ASSESSING NORTHERN GANNET AVOIDANCE OF OFFSHORE WINDFARMS

EAST ANGLIA OFFSHORE WIND LTD

Final

DATE: 20 June 2014

APEM REF: 512775

CLIENT:	East Anglia Offshore Wind Ltd
ADDRESS:	4th Floor, 1 Atlantic Quay, Glasgow G2 8JB CF46 6LY
APEM REF:	512775

PROJECT DIRECTOR:	Dr Stuart Clough
PROJECT MANAGER:	Dr Mark Rehfisch
WRITTEN BY:	Dr Mark Rehfisch, Zoe Barrett, Laura Brown, Dr Roger Buisson, Dr Rafael Perez-Dominguez & Dr Stuart Clough

---

Revision and Amendment Register

Version Number	Date	Section(s)	Page(s)	Summary of Changes	Signed off by
Draft Final	28/04/2014	5	12	Initial Release	M Rehfisch
Final	09/06/2014	5	26	Second draft release	M Rehfisch
Final	17/06/2014	5	26	Final release	M Rehfisch

Contents

EXECUTIVE SUMMARY

1. A novel approach is presented for estimating northern gannet *Morus bassanus* macro- and micro-avoidance of offshore windfarms from high resolution digital images gathered from aerial survey. This approach calculates macro- and micro-avoidance based on the measured change in gannet density at a distance from the windfarm and inside the windfarm.

2. Four aerial surveys of the built Greater Gabbard offshore windfarm (GGOWF) were carried out between 30 October 2014 and 23 November 2014, a period of high gannet autumn passage off the East Anglian coast and in the southern North Sea.

3. Digital images were collected by planes flying at over 300 m leading to no observable disturbance to the birds and thus minimising any bias in the data. Each survey consisted of between 14 and 20 pseudo-randomly generated transects, with the caveat that each transect had to either cross or abut the windfarm. Each transect started and ended 10 km before and after the GGOWF, respectively. In total the four surveys covered 320% and 75% of the windfarm footprint and buffer areas, respectively, with 570 m wide transects.

4. In total 336 gannets were recorded in the images during the four autumn passage surveys of which eight and 328 were recorded within and outside the GGOWF footprint, respectively. The gannets had a minimum recorded approach distance of 443 m and 359 m away from the nearest turbine within and outside the footprint, respectively.

5. A zero-inflated negative binomial model is used to describe the relationship between the distance to the nearest turbine and gannet counts outside of the GGOWF footprint.

6. The model suggests that gannet numbers change with distance to the built windfarm (P=0.0518). Gannet counts increase from zero close to the turbines to reach a "background at sea" plateau two kilometres away from the nearest turbine. The lower density within two kilometres of the windfarm is likely to reflect gannets avoiding the vicinity of the GGOWF.

7. A macro-avoidance value of 95.02% has been calculated for gannets as the percentage change from their background at sea density 4 km or more outside of the GGOWF compared to their density within the GGOWF footprint. A distance of 4 km outside the GGOWF is used rather than 2 km to ensure that a robust background gannet density is used. Observing no birds closer than 359 m to a turbine suggests 100% micro-avoidance and an overall avoidance value of 100%.

8. In conclusion, the results of this study strongly suggest that northern gannets avoid the close proximity of built windfarms, at least during the autumn passage period and they support previous studies that also showed strong avoidance. A 95.02% macro-avoidance value, a 100% micro-avoidance value and a 100% total avoidance value is indicated by the data. Based on the published offshore micro-avoidance value of 97.6% we estimate total avoidance to be 99.9%. It is therefore not unreasonable from the evidence of this study, taken together with previous studies, to suggest that an avoidance rate of 99.5%, at least for autumn passage gannets, may be appropriately precautionary for use in collision risk modelling.

1. Introduction

1. In the UK the prediction of the possible numbers of flying birds that collide with the moving blades of a windfarm is usually carried out using the Band collision risk model (CRM). This model was originally developed for onshore windfarms (Band 2000) and has been revised and refined over the years to include a model for specific application to offshore wind farms (Band, 2012). The model carries out a staged series of calculations starting from the flux of birds passing through the windfarm, as determined by site-specific surveys undertaken before the windfarm is constructed. Each stage of the model reduces, based on the characteristics of each bird species and the parameters of the wind farm, the number of birds that might be at risk of collision. Currently there are two types of Band CRM; the Basic Band Model and the Extended Band Model. The main difference between these models is that the Extended model uses information on the distribution of the proportion of birds flying at different heights within the upper and lower swept height limits[1] when predicting the number of birds that make a transit through the rotor swept area, whereas the Basic model assumes a uniform distribution of birds within the upper and lower swept height limits (ie at potential collision height). The output of both models in the penultimate stage is a prediction of the number of birds that collide assuming that each bird has taken no avoiding action. The final stage of the modelling process is to apply an avoidance factor. This single figure accounts for the behaviour that a flying bird might exhibit when encountering the constructed windfarm in order to avoid colliding with the turbines. Such avoiding actions might be taken at some distance from the windfarm, on a close approach to the outside of the windfarm, or on a close approach to the moving turbine blades.

2. The post-construction monitoring of onshore windfarms has allowed the theoretical avoidance factor to be replaced, for some species, with a correction factor that has been determined from the comparison of the number of birds killed by the operating windfarm (with suitable adjustment for the undetected corpses) with the number predicted to collide by the Band CRM from pre-construction flight activity information. This correction factor, like the theoretical avoidance factor, combines the avoiding actions that might be taken by a bird at some distance from the windfarm, on a close approach to the outside of the windfarm, or on a close approach to the moving turbine blades.

3. As the collection of the corpses resulting from any collisions at constructed offshore windfarms is very difficult an alternative approach has been taken to produce empirical measures of bird avoidance actions. The approach used has been to track bird flights using radar or cameras or observers or a combination of tracking methods and to record any avoiding action observed. The results of this tracking method have been expressed as the percentage of birds having taken 'macro-avoidance' or 'micro-avoidance'. A recent definition of these terms is provided in Cook *et al*. (2012) that states:

Macro-avoidance	Avoidance of the whole wind farm
Micro-avoidance	Avoidance of individual turbines within a wind farm

[1] For seabirds this is either derived from the BTO modelling of a large number of boat-based baseline surveys [model Option 3] or from surveys of bird flight heights at the specific site for which the CRM is being carried out [model Option 4]

4. Macro- and micro-avoidance values can be combined to produce an overall figure for avoidance that can be used in the Band CRM.

5. An example of this bird tracking method are the visual observation and radar studies in The Netherlands that provided evidence that northern gannets *Morus bassanus* strongly avoid built offshore windfarms (Krijgsveld *et al*. 2011). "*The high proportion of gannets outside the wind farm corresponds with birds flying in a wide range around the wind farm, not even passing the edge*" and "*deflection*" away from the wind farm "*was highest in gannets, that approached the wind farm closely before changing direction*" (Krijgsveld *et al*. 2011: pp 175 & 193, respectively). However this behavioural information has not yet been accepted as providing sufficient evidence to depart from the 'default' and precautionary value of a 98% avoidance rate for seabirds to be applied in Band CRM in offshore windfarm Environmental Impact Assessments (EIAs) submitted as part of applications for consent. This 'default' 98% avoidance rate for seabirds is likely to overestimate the number of predicted collisions. What is a problem for a single site becomes a major consenting issue at the in-combination stage when what could be a series of overly precautionary collision estimates are summed leading to cumulative mortality estimates that if true could lead to gannet population declines at various spatial scales.

