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

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Wind farm locations around the UK and neighbouring areas.

(Adrian Judd, with permission)
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

1. Construction (& survey)

2. Operation

3. Decommission
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

- Construction
  - energy conversion device
  - substation
  - cables

- Operation

- Decommission

Effectors

- Sediment – removal
  - disturbance

- Cable
  - laying
  - routing
  - type
  - scale
  - pile driving
- Areal extent
- Timing of activity

- Cable
  - rating
  - array configuration
- Electricity
  - amount
  - frequency
  - variability
- Moving parts
- Structure – type
  - scale

- Sediment disturbance
- Structure removal
- Cable removal
- Areal extent
- Timing of activity

ORED = Offshore renewable energy developments
Effects & impacts of ecological relevance

ORED Activity
- Construction
  - Energy conversion device
  - Substation
  - Cables
- Operation
- Decommission

Effectors
- Sediment – removal
  - Disturbance
- Cable – laying
  - Routing
- Structure – type
  - Scale
  - Pile driving
- Areal extent
- Timing of activity
- Cable – rating
- Array configuration
- Electricity – amount
  - Frequency
  - Variability
- Moving parts
- Structure – type
  - Scale

Effects on Coastal Environment
- Habitat removal
- Smothering - species
  - Habitat
- Increased turbidity
- Contaminant remobilisation
- Increased Bio Oxygen Demand
- Increased noise & vibration
- Noise & vibration
  - Electromagnetic field (EMF)
    - Frequency
    - Amplitude
- Collision – above water
  - Below water
- Increased habitat heterogeneity
  - Colonisation opportunity
- Sediment transport
  - Water movement characteristics

ORED = Offshore renewable energy developments
Effects & impacts of ecological relevance

ORED Activity
- Construction
  - energy conversion device
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Effects on Coastal Environment
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Potential Ecological Response
- Sedentary species:
  - Reduced diversity
  - Increase in opportunist abundance
- Mobile species:
  - Temporary displacement
  - Long-term displacement
  - Hearing loss
  - Indirect effects
- 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

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
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 (e.g. 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

Navigation marker buoys

Sea surface

Flat, sandy sea bed

Anchors/mooring

Sinkable polyethylene collar

Buoyancy

Zip access

Bridle mooring to mesocosm 2

Floating polyethylene collar

40m

5m

10-15m

Floating polyethylene collar

Anchors/mooring

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

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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
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)

Pinnipeds (seals)

Crustaceans (crabs & lobsters)
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

- 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: 10\(\mu\)V/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

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

Live

![Bar chart showing mean step length for different fish individuals and trials.](chart.png)
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 response
  • Attracted to emission at lower end 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 $\geq 1,000$ km)
Sound and marine life
Functions of sound for marine life

Communication
Finding food

Stunning prey
Eavesdropping

Navigation
Theoretical zones of noise influence

- Detection
- Masking
- Response
- Hearing loss, discomfort, injury

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

**Acoustic pressure:** $\text{SPL (dB)} = 20 \log_{10} \left( \frac{P}{P_0} \right)$

- $P_0$ underwater = $1 \mu\text{Pa}$; $P_0$ air = $20 \mu\text{Pa}$

**Pitch:** $\text{Hz} = \text{cycles} / \text{s} \ (\text{pitch})$
Hearing in cetaceans

![Graph showing hearing sensitivity of different cetaceans.]

- **Bottlenose dolphin (Johnson 1967)**
- **Risso’s dolphin (Nachtigall et al. 1995)**
- **Striped dolphin (Kastelein et al. 2003)**
- **Killer whale (Szymanski et al. 1999; Behaviour)**
- **Killer whale (Szymanski et al. 1999; ABR)**
- **Harbour porpoise (Kastelein et al. 2002)**
Hearing in fish

SPL (dB re 1 µPa)

- Bass (Nedwell et al. 2004)
- Cod (Offut 1974)
- Cod (Hawkins & Myrberg 1983)
- Dab (Hawkins & Myrberg 1983)
- Bass (Nedwell et al. 2004)
- Herring (Enger 1967)
- Pollack (Chapman 1973)
- Pollack (Chapman & Hawkins 1969)
- Pollack (Hawkins & Myrberg 1983)
- Atlantic Salmon (Hawkins & Johnstone 1978)
- Little Skate (Casper et al. 2003)
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)
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

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 Thomsen¹, Christina Mueller-Blenkle¹, Andrew Gill², Julian Metcalfe¹, Peter McGregor³, Victoria Bendall¹, Daniel Wood¹, Mathias Andersson⁴, Peter Sigray⁴

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

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

- Zip access
- Sea surface
- Flat, sandy sea bed
- Anchors/mooring
- Sinkable polyethylene collar
- Buoyancy
- Navigation marker buoys
- Floating polyethylene collar
- 40m
- 5m
- 10-15m
- Bridle mooring to mesocosm 2
- Flat, sandy sea bed
- Anchors/mooring
- Sinkable polyethylene collar
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

(Sole mean speed 2-5 exposure (n=14,8))

Wilcoxon test
near mesocosm p = 0.03
far mesocosm not significant

before during after

playback

body lengths per second

0.0 0.1 0.2 0.3 0.4 0.5 0.6

(RL = 144 – 156 dB re 1µPa Peak 6.5 x10^{-3} to 8.6 x10^{-4} m/s² 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; $6.5 \times 10^{-3}$ to $8.6 \times 10^{-4}$ m/s² peak)
Directional response (sole)

Before

During
## Conclusions

<table>
<thead>
<tr>
<th>Objective</th>
<th>Conclusions</th>
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<tbody>
<tr>
<td>Effects of pile-driving sound sources on the behaviour of marine fish</td>
<td>First field relevant experimental data that pile-driving sound affects the behaviour of cod and sole</td>
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<td>Threshold for behavioural response</td>
<td>No single threshold but range over which behavioural response occurs</td>
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<td>Characteristics, scale and duration of responses</td>
<td>Variety of responses (swimming speed, freezing, directional movement), differences between individuals and species; some indications for habituation (for discussion)</td>
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Coastal environment WILL be affected by Offshore Windfarms
- including effects on the behaviour of marine life
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.