Kentish Flats Offshore Wind Farm: Diver Surveys 2011-12 and 2012-13

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Report Completed by Dr Steve Percival, Ecology Consulting

On Behalf of Vattenfall Wind Power

Ecology Consulting, Swallow Ridge Barn, Old Cassop, Durham, DH6 4QB, UK.

Email: steve.percival@ecologyconsult.co.uk

Executive Summary

Surveys of the distribution and abundance of red-throated divers at the Kentish Flats wind farm during the pre-construction, construction and post-construction phases of the wind farm have been undertaken over 10 years prior to 2011-12 and have been reported previously. This report presents an analysis of new data sets from surveys completed at Kentish Flats during 2011-12 and 2012-13.

The original statistical analysis carried out for the monitoring conducted under the FEPA licence of the effects of the Kentish Flats wind farm on bird populations utilised a BACI (before-after-control-impact) approach. However it was acknowledged in the monitoring reports that this was of relatively low power which meant that no statistically significant effect was identified although a qualitative assessment suggested an avoidance of the site by divers.

Evidence has been found of displacement of divers from within the wind farm site, with this effect apparent in all seven years of post-construction monitoring. The 2011-12 and 2012-13 results have confirmed a much reduced diver density within the wind farm, and provided further data to inform the estimation of the magnitude of that displacement. The precise magnitude of the effect is dependent on exactly which comparisons are made and whether account is taken on the variability in diver populations in the wider survey area. However, the analysis presented here suggests a displacement of between 89% (comparing recent densities within and outside the wind farm) and 94% (comparing with previous pre-construction densities).

Outside the wind farm the results are less clear. The area within 3km of the wind farm has consistently held lower densities of divers than during the pre-construction period, but there has also been a decline in divers in the survey area generally (and the extent of the control area is insufficient to enable a full BACI analysis to be undertaken, particularly in light of the high variability in numbers in that area between years). The new data from a wider survey area has enabled the geographic extent of the diver displacement to be investigated further. This new analysis suggests that comparison with the pre-construction baseline has over-estimated the displacement effect in these zones (which might be better explained by spatial and/or temporal changes in the wider diver population). The gradient analysis showed no evidence of diver displacement beyond 1km from the wind farm in 2011-12 and in 2012-13.

There was some suggestion from the 2008-09 data in particular that the magnitude of the diver displacement may be decreasing through time; divers may be habituating to the presence of the wind turbines. The 2011-12 and 2012-13 data do not however provide support to such a hypothesis of habituation, with no records at all within the wind farm in 2012-13.

As noted in the previous reports, the biological importance of diver displacement is not yet clear and needs to be addressed with reference to the context of the wider diver population within the Outer Thames Estuary. It is also important to recognise that the results for this site may not be directly applicable to other wind farm sites given the Kentish Flats wind farm's relatively small number of turbines and footprint size, and its relatively low importance for divers. It is possible, for example, that divers using a site of

greater importance/attractiveness to them may be less likely to be affected by disturbance than those at Kentish Flats.

Contents

1. Introduction

Background

Bird survey work for the Kentish Flats offshore wind farm was carried out between 2001 and 2007 using both boat based and aerial survey methods. Initially this provided baseline data for the project impact assessment and Environmental Statement [ES]. Subsequently a FEPA monitoring program through the pre-construction (2002 – 2003) and construction phase (August 2004 – August 2005) and for 3 years post-construction has been completed. The final ornithological monitoring report was produced by Environmentally Sustainable Systems Ltd [ESS], the project lead ornithological consultants, in July 2008 (Gill *et al*. 2008) which reported on the findings of the three year post-construction monitoring program.

The key ornithological issue identified at the Kentish Flats as a result of the FEPA monitoring is a possible effect on divers during the operational phase. The Thames Estuary as a whole has recently been shown to be of major international importance to this group, particularly red-throated divers, with a wintering population estimated at about 8,000 birds (O'Brien *et al*. 2008). The conclusion of the ESS monitoring report with respect to divers was that there was no evidence of any statistically significant effects of the wind farm on divers (when comparing the wind farm with the available data for the control site), although they did note an apparent displacement of divers from the operational turbine array based on a qualitative review and observations reported by the bird surveyors.

The bird monitoring required under the FEPA licence issued for the Kentish Flats wind farm site came to an end in 2008 and the final bird monitoring report has been accepted by Natural England and the Marine Fisheries Agency (MFA) so that no further statutory requirement for monitoring exists at the site. However, in recognition of the observations relating to the apparent avoidance of the turbine area by divers, Vattenfall (the owners and operators of the Kentish Flats site) has undertaken further, focused boat based surveys during the winters of 2008/2009 (Percival 2009), 2009/10 (Percival 2010), 2010/11 (reported in the Kentish Flats Extension Environmental Statement Offshore Ornithology chapter), 2011/12 and 2012/13 on a voluntary basis to further investigate this issue. This report covers the fourth and fifth of those additional winter periods.

The original statistical analysis of the effects of the Kentish Flats wind farm on bird populations utilised a BACI (before-after-control-impact) approach. However it was acknowledged in the monitoring reports that this was of relatively low power which meant that no statistically significant effect was identified. There was also an issue regarding the limited extent of the boat survey area, which made it difficult to exclude the possibility of any effect beyond the survey area boundary, and hence to define the extent of the disturbance zone.

The 2011/12 and 2012/13 surveys included an extension to the survey area to include areas at greater distance from the wind turbines than had been surveyed previously, to obtain data to enable the extent of any disturbance effect to be more precisely defined.

Objectives

The current study has allowed the application of a more powerful statistical approach using the specific recorded locations of each diver observation. Diver densities recorded in zones within and around the wind farm and their distances from wind turbine locations (before/during and after construction) have been analysed. Although limited by the extent of the survey area and the lower coverage of the control area, this approach has enabled a revised statistical analysis to be undertaken and updated conclusions to be reached that accord better with the observations made by field observers and reported in the previous monitoring reports – for a detailed account of the revised analysis of the FEPA data see Percival (2009).

The data re-analysis has shown that there has clearly been a notable decline in diver numbers within the wind farm/buffer zone following construction, at a time when the wider population (as determined from the aerial surveys) appears to have been relatively stable (as was that in the control area, albeit with a limited data set). This confirms the qualitative observations made in the previous Kentish Flats monitoring reports. There has been a statistically significant decrease in diver numbers within the wind farm site and its surrounds. There has not only been a decrease in numbers but also a shift in distribution away from the wind turbines, most markedly within 500m. The current report provides additional field data from two more winter periods to test this result further, including from a wider area around the wind farm, to examine the patterns of diver distribution and behaviour in relation to the operational wind farm. It also presents further analysis of the full pre-construction, construction and post-construction surveys, developing the statistical analyses presented previously (Percival 2010).

