Report

Project Name:	Analysis of Bird Data for the Fall of Warness Area, Orkney
Reference:	
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Analysis of Bird Data for the Fall of Warness Area, Orkney

Final Report for EMEC
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Introduction

This report gives a review of the statistical analyses of the Fall of Warness bird data provided by SMRU Ltd. For clarity, technical details of the statistical models are separated from the main results in each section.

The main objectives of this analysis were:

- assess the distribution of birds across the study site and across time
- provide outputs that summarise their distribution
- ascertain relationships between collected environmental variables and the observed relative bird abundances
- determine the effects of varying levels of observation effort on the ability to detect a variety of turbine impacts on seabird abundances.

The data collection and analysis is thought to ultimately allow the detection of changes in the bird usage of the Fall of Warness region through time. This might be in terms of their use of the space, and/or their response to measured environmental conditions e.g. they may shift preferred locations of activity or become active at different times of day. This would form the basis of an environmental impact assessment for the placement of the proposed undersea turbines.

Initial Caveats:
The terms *abundance*/*counts*/*numbers* will be used throughout this report – this requires initial clarification. The nature of the study (a fixed observation point) means that there is likely to be a lower probability of observing animals the greater the distance from the observation point. For example comparing 2 sites, one far and one near – even with equal numbers of animals, the further site will have an apparently lower abundance due to lower probability of detection.

Due to this, any numbers derived cannot be interpreted as true count estimates without proper account of this detection probability (inestimable for the current data). The terms used here will be synonymous with detected numbers. However, the intended use is for measuring relative change through *time*, which can be ascertained if the study design remains unchanged and detectability remains constant. Relative spatial sightings are similarly affected by detection probability.

It is assumed throughout that inference is restricted to times similar to those sampled i.e. general daylight hours.

The term *bird* is synonymous with the species represented in the dataset provided by SMRU Limited.

Data Details

This section briefly outlines the data manipulation, exploratory analysis and final analyses applied. Greater detail is given in the relevant sections.

Software

All data analysis was performed in the statistical data package R, with associated addon packages as required[1].

Data Preprocessing

The following are notes relating to the data manipulation performed on the environmental and species count data contained within the files provided to DMP by SMRU Limited.

Summary:

Data preprocessing comprised of the actions previously detailed in the 2006 analysis. In general data pre-processing consisted of the following:

- Alteration of all mis-spelt codes.
- Reduction of the numbers of categories in variables (e.g. precipitation) to a smaller more tractable set.
- Inference of missing values where possible e.g. tide heights inferred from time and date.

Data Available

All environmental data available were initially considered as candidates for prediction of bird abundance.

The environmental variables considered for the models of bird counts were therefore:

- *Wind strength*: a score measured from 0--5
- *Precipitation*: 8 categories
- *State of tide*: 4 categories
    - Ebb, Flood, High, Low
- *Water flow speed*: 5 categories

    - Fast, Moderate, Slack, Slow, Very Fast
- *Water flow direction*: 4 categories:
    - North, North-West, Slack, South-East
- *Cloud cover*: a percentage score
- *Observation Day*: represented as a proportion of months from July 2006 to June 2007
- *Sub-area*: 25 categories as combinations of A, B, C, D, E with 0, 1, 2, 3, 4 which represent the spatial position of the birds sighted (see Figure 9)
- *Time of day*
- *Time at high tide*
- *Time at low tide*
- *Tide height at high tide*
- *Tide height at low tide*

Modelling relative bird abundances 2006—2007.

Overview

The modelling methods used here are in keeping with the 2006 analysis. The method used here is flexible and naturally accommodates relative abundance data collected over time. This helps ensure sound model predictions and realistic confidence about these predictions.

Models for data collected over time deserve special consideration. Specifically, observations collected close together in time are likely to be more similar than observations collected from different days and when ignored this can mean random fluctuations in bird counts over time are confused with real underlying increases or decreases. As a result, time-based statistical methods which naturally accommodate data of this sort were used for this analysis.

Model flexibility was considered important for this analysis, since bird numbers are unlikely to increase (or decrease) at a constant average rate for each variable (eg. across the year) and so flexible curves were permitted for all variables in the model, where appropriate. eg. Cloud cover, time of day and tide height at high tide.

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[1] R Development Core Team (2005) *R: A Language and Environment for Statistical Computing* R Foundation for

The confidence attributed to model predictions was also considered important in this analysis. Without identifying a realistic range of plausible bird counts before any potential impact, it is virtually impossible to determine if there has been a real change in bird counts after any impact.

