The dB_{ht} ; a metric for assessing the behavioural and auditory effects of underwater noise

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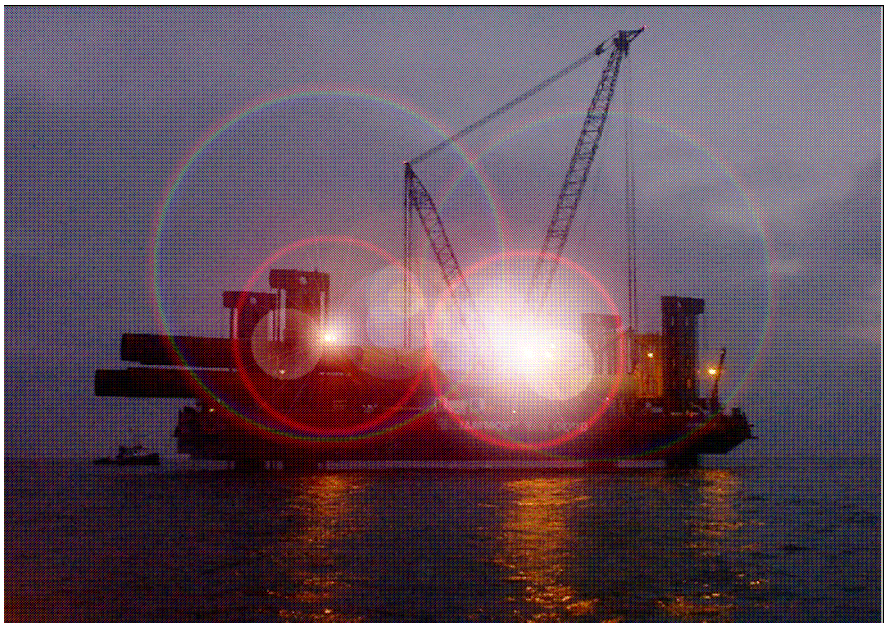
Introduction

- Two main effects of underwater noise include *injury* and *auditory effects* (behavioural and deafness)
- Auditory effects linked with the sensation of “unbearable loudness”.
- Occur at relatively low level and hence can affect much larger areas than physical injury, also secondary lethal effects e.g. stranding, hence major environmental issue



But what is deafening to a dolphin? Or ear splitting to an eel? How many cod will be affected by my seismic survey, or harbour porpoise by piling?

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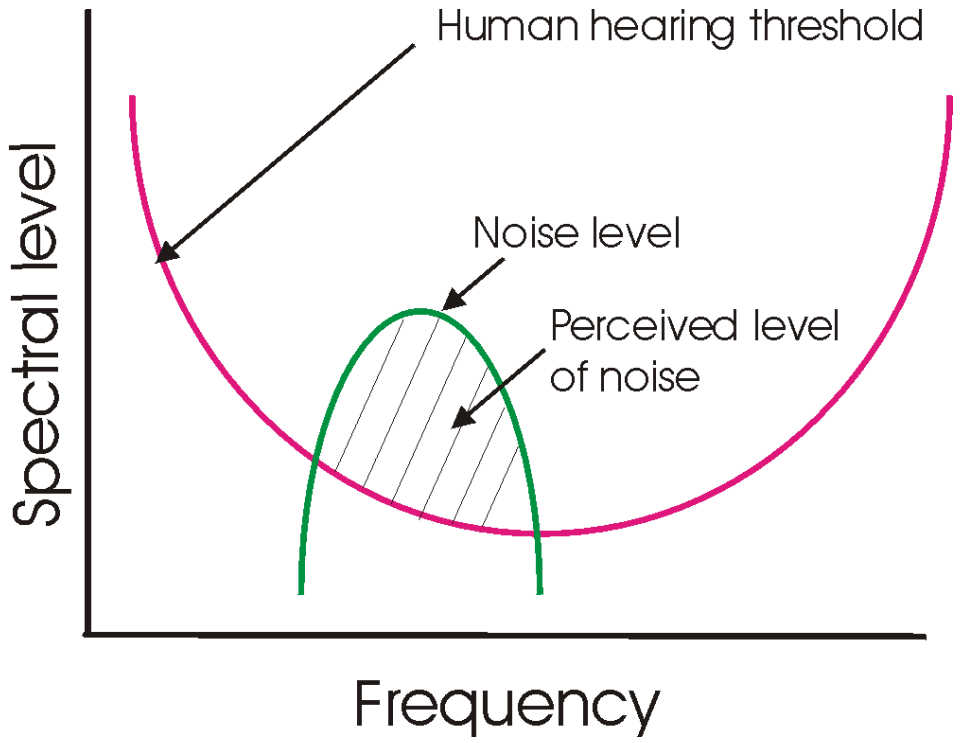
What does “loud” mean?

dB(A) used for effects of sound on humans embodies model of human hearing



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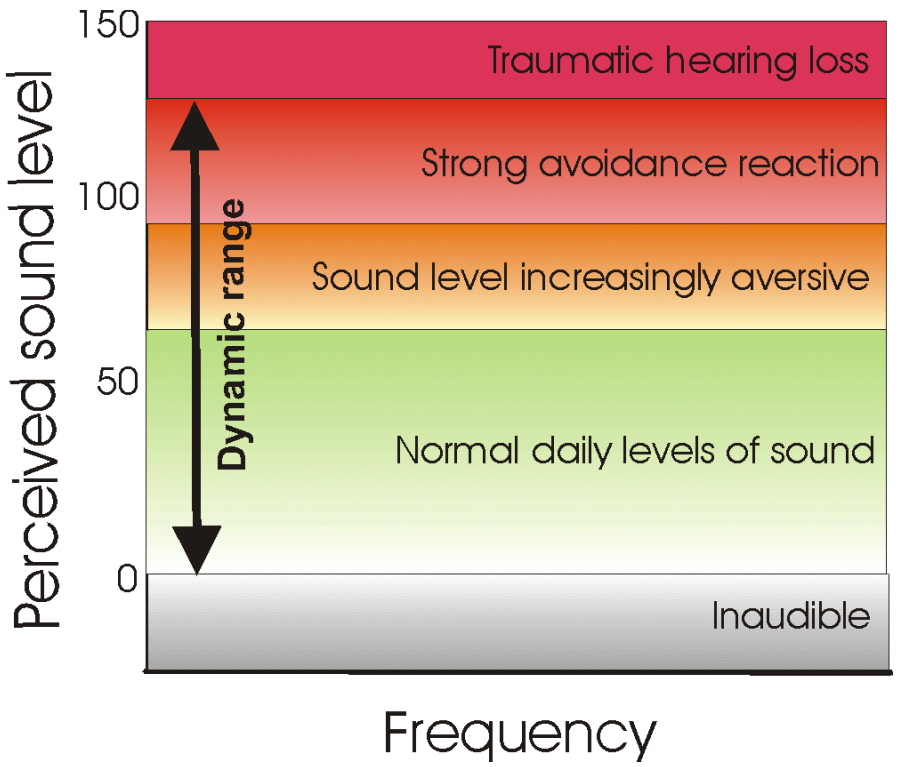
Dynamic range of hearing