One of key issues with previous data was determining the geographical extent of the effect of the wind farm on divers, so in 2011-12 and 2012-13 the survey area was extended in order to investigate this question further.

There was some suggestion from previous analyses that the magnitude of the displacement may be decreasing through time; divers may be starting to habituate to the presence of the wind turbines. A key objective of the 2011-12 and 2012-13 work was therefore to obtain further data to test this hypothesis.

2. Survey Methodology

The survey methodology for 2011-12 and 2012-13 was the same as that followed in the previous three winters (Camphuysen *et al*. 2004), though with a wider spread of survey transects. In order to obtain data from a wider area around the wind turbines new transects were added to the existing ones and the existing ones were extended. To ensure that the survey could be completed within a single survey day the transect interval was increased from 1km to 2km. The extent of the survey transects and those used previously are shown in Figure 1. As noted before, the previous 1km transect separation, rather than the more usual 2km separation, meant that the potential for double-recording of mobile species such as divers was more likely. The absolute population estimates should therefore be treated with caution as they may over-estimate the actual numbers. However, for the purposes of this analysis it has been assumed that this has not led to any systematic bias in the data set.

The same surveyors were used as previously, with, as in the previous three winters, the survey scan was extended from 90 to 180 degrees, recording on both sides of the boat to increase the survey area.

The same vessel was used for the 2011-12 and 2012-13 surveys as for the pre-construction, the construction phase and the first winter's post-construction surveys, the 'Arie Dirk'. This vessel cruises the transects at about 8 knots and has a viewing height of about 5m above the level of the sea. It is ideal for the work being of a size and a manoeuvrability (with an experienced local crew) to enable safe operation close inshore and around busy shipping channels.

The survey area had been extended in 2009-10 and 2010-11 to cover a wider area around the wind farm site, primarily to provide baseline data for the extension to the wind farm (which has now been consented and is scheduled for construction during 204 and 2015), and this was further extended in 2011-12 and 2012-13.

The results for that additional area are shown in the bird distribution maps but are presented separately for the population estimates, to maintain consistency and comparability with previous surveys over the main core area that has been surveyed over a longer term.

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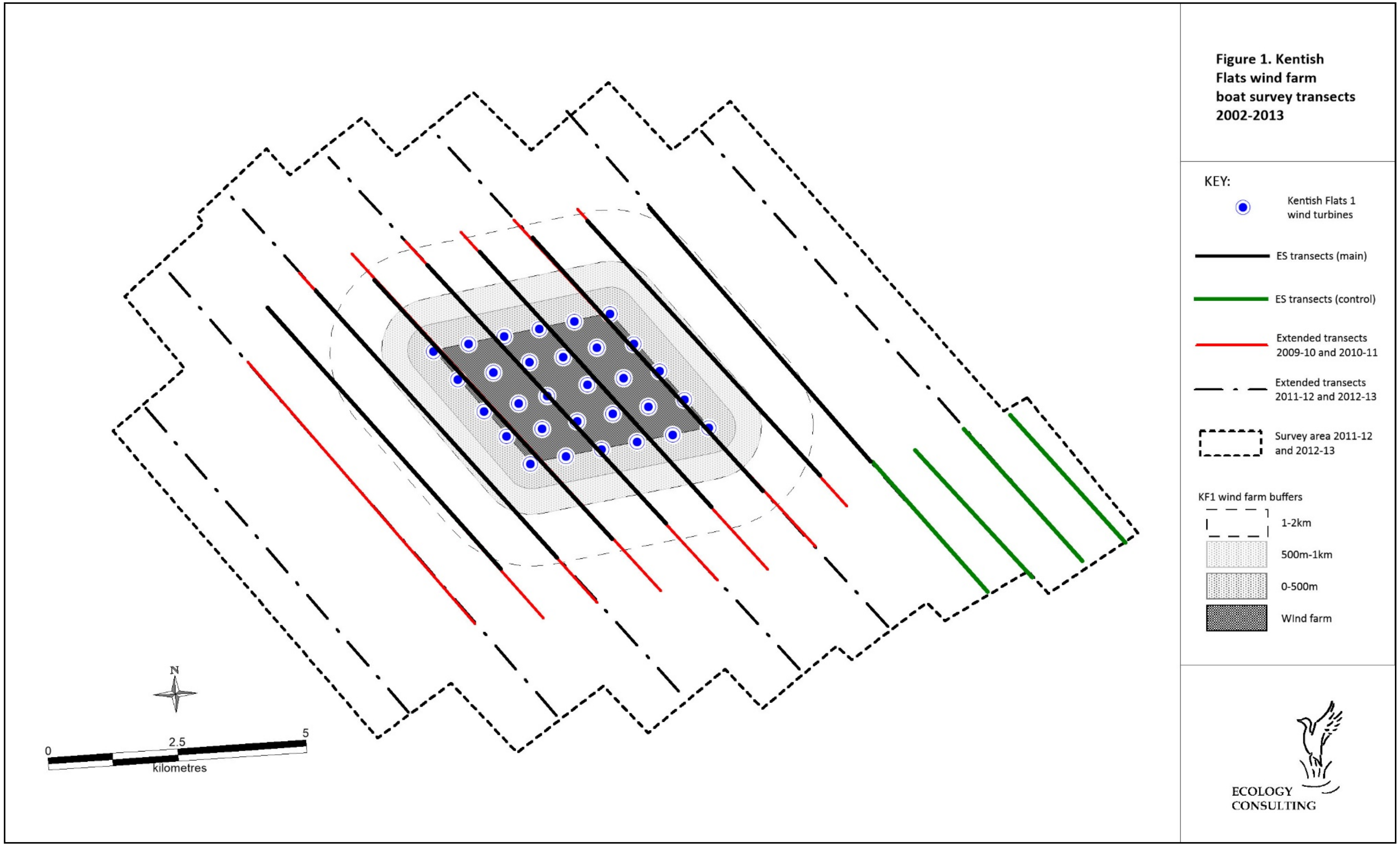

Figure 1. Kentish Flats wind farm boat survey transects 2002-2013

A total of ten surveys were carried out during October-March 2011-12. The survey dates were as follows:

- 14/10/11
- 25/10/11
- 14/11/11
- 4/12/11
- 12/12/11
- 9/1/12
- 27/1/12
- 9/2/12
- 17/2/12
- 20/3/12

A further twelve surveys were carried out during October-March 2012-13. The survey dates were as follows:

- 7/10/12
- 30/10/12
- 17/11/12
- 27/11/12
- 4/12/12
- 19/12/12
- 14/1/13
- 22/1/13
- 8/2/13
- 19/2/13
- 5/3/13
- 18/3/13.