6. This report describes how gannet avoidance of offshore windfarms during the autumn passage period was explored empirically using a novel approach that is able to determine values for macro-avoidance and micro-avoidance.

7. Specifically for this study, the definitions of Cook *et al*. (2012) of macro- and micro-avoidance have been developed to describe both the gannet behaviour and how the changed distribution resulting from that behaviour can be measured and analysed:

   Macro-avoidance is defined in behavioural terms as:
      The gannet does not enter the area that is bounded by the outer turbines of the array
   Macro-avoidance is defined in measurable terms as:
      A change in gannet background at sea density relative to its density within the windfarm.

8. With regard to defining the area within which micro-avoidance will be measured in this study, accounting for rotor radius (53.5 m from 4C (2014)), bird wingspan (ca 2 m) and vortex effects (of uncertain size but presumed to be in the order of 20 m) it would seem reasonable to expect micro-avoidance to occur within less than 75 m of each turbine hub.

9. A hypothesis-testing approach was taken predicting before data collection that gannet densities would be lowest adjacent to the windfarm rising rapidly to reach a background at sea density (Figure 1).

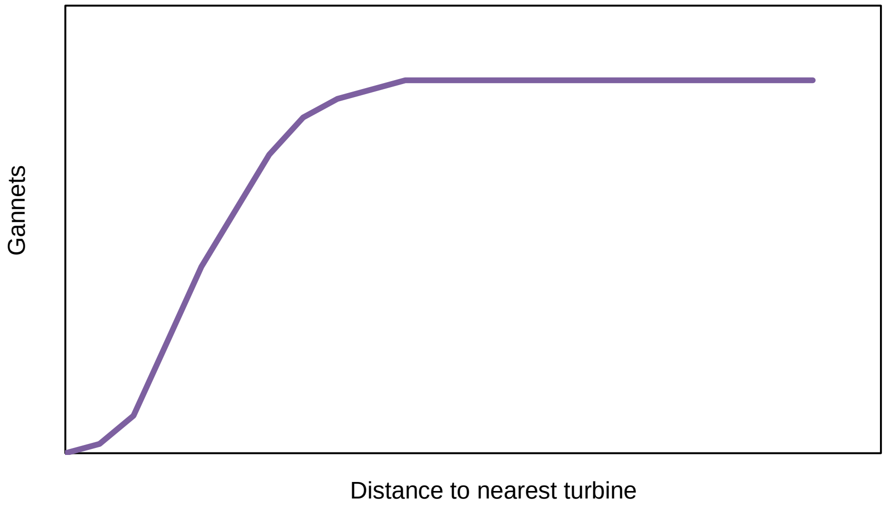


Figure 1 Diagrammatic conceptual presentation of how gannet numbers could change with distance to the nearest turbine proposed by the authors. Krijgsveld *et al*. (2011) suggest 5 km avoidance for many seabirds and “deflectance” for gannets at 500 m. If deflectance were to occur this conceptual curve would be expected to feature a “hump” on it to reflect the extent of the deflectance. Please note that this graph could include birds inside the windfarm footprint.

10. This novel approach to assessing seabird avoidance relies on high quality, unbiased high resolution digital images obtained using aerial survey that due to the flight height of the survey platform minimises disturbance to the birds.

2. Methods

2.1 Approach

11. The methodological approach taken is in two stages. First, the distance at which gannets start reacting to a built windfarm is estimated by modelling gannet density with distance to windfarm. Beyond this distance is where we can expect to record background at sea gannet densities where the birds are not affected by the windfarm.

12. Second, any change in gannet densities between the background at sea and the within windfarm footprint provides an estimate of macro-avoidance. Any further decline in gannet density within 75 m of all hubs (see paragraph 7 in Introduction for further details) provides an estimate of micro-avoidance.

13. As described by Cook *et al*. (2012) total avoidance is calculated as follows:

    (1 – Total Avoidance) = (1 – Macro-avoidance) × (1 – Micro-avoidance)

2.2 Data collection

14. Following discussions with the windfarm operator, APEM completed 4 aerial survey campaigns to sample gannet distributions in the footprint area of the Greater Gabbard offshore wind farm (GGOWF) and its vicinity using digital imagery.

15. To determine in a statistically defensible manner any relationship between gannet numbers or density and distance to an offshore wind farm during migration the study aimed to record the location of a minimum of 200 gannets over a period of four days to allow for possible differences in behaviour with weather. A sample of 200 was predicted to be sufficient to identify a strong relationship between animal numbers and a “factor”. If no relationship were to be observed between gannet numbers or density and distance to windfarm from 200 birds it is unlikely that a less clear relationship would be strong enough to lead to a substantial change in gannet avoidance rate.

16. It was estimated that four flights each comprising ten quasi-randomly selected transects (Figure 2) should obtain the target 200 records of individual gannets. Each straight line transect would start 10 km away from the nearest point of the GGOWF, cross or abut the GGOWF, and finish 10 km on the other side of the nearest point of the GGOWF. The sampling effort of 1000 km^2 of images required was estimated from known densities of over 0.2 gannets / km^2 passing through this part of the North Sea during the peak autumn passage period of October to November (Stone *et al*. 1995, 2008-2010 GGOWF survey information). By each transect crossing or abutting the GGOWF a high proportion of the imagery was collected in the windfarm footprint or near the turbines, the key areas where collisions could occur.

