London Array Ltd

London Array offshore wind farm

Aerial survey methods, data collection and statistical analysis

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1 Introduction

This report summarises the findings of aerial surveys of the proposed London Array Ltd. offshore wind farm site, and associated control zones, for birds and marine mammals. Surveys were undertaken between November 2009 and May 2010 by APEM. The aim of this project was two-fold: firstly, to demonstrate the appropriateness of our aerial method for offshore surveys, and secondly to provide data describing the distribution and association of birds and marine mammals within and around the proposed wind farm site, with particular focus on the red-throated diver (also referred to here as RTD), *Gavia stellata*. The red-throated diver is listed under Annex I of the EU Birds Directive (79/409/EEC) as being a rare or vulnerable species, meaning that EU member states are obligated to identify and designate key areas of habitat used by the species as Special Protection Areas (SPAs). Sites supporting 1% or more of the Great Britain population of an Annex I species are automatically considered for SPA designation (Stroud *et al.* 2001)[1].

Importance of the Outer Thames Estuary for red-throated divers

During the non-breeding season, red-throated divers aggregate in often large groups in offshore areas. The importance of the Outer Thames Estuary as such a location for the species was first realised in 1989, with later aerial surveys undertaken for the DTI by the Wildfowl & Wetlands Trust (2005/06 – 2006/07), some as part of investigations for London Array, recording as much as 38% of the GB wintering population. Over the wider Greater Thames area, from Norfolk to Kent, estimates of 8,130 red-throated divers have been made, representing 47% of the national estimate (O'Brien *et al.* 2008)[2]. This led the statutory agencies to move towards protecting the area, based on the exceedance of the 1% critierion. The Outer Thames Estuary is thus currently a potential Special Protection Area (pSPA) for red-throated diver, covering over 390,000 ha of offshore habitat between Kent and Norfolk.

Methodological background

Described below is the methodology for monitoring the pre-construction distribution and abundance of birds and marine mammals within the London Array site (Figure 1). The methodology used has been developed by APEM to provide robust data, sufficient to meet the requirements of the Food and Environment Protection Act (FEPA) 1985, though surveys are not intended solely for this purpose. However, this report is an investigation of survey methodology and survey areas; it is not a FEPA monitoring or baseline report and does not need to present abundance and distribution of birds by species.

The survey approaches adopted as part of this project make reference to accepted guidance in this field particularly in relation to bird monitoring aerial surveys including guidance produced by COWRIE, Department for Environment Food and Rural Affairs (DEFRA), Countryside Council for Wales (CCW) and Joint Nature Conservation Committee (JNCC). A workshop hosted in 2009 by the British Trust for Ornithology (BTO) and attended by several bodies such as The Crown Estate (TCE), COWRIE, APEM Ltd, Natural England (NE), CCW, the Royal Society for the Protection of Birds (RSPB), JNCC and St. Andrews University amongst others, identified the minimum appropriate resolution and methodology necessary to

[1] Stroud, D.A., Chambers, D., Cook, S., Buxton, N., Fraser, B., Clement, P., Lewis, I., McLean, I., Baker, H. & Whitehead, S. 2001. *The UK SPA Network: its scope and content*. Vols 1 – 3, JNCC, Peterborough.

[2] O'Brien, S.H., Wilson, L.J., Webb, A. & Cranswick, P.A. 2008. Revised estimate of wintering Red-throated Divers *Gavia stellata* in Great Britain. Bird Study *55*, 152-160.

undertake high-resolution digital stills and visual survey approaches. It was also recommended that improvements are incorporated as technology evolves.

1.1 Traditional survey approach (visual and digital)

Traditional approaches to surveying offshore populations of birds have included shore- and boat-based surveys and more recently, the use of conventional distance sampling (CDS) from aircraft. The aerial CDS approach involves flying transects within the area of interest, with trained observers identifying bird species and estimating abundance across four pre-defined ‘distance’ bands. These extend laterally from the aircraft on either side so that one observer covers port and one starboard. Distance bands range from 44-1000 m from the aircraft; therefore, transects are separated by 2 km so that approximately 96% of the area may be assessed. The area underneath the aircraft, from the flightline out to 44 m, is not visible by the observers and results in ~96% coverage. CDS uses several parameters including the size of the region (*A*), the number of flocks (detections), the effort (length of transect searched), search region half-width (i.e. 1 km) and the expected flock size to form a framework for a detection function model. When fitted to those parameters, the expected flock size in the region is estimated from a regression of probability of detection taking into account the difficulty of seeing either small flocks or single birds.

There are several limitations to this approach including questionable detection beyond the two distance bands adjacent to the aircraft (i.e. beyond 282 m). Observers commonly scan for a pre-determined ‘search image,’ namely the size, shape and colouration of the species of interest, e.g. red-throated diver. Consequently, observers may greatly underestimate the presence of non-target bird species and thus, may also underestimate the importance of a region (habitat) to those non-target species. These limitations are exacerbated by the fact that no permanent record is created, allowing no scope for secondary assessment. However, perhaps most importantly, the dangers associated with flying at 76m and potential collision risks[3] are considered unacceptably high.

1.2 Digital stills approach

With the advent of digital stills cameras, all of the limitations of visual approaches can be overcome. There are significant benefits which include:

- a permanent record;
- removal of subjectivity;
- statistical analysis;
- geo-referencing of bird positioning; and
- quality assurance.

APEM collects digital stills imagery typically at a resolution of 3 cm *Ground Sampling Distance* (GSD) for aerial bird surveys. Each image covers an area of approximately 31,000 m^2 and birds can be identified to group (*e.g.* auk, diver, seaduck) and to species (*e.g.* red-throated diver). A coarser resolution of 7 cm (GSD) may also be adopted allowing birds to be

[3]The introduction of Met Masts within offshore areas has introduced a potentially significant collision risk - the height of a Met Mast is below the legal requirement for Civil Aviation Authority (CAA) notification and are not required for inclusion on aeronautical charts.

enumerated over a larger area (~169,000 m^2); however, this resolution does not allow birds to be identified to group or species level.

1.3 Population estimates using traditional survey approaches

First attempts were aimed at replicating the CDS approach by flying 2 km transects, but replacing observers with digital cameras and focusing solely on the inner two distance bands (i.e. truncating the data set for distances <282 m). However, there are some potentially important limitations of using the CDS approach in developing population estimates from digital data.

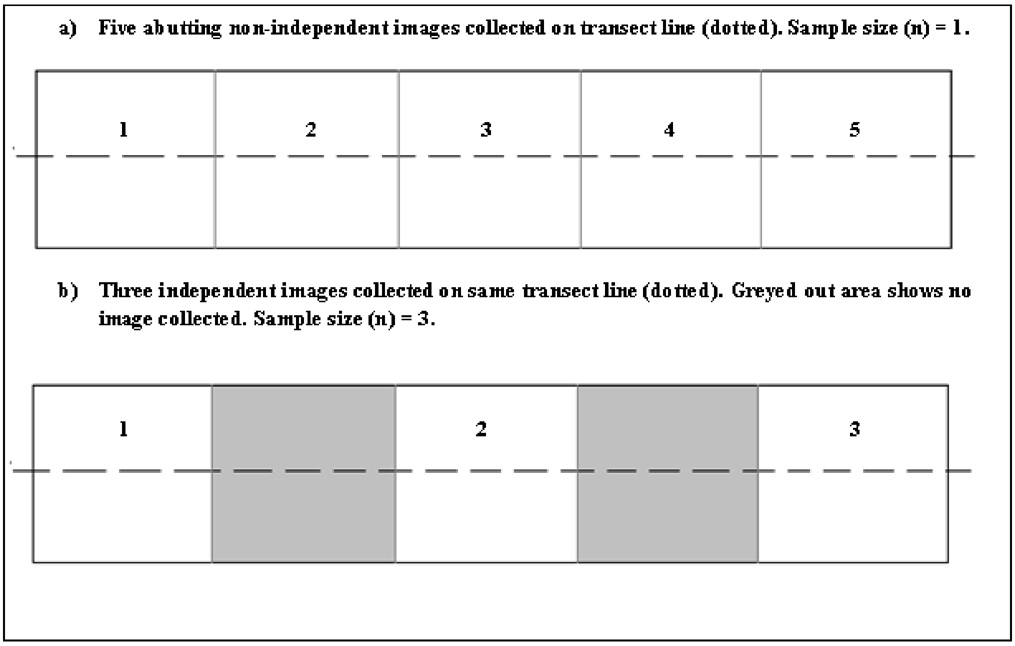
1.4 Spatial autocorrelation and independence of data

Transects are ‘built-up’ from multiple digital still images abutting one another. While each transect is comprised of multiple ‘sample’ images, each is spatially autocorrelated with the next. As such, each image cannot be considered to provide an independent estimate of the density of birds within that area (the size of the image) and all images collected from that transect, whether it be 10 or 10,000, must be considered as one. Therefore, the sample unit of the area is at the *transect* level *e.g,.* if eight transects are required to survey a given area, then there are eight replicate transects. This greatly constrains the number of samples and in turn reduces the statistical power of the analysis, *i.e.* our ability to confidently detect potential changes in population size, such that bird abundances are likely to be over- or underestimated – particularly for bird species that display highly patchy distributions.

1.5 APEM aerial surveys - survey design

To address the limitation of using transect data in the development of population estimates, APEM developed an alternative approach, with refinements from Dr Eric Rexstad (St. Andrews University Research Unit of Wildlife Population Assessment Centre (RUWPAC)). Returning to first principle ecological sampling techniques, APEM developed a grid survey methodology; a primary aim of which is to derive sufficient independent estimates of bird density (and distribution) to achieve a predefined level of confidence (*a priori*) of population size. A fundamental component of this approach is that sampling unit is at the *image* level, each of which provides an independent estimate of bird density for the survey region. For example, if a section of a transect contains five digital images, then under a transect approach, these data would provide only a single estimate of bird populations. Under a grid approach however, these images would provide three independent estimates as long as the images are not abutting (see example below). Therefore, far more independent images (and thus samples) are generated from a grid than would be for the same area with transects.

This greatly enhances the statistical power of estimates, while reducing the number of images required in comparison to CDS methods, resulting in greater confidence in the findings of the data and reflecting a more accurate estimate of the population. It is assumed that the grid coarseness is sufficiently large to ensure that flocks of birds do not occur in multiple images.



1.6 Confidence and precision of estimates

When comparing population estimates between sampling sites and/or time periods, there is a relationship between sample size and the level of detectable difference in population estimates. Bohlin[4] developed a class system of varying levels of precision and identifiable change, using *CV* as the index of dispersion (Elliott 1977[5]), whereby:

- Class 1 studies require a high degree of precision, corresponding to detecting a population change factor as small as 1.2. This level of precision corresponds to a coefficient of variation (*CV*) not larger than ~0.05.

- Class 2 studies require an intermediate level of precision, corresponding to detecting a population change factor as small as 1.5. This corresponds to a *CV* no larger than 0.10.

- Class 3 studies require a lower level of precision, corresponding to detecting a population change factor as small as 2. This corresponds to a *CV* no larger than 0.16.

Class 3 is considered to be the minimum level necessary and is the basis for the design of the national fish monitoring programmes and the impact assessment monitoring programmes of the Environment Agency. Although detecting a doubling or halving of the population is not as sensitive as a Class 1 or Class 2 change, from a practical perspective a higher level of precision, especially for a single species alone such as red-throated diver, is unlikely to be achieved by any current method.

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[4] Bohlin, T. (1990) Estimation of population parameters using electric fishing: aspects of the sampling design with emphasis on salmonids in streams. In: Cowx, I.G. and Lamarque, P. (eds.) *Fishing with electricity*, Fishing News Books, Oxford, pp 156-173.

[5] Elliott, J.M. (1977) *Some methods for the statistical analysis of samples of benthic invertebrates.* Freshwater Biological Association, Scientific Publication no. 25.

The pilot study tested the number of images required to achieve the required precision, as defined by the recent COWRIE workshop (Thaxter & Burton 2009[6]; i.e. $CV < 0.16$), for the gridded HR method.

2 Methods

The design of aerial surveys for the London Array area and adjacent control zone (Figure 1) was developed to record all bird species but with a particular focus on assessment of red-throated diver. This species is the qualifying feature of the Outer Thames Estuary pSPA and likely to be the ornithological focus of any future EIA.

