Natural England Commissioned Report NECR260

Digital video aerial surveys of red-throated diver in the Outer Thames Estuary Special Protection Area 2018

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Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Background

The Outer Thames Estuary SPA was classified in 2010 in recognition of its importance to wintering red-throated diver *Gavia stellata* which is listed in Annex I of the Birds Directive. Wintering red-throated divers occur throughout the Outer Thames Estuary SPA and use the SPA in numbers of international importance. The peak mean population at classification in 2010 was estimated to be 6,466 individuals. This figure was derived from visual aerial surveys between 1989 and 2006/07.

Two aerial surveys of the Outer Thames Estuary SPA were conducted during January and February 2013. These surveys used high resolution digital still images and produced a peak population estimate of 14,161 individuals, more than twice the classified population.

In late 2017, the Outer Thames Estuary SPA was re-classified with additional qualifying features (breeding common tern *Sterna hirundo* and little tern *Sternula albifrons*) and with amended boundaries that include additional areas of importance to these new qualifying features. This report describes the results of two further aerial surveys of the now enlarged Outer Thames Estuary SPA, conducted in early 2018, this time using high resolution digital video imagery.

The primary objective of the project was to determine an up-to-date population estimate of red-throated divers and an improved understanding of the distribution of birds within the now enlarged Outer Thames Estuary SPA. The intention is that the population estimates of red-throated divers will, if it is considered appropriate to do so, be used in conjunction with the results of the surveys in 2013 to generate a revised baseline population for the site and to amend the target for the population abundance attribute for this species within the Conservation Advice package for the SPA.

The population abundance estimate will also provide a comparison for future site monitoring to report on the condition of the site as part of a rolling monitoring programme. This will help Natural England to fulfil existing and anticipated reporting requirements under the Habitats Regulations, the Marine Strategy Framework Directive and the Marine and Coastal Access Act 2009.

A secondary objective of the project was to generate population estimates for, and an understanding of the distribution of, all other species of birds and marine mammals encountered during these winter surveys of the Outer Thames Estuary SPA.

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Further information

This report can be downloaded from the Natural England Access to Evidence Catalogue: **http://publications.naturalengland.org.uk/** . For information on Natural England publications contact the Natural England Enquiry Service on 0300 060 3900 or e-mail **enquiries@naturalengland.org.uk**.

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Executive Summary

1 HiDef Aerial Surveying Limited ('HiDef') were contracted by Natural England to undertake digital aerial surveys of the Outer Thames Estuary SPA with the core objective being to ascertain numbers of red-throated diver *Gavia stellata*. Recording of secondary species was to take place but was not deemed the priority of the project.

2 This report provides information on the methods undertaken through the survey flights on two dates in February 2018 and the collation of data, including object and species identification, and post survey analysis.

3 Flights were undertaken on 4 and 17 February 2018, with two Diamond Aviation ('DA') 42 Twin Star aircraft flying sorties on each date. Results for these surveys are presented in this report alongside comparisons with previous surveys.

4 When this contract was commissioned (autumn 2017) a decision to extend the existing Outer Thames Estuary SPA to include an additional c.95km^2 of sea, adjacent to its existing southern boundary off the Essex coast, with a revised pSPA boundary was pending. This was approved during the course of the contract. Therefore, two sets of numbers are presented at key points in the report to describe numbers within the new, extended SPA boundary and within the smaller boundary of the 'original' SPA. The latter allows easier comparisons with previous surveys that covered only the original SPA.

5 The new pSPA enlarges the existing Outer Thames Estuary SPA (classified solely for non-breeding red-throated divers) to include three new areas identified as being of importance for foraging terns *Sterna sp*. breeding at other (already classified) SPAs on shore; these are parts of the Rivers Yare and Bure, a small riverine section at Minsmere, and both estuarine and marine areas around Foulness. The pSPA therefore comprises areas for foraging breeding seabirds and non-breeding waterbirds. The feature of the existing SPA is retained, and new qualifying features are added based on a review of up-to-date bird abundance information. The total area of the Outer Thames Estuary pSPA is approx. 391,910 ha (392km^2).

6 This report provides a new population estimate for the original Outer Thames Estuary SPA for red-throated diver of 21,997. The estimated total for the new, enlarged SPA (formerly the pSPA) is 22,280. Both these figures are approximately 3.5 times greater than the notified population of the original SPA (6,466 individuals).

7 This increase in the recorded number of red-throated divers, coupled with the numbers of individuals of other species recorded has resulted in a peak waterbird population estimate across the original SPA of 41,918 and across the newly enlarged SPA of 46,056 individuals. This suggests that on occasion the SPA supports an assemblage of wintering waterbirds well in excess of the size (20,000 individuals) required to consider this to be a qualifying feature of the SPA.

8 Red-throated divers appear to use the additional area now included within the larger revised SPA boundary at low densities and at high tide when mudflats are covered.

9 Anthropogenic effects on the distribution of several species were detected, notably strong displacement of red-throated diver was noted from areas within offshore windfarms and from areas of shipping activity. This lead to higher densities of birds at points furthest from anthropogenic activity.

1 Introduction

1 The Outer Thames Estuary Special Protection Area ('SPA') was originally designated for wintering red-throated diver *Gavia stellata* which is listed in Annex I of the EU Birds Directive. The wintering population of red-throated divers in Great Britain is estimated to be 17,116 individuals (O'Brien and others 2008), representing between 10% and 19% (depending on the areas included) of the NW European non-breeding population. The Great Britain population estimate is derived from shore-based observations together with more specific aerial and boat surveys. Surveys from boats and aircraft have been responsible for identifying much larger numbers wintering in British coastal waters than previously known and the Great Britain population estimate is still considered to be an underestimate (O'Brien and others 2008).

2 Wintering red-throated divers occur throughout the Outer Thames Estuary SPA and use the SPA in numbers of international importance. The peak mean estimate of the population at designation in 2010 was estimated at 6,466 individuals, 38% of the GB population (Natural England & JNCC 2010). This figure was derived from visual aerial survey work between 1989 and 2006/07. Re-surveys of the entire SPA in early 2013, using digital aerial imagery produced a peak population estimate of 14,161 (APEM 2013; Goodship and others 2015)

3 In 2016, a Departmental Brief was the subject of public consultation on a proposal to add new species to the list of qualifying features of the Outer Thames Estuary SPA and to amend the near-shore boundaries of the site to increase its size to accommodate areas of importance to these additional species of terns (Natural England & JNCC 2015). The Departmental Brief (Natural England & JNCC 2015) did not however, due to a lack of sufficient new evidence, propose any amendment to the seaward boundary of the site or any increase in the size of the population of red-throated divers supported, due to its extended area. At the time of project planning (July 2017) the site was, therefore, considered to be a potential Special Protection Area (pSPA) with altered boundaries and additional features. These changes were adopted in October 2017, during the contract period, resulting in a small increase in area to the SPA boundary, but no associated change to the size of the population of red-throated diver protected within the site.

4 HiDef Aerial Surveying Limited ('HiDef') was contracted by Natural England after a competitive tender process in autumn 2017. The core aim of the contract was to undertake one digital photographic/video aerial survey of the areas within the boundary of the Outer Thames Estuary SPA (and within the amended boundaries of the (at that time) Outer Thames Estuary pSPA) (Figure 1). This resulted in the survey area in the southern sector increasing in size from 2209km² to 2304km². The surveys were proposed to be conducted between 1 November 2017 and 28 February 2018 and the survey images analysed to derive design-based estimates of the red-throated diver population within the SPA/pSPA and the populations of any other species of interest captured in the survey images.

5 Written reports were to be provided, including a description of results of analysis to calculate estimates of abundance (and confidence intervals around those) of red-throated divers in the SPA and its sub-sections, and maps of their distribution. It was also agreed

that files of the processed data and GIS shapefiles generated from the data analysis would be provided as part of the contract.

6 There were two core objectives for this contract. These were:

- A: To conduct one high precision digital aerial survey to determine a new, statistically robust, design-based, baseline population estimate for wintering red-throated divers in the Outer Thames Estuary SPA/pSPA.
- B: To produce maps showing each of: i) the transects flown, ii) the raw sightings data and iii) a density surface derived from simple statistical analyses of those data (for example, kriged interpolation, kernel density estimation ('KDE') etc.) depicting the distribution and spatial variation in the density of red-throated divers within the Outer Thames Estuary SPA/pSPA. (Maps should be fully compatible with ESRI ArcGIS 9.3.1)

7 There were also several optional objectives specified in the invitation to tender, of which the following formed part of the final contract:

- C: To conduct a second, high precision digital aerial survey to determine a second, new, statistically robust, design-based baseline population estimate for wintering red-throated divers in the Outer Thames Estuary SPA/pSPA.
- D: As for B but repeated using the data from the optional 2nd survey.
- I: To produce statistically robust, design-based population estimates of other bird and marine mammal species/groups of interest within the Outer Thames Estuary SPA/pSPA on one survey conducted in fulfilment of objective A.
- J: To produce maps showing each of: i) the transects flown, ii) the raw sightings data and iii) the density surface derived from simple statistical analyses of those data (for example kriged interpolation, KDE etc.) depicting the distribution and spatial variation in the density of each other species/group of bird and marine mammal of interest within the Outer Thames Estuary SPA/pSPA on one survey conducted in fulfilment of objective A. (Maps should be fully compatible with ESRI ArcGIS 9.3.1)
- K: As for objective I but repeated using the data from the optional 2nd survey (in fulfilment of objective C).
- L: As for J but repeated using the data from the optional 2nd survey (in fulfilment of objective C).

8 HiDef provided a description at tender stage of how the works would be completed, providing details of the HiDef digital video aerial survey method, a power analysis of potential survey scenarios, a proposed survey design based on these scenarios, a description of the proposed analysis methods and reporting outline.

9 The need to access parts of the survey area to which access is constrained by Ministry of Defence activities, restricted planned flights to weekends. Inclement weather on all weekends during January 2018 precluded planned surveys in that month. Thus, two separate surveys were undertaken, in agreement with Natural England, on 4 and 17

February 2018, following the survey design shown in Figure 2. Results and analysis for these surveys are presented in this report.

2 Methods

2.1 Survey flights

10 A series of strip transects was flown on two dates: 4 and 17 February 2018, following protocols agreed with Natural England in November 2017.

11 HiDef designed the survey methodology to provide information suitable to support an assessment of the abundance and distribution of red-throated diver, other seabird species and marine mammals in the designated SPA as well as collecting automated (vessel) identification system ('AIS') data, primarily within the southern area of the survey.

12 HiDef designed a survey that placed transects at 3.3 km apart across the southern survey area in which red-throated diver densities are on average greatest, and at 5km apart across the two northern survey areas in which diver densities tend to be less (Figure 1 and Figure 2). The survey design consisted of 42 transects and achieved 13% coverage of the site overall; 15% in the high density southern stratum and 10% in the low-density stratum in the northern sector.

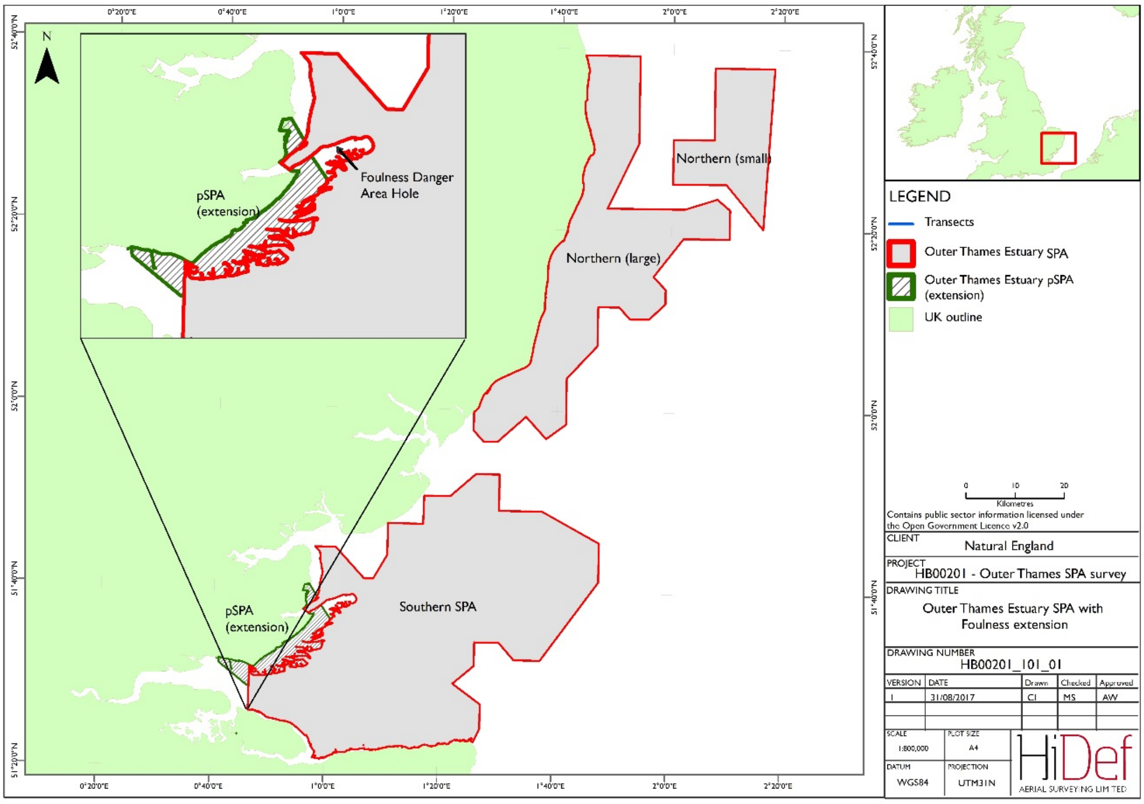

Figure 1 Survey areas for the Outer Thames Estuary SPA with (inset) 'Foulness pSPA extension' and the Foulness Danger Area Hole*

*The landward boundary of the original Outer Thames Estuary SPA abutted that of the Foulness SPA and so excluded the intertidal flats within that SPA. The boundary of the Outer Thames Estuary pSPA was amended to include all areas considered to be of greatest importance to foraging common terns originating from the Foulness SPA; that is all sea areas below mean high water mark within a certain distance from the colony (Natural England and JNCC 2015). Although covering most of the Foulness flats, the limit to this area of importance to the terns did not extend across the north-easternmost parts of the Foulness SPA mudfalts and so this area remains excluded from the pSPA boundary – so creating a ‘hole’. This hole happens to lie within the (military) aviation danger areas D138 and D138C.

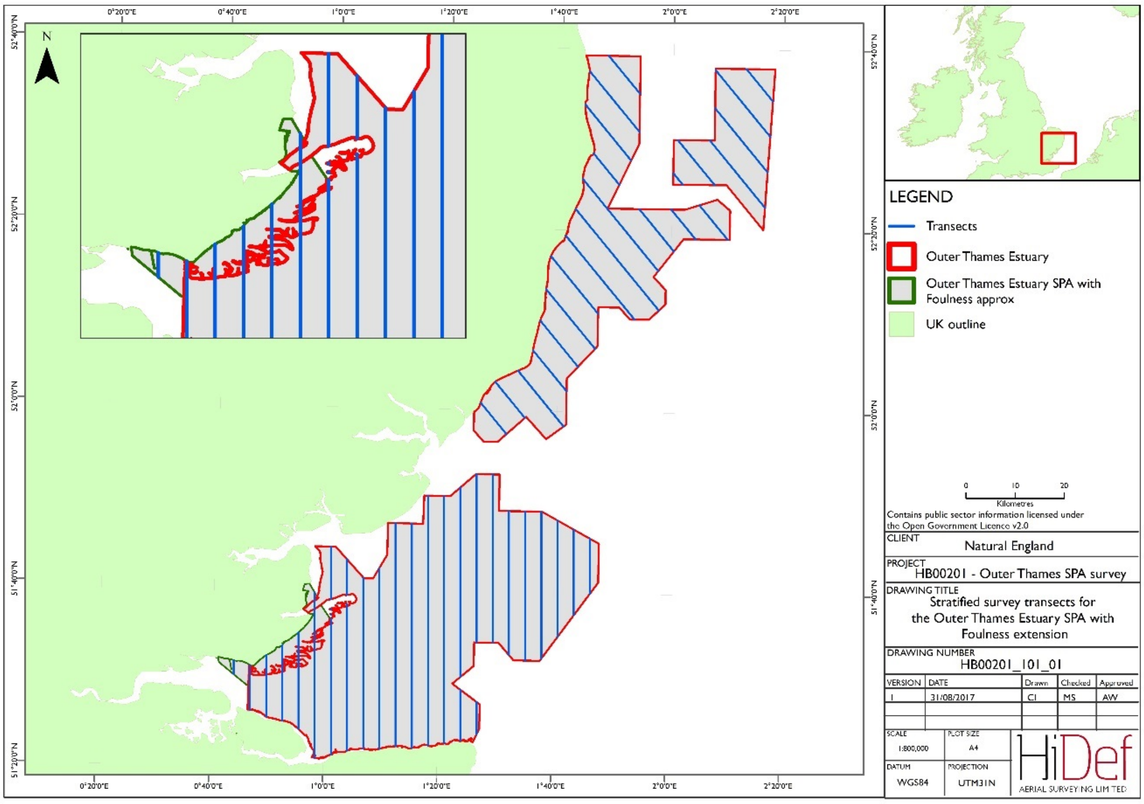

Figure 2 Survey design showing stratified survey transects for the Outer Thames Estuary SPA with (inset) ‘Foulness pSPA extension’

13 As part of the survey design process, using survey data gathered under contract to Natural England by APEM Ltd in 2013 (APEM 2013), and provided to all tenderers by Natural England, a power analysis of different survey scenarios was conducted. HiDef ran power analysis of potential survey scenarios using a design-based analysis of the survey data provided. This required research to replicate the analysis carried out in APEM (2013) owing to insufficient detail of methods in this report and in the survey meta-data. In this we clipped all survey data to within the existing SPA boundary, assumed that all images averaged 201m x 269m in dimension, leaving 63 transects within the boundary (64 were flown in both surveys). Distance 7.1 was used to generate abundance estimates, measures of coefficient of variance (‘CV’) and bootstrapped confidence intervals, in which a uniform model was used (with 0 adjustment terms), assumed poisson distribution and right truncated at 0.13434 km (Table 1). Transect length was adjusted by combining whole or part transects of data to simulate increasing the strip width. This method was independently peer reviewed by DMP Statistical Solutions.

Table 1 Results of power analysis of different potential design-based survey scenarios for the OTE SPA

Scenario	Number transects	Abundance	L95% CI	U95% CI	CV (%)
January non-stratified survey, 269m total transect width	63	11,433	9663	13296	7.82
January survey, non-stratified survey, 500m total transect width	32	11,476	9622	13543	9.93
February non-stratified survey, 269m total transect width	63	14,737	9062	21,213	21.36
February survey, non-stratified survey, 500m total transect width	32	14,710	8072	21,037	22.37
February survey, 500m total transect width, 15 transects in high density stratum and 17 in low density stratum.	32	14,279	9423	18,708	16.91
As above but 19 transects in high density stratum (5 random iterations)	36	14,174	9682	18,299	15.38
As above but 24 transects in high density stratum (10 random iterations)	40	14,763	10,920	18,335	12.94

14 HiDef concluded that there was a discrepancy in the CVs between the new calculations and those published in APEM (2013); HiDef assume that the CV scores for January applied to February and vice versa. We concluded that using fewer, more widely spaced transects of about double the width of those used in 2013 would result in a slight increase in CV. Stratification into two regions would improve the precision but increasing the effort by 50% in the high diver density stratum based on February data would give sufficient coverage to be reasonably certain of achieving about 13% CV, even during the February survey when uncertainty in the abundance estimates was greatest.

15 Additional improvements in precision could potentially be achieved by better orientation of the transects to cross perpendicular to the diver density gradient (not the case in 2013) and by attempting to ensure that all surveys were completed in a single day (the survey was spread over two days in January 2013 and over several days in February 2013), to reduce the amount of variance caused by bird movement between zones.

16 As a result of this investigation HiDef undertook a transect-based survey design in which strip transects were placed approximately perpendicular to the depth contours along the coast. Such a design increases the chance that each transect samples a similar range of habitats (primarily relating to water depth) and helps to reduce the difference in bird and mammal abundance estimates between transects.

17 Surveys were undertaken using two aircraft each equipped with four (4) HiDef Gen II cameras with sensors set to a resolution of 2 cm Ground Sample Distance (‘GSD‘). Each camera sampled a strip of 125 m width, separated from the next camera by ~20 m, thus providing a combined sampled width of 500 m within a 575 m overall strip (Figure 3). Data from all four cameras was reviewed.

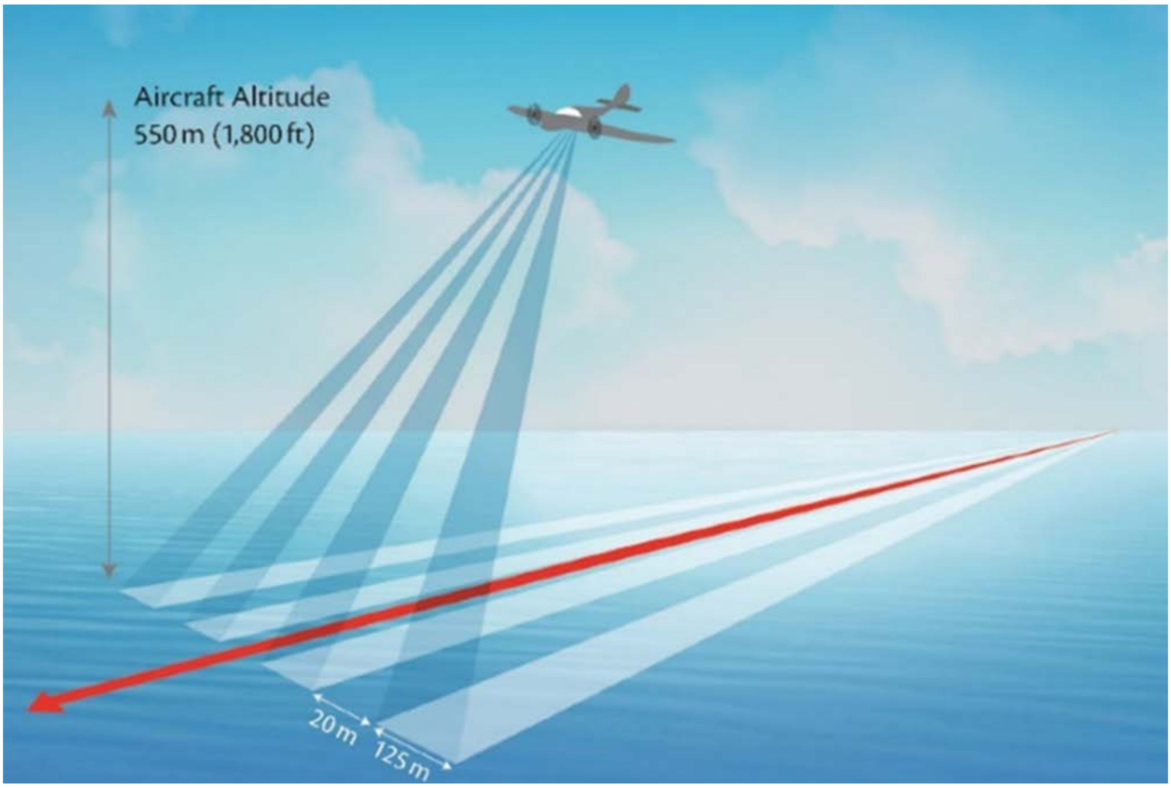

Figure 3 Illustration of HiDef video camera system in operation with cameras pointed slightly forwards and showing strip width of imagery recorded

18 The surveys were flown using a Diamond DA42 aircraft flying along the transect pattern shown in Figure 2 at a height of approximately 550 m above sea level (‘ASL’) (~1800 ft). Flying at this height ensures that there is no risk of flushing those species which have been proven to be easily disturbed by aircraft noise and presence, such as red-throated diver and scoter.

19 It is also a height that allows good clearance of offshore structures such as wind turbines, which require a minimum 150 m clearance from aircraft at all times. This is a stipulation of the European Aviation Safety Agency (EASA).

20 Position data for the aircraft was captured from a Garmin GPSMap 296 receiver with differential GPS enabled to give 1m for the positions and recording updates in location at 1 second intervals for later matching to bird and marine mammal observations.

21 At the early planning stage, it was identified that the survey design would take more than one day to complete due to the area of coverage. To minimise the effect of movement of red-throated divers between transects and different survey sectors, HiDef endeavoured successfully to complete all surveys in a single day by deploying two aircraft on the same day. This allowed a more effective ‘snapshot’ of the population to be achieved. Both aircraft commenced surveys from a central position, moving further apart as the survey progressed – one aircraft moving overall northwards, the other to the south. The phenomenon of red-throated diver movements in the Outer Thames was highlighted by Webb and others (2009) and could potentially cause significant bias to any abundance estimates from surveys that do not minimise this effect.

22 This method differed from the two high resolution digital stills aerial surveys of the Outer Thames Estuary SPA that were conducted during multiple days in January and February 2013 (APEM 2013). Each survey then was flown on a series of transects separated by 1.8 km, collecting abutting 3 cm resolution imagery. Average coverage was 15%. Population estimates of red-throated divers were calculated using two methods: 1) a design-based method and 2) a model-based method using a Generalised Additive Modelling (‘GAM’) framework.

2.2 Data Review and Object Detection

23 Data were viewed by trained aerial data reviewers who marked any objects in the footage as requiring further analysis, as well as determining which objects were birds, marine megafauna (defined within this report as cetaceans, pinnipeds or other large, non-avian marine fauna) or anthropogenic objects such as ships or buoys.

24 As part of HiDef's quality assurance ('QA') process, an additional 'blind' review of 20% of the raw data was carried out and the results compared with those of the original review. If 90% agreement is not attained during the QA process, then corrective action is initiated: the remaining data set is reviewed and where appropriate, the failed reviewer's data discarded and all the data re-reviewed. In addition, additional training is then given to the reviewer to improve performance.

25 As part of the video review process objects are only recorded where it reaches a reference line (known as 'the red line') which defines the true transect width of 125m for each camera. Due to each object being recorded in multiple video frames it is essential to ensure that the object is only recorded once, and not multiple times. As such the 'red line' system is introduced to ensure accurate data recording. By excluding objects that do not cross the red line, biases to abundance estimates caused by flux (movement of objects in the video footage relative to the aircraft, such as 'wing wobble') are eliminated.

2.3 Object Identification

26 Images marked as requiring further analysis, that is those in which objects had been detected, were reviewed by specialist ornithologists[1] for identification to the lowest taxonomic level possible and for assessment of the approximate age and the sex of each animal, as well as any behaviour traits visible from the imagery.

27 At least 20% of all objects were subjected to an external QA process. If 90% agreement is not attained then corrective action is initiated: if appropriate, the failed reviewer's data is discarded and the data re-reviewed. Any disputed identifications are passed to a third-party expert ornithologist for a final decision[1].

28 Each animal was assigned to at least a species group (genus/family), and where possible each was also assigned a species identification with confidence levels of 'Possible', 'Probable' or 'Definite'. Any animals that could not be identified to species level were assigned to a category 'No ID' in the species column.

29 The aims of identification are four-fold:

- To identify objects detected by the reviewers and classify as many to species level as possible;
- To discriminate between animate and inanimate objects, and where apparent to detect new objects;

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[1] HiDef currently employs three (3) of the ten (10) current members of the British Birds Rarities Committee ('BBRC') as expert ornithologists

- To record additional information where possible, such as behaviour, age and sex;
- To ensure identifications are as accurate as possible through a robust audit process.

30 Confidence in identification is based on qualitative rather than quantitative factors based on a uniquely skilled aerial imagery identification team:

- ‘Definite’: as certain as reasonably possible;
- ‘Probable’: very likely to be this species or species group;
- ‘Possible’: more likely to be this species or species group than anything else.

31 Quantifying percentage certainty is a very subjective matter. For example, if you are 75% certain that a definite ‘large auk’ is a guillemot, it does not follow that there is a 25% chance that it is a razorbill. What it actually takes to reach levels of certainty are the prescriptive number of identification features that an image shows and how clear and robust these features show, that is colour, tone, size, shape and jizz.

32 Objects were identified to species where possible, or alternatively fall within wider species groups (Table 2). Most species groups are self-explanatory. The exception however is that on occasion auks and divers, if undertaking behaviour such as diving, can be more problematic to identify.

Table 2 First level species groups used in identification process prior to species categorisation

Species group (No ID)	
Duck species	Gull species
Diver species	Large auk
Fulmar / gull species	Auk species
Cormorant / shag	Auk / small gull
Wader species	Large auk / diver species
Small gull species	Passerine species
Black-backed gull species	Seal species
Large gull species	Seal / small cetacean species

33 Surfacing behaviour was defined as any surfacing behaviour that occurred while the non-avian animal was visible. However, for harbour porpoise surfacing behaviour was also classified as 'snapshot surfacing' if the animal's dorsal fin was above the water in the frame nearest to the horizontal centre line.

34 Additional information was recorded for each bird on their basic behaviour (whether the bird was sitting, loafing on land or other objects or flying; in the latter case the direction of travel was also recorded. More detail was recorded where possible on foraging behaviour, approximate age and sex and any other details of interest.

2.4 Final processing

35 All data were geo-referenced, taking into account the offset from the transect line of the cameras, and compiled into a single output; Geographical Information System ('GIS') files for the Observation and Track data are issued in ArcGIS shapefile format, using UTM31N projection, WGS84 datum.

2.5 Data analysis

2.5.1 Data treatment

36 After basic review and identification had been undertaken, data were processed for estimating abundance and distribution of the key species and species groups. In line with the core objectives the focus remained on red-throated divers.

37 For species groups which include different genera (for example small gull/auk), species level identification is used to assign to species group (for example large auk). Where identification to species level isn't possible, a broader species group category is instead used for that record (for example large auk rather than allocating exactly to guillemot or razorbill).

2.5.2 Abundance Estimates

38 The abundance of each species observed is provided. Both raw data and post identification and audit analysis are presented.

39 Density and population estimates, as well as the upper and lower 95% confidence limits were derived by way of a blocked bootstrapping technique in order to ensure equal transect effort was sampled across each iteration. This was done by using transect ID as the sampling unit with replacement, and then randomly sampling until the total length of the sampled transects equalled approximately the total length of transects surveyed. We calculated the mean and standard deviation of the sampled means, as well as the relative standard error as defined by the standard deviation divided by the mean. Data were processed in the R programming language (version 3.4.3) and code can be provided on request.

40 Distance sampling is a commonly used method of calculating the density and abundance of animals from surveys that considers the problem of detection probability. The key concept of the distance method is that the probability of detecting an animal decreases as the distance from the observer increases (Buckland and others 1993). It isn't generally required for digital aerial data because of the uniform detection rates at all distances from the transect line. However, HiDef used it because it is a well-established method for calculating density and abundance from transect-based data using design-based methods even without employing the distance component of the application.

41 In the case of this aerial survey, we can apply the distance sampling technique because we have a known strip transect width and cannot detect birds outside of that area. Distance allows us to take this issue into account for good estimates of density and abundance. Furthermore, we can bootstrap this output within the distance framework to obtain 95% confidence limits on our estimates.