Statistical Computing, Vienna, Austria. http://www.R-project.org

Technical Details

Models for the average number of birds sighted were fitted using Generalized Additive Models (GAMs) with log link and Quasi-Poisson errors. Splines were used to model the continuous explanatory variables while categorical variables were fitted as factors.

Robust standard errors estimated using Generalized Estimating Equations (GEEs) were used to adjust for temporal auto correlation in the errors. Specifically, observations within days were permitted to be correlated and since the data set was of considerable size and GEE standard errors are robust to the nature of the correlation specified, a working independence structure was used.

Variance inflation factors were used to detect collinearity in the model covariates and model selection was carried out using the QIC statistic and GEE-based *p*-values. The full model contained continuous variables as splines, while categorical variables (such as sub-area) entered the model as factors. Variables deemed to be non-significant were trialled as linear terms and then omitted from the model altogether if necessary.

Results

Overview

This section gives the results of analyses for all bird species combined. Birds were more likely sighted in conditions favourable for viewing, i.e. when visibility is good and during daylight hours. Additionally, more birds were sighted when winds were low, in slow/moderate water flow and in Ebb and Flood tides.

The following variables were deemed predictors of relative bird abundance in this area:

- Wind Strength,
- Wind Direction,
- Tidal State,
- Water flow speed,
- Visibility,
- Time of day,
- Low Tide Height,

- Observation day and
- Sub-area.

Model variables retained

Three pairs of variables were collinear and so for each pair, the covariate that returned greater predictive power was considered for model selection (see table below).

Variable pair	**Variable chosen**
Wind Direction/Precipitation	Wind direction
Flow Direction/Flow Speed	Flow speed
High tide height/ Low tide height	Low Tide Height

The following variables were retained in the model. In each of the following figures, model relationships are represented along the horizontal axis and model coefficient values on the vertical[2]. In all cases the estimate is given by a small central point, with the 95% confidence bounds represented by vertical lines.

Plot interpretation: Higher coefficient values indicate greater predicted numbers of birds. Categories that have confidence bounds that are distinct from the horizontal line can be considered statistically different from the baseline level at the 5% level; baseline level information is included in figure captions.
Additionally, all interpretations are made assuming all other terms in the model are held constant; e.g. all else being equal, significantly more birds are predicted to be observed in group A than in group B.

[2] Coefficient values are given on the scale of the link function.

- **Wind strength:**

Bird numbers were generally found to decrease with increasing wind strength. Significantly more bird numbers are predicted in wind strengths of *0* (the baseline) compared with categories 3 and 4 (Figure 1).

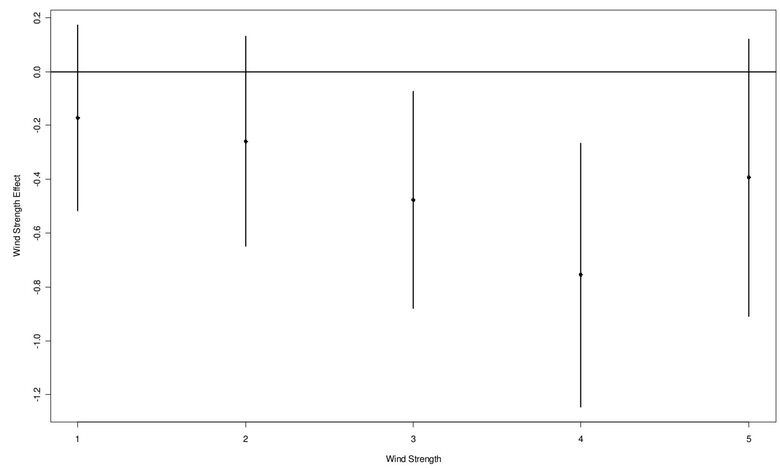


Figure 1: Relative effects of *Wind Strength* on estimated numbers of birds. Dots indicate estimates, vertical lines the 95% uncertainty bounds.

- **Wind direction:**

Bird numbers appeared to be similar across wind direction groups. The estimated number of birds in the *none* and *variable* groups were higher on average than in the East (the baseline), however the *East* was not statistically distinct from any other groups (Figure 2).