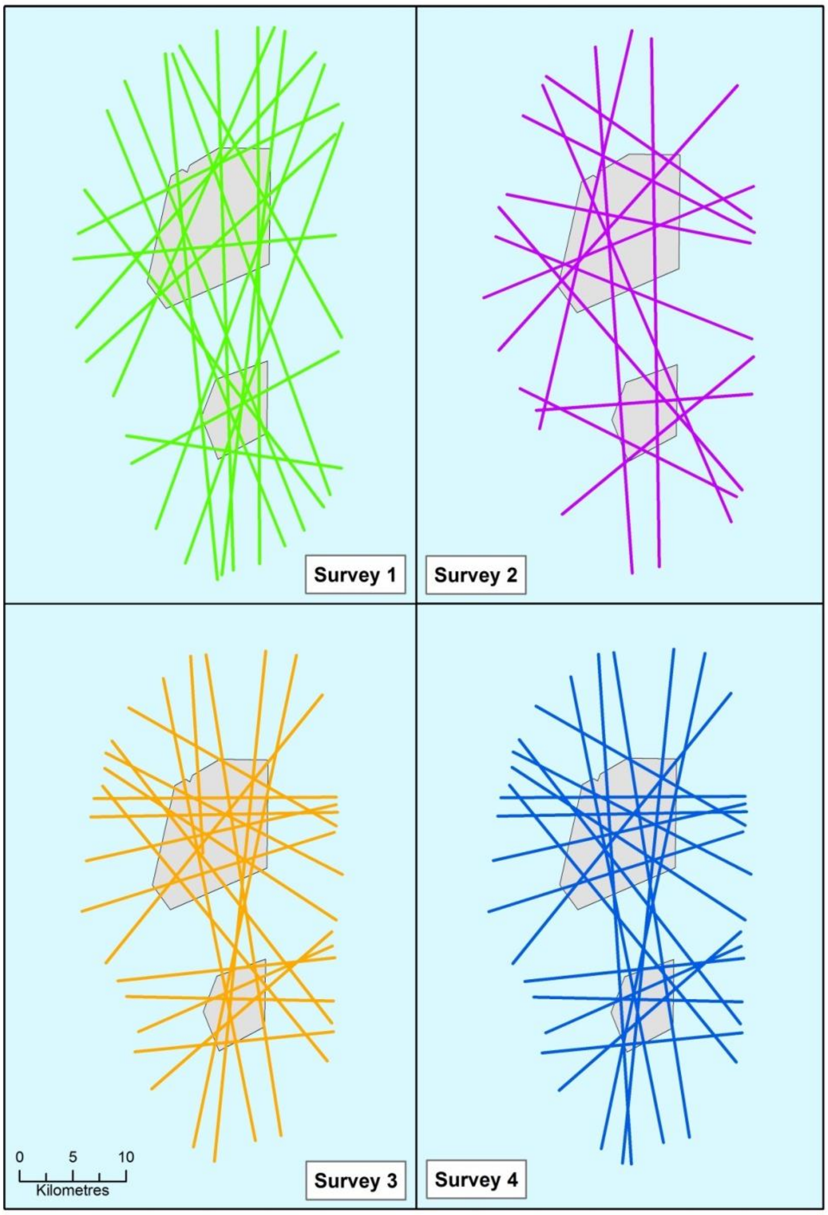


Figure 2 Gannet survey of the Greater Gabbard windfarm using quasi-random transects. The outlines of the Greater Gabbard windfarm footprints are shown in grey.

17. The four aerial surveys of the GGOWF were carried out between 30 October 2014 and 23 November 2014, a period of high gannet autumn passage off the East Anglian coast and in the southern North Sea. The four flights collected images from 19, 14, 20 and 20 transects. The flights were undertaken using Vulcanair P68 twin-engine survey aircraft. The digital still images were collected using a GPS-linked bespoke flight management system from a height of over 1,000 feet to help ensure minimal disturbance. The data were captured along a continuous transect ca 570 m wide. The crew noted any vessels in the survey area.

18. Gannets identified from the images were 'snagged' (i.e. located within the images) and Quality Assured (QA) internally by the APEM UKAS-accredited ornithology team. Each gannet was georeferenced with an accuracy of 20 m or less.

2.3 Data analysis

19. The dataset consists of 34,497 individual observations (images) each representing an aerial photograph of the survey area (Tables 2 and 3). Between one and five gannets were present in 260 images. The 73 transects led to a total image coverage of 1,459 km^2, equating to 320% and 75% of the windfarm footprint and buffer areas, respectively.

Table 1 Structure of the Gannet dataset used in the analysis. “Rank" is the observation number, "GannCount" (or "GannCount01") is the number of gannets counted in each photograph (response variable), and all other variables were used to try and explain the observed gannet numbers.

Variable name	Type	Comment
Rank	Integer	34,497 observations / images
GannCount	Integer	Number of gannets - range 0 to 5
GannCount01	Numerical	Presence / absence of gannets
TurbineDist	Numerical	Distance to turbine (m)
SQRTurbineDist	Numerical	Square root of distance to turbine (m)
fSurvey	Factor	4 levels representing 4 survey days
Footprint	Factor	2 levels: 1 = within and 0 = without

20. Only images taken outside of the GGOWF footprint were included in the modelling. The explanatory variable (GannCount) was characterised by a large proportion of zero counts (98.9%). This is a common problem for the analysis of ecological datasets where the subjects of interest have a low probability of capture or detection. Zero-inflated (ZI) count models have been used to investigate the underlying distribution patterns under such conditions (Jackman 2012). The ZI approach consists of two parts: a binary (probability) model to account for the excess zeros (overdispersion) and a count model to evaluate the effect of the covariates on the response variable. Both are fitted simultaneously using a range of explanatory variables.

21. The gannet counts were modelled using distance to the nearest turbine on the windfarm periphery as the main explanatory variable. The model allowed for differences in migrating gannet numbers that could be brought about by weather or other stochastic / random variables on individual survey dates. This was done by having a “Survey” variable (fSurvey) that could account for unexplained survey-specific factors affecting gannet counts, such as differences in weather between survey days that could lead to the increased presence of migrating birds. The initial data exploration and model selection approach are presented in Appendix 1.

22. The expectation was to find gannet counts increasing with turbine distance (proxy for distance to the windfarm) if gannets actively avoid the windfarm area. Conversely, the expectation would be that at a certain distance threshold from the nearest turbine, gannet counts would remain broadly constant as representing normal ‘gannet at sea’ density.

3. Results

3.1 Gannet distributions

23. In total 336 gannets were recorded in the 34,497 survey images during the four autumn passage surveys (Table 2, Figure 3, Appendix 1). The four surveys collected 12,979, 2,900, 9,140 and 9,478 images, respectively. Of these gannets, 328 were outside the windfarm. It is important to note that a proportionally high survey effort was close to the turbines adding confidence that birds near the turbines would not be missed (Table 2). For example, 39% (13,456) of the images were gathered within 1 km of a turbine.

Table 2 Number of digital images collected according to distance to nearest turbine. Note uneven divisions of distances to nearest turbine to provide more detail of image and gannet numbers close to turbines.

Distance to nearest turbine *km*	Number of digital images inside and outside windfarm footprint			Gannets		
	Inside	Outside	Total	Inside	Outside	Total
0 - 0.25	2,065	65	2130	0	0	0
0.25 – 0.5	5,645	418	6063	2	2	4
0.5-0.75	2,683	836	3519	3	6	9
0.75-1	777	967	1744	2	12	14
1-1.25	142	952	1094	1	11	12
1.25-1.5		955	955		8	8
1.5 - 1.75		873	873		6	6
1.75 - 2		961	961		15	15
2 - 2.5		1862	1862		47	47
2.5 - 3		1732	1732		28	28
3 - 4		3390	3390		45	45
4 - 5		2536	2536		46	46
5 - 6		2476	2476		32	32
6 - 7		2412	2412		25	25
7 - 8		1264	1264		22	22
8 - 9		789	789		12	12
9 - 10		521	521		7	7
10+		178	178		4	4
TOTAL	11,311	23,186	34,497	8	328	336

24. Up to a distance of two kilometres, both inside and outside of the GGOWF, the density of gannets decreased strongly as turbines became closer (Table 3). This decrease was especially strong within the windfarm footprint providing evidence that birds are actively avoiding turbines and do not get disorientated within a windfarm. The proportionally high survey effort close to the turbines adds confidence that the birds are avoiding the turbines.