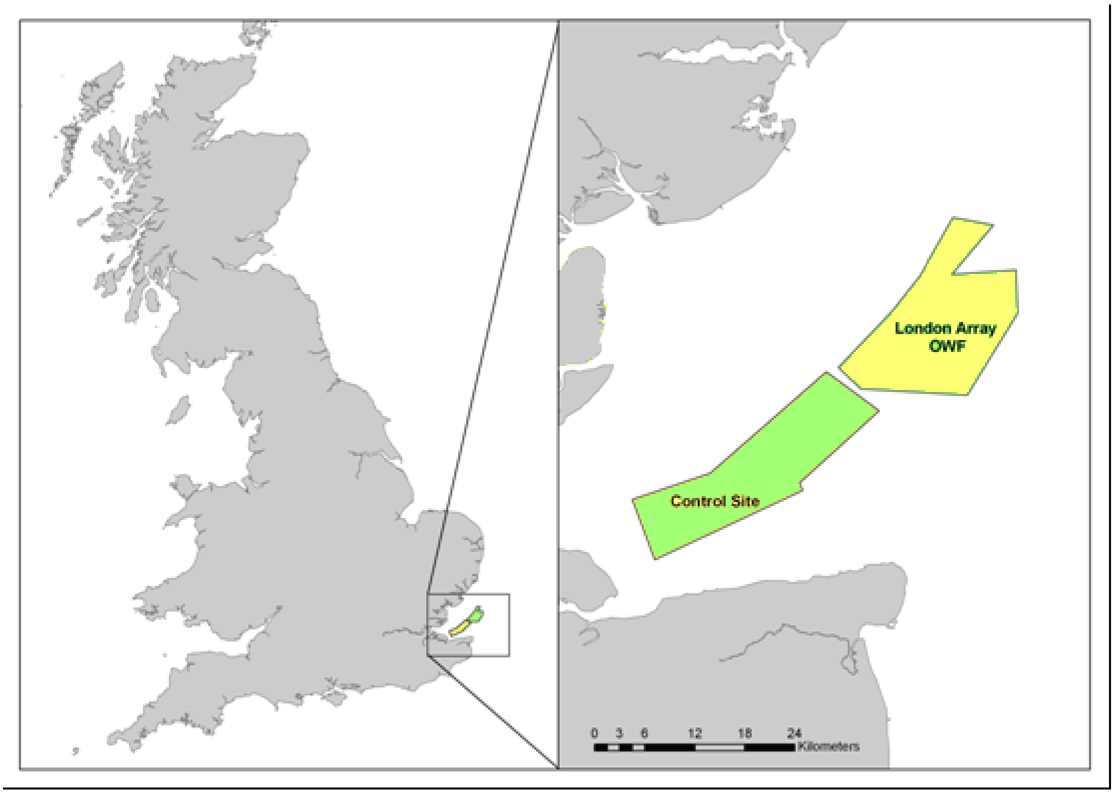

Figure 1. Layout of London Array proposed site (yellow polygon) and control site (green polygon), in the Thames Estuary. The control site was selected based on proximity to the proposed offshore wind farm.

The principal survey period was between November 2009 and April 2010, coinciding with non-breeding season movements of red-throated divers to marine areas around the UK. These pre-construction surveys were designed to ensure that the data generated are compatible with previous aerial survey data from local, regional and national offshore wind farm sites and were gathered using the standard visual aerial survey methodology[7].

[6] Thaxter, C. B.and N.H.K. Burton (2009) High Definition Imagery for Surveying Seabirds and Marine Mammals: A Review of Recent Trials and Development of Protocols. British Trust for Ornithology Report Commissioned by Cowrie Ltd.
[7] Camphuysen, C.J., *et al*. (2004) Towards standardised seabird at sea census techniques in connection with environmental impact assessments for offshore wind farms in the UK: a comparison of ship and

2.1 Pilot study (November 2009)

Grid spacing determination

The precision of a population estimate using any survey method is determined by two components; the distribution (and abundance) of birds within the survey region, and the sample size (number of images). A pilot study was undertaken in November 2009 to provide an initial assessment of the distribution of birds within the Outer Thames Estuary region. These data allowed an initial assessment of the coarseness (spacing) of grid (an image is collected at each grid internode) required to achieve a predefined level of confidence (target *CV* of < 0.16).

Pilot study methods

The pilot study of the London Array area adopted a preliminary grid spacing of 750 m (equivalent to 602 sample images) and images were collected from one of three zones. Each image was assessed by trained observers and the presence and abundance of birds and cetaceans present within each image was recorded. A bootstrap (with replacement) approach was used to generate a random sample from the 602 images collected. This process was repeated for all combinations of images *i.e.* using 1 of 602 images, 2 of 602 images up to the inclusion of all 602 images in the sample, and resulting in 602 mean estimates. This is a stochastic process (mean estimates change with each recalculation of the data sheet). Markov Chain Monte Carlo (MCMC) simulations were used to estimate the precision surrounding each mean associated with each sample size. A total of 1000 iterations (simulations) were run for the mean estimate.

For the purposes of the pilot study, images were analysed for the principal species of interest, namely red-throated diver.

Pilot study results

A total of 771 red-throated divers were recorded within the 602 images collected from the London Array area (Figure 2). 602 images represent approximately 8% of the London Array (including control) area using 3 cm resolution imagery. A total of 7525 images would be required to achieve 100% coverage of the region.

Monte Carlo simulations of the population data indicated the likelihood of encountering red-throated divers within each image was 1.3 ± 0.4 (Table 1). Assessment of distribution data (number of red-throated diver per image) suggested an even distribution of red-throated diver throughout the survey area (Figure 2).

As a result of the even distribution of red-throated divers throughout the London Array region, an accurate estimate of the population mean *i.e.*, ~1.3 red-throated diver per image, was achieved using only a small proportion of the total images collected (Figure 3). The pilot data suggested that approximately 100 images were required to estimate accurately red-throated diver densities for the region. However, the precision of the estimate was poor when

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aerial sampling methods for marine birds, and their applicability to offshore wind farm assessments. NIOZ report to COWRIE.

a low number of images were used in mean estimates (Figure 3). For example, if 100 images were used to generate mean density estimates, the confidence limits would range from between 0.44 and 2.50 red-throated diver per image (Figure 3). As the number of images included in the estimate increases, the precision surrounding the estimate also increases, up to a maximum precision of 1.3 ± 0.4, where all sample image red-throated diver counts were included in the mean estimate (Table 1. Pilot study Red-throated diver abundance (8% coverage) and population extrapolation estimates for the London Array area. Data are mean ± 95% CL derived from Monte Carlo simulations (*n* = 1000).).

Table 1. Pilot study Red-throated diver abundance (8% coverage) and population extrapolation estimates for the London Array area. Data are mean ± 95% CL derived from Monte Carlo simulations (*n* = 1000).

	RTD	Population (8%)	Extrapolation (100%)
Mean	1.3	766	9579
+CL	1.76	1061	13263
-CL	0.89	533	6663

Pilot study recommendations - grid spacing revision

The findings of the pilot study suggested that the number of images collected were sufficient to allow a mean population estimate with sufficient precision for the purposes of enumerating red-throated diver in the Outer Thames Estuary. In fact, it was considered that the number of images could be reduced by ~50% whilst retaining an acceptable level of precision around the mean estimate (Figure 3). A 50% reduction in image number corresponded to an increase in grid coarseness from 750 m to 1000 m. This grid spacing was adopted for the following survey (Survey 1-main survey).

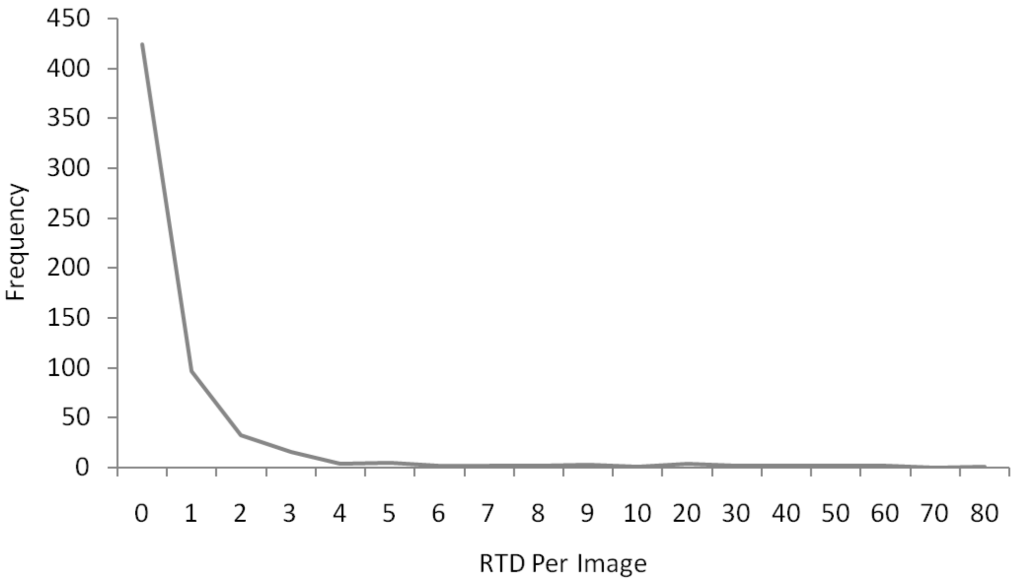

Figure 2. Frequency histogram of red-throated diver distribution within a sample image in the pilot study area (*n* = 602).

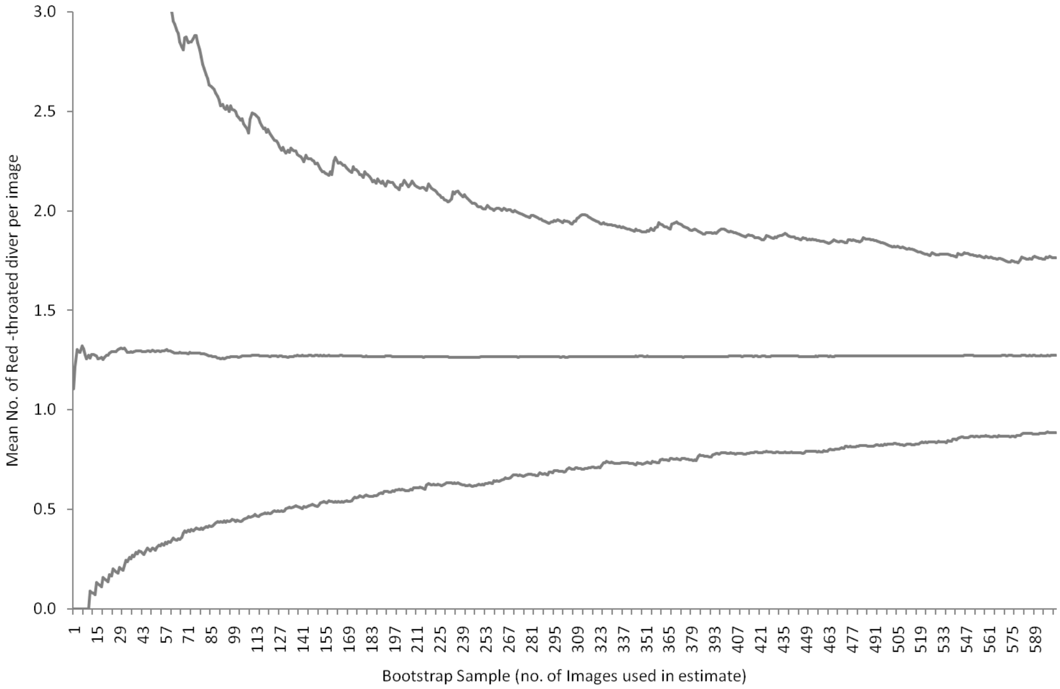

Figure 3. Red-throated diver. Monte Carlo simulation (1000 iterations) estimating the mean (± CL) number of birds within an image based on a bootstrap sample of the pilot study data (*n*=602).

2.2 Comparison survey

As part of this project, comparison surveys were undertaken to contrast and compare aerial survey data collected using digital stills technology and standard conventional distance sampling (CDS) approach. There were several aims of the comparison survey:

- determine the efficacy of digital stills and visual approaches in identifying bird and marine mammals;
- compare population estimates of red-throated diver and other bird species derived from digital stills and visual survey approaches;
- assess the precision of grid-based digital stills and visual survey approaches for the London Array area;
- determine if data collected using digital stills and visual survey approaches are cross-comparable.

A workshop hosted by the BTO and attended by several bodies such as The Crown Estate (TCE), COWRIE, NE, CCW, RSPB, JNCC and St. Andrews University amongst others, identified that image resolution and survey design were of primary concern for the accurate and effective assessment of bird populations using aerial digital imaging[6]. The main findings of the workshop suggested a minimum image resolution of 5 cm was sufficient to identify (speciate) birds and that traditional transect methods (while appropriate for visual survey methods) were not an effective use of resources in terms of providing statistically robust data for digital stills methods.

The three different survey types (below) are flown at different altitudes and therefore result in the generation of images at different resolutions:

1. High altitude / lower resolution (7 cm GSD);
2. High Resolution (HR) gridded (3 cm GSD); and
3. Standard visual (low altitude).

There is an increased chance of disturbing (flushing) the birds when flying at low altitude, particularly when as low as 76 m used for standard visual surveys. Therefore, the highest altitude surveys were flown first and the lowest altitude last. The order in which each of the methods appear above were the order in which they were flown on the days of the comparison survey(s).