3. Data Analysis

The initial analysis presented in this report followed the same analytical strategy as in the 2008-09 and 2009-10 report. This sought to address the specific questions of:

- How have diver numbers changed following construction of the wind farm?
- How has diver distribution changed and is this continuing to change through time?

The diver population estimates have been presented for the four main zones that have been surveyed at this site:

- The main core wind farm plus buffer, '*Main'* – surveyed throughout including ES baseline – shown in Figure 1 as black transects ('*ES transects (main)*');
- The ES control area, '*Control'* - surveyed throughout including ES baseline – shown in Figure 1 as green transects ('*ES transects (control)*');
- The 2009-10 extended area, '*Ext0910*' – surveyed since the 2009-10 winter – shown in Figure 1 as red transects; and
- The 2011-12 extended area, '*Ext1112*' – surveyed in 2011-12 and 2012-13 only – shown on Figure 1 as dot and dashed black line.

One key principle in these analyses was to maximise the use of the information contained within the raw data, for example by using raw diver locations rather than just transect summaries.

Mean diver abundance was calculated for each wind farm zone/buffer (wind farm, 500m, 1km, 2km, 3km and control) each period to provide an initial visual summary of the data.

Additional analysis has been introduced in this report, using smaller-scale sampling to undertake more detailed statistical testing. The analysis for the initial post-construction monitoring (ESS 2008) used the transect as the sampling unit but this lacked statistical power through small sample size (only 8 longer transects through the wind farm site plus buffer and 4 shorter ones in the control area), high variability between counts and fact that transects included range of distances from the wind farm. This design does not allow for examination of changes in bird abundance in relation to distance from the wind farm, as each transect was aligned to pass through the wind farm and the buffer zones (to 2-3km from the site). Therefore to aid the spatial analysis and help determine if there were any relationships between changes in bird abundance and proximity to the wind farm, each transect was sub-divided into 500m segments. End sections of each transect of less than 500m were discarded from the analysis. The 500m distance was chosen using professional judgement to give a reasonable sample unit whilst at the same time sufficiently high spatial precision for the analysis. This enabled much better spatial precision of the analysis to be undertaken, but did introduce the potential issue of spatial autocorrelation between samples. This was taken into account in the analysis using a Generalised Least Squares statistical modelling approach (Zuur *et al*. 2009), with the location of each transect sub-section – easting and northing – incorporated as explicit spatial variables.

A GIS (MapInfo) was used to extract bird numbers in each 500m transect sub-section from the main survey database, summed over each survey year (one pre-construction, one construction and three post-construction) and standardised as the mean diver density per survey visit in each year (to take into count different numbers of surveys in each season), for the main diver season (October-March). This mean density estimate per 500m sub-section of transect was use in the further analysis as an index of bird abundance.

A gradient analysis was undertaken for each of the two years for which the wider surveys were carried out, 2011-12 and 2012-13, testing the null hypothesis of no difference in bird abundance across each wind farm zone/buffer up to 6km from the wind farm at 1-km intervals (to provide a sufficient sample within each zone). As above the 500m sub-sections of each transect were used as the sample unit, taking into account spatial correlation as described above. This analysis had the considerable advantage that it was less affected by wider changes in diver distribution and abundance, so has the potential to provide a more robust assessment of the effects of the wind farm on divers. Previous analyses (Percival 2010) had been unable to definitively determine the extent of the zone over which divers were displaced by the wind farm, as the survey area then had extended to only 2-3km from the wind turbines and an effect beyond that distance could not be discounted. However data from the wider extended survey area covered during 2011-12 and 2012-13 enabled the extent of the displacement zone to be more precisely investigated.

4. Survey Results

5.1 Diver distribution and abundance 2011-12 and 2012-13

The diver distribution maps (based on the raw sightings) from the 2011-12 and 2012-13 boat surveys are shown in Figure 2. The main concentration of divers in 2011-12 was found on the western edge of the survey area, with a fairly even lower density across most of the rest of the survey (though with few sightings within the wind farm itself). In 2012-13 the larger diver flocks were more widely scattered, though with no sightings at all within the wind farm and fewer in the northern part of the survey area than in the southern part.

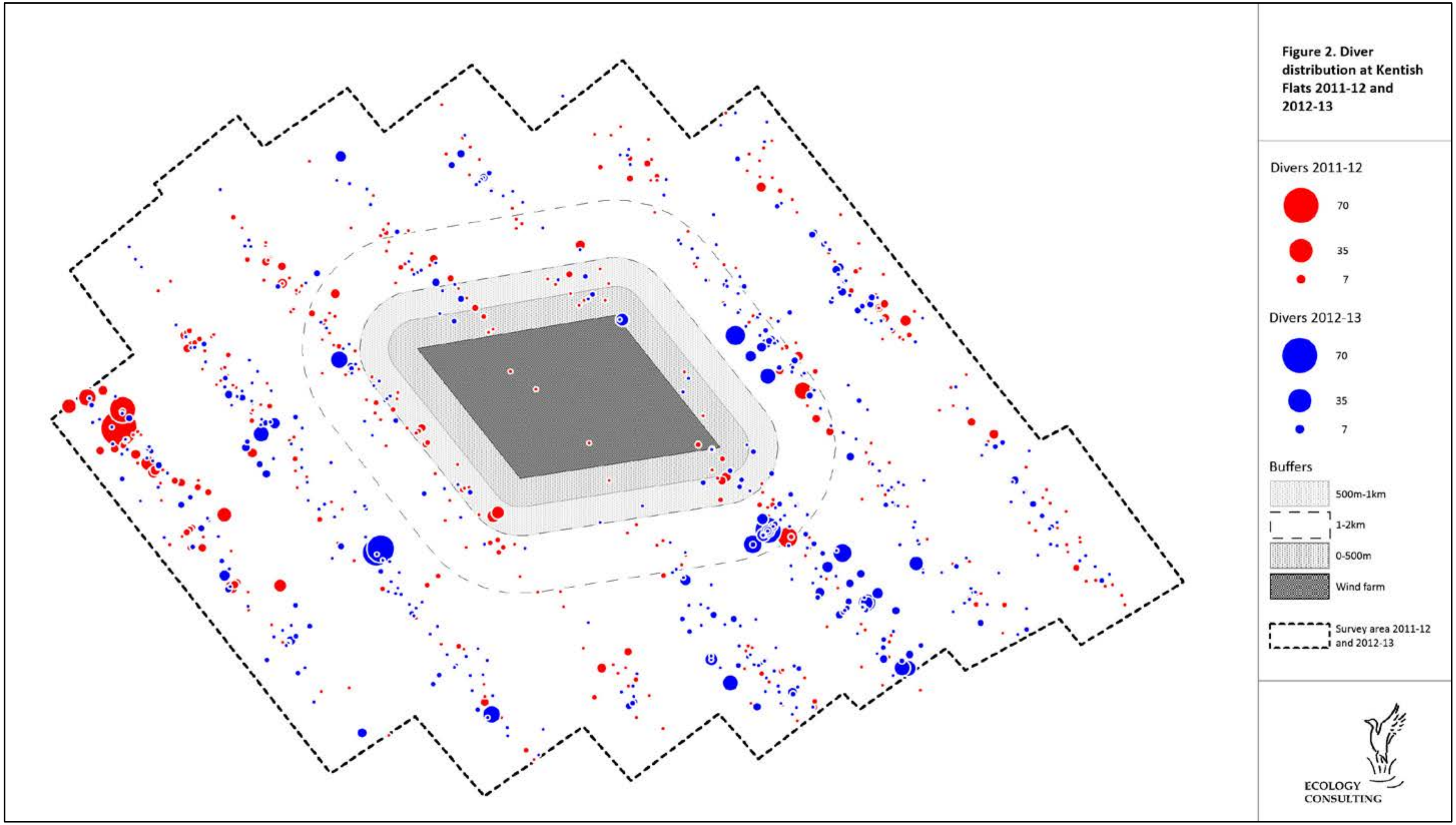
Figure 2. Diver distribution at Kentish Flats 2011-12 and 2012-13
Divers 2011-12
70
35
7
Divers 2012-13
70
35
7
Buffers
500m-1km
1-2km
0-500m
Wind farm
Survey area 2011-12 and 2012-13
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As found previously, a very high proportion (98%) of all of the divers that were identified to species in 2011-12 and 2012-13 were red-throated divers. The remainder of the identified divers were black-throated.

