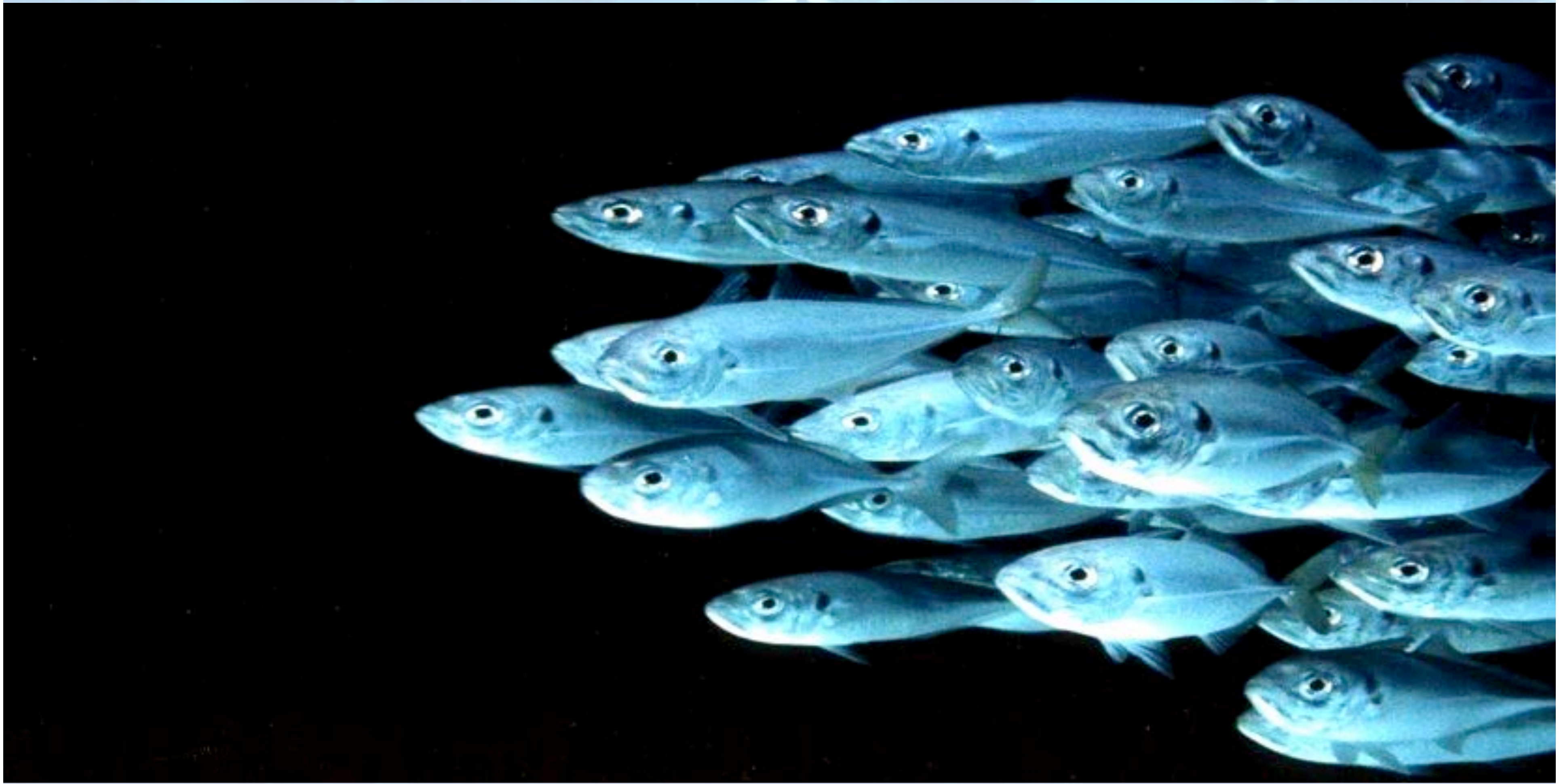
Potential Effects of Sound on Marine Fish



Tony Hawkins
Loughine Ltd

Underwater sound levels have been increasing since the 1830s

Continuous Underwater Sound Sources

Shipping - large & small vessels

Vibrating pile drivers - installing wind turbines & oil platforms, building docks & bridges

Dredging – removing gravel and other seabed materials

Operating renewable energy devices – utilising wind, wave and tidal energy

Fishing gears – especially those in contact with the seabed

Intermittent or Pulsed Underwater Sound Sources

Explosions – disposal of munitions, removal of redundant installations

Percussive pile drivers – installing wind turbines & oil platforms, building docks & bridges

Seismic airguns - surveys for oil and gas deposits

Sonar systems - operating at high, medium and low frequencies for the detection of underwater objects (often producing long pulses or "chirps")