It was important that the three survey types were conducted over the same area within a short time period (i.e., within a day or two days) in order to minimise spatial and temporal variation. The comparison survey was initially planned to be undertaken in conjunction with the first main survey undertaken in December 2009.

2.3 Inclement Weather

Unexpectedly severe weather over the winter of 2009/2010 meant that it was not possible to complete the comparison survey as described above (Plate 1). A consistently low cloud base (<1500ft) prevented the high-altitude survey from being undertaken; the high-altitude approach requires a minimum cloud base of ~1800ft. As such, comparison surveys were undertaken in conjunction with all main surveys (see below).

Plate 1. Inclement winter weather in 2009/2010.

2.4 Population estimates - data extrapolation

Population estimates for control and offshore wind farm zones were derived using different methods for each survey approach.

7 cm high-altitude digital stills

No extrapolation of data is required for 7 cm imagery, as this survey approach represents total coverage of a survey area and therefore, absolute (total) counts – effectively a census of bird numbers.

3 cm high-resolution grid digital stills

The grid survey has been designed so that each image represents a *random* and *independent* sample of the survey area. The number of replicates (images) within a sample of the area using the grid survey design is determined by the coarseness (spacing) of the grid. For example, using a 1 km grid survey design, only 540 images are collected within the offshore wind farm zone. However, a total of 8079 images would be required for 100% cover of the offshore wind farm zone based on the resolution and footprint size of APEM's 3 cm imagery. Given that each image represents an independent sample of the survey zone, data from digital stills imagery can be collated to generate a mean estimate (and associated precision around that mean; *CV*) for an image in that zone (based on 540 counts). The mean estimate is then multiplied up (extrapolated) as if 100% of the images had been collected.

Standard visual approach

Population estimates using data collected using the standard visual survey approach are derived using conventional distance sampling (CDS) analysis (Buckland *et al*. 2001[8]). The CDS methodology is implemented using the program Distance 6 (Thomas *et al*. 2009[9]) and estimates bird abundance ($\hat{N}$) using the following function:

$$\hat{N} = A\frac{n}{2L\hat{\mu}}\hat{E}[s]$$

where *A* is the size of the study region, *n* is the number of detected flocks, *L* is the length of transects searched, $\hat{\mu}$ is the effective search half-width (esw) and $\hat{E}[s]$ is the expected flock size. The esw is obtained from a detection function model fitted to the distribution of perpendicular distances. The expected flock size is obtained from a regression of probability of detection against the logarithm of flock size.

Based on the fitted model from the data, density can be estimated throughout the region of interest, and variance of the abundance (*CV*) is obtained using a bootstrap simulation approach.

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[8] Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L., & Thomas, L. (2001). *Introduction to Distance sampling: Estimating abundance of biologicalpopulations.* OUP, Oxford.

[9] Thomas, L., Laake, J.L., Rexstad, E., Strindberg, S., Marques, F.F.C., Buckland, S.T., Borchers, D.L., Anderson, D.R., Burnham, K.P., Burt, M.L., Hedley, S.L., Pollard, J.H., Bishop, J.R.B. and Marques, T.A. (2009). Distance 6.0. Release 1. Research Unit for Wildlife Population Assessment, University of St. Andrews, UK. http://www.ruwpa.st-and.ac.uk/distance/

2.5 Main study

APEM undertook four main surveys as part of the initial London Array aerial surveys in December 2009, January 2010, February 2010 and April 2010 in the Outer Thames Estuary. The surveyed zones corresponded to the proposed location of the offshore wind farm (Zone 1) and a control area, which was arbitrarily divided into two smaller sub-zones (Zones 2 and 3) to allow greater flexibility in the advent of inclement weather (Figure 4). However, for all population estimates, both control sub-zones are considered as one single combined zone. The area of the control and offshore wind farm zones were approximately equal at 228 km^2 and 249 km^2 respectively.

Due to inclement weather conditions, all surveys were affected in some way. The breakdown of survey effort for each of the four surveys is shown in the relevant figures below.

2.5.1 Survey 1

The first main survey was undertaken in December 2009 and as described above, inclement weather (low cloud base) prevented the collection of high altitude imagery (7 cm) from all zones, and 3 cm grid data from the offshore wind farm zone (Figure 4 and Table 2). As such, digital stills imagery was collected from the control zones and visual survey data from all zones.

Population estimates

A total of 52 birds, eight of which were red-throated diver, were recorded within the control zone using digital stills imagery over effectively 4% of the total survey area. In contrast, 82 birds, 55 of which were red-throated diver, were recorded using the standard visual survey approach over effectively 96% of the total survey area. In the offshore wind farm zone, a total of 79 birds (59 red-throated diver) were recorded (Table 3). No marine mammals were recorded during this survey.

Absolute count data (Table 3) were extrapolated to provide a population estimate, equivalent to 100% coverage of the control for 3 cm digital stills imagery data, and using conventional distance sampling procedures (CDS) for the visual survey approach (Table 3). Population estimates using only red-throated diver absolute count data were similar when derived from either digital stills or visual survey approaches (501 and 479 red-throated diver respectively; Table 4). In contrast, population estimates including all bird species using the visual survey approach were lower in comparison to the digital stills approach (Table 4). Population estimates using CDS predicted approximately 39% of the total birds estimate using the digital stills approach (Table 4; All Birds).

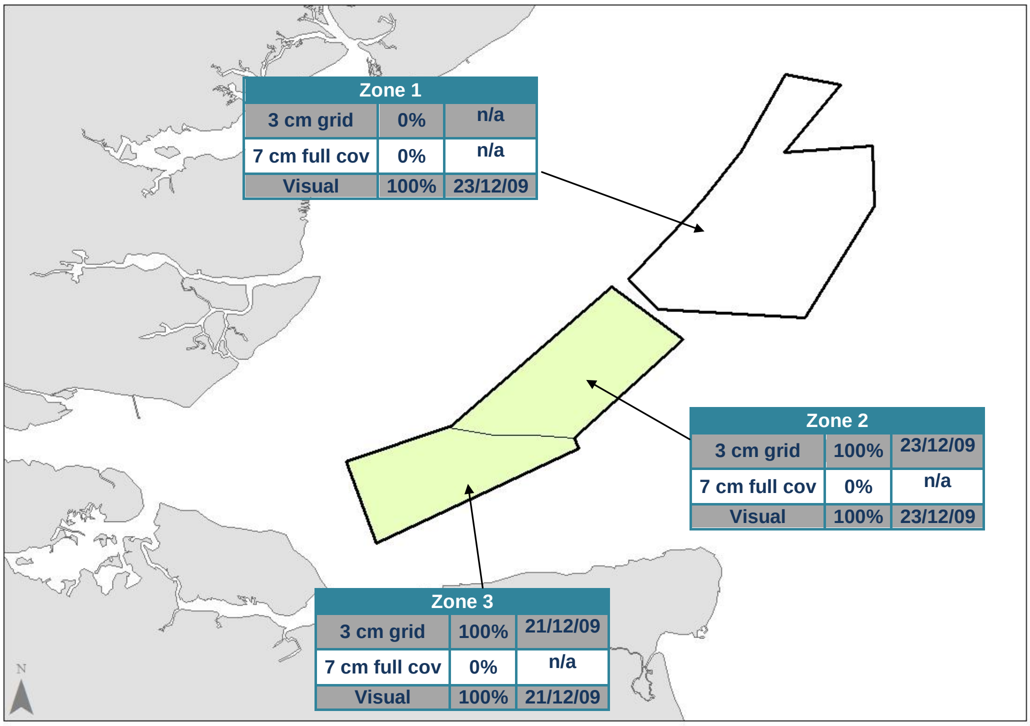


Figure 4. Survey 1. London Array offshore wind farm and control site (sub-divided into two halves). Coloured areas indicate locations where 3 cm digital stills imagery was collected.

Table 2. Summary of survey effort for Survey 1.

Survey Approach	Zone 1	Zone 2	Zone 3
7 cm high altitude	×	×	×
3 cm high resolution	×	100%	100%
Standard visual	100%	100%	100%

Table 3. Red-throated diver and All bird species. Absolute counts (abundance) of bird species recorded within the London Array offshore wind farm and control zones.

Survey 1	OWF (Zone 1)		Control (Zone 2 & 3)	
Approach/Species	All Birds	RTD	All Birds	RTD
3 cm (HR) grid	×	×	52	8
Standard visual	79	59	82	55

Table 4. Red-throated diver and All bird species. Population estimates (abundance) of bird species within the London Array offshore wind farm and control zones. Estimates are extrapolated as described in *Population estimates - data extrapolation* (see above).

Survey 1	OWF (Zone 1)		Control (Zone 2 & 3)	
Approach/Species	**All Birds**	**RTD**	**All Birds**	**RTD**
3 cm (HR) grid	×	×	1559	501
Standard visual	558	420	602	479

Population estimate precision

The population estimates derived from 3 cm digital still and visual survey approaches result in a mean value (e.g. number of red-throated diver per image) and a level of confidence (precision) surrounding that mean estimate. A Coefficient of Variation (*CV*) of less than 0.16 was the pre-determined level of precision for offshore aerial surveys of bird and marine mammal populations. A *CV* of 0.16 is a level of precision suitable for detecting a *halving* or *doubling* of the population.

The *CV* of the population estimates derived from digital stills and visual surveys data are shown in Table 5. The target *CV* (< 0.16) was not achieved when a 1 km grid survey design or the visual survey approach was used for either all birds or red-throated diver only population estimates (Table 5). A 750 m grid survey design was simulated to assess if a finer survey grid would provide an increased level of precision around the population estimate. This indicated that the target *CV* for the population estimate for all birds would be achieved (*CV* = 0.10) if a 750 m grid spacing had been used (Table 5); however, for estimates of red-throated diver, the target *CV* would still not be met (*CV* = 0.58).

Table 5. Red-throated diver and All bird species. Coefficient of variation (*CV*) of population estimates derived from digital stills (1 km and 750 m grid) and visual survey data for the London Array offshore wind farm and control zones.

Survey 1	OWF (Zone 1)		Control (Zone 2 & 3)	
Approach/Species	**All Birds**	**RTD**	**All Birds**	**RTD**
3 cm (HR) 1 km grid	×	×	0.22	0.67
3 cm (HR) 750m grid	×	×	0.10*	0.58
Standard visual	0.17	0.22	0.19	0.29

* indicates target *CV* < 0.16 met

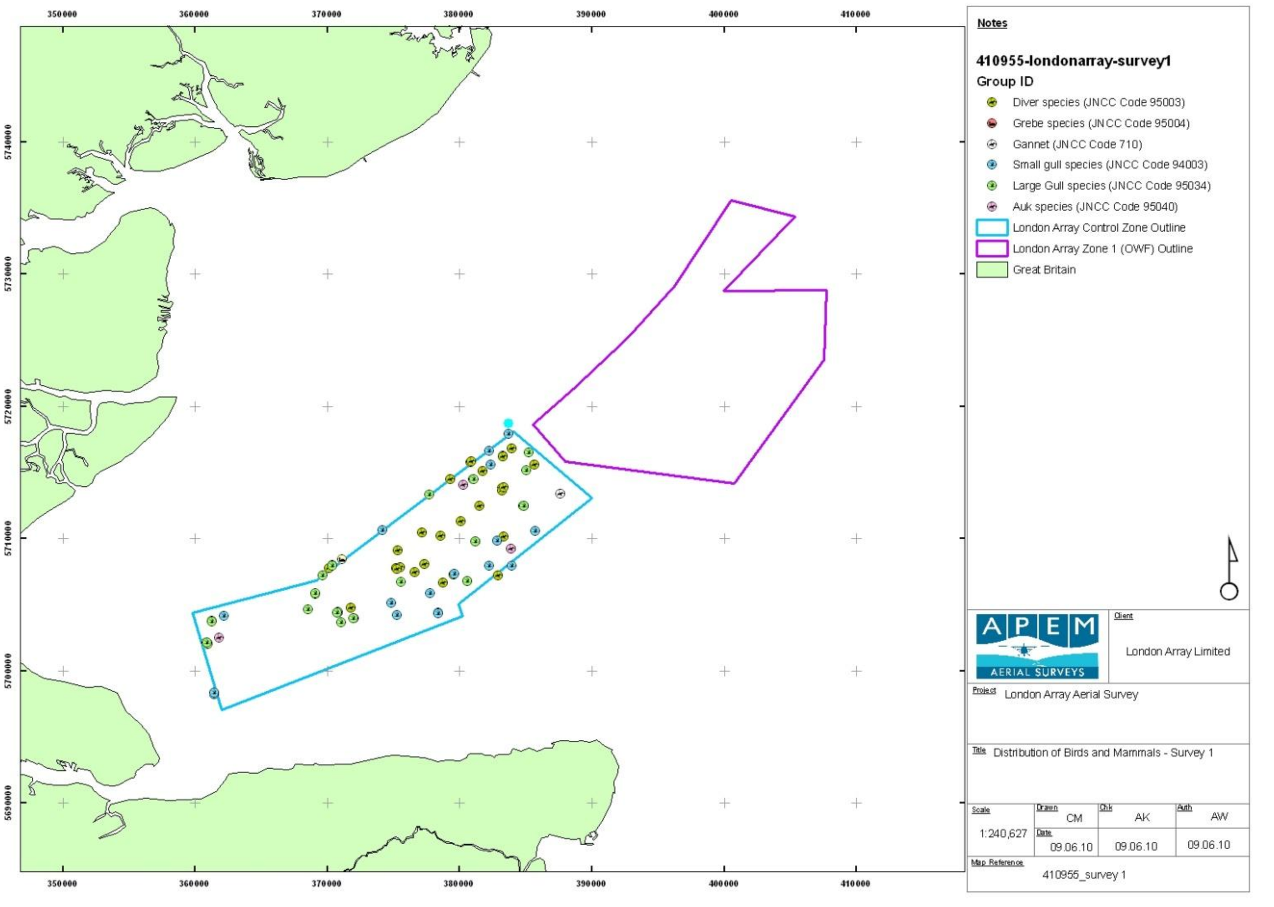


Figure 5. Species distribution summary for survey 1 derived from digital stills photography (3 cm GSD). London Array offshore wind farm and control site (sub-divided into two halves). Shown are visual survey transects (blue lines) for illustrative purposes. Each point represents one bird/mammal.