42 This Distance sampling method was applied to red-throated diver only as this was the focal species of the survey. As the focal species, this approach added certainty and validation to the alternative method used, which is known as 'block bootstrapping' which was applied to all other species.

43 For this analysis, we used Distance version 7.1 (Thomas and others 2010) using the conventional distance sampling analysis engine. Data were stratified by region (that is the large Northern area, the smaller Northern area, and the Southern SPA area), and then by transect. The transect stratum was used to calculate the encounter rates, and the global

density estimate was calculated as the mean, weighted by the transect areas. We applied a uniform – cosine detection function with a fixed two-sided width of 250m (the birds could only be seen within each 250m transect band), and no adjustment terms were applied. Bootstrapping was performed via a non-parametric bootstrap, 1000 times, with the observations being resampled from within each transect.

44 Using the same transect sampling regime to calculate the population estimate of red-throated divers in the original (smaller) SPA and the new, extended SPA boundary resulted in a larger point estimate of the population size in the smaller original SPA boundary than in the revised, larger boundary. While this result is counter-intuitive, it is not unusual for this to occur when the two sites are very close to each other in size, especially given that the confidence limits for both estimates overlap substantially. To provide a more useful estimate of the population size of red-throated divers within the additional sea area now included within the revised, larger SPA and, for comparison with previous surveys of the old SPA boundary, we calculated the population size of red-throated divers in the extension area using the output from the kernel density estimation ('KDE') modelling (see below). The population size within each grid cell (polygon) of the KDE surface for red-throated divers was calculated by multiplying the density by the surface area of each cell. Using ArcGIS 10.4, we selected the grid cells that occurred in the extended part of the new SPA boundary and summed the population size of the selected cells. This gives a population estimate but no confidence intervals for this small area.

2.5.3 Density Mapping

45 The density maps have been derived using a Watson-Nadaraya type kernel density estimation ('KDE') technique (Simonoff, 1996). In KDE, a small 'window' function (the kernel) is used to calculate a local density at each point in the study area. To evaluate the density at a given point, the kernel is centred on that point and all the observations within the window are summed to obtain a local count. The total area of the transect(s) intersecting the window is then summed to obtain a local measure of effort. By dividing the local count by the local effort, a local density estimate is obtained. To build a density map, the study area is covered with a fine mesh of study points and the density is calculated at each point in the mesh in turn.

46 Kernel techniques are robust and not as complex as other density estimation techniques because they have few parameters; as a result, they are arguably the easiest density surface technique to reproduce independently. The only variables are the size and shape of the kernel or window function. For these analyses, we have used a Gaussian window function, which has the advantages of being smooth, rotationally symmetric and easy to compute. The shape of the Gaussian is determined by a single width parameter; the selection of this parameter is the only variable in the computation of the density maps.

47 Rather than set the width parameter arbitrarily, we have used a leave-one-out cross validation method. Cross validation estimates the predictive power of a model by removing some of the data from the data set and using the remainder of the data and the model to predict the values for the data that were removed. The closer the predicted values represent the removed data, the better the model performance and the width parameter used in the model.

48 To apply cross validation to the survey area, each transect is subdivided into 1 km long segments. To evaluate a particular choice of kernel width, each segment is removed in turn, the kernel and the remaining data are used to predict the density of the missing segment and the known value subtracted from the prediction to obtain an error score. This process is repeated for every segment and the error scores for all segments are squared and summed to give a total performance score for that particular choice of kernel width. The kernel width is then varied and the process repeated; if the new score is lower than the old, the new kernel width is a better choice than the previous value. An exhaustive search over all kernel widths is then used to identify the best global choice. The result of the process is a smooth density estimate which has been derived without any manual parameter selection. The whole process is repeated from scratch for each map, as different kernel sizes are appropriate for different species.

49 It should be noted that several of the KDE maps are effectively flat. These correspond to distributions where the density surface as obtained from a small local kernel was not effective at predicting missing data; this can happen with evenly distributed birds but can also happen for very sparse distributions. In the case of sparse distributions, the ‘flat’ map does not necessarily mean that the true underlying distribution is ‘flat’; it could mean that the data doesn’t contain enough evidence to determine what the underlying distribution is. It is therefore useful to refer back to the population estimates for the corresponding map when looking at these ‘flat’ densities; we have also overlaid the relevant raw observations as dots to help with interpretation of the maps. In extreme cases, the density maps were not included in the results section, and the data presented simply as dot maps.

3 Additional survey parameters

3.1 AIS data collection

50 HiDef installed an automated identification system ('AIS') receiver in one aircraft, flying over the southern sector, for both surveys, which provided detailed real-time information on the location of different ship types. This is considered to offer superior detail on ship activity that may cause disturbance to red-throated divers than might be obtained from simple monthly summaries of shipping activity. Tracking outputs are presented here (Figure 4 and Figure 5) to illustrate the type of data collected and the routes followed by vessels. The range of the AIS receiver was less than hoped, in relation to the northern area, but good data were received from the high-density stratum in the south. In a further analysis, the output from Figure 4 was used to define the location of shipping lanes in a simple GIS analysis, in which distance of outputs of raw observations and modelled KDE outputs of red-throated diver distribution were measured from the line representing the shipping lanes.

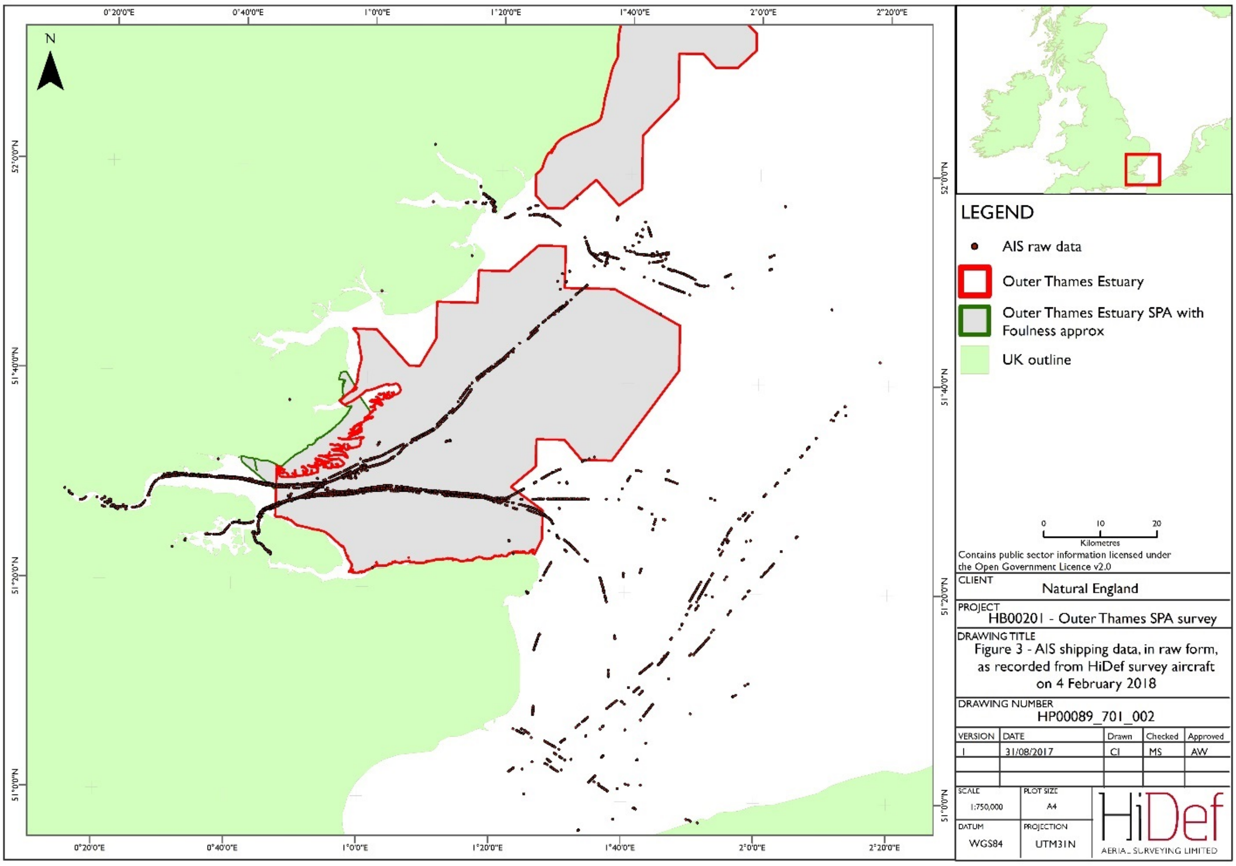

Figure 4 AIS shipping data, in raw form, as recorded from HiDef survey aircraft on 4 February 2018

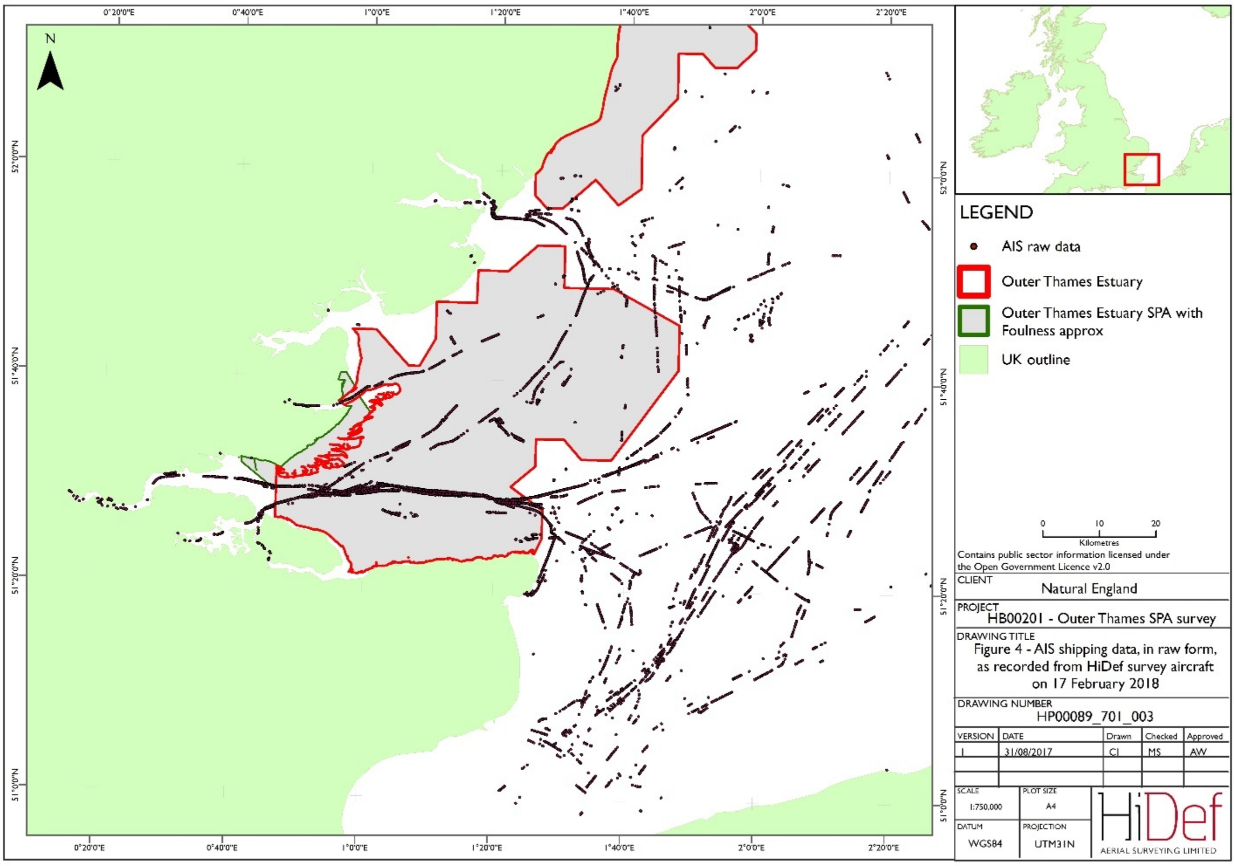

Figure 5 AIS shipping data, in raw form, as recorded from HiDef survey aircraft on 17 February 2018

3.2 Flight restrictions

51 HiDef noted the presence of (military) aviation danger areas D138 and D138C located around Foulness (firing ranges) which are often active up to 6000 ft. ASL. While military activity is broadcast through notices to airmen (‘NOTAMs’), military ranges are usually active throughout daylight hours. HiDef staff negotiated access to this area by prior contact with the range controllers at Shoeburyness range and with the contractor Quinetiq. Potential ‘cold’ periods for the range, when it would be possible to penetrate the danger areas safely were identified. These all related to weekends, and no times during weekdays were offered despite repeated requests. Unfortunately, no suitable weather windows in January 2018 corresponded with these restrictions but fortunately, they did so on 4 and 17 February 2018 when surveys took place.

52 Aircraft flight height was maintained at c.550 m to ensure full legal clearance over man-made structures in the area such as wind turbines. These must be overflown with 150 m clearance as a minimum.

4 Project Management

53 Post tender acceptance, an initial meeting was held by telephone between Richard Caldow of Natural England and Martin Scott and Andy Webb of HiDef.

54 HiDef agreed to tailor flights to around high tide in the Foulness area, where possible, or to at least times when mud flats would not be fully exposed, increasing the possibility of usage by divers. This was done as well as possible within the constraints imposed by only being able to conduct flights in this area at weekends.

55 Temporal spacing of flights was agreed. Ideally this was to be one flight in late January and the other in mid-February, but weather and military restriction issues did not allow this. Both flights were eventually flown, 13 days apart, in February with prior agreement from Natural England.

56 A press statement was agreed by both parties and published on the HiDef website (http://hidef.bioconsult-sh.de/en/news-archive/natural-england-chooses-hidef-for-outer-thames-surveys/).

57 Ongoing dialogue continued between HiDef and Natural England during the contract period to ensure smooth delivery first of a draft report, then during fuller data analysis and reporting.

5 Results

5.1 Survey results

58 The analysis of data to species level used all levels of identification confidence, with the overall identification rate of birds and non-avian animals to species level for the two surveys shown in Table 3.

Table 3 Survey identification rates at the Outer Thames in February 2018

Survey date	ID rate (%)
4 February 2018	93.34%
17 February 2018	91.71%
Average	**92.53%**

59 The total number of objects detected in each survey flight, as well as numbers of species and species group are presented in Table 4 to Table 5.

60 Red-throated diver was the principal species of interest in this survey programme. Some 1333 were recorded on 4 February, while 2917 were recorded in total on 17 February. These results were attained by the aircraft following the same transect routes in each survey. Note that the identification of no other diver species was confirmed during these surveys.

Table 4 Number of objects detected during each survey assigned to species level in February 2018

Species	Scientific Name	Survey 1 4 February 2018 Southern area	Survey 1 4 February 2018 Northern areas	Total of Survey 1	Survey 2 17 February 2018 Southern area	Survey 2 17 February 2018 Northern areas	Total of survey 2
Shelduck	*Tadorna tadorna*	0	0	0	5	0	5
Common scoter	*Melanitta nigra*	78	0	78	24	49	73
Surf scoter	*Melanitta perspicillata*	0	0	0	1	0	1
Red-breasted merganser	*Mergus serrator*	0	0	0	3	0	3
Red-throated diver	***Gavia stellata***	**1241**	**90**	**1331**	**2439**	**478**	**2917**
Fulmar	*Fulmarus glacialis*	0	8	8	0	6	6
Gannet	*Morus bassanus*	0	0	0	69	4	73
Cormorant	*Phalacrocorax carbo*	68	6	74	172	25	197
Great crested grebe	*Podiceps cristatus*	48	1	49	127	10	137
Oystercatcher	*Haematopus ostralegus*	2	0	2	0	0	0
Sanderling	*Calidris alba*	0	0	0	44	0	44
Curlew	*Numenius arquata*	0	0	0	8	0	8
Kittiwake	*Rissa tridactyla*	109	8	117	32	11	43

Species	Scientific Name	Survey 1 4 February 2018 Southern area	Survey 1 4 February 2018 Northern areas	Total of Survey 1	Survey 2 17 February 2018 Southern area	Survey 2 17 February 2018 Northern areas	Total of survey 2
Little gull	*Hydrocoloeus minutus*	0	0	0	2	1	3
Black-headed gull	*Chroicocephalus ridibundus*	124	5	129	352	11	363
Mediterranean gull	*Larus melanocephalus*	0	1	1	3	0	3
Common gull	*Larus canus*	163	20	183	512	58	570
Lesser black-backed gull	*Larus fuscus*	4	0	4	46	10	56
Herring gull	*Larus argentatus*	99	7	106	199	95	294
Great black-backed gull	*Larus marinus*	164	22	186	311	39	350
Guillemot	*Uria aalge*	8	35	43	349	37	386
Razorbill	*Alca torda*	9	3	12	46	2	48
Rock dove	*Columba livia*	2	0	2	1	0	1
Grey seal	*Halichoerus grypus*	2	0	2	7	0	7
Harbour seal	*Phoca vitulina*	0	0	0	6	0	6
Harbour porpoise	*Phocoena phocoena*	25	3	28	65	30	95
Total		**2146**	**209**	**2355**	**4823**	**866**	**5689**

Table 5 Number of objects with no species ID detected during each survey and so assigned to each species group in February 2018

Species group (No ID)	Survey 1 4 February 2018 Southern area	Survey 1 4 February 2018 Northern area	Total of Survey 1	Survey 2 17 February 2018 Southern area	Survey 2 17 February 2018 Northern area	Total of Survey 2
Duck species	1	0	1	0	0	0
Diver species	2	0	2	1	0	1
Fulmar / gull species	1	0	1	2	1	3
Cormorant / shag	0	0	0	0	1	1
Wader species	0	0	0	64	0	64
Small gull species	41	1	42	39	8	47
Black-backed gull species	5	2	7	4	3	7
Large gull species	13	1	14	15	15	30
Gull species	37	1	38	30	13	43
Large auk	6	8	14	52	11	63
Auk species	0	1	1	6	0	6
Auk / small gull	0	0	0	10	3	13
Large auk / diver species	35	10	45	34	8	42
Passerine species	0	0	0	4	0	4
Seal species	6	0	6	35	7	42
Seal / small cetacean species	10	4	14	10	11	21
Total	**157**	**28**	**185**	**307**	**81**	**387**

5.2 Abundance estimates

61 The density, total estimated population, upper and lower 95% CI, standard deviation and CV for each species and species group have been calculated using strip transect analysis and are presented in Table 6 to Table 29. Data have been presented for the entire original SPA (Table 6, Table 7, Table 10 and Table 11), the entire new pSPA (Table 8, Table 9, Table 12 and Table 13), the southern part of the original SPA (Table 14, Table 15, Table 22 and Table 23), the enlarged southern part of the new pSPA (Table 16, Table 17, Table 24 and Table 25), and the larger (Table 18, Table 19, Table 26 and Table 27) and smaller (Table 20, Table 21, Table 28 and Table 29) northern parts of the SPA/pSPA (which are effectively unchanged). Highlights for the species observed are listed in this section. A comparison of the 2013 and 2018 data is provided in Table 32.

62 Densities for all birds were recorded for each of the surveys and had relatively high densities. During Survey 1 on 4 February, density estimates for all birds in all areas of the original SPA were recorded at 4.80 birds/km² and at 4.86 birds/km² in the newly enlarged SPA. This equated to 18,260 birds (± 95% CI 14,273 – 22,410) in the original SPA and 19,071 birds (± 95% CI 14,990 – 23,411) in the newly enlarged SPA. During Survey 2 on 17 February, density estimates increased and were recorded at 11.01 birds/km² and 11.73 birds/km² in the original SPA and the newly enlarged SPA respectively. This equated to a population estimate of 41,918 birds (± 95% CI 32,965 – 51,586) in the original SPA and 46,056 birds (± 95% CI 36,150 – 57,008) in the newly enlarged SPA.

63 Low densities of common scoter *Melanitta nigra* were recorded at 0.23 birds/km² and 0.07 birds/km² in Survey 1 and Survey 2 respectively in the southern area (SPA). This equated to 515 birds (± 95% CI 0 – 1480) and 161 birds (± 95% 0 – 466). In the pSPA, density estimates were calculated at 0.22 birds/km² which equated to 513 birds (± 95% CI 0 – 1485) in Survey 1 and 0.07 birds/km² in Survey 2 which equated to 160 birds (± 95% CI 0 – 466). Within the northern areas, common scoter were recorded only in the large area at 0.42 birds/km² in Survey 2 equating to 509 birds (± 95% CI 0 – 1466).

64 One surf scoter *Melanitta perspicillata* was recorded in the southern area during Survey 2.

65 Three red-breasted mergansers *Mergus serrator* were only recorded in the southern area during Survey 2.

66 Red-throated diver was the most abundant species and was recorded in all areas with an increase in density recorded across all areas between Survey 1 and Survey 2. In Survey 1 (SPA southern area), red-throated diver density was calculated at 3.64 birds/km² which equated to 8021 birds (± 95% CI 6421 – 9695) and increased to a peak density of 7.10 birds/km² in Survey 2, equating to 15,671 birds (± 95% CI 10,531 – 21,265). Across the whole of the larger pSPA southern area, including the Foulness extension, density estimates for red-throated divers were somewhat lower at 3.51 birds/km² in Survey 1 and 6.88 birds/km² in Survey 2. This equated to a population estimate of 8161 birds (± 95% CI 6520 – 9841) and 16,002 birds (± 95% CI 10,841 – 21,682) respectively. In the large northern area, red-throated diver density was calculated at 0.62 birds/km² in Survey 1 and 3.77 birds/km² in Survey 2. This equated to 756 birds (± 95% CI 504 – 1019) and 4587 birds (± 95% CI 2499 – 7114) respectively. In the small northern area, the density estimates were calculated at 0.34 birds/km² and 0.53 birds/km² for this species equating to 132 birds (± 95% CI 76 – 196) and 204 birds (± 95% CI 137 – 274) in Survey 1 and Survey 2 respectively. Overall, across the entire original SPA the density estimate for red-throated

divers was 2.66 birds/km² in Survey 1 equating to 10,136 birds (± 95% CI 7763 – 12,626) and 5.78 birds/km² in Survey 2 which equated to 21,997 birds (± 95% CI 15,351 – 29,415) within the SPA. Across the entire pSPA area, the density estimates for the species were calculated to be 2.58 birds/km² in Survey 1 equating to 10,148 birds (± 95% CI 7868 – 12,544) and 5.68 birds/km² in Survey 2 equating to 22,280 birds (± 95% CI 15,611 – 29,784). Thus, while the average density estimates of red-throated divers across the entire pSPA were somewhat lower than in the original SPA boundary, the population estimates within the pSPA are slightly greater than in the original SPA boundary. Only three divers were not identified to species level over both survey dates (Table 3). A summary table for red-throated diver is presented in Table 30.

67 Figure 6 shows how the red-throated diver density changes between the two surveys. It also shows how the density differs between the London Array, Kentish Flats and Gunfleet Sands windfarms compared to the remainder of the site (wind farm areas based on data from Crown Estate March 2018). The marked difference is suggestive of a significant displacement effect. There is an opportunity for further analysis of this effect to be investigated, but this is out with the scope of this contract.

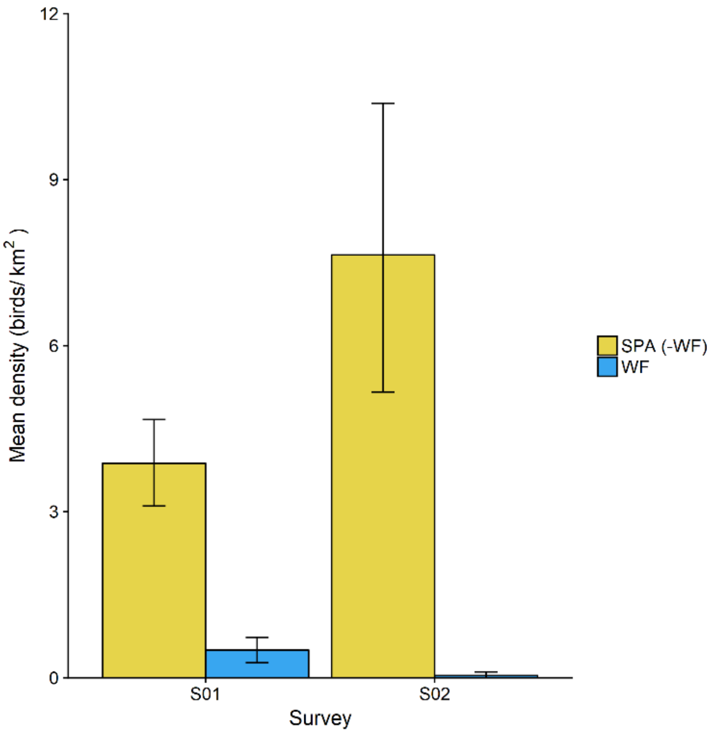

Figure 6 Red-throated diver mean density (birds/km²) within the SPA, excluding the areas within the footprints of wind farms (SPA (-WF)), and within those windfarm footprints (WF) for Survey 1 and Survey 2.

68 In 2013, multiple black-throated diver *Gavia arctica* and great northern diver *Gavia immer* were recorded (APEM, 2013). None were recorded in 2018. Historical surveys show both species to be very rare in the Outer Thames with low single figure counts recorded in survey between 1989 and 2007 (Webb and others 2009). 2018 counts failed to record either of these species, again suggesting they only occur very rarely. This contrasts markedly with the assertion made in the report of the 2013 surveys (APEM 2013) which provided population estimates in the hundreds of each species (Table 32).

69 Fulmar *Fulmarus glacialis* density estimates were calculated at 0.03 birds/km² in the large northern area for both surveys with an estimated population at 31 birds (± 95% CI 0 – 71) in Survey 1 and 41 birds (± 95% CI 0 – 82) in Survey 2. Within the small northern area density estimates were recorded at 0.13 birds/km² equating to 51 birds (± 95% CI 18 – 89) in Survey 1 and decreased to 0.05 birds/km² in Survey 2. This equated to 21 birds (± 95% CI 0 – 53). There were no observations of the species within the southern area on either survey.

70 Gannet *Morus bassanus* were recorded in the southern and the large northern areas in Survey 2 only. Within the southern part of the SPA, density estimates were calculated at 0.19 birds/km² which equated to 429 birds (± 95% 138 – 798) and in the southern part of the pSPA, a density was calculated at 0.18 birds/km² also equating to 429 birds (± 95% CI 139 – 792). In the large northern area, a low density estimate of gannets was obtained at 0.03 birds/km² which equated to 41 birds (± 95% CI 10 – 81).

71 Cormorant *Phalacrocorax carbo* were also only recorded in the southern area and large northern area in either survey. In Survey 1 in the southern area (SPA), density was calculated at 0.14 birds/km² and this increased to 0.49 birds/km² in Survey 2. This equated to 431 birds (± 95% CI 117 –784) and 1092 birds (±95% CI 196 – 2397) respectively. In the southern area pSPA, the species density estimate was calculated at 0.19 birds/km² in Survey 1 which equated to 448 birds (± 95% CI 128 – 819) and in Survey 2, a density was calculated at 0.49 birds/km² equating to 1140 birds (± 95% CI 220 – 2468). Within the large northern area, cormorant density estimates of 0.05 birds/km² were recorded in Survey 1 and increased to 0.25 birds/km² in Survey 2 equating to a population estimates of 62 birds (± 95% CI 21 – 104) in Survey 1 and 257 birds (± 95% CI 59 – 546) in Survey 2.

72 Great crested grebe *Podiceps cristatus* density estimates of 0.14 birds/km² and 0.38 birds/km² in Survey 1 and Survey 2 were recorded in the southern area of the SPA. This equated to 315 birds (± 95% CI 71 – 608) and 836 birds (± 95% CI 392 – 1327). In the southern area of the pSPA, density estimates were calculated at 0.14 birds/km² in Survey 1 and 0.36 birds/km² in Survey 2 which equated to 318 birds (± 95% CI 72 – 622) and 839 birds (± 95% CI 402 – 1316) respectively. In the large northern area, great crested grebes were recorded at densities of 0.01 birds/km² equating to 11 birds (± 95% CI 0 – 30) in Survey 1 and 0.08 birds/km² equating to 103 birds (± 95% CI 30 – 187) in Survey 2.

73 Some 44 sanderling *Calidris alba* were recorded (in flight) in the southern survey area during Survey 2.

74 Kittiwake *Rissa tridactyla* density was calculated at 0.32 birds/km² in the southern area of the SPA for Survey 1 and decreased to 0.10 birds/km² in Survey 2. This equated to 710 birds (± 95% CI 475 – 964) and 211 birds (± 95% CI 134 – 297) respectively. In the southern area of the pSPA, a density was calculated at 0.31 birds/km² and 0.09 birds/km² in Survey 1 and Survey 2 which equated to 718 birds (± 95% CI 485 – 973) and 212 birds (± 95% CI 132 – 300) respectively. Density was calculated at 0.04 birds/km²in Survey 1 and 0.07 birds/km² in Survey 2 within the large northern area. In the small northern area, density estimates for kittiwake were calculated at 0.08 birds/km² in Survey 1 equating to 31 birds (± 95% CI 10 – 52) and 0.08 birds/km² in Survey 2 which equated to 31 birds (± 95% CI 0 – 62).

75 Little gull *Hydrocoloeus minutus* were only recorded in Survey 2 in the southern area and the small northern area. Density was calculated at 0.003 birds/km² equating to 7 birds (±

95% CI 0 – 20) in the southern area of the SPA, and 0.003 birds/km² in the southern area of the pSPA equating to 7 birds (± 95% CI 0 – 20) and 0.03 birds/km² in the small northern area which equated to 11 birds (±95% CI 0 – 29).

76 Black headed gull *Chroicocephalus ridibundus* density estimates in the southern area of the original SPA were calculated at 0.19 birds/km² and 0.39 birds/km² in Survey 1 and Survey 2 equating to 414 birds (± 95% CI 105 – 783) and 864 birds (± 95% CI 192 – 1717) respectively. Within the southern part of the newly enlarged pSPA, density estimates were calculated at 0.34 birds/km² and 0.90 birds/km² in Survey 1 and Survey 2 equating to 790 birds (±95% CI 236 – 1488) and 2083 birds (± 95% CI 472 – 4270) in Survey 2. The species was only recorded in the large northern area during Survey 2 with a density estimate of 0.03 birds/km². Within the small northern area, density estimates were similar with estimates of 0.13 birds/km² and 0.18 birds/km² in Survey 1 and Survey 2 which equated to 52 and 71 birds respectively.

77 Mediterranean gull *Larus melanocephalus* density was calculated at 0.01 birds/km² in the large northern area during Survey 1 equating to 11 birds (± 95% CI 0 – 30). Density was calculated at 0.01 birds/km² in the southern area during Survey 2 which equated to 14 birds (± 95% CI 0 – 27).