The population estimates in each area based on the 2011-12 and 2012-13 survey data are summarised in Figures 3 and 4 for each winter respectively. These Figures shows the estimated diver population for each survey for each of these areas. As previously these numbers have been calculated using correction factors to allow for survey coverage and for declining detectability of birds at increasing distance from the survey vessel (calculating the distance correction factors in the same way as previously (Percival 2009, 2010). The population estimates and the further analysis have all used data recorded within 300m of the survey vessel. Diver numbers were highly variable through both winter periods, as found in previous years.

As well as the main and control areas that have been surveyed since the ES baseline surveys, Figures 3 and 4 also shows the population estimates for the extended survey areas surveyed in 2009-10 and 2011-12 for the first time. The 2011-12 extension to the survey area held more divers than the other parts of the survey area in both 2011-12 and 2012-13.

Figure 3. Diver population estimates for the 2011-12 surveys, showing the estimated numbers within the 'Main' wind farm plus buffer, 'Control' area and in the 2009-10 ('Ext0910') and 2011-12 ('Ext1112') survey area extensions.

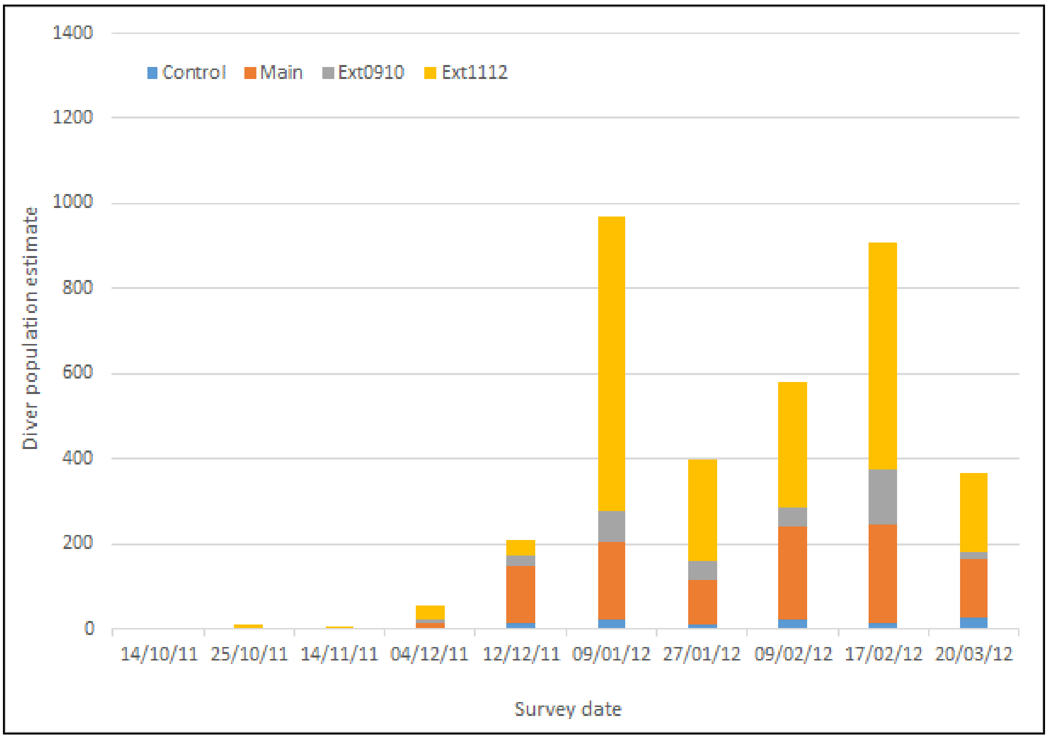
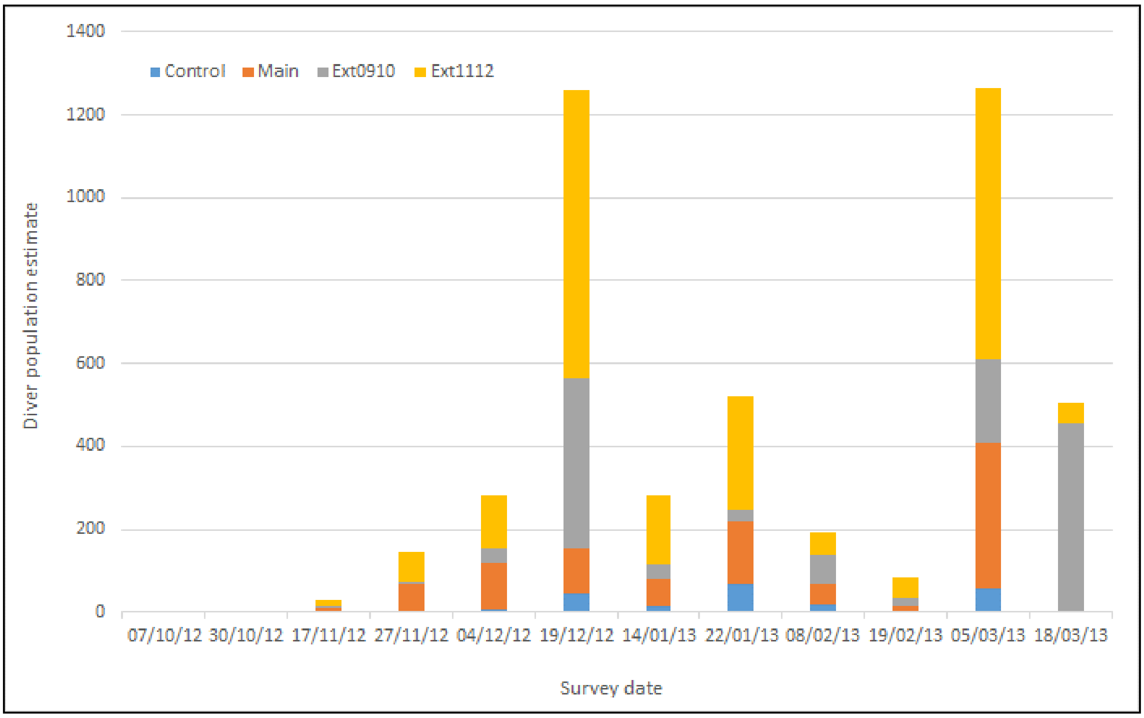