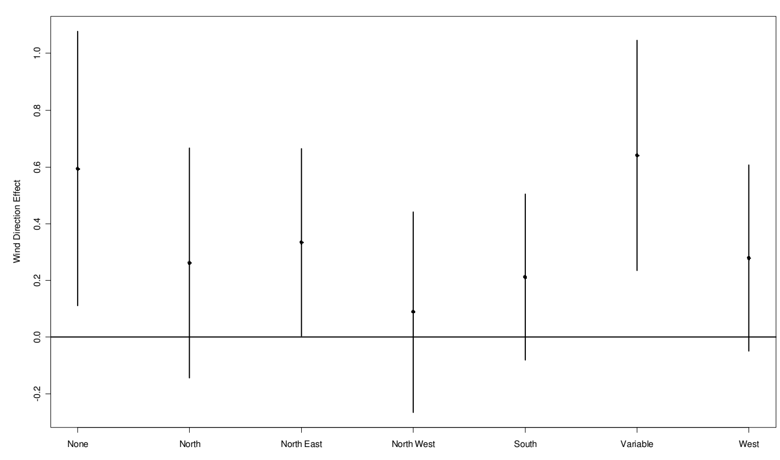


Figure 2: Relative effects of *Wind Direction* on estimated numbers of birds. Dots indicate estimates, vertical lines the 95% uncertainty bounds.

- **Tidal State:**

Bird sightings were most abundant in the *Ebb* (the baseline) and *Flood* tide states (Figure 4) and significantly more birds were sighted during *Flood* and *Ebb* tides compared with *High* and *Low* tide states.

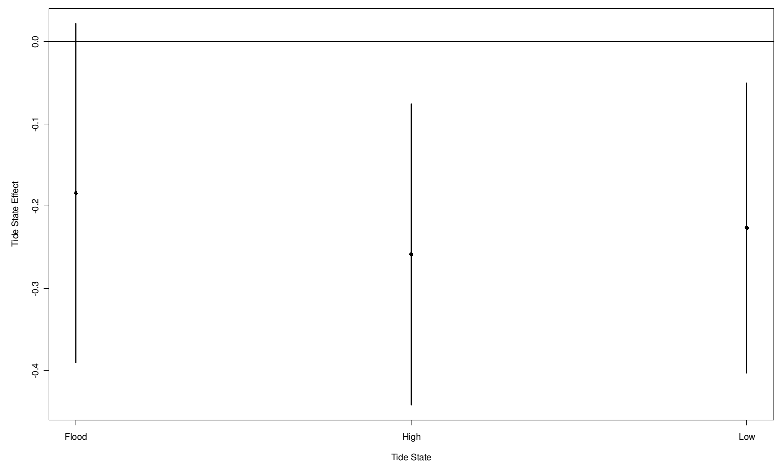


Figure 3: Relative effects of *Tidal State* on estimated numbers of birds. Dots indicate estimates, vertical lines the 95% uncertainty bounds.

- **Water flow speed:**

Only the *Very Fast* water flow speed was found to differ significantly from any other levels (Figure 5). This category exhibited significantly lower bird numbers than the baseline category.

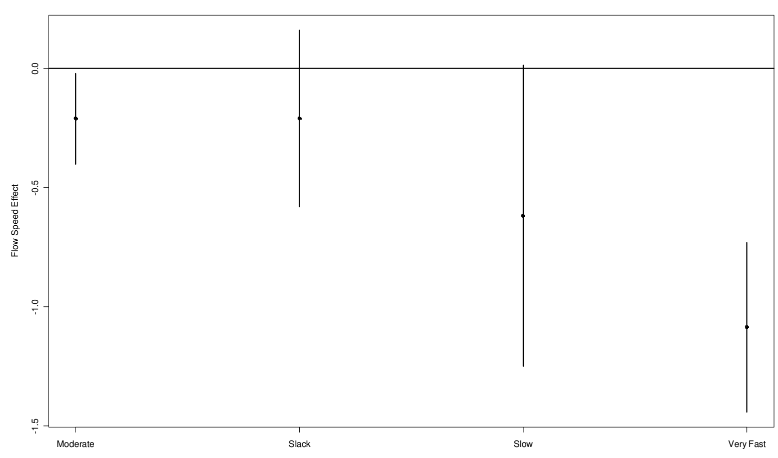
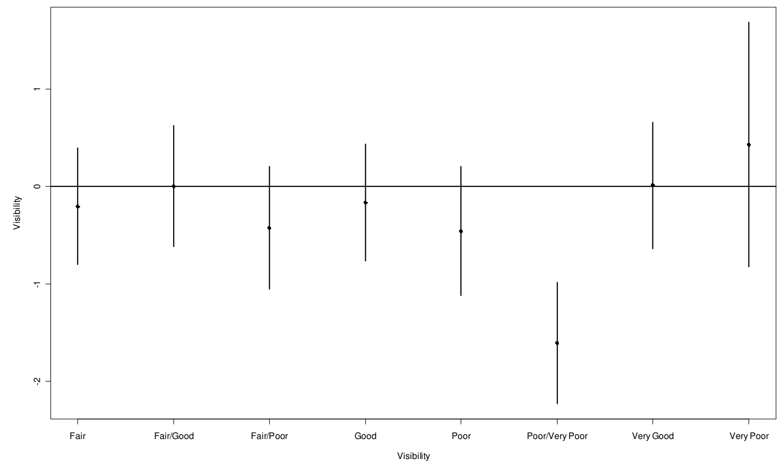


Figure 4: Relative effects of *Water Flow Speed* on estimated numbers of birds. Dots indicate estimates, vertical lines the 95% uncertainty bounds.

