Digital video aerial surveys of marine birds and mammals at Solway Firth SPA: February 2021

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Harker, A.J., Pavat, D. and Humphries, G.

Published August 2022

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Further information

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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.

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Executive Summary

Extending between the coasts of Dumfries and Galloway, southwest Scotland and Cumbria, northwest England, the Solway Firth SPA is a large estuarine and marine site first designated in 1992 under the European Union 'Birds Directive' (2009/147/EC). Qualifying interests for the site include multiple waterfowl, wader, and gull species, qualifying under Article 4.1 (Annex I) and Article 4.2.

In January 2021, NatureScot and Natural England commissioned HiDef Aerial Surveying Limited ('HiDef') to undertake a high-resolution digital video aerial survey for marine megafauna, ornithological and human activity within the Solway Firth SPA. In January 2022, HiDef was commissioned to undertake analyses on these data, to derive density and population estimates for all species identified during the survey, with a focus on selected qualifying bird species.

One survey was flown in February 2021. HiDef designed a survey that placed 2.5km-spaced transects across the SPA area ('the survey area'). The total survey area was approximately 1,357km^2. For data presentation and analysis, the data was further divided into a near-shore area (extending up to 2km from the coast, equating to approximately 402km^2) and a marine area (excluding areas within 2km of the coast, equating to approximately 955km^2).

The survey was undertaken using an aircraft equipped with four HiDef Gen II cameras with sensors set to a resolution of 2cm Ground Sample Distance (GSD). Each camera sampled a strip of 125m width, separated from the next camera by ~25m, to provide a combined sampled width of 500m within a 575m overall strip. Approximately 20% coverage of the survey area was achieved during the survey. Data from all four cameras were analysed.

Data analysis followed a two-stage process in which video footage was reviewed (with a 20% random sample used for audit) and detected objects were identified to species or species group level (again with 20% selected at random for audit). The audit of both stages requires 90% agreement to be achieved.

Density and abundance estimates were calculated using strip transect analysis and kernel density estimation (KDE) was used to create density surface maps. Apportioning of unidentified birds was undertaken to produce the final estimates. Known diving rates of three species (guillemot (*Uria aalge*), razorbill (*Alca torda*) and harbour porpoise (*Phocoena phocoena*)) were used to estimate the proportion of diving birds that would be underwater at the time of survey for the calculation of absolute abundance and density.. In addition, bird behaviour is also provided.

The digital aerial survey recorded a total of 28,928 birds of 38 species and 41 non-avian animals of one species within the SPA. Additionally, 714 birds were partially identified to 10 species groups and four non-avian animals were partially identified to two species groups. An identification rate to species level of 97.57% was achieved throughout the survey. Shore-based surveys targeting common goldeneye (*Bucephala clangula*), goosander (*Mergus merganser*) and cormorant (*Phalacrocorax carbo*) recorded 1,150 birds between 10th and 15th February 2021, at six locations along the Cumbrian coast within the SPA boundary.

Supplementary shore-based count data of roosting birds provided by Natural England, for sites along the English coast only, were collected between the 10th and 15th of February 2021. Summed peak counts for each species per shore-based survey site were used to supplement population and density estimates from the digital aerial survey for three species (common goldeneye, goosander and cormorant). Raw data were compared to those collected during the digital aerial survey.

Between the near-shore and marine areas, more birds were recorded in the near-shore area within 2km of the coast. The most frequently recorded species from the digital aerial survey were dunlin (*Calidris alpina*), followed by common scoters (*Melanitta nigra*). For shore-based surveys, cormorants were the most frequently recorded species, recorded at Workington Harbour Wall.

1 Introduction

1 Extending between the coasts of Dumfries and Galloway, southwest Scotland and Cumbria, northwest England, the Solway Firth SPA is a large estuarine and marine site first designated in 1992, covering approximately 1,375km^2. The site was re-classified to include a marine extension to the Upper Solway Flats and Marshes SPA and renamed as the Solway Firth SPA in December 2020.

2 The Solway Firth SPA was originally designated to protect non-breeding populations of the following Annex 1 species of the European Union 'Birds Directive' (2009/147/EC): red-throated diver (*Gavia stellata*); whooper swan (*Cygnus cygnus*); barnacle geese (*Branta leucopsis*); golden plover (*Pluvialis apricaria*) and bar-tailed godwit (*Limosa lapponica*). It was also designated under Article 4.2 of the 'Birds Directive' to protect migratory species, including pink-footed geese (*Anser brachyrhynchus*); pintail (*Anas acuta*); greater scaup (*Aythya marila*); oystercatcher (*Haematopus ostralegus*); knot (*Calidris canutus*); curlew (*Numenius arquata*) and redshank (*Tringa totanus*), as well as ringed plover (*Charadrius hiaticula*) during the non-breeding (passage) period (JNCC, 2020).

3 The Solway Firth SPA is also designated to protect its non-breeding waterbird assemblage. After extension of the marine area of the Solway SPA in 2020 by combining the Upper Solway Flats and Marshes SPA (SNH and NE, 2017; JNCC, 2020), multiple non-breeding gull and non-breeding waterfowl were added under the protection of the SPA including, shelduck (*Tadorna tadorna*); teal (*Anas crecca*); common goldeneye (*Bucephala clangula*, hereafter 'goldeneye'); grey plover (*Pluvialis squatarola*); sanderling (*Calidris alba*); dunlin (*Calidris alpina*); common scoter (*Melanitta nigra*), goosander (*Mergus merganser*); great cormorant (*Phalacrocorax carbo*, hereafter 'cormorant'); black-headed gull (*Chroicocephalus ridibundus*); common gull (*Larus canus*) and herring gull (*Larus argentatus*) (JNCC, 2020).

4 In January 2021, NatureScot and Natural England commissioned HiDef Aerial Surveying Limited ('HiDef') to undertake a high-resolution digital video aerial survey for marine megafauna, ornithological and human activity over the existing Solway Firth SPA and a proposed extension area. The focus of the survey was on the wintering qualifying features of the SPA that forage and/or roost within the sub-tidal marine areas of the site. Red-throated diver, common scoter and goosander were chosen as focal species, with greater scaup, goldeneye and cormorant also being of interest. Table 1 provides a summary of the qualifying species for the SPA, their populations at citation and their priority within this report.

5 One survey was performed in February 2021. In January 2022, HiDef was commissioned to undertake analyses on these data, to derive density and population estimates for selected qualifying bird species at an SPA level. These data will also be used to inform current and new planning enquiries and environmental assessments.

6 This report provides the results from one digital aerial survey on 11th February 2021 and is presented alongside data provided by Natural England from shore-based surveys between 10th and 15th February 2021. Observations and survey effort are summarised, and results presented as density surface distribution maps. Density and population estimates with 95% confidence intervals (CIs) are presented for Solway Firth SPA, as well as for a near-shore area (including areas up to 2km from the coast) and a marine area (excluding areas within 2km of the coast), and presented alongside shore-based count data. Summarised data on behaviour ratios for seabirds is also presented.

Table 1 Solway Firth SPA features and citation population size (individuals)

SPA feature type	Species	Latin name	Population at citation (individuals)	Report priority
European importance of non-breeding Annex 1 species	Red-throated diver	*Gavia stellata*	521	Focal
	Whooper swan	*Cygnus cygnus*	250	
	Barnacle goose	*Branta leucopsis*	12300	
	European golden plover	*Pluvialis apricaria*	3380	
	Bar-tailed godwit	*Limosa lapponica*	4800	
European importance of migratory species	Pink-footed goose	*Anser brachyrhynchus*	14900	
	Northern pintail	*Anas acuta*	1400	
	Greater scaup	*Aythya marila*	2300	Additional
	Eurasian oystercatcher	*Haematopus ostralegus*	33850	
	Red knot	*Calidris canutus*	15300	
	Eurasian curlew	*Numenius arquata*	6700	
	Common redshank	*Tringa totanus*	2100	
European importance of non-breeding (passage) species	Ringed plover	*Charadrius hiaticula*	981	
Additional component of the non-breeding waterbird assemblage	Common shelduck	*Tadorna tadorna*	1600	
	Eurasian teal	*Anas crecca*	1400	
	Northern shoveler	*Anas clypeata*	120	
	Common goldeneye	*Bucephala clangula*	300	Additional
	Grey plover	*Pluvialis squatarola*	720	
	Sanderling	*Calidris alba*	260	
	Dunlin	*Calidris alpina alpina*	11900	
	Ruddy turnstone	*Arenaria interpres*	600	
	Black (common) scoter	*Melanitta nigra*	1588	Focal
	Goosander	*Mergus merganser*	146	Focal
	Northern lapwing	*Vanellus vanellus*	5037	
	Great cormorant	*Phalacrocorax carbo*	581	Additional
	Black-headed gull	*Larus ridibundus*	13732	Supplemental
	Common gull	*Larus canus*	12486	Supplemental
	Herring gull	*Larus argentatus*	3034	Supplemental
Non-SPA species of interest				
Relevance to understanding offshore wind farm interactions	Common guillemot	*Uria aalge*		Supplemental
	Razorbill	*Alca torda*		Supplemental
	Great black-backed gull	*Larus marinus*		Supplemental

2 Methods

2.1 Digital aerial survey flights

7 A series of strip transects were flown once in February 2021, following the protocol agreed in January 2021 (HP00134-001).

8 HiDef designed a survey that placed 2.5km-spaced transects across the SPA to create an overall survey area of 1,356.5km^2 (Figure 1). Upon the request of Natural England, the survey area was further split into near-shore (including areas up to 2km from the coast) and marine (excluding areas within 2km of the coast) areas during post-processing, giving stratified survey areas of 401.8km^2 and 954.8km^2 respectively. The river delta regions around the rivers Eden and Esk and the rivers Wampool and Waver were included in the near-shore regions.

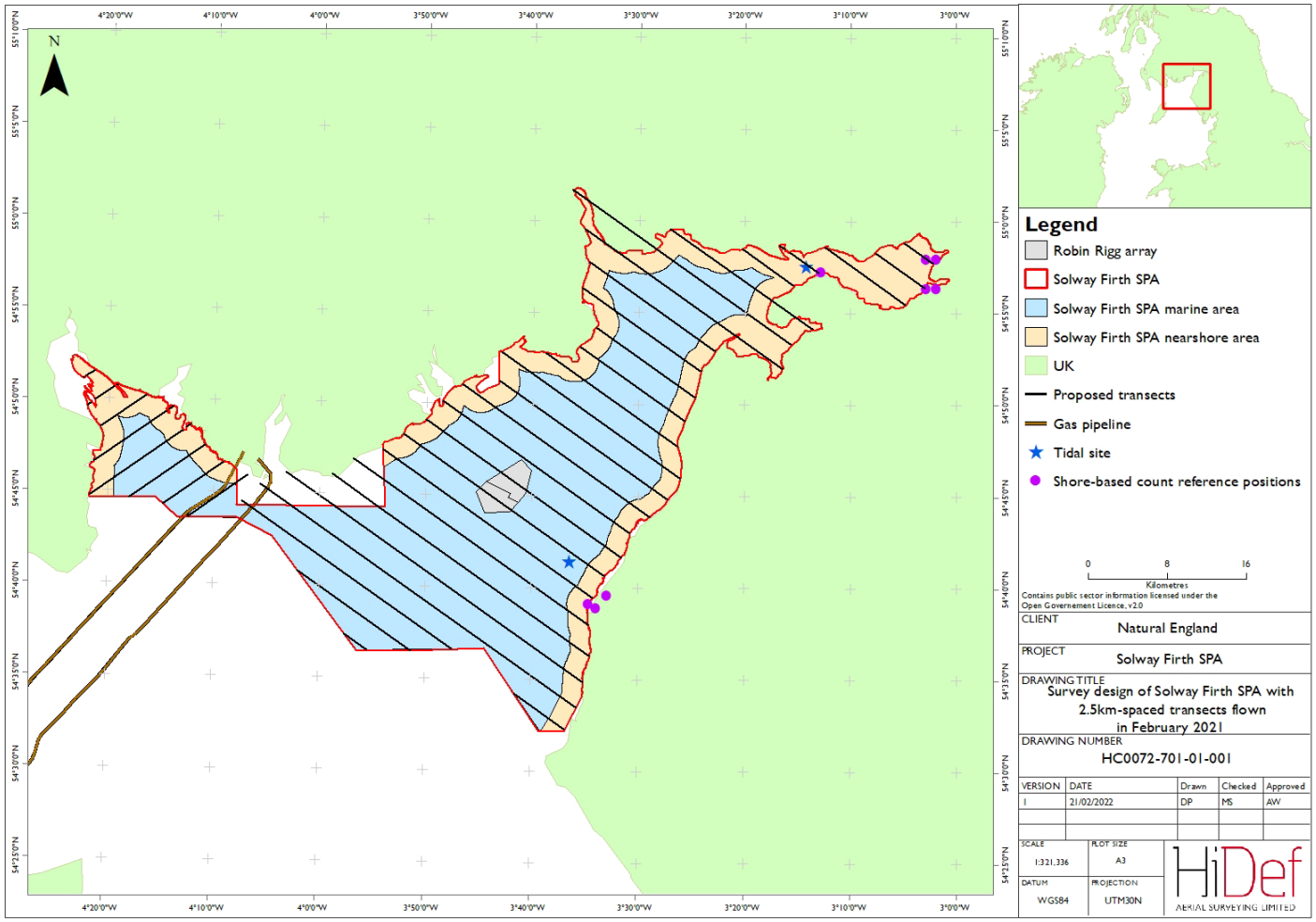
9 The survey design proposed by HiDef consisted of 35 strip transects extending roughly north-east to south-west, perpendicular to the depth contours along the coast. This ensures each transect samples a similar range of habitats (primarily relating to water depth) to reduce variation in abundance estimates between transects.

10 Surveys were undertaken using an aircraft equipped with four HiDef Gen II cameras with sensors set to a resolution of 2cm Ground Sample Distance (GSD). Each camera sampled a strip of 125m width, separated from the next camera by ~25m, thus providing a combined sampled width of 500m within a 575m overall strip. A minimum target of 20% site coverage was agreed, with data from all four cameras being processed.

11 The survey was flown along the transect pattern shown in Figure 1 at a height of approximately 550m above sea level (ASL; ~1800'). Flying at this height ensures that there is no risk of flushing species that are easily disturbed by aircraft noise. Thaxter *et al.* (2016) recommends a minimum flight altitude between 460 – 500m ASL.

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

Figure 1 Solway Firth SPA survey design for digital aerial survey with 2.5km-spaced transects



2.2 Data review and object detection

13 Data were viewed by trained reviewers who marked any objects in the footage as requiring further analysis, as well as determining which are 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.

14 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 was not attained during the QA process, then corrective action was initiated: the remaining data set was reviewed and where appropriate, the failed reviewer's data discarded and all the data re-reviewed. In addition, further training was then given to the reviewer to improve performance.

15 Objects were only recorded where they reached a reference line (known as 'the red line') which defined the true transect width of 125m for each camera. By excluding objects that did 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 where the survey craft is buffeted by airflow) were eliminated.

2.3 Object identification

16 Images marked as requiring further analysis were reviewed by specialist ornithologists[1] and marine mammal specialists[2] 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.

17 At least 20% of all objects were selected at random and subjected to a separate 'blind' QA process. If less than 90% agreement was attained for any individual camera then corrective action was initiated: if appropriate, the failed identifier's data were discarded, and the data re-identified. Any disputed identifications were passed to a third-party expert ornithologist for a final decision[1]. The level of agreement within the QA process is calculated as the final number of agreements as a percentage of all identifications subjected for QA for the entire survey.

18 All objects were assigned to a species group and where possible, each of these then further identified to species level. The species identifications were given a confidence rating of 'possible', 'probable' or 'definite'[3].

19 It is important to note that these confidence ratings are not standardised. The likelihood of achieving a definite or probable identification is not consistent for all component members of a species group. For example, someone undertaking identification of a large auk will find it easier to be confident of guillemot (*Uria aalge*) identification than razorbill (*Alca torda*). Confidence scores should not be used to filter or weight the probability of 'large auk' being one species or another in any analysis, as this will lead to biased results, particularly if the identification rate is low.

20 Any animals that could not be identified to species level were assigned to a category 'No ID'. If, on occasion, the unidentified bird is suspected of belonging to two possible genera, then a broader group

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1 HiDef currently employs four of the ten current members of the British Birds Rarities Committee ('BBRC') as expert ornithologists

2 HiDef staff have long-standing experience in marine mammal identification, regularly undertaking boat surveys as part of ESAS (European Seabirds At Sea Partnership). They process thousands of cetacean images, hold regular internal training sessions and have access to marine specialists within our wider company BioConsult SH.

3 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.

category may be used. For example, a bird would usually be assigned to the group category 'Shearwater species' if identified as a Manx shearwater (*Puffinus puffinus)*, or to 'Large Auk species' if identified as a guillemot. However, if the bird has the potential to be either, then it would be assigned to a wider group category 'Shearwater / Auk species' and the species level recorded as 'No ID'.

21 In the case of birds, additional information was recorded on basic behaviour (i.e., whether the bird was sitting, loafing on land or other objects, or flying). Detail was recorded where possible on foraging behaviour, approximate age, sex and any other details of interest. Aging of birds was based on moults and is mostly conducted on flying individuals and species which show seasonal variation in plumage.

22 Marine mammals and other marine megafauna were recorded using the same process. Animals were first assigned to a species group (e.g., 'cetacean species') and then given a species level identification (e.g. 'harbour porpoise', 'minke whale' or 'No ID'). If a precise species group could not be ascertained, then the record was assigned to a broader group category (e.g., 'seal or small cetacean species') and the species level recorded as 'No ID'.

23 In the case of marine mammals, surfacing behaviour was also recorded as either 'surfacing', 'surfacing at red line', 'submerged' or 'unknown'. Surfacing behaviour was defined as any part of the non-avian animal's body breaking the surface of the water in any frame. However, for the purposes of calculating availability bias (section 2.5.3), harbour porpoise (*Phocoena phocoena*) surfacing behaviour was also classified if the animal's dorsal fin was above the water in the frame nearest to the 'red line' on the operator's screen ('surfacing at red line'). Sexing and aging of marine mammals was carried out where possible.

24 Anthropogenic activity was recorded as either 'man-made object', 'fishing boat' or 'other boat'. Further details were noted in the comments, including further specifying the type of object (e.g. 'fishing buoy', 'marker buoy', 'wind turbine').

2.4 Final processing

25 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 UTM30N projection, WGS84 datum.

2.5 Data analysis

2.5.1 Data treatment

26 Raw count data were trimmed to the full SPA, the near-shore area and the marine area prior to presentation in the report. After basic presentation, data were processed to estimate density, abundance and distribution of key species and species groups.

27 Records identified to species level were separated out from records of individuals identified to group level only, and the following analyses undertaken on both datasets. Apportioning of 'unidentified' birds to species level was undertaken. All confidence levels of species identifications were used in the analysis. In the analysis of species groups, rationalisation of the full list of species groups was carried out to simplify the interpretation.

2.5.2 Population estimates

28 Population estimates were calculated for the full SPA, the near-shore area and the marine area.

29 Each strip transect was treated as a statistically independent random sample from the site. The length and breadth (i.e. the width of the field of view of the camera) of each transect were multiplied together to give the transect area; dividing the number of observations for each species on each transect by the transect area gives a point estimate of the density of that species for the transect. The density of animals at the site (and hence the population size by multiplying by the area of the site), the standard deviation, the 95% confidence intervals (CIs) and coefficient of variance (CV) were then estimated using a non-parametric block bootstrap method with replacement (Buckland *et al.,* 2001), to ensure equal transect effort was sampled across each bootstrap iteration. This was done by using transect ID as the sampling unit with replacement. A group of transects were randomly sampled until their total length equalled approximately the same length as the total survey length.

30 A total of 1,000 bootstrap iterations were performed from which we calculated the mean and standard deviation of the sampled means, as well as the relative standard error (or CV) as defined by the standard deviation divided by the mean. Data were processed in the R programming language (version 4.1.1) and code can be provided on request.

31 The density estimate is expressed as the average number of animals per square km in the whole survey area. The population estimate is expressed as the estimated number of animals within the whole survey area. The upper and lower confidence limits (CLs) define the range that the population estimate falls within with 95% certainty. The CV is a measure of the precision of the population and density estimates.

32 For most species these abundance estimates relate to absolute abundance, but for diving species such as auks, the abundance relates to relative abundance due to a proportion of animals being submerged at the time of survey. In Section 2.5.3 we describe our method for taking account of species availability to generate estimates of absolute abundance for auks and harbour porpoise.

33 Apportioning of 'unidentified' birds and marine mammals to species level was also undertaken for the purposes of calculating population estimates. The number of unidentified animals in each species group were assigned to species where appropriate, based on their respective abundance ratios. For example, if identified guillemots and razorbills occurred in a 4:1 ratio, then 80% of unidentified large auks would be assigned to guillemot and 20% assigned to razorbill.

2.5.3 Availability bias

34 In wildlife surveys, a proportion of seabirds or marine mammals that spend any time underwater, especially while feeding, will not be detectable at the surface. This 'availability bias' leads to an under-estimate of their abundance during surveys. For species that make long dives underwater, this bias might be significant (for example, guillemot).

35 There are two main approaches to account for availability bias: by using double platform surveys (for example Borchers *et al.,* 2002) which can be logistically difficult to achieve and relatively expensive; and by using known data on time spent underwater to apply correction factors to abundance estimates (for example Barlow *et al.,* 1988).

36 Following Barlow *et al.* (1988) the probability that an animal is available at the surface is calculated as:

$$\Pr(being\ visible) = \frac{(s+t)}{(s+d)}$$

Where s is the average time spent at the surface, t is the window of time that the animal is within view and d is the average time below the surface. In the case of digital video surveys, the value of t is negligibly small and is treated as 0.