Figure 3 Distribution of gannets around Greater Gabbard Offshore Windfarm

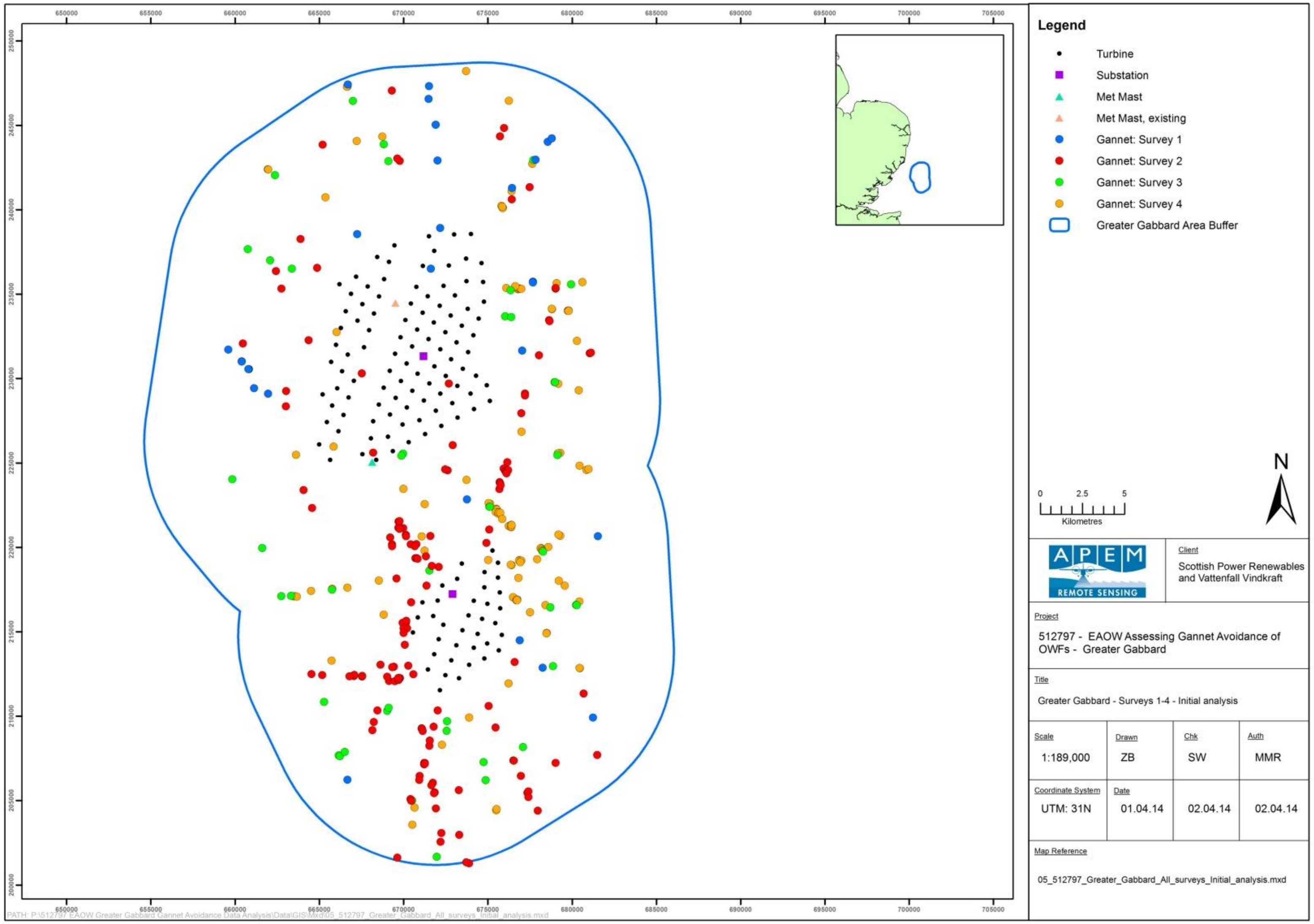
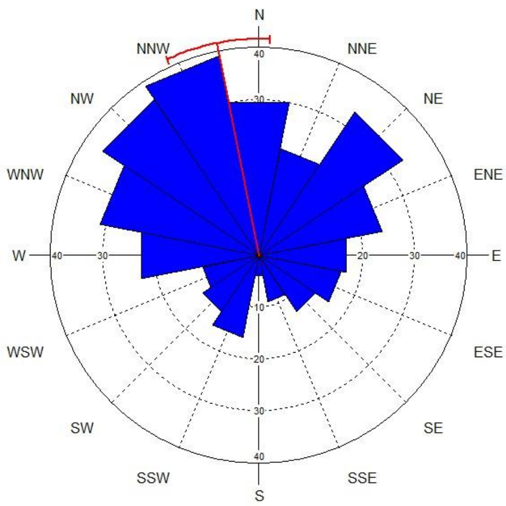


Table 3 Density of gannets inside and outside the GGOWF footprint according to distance to nearest turbine.

Distance to nearest turbine *km*	Gannet densities inside and outside windfarm footprint km^{-2}	
	Inside	Outside
0 - 0.25	0	0
0.25 – 0.5	0.0085	0.1138
0.5-0.75	0.0261	0.1647
0.75-1	0.0615	0.2927
1-1.25	0.1611	0.2782
1.25-1.5		0.1979
1.5 - 1.75		0.1598
1.75 - 2		0.377
2 - 2.5		0.5946
2.5 - 3		0.3836
3 - 4		0.3146
4 - 5		0.4294
5 - 6		0.3094
6 - 7		0.2427
7 - 8		0.3938
8 - 9		0.3413
9 - 10		0.3027
10+		0.4803

25. The nearest gannets to a turbine within and without the windfarm footprint were 443 m and 359 m away from the device, respectively.

Figure 4 Flight direction of gannets around GGOWF (mean and standard deviation in red).



26. Most gannets during the four surveys were recorded flying in a northerly direction (Figure 4). This matches observations made at Thorpeness, Suffolk in November 2013 and recorded on Trektellen (eg 17 and 23 November).

3.2 Change in gannet counts with distance to turbine

27. The count model evaluated takes the following form:

Logit (GannCount) = Intercept + b1 (SQRTurbineDist)

where b1 is a constant

28. The count model was implemented with a negative binomial where the Logit of the outcome is predicted with the explanatory variable distance to the nearest turbine. The model was constructed and evaluated using R (library pscl) (Table 4).

Table 4 Syntax and model summary. Under the zero inflation approach two models are fit simultaneously. The count model (top) accounts for the probability of excess zeroes and the zero-inflation model (bottom) predicts the response variable according to the selected covariates. The model was constructed with a binomial fit to estimate the zero-inflation coefficients and a negative binomial fit for the count model coefficients.

Model = *zeroinfl(formula = GannCount ~ SQRTurbineDist + fSurvey | SQRTurbineDist, data = GannetDataframe, dist = "negbin", link = "logit")*					
	Estimate	Std. Error	z value	Pr(>|z|)	
Count model coefficients (negative binomial with logit link):					
(Intercept)	-5.397419	0.464961	11.608	-< 2e-16	***
SQRTurbineDist	-0.00198	0.005854	-0.339	0.7342	
fSurvey2	2.953604	0.225161	13.118	< 2e-16	***
fSurvey3	0.732523	0.243202	3.012	0.0026	*
fSurvey4	1.606030	0.214037	7.504	6.21e-14	***
Log(theta)	-2.900140	0.179019	-16.200	< 2e-16	***
Zero-inflation model coefficients (binomial with logit link):					
(Intercept)	3.30936	1.60727	2.059	0.0395	*
SQRTurbineDist	-0.12218	0.06282	-1.945	0.0518	(*)
Theta = 0.055 Number of iterations in BFGS optimization: 52 Log-likelihood: -1456 on 8 Df *** P<0.001 ** P<0.01 * P<0.05 (*) P<0.10					

29. Survey day (fSurvey) has a strong effect in the count model suggesting that gannet counts vary across survey events. This is almost certainly due to the fact that migrating bird numbers can vary from day to day, with high migration intensity often being associated with good weather conditions. The level of significance in the zero-inflation model (Table 4)

suggests that the number of gannets changes with distance. The model estimates show a sharp increase in gannet counts with distance that peaks at approximately 2,000 m from the nearest turbine (Figure 5). The model estimates are supported by the observed gannet densities (Table 3). This trend being shared across surveys increases confidence that the general pattern of distribution has an ecological meaning (Figure 6). Further from this point the members are relatively constant and probably reflect normal gannet abundance at offshore locations away from the turbine or background at sea numbers.