- **Visibility:**

Significantly fewer birds were seen in *poor/very poor* visibility than when visibility was not recorded (the baseline). Bird numbers in the other visibility categories were relatively similar.



- **Time of day:**

Under the model, the greatest numbers of birds are found early in the sampling day, falling away after this point (Figure 5). Naturally, low light levels may have a confounding effect on these results.

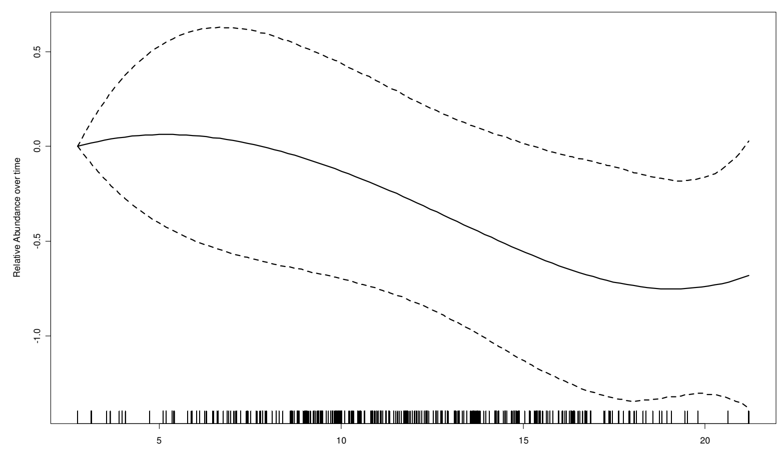


Figure 5: Effects of *Time of Day* on estimated numbers of birds. Solid curve indicates estimated function, dotted curve above and below indicate the 95% confidence envelope.

- **Low tide height:**

Bird counts are predicted to steadily increase for low tide heights in excess of approximately 1m. There is also however, a great deal of uncertainty about this relationship and the data is sparse for high tide heights (Figure 6).

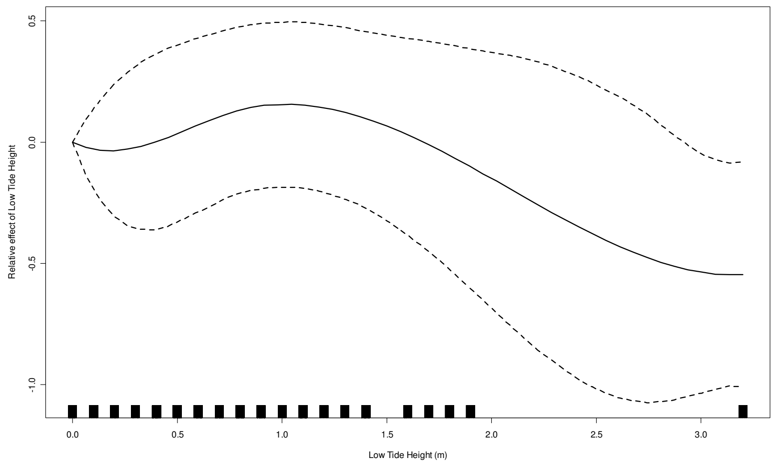


Figure 6: Effects of *Low Tide Height* on estimated numbers of birds. Solid curve indicates estimated function, dotted curve above and below indicate the 95% confidence envelope.

- **Observation Day:**

Bird numbers appeared to change seasonally with a peak in numbers in March-April 2007 (Figure 7).

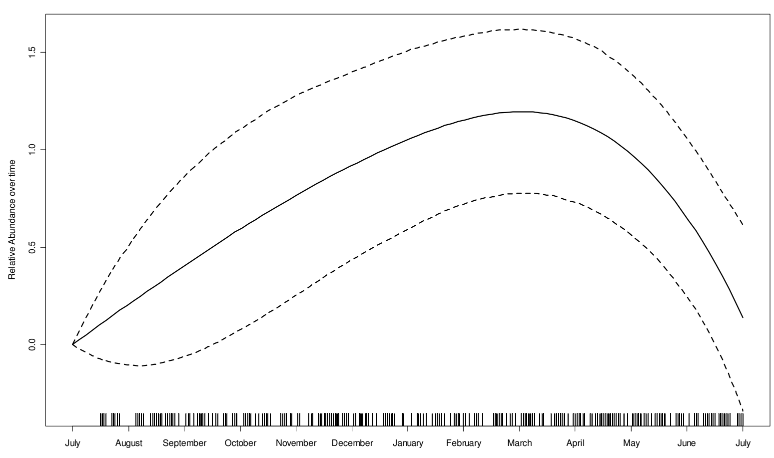


Figure 7: Relative effects of *Date* on estimated numbers of birds. The x-range represents July 2006—July 2007. Dots indicate estimates, vertical lines the 95% uncertainty bounds.