2.5.2 Survey 2

The second main survey was undertaken in January 2010. However, as with Survey 1, inclement weather disrupted the collection of high altitude imagery (7 cm) from all zones. Patchy cloud between 1500-1800ft prevented 100% of the zones from being surveyed, however, data from 30% of both control and offshore wind farm zones were collected (Figure 6 and Table 6). 100% of the zones were surveyed using both 3 cm digital stills and visual survey approaches.

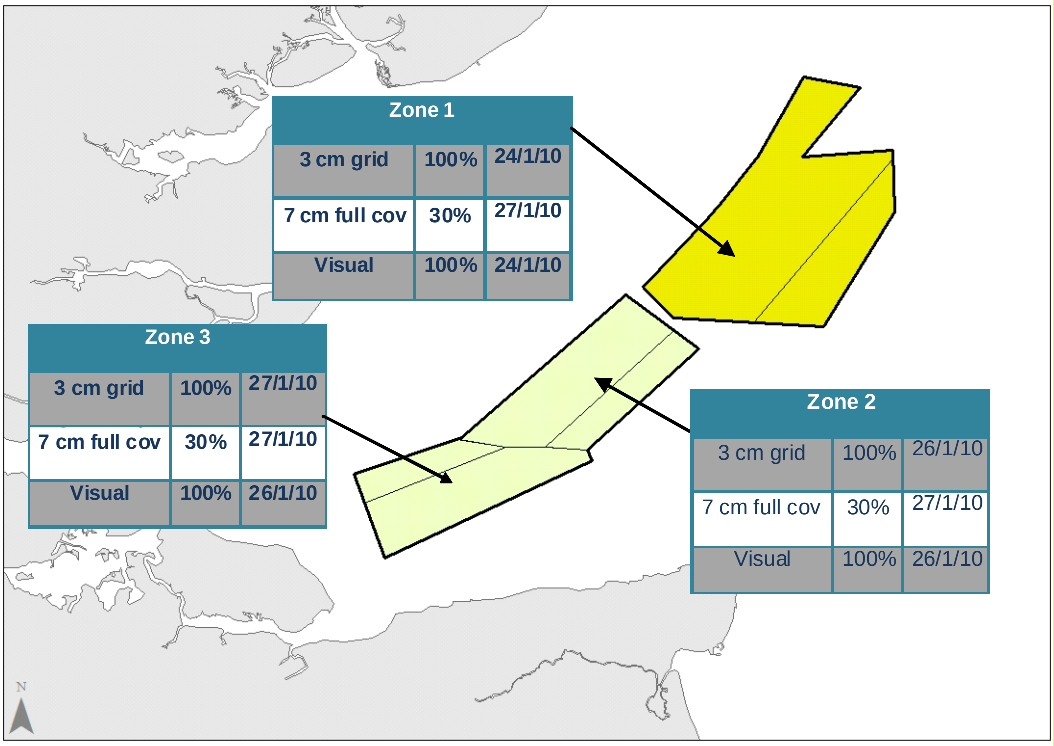


Figure 6. Survey 2. London Array offshore wind farm and control site (sub-divided into two halves). Coloured areas indicate locations where 3 cm digital stills imagery was collected.

Table 6. Summary of survey effort for Survey 2.

Survey Approach	Zone 1	Zone 2	Zone 3
7 cm high altitude	30%	30%	30%
3 cm high resolution	100%	100%	100%
Standard visual	100%	100%	100%

Population estimates

A total of 75 and 79 birds, two and 22 of which were red-throated diver were recorded within the control zone and offshore wind farm zones respectively, using digital stills imagery at 3 cm resolution (effective coverage of survey areas: 4%). In contrast, 69 and 128 birds, 48 (~70% of total) and 97 (76% of total) of which were red-throated diver, were recorded using the standard visual survey approach (effectively 96% coverage of survey area) in control and offshore wind farm zones (Table 7). The 7 cm high altitude digital stills approach indicated a total population size of 382 and 339 birds in the offshore wind farm and control zone respectively (Table 7).

A total of 26 cetaceans were recorded during Survey 2, with 6 found within the Control zone and the remaining 20 within the offshore wind farm zone (Figure 7). Cetaceans appeared to be associated with edges of sand bank regions (Figure 7).

Absolute count data (Table 8) were extrapolated to provide a population estimate, equivalent to 100% coverage of the control for 3 cm digital stills imagery data, and using conventional distance sampling procedures (CDS) for the visual survey approach (Table 8). In contrast to survey 1, population estimates derived from digital stills and only using red-throated diver absolute count data were lower, but not significantly so (see *Survey Overview* below), than visual survey approaches (204 and 362 red-throated diver respectively). Again, population estimates including all bird species using the visual survey approach underestimated the abundance of all birds within a given area in comparison to the digital stills approach (Table 8). Population estimates using CDS predicted approximately 19% of the total birds estimate using the digital stills approach (Table 8; All Birds). The 7 cm high-altitude data also greatly underestimated population abundance in comparison to both 3 cm digital stills and visual survey approaches.

Population estimate precision

The *CV* of the population estimates derived from digital stills and visual surveys data are shown in Table 9. The target *CV* (< 0.16) was achieved using a 1 km digital stills grid survey design, but not when using the visual survey approach for all birds (Table 9). Population estimates of red-throated diver populations only did not achieve the target *CV* of 0.16 using the 1 km digital stills grid or visual survey approach (Table 9). However, a 750 m grid survey design supported the target *CV* being met for red-throated diver within the offshore wind farm zone (*CV* = 0.15), but not the control zone (Table 9). All bird population estimate precision was also further improved, lowering from an average *CV* of 0.14 to an average *CV* of 0.05 for offshore wind farm and control zones combined.

Table 7**.** Red-throated diver and All bird species. Absolute counts (abundance) of bird species recorded within the London Array offshore wind farm and control zones.

Survey 2	OWF (Zone 1)		Control (Zone 2 & 3)	
Approach/Species	**All Birds**	**RTD**	**All Birds**	**RTD**
7 cm high altitude	633	n/a	99	n/a
3 cm (HR) grid	79	22	57	2
Standard visual	128	97	69	48

Nb - RTD cannot be enumerated using 7 cm high altitude data as species identification is not possible at this resolution.

Table 8. Red-throated diver and All bird species. Population estimates (abundance) of bird species within the London Array offshore wind farm and control zones. Estimates are extrapolated as described in *Population estimates - data extrapolation* (see above).

Survey 2	OWF (Zone 1)		Control (Zone 2 & 3)	
Approach/Species	**All Birds**	**RTD**	**All Birds**	**RTD**
7 cm high altitude	2110	n/a	339	n/a
3 cm (HR) grid	4799	1336	3179	204
Standard visual	1113	884	615	362

Nb - RTD cannot be enumerated using 7 cm high altitude data as species identification is not possible at this resolution.

Table 9**.** Red-throated diver and All bird species. Coefficient of variation (*CV*) of population estimates derived from digital stills (1 km and 750m grid) and visual survey data for the London Array offshore wind farm and control zones.

Survey 2	OWF (Zone 1)		Control (Zone 2 & 3)	
Approach/Species	**All Birds**	**RTD**	**All Birds**	**RTD**
7 cm high altitude	n/a	n/a	n/a	n/a
3 cm (HR) 1 km grid	0.14*	0.26	0.14*	0.48
3 cm (HR) 750m grid	0.07*	0.15*	0.02*	0.35
Standard visual	0.19	0.33	0.19	0.22

* indicates target *CV* < 0.16 met.
CV not applicable to 7 cm data as an absolute value.

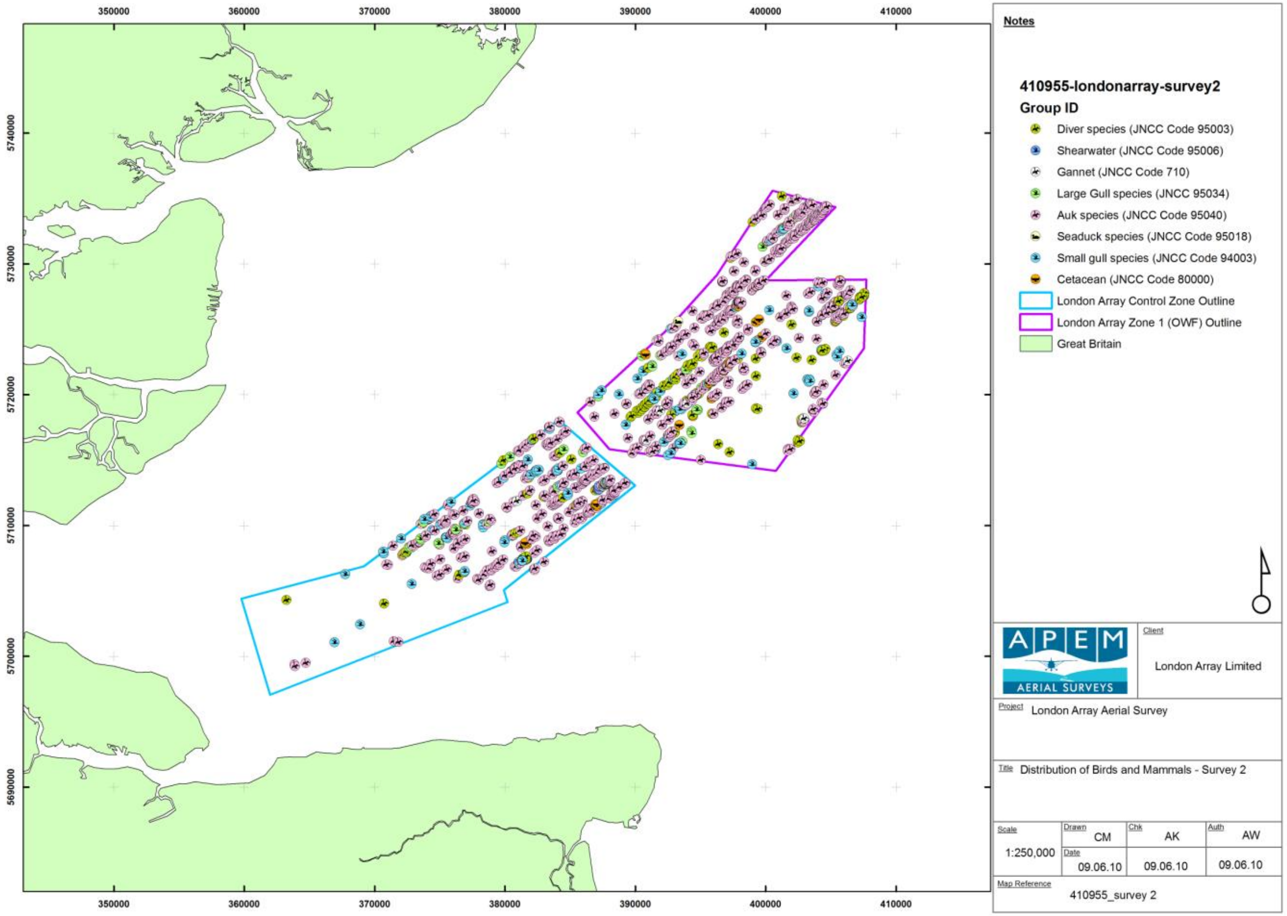


Figure 7. Species distribution summary for survey 2 derived from digital stills photography (3 cm GSD). London Array offshore wind farm and control site (sub-divided into two halves). Shown are visual survey transects (blue lines) for illustrative purposes. Each point represents one bird/mammal.

