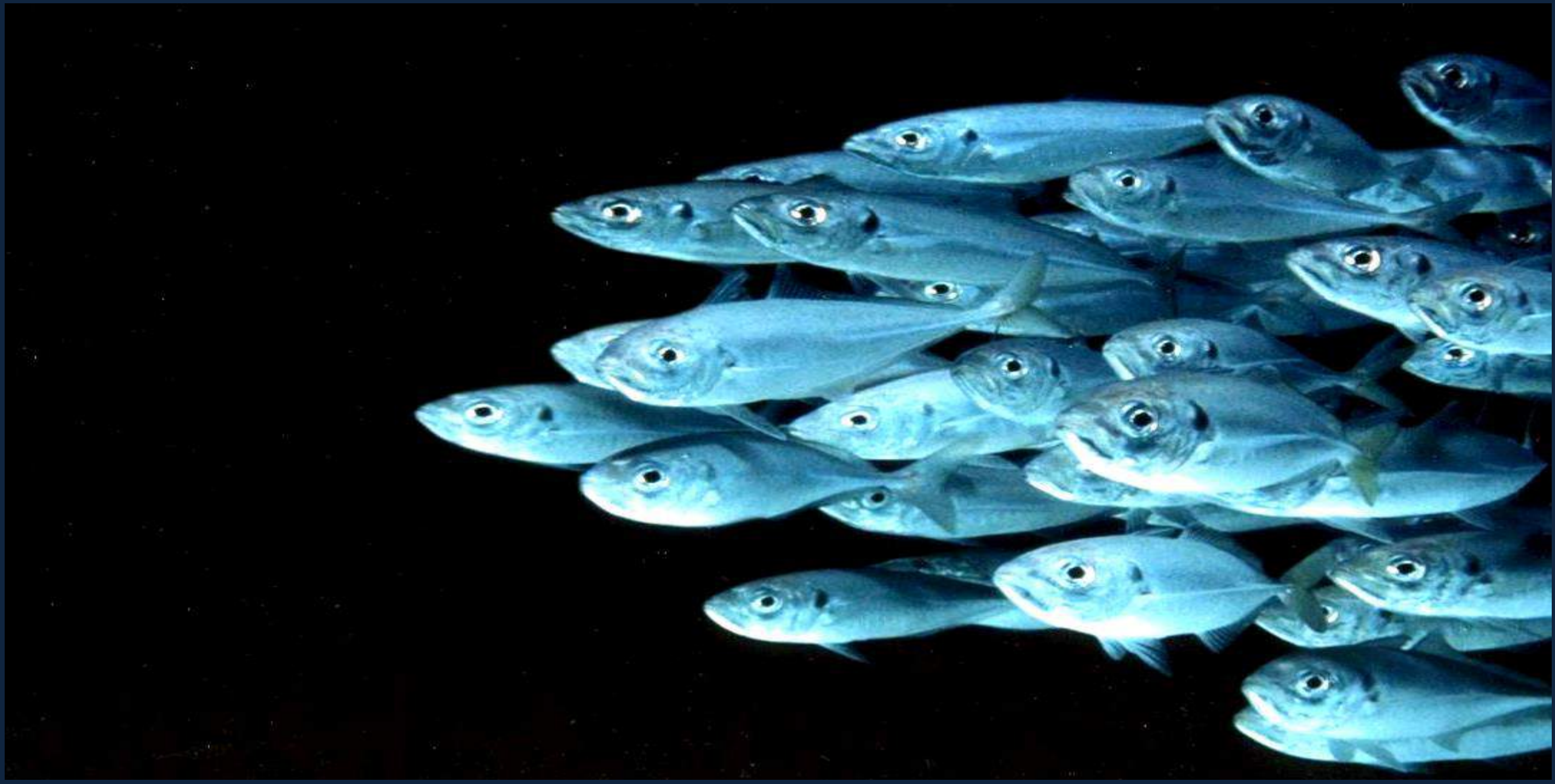
Developing a better understanding of the impact of noise in the marine environment



Tony Hawkins

Loughine Marine Research Aberdeen

Let's look at:

The different sources of underwater noise

The importance of sound to marine animals

How we are assessing the impact of noise

How we might do it better

Man-made underwater noise has been increasing since the 1830s

Large modern ships are very noisy

Shipping noise levels have increased by 10 dB from the 1960s to 1990s, i.e. an increase of 3 dB per decade