- **Sub-area:**

All sub-areas give significantly higher predicted bird numbers than sub-area *A0* (the baseline) which has the lowest estimate. In keeping with the previous analysis, sub-areas close to land (eg. *E0—E4,* and *A2-A3*) are predicted to exhibit more diving birds than sub-areas far from land.

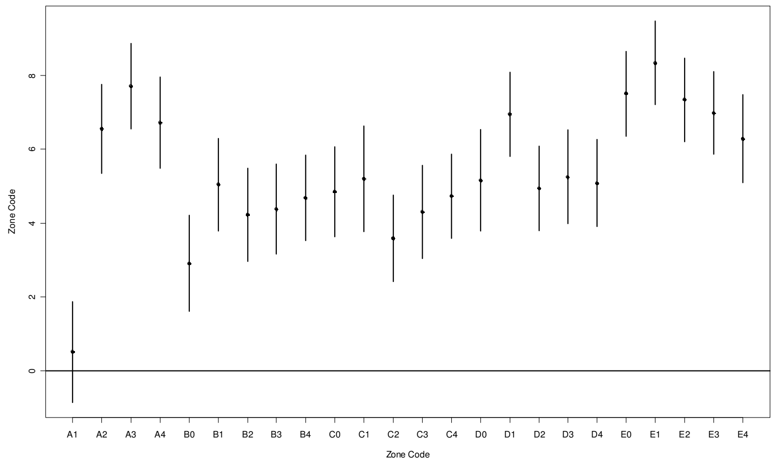


Figure 8: Relative effects of *Sub Area* on estimated numbers of birds. Dots indicate estimates, vertical lines the 95% uncertainty bounds.

The sub-areas with the highest estimated counts are those very near the island opposite the survey observation post, and the land adjacent to the survey position. Considering uncertainty in these estimates (Figure 9) this spatial pattern is still apparent. The caveat relating to detection probability (§0) is reiterated here.

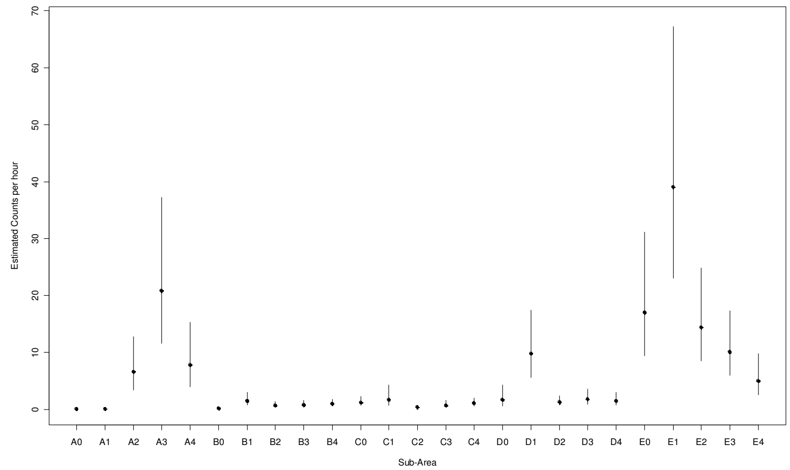


Figure 9: Estimated relative bird abundance (per observation hour) by sub-area for average values of model covariates. These predictions correspond to January 2007. *Note: estimated abundances are subject to the caveat of page 2.* Grid as supplied by SMRU as shown on page 13.