78 Common gull *Larus canus* was one of the most abundant species. In the southern area of the SPA, density was calculated at 0.44 birds/km² and 1.34 birds/km² which equated to 975 birds (±95% CI 598 – 1416) in Survey 1 and 2946 birds (± 95% CI 1781 – 4325) in Survey 2. For this species density estimates were calculated at 0.46 birds/km² and 1.39 birds/km² in the pSPA southern area for Survey 1 and Survey 2 respectively. This equated to 1076 birds in Survey 1 and 3239 birds in Survey 2. Within the large northern area, density was calculated at 0.10 birds/km² in Survey 1 which equated to 122 birds (± 95%CI 50 – 210) and 0.42 birds/km² in Survey 2 equating to 511 birds (± 95% CI 257 – 796). In the small northern area, density was calculated at 0.21 birds/km² in Survey 1 and 0.08 birds/km² in Survey 2 equating to 81 birds and 31 birds respectively.

79 Lesser black-backed gull *Larus fuscus* density was calculated at 0.01 birds/km² equating to 27 birds (± 95% CI 7 – 46) in the southern area of the both the original SPA and the newly enlarged pSPA during Survey 1. The species was not recorded in either of the northern areas during Survey 1. In Survey 2, density was calculated at 0.12 birds/km², 0.08 birds/km² and 0.03 birds/km² in the southern, large northern and small northern areas respectively. This equated to population estimates of 263 birds (± 95% CI 165 – 376), 93 birds (± 95% CI 51 – 140) and 11 birds (± 95% CI 0 – 30) respectively.

80 Density estimates for herring gull *Larus argentatus* were calculated at 0.28 birds/km² and 0.44 birds/km² in the southern area of the SPA for Survey 1 and Survey 2. This equated to 624 birds (± 95% CI 163 –1375) in Survey 1 and 968 birds (± 95% CI 691 – 1262) in Survey 2. In the southern area of the pSPA, density estimates were calculated at 0.28 birds/km² and 0.45 birds/km² for Survey 1 and Survey 2 equating to 647 birds and 1047 birds respectively. Within the large northern area, density was calculated at 0.06 birds/km² equating to 72 birds (± 95% CI 10 – 149) in Survey 1 and increased to 0.77 birds/km² equating to 931 birds (± 95% CI 457 – 1504) in Survey 2. Herring gull were only recorded in the small northern area during Survey 2 with a density estimate of 0.05 birds/km² which equated to 21 birds (± 95% CI 0 – 44).

81 Great black-backed gull *Larus marinus* density was calculated at 0.48 birds/km² and 0.19 birds/km² in the southern area of the SPA and large northern area during Survey 1. This equated to 1053 birds (± 95% CI 751 – 1409) and 226 birds (± 95% CI 120 – 347) respectively. During Survey 2, density was calculated at 0.86 birds/km², 0.27 birds/km² and 0.16 birds/km² in the southern part of the SPA, large northern and small northern areas respectively. This equated to 1889 birds (± 95% CI 1485 – 2357) in the southern area of the SPA, 329 birds (± 95% CI 230 – 429) in the large northern area and 61 birds (± 95% CI 27 – 104) in the small northern area.

82 Guillemot *Uria aalge* were recorded in all areas in both surveys. In the southern area of the SPA, density was calculated at 0.02 birds/km² in Survey 1 and increased to 0.95 birds/km² in Survey 2. This equated to 2091 birds (± 95% CI 1180 – 3131) in Survey 2. Across the southern part of the pSPA, the density estimate was the same in Survey 1 as in the SPA (0.02 birds/km²) but somewhat lower (0.90 birds/km²) in Survey 2. In the large northern area, guillemot density was calculated at 0.04 birds/km² in Survey 1 and increased to 0.24 birds/km² in Survey 2. These equated to 51 birds (± 95% CI 19 – 91) and 288 birds (± 95% CI 151 – 438) respectively. In the small northern area, density was calculated at 0.76 birds/km² in Survey 1 and decreased to 0.19 birds/km² in Survey 2. This equated to 294 birds (± 95% CI 149 – 441) in Survey 1 and 72 birds (± 95% CI 41 – 108) in Survey 2.

83 Razorbill *Alca torda* were recorded in all areas apart from the small northern area in Survey 2. Relatively low numbers were recorded across the surveys with the lowest density estimate at 0.02 birds/km² in the large northern area during Survey 2 and the highest density estimate at 0.13 birds/km² in the southern area of the SPA on Survey 2. This equated to 291 birds (± 95% CI 171 – 419) in Survey 2 in the southern area.

84 Grey seal *Halichoerus grypus* were only recorded in the southern area of the SPA/pSPA in both surveys with density calculated at 0.01 animals/km² and 0.02 animals/km² in Survey 1 and Survey 2 respectively. This equated to a population estimate of 14 animals (± 95% CI 0 – 32) and 47 animals (± 95% CI 20 – 77) respectively.

85 Harbour seal *Phoca vitulina* were only recorded in Survey 2 in the southern area in the SPA/pSPA with a low density calculated at 0.02 animals/km² equating to 40 animals (± 95% CI 13– 47).

86 Harbour porpoise *Phocoena phocoena* density estimates were higher in Survey 2 than in Survey 1: in the southern area of the SPA density was calculated at 0.08 animals/km² in Survey 1 and 0.21 animals/km² in Survey 2 which equated to 166 animals (± 95% CI 71 – 279) and 458 animals (± 95% CI 241 – 685) respectively. In the pSPA southern area, the species density estimate was calculated at 0.07 animals/km² in Survey 1 and 0.18 animals/km² in Survey 2 which equated to 164 and 427 animals respectively. Within the large northern area, density was calculated at 0.02 animals/km² in Survey 1 equating to 21 animals (± 95% CI 0 – 60) and 0.14 animals/km² in Survey 2 equating to 175 animals (± 95% CI 80 – 290). In the small northern area, harbour porpoise density was calculated at 0.03 animals/km² in Survey 1 increasing to 0.34 animals/km² in Survey 2. This equated to 11 animals (± 95% CI 0 – 29) and 132 animals (± 95% CI 65 – 217) respectively. A summary table for this species is shown in Table 31.

Table 6 Abundance estimates of species groups across the entirety of the original SPA during 4 February 2018

Category	Density estimate (n/km^2)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Broad category						
All birds	4.80	18,260	14,273	22,410	2492	13.65%
All non-avian animals	0.10	377	253	517	81	21.53%
Species group						
Duck species	0.16	609	8	1769	566	92.99%
Diver species	2.65	10,107	7825	12,568	1441	14.25%
Fulmar / gull species	0.02	70	24	123	30	42.68%
Cormorant species	0.15	559	178	1004	250	44.72%
Grebe species	0.10	375	85	721	195	51.84%
Wader species	0.00	0	0	0	0	NA
Small gull species	0.78	2983	1837	4340	756	25.34%
Black-backed gull species	0.18	688	458	941	148	21.41%
Large gull species	0.40	1532	905	2357	450	29.32%
Gull species	0.11	434	116	969	269	62.03%
Large auk	0.13	511	282	792	157	30.67%
Auk species	0.00	8	0	23	8	99.05%
Auk / small gull	0.00	8	0	23	8	99.64%
Large auk / diver species	0.09	356	255	464	64	17.79%
Passerine species	0.00	16	0	46	16	95.95%

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Seal species	0.02	62	31	93	19	29.55%
Cetacean species	0.06	216	112	340	70	32.41%
Seal / small cetacean species	0.03	101	61	146	26	25.38%

Table 7 Abundance estimates of species across the entirety of the original SPA during 4 February 2018

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Species						
Common scoter	0.16	612	0	1765	572	93.45%
Red-throated diver	**2.66**	**10,136**	**7763**	**12,626**	**1464**	**14.44%**
Fulmar	0.02	63	16	115	30	46.81%
Cormorant	0.15	555	176	995	248	44.67%
Great crested grebe	0.10	380	85	731	195	51.31%
Oystercatcher	0.00	0	0	0	0	0.00%
Kittiwake	0.24	895	594	1220	192	21.36%
Black-headed gull	0.14	524	155	977	252	48.02%
Mediterranean gull	0.00	8	0	23	8	98.80%
Common gull	0.34	1297	829	1836	310	23.88%
Lesser black-backed gull	0.01	31	8	54	14	44.21%
Herring gull	0.21	794	231	1693	454	57.18%
Great black-backed gull	0.37	1409	1014	1853	255	18.11%
Guillemot	0.09	326	138	554	128	39.01%
Razorbill	0.02	93	39	154	35	37.65%
Rock dove	0.00	16	0	46	15	96.38%
Grey seal	0.00	16	0	38	11	69.46%

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Harbour porpoise	0.06	217	108	345	73	33.51%

Table 8 Abundance estimates of species groups across the entirety of the newly enlarged pSPA during 4 February 2018

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Broad category						
All birds	4.86	19,071	14,990	23,411	2537	13.30%
All non-avian animals	0.10	376	253	515	81	21.51%
Species group						
Duck species	0.15	608	8	1763	565	93.00%
Diver species	2.59	10,171	7854	12,571	1438	14.13%
Fulmar / gull species	0.02	70	23	122	30	42.38%
Cormorant species	0.14	568	183	1019	251	44.07%
Grebe species	0.10	377	91	726	194	51.25%
Wader species	0.00	16	0	46	16	100.21%
Small gull species	0.91	3574	2183	5190	913	25.53%
Black-backed gull species	0.18	702	474	951	147	20.86%
Large gull species	0.41	1607	968	2411	446	27.71%
Gull species	0.11	443	123	977	272	61.38%
Large auk	0.13	517	283	792	157	30.26%
Auk species	0.00	8	0	23	8	101.20%
Auk / small gull	0.00	8	0	23	8	99.93%
Large auk / diver species	0.09	355	254	462	64	17.90%
Passerine species	0.00	16	0	46	15	96.75%

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Seal species	0.02	62	31	92	18	29.07%
Cetacean species	0.05	216	108	340	71	32.89%
Seal / small cetacean species	0.03	100	61	145	26	25.91%

Table 9 Abundance estimates of species across the entirety of the newly enlarged pSPA during 4 February 2018

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Species						
Common scoter	0.15	605	0	1762	576	95.18%
Red-throated diver	**2.58**	**10,148**	**7868**	**12,544**	**1434**	**14.12%**
Fulmar	0.02	62	16	115	30	47.22%
Cormorant	0.15	572	184	1014	250	43.62%
Great crested grebe	0.10	375	91	726	193	51.49%
Oystercatcher	0.00	16	0	46	16	100.72%
Kittiwake	0.23	899	603	1222	187	20.75%
Black-headed gull	0.25	962	311	1767	454	47.12%
Mediterranean gull	0.00	8	0	23	8	98.97%
Common gull	0.36	1406	930	1950	314	22.31%
Lesser black-backed gull	0.01	31	8	54	14	43.78%
Herring gull	0.21	808	259	1711	454	56.16%
Great black-backed gull	0.36	1425	1031	1875	255	17.87%
Guillemot	0.08	322	134	554	130	40.17%
Razorbill	0.02	93	39	154	36	38.33%
Rock dove	0.00	16	0	46	16	98.53%
Grey seal	0.00	16	0	38	11	69.98%

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Harbour porpoise	0.05	216	108	342	71	32.85%

Table 10 Abundance estimates of species groups across the entirety of the original SPA during 17 February 2018

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Broad category						
All birds	11.01	41,918	32,965	51,586	5732	13.67%
All non-avian animals	0.34	1292	1013	1596	177	13.69%
Species group						
Duck species	0.16	591	16	1352	423	71.56%
Diver species	5.77	21,971	15,354	29,394	4261	19.39%
Fulmar / gull species	0.02	70	16	130	34	48.26%
Gannet species	0.14	534	198	960	236	44.17%
Cormorant species	0.39	1502	383	3059	840	55.93%
Grebe species	0.28	1062	532	1658	345	32.46%
Wader species	0.21	798	0	2386	800	100.30%
Small gull species	1.44	5498	3435	7980	1386	25.20%
Black-backed gull species	0.45	1701	1377	2057	205	12.03%
Large gull species	0.88	3360	2586	4202	490	14.59%
Gull species	0.20	779	503	1080	175	22.47%
Large auk	0.92	3486	2121	5061	895	25.66%
Auk species	0.01	55	16	99	25	44.46%
Auk / small gull	0.02	78	38	124	27	34.56%
Large auk / diver species	0.12	451	304	612	93	20.60%

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Passerine species	0.01	39	0	100	32	81.35%
Seal species	0.11	404	267	548	86	21.15%
Cetacean species	0.19	733	483	1004	159	21.58%
Seal / small cetacean species	0.04	155	98	221	38	24.25%

Table 11 Abundance estimates of species across the entirety of the original SPA during 17 February 2018

Category	Density estimate (n/km^2)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Species						
Shelduck	0.00	0	0	0	0	0.00%
Common scoter	0.15	567	0	1315	417	73.61%
Surf scoter	0.00	8	0	23	8	99.83%
Red-breasted merganser	0.01	24	0	54	18	73.51%
Red-throated diver	**5.78**	**21,997**	**15,351**	**29,415**	**4299**	**19.54%**
Fulmar	0.01	46	15	93	27	57.16%
Gannet	0.14	536	188	971	240	44.67%
Cormorant	0.39	1493	365	3077	844	56.52%
Great crested grebe	0.28	1070	527	1663	349	32.61%
Sanderling	0.09	336	0	1011	340	101.19%
Curlew	0.00	0	0	0	0	0.00%
Kittiwake	0.09	334	231	449	67	20.00%
Little gull	0.00	16	0	38	11	69.50%
Black-headed gull	0.29	1099	306	2112	550	49.98%
Mediterranean gull	0.00	16	0	31	11	66.60%
Common gull	1.02	3875	2467	5591	962	24.81%
Lesser black-backed gull	0.10	387	267	524	79	20.35%

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Herring gull	0.49	1859	1342	2444	340	18.27%
Great black-backed gull	0.66	2513	1964	3130	355	14.12%
Guillemot	0.72	2737	1624	3982	722	26.34%
Razorbill	0.09	357	209	514	94	26.15%
Rock dove	0.00	8	0	23	8	97.72%
Grey seal	0.01	55	23	92	21	38.18%
Harbour seal	0.01	47	15	92	25	51.74%
Harbour porpoise	0.19	737	485	1011	160	21.60%

Table 12 Abundance estimates of species groups across the entirety of the newly enlarged pSPA during 17 February 2018

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Broad category						
All birds	11.73	46,056	36,150	57,008	6362	13.81%
All non-avian animals	0.33	1301	1030	1606	176	13.53%
Species group						
Duck species	0.16	622	39	1389	422	67.90%
Diver species	5.66	22,208	15,671	29,445	4232	19.05%
Fulmar / gull species	0.02	70	16	130	34	48.29%
Gannet species	0.14	531	191	957	237	44.63%
Cormorant species	0.39	1528	427	3088	844	55.19%
Grebe species	0.27	1054	532	1628	334	31.66%
Wader species	0.52	2024	30	4660	1431	70.69%
Small gull species	1.95	7658	4135	12,086	2439	31.84%
Black-backed gull species	0.45	1781	1449	2134	210	11.77%
Large gull species	0.89	3502	2706	4352	499	14.24%
Gull species	0.24	934	644	1246	185	19.76%
Large auk	0.89	3488	2101	5076	906	25.96%
Auk species	0.01	54	16	97	24	44.17%
Auk / small gull	0.02	93	46	146	31	33.10%
Large auk / diver species	0.11	449	300	609	94	20.92%

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Passerine species	0.01	39	0	99	31	81.15%
Seal species	0.10	408	276	552	85	20.69%
Cetacean species	0.19	735	484	1012	161	21.77%
Seal / small cetacean species	0.04	162	104	226	38	23.02%

Table 13 Abundance estimates of species across the entirety of the newly enlarged pSPA during 17 February 2018

Category	Density estimate (n/km^2)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Species						
Shelduck	0.01	32	0	92	31	96.64%
Common scoter	0.14	568	0	1310	422	74.39%
Surf scoter	0.00	8	0	23	8	97.89%
Red-breasted merganser	0.01	24	0	54	18	73.69%
Red-throated diver	**5.68**	**22,280**	**15,611**	**29,784**	**4293**	**19.26%**
Fulmar	0.01	47	15	92	27	56.49%
Gannet	0.14	538	197	979	242	44.89%
Cormorant	0.39	1519	415	3056	827	54.40%
Great crested grebe	0.27	1055	538	1622	334	31.63%
Sanderling	0.09	337	0	1009	342	101.45%
Curlew	0.02	62	0	151	44	70.74%
Kittiwake	0.08	331	229	447	67	20.19%
Little gull	0.00	16	0	38	11	69.18%
Black-headed gull	0.64	2514	641	5027	1384	55.02%
Mediterranean gull	0.00	16	0	38	11	68.32%
Common gull	1.07	4185	2711	5933	990	23.65%
Lesser black-backed gull	0.10	393	275	528	78	19.74%

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Herring gull	0.49	1939	1413	2518	337	17.39%
Great black-backed gull	0.66	2587	2059	3194	347	13.39%
Guillemot	0.70	2739	1623	4029	724	26.43%
Razorbill	0.09	356	208	513	93	25.97%
Rock dove	0.00	8	0	23	8	98.47%
Grey seal	0.01	55	23	92	21	37.85%
Harbour seal	0.01	47	15	91	24	51.59%
Harbour porpoise	0.19	731	483	1009	160	21.86%

Table 14 Abundance estimates of species groups in the southern area (SPA only) during 4 February 2018

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Broad category						
All birds	6.37	14,056	11,236	17,000	1745	12.41%
All non-avian animals	0.13	283	187	394	64	22.39%
Species group						
Duck species	0.23	515	7	1484	476	92.32%
Diver species	3.65	8049	6459	9725	990	12.30%
Fulmar / gull species	0.00	7	0	20	7	93.38%
Cormorant species	0.20	435	117	794	202	46.46%
Grebe species	0.14	316	71	611	163	51.36%
Wader species	0.00	0	0	0	0	0.00%
Small gull species	1.05	2320	1396	3439	621	26.76%
Black-backed gull species	0.22	494	312	695	117	23.65%
Large gull species	0.54	1187	680	1832	359	30.25%
Gull species	0.17	365	98	804	221	60.60%
Large auk	0.06	138	70	216	45	32.44%
Auk / small gull	0.00	7	0	20	7	98.90%
Large auk / diver species	0.10	229	154	314	49	21.23%
Passerine species	0.01	14	0	39	13	96.52%
Seal species	0.02	53	32	78	15	27.73%

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Cetacean species	0.07	165	78	265	58	34.74%
Seal / small cetacean species	0.03	66	38	97	18	27.38%

Table 15 Abundance estimates of species in the southern area (SPA only) during 4 February 2018

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Species						
Common scoter	0.23	515	0	1480	481	93.35%
Red-throated diver	**3.64**	**8021**	**6421**	**9695**	**1004**	**12.50%**
Cormorant	0.19	431	117	784	201	46.56%
Great crested grebe	0.14	315	71	608	163	51.58%
Oystercatcher	0.00	0	0	0	0	0.00%
Kittiwake	0.32	710	475	964	148	20.85%
Black-headed gull	0.19	414	105	783	208	50.07%
Common gull	0.44	975	598	1416	251	25.66%
Lesser black-backed gull	0.01	27	7	46	11	41.53%
Herring gull	0.28	624	163	1375	379	60.63%
Great black-backed gull	0.48	1053	751	1409	201	19.01%
Guillemot	0.02	53	13	113	32	60.69%
Razorbill	0.03	59	19	110	28	47.36%
Rock dove	0.01	13	0	39	13	97.43%
Grey seal	0.01	14	0	32	10	69.78%
Harbour porpoise	0.07	164	78	266	58	34.93%

Table 16 Abundance estimates of species groups in the southern area (pSPA) during 4 February 2018

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Broad category						
All birds	6.36	14,797	11,875	17,863	1818	12.28%
All non-avian animals	0.12	283	187	393	63	22.21%
Species group						
Duck species	0.22	518	7	1494	484	93.33%
Diver species	3.51	8168	6528	9828	1006	12.31%
Fulmar / gull species	0.00	7	0	20	7	96.13%
Cormorant species	0.19	448	125	812	208	46.50%
Grebe species	0.14	318	73	609	162	50.96%
Wader species	0.01	14	0	39	14	100.98%
Small gull species	1.21	2817	1671	4137	753	26.73%
Black-backed gull species	0.22	508	325	711	118	23.22%
Large gull species	0.54	1262	739	1923	362	28.65%
Gull species	0.16	370	103	816	223	60.40%
Large auk	0.06	145	73	225	46	31.64%
Auk / small gull	0.00	7	0	20	7	96.67%
Large auk / diver species	0.10	232	156	316	49	21.15%
Passerine species	0.01	14	0	39	13	96.56%
Seal species	0.02	53	32	78	15	27.40%

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Cetacean species	0.07	166	79	269	59	35.22%
Seal / small cetacean species	0.03	67	38	98	19	28.11%

Table 17 Abundance estimates of species in the southern area (pSPA) during 4 February 2018

Category	Density estimate (n/km^2)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Species						
Common scoter	0.22	513	0	1485	475	92.64%
Red-throated diver	**3.51**	**8161**	**6520**	**9841**	**1000**	**12.25%**
Cormorant	0.19	448	128	819	210	46.71%
Great crested grebe	0.14	318	72	622	165	51.76%
Oystercatcher	0.01	14	0	39	14	99.39%
Kittiwake	0.31	718	485	973	148	20.62%
Black-headed gull	0.34	790	236	1488	388	49.12%
Common gull	0.46	1076	679	1536	262	24.28%
Lesser black-backed gull	0.01	27	7	46	12	42.10%
Herring gull	0.28	647	190	1406	380	58.80%
Great black-backed gull	0.46	1070	769	1417	200	18.62%
Guillemot	0.02	53	13	114	32	60.05%
Razorbill	0.03	60	20	109	28	46.71%
Rock dove	0.01	14	0	39	13	96.19%
Grey seal	0.01	14	0	32	10	68.43%
Harbour porpoise	0.07	164	77	267	59	35.41%

Table 18 Abundance estimates of species groups in the northern area (large) during 4 February 2018

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Broad category						
All birds	1.27	1543	1207	1884	1884	13.34%
All non-avian animals	0.03	42	10	82	82	58.23%
Species group						
Diver species	0.62	754	501	1020	1020	21.01%
Fulmar / gull species	0.03	31	0	71	71	71.70%
Cormorant species	0.05	61	21	102	102	40.11%
Grebe species	0.01	11	0	30	30	96.23%
Small gull species	0.16	194	118	284	284	26.66%
Black-backed gull species	0.12	143	71	221	221	32.15%
Large gull species	0.15	183	50	341	341	48.88%
Gull species	0.01	11	0	30	30	96.53%
Large auk	0.07	82	30	144	144	43.12%
Large auk / diver species	0.06	72	30	119	119	37.36%
Cetacean species	0.02	21	0	60	60	97.37%
Seal / small cetacean species	0.02	21	0	49	49	68.20%

Table 19 Abundance estimates of species in the northern area (large) during 4 February 2018

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Species						
Red-throated diver	**0.62**	**756**	**504**	**1019**	**1019**	**20.90%**
Fulmar	0.03	31	0	71	71	71.98%
Cormorant	0.05	62	21	104	104	40.50%
Great crested grebe	0.01	11	0	30	30	97.84%
Kittiwake	0.04	51	20	88	88	40.76%
Mediterranean gull	0.01	11	0	30	30	94.85%
Common gull	0.10	122	50	210	210	40.42%
Herring gull	0.06	72	10	149	149	58.26%
Great black-backed gull	0.19	226	120	347	347	30.64%
Guillemot	0.04	51	19	91	91	45.44%
Razorbill	0.02	21	0	49	49	69.56%
Harbour porpoise	0.02	21	0	60	60	96.91%

Table 20 Abundance estimates of species groups in the northern area (small) during 4 February 2018

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Broad category						
All birds	1.97	760	674	853	53	6.92%
All non-avian animals	0.05	21	0	58	20	93.41%
Species group						
Diver species	0.31	121	75	172	30	24.42%
Fulmar / gull species	0.13	51	18	89	22	42.63%
Small gull species	0.42	161	47	286	73	45.18%
Large auk	0.97	374	201	550	107	28.37%
Auk species	0.03	11	0	27	9	83.47%
Large auk / diver species	0.10	41	17	74	20	47.47%
Cetacean species	0.03	11	0	30	10	92.43%
Seal / small cetacean species	0.03	11	0	29	10	94.12%

Table 21 Abundance estimates of species in the northern area (small) during 4 February 2018

Category	Density estimate (n/km^2)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Species						
Red-throated diver	**0.34**	**132**	**76**	**196**	**37**	**27.85%**
Fulmar	0.13	51	18	89	22	42.92%
Kittiwake	0.08	31	10	52	13	42.71%
Black-headed gull	0.13	52	0	123	38	73.68%
Common gull	0.21	81	9	190	57	69.87%
Guillemot	0.76	294	149	441	89	30.12%
Razorbill	0.03	11	0	28	10	89.84%
Harbour porpoise	0.03	11	0	29	10	93.39%

Table 22 Abundance estimates of species groups in the southern area (SPA) during 17 February 2018

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Broad category						
All birds	13.53	29,855	23,153	37,111	4267	14.29%
All non-avian animals	0.36	790	576	1024	136	17.18%
Species group						
Duck species	0.08	182	7	500	162	89.18%
Diver species	7.06	15,569	10,486	21,212	3254	20.89%
Fulmar / gull species	0.01	14	0	39	13	93.54%
Gannet species	0.19	425	135	791	202	47.48%
Cormorant species	0.50	1097	195	2378	688	62.73%
Grebe species	0.38	833	385	1327	286	34.23%
Wader species	0.31	685	0	2012	685	100.03%
Small gull species	1.87	4128	2414	6162	1146	27.75%
Black-backed gull species	0.55	1213	974	1473	152	12.53%
Large gull species	0.94	2071	1554	2641	331	15.97%
Gull species	0.25	546	326	785	141	25.69%
Large auk	1.20	2657	1490	3973	760	28.60%
Auk species	0.02	47	14	83	21	43.84%
Auk / small gull	0.02	47	20	78	18	38.17%
Large auk / diver species	0.15	322	209	447	72	22.32%

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Passerine species	0.01	33	0	84	27	80.26%
Seal species	0.14	303	203	407	63	20.54%
Cetacean species	0.19	429	240	642	124	28.78%
Seal / small cetacean species	0.03	60	26	101	24	39.31%

Table 23 Abundance estimates of species in the southern area (SPA) during 17 February 2018

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Species						
Shelduck	0.00	0	0	0	0	NA
Common scoter	0.07	161	0	466	158	98.28%
Surf scoter	0.00	7	0	20	7	97.77%
Red-breasted merganser	0.01	20	0	46	15	73.87%
Red-throated diver	**7.10**	**15,671**	**10,531**	**21,265**	**3273**	**20.88%**
Gannet	0.19	429	138	798	203	47.15%
Cormorant	0.49	1092	196	2397	693	63.41%
Great crested grebe	0.38	836	392	1327	283	33.83%
Sanderling	0.13	289	0	851	287	99.39%
Curlew	0.00	0	0	0	0	NA
Kittiwake	0.10	211	134	297	50	23.43%
Little gull	0.00	7	0	20	7	94.81%
Black-headed gull	0.39	864	192	1717	467	54.08%
Mediterranean gull	0.01	14	0	27	9	66.30%
Common gull	1.34	2946	1781	4325	782	26.55%
Lesser black-backed gull	0.12	263	165	376	65	24.42%
Herring gull	0.44	968	691	1262	174	17.89%

Category	Density estimate (n/km^2)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Great black-backed gull	0.86	1889	1485	2357	266	14.03%
Guillemot	0.95	2091	1180	3131	595	28.45%
Razorbill	0.13	291	171	419	76	26.01%
Rock dove	0.00	7	0	20	7	96.11%
Grey seal	0.02	47	20	77	18	36.97%
Harbour seal	0.02	40	13	76	20	49.62%
Harbour porpoise	0.19	428	238	638	123	28.62%

Table 24 Abundance estimates of species groups in the southern area (pSPA) during 17 February 2018

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Broad category						
All birds	14.48	33,671	25,844	42,188	4936	14.66%
All non-avian animals	0.35	805	591	1039	137	16.93%
Species group						
Duck species	0.09	213	14	532	166	78.09%
Diver species	6.87	15,976	10,764	21,816	3345	20.94%
Fulmar / gull species	0.01	14	0	39	13	93.12%
Gannet species	0.19	431	138	791	203	46.96%
Cormorant species	0.49	1129	229	2442	696	61.58%
Grebe species	0.36	838	409	1313	276	32.94%
Wader species	0.72	1685	25	3917	1204	71.42%
Small gull species	2.57	5984	3039	9678	2040	34.09%
Black-backed gull species	0.55	1285	1041	1555	157	12.19%
Large gull species	0.95	2217	1687	2796	338	15.24%
Gull species	0.29	679	445	938	152	22.27%
Large auk	1.15	2673	1496	4018	763	28.52%
Auk species	0.02	46	14	82	21	43.82%
Auk / small gull	0.03	60	26	98	22	36.74%
Large auk / diver species	0.14	323	208	452	74	22.91%

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Passerine species	0.01	34	0	85	28	81.44%
Seal species	0.13	310	210	415	63	20.14%
Cetacean species	0.18	429	234	649	126	29.25%
Seal / small cetacean species	0.03	66	31	108	24	35.89%

Table 25 Abundance estimates of species in the southern area (pSPA) during 17 February 2018

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Species						
Shelduck	0.01	27	0	77	26	95.93%
Common scoter	0.07	160	0	466	157	98.21%
Surf scoter	0.00	7	0	20	7	98.29%
Red-breasted merganser	0.01	20	0	46	15	73.06%
Red-throated diver	**6.88**	**16,002**	**10,841**	**21,682**	**3312**	**20.69%**
Gannet	0.18	429	139	792	203	47.22%
Cormorant	0.49	1140	220	2468	704	61.74%
Great crested grebe	0.36	839	402	1316	278	33.06%
Sanderling	0.13	296	0	855	292	98.94%
Curlew	0.02	53	0	127	38	71.06%
Kittiwake	0.09	212	132	300	52	24.32%
Little gull	0.00	7	0	20	7	96.55%
Black-headed gull	0.90	2083	472	4270	1187	56.95%
Mediterranean gull	0.01	14	0	31	9	67.76%
Common gull	1.39	3239	2051	4653	798	24.62%
Lesser black-backed gull	0.12	271	176	382	63	23.23%
Herring gull	0.45	1047	770	1335	173	16.50%

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Great black-backed gull	0.84	1962	1560	2420	264	13.42%
Guillemot	0.90	2103	1175	3172	607	28.85%
Razorbill	0.12	291	169	423	78	26.54%
Rock dove	0.00	7	0	20	7	95.67%
Grey seal	0.02	47	20	76	17	36.34%
Harbour seal	0.02	40	13	73	20	49.64%
Harbour porpoise	0.18	427	234	642	125	29.22%

Table 26 Abundance estimates of species groups in the northern area (large) during 17 February 2018