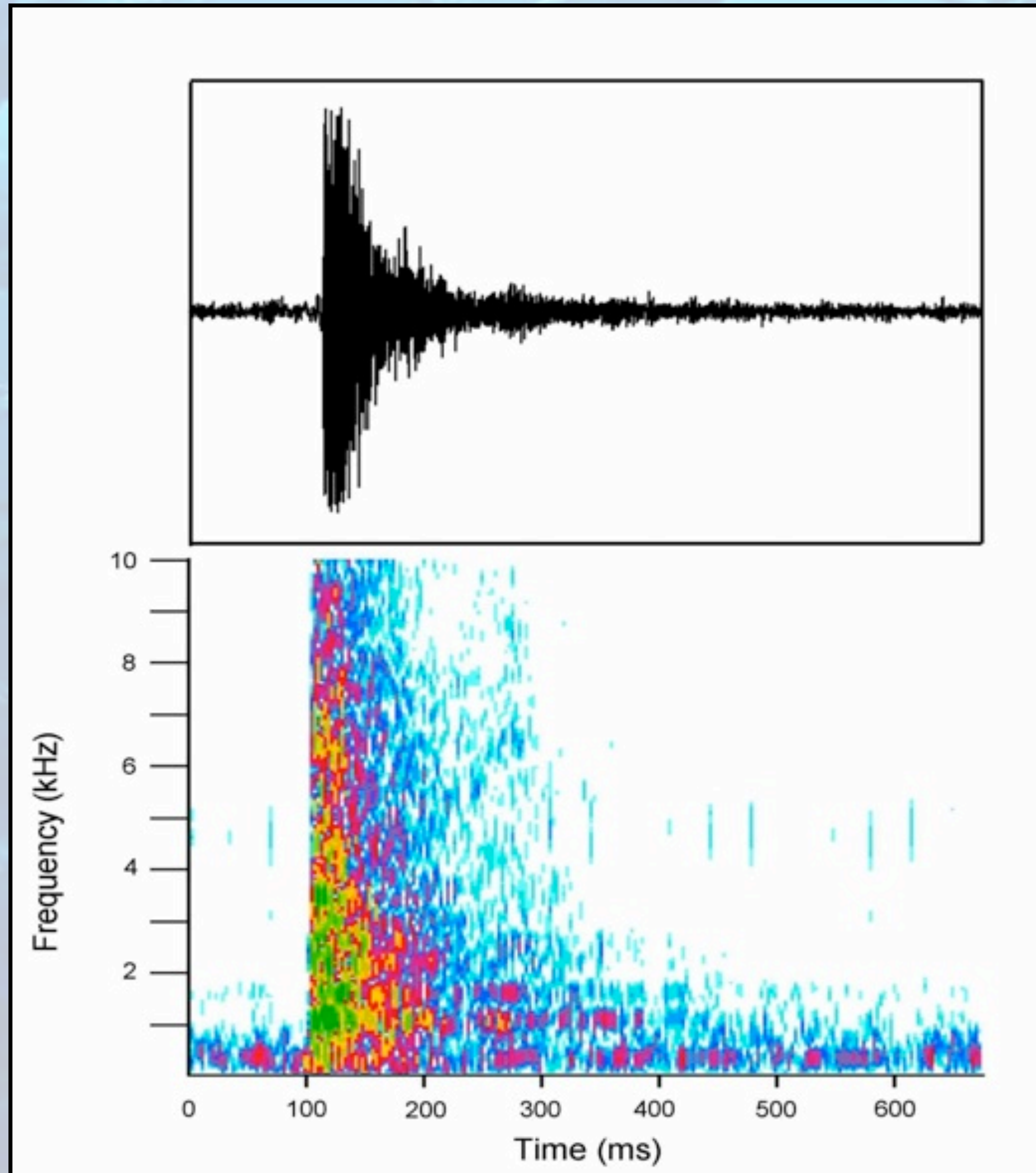
Pile driving is especially noisy

Construction of offshore wind farms can involve extensive pile driving

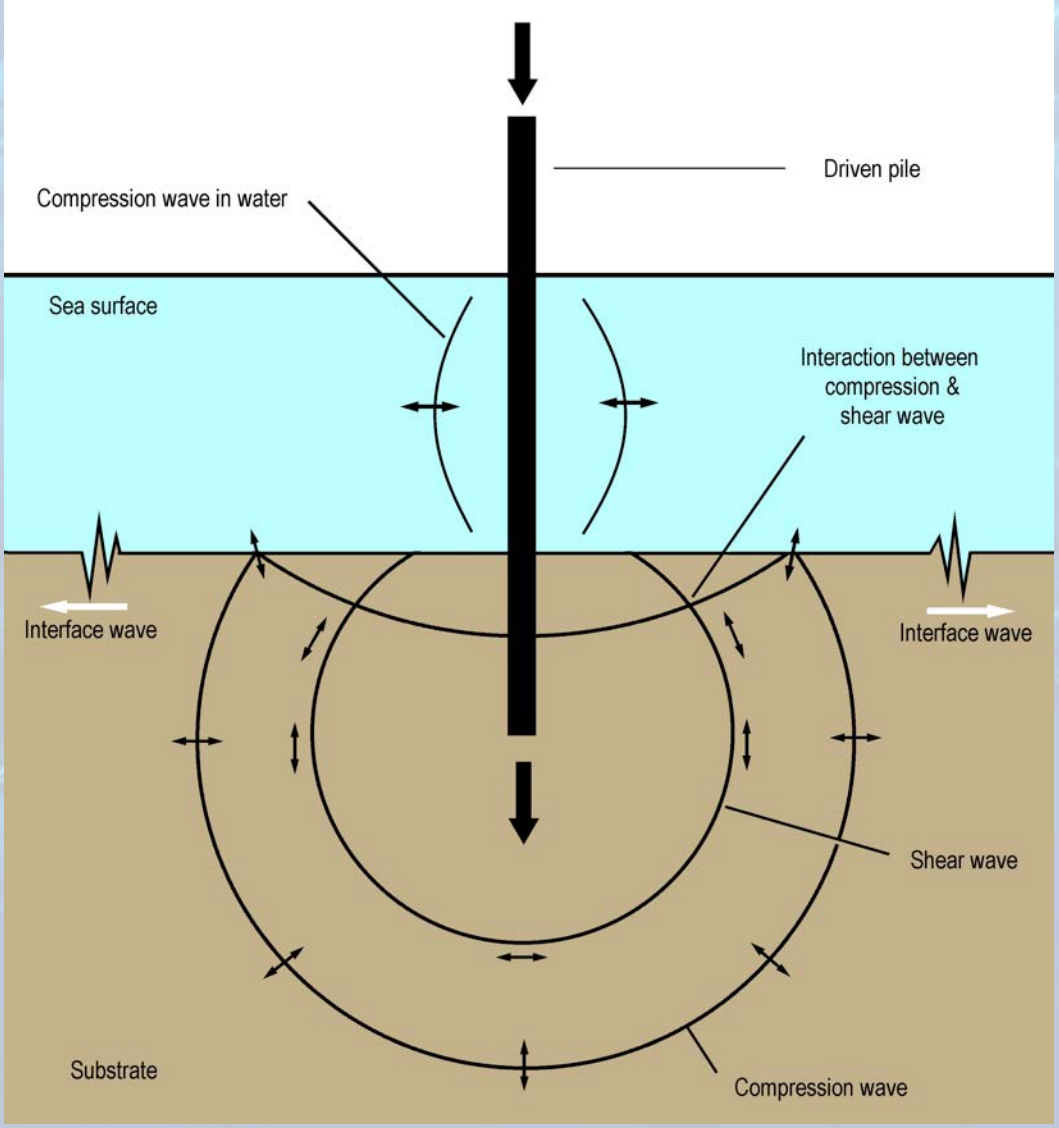
Pile driving sounds

Waveform

Spectrogram



Pile driving results in sound propagation through the water & seabed, and includes interface waves



Does noise affect fish?

We need to evaluate the risks to fishes from exposure to noise

We need to know those levels of sound that may have adverse consequences

And those that do not

The critical levels constitute **Sound Exposure Criteria**

What is sound?

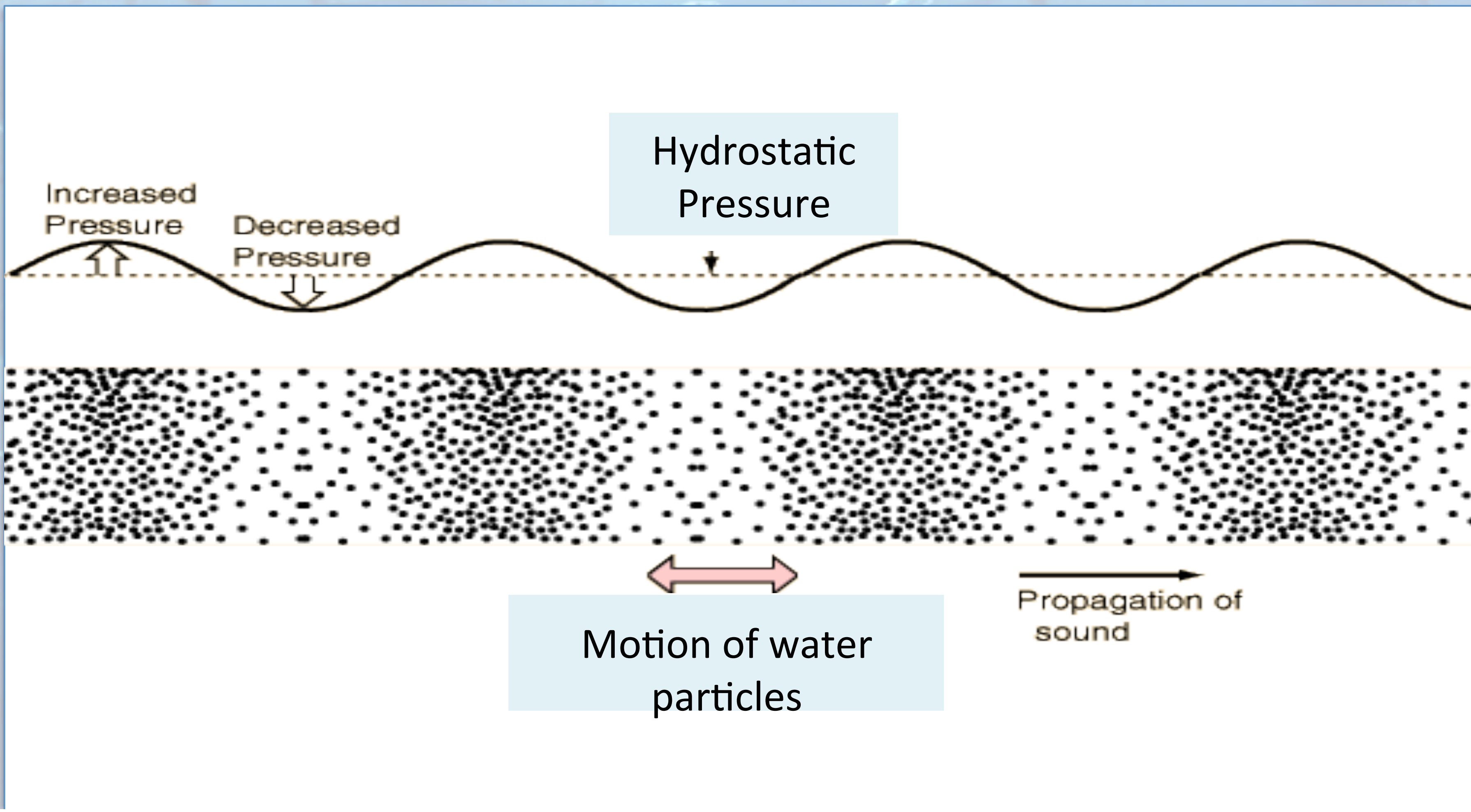
Sound is generated by the movement or vibration of any object immersed in a medium

Sound propagates through the medium at a speed that depends on its density and elasticity

Sound consists of **fluctuations in pressure**, but is also accompanied by **back and forth motion** of the water

Sound can be detected as the fluctuations in pressure, the sound pressure

But the back and forth motion of the water, the particle motion, is especially important to fish



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

Some of this noise is continuous and lasts for a long time

Other louder sounds are present only for short periods

But how important are sounds to fish?

How will exposure to noise affect them?

Visibility is often poor underwater

Sound provides an effective way for fish to communicate with one another

Hearing is also an everyday sense, used to give the fish knowledge of the surrounding world

Sound is very important for many fish

Sound is used for:

- Communication and social interaction
- Foraging and finding prey
- Predator avoidance
- Orientation and Navigation
- Habitat selection

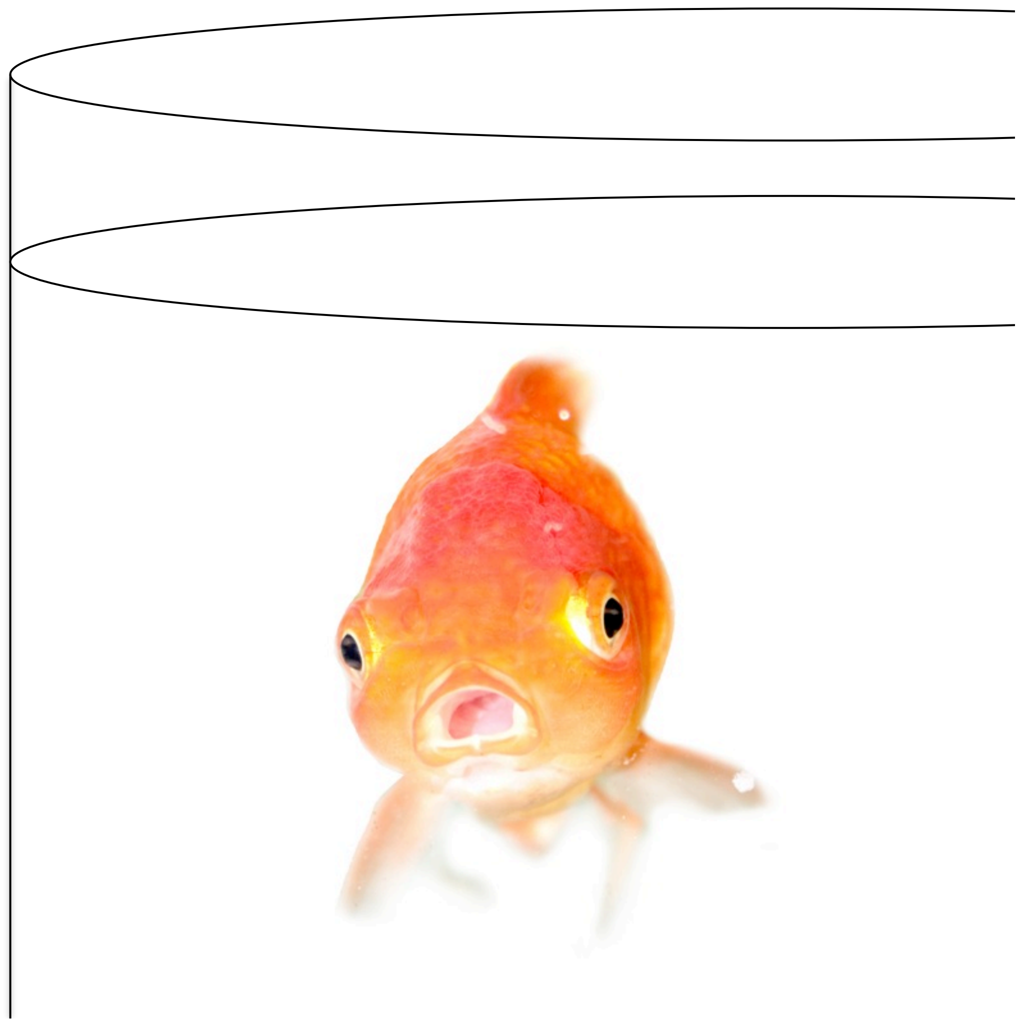
How well can fish detect sounds?