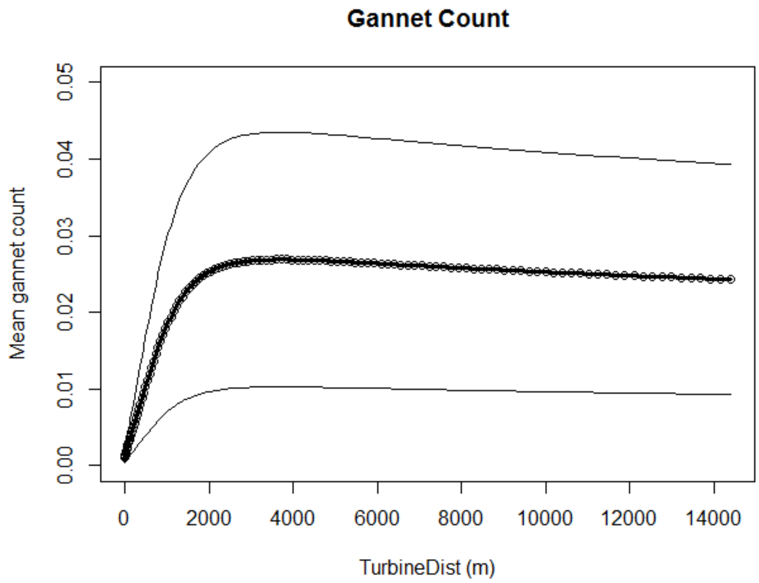


Figure 5 Graphical output of the ZI gannet count model. The figure presents the mean predicted gannet counts (middle line) and the standard error (top and bottom lines) of the four survey event. "Mean gannet count" represents the number of gannets predicted per image.

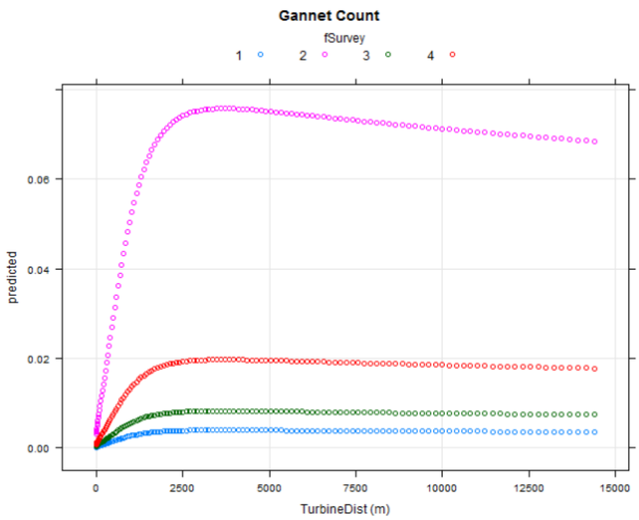


Figure 6 Graphical output of the ZI gannet count model for each separate survey. "Predicted" represents the number of gannets predicted per image.

3.3 Macro- and micro-avoidance calculations

30. Macro-avoidance is estimated to be 95.02% based on the change in density between the background at sea density of gannets and the density of gannets recorded within the windfarm footprint (Table 5). Although the model suggests that the gannet at sea densities start some 2 km from the GGOWF, only gannet densities greater than 4 km from the GGOWF have been used to help ensure that the background density used only comprises birds far enough away from the windfarm that they should be unaffected by it.

Table 5 Macro avoidance parameters and calculation.

	Gannet *numbers*	Area surveyed *km²*	Mean density *km⁻²*		Avoidance *%*
Footprint	8	473.1040	0.01691	A	
4-11 km outside (background at sea density)	148	435.9712	0.33947	B	
Macro-avoidance (1 – A / B)					95.02%

31. No birds were recorded closer than 359 m to a turbine. As a result the density of birds at the distance at which micro-avoidance could be occurring can only be calculated as 0 birds per km^2. As a result the evidence available is that there is 100% micro-avoidance occurring.

32. The few micro-avoidance estimates have been made using radar and / or visual observations (Krijgsveld *et al*. 2012, Desholm & Kahlert 2005) and it is Krijgsveld et al. (2012) who have generated the greatest number of species-specific estimates. However these were based on a single constant micro-avoidance rate measured using radar that will have been influenced by the large number of passerines in the sample. This is possibly unfortunate as the avoidance behaviour of passerines may be different to that of gannets. In this study, having sampled proportionally most in the areas adjacent to the turbines and yet observed no birds closer than 359 m to a turbine the evidence points to 100% micro-avoidance.

33. As the evidence points to 100% micro-avoidance, clearly the overall avoidance would also be 100%.

4. Discussion

34. The distribution of gannets in the vicinity of the GGOWF is represented diagrammatically in Figure 3 and Appendix 1. Only eight of the 336 gannets recorded were within the turbine array. The nearest gannets to a turbine hub were 443 m and 359 m away within and without the GGOWF footprint, respectively.

35. For simplicity and ease of interpretation no extra covariates have been added to the models and all of the data have been pooled into a single analysis. It is important to note that the spatial location of the observation (image) with respect to the windfarm or the observed gannet(s) flight direction is not considered in the model.

36. The model describes gannet counts increasing with distance outside of the windfarm for about 2 km indicating a strong avoidance reaction (Figures 5 and 6). This increase is apparent when looking at the change in gannet density with distance to turbines both within and without the footprint (Table 3). The model then describes gannet counts reaching a plateau of about 0.025 gannets per image before starting a very slow gradual decline. This gradual decline is especially clear for the second survey that recorded the highest gannet counts (Figure 6). This gannet peak at about 2 km may reflect a change in behaviour by the birds when they become aware of the offshore windfarm. If the gannets were to spend more time at that distance while considering how to respond to the potential hazard this would lead to an apparent slight increase in their presence and thus density at that distance. This sort of behaviour has been called “deflectance” by Krijgsveld et al. (2012). The pattern is consistent across surveys and appears to be independent of absolute gannet counts, although part of the similarity may be due to the type of curve fit to the data. The consistent pattern between surveys demonstrates that the results are robust. The distribution of gannet counts is as hypothesized at the start of the study, allowing for some deflectance, and therefore is consistent with the presumption that gannets strongly avoid windfarms.

Table 6 A comparison of gannet avoidance rates.

Site	Avoidance rate (%)			Approach	Study
	Macro-	Micro-	Total		
Greater Gabbard (this study)	95.02	*100* [1]	*100*	Digital aerial images	This study
		97.6 [2]	99.88	Digital aerial images	This study & Krijgsveld *et al.* 2011
Egmond aan Zee	72			Visual observations	Christensen *et al*. 2004 in Cook *et al*. 2012
Egmond aan Zee	64	97.6 [2]	99.1	Visual with radar	Krijgsveld *et al.* 2011
Horns Rev 2	86 [3]			Radar / range-finder	Skov *et al*. 2011

[1] Estimate based on no gannets being seen closer than 359 m from a turbine.