2.5.3 Survey 3

The third main survey was undertaken in February 2010. As with Survey 1, inclement weather disrupted the collection of imagery from all zones. Patchy cloud between 800-1800ft allowed only 70% and 60% of the offshore wind farm and control zone 2 to be surveyed using 3 and 7 cm imagery (Figure 8 and Table 10). Control zone 3 was not surveyed due to inclement weather conditions preventing completion of the survey within that area. Visual surveys were not undertaken during this survey period due to presence of newly developed Met Masts being observed and introducing a significant collision hazard. Therefore, visual surveys were postponed for this survey while clarification from the CAA and Crown Estate regarding Health and Safety procedures was sought.

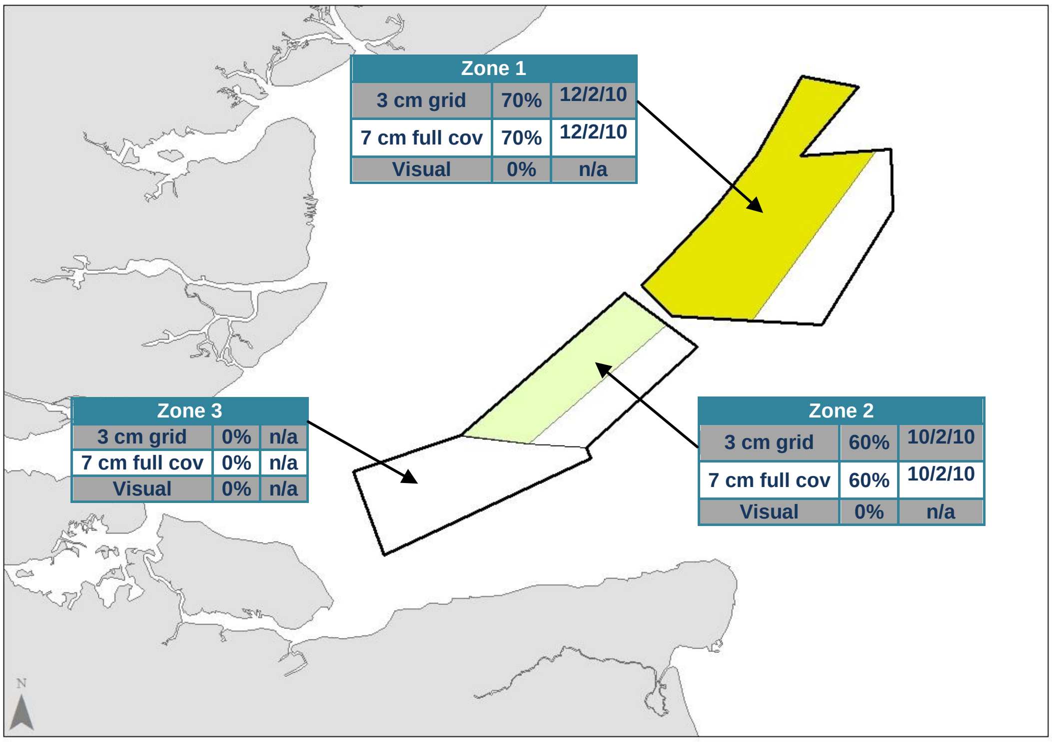


Figure 8. Survey 3. London Array offshore wind farm and control site (sub-divided into two halves). Coloured areas indicate locations where 3 cm and 7 cm digital stills imagery was collected. Visual survey data was not collected due to the identification of Met Masts within the survey region.

Table 10**.** Summary of survey effort for Survey 3.

Survey Approach	Zone 1	Zone 2	Zone 3
7 cm high altitude	70%	60%	×
3 cm high resolution	70%	60%	×
Standard visual	×	×	×

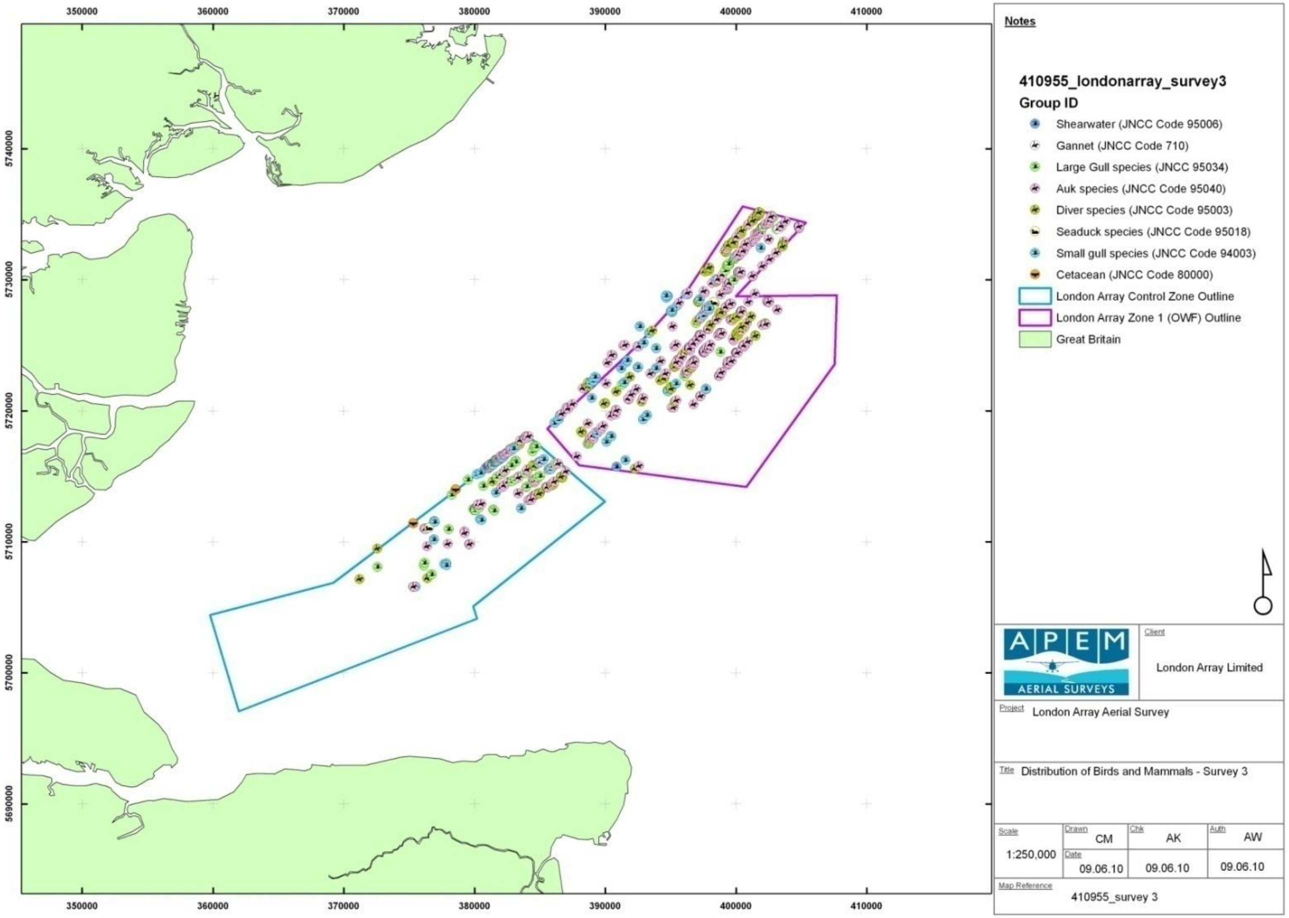


Figure 9. Species distribution summary for survey 3 derived from digital stills photography (3 cm GSD). London Array offshore wind farm and control site (sub-divided into two halves). Shown are visual survey transects (blue lines) for illustrative purposes. Each point represents one bird/mammal.

Population estimates

A total of 140 and 96 birds were recorded within the offshore wind farm and control zones respectively using 3 cm digital stills imagery. (Table 11). Of these birds, 10 and two were recorded as red-throated divers in the offshore wind farm or control zones respectively.

A total of 730 and 160 birds were estimated from 511 and 96 birds recorded using 7 cm high altitude imagery. Extrapolated 3 cm imagery absolute count data (Table 12) suggested an all bird population size of approximately 2390 and 2110 birds within offshore wind farm and control zones. It is predicted that 607 (~25%) and 100 (~5%) of those were Red-throated diver.

In contrast to Survey 2, very few cetaceans were caught on camera with only two recorded during Survey 3. Both cetaceans were recorded a short distance from each other and located at the northern edge of the Control zone (Figure 9).

Table 11. Red-throated diver and All bird species. Absolute counts (abundance) of bird species recorded within the London Array offshore wind farm and control zones.

Survey 3	**OWF (Zone 1)**		**Control (Zone 2)**	
Approach/Species	**All Birds**	**RTD**	**All Birds**	**RTD**
7 cm high altitude	511	n/a	96	n/a
3 cm (HR) grid	140	12	38	2
Standard visual	*	*	*	*

Nb - RTD cannot be enumerated using 7 cm high altitude data as species identification is not possible at this resolution.

*Met Mast identification resulting in flights on-hold for Survey 3.

Table 12**.** Red-throated diver and All bird species. Population estimates (abundance) of bird species within the London Array offshore wind farm and control zones. Estimates are extrapolated as described in *Population estimates - data extrapolation* (see above).

Survey 3	**OWF (Zone 1)**		**Control (Zone 2 & 3)**	
Approach/Species	**All Birds**	**RTD**	**All Birds**	**RTD**
7 cm high altitude	730	n/a	160	n/a
3 cm (HR) grid	2390	221	2110	78
Standard visual	n/a	n/a	n/a	n/a

Nb - RTD cannot be enumerated using 7 cm high altitude data as species identification is not possible at this resolution.

Population estimate precision

The *CV* of the population estimates derived from digital stills are shown in Table 13. The target *CV* (< 0.16) was achieved using a 1 km digital stills grid survey design. As in Survey 2, a 750 m grid survey design further improved the *CV* of the population estimate from an average of 0.12 (OWF and Control zones combined) to 0.06. Analyses including solely Red-throated diver recordings did not achieve the pre-determined level of precision with either the 1 km or 750 m grid spacing, with a *CV* of 0.31 and 0.23 in the offshore wind farm zone and 0.72 and 0.54 in the control zone respectively.

Table 13**.** Red-throated diver and All bird species. Coefficient of variation (*CV*) of population estimates derived from digital stills (1 km and 750 m grid) and visual survey data for the London Array offshore wind farm and control zones.

Survey 3	**OWF (Zone 1)**		**Control (Zone 2 & 3)**	
Approach/Species	**All Birds**	**RTD**	**All Birds**	**RTD**
7 cm high altitude	n/a	n/a	n/a	n/a
3 cm (HR) 1 km grid	0.08*	0.31	0.16*	0.72
3 cm (HR) 750m grid	0.05*	0.23	0.06*	0.54
Standard visual	n/a	n/a	n/a	n/a

* indicates target *CV* < 0.16 met.
CV not applicable to 7 cm data as an absolute value.

2.5.4 Survey 4

The fourth main survey was undertaken in April 2010. Digital stills imagery at 3 cm and 7 cm resolution and visual survey data was collected from the offshore wind farm zone and from two-thirds of the control zone (Figure 10). Each of the three methods was completed within each sub-zone on the same day as shown in Figure 10 and Table 14. The remaining sub-section of control zone 2/3 was not collected due to inclement weather. The grid spacing for this survey was reduced to 670 m as fewer birds were expected within the region.

Population estimates

A total of 17 and 25 birds were recorded from 3 cm digital imagery within the control zone and offshore wind farm zones (coverage effectively 8.0% and 8.1% of total area), of which one and 15 were red-throated diver (Table 15). In comparison, the standard visual approach identified 51 and 84 birds with effective coverage of 96%, 15 and 9 of which were red-throated diver (Table 15). A total of 311 birds, and 231 birds were recorded using 7 cm imagery.

The 7 cm high altitude digital stills approach indicated a total population size of 231 birds in the offshore wind farm zone (due to 100% coverage) and 457 birds in the control zone (Table 16). Extrapolation of 3 cm digital stills imagery suggested a total population size of 210 and 553 birds, and the standard visual approach predicted a population size of 183 and 506 birds in the offshore wind farm and control zone respectively (Table 16).

Marine mammals were particularly abundant during Survey 4, with a total of 35 cetaceans being recorded. An increase in the abundance of cetacean species is perhaps unsurprising as some species tend to become more commonly sighted during spring and summer months as they move nearer shore in response to food availability. Cetaceans were well distributed throughout the offshore wind farm zone, with only a small proportion found within the control zone (Figure 10).

