

Observing the behavioral response of herring exposed to mid-frequency sonar signals

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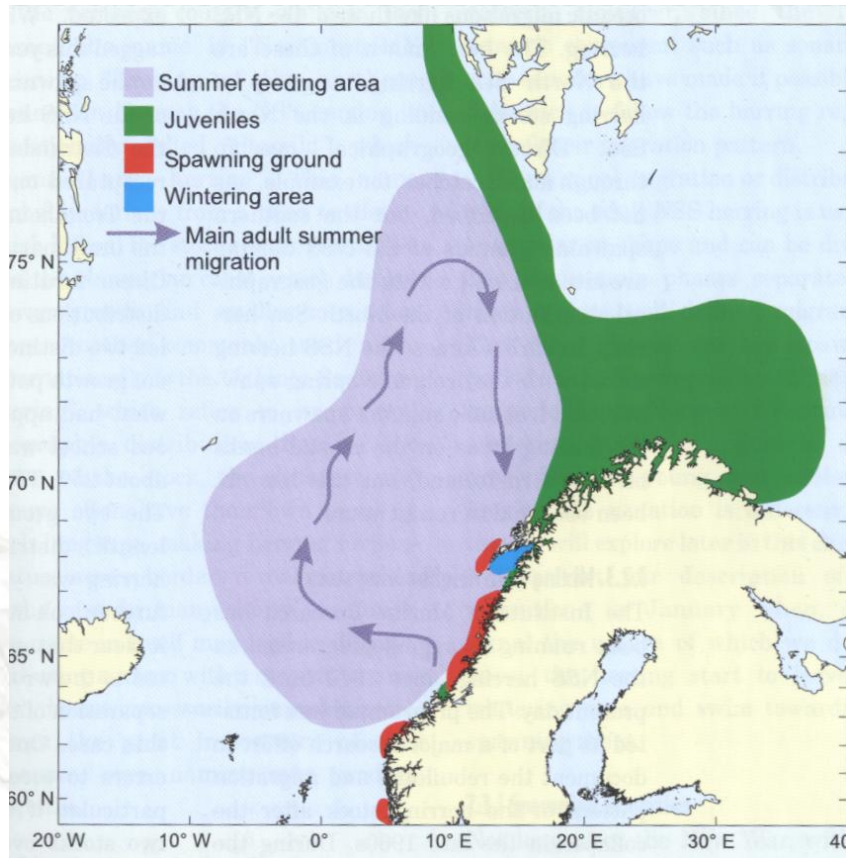


Outline

- The Norwegian Spring Spawning Herring
- The exposure sources
- The observation tools
- The experiments – methods and results
- Concluding remarks



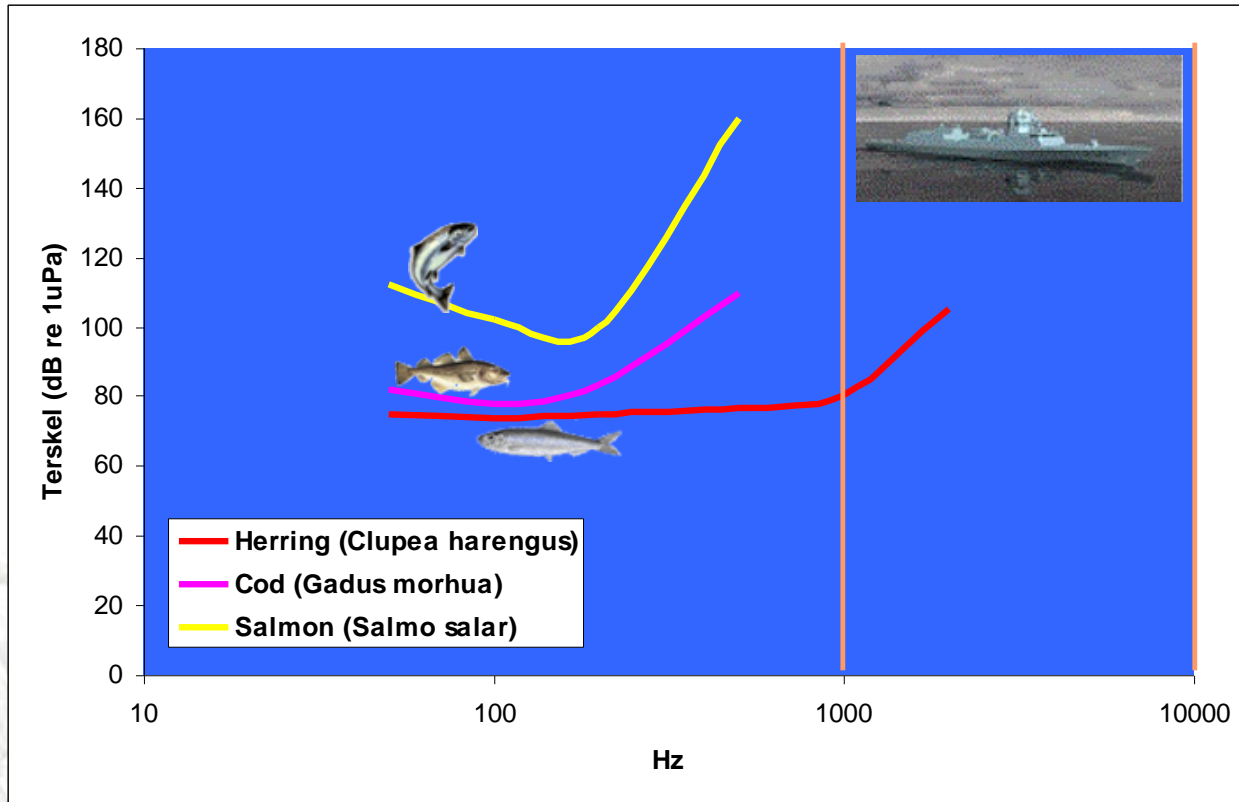
Norwegian Spring Spawning Herring (NSS)



- One of the largest fish stocks in the world.
- Important fishery resource in Norway.
- Yearly distribution spread over entire Norwegian Sea and coast, overlapping with the operation areas of the frigates.
- How the herring react to a sound disturbance may vary between season and site.