Figure 4. Diver population estimates for the 2012-13 surveys, showing the estimated numbers within the 'Main' wind farm plus buffer, 'Control' area and in the 2009-10 ('Ext0910') and 2011-12 ('Ext1112') survey area extensions.



5.2 *Effects of the Wind Farm on Diver Distribution and Abundance*

Diver Population Changes

The mean and peak diver counts through the main diver period (Nov-Mar) are summarised in Table 1 for the main core wind farm/buffer area and for the control area that have been surveyed since the ES baseline. There has been a marked drop in diver numbers in the main core wind farm/buffer study area since the construction of the wind farm and this has continued into 2011-12 and 2012-13 (though mean and peak counts were higher than in 2010-11).

Table 1.Mean and peak diver population estimates for the main core wind farm/buffer and control areas, 2002-2013.

Winter	Phase	Main core wind farm + buffer		Control	
		Mean	Peak	Mean	Peak
2002-03	Pre	482	2125	42	187
2003-04	Pre	189	503	4	17
2004-05	Construction	533	1914	11	49
2005-06	Post	90	382	17	60
2006-07	Post	99	281	12	47

Winter	Phase	Main core wind farm + buffer		Control	
		Mean	Peak	Mean	Peak
2008-09	Post	76	140	81	343
2009-10	Post	80	189	20	53
2010-11	Post	20	48	4	7
2011-12	Post	126	230	15	26
2012-13	Post	88	354	22	70

There has clearly been a decline in diver numbers within the main core wind farm/buffer zone following construction (albeit with large fluctuations between years). The numbers were higher in 2012-12 and 2012-13 than in the previous three winters, but were still considerably lower than recorded in the pre-construction and construction phase winters. This adds further evidence to the qualitative observations made in the Kentish Flats monitoring reports prior to the 2008-09 season and to the analysis presented in the 2008-09 (Percival 2009) and 2009-10 (Percival 2010) reports. The higher numbers recorded in the Control area in 2008-09 were not observed in any subsequent years (numbers rather returned to their more usual lower level). The limited extent of the Control area and the relatively low numbers of divers using it (apart from in 2008-09) mean that a full BACI analysis of the effects of the wind farm has not been possible.

Diver Distribution in relation to the Wind Farm

Previous analysis of the spatial pattern of the changes in diver distribution and abundance in relation to the wind farm used the following zones: wind farm footprint and buffers of 500m, 1km, 2km and 3km. Though data were obtained from a wider area (up to 6km from the wind farm) in 2011-12 and 2012-13, initial comparison has been made with these previous analyses to 3km, updating these results to include that data from these two more recent winters.

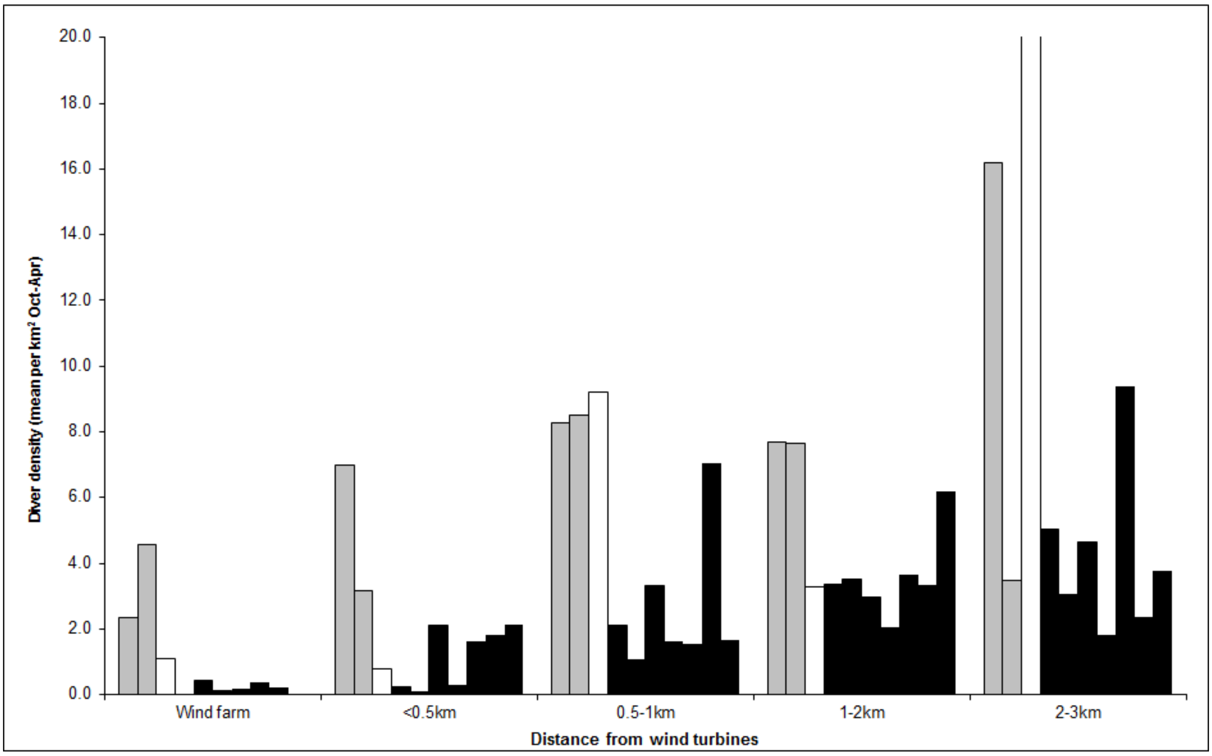
Table 2 gives the diver densities (population estimates standardised for the area in each buffer zone to give a mean density per km^2) observed in each of the buffer zones and the proportionate change in diver density observed in each during the pre-construction, construction and post-construction periods. Densities during the construction phase declined in the zones within 500m of the wind turbines and in the 1-2km zone, with higher numbers recorded in the 0.5-1km and 2-3km zones. Densities recorded during the post-construction surveys have been rather lower across the whole survey area, though with the greatest magnitude of that decline highest within the wind farm.

