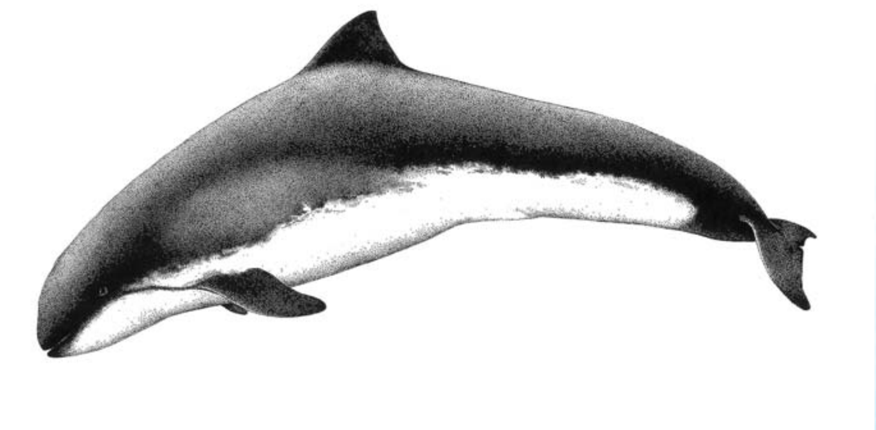
Effects of offshore Wind Farms on Marine Mammals and Fish – The European Experience



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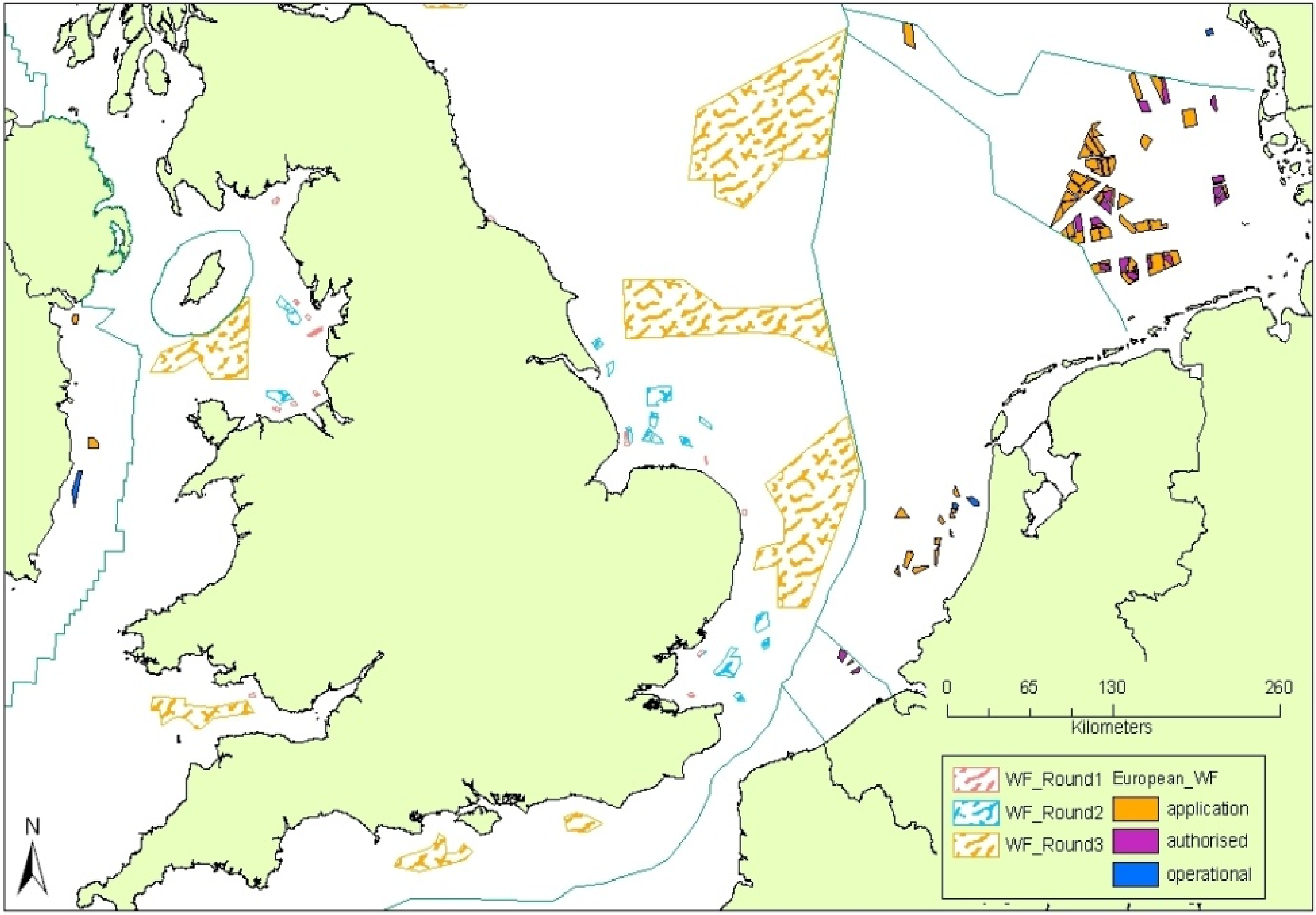
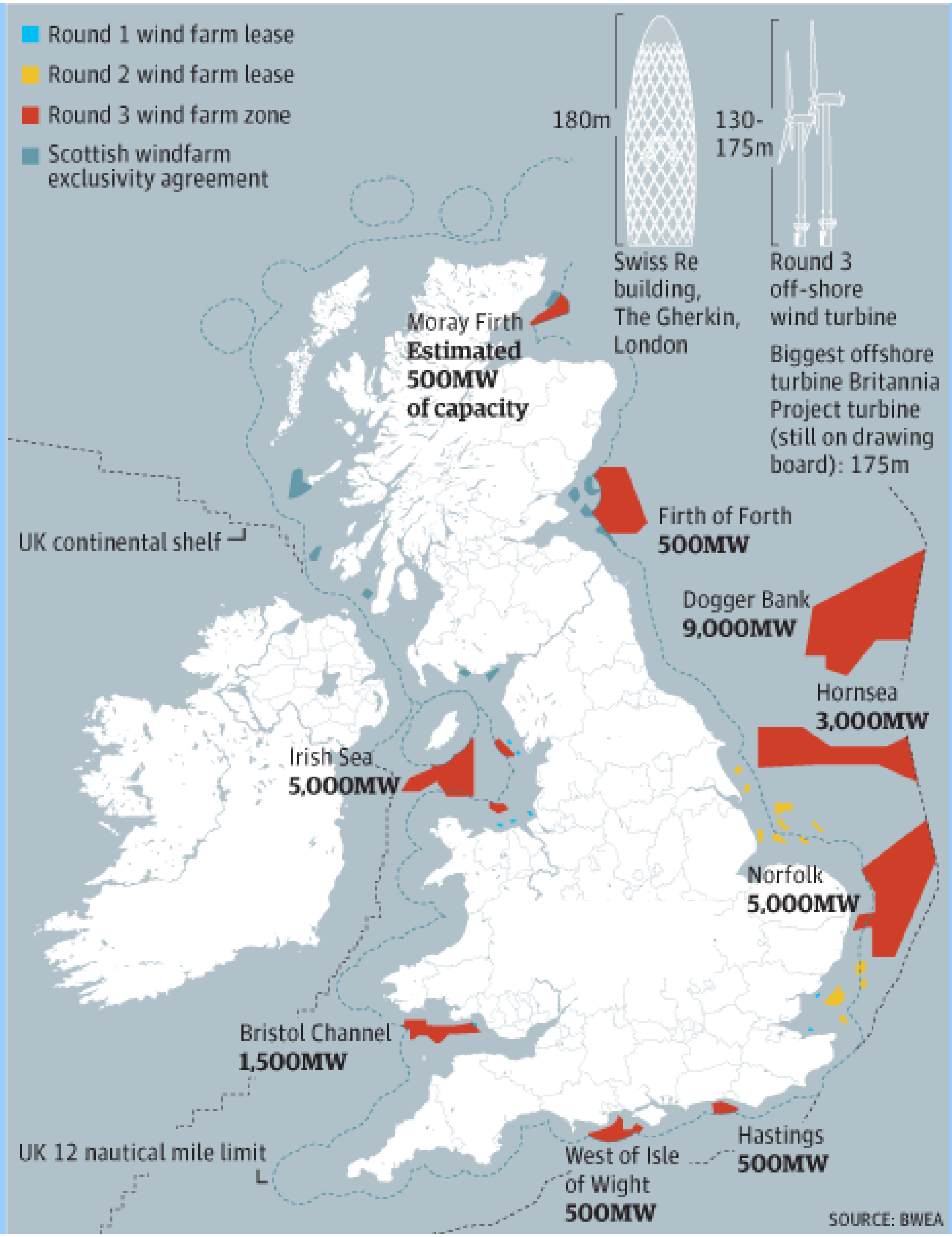
Cefas

Wind farm locations around the UK and neighbouring areas.



(Adrian Judd, with permission)


Round 1 wind farm lease
Round 2 wind farm lease
Round 3 wind farm zone
Scottish windfarm exclusivity agreement
180m
130-175m
Swiss Re building, The Gherkin, London
Round 3 off-shore wind turbine
Biggest offshore turbine Britannia Project turbine (still on drawing board): 175m
Moray Firth
Estimated 500MW of capacity
Firth of Forth
500MW
UK continental shelf
Dogger Bank
9,000MW
Hornsea
3,000MW
Irish Sea
5,000MW
Norfolk
5,000MW
Bristol Channel
1,500MW
UK 12 nautical mile limit
Hastings
500MW
West of Isle of Wight
500MW
SOURCE: BWEA

Spatial & Temporal considerations

- Extent of development
  - Multiple devices
  - Cable array
  - Sub-station & connection to shore
  - Environmental footprint
  - Other wind farms & renewable options
- Time scale of development
- Other uses of the coastal zone

Phases of impacts of ecological relevance

Effects & impacts of ecological relevance

ORED Activity
Construction -energy conversion device - substation - cables
Operation
Decommission

ORED = Offshore renewable energy developments

Effects & impacts of ecological relevance

ORED Activity	Effectors
Construction -energy conversion device - substation - cables	Sediment – removal - disturbance Cable - laying - routing Structure - type - scale - pile driving Areal extent Timing of activity
Operation	Cable - rating - array configuration Electricity - amount - frequency - variability Moving parts Structure – type - scale
Decommission	Sediment disturbance Structure removal Cable removal Areal extent Timing of activity

ORED = Offshore renewable energy developments

Effects & impacts of ecological relevance

ORED Activity	Effectors	Effects on Coastal Environment
Construction -energy conversion device - substation - cables	Sediment – removal - disturbance Cable - laying - routing Structure - type - scale - pile driving Areal extent Timing of activity	Habitat removal Smothering - species - habitat Increased turbidity Contaminant remobilisation Increased Biol Oxygen Demand Increased noise & vibration
Operation	Cable - rating - array configuration Electricity - amount - frequency - variability Moving parts Structure – type - scale	Noise & vibration Electromagnetic field (EMF) - frequency - amplitude Collision - above water - below water Increased habitat heterogeneity - colonisation opportunity Sediment transport Water movement characteristics
Decommission	Sediment disturbance Structure removal Cable removal Areal extent Timing of activity	Habitat removal Smothering - species - habitat Increased turbidity Contaminant remobilisation Increased Biol Oxygen Demand Decreased habitat heterogeneity New colonisation opportunity Increased noise & vibration

ORED = Offshore renewable energy developments

Effects & impacts of ecological relevance

ORED Activity	Effectors	Effects on Coastal Environment	Potential Ecological Response
Construction -energy conversion device -substation -cables	Sediment – removal - disturbance Cable - laying - routing Structure - type - scale - pile driving Areal extent Timing of activity	Habitat removal Smothering - species - habitat Increased turbidity Contaminant remobilisation Increased Biol Oxygen.Demand Increased noise & vibration	*Sedentary species:* Reduced diversity Increase in opportunist abundance *Mobile species:* Temporary displacement Long-term displacement Hearing loss Indirect effects
Operation	Cable - rating - array configuration Electricity - amount - frequency - variability Moving parts Structure – type - scale	Noise & vibration Electromagnetic field (EMF) - frequency - amplitude Collision - above water - below water Increased habitat heterogeneity - colonisation opportunity Sediment transport Water movement characteristics	*Acoustic species:* Individual disturbance Population disturbance *EMF sensitive species:* Individual attraction/avoidance Population attraction/avoidance Altered migration - temporary - long term Injury/fatality of individuals Changes to - diversity - abundance - biomass - connectivity - community structure Indirect effects
Decommission	Sediment disturbance Structure removal Cable removal Areal extent Timing of activity	Habitat removal Smothering - species - habitat Increased turbidity Contaminant remobilisation Increased Biol Oxygen Demand Decreased habitat heterogeneity New colonisation opportunity Increased noise & vibration	*Sedentary species:* Reduced diversity Increase in opportunist abundance *Mobile species:* Temporary displacement Long-term displacement Reduction in biomass Indirect effects

ORED = Offshore renewable energy developments

Source: Gill (2005) Journal of Applied Ecology 42, p605-615

Investigating potential interactions between marine organisms and offshore wind energy

- Baseline understanding of the organisms of interest
- Consider the different phases
  - Installation
  - Operation
  - Decommissioning
- Appropriate spatial scale
- Appropriate temporal scale
- Policy driven (eg. EIA & MSFD)
- Relevance to offshore industry, regulators, other stakeholders

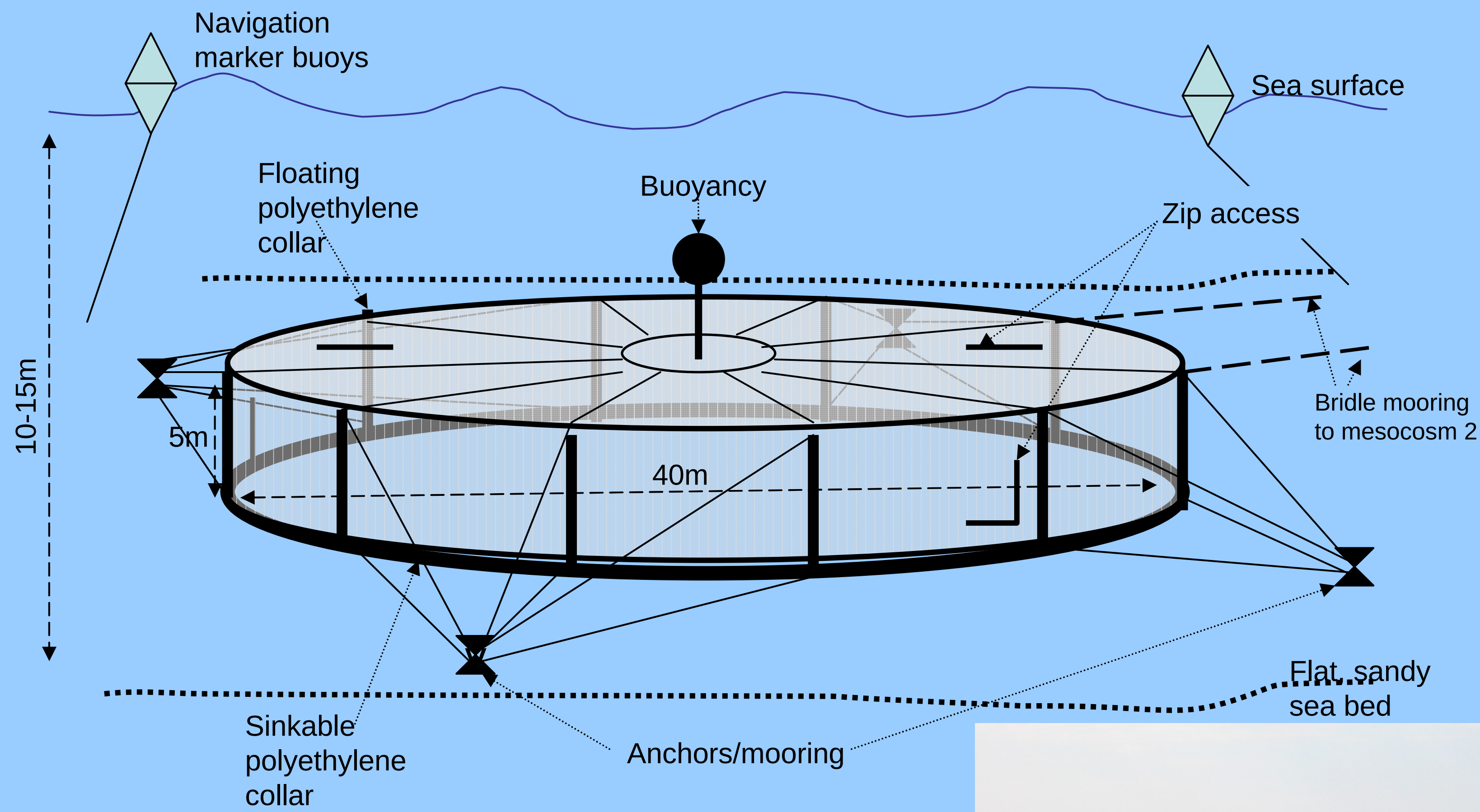
COWRIE studies
- taking the lab out into the field