37 Due to a lack of diving rate data for many species, availability bias corrections were only conducted on three species: guillemots, razorbills and harbour porpoise. When considering population estimates calculated for other diving species, it should be noted that population estimates for the survey area are likely to be underestimated.

2.5.3.1 Seabirds

38 Using Barlow's method, the proportion of time that an animal is available at the surface was calculated (Pr (visible)) for guillemot and razorbill. Absolute density, corrected for availability, is then obtained by dividing the density of birds observed by the Pr(visible).

39 For guillemots and razorbills, data obtained during the breeding season using data loggers were used to estimate availability bias. Thaxter *et al.* (2010) give mean times for these species engaged in flying, feeding and underwater per trip during the chick-rearing period.

40 Thus, the proportion of time that guillemots and razorbills are available at the surface (Pr(visible)) was estimated at 0.7595 and 0.8182, respectively.

41 The estimates of Pr(visible) for guillemots and razorbills were used to correct relative abundance estimates of birds sitting on the sea. These corrected abundance estimates for sitting birds are then added to the abundance estimate of flying birds to give an overall absolute abundance for the species.

2.5.3.2 Marine mammals

42 Harbour porpoise abundance is also affected by availability bias, and further complicated because detections of animals are possible while they are submerged. There are two approaches to using known diving rates to correct for availability bias for this species: to apply a correction factor to the density of animals that were recorded surfacing only using data on the surfacing rates from tagged animals; or to apply a correction factor to the density of all animals (at the surface and subsurface) using the proportion of time spent at known depths by tagged animals.

43 The depth above which animals are available for detection is not known and is likely to vary according to the turbidity of the water, and perhaps other factors, but has been estimated to be 2m by Teilmann *et al.* (2013) when correcting for availability bias during visual aerial surveys of harbour porpoise.

44 Teilmann *et al.* (2013) provides detailed information which accommodates variation in time of year, geographical location and time of day in the proportion of time spent in the surface 2m of the water column and breaking the surface. All of these metrics relate to model outputs in Teilmann *et al.* (2013) and are used to refine the predicted amount of time that harbour porpoise spend surfacing in the outputs.

45 The tagging study of Teilmann *et al.* (2013) did not extend to the area of Irish Sea surrounding this project, and no other data are available on surfacing behaviour for this species in the relevant area. For our analysis, we assumed that diving behaviour in the survey area is comparable to that of the study area of Teilmann *et al.* (2013).

46 To estimate the density of surfacing harbour porpoise all detectable animals were used, and we calculated the proportion where the dorsal fin was snapshot surfacing. Snapshot surfacing indicates where the dorsal fin is clear of the water surface in the middle frame of the sequence in which the

animal is present. This was done using data from all months combined because sample sizes were too small to be accurate when calculating the surfacing proportions in individual months. We multiplied the calculated density of harbour porpoise by the proportion of snapshot surfacing encounters in our surveys and divided this by the proportion of surfacing behaviour from Teilmann *et al.* (2013) in Table 2, to derive the estimates of absolute density and abundance.

Table 2 Correction factors used to account for availability bias for harbour porpoise at different times of the year and at different times of the day (after Teilmann *et al.*, 2013)

Month	Behaviour			
	Surface		0 – 2 m	
	09:00 – 15:00	15:00 – 21:00	09:00 – 15:00	15:00 – 21:00
January	0.0490	0.0476	0.4381	0.418614
February	0.0398	0.0384	0.3748	0.355348
March	0.0543	0.0529	0.4637	0.444271
April	0.0646	0.0632	0.5708	0.551331
May	0.0563	0.0549	0.5262	0.506735
June	0.0518	0.0503	0.5093	0.489809
July	0.0493	0.0479	0.5116	0.492099
August	0.0530	0.0516	0.4508	0.431293
September	0.0420	0.0406	0.4468	0.427348
October	0.0413	0.0399	0.4422	0.42276
November	0.0406	0.0392	0.4439	0.424431
December	0.0429	0.0415	0.4790	0.459555

2.5.4 Density mapping

47 Density maps were created to display the distribution of focal and additional species. Focal (red-throated diver, common scoter, goosander, greater scaup, common goldeneye and cormorant) and additional species (guillemot, razorbill, black-headed gull, common gull, herring gull and great black-backed gull (*Larus marinus*)) were selected by the client. For diving species (guillemot, razorbill and harbour porpoise), density mapping was undertaken using 'relative' density estimates, *prior* to adjustment for availability bias.

48 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 survey 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.

49 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.

50 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 was removed. The closer the predicted values represent the removed data, the better the model performance and the width parameter used in the model.

51 To apply cross validation to the survey area, each transect is subdivided into 1km long segments. To evaluate a particular choice of kernel width, each segment is removed in turn, use the kernel and the remaining data to predict the density of the missing segment and subtract the known value 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. All maps were created in ArcMap version 10.8.1.

52 It should be noted that several of the KDE maps are effectively flat (i.e. they appear uniform in colour). 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 observations as dots to help with interpretation of the maps.

53 All maps in this report contain data made available by the EMODnet Human Activities project, www.emodnet-humanactivities.eu, funded by the European Commission Directorate General for Maritime Affairs and Fisheries.

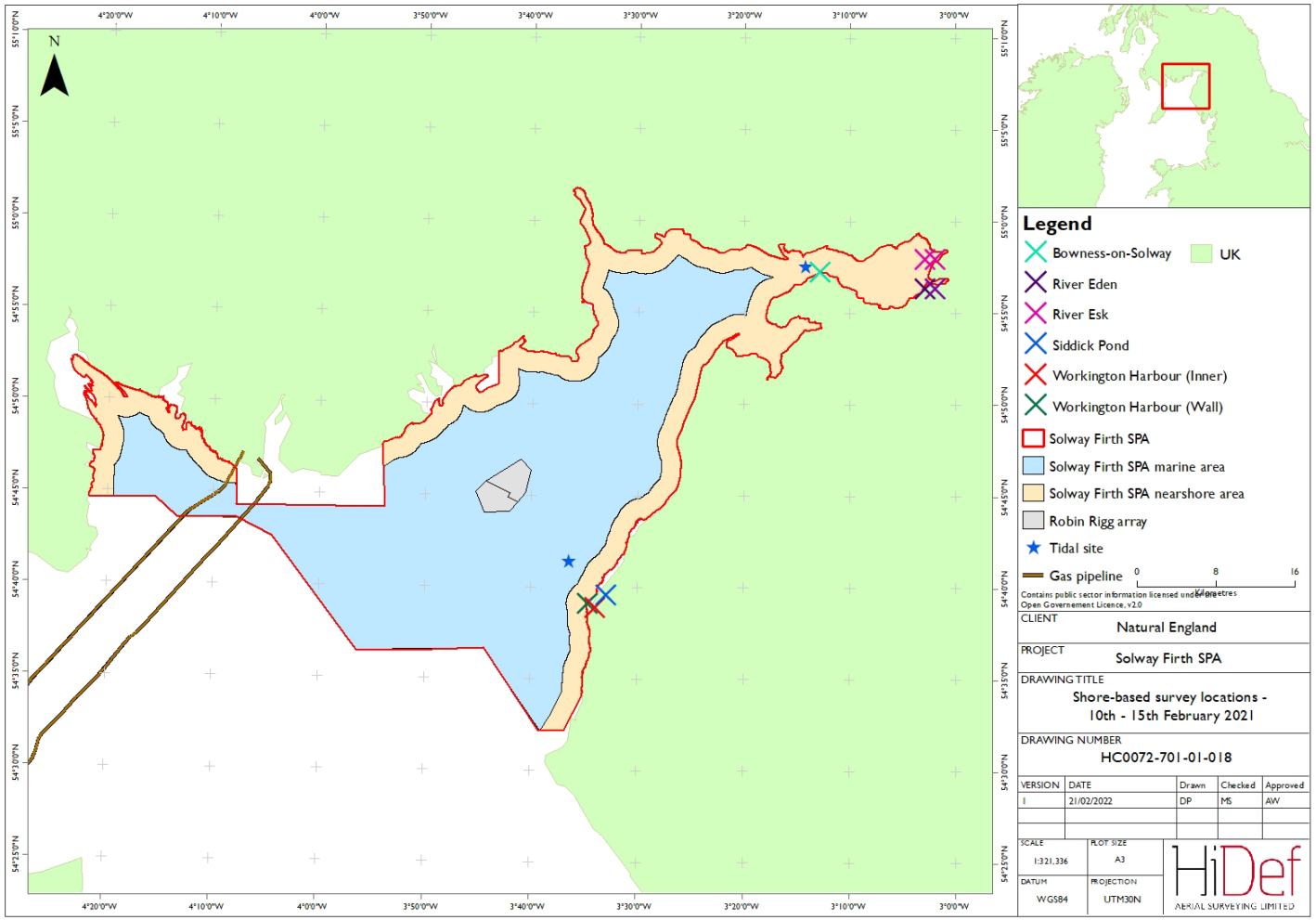
2.5.5 Shore-based data

54 Shore-based counts of roosting birds were collected by observers between 10th and 15th February 2021 at six locations along the Cumbrian coast within the SPA boundary: Workington Harbour (inner), Workington Harbour Wall, Siddick Pond, Bowness-on-Solway, River Esk and the River Eden (Figure 2).

55 Data collected on the same day as the digital aerial survey (11th February) were collected through vantage-point targeted counts of known roost gatherings, timed to coincide with the flight. For Workington shore-based counts of cormorants, observers watched the plane as they counted to minimise risk of double counting. Suitable distances from roosts were maintained to ensure no disturbance. Data collection on the remaining survey days was achieved through a mix of fixed vantage-point surveys (e.g. River Esk) and counts on linear walks (e.g. River Eden; Natural England, pers. comm.).

56 For species recorded in both the digital aerial survey and shore-based surveys, peak counts of species identified at each site in shore-based surveys were used to derive a total which was added to population estimates for the full SPA and near-shore. This is to reduce the risk of double counting birds (e.g. cormorants on the roost that would have likely been the same birds on both survey occasions). Shore-based counts were added to population estimates and added to CL's, densities estimates were adjusted accordingly. Raw data from shore-based surveys are presented in Appendix III: Shore-based count data.

Figure 2 **Shore-based survey locations within the Solway Firth SPA**



3 Results

3.1 Survey effort

57 The date, number of transects and survey effort for the digital aerial survey (as expressed by length of transects) for the full SPA, the near-shore area and the marine area are presented in Table 3. The number of transects and the total length of transects are those used in subsequent analysis (see Figure 3 for the aircraft flight pattern).

58 No survey effort is presented for shore-based data.

59 A summary of the state of the tide at the time of survey and the dates of spring and neap tides around the survey date is presented in Table 4. The survey fell between the spring and neap tides, starting one hour before high tide. Since the survey was flown over high water, many of the shallow intertidal sandbanks and mudflats, usually exposed at low water, were likely to have been submerged at the time of the survey. Most of the survey occurred during the ebb tide, where water was moving out of the estuary towards the Irish Sea.

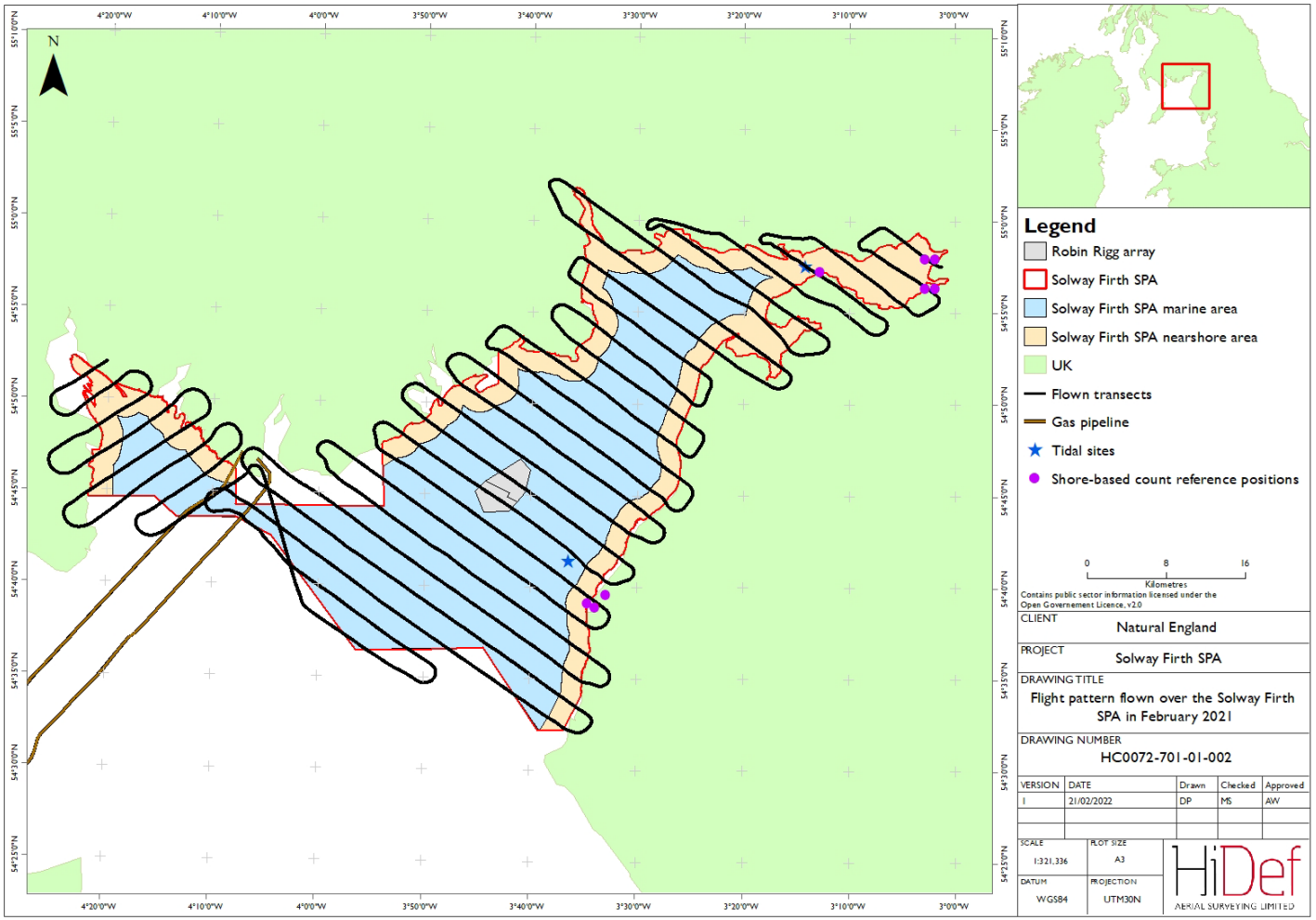
Table 3 Survey effort from digital aerial survey within the Solway Firth SPA, 11 February 2021

Survey area	Number of transects analysed	Total length of transects analysed (km)	Area Covered (km^2)	Area Covered (%)
Full SPA	35	539.71	269.85	19.9
Near-shore area	32	158.45	79.22	19.7
Marine area	27	380.37	190.17	19.9

Table 4 Survey summary of flight time and predicted environmental conditions within the Solway Firth SPA, 11 February 2021

Survey date	Survey start time	Survey end time	Time of high tide, Workington Harbour (UTC)	Time of low tide, Workington Harbour (UTC)	Date of neap tide	Date of spring tide
11th February 2021	10:05	14:20	11:16	17:56	7th February 2021	14th February 2021

Figure 3 Digital aerial survey flight pattern over Solway Firth SPA, 11th February 2021



3.2 Survey results

60 For digital aerial data, each animal was assigned to at least a species group, and where possible these were 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. The analysis of data to species level uses all levels of identification confidence. The overall identification rate of birds to species level (not including 'No ID's) for the survey is given in Table 5.

61 The total number of objects detected in the digital aerial survey flight, as well as numbers of species and species group are presented in Table 6 and Table 7.

62 Summed peak counts across shore-based surveys between 10th and 15th February 2021 to be added to digital aerial survey data are presented in Table 8. Raw data can be found in Appendix III: Shore-based count data.

Table 5 Solway Firth SPA survey identification rate from digital aerial survey, 11th February 2021

Survey date	ID rate (%)
11 February 2021	97.57

Table 6 Number of objects detected assigned to species level in the Solway Firth SPA, the near-shore area and the marine area from digital aerial survey, 11th February 2021

Species	Scientific Name	SPA area	Near-shore area	Proportion of total observations (%)	Marine area	Proportion of total observations (%)
Barnacle goose	*Branta leucopsis*	2052	2052	100	0	0
Pink-footed goose	*Anser brachyrhynchus*	4	4	100	0	0
Shelduck	*Tadorna tadorna*	363	363	100	0	0
Wigeon	*Mareca penelope*	1903	1903	100	0	0
Mallard	*Anas platyrhynchos*	399	399	100	0	0
Pintail	*Anas acuta*	451	451	100	0	0
Teal	*Anas crecca*	1242	1242	100	0	0
Greater scaup	*Aythya marila*	159	159	100	0	0
Common scoter	*Melanitta nigra*	5886	965	16	4921	84
Common goldeneye	*Bucephala clangula*	44	44	100	0	0
Goosander	*Mergus merganser*	15	14	93	1	7
Great crested grebe	*Podiceps cristatus*	1	0	0	1	100
Oystercatcher	*Haematopus ostralegus*	3474	3474	100	0	0
Lapwing	*Vanellus vanellus*	3	3	100	0	0
Grey plover	*Pluvialis squatarola*	39	39	100	0	0
Ringed plover	*Charadrius hiaticula*	1	1	100	0	0
Curlew	*Numenius arquata*	1171	1171	100	0	0

Species	Scientific Name	SPA area	Near-shore area	Proportion of total observations (%)	Marine area	Proportion of total observations (%)
Bar-tailed godwit	*Limosa lapponica*	53	53	100	0	0
Turnstone	*Arenaria interpres*	4	4	100	0	0
Knot	*Calidris canutus*	490	490	100	0	0
Sanderling	*Calidris alba*	18	18	100	0	0
Dunlin	*Calidris alpina*	8109	8109	100	0	0
Redshank	*Tringa totanus*	397	397	100	0	0
Greenshank	*Tringa nebularia*	1	1	100	0	0
Kittiwake	*Rissa tridactyla*	5	1	20	4	80
Black-headed gull	*Chroicocephalus ridibundus*	443	434	98	9	2
Common gull	*Larus canus*	1023	766	75	257	25
Great black-backed gull	*Larus marinus*	28	16	57	12	43
Herring gull	*Larus argentatus*	107	74	69	33	31
Lesser black-backed gull	*Larus fuscus*	5	3	60	2	40
Guillemot	*Uria aalge*	624	24	4	600	96
Razorbill	*Alca torda*	97	7	7	90	93
Black guillemot	*Cepphus grylle*	1	1	100	0	0
Red-throated diver	*Gavia stellata*	180	37	21	143	79
Shag	*Phalacrocorax aristotelis*	5	4	80	1	20

Species	Scientific Name	SPA area	Near-shore area	Proportion of total observations (%)	Marine area	Proportion of total observations (%)
Cormorant	*Phalacrocorax carbo*	115	40	35	75	65
Grey heron	*Ardea cinerea*	4	4	100	0	0
Carrion crow	*Corvus corone*	12	12	100	0	0
Harbour porpoise	*Phocoena phocoena*	41	3	7	38	93
Total		**28969**	**22782**	**79**	**6187**	**21**

Table 7 **Number of objects with no species ID assigned to species groups in the Solway Firth SPA, the near-shore area and the marine area from digital aerial survey, 11th February 2021**

Species group (No ID)	SPA area	Near-shore area	Marine area
Duck species	178	177	1
Wader species	436	436	0
Small gull species	18	16	2
Large gull species	1	1	0
Gull species	3	2	1
Large auk	57	3	54
Auk species	1	0	1
Auk / small gull	3	0	3
Large auk / diver species	2	0	2
Small bird species	15	15	0
Seal species	3	0	3
Seal / small cetacean species	1	0	1
Total	**718**	**650**	**68**

Table 8 Summed peak counts from shore-based survey to be added to digital aerial survey data

Species	Scientific name	Total to be added
Goldeneye	*Bucephala clangula*	54
Goosander	*Mergus merganser*	66
Cormorant	*Phalacrocorax carbo*	648
Total		**111**

3.3 Species distribution and abundance

63 The density, total estimated population and upper and lower 95% CLs are presented below. Complete estimates, including standard deviation and CV, for all species and species groups are presented in Appendix I: Density and population estimates.

64 An explanation of these parameters is presented in Table 9.

65 For certain diving species (guillemot, razorbill and harbour porpoise), estimates were adjusted to account for availability bias (2.5.3) and estimate absolute abundance. The adjusted (absolute) density and abundances provide the best estimate of abundance at the time of survey. No calculation of availability bias was carried out for any other diving species due to the low numbers present and/or lack of information about diving patterns, and so estimates for such species should be seen as under representative. Absolute density and abundance estimates can be found in Appendix II and are also presented in this results section instead of relative density for the relevant key species.

66 Distribution patterns of focal (red-throated diver, common scoter, goosander), additional (greater scaup, goldeneye, cormorant) and supplemental species (gulls and auks) are presented as density maps, in which a density surface depicts the estimated number of individuals per km^2.