Table 2. Diver densities (number per km²) in each of the wind farm buffer zones during the pre-construction, construction and post-construction periods, and the percentage change from the pre-construction baseline.

Period	**Wind farm**	**0-0.5km**	**0.5-1km**	**1-2km**	**2-3km**
Pre-construction	3.5	5.1	8.4	7.7	9.8
Construction	1.1	0.8	9.2	3.3	48.0
Post-construction	0.2	1.2	2.6	3.6	4.3
% change from pre-construction baseline densities					
Construction	-68%	-84%	10%	-57%	388%
Post-construction	-94%	-77%	-69%	-53%	-56%

The diver densities from each of the distance zones around the wind farm from each survey year are shown in Figure 5.

Figure 5. Diver densities across each of the zones up to 3km from the Kentish Flats wind farm during the pre-construction (grey bars), construction (white bars) and post-construction (black bars) periods.



Diver Proportionate Distribution in relation to the Wind Farm

An alternative way to explore the effects of the wind farm is to look at the proportionate distribution of birds across these zones. This takes into account differences in overall numbers between years by analysing the proportion of diver records from each of the buffer zones rather than the counts/densities. For each zone the population estimates are expressed as a proportion of all of the records from within the study area.

Table 3 summarises the diver proportionate distributions observed in each of the buffer zones and the percentage change in those proportions observed in each during the pre-construction, construction and post-construction periods. The percentage of diver records from within the wind farm has declined from 9% pre-construction to only 2% during construction and post-construction. This represents a reduction by 79% from the pre-construction value during construction and by 82% from the pre-construction value during the post-construction period. Substantial percentage declines were also recorded in the 0-0.5km buffer zone around the wind farm (10% of records prior to construction, 1% and 5% during construction and post-construction respectively). This represents a reduction by 89% of the pre-construction value during construction and by 47% from the pre-construction value during the post-construction period. The changes more than 500m from the wind farm are rather lower, though the results do suggest a smaller-scale reduction up to 1km from the wind farm (where the percentage of diver records has dropped by 24% of the pre-construction baseline during construction and by 10% post-construction). Beyond 1km no decline in the proportionate distribution was apparent during the post-construction period.

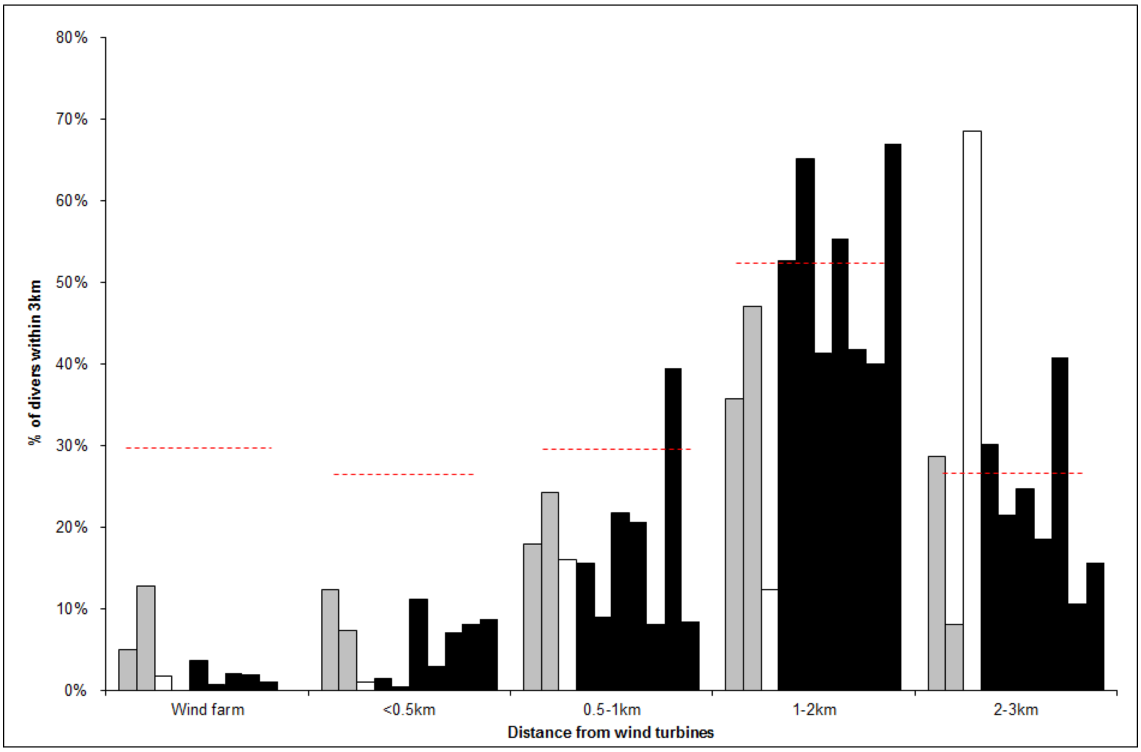
These changes in the proportionate distribution are considered here to be more robust than the changes in density (Table 2) as they are less sensitive to changes in the overall diver numbers in the region. Table 3 shows a decrease in diver numbers within the wind farm site and its surrounds, and this has continued through to 2012-13. There has not only been a decrease in numbers but also a shift in distribution away from the wind turbines, most markedly within 500m.

Table 3. The proportions of diver records in each of the wind farm buffer zones during the pre-construction, construction and post-construction periods, and the percentage change in those proportions from the pre-construction baseline.

Period	**Wind farm**	**0-0.5km**	**0.5-1km**	**1-2km**	**2-3km**
Pre-construction	9%	10%	21%	41%	18%
Construction	2%	1%	16%	12%	69%
Post-construction	2%	5%	19%	49%	24%
% change from pre-construction baseline proportions					
Construction	-79%	-89%	-24%	-70%	272%
Post-construction	-82%	-47%	-10%	19%	33%

The proportionate distributions of divers from each of the distance zones around the wind farm from each survey year are shown in Figure 6.

Figure 6. Diver proportionate distribution across each of the zones up to 3km from the Kentish Flats wind farm during the pre-construction (grey bars), construction (white bars) and post-construction (black bars) periods. Red dashed lines indicate the % that each zone comprises of the survey area.