- Set out the research question to answer (e.g.)
  - Q. Do electromagnetic sensitive fish respond to EMF emitted by offshore wind farm cables?
  - Q. Does pile driving affect the behaviour of marine fish

- Mesocosm (large fish pen) based study
- Focus on semi-realism but study control
- Remote coastal site away from background EMF & noise
- Relevant species with different attributes
- Behavioural study with remote methods



COWRIE Mesocosm Studies



A large-scale experiment to determine the response of electrosensitive fish to electromagnetic fields (EMF) generated by offshore windfarms

Andrew B. Gill[1]*, Ian Gloyne-Phillips[3], Yi Huang[4], Julian Metcalfe[2], Andrew Pate[4], Joe Spencer[4], Vicky Quayle[2] & Victoria Wearmouth[1]

1 – Cranfield University; 2 – Centre for Fisheries, Environment and Aquaculture Science (CEFAS), 3 - CMACS Ltd, 4 – Centre for Intelligent Monitoring Systems (CIMS), University of Liverpool

Cranfield UNIVERSITY

Cefas

CMACS

Centre for Marine and Coastal Studies Ltd

CIMS

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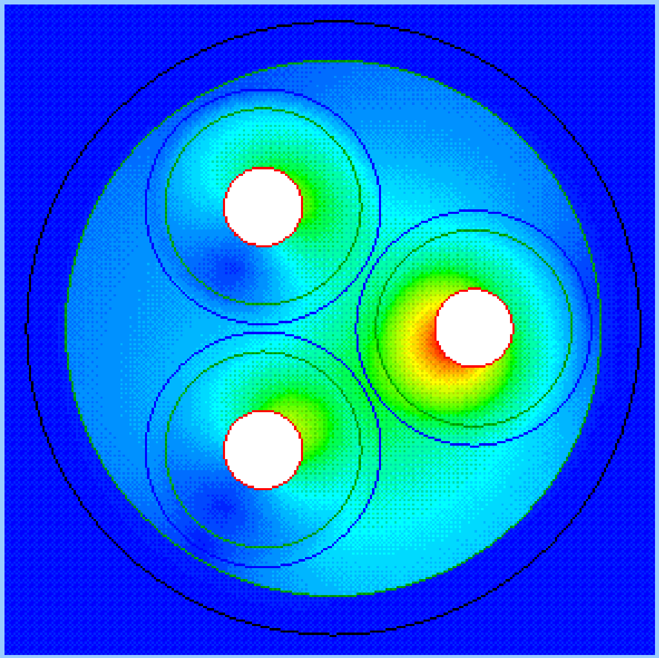
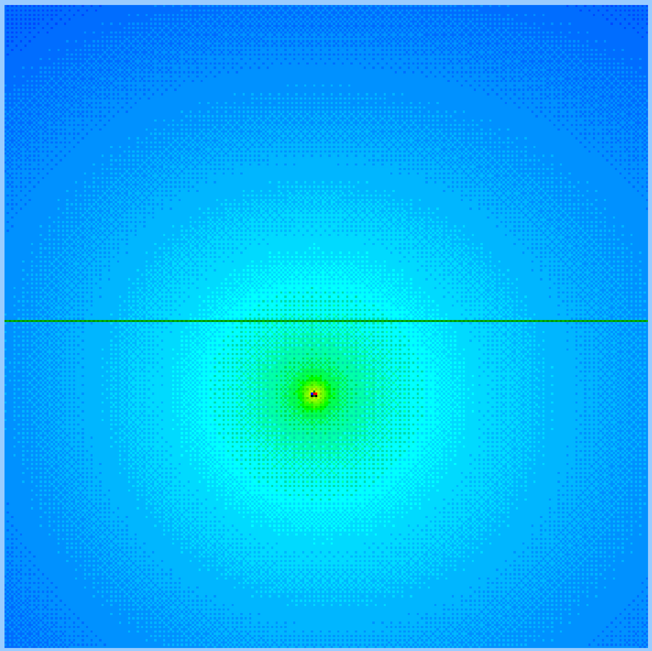
www.cranfield.ac.uk

Electromagnetic field (EMF) emissions from wind farm cables



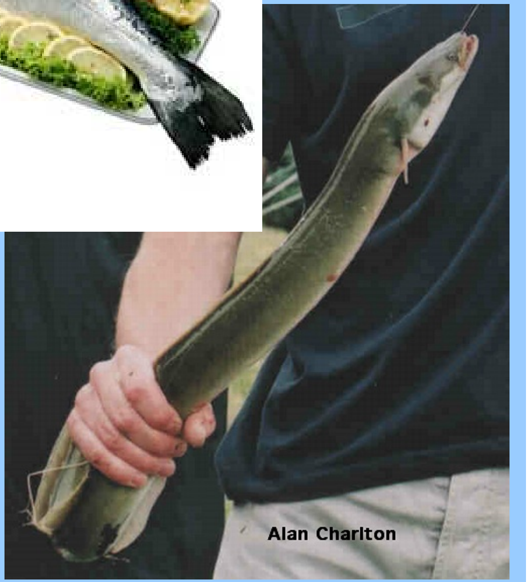
X-section cable (internal) – magnetic field



X-section cable (external) - magnetic field

Magnetic fields

- Focus - migration behaviour
  - behaviour in relation to the cable trace



Fish (common eels & salmonids)

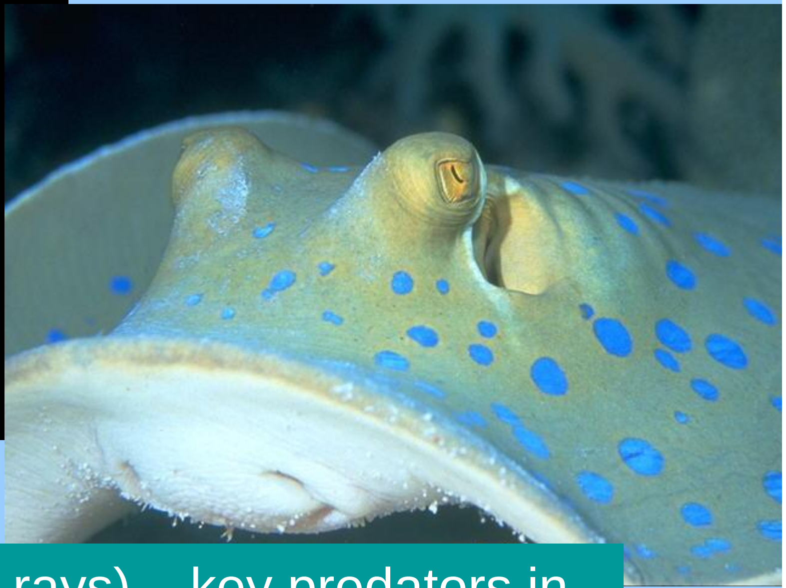
Chelonians (turtles)

Cetaceans (whales & dolphins)

Crustaceans (crabs & lobsters)

Pinnipeds (seals)

Elasmobranchs (sharks, skates and rays) – Electro- & Magneto-reception



Elasmobranchs (sharks, skates and rays) – key predators in coastal ecosystems and increasing conservation concern

Density distribution of Thornback Ray, functional benthic habitat & offshore wind farm sites

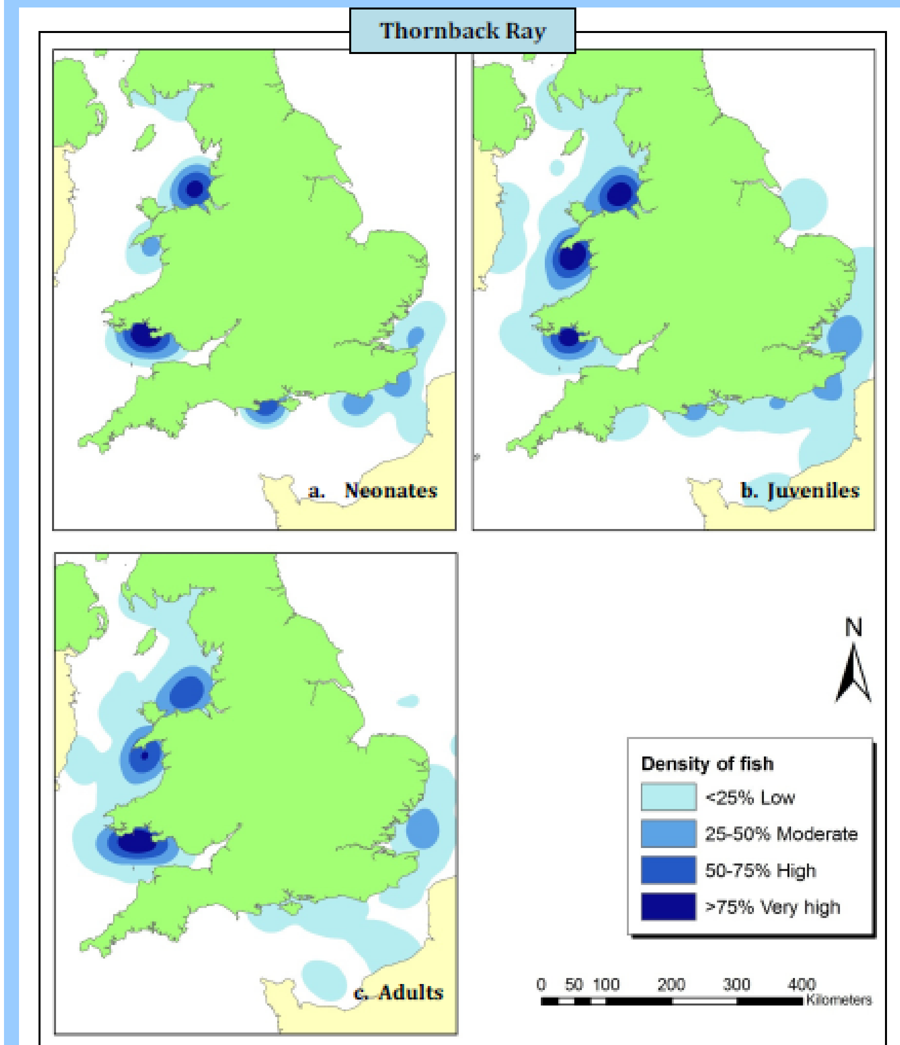


Figure 13. Density distributions of the Thornback Ray obtained with the modelling for each of the age category. (Sources: EDINA and CEFAS)

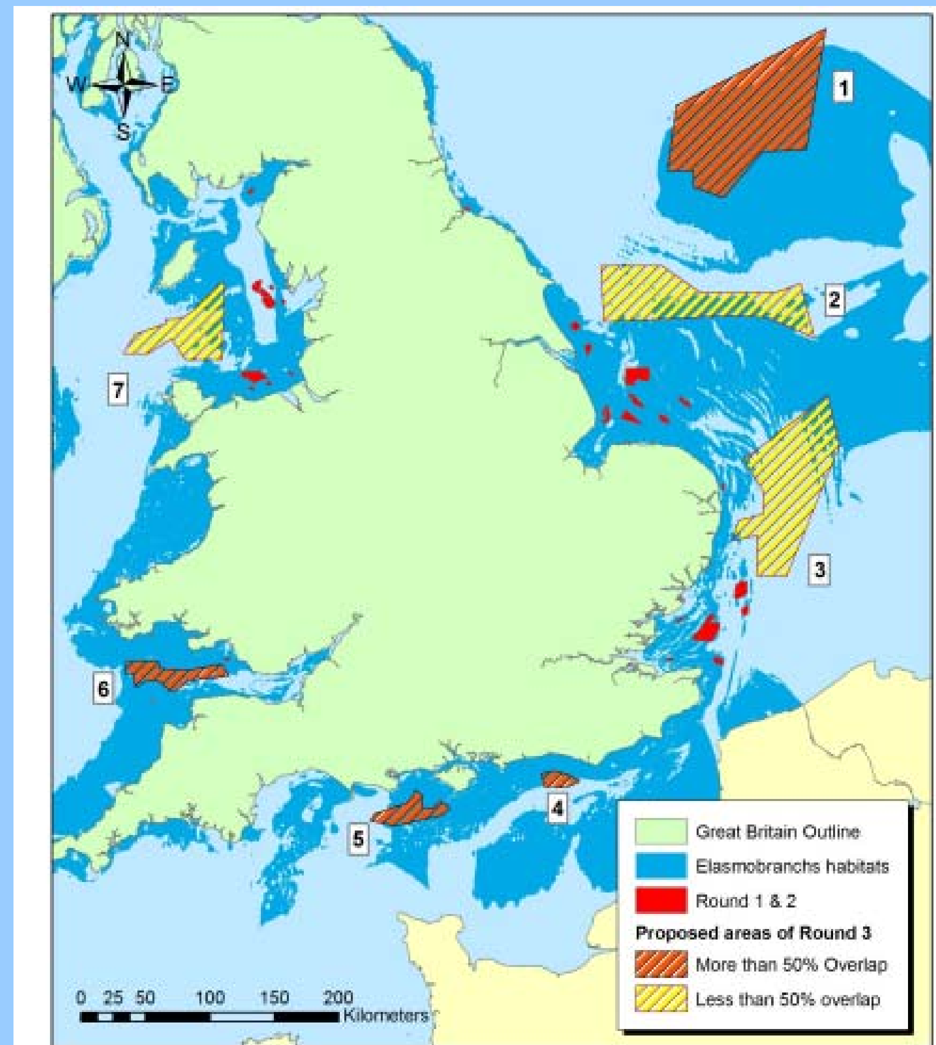
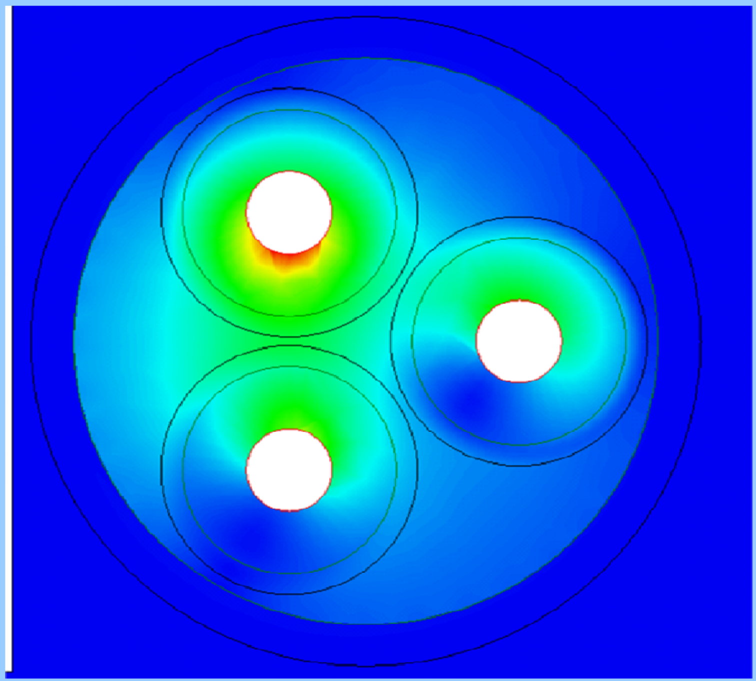
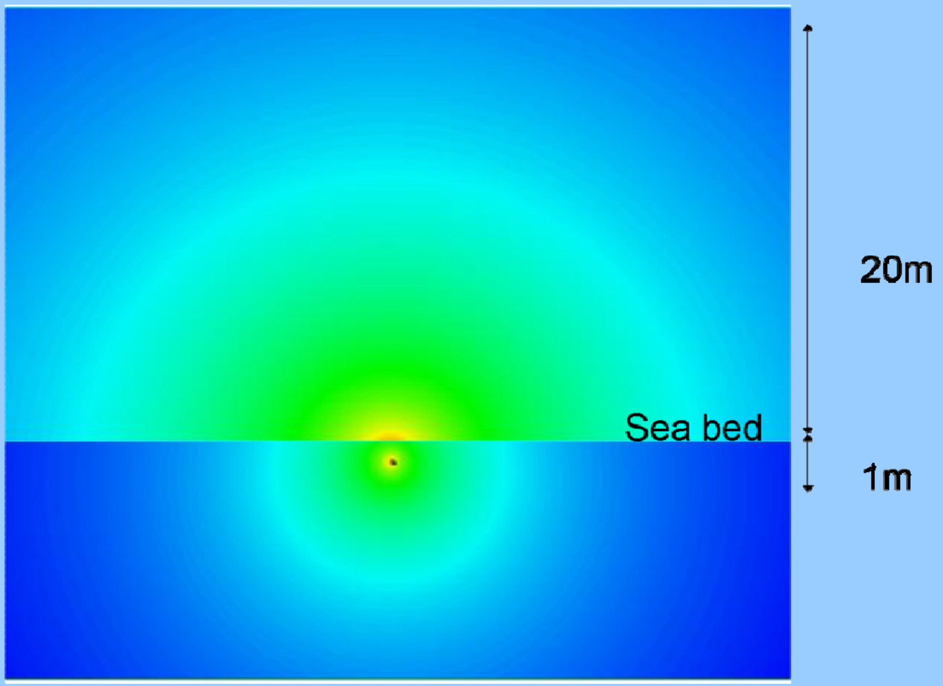