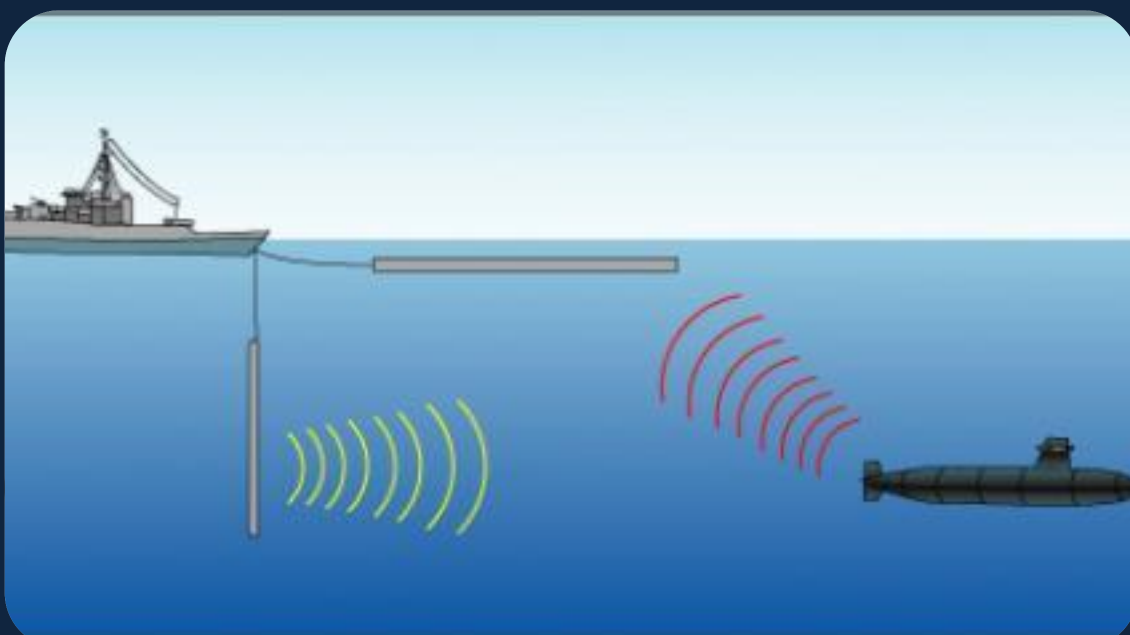
Even small pleasure boats are noisy

Fishing is noisy, with both the boat and the fishing gear generating sounds

Beam trawlers are especially noisy

Dredging of aggregates is noisy

Low frequency naval sonars are noisy



Offshore oil and gas activities are noisy

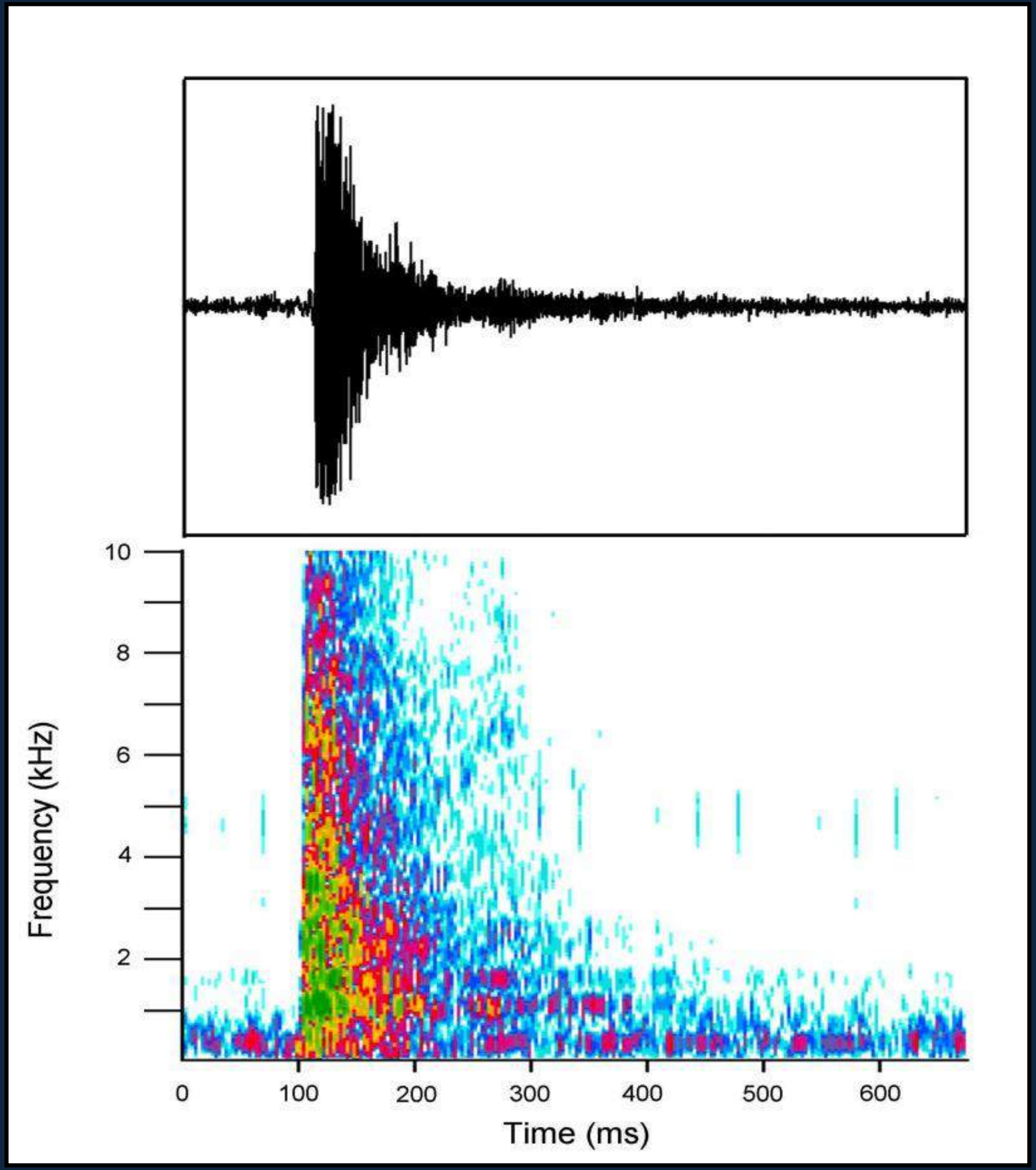
Seismic exploration for oil and gas is especially noisy, with airgun arrays generating loud impulsive sounds

Pile driving for the installation of bridges, quays and offshore structures also generates loud impulsive sounds

Pile driving sounds

Waveform

Spectrogram



Construction of offshore wind farms can require extensive pile driving

Noise levels in the sea are changing dramatically as a result of human activities

What effects are these changes having upon animal populations and biodiversity?