Human dynamic range of hearing about 130 dB

Inaudible below 0 dB, traumatic loss above 130 dB

Sound “unpleasantly loud” from 90 dB upwards, causes behavioural response

Can this be applied to other animals?

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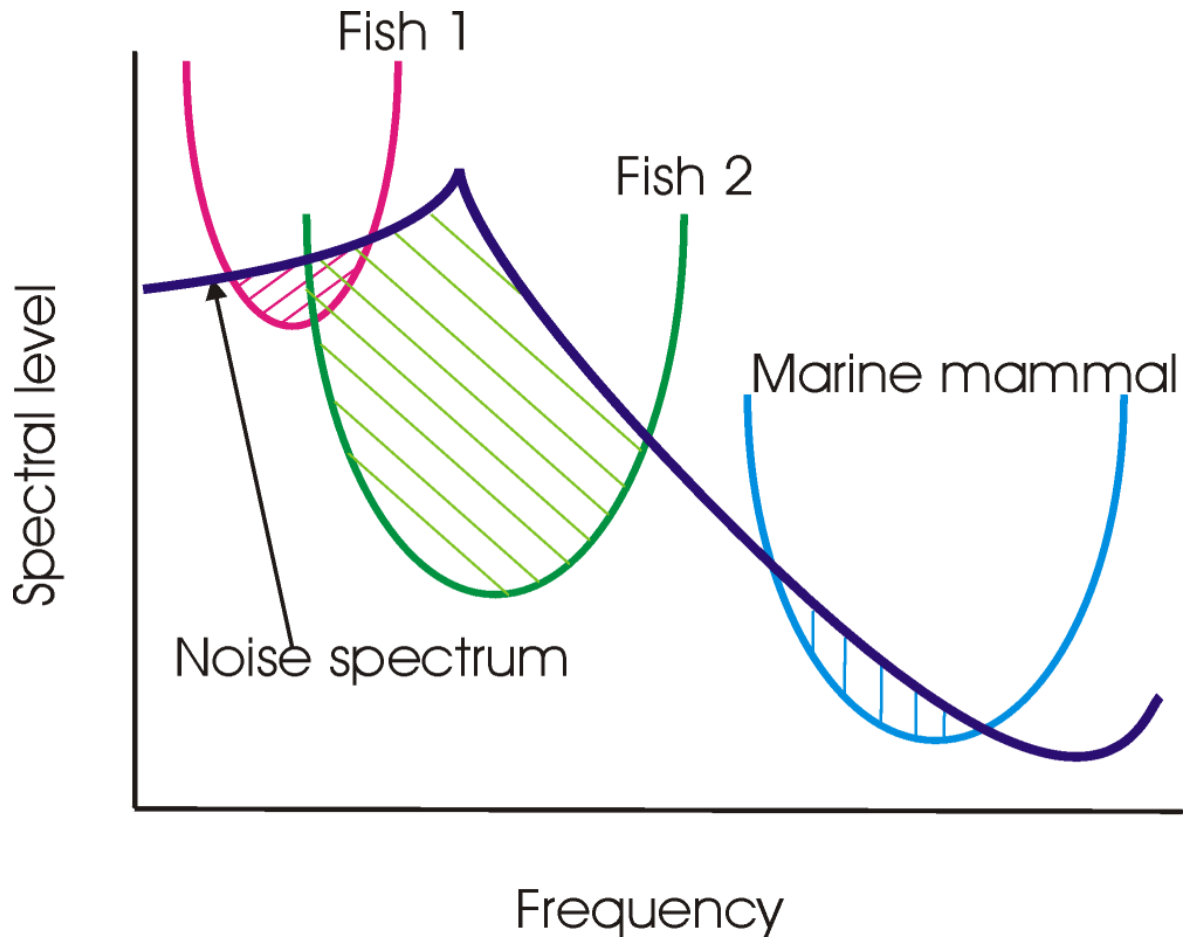
Concept of dB_{ht}



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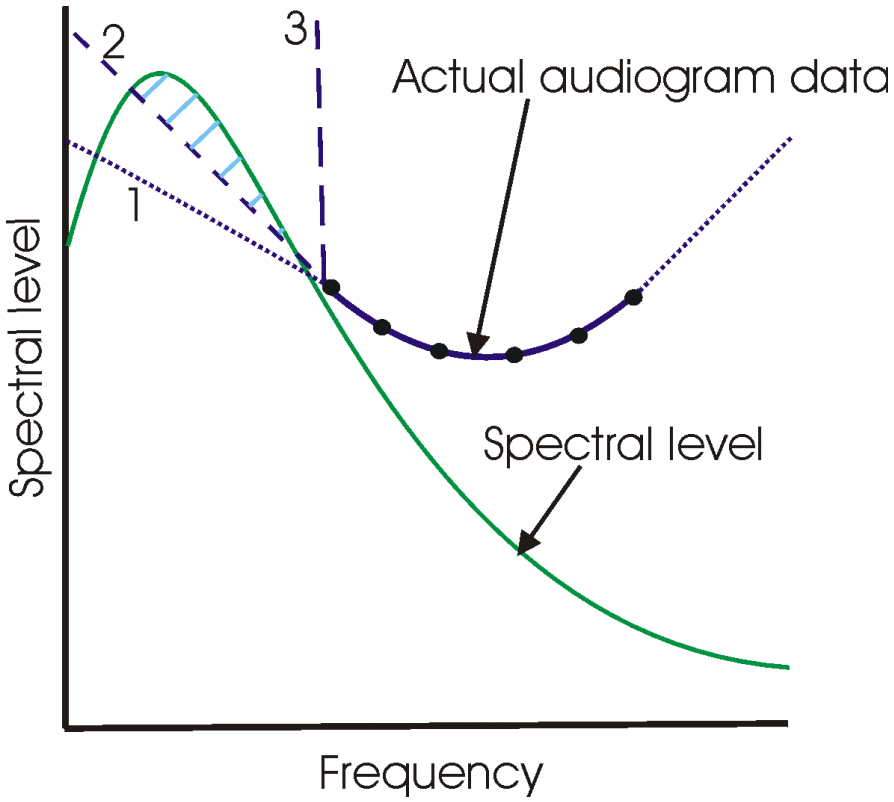
Imperfections of audiograms