Figure 18. Possible overlap areas of round 3 (red stripes) with the extracted elasmobranchs habitats (blue). (Source: the Crown Estate, EDINA and MESH)

EMF emissions from AC windfarm cables



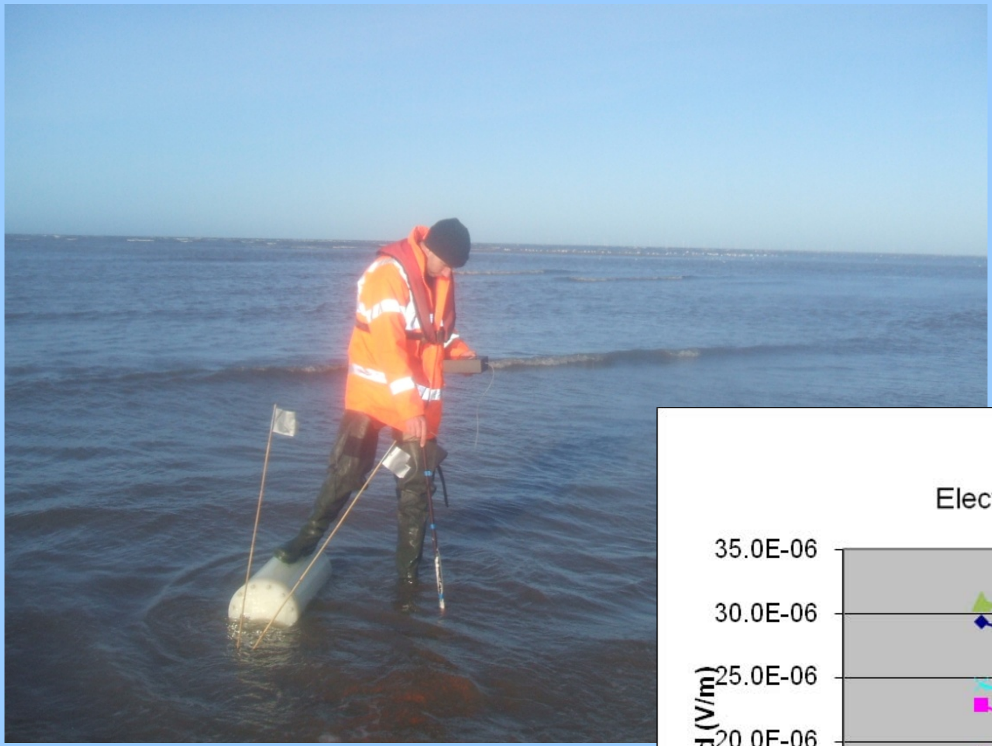
Cable x-section (internal)
Magnetic field

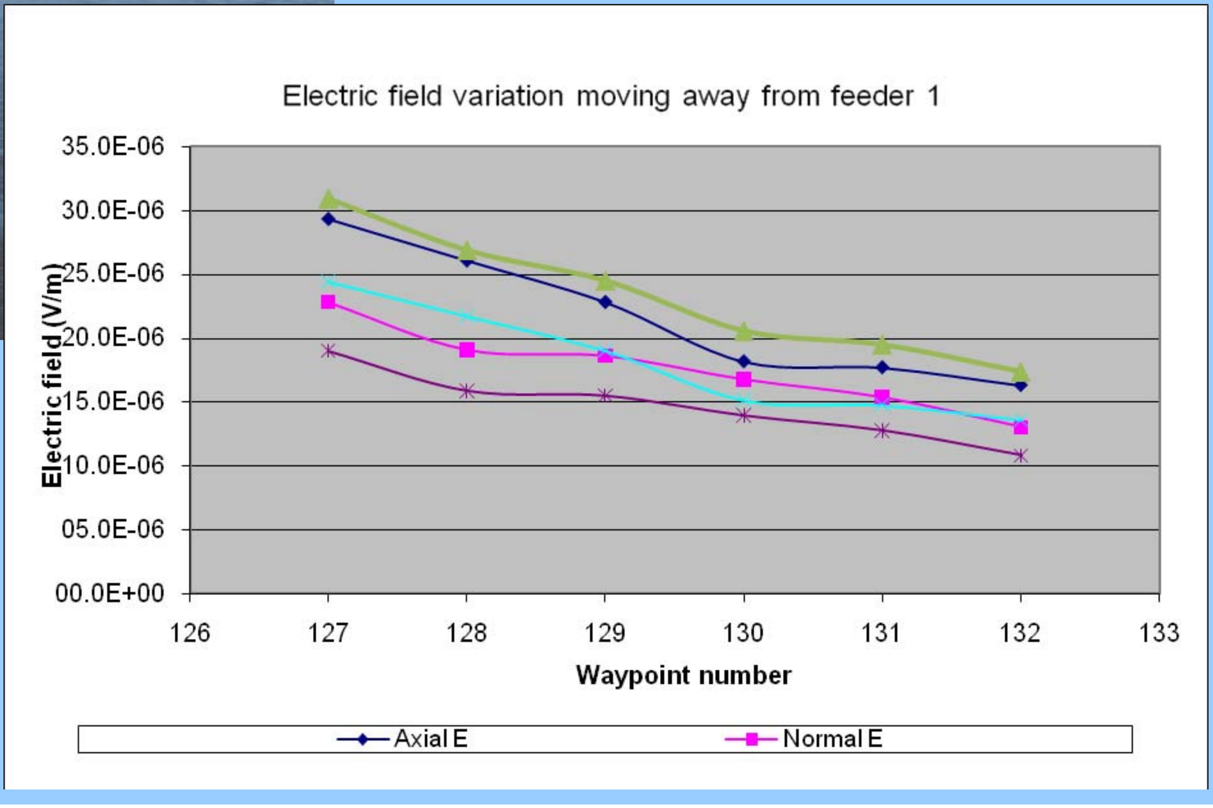


Cable x-section (external)
Induced electric field

- Approximates to E field of 0.9μV/cm (50 Hz) at surface of seabed

Measured electric and magnetic field of operational wind farm cable



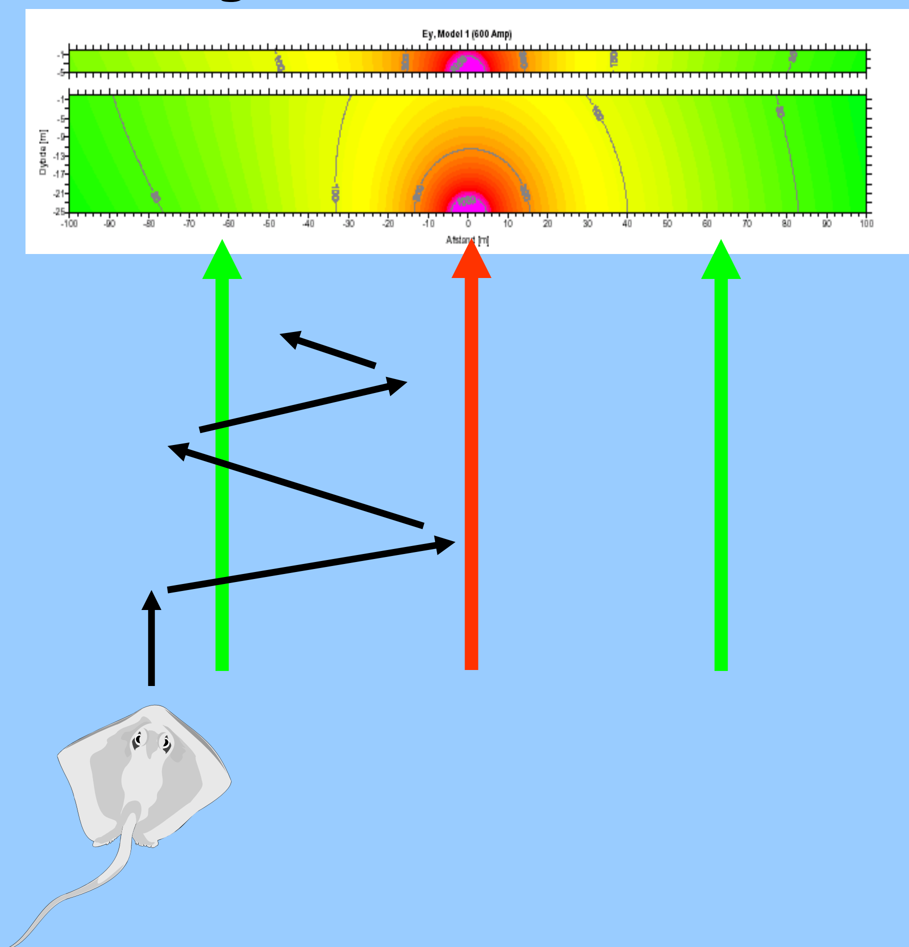


Response to E-field

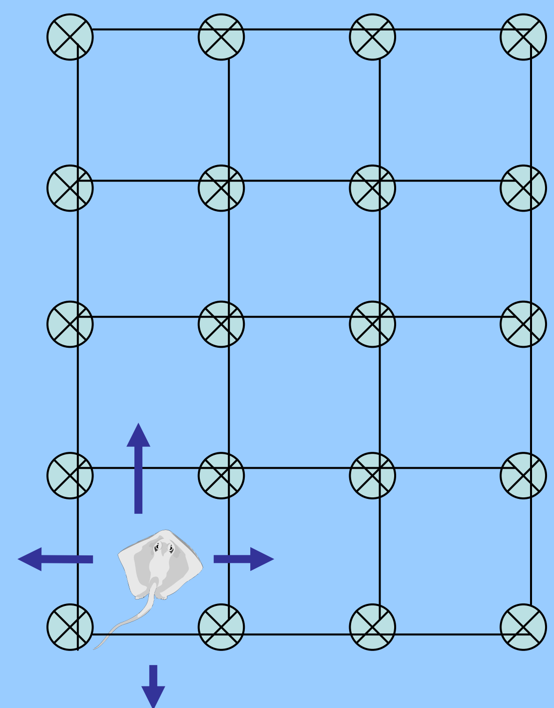
Elasmobranchs E field detection range: 10μV/cm – 5nV/cm
(variable low frequencies)