It is important to determine whether a particular species responds to **sound pressure** or **particle motion**

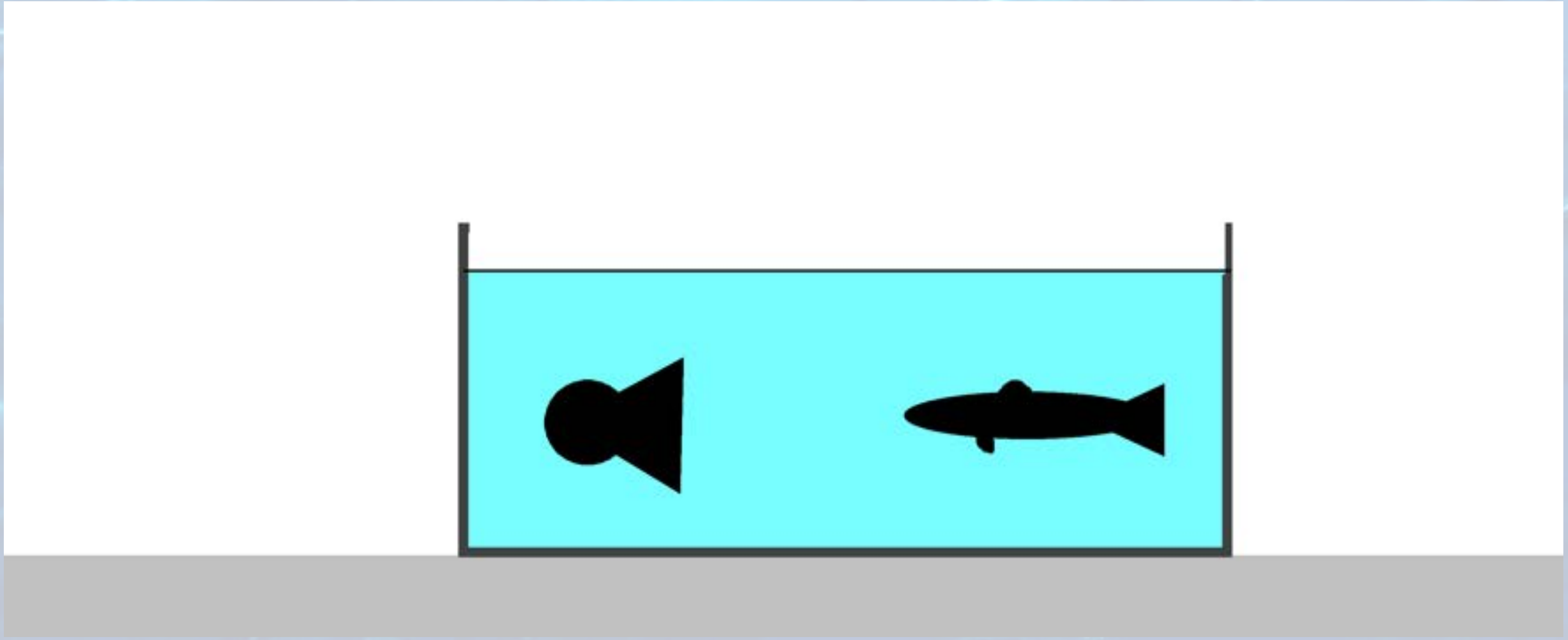
Hearing experiments must be carried out under carefully controlled acoustic conditions, where both sound pressure and particle motion levels can either be measured or estimated

Hearing experiments on fish have been carried out in small tanks, often with the sound generated in the air above the tank

The levels of particle motion in water are then very low



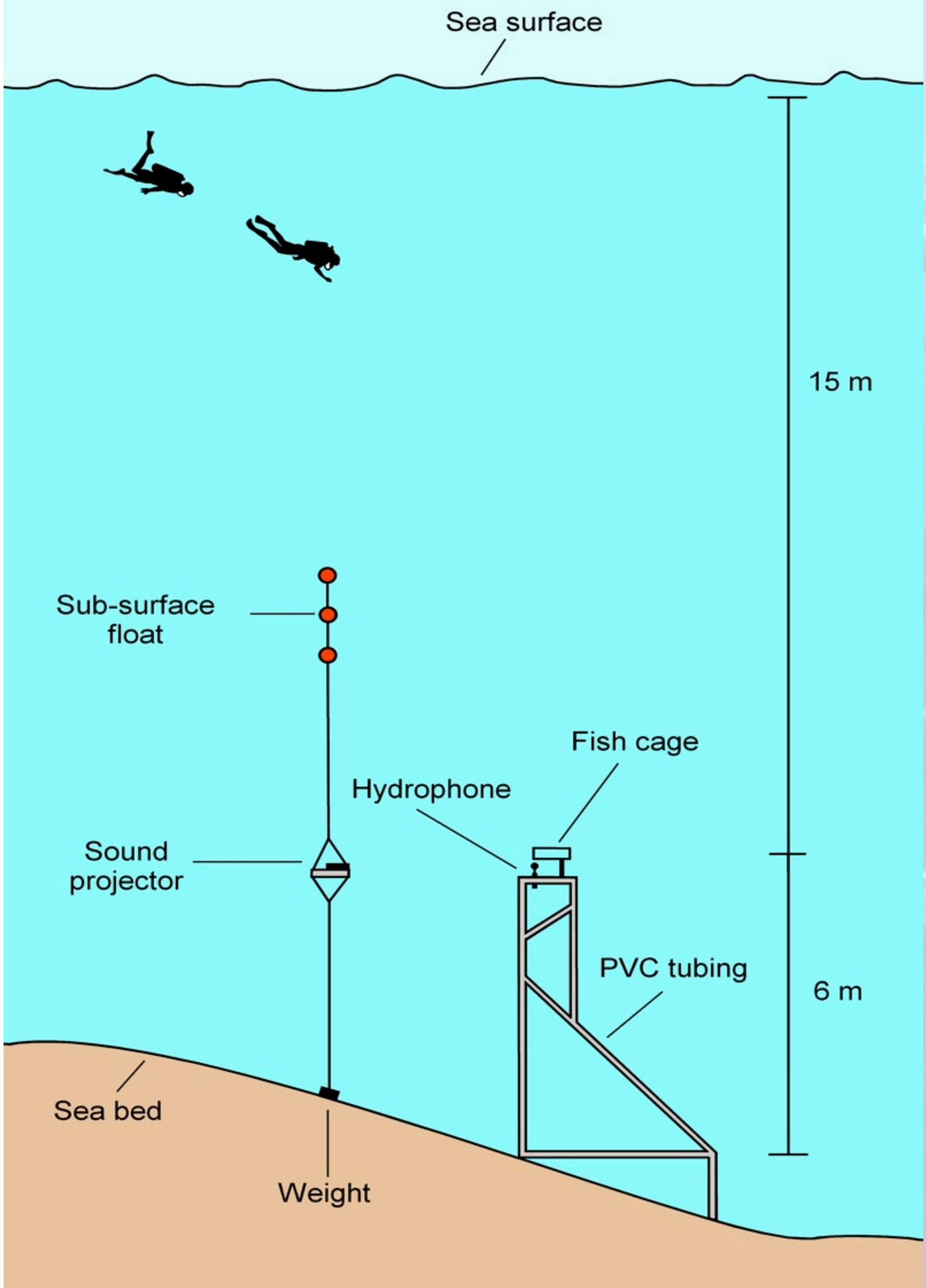
In contrast a loudspeaker immersed in water in a small tank generates **high levels of particle motion** and **low levels of sound pressure**



It is especially difficult to reproduce low frequency sounds in shallow tanks and to measure the particle motion components of sounds

It is very important to carry out hearing experiments under appropriate acoustic conditions

The most successful experiments have been carried out in the sea or in specially designed tanks

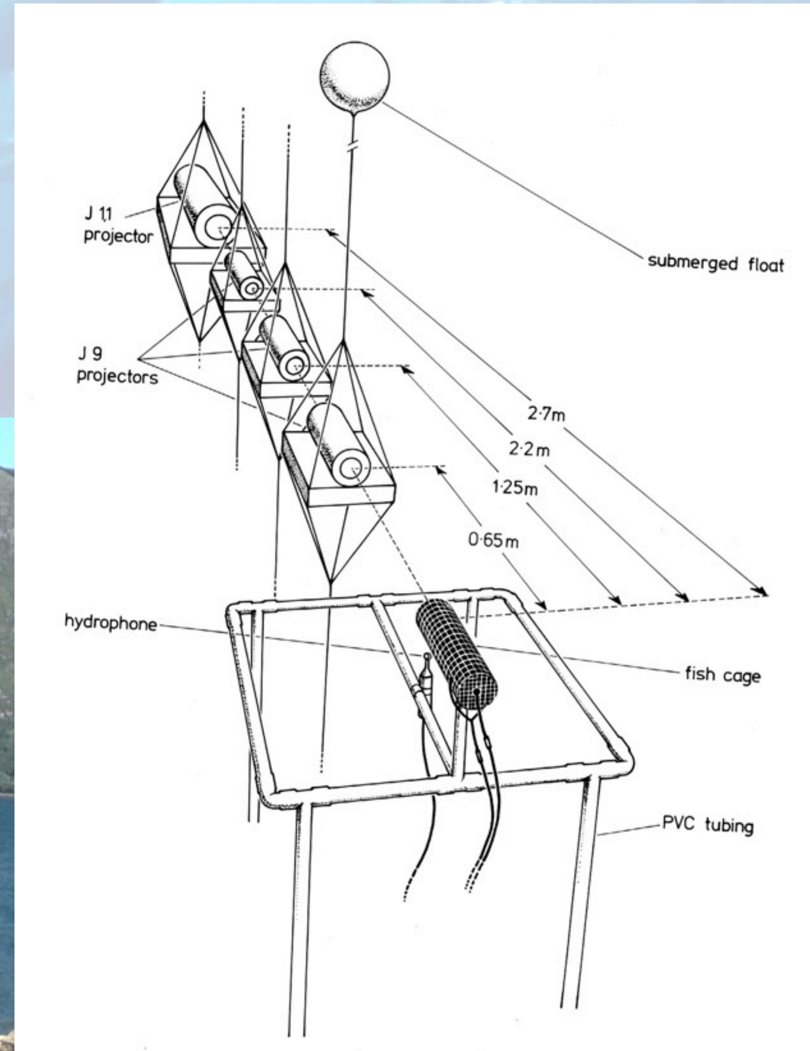


An appropriate experimental set-up, where the fish were held in a cage in midwater in the sea