The analyses of both the diver densities and proportionate distributions both show diver declines within 1km of the wind farm and the greatest reductions with the wind farm. However the reduction in diver density recorded post-construction out to the 2-3km zone means that, despite the proportionate distribution results, a displacement effect beyond 1km could not be ruled out (primarily as a result of the limited spatial extent of the ES survey area). The survey area was therefore extended further in 2011-12 and 2012-13, to obtain data on diver distribution and abundance at greater distance from the wind farm and enable the spatial extent of the observed displacement effect to be investigated in more detail.

Spatial Distribution of Divers in relation to Distance from Wind Turbines

Analysis was undertaken of the spatial distribution of diver records in relation to distance from the wind turbines (within the main core wind farm plus buffer survey area covered for the pre-construction baseline surveys, up to 3km from the wind turbine locations). If the birds were displaced then one would expect that distance to increase after the turbines had been constructed. For this analysis the control area data have been excluded due to the reduced coverage of the surveys in that area and so that the analysis focussed more closely on the area in proximity to the wind farm. The results summarised in Table 4 show that divers were found significantly further from the turbines during the construction and post-construction surveys (ANOVA F=7.36, $p_{9,1501}<0.001$). Pairwise comparisons showed that the post-construction diver distances from turbines were significantly greater than pre-construction for all of the years compared, apart from 2010-11 (when that difference was not quite statistically significant at p>0.05). The mean distance to a series of random points is also given for comparison.

The surveys since 2009-10 had shown a lower reduction in the mean distance from the earlier post-construction surveys, suggestive of an increasing tolerance of the turbines, but the most recent year, 2012-13, had the greatest mean distance from the turbines distance of all.

Table 4. Distances between diver records and the wind turbine locations during the pre-construction, construction and post-construction phases.

Period	Mean distance from turbines (km)	Standard error	95% confidence limits
Pre-construction (2002-03)	1.21	0.05	1.12-1.3
Pre-construction (2003-04)	1.11	0.05	1-1.21
Construction (2004-05)	1.33	0.05	1.23-1.43
Post-construction (2005-06)	1.48	0.08	1.32-1.64
Post-construction (2006-07)	1.52	0.06	1.4-1.64
Post-construction (2008-09)	1.51	0.06	1.39-1.63
Post-construction (2009-10)	1.40	0.06	1.29-1.51
Post-construction (2010-11)	1.32	0.10	1.12-1.52
Post-construction (2011-12)	1.40	0.06	1.29-1.51
Post-construction (2012-13)	1.61	0.06	1.49-1.73
Random points	1.09	0.04	1.01-1.17

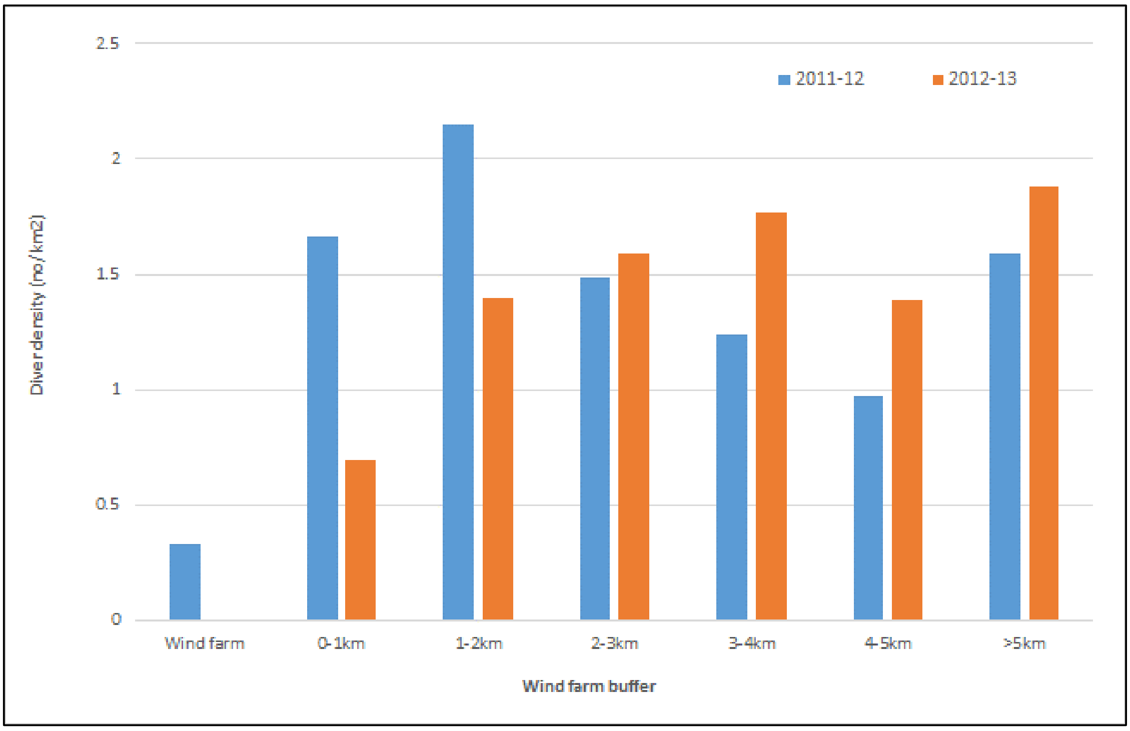
Diver densities in relation to the wind farm: wider 2011-12 and 2012-13 survey gradient analysis

The median diver densities within the wind farm and in 1-km buffers from the site, calculated from the transect segment (500m) data for 2011-12 and 2012-13 are shown in Figure 7. Transect segments from within the main shipping channels have been excluded as these have been shown to support reduced diver densities (Percival 2011).

A non-parametric analysis of variance (Kruskal-Wallis) was used to test the null hypothesis of no difference between these median diver densities between zones for each of the two wider survey years. This showed there to be a statistically significant difference in diver density between the zones in both 2011-12 (H_6= 24.3, p<0.001) and 2012-13 (H_6= 22.5, p=0.001).

In 2011-12 reduced diver densities were only observed within the wind farm. The 0-1km and 1-2km buffers around the wind farm actually held higher diver densities than the more distant buffer zones. In 2012-13 a reduced diver density was also observed in the 0-1km zone. Comparing the diver densities recorded within the wind farm with those in the more distance (>3km) buffer zones gave reductions of 74% in 2011-12 and 100% in 2012-13, or 89% combining the results from the two winters.

Figure 7. Median diver density per 500m transect segment in relation to wind farm and buffer zones, 2011-12 and 2012-13.