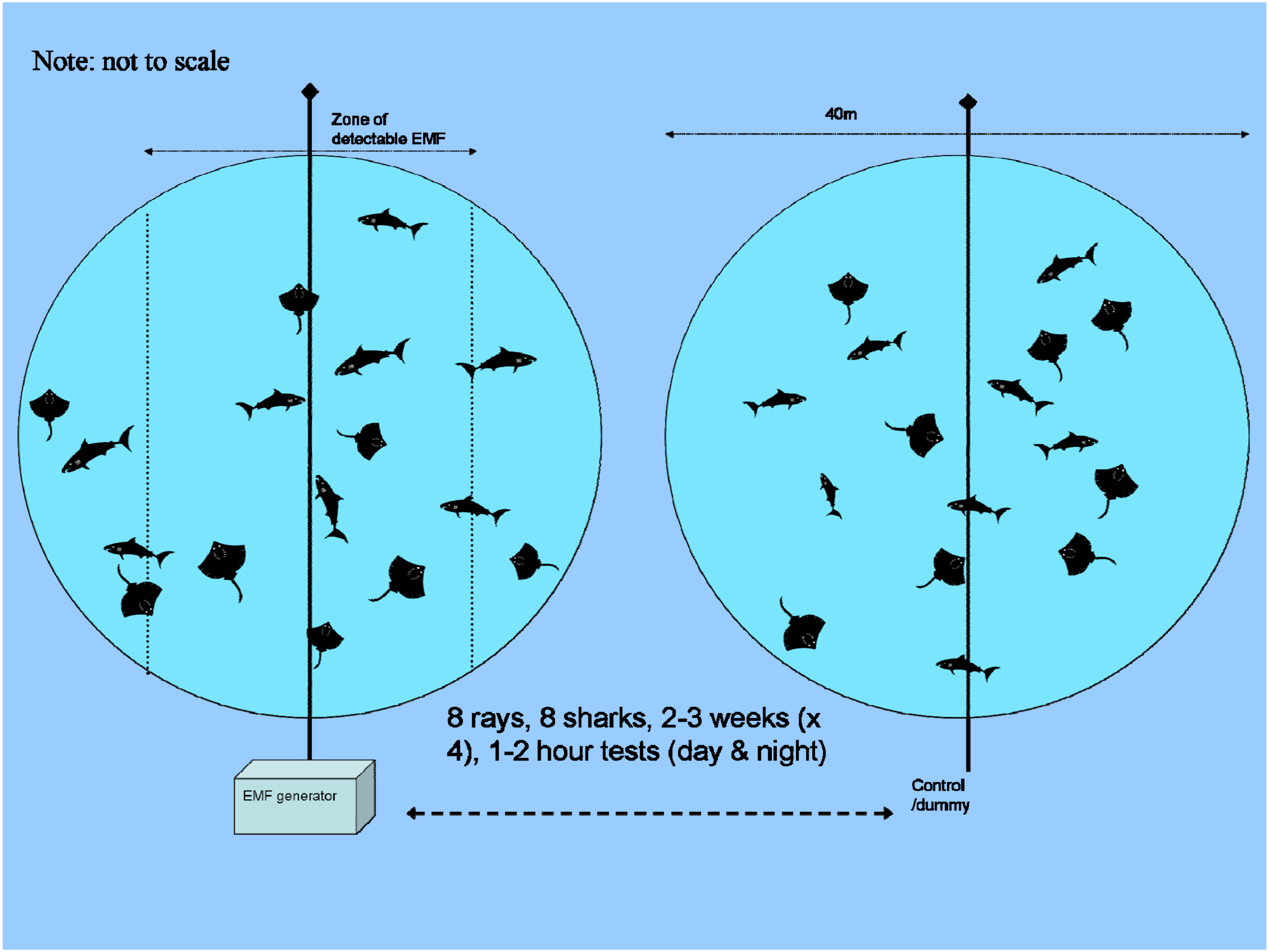
Potential effects?
- working hypothesis

Along/over the cable trace

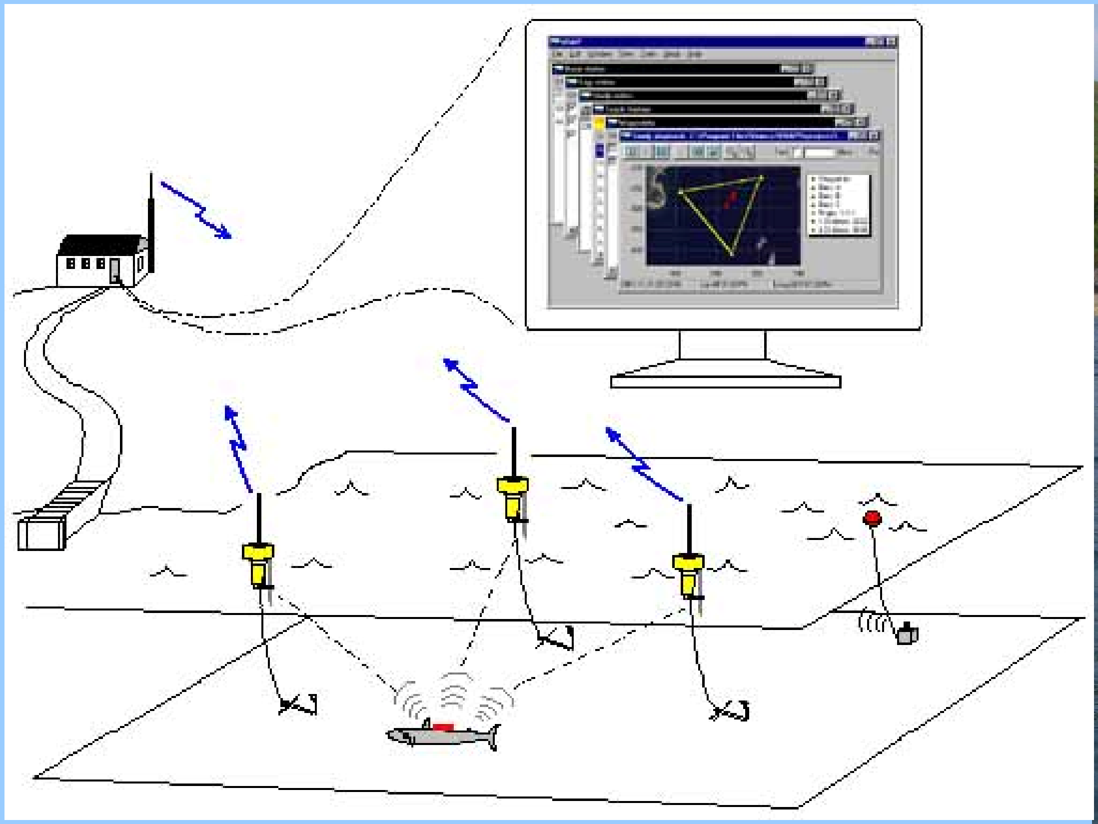


Within the cable array



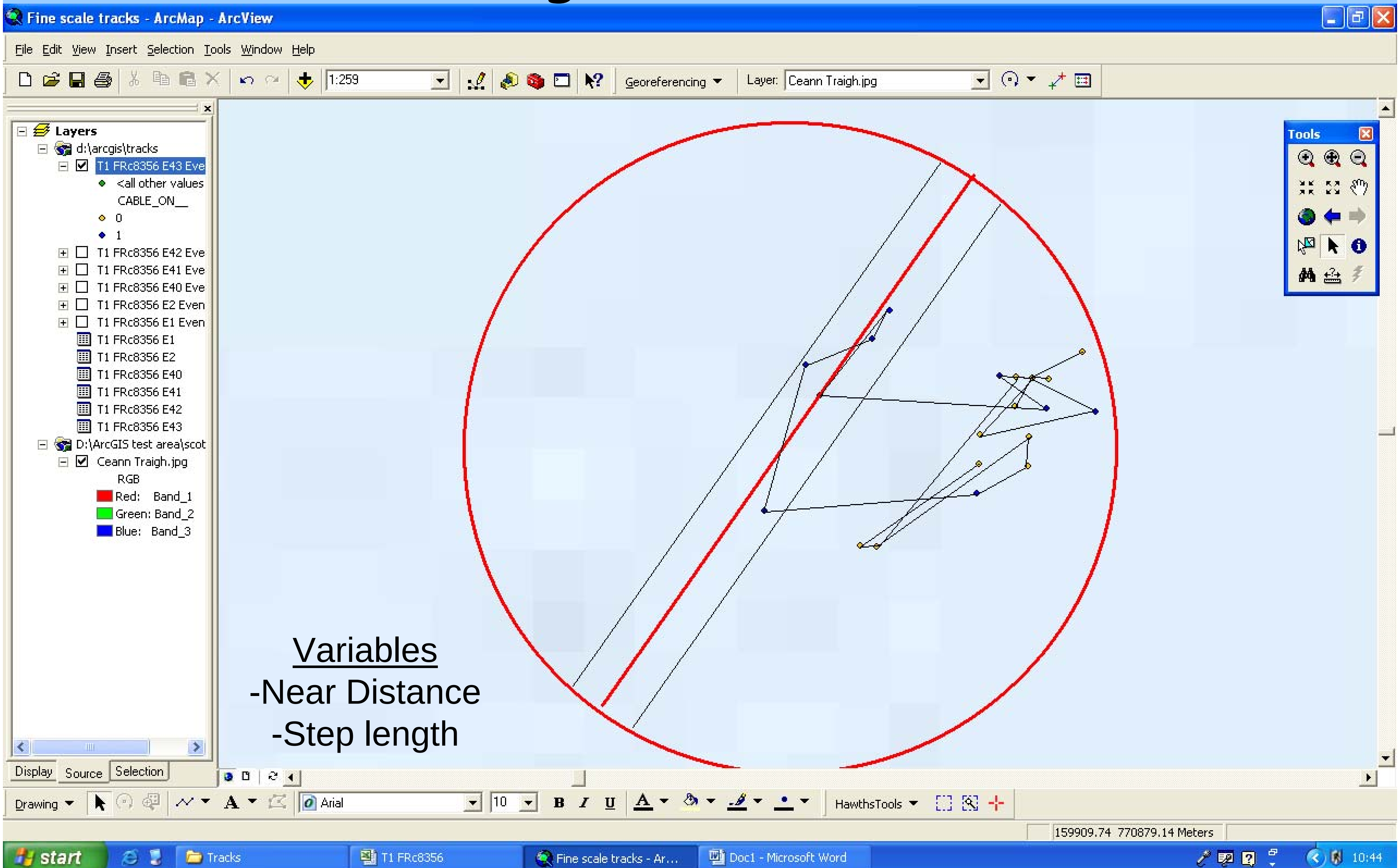

Note: not to scale
Zone of
detectable EMF
40m
8 rays, 8 sharks, 2-3 weeks (x 4), 1-2 hour tests (day & night)
EMF generator
Control
/dummy

Movement tracking



(Figure © by Vemco)

Fine scale movement of ray during 3 hour event



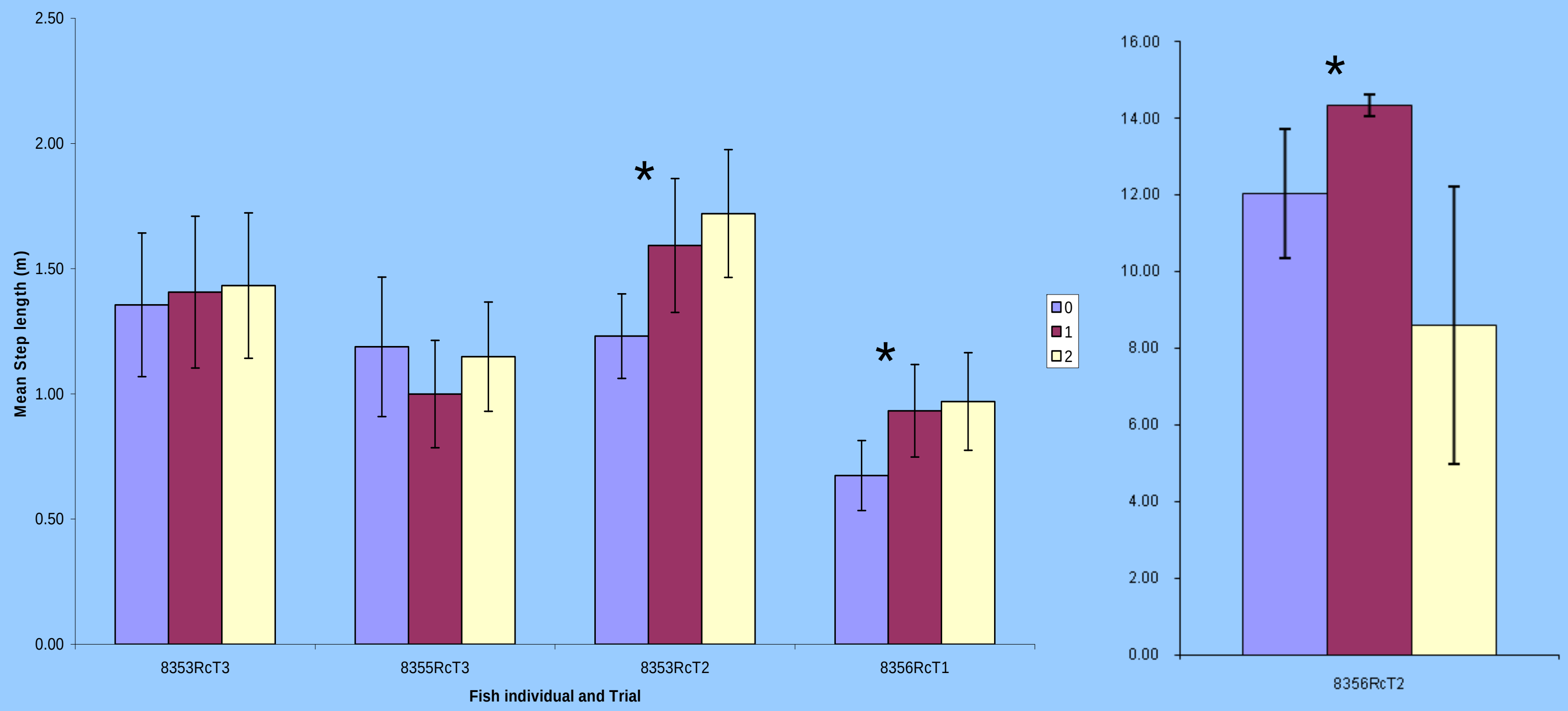
<u>Variables</u>

-Near Distance

-Step length

Mean Step length (+/-95%C.L.) of individual rays

Live



EMF Conclusions

EMF at wind farms-

- Both electric and magnetic fields are emitted by OWF cables

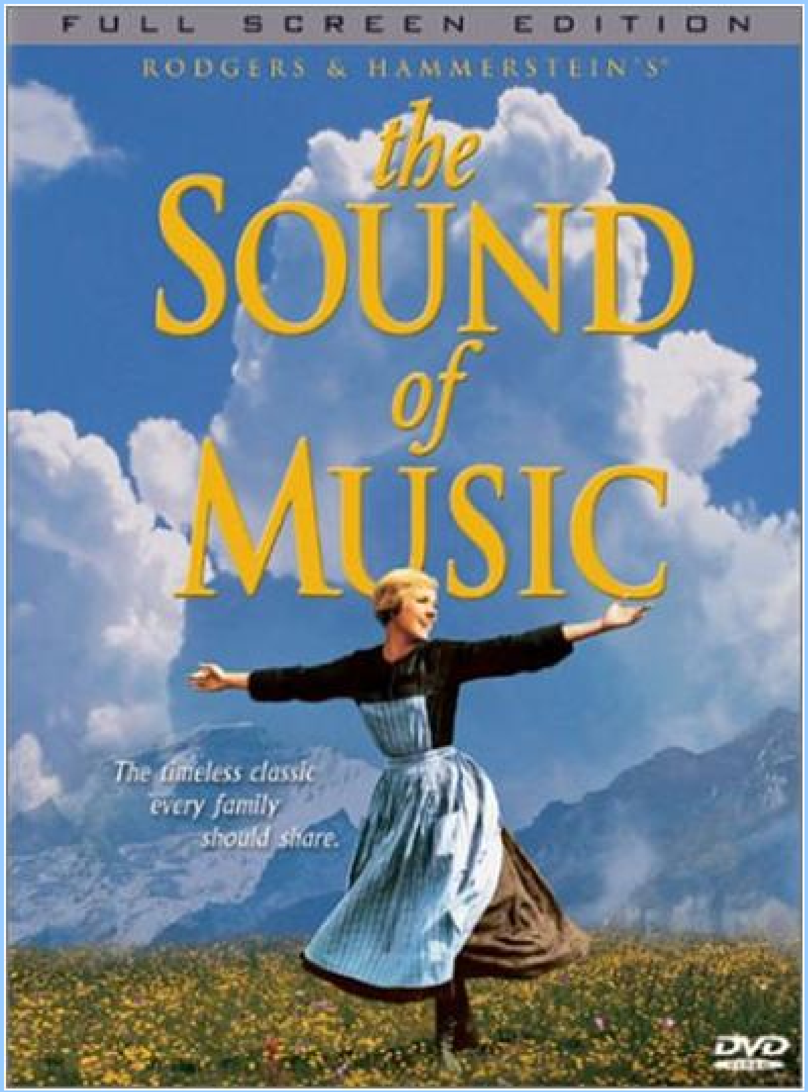
Individual effects-

- EM sensitive fish can detect EMF from subsea AC cables
  - Variable respons
  - Attracted to emis
    of sensitivity

Population effects-

- Need to determine if this attraction is repetitive
- Does avoidance occurs at higher emissions of EMF