Table 9 Terms used in population analysis

Term	Definition
Density estimate *(animals/km^2)*	The average number of animals per square km surveyed over the whole area
Population estimate *(number)*	The mean number of animals estimated within the survey area
95% confidence interval *(CI)*	A measure of uncertainty in the mean value. If the analysis was repeated, 95% of the time the mean population estimate would fall within this range. The smaller the CI range the more confident we can be that the mean estimate is an accurate reflection of the true population size.
Confidence limits (CLs)	The upper and lower values that define the range of the 95% confidence interval.
Standard deviation *(SD)* of population estimate	The amount of variation or dispersion of a set of values. A low SD indicates that the bootstrap values tend to be close to the mean of the set.
CV (%)	The coefficient of variation is a standard measure that describes the dispersion of data points around the mean. The lower the CV the more precise the estimate. It is calculated as the SD / mean.
Relative abundance	In the case of diving birds and mammals, this is the estimated population size based on animals recorded on or above the sea surface and does not account for any that may be diving and thus submerged at the time of survey.
Absolute abundance	The most accurate estimate of population size. In the case of diving birds and mammals, this includes an estimate for the number that are believed to be submerged at the time of survey.
Apportioning of animals identified to species group level	The number of unidentified animals in each species group are assigned to species where appropriate, based on respective abundance ratios. For example, if identified guillemots and razorbills occurred in a 4:1 ratio, then 80% of unidentified birds would be assigned to guillemot and 20% assigned to razorbill.

3.3.1 Focal species

3.3.1.1 Common scoter

67 Within the Solway Firth SPA, the common scoter population was estimated at 29,866 birds (95% CI 12,408 – 49,281).

68 Compared to other species recorded during the project, common scoters were observed in relatively high numbers (Figure 4). Apportioned density estimates for common scoters calculated for the marine area were higher than in the near-shore area, estimated at 26.09 birds/km^2 (95% CI 9.56 – 46.67) and 12.61 birds/km^2 (95% CI 3.30 – 24.39) respectively (Table 10). For the marine area, density estimates equated to a population estimate of 24,928 birds (95% CI 9,135 – 44,590).

69 Birds were generally found in the centre and northwest of the SPA, with the highest densities found within the marine area (Figure 5).

70 Over the full SPA, 99% of birds were recorded sitting on the water. When comparing bird behaviour between the near-shore and marine areas, the proportions were similar, with 97% and 99% of birds sitting on the water, respectively (Table 23 to Table 25).

Figure 4 Number of common scoters recorded within the Solway Firth SPA, the near-shore area and the marine area from digital aerial survey

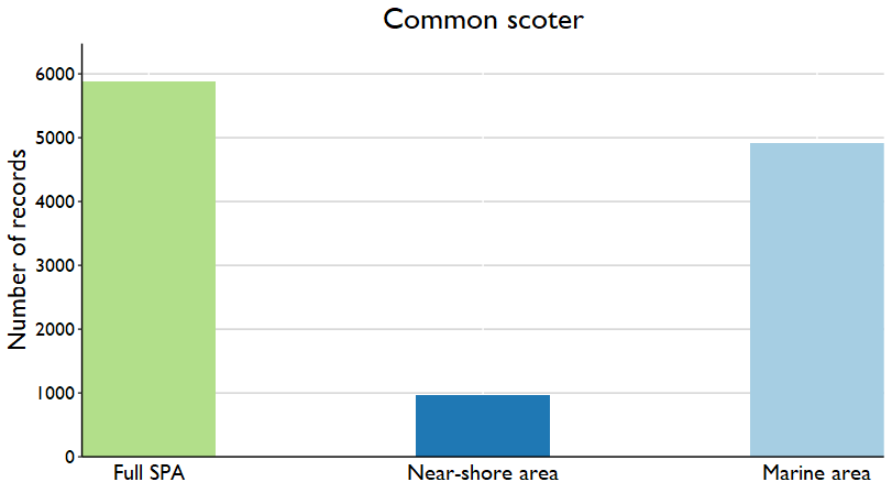
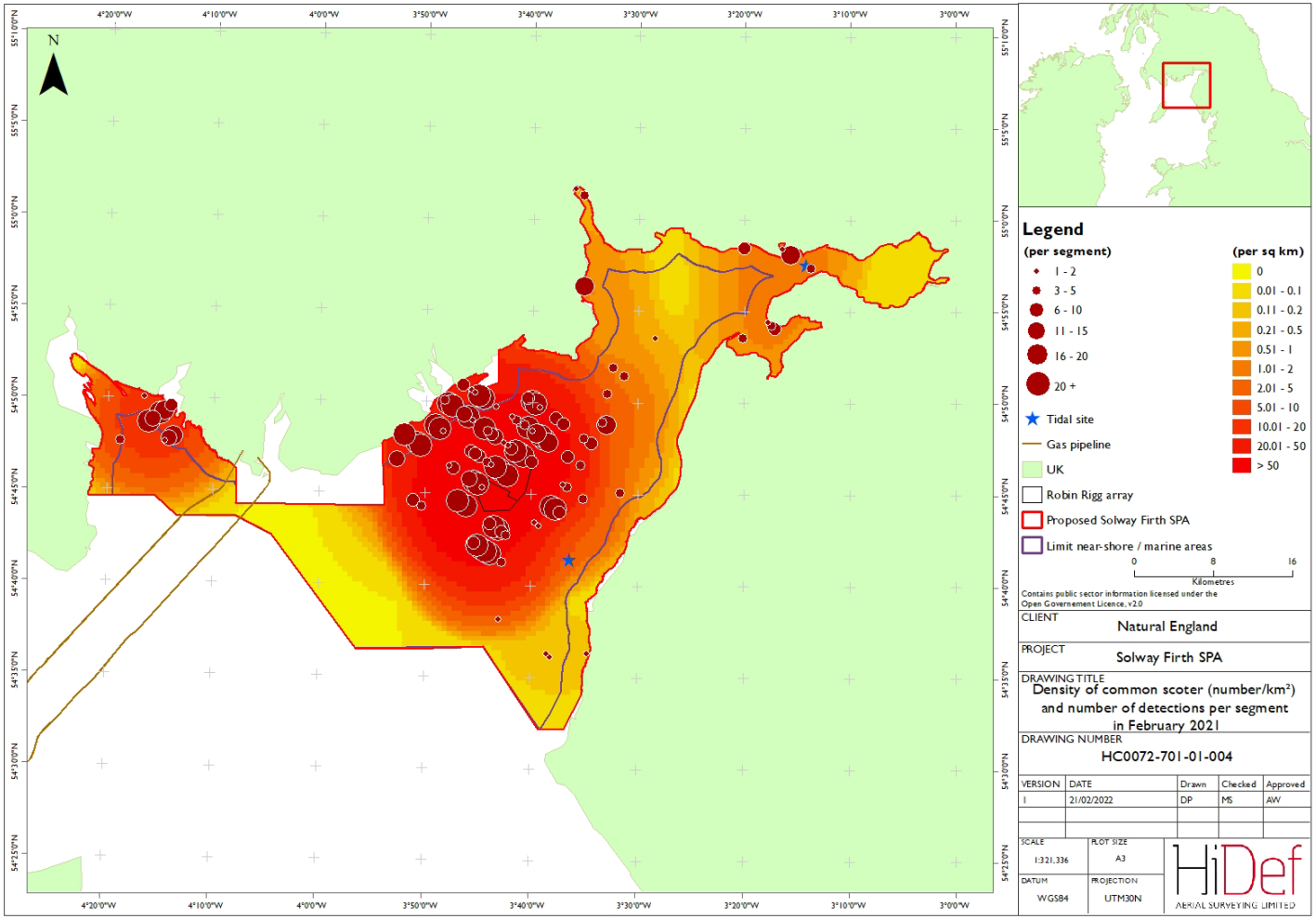


Table 10 Unapportioned and apportioned density and population estimates for common scoter in the Solway Firth SPA, the near-shore area and the marine area in February 2021

Survey area	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Unapportioned								
Full SPA	21.62	8.03	36.57	29355	10908	49648	9954	33.91
Near-shore area	11.64	2.96	22.71	4681	1190	9131	2051	43.80
Marine area	25.85	9.21	44.67	24701	8805	42680	8921	36.11
Apportioned								
Full SPA	22.00	9.14	36.30	29866	12408	49281	9635	32.26
Near-shore area	12.61	3.30	24.39	5069	1328	9808	2167	42.74
Marine area	26.09	9.56	46.67	24928	9135	44590	9125	36.60

Figure 5 Density of common scoters (number/km²) and number of detections per segment in the Solway Firth SPA in February 2021



3.3.1.2 Red-throated diver

71 Within the Solway Firth SPA, the red-throated diver population was estimated at 911 birds (95% CI 571 – 1,279).

72 Red-throated divers were recorded in moderate numbers compared to other species, primarily recorded in the marine area (Figure 6). Apportioned densities were calculated at 0.76 birds/km^2 (95% CI 0.44 – 1.13) and 0.44 birds/km^2 (95% CI 0.20 – 0.73) for the marine and near-shore areas respectively (Table 11). The population estimates for the species in the marine area was calculated at 726 birds (95% CI 424 – 1,085).

73 Birds were mainly found in the centre and northwest of the SPA, with the highest densities found within the marine area (Figure 7).

74 Within the SPA, 99% of birds were recorded as sitting on the water. When comparing behaviour between the two stratified areas, the proportions were similar, with 100% and 99% of birds sitting on the water, respectively (Table 23 to Table 25).

Figure 6 Number of red-throated divers recorded within the Solway Firth SPA, the near-shore area and the marine area from digital aerial survey

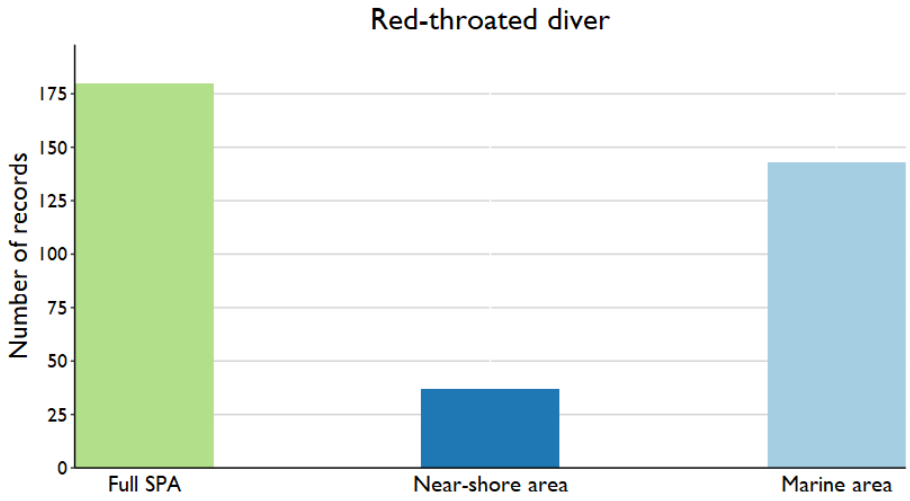
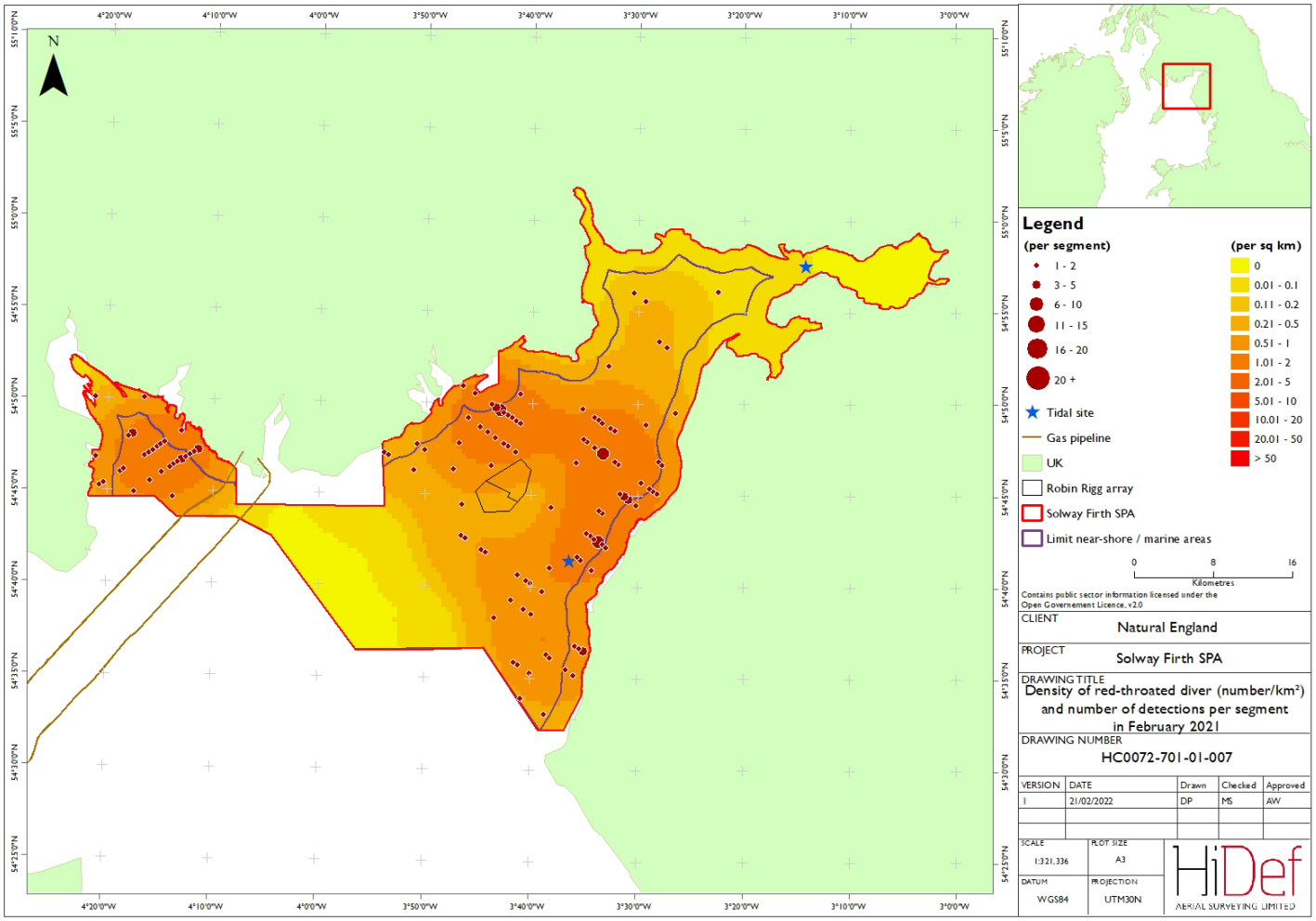


Table 11 Unapportioned and apportioned density and population estimates for red-throated diver in the Solway Firth SPA, the near-shore area and the marine area in February 2021

Survey area	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Unapportioned								
Full SPA	0.67	0.42	0.95	904	565	1286	182	20.09
Near-shore area	0.44	0.21	0.7	177	86	284	51	28.76
Marine area	0.75	0.44	1.09	721	422	1038	162	22.42
Apportioned								
Full SPA	0.67	0.42	0.94	911	571	1279	185	20.25
Near-shore area	0.44	0.20	0.73	177	83	295	54	30.14
Marine area	0.76	0.44	1.13	726	424	1085	165	22.68

Figure 7 Density of red-throated divers (number/km²) and number of detections per segment in the Solway Firth SPA in February 2021



3.3.1.3 Goosander

75 Within the Solway Firth SPA, the goosander population was estimated at 317 birds (95% CI 241 – 479).

76 Goosanders were primarily recorded in the near-shore area (Figure 8). Apportioned densities equated to 0.17 birds/km^2 (95% CI 0.0 – 0.50) and 0.01 birds/km^2 (95% CI 0.00 – 0.02) for the near-shore and marine areas respectively, equating to a population estimate for the full SPA of 317 birds (95% CI 241 – 479; Table 12).

77 Shore-based data recorded 120 birds between 10th and 15th February 2021, observed at Workington Harbour (Inner), Siddick Pond, River Esk and River Eden (Table 22).

78 Birds were mainly found in the northeast of the SPA, with the highest densities found within the near-shore area, off the coasts of Newbie and Powfoot, Dumfries and Galloway (Figure 9).

79 From the digital aerial survey, 100% of birds were recorded sitting on the water (15 birds), with 14 of these located in the near-shore area and one bird recorded in the marine area (Table 23 to Table 25).

Figure 8 Number of goosanders recorded within the Solway Firth SPA, the near-shore area and the marine area from digital aerial survey and shore-based counts

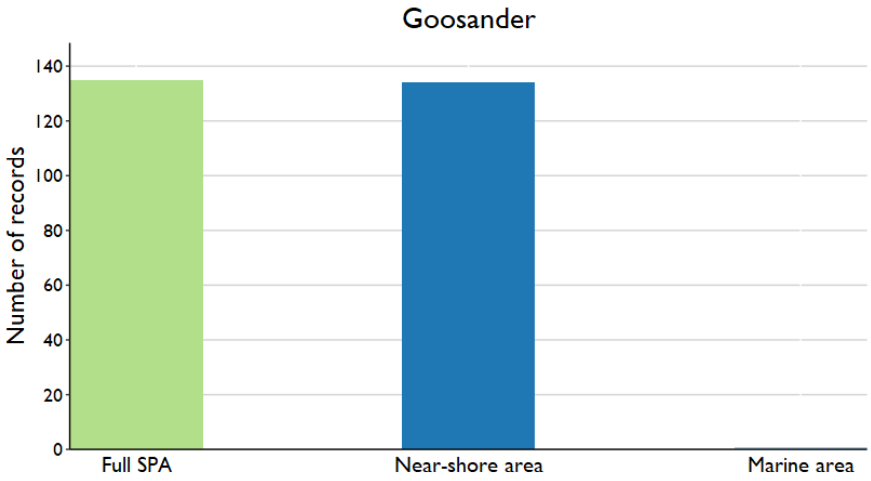
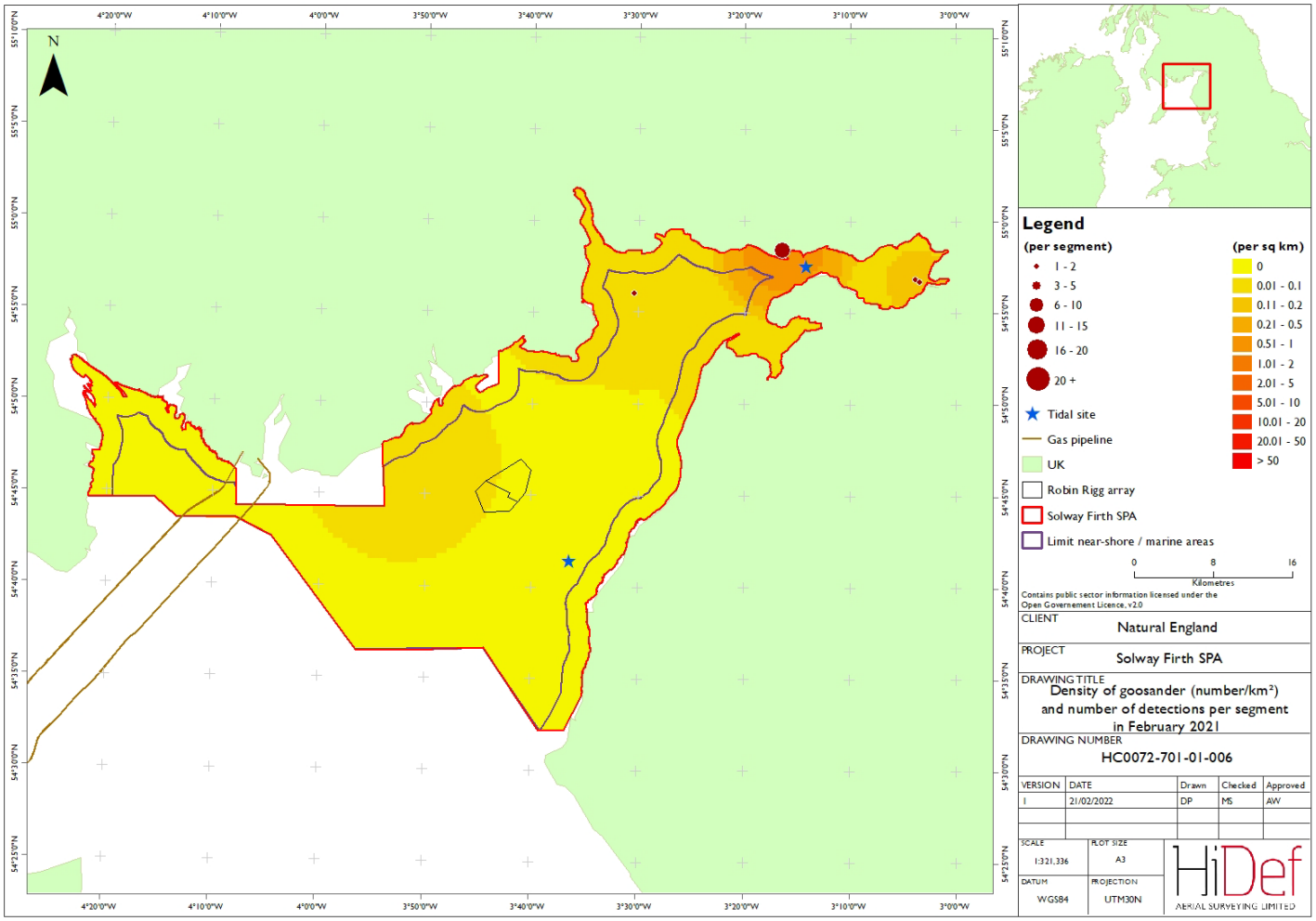


Table 12 Unapportioned and apportioned density and population estimates for goosander in the Solway Firth SPA, the near-shore area and the marine area in February 2021, from digital aerial and shore-based surveys

Survey area	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Unapportioned								
Full SPA	0.10	0.05	0.20	140	66	276	63	84.36
Near-shore area	0.35	0.16	0.68	139	66	273	63	85.45
Marine area	0.01	0.00	0.02	5	0	15	5	100.38
Apportioned								
Full SPA	0.11	0.05	0.22	143	67	305	64	82.53
Near-shore area	0.34	0.17	0.67	136	67	269	61	87.41
Marine area	0.01	0.00	0.02	5	0	15	5	97.2

Figure 9 Density of goosanders (number/km²) and number of detections per segment in the Solway Firth SPA in February 2021



3.3.2 Additional species

3.3.2.1 Greater scaup

80 Within the Solway Firth SPA, the greater scaup population was estimated at 804 birds (95% CI 4 – 2383).

81 All greater scaup were recorded in the near-shore area (Figure 10). Apportioned density estimates for greater scaups were greater in the near-shore area than in the marine area with 2.01 birds/km^2 (95% CI 0.01 – 5.83) and 0.59 birds/km^2 (95% CI 0.00 – 1.75) calculated respectively (Table 13). Although no greater scaup were recorded in the marine area, unidentified individuals within the duck species group were incorporated into estimates during apportioning.