Mid-frequency sonar and fish hearing



- Mid-frequency naval sonars: 1-10 kHz.
- Hearing generalist fishes (e.g salmon, cod): < 500Hz.
- Hearing specialists, e.g herring; up to 4 kHz.

- Lower frequency range well within hearing range of herring (*Clupea harengus*).



- Potential effects: reduced hearing, masking or behavioral effects.

Outline

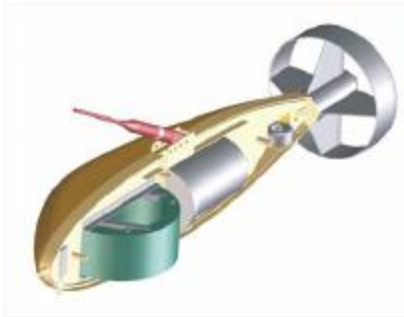
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Sonar sources

SOCRATES (Sonar CalibRAtion and TESting)

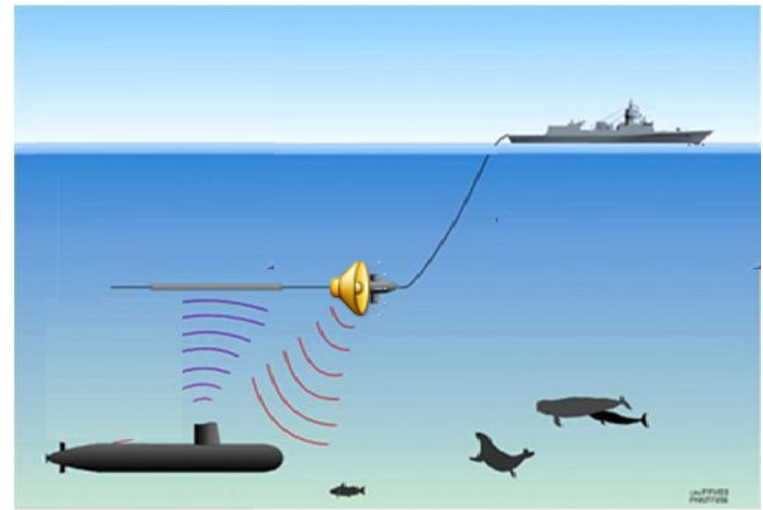
- Sonar source used for operational experiments for the Royal Netherlands Navy (RNLN).
- Two free flooded transducers; 1-2 kHz and 6-7 kHz (190 and 214 dB re 1 μ Pa max power, respectively).



Sonar sources

Nansen frigate sonar

- Combined active/passive towed array sonar (CAPTAS mk 2, Thales Underwater Systems) towed from a Fritjof Nansen class multipurpose frigate operated by the Royal Norwegian Navy.
- Signaltypes: 1-1.6 kHz hyperbolic frequency modulated up-sweep (FM) and a 1 kHz weighted continuous wave signal (CW).
- Transmitted source level was $215 \text{ dB}_{\text{rms}}$ re $1 \mu\text{Pa}$ at 1m, maximum level is classified information.



Sonar sources

Underwater speaker

- Killer whale feeding sounds played back from an underwater speaker, Lubell Labs model LL916.
- Frequency response of 21 Hz to 200 kHz, with a high pass filter of frequencies below 800 Hz.
- The sound played back included pulsed calls, whistles and tail slaps from feeding killer whales.
- Source level of the played back sounds were 150-160 dB_{RMS} (re 1 μPa @ 1 m), similar to described levels of feeding killer wha



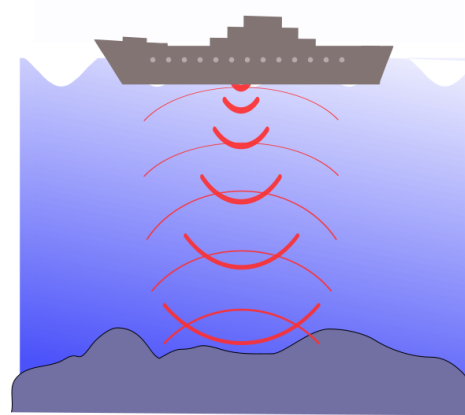
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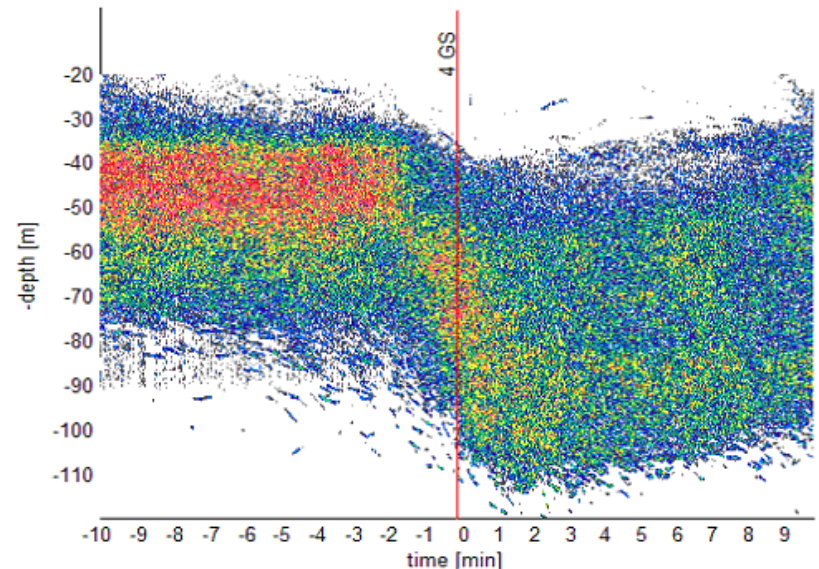
Echosounders