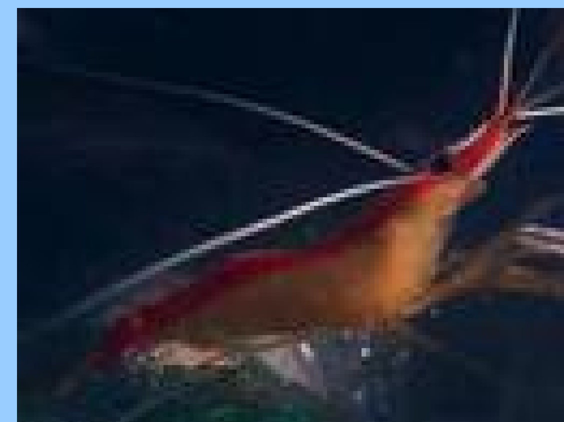
Underwater sound



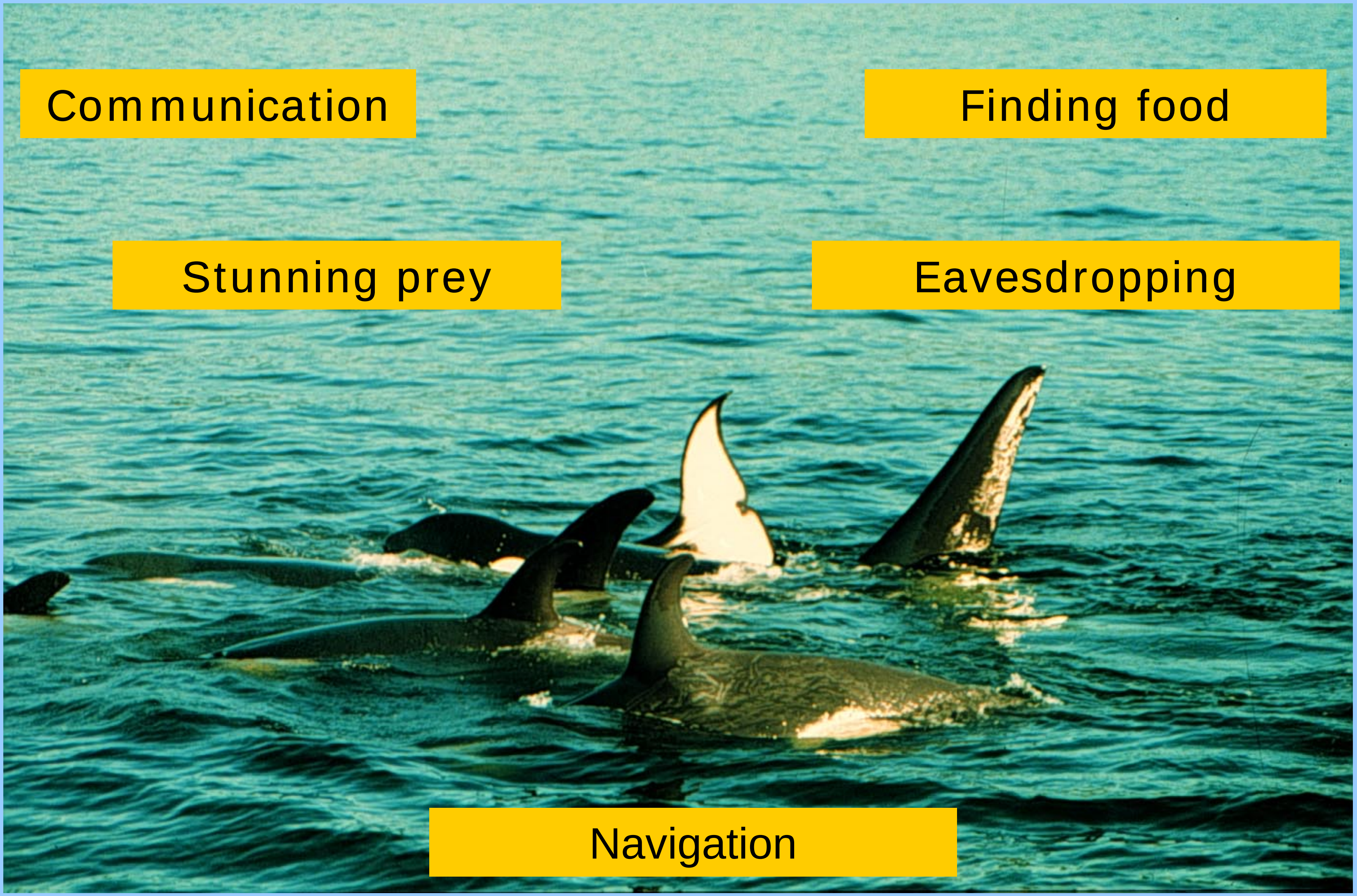
- Four times faster than air
- Less attenuation
- Very long ranges (SOFAR

channel = > 1,000 km)

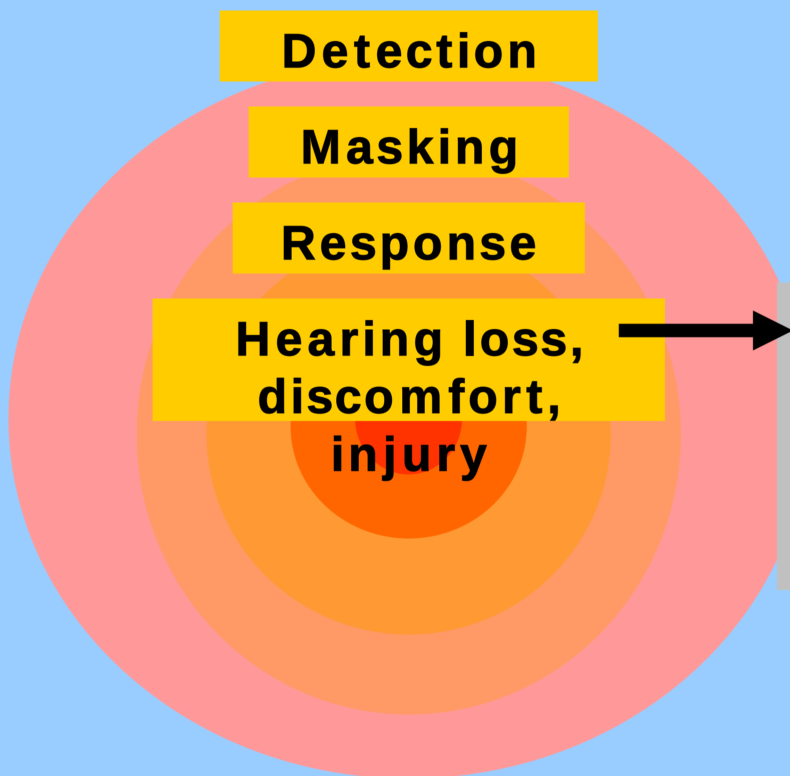
Sound and marine life



Functions of sound for marine life



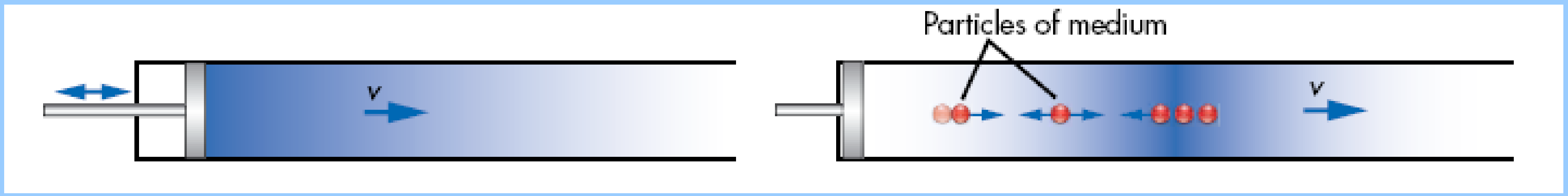
Theoretical zones of noise influence



- TTS = Temporary threshold shift
- PTS = Permanent threshold shift

(Richardson et al. 1995)

Important units



➢ Sound consist of pressure fluctuations (compressions and rarefactions of molecules)

➢ Pressure fluctuations propagate through medium

➢ Sound consists of

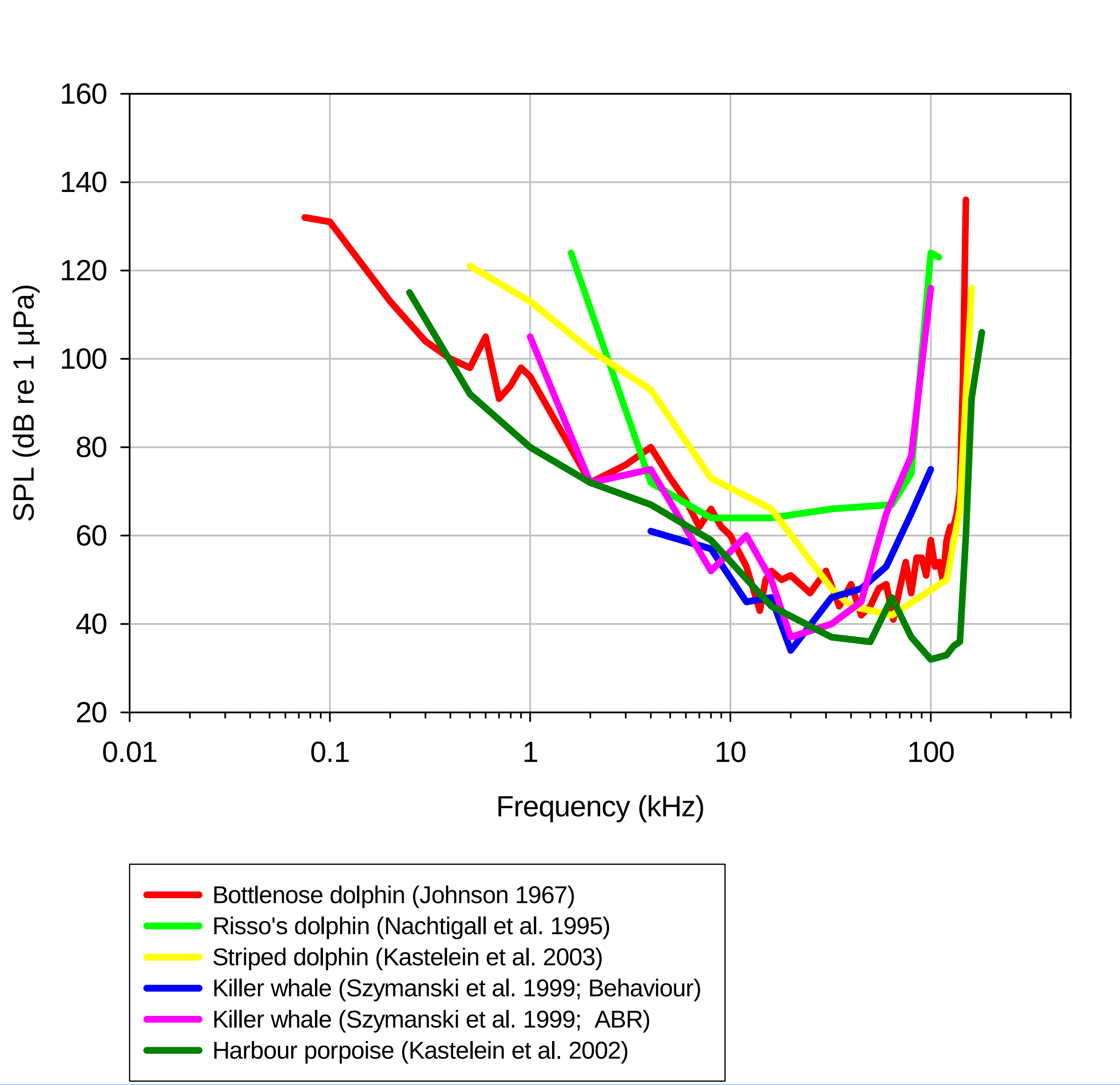
- pressure component
- particle motion component

<u>Acoustic pressure:</u> SPL (dB) = 20 $\log_{10}(P/P_0)$

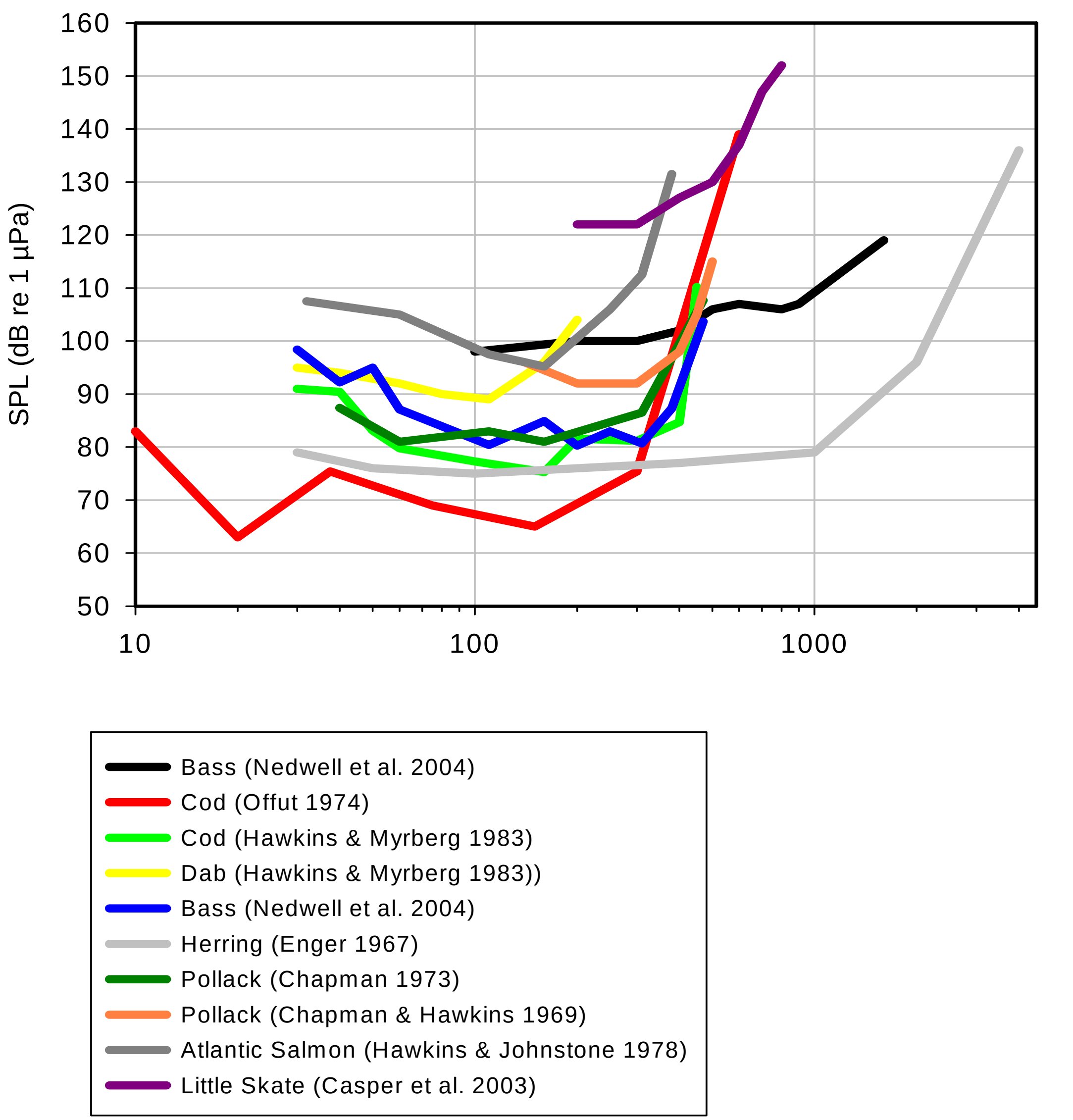
P_0 underwater = 1µPa; P_0 air = 20 µPa

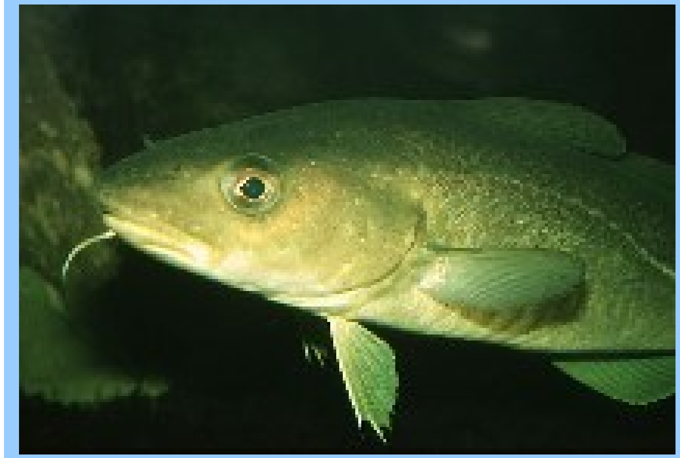
<u>Pitch:</u> Hz = cycles / s (pitch)