N.B. *The column for 2012-13 for the wind farm zone is blank because the median diver density in that zone in that year was zero.*

Analysis of the spatial structure of the data showed that both the 2011-12 and 2012-13 data exhibited some spatial autocorrelation between adjacent samples though with a greater effect in 2011-12 (Moran's I test, p<0.001 in 2011-12 and p=0.04 in 2012-13). A more detailed statistical analysis was therefore undertaken, to take into account this spatial autocorrelation using a Generalised Least Squares statistical modelling approach (Zuur *et al*. 2009), with the location of each transect sub-section – easting and northing – incorporated as explicit spatial variables. Again, as above transect segments from within the main shipping channels have been excluded from the analysis. This modelling yielded a similar result to the previous non-parametric analysis for 2011-12, with a statistically significant difference in diver density between zones ($F_{6,130} = 4.55$, $p<0.001$). For 2012-13, however, the result was not statistically significant ($F_{6,130} = 1.15$, $p=0.34$). This was considered to result from high variability within the data and small sample sizes (particularly within the wind farm) that resulted from sampling at a 2-km separation rather than the previous 1-km inter-transect distance.

Previous analyses looking at the proportionate distribution of the divers had suggested that displacement effects of the wind farm on the divers may be minted to a 1km buffer around the wind farm (Table 3). However the area even within 3km of the wind farm has consistently held lower densities of divers than during the pre-construction period, and there has been a decline in divers in the survey area generally (and the extent of the control area is insufficient to enable a full BACI analysis to be undertaken, particularly in light of the high variability in numbers in that area between years). The new data from a wider survey area has enabled this to be investigated further. They suggest that comparison with the pre-construction baseline has over-estimated the displacement effect in these zones (which might be better explained by spatial and/or temporal changes in the wider diver population). The diver density in the 0-1km zone in 2011-12 was actually higher than elsewhere in the survey area, though lower in 2012-13. When the analysis was restricted to locations outside the wind farm, no significant difference in diver density between zones was found, using non-parametric analysis of variance (2011-12: $H_5 = 6.0$, $p=0.31$; 2012-13: $H_5 = 6.2$, $p=0.29$). There is therefore no statistically significant evidence of displacement outside the wind farm from this gradient analysis in either year.

5. Conclusions

The analysis of the 2011-12 and 2012-13 data collected at Kentish Flats has shown that the decrease in diver numbers within the wind farm site has continued into the sixth and seventh winters since construction.

Evidence has been found of displacement of divers from within the wind farm site, with this effect apparent in all seven years of post-construction monitoring. The 2011-12 and 2012-13 results have confirmed a much reduced diver density within the wind farm, and provided further data to inform the estimation of the magnitude of that displacement. The precise magnitude of the effect is dependent on exactly which comparisons are made and whether account is taken on the variability in diver populations in the wider survey area. However, the analysis presented here suggests a displacement of between 89% (comparing recent densities from most recent two winters within and outside the wind farm) and 94% (comparing all of the post-construction data with the previous pre-construction densities).

There had previously been some indications of an increased use of the area in proximity to the wind turbines compared with previous post-construction years (particularly in 2008-09) and it was thought that this may indicate that the divers were starting to habituate to the presence of the wind turbines. However use of the wind farm site by divers continued to be very low in 2011-12 and 2012-13 and did not support this hypothesis.

An important question with regard to the local effect of the Kentish Flats wind farm on divers (displacing divers from the wind farm site and its surrounds) is its context in the wider Outer Thames Estuary SPA diver population. The area affected is very small as a proportion of the area used by divers (the wind farm plus a 500m buffer occupies only 0.004% of the Outer Thames SPA), and the aerial survey results suggest that Kentish Flats is not particularly important for divers (with a density of 2.1 divers per km^2, compared with densities of 1.6 per km^2 over the SPA as a whole, up to a peak of 14.8 per km^2 in more preferred parts of the SPA, Percival 2011). This displacement effect is therefore probably negligible in the context of the Outer Thames diver population as a whole but further investigation would be needed to test this hypothesis. Further monitoring data from other offshore wind farms should also provide useful data to address this question, though methods for that monitoring should be tailored to obtain the best possible data on divers.

Studies of divers at existing offshore wind farms have also reported displacement from the wind farms but to a varying degree. At Horns Rev I very few divers were found within the wind farm after construction, during a three-year monitoring programme (Petersen *et al*. 2006) and a reduction in density was reported up to 2km from the wind farm. The same publication also reported a reduced diver utilisation of areas within 2km of the Nysted wind farm after construction. A further study of the Horns Rev 2 wind farm (Petersen *et al*. 2014) reported possible diver displacement 5-6km from that wind farm (though this was based on density surface modelling that actually showed reduced diver density in the post-construction period lower to a rather improbable 13km from the wind farm, suggestive that factors other than the wind farm may have been contributing to the observed redistribution from the wind farm).

Post-construction monitoring at the Egmond aan Zee wind farm project (Leopold *et al*. 2010) has not found any significant effects on divers, though that wind farm is located outside the divers' main preferred areas.

Post-construction monitoring of the Thanet offshore wind farm (Percival 2013) found a similar result to that at Kentish Flats, with a clear reduction in diver numbers within the wind farm site following construction (with a mean reduction of 73% from the pre-construction level over the three post-construction years). Outside that wind farm, however, no evidence was apparent of any reduction from the pre-construction level.

The Kentish Flats diver data have also been the subject of a research project under the Crown Estate's Strategic Ornithological Support Services (SOSS) programme (Rexstad and Buckland 2012). That project adopted a density surface modelling approach and suggested a lower abundance of diver in the north-eastern portion of the study area (approximately 2km from the wind farm), but did not identify any significant diver displacement within the wind farm site or its surrounds.

As noted in previous reports on the Kentish Flats site, it is also important to recognise that the results for this site may not be directly applicable to other wind farm sites given the Kentish Flats wind farm's relatively small number of turbines and footprint size, and its relatively low importance for divers. Divers using a site of greater importance/ attractiveness to them may be less likely to be affected by disturbance than those at

Kentish Flats. Differences in susceptibility to disturbance in relation to resource availability have been noted in other bird-wind farm interactions. For example, foraging barnacle geese have been reported as being displaced from as far as 600m from wind turbines on farmland habitat in winter (Kowallik and Borbach-Jaene 2001) yet birds from the same population feed as close as 25m to turbines during spring staging on Gotland (Percival 1998), where the birds are feeding on a much scarcer and more nutritionally valuable saltmarsh habitat in proximity to wind turbines. Displacement from less preferred feeding sites may more readily occur than from more important foraging areas (where birds may be more tolerant of the presence of the wind turbines).

The planned post-construction monitoring of the Kentish Flats Extension (following installation of an additional 15 wind turbines to the south and west of the existing Kentish Flats wind farm scheduled for 2014 and 2015) will enable further monitoring of the effects of the Kentish Flats wind farms on the divers. The Extension has a more comprehensive pre-construction baseline data set than the original wind farm, collected over a longer period of time and over a wider survey area, so this should enable the interaction between divers and wind farm to be better understood.

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