Visibility is often poor underwater

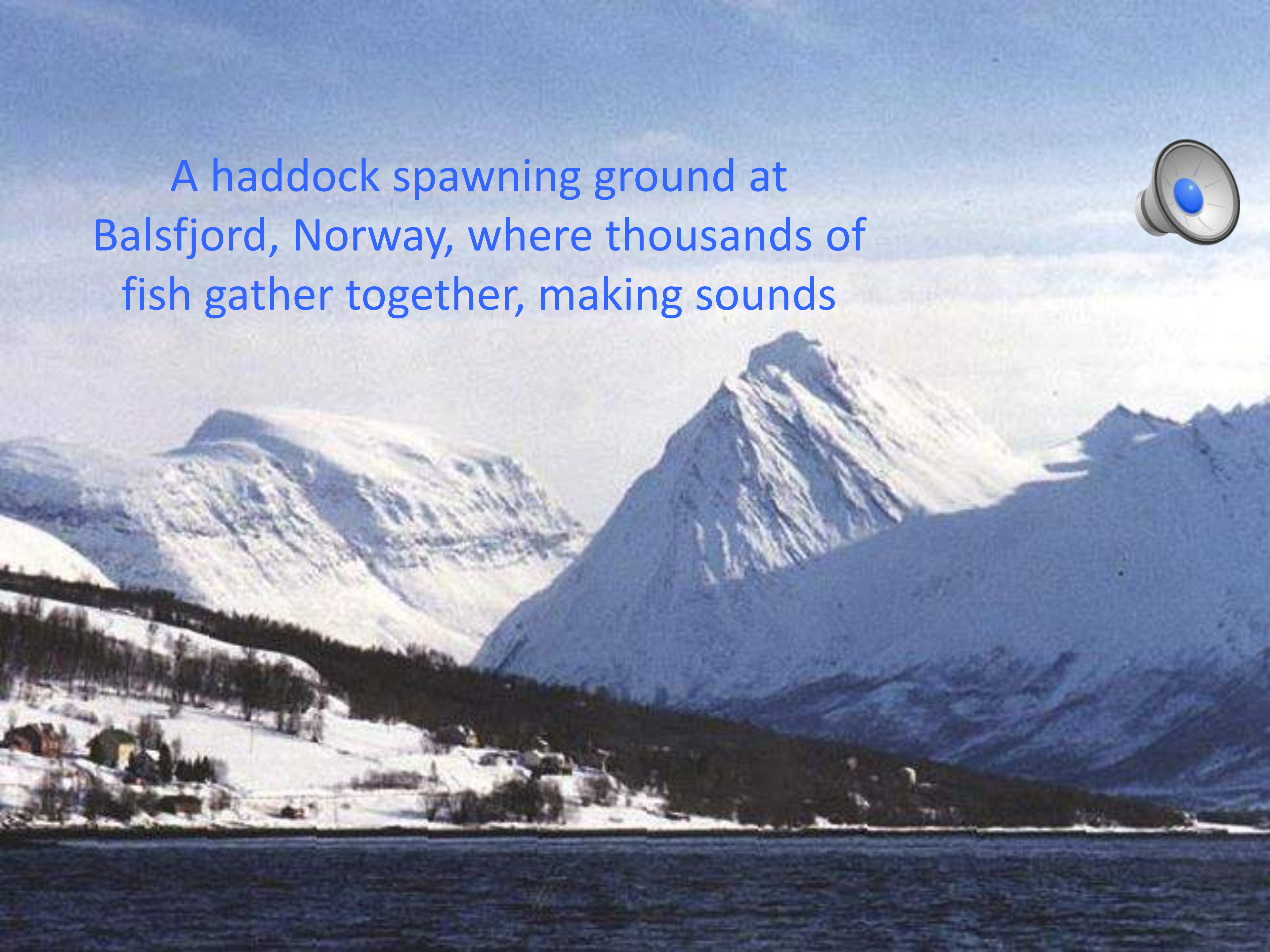
Sound travels further and faster underwater and provides an effective way for marine animals to communicate with one another

Sound is used by marine animals for:

- Communication
- Foraging, including finding prey through echo-location
- Prey avoidance
- Orientation and Navigation
- Habitat selection

Many fish make sounds

Haddock make sounds during spawning


A haddock spawning ground at
Balsfjord, Norway, where thousands of
fish gather together, making sounds

Many Marine Mammals Make Sounds

Common Seals

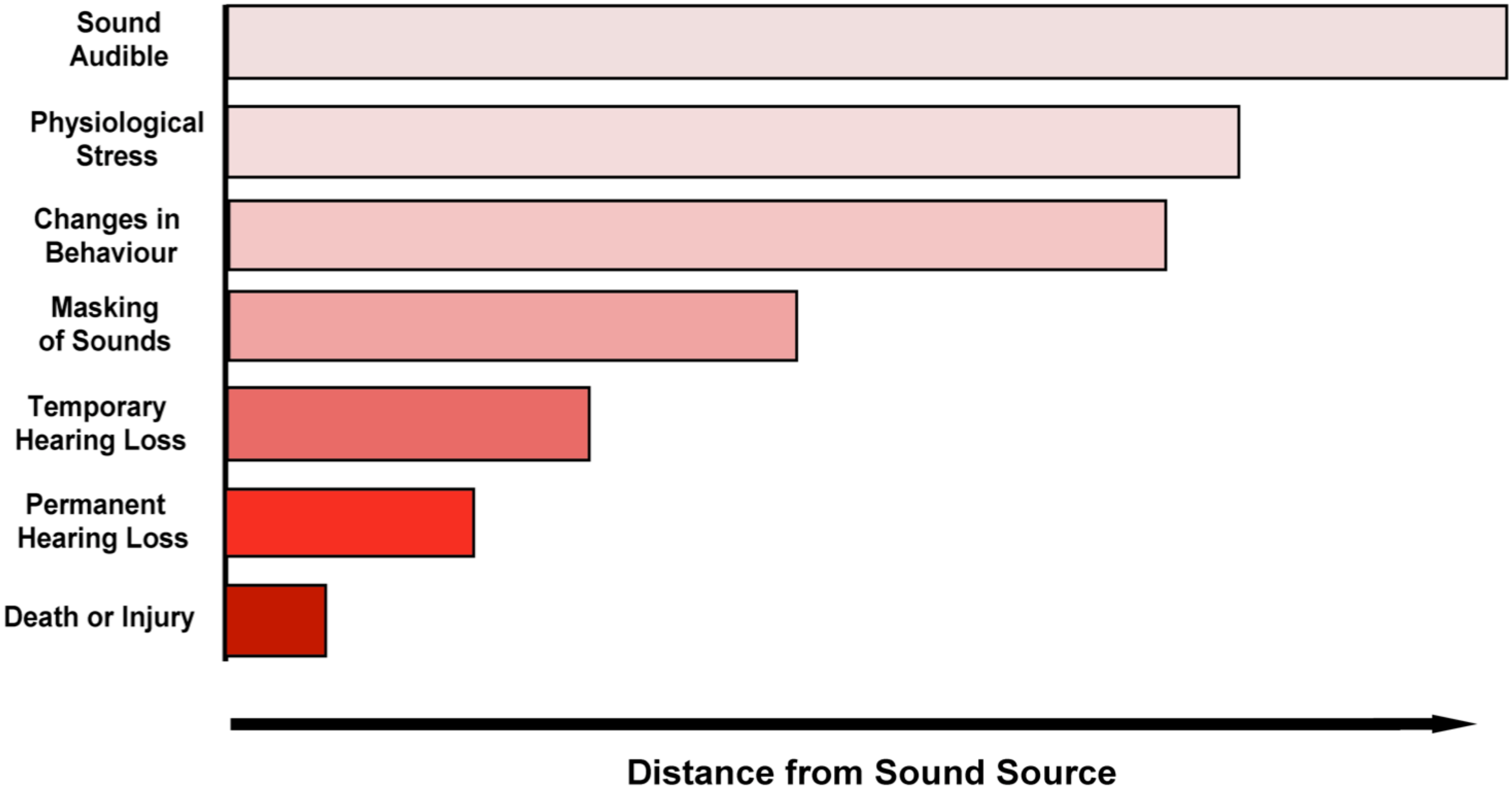
So do some Invertebrates!

The Snapping Shrimp

How can man-made noise affect the health and behaviour of marine animals?