82 Birds were mainly found in the north of the SPA, with the highest densities occurring within the near-shore area northwest of the Robin Rigg array, close to the Dumfries and Galloway coast (Figure 11).

83 During the survey, 100% of birds were recorded sitting on the water (159 birds; Table 23 and Table 24).

Figure 10 Numbers of greater scaup recorded within the Solway Firth SPA, the near-shore area and the marine area from digital aerial survey

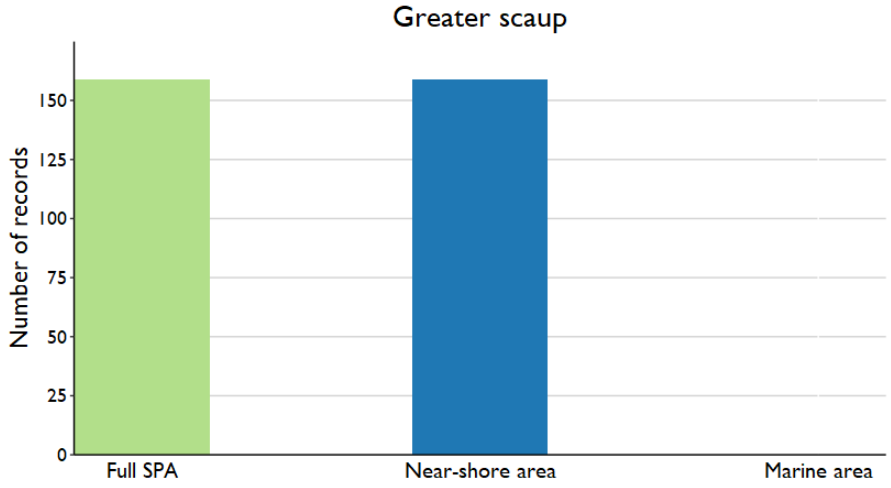
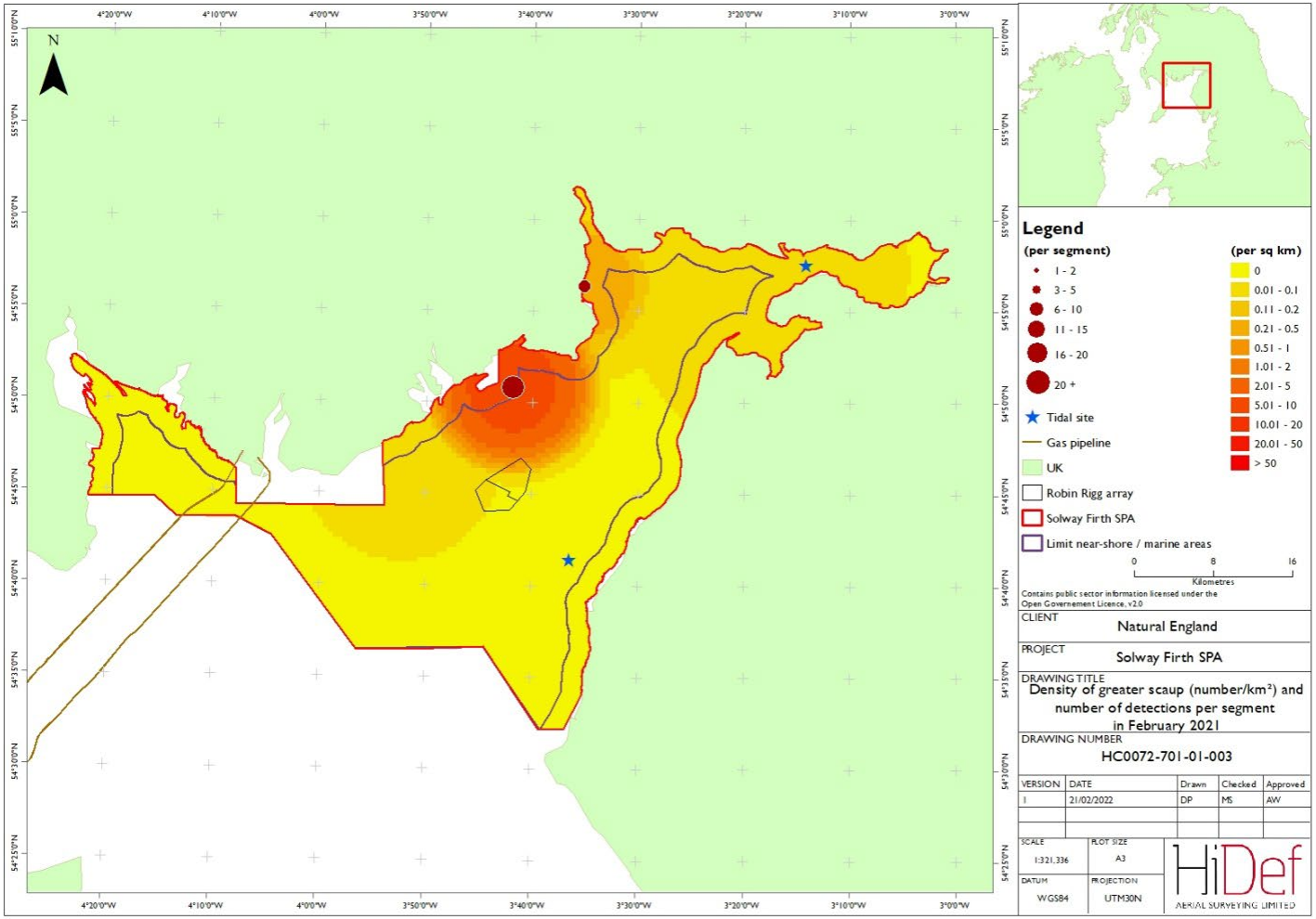


Table 13 Unapportioned and apportioned density and population estimates for greater scaup in the Solway Firth SPA, the near-shore area and the marine area in February 2021

Survey area	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Unapportioned								
Full SPA	0.57	0.00	1.71	777	0	2328	725	93.27
Near-shore area	2.00	0.00	5.86	806	0	2356	744	92.35
Marine area	0.00	0.00	0.00	0	0	0	0	0.00
Apportioned								
Full SPA	0.59	0.00	1.75	804	4	2383	769	95.65
Near-shore area	2.01	0.01	5.83	808	5	2347	748	92.49
Marine area	0.00	0.00	0.00	1	0	1	1	91.95

Figure 11 Density of greater scaup (number/km²) and number of detections per segment in the Solway Firth SPA in February 2021



3.3.2.2 Common goldeneye

84 Within the Solway Firth SPA, the common goldeneye population was estimated at 221 birds (95% CI 12 – 588).

85 All common goldeneyes were recorded in the near-shore area (Figure 12). Apportioned density estimates for the species were estimated at 0.58 birds/km^2 (95% CI 0.05 – 1.44) for the near-shore area, equating to a population estimate of 234 birds (95% CI 19 – 582; Table 14). Population and density estimates for the species in the marine area can be attributed to the apportioning of unidentified birds within the duck species group.

86 Birds were generally distributed to the northeast of the SPA, with the highest densities found within the near-shore area, south of Dumfries, Scotland (Figure 13).

87 During the survey, 100% of birds were recorded as sitting on the water (44 birds; Table 23 and Table 24).

Figure 12 Numbers of common goldeneye recorded within the Solway Firth SPA, the near-shore area and the marine area from digital aerial survey

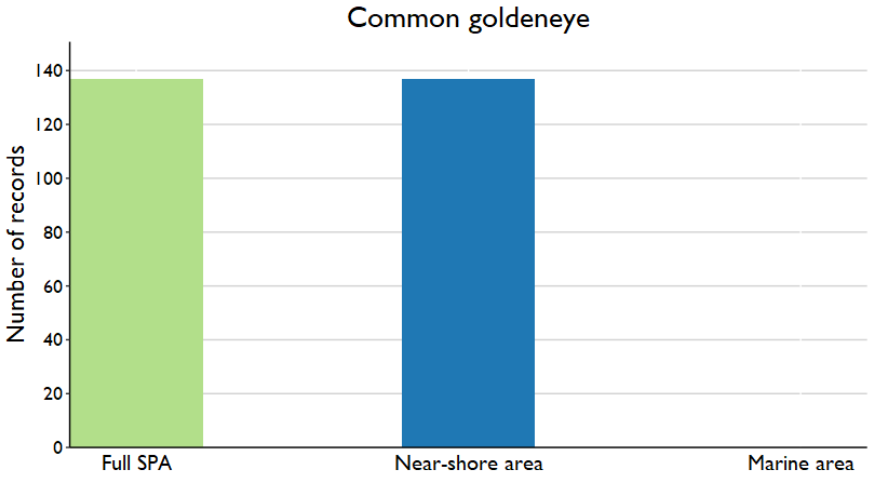
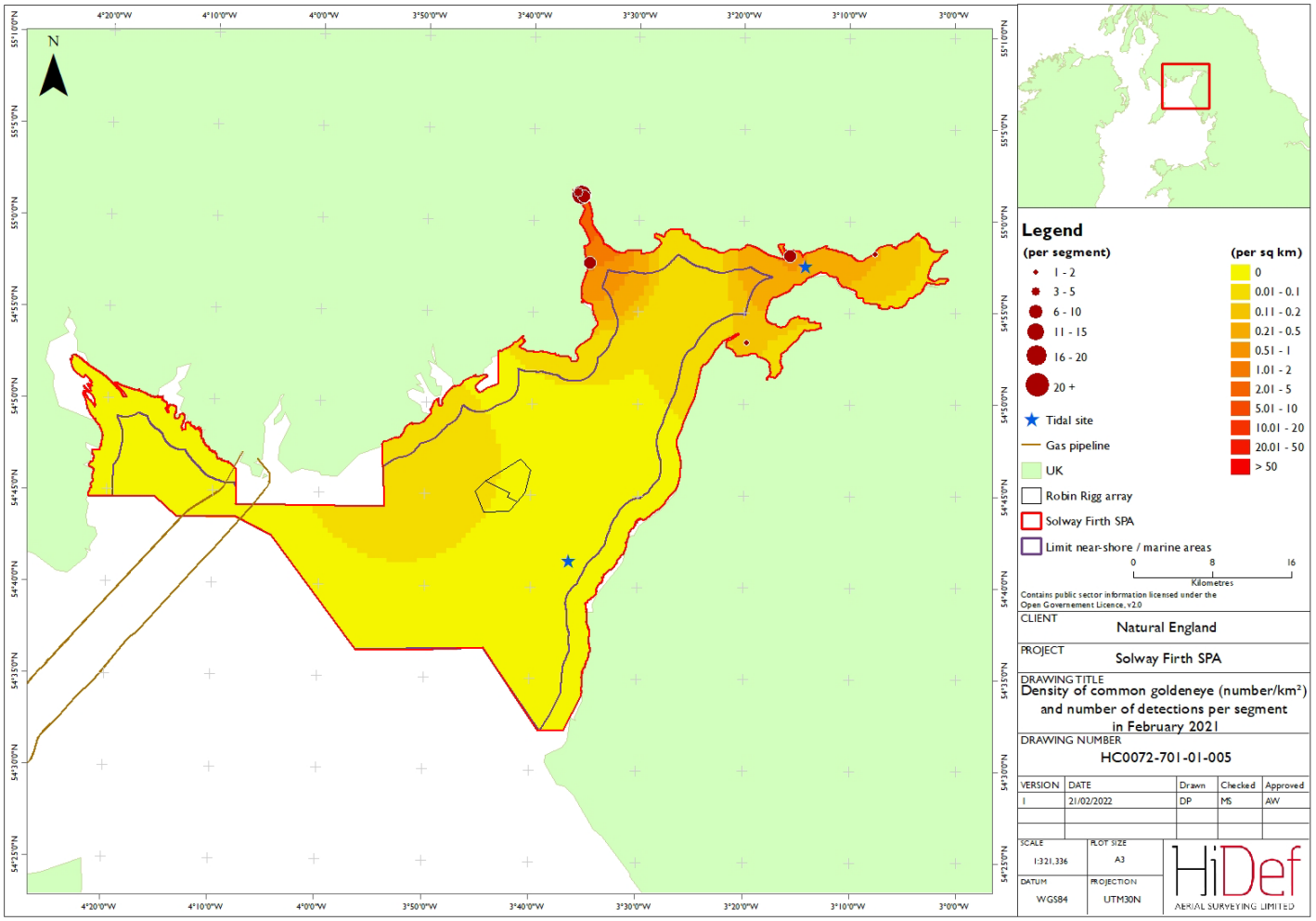


Table 14 Unapportioned and apportioned density and population estimates for common goldeneye in the Solway Firth SPA, the near-shore area and the marine area in February 2021, from digital aerial and shore-based surveys

Survey area	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Unapportioned								
Full SPA	0.20	0.05	0.45	273	69	614	146	66.48
Near-shore area	0.67	0.17	1.52	270	69	611	148	68.23
Marine area	0.00	0.00	0.00	0	0	0	0	0.00
Apportioned								
Full SPA	0.20	0.05	0.47	275	66	642	156	70.33
Near-shore area	0.72	0.18	1.58	288	73	636	156	66.74
Marine area	0.00	0.00	0.00	1	0	1	1	96.41

Figure 13 Density of common goldeneyes (number/km²) and number of detections per segment in the Solway Firth SPA in February 2021



3.3.2.3 Cormorant

88 Within the Solway Firth SPA, the cormorant population was estimated at 1,517 birds (95%CI 1,042 – 2,144).

89 Cormorants were recorded throughout the SPA, present in the near-shore and marine areas (Figure 14). Apportioned density estimates were calculated at 0.50 birds/km^2 (95% CI 0.09 – 1.19) and 0.39 birds/km^2 (95% CI 0 – 1.00) respectively (Table 15). This equated to a population estimate for the near-shore area of 1,139 (95% CI 973 – 1,418) birds.

90 All observations of cormorants from shore-based surveys were recorded at Workington Harbour Wall, occurring on the 10th and 11th of February 2021 (Table 22).

91 During the digital aerial survey, birds were predominately distributed to the south of the SPA, along the Cumbrian coast between Maryport and Whitehaven, with the highest densities found within the near-shore area (Figure 15).

92 Within the SPA, most birds (62%) were recorded flying, with 38% recorded as sitting on the water. In the near-shore area, 95% of birds were recorded sitting on the water while in the marine area, 91% of birds were recorded flying, with only seven birds recorded as sitting on the water (Table 23 to Table 25).

Figure 14 Number of cormorants recorded within the Solway Firth SPA, the near-shore area and the marine area from digital aerial survey and shore-based counts

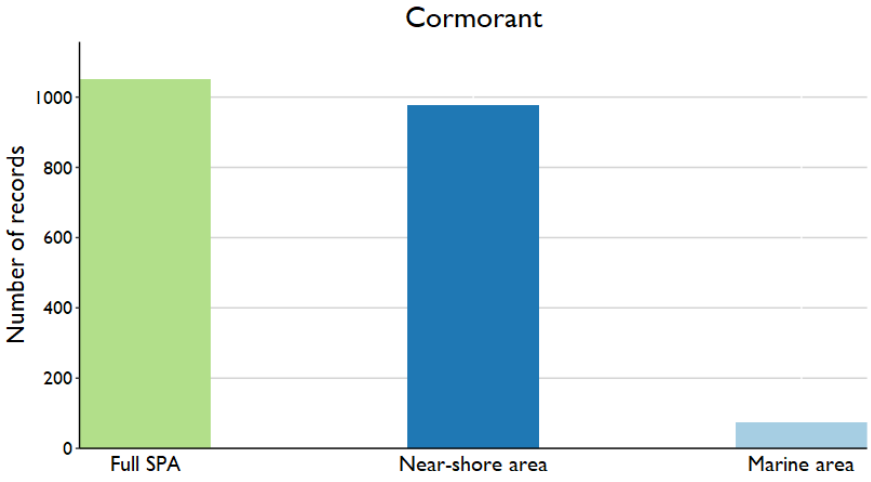
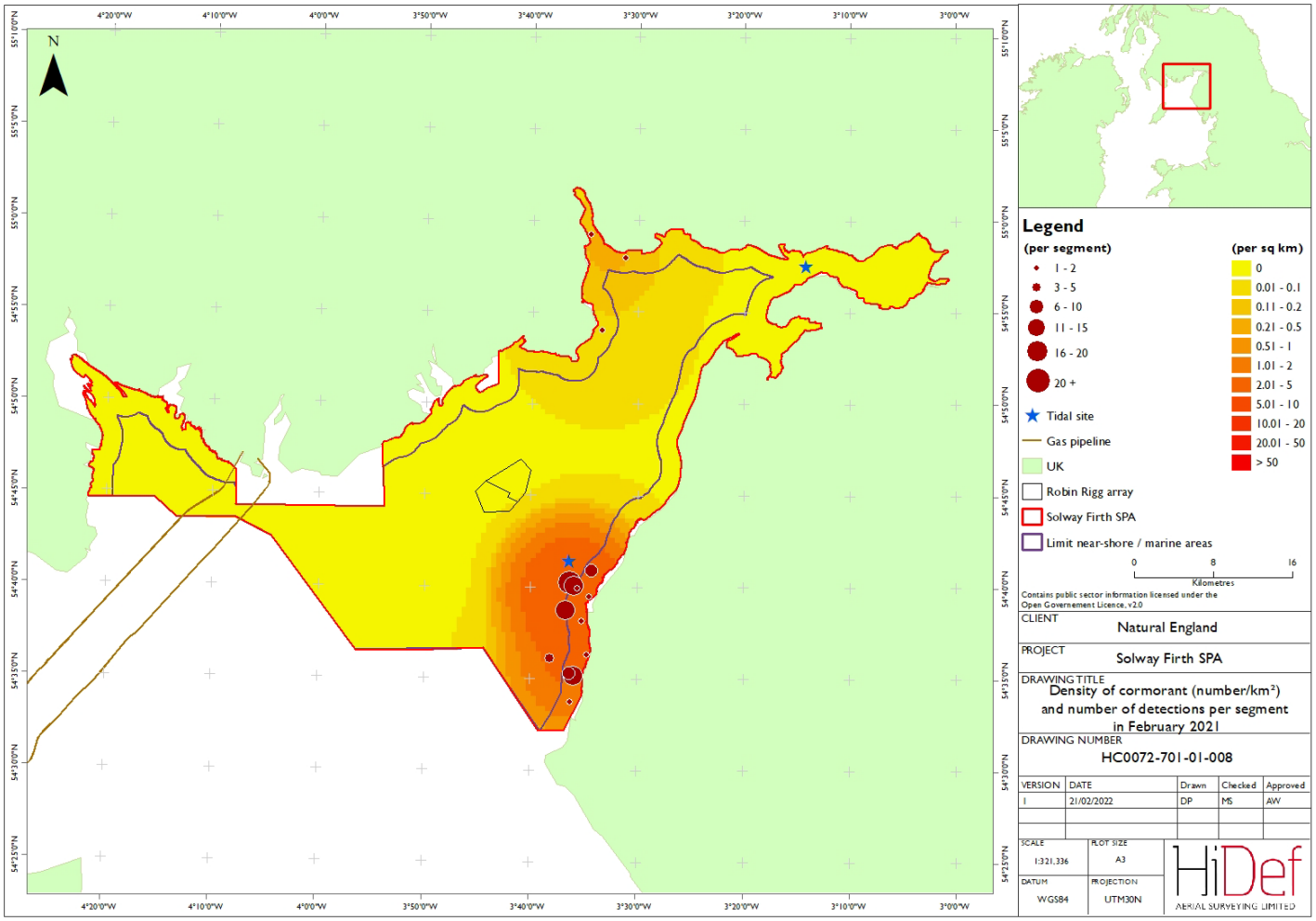


Table 15 Unapportioned and apportioned density and population estimates for cormorant in the Solway Firth SPA, the near-shore area and the marine area in February 2021, from digital aerial and shore-based surveys

Survey area	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Unapportioned								
Full SPA	0.80	0.46	1.25	1089	624	1700	275	49.00
Near-shore area	1.82	1.40	2.55	731	563	1025	124	60.96
Marine area	0.40	0.02	0.95	384	24	912	250	65.07
Apportioned								
Full SPA	0.82	0.47	1.28	1108	633	1735	288	49.55
Near-shore area	1.82	1.40	2.51	730	564	1009	127	62.98
Marine area	0.39	0.00	1.00	371	0	955	253	67.99

Figure 15 Density of cormorants (number/km²) and number of detections per segment in the Solway Firth SPA in February 2021



3.3.3 Supplemental species

3.3.3.1 Black-headed gull

93 Within the Solway Firth SPA, the black-headed gull population was estimated at 2,389 birds (95%CI 243 – 7,450).

94 Black-headed gulls were recorded throughout the SPA, primarily distributed within the near-shore area (Figure 16). Apportioned densities were calculated at 5.81 birds/km^2 (95% CI 0.59 – 15.1) and 0.05 birds/km^2 (95% CI 0.01– 0.10) respectively (Table 16).