- Simrad EK60, Frequency 38kHz, 120kHz and 333kHz
- Narrow beam



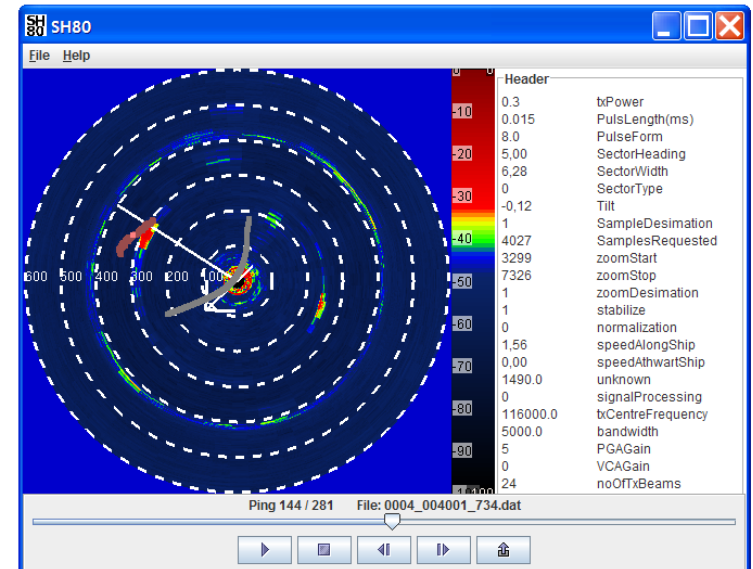
Simrad ES38DD

- Analysed in Matlab
- Results
 - Vertical distribution
 - Density by echo integration
- Example from Ona et al 2007.



Omnidirectional sonar

- Simrad SH80, frequency 116kHz,
Tilt +10 to -60 deg
- Analysis by Large Scale Survey system (Patel et al, in prep)
- Results
 - position
 - Relative density estimate



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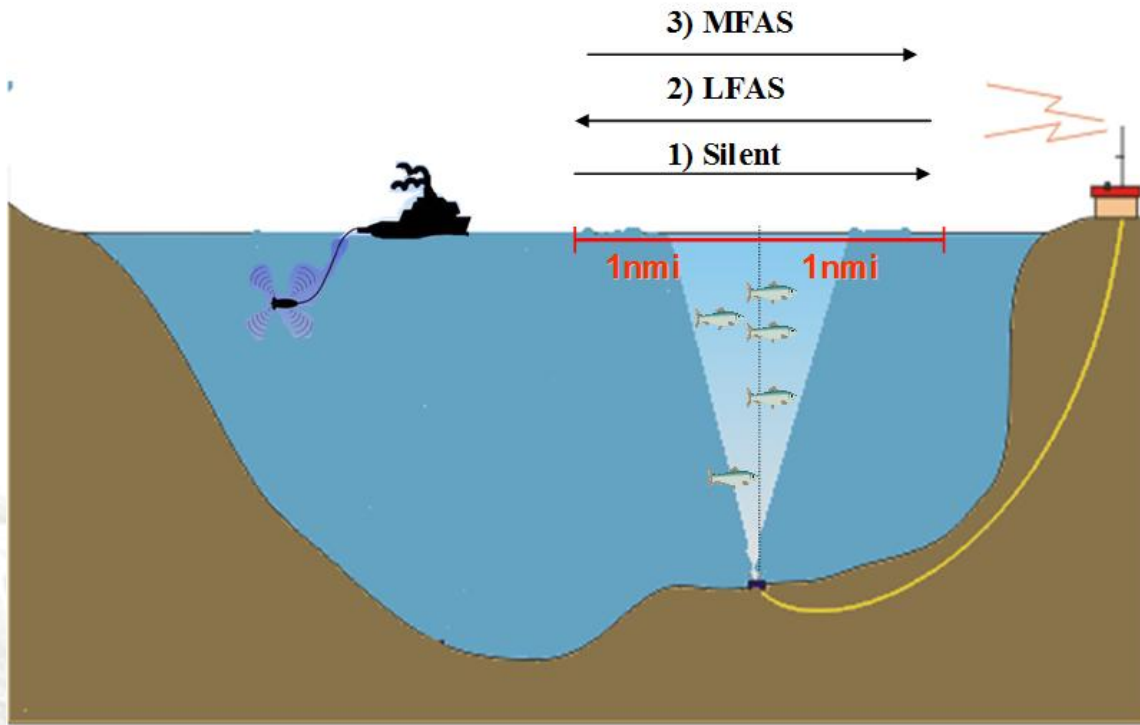


The experiments

- Stationary herring layers in fjord area
 - Exposure: SOCRATES source , killer whale playback
 - Method: Bottom mounted echo sounder
- Dynamic schools of herring in open ocean
 - Exposure : SOCRATES source, killer whale playback
 - Method: Sonar
- Controlled net pen experiments over a seasonal cycle
 - Exposure : Nansen class frigate, ring transducer, outboard engine, impulse
 - Method: Echosounder and video



Stationary herring layers in fjord area

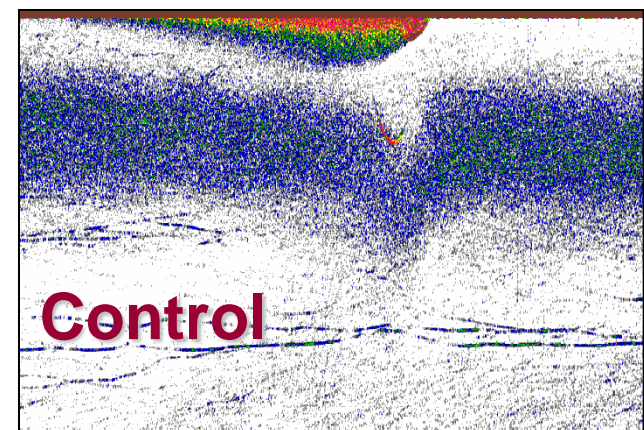
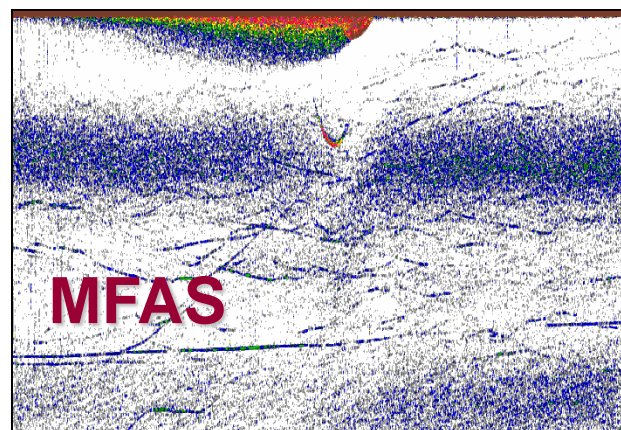
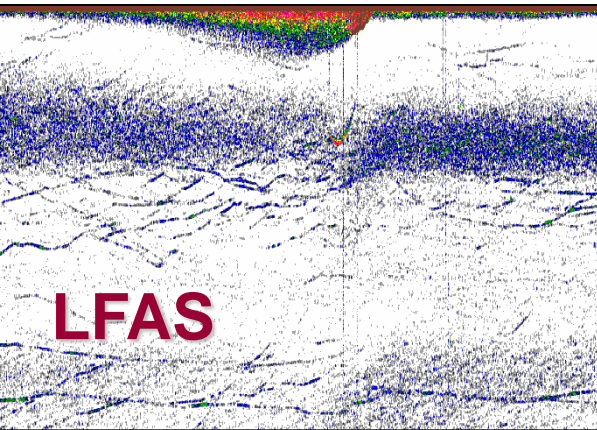