Under some circumstances, assumptions that have to be made about low or high frequency extrapolation of audiograms has a major bearing on the dB_{ht} value calculated

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The dB_{ht} (*Species*)

- Generalisation of dB(A) used for human behavioural effects and noise induced deafness; can be applied to any species where hearing sensitivity (audiogram) for species known.
- Frequency weighting technique for determining the level of sound relative to hearing threshold (ht), hence dB_{ht}.
- Sound passed through filter that mimics the hearing ability of the species; level of sound is measured after the filter; dB_{ht} (*Species*) hypothesis proposes effect of the sound for any species primarily related to this *perceived* level ("loudness").
- Specific name must generally be appended, e.g. 90 dB_{ht} (*clupeia harengis*) = "90 dB above the hearing threshold of herring"

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Benefits of metric

- A simple metric relating noise to its effect in an identical manner to airborne noise criteria, *e.g.* “The majority of animals will avoid sound at 90 dB_{ht} or more.”
- Enables simple regulatory criteria (“the sound shall not exceed 75 dB_{ht} at the stated range for the specified species….”).
- Probabilistic model, allows estimation of percentage of individuals reacting as a function of level
- Allow non-expert personnel to measure and interpret noise (Species Sound Level Meter)

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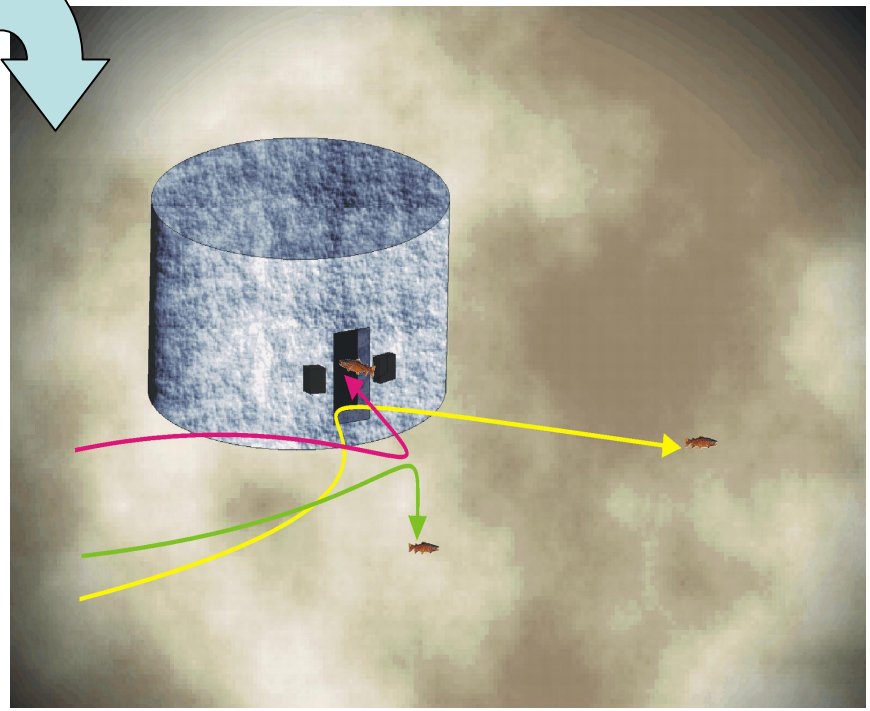
Levels of sound causing avoidance: Doel



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Measurements of efficiency

Species	Common name	Efficiency (%)
Clupea harengis	Herring	94.7
Sprattus sprattus	Sprat	87.9
Dicentrarchus labrax	Bass	75.6
Osmerus eperlanus	Smelt	53.5
Perca fluviatilis	Perch	51.2
Solea solea	Dover sole	46.6
Pomatoschistus sp.	Goby	46.1
Abramis bjoerkna	Bream	40.1
Platichthys flesus	Flounder	37.7

The efficiency (percentage reduction in catch) in the cooling water of the Doel nuclear power plant; measurements on c. 350,000 fish by Leuven University. Signal swept sine from 20 Hz to 500 Hz.

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Re-interpretation of existing data: INHS

- Bighead Carp barrier experiments at Illinois Natural History Survey's Wolff Hatchery in Illinois USA; same signal as Doel
- Number of successful and unsuccessful attempts to pass recorded continually over 6 hour period.
- Found to be 57% effective
- Good quality audiograms available; sound had maximum level of 55.2 dB_{ht} (*Hypophthalmichthys molitrix*)