95 Birds were mainly distributed to the northeast of the SPA, with the highest densities found within the near-shore area of the SPA (Figure 17). Few birds were observed to the south of the SPA, towards the mouth of the estuary.

96 Within the SPA, most birds (76%) were recorded as sitting on the water. In the near-shore area, 78% of birds were recorded sitting on the water while in the marine area, 100% of birds were recorded as flying (Table 23 to Table 25).

Figure 16 Number of black-headed gulls recorded within the Solway Firth SPA, the near-shore area and the marine area from digital aerial survey

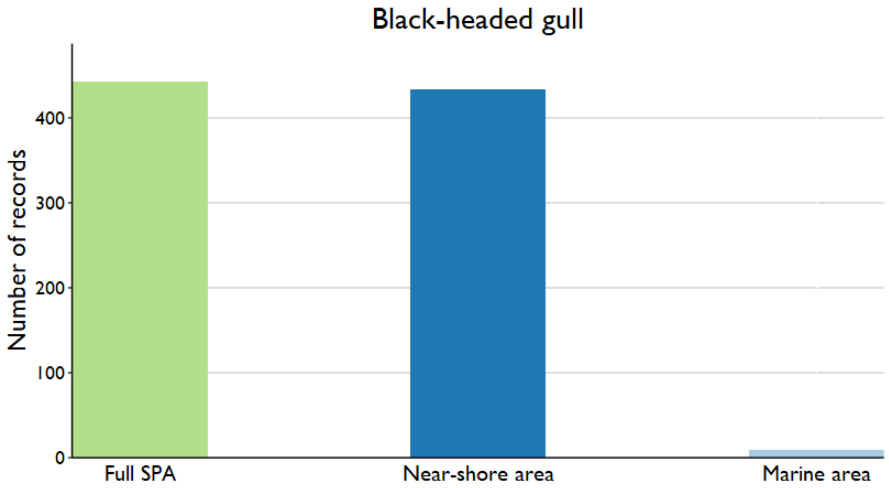
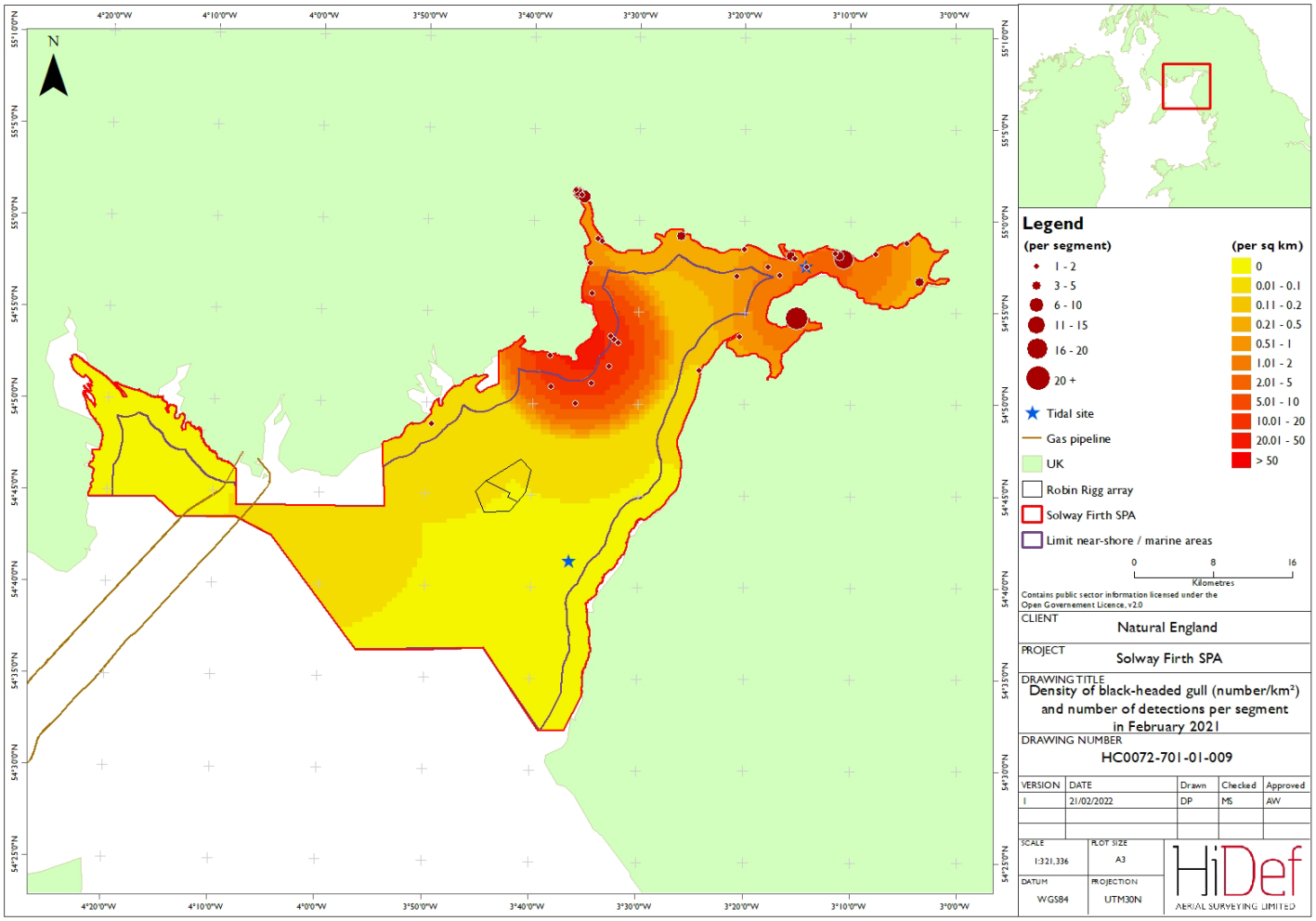


Table 16 Unapportioned and apportioned density and population estimates for black-headed gull in the Solway Firth SPA, the near-shore area and the marine area in February 2021

Survey area	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Unapportioned								
Full SPA	1.65	0.14	4.46	2240	185	6054	1856	82.88
Near-shore area	5.41	0.55	14.58	2178	221	5861	1780	81.71
Marine area	0.05	0.01	0.09	46	10	90	21	45.42
Apportioned								
Full SPA	1.76	0.18	5.49	2389	243	7450	1877	78.55
Near-shore area	5.81	0.59	15.1	2338	239	6070	1811	77.43
Marine area	0.05	0.01	0.1	48	13	94	22	44.32

Figure 17 Density of black-headed gulls (number/km²) and number of detections per segment in the Solway Firth SPA in February 2021



3.3.3.2 Common gull

97 Within the Solway Firth SPA, the common gull population was estimated at 5,219 birds (95% CI 2,594 – 8,819).

98 Common gulls were recorded in relatively high numbers compared to other species (Figure 18). Apportioned densities were calculated at 9.97 birds/km^2 (95% CI 3.72 – 18.22) and 1.37 birds/km^2 (95% CI 0.92 – 1.84) for the near-shore and marine areas respectively (Table 17), equating to a population estimate for the near-shore area of 4,008 birds (95% CI 1,498 – 7,328).

99 Birds were distributed throughout the survey area, with the highest densities found to the north, in the Inner Solway Firth, towards Bowness-on-Solway (Figure 19).

100 Within the SPA, 64% of birds were recorded sitting on the water. In the near-shore area, 87% of birds were recorded sitting on the water, while in the marine area, 87% of birds were recorded flying (Table 23 to Table 25).

Figure 18 Number of common gulls recorded within the Solway Firth SPA, the near-shore area and the marine area from digital aerial survey

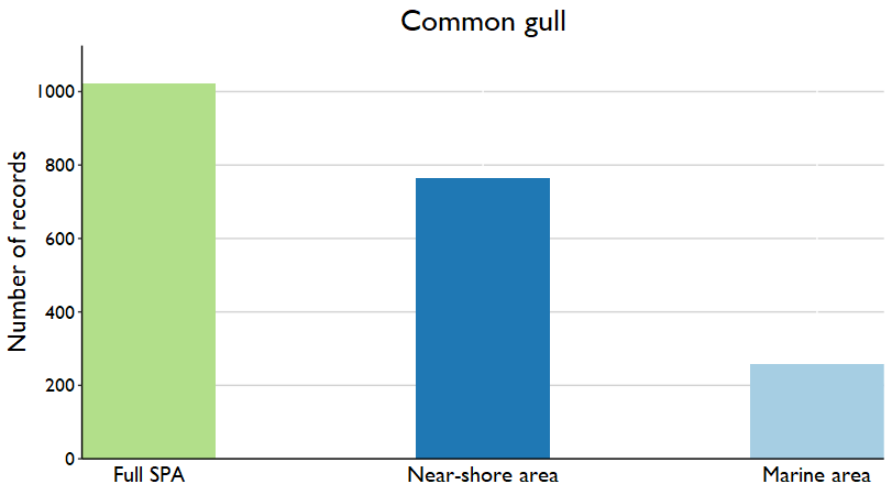
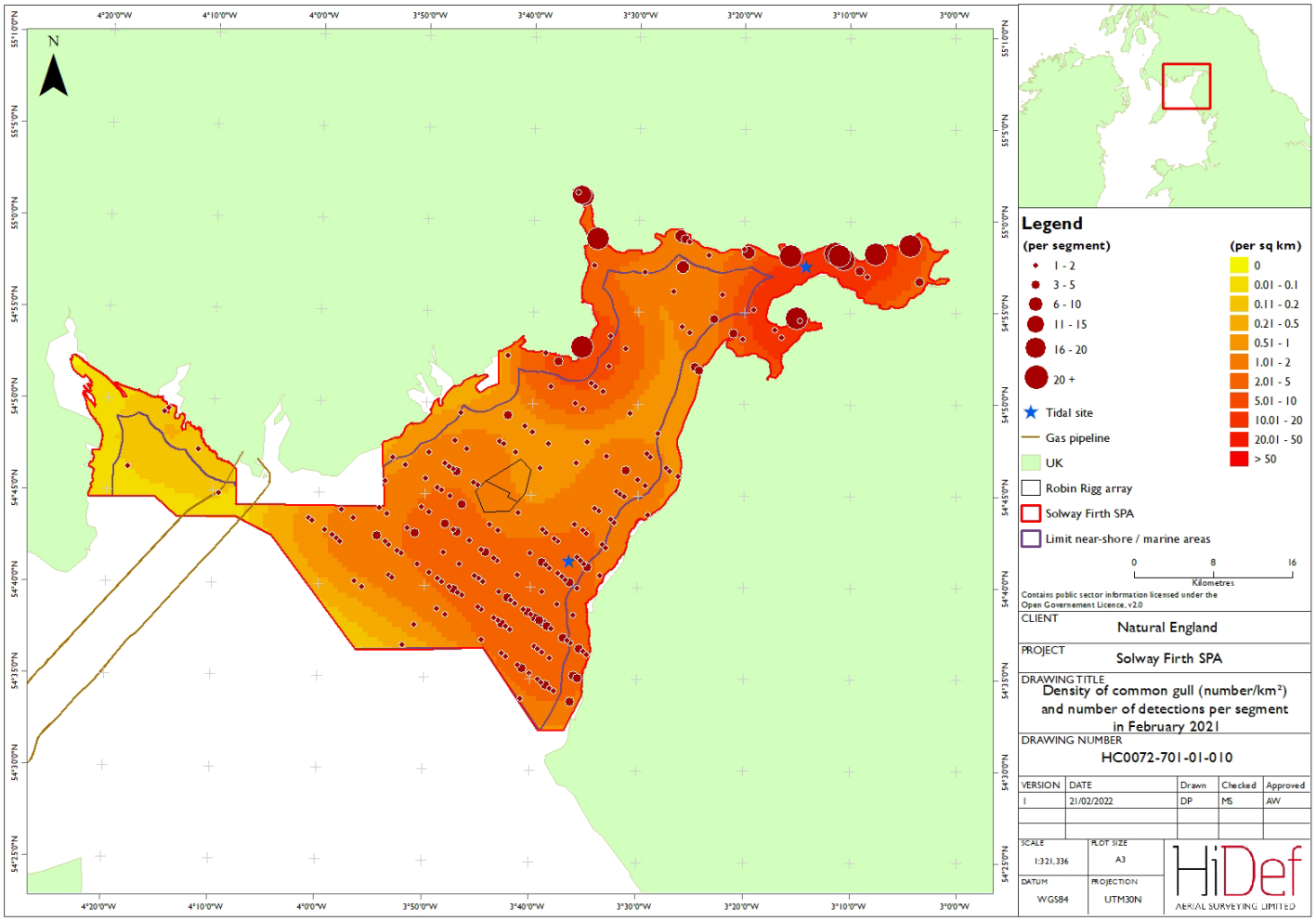


Table 17 Unapportioned and apportioned density and population estimates for common gull in the Solway Firth SPA, the near-shore area and the marine area in February 2021

Survey area	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Unapportioned								
Full SPA	3.7	1.82	6.36	5029	2469	8638	1552	30.86
Near-shore area	9.65	3.55	18.58	3882	1429	7472	1557	40.10
Marine area	1.35	0.87	1.83	1286	834	1754	231	17.92
Apportioned								
Full SPA	3.84	1.91	6.5	5219	2594	8819	1614	30.92
Near-shore area	9.97	3.72	18.22	4008	1498	7328	1542	38.46
Marine area	1.37	0.92	1.84	1306	878	1761	229	17.51

Figure 19 Density of common gull (number/km²) and number of detections per segment in the Solway Firth SPA in February 2021



3.3.3.3 Great black-backed gull

101 Within the Solway Firth SPA, the great black-backed gull population was estimated at 142 birds (95%CI 80 – 214).

102 Great black-backed gulls were recorded in moderate numbers compared to other gull species (Figure 21). Higher densities were calculated for the near-shore area compared to the marine area, with apportioned densities equating to 0.21 birds/km^2 (95% CI 0.09 – 0.36) and 0.06 birds/km^2 (95% CI 0.02 – 0.12) respectively. The population estimate for the near-shore area was calculated at 84 birds (95% CI 36 – 144; Table 18)

103 Birds were detected throughout the SPA, with many birds distributed to the north and southeast (Figure 21).

104 Within the SPA, 61% of birds were recorded sitting on the water. In the near-shore area, 73% of birds were recorded sitting on the water while in the marine area, proportions were roughly equal (Table 23 to Table 25).

Figure 20 Number of great black-backed gulls recorded within the Solway Firth SPA, the near-shore area and the marine area from digital aerial survey

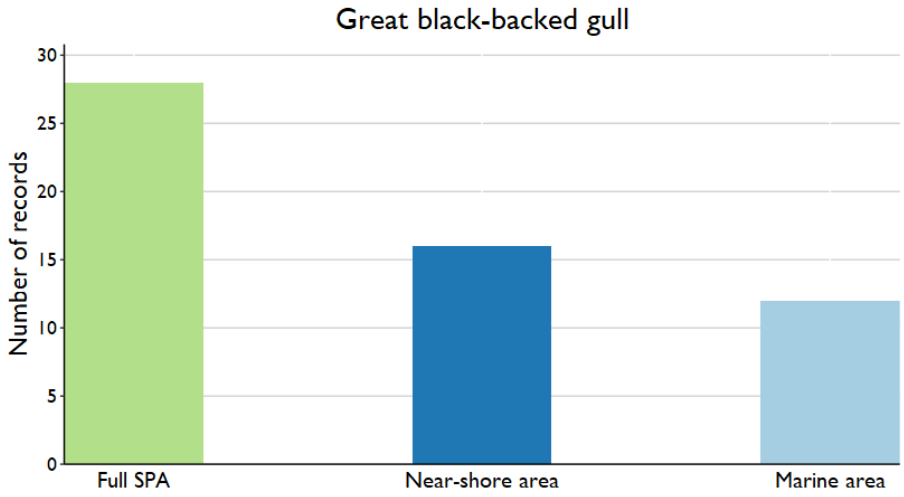
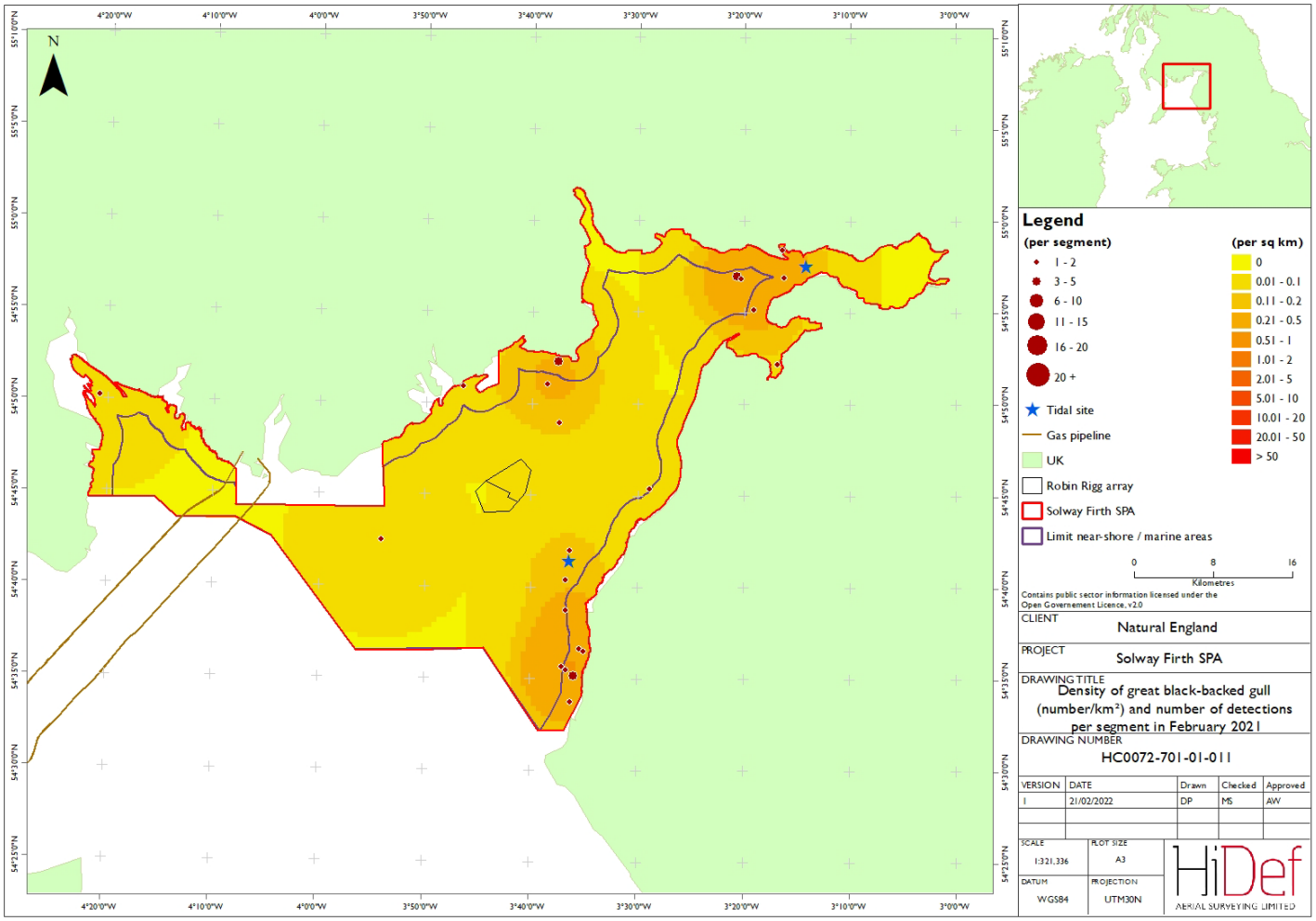


Table 18 Unapportioned and apportioned density and population estimates for great black-backed gull in the Solway Firth SPA, the near-shore area and the marine area in February 2021

Survey area	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Unapportioned								
Full SPA	0.10	0.06	0.16	143	81	220	36	24.99
Near-shore area	0.21	0.09	0.35	83	35	141	28	33.38
Marine area	0.06	0.02	0.12	62	20	117	25	38.98
Apportioned								
Full SPA	0.10	0.06	0.16	142	80	214	35	24.52
Near-shore area	0.21	0.09	0.36	84	36	144	27	32.39
Marine area	0.06	0.02	0.12	61	20	115	25	40.43

Figure 21 Density of great black-backed gull (number/km²) and number of detections per segment in the Solway Firth SPA in February 2021



3.3.3.4 Herring gull

105 Within the Solway Firth SPA, the herring gull population was estimated at 542 birds (95%CI 309 – 830).

106 Herring gulls were recorded across the SPA, with more birds recorded in the near-shore area than the marine area (Figure 22). Apportioned densities were calculated at 0.93 birds/km^2 (95% CI 0.46 – 1.57) and 0.19 birds/km^2 (95% CI 0.11 – 0.28) respectively (Table 19). Population estimates for the near-shore area were calculated at 375 birds (95% CI 184 – 634).

107 Birds were detected throughout the survey area, with the highest densities found in the near-shore area, to the northwest and southwest of the SPA (Figure 23).

108 Within the SPA, 66% of birds were recorded flying. In the near-shore area, 57% of birds were recorded flying with while in the marine area, 85% of birds were recorded flying (Table 23 to Table 25).