[2] It is important to note that this constant micro-avoidance rate used for all species was measured using radar and may be influenced by the large number of passerines that were tracked.

[3] In this study the total number of tracks is determined and the percentage of the number of tracks that entered the wind farm is calculated and this is subtracted from 100%. As the report does not state how the number of relevant tracks is estimated and from what area it is not possible to assess the validity of the results.

37. The survey data collected as part of this project strongly suggests that gannets avoid the immediate proximity of built windfarms and this confirms previous findings (Table 6, Krijgsveld *et al*. 2012). The gannet distribution data gathered for this project make it possible to estimate macro-avoidance to be 95.02%, at least during autumn passage, the highest macro-avoidance value that the authors have come across for any species (see, for example, Cook *et al*. 2012).

38. The macro-avoidance rate determined from this study of gannets flying outside of and within the GGOWF is equally applicable to the Basic and Extended Band collision risk models, providing as a starting point, a minimum value for use in both models. This macro-avoidance rate though is only one component of the overall avoidance rate needed for both the Basic and Extended Band collision risk models. A suggestion for calculating an overall avoidance rate has been made by combining this macro-avoidance figure with the micro-avoidance figure from the Egmond aan Zee study (Krijgsveld *et al*. 2011). The Basic and Extended Band models differ in the way that they calculate bird flights close to the sweep of the turbine blades in what from observations is considered to be in the micro-avoidance zone. This is stated in Band 2012 Paragraph 61(ii) as "*If most of the birds flying at risk height (ie above the minimum level of the rotor) do so at a level not far above the bottom edge of the rotor, the probability of passing through the rotor disc is relatively small, simply because the rotor circle occupies less width at that level than, for example, at the midpoint of its diameter. Therefore the expected number of rotor transits is reduced. For some species the reduction may be 50% or more, reducing the collision risk in proportion*." It is considered that this additional degree of avoidance in the Extended model is not included in the Basic model and has to be accounted for by a reduction in the overall avoidance rate to be applied in the Extended model compared to the Basic model. It is not clear to what extent the fine detail of flight paths was recorded in the Egmond aan Zee study that would match the differences in the Basic and Extended Band model and as a result the extent to which their derived micro-avoidance rate can be applied equally to the Basic and Extended Band model. This means that the uncertainty in determination of overall avoidance rate rests at the micro- level.

5. Conclusions

39. The results of this study strongly suggest that northern gannets avoid the close proximity of built windfarms, at least during the autumn passage period. The results also support previous studies that showed strong avoidance.

40. A 95% macro-avoidance value can be determined from the data.

41. The data indicate a 100% micro-avoidance value along with a 100% total avoidance value.

42. Using the Krijgsveld *et al.* 2011 generic micro-avoidance rate of 97.6% a total avoidance rate of 99.9% is estimated.

43. The macro-avoidance rate determined from this study is considered equally applicable to the Basic and Extended Band collision risk models but uncertainty arises over applicability when it is combined with micro-avoidance values derived from other studies to calculate an overall avoidance rate. This is because of differences in the way in which the Basic and Extended Band models treat flights close to the rotor sweep in the micro-avoidance zone.

44. It is not unreasonable from the evidence of this study, taken together with previous studies, to suggest an avoidance rate of 99.5%, at least for autumn passage gannets, may be appropriately precautionary for use in collision risk modelling.

References

4C. 2014. http://www.4coffshore.com/windfarms/windfarms.aspx?windfarmId=UK05 Accessed 9 June 2014.

Band, W. 2000. *Windfarms and birds: Calculating a theoretical collision risk assuming no avoidance*. Scottish Natural Heritage, Battleby.

Band, W. 2012. *Using a collision risk model to assess bird collision risks for offshore windfarms*. The Crown Estate Strategic Ornithological Support Services (SOSS) report SOSS-02. BTO-SOSS Website.

Cook, A.S.C.P., Johnston, A., Wright, L.J., and Burton, N.H.K. 2012. *A review of flight heights and avoidance rates of birds in relation to offshore windfarms*. The Crown Estate Strategic Ornithological Support Services (SOSS) report SOSS-02. BTO-SOSS Website.

Christensen, T.K., Hounisen, J.P., Clausager, I. & Petersen, I.K. 2004. *Visual and radar observations of birds in relation to collision risk at the Horns Rev offshore wind farm*. National Environmental Research Institute, Denmark.

Desholm, M. & Kahlert, J. 2005. Avian collision risk at an offshore wind farm. *Biology letters* **1**, 296-298.

Jackman, S. 2012. pscl: Classes and Methods for R Developed in the Political Science Computational Laboratory, Stanford University. Department of Political Science, Stanford University. Stanford, California. R package version 1.04.4. URL http://pscl.stanford.edu/

Krijgsveld, K.L., Fijn, R.C., Japink, M., van Horssen, P.W., Heunks, C., Collier, M.P., Poot, M.J.M., Beuker, D., Dirksen, S. 2011. *Effect studies Offshore Wind Farm Egmond aan Zee. Final report on fluxes, flight altitudes and behaviour of flying birds*. NoordzeeWind report nr OWEZ_R_231_T1_20111114_flux&flight.

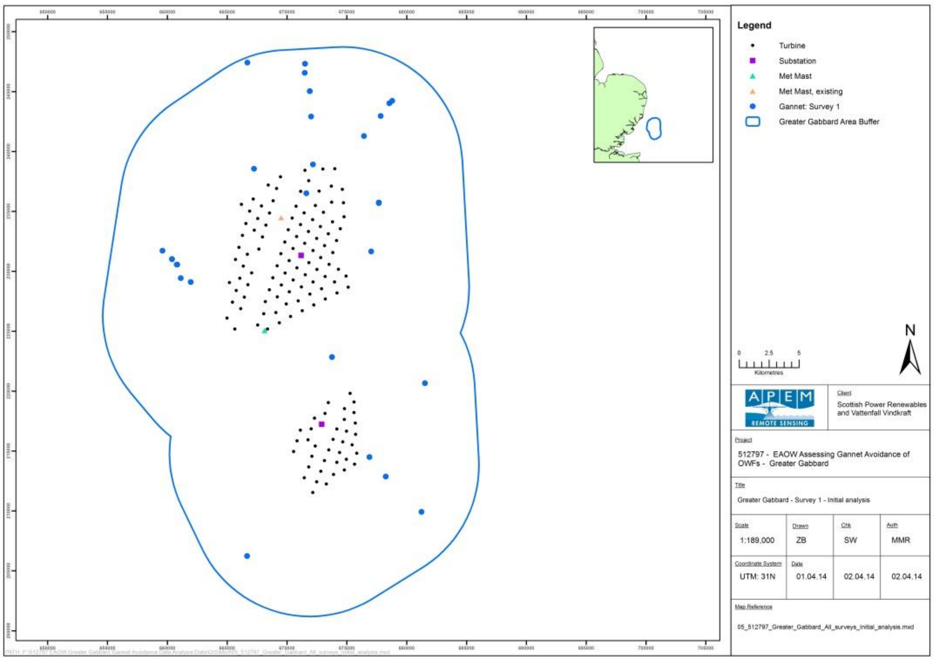
Skov, H., Leonhard, S.B., Heinänen, S., Zydelis, R., Jensen, N.E., Durinck, J., Johansen, T.W., Jensen, B.P., Hansen, B.L., Piper, W. and Grøn, P.N. 2012. *Horns Rev 2 Monitoring 2010-2012. Migrating Birds.* Orbicon, DHI, Marine Observers and Biola. Report commissioned by DONG Energy