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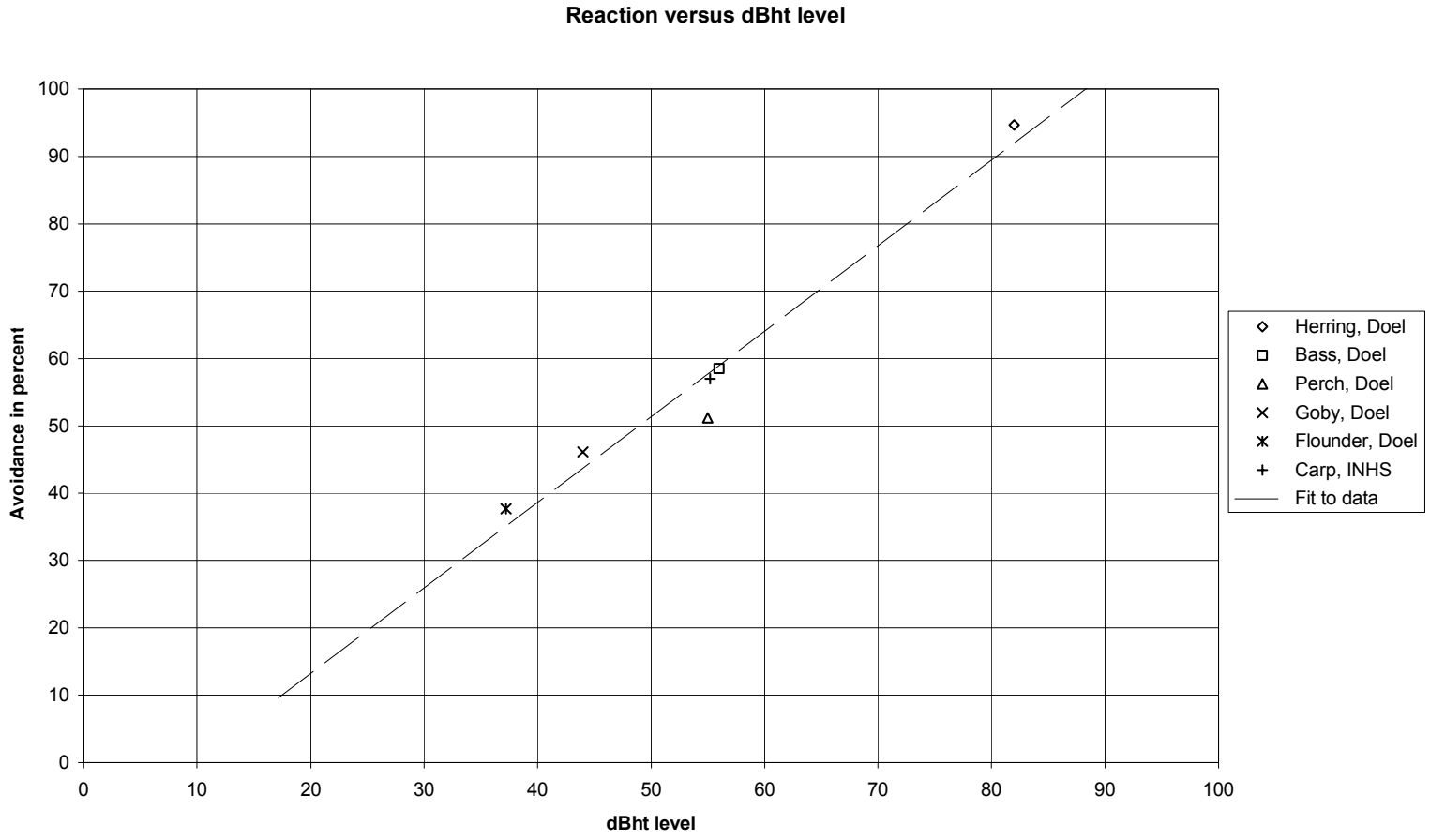
Analysis of Doel and INHS data

Reaction vs dB_{ht} level; free water



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Open water results

- Significant size of Doel data set (350,000 fish) yields high reliability of data
- Some public domain audiograms used to analyse data, also had to undertake audiogram measurements where required
- Indicates good fit to linear increase of probability of reaction with increasing dB_{ht} level; extremely useful as it allows the *probability* of an effect on individuals to be predicted
- Indicates 90 dB_{ht} as “strong reaction” level at which effectively all individuals react

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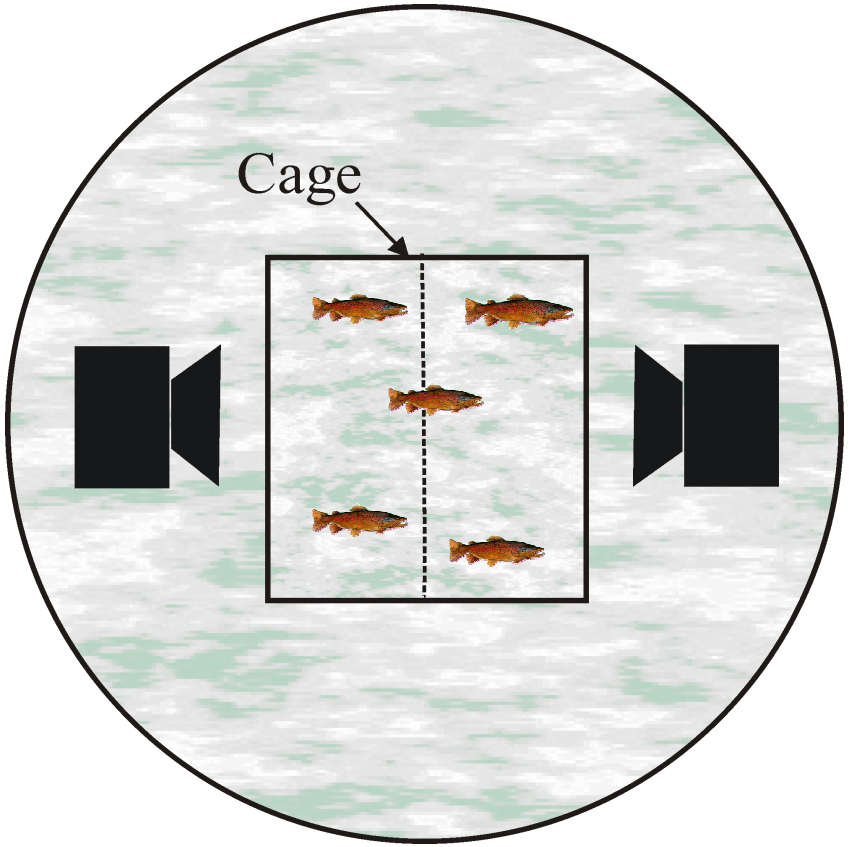
Laboratory tests: Reaction trials