- Herring reactions measured as density (s_v) and median depth of herring layer.

- Overwintering herring distributed in stationary layers in a sheltered fjord.
- Randomized block design of three exposure types:
 - 1) Silent (control)
 - 2) LFAS (1-2 kHz)
 - 3) MFAS (6-7 kHz)
- Source ship approached gradually from 1 nmi distance.



Reactions to sonar transmission

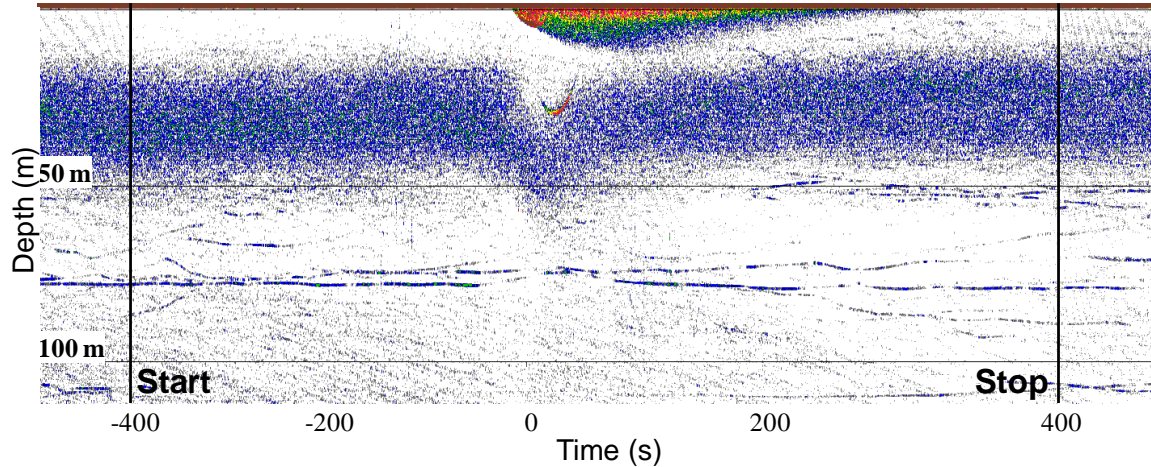


- Echogram similar for all transmission types.
- Downwards reaction around vessel passage.
- Likely caused by avoidance of vessel or towed body source.