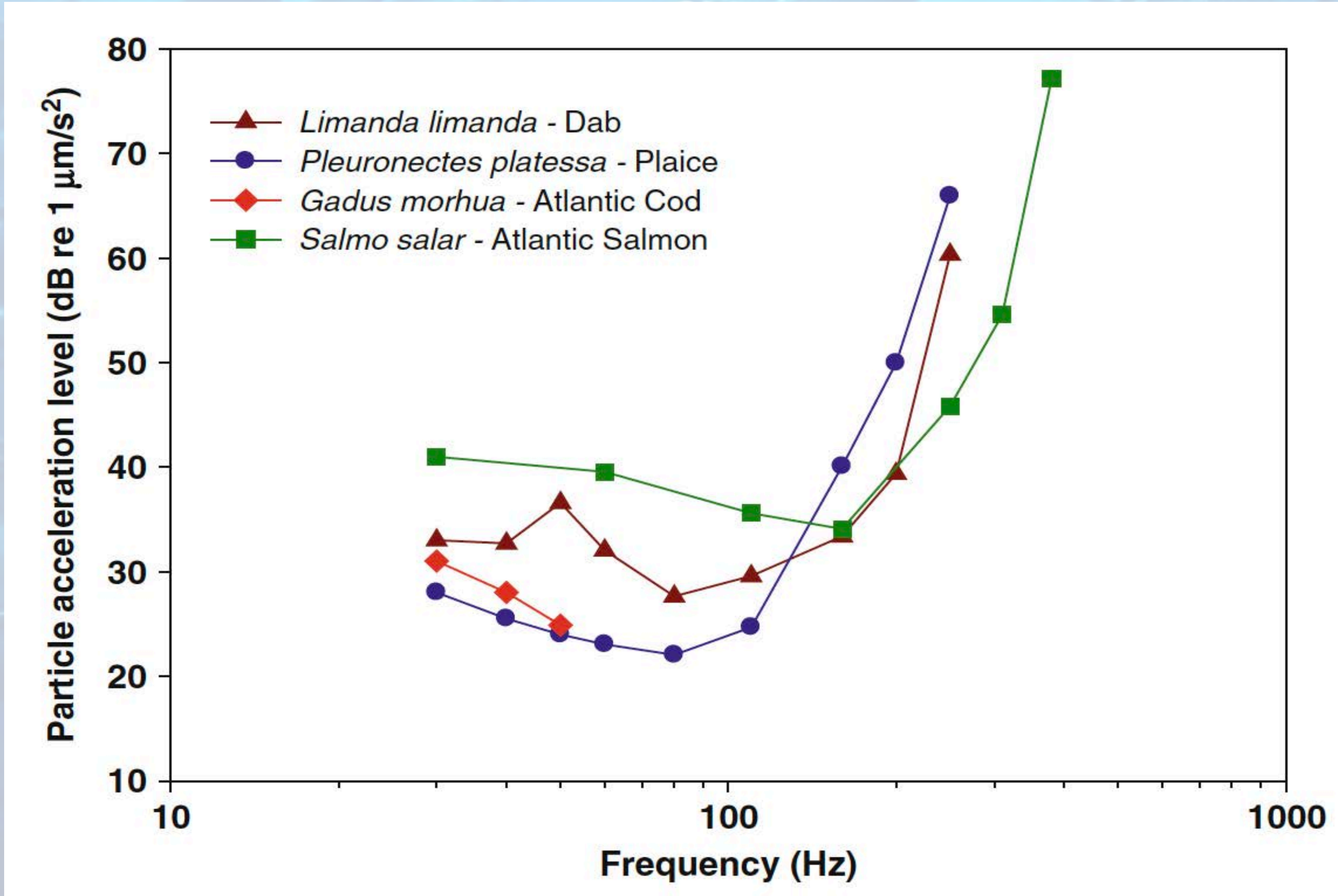
Sounds were played back to the fish from loudspeakers at different distances

The near-field effect was used to vary the ratio of particle motion to sound pressure