- Major experimental collaboration with Babtie and Plymouth University
- ‘Choice-chamber’; 5 fish per species x 7 sounds;
- Avoidance response defined as move into opposite half of cage
- Calibrated and dB_{ht} calculated for pressure and particle velocity



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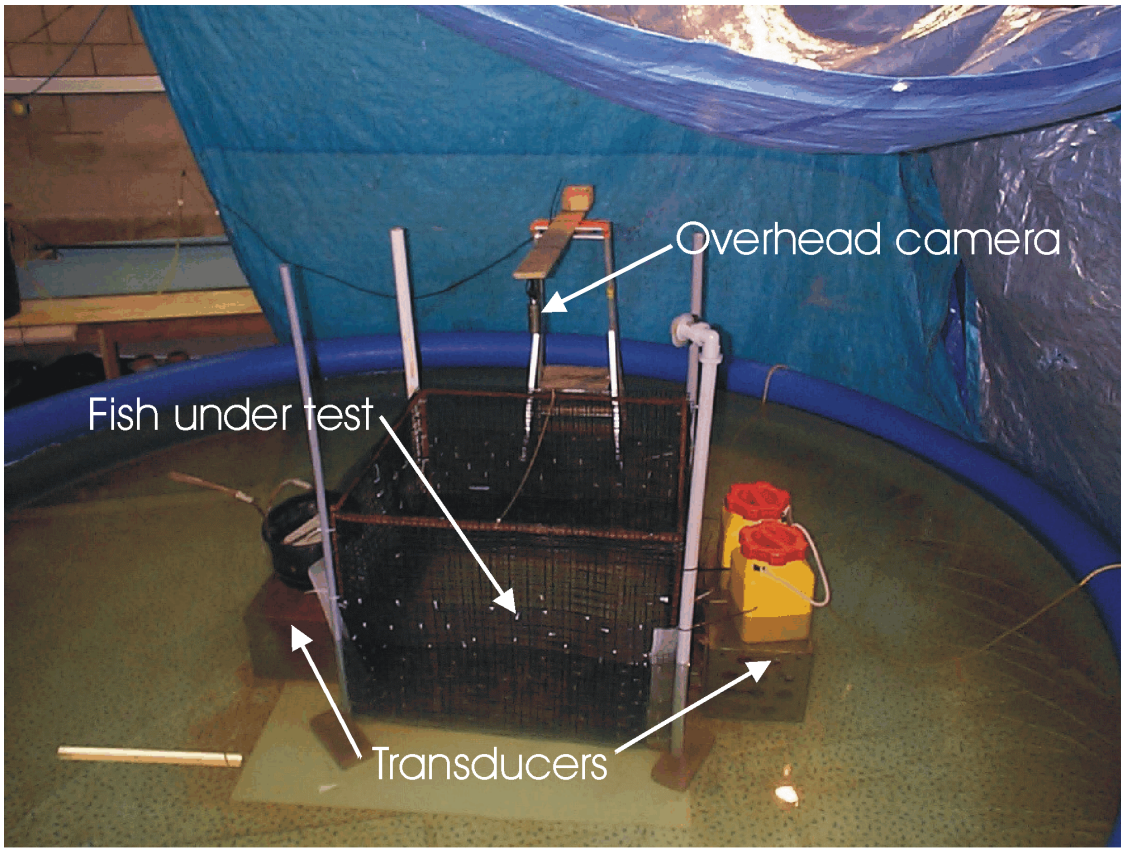
Experiment for reaction trials



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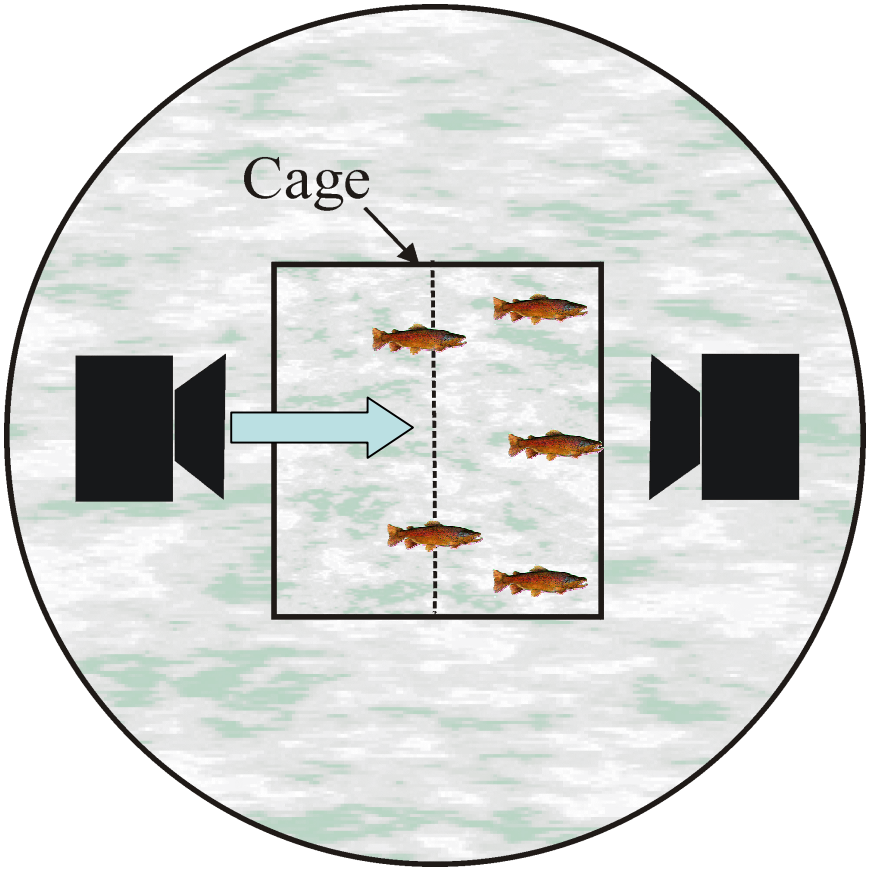
Laboratory tests: Reaction trials