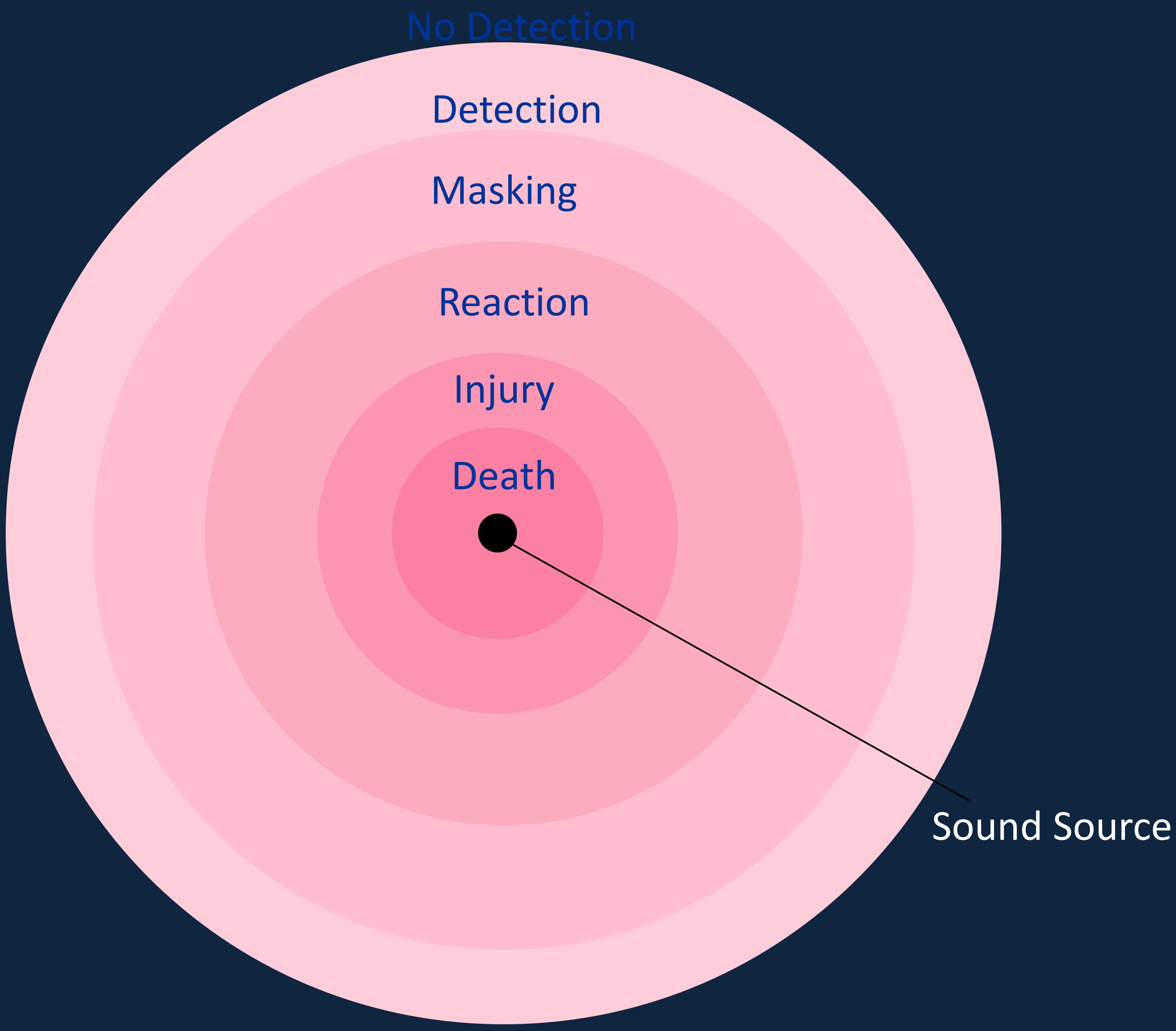
Much will depend on the level of the noise

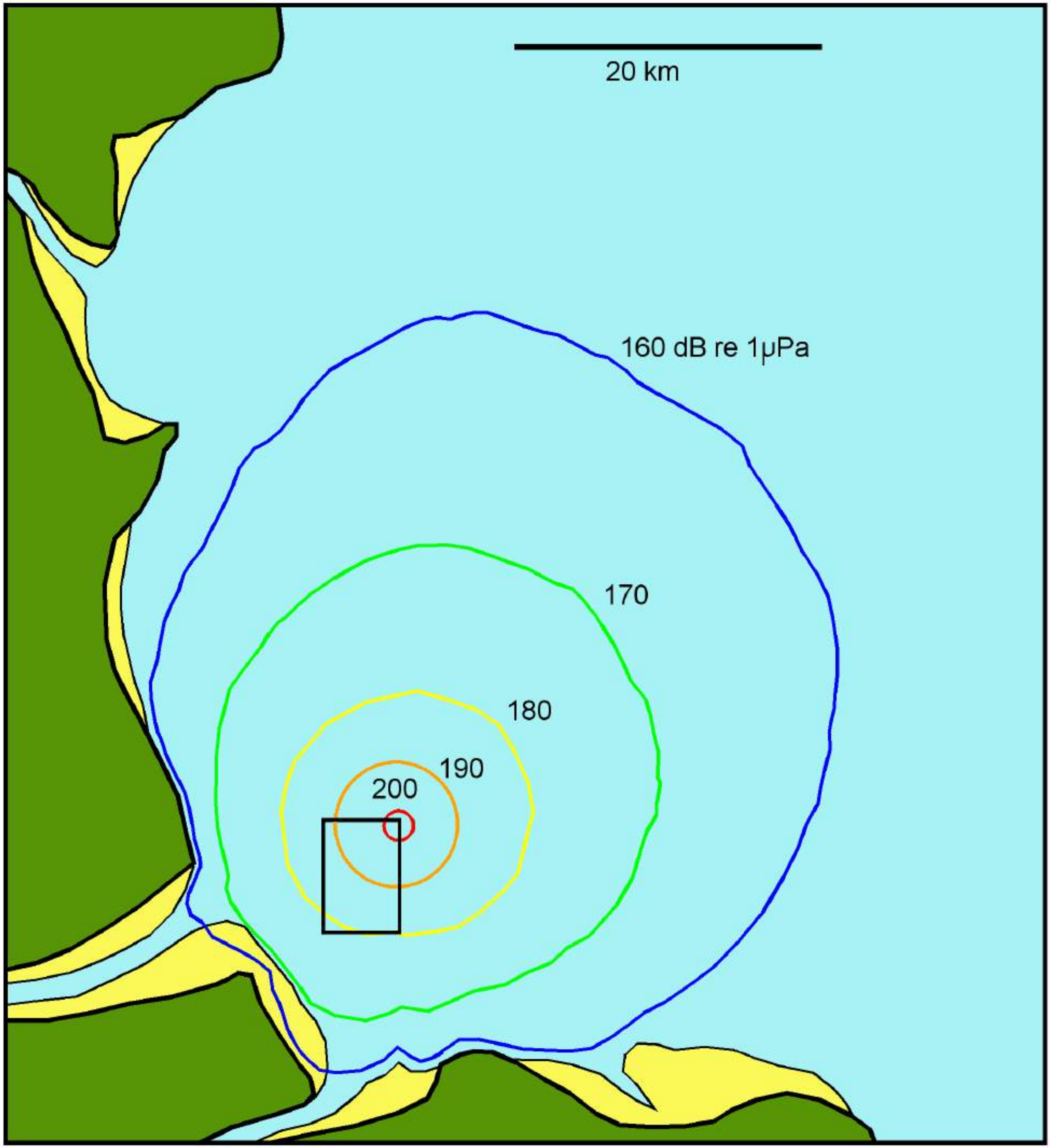
The effects of noise on animals will vary with distance from the source



