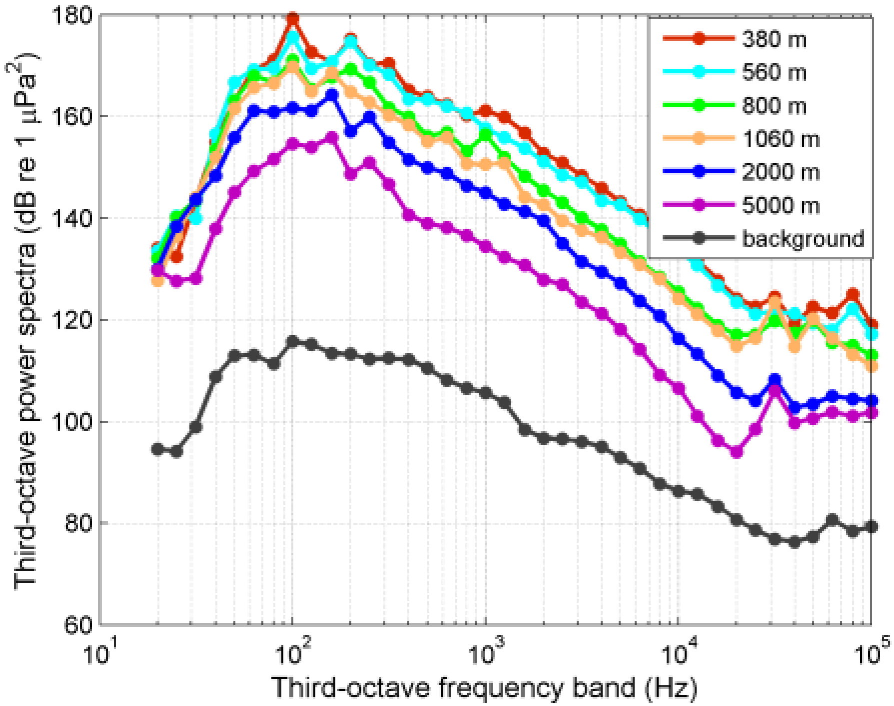


Temporal/spatial variation

Example: data from fixed recording system, entire piling sequence







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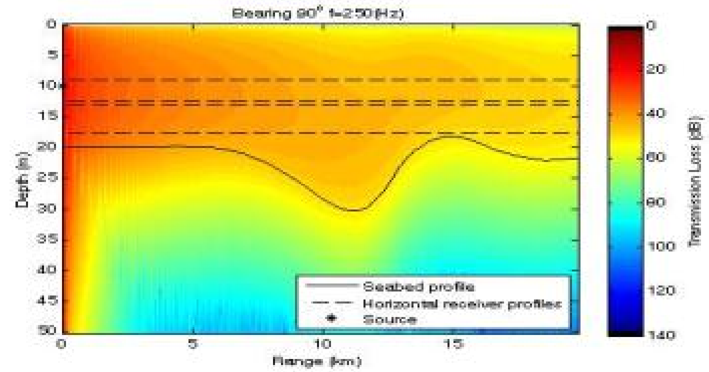
Source Level determination

- Measure of the acoustic output of source versus range
  - far field, free field parameter, related to source acoustic power
  - characteristic of source, not environment
  - units: dB re 1 µPa at 1 m (but not equal to pressure at 1 m range !)
- Derived from measured received level in the far-field corrected for propagation loss
  - SL = RL + TL
- Propagation model needed



- Why do we want Source Level?
  - To compare acoustic output of sources
  - To propagate sound outward to determine impact zones
- Not all propagation models are compatible with point, monopole source
- “Standard” models available:
  - Ray tracing, normal mode, parabolic equation, wavenumber integration