Hearing in cetaceans

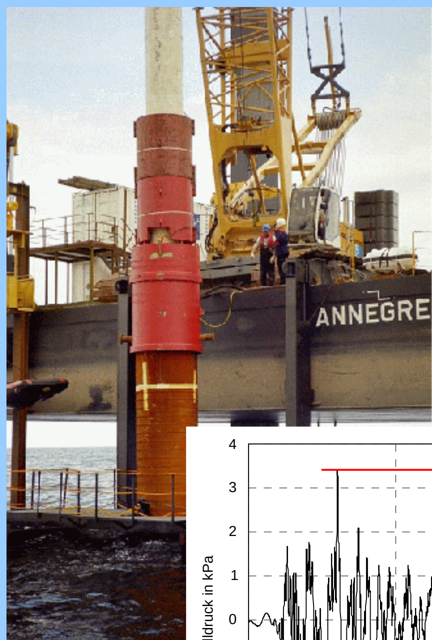


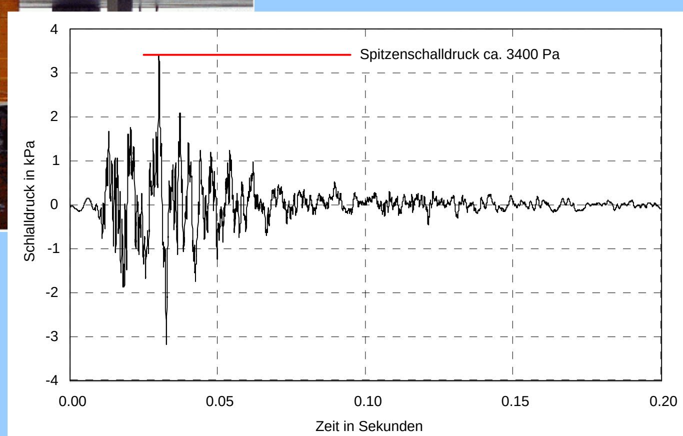
Hearing in fish





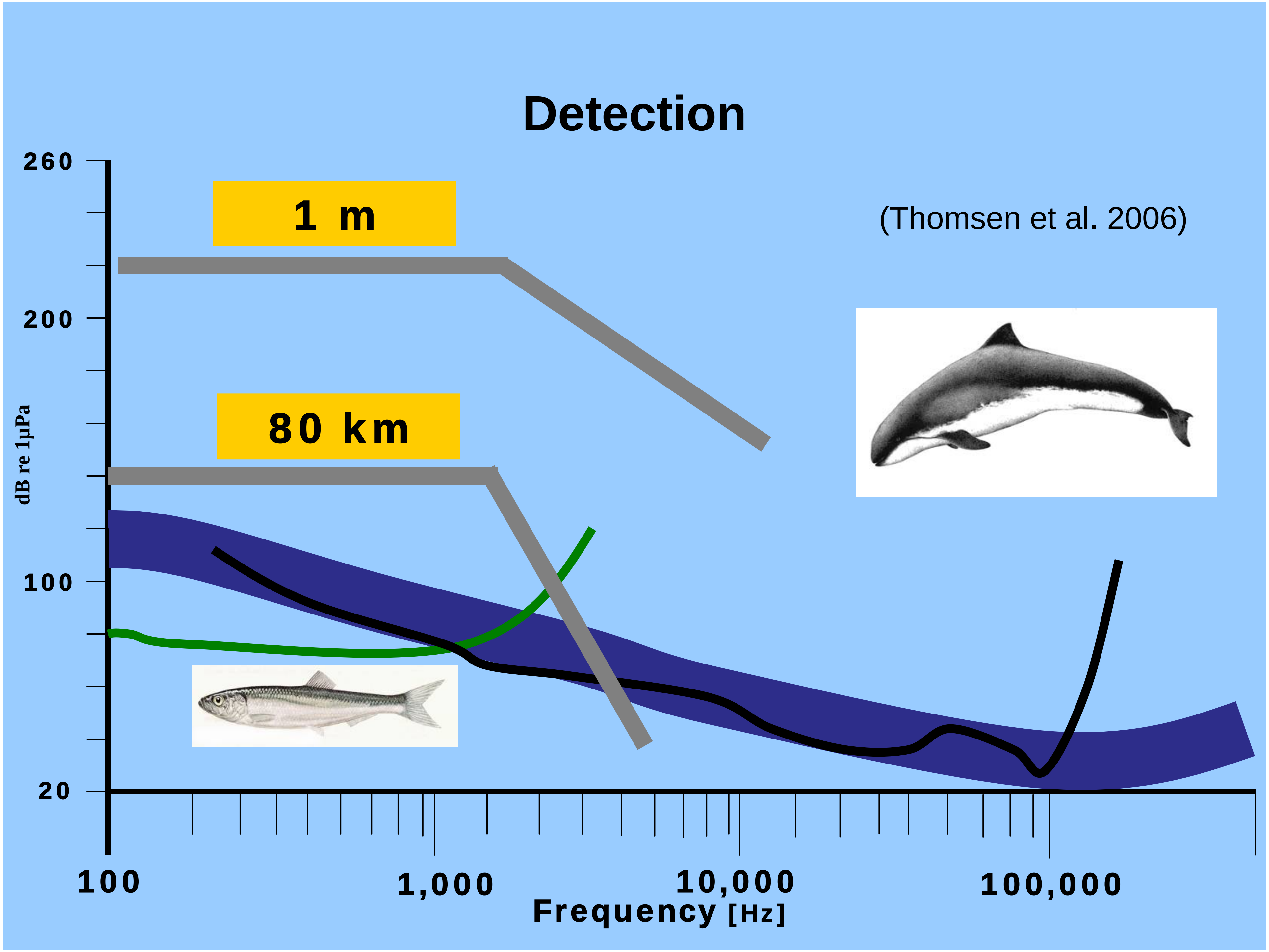
Construction noise



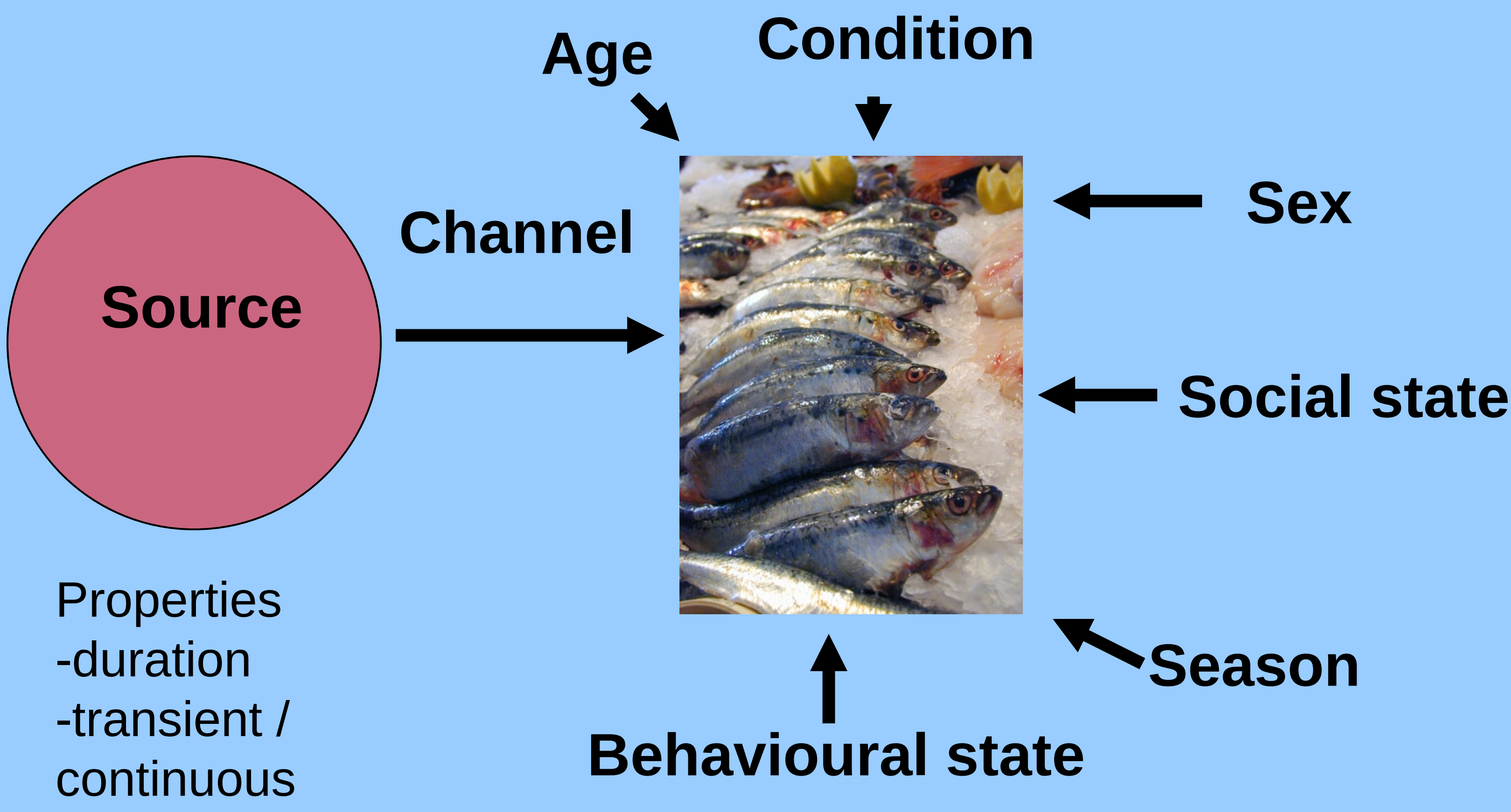


- Impact pile driving with very high sound pressure levels
- 228 dB re 1µPa peak – 257 dB re 1µPa peak to peak (1m)
- Several hundred strikes per pile
- Main energy at lower frequencies < 1kHz

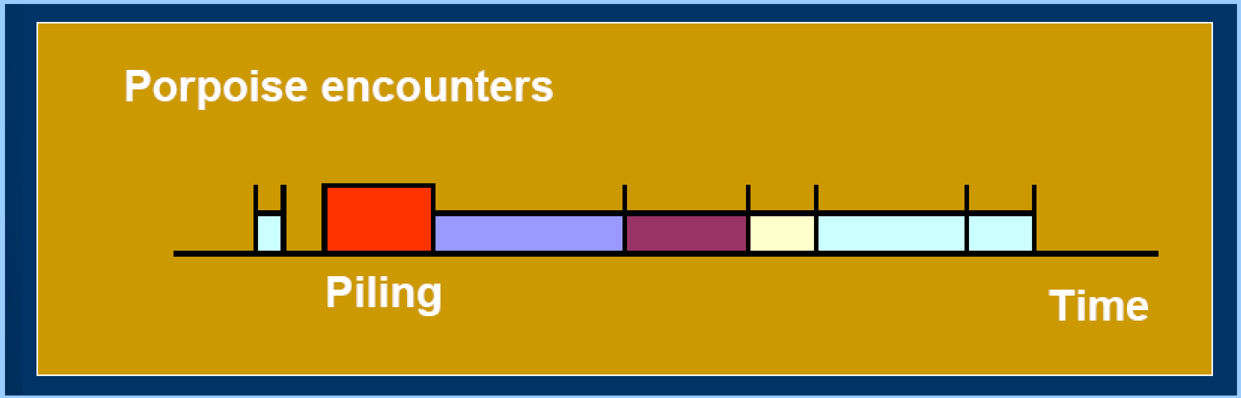
(ITAP 2005; Thomsen et al. 2006; Nedwell et al. 2007; review in OSPAR 2009)


Detection
(Thomsen et al. 2006)
1 m
80 km
260
200
100
20
dB re 1µPa
100
1,000
10,000
100,000
Frequency [Hz]

Response


Age
Condition
Source
Channel
Sex
Social state
Season
Behavioural state
Properties
-duration
-transient /
continuous

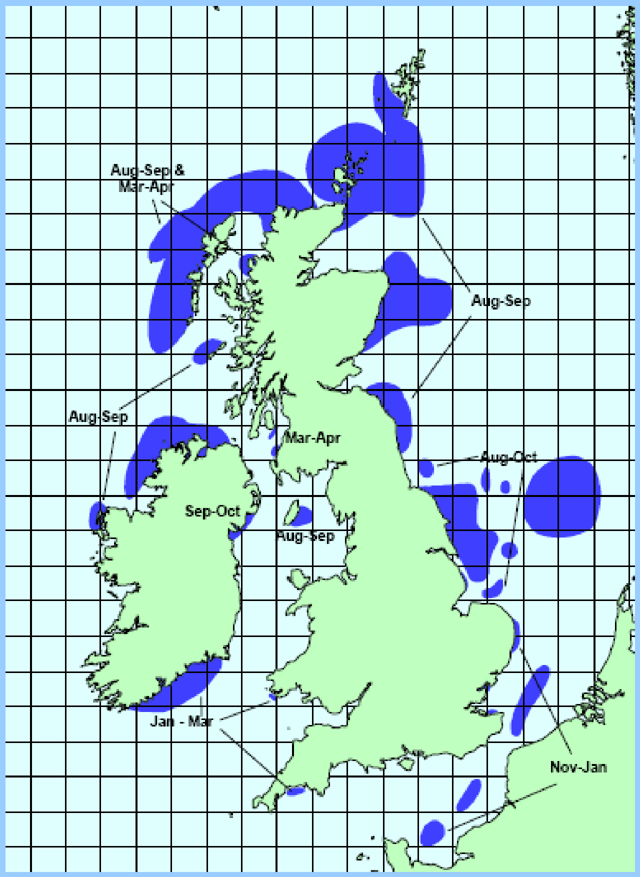
Response: harbour porpoises



- Reduced sightings during impact pile driving
- Decreased clicking rate
- 15-20 km from source
- Short-term effect at Horns Reef
- Long term effect at Nysted

(Tougaard et al. 2003, 2005,
2007 Carstensen 2006)

Possible consequences of disturbance

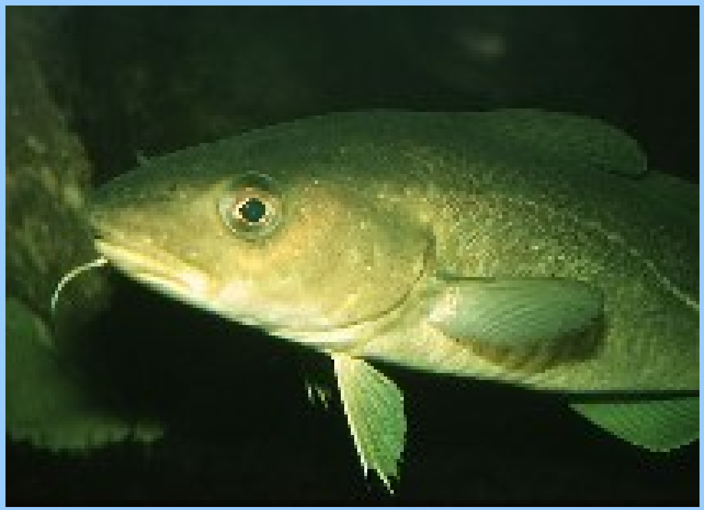


Displacement from spawning and / or fishing grounds

- Reduced reproduction and survival
- Reduced catches

(Herring; map from Coull et al. 1998 currently updated by Cefas; see Engas et al. 1996)

Effects of pile driving sound on the behaviour of marine fish



Frank Thomsen[1], Christina Mueller-Blenkle[1], Andrew Gill[2], Julian Metcalfe[1], Peter McGregor[3], Victoria Bendall[1], Daniel Wood[1], Mathias Andersson[4], Peter Sigray[4]

1) Cefas, 2) Cranfield University Cranfield, 3) Cornwall College Newquay, 4) Stockholm University