Reference Grid

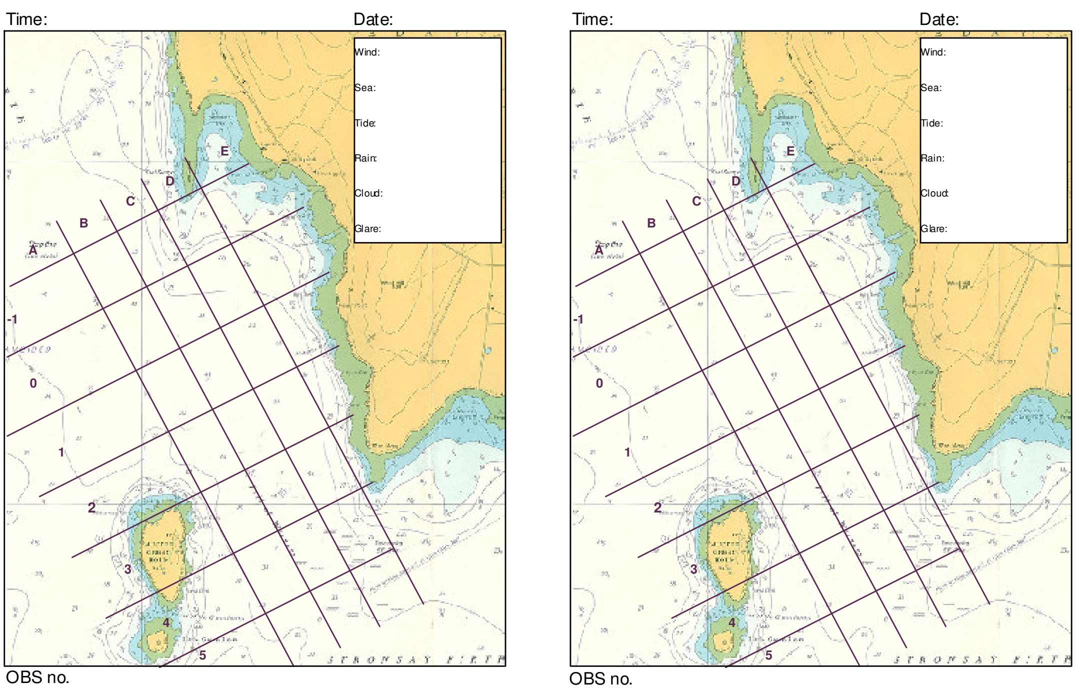


Figure 10: Eday survey grid as supplied by Aurora Environmental Limited.

Detecting turbine effects under different sampling frequencies.

Overview

To assess the ability of the model to detect changes in bird numbers due to a `turbine' effect under different sampling regimes, a simulation exercise was used. Specifically, data were generated under various sampling frequencies using the existing model and the ability of these models at detecting a `turbine' effect under these realities was measured.

These success rates were determined for small, moderate and large turbine effects (causing a reduction in bird numbers by 5%--75%) for a variety of sampling frequencies. The length of time it would take to detect these `turbine' effects was also examined by re-assessing these success rates at 1 month, 6 months and 12 months post turbine installation.

For rigour, the variability in the abundance data and the time dependent nature of the observation process was included in this simulation exercise; these factors can heavily dictate whether turbine effects are detected.

Technical details

Over-dispersed auto-correlated Poisson data was simulated using the parameter estimates (as parameter values) obtained for the model fitted to the pre-turbine data. Specifically, observations collected on the same day were assumed to have an AR(1) correlation structure and these errors were added on the scale of the link function. While inducing auto-correlation in this way is unlikely to be identical to the true auto-correlation in the data, the GEE approach used here is robust to misspecification of this type. The amount of overdispersion used to generate the data was chosen such that the estimated dispersion parameter was very close to that obtained using the actual data (approximately 26 in this case).

A binary term was used to simulate a turbine effect, and turbine parameters were used to simulate small, moderate and large turbine effects. Specifically turbine parameter values resulting in 25%, 50%, 75%, 85%, and 95% of existing bird abundances were simulated, and the percentage of simulations which successfully detected a significant turbine effect (at the 5% level) were determined for each combination of turbine effect, sampling regime and time after turbine installation. Coverage rates of the turbine effect parameter (using

the GEE-based confidence intervals) were also calculated to evaluate the success of this approach at recovering the true turbine effect.
The sampling regimes were set at 25%, 50%, 75%, 85%, 95% and 100% of existing sampling effort and to simulate reduced effort, the appropriate number of days were randomly omitted from the simulated data set and the model fitted. Days were omitted at random irrespective of the whether the turbine was simulated to be operating.

At least 150 simulations were run for each combination of effect, turbine effect and time after installation; the exact number of which was determined by computation time. For instance, low effort, high turbine effect combinations returned very low numbers in some sub-areas and model convergence was slow in these cases. Due to time constraints, models containing only Month and turbine were fitted to the simulated data. While in practice a full model would be fitted to these data (e.g. with time of day etc also included) turbine estimates and *p*-values appeared to be the same under larger and smaller models.

Results

Summary

The following conclusions can be made:

- *Small* turbine effects (e.g. a reduction of 5% in bird numbers) are unlikely to be detected (<20%) even when observation frequency is at current levels and the turbine has been in place for 12 months.