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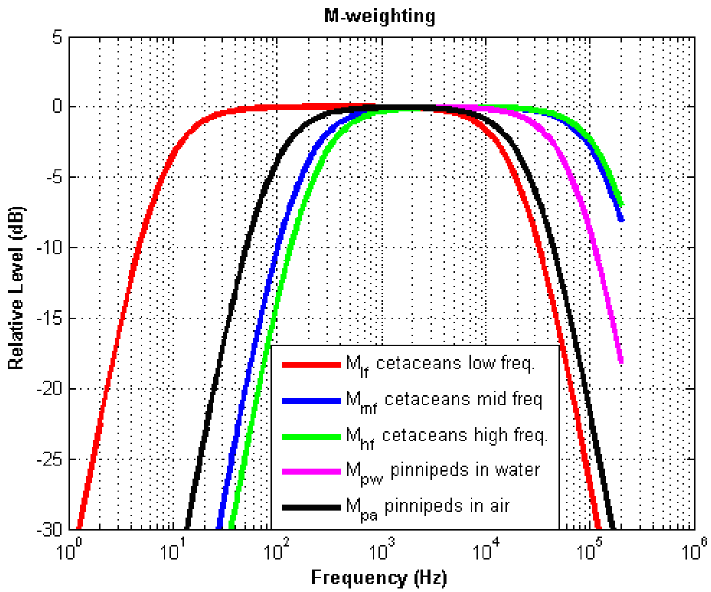
Impact assessment

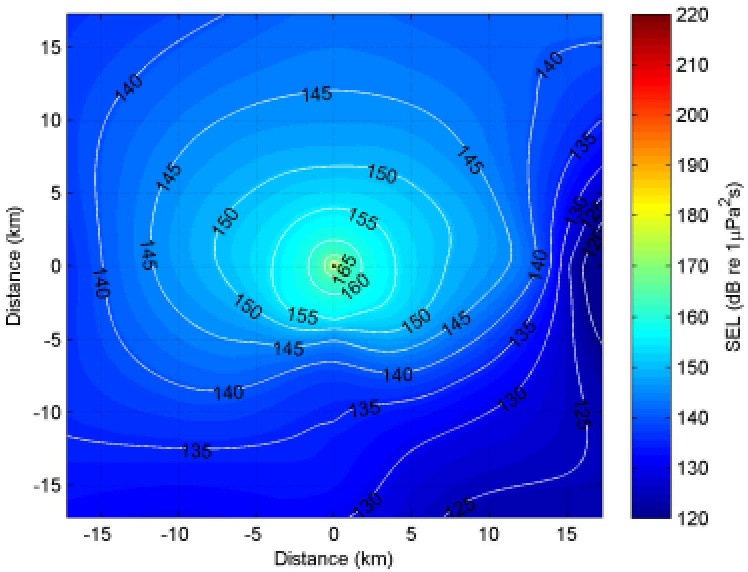
Receptor sensitivity

- weighting according to species sensitivity
  - heavily used in early UK work
  - need “standard” species audiograms
- Southall *et al* (M-weighting) for mammals