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Broad category						
All birds	6.84	8320	5705	11263	1692	20.33%
All non-avian animals	0.27	328	200	481	86	25.99%
Species group						
Duck species	0.41	495	0	1462	482	97.34%
Diver species	3.72	4528	2440	7019	1407	31.07%
Fulmar / gull species	0.04	52	0	111	34	64.42%
Gannet species	0.03	41	10	81	23	55.36%
Cormorant species	0.22	270	69	561	154	57.04%
Grebe species	0.08	103	30	188	48	46.13%
Small gull species	0.56	685	358	1027	202	29.48%
Black-backed gull species	0.24	288	191	391	61	21.16%
Large gull species	0.98	1190	654	1861	370	31.03%
Gull species	0.15	185	81	297	66	35.23%
Large auk	0.28	340	185	505	97	28.37%
Auk / small gull	0.03	31	0	71	22	70.61%
Large auk / diver species	0.07	83	30	150	37	44.19%
Seal species	0.05	62	10	123	35	56.64%
Cetacean species	0.14	174	79	291	66	37.55%

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Seal / small cetacean species	0.08	93	51	133	25	26.10%

Table 27 Abundance estimates of species in the northern area (large) during 17 February 2018

Category	Density estimate (n/km^2)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Species						
Common scoter	0.42	509	0	1466	485	95.36%
Red-throated diver	**3.77**	**4587**	**2499**	**7114**	**1420**	**30.94%**
Fulmar	0.03	41	0	82	27	64.57%
Gannet	0.03	41	10	81	23	55.08%
Cormorant	0.21	257	59	546	155	59.95%
Great crested grebe	0.08	103	30	187	48	46.00%
Kittiwake	0.07	82	30	143	36	43.23%
Black-headed gull	0.03	41	10	80	22	53.31%
Common gull	0.42	511	257	796	164	32.05%
Lesser black-backed gull	0.08	93	51	140	27	28.94%
Herring gull	0.77	931	457	1504	320	34.37%
Great black-backed gull	0.27	329	230	429	61	18.51%
Guillemot	0.24	288	151	438	89	30.56%
Razorbill	0.02	21	0	41	13	61.64%
Harbour porpoise	0.14	175	80	290	65	36.84%

Table 28 Abundance estimates of species groups in the northern area (small) during 17 February 2018

Category	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Broad category						
All birds	1.69	652	491	826	103	15.73%
All non-avian animals	0.39	152	76	245	53	34.49%
Species group						
Diver species	0.53	204	139	273	41	19.93%
Fulmar / gull species	0.05	21	0	52	17	81.85%
Small gull species	0.40	154	20	356	105	68.00%
Black-backed gull species	0.21	82	43	137	30	36.15%
Large gull species	0.08	31	9	57	15	47.95%
Large auk	0.40	153	117	192	23	14.94%
Large auk / diver species	0.03	10	0	26	9	83.50%
Cetacean species	0.34	133	64	218	47	34.99%
Seal / small cetacean species	0.05	21	0	40	11	52.85%

Table 29 Abundance estimates of species in the northern area (small) during 17 February 2018

Category	Density estimate (n/km^2)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Species						
Red-throated diver	**0.53**	**204**	**137**	**274**	**42**	**20.24%**
Fulmar	0.05	21	0	53	17	81.80%
Kittiwake	0.08	31	0	62	19	58.96%
Little gull	0.03	11	0	29	10	90.71%
Black-headed gull	0.18	71	0	197	64	89.98%
Common gull	0.08	31	0	61	17	55.25%
Lesser black-backed gull	0.03	11	0	30	11	101.85%
Herring gull	0.05	21	0	44	13	62.05%
Great black-backed gull	0.16	61	27	104	25	39.59%
Guillemot	0.19	72	41	108	20	27.52%
Harbour porpoise	0.34	132	65	217	47	35.09%

Table 30 Summary of abundance estimates of red-throated diver across all survey areas during 4 and 17 February 2018

Area	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Survey 1 – 4 February 2018						
All areas SPA	2.66	10,136	7763	12,626	1464	14.44%
All areas newly enlarged SPA	2.58	10,148	7868	12,544	1434	14.12%
South SPA	3.64	8021	6421	9695	1004	12.50%
South newly enlarged SPA	3.51	8161	6520	9841	1000	12.25%
North (large)	0.62	756	504	1019	1019	20.90%
North (Small)	0.34	132	76	196	37	27.85%
Survey 2 – 17 February 2018						
All areas SPA	5.78	21,997	15,351	29,415	4299	19.54%
All areas newly enlarged SPA	5.68	22,280	15,611	29,784	4293	19.26%
South SPA	7.1	15,671	10,531	21,265	3273	20.88%
South newly enlarged SPA	6.88	16,002	10,841	21,682	3312	20.69%
North (large)	3.77	4587	2499	7114	1420	30.94%
North (Small)	0.53	204	137	274	42	20.24%

Table 31 Summary of abundance estimates of harbour porpoise across all survey areas during 4 and 17 February 2018

Area	Density estimate (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)	Standard deviation of population estimate (number)	CV (%)
Survey 1 – 4 February 2018						
All areas SPA	0.06	217	108	345	73	33.51%
All areas newly enlarged SPA	0.05	216	108	342	71	32.85%
South SPA	0.07	164	78	266	58	34.93%
South newly enlarged SPA	0.07	164	77	267	59	35.41%
North (large)	0.02	21	0	60	60	96.91%
North (Small)	0.03	11	0	29	10	93.39%
Survey 2 – 17 February 2018						
All areas SPA	0.19	737	485	1011	160	21.60%
All areas newly enlarged SPA	0.19	731	483	1009	160	21.86%
South SPA	0.19	428	238	638	123	28.62%
South newly enlarged SPA	0.18	427	234	642	125	29.22%
North (large)	0.14	175	80	290	65	36.84%
North (Small)	0.34	132	65	217	47	35.09%

Table 32 Comparison of the number of raw observations and population abundance estimates within the entire original SPA (and confidence limits around those) for each species/species group between the digital still aerial survey in 2013 (APEM 2013) and the digital video aerial survey in 2018 (current study) that yielded the peak population abundance estimate of each species/group in each winter. Shaded cells denote instances of species/species groups which were recorded in only one or other year.

Species / group	HiDef Survey yielding peak abundance estimate	APEM Survey yielding peak abundance estimate	HiDef Raw Observations	APEM Raw Observations	HiDef Population estimate (number)	APEM Population estimate (number)	HiDef Lower 95% confidence limit of population (number)	APEM Lower 95% confidence limit of population (number)	HiDef Upper 95% confidence limit of population (number)	APEM Upper 95% confidence limit of population (number)
Greylag goose		Survey 1		5		34		5		94
Shelduck[2]	Survey 2	Survey 2	5	7	0	46	0	7	0	137
Wigeon		Survey 1		30		201		30		557
Scaup		Survey 1		11		74		11		181
Common scoter	Survey 1	Survey 1	78	475	612	3,190	0	732	1765	6,332
Surf scoter	Survey 2		1		8		0		23	
Red-breasted merganser	Survey 2	Survey 2	3	6	24	40	0	6	54	120
Red-throated diver	**Survey 2**	**Survey 2**	**2,917**	**2,132**	**21,997**	**14,161**	**15,351**	**8,230**	**29,415**	**22,245**
Black-throated diver		Survey 1		33		222		121		329

[2] For this species, the raw observations were located outside the SPA in the pSPA and so shows no population estimate within this table

Species / group	HiDef Survey yielding peak abundance estimate	APEM Survey yielding peak abundance estimate	HiDef Raw Observations	APEM Raw Observations	HiDef Population estimate (number)	APEM Population estimate (number)	HiDef Lower 95% confidence limit of population (number)	APEM Lower 95% confidence limit of population (number)	HiDef Upper 95% confidence limit of population (number)	APEM Upper 95% confidence limit of population (number)
Great northern diver		Survey 1		37		248		134		369
Fulmar	Survey 1	Survey 1	8	26	63	175	15	101	115	262
Gannet	Survey 2	Survey 2	73	181	536	1,202	188	279	971	2,697
Cormorant	Survey 2	Survey 1	197	104	1493	698	365	104	3077	1,699
Shag		Survey 1		28		188		28		450
Great crested grebe	Survey 2	Survey 1	137	60	1070	403	527	208	1663	685
Oystercatcher[3]	Survey 1	Survey 1	2	108	0	725	0	108	0	1,840
Lapwing		Survey 2		19		126		19		379
Sanderling	Survey 2		44		336		0		1011	
Curlew	Survey 2		8		0		0		0	
Redshank		Survey 1		56		376		56		1,128
Great skua		Survey 2		1		7		1		20
Kittiwake	Survey 1	Survey 2	117	539	895	3,580	594	1,727	1,220	6,071
Little gull	Survey 2		3		16		0		38	
Black-headed gull	Survey 2	Survey 2	363	603	1099	4,005	306	1,621	2,112	7,572

[3] For this species, the raw observations were located outside the SPA in the pSPA and so shows no population estimate within this table

Species / group	HiDef Survey yielding peak abundance estimate	APEM Survey yielding peak abundance estimate	HiDef Raw Observations	APEM Raw Observations	HiDef Population estimate (number)	APEM Population estimate (number)	HiDef Lower 95% confidence limit of population (number)	APEM Lower 95% confidence limit of population (number)	HiDef Upper 95% confidence limit of population (number)	APEM Upper 95% confidence limit of population (number)
Mediterranean gull	Survey 2		3		16		0		31	
Common gull	Survey 2	Survey 1	570	1,847	3875	12,403	2,467	2,203	5,591	30,110
Lesser black-backed gull	Survey 2	Survey 1	56	87	387	584	267	329	524	927
Herring gull	Survey 2	Survey 2	294	456	1859	3,029	1,342	1,614	2,444	4,975
Great black-backed gull	Survey 2	Survey 1	350	214	2513	1,437	1,964	719	3130	2,666
Guillemot	Survey 2	Survey 1	386	2	2737	13	1624	2	3982	54
Razorbill	Survey 2		48		357		209		514	
Rock dove	Survey 1		2		8		0		23	
Grey seal	Survey 2		7		55		23		92	
Harbour seal	Survey 2		6		47		15		92	
Harbour porpoise	Survey 2		95		737		485		1011	
Duck species		Survey 1		64		430		64		1289
Grebe species		Survey 1		2		13		2		34
Wader species		Survey 1		588		3948		588		11845
Skua species		Survey 1 / Survey 2		1		7		1		20
Small gull species		Survey 1		98		658		443		907

Species / group	HiDef Survey yielding peak abundance estimate	APEM Survey yielding peak abundance estimate	HiDef Raw Observations	APEM Raw Observations	HiDef Population estimate (number)	APEM Population estimate (number)	HiDef Lower 95% confidence limit of population (number)	APEM Lower 95% confidence limit of population (number)	HiDef Upper 95% confidence limit of population (number)	APEM Upper 95% confidence limit of population (number)
Guillemot / razorbill		Survey 1		838		5627		4009		7487

5.3 Distribution patterns

87 The distribution patterns of the most abundant species and species groups are presented as density maps, derived by applying kernel density estimation, in which a density surface depicts the estimated number of individuals per km² (Figure 7 to Figure 24 and Figure 27). Fuller details of bird numbers are presented in Table 6 to Table 32.

88 Species or species groups for which there were too few observations to generate density maps are presented as dot maps only (Figure 25 to Figure 26 and Figure 28 to Figure 29). These are provided for reference only.

89 Anthropogenic activity is presented as dot maps for reference only (Figure 30 to Figure 32). These include wind turbines, fishing buoys, and boats. This is largely confined to the southern sectors with a coastal bias to most objects. The AIS receiver covered a recording sweep of at least 40km from the aircraft. An AIS device was only operating in the aircraft that flew the southern sector, but this did provide data for much of the northern sector also. Further offshore are three wind farms - the London Array, Kentish Flats and Gunfleet Sands sites.

90 In all of the distribution maps, the Foulness Danger Area ‘Hole’ can be seen to the east of the Essex coast, at the north-eastern limit to the intertidal flats off Foulness. Although this area was overflown on two transects on each survey (Figure 2), records of birds seen in this area were not included in deriving population abundance estimates or producing density maps because, for reasons explained in the footnote to Figure 1, the area lies outwith the boundary of the newly re-classified Outer Thames Estuary SPA.

91 Red-throated diver (Figure 7 to Figure 10) was the most abundant species during both surveys and showed high densities and a widespread distribution. In the northern sector birds were further from the coast in the first survey than the second, when densities also increased. The distribution was similar in both surveys for the southern zone, but densities showed a strong increase notable in waters either side of the shipping lanes and the London Array wind farm. Such concentrations, where birds are squeezed between areas of human activity, strongly suggests that the birds are undertaking displacement behaviour. While still favouring the area as a whole they are being pushed away from some localities and clustering as a result. This is particularly notable during the second survey.

92 Common scoter (Figure 11) numbers were low with no clear spatial pattern to the records. In the second survey numbers were slightly higher with two small groups recorded near Aldeburgh and another at the far east of the survey area (where they associated with a surf scoter).

93 Gannet (Figure 12) were only recorded in the second survey with records typically away from the coast and with a strong bias to the most offshore part of the southern zone. No gannets were recorded within the footprint of London Array windfarm.

94 Cormorant (Figure 13) show several density hotspots off Dengie National Nature Reserve in Essex and to the north offshore from Walton-on-the Naze. Lower numbers occurred consistently at the mouth of the Thames. There appeared to be no attraction to the London array wind farm.

95 Great crested grebe (Figure 14) favoured the southern Kent coastal area. In the north a scatter of records occurred around Aldeburgh during the second survey.

96 Kittiwake (Figure 15) is a typically pelagic species so the distribution of records in survey one was as expected with low densities. Densities dropped further in the second survey period with birds also then being found further offshore. These movements may be weather related with the first survey following some windy conditions which may have displaced birds into the survey area while in the second period a more typical distribution was maintained.

97 Black-headed gull (Figure 16) showed similar patterns in both survey rounds. Very few birds were seen in the north, with concentrations in the south close to the north east Kent coast and around Southend-on-Sea and off Shoeburyness.

98 Common gull (Figure 17) were present on both surveys across much of the survey zone. There was a minor increase in density between the first and second surveys in the north with the distribution widening slightly also. This increase was mirrored in the south with birds more widely scattered in the second survey (than in the first survey) when their distribution was less coastal than that of black-headed gulls but more coastal than that of kittiwake.

99 Lesser black backed gull (Figure 18) were rare on the first survey, but numbers strongly increased in the second survey with a widespread, scattered distribution of birds at low density. This pattern is likely to be linked with the species being an early spring migrant and birds returning from more southern latitudes to UK waters in mid-February.

100 Herring gull (Figure 19) showed linkage to coastal towns during the first survey. In the second survey this pattern was diluted, and birds were more dispersed across the entire southern sector although still with a bias towards coastal areas. A similar pattern emerged in the northern zone.

101 Great black-backed gull (Figure 20) showed a widely scattered distribution over both surveys and all sectors. Most records related to low numbers of birds with a slight skew towards shipping lanes in the southern sector. Birds seem to also avoid the area around the London array wind farm.

102 Guillemot (Figure 21) were largely absent during the first survey bar a cluster of records in the small north east sector of the northern survey zone. Numbers in this area had dispersed by the second survey but there was a strong bias to offshore waters at the east of the survey site in the southern sector.

103 Razorbill (Figure 22) were recorded with greater frequency during the second survey, especially in eastern sectors of the southern survey zone. Birds were at low density and showed signs of displacement from the three constructed wind farms.

104 Harbour porpoise (Figure 27) were recorded in the more pelagic areas of the site. Animals were always at low densities but clearly showed a bias towards the eastern survey areas during the second survey round. Animals would appear to show displacement effects from the London Array wind farm.

105 Seal species (Figure 28 and Figure 29) records showed a bias towards the southern survey zone, with animals distributed across a wide area. Most of the individuals that received a positive identification (Figure 28) were noted as grey seals.

5.3.1 Distribution maps for red-throated diver

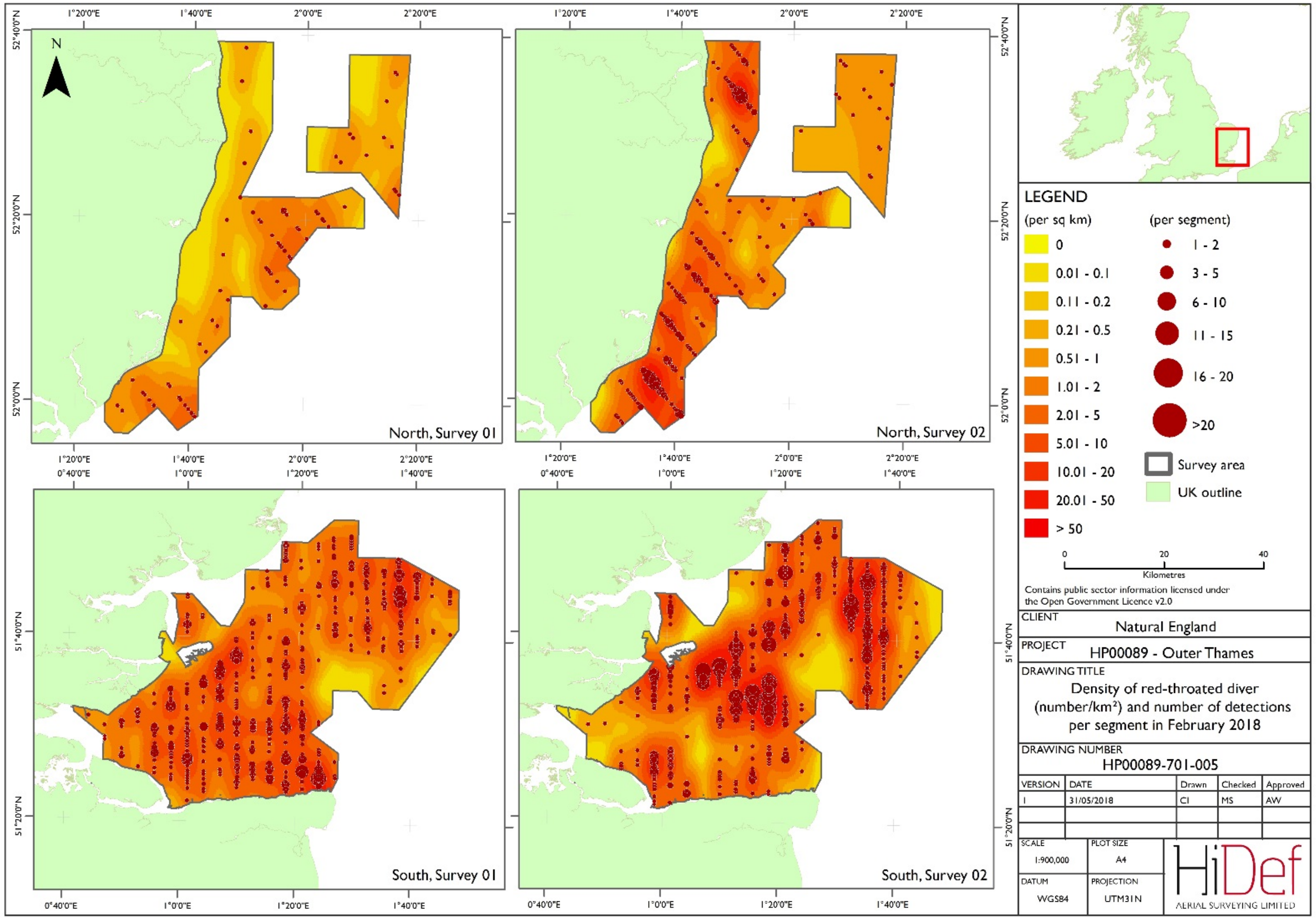

Figure 7 Density of red-throated diver (number/km²) and number of detections per segment in February 2018

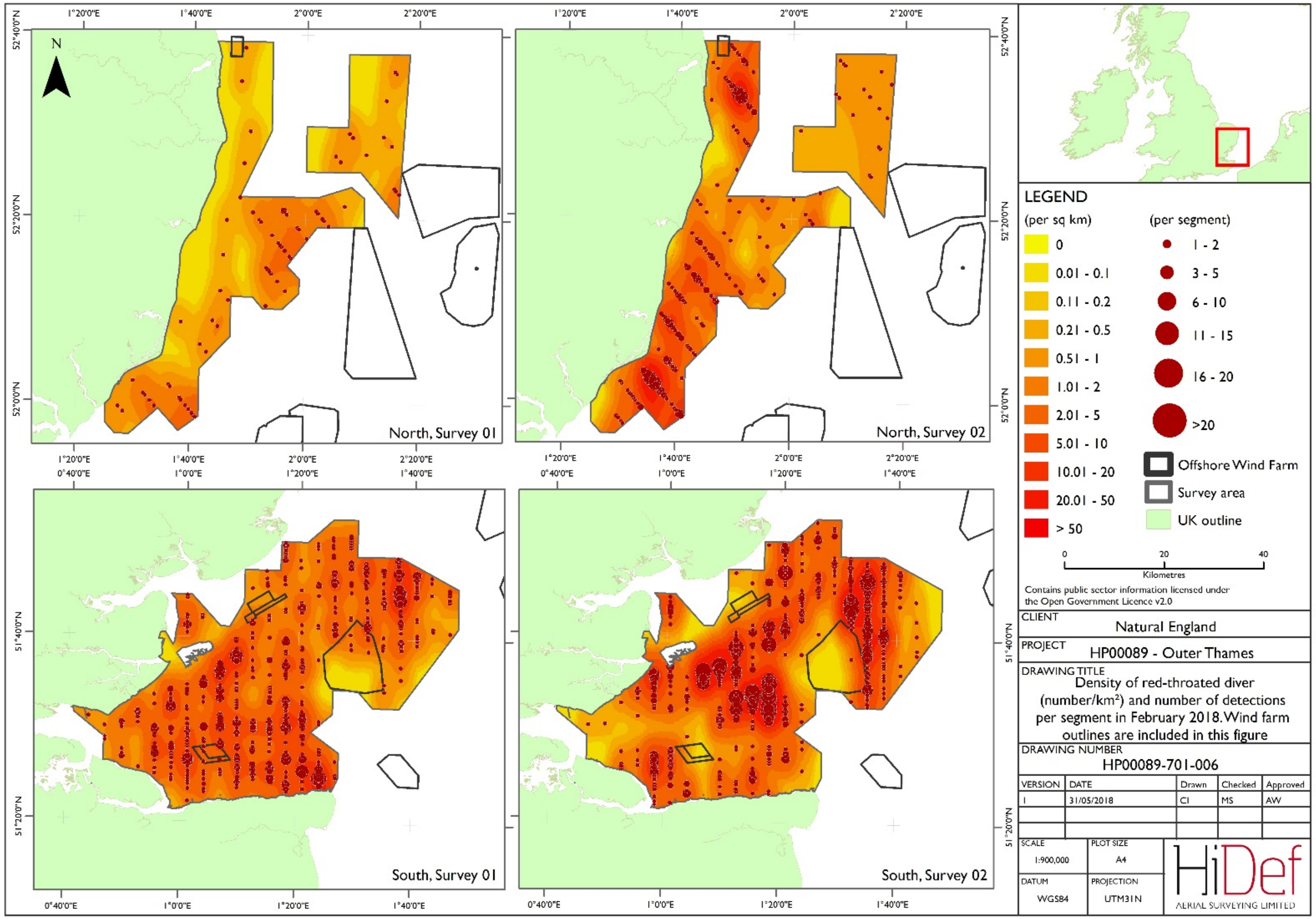

Figure 8 Density of red-throated diver (number/km²) and number of detections per segment in February 2018. Windfarm outlines are included in this figure

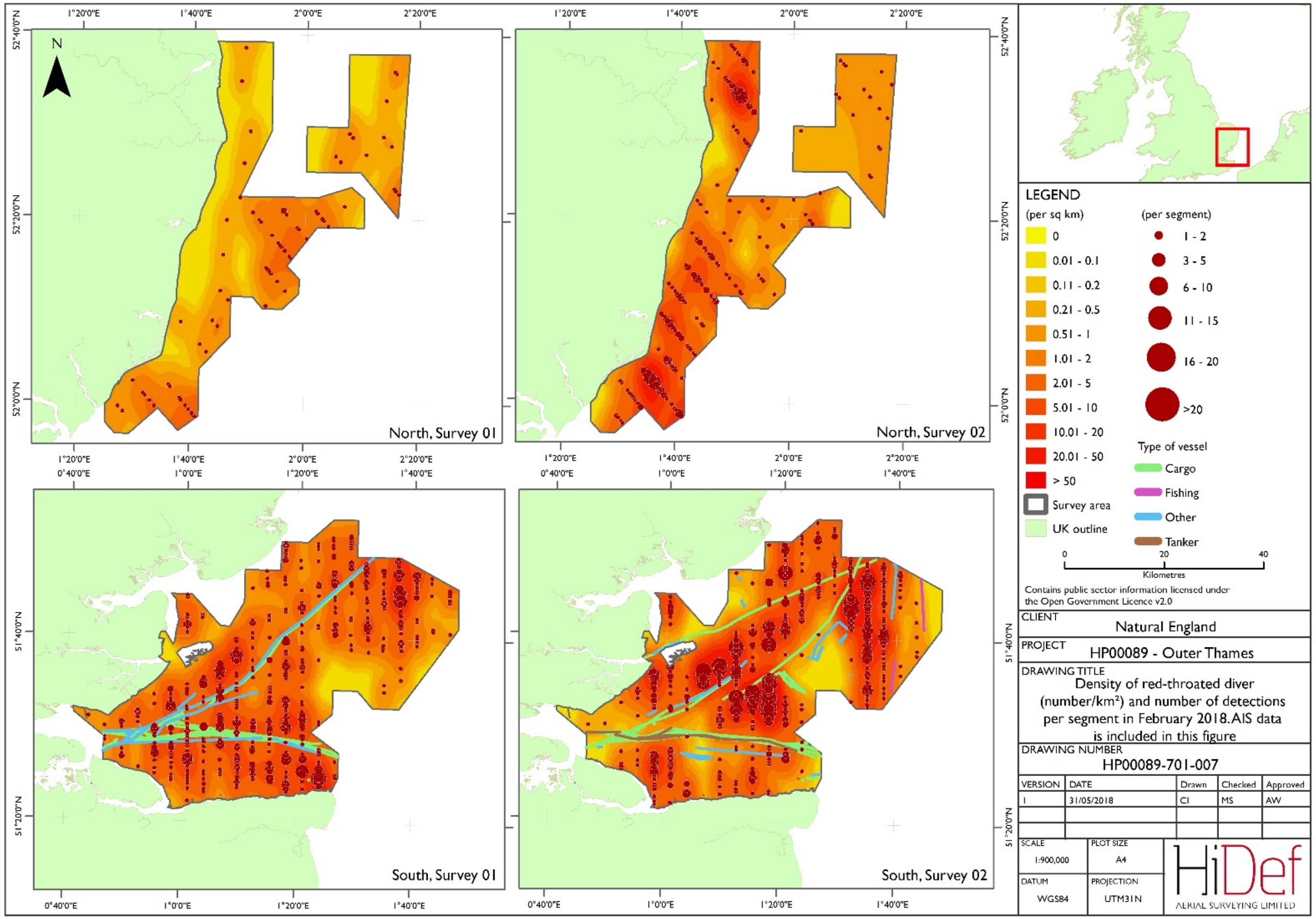

Figure 9 Density of red-throated diver (number/km²) and number of detections per segment in February 2018. AIS data is included in this figure which relates to the raw data shown in Figure 4 and Figure 5

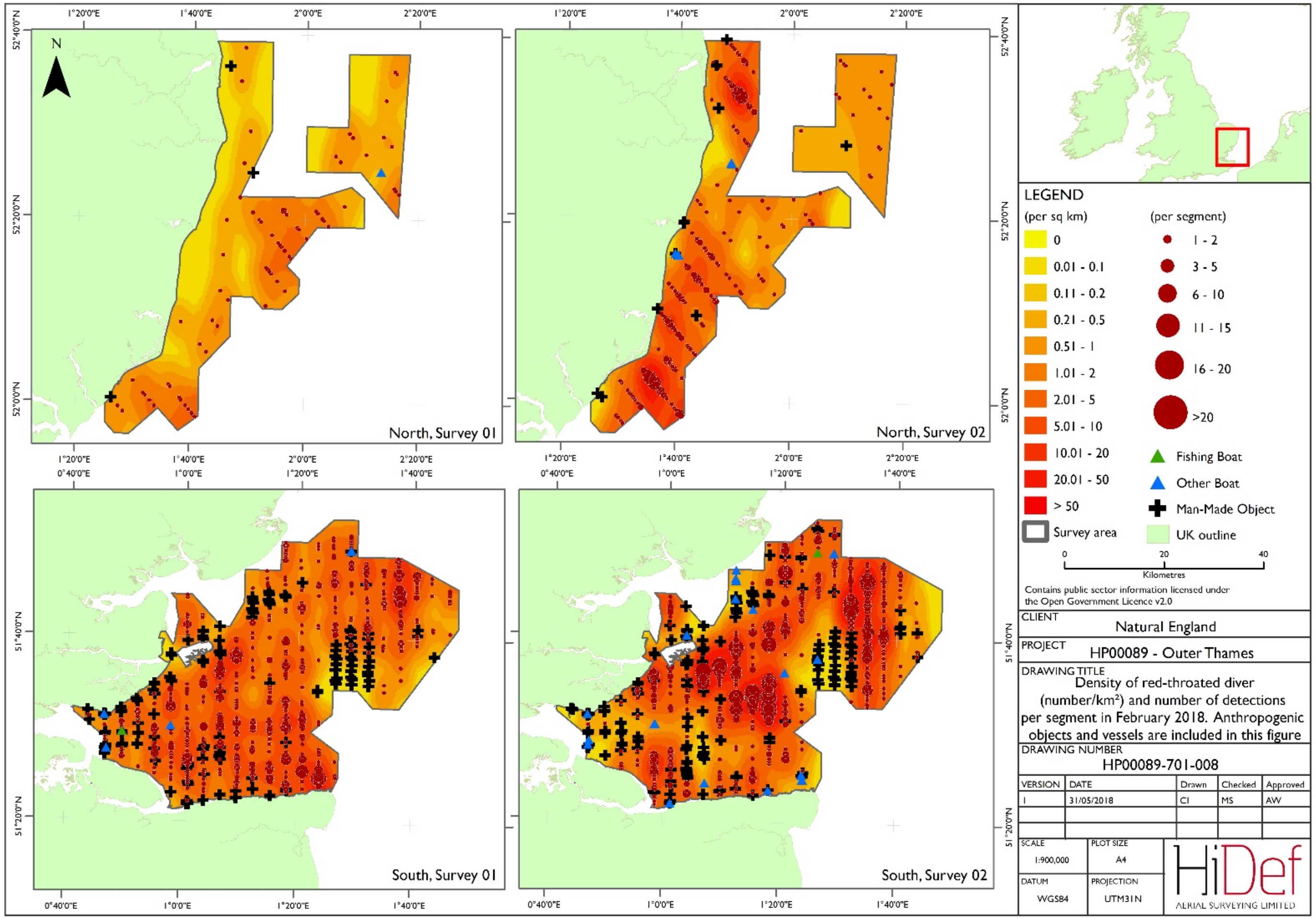

Figure 10 Density of red-throated diver (number/km²) and number of detections per segment in February 2018. Anthropogenic objects and vessels are included in this figure