Zones of effect can be drawn up

Zones of Response (following Richardson et al)





Modelling of peak to peak Sound Pressure Level contours for driving a single pile

Assessing the Impact of Noise

We need to know:

Which levels of noise have adverse effects?

And which do not?

Sound Exposure Criteria set limits to the received levels for particular sources

Sound Exposure Criteria

Limits may be set for:

Death or Injury

Hearing impairment

Masking of biologically important sounds

Changes in behaviour & other vital functions

Different Criteria are required for different sounds

For continuous sounds:

Levels are specified as average sound levels

For impulsive sounds:

Peak levels are specified

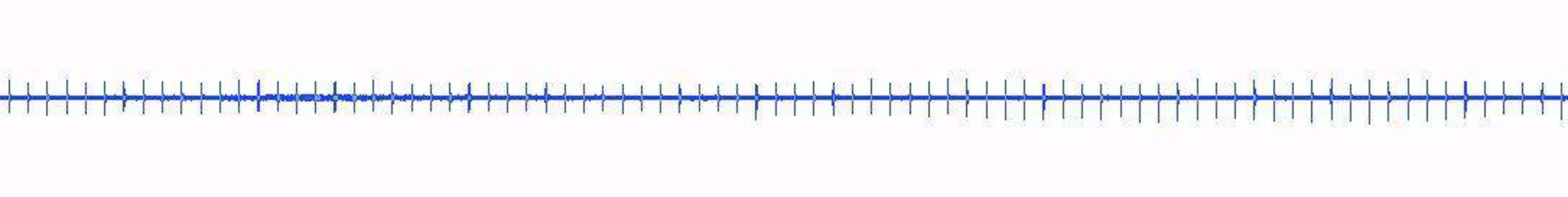
Sound exposure levels are also specified (the total energy within each pulse, or of many pulses)

Criteria for Injury to Fish from Pile Driving (USA)

Peak Sound Pressure Level	206 dB re 1 μPa
Cumulative Sound Exposure Level	187 dB re 1 $\mu Pa^2 \cdot s$

NB: The period of accumulation is not specified

Cumulative Levels must be used with care



These two sequences yield similar cumulative SEL levels

But a few high level pulses can do much more damage than a large number of low level pulses

The Wrong Metrics?

Levels are usually expressed in terms of sound pressure

Many fishes and invertebrates primarily detect particle motion

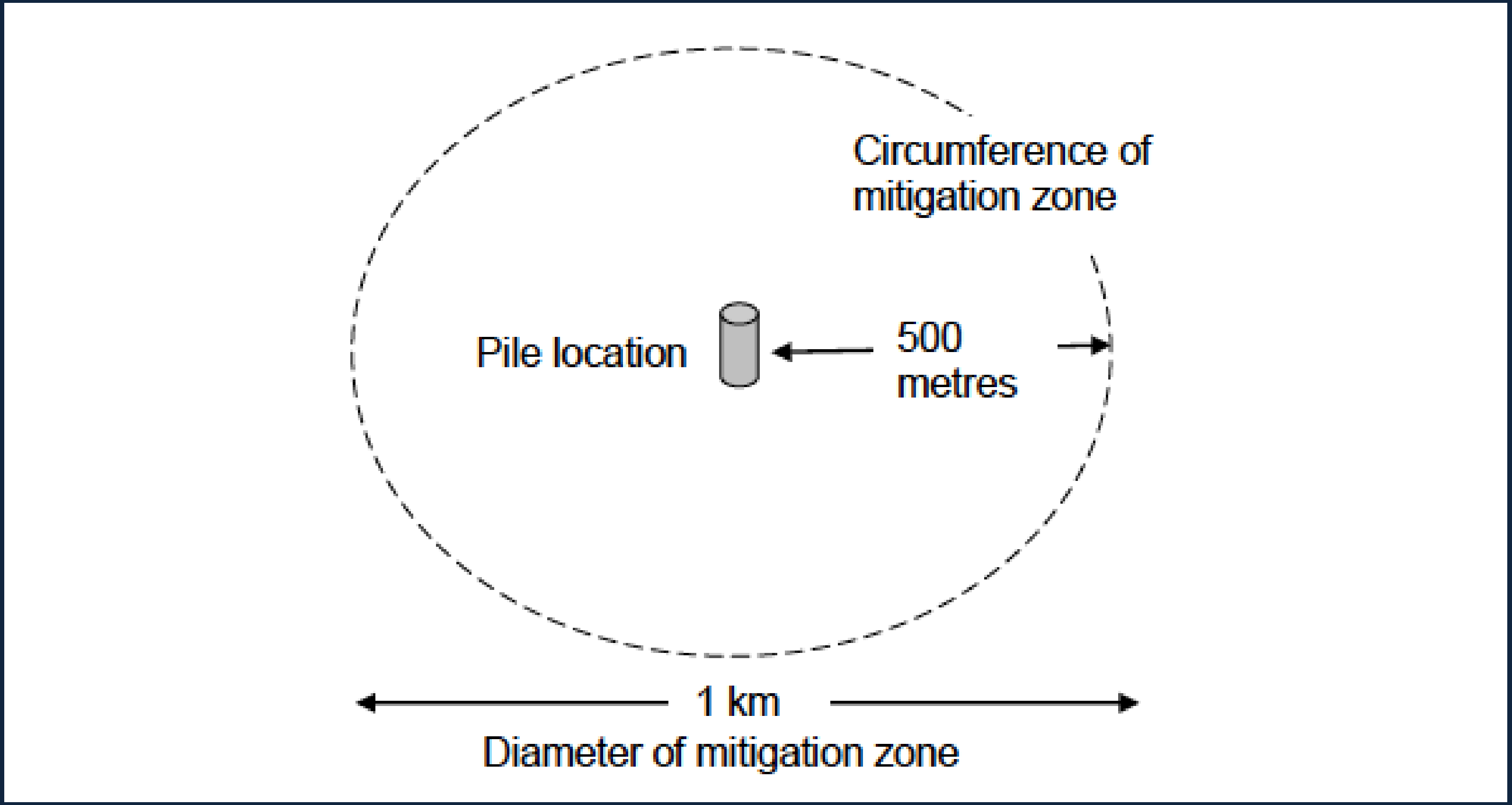
Sensitivity to particle motion is often not considered in setting sound exposure criteria or modelling sound propagation