Impact zones

- Need propagation model
- Need threshold levels for biological effects



Different regulations in other countries

- In Germany, maximum level stipulated
- In UK, impact zones calculated

Cumulative impact

- Use of SEL metric allows cumulative exposure to be calculated

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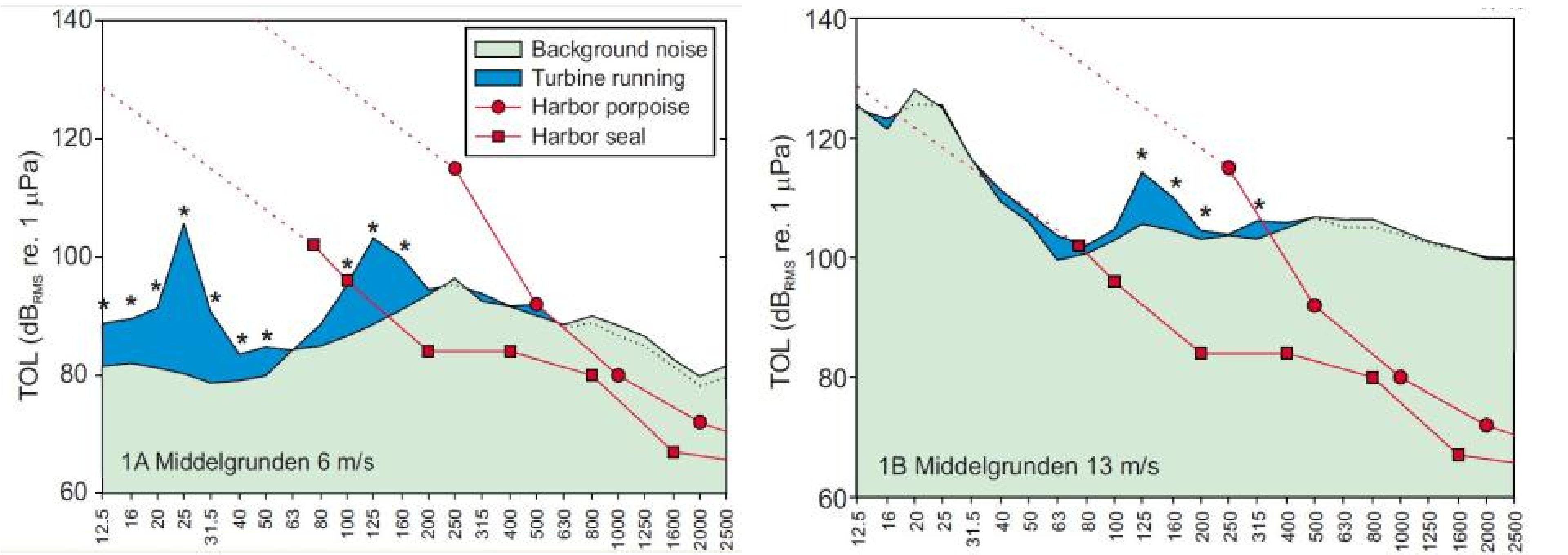
Operational noise

- Low frequency noise during operation
- Low noise levels radiated – much lower than construction noise
- Depends on turbine operation – wind speed
- Mechanical sources – gearbox etc…
- However, noise is long-term - for duration of windfarm