Loch Torridon Acoustic Range, Scotland

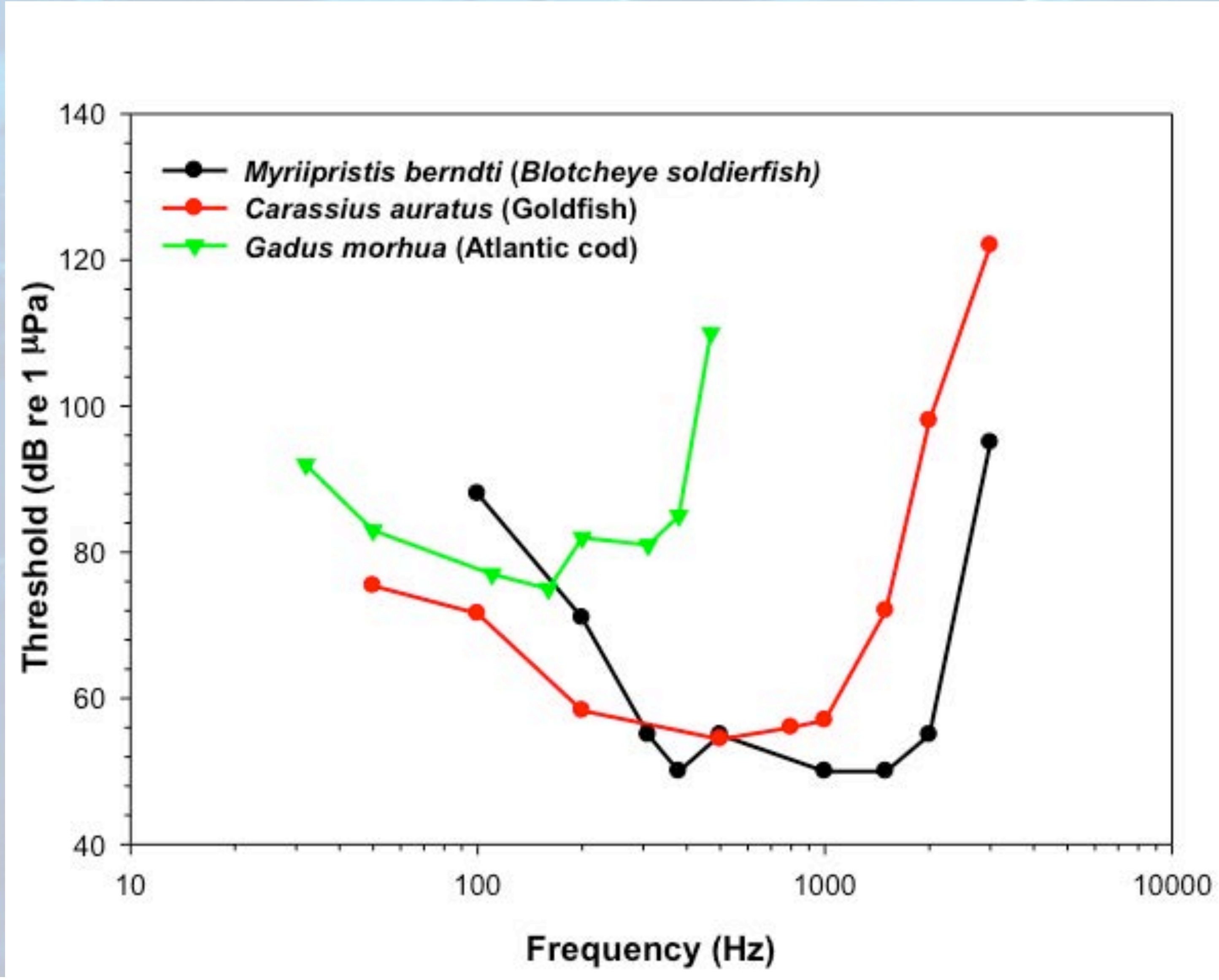


Audiograms for particle motion sensitive fish

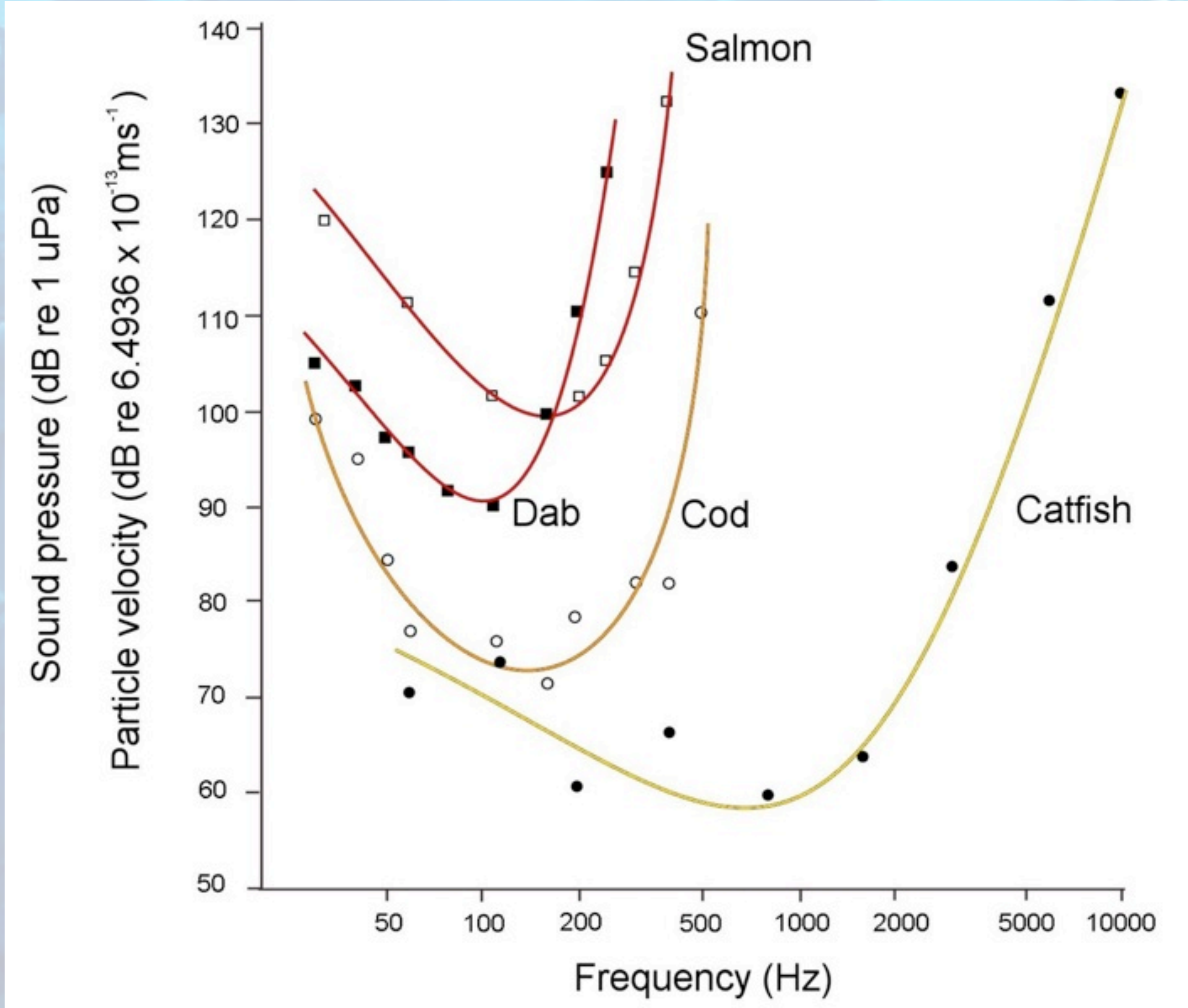


Audiograms for sound pressure sensitive fish

Fish where the ear is more closely connected to the swimbladder have a wider frequency range



Comparisons under similar acoustic conditions



Valid hearing thresholds have been determined for only a few species of fish

Some, like the **plaice** and **salmon** are sensitive only to particle motion

Others, like the **cod**, are sensitive to sound pressure

Even those that detect sound pressure use particle motion to determine sound direction

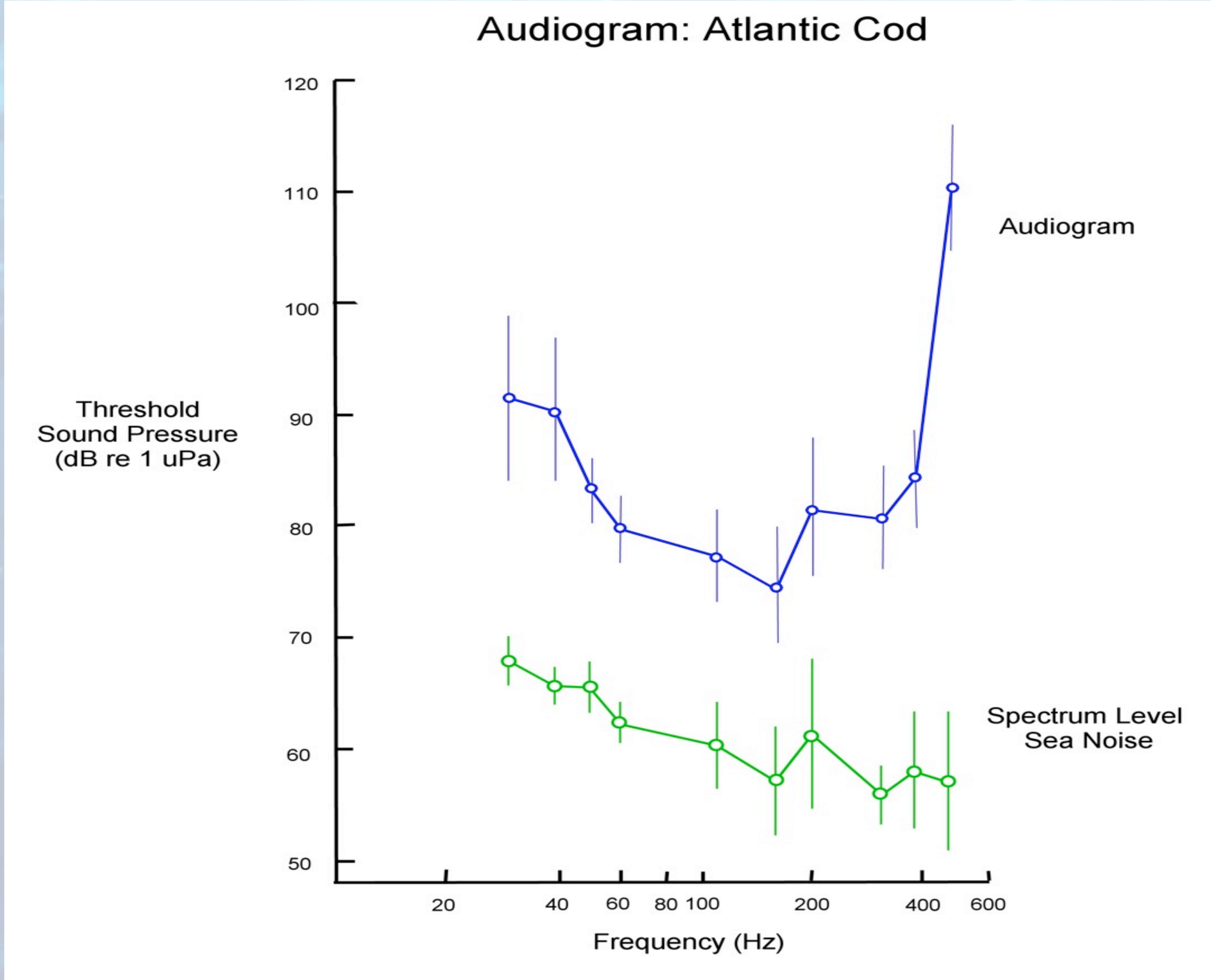
Fish can discriminate between different sounds

Cod can discriminate between sounds of differing frequency and amplitude and filter out sounds from noise

Cod can also discriminate between sounds coming from different directions and distances

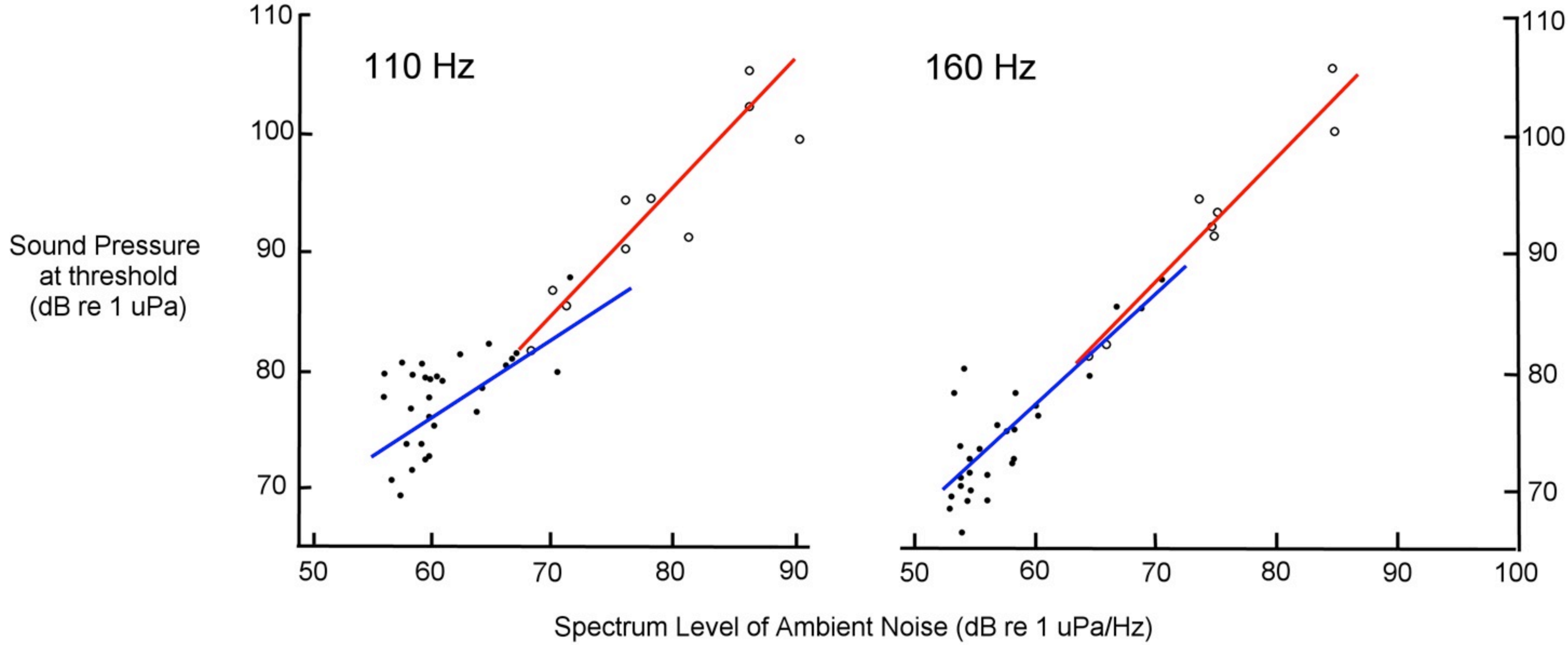
Thus, fish can locate and identify different sound sources with some precision

Background levels of sea noise can affect the hearing abilities of some fishes at low frequencies



As the level of background noise changes, so do the thresholds for cod

blue = natural sea noise red = man-made white noise



Relationship between Auditory Thresholds and Spectrum Level of Noise for Atlantic Cod *Gadus morhua*