Current Criteria for Marine Mammals (USA)

Estimated acoustic threshold levels for the onset of Permanent Threshold Shift		
Hearing Group	**Impulsive Sounds**	**Non-impulsive Sounds**
Low-Frequency (LF) Cetaceans	230 dB peak & 192 dB SELcum	230 dB peak & 207 dB SELcum
Mid-Frequency (MF) Cetaceans	230 dB peak & 187 dB SELcum	230 dB peak & 199 dB SELcum
High-Frequency (HF) Cetaceans	202 dB peak & 154 dB SELcum	202 dB peak & 171 dB SELcum
Phocid Pinnipeds (Underwater)	230 dB peak & 186 dB SELcum	230 dB peak & 201 dB SELcum
Otariid Pinnipeds (Underwater)	230 dB peak & 203 dB SELcum	230 dB peak & 218 dB SELcum

Mitigation Zones for Pile Driving for Marine Mammals (UK)

The extent of this zone represents the estimated area in which a marine mammal could be exposed to sound that could cause injury



Exposure Criteria for Pile Driving for Marine Mammals (Germany)

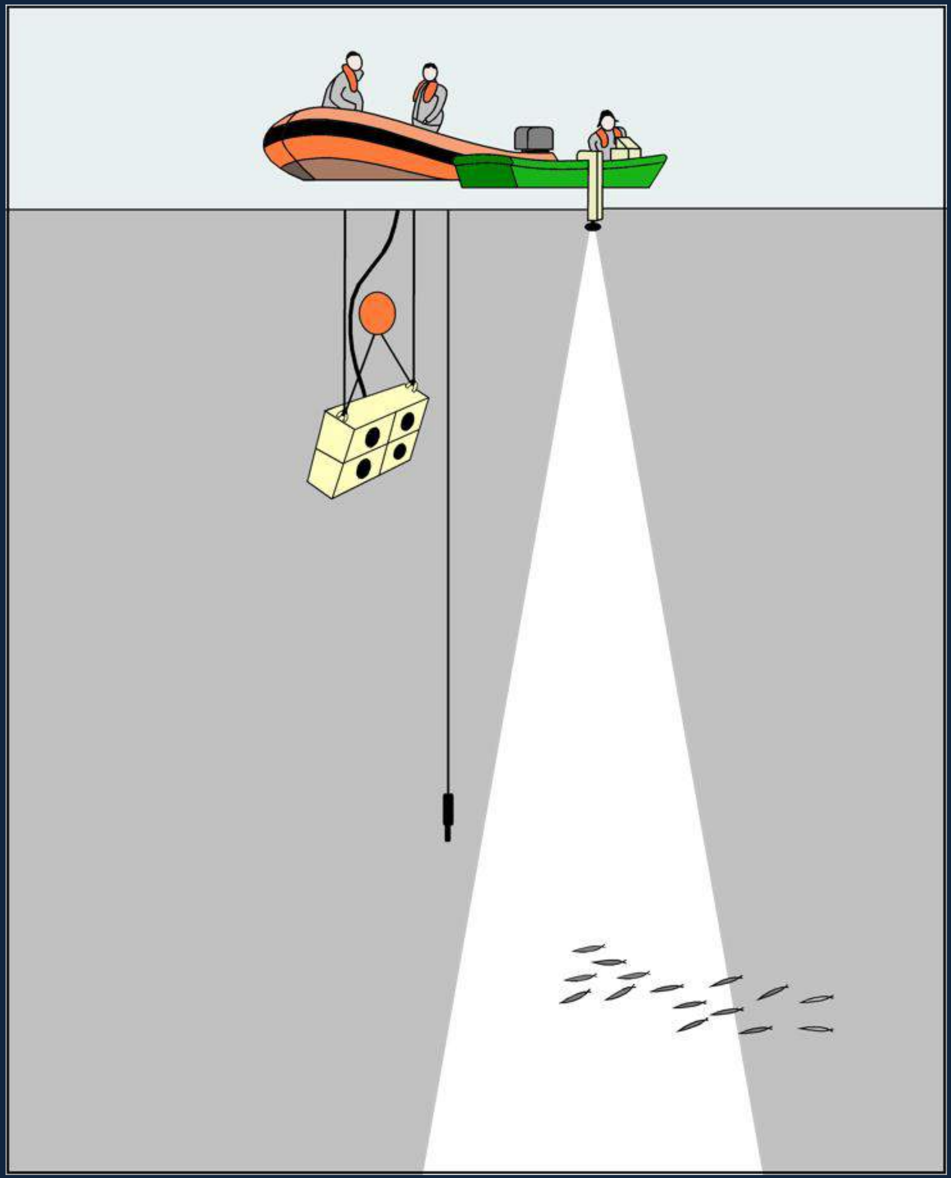
A dual noise exposure threshold of 160 dB (SEL) and 190 dB (SPL) at distances of up to 750 m from a piling site has to be met.