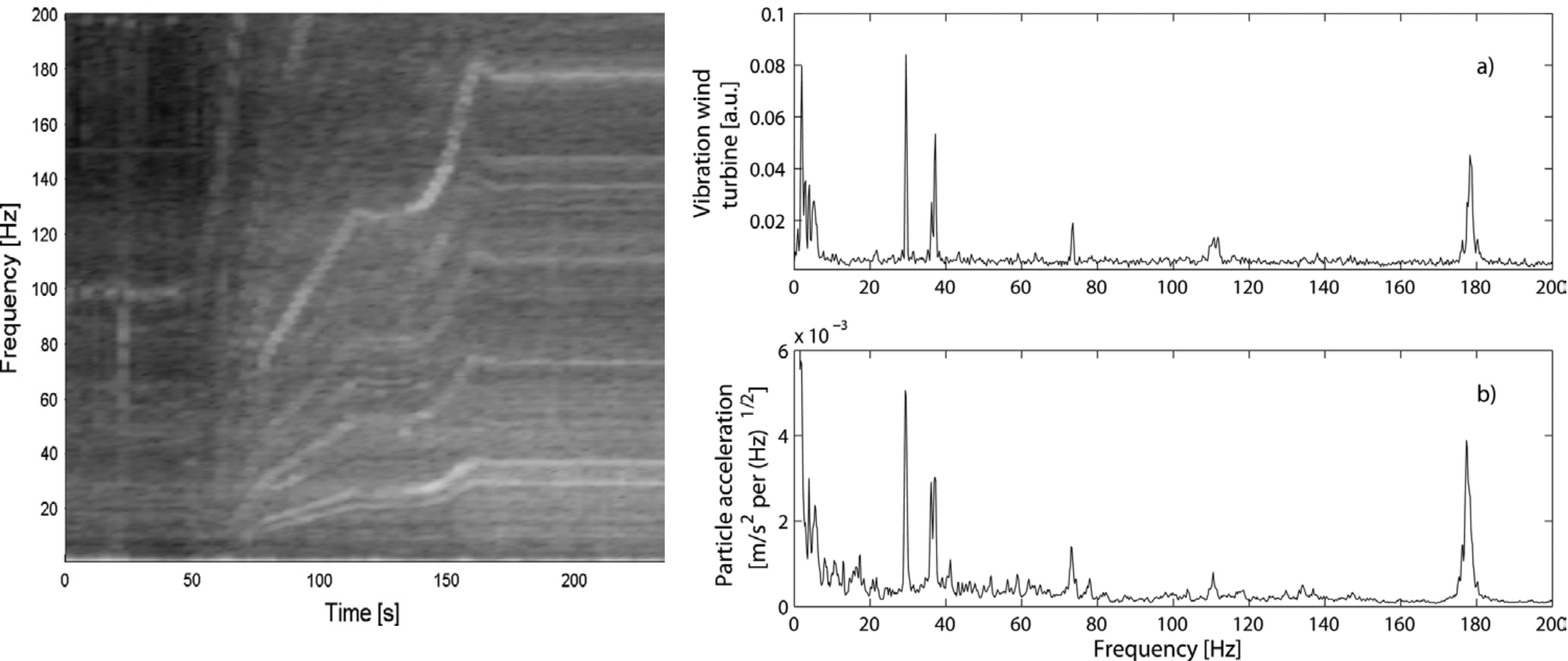
Tougaard et al, JASA, 2009



Operational noise

- Noise can contain tonal components
- Frequencies depend on turbine speed
- Structural vibration couples into water column and seabed

Sigray & Andersson, JASA, 2011



Standardisation: ISO TC43 (Acoustics)

- New Sub-Committee within ISO TC43
- SC3 title: "Underwater Acoustics“
  - First Meeting of SC3 was: 11th – 13th June 2012
  - Next meeting: Berlin, May 2013

Scope of TC43 Sub-Committee 3

Standardization in the field of underwater acoustics (including natural, biological, and anthropogenic sound), including **methods of measurement and assessment of the generation, propagation and reception** of underwater sound and its reflection and scattering in the underwater environment including the seabed, sea surface and biological organisms, and also including all aspects of the **effects of underwater sound** on the underwater environment, humans and marine aquatic life.

ISO TC43 Work

Existing work

- Ship noise in deep water (WG1):
  - ISO PAS 17028 published- essentially same as ANSI S12.64
  - revision work already begun (led by USA)

New work

- Definitions and terminology (WG2)
  - New work item proposal now approved (NL proposal)
  - Countries participating: NL, UK, US, DE, DK, AU, RU, JP
- Marine impact pile driving (WG3)
  - New work item proposal now approved (UK proposal)
  - Countries participating: DE, UK, NL, US, NO, AU, IT, JP, DK
- Other future likely items:
  - Ship Noise in shallow water
  - Ambient noise,
  - Impulsive sources – air guns, explosives …

Summary: why standardisation needed

- Needed for
  - Obtaining "correct" values
  - Harmonisation for comparison purposes
- International collaboration desirable
- Consensus view
- Open source methodology
- Peer-reviewed publications

Outstanding issues

- **Standardisation topics**
  - Metrics (peak, peak to peak, energy, SEL, etc)
  - Effective source level definition
  - Measurement methodology
  - All relevant data recorded
- Further **research needed**
  - Physical model needed for radiation mechanisms
  - Validated propagation models
  - Understand dependencies
  - Better predictive utility
  - Need to measure particle velocity and vibration (important for fish)

Questions ?

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The National Measurement System delivers world-class measurement science & technology through these organisations

The National Measurement System is the UK's national infrastructure of measurement Laboratories, which deliver world-class measurement science and technology through four National Measurement Institutes (NMIs): LGC, NPL the National Physical Laboratory, TUV NEL The former National Engineering Laboratory, and the National Measurement Office (NMO).