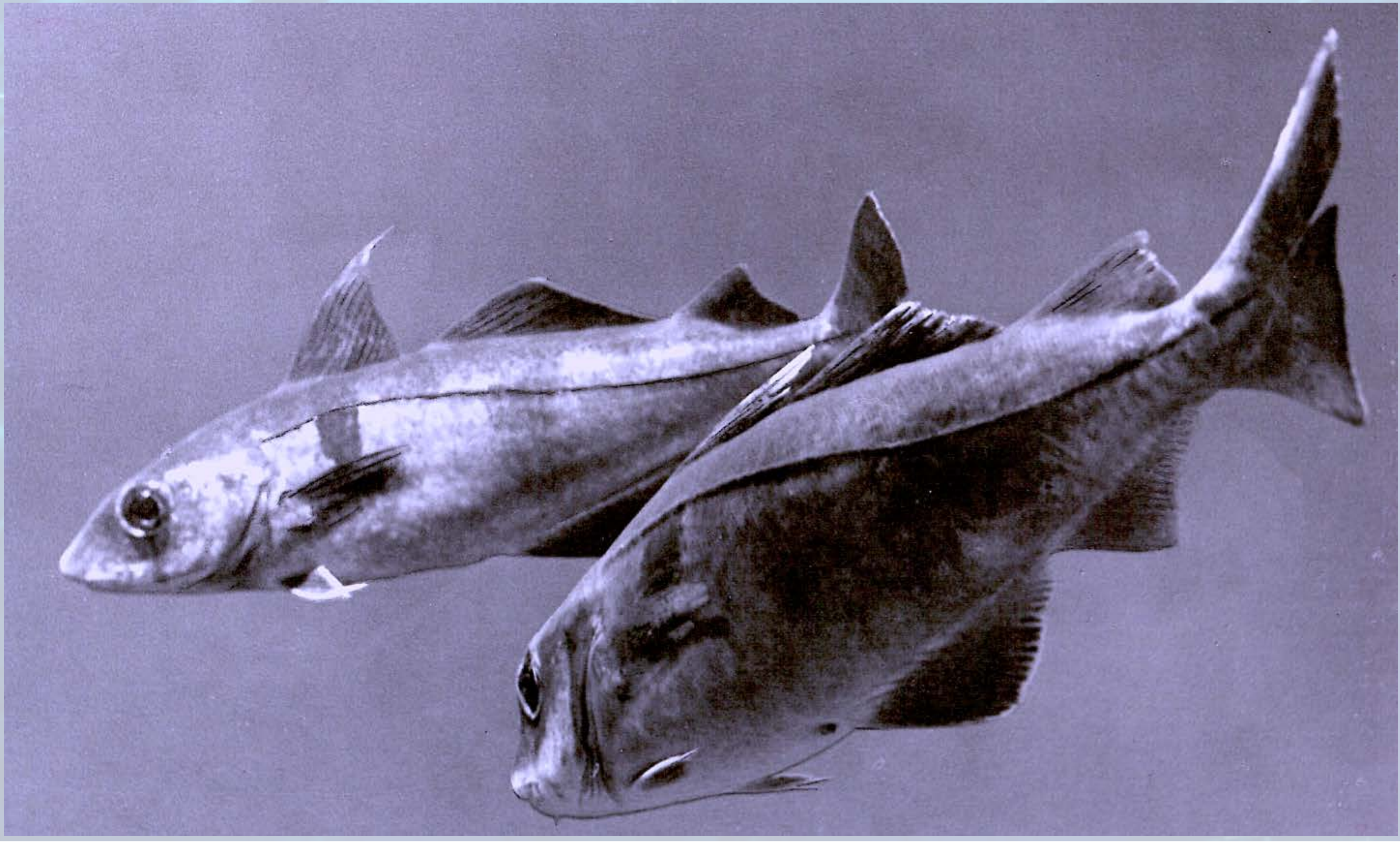
This phenomenon is called **Masking**

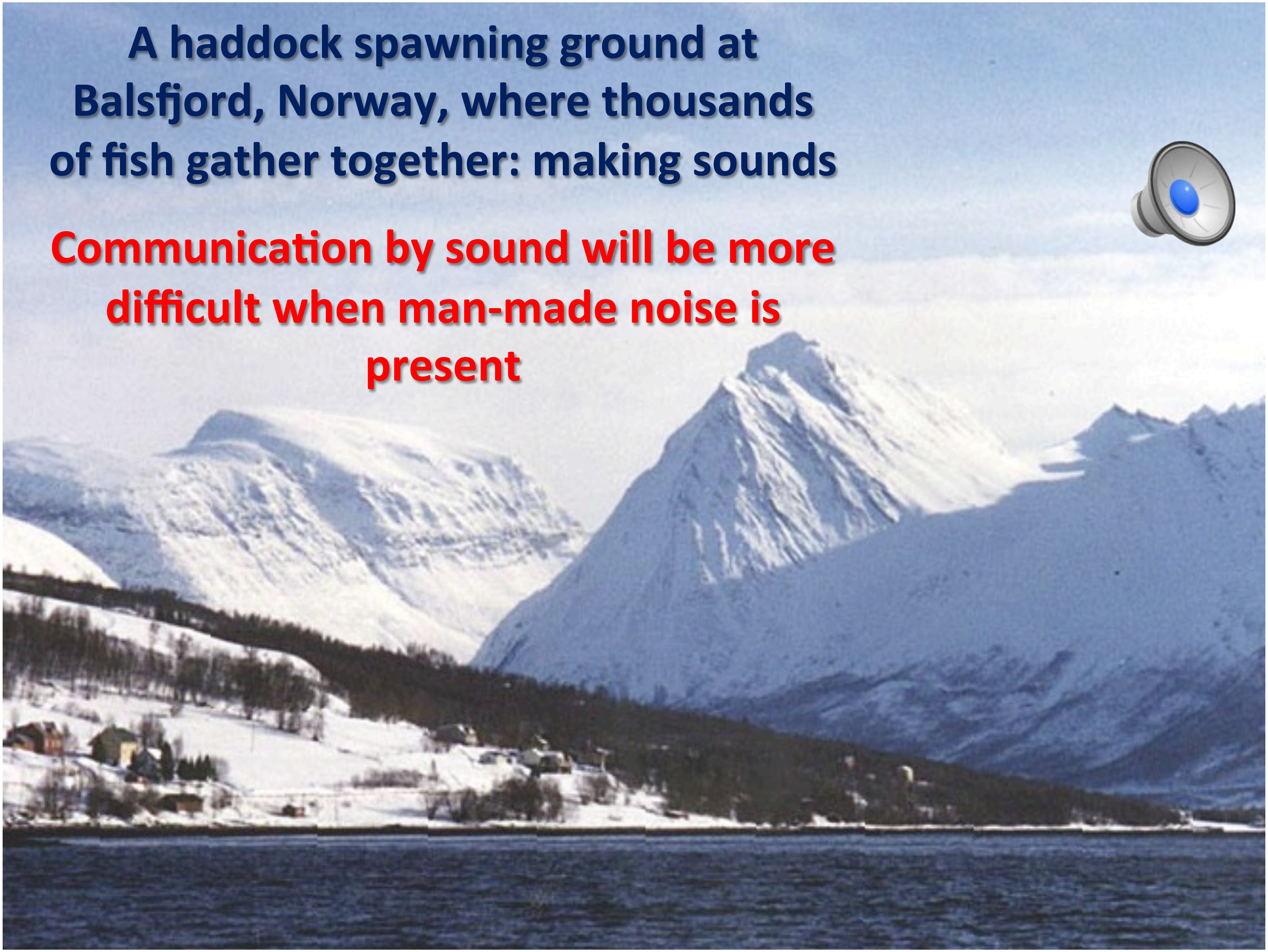
There is a high risk that man-made noise will cause masking

Masking reduces the range over which fish can detect sounds of biological importance

Many fish make sounds

Spawning Haddock




A haddock spawning ground at Balsfjord, Norway, where thousands of fish gather together: making sounds
Communication by sound will be more difficult when man-made noise is present

Potential effects on behavior of exposure to man-made sounds

Interference with communication - through masking of biologically important sounds

Displacement – from feeding grounds and other preferred habitats

Interference with migrations – delaying or preventing fish reaching their destinations

Physiological stress – affecting behavior, growth and reproductive capacity

How do we decide whether sounds have adverse effects upon fish?

Can we set **Sound Exposure Criteria** for:

Death or Injury?

Hearing impairment?

Masking of biologically important sounds?

