Mackenzie, M. & Peterson, I.K. 2013. *BOU Proceedings – Marine Renewables and Birds*
http://www.bou.org.uk/bouproc-net/marine-renewables/mackenzie-&-petersen.pdf

This paper forms part of the proceedings from the BOU conference ***Marine Renwables and Birds***
Other papers from these proceedings can be viewed at www.BOUPROC.net.

Wind farm displacement studies from Nysted, Denmark

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The Rødsand I offshore wind farm was established in the Danish part of the Baltic Sea in 2002. It comprises a total of 72 turbines, covering 24 km^2 at water depth of 6–10 m. The Rødsand II offshore wind farm was established only 3 km west of the Rødsand I wind farm in 2009. It comprises a total of 90 wind turbines, covering 34 km^2 at water depth between 6 and 12 m.

The abundance and distribution of Long-tailed Duck *Clangula hyemalis* was monitored from 2000 to 2011, covering the more than 1000 km^2 around both wind farm sites with the aim to evaluate potential displacement of ducks from the wind farm sites. These data were modelled in their entirety but potential changes in duck distribution and abundance were considered between three phases: the baseline period, post-installation of Rødsand I and post-installation of Rødsand II.

The data available for analysis comprise transect data over a number of survey days providing count data (corrected for imperfect detection), which are likely to be spatially and temporally auto-correlated. More traditional generalized linear model (GLM)/generalized additive model (GAM) methods require independence in model residuals and violation of this assumption can result in falsely identifying impact effects (as the resulting *P*-values are typically too small when this correlation is positive). For this reason, generalized estimating equations (GEEs) were used to generate reliable 95% confidence intervals to assess where any significant differences might be (between baseline period and installation of Rødsand I and Rødsand II) and 'best-case' and 'worst-case' values for the size of any differences at the geo-referenced locations. The uncertainty in both the detection function and the surface fitting stages was considered when generating these geo-referenced confidence intervals.

Careful attention was paid to the model selection process. Models which are too smooth for the underlying surface can miss impact effects, and models which are too flexible can falsely identify impact effects. For this reason, spatially adaptive models were fitted to these data and model flexibility was targeted into areas of the spatial surface (and areas of the depth relationship) in greatest need. This is achieved using a spatially adaptive smoothing algorithm (SALSA) for the one-dimensional covariate (Depth) and the two-dimensional spatial surface governed by cross-validation for correlated data.

There was good agreement between the input data and the fitted models post-installation of Rødsand I and Rødsand II. A significant redistribution of sea ducks in the survey area post-baseline away from the wind farm was evident for both Rødsand I and Rødsand II. Specifically, the sea ducks were seen to move away from Rødsand I into shallower waters farthest from the wind farm while the ducks also moved away from Rødsand II into shallow waters adjacent to Rødsand I (which were popular with sea ducks in the baseline period but fell out of favour post-Rødsand I and pre-Rødsand II).

Abundance in the survey area appeared to slightly increase post-Rødsand I and decrease post-Rødsand II when compared with baseline numbers, although these changes in estimated abundance were not statistically significant when considering all the relevant uncertainties: parameter uncertainties in the surface and detection function fitting and adjustments for the temporal autocorrelation in model residuals and extra-Poisson variability.