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Source: TNO Report TNO-DV 2009 C085 (2009)

Table 5.2. Estimation of total acoustic energy for the largest anthropogenic sources.

Type of source	Order of magnitude estimate of annual average of acoustic power output in the North Sea [GJ/year]	Order of magnitude estimate of frequency [kHz]	Order of magnitude estimate of absorption [dB/km]	Order of magnitude estimate of total (free space) energy $E = W/(2\alpha c)$ [kJ]
Airgun arrays	100	0.1	0.0012	**8000**
Shipping	270	0.3	0.01	**3000**
Wind farm construction (pile driving)	9	0.1	0.0012	**700**
Explosions	7	0.1	0.0012	**500**
Navigation echo sounders	60	30	8.2	0.7
Fisheries sonar	10	30	8.2	0.1
Military search sonar[12]	0.2	10	1.2	0.02

EU MSFD: TG 11 *Indicators*

Intended as over-arching strategy

- **not** intended as replacement for local EIAs

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

— Proportion of days and their distribution within a calendar year over areas of a determined surface, as well as their spatial distribution, in which anthropogenic sound sources exceed levels that are likely to entail significant impact on marine animals measured as Sound Exposure Level (in dB re 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

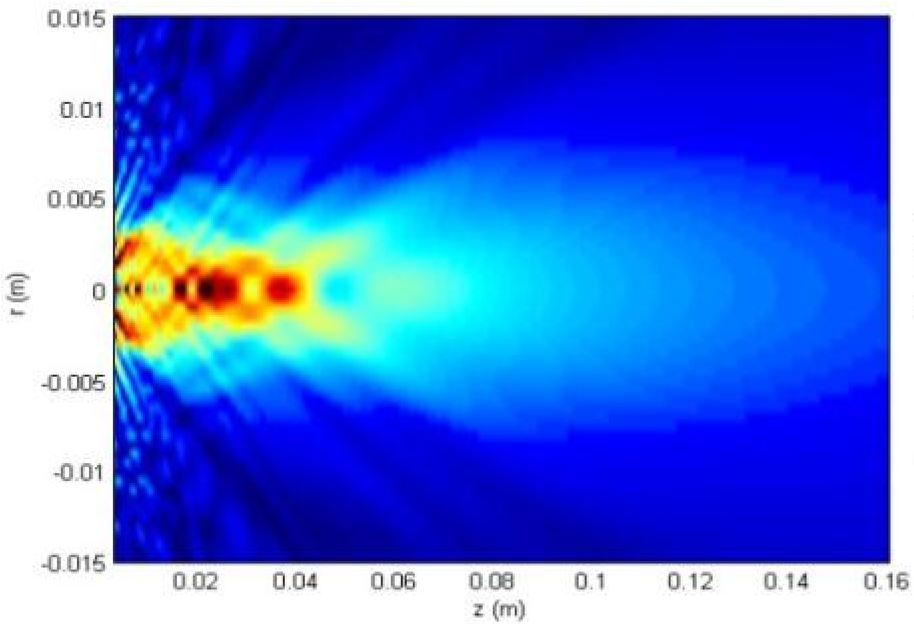
11.2. Continuous low frequency sound

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

Acoustic near-field

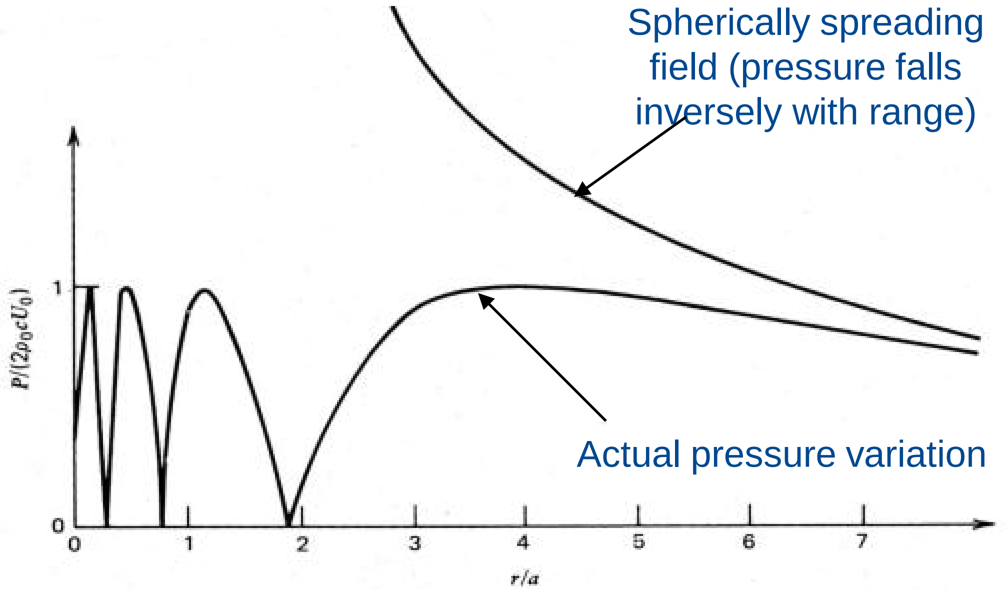
- **Near-field** is region close to the source where waves originating from different parts of the source interfere
- Pressure variation highly complex
- In **far-field**, waves from all parts of the source are substantially in phase