Major series of about 600 individual experiments

Imperfect experimental philosophy

•*e.g.* 100 % avoidance (movement away from transducer)

•but only 60% measured effectiveness



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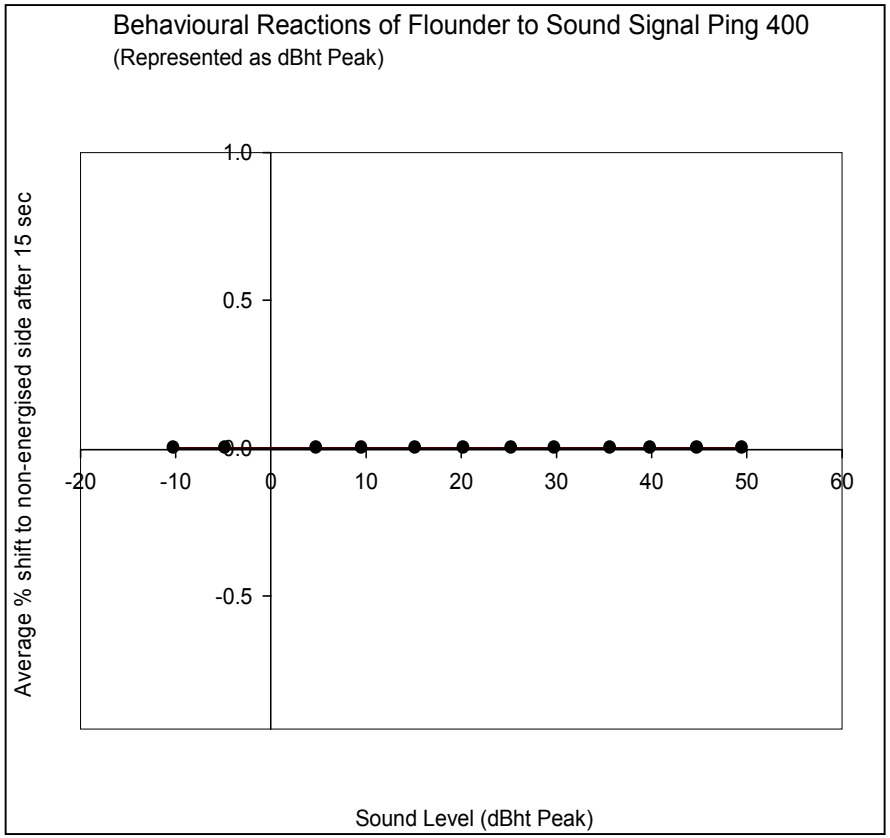
A typical reaction for Flounder

- Flounder instinct is to hide - react to noise by staying motionless on the bottom, hence no avoidance reaction
- The dB_{ht} offers a criteria for the likelihood of a behavioural reaction, *but requires biological interpretation as to the nature and significance of the reaction*



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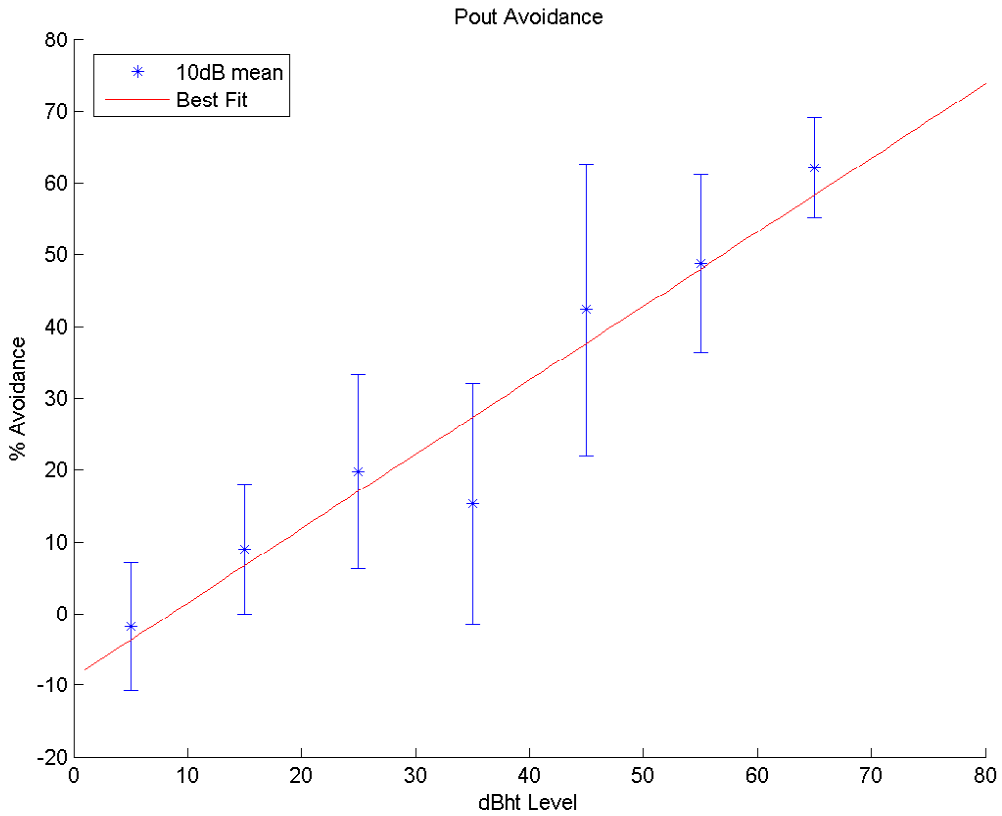
Pouting, averaged in 10 dB bins