Figure 22 Number of herring gulls recorded within the Solway Firth SPA, the near-shore area and the marine area from digital aerial survey

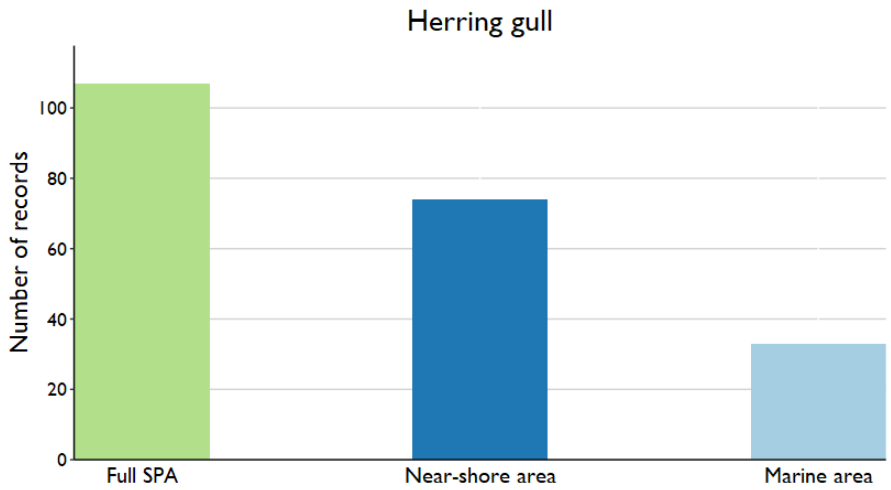
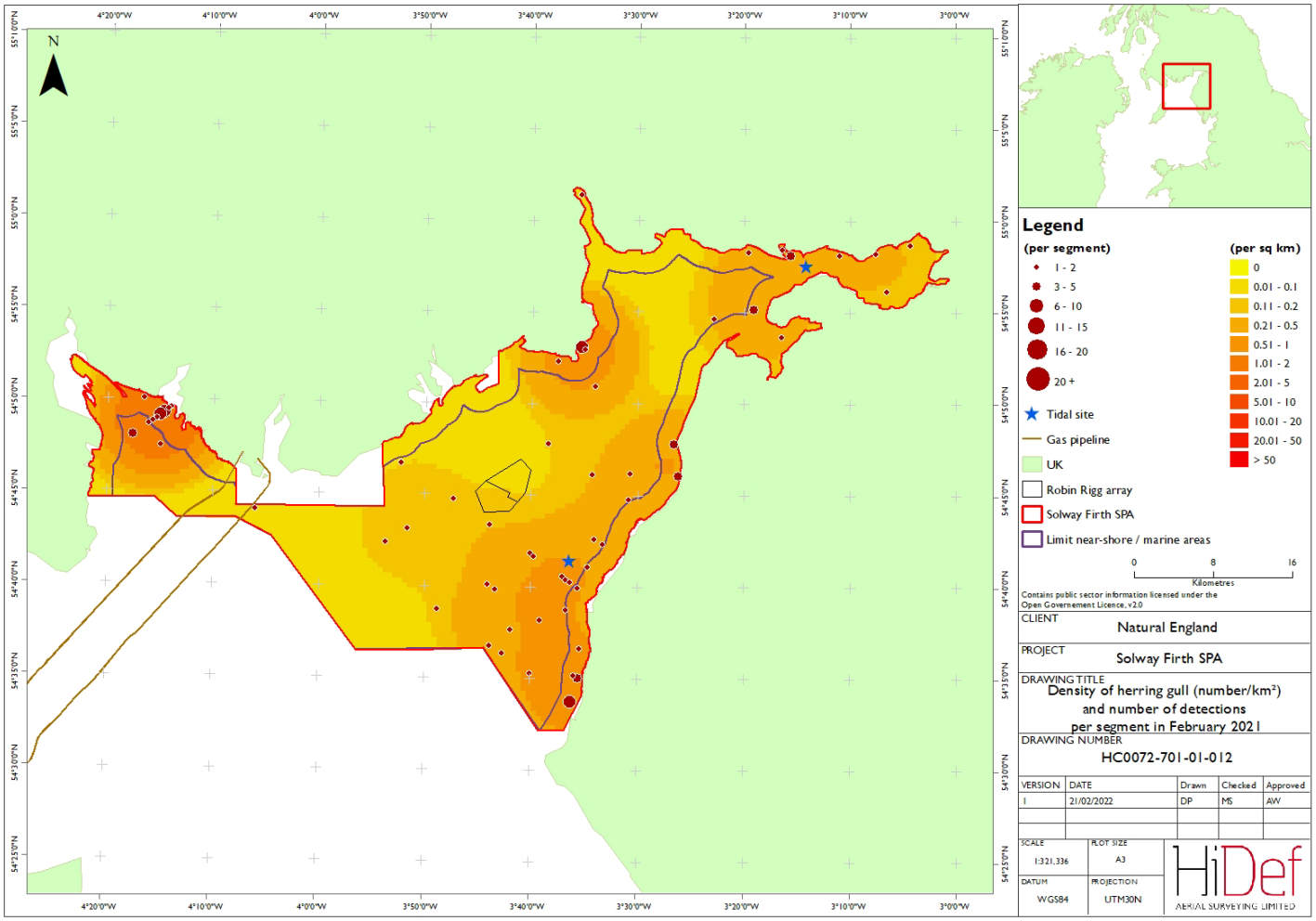


Table 19 Unapportioned and apportioned density and population estimates for herring gull in the Solway Firth SPA, the near-shore area and the marine area in February 2021

Survey area	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Unapportioned								
Full SPA	0.39	0.23	0.61	531	309	826	135	25.28
Near-shore area	0.91	0.44	1.55	368	177	625	116	31.35
Marine area	0.18	0.10	0.29	175	96	273	45	25.55
Apportioned								
Full SPA	0.40	0.23	0.61	542	309	830	138	25.37
Near-shore area	0.93	0.46	1.57	375	184	634	114	30.26
Marine area	0.19	0.11	0.28	178	101	269	43	24.20

Figure 23 Density of herring gulls (number/km²) and number of detections per segment in the Solway Firth SPA in February 2021



3.3.3.5 Guillemot

109 Within the Solway Firth SPA, the guillemot population was estimated at 4,380 birds (95%CI 2,343 – 6,769).

110 Guillemots were recorded across the SPA, with more records present in the marine area than the near-shore area (Figure 24). When accounting for birds underwater at the time of the survey, apportioned densities were calculated at 4.40 birds/km^2 (95% CI 2.55 – 6.40) and 0.41 birds/km^2 (95% CI 0.16 – 0.72) respectively, equating to a population estimate in the marine area of 4,205 birds (95% CI 2,437 – 6,121) (Table 20).

111 Birds were detected throughout the SPA, with the highest densities found south of the Robin Rigg array (Figure 25).

112 As is expected for the species, 97% of birds were recorded as sitting on the water. Proportions of sitting birds was similar between the two stratified survey areas, with 100% and 97% of birds recorded as sitting on the water in the near-shore and marine areas respectively (Table 23 to Table 25).

Figure 24 Number of guillemots recorded within the Solway Firth SPA, the near-shore area and the marine area from digital aerial survey

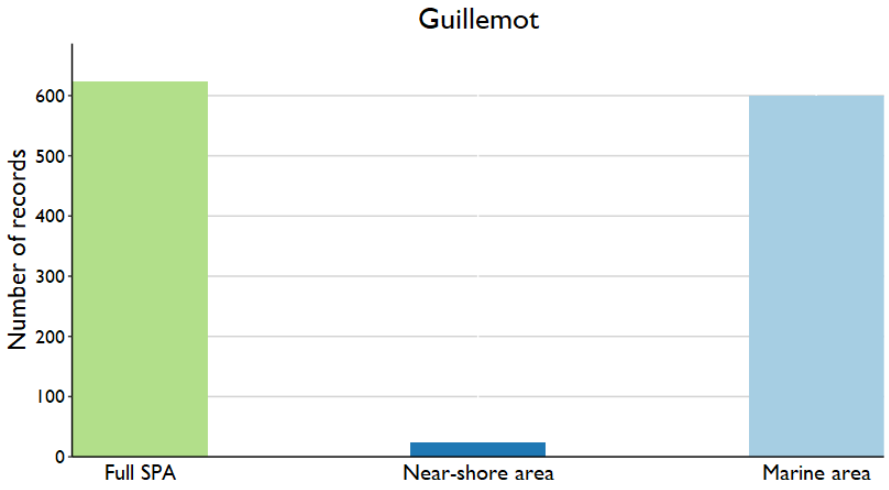
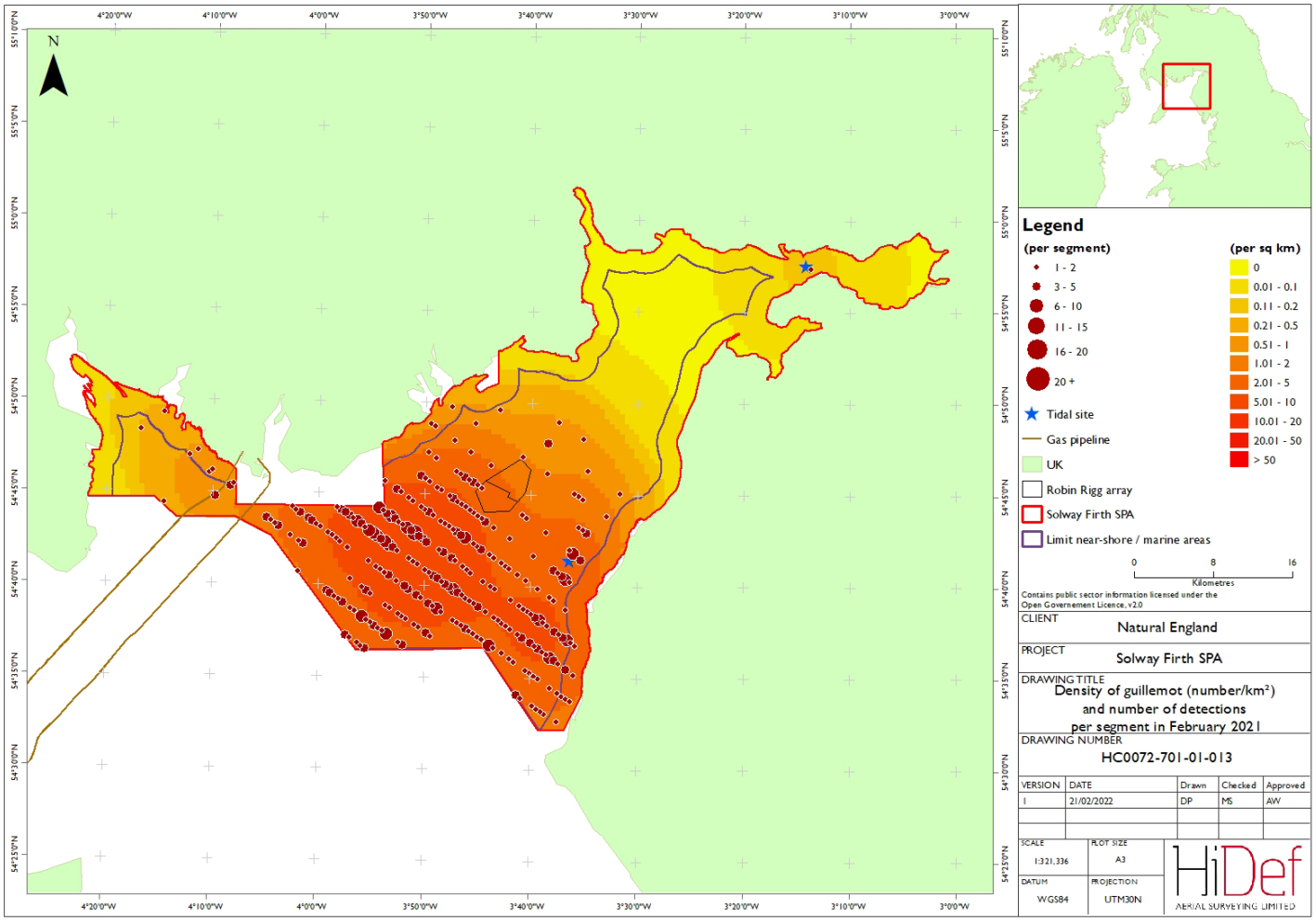


Table 20 **Unapportioned and apportioned absolute density and population estimates for guillemot in the Solway Firth SPA, the near-shore area and the marine area in February 2021, taking into account the potential number of birds as being unavailable for detection**

Survey area	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Unapportioned								
Full SPA	3.03	1.43	4.96	4108	1940	6730	1182	28.77
Near-shore area	0.39	0.14	0.68	157	59	274	60	38.22
Marine area	4.09	2.29	6.03	3907	2198	5761	973	24.9
Apportioned								
Full SPA	3.23	1.73	4.99	4380	2343	6769	1214	27.72
Near-shore area	0.41	0.16	0.72	167	66	294	63	37.72
Marine area	4.40	2.55	6.40	4205	2437	6121	1057	25.14

Figure 25 Density of guillemots (number/km²) and number of detections per segment in the Solway Firth SPA in February 2021



3.3.3.6 Razorbill

113 Within the Solway Firth SPA, the razorbill population was estimated at 637 birds (95%CI 286 – 1,059).

114 Razorbills were recorded across the SPA, with more birds recorded in the marine area than in the near-shore area (Figure 26). When accounting for birds likely to be underwater at the time of the survey, apportioned densities were calculated at 0.61 birds/km^2 (95% CI 0.32 – 0.97) and 0.11 birds/km^2 (95% CI 0.00 – 0.31) for the marine and near-shore areas respectively, equating to a population estimate for the marine area of 590 birds (95% CI 309 – 924; Table 21).

115 Birds were detected throughout the SPA, with the highest densities found in the centre of the SPA in the marine area, south of the Robin Rigg array (Figure 27).

116 Similar to guillemot, the majority of birds (97%) were recorded as sitting on the water. In the near-shore area, 86% of birds were recorded as sitting on the water, while in the marine area, 98% of birds were recorded as sitting on the water (Table 23 to Table 25).

Figure 26 Number of razorbills recorded within the Solway Firth SPA, the near-shore area and the marine area from digital aerial survey

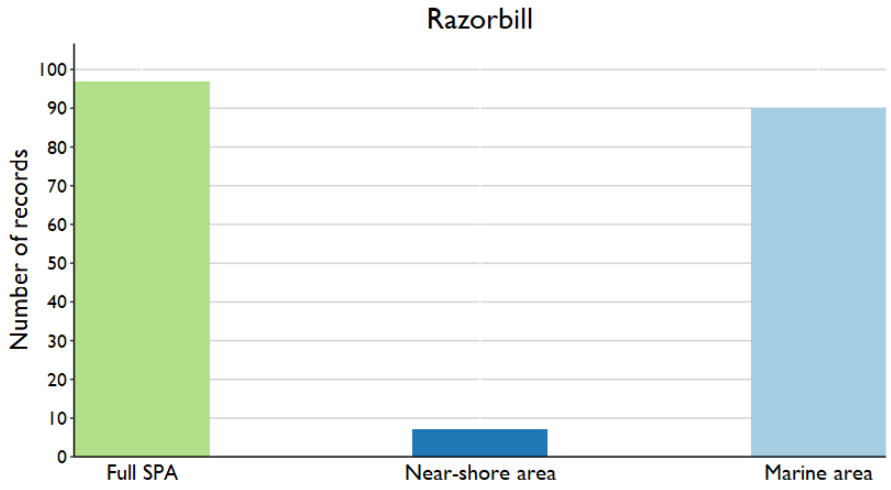
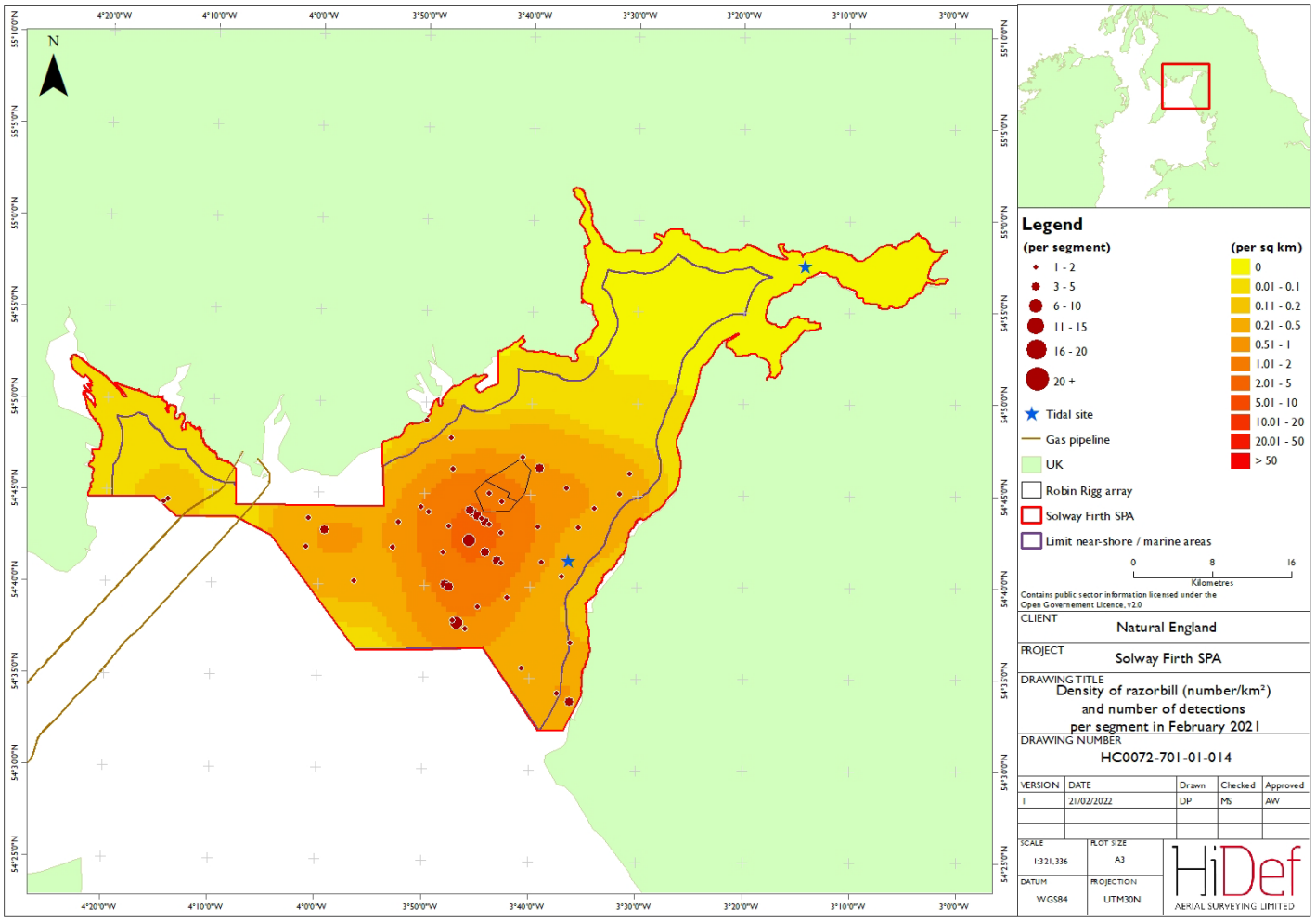


Table 21 Unapportioned and apportioned absolute density and population estimates for razorbill in the Solway Firth SPA, the near-shore area and the marine area in February 2021, taking into account the potential number of birds as being unavailable for detection

Survey area	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Unapportioned								
Full SPA	0.44	0.18	0.71	595	253	975	208	34.96
Near-shore area	0.10	0.00	0.30	41	0	121	37	90.24
Marine area	0.57	0.27	0.95	545	262	896	178	32.66
Apportioned								
Full SPA	0.46	0.21	0.78	637	286	1059	214	33.59
Near-shore area	0.11	0.00	0.31	44	1	125	37	84.09
Marine area	0.61	0.32	0.97	590	309	924	175	29.66

Figure 27 Density of razorbills (number/km²) and number of detections per segment in the Solway Firth SPA in February 2021



3.4 Shore-based surveys

117 Shore-based data collected between 10th and 15th February 2021 are compared to digital aerial survey data from 11th February 2021 in this section. Focal counts for three species (common goldeneye, goosander and cormorant) were conducted during shore-based surveys at six locations along the Cumbrian coast, within the SPA boundary.

118 It is important to note that in some locations, shore-based counts took place on different days to the digital aerial survey. For a full breakdown of dates and times of shore-based counts please refer to Appendix III: Shore-based count data. It should also be acknowledged that digital aerial surveys did not include birds on roosts, such as cormorants, only individuals present on/above the water.

119 The distributions of the three species of interest from shore-based surveys are presented in Figure 28. Generally, cormorants were distributed to the south of the survey area along the Cumbrian coast, compared to goosander which were primarily present to the north in the inner Solway Firth. Most common goldeneye observations were located within the near-shore area to the north, along the Scottish coast.

120 For comparison, 2km buffers were placed around shore-based survey locations, as this was deemed to be the maximum distance at which birds can be correctly identified to species level during shore-based surveys. Observations from the digital aerial surveys falling within these buffers are displayed in Figure 28 and Figure 29 and a comparison of species identified at each location by the two methods is presented in Table 22. Only species included in shore-based counts (common goldeneye, goosander and cormorant) are presented.

121 Common goldeneye were not recorded within shore-based survey 2km buffers during the digital aerial survey, however they were recorded at River Esk/Eden in shore-based surveys. At all locations, more birds were recorded using shore-based rather than digital aerial surveys.

122 To derive population estimates using data from survey methods while minimising the chance of double counting, only peak counts for each species at each shore-based site were added to digital aerial data. These combined population estimates can be found in the relevant species section.