5.3.2 Distribution maps for common scoter

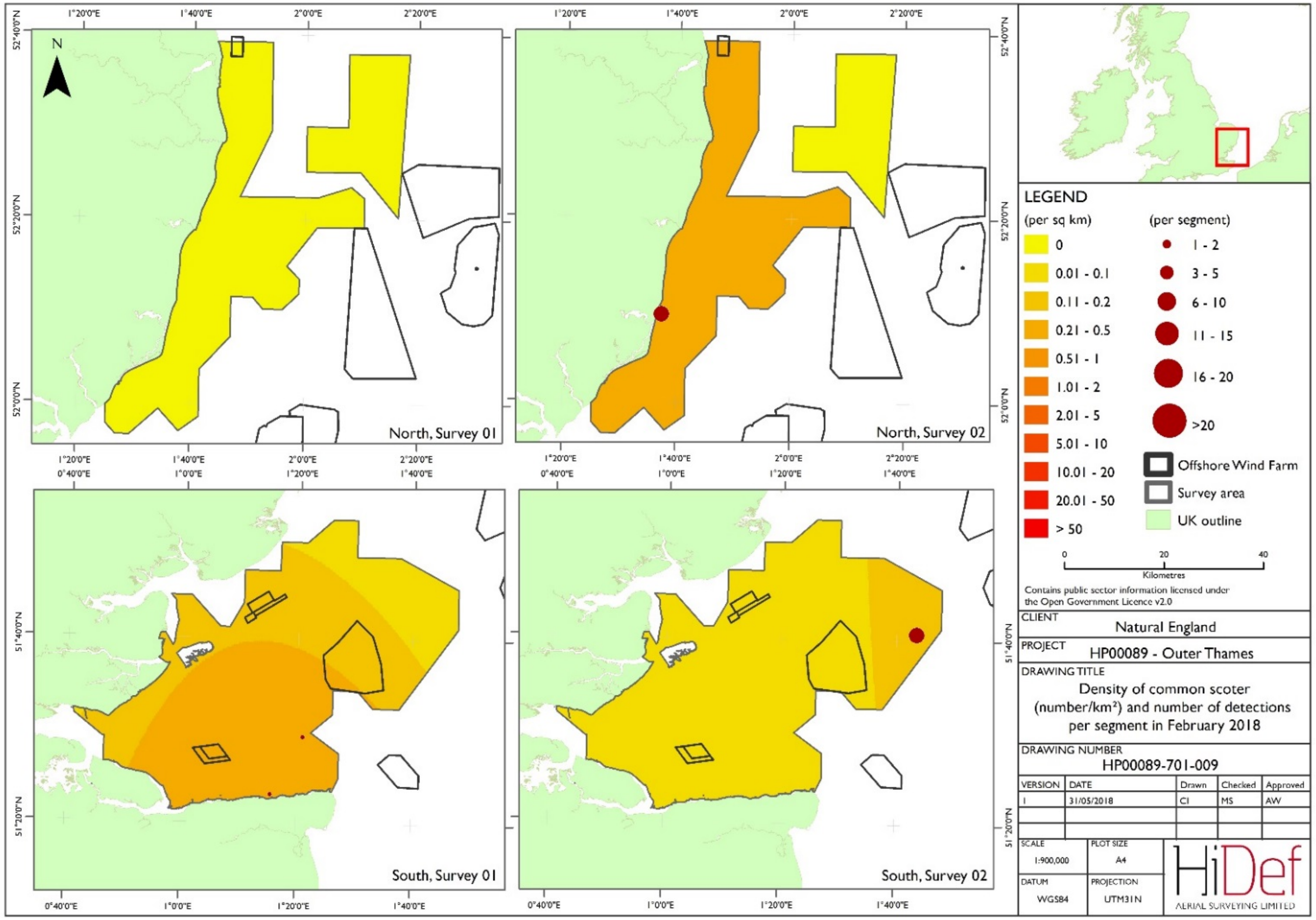

Figure 11 Density of common scoter (number/km²) and number of detections per segment in February 2018

5.3.3 Distribution maps for gannet

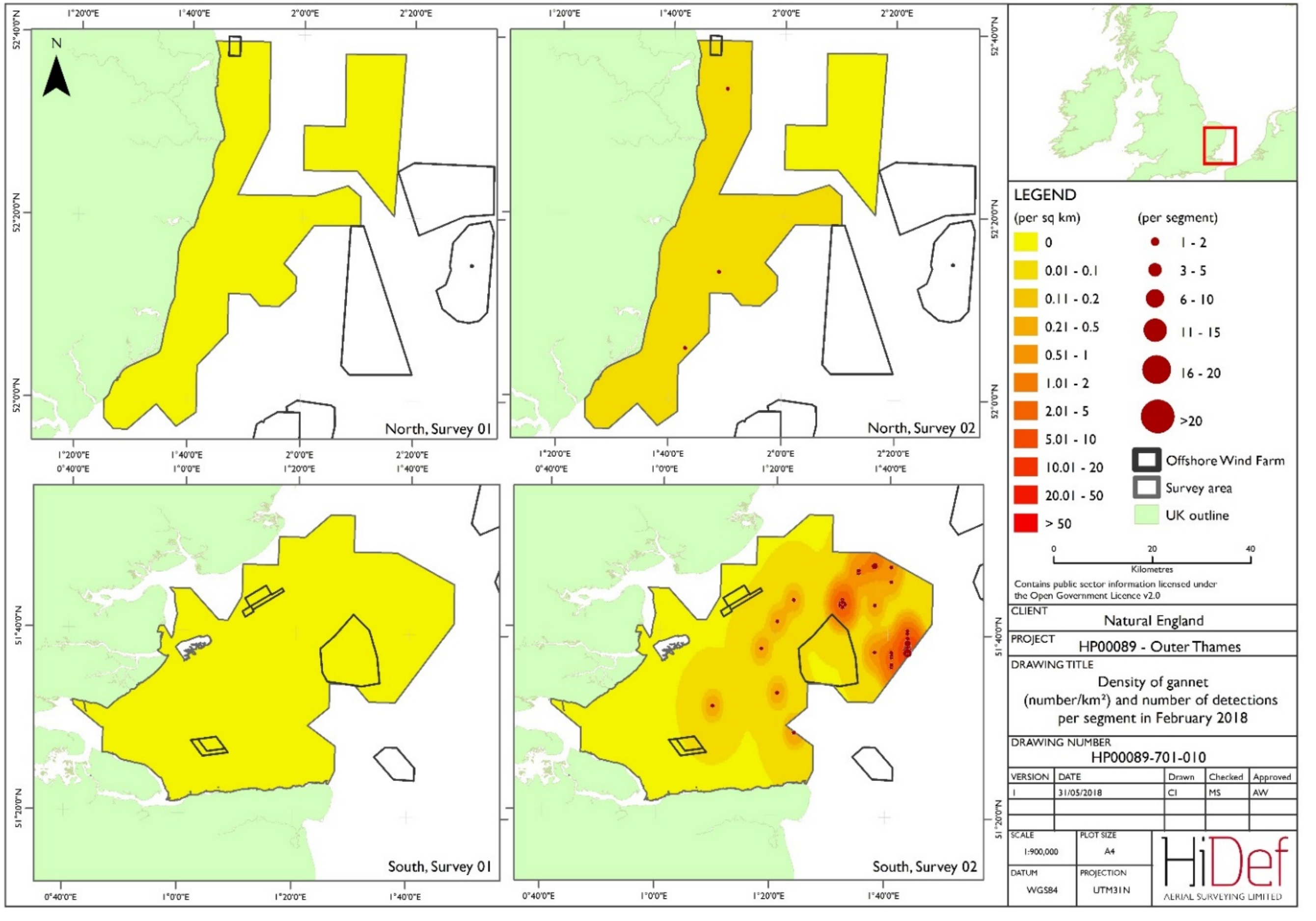

Figure 12 Density of gannet (number/km²) and number of detections per segment in February 2018

5.3.4 Distribution maps for cormorant

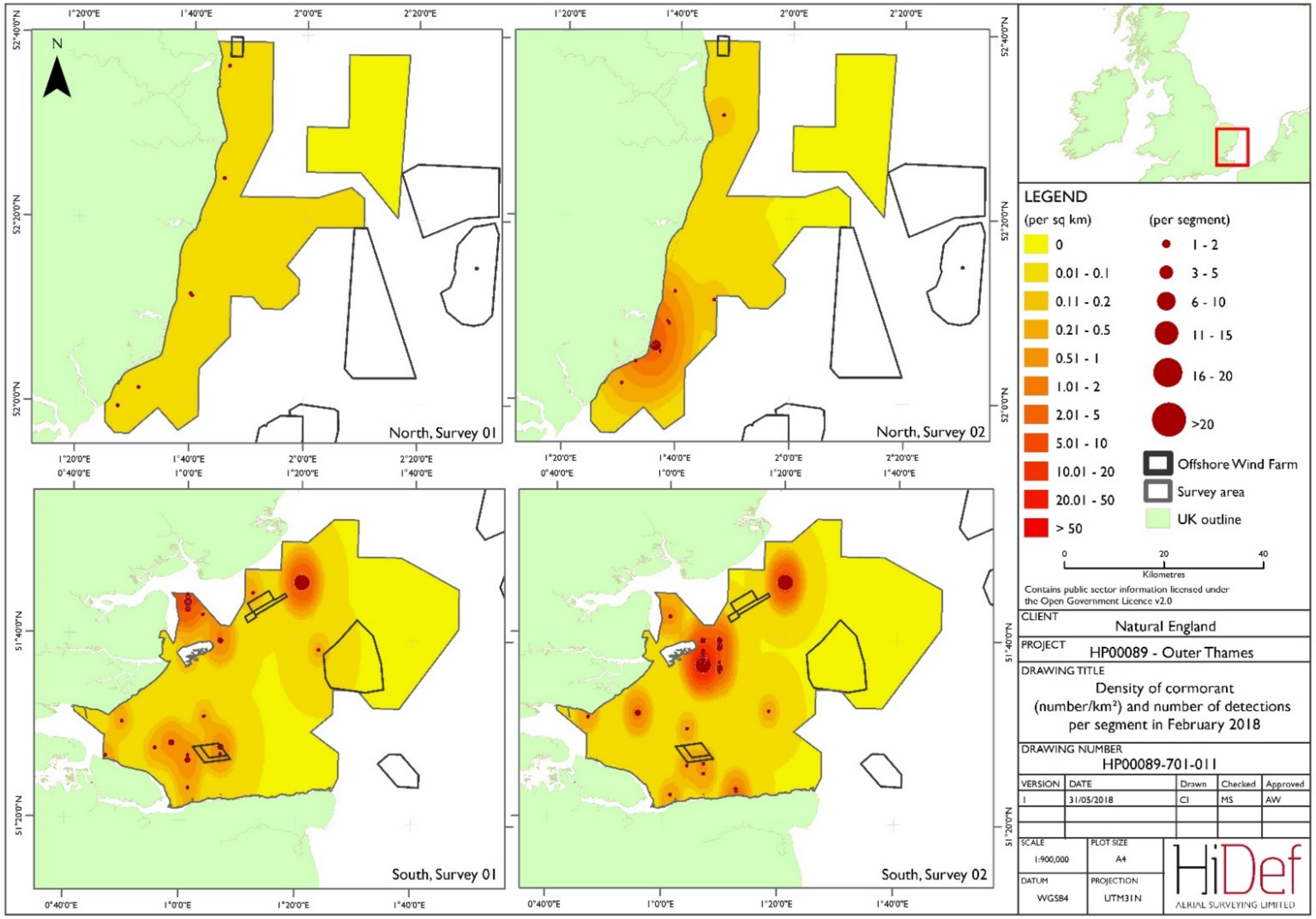

Figure 13 Density of cormorant (number/km²) and number of detections per segment in February 2018

5.3.5 Distribution maps for great crested grebe

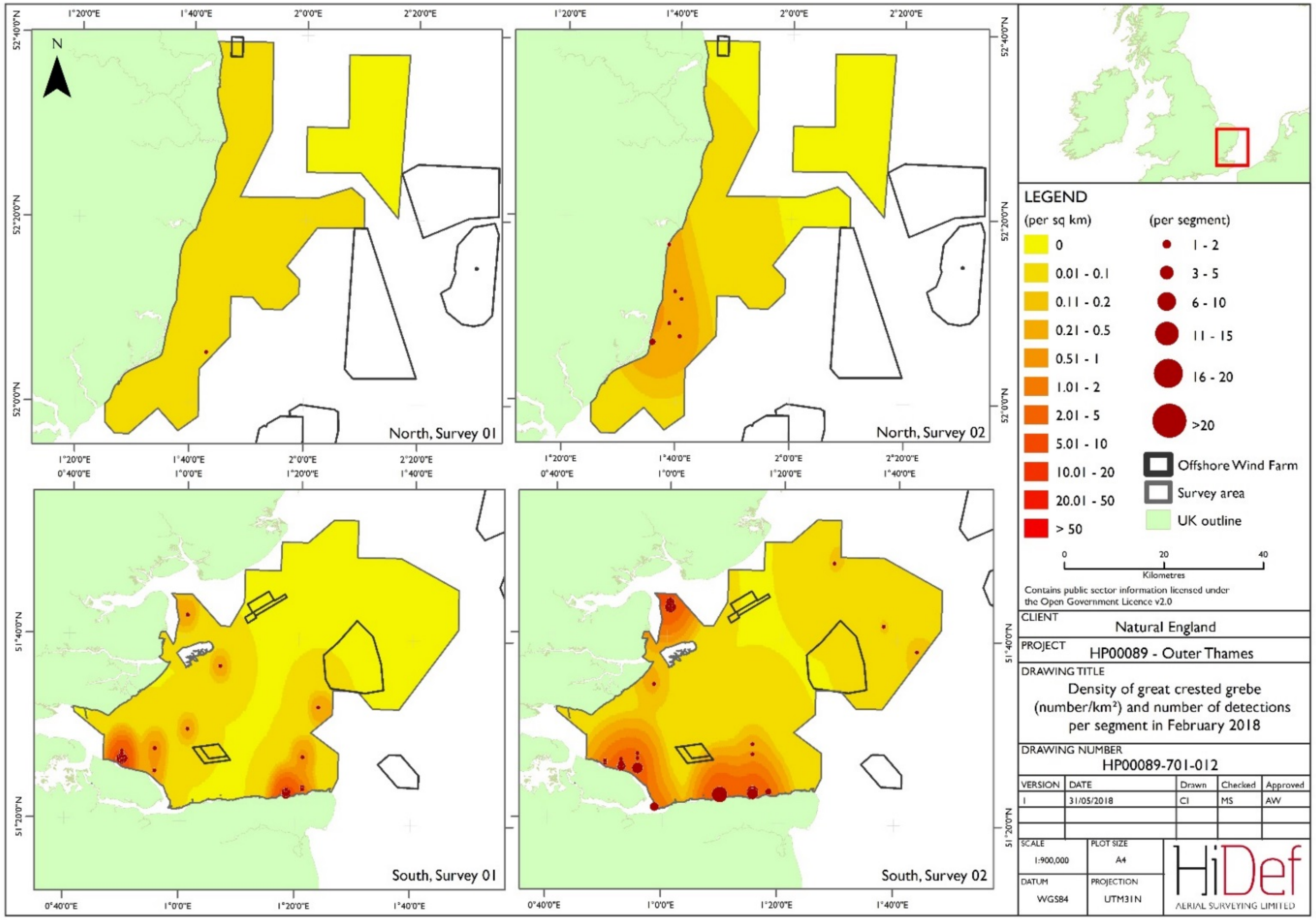

Figure 14 Density of great crested grebe (number/km²) and number of detections per segment in February 2018

5.3.6 Distribution maps for kittiwake

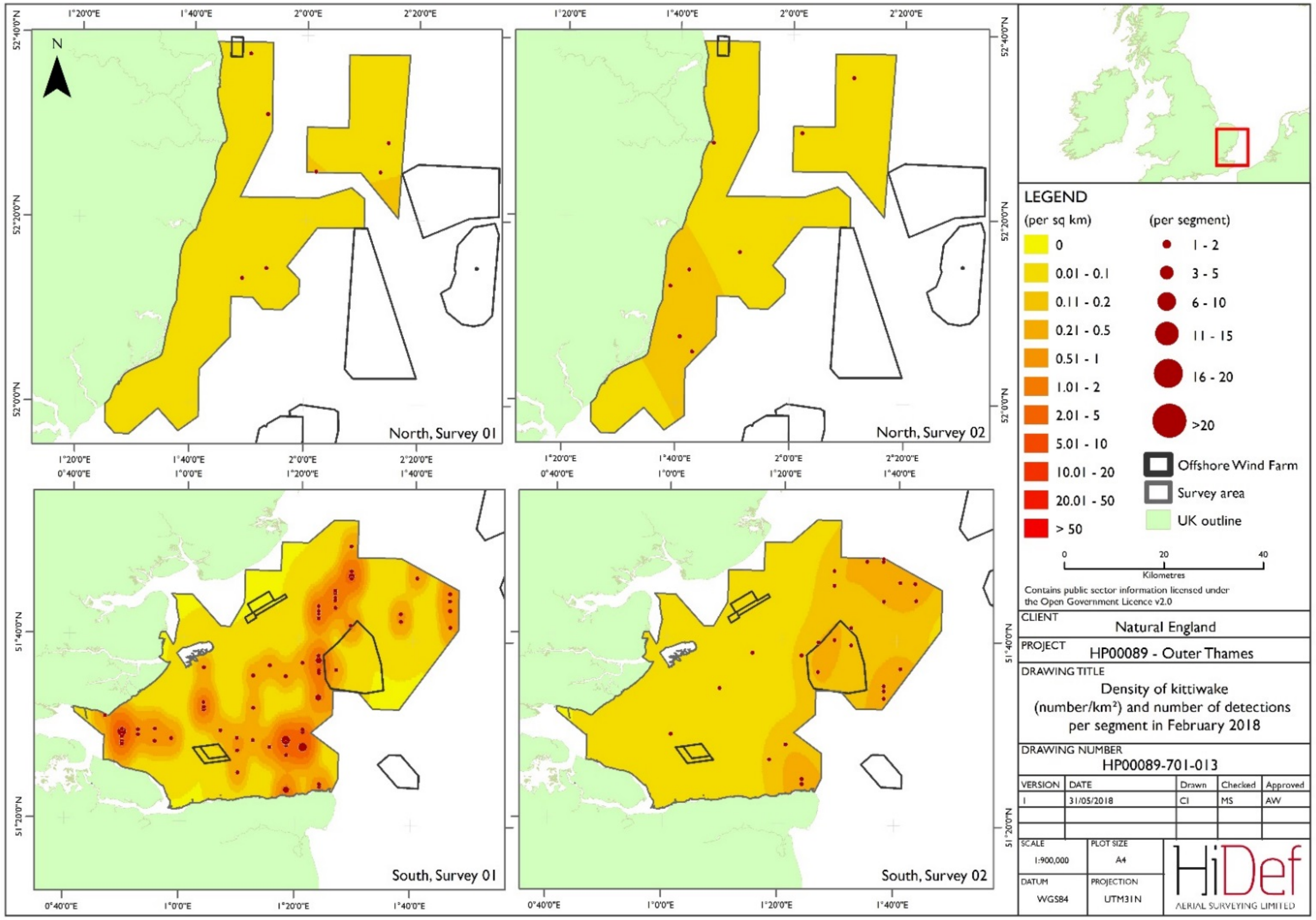

Figure 15 Density of kittiwake (number/km²) and number of detections per segment in February 2018

5.3.7 Distribution maps for black-headed gull

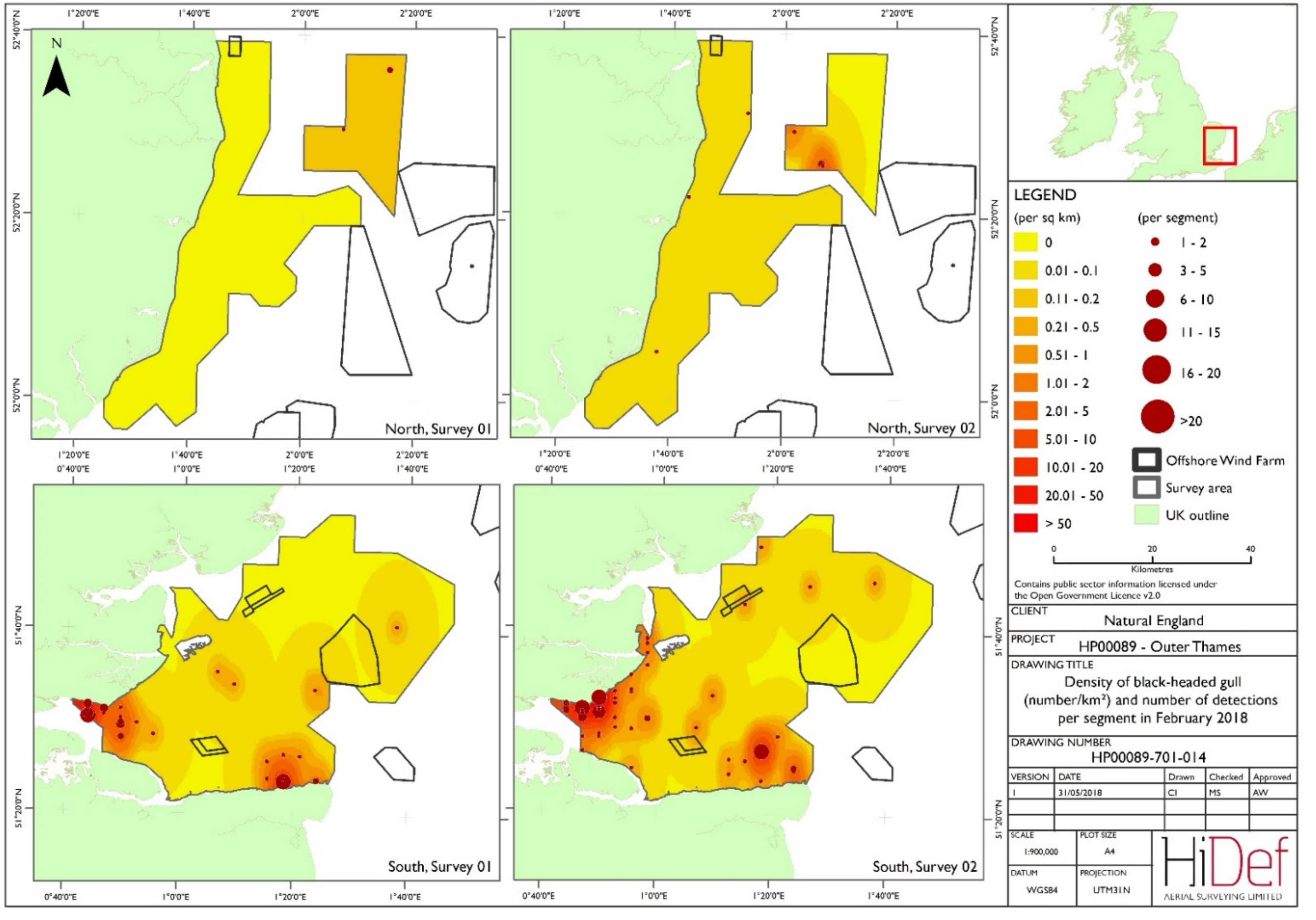

Figure 16 Density of black-headed gull (number/km²) and number of detections per segment in February 2018

5.3.8 Distribution maps for common gull

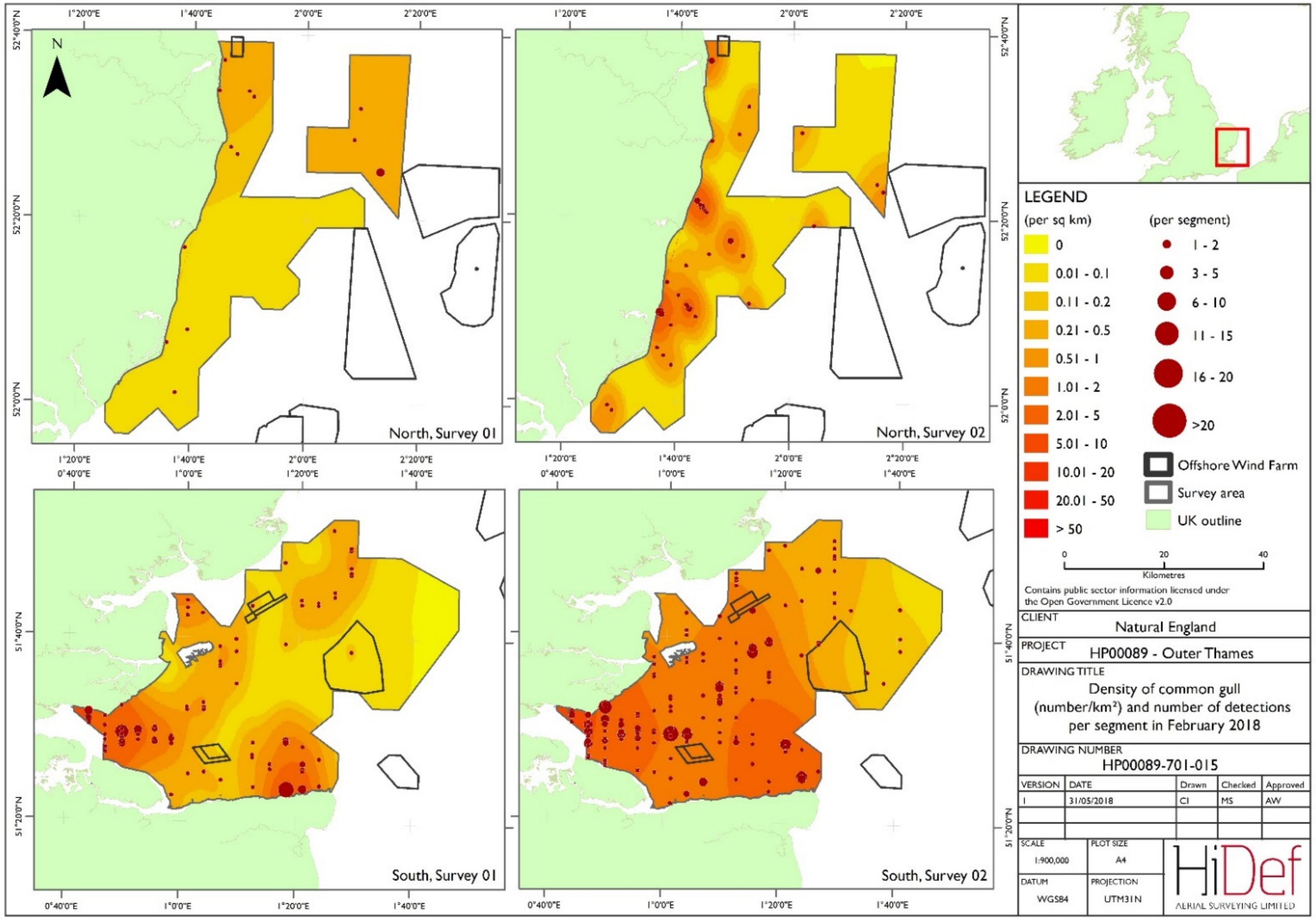

Figure 17 Density of common gull (number/km²) and number of detections per segment in February 2018

5.3.9 Distribution maps for lesser black-backed gull

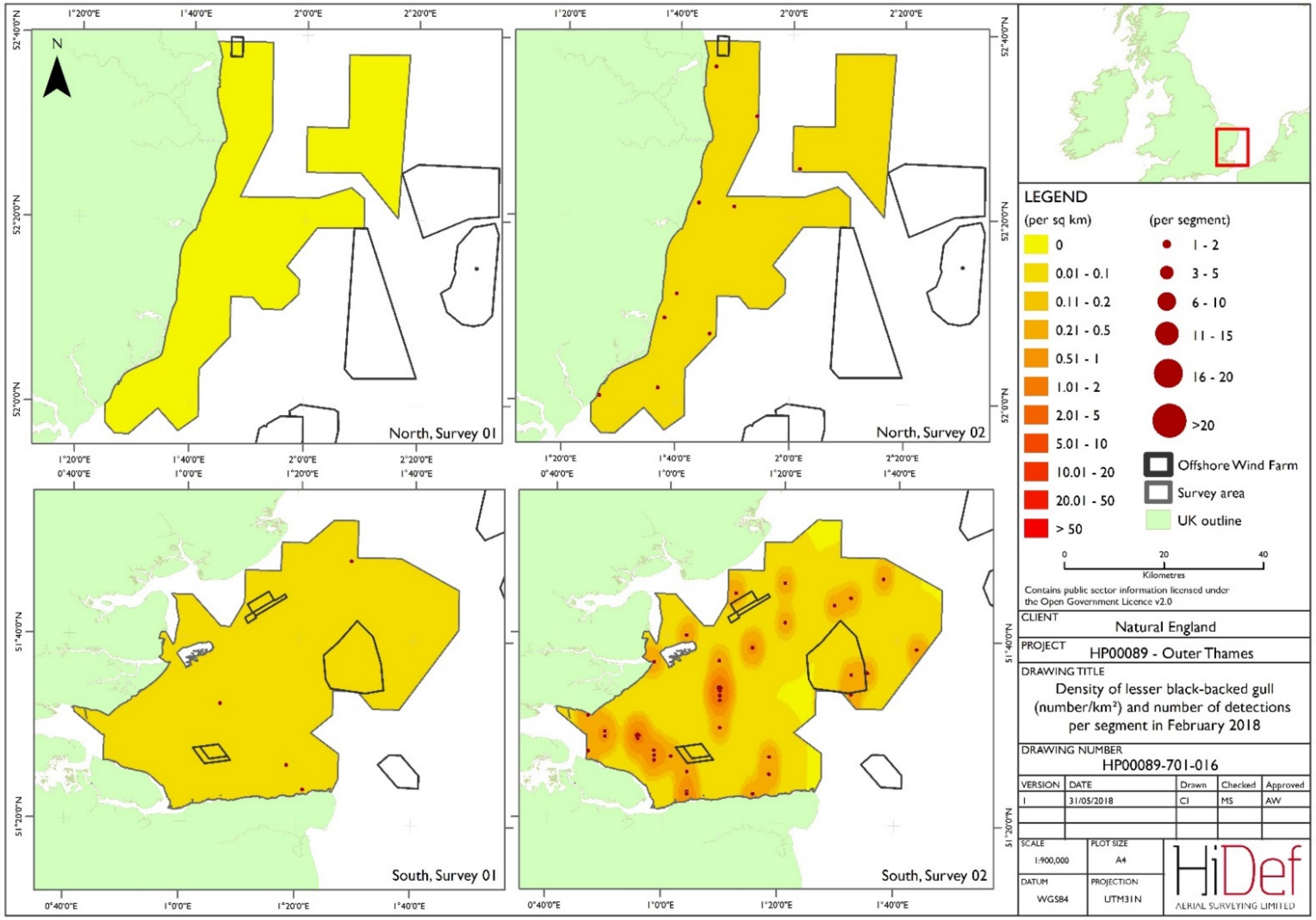

Figure 18 Density of lesser black-backed gull (number/km²) and number of detections per segment in February 2018