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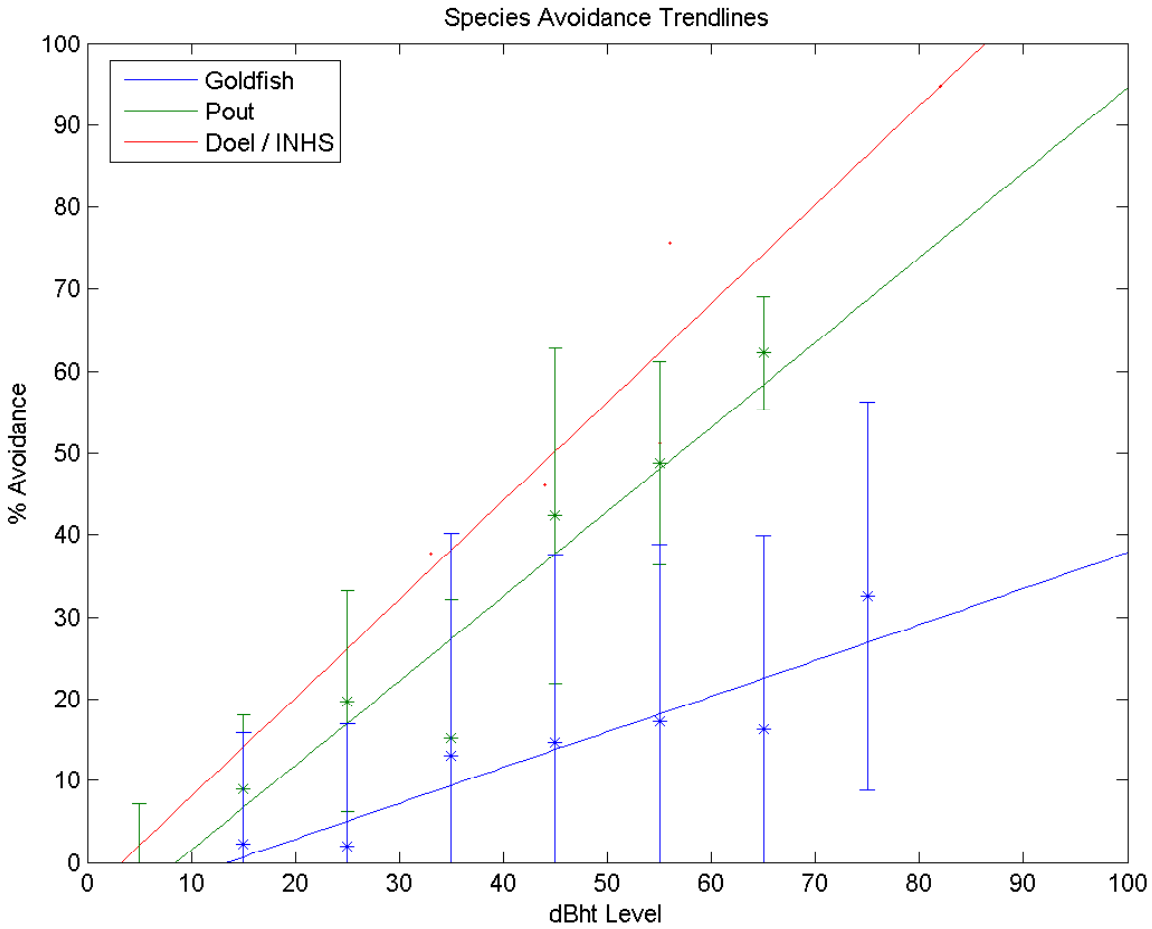
Synthesis of results



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Factors affecting confined reactions

- Physiological state of fish
- Different reaction behaviours, e.g. move away, move close to bottom etc.)
- ‘Follow-my-leader' effect, i.e. they all follow or stick by one sensitive or insensitive leader
- Balance of pressure to move away from source with pressure to stay away from cage walls and other members of shoal

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Examples: collapsing existing published data

Effect	Estimated dB_{ht} level	Source
Porpoise excluded within 10-15 km of piling	89 dB_{ht} (*Phocoena phocoena*) at 10 km	Tougard *et al*: Study of piling for offshore windfarm at Horns' reef
No Ringed Seals observed within 46 m of piling	83 dB_{ht} (*Phoca hispida*) @ 46 m (based on common seal audiogram)	Blackwell: Study of tolerance of seals to pile driving
Tolerance of seismic @ 180-190 dB lin by Ringed Seals	93-103 dB_{ht} (*Phoca hispida*) tolerated (based on common seal audiogram)	Harris *et al*; Tolerance of seals to seismics in Prudhoe Bay region
TTS in bottlenose dolphin octave band white noise, 30-50 minutes	98 dB_{ht} (*Tursiops truncatus*)	Nachtigall *et al* 2003, 2004 Pool tests on captive dolphins
TTS in bottlenose dolphin, 3 kHz tones, 1 – 8 secs	133 - 135 dB_{ht} (*Tursiops truncatus*)	Finneran and Carder 2005 Pool tests on captive dolphins
Divers "very severe" 500 – 2500 Hz @ 157 dB lin.	87-90 dB_{ht} (*Homo sapiens;* submerged)	Fothergill *et al*. Study of diver aversion to low frequency underwater sound

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Experimental conclusions

On the basis of the experimental and public domain information, we have proposed the following criteria for the effects of noise.

Level in dB_{ht}(*Species*)	**Effect**
Less than 0	None
0 to 50	Mild reaction by minority of individuals
50 to 90	Stronger reaction by majority of individuals but habituation at lower levels may limit effect
90 and above	Strong avoidance reaction by all individuals
Above 110	Tolerance limit of sound; unbearably loud
Above 130	Possibility of traumatic hearing damage from single event

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Interpretation of measured noise