- In far-field, waves appear to spread spherically from "acoustic centre"

Near-field of real source transducer



Source Level

- **Source level** is a measure of acoustic output amplitude
- Related to radiated acoustic power
- Obtained from measurements in far-field projected back to 1 m away from acoustic centre
- Units: **dB re 1 µPa at 1 m**
- Not equal to pressure at 1 m range !



On axis response of circular plane piston of *ka* = 25. (After Kinsler & Frey, 1981)

Air versus water: an analogy

Who feels richer, a Canadian or an American ?

- Both are paid in dollars, units with the same name, but different values. So you can correct for that using an exchange rate (analogous to the use of different reference pressures: 20 µPa or 1 µPa).
- But the cost of living in Canada is higher than the US, so the same amount of money does not go as a far in Canada as the US, which again you can correct for using the retail price index (analogous to the different acoustical impedances).
- Finally with the same “spending power” how rich you feel depends on how much money people around you have, you need less money in India to feel rich than in the US. The final factor is a subjective factor and is probably much harder to correct for and is analogous to perceived loudness.

Prof Paul White, ISVR

Piling noise: Measurement requirements

Ideally, need to characterise source (in terms of **Source Level**)

- Would like to measure sound field
  - Variation over (large) range
  - Time variation of source output
  - Near field (ideally using arrays)
  - Field in sediment (geophones)
  - Particle velocity in field
  - Levels near to sensitive sites
  - Wideband recordings

BUT:

- procedure must be cost effective and logistically realistic

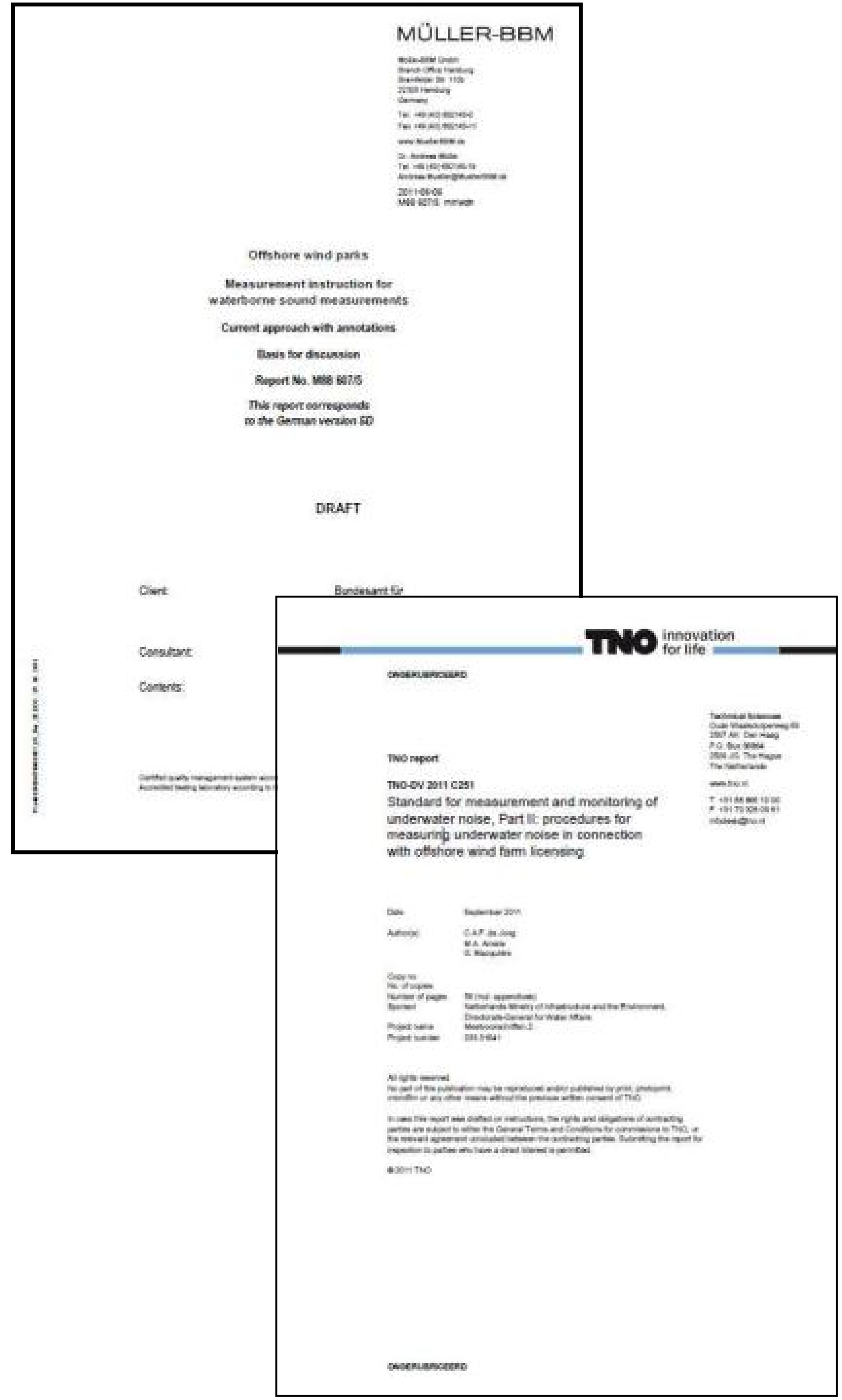
In practice, what has been done is:

- measure along individual radial transects
- entire sequence measured using static hydrophones
- limited no. of hydrophones
- restricted minimum and maximum range

Piling measurement protocols

- GERMANY
- Radiated noise monitoring
  - Hydrophones at ~750 m
- Limits placed on received levels:
  - SEL: 160 dB re 1 dB re 1 μPa^2·s
  - Peak pressure of 190 dB re 1 μPa

- NETHERLANDS
- Source characterisation
  - Range dependent
  - Fixed location
- Peak pressure and SEL reported


MÜLLER-BBM

Offshore wind parks

Measurement instruction for waterborne sound measurements

Current approach with annotations

Basis for discussion

This report corresponds to the German version 5D

DRAFT

Client: Bundesamt für

Consultant:

Contents:

TNO innovation for life

ONGERUBRICEERD

TNO report

TNO-DV 2011 C251

Standard for measurement and monitoring of underwater noise, Part II: procedures for measuring underwater noise in connection with offshore wind farm licensing

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Human response

- Divers and swimmers

- Hearing less sensitive underwater
- Bone conduction important
- Air-filled diving hood is shield

- Breathing apparatus significant source of sound
- Also power tools used by offshore divers
- No thresholds legally set