5.3.10 Distribution maps for herring gull

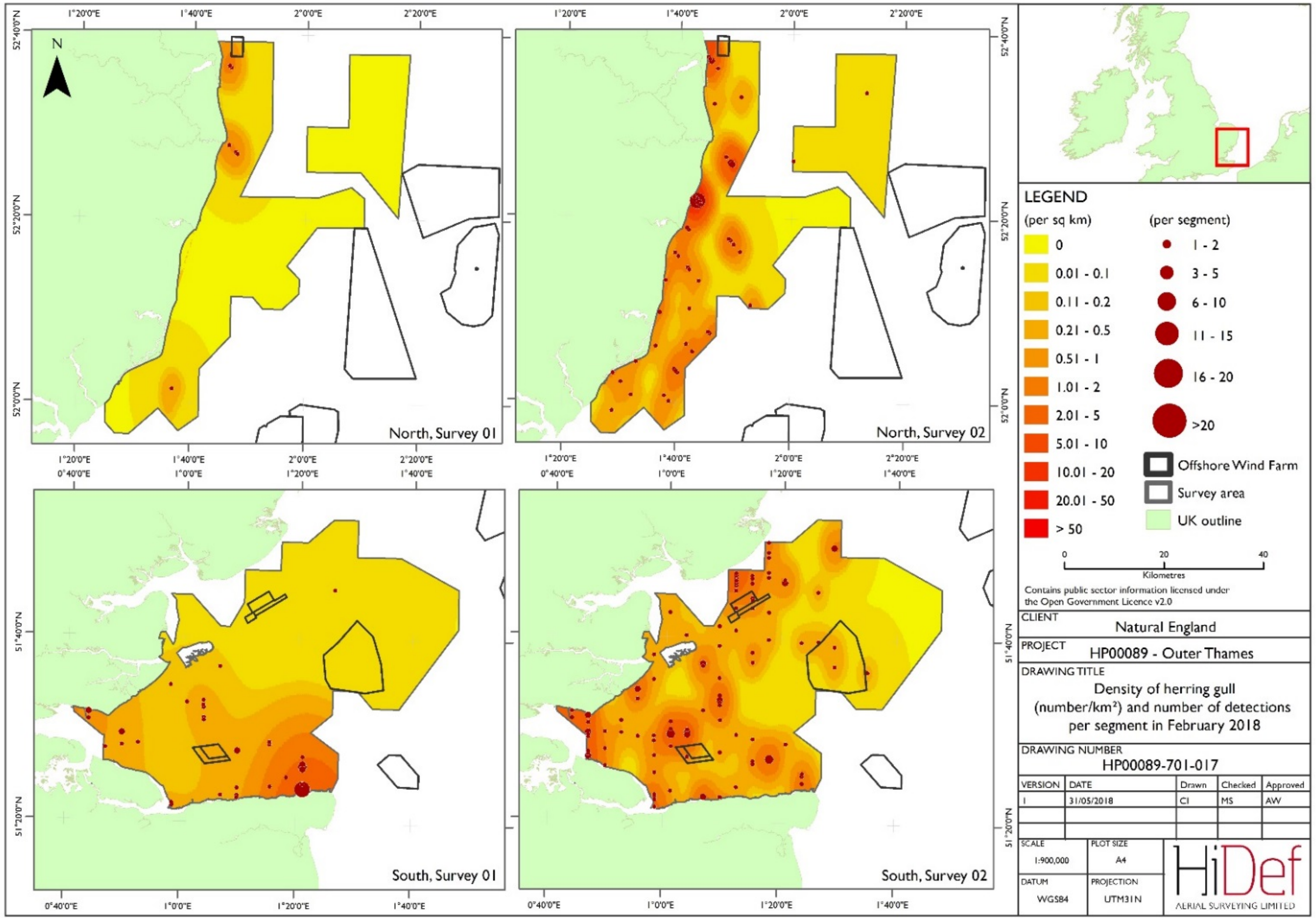

Figure 19 Density of herring gull (number/km²) and number of detections per segment in February 2018

5.3.11 Distribution maps for great black-backed gull

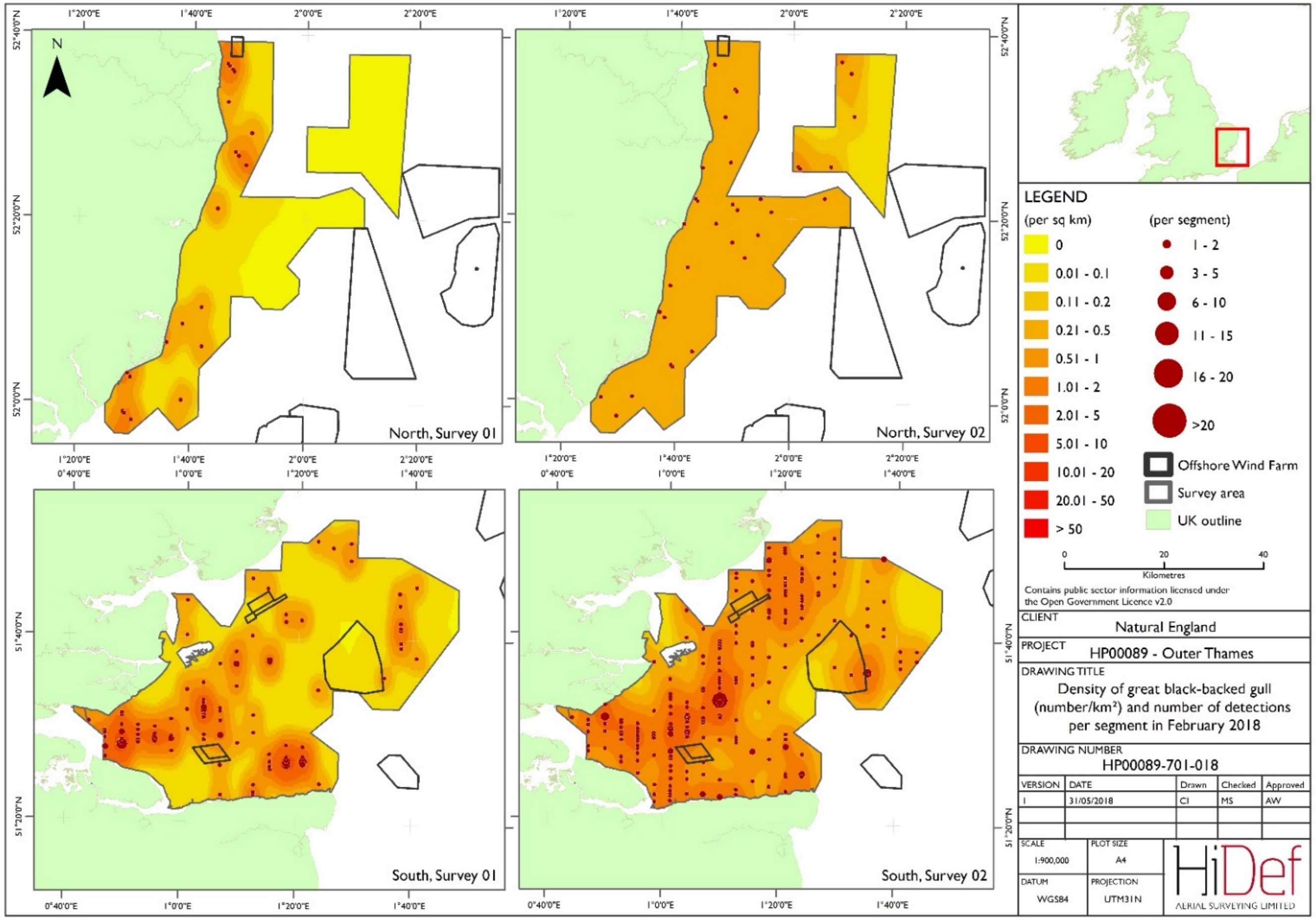

Figure 20 Density of great black-backed gull (number/km²) and number of detections per segment in February 2018

5.3.12 Distribution maps for guillemot

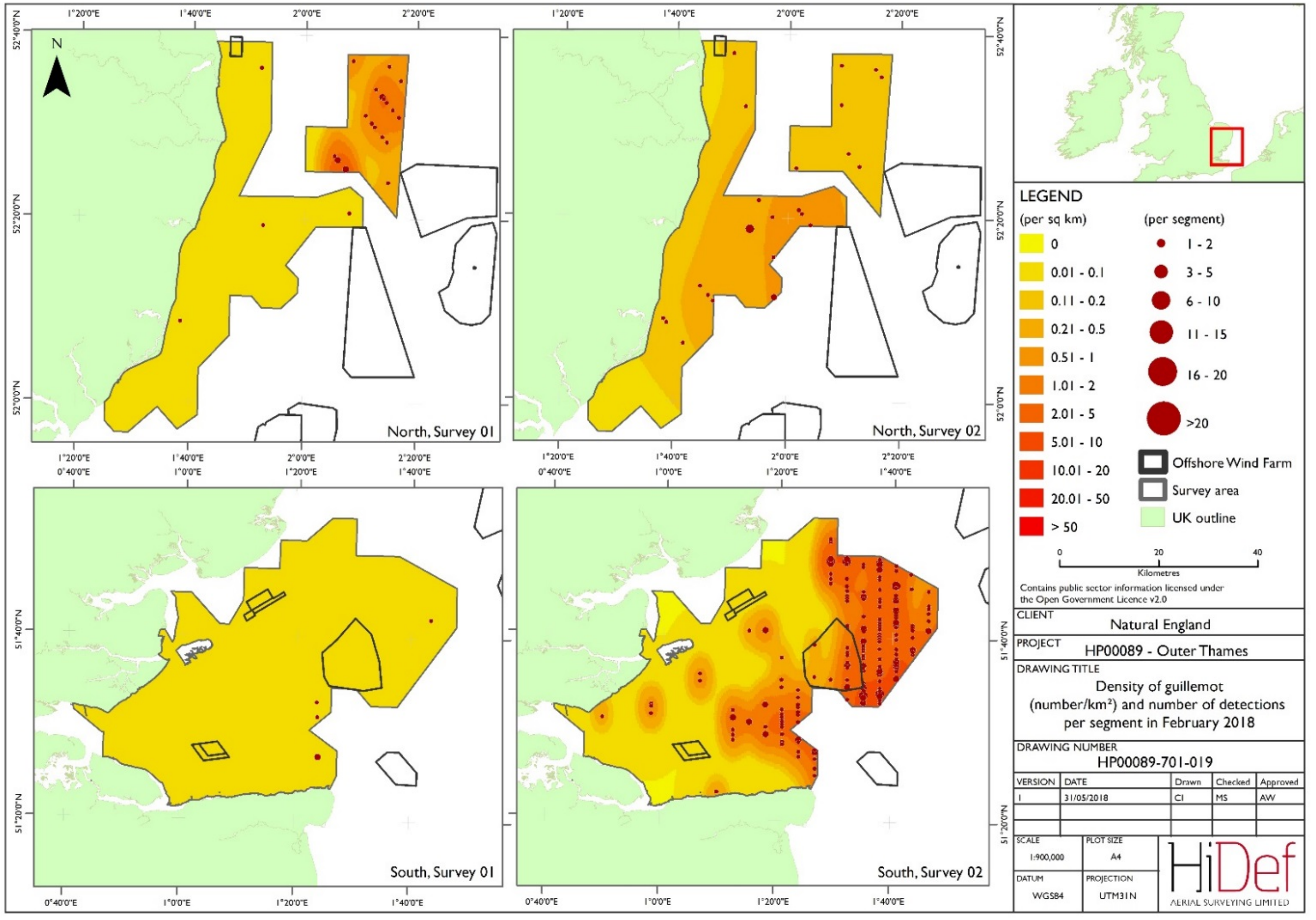

Figure 21 Density of guillemot (number/km²) and number of detections per segment in February 2018

5.3.13 Distribution maps for razorbill

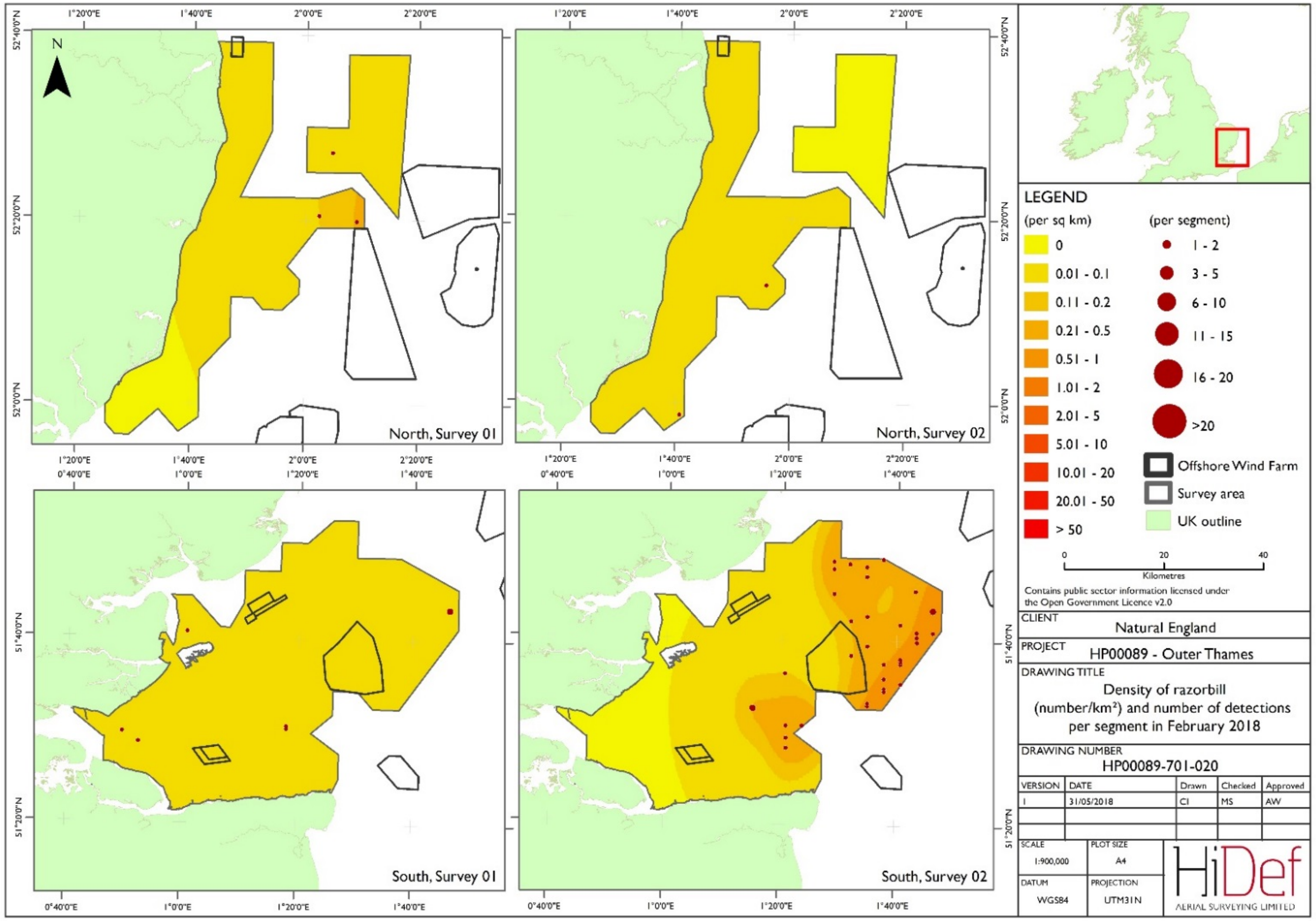

Figure 22 Density of razorbill (number/km²) and number of detections per segment in February 2018

5.3.14 Distribution maps for all large gull species

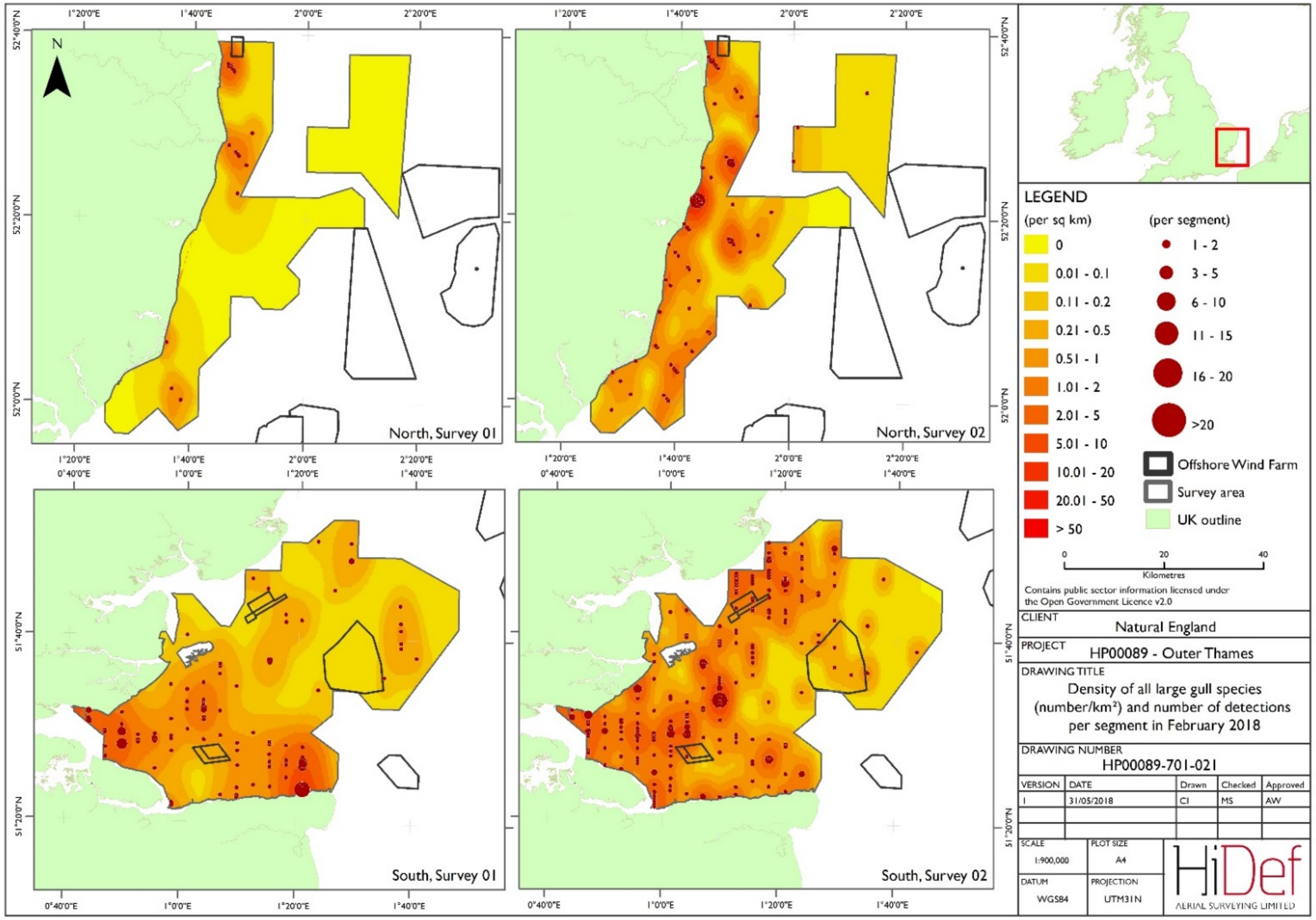

Figure 23 Density of all large gull species (number/km²) and number of detections per segment in February 2018

5.3.15 Distribution maps for all small gull species

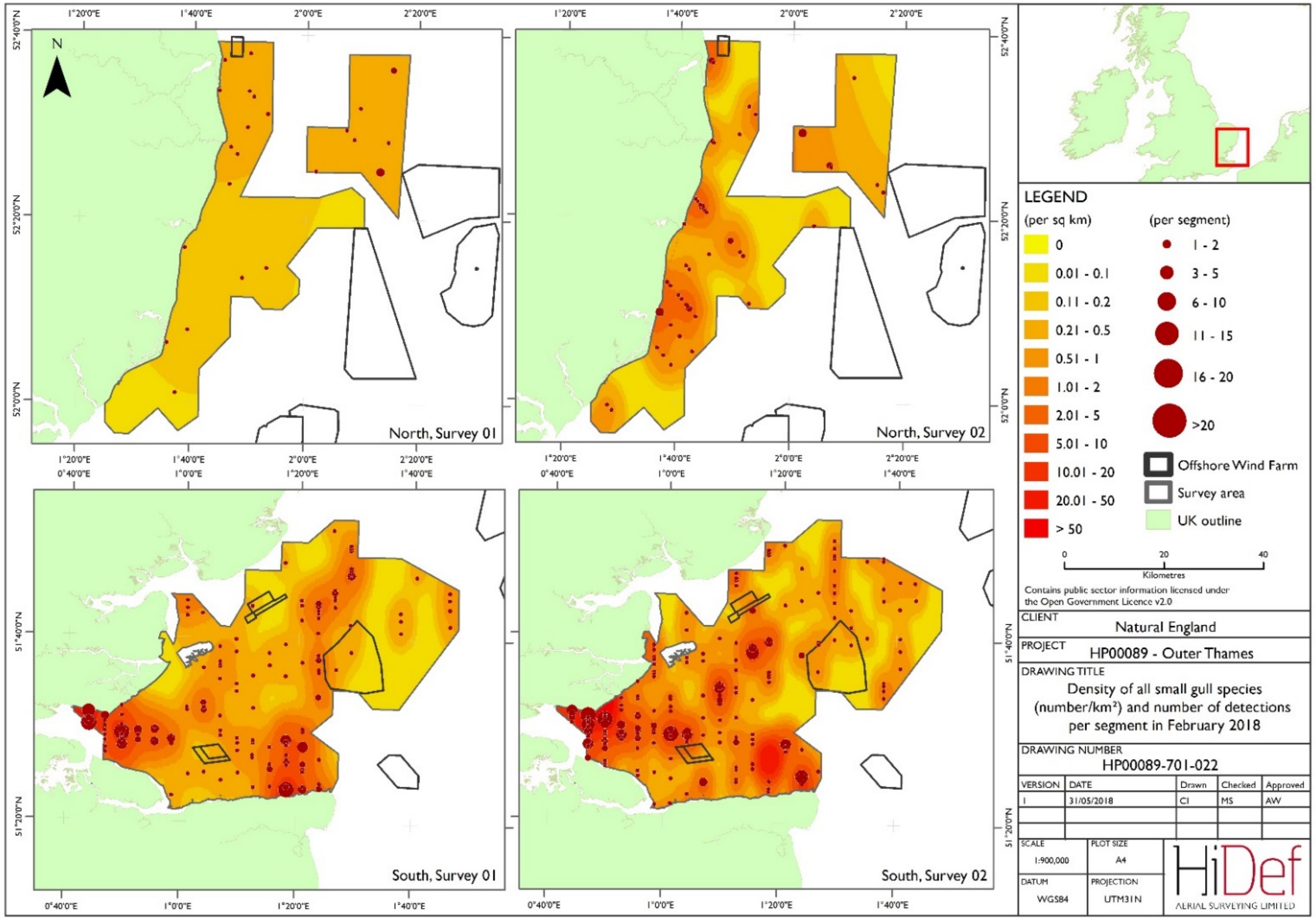

Figure 24 Density of all small gull species (number/km²) and number of detections per segment in February 2018

5.3.16 Distribution maps for less abundant bird species

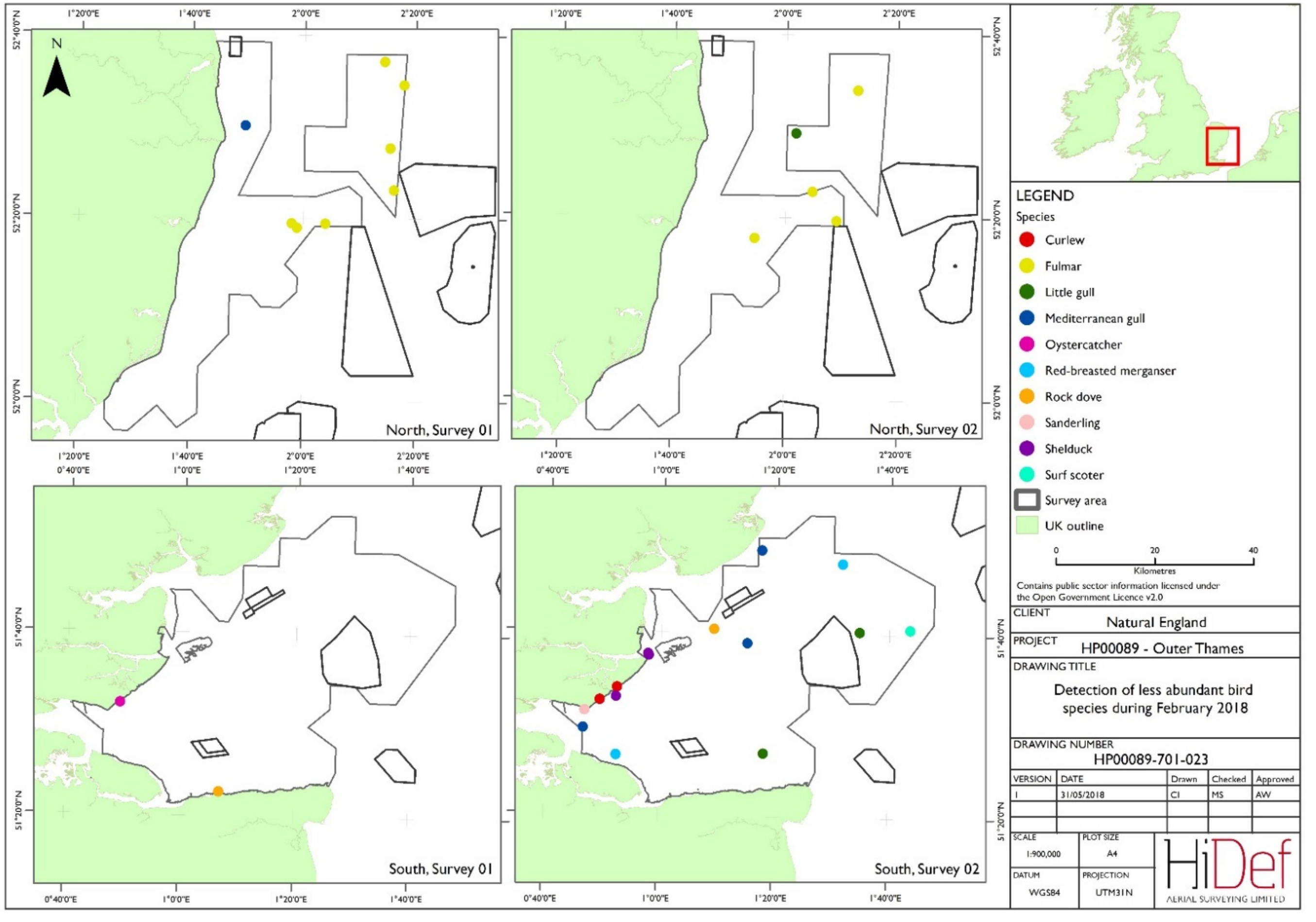

Figure 25 Detections of less abundant bird species (number/km²) during February 2018

5.3.17 Distribution maps for unidentified bird species

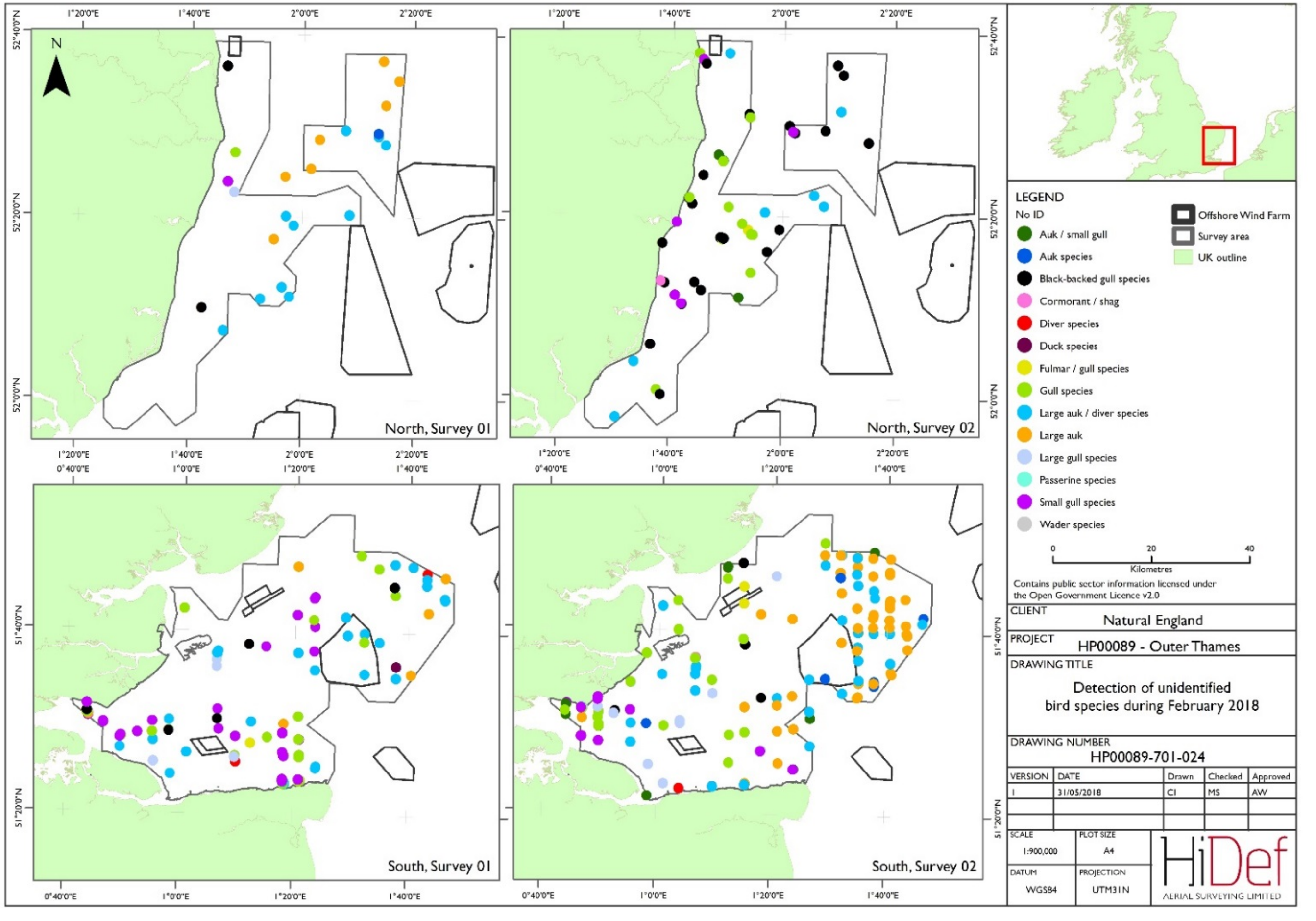

Figure 26 Detections of unidentified bird species (number/km²) during February 2018