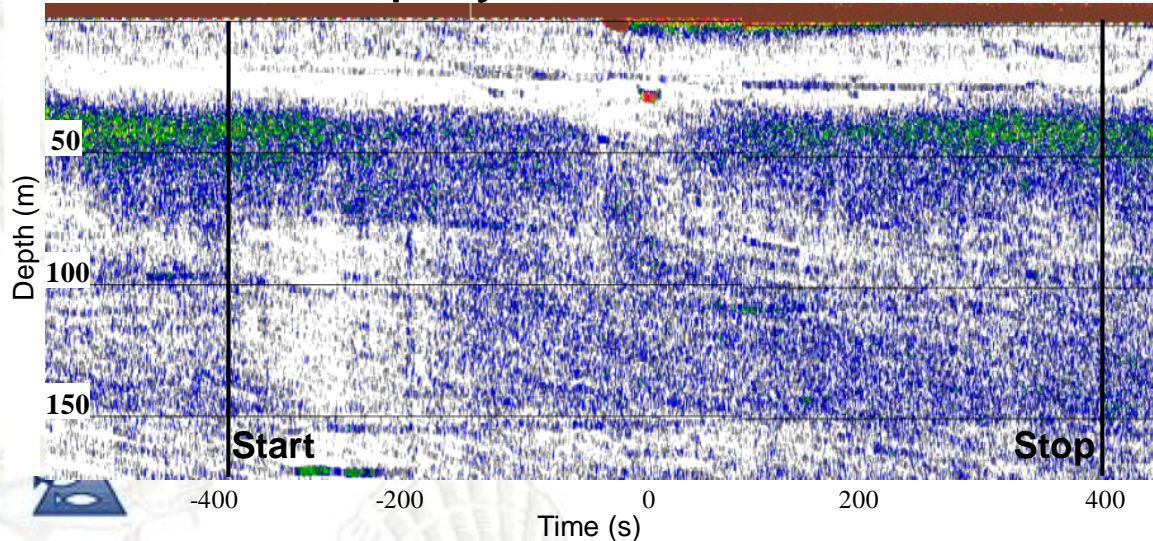


Reactions to killer whale playback

Control

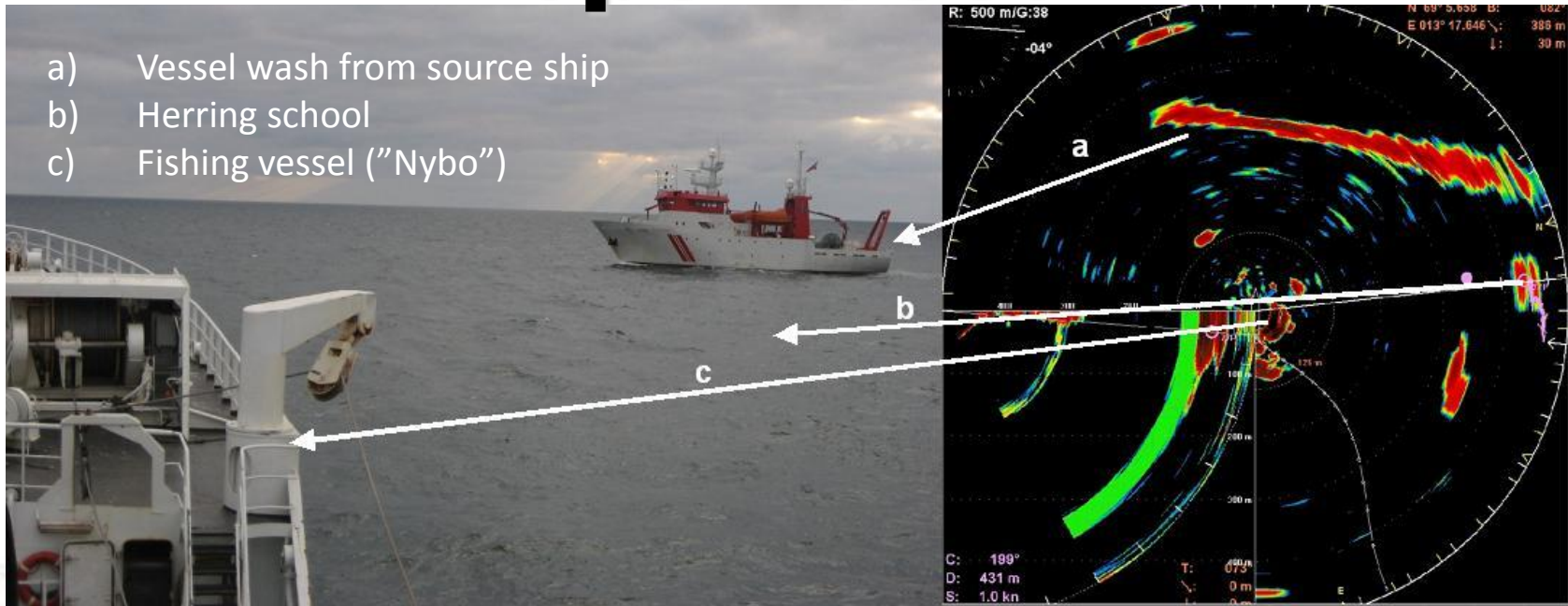


Killer whale playback



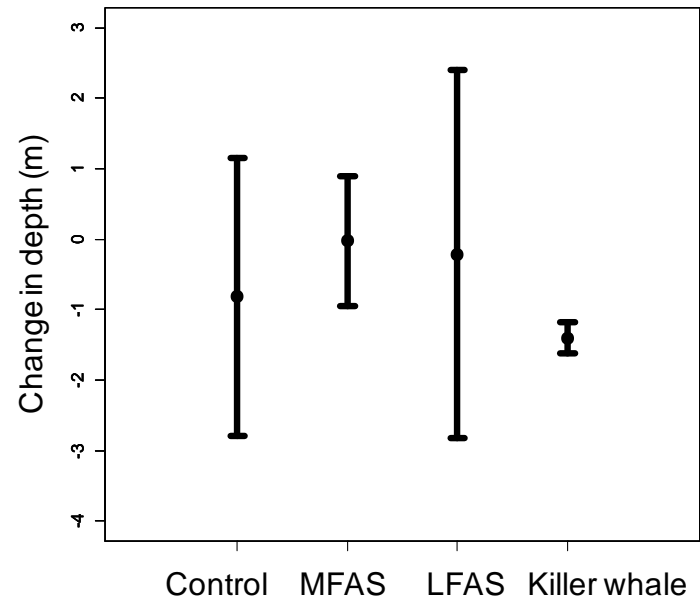
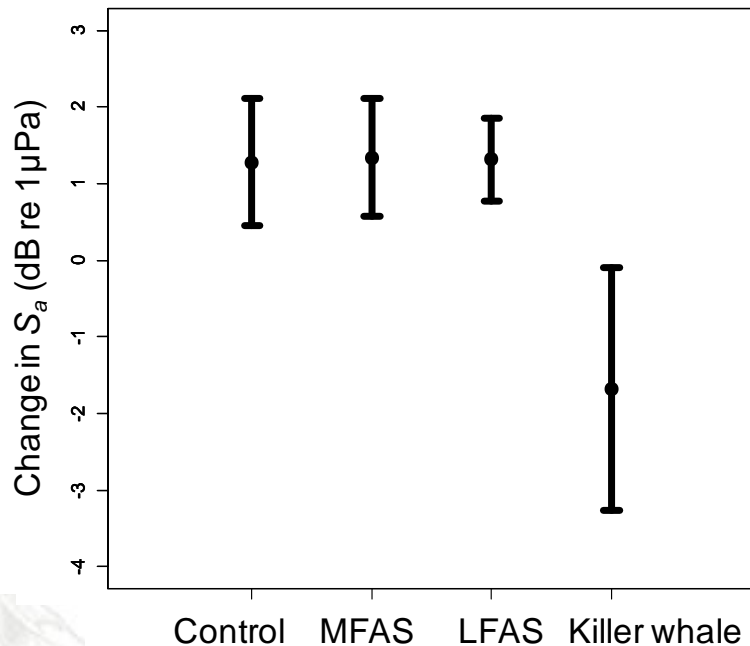
- Strong immediate response.
- Significantly different from control
- Verify non-avoidance of sonar transmission.

Dynamic schools of herring in open ocean



- Migrating herring schools in deep, oceanic waters.
- Same block design as for echosounder experiment.
- Source ship passes with transmitting source while herring school is monitored from fishing vessel.
- Herring reactions measured as school density (s_a) and depth of the school, revealing changes in school dynamics and vertical movement in response to sonar transmission.

Reactions to sonar transmission and killer whale playback



- No significant differences between sonar transmission and control.
- Killer whale playback induced a vertical movement and change in school density, typical avoidance reactions.