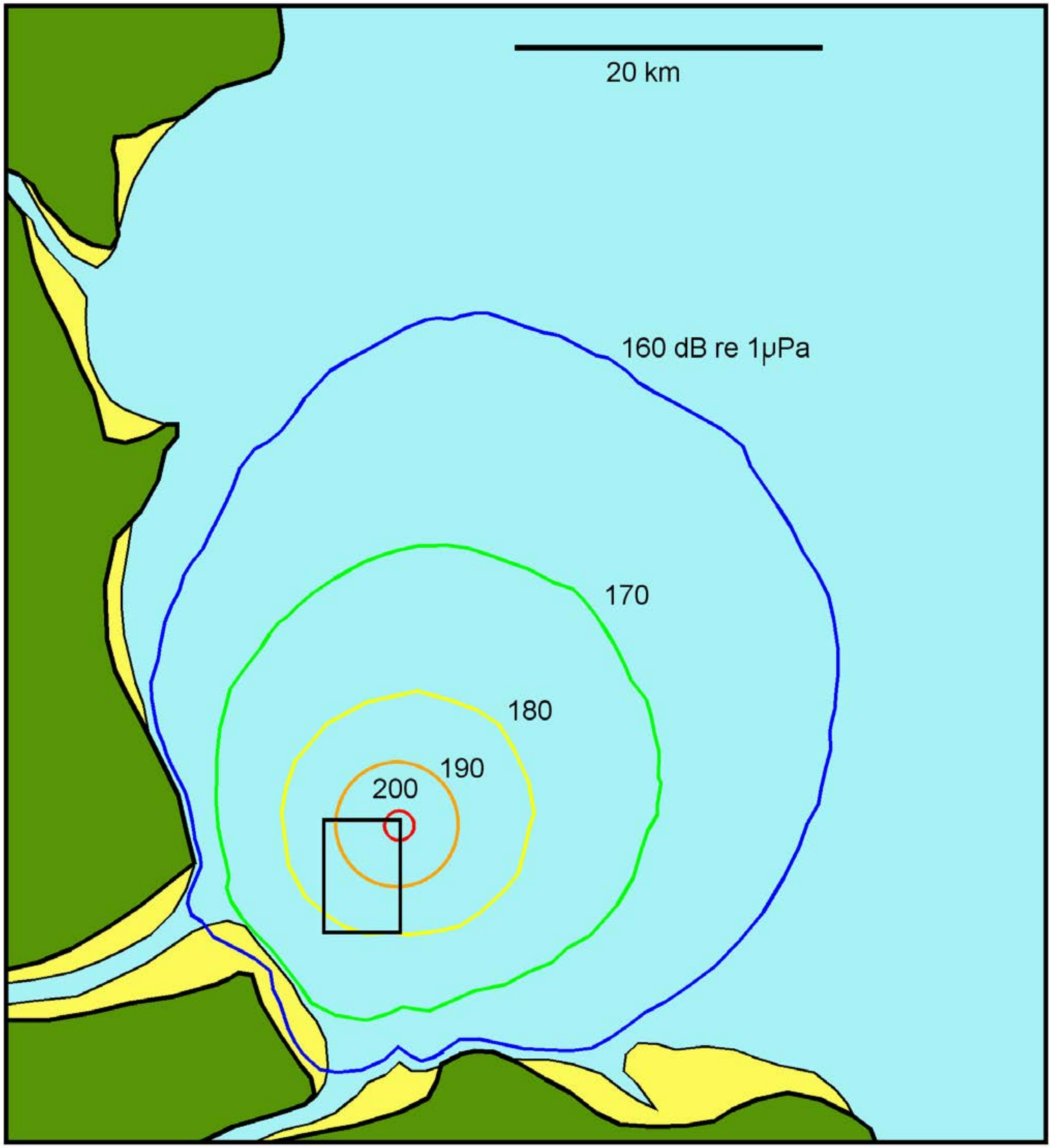
Changes in behavior?

Different effects will occur at different distances

It is important to define the areas likely to be affected by sound:

- First by defining those levels that have adverse effects – **setting Sound Exposure Criteria**

- Then by **mapping the area likely to be affected**, through the use of sound propagation models



Modelling of Sound Pressure Level contours for driving a single pile

Defining Sound Exposure Criteria

Experiments have been carried out to define those levels of sound that:

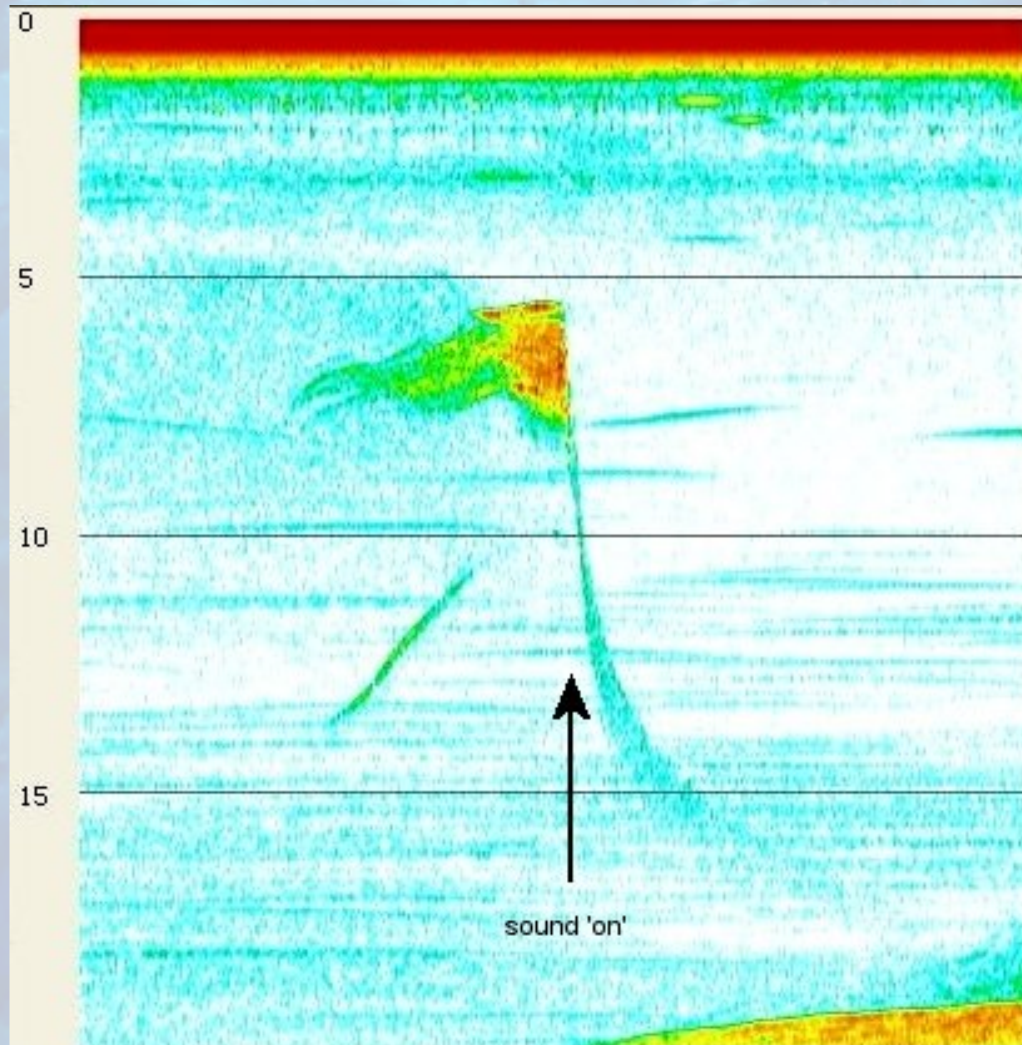
Kill fish, injure them, or cause hearing damage

Behavioral effects are likely to take place over much wider areas, but are much more difficult to examine

Fish reacting to man-made sounds

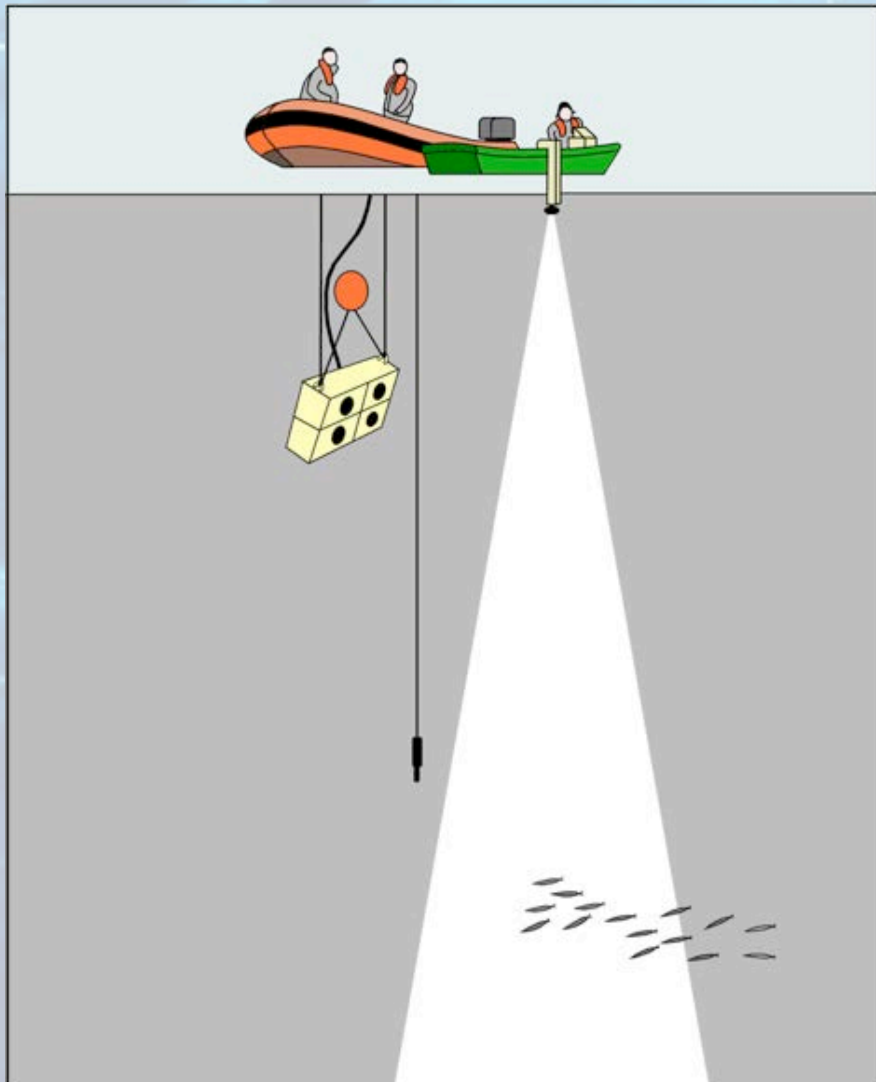
A school of mackerel dives & disperses in response to sound playback

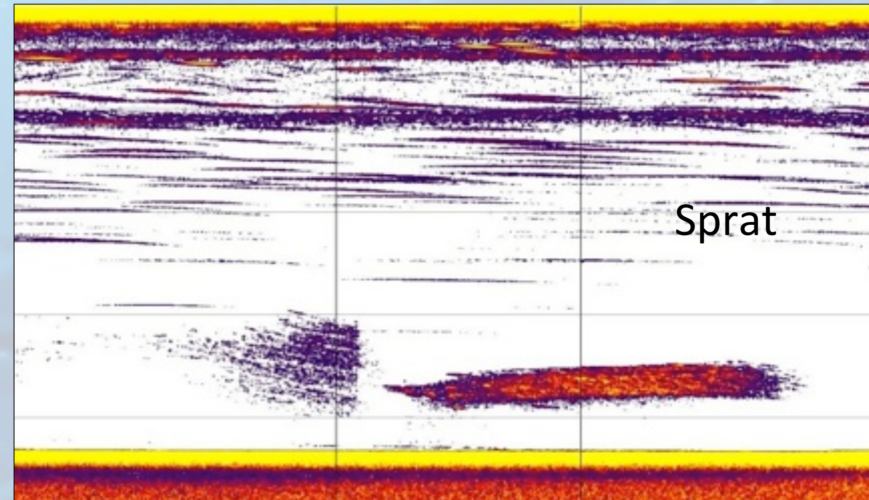
Depth (m)