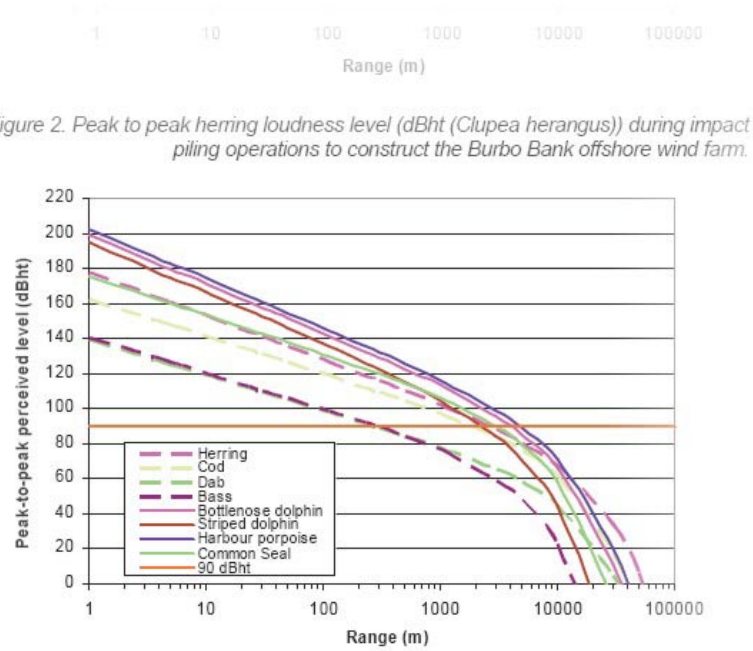

Figure 2. Peak to peak herring loudness level (dBht (Clupea herangus)) during impact piling operations to construct the Burbo Bank offshore wind farm.

Figure 3. Peak to peak perceived sound level (dB_{ht}) for various marine species during impact piling operations to construct the Burbo Bank offshore wind farm.

Typical survey of recorded noise shows significant variations in expected effect range, from 300 metres for flatfish up to 5 km for dolphins

(*Underwater noise survey during impact piling to construct the Burbo Bank Offshore Wind Farm*. S J Parvin and J R Nedwell Company Subacoustech Ltd. Report Number 726R0103 25th October 2006)

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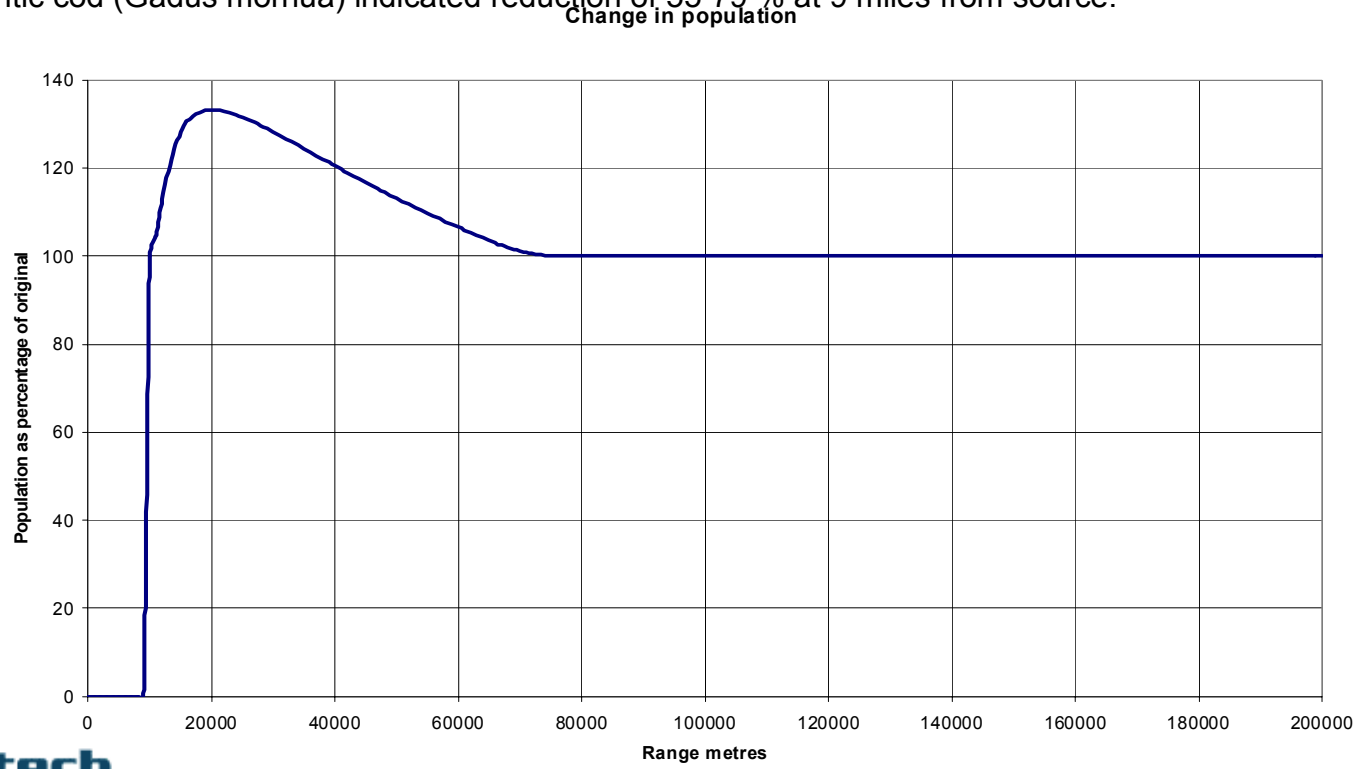
Predictive modelling of seismics

Effects of seismic shooting on local abundance and catch rates of cod (Gadus morhua) and haddock (Melanogrammus aeglefinus) Arill Engås, Svein Løkkeborg, Egil Ona, and Aud Vold Soldal. Can. J. Fish. Aquat. Sci. 53: 2238.2249 (1996). Reports on seismic survey; reductions in catch rates "were observed 18 nautical miles from the seismic shooting area, and were reduced by about 70% within the shooting area"

Lokkeborg, S. and Soldal, A.V. (1993) The influence of seismic exploration with airguns on cod (Gadus morhua) behavior and catch rates. ICES Marine Science Symposium. 196, pp. 62-67. Longline catching of Atlantic cod (Gadus morhua) indicated reduction of 55-79 % at 9 miles from source.



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Summary

1. The dB_{ht}(Species) offers a means of objectively evaluating or predicting the expected effects of noise on a wide range of species.

2. Validation has involved three different approaches; reaction of a range of fish species in the laboratory, reactions of a large number of species and individuals deflected by acoustic fish guidance systems; and by use of public domain information.

3. The results indicate clear dependence of the level of effect on the level of the sound, with an increasing percentage of the fish reacting as the sound level increases, and the majority of individuals reacting strongly at 90 dB_{ht}(Species) or more.

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