Net pen experiments

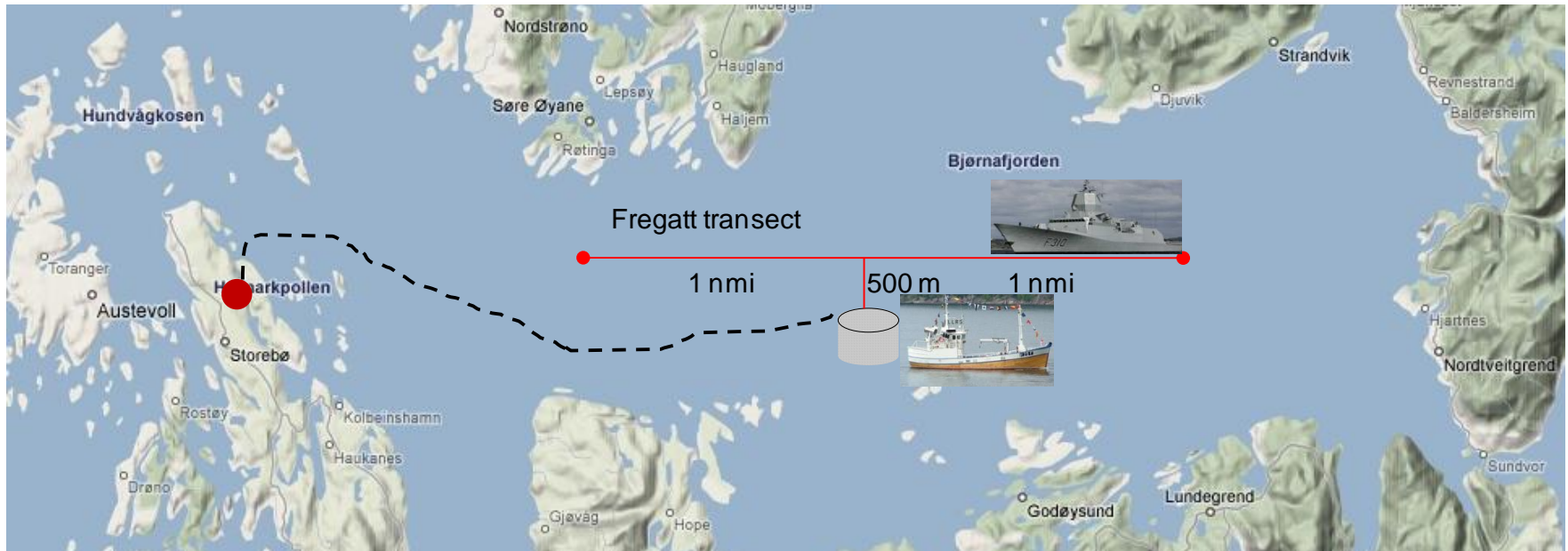


- Wild herring were captured and transferred to net pens.
- Held in captivity throughout a year in an aquaculture facility.

- During experiments, herring were transferred to a smaller pen and towed to experimental location.
- Experiments conducted at different times of the year, corresponding to overwintering, spawning and feeding periods of herring.



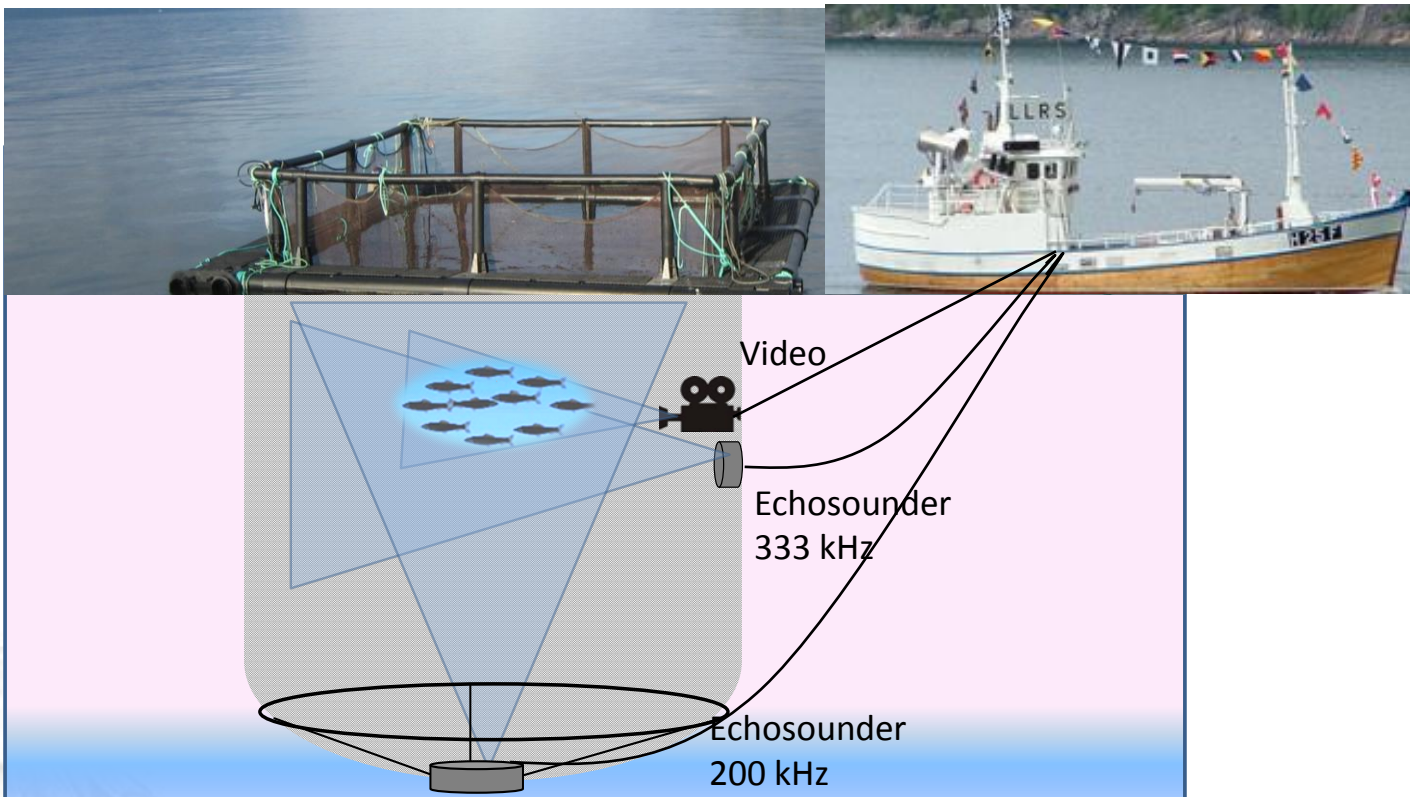
Net pen experiments



- Net pen towed from station to middle of fjord by fishing vessel.
- Frigate passed the herring net pen in a 2 nmi transect.
- Blockdesign with 4 types of exposure:
 - FM continous (1-2 kHz)
 - FM sudden (1-2 kHz)
 - CW
 - Control