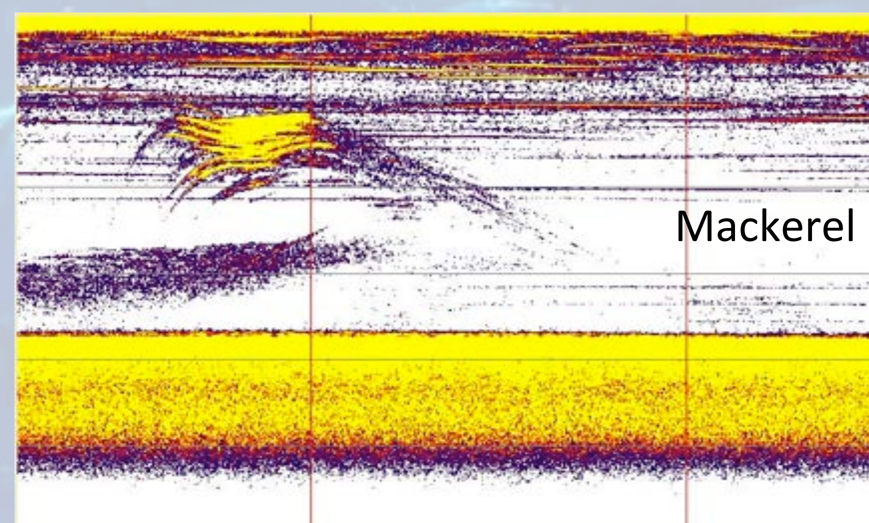


Recent Experiments on Wild Fish

Sound levels were varied to prepare dose/response curves

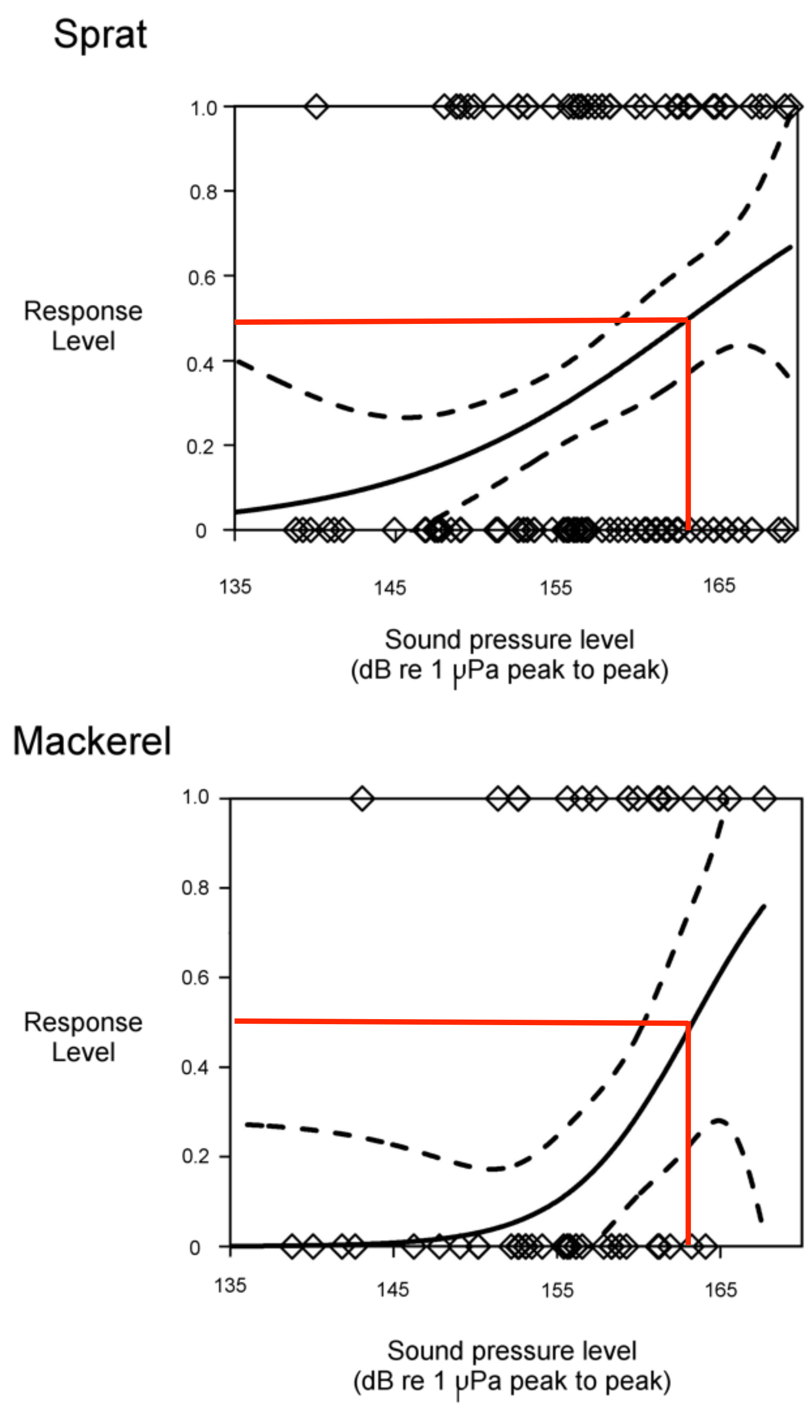






It proved possible to draw up Dose/ Response Curves for both sprat and mackerel

The 50% response level was almost identical for both species, although sprat have better hearing than mackerel



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}

Such levels provide **Sound Exposure Criteria**

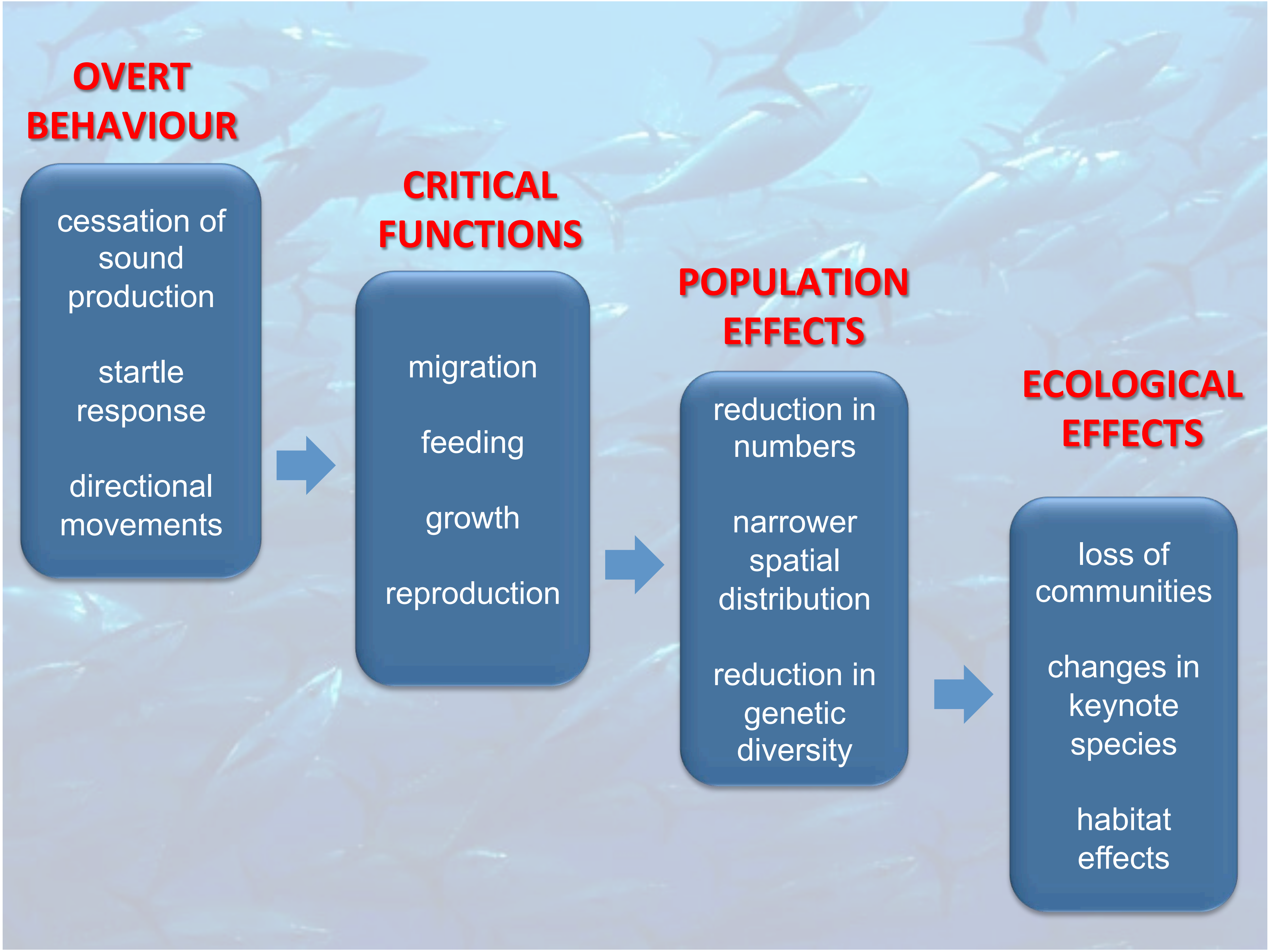
Currently, risk assessment often involves dubious assumptions & predictions

Sound exposure criteria are often assumed rather than based on real data

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

Sound propagation models have seldom been validated and they often 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


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

So, human sources of sound need to be regulated to avoid effects upon fish populations

Currently, we have some limited information on the effects of ***acute*** exposure of fish to some sounds, in terms of injury, effects on hearing, and behavioural changes

But we do not really know what the overall effects are on fish populations

In particular, we know very little about the chronic effects of cumulative exposure to the many sources of noise now present in the sea


Conserving Natural Marine Soundscapes
is also Important