Figure 28 **Observations of common goldeneye, goosander and cormorant from the digital aerial survey 11th February 2021, in addition to shore-based survey locations**

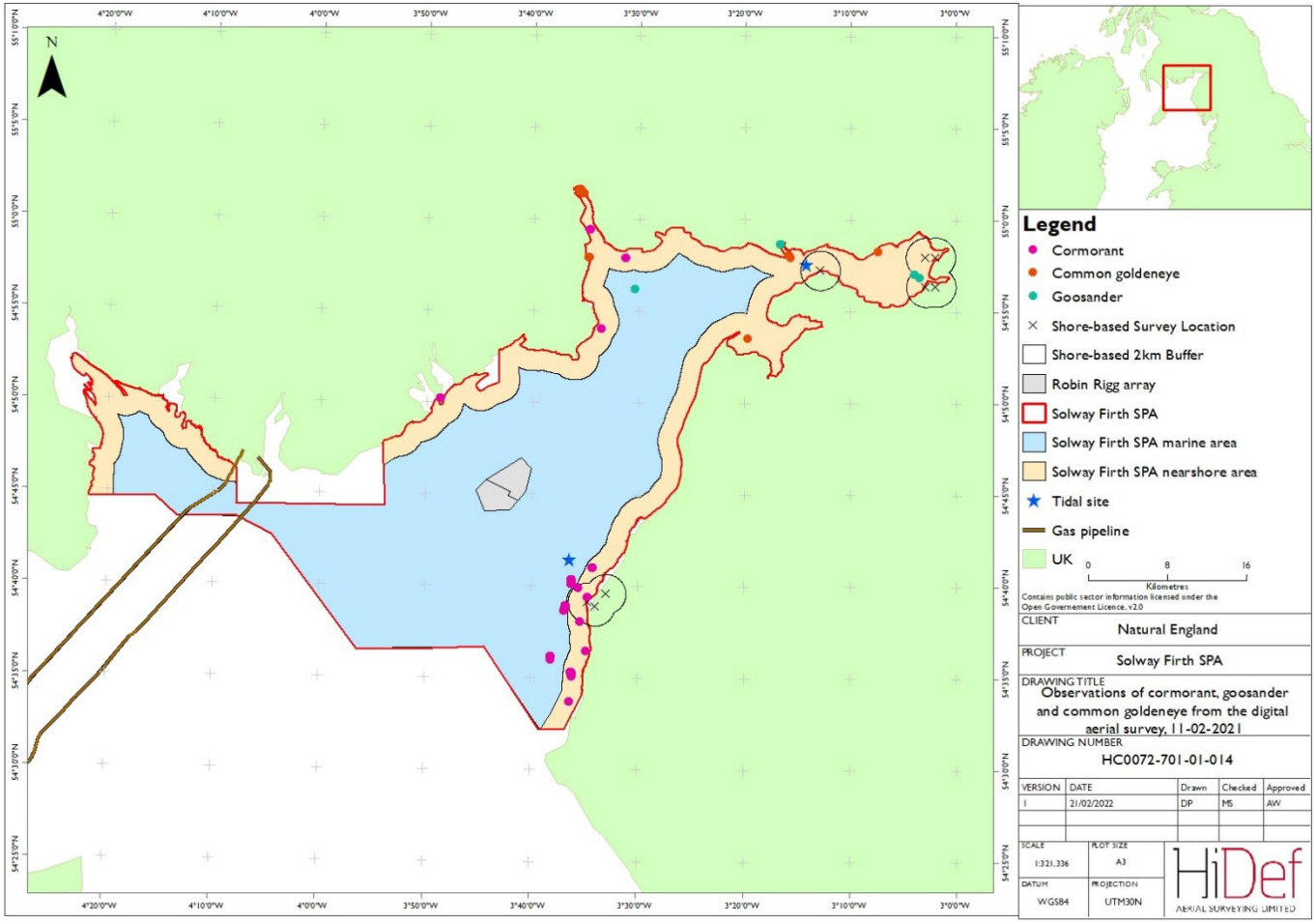


Figure 29 Observations from digital aerial survey falling within shore-based 2km survey buffers, 11th February 2021

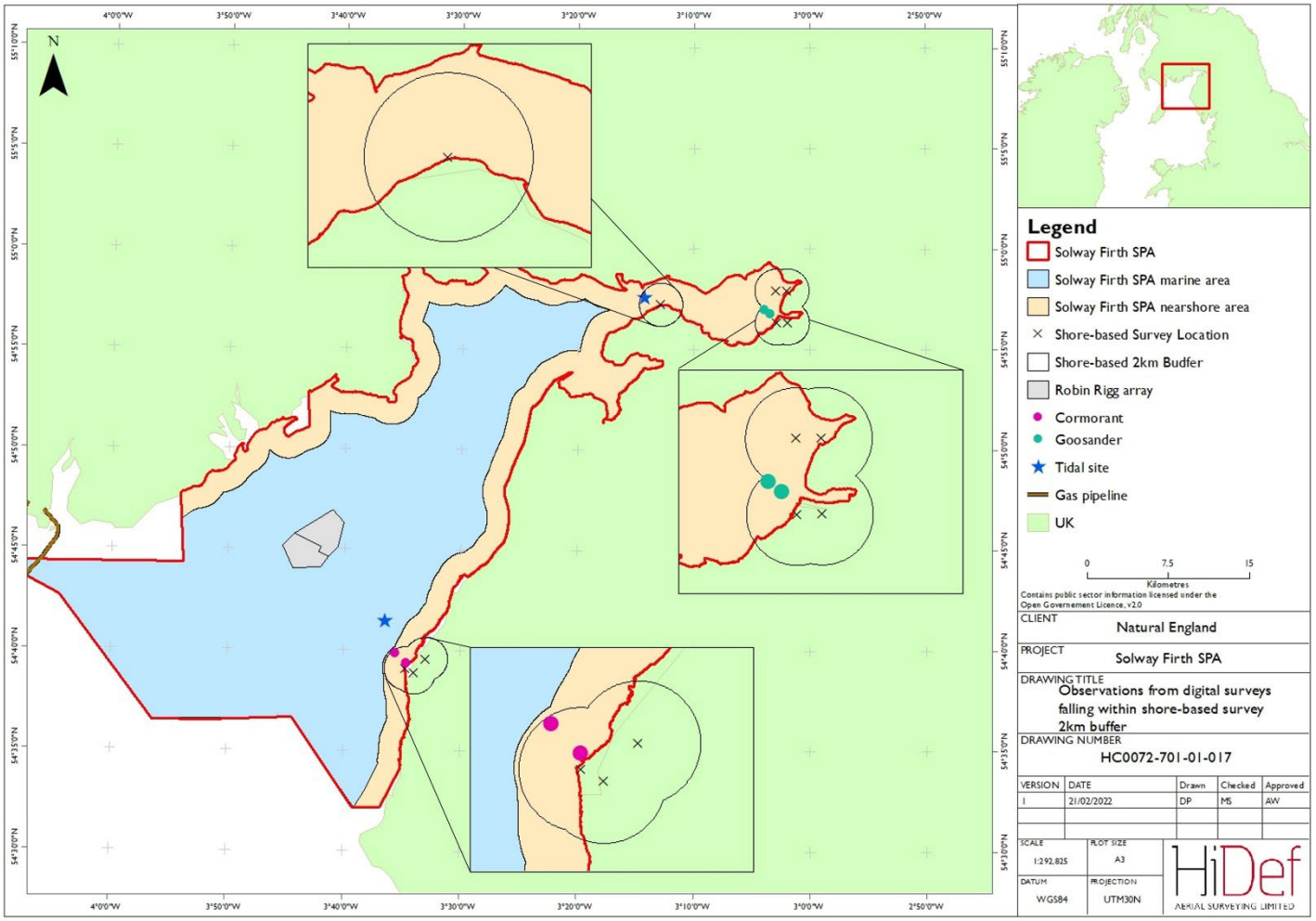


Table 22 Numbers of observations of species from digital aerial and shore-based surveys within 2km buffer of shore-based locations. Observations from shore-based surveys occurring between 10th and 15th February at each site have been summed.

Species	Workington (all sites)	Bowness-on-Solway	River Esk/Eden	Total
Digital aerial				
Common goldeneye	0	0	0	0
Goosander	–	–	28	28
Cormorant	107	–	–	107
Shore-based				
Common goldeneye	0	0	93	93
Goosander	111	0	9	120
Cormorant	937	0	0	937
Total	**1299**	**201**	**403**	**1903**

Note: Due to proximity of survey locations, some 2km buffers overlap. Workington Harbour (Inner), Workington Harbour Wall and Siddick pond have been combined and presented as Workington (all sites). River Esk and River Eden sites have also been combined and are presented together as summed counts. See Figure 28 for buffer locations.

3.5 Bird behaviour

123 The behaviour of birds recorded within the full SPA, the near-shore and the marine area are presented in Table 23 to Table 25. The ratios of flying and sitting birds are also presented.

Table 23 Behaviour of birds recorded within the Solway Firth SPA in February 2021

Species	Diving	Flying	Sitting	Taking Off	Flying (%)	Sitting (%)	Total
Barnacle goose	0	2050	0	0	100	0	2050
Pink-footed goose	0	4	0	0	100	0	4
Shelduck	0	55	195	0	22	78	250
Wigeon	0	73	1599	0	4	96	1672
Mallard	0	2	345	0	1	99	347
Pintail	0	0	362	0	0	100	362
Teal	0	0	803	0	0	100	803
Scaup	0	0	159	0	0	100	159
Common scoter	0	64	5818	4	1	99	5886
Goldeneye	0	0	44	0	0	100	44
Goosander	0	0	15	0	0	100	15
Great crested grebe	0	0	1	0	0	100	1
Oystercatcher	0	328	27	0	92	8	355
Lapwing	0	3	0	0	100	0	3
Grey plover	0	13	0	0	100	0	13
Ringed plover	0	1	0	0	100	0	1
Curlew	0	1061	0	0	100	0	1061
Bar-tailed godwit	0	47	0	0	100	0	47
Turnstone	0	4	0	0	100	0	4

Species	Diving	Flying	Sitting	Taking Off	Flying (%)	Sitting (%)	Total
Knot	0	255	0	0	100	0	255
Sanderling	0	1	0	0	100	0	1
Dunlin	0	3533	3	0	100	0	3536
Redshank	0	2	1	0	67	33	3
Greenshank	0	0	0	0	0	0	0
Kittiwake	0	4	1	0	80	20	5
Black-headed gull	0	69	218	0	24	76	287
Common gull	0	293	529	3	36	64	825
Great black-backed gull	0	9	14	0	39	61	23
Herring gull	0	66	34	0	66	34	100
Lesser black-backed gull	0	4	1	0	80	20	5
Guillemot	0	19	605	0	3	97	624
Razorbill	0	3	94	0	3	97	97
Black guillemot	0	0	1	0	0	100	1
Red-throated diver	0	2	178	0	1	99	180
Shag	0	2	3	0	40	60	5
Cormorant	0	70	43	0	62	38	113
Grey heron	0	0	0	0	0	0	0
Carrion crow	0	8	0	0	100	0	8

Table 24 Behaviour of birds recorded within the near-shore area in February 2021

Species	Diving	Flying	Sitting	Taking Off	Flying (%)	Sitting (%)	Total
Barnacle goose	0	2050	0	0	100	0	2050
Pink-footed goose	0	4	0	0	100	0	4
Shelduck	0	55	195	0	22	78	250
Wigeon	0	73	1599	0	4	96	1672
Mallard	0	2	345	0	1	99	347
Pintail	0	0	362	0	0	100	362
Teal	0	0	803	0	0	100	803
Scaup	0	0	159	0	0	100	159
Common scoter	0	33	932	0	3	97	965
Goldeneye	0	0	44	0	0	100	44
Goosander	0	0	14	0	0	100	14
Oystercatcher	0	328	27	0	92	8	355
Lapwing	0	3	0	0	100	0	3
Grey plover	0	13	0	0	100	0	13
Ringed plover	0	1	0	0	100	0	1
Curlew	0	1061	0	0	100	0	1061
Bar-tailed godwit	0	47	0	0	100	0	47
Turnstone	0	4	0	0	100	0	4
Knot	0	255	0	0	100	0	255

Species	Diving	Flying	Sitting	Taking Off	Flying (%)	Sitting (%)	Total
Sanderling	0	1	0	0	100	0	1
Dunlin	0	3533	3	0	100	0	3536
Redshank	0	2	1	0	67	33	3
Greenshank	0	0	0	0	0	0	0
Kittiwake	0	1	0	0	100	0	1
Black-headed gull	0	60	218	0	22	78	278
Common gull	0	69	496	3	12	87	568
Great black-backed gull	0	3	8	0	27	73	11
Herring gull	0	38	29	0	57	43	67
Lesser black-backed gull	0	2	1	0	67	33	3
Guillemot	0	0	24	0	0	100	24
Razorbill	0	1	6	0	14	86	7
Black guillemot	0	0	1	0	0	100	1
Red-throated diver	0	0	37	0	0	100	37
Shag	0	1	3	0	25	75	4
Cormorant	0	2	36	0	5	95	38
Grey heron	0	0	0	0	0	0	0
Carrion crow	0	8	0	0	100	0	8

Table 25 Behaviour of birds recorded within the marine area in February 2021

Species	Diving	Flying	Sitting	Taking Off	Flying (%)	Sitting (%)	Total
Common scoter	0	31	4886	4	1	99	4921
Goosander	0	0	1	0	0	100	1
Great crested grebe	0	0	1	0	0	100	1
Kittiwake	0	3	1	0	75	25	4
Black-headed gull	0	9	0	0	100	0	9
Common gull	0	224	33	0	87	13	257
Great black-backed gull	0	6	6	0	50	50	12
Herring gull	0	28	5	0	85	15	33
Lesser black-backed gull	0	2	0	0	100	0	2
Guillemot	0	19	581	0	3	97	600
Razorbill	0	2	88	0	2	98	90
Red-throated diver	0	2	141	0	1	99	143
Shag	0	1	0	0	100	0	1
Cormorant	0	68	7	0	91	9	75

4 Conclusions

124 The provision of high-resolution digital aerial video footage provided robust spatial distributions of bird and marine mammal populations in the Solway Firth SPA, off the Dumfries and Galloway and Cumbrian coasts. The survey design allows calculation of repeatable estimates of species spatial abundance, and the digital aerial platform provides a unique, auditable record of species identification.

125 The digital aerial survey recorded a total of 28,928 birds of 38 species and 41 non-avian animals of one species within the SPA. Additionally, 714 birds were partially identified to 10 species groups and four non-avian animals were partially identified to two species groups. An identification rate to species level of 97.57% was achieved throughout the survey. Shore-based surveys recorded 1,150 birds of three species between 10th and 15th February 2021, at six locations along the Cumbrian coast within the SPA boundary.

126 Between the near-shore and marine areas, more animals were recorded in the near-shore area. The most frequently recorded species from the digital aerial survey were dunlins, followed by common scoters. For shore-based surveys, cormorants were the most frequently recorded species, recorded only at Workington Harbour Wall.

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Appendix I: Density and population estimates

127 The density, total estimated population, upper and lower 95% CLs, standard deviation and CV for each species and species group have been calculated using strip transect analysis are presented from the digital aerial survey only. Estimates are presented for the full SPA (Table 26 to Table 28), near-shore area (Table 29 to Table 31) and marine area (Table 32 to Table 34).

128 For population estimates including species recorded during shore-based surveys (greater scaup, common goldeneye, cormorant), please see the relevant species sections in Section 3.3.

Table 26 Abundance estimates of species groups from the digital aerial survey of the Solway Firth SPA, 11th February 2021

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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	109.23	60.00	167.02	148280	81451	226731	37189	25.08
All non-avian animals	0.17	0.10	0.25	230	130	346	57	24.79
Species group								
Goose species	7.50	0.02	21.60	10184	26	29328	8679	85.23
Duck species	39.40	21.98	56.98	53484	29841	77349	12112	22.65
Grebe species	0.00	0.00	0.01	5	0	16	5	95.91
Wader species	54.14	16.30	101.68	73499	22124	138037	30375	41.33
Small gull species	5.21	1.94	9.75	7079	2641	13234	2773	39.17
Black-backed gull species	0.05	0.02	0.08	65	29	110	21	32.44
Large gull species	0.40	0.24	0.64	541	322	870	140	25.87
Gull species	0.36	0.18	0.57	495	245	780	137	27.63
Large auk	2.86	1.46	4.28	3885	1984	5816	961	24.74
Auk species	0.01	0.00	0.02	11	0	25	7	66.74
Auk / small gull	0.01	0.00	0.03	20	0	45	12	57.01
Large auk / diver species	0.02	0.00	0.04	27	5	56	15	54.84
Diver species	0.66	0.43	0.94	900	579	1281	180	19.91
Fulmar / gull species	0.00	0.00	0.01	6	0	16	5	92.84

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Cormorant / shag	0.44	0.10	0.91	592	136	1237	277	46.76
Passerine species	0.05	0.01	0.10	65	15	139	33	50.26
Small bird species	0.07	0.01	0.16	91	10	214	52	57.51
Seal species	0.01	0.00	0.03	16	0	40	11	69.09
Cetacean species	0.15	0.09	0.23	210	121	311	50	23.48
Seal / small cetacean species	0.00	0.00	0.01	5	0	15	5	92.19

Table 27 Unapportioned abundance estimates of species from the digital aerial survey of the Solway Firth SPA, 11th February 2021

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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								
Barnacle goose	7.34	0.01	21.25	9970	10	28853	8408	84.33
Pink-footed goose	0.01	0.00	0.04	20	0	51	15	70.94
Shelduck	1.37	0.32	2.73	1855	437	3702	850	45.78
Wigeon	6.88	0.78	15.16	9344	1053	20582	4890	52.33
Mallard	1.49	0.41	3.01	2025	562	4083	896	44.23
Pintail	1.68	0.14	3.74	2279	194	5075	1259	55.25
Teal	4.49	1.01	9.53	6093	1378	12932	2928	48.06
Scaup	0.57	0.00	1.71	777	0	2328	725	93.27
Common scoter	21.62	8.03	36.57	29355	10908	49648	9954	33.91
Goldeneye	0.16	0.01	0.41	219	15	560	146	66.48
Goosander	0.05	0.00	0.15	74	0	210	63	84.36
Great crested grebe	0.00	0.00	0.01	5	0	16	6	104.51
Oystercatcher	12.86	2.87	26.14	17455	3898	35491	8124	46.54
Lapwing	0.01	0.00	0.03	15	0	41	12	74.99
Grey plover	0.14	0.00	0.38	189	0	520	139	73.10
Ringed plover	0.00	0.00	0.01	6	0	16	5	98.63
Curlew	4.35	1.00	8.86	5905	1356	12023	2791	47.27

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Bar-tailed godwit	0.19	0.02	0.47	263	25	645	162	61.51
Turnstone	0.01	0.00	0.04	20	0	60	20	96.97
Knot	1.79	0.31	3.75	2427	425	5094	1237	50.95
Sanderling	0.07	0.00	0.18	94	0	247	69	72.89
Dunlin	29.13	4.97	59.16	39540	6746	80312	18595	47.03
Redshank	1.46	0.42	2.75	1989	568	3737	841	42.28
Greenshank	0.00	0.00	0.01	6	0	20	6	104.77
Kittiwake	0.02	0.00	0.04	26	0	55	14	53.90
Black-headed gull	1.65	0.14	4.46	2240	185	6054	1856	82.88
Common gull	3.70	1.82	6.36	5029	2469	8638	1552	30.86
Great black-backed gull	0.10	0.06	0.16	143	81	220	36	24.99
Herring gull	0.39	0.23	0.61	531	309	826	135	25.28
Lesser black-backed gull	0.02	0.00	0.04	26	0	60	16	62.68
Guillemot	2.29	1.25	3.57	3109	1703	4844	823	26.47
Razorbill	0.36	0.17	0.59	491	234	803	146	29.57
Black guillemot	0.00	0.00	0.01	6	0	16	6	97.29
Red-throated diver	0.67	0.42	0.95	904	565	1286	182	20.09
Shag	0.02	0.00	0.04	26	5	54	13	50.31
Cormorant	0.41	0.07	0.86	561	96	1172	275	49.00

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Grey heron	0.01	0.00	0.04	20	0	60	16	80.10
Carrion crow	0.04	0.01	0.1	61	10	140	33	54.39
Harbour porpoise	0.15	0.09	0.23	206	120	310	50	24.14

Table 28 Apportioned abundance estimates of species from the digital aerial survey of the Solway Firth SPA, 11th February 2021

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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								
Barnacle goose	7.58	0.00	22.58	10292	5	30652	8857	86.05
Pink-footed goose	0.01	0.00	0.04	21	0	50	14	68.83
Shelduck	1.37	0.35	2.70	1861	477	3668	840	45.10
Wigeon	7.22	1.33	15.09	9802	1807	20485	4921	50.20
Mallard	1.51	0.38	3.12	2051	519	4230	968	47.16
Pintail	1.68	0.17	3.62	2278	237	4908	1204	52.83
Teal	4.83	1.02	10.09	6555	1385	13703	3034	46.28
Scaup	0.59	0.00	1.75	804	4	2383	769	95.65
Common scoter	22.00	9.14	36.30	29866	12408	49281	9635	32.26
Goldeneye	0.16	0.01	0.43	221	12	588	156	70.33
Goosander	0.06	0.00	0.18	77	1	239	64	82.53
Great crested grebe	0.00	0.00	0.01	5	0	16	5	100.50
Oystercatcher	13.81	3.09	27.65	18746	4196	37542	8621	45.99
Lapwing	0.01	0.00	0.03	16	1	41	12	74.98
Grey plover	0.15	0.00	0.40	204	5	542	146	71.48
Ringed plover	0.00	0.00	0.01	6	1	16	5	93.81
Curlew	4.40	1.10	8.71	5973	1497	11824	2656	44.47