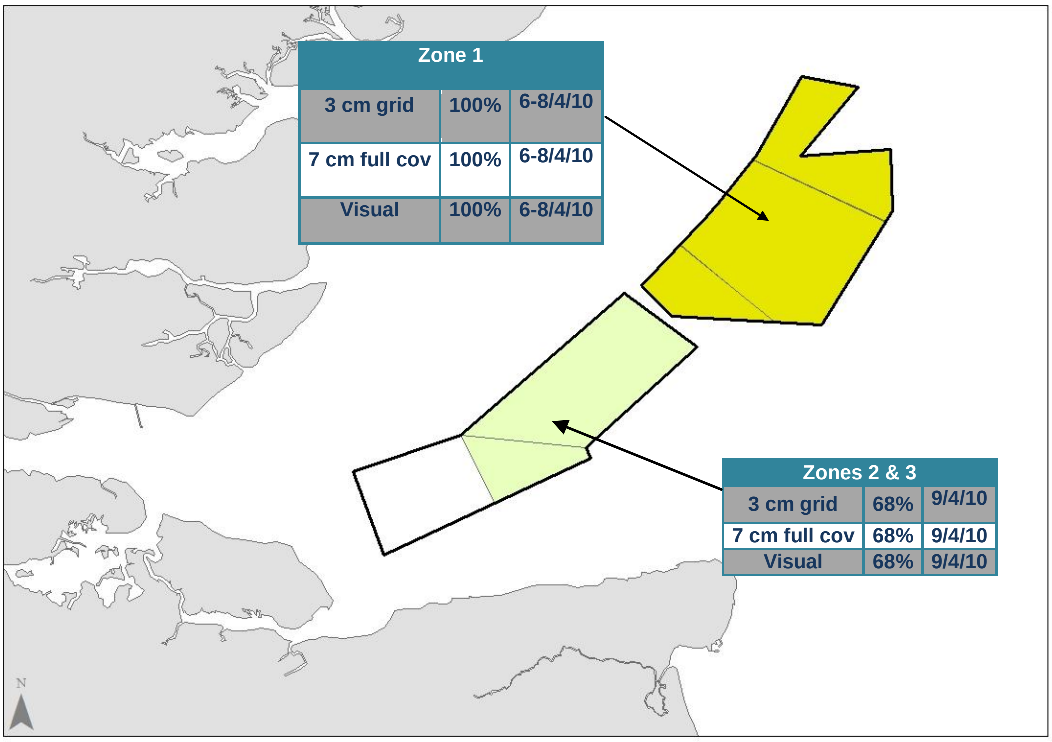


Figure 10. Survey 4. London Array offshore wind farm (sub-divided into three sections) and control zone. Coloured areas indicate locations where digital stills imagery was collected.

Table 14. Summary of survey effort for Survey 4.

Survey Approach	Zone 1	Zone 2/3
7 cm high altitude	100%	68%
3 cm high resolution	100%	68%
Standard visual	100%	68%

Table 15. Red-throated diver and All bird species. Absolute counts (abundance) of bird species recorded within the London Array offshore wind farm and control zones.

Survey 4	OWF (Zone 1)		Control (Zone 2 & 3)	
Approach/Species	**All Birds**	**RTD**	**All Birds**	**RTD**
7 cm high altitude	231	n/a	311	n/a
3 cm (HR) grid	17	1	25	15
Standard visual	51	15	84	9

Nb - RTD cannot be enumerated using 7 cm high altitude data as species identification is not possible at this resolution.

Table 16. Red-throated diver and All bird species. Population estimates (abundance) of bird species within the London Array offshore wind farm and control zones. Estimates are extrapolated as described in *Population estimates - data extrapolation* (see above).

Survey 4	OWF (Zone 1)		Control (Zone 2 & 3)	
Approach/Species	**All Birds**	**RTD**	**All Birds**	**RTD**
7 cm high altitude	231	n/a	457	n/a
3 cm (HR) grid	210	31	553	189
Standard visual	183	87	506	186

Nb - RTD cannot be enumerated using 7 cm high altitude data as species identification is not possible at this resolution.

Population estimate precision

The *CV* of the population estimates derived from digital stills and visual surveys data are shown in Table 17. The target *CV* (< 0.16) was not achieved using a 1 km digital stills grid survey design, nor when using the visual survey approach for all birds or Red-throated diver (Table 17). The use of a 670 m grid survey design supported the target *CV* being met for all birds, both within the offshore wind farm zone (*CV* = 0.13), and the control zone (*CV* = 0.06) (Table 17).

Table 17. Red-throated diver and All bird species. Coefficient of variation (*CV*) of population estimates derived from digital stills (1 km and 670 m grid) and visual survey data for the London Array offshore wind farm and control zones.

Survey 4	**OWF (Zone 1)**		**Control (Zone 2 & 3)**	
Approach/Species	**All Birds**	**RTD**	**All Birds**	**RTD**
7 cm high altitude	n/a	n/a	n/a	n/a
3 cm (HR) 1 km grid	0.24	1.00	0.17	0.26
3 cm (HR) 670m grid	0.13*	1.00	0.06*	0.18
Standard visual	0.34	0.45	0.39	0.28

* indicates target *CV* < 0.16 met.
CV not applicable to 7 cm data as an absolute value.

2.5.5 Survey overview

A comparative assessment of 3 cm digital stills and visual survey data was undertaken. Survey data from digital stills and visual methods were normalised to a standardised unit (birds/km^2) and abundance estimates compared using a paired t-test (Sokal & Rohlf 2003[10]).

All Birds
In cases where all birds were included in population estimates, in general, the visual survey approach estimated lower bird numbers within a region in comparison to digital stills methods (Figure 11;

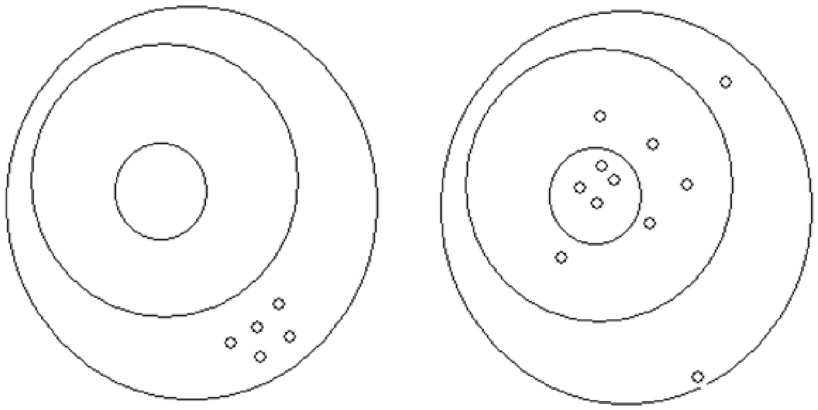
Table 18; *t*-test, $p < 0.001$). Digital stills predicted, on average, 6.5× more birds than the standard visual approach when all birds were included in the analysis (

Table 18). The greater detection rate of multiple species of bird using 3 cm digital stills over the visual survey method resulted in much larger fluctuations in species abundance between survey periods. As such the variance within the digital stills data set when all birds are included is far greater (~34× greater) than the variance observed in the visual survey data set. Reduction in the magnitude of the variance can be achieved by grouping birds into JNCC groups or species categories, e.g.

Table 18 and
Table 19.

The relationship between variance (i.e. precision) and accuracy can be explained by the figure below. As the digital stills method records greater numbers of birds, variance is wider. This is inherent in data with larger values and a greater range; however, accuracy is higher. The visual method records less birds and therefore has inherently less variance, though lower variance means estimates of this (inaccurate) figure will tend to agree with each other.

[10]Sokal, R.R. & Rohlf, F.J (2003). *Introduction to Biostatistics.* Prentice Hall, New Jersey.



a) Target on left has five estimates which are similar (more precise) but are all far from the bullseye (inaccurate).
b) Target on right has 11 estimates which show more variance but are generally closer to the bullseye (more accurate).

Table 18. All birds. Paired two-sample *t*-test for means including all birds.

Description	**3 cm HR 1 km grid**	**Standard visual**
Mean (birds/km^2)	16.6	2.5
Variance	111.5	3.3
Observation (*n*)	10	10
df	9	
t Stat	4.73	
p-value	**0.001****	

Table 19. Red-throated diver. Paired two-sample *t*-test for means including Red-throated diver only.

Description	**3 cm HR 1 km grid**	**Standard visual**
Mean (birds/km^2)	2.9	1.8
Variance	14.8	2.2
Observation (*n*)	10	10
df	9	
t Stat	1.24	
p-value	**0.12**	

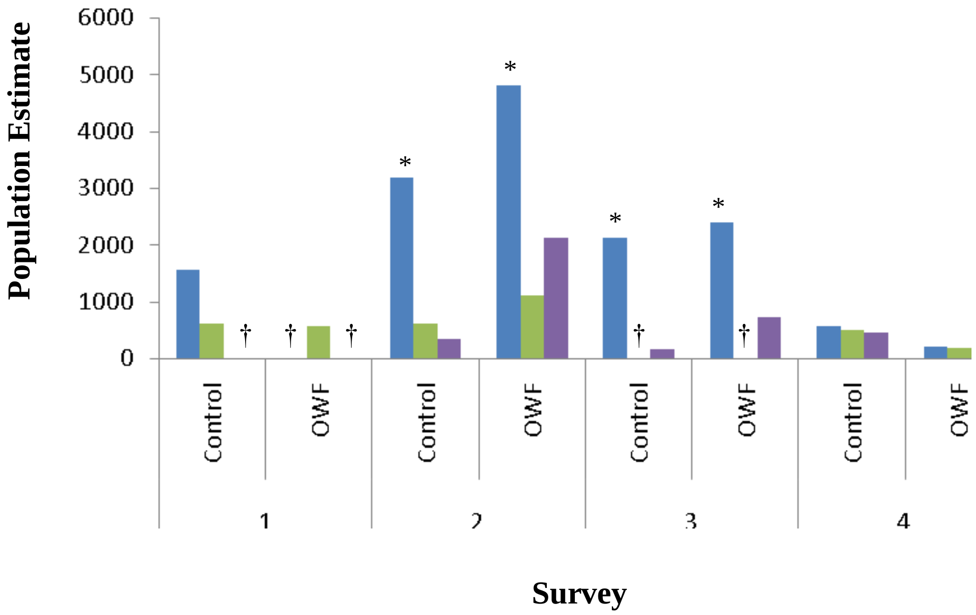


Figure 11. All birds. Population estimates based on extrapolated data from 3 cm digital stills imagery and 1 km grid spacing (blue), visual surveys (green), and total counts from 7 cm high altitude imagery (purple). * indicates target $CV < 0.16$ met; † not collected.

Red-throated diver

In cases where only red-throated diver were included in population estimates, in general, there was parity between estimates derived from digital stills and visual survey approaches (Figure 12,
Table 19, *t*-test, $p = 0.12$).

However, while not significant, as with the comparison including all birds, digital stills predicted greater numbers of red-throated diver, (approximately 1.5× more birds) than the standard visual approach (
Table 19).

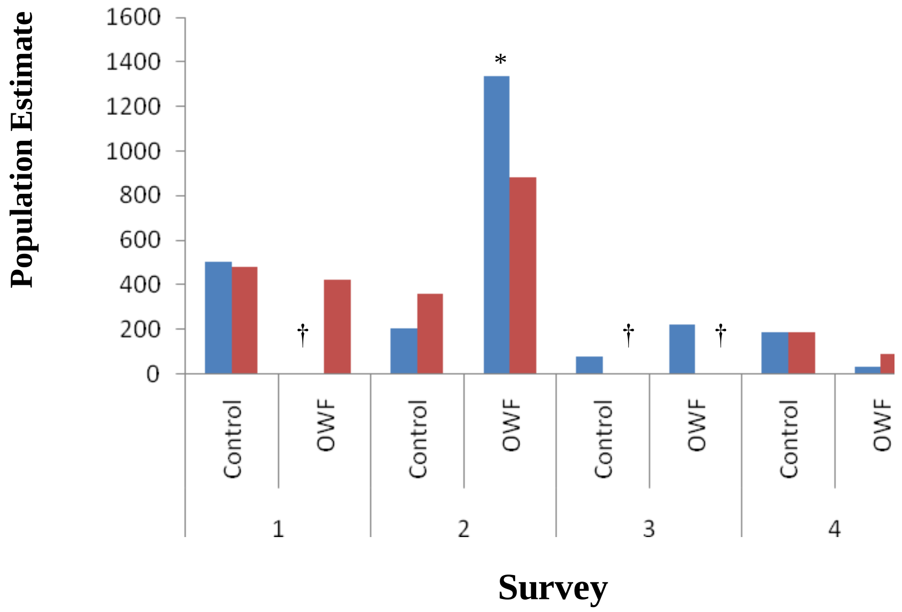


Figure 12. Red-throated diver population estimates based on extrapolated data from 3 cm digital stills imagery and 1 km grid spacing (blue) and visual surveys (red). *Target *CV* < 0.16 met using a 750m grid; † not collected.

