A combination of empirical and modelled datasets reveals associations between deep diving seabirds and oceanographical processes at fine spatiotemporal scales in a high energy habitat.
Collision Risks and Spatial Overlap

- Impacts of tidal stream turbines on seabird populations unknown.
- Quantifying collision risks between deep diving seabirds and devices prioritised.
- Estimating spatial overlap an essential component of quantifying collision risk
- Understand and predict seabird foraging distributions within the tidal pass habitats favoured for installations
Fall Of Warness, Orkney, UK

- Typical tidal pass habitat
- Strong bidirectional currents
- Complex topography
- Complex bathymetry

Seabed Roughness
(Arbitrary Unit)

Seabed Hardness
(Arbitrary Unit)

Depth
(Metres)

Slope
(Degrees)

Bathymetry is from multibeam sonar
Seabed characteristics are from echosounder
Fall Of Warness, Orkney, UK

- Ebb-Flood Tidal Cycle
- Variations in feature location
- Upwelling/Downwelling
- Turbulence
- Current Speeds

FVCOM 3D Hydrodynamic Model Outputs
• Neap-Spring Tidal Cycle
• Variations in feature extent
• Upwelling/Downwelling
• Turbulence
• Current Speeds

FVCOM 3D Hydrodynamic Model Outputs

Neap (Ebb)  Spring (Ebb)

Upwelling (cm/s)
Turbulence (Eddy Viscosity)
Speed (m/s)
Understanding and Predicting Seabird Distributions

- Seabirds associate with physical conditions that promote prey availability.

- Prey availability difficult to collect and quantify over entire tidal pass habitats.

- Understanding associations between seabirds and physical conditions enables predictions of distributions.

- Concurrent seabird and physical datasets need collecting over several seasons and tidal states.
Vessel Based Observers

103 transects

May and October

2012 and 2013

Zigzag route against currents

Only seabirds upon the sea surface recorded

Positions calculated to an estimated accuracy of several hundred metres
Seabird Distributions

4 Abundant Deep Diving Species
Behavioural Differences
Ecological Differences

Atlantic Puffin *Fratercula arctica*
Feed primarily within water column
Present during May
4 Abundant Deep Diving Species
Behavioural Differences
Ecological Differences

Common Guillemot *Uria aalge*
Feed primarily within water column
Present during May
Seabird Distributions

4 Abundant Deep Diving Species
Behavioural Differences
Ecological Differences

Black Guillemot *Cepphus grylle*
Feed primarily upon seabed
Present during May and October.
4 Abundant Deep Diving Species
Behavioural Differences
Ecological Differences

**European Shag** *Phalacrocorax aristotelis*
Feed primarily upon seabed
Present during May and October.
# General Linear Mixed Effect Models

## Seabird Abundances
- Atlantic Puffin (May)
- Black Guillemot (May, Oct)
- Common Guillemot (May)
- European Shag (May, Oct)

## Environmental Variables
- Speed
- Turbulence
- Upward Currents
- Seabed (Roughness/Hardness)

## Random Variables
- DateTime

## Run Model
- Poisson Distribution
- Selected Models using p-values

## Predictions
- Used Model Coefficients

## Seabird Foraging Distribution Dataset

## Physical Conditions Dataset
## Model Outputs

- Variations in microhabitat associations among species.
- Seasonal variations in species microhabitat associations.
- Variations in microhabitat associations complexities.
- Benthic foragers always associated with soft/rough substrate.
- Pelagic foragers always associated with fast current speeds.

<table>
<thead>
<tr>
<th>Season</th>
<th>Species</th>
<th>Speed</th>
<th>Turbulence</th>
<th>Upwelling</th>
<th>Substrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer</td>
<td>Atlantic Puffin</td>
<td>Positive</td>
<td>Positive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>Common Guillemot</td>
<td>Positive</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>Black Guillemot</td>
<td>Negative</td>
<td>Positive</td>
<td>Downwelling</td>
<td>Soft/Rough</td>
</tr>
<tr>
<td>Winter</td>
<td>Black Guillemot</td>
<td>Positive</td>
<td></td>
<td>Neither</td>
<td>Soft/Rough</td>
</tr>
<tr>
<td>Summer</td>
<td>European Shag</td>
<td></td>
<td></td>
<td>Downwelling</td>
<td>Soft/Rough</td>
</tr>
<tr>
<td>Winter</td>
<td>European Shag</td>
<td></td>
<td></td>
<td></td>
<td>Soft/Rough</td>
</tr>
</tbody>
</table>
Predicted Distributions

Atlantic Puffin (Summer)

High Spatial Overlap
Increases during spring tides
Increases during ebb tides

Black Lines = Turbine Area

Flood

Ebb

Neap

Spring
Predicted Distributions

Common Guillemot (Summer)

High Spatial Overlap
Increases during spring tides
Increases during ebb tides

Black Lines = Turbine Area
Predicted Distributions

Black Guillemot (Summer)

Low Spatial Overlap

Black Lines = Turbine Area
Predicted Distributions

Black Guillemot (Winter)

Moderate Spatial Overlap

Black Lines = Turbine Area

Flood

Ebb

Neap

Spring
Predicted Distributions

European Shag (Summer)

Low Spatial Overlap

Flood

Ebb

Black Lines = Turbine Area
Predicted Distributions

European Shag (Winter)

Low Spatial Overlap

Black Lines = Turbine Area

Flood

Ebb

Neap

Spring
Conclusions

Differences in associations among species and within species over time.

Several ecological explanations relating to resource competition and foraging behaviours.

However, results highlight which and when species are most likely to forage near tidal stream turbines.

Quantitative measures enable predictions of spatial overlap at population levels.

Atlantic Puffin
Summer Resident
High Spatial Overlap
Increases in Ebb and Spring Tides

Common Guillemot
Summer and Winter Resident
Moderate Spatial Overlap in Winter

Black Guillemot
Summer and Winter Resident
High Spatial Overlap
Increases in Ebb and Spring Tides

European Shag
Summer and Winter Resident
Low Spatial Overlap
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