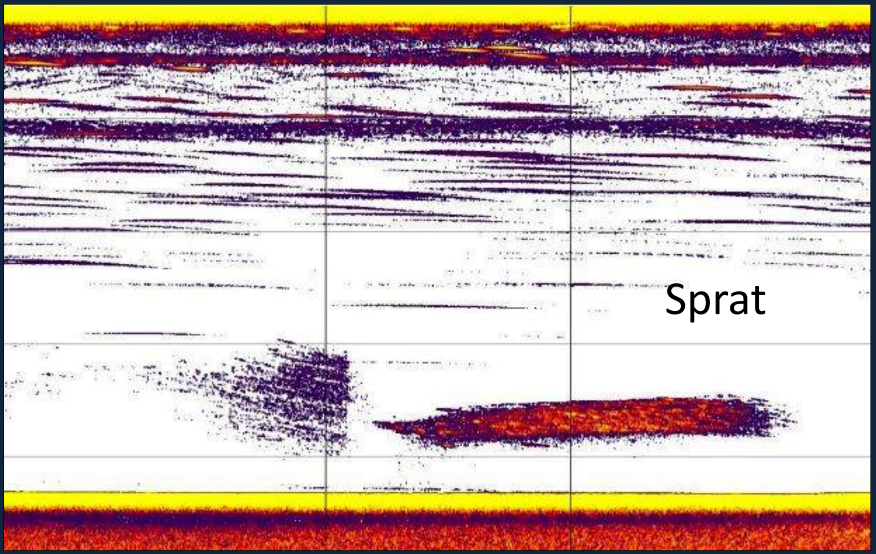
These more stringent criteria have led to intense efforts to develop and apply efficient sound reduction and mitigation techniques

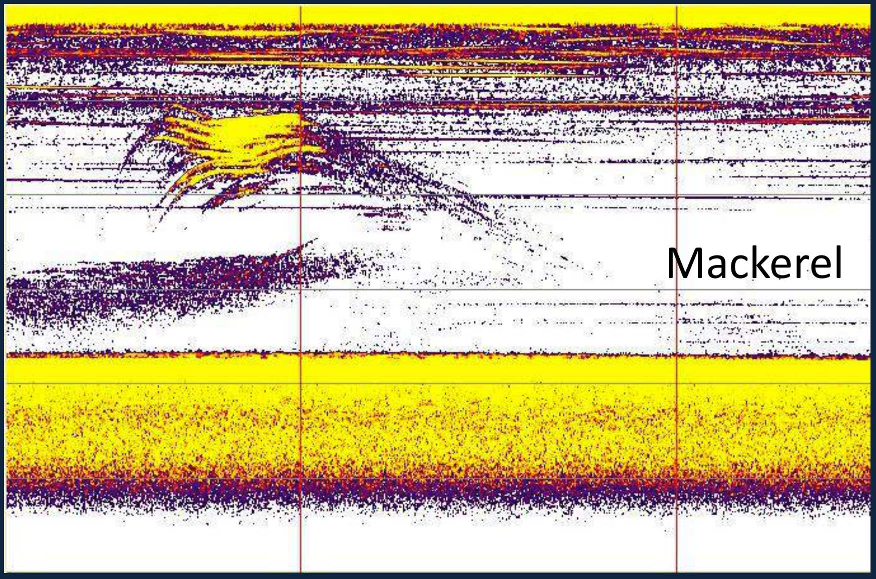
The major problem is that there are few data on those sound levels that actually produce effects

In particular there are few data on noise levels resulting in changes in the behaviour of free-living animals

Recent Experiments on Wild Fishes







50% Response levels to impulsive sounds

Sprat

Peak to peak sound pressure level 163.2 dB re. 1 μPa

Single strike sound exposure level 135.0 dB re. 1 $\mu Pa^2.s$

Mackerel

Peak to peak particle velocity level -80.0 dB re. 1 m s^{-1}

Single strike particle velocity exposure level - 101.7 dB re 1 m^2s^{-1}

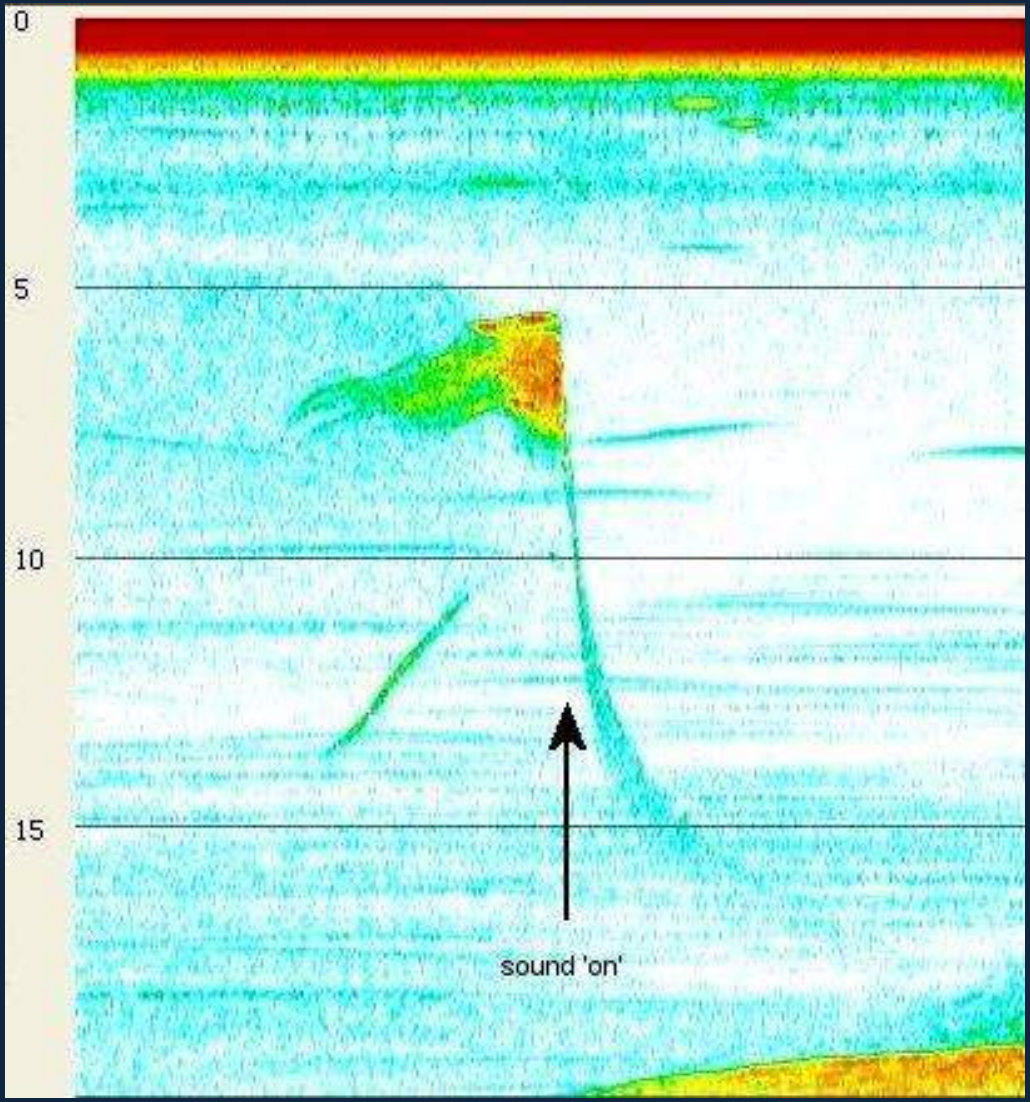
Effects and Impacts

An animal may respond to sounds but this does not necessarily mean that conservation interests are affected