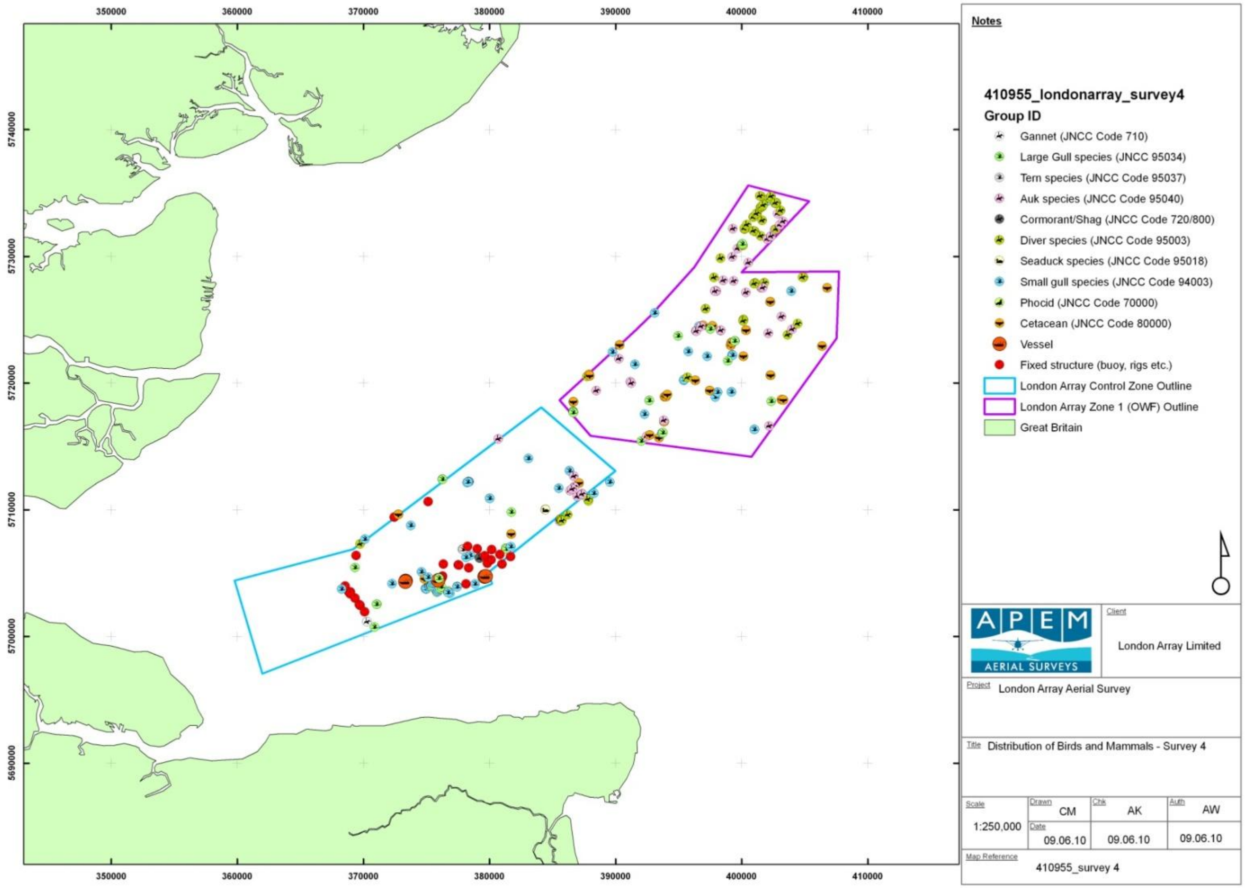


Figure 13. Species distribution summary for survey 4 derived from digital stills photography (3 cm GSD). London Array offshore wind farm and control site (sub-divided into two halves). Shown are visual survey transects (blue lines) for illustrative purposes. Each point represents one bird/mammal.

Digital stills vs. standard visual survey approaches

A clear and consistent pattern was observed between the number of birds recorded using digital stills and the number recorded using the standard visual survey approach. Relationships were identified for estimates including all birds or solely red-throated diver (Figure 14). Based on these relationships, data collected using digital still imagery could be used to approximate the population size that might have resulted if surveyed using standard visual methods. Alternatively, where historic data have been collected using the standard visual approach and assuming a similar population structure is present within those areas, population estimates may be revised to estimate the number of non-target species birds (i.e. not red-throated diver) that might have been missed but detected by the digital stills approach. This therefore provides a method for ensuring compatability of digital stills data with data collected previously by the visual survey method.

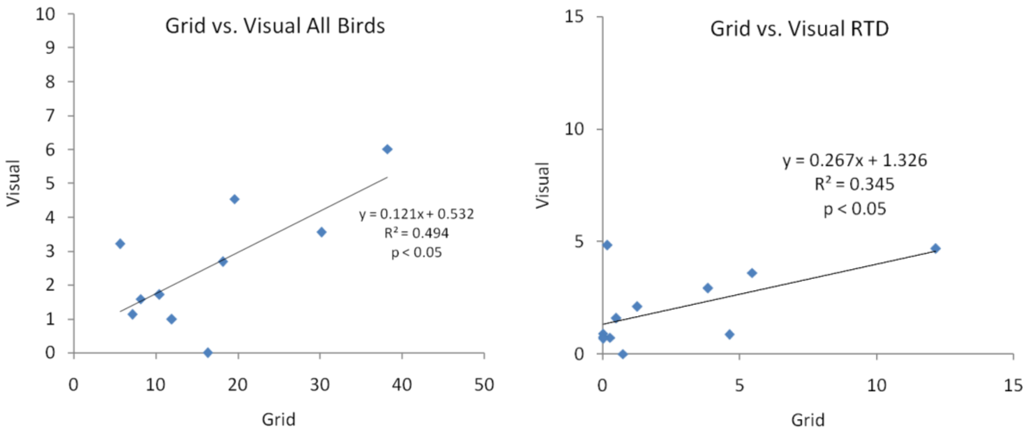


Figure 14. Relationship between the density of birds (birds/km^2) recorded using digital stills imagery and the standard visual survey. Shown are significant regressions. Each data point represents one comparison survey event.

3 Discussion

As part of the London Array 2009/2010 scoping surveys, three approaches for undertaking population assessments of offshore bird and marine mammal populations were assessed; 1) 3 cm high resolution digital stills grid; 2) 7 cm high altitude digital stills (total coverage); and 3) standard visual 2 km transect surveys. The application, appropriateness and efficacy of digital stills photography and APEM's survey design methods for enumerating bird populations within and surrounding offshore wind farm sites are clearly demonstrated by the four surveys undertaken as part of this assessment.

The findings of the four surveys demonstrate that the London Array area is used by a number of species throughout the winter season. Digital stills, in particular, demonstrated that temporal fluctuations in the usage of the London Array area over the duration of the project could be detected. For example, red-throated diver and other bird species were most abundant in January 2010 (Survey 2) and least abundant during April 2010 (Survey 4).

Marine mammals were recorded in three out of the four surveys and were particularly abundant during Surveys 2 and 4 (see Figure 10). The paucity of marine mammals during

Survey 1 is perhaps unsurprising as the these species tend to move nearer inshore during spring and summer months. The lower abundance observed during Survey 3 may be attributed to the poor weather conditions during that survey period which may have resulted in few prey resources within the region (e.g. dispersal of fish shoals).

Bird species were identified to a minimum of JNCC 'group' level, irrespective of the survey method i.e., 3 cm digital stills and visual survey. However, estimates of abundance varied between these two methods with the digital stills approach (using a grid survey design) predicting significantly greater population sizes than the standard visual method when all birds were included in the search criteria. When survey data were analysed to include only red-throated divers, in general, both the 3 cm digital stills imagery and standard visual approach demonstrated similar sensitivity and population size estimates for the London Array region. During periods of high red-throated diver abundance, digital stills produced greater estimates of abundance than the visual method, most likely attributable to the ability to enumerate large numbers of birds *post-hoc* using the digital method, a procedure which is not possible for visual surveys. During periods when densities are very low, the visual method has a higher relative encounter rate than the digital method. However, surveys are scheduled traditionally to coincide with periods when the target species are most abundant within the survey area. During these periods of high abundance, digital methods are likely to be the most effective in determining population abundance with the greatest level of precision.

For instance, on Survey 2, when the maximum abundance of red-throated divers was recorded, 1,366 red-throated divers were estimated in the wind farm area alone using 3 cm digital stills, with a *CV* of 0.15. In the same area, visual survey methods estimated 884 of the same species, with a *CV* of 0.33. To contextualise, the digital stills estimate represents 21% of the pSPA qualifying total (6,486 red-throated divers), and the visual survey method represents 13% of the same figure.There is thus an 8% difference in estimates relative to the pSPA total at peak abundance. The offshore wind farm area represents 5% of the pSPA area.

The differences in bird abundance estimated by the standard visual survey method in comparison to the digital stills approach, particularly when all birds are included in the assessment, are clear. This can be rationalised by the procedures used by the standard visual method, which, prior to developments in digital remote sensing, were considered the optimal and standard method of assessing key species within the region of interest (e.g., solely red-throated diver or common scoter, *Melanitta nigra*). Observers commonly search for a pre-determined 'image' of the species in question. This includes characteristics such as the size, shape, plumage, behaviour and 'jizz' (overall impression) of that species. Species that are not included in the target list are therefore, more likely to be missed or ignored, particularly in cases where the target species are very abundant. Therefore, the accuracy of the data generated using this survey method is likely to be good for detection of the target species but less good for detection of non-target species. This expectation is borne out by the findings of the London Array surveys, in which, abundance estimates for red-throated diver were comparable between digital stills and the standard visual method, but abundance estimates including all birds were lower using the visual method. Numbers of auks illustrate this; on Survey 2, a total of seven auks were recorded across all zones surveyed. Figure 7 shows that digital stills physically recorded (not extrapolated) over ten times as many auks (75) on the same survey.

It is unlikely that the 3 cm digital stills method over-estimated bird numbers. Survey design and protocol are tailored to deliver estimates with as high a level of precision as is practical, reflected in the target *CV* being met on several surveys (and not at all for visual method surveys). The inverse relationship between sampling size and sampling error means that the digitial stills method should provide estimates with less sampling error; estimates are based on hundreds of samples (i.e. images) rather than tens of samples (i.e. transects, which are considered the replicates for visual spotter surveys). Survey areas were covered in one day by the 3 cm digital still method (with the exception of surey 4, when estimates were very low) meaning that temporal variation is unlikely to have inflated population estimates.

Part of the survey rationale was to explore the effectiveness of images collected at differing flight altitudes (and thus different image resolutions) in numerating bird populations. Flight altitude is a trade-off between image resolution (decreasing with altitude) and coverage footprint (increasing with altitude). Estimates of all birds made by the high altitude low resolution 7 cm method were usually lower than those from the 3 cm high resolution method. This is likely because birds recorded by the former method were more difficult to detect, owing to the resolution being over twice as large at 3 cm. Therefore a total population count was not possible in this case; however, as the aim was to survey parts of the site at 3 cm and 7 cm resolution in one day, there was insufficient time to change camera lenses between surveys. In other scenarios, different lenses and camera formats could deliver suitable images from high altitude.

Grid survey design and population estimate precision

APEM have developed a grid survey design - analogous to first principles ecological sampling of terrestrial habitats - to derive *independent* and *representative* sample data describing the identity and abundance of bird and marine mammal species within the survey region. A fundamental aim was to develop an approach which can identify and enumerate bird populations and provide a population estimate for that region with a predetermined level of confidence. A *CV* of 0.16 was considered an appropriate level of confidence for population estimates – equivalent to detecting a halving or doubling of the population size.

The use of a grid survey design provides the most robust method of quantifying the variation in population structure (i.e. number and distribution of bird species) by increasing the sample size (number of images) used in population estimates. As sample size increases, so does the confidence in our population estimate. However, the precision of the population estimate (in the absence of an absolute count, i.e. 100% coverage) is determined by the spatial distribution of birds. For example, if birds are evenly distributed throughout the survey region, the precision of the estimate (variation in the number of birds likely to be encountered within each replicate sample image) is likely to be greater than if the birds are clumped within a small section of the total area. As such, it may be that the predefined level of precision surrounding the mean estimate (i.e. $CV < 0.16$) may not be achievable for that given area.

It should be stressed that when bird abundances are very low this would remain the case regardless of grid resolution; even taking an increasing number of samples at ever smaller grid internode distances would not always result in a *CV* of < 0.16. This is due to the fact that most images would contain zero birds, with a few containing positive scores. These zeros prevent the *CV* from being lowered. Removing zeroes from the dataset – of which there are likely to be many at low abundance – has the effect of reducing the variance and is inappropriate. Applying this to Survey 1 (Control Zone), the *CV* is reduced from 0.67 to 0.16 (i.e., the target level). However, we do not believe this approach is statistically valid, as it does not accurately represent the natural variation in red-throated diver abundance and distribution – the very thing we wish to explain.

The London Array surveys indicated that the target *CV* of < 0.16 was met in analyses including all birds for all surveys using the digital stills with grid survey approach. The target *CV* was achieved using a 1 km grid during peak periods of bird abundance, namely January and February 2010. During periods when birds were less abundant (survey 1 and 4), the target *CV* was achieved when a 750 m grid was used. This indicates that bird usage of the London Array region is relatively homogeneous throughout the survey region, and not concentrated on the wind farm area. At no time was the target *CV* achieved when using the visual survey method for analyses including all birds or red-throated diver only.