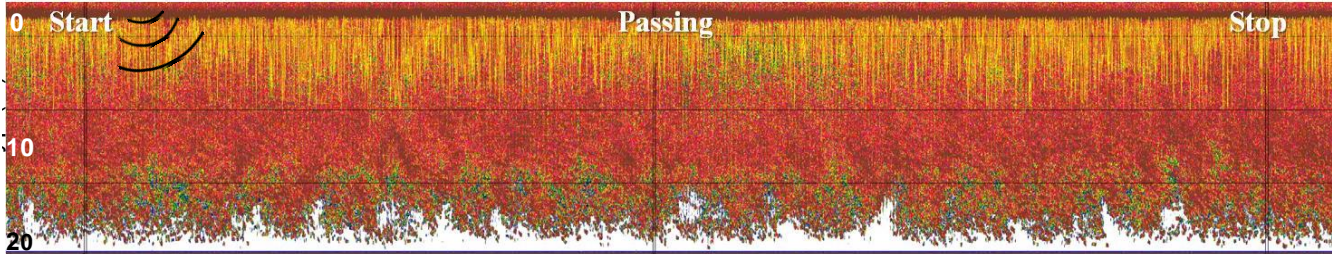
Net pen monitoring



- Horizontal and vertical echosounder recording horizontal and vertical movements within the pen.
- Videocamera to monitor small scale reactions.
- Controlled and monitored onboard fishing vessel.

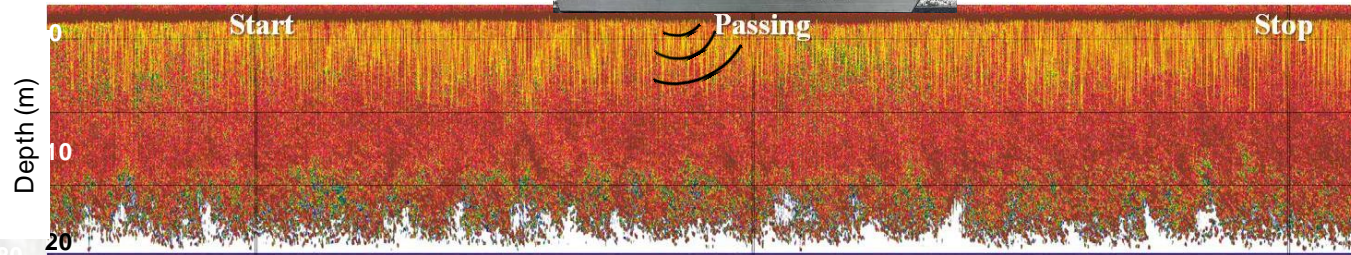


Reactions to sonar transmission



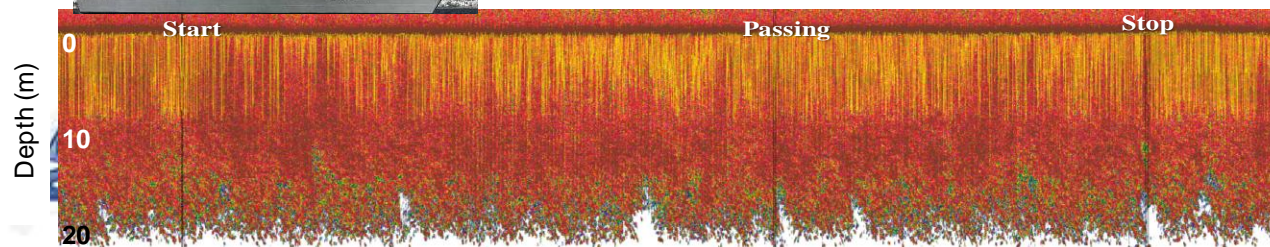
Sonar continuous

Exposure increase gradually (FM+CW)



Sonar sudden

Start exposure at max level (FM)



Control

Passage with frigate without sonar exposure



LowFreq 2009

Positive control experiments

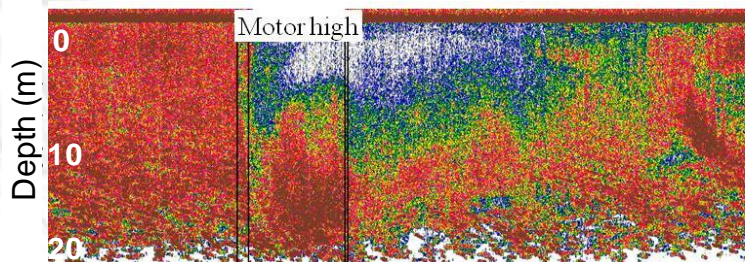
Engine noise and impulse

- Outbound engine, 30 sec
- Hit net fence with stick; "dunk"