5.3.18 Distribution maps for harbour porpoise

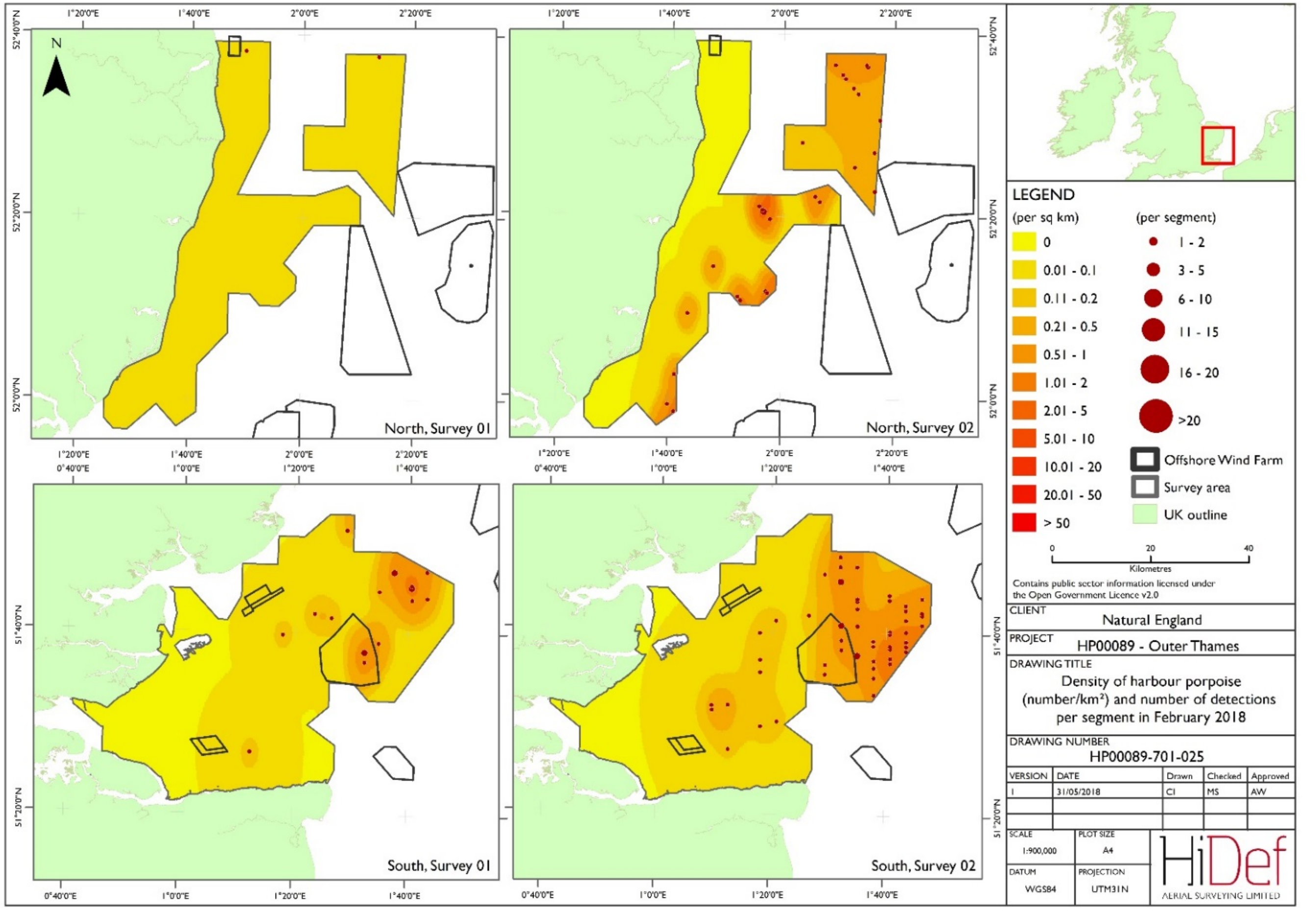

Figure 27 Density of harbour porpoise (number/km²) and number of detections per segment during February 2018

5.3.19 Distribution maps for less abundant non-avian animal species

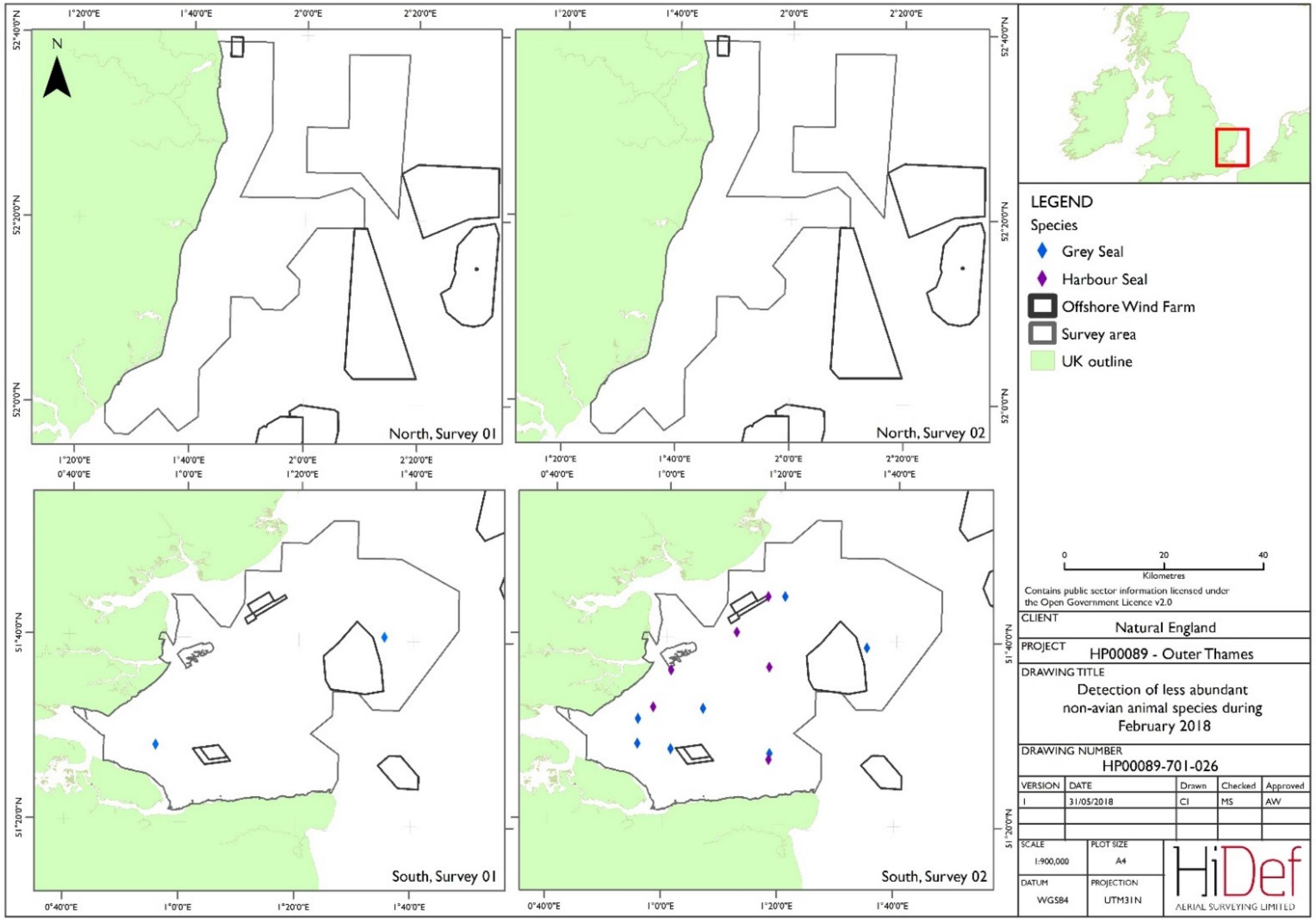

Figure 28 Detections of less abundant non-avian animal species (number/km²) during February 2018

5.3.20 Distribution maps for unidentified non-avian animals

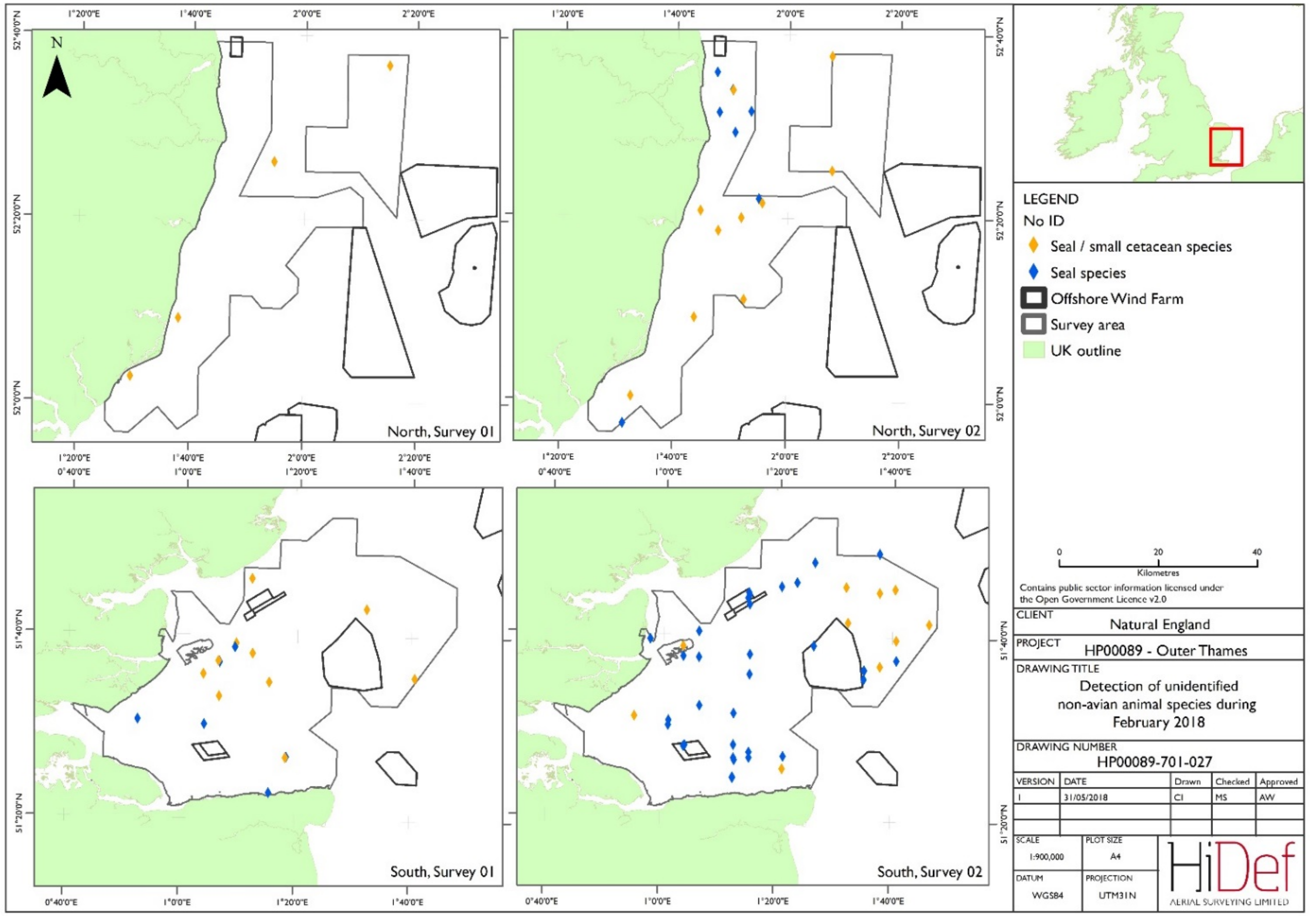

Figure 29 Detections of unidentified non-avian animal species (number/km²) during February 2018

5.3.21 Distribution maps for vessel activity

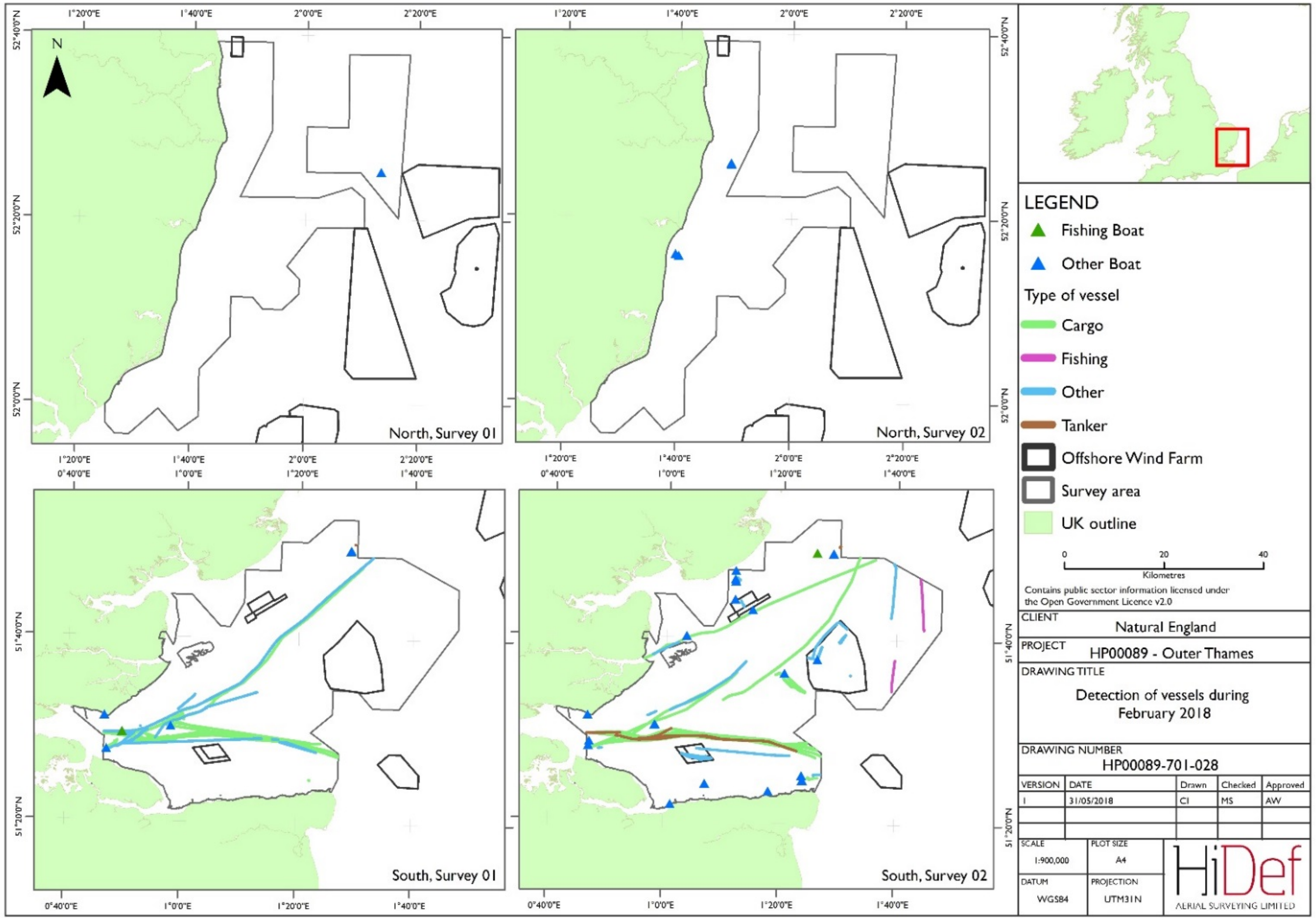

Figure 30 Detections of vessel activity during February 2018. Type of vessel is indicated by AIS data.

5.3.22 Distribution maps for anthropogenic activity

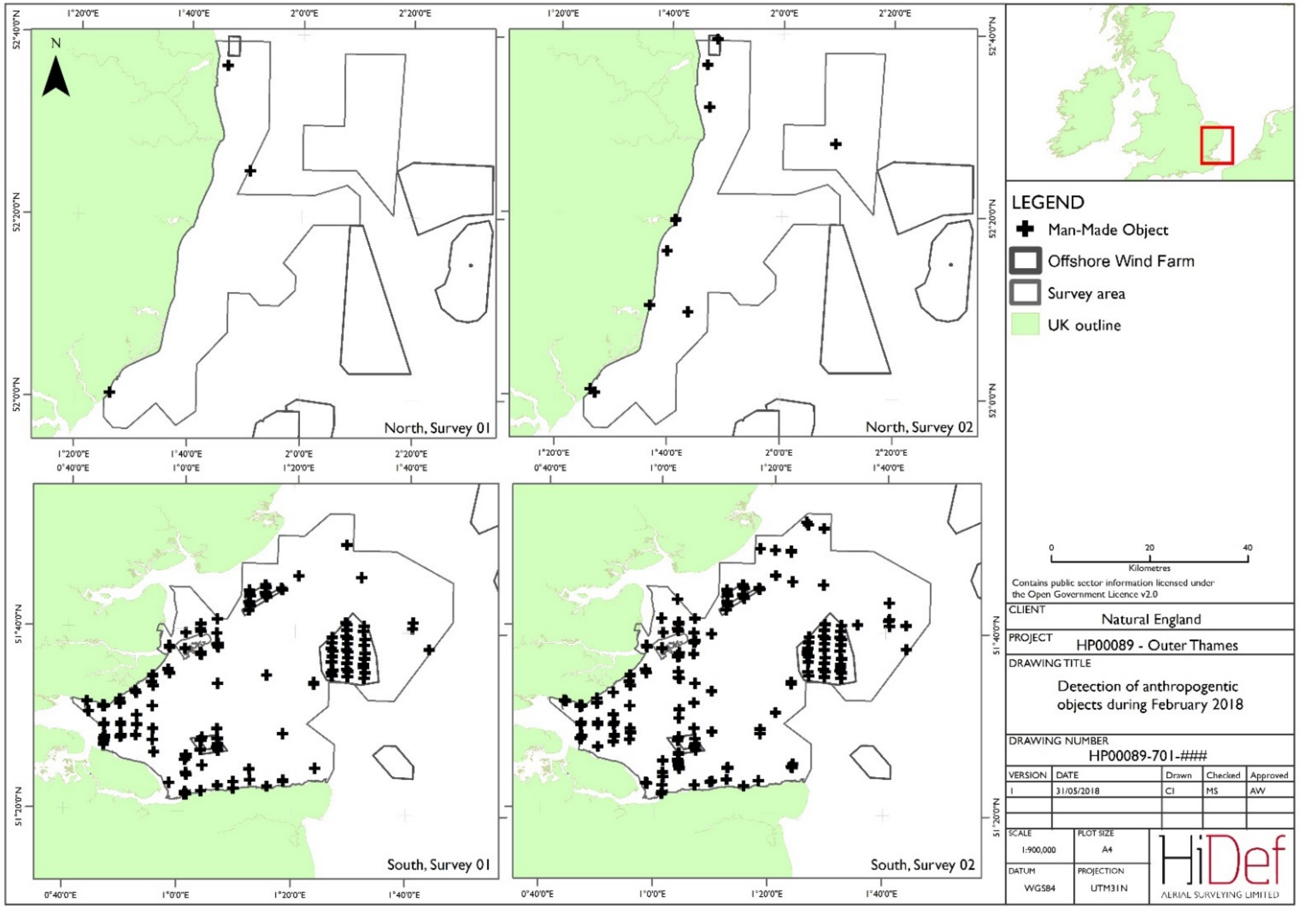

Figure 31 Detections of anthropogenic activity during February 2018

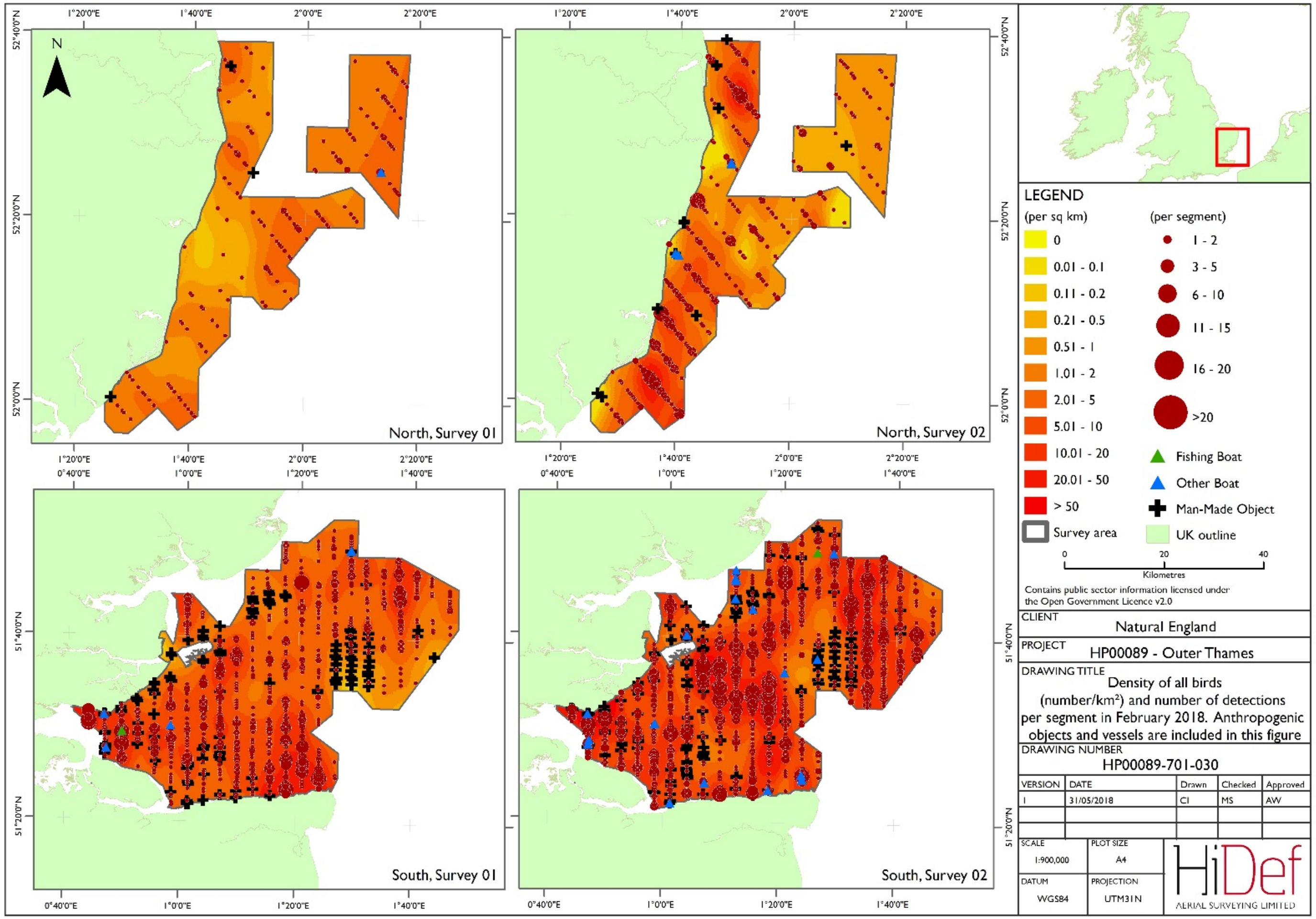

Figure 32 Detections of anthropogenic activity and all birds during February 2018

5.4 Use of the extended part of the SPA by red-throated divers

106 The pSPA includes a section of coastal mudflats off Foulness which are flooded at high tide. Birds were recorded in the outer fringe of this area on both surveys (Figure 33 and Figure 34). No surveys were flown at low tide.

107 The number of red-throated divers estimated to occur in the recently extended part of the SPA around Foulness was calculated by selecting the grid cells from the kernel density estimation plots of their distribution and calculating the population size from the mean density times the area of the selected cells. These more accurate but deterministic estimates of the number of individuals is presented in Table 33.

Table 33 Red-throated diver population estimates for the area of the SPA extension area only, derived using kernel density estimation density calculations.

Survey	SPA Extension only (population estimate)
Survey 1	101
Survey 2	229

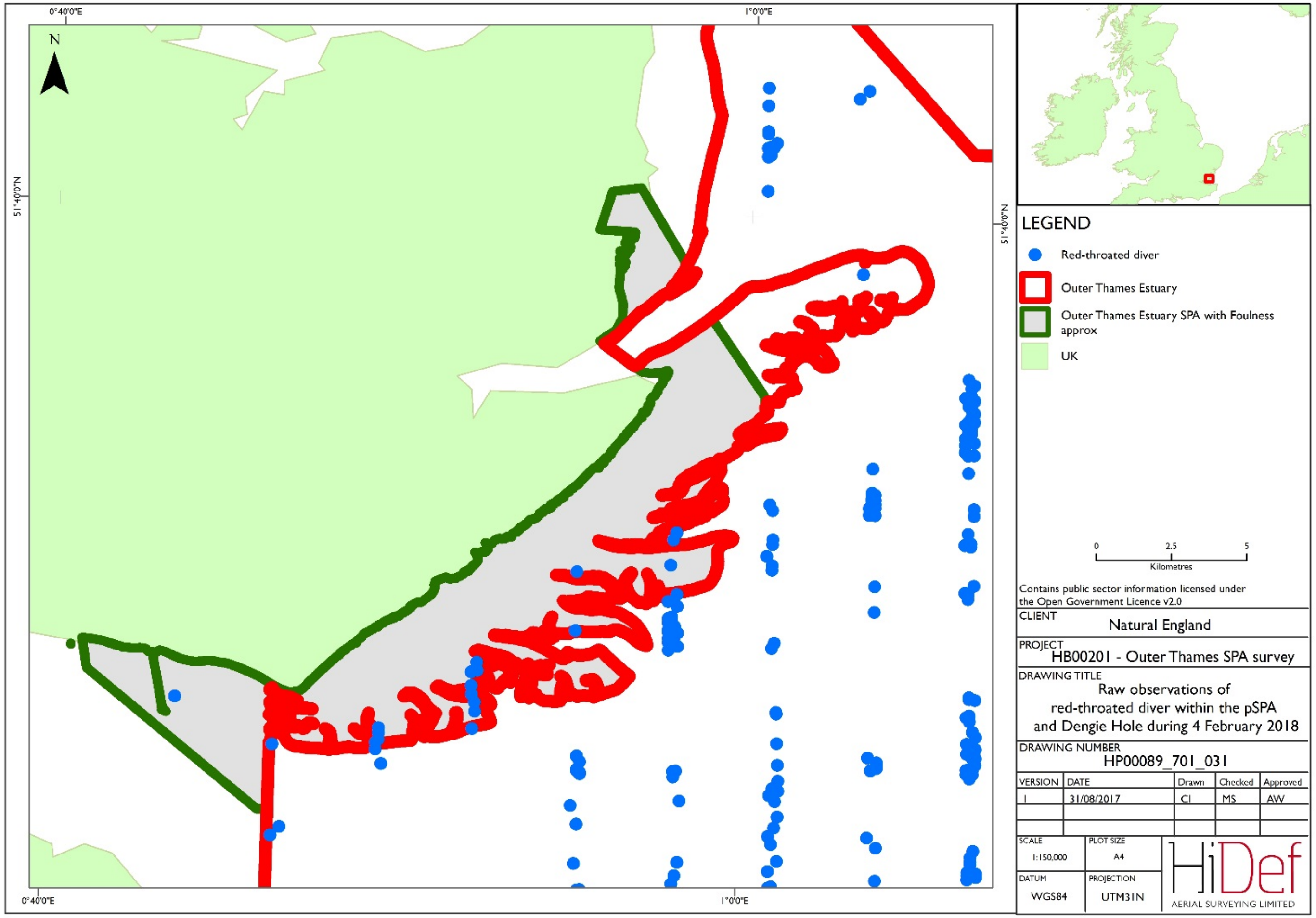

Figure 33 Raw observations of red-throated diver within the pSPA and 'Foulness Danger Area' during 4 February 2018

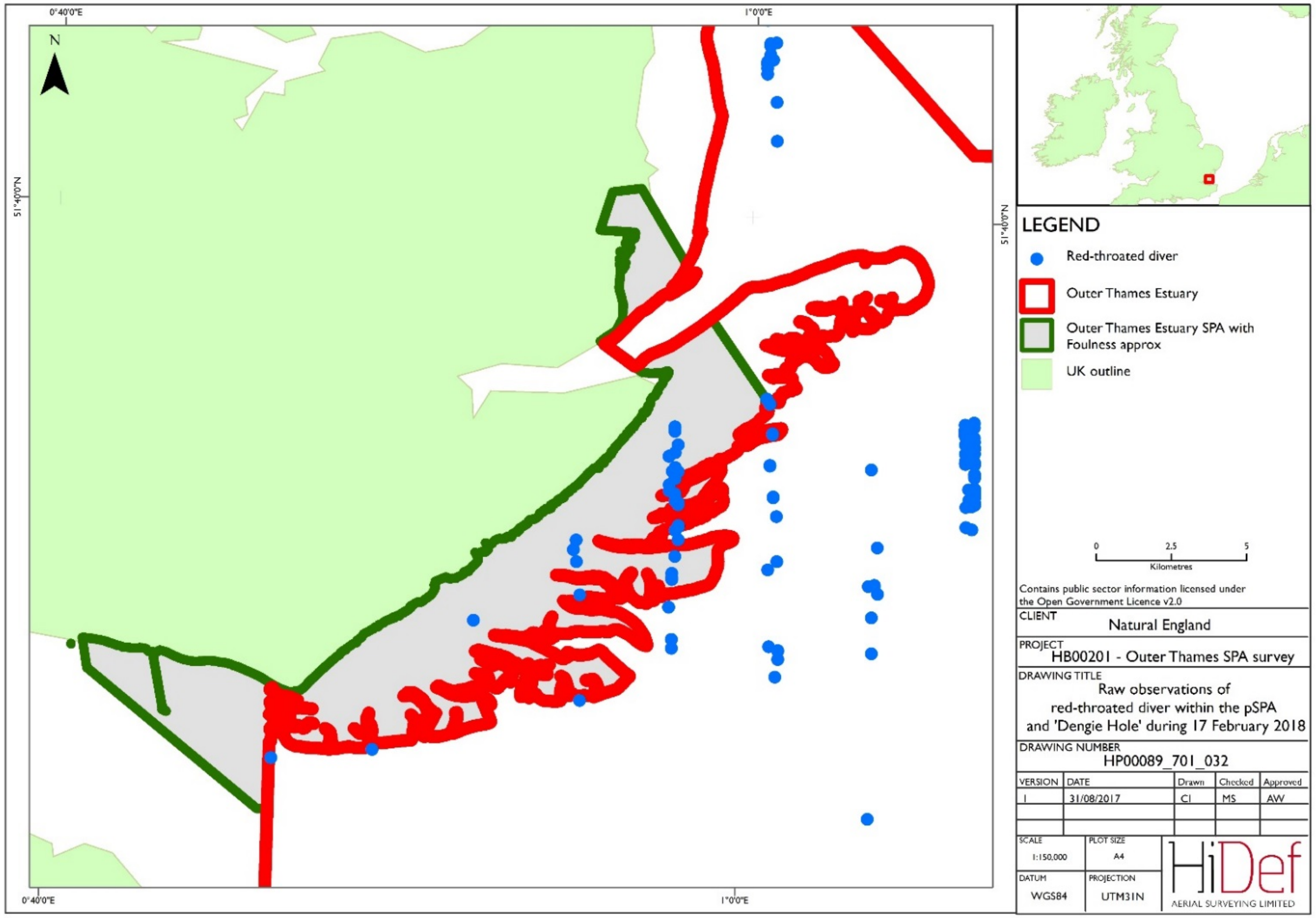

Figure 34 Raw observations of red-throated diver within the pSPA and 'Foulness Danger Area' during 17 February 2018

5.5 Behaviours of seabirds and non-avian animals

108 The behaviour of seabirds has been categorised as follows: flying and sitting. The number of each observed is presented in Table 34 to Table 37. In addition, the surfacing behaviour for all non-avian animals is presented in Table 38. Snapshot surfacing indicates where the head of a seal or dorsal fin of a cetacean is clear of the water surface in the middle frame of the sequence in which the animal is present. Surfacing is defined as when the animal breaches the surface on a frame which is not in the middle of the sequence where the animal is present.