In analyses including solely red-throated diver, the target *CV* was only met during the peak period of abundance (survey 2; *CV* = 0.15) and when using a 750 m grid. This indicates that the number of red-throated diver are relatively localised within the London Array region *i.e.*, birds are associated with specific areas resulting in large areas (many images) with no red-throated diver and small areas with red-throated diver present (few images). This distribution pattern is reflected in the data as a large variance surrounding the population estimate.

When bird abundance is extremely low, the *CV* of 0.16 may not be realised even at the finest resolution grids. To maximise the chances of achieving the desired level, the method and grid spacing for 2010/11 are being considered and will be reported elsewhere.

Red-throated diver ecology

It is likely that the distribution and abundance of birds and particularly red-throated diver within the London Array area may be determined by several environmental factors such as temperature, salinity, light, food, depth (bathymetry) and disturbance. To our knowledge, the distribution of birds and cetaceans within the London Array area has not been correlated with any environmental variables, though this will be covered to some extent by the wider project. Such variables have the potential to greatly affect the use of the region by those species and confound any patterns that may be observed from the pre-construction survey data. From these initial surveys, a 'preference' for specific areas within the London Array area by red-throated divers and auks appears to be present (e.g. Figure 7). This association appears to be correlated with sand bank regions and thus, likely to be attributed to depth and food resources. Red-throated divers commonly associate with depths of 0 – 20 m and prey upon fish such as herring *Clupea harengus* and sprat *Sprattus sprattus*, whereas auks feed predominantly on sand eels *Ammodytes spp*. Sand banks are frequently used by such fish as nursery and feeding habitat, possibly explaining patterns in bird distribution. Additionally, red-throated divers seem to prefer shallow water with a sloped, complex sea bed (Maclean *et al*. 2007[11]) and the boundary zone between open water and estuaries (Skov & Prins 2001[12]). Additional bathymetric and salinity data would help test these preferences here.

Offshore wind farm potential effects and environmental gradients

A greater understanding of the effect (magnitude and direction) of likely key variables in determining species abundance and distribution patterns would enhance appreciation of potential impacts that may result from the construction and operation of offshore wind farms.

[11] Maclean, I.M.D., Skov, H. & Rehfisch, M.M. 2007. Further use of aerial surveys to detect displacement at offshore wind farms. BTO research Report No. 482 to COWRIE. BTO, Thetford.

[12] Skov, H. & Prins, E. 2001. Impact of estuarine fronts on the dispersal of piscivorous birds in the German Bight. Marine Progress Series *214*, 279-287.

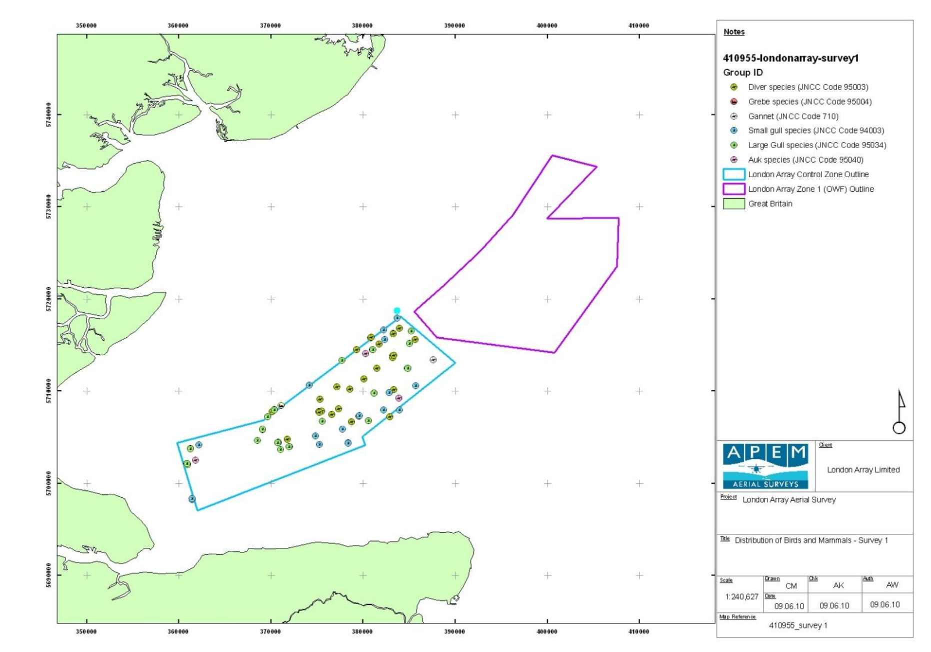
The use of generalised buffer and control zones is unlikely to reveal displacement of birds, as such zones are usually selected somewhat arbitrarily; prior knowledge of environmental gradients would allow the most suitable areas for birds (in terms of, for example, habitat, water depth, prey resources) to be surveyed. In turn, this would unmask potentially hidden impacts of wind farm construction and operation.

Bathymetric data to explain water depth is considered a useful co-variate to inform bird distribution, as it is likely to determine prey distribution and availability. Such data could be used in predictive models to assess areas most likely preferred by (e.g.) red-throated divers or cetaceans. Survey effort could then focus on these areas to see if usage changes at various stages of wind farm development, and thus if development has impacted the relevant population.

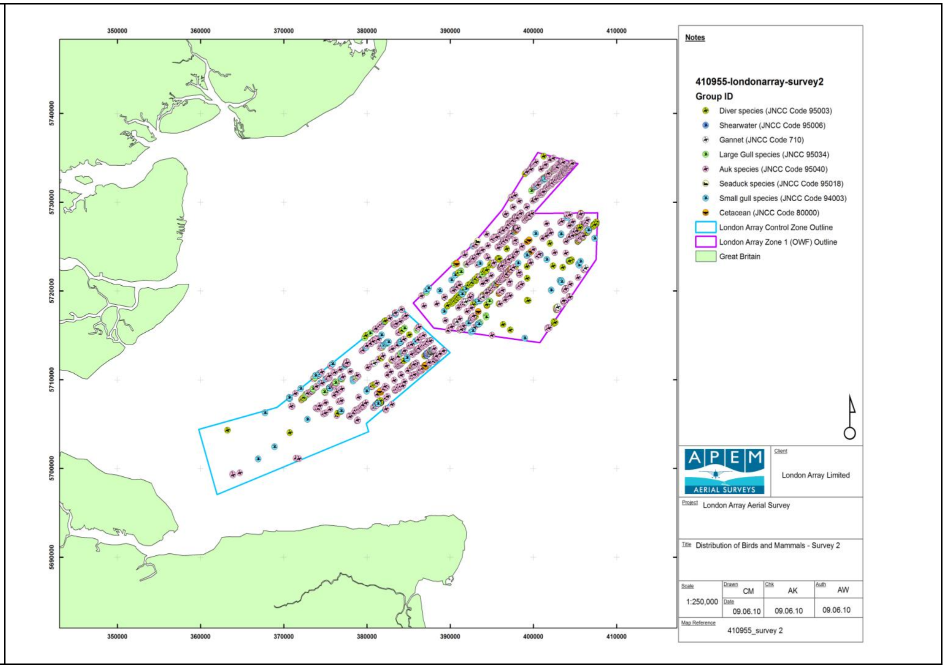
4 Conclusions

- 3 cm high resolution digital stills methods were used to describe bird and cetacean abundance and distribution in the London Array control and wind farm areas.
- The area is used by a number of bird species throughout the winter, with temporal fluctuation in numbers. Peak abundances of all birds were recorded in January, with 1,336 and 884 red-throated divers estimated in the wind farm area by 3 cm stills and standard visual methods respectively.
- Digital stills reveal up to 6.5 times as many birds as the visual spotter method. Differences in estimates by digital stills and visual methods show a clear and consistent pattern.
- At times of peak red-throated diver abundance within the offshore wind farm area (January), estimates in relation to the pSPA total (6,486) were 8% lower by visual method (13% of SPA total estimated) than 3 cm digital stills method (21% estimated). The offshore wind farm area represents 5% of the pSPA area.
- The digital stills method reached the desired *CV* of < 0.16 for all birds (on 1 km or 750 m grids) and for red-throated diver when most abundant (750 m grid). Visual method surveys failed to achieve the required *CV* at any time.
- Birds were fairly homogenously distributed throughout control and offshore wind farm zones, with an apparent association of red-throated divers and auks to sand banks.
- To provide pre-construction monitoring of the London Array offshore wind farm area, aerial survey using the 3 cm high resolution digital stills method is the preferred approach. The exact grid resolution will be determined after further analysis and discussions with the ORP. However it is likely to be in the region of 750 m.

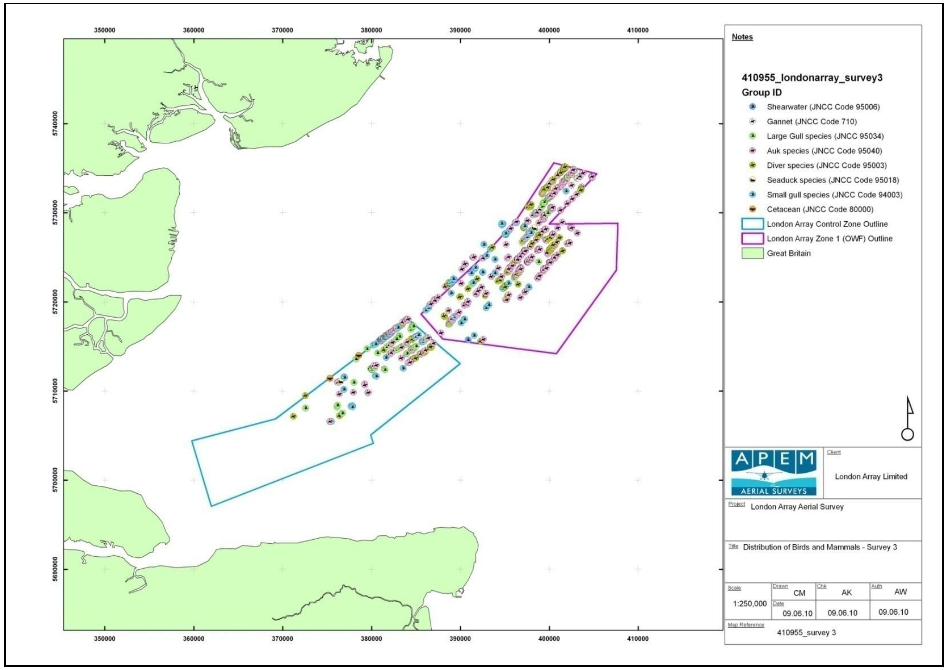
5 Annex I: Bird distribution in London Array wind farm and control zones 2009/10 from digital aerial stills (3 cm resolution)



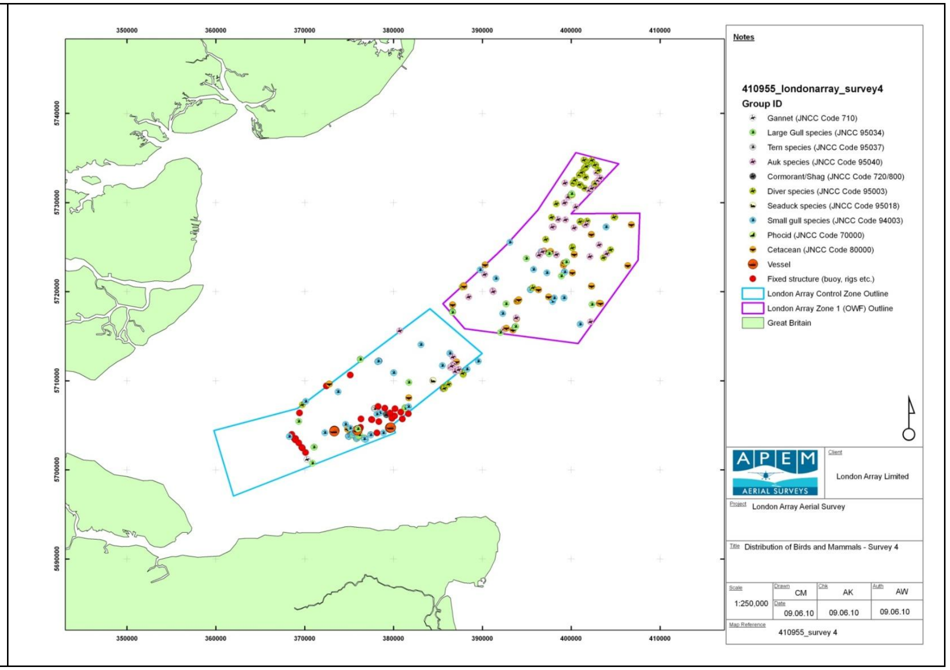
a) Survey 1, December 2009



b) Survey 2, January 2010



c) Survey 3, February 2010



d) Survey 4, April 2010