- *Moderate turbine effects* (eg. a reduction of 15% in bird numbers) are highly likely to be detected (>90% success) after 6 months of turbine operation provided sampling effort/frequency remains at current levels.

- *Large* turbine effects (e.g. a reduction of 75% in bird numbers) are highly likely to be detected (>75% success) even when sampling frequency is half of current levels provided the turbine has been in place for 6 months or more.

- While conclusive evidence for turbine effects was rarely exhibited for relatively small turbine effects, the model was able to correctly describe the magnitude of all turbine effects used in this study.

One month after turbine in operation

Upper numbers in the table below indicate the percentage of simulations where a statistically significant `turbine' effect (i.e. change in bird numbers) was detected. The lower number in parentheses gives percentage of simulations where the correct magnitude of effect was detected.

Table 1: Ability to detect varying levels of turbine impact one month after installation, given varying levels of effort.

Simulated Turbine Effect		Large	Moderate		Small	
Percentage reduction in birds		**75%**	**50%**	**25%**	**15%**	**5%**
Sampling frequency as a proportion of current frequency	**75%**	100% (96.7%)	90.7% (97.3%)	30.0% (96.7%)	10.7% (98.7%)	8.0% (96.0%)
	85%	100% (96.7%)	94.0% (98.0%)	27.3% (98.0%)	14.7% (97.3%)	4.0% (100%)
	95%	100% (97.3%)	98.0% (98.7%)	24.0% (99.3%)	9.3% (100%)	1.3% (100%)
	100%	100% (98.7%)	98.0% (99.3%)	28.7% (100%)	7.3% (99.3%)	1.3% (100%)

Reductions of 50% or more are easily detected when sampling frequency is at least 75% of current sampling frequency, even after just one month of turbine operation. Detecting smaller reductions after just one month however, is relatively unlikely even when sampling effort is left at current levels. Detecting a very small (e.g. 5% or less reduction) is unlikely and highly variable across sampling effort after just one month of operation.

There is some variability in the success rates of turbine detection across sampling frequencies for a particular turbine effect. For instance, the success rates for small-to-moderate reductions in bird numbers at 75%-85% of current sampling effort appear to be higher than the success rates at higher (and current) effort levels. These small differences are almost certainly due to natural fluctuations in the simulated-based approach rather than due to real underlying differences in success rates for different sampling frequencies.

For instance, when the data sets are larger and/or the turbine has been in operation longer the sampling effort/success relationship is more clear (see Table 2 and Table 3 results for a 15% reduction in bird numbers). Very small differences such as 5% reductions are the most difficult to detect (given the apparent variability in the data) and so more data is needed to see the effort/success relationship in the long run (although there is some evidence for this for a 5% reduction in Table 3).

Evidence for some specified (real) turbine effect can only increase with sampling effort and/or longer term monitoring of abundance and it is highly likely that simulations that run longer after-turbine installation (with more replicates) would make this clearer.

Six months after turbine in operation

Upper numbers in the table below indicates the percentage of simulations where a significant change in bird numbers was detected. Lower number in parentheses gives percentage of simulations where the correct magnitude of effect was detected.

Table 2: Ability to detect varying levels of turbine impact six months after installation, given varying levels of effort.

Simulated Turbine Effect		Large	Moderate		Small	
Percentage reduction in birds		**75%**	**50%**	**25%**	**15%**	**5%**
Sampling frequency as a proportion of current frequency	**25%**	100% (99.3%)	99.3% (90.7%)	67.3% (92.7%)	44% (88.6%)	11.3% (94.0%)
	50%	100% (99.3%)	100% (96.7%)	94.7% (99.3%)	50.7% (97.3%)	10.7% (98.0%)
	75%	100% (99.3%)	100% (98.0%)	100% (100%)	69.3% (99.3%)	8.7% (98.7%)
	85%	100% (99.3%)	100% (99.3%)	100% (99.3%)	78% (100%)	9.9% (100%)
	95%	100% (99.3%)	100% (100%)	100% (99.3%)	86.7% (100%)	8.7% (100%)
	100%	100% (99.3%)	100% (100%)	100% (100%)	91.3% (100%)	4.7% (100%)

Reductions of 25% or more are easily detected when sampling frequency is at least 75% of current sampling frequency, after 6 months of turbine operation. Detecting smaller reductions at this time point becomes less likely as the turbine effect gets smaller and survey effort is decreased. Notably, if bird numbers drop by about 15% survey effort must continue at current levels to ensure this effect is detected. As before, detecting a very small (e.g. 5% or less reduction) is unlikely and highly variable across sampling effort even after 6 months of operation. For reasons stated for the one-month results, success rates naturally vary across the small turbine effects.