Acknowledgements

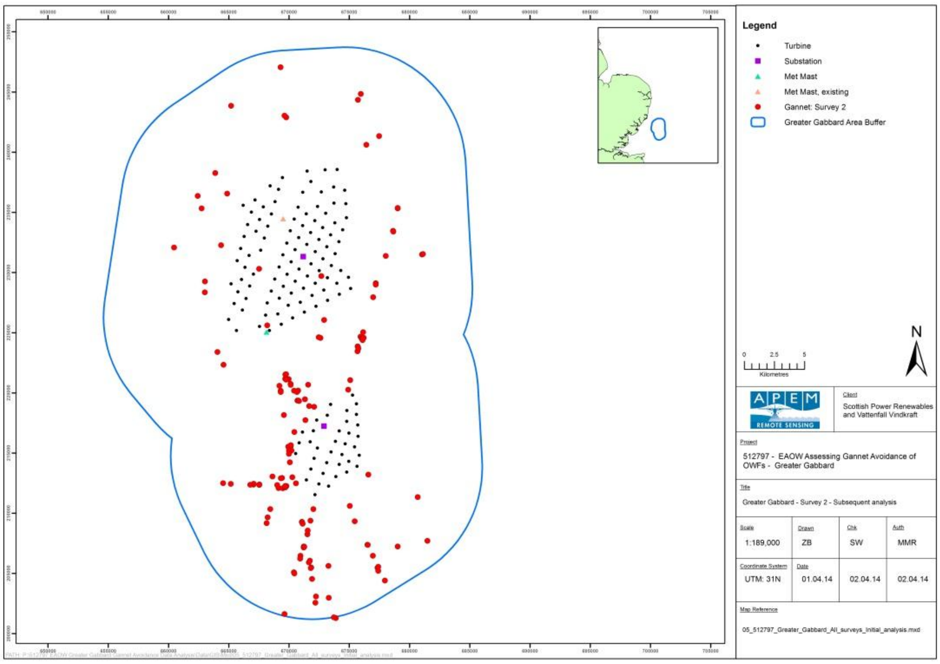
Thanks are due to EAOW for funding this study. Thanks are also due to Sam Andrews, Laura Brown and Beth Goddard who helped produce the figures.

Appendix 1 Individual survey maps showing gannet distribution in the context of the Greater Gabbard Offshore Windfarm.