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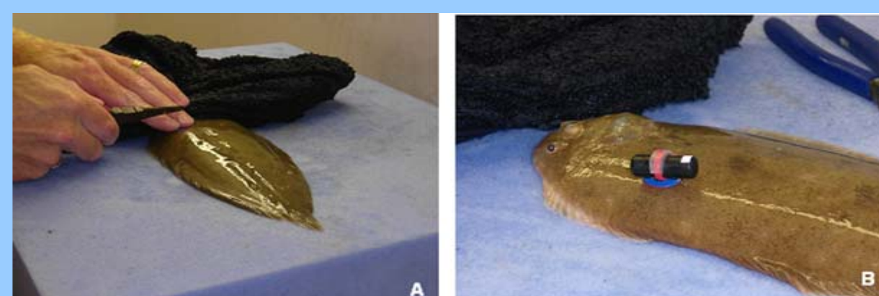
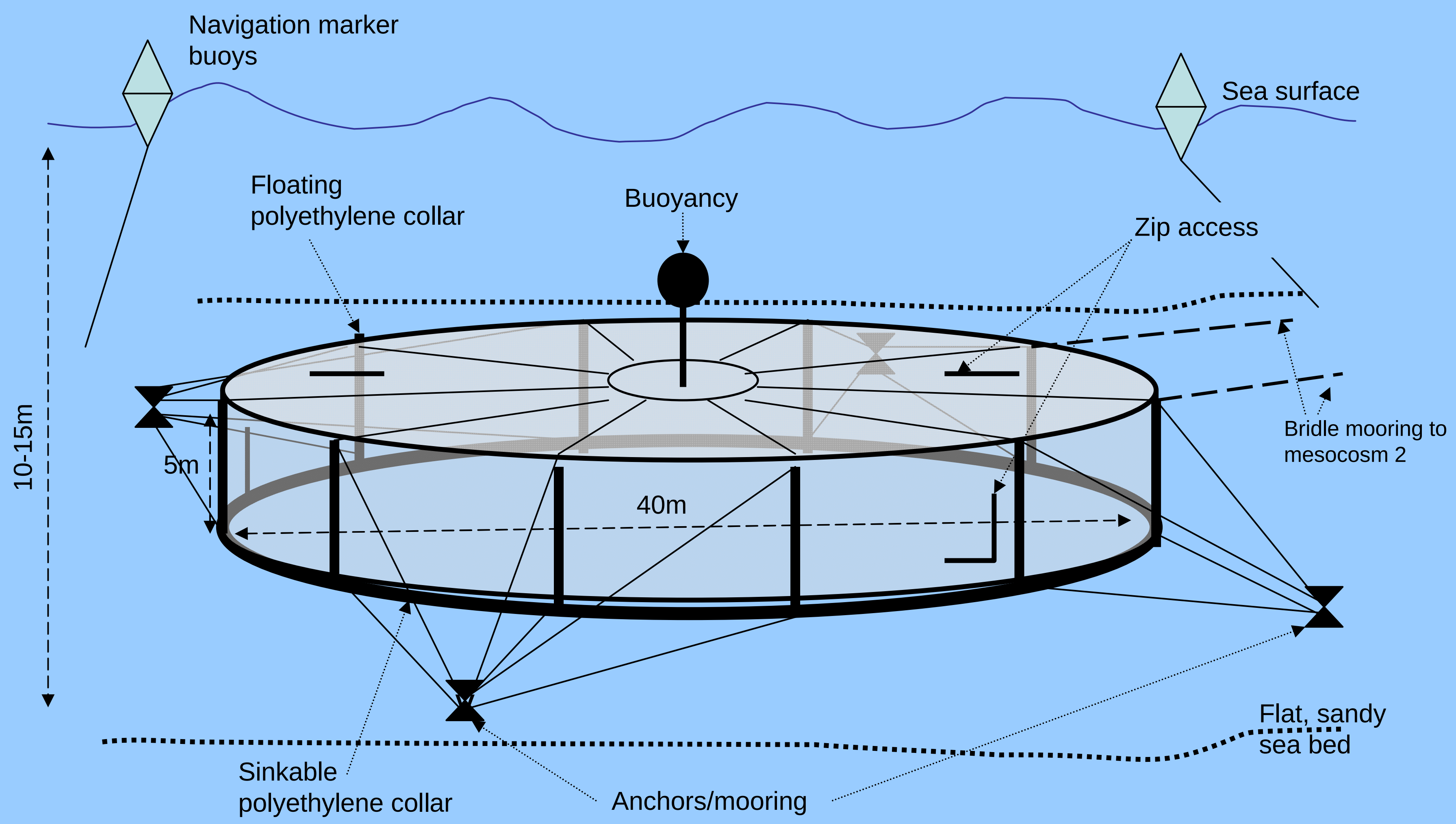
Objectives

Experimental study on the effects of pile-driving sound on cod and sole



COWRIE Mesocosm Studies



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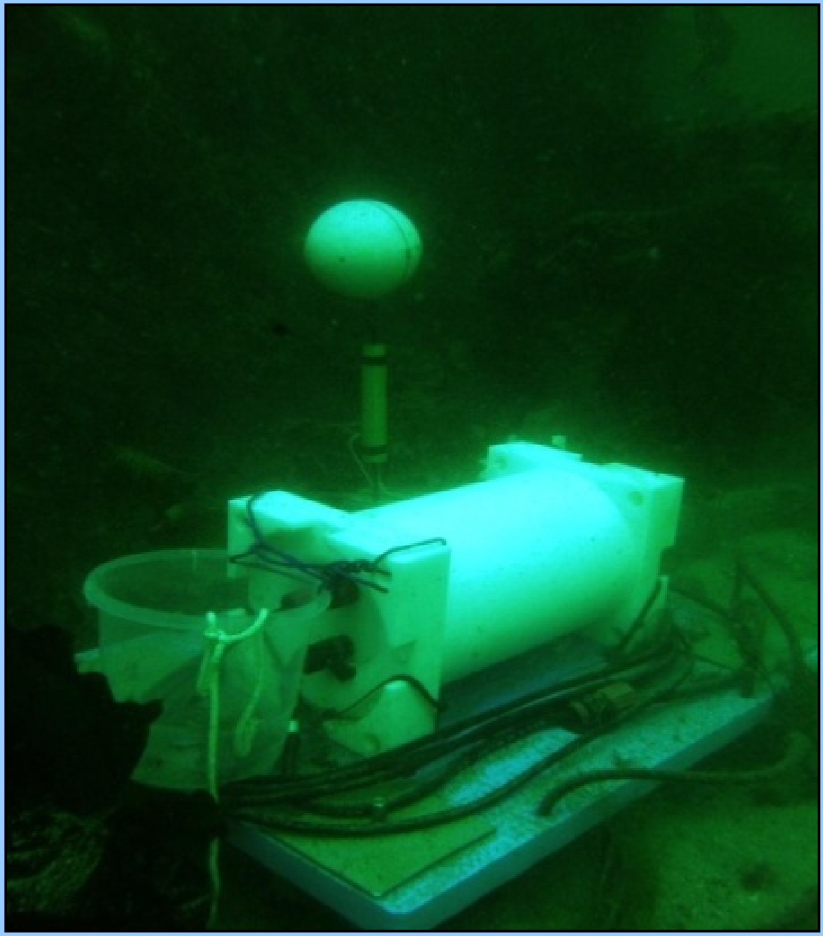
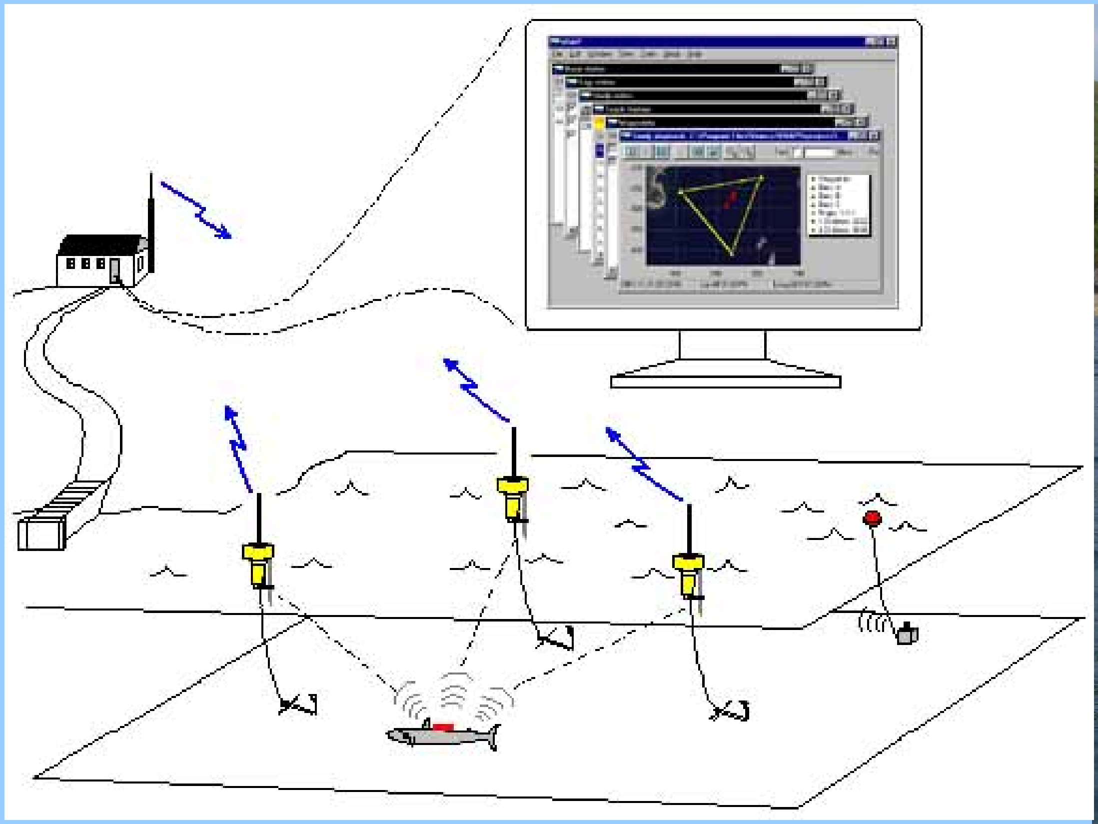
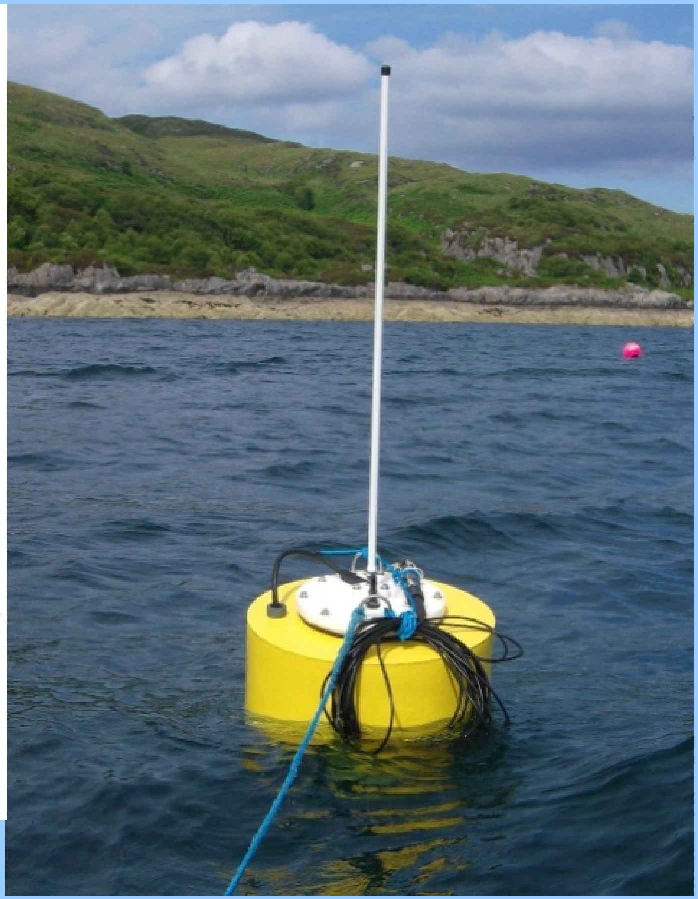
Playback and recording



(Pictures ©Christina Mueller, Mathias Andersson)

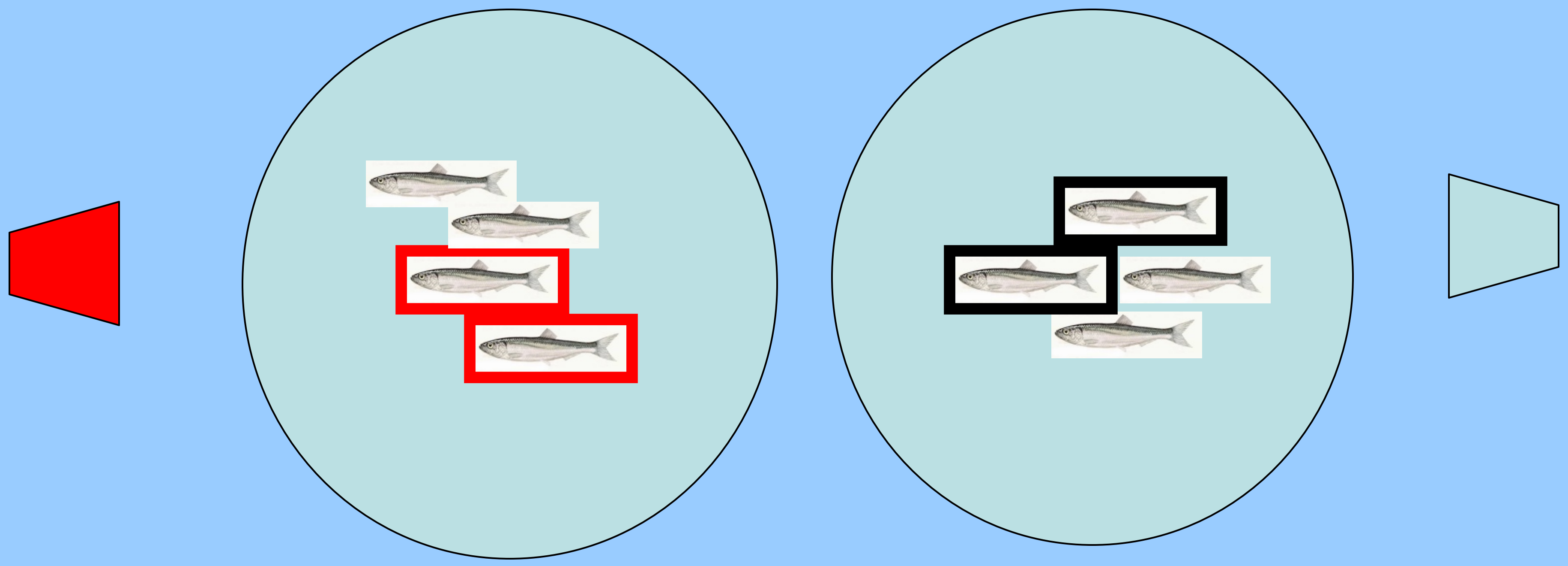
Movement tracking



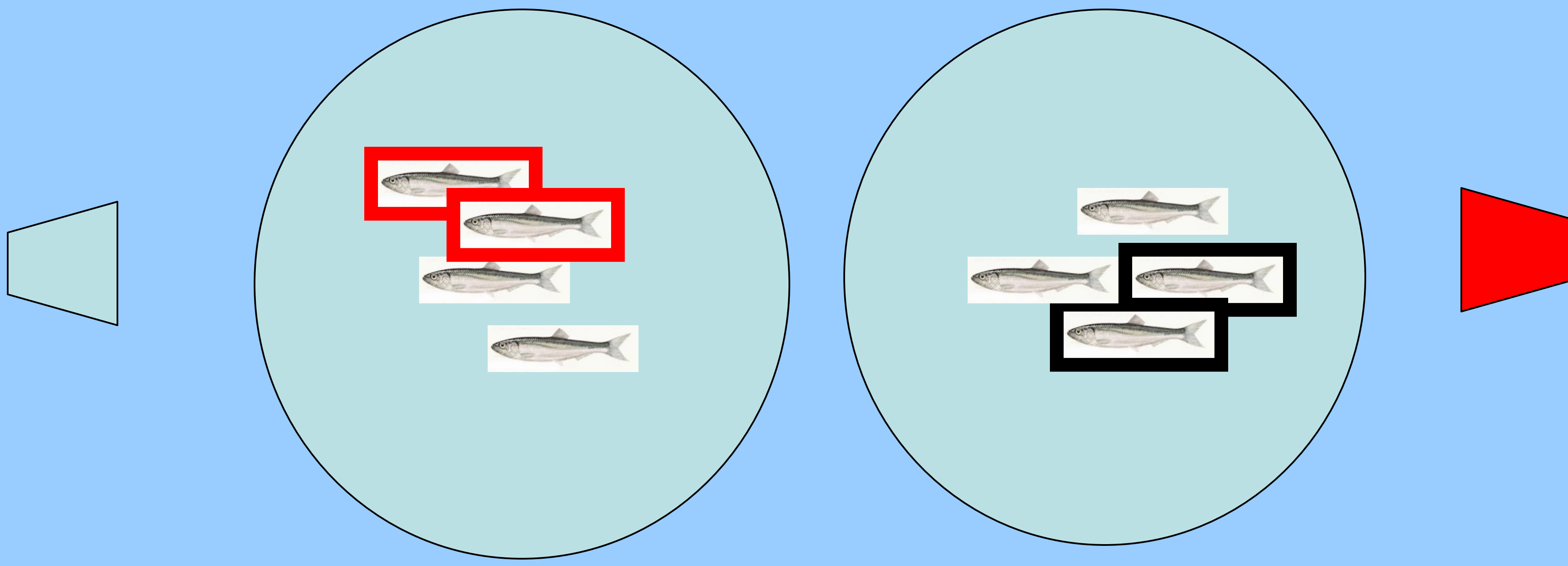


(Figure © by Vemco)