109 Low numbers of red-throated diver were recorded flying with 13% and 4% recorded flying in Survey 1 and 2 respectively in the southern area and 1% and 3% flying in the combined northern areas. This indicates the flight height of the plane is successful in not flushing this sensitive species.

Table 34 Summary of seabird behaviours during Survey 1 (South) on 4 February

Species	Number recorded diving	Number recorded flying	Number recorded sitting	Number recorded sitting on a man-made object	Number recorded taking off	% Flying	Total
Common scoter	0	0	49	0	0	0%	49
Red-throated diver	0	62	411	0	5	13%	478
Fulmar	0	6	0	0	0	100%	6
Gannet	0	2	2	0	0	50%	4
Cormorant	1	14	10	0	0	56%	25
Great crested grebe	0	0	10	0	0	0%	10
Kittiwake	0	11	0	0	0	100%	11
Little gull	0	1	0	0	0	100%	1
Black-headed gull	0	11	0	0	0	100%	11
Common gull	0	43	15	0	0	74%	58
Lesser black-backed gull	0	7	3	0	0	70%	10
Herring gull	0	49	46	0	0	52%	95
Great black-backed gull	0	23	15	1	0	59%	39
Guillemot	0	14	23	0	0	38%	37
Razorbill	0	1	1	0	0	50%	2
No ID							
Fulmar / gull species	0	1	0	0	0	100%	1
Cormorant / shag	0	1	0	0	0	100%	1

Species	Number recorded diving	Number recorded flying	Number recorded sitting	Number recorded sitting on a man-made object	Number recorded taking off	% Flying	Total
Small gull species	0	0	8	0	0	0%	8
Black-backed gull species	0	3	0	0	0	100%	3
Large gull species	0	9	6	0	0	60%	15
Gull species	0	1	12	0	0	8%	13
Large auk	0	2	9	0	0	18%	11
Auk / small gull	0	1	2	0	0	33%	3
Large auk / diver species	0	0	8	0	0	0%	8
Total	**1**	**280**	**675**	**1**	**5**	**29%**	**962**

Table 35 Summary of seabird behaviours during Survey 1 (North) on 4 February

Species	Number recorded flying	Number recorded sitting	% Flying	Total
Red-throated diver	1	89	1%	90
Fulmar	8	0	100%	8
Cormorant	2	4	33%	6
Great crested grebe	0	1	0%	1
Kittiwake	8	0	100%	8
Black-headed gull	5	0	100%	5
Mediterranean gull	1	0	100%	1
Common gull	20	0	100%	20
Herring gull	6	1	86%	7
Great black-backed gull	18	4	82%	22
Guillemot	0	35	0%	35
Razorbill	1	2	33%	3
No ID				
Small gull species	0	1	0%	1
Black-backed gull species	1	1	50%	2
Large gull species	1	0	100%	1
Gull species	1	0	100%	1
Large auk	1	7	13%	8
Auk species	0	1	0%	1

Species	Number recorded flying	Number recorded sitting	% Flying	Total
Large auk / diver species	0	10	0%	10
Total	**78**	**176**	**31%**	**254**

Table 36 Summary of seabird behaviours during Survey 2 (South) on 17 February 2018

Species	Number recorded diving	Number recorded flying	Number recorded sitting	Number recorded sitting on a man-made object	Number recorded taking off	% Flying	Total
Shelduck	0	0	4	1	0	0%	5
Common scoter	0	24	0	0	0	100%	24
Surf scoter	0	1	0	0	0	100%	1
Red-breasted merganser	0	2	1	0	0	67%	3
Red-throated diver	3	88	2345	0	3	4%	2439
Gannet	0	28	41	0	0	41%	69
Cormorant	2	21	112	35	2	12%	172
Great crested grebe	0	0	127	0	0	0%	127
Sanderling	0	44	0	0	0	100%	44
Curlew	0	0	0	0	0	#DIV/0!	0
Kittiwake	0	27	5	0	0	84%	32
Little gull	0	2	0	0	0	100%	2
Black-headed gull	0	98	253	1	0	28%	352
Mediterranean gull	0	3	0	0	0	100%	3
Common gull	0	274	238	0	0	54%	512
Lesser black-backed gull	0	22	24	0	0	48%	46
Herring gull	0	114	84	1	0	57%	199
Great black-backed gull	0	185	123	1	2	59%	311

Species	Number recorded diving	Number recorded flying	Number recorded sitting	Number recorded sitting on a man-made object	Number recorded taking off	% Flying	Total
Guillemot	0	5	344	0	0	1%	349
Razorbill	0	1	45	0	0	2%	46
Rock Dove	0	1	0	0	0	100%	1
No ID							
Diver species	0	0	1	0	0	0%	1
Fulmar / gull species	0	0	2	0	0	0%	2
Cormorant / shag	0	0	1	0	0	0%	1
Wader species	0	60	1	0	0	98%	61
Small gull species	0	2	9	0	0	18%	11
Black-backed gull species	0	3	1	0	0	75%	4
Large gull species	0	3	12	0	0	20%	15
Gull species	0	3	26	1	0	10%	30
Large auk	0	0	52	0	0	0%	52
Auk species	1	0	5	0	0	0%	6
Auk / small gull	0	0	10	0	0	0%	10
Large auk / diver species	0	0	34	0	0	0%	34
Passerine species	0	4	0	0	0	100%	4
Total	**6**	**1015**	**3900**	**40**	**7**	**20%**	**4968**

Table 37 Summary of seabird behaviours during Survey 2 (North) on 17 February 2018

Species	Number recorded flying	Number recorded sitting	Number recorded sitting on a man-made object	Number recorded taking off	% Flying	Total
Common scoter	1	77	0	0	1%	78
Red-throated diver	38	1202	0	1	3%	1241
Cormorant	9	26	32	1	13%	68
Great crested grebe	0	48	0	0	0%	48
Oystercatcher	2	0	0	0	100%	2
Kittiwake	93	16	0	0	85%	109
Black-headed gull	80	43	0	1	65%	124
Common gull	135	25	0	0	84%	160
Lesser black-backed gull	1	3	0	0	25%	4
Herring gull	42	49	2	0	45%	93
Great black-backed gull	62	95	0	0	39%	157
Guillemot	0	8	0	0	0%	8
Razorbill	2	7	0	0	22%	9
Rock dove	2	0	0	0	100%	2
No ID						
Duck species	0	1	0	0	0%	1
Diver species	0	2	0	0	0%	2
Fulmar / gull species	1	0	0	0	100%	1

Species	Number recorded flying	Number recorded sitting	Number recorded sitting on a man-made object	Number recorded taking off	% Flying	Total
Small gull species	11	29	1	0	27%	41
Black-backed gull species	5	0	0	0	100%	5
Large gull species	1	11	0	1	8%	13
Gull species	12	23	0	0	34%	35
Large auk	1	5	0	0	17%	6
Large auk / diver species	0	35	0	0	0%	35
Total	**529**	**1811**	**36**	**5**	**22%**	**2381**

Table 38 Summary of surfacing behaviour for non-avian animals during February 2018

Species	Submerged	Surfacing	Snapshot surfacing	% Surfacing	Total
Grey seal	4	1	3	50%	8
Harbour seal	1	0	3	75%	4
Harbour porpoise	67	14	42	46%	123
No ID					
Seal species	10	3	35	79%	48
Seal / small cetacean species	22	6	6	35%	34
Total	**104**	**24**	**89**	**52%**	**217**

6 Discussion

110 The surveys were successful in characterising the bird and mammal species present in the Outer Thames survey area, recording a total of 7906 birds of 23 species and 138 marine mammals of 3 species. A further 572 animals were recorded which were not assigned to a named species.

111 The survey extended over the open shore areas of Foulness which at the outset of the project were part of the pSPA but have since been included within the revised boundary of the newly re-classified Outer Thames Estuary SPA. However, some other more enclosed areas out with the original SPA boundary but also now included within the revised SPA boundary, that is the sections within the Rivers Crouch and Roach, and Rivers Yare and Bure and River Blyth, were not surveyed. These sections omitted from our study area for digital aerial surveys can be counted more effectively from land under the WeBS programme. For the sake of completeness, the small 'hole' off Foulness that is now surrounded by the new SPA boundary was flown and the imagery analysed, but the numbers recorded in this area were not included in the abundance estimates.

112 Surveys were originally programmed for the months of January and February when red-throated diver density in the SPA is known to be highest (Webb and others 2009). Restrictions applied through a military flight zone and poor weather in January resulted in the initial survey slipping into early February. Both surveys ultimately took place that month, 13 days apart.

113 At tender stage HiDef noted the presence of aviation danger areas D138 and D138C located around Shoeburyness and Foulness which are often active up to 6000 ft. asl. This was known to be a restriction and dialogue with the relevant parties began early. Despite negotiation it was only possible to attain flight consent at weekends when the danger area was deemed safe. This combined with weather issues subsequently meant that opportunities to survey had to be taken when they arose.

114 The survey design consisted of 42 transects and achieved 13% coverage of the site overall; 15% in the high density southern stratum and 10% in the low-density stratum in the northern sector. This contrasted with the 2013 method of survey which was flown on a series of transects separated by 1.8 km, collecting abutting 3 cm resolution imagery, providing average coverage of 15%.

115 To minimise the effect of movement of red-throated divers between transects and different sectors, HiDef made a commitment to complete all survey in a single day by deploying two aircraft on the same day. This phenomenon of red-throated diver movements in the Outer Thames was highlighted by Webb and others (2009) and could have potentially caused significant bias to any abundance estimates from surveys that did not minimise this effect. The 2013 survey undertook surveys over two dates in January and three dates in February. As such there was potential for movement of birds between dates and a subsequent potential loss of accuracy in the ability to provide a clean snapshot of red-throated diver numbers.

116 The number of red-throated divers recorded in the survey imagery was extrapolated to the SPA boundary, using design-based analysis methods. Density and population estimates, as well as the upper and lower 95% confidence limits were derived by way of a blocked bootstrapping technique.

117 Only one diver species, red-throated, was recorded during the surveys. They were present in high numbers and high densities, particularly in the southern sector of the survey zone.

118 Survey results are presented in Table 6 to Table 29. A summary table is provided in Table 4. The peak estimate of red-throated diver within the original SPA boundary occurred in the second survey on 17 February 2018; that is 21,997 individuals. Considering also the additional area off Foulness that is now included within the revised boundary of the newly re-classified SPA, the peak estimate of red-throated divers across the entire extended SPA also occurred in the second survey; that is 22,280 individuals These figures represent more than 340% of the population for which the Outer Thames Estuary SPA was first classified in 2010; that is 6,466 individuals.

119 We estimated the population size of red-throated divers in the small area of sea off Foulness that is now included within the recent extension to the OTE SPA using a deterministic method based on the numbers estimated using kernel density estimation. While this method gave a more sensible population estimate than the stochastic transect-based method, it gave no confidence limits to this sub-sample and couldn't be used to adjust the population estimates of red-throated divers within the original SPA boundary. A better approach would have been to use a stochastic spatially-explicit modelling method to estimate the population size, such as the MRSea suite of modelling tools (Mackenzie and others 2013).

120 Over the years various attempts have been made to estimate the red-throated diver population in the Outer Thames. The results of these are summarised in Table 39 and show the overall trend for increased populations.

Table 39 Summary of known recognised estimates of red-throated diver populations in the Outer Thames (accounts derived from Webb and others 2009 and APEM 2013))

Survey date	Red-throated diver population estimate	Lower 95% confidence limit of population	Upper 95% confidence limit of population	Survey method used	Comment on surveys
January 2002	2,460	1,667	3,630	Visual aerial survey	Covered Greater Thames area >900,000ha.
January 2003	10,884	8,115	13,439	Visual aerial survey	Covered Greater Thames area >900,000ha.
February 2004	7,688	5,041	11,725	Visual aerial survey	Covered Greater Thames area >900,000ha.

Survey date	Red-throated diver population estimate	Lower 95% confidence limit of population	Upper 95% confidence limit of population	Survey method used	Comment on surveys
Jan/Feb 2005	6,123	4,996	7,504	Visual aerial survey	Covered Greater Thames area >900,000ha.
January 2006	5,291	3,745	7,179	Visual aerial survey	Covered Greater Thames area >900,000ha.
Feb/March 2007	3,106	2,035	4,589	Visual aerial survey	Covered Greater Thames area >900,000ha.
Peak mean over the period 1989-2006/07	6,466			Visual aerial survey	Outer Thames SPA (a smaller subset of the Greater Thames) c.379,268ha. Calculated by averaging peaks in annual estimates in numbers. Webb and others (2009).
January 2013	11,248	8,649	14,155	Digital still aerial survey undertaken over two days (3cm resolution)	Outer Thames SPA (a smaller subset of the Greater Thames) c.379,268ha. APEM (2013)
February 2013	14,161	8,230	22,245	Digital still aerial survey undertaken over two days (3cm resolution)	Outer Thames SPA (a smaller subset of the Greater Thames) c.379,268ha. APEM (2013)

Survey date	Red-throated diver population estimate	Lower 95% confidence limit of population	Upper 95% confidence limit of population	Survey method used	Comment on surveys
February 2018 (survey 1)	10,136	7,763	12,626	Digital video aerial survey undertaken on a single day (2cm resolution)	Outer Thames SPA (a smaller subset of the Greater Thames c.388,768ha)
February 2018 (survey 1)	10,148	7,868	12,544	Digital video aerial survey undertaken on a single day (2cm resolution)	Outer Thames pSPA (a smaller subset of the Greater Thames but c95km² larger than the SPA)
February 2018 (survey 2)	21,997	15,351	29,415	Digital video aerial survey undertaken on a single day (2cm resolution)	Outer Thames SPA (a smaller subset of the Greater Thames c.388,768ha)
February 2018 (survey 2)	22,280	15,611	29,784	Digital video aerial survey undertaken on a single day (2cm resolution)	Outer Thames pSPA (a smaller subset of the Greater Thames but c95km² larger than the SPA)

121 These population estimates (Table 39) should still be regarded as minima for all of these surveys given that all of them will have been affected by not all birds being above the sea surface and so available for detection (known as availability bias). In common with all previous studies detailed in Table 39, we made no correction for this affect for red-throated diver or any other diving species, including harbour porpoise. While it is possible to correct approximately for availability bias for many species using known diving rates, we did not do this for red-throated divers because accurate dive rate data are not known to exist.

122 The survey results in Table 39 are not directly comparable because they follow different methods and different sizes of study area. However, they do show large variation in results within similar parameters (that is total population and area) and survey areas, tending

toward an increase in recent years. A full exploration of the variation and apparent increase in recent years would require returning to review original data but the following points, as a minimum, seem likely to be relevant:

- Genuine increase in divers in the survey area over time;
- Changes in anthropogenic activity in the area, notably the introduction of the London Array, Kentish Flats, Gunfleet Sands and Scroby Sands wind farms;
- Changes in environmental variables;
- Changes (improvements) in methodology, that is differences in survey design and analytical techniques;
- Changes in technology utilised in surveys resulting in improved detection rates or reduced levels of bias; that is from boat to aircraft and improved imaging methods.

123 Other species were recorded, and data processed, with results presented, but the focus of the contract relates to red-throated diver. From data collected relating to divers distance modelling was applied and an estimated population for red-throated diver provided.

124 It should be noted that the area of the pSPA (now fully re-classified as a SPA) represents a slight increase over that of the original size of the SPA (as classified in 2010). This increase includes the tidal flats around parts of the Essex coast, of about 9500 ha, which have been included in the SPA primarily in recognition of their importance as foraging grounds for breeding common terns *Sterna hirundo* originating from the colony within Foulness SPA. The surveys did not record divers in this area of exposed mudflats and thereby often unsuitable habitat for divers. However, there were a number of raw observations of red-throated divers in the extension to the SPA in areas where the sea covered the mudflats, and extrapolated data from KDE for this area suggest red-throated diver population estimates of 101 individuals in Survey 1 and 229 individuals in Survey 2 in this area into which the Outer Thames Estuary SPA now extends (Table 33).

125 Counts derived using the same transect sampling regime to calculate the population estimate of red-throated divers in the original (smaller) SPA and the new, extended SPA boundary resulted in a larger point estimate of the population size in the smaller SPA boundary than the larger, encompassing boundary.

126 The first survey took place in weather conditions in which the sea state was greater than that encountered in the second survey flights. While such weather events can impact on digital aerial survey results, it was expected that the later survey would encounter a higher number of birds (Webb and others 2009) given a review of previous survey data and known movements of the species. However, the increase in bird density between the first and second surveys affected most species, including gannets, which are very easily detected regardless of sea state, while a more cryptic species, the kittiwake, was more abundant in the first survey when the sea state was rougher. Sea state in Survey 1 was still within the normal boundaries for surveying.

127 As predicted at the tender stage, the surveys confirmed that the northern section could be deemed to be a low-density survey stratum within a stratified sampling design, and the southern section of the SPA a high-density stratum.

128 The only previous digital aerial surveys of the entire Outer Thames Estuary SPA were conducted in early 2013 by APEM Ltd. (APEM 2013). These surveys yielded design-based estimates of the population of red-throated divers within the original SPA boundary of 11,248 (± 95% CI 8,649 – 14,155) in January 2013 and 14,161 (± 95% CI 8,230 – 22,245) in February 2013. The former population estimate, and its confidence limits, are very similar to those recorded in survey 1 in 2018 (10,136 ± 95% CI 7,763 –12,626). The figure of 14,161 recorded in February 2013 exceeds that recorded in survey 1 in 2018 (10,136) and the upper 95% CI of that (12,626). However, 14,161 is considerably less than the population estimate of 21,997 recorded in survey 2 in 2018 and is indeed less than the lower 95% CI of that population estimate (15,351). The upper 95% CI around the February 2013 population estimate (22,245) is however very similar to the mean population estimate in survey 2 in 2018 (21,997). Thus, broadly speaking the results obtained in 2013 and 2018 are reasonably consistent.

129 In combination with the estimated red-throated diver populations within the newly enlarged SPA of 10,148 (Survey 1) and 22,280 (Survey 2), the population estimates for all other species/ species groups combined yield total estimated abundances across this area of 19,071 individuals (Survey 1) and 46,056 individuals (Survey 2). For the wintering waterbird assemblage within a SPA to be considered as a qualifying feature of that site, UK SPA selection guidelines require that the peak count must exceed 20,000 individuals on a regular basis (JNCC 1999). The results of the 2018 surveys indicate that at least on one occasion the SPA supported an assemblage of wintering waterbirds well in excess of the size required to consider this assemblage to be a qualifying feature of the SPA.

130 Population estimates were derived from mean bootstrapped density which gives mostly small variations in values. This can lead to small anomalies in which the sum of populations in the sub-sections of the SPA do not add up to the estimate obtained for the whole SPA, and in which the smaller site boundary for the original SPA has a larger population estimate than for the larger extended SPA. In these cases, the population estimate from analysis for the entire area, and not the sum of parts, should be used in further management of the site.

6.1 Changes in survey technique and methods – an evolving process

131 In 2018, the survey transects were flown perpendicular to the coast. Effectively this was north to south across the southern sector, and south-east to north-west across the northern zones. This was in contrast to the 2013 survey pattern which was flown south-west to north-east across the southern sector and north-south across the northern zone. While this, and the fact that both surveys were flown on a single day, might be reasons for an increase in the peak population estimates for red-throated divers in the SPA between 2013 and 2018, the peak population estimate for 2018 (21,997) is within the confidence limits of the 2013 peak survey (8,230 – 22,245).

132 HiDef recorded no other diver species apart from red-throated but other diver species were reported consistently during surveys in 2013, with 222 black-throated diver and 248 great northern diver estimated in a single survey (APEM 2013). This result, if proved to be a regularly occurring concentration of these species would justify inclusion of these species in the SPA citation. Webb and others (2009) also found that the presence of these species in visual aerial surveys and in shore-based surveys was rare. It is highly likely that this difference was due to improved identification techniques utilised in 2018 surveys and suggests that reports of the occurrence in 2013 of these species, in such numbers, was erroneous.

133 The technique deployed by HiDef differs from that utilised in 2013 in that HiDef uses digital video rather than digital stills technology. In terms of identification this allows 5 – 7 still images of an object to be reviewed from slightly different angles as the aircraft passes. This contrasts with a single, plan view achieved via the digital stills process. Overall, video provides the identifying team with greater opportunity, and thereby increasing certainty, to come to a conclusive identification.

134 Video footage was attained as 2cm GSD, rather than 3cm GSD as in surveys five years previously. Ground Sample Distance (GSD) is the area of ground that is shown per pixel. The lower the GSD, then the better resolution, but there is a trade-off in other areas of photographic quality once GSD moves below 2cm. This step change in resolution, from 3 to 2, allows identifiers to make more accurate identifications and reduces risk related to errors in identification.

135 Prior to the introduction of digital aerial surveys, visual aerial surveys were flown. These comprised of observers viewing from the aircraft as it flew over the survey zone. This method was introduced to overcome the known bias resulting from red-throated divers avoiding boats (for example Schwemmer and others 2011; Camphuysen and others 2004) and so leading to under recording. A drawback of both these methods is the lack of ability to review or audit any data collected: "*what's hit's history, what's missed is mystery*".

136 Overall, digital video aerial survey provides a more robust data source, as the aircraft flies at a height which negates disturbance issues; the low level of divers noted in flight in 2018 surveys suggest these were not flushed due to the aircraft flying at a higher altitude, while providing a higher degree of confidence in identifications, which can be audited at a later date if queries arise. This degree of confidence is higher as video produces multiple images of the same object compared to the single image of digital still.

6.2 Changes in distribution

137 Shipping data were collated at the time of the survey via an AIS device in one aircraft. This allowed shipping movements on the day of survey to be followed (Figure 30). Additional anthropogenic activity was plotted (Figure 31) and compared visually against species distribution patterns. This suggested that the distribution of a number of species appeared to be affected by human activity in the area.

138 Red-throated divers clearly show displacement from wind turbines and shipping lanes (Figure 8 to Figure 10) but quantifying these movements is out with the scope of this contract.

139 Dierschke and others (2017) raised the issue of displacement and energetics and the consequences which may follow for individuals and also at a population level. Given the construction and operation of several offshore windfarms within the Outer Thames Estuary SPA in recent years and the evidence of marked displacement of divers within this study (and as reported in many previous studies) on the one hand and the simultaneous rise in population estimates of red-throated divers across the SPA as a whole on the other hand, further work is needed on this issue.

140 Displacement has been shown to be a factor influencing the distribution of red-throated divers at other sites with wind farm infrastructure in place (Webb and others 2017; Petersen and others 2014; Dierschke and others 2017). Given the increase in wind farms in the southern North Sea, both within and out with UK waters, it may be that birds are being

displaced over a wider area than previously thought and larger, more focussed aggregations are now forming in the remaining areas of suitable habitat.

141 Figure 35 and Figure 36 show preliminary analysis relating to mean density and abundance of divers from the two surveys in relation to distance from shipping lanes. These show some consistency in aggregation of birds in areas away from shipping traffic (and possibly other man-made structures). Highest densities of birds occur c.5-8km from shipping lanes. This initial output warrants further interpretation and modelling. It is interesting to note that the pattern found here of the density of divers increasing over the first few kilometres from shipping lanes to reach a peak at some distance, followed by a decline from those peak densities in areas even further from shipping lanes was also reported in an analysis of similar survey and shipping data in Liverpool Bay SPA (Burt and others 2017) albeit that in that study peak densities occurred at a distance of c 2km.

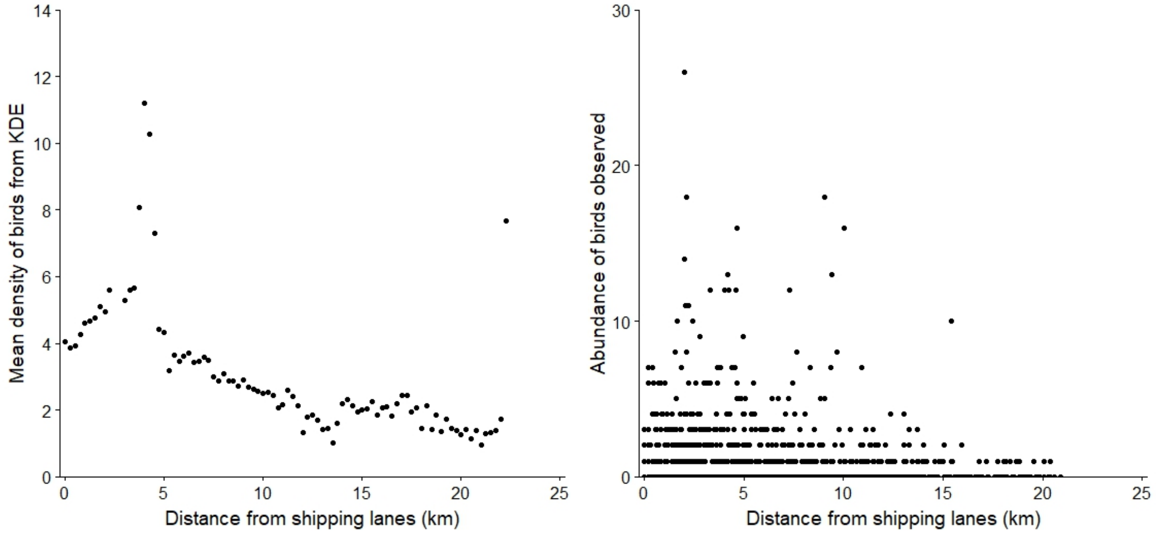

Figure 35 Red-throated diver distance to shipping survey 1. The left graph shows the mean density per grid cell from the KDE surface modelling and on the right is the absolute numbers for each and every transect segment.

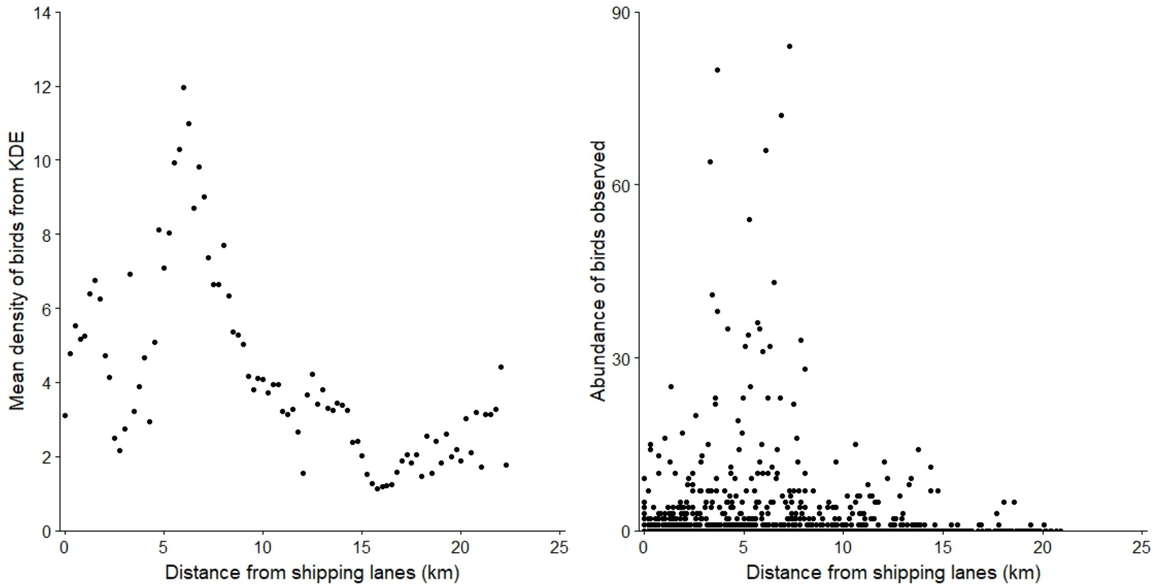

Figure 36 Red-throated diver distance to shipping survey 2. The left graph shows the mean density per grid cell from the KDE surface modelling and on the right is the absolute numbers for each and every transect segment.

6.3 Recent survey work elsewhere in the southern North Sea

142 Recent work in the southern North Sea (http://bioconsult-sh.de/en/projects/loon-radio-telemtry/) has seen divers caught and equipped with satellite transmitters on their wintering area within the German Exclusive Economic Zone (EEZ). A considerable volume of data has been collected and is currently being fully analysed (reporting due in Q3 2018). Considering offshore windfarm developments, spatial distribution and temporal characteristics of habitat use of divers will be analysed to set a basis for the relation of habitat loss due to offshore windfarms and habitat requirements of divers. Outcomes form this project seem likely to assist in discussion of displacement of birds in the Outer Thames area and elsewhere in UK waters.

7 Conclusions

143 The surveys were successful in characterising the bird and mammal species present in the Outer Thames survey area, recording a total of 7906 birds of 23 species and 138 marine mammals of 3 species. A further 572 animals were recorded which were not assigned to a species, an identification rate to species level of 92.53% across the survey programme.

144 In line with the core contract objectives two new population estimates of 10,136 (Survey 1) and 21,997 (Survey 2) red-throated divers are provided within the original Outer Thames Estuary SPA boundary, or of 10,148 (Survey 1) and 22,280 (Survey 2) within the somewhat larger boundary of the newly reclassified SPA.

145 Updated population estimates of other species are provided (Table 32), some of which could be considered in any future review of the qualifying features of this SPA. The large estimated population of red-throated divers combined with the population estimates for all the other species or species groups yields a peak abundance across all bird species within the boundaries of the newly re-classified SPA of 46,056 individuals. This is more than double the threshold size set out in the UK SPA selection guidelines for an assemblage to be considered as a qualifying feature of a SPA.

146 Consideration should be given as to whether other marine SPAs recently designated for divers, grebes, scoters and other sea-ducks (for example Greater Wash SPA), or pSPAs that are yet to be classified (for example Solway Firth pSPA) would benefit from new, post-classification surveys using modern survey methods, not least to ensure that their baseline populations are re-estimated using the most up-to-date approaches and technology. Such surveys would also allow the updating of national, and international, population numbers and provide a sound basis for the setting of Conservation Objectives for these newly classified sites.

147 This study provides a basis for additional analysis to determine the effects of different anthropogenic activities in the SPA, such as shipping and the locations of wind farms on the distribution of key species of interest, notably red-throated divers.

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