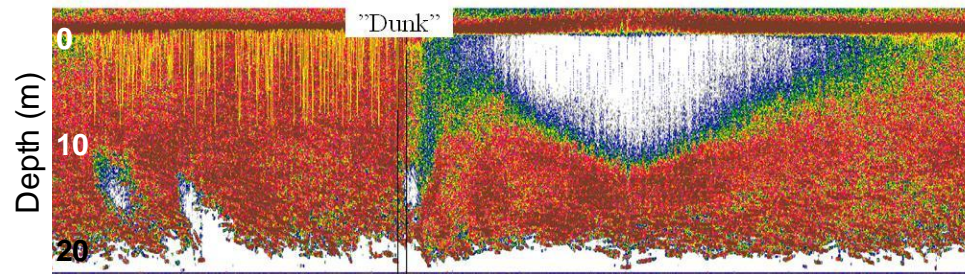


Results

Engine noise



Impulse



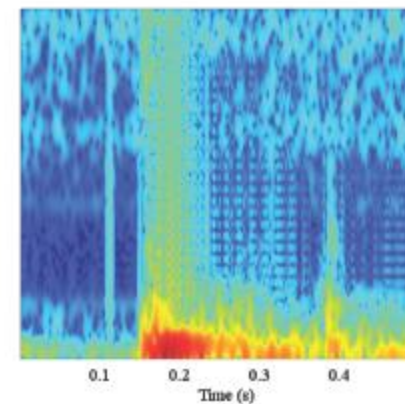
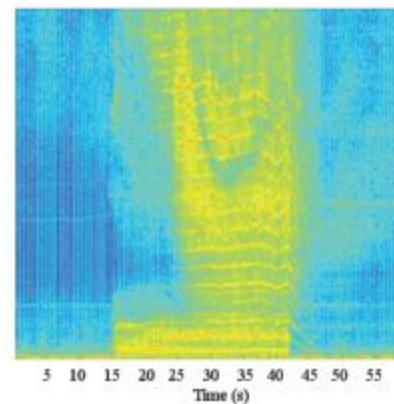
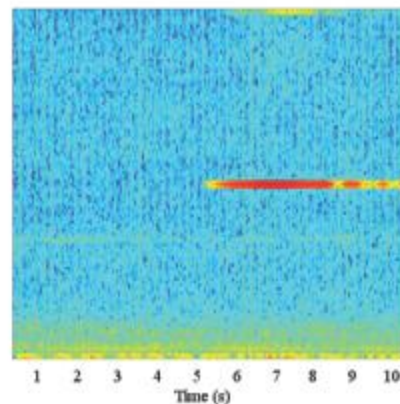
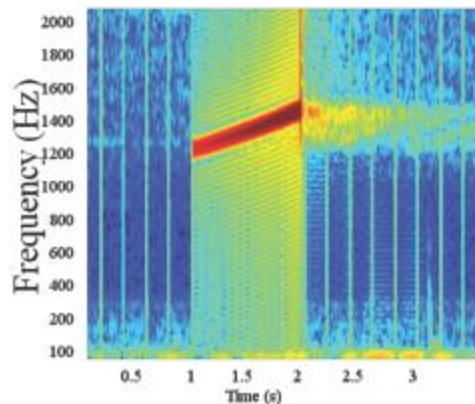
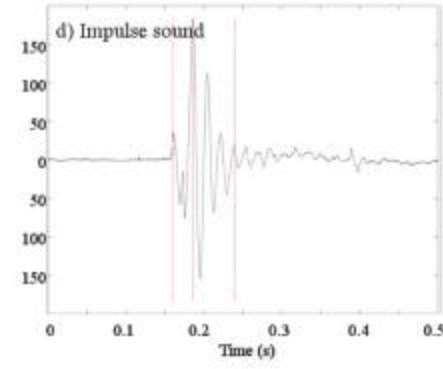
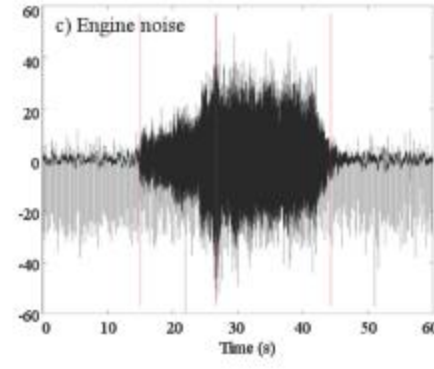
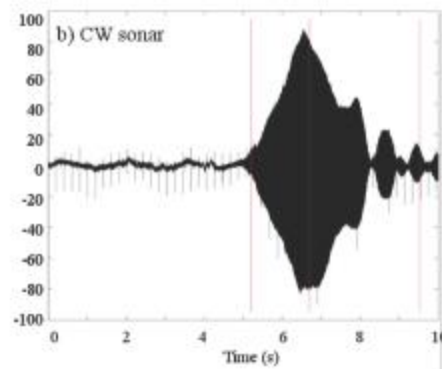
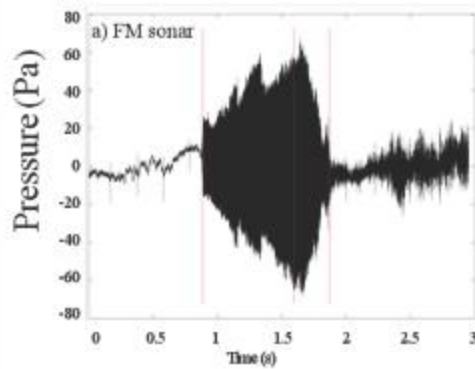
Immediate downward movement of herring, significant change in vertical structure compared to sonar transmission and control.





Exposure inside net pen

| | Received level (RL) | Sound exposure level (SEL ¹) | B-Duration ¹ | Peak pressure ² | A-Duration ² | Signal rise time ² | Impulse ² |
|------|------------------------|--|-------------------------|----------------------------|-------------------------|-------------------------------|----------------------|
| Unit | dB re 1 μ Pa [RMS] | dB re (1 μ Pa ² s) [RMS] | s | Pa | ms | ms | μ Pa s |
| FM | 168 | 168 | 0.9483 | 947 | 0.270 | 0.153 | 166 000 |
| CW | 150 | 156 | 4.34 | 94.9 | 0.458 | 0.161 | 28 000 |
| MB | 137 | 152 | 29.2 | | | | |
| IMP | 156 | 145 | 0.08 | 183 | 10.3 | 4.4 | 1 216 600 |



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Summary

- No observed behavioural change in herring exposed to the sonar sources
- Stronger reaction to vessel noise
- Reaction initiated during killer whale playback
- The impulse (maybe not suprisingly) seem to be a very important measure



Further reading

- Fjord experiment:
 - Doksæter et al. Behavioural responses of herring (*Clupea harengus*) to 1-2 and 6-7 kHz sonar signals and killer whale feeding sounds
The Journal of the Acoustical Society of America, **2009**, 125, 554-564
- Open ocean experiment
 - Doksæter et al. In prep.
- Net pen experiment
 - Doksæter et al. Submitted to JASA.