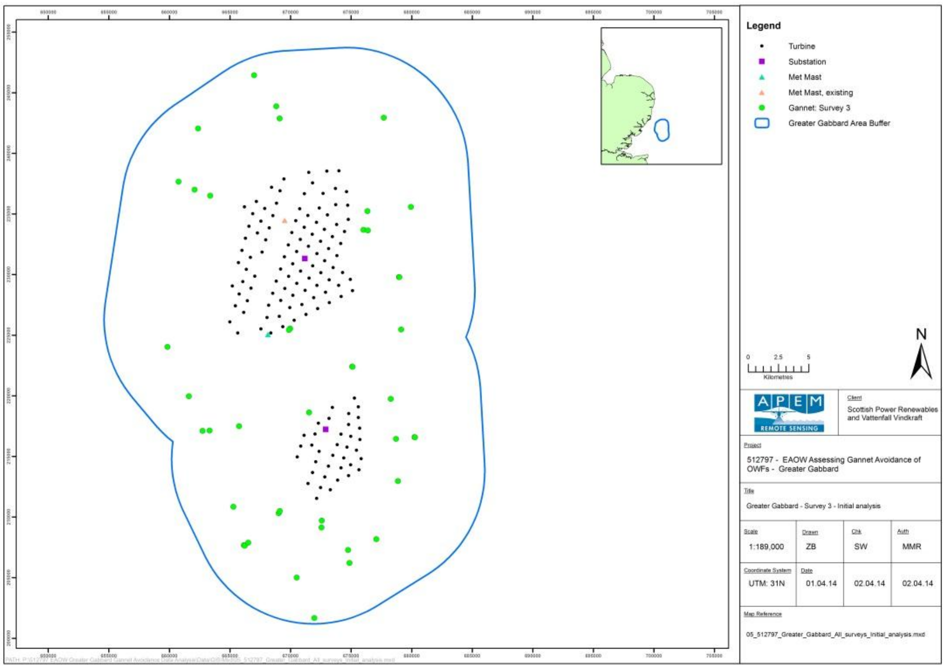
a) Survey 1



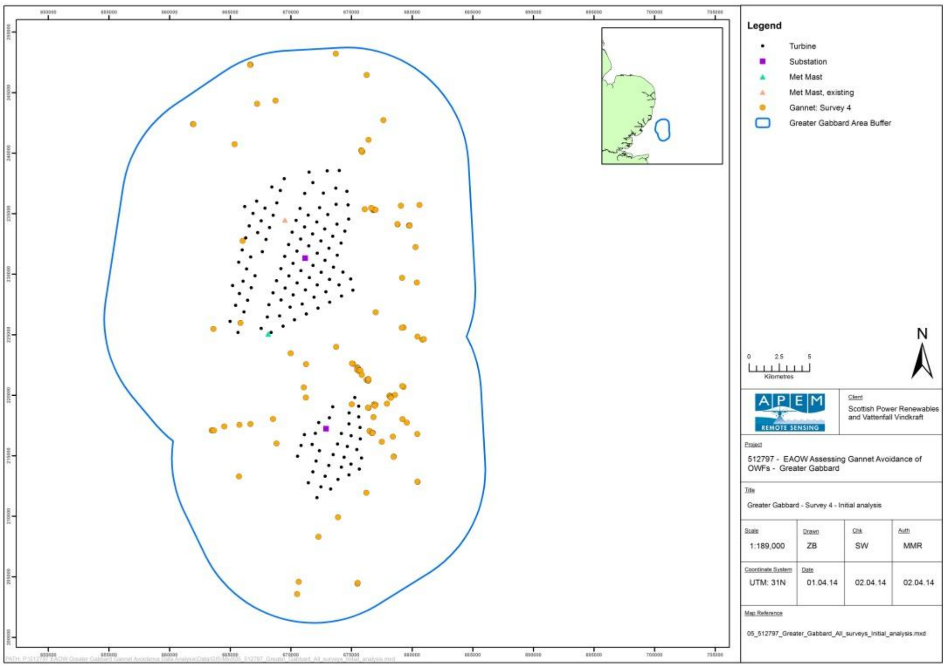
b) Survey 2



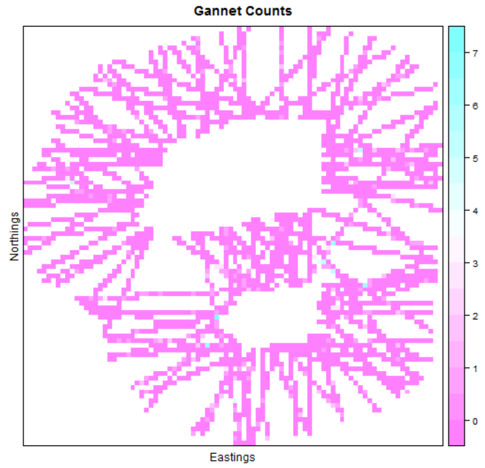
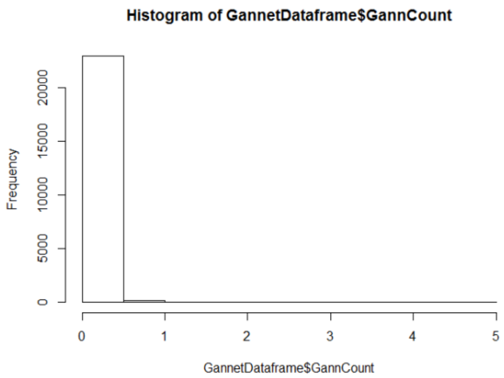
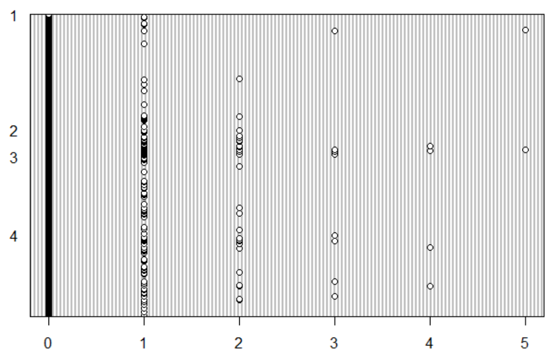
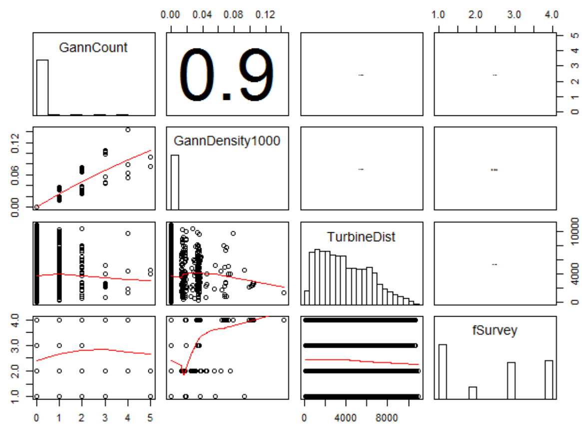
c) Survey 3



d) Survey 4



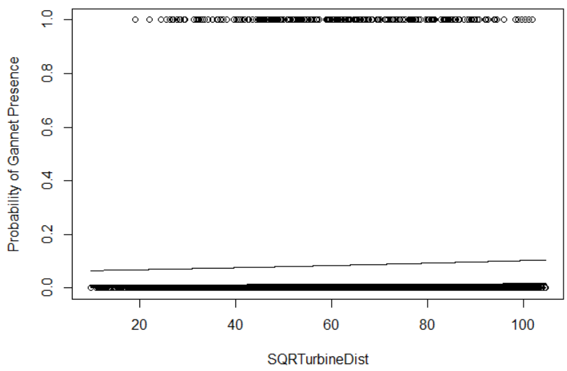
Appendix 2 Initial data exploration and model approach selection.

<table>
<tr><th>Analysis +code</th><th>Plots</th></tr>
<tr><td>Import;
> names(GannetDataframe)
"Rank" "TurbineDist" "GannCount" "Survey"
"TurbineID" "FootprintArea" "GannDensity"
"GannDensity1000" "DistBand500" "DistBand250m"
"Eastings" "Northings" "TurbFootprint"</td><td>Data level plot illustrating the images used in the analysis and the large amount of zeroes in the dataset.

</td></tr>
<tr><td>Histogram of gannet counts per image

</td><td>Gannet count per image (x-axis)by survey (y-axis)

</td></tr>
<tr><td>Note: The only practical explanatory variable is distance. Density and counts are highly correlated both could be used as response variable.</td><td>Correlation plots between variables with correlation coefficients and frequency histograms.

</td></tr>
</table>

Generalised Linear mixed-effects model (GLMM)

```
library (MASS)

M.glmm<- glmmPQL(GannCount01 ~ SQRTurbineDist, random =
~1|fSurvey, family = binomial,
data = GannetDataframe)
summary(M.glmm)

Linear mixed-effects model fit by maximum likelihood
 Data: GannetDataframe
Random effects:
 Formula: ~1 | fSurvey
       (Intercept)  Residual
StdDev:    1.088474 0.9841691

Variance function:
 Structure: fixed weights
 Formula: ~invwt
Fixed effects: GannCount01 ~ SQRTurbineDist
                      Value Std.Error    DF            t-value     p-value
(Intercept)   -4.853849 0.5813948 23182 -8.348629 0.0000
SQRTurbineDist  0.005510 0.0031019 23182  1.776255
0.0757
 Correlation:
 (Intr) SQRTurbineDist -0.329

Standardized Within-Group Residuals:
       Min          Q1          Med          Q3         Max
-0.26774588 -0.11365471 -0.08314414 -0.05528594
20.97518383

Number of Observations: 23187
Number of Groups: 4
```

Visualizing the model



The GLMM model was greatly influenced by the large amount of zeroes in the dataset.

Zero Inflated model

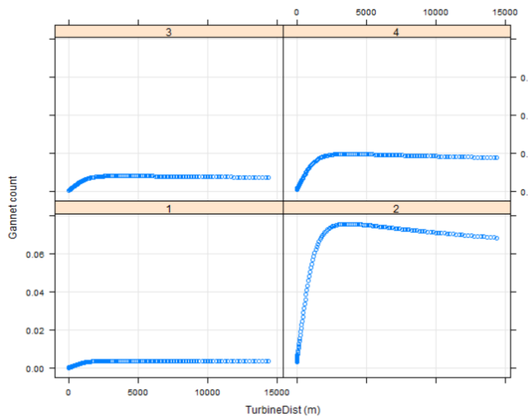
zinb

```
zinb = zeroinfl(GannCount ~ SQRTurbineDist + fSurvey |
SQRTurbineDist,
data=GannetDataframe,dist="negbin",link="logit")

summary(zinb)
Call:
zeroinfl(formula = GannCount ~ SQRTurbineDist + fSurvey |
SQRTurbineDist, data = GannetDataframe,
    dist = "negbin", link = "logit")

Pearson residuals:
    Min       1Q   Median      3Q      Max

-0.17795 -0.11810 -0.08294 -0.06016 76.97009
```

<u>Count model</u> coefficients (negbin with log link):

```
Estimate Std. Error z value Pr(>|z|)
(Intercept)  -5.397419   0.464961 -11.608  < 2e-16 ***

SQRTurbineDist -0.00198  0.005854 -0.339   0.7342
```

Visualizing the model



fSurvey2 2.953604 0.225161 13.118 < 2e-16 ***

fSurvey3 0.732523 0.243202 3.012 0.0026 **

fSurvey4 1.606030 0.214037 7.504 6.21e-14 ***

Log(theta) -2.900140 0.179019 -16.200 < 2e-16 ***

Zero-inflation model coefficients (binomial with logit link):
Estimate Std. Error z value Pr(>|z|)
(Intercept) 3.30936 1.60727 2.059 0.0395 *

SQRTurbineDist -0.12218 0.06282 -1.945 0.0518

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Theta = 0.055
Number of iterations in BFGS optimization: 52
Log-likelihood: -1456 on 8 Df

The Zero Inflated model greatly conforms the a-priory assumptions expecting reduced gannet count near the windfarm and a plateau further away indicative of gannets not affected by the presence of the turbines.