It is important to show that there have been adverse effects upon:

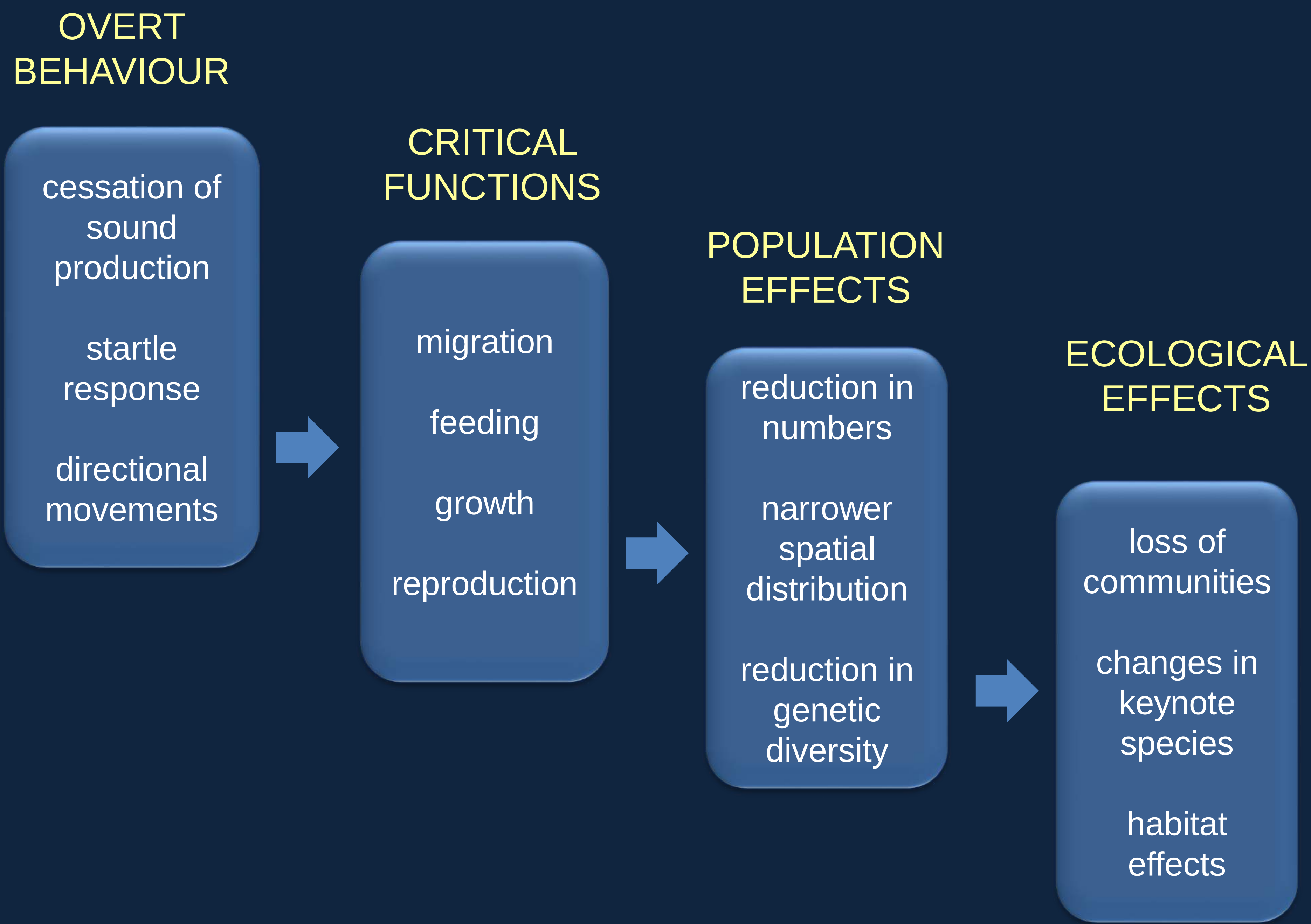
- The integrity of a conserved habitat
- The sustainability of a species or population
- Or to show that a protected species has been disturbed

What is the significance of an observed reaction to man-made sounds?



Translating observed behaviour into population impacts requires further information

The Population Consequences of Acoustic Disturbance (PCAD) model has been developed and others are being explored


OVERT BEHAVIOUR
cessation of sound production
startle response
directional movements
CRITICAL FUNCTIONS
migration
feeding
growth
reproduction
POPULATION EFFECTS
reduction in numbers
narrower spatial distribution
reduction in genetic diversity
ECOLOGICAL EFFECTS
loss of communities
changes in keynote species
habitat effects

Impact Assessment currently involves dubious assumptions & predictions

Sound exposure criteria are often assumed and are not based on real data

The metrics employed are often inappropriate, especially for fishes and invertebrates

Sound propagation models have seldom been validated and they do not predict particle motion levels. They are especially poor for shallow water conditions

Actual impacts on populations are often unknown and difficult to assess

We need better ways of determining whether man-made underwater noise is having adverse effects upon animals and aquatic communities

Can the Marine Strategy Framework help with this?

The MSFD sets out to ensure that the introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment

The objective is to achieve Good Environmental Status

Two “Indicators” have been chosen:

The numbers of high amplitude, low and mid-frequency impulsive sounds (e.g. pile driving strikes, airgun pulses)

Levels of low frequency continuous sound (e.g. ship noise)

Monitoring of these two indicators is currently taking place

Is this sufficient?

We are simply monitoring noise levels

Shouldn’t we be trying to define Good Environmental Status for Marine Soundscapes?


Soundscapes are as important as Landscapes

What do we really need to do?

Examine the characteristics of different noise sources;

Derive real sound exposure criteria for death and mortal injury, and hearing damage;

Examine the masking effects of raised noise levels;

Describe behavioural changes in response to sounds for animals in the wild and examine effects on populations;

Examine natural soundscapes and decide if any need protection;

Investigate procedures for mitigating the effects of noise.