Playback Group 1, trial 1

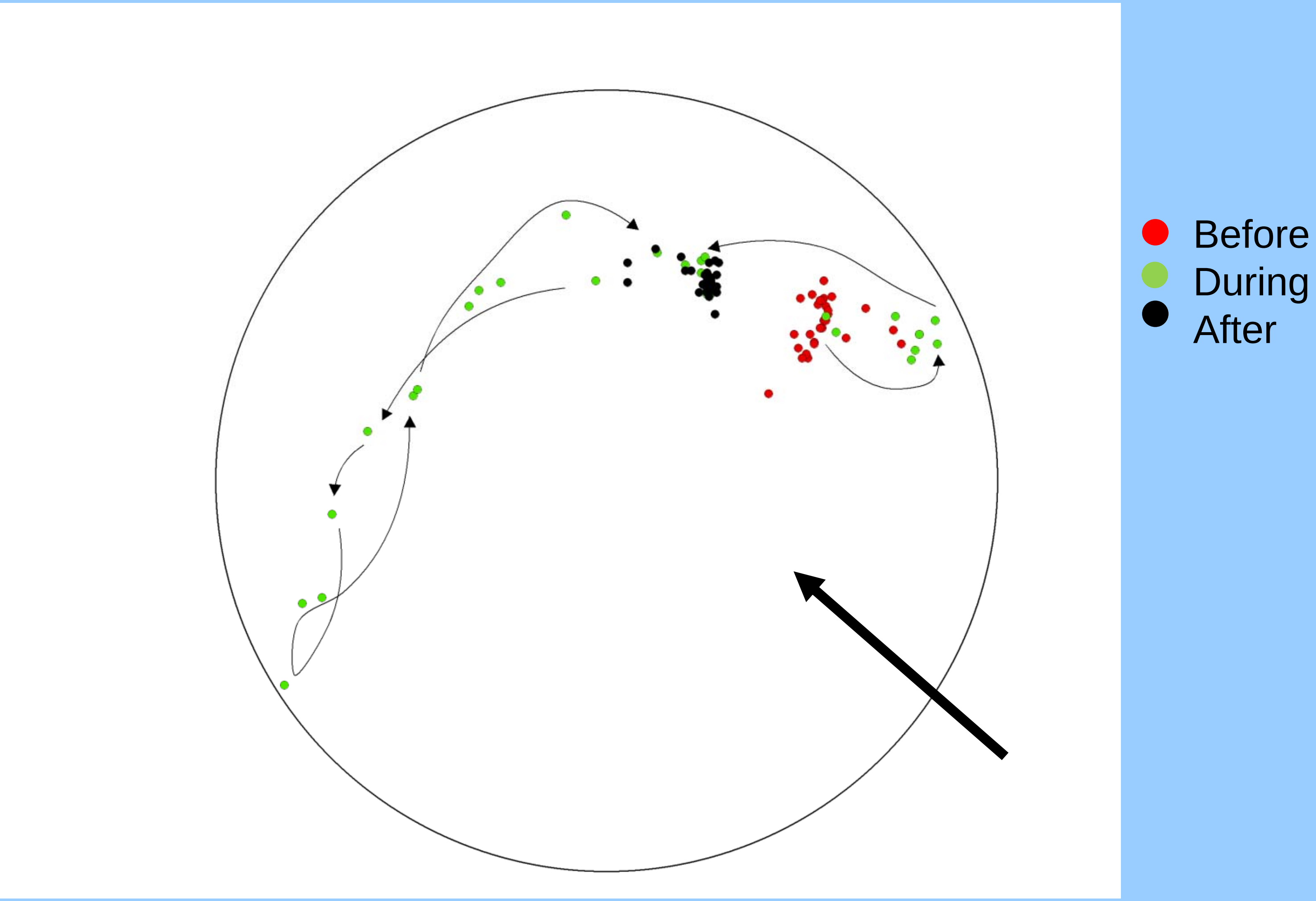


Playback Group 1, trial 2....cont'd

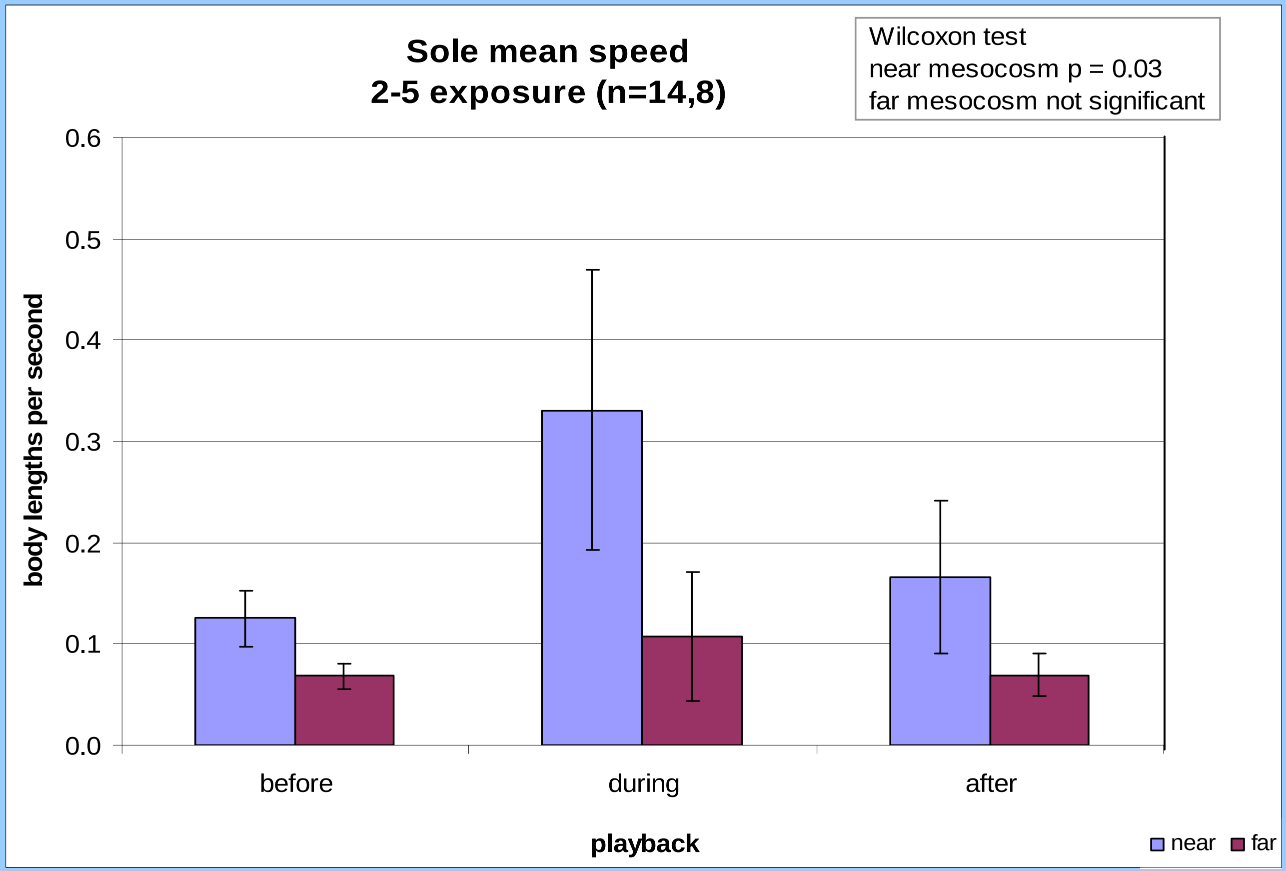


- Trial with 4 fish each (2 M1 2 M2), 62 trials, 50 Individuals
- Recordings of position, speed and direction of movement of fish
- Over 4,000 positional data points

Movement response



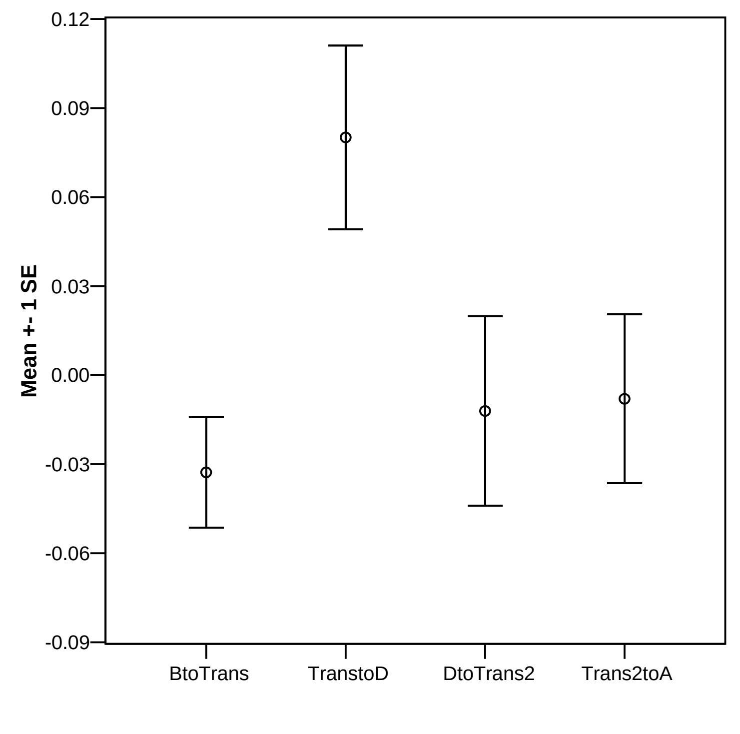
Swimming speed increase in sole



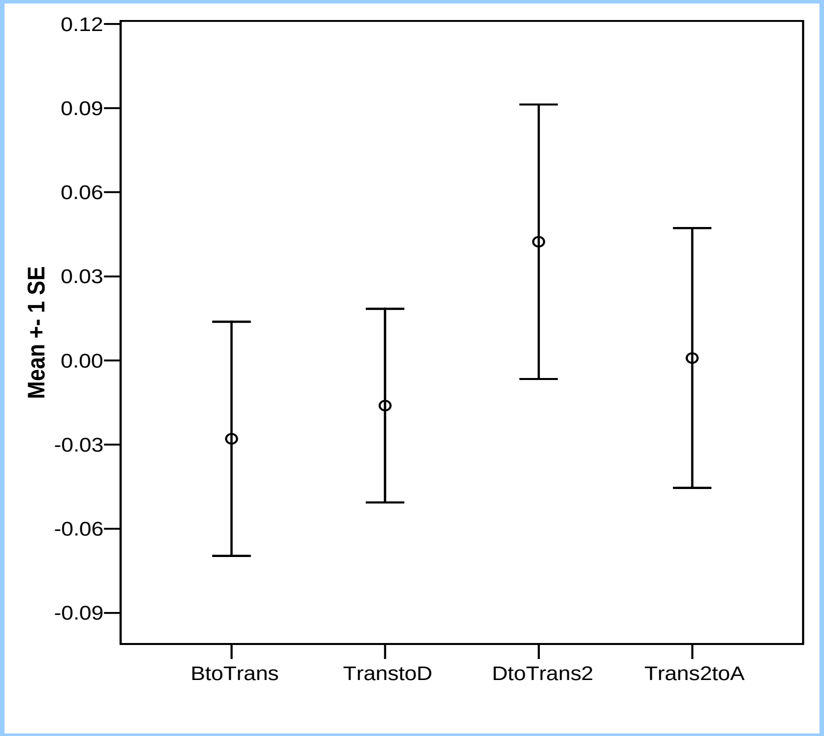
(RL = 144 – 156 dB re 1µPa Peak 6.5 x10^{-3} to 8.6 x10^{-4} m/s^2 peak in near mesocosm)

Freezing response in cod

Near mesocosm

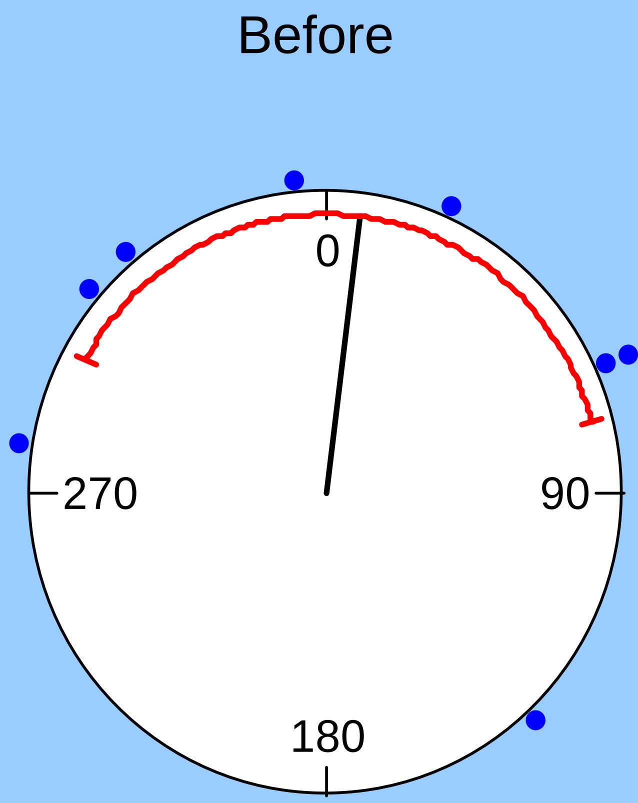


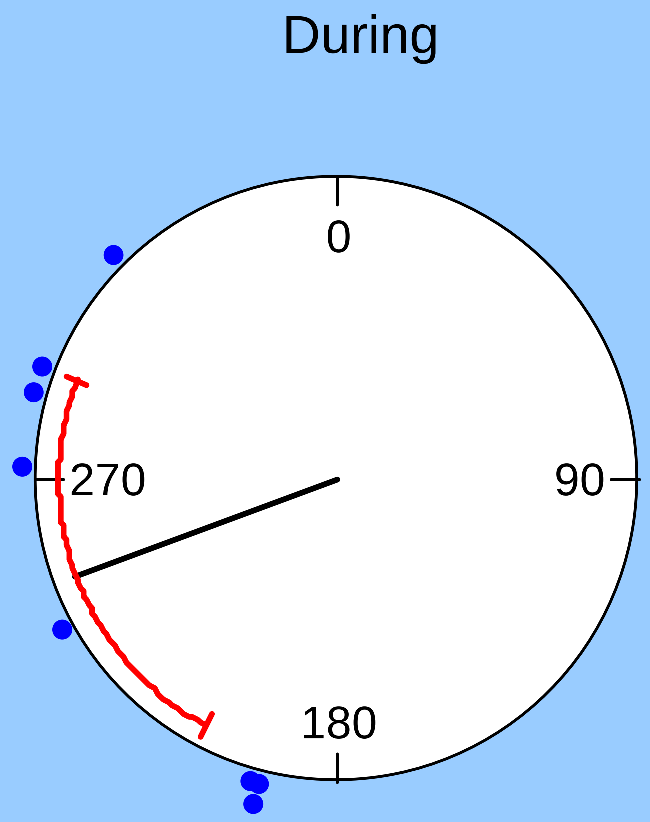
Far mesocosm



(non-parametric repeated measures 1-way ANOVA; H = 13.98, df = 3, P = 0.0029; RL = 140 – 161 dB re 1µPa Peak; 6.5 x10^{-3} to 8.6 x10^{-4} m/s^2 peak)

Directional response (sole)





Conclusions

Objective	Conclusions
Effects of pile-driving sound sources on the behaviour of marine fish	First field relevant experimental data that pile-driving sound affects the behaviour of cod and sole
Threshold for behavioural response	No single threshold but range over which behavioural response occurs
Characteristics, scale and duration of responses	Variety of responses (swimming speed, freezing, directional movement), differences between individuals and species; some indications for habituation (for discussion)


Coastal environment WILL be affected by Offshore Windfarms
- including effects on the behaviour of marine life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Assessment of the effects essential and needs to have wide scope
Relevant data and research required to address specific information gaps


Environmental management of offshore wind
farms needs to be updated based on science