Twelve months after turbine in operation

Upper numbers in the table below indicate the percentage of simulations where a significant change in bird numbers was detected. Lower number in parentheses gives percentage of simulations where the correct magnitude of effect was detected.

Table 3: Ability to detect varying levels of turbine impact twelve months after installation, given varying levels of effort.

Simulated Turbine Effect		Small	
Percentage reduction in birds		**15%**	**5%**
Sampling frequency as a proportion of current frequency	**25%**	48.6% (92%)	1.3% (97.3%)
	50%	80.6% (98.9%)	14.6% (98%)
	75%	100% (100%)	14.6% (99.3%)
	85%	99.3% (99.3%)	14% (100%)
	95%	98% (100%)	16.6% (100%)
	100%	100% (100%)	14.6% (100%)

As before, reductions in bird numbers are more easily detected as sampling frequency increases. Specifically, if bird numbers drop by about 15%, survey effort must be set at >75% of current levels to ensure this effect is reliably detected after a full 12 months of turbine operation. Detecting a very small (e.g. 5% or less reduction) is less likely but improves with sampling effort and the longer the turbine has been in place. For reasons stated for the one-month results, success rates naturally vary across the small turbine effects, although this variability is less so for the 12 month results.

Conclusions

This study provides information that may be used to determine bird abundances relatively *through time*. This can provide a basis for temporal monitoring by permitting comparisons across time.

A sound statistical model has been formulated to allow relative bird abundances to be predicted for the site as a whole under differing environmental conditions, and for each sub-area. Further, special attention has been paid when presenting best and worse case scenarios (using 95% confidence limits) to ensure comparisons made during this analysis (eg. across sub-area) and any future comparisons are reasonable.

The average number of birds sighted appears to differ across the sub-areas sampled, with greater numbers detected in the sub-areas near land, eg. areas E1, E2 and A3. Bird abundance appears to be seasonal. Specifically, more birds were sighted in March-April 2007 when compared with other monthly values. Confirmation of seasonal patterns can only be confirmed by considering several years data.

There are clear relationships between monitoring times after turbine installation, the magnitude of the turbine effect and the amount of survey effort conducted. Specifically, increasing effort and length of monitoring after installation increases the probability of detecting an effect. Large effects can be detected with smaller expenditures of effort and over a shorter time period than smaller effect sizes.

It follows that reductions in survey effort below current levels can be achieved with no loss of effectiveness only if turbine operation results in a large drop in bird numbers or if the survey window is large. The full results are displayed in Table 1, Table 2 & Table 3. Some specific examples from these follow:

- If the turbine effect was a decrease in general bird numbers of less than 5%, simulations indicate it is unlikely (approx < 17%) to be detected over a one year monitoring period with the current surveying effort. Decreasing the survey effort to a quarter of the current level would substantially reduce the ability to detect an impact of this magnitude.

- Given a one year post-turbine installation monitoring window, a survey effort of 75% or more of the current level appears effectively certain to detect an impact/decrease in bird numbers of a 15% or more.

- Over a six month post-turbine monitoring window, an effective reduction in bird numbers of 5% is unlikely to be detected under the current surveying effort. Reduction of survey effort by a quarter would permit the detection of reductions in bird numbers of 25% or more with near certainty.

- A one month post-turbine monitoring window with the current surveying rates would allow detection of only large reductions in bird numbers (50% or more). Reductions of 25% or less are unlikely to be detected over this time frame.

Limitations/Caveats

Absolute estimates of bird abundance are unable to be obtained from the data at hand. For instance, there may be the possibility of repeatedly counting the same individuals through time and this could seriously bias estimates of absolute abundance. However, relative abundance information can be extracted which is suitable for monitoring changes through time.

We continue to have concerns about the apparent relationship between the distance from the observer and observed bird abundance. i.e. predicted bird abundance is highest near land. For instance it is well known that the probability of detecting an animal decreases as the distance from the observer increases and animals are more easily identified against a contrasting background. If detection primarily determines the number of birds recorded by the observer rather than the number of birds present, then this model will not adequately reflect underlying differences in sub-area to sub-area abundances[3].

[3] This is not an uncommon issue. If the detection function can be modelled then absolute abundance figures can be generated.

That said, if the sampling and observer protocol and detection rates stay constant with time, valid comparisons can still be made across time using this approach.

Augmentation of the current survey design would go some ways to addressing these detection concerns. Specifically, additional observers placed at (randomly) chosen locations could provide bird counts concurrent with the observer already in place, and any bias in the current design could be objectively evaluated. Further, this augmented design could also be used to correct for any biases which emerge; counts for affected sub-areas could be inflated or deflated according to the extent and nature of the bias revealed.