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Bar-tailed godwit	0.20	0.02	0.46	277	22	628	162	58.46
Turnstone	0.02	0.00	0.04	21	1	61	21	96.50
Knot	1.82	0.36	3.71	2475	489	5043	1193	48.20
Sanderling	0.07	0.00	0.18	95	2	240	67	69.99
Dunlin	31.61	7.61	65.05	42906	10335	88306	19771	46.08
Redshank	1.48	0.36	2.89	2015	494	3920	870	43.14
Greenshank	0.00	0.00	0.01	6	1	16	5	97.15
Kittiwake	0.02	0.00	0.04	26	5	55	14	52.20
Black-headed gull	1.76	0.18	5.49	2389	243	7450	1877	78.55
Common gull	3.84	1.91	6.5	5219	2594	8819	1614	30.92
Great black-backed gull	0.10	0.06	0.16	142	80	214	35	24.52
Herring gull	0.40	0.23	0.61	542	309	830	138	25.37
Lesser black-backed gull	0.02	0.00	0.05	27	1	66	17	62.51
Guillemot	2.50	1.28	3.75	3390	1742	5098	862	25.40
Razorbill	0.39	0.19	0.62	536	264	848	148	27.54
Black guillemot	0.01	0.00	0.02	10	0	25	7	70.02
Red-throated diver	0.67	0.42	0.94	911	571	1279	185	20.25
Shag	0.02	0.00	0.04	25	5	51	13	53.09
Cormorant	0.43	0.08	0.89	580	105	1207	288	49.55

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Grey heron	0.02	0.00	0.05	31	5	73	18	57.39
Carrion crow	0.05	0.01	0.09	62	10	126	31	49.88
Harbour porpoise	0.15	0.09	0.22	204	117	299	48	23.41

Table 29 Abundance estimates of species groups from the digital aerial survey of the Solway Firth SPA, for the near-shore area only

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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	278.16	153.67	426.27	111846	61789	171402	28800	25.75
All non-avian animals	0.04	0.00	0.09	16	0	36	9	56.23
Species group								
Goose species	25.67	0.10	72.01	10324	41	28956	8497	82.30
Duck species	72.36	38.69	114.22	29097	15557	45930	7658	26.32
Wader species	160.71	66.33	277.48	64622	26670	111573	21902	33.89
Small gull species	15.37	4.31	31.28	6179	1735	12579	2708	43.82
Black-backed gull species	0.10	0.04	0.19	42	15	76	17	40.10
Large gull species	0.94	0.47	1.57	378	188	632	112	29.50
Gull species	0.42	0.18	0.71	168	74	284	56	33.30
Large auk	0.42	0.15	0.79	168	60	319	68	40.65
Auk species	0.01	0.00	0.04	5	0	16	5	93.95
Large auk / diver species	0.01	0.00	0.04	6	0	16	5	96.68
Diver species	0.44	0.21	0.69	175	83	280	52	29.18
Cormorant / shag	0.55	0.12	1.31	222	50	529	131	58.95
Passerine species	0.17	0.05	0.33	67	20	131	30	43.62
Small bird species	0.23	0.03	0.52	94	11	211	50	53.59

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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	0.04	0.00	0.09	16	0	35	9	54.76

Table 30 Unapportioned abundance estimates of species from the digital aerial survey of the Solway Firth SPA, for the near-shore area only

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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								
Barnacle goose	25.50	0.03	68.95	10254	11	27724	8500	82.89
Pink-footed goose	0.05	0.00	0.13	21	0	51	15	68.64
Shelduck	4.54	1.48	8.67	1824	594	3485	773	42.39
Wigeon	24.09	5.02	48.05	9688	2019	19322	4391	45.32
Mallard	5.08	1.78	9.75	2044	716	3922	818	40.00
Pintail	5.75	0.97	12.18	2311	389	4896	1177	50.94
Teal	15.73	4.69	28.78	6324	1885	11572	2536	40.11
Scaup	2.00	0.00	5.86	806	0	2356	744	92.35
Common scoter	11.64	2.96	22.71	4681	1190	9131	2051	43.80
Goldeneye	0.54	0.04	1.38	216	15	557	148	68.23
Goosander	0.18	0.00	0.51	73	0	207	63	85.45
Oystercatcher	36.11	8.40	69.07	14522	3379	27775	6080	41.87
Lapwing	0.04	0.00	0.10	15	0	41	11	73.61
Grey plover	0.51	0.04	1.27	205	15	513	136	66.18
Ringed plover	0.01	0.00	0.04	5	0	16	5	98.40
Curlew	14.92	4.83	27.91	6000	1941	11222	2421	40.35
Bar-tailed godwit	0.69	0.09	1.45	278	35	582	146	52.27

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Turnstone	0.05	0.00	0.15	21	0	61	20	97.69
Knot	6.17	1.09	12.82	2480	437	5154	1214	48.95
Sanderling	0.23	0.00	0.57	93	0	230	64	68.78
Dunlin	94.39	25.98	175.21	37952	10449	70454	15521	40.89
Redshank	5.01	1.64	8.66	2016	659	3482	723	35.84
Greenshank	0.01	0.00	0.04	5	0	16	5	98.70
Kittiwake	0.01	0.00	0.04	5	0	16	5	100.52
Black-headed gull	5.41	0.55	14.58	2178	221	5861	1780	81.71
Common gull	9.65	3.55	18.58	3882	1429	7472	1557	40.10
Great black-backed gull	0.21	0.09	0.35	83	35	141	28	33.38
Herring gull	0.91	0.44	1.55	368	177	625	116	31.35
Lesser black-backed gull	0.04	0.00	0.10	16	0	41	12	76.23
Guillemot	0.29	0.10	0.51	116	40	205	42	36.15
Razorbill	0.09	0.00	0.23	35	0	92	26	73.39
Black guillemot	0.01	0.00	0.04	5	0	16	5	99.94
Red-throated diver	0.44	0.21	0.70	177	86	284	51	28.76
Shag	0.05	0.00	0.11	21	0	46	13	59.65
Cormorant	0.50	0.09	1.23	203	35	497	124	60.96
Grey heron	0.05	0.00	0.14	20	0	55	16	77.38

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Carrion crow	0.15	0.04	0.31	61	15	125	29	47.01
Harbour porpoise	0.04	0.00	0.09	15	0	35	9	57.62

Table 31 Apportioned abundance estimates of species from the digital aerial survey of the Solway Firth SPA, for the near-shore area only

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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								
Barnacle goose	26.24	0.03	72.08	10549	11	28982	8371	79.35
Pink-footed goose	0.05	0.00	0.13	21	0	51	15	71.08
Shelduck	4.68	1.46	9.11	1884	589	3662	773	41.05
Wigeon	24.66	4.07	50.91	9917	1636	20472	4659	46.98
Mallard	5.18	1.82	9.93	2083	733	3992	832	39.92
Pintail	5.86	1.01	11.62	2355	405	4674	1123	47.69
Teal	16.2	4.43	30.34	6513	1782	12201	2731	41.93
Scaup	2.01	0.01	5.83	808	5	2347	748	92.49
Common scoter	12.61	3.30	24.39	5069	1328	9808	2167	42.74
Goldeneye	0.58	0.05	1.44	234	19	582	156	66.74
Goosander	0.17	0.00	0.50	70	1	203	61	87.41
Oystercatcher	38.58	11.58	71.03	15515	4657	28562	6125	39.47
Lapwing	0.04	0.00	0.10	15	1	41	12	74.40
Grey plover	0.50	0.02	1.31	203	8	526	136	66.77
Ringed plover	0.01	0.00	0.04	6	1	16	5	96.35
Curlew	15.18	5.06	28.59	6103	2036	11496	2383	39.05
Bar-tailed godwit	0.69	0.08	1.53	277	34	614	152	54.82

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Turnstone	0.05	0	0.15	22	1	62	21	95.65
Knot	6.40	1.32	12.56	2573	533	5052	1168	45.40
Sanderling	0.25	0	0.64	101	2	258	68	67.77
Dunlin	96.75	28.56	177.5	38904	11485	71372	15666	40.27
Redshank	5.26	1.88	9.54	2115	755	3838	799	37.77
Greenshank	0.01	0	0.05	6	1	21	6	98.36
Kittiwake	0.01	0	0.04	5	1	16	5	99.51
Black-headed gull	5.81	0.59	15.1	2338	239	6070	1811	77.43
Common gull	9.97	3.72	18.22	4008	1498	7328	1542	38.46
Great black-backed gull	0.21	0.09	0.36	84	36	144	27	32.39
Herring gull	0.93	0.46	1.57	375	184	634	114	30.26
Lesser black-backed gull	0.04	0	0.10	16	0	41	12	72.73
Guillemot	0.31	0.12	0.53	123	50	215	44	35.36
Razorbill	0.09	0	0.23	36	2	92	26	70.96
Black guillemot	0.01	0	0.04	6	0	16	5	94.95
Red-throated diver	0.44	0.2	0.73	177	83	295	54	30.14
Shag	0.05	0	0.11	21	0	46	13	61.49
Cormorant	0.50	0.09	1.19	202	36	481	127	62.98
Grey heron	0.08	0.01	0.16	31	5	66	17	53.74

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Carrion crow	0.15	0.04	0.29	60	15	119	28	46.07
Harbour porpoise	0.04	0.00	0.09	16	0	36	9	57.61
Barnacle goose	26.24	0.03	72.08	10549	11	28982	8371	79.35

Table 32 Abundance estimates of species groups from the digital aerial survey of the Solway Firth SPA, for the marine area only

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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	39.54	20.08	64.52	37784	19184	61647	10802	28.59
All non-avian animals	0.22	0.12	0.34	211	115	328	55	25.68
Species group								
Duck species	26.19	9.82	46.47	25022	9386	44404	9048	36.16
Grebe species	0.01	0.00	0.02	6	0	15	5	92.54
Wader species	6.81	0.00	20.38	6509	0	19475	6577	101.05
Small gull species	1.11	0.80	1.43	1065	769	1367	157	14.68
Black-backed gull species	0.03	0.00	0.07	26	0	67	18	67.75
Large gull species	0.17	0.10	0.27	166	94	257	44	26.27
Gull species	0.34	0.14	0.56	330	137	532	100	30.34
Large auk	3.94	2.36	5.61	3764	2256	5364	815	21.64
Auk species	0.01	0.00	0.02	6	0	15	5	94.23
Auk / small gull	0.02	0.00	0.05	20	0	45	11	53.57
Large auk / diver species	0.02	0.00	0.05	21	0	45	12	56.02
Diver species	0.76	0.46	1.13	727	436	1077	159	21.79
Fulmar / gull species	0.01	0.00	0.02	6	0	15	5	93.94
Cormorant / shag	0.39	0.01	0.94	370	10	898	246	66.49

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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	0.00	0.04	16	0	40	11	67.86
Cetacean species	0.20	0.12	0.30	191	111	288	47	24.32
Seal / small cetacean species	0.01	0.00	0.02	5	0	15	5	97.03

Table 33 Unapportioned abundance estimates of species from the digital aerial survey of the Solway Firth SPA, for the marine area only

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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	25.85	9.21	44.67	24701	8805	42680	8921	36.11
Goosander	0.01	0.00	0.02	5	0	15	5	100.38
Great crested grebe	0.01	0.00	0.02	5	0	15	5	96.80
Oystercatcher	3.12	0.00	9.48	2986	0	9056	2950	98.77
Dunlin	3.46	0.00	10.47	3306	0	10004	3140	94.97
Kittiwake	0.02	0.00	0.05	20	0	44	11	56.13
Black-headed gull	0.05	0.01	0.09	46	10	90	21	45.42
Common gull	1.35	0.87	1.83	1286	834	1754	231	17.92
Great black-backed gull	0.06	0.02	0.12	62	20	117	25	38.98
Herring gull	0.18	0.10	0.29	175	96	273	45	25.55
Lesser black-backed gull	0.01	0.00	0.03	10	0	25	7	64.48
Guillemot	3.18	1.82	4.67	3039	1740	4461	703	23.11
Razorbill	0.47	0.23	0.74	452	221	712	124	27.43
Red-throated diver	0.75	0.44	1.09	721	422	1038	162	22.42
Shag	0.01	0.00	0.02	6	0	15	5	95.34
Cormorant	0.4	0.02	0.95	384	24	912	250	65.07
Harbour porpoise	0.2	0.11	0.3	190	106	288	46	23.89

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Common scoter	25.85	9.21	44.67	24701	8805	42680	8921	36.11
Goosander	0.01	0.00	0.02	5	0	15	5	100.38
Great crested grebe	0.01	0.00	0.02	5	0	15	5	96.80
Oystercatcher	3.12	0.00	9.48	2986	0	9056	2950	98.77
Dunlin	3.46	0.00	10.47	3306	0	10004	3140	94.97
Kittiwake	0.02	0.00	0.05	20	0	44	11	56.13
Black-headed gull	0.05	0.01	0.09	46	10	90	21	45.42
Common gull	1.35	0.87	1.83	1286	834	1754	231	17.92
Great black-backed gull	0.06	0.02	0.12	62	20	117	25	38.98
Herring gull	0.18	0.10	0.29	175	96	273	45	25.55
Lesser black-backed gull	0.01	0.00	0.03	10	0	25	7	64.48
Guillemot	3.18	1.82	4.67	3039	1740	4461	703	23.11
Razorbill	0.47	0.23	0.74	452	221	712	124	27.43
Red-throated diver	0.75	0.44	1.09	721	422	1038	162	22.42
Shag	0.01	0.00	0.02	6	0	15	5	95.34
Cormorant	0.40	0.02	0.95	384	24	912	250	65.07
Harbour porpoise	0.20	0.11	0.30	190	106	288	46	23.89

Table 34 Apportioned abundance estimates of species from the digital aerial survey of the Solway Firth SPA, for the marine area only

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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	0.00	0.00	1	0	1	1	90.71
Wigeon	0.00	0.00	0.00	1	0	3	1	95.85
Mallard	0.00	0.00	0.00	1	0	1	1	92.47
Pintail	0.00	0.00	0.00	1	0	1	1	93.75
Teal	0.00	0.00	0.00	1	0	2	1	91.67
Scaup	0.00	0.00	0.00	1	0	1	1	91.95
Common scoter	26.09	9.56	46.67	24928	9135	44590	9125	36.60
Goldeneye	0.00	0.00	0.00	1	0	1	1	96.41
Goosander	0.01	0.00	0.02	5	0	15	5	97.20
Great crested grebe	0.01	0.00	0.02	5	0	15	6	102.27
Oystercatcher	2.95	0.00	9.56	2824	0	9138	3067	108.61
Lapwing	0.00	0.00	0.00	1	0	1	1	97.41
Grey plover	0.00	0.00	0.00	1	0	1	1	98.27
Ringed plover	0.00	0.00	0.00	1	0	1	1	103.43
Curlew	0.01	0.00	0.03	9	0	25	9	100.33
Bar-tailed godwit	0.00	0.00	0.00	1	0	2	1	98.72
Turnstone	0.00	0.00	0.00	1	0	1	1	98.01

Category	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Knot	0.00	0.00	0.01	3	0	8	3	96.79
Sanderling	0.00	0.00	0.00	1	0	1	1	92.45
Dunlin	3.44	0.00	10.62	3285	0	10144	3396	103.37
Redshank	0.00	0.00	0.00	1	0	3	1	94.97
Greenshank	0.00	0.00	0.00	1	0	1	1	102.59
Kittiwake	0.02	0.00	0.05	20	1	45	12	55.91
Black-headed gull	0.05	0.01	0.10	48	13	94	22	44.32
Common gull	1.37	0.92	1.84	1306	878	1761	229	17.51
Great black-backed gull	0.06	0.02	0.12	61	20	115	25	40.43
Herring gull	0.19	0.11	0.28	178	101	269	43	24.20
Lesser black-backed gull	0.01	0.00	0.03	11	0	25	7	62.67
Guillemot	3.41	1.93	5.23	3255	1846	4996	778	23.90
Razorbill	0.51	0.27	0.79	488	262	752	126	25.83
Black guillemot	0.01	0.00	0.02	5	0	15	5	92.56
Red-throated diver	0.76	0.44	1.13	726	424	1085	165	22.68
Shag	0.01	0.00	0.02	5	0	16	6	104.03
Cormorant	0.39	0.00	1.00	371	0	955	253	67.99
Harbour porpoise	0.20	0.12	0.31	190	111	295	47	24.62

Appendix II: Absolute population estimates

129 Population estimates for three species (guillemot, razorbill and harbour porpoise) were divided by a correction factor as outlined in section 2.5.3, to take account of availability bias and give estimates of absolute abundance. Adjusted absolute estimates are presented alongside relative estimates.

Table 35 **Absolute monthly density and population estimates for guillemot in the Solway Firth SPA areas in February 2021 accounting for the potential number of birds estimated as being unavailable for detection.**

Survey area	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Relative estimates								
Unapportioned								
Full SPA	2.29	1.25	3.57	3109	1703	4844	823	26.47
Near-shore area	0.29	0.10	0.51	116	40	205	42	36.15
Marine area	3.18	1.82	4.67	3039	1740	4461	703	23.11
Apportioned								
Full SPA	2.5	1.28	3.75	3390	1742	5098	862	25.4
Near-shore area	0.31	0.12	0.53	123	50	215	44	35.36
Marine area	3.41	1.93	5.23	3255	1846	4996	778	23.9
Absolute estimates								
Unapportioned								
Full SPA	3.03	1.43	4.96	4108	1940	6730	1182	28.77
Near-shore area	0.39	0.14	0.68	157	59	274	60	38.22
Marine area	4.09	2.29	6.03	3907	2198	5761	973	24.9

Survey area	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Apportioned								
Full SPA	3.23	1.73	4.99	4380	2343	6769	1214	27.72
Near-shore area	0.41	0.16	0.72	167	66	294	63	37.72
Marine area	4.40	2.55	6.40	4205	2437	6121	1057	25.14

Table 36 **Absolute monthly density and population estimates for razorbill in the Solway Firth SPA areas in February 2021 accounting for the potential number of birds estimated as being unavailable for detection.**

Survey area	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Relative estimates								
Unapportioned								
Full SPA	0.36	0.17	0.59	491	234	803	146	29.57
Near-shore area	0.09	0.00	0.23	35	0	92	26	73.39
Marine area	0.47	0.23	0.74	452	221	712	124	27.43
Apportioned								
Full SPA	0.39	0.19	0.62	536	264	848	148	27.54
Near-shore area	0.09	0.00	0.23	36	2	92	26	70.96
Marine area	0.51	0.27	0.79	488	262	752	126	25.83
Absolute estimates								
Unapportioned								
Full SPA	0.44	0.18	0.71	595	253	975	208	34.96
Near-shore area	0.10	0.00	0.30	41	0	121	37	90.24
Marine area	0.57	0.27	0.95	545	262	896	178	32.66

Survey area	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (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 (%)
Apportioned								
Full SPA	0.46	0.21	0.78	637	286	1059	214	33.59
Near-shore area	0.11	0.00	0.31	44	1	125	37	84.09
Marine area	0.61	0.32	0.97	590	309	924	175	29.66

Table 37 **Absolute monthly density and population estimates for harbour porpoise in the Solway Firth SPA areas in February 2021 accounting for the potential number of birds estimated as being unavailable for detection. Adjusted estimates are likely to vary slightly from true values since surfacing rate used in calculations derived from one survey.**

Survey area	Density estimate (n/km²)	Lower 95% confidence limit of density (n/km²)	Upper 95% confidence limit of density (n/km²)	Population estimate (number)	Lower 95% confidence limit of population (number)	Upper 95% confidence limit of population (number)
Relative estimates						
Unapportioned						
Full SPA	0.15	0.09	0.23	206	120	310
Near-shore area	0.04	0.00	0.09	15	0	35
Marine area	0.2	0.11	0.30	190	106	288
Apportioned						
Full SPA	0.15	0.09	0.22	204	117	299
Near-shore area	0.04	0.00	0.09	16	0	36
Marine area	0.20	0.12	0.31	190	111	295
Absolute estimates						
Unapportioned						
Full SPA	2.39	1.43	3.66	3282	1912	4938
Near-shore area	0.64	0.00	1.43	239	0	558
Marine area	3.19	1.75	4.78	3027	1689	4588

Apportioned						
Full SPA	2.39	1.43	3.50	3250	1864	4763
Near-shore area	0.64	0.00	1.43	255	0	573
Marine area	3.19	1.91	4.94	3027	1768	4699

Appendix III: Shore-based count data

130 Shore-based count data of roosting birds of three species (common goldeneye, goosander and cormorant) were collected by Natural England in February 2021 at six locations along the Cumbrian coast within the SPA boundary: Workington Harbour (inner), Workington Harbour Wall, Siddick Pond, Bowness-on-Solway, River Esk and the River Eden (Figure 1). Raw data from shore-based surveys are presented below.

Table 38 Shore-based count data of roosting birds collected by Natural England in the Solway Firth SPA in February 2021. Shaded rows indicate data collected on the same day as HiDef digital aerial survey

Date	Time	Location and/or Grid reference of observer	Latitude	Longitude	Species	Number of observations
10 February 2021	11:00	Workington Harbour (inner)	54.648465	-3.566115	Goosander	57
10 February 2021	11:00	Workington Harbour (wall)	54.651805	-3.577586	Cormorant	409
11 February 2021	12:00	Workington Harbour (inner)	54.648465	-3.566115	Goosander	54
11 February 2021	12:30	Workington Harbour (wall)	54.651805	-3.577586	Cormorant	528
11 February 2021	12:30	Siddick Pond	54.65958	-3.54892	Goosander	0
11 February 2021	12:30	Bowness-on-Solway	54.95426	-3.21425	All species	0
12 February 2021	07:45	River Esk (NY3364 and NY3464)	54.966101 54.966235	-3.0480281 -3.0324116	Goldeneye	6+
12 February 2021	15:30	River Eden (NY3361 and NY3461)	54.939147 54.939281	-3.0473268 -3.0317207	Goldeneye	12
13 February 2021	14:00	River Esk (NY3364 and NY3464)	54.966101 54.966235	-3.0480281 -3.0324116	Goldeneye	42
15 February 2021	08:00	River Esk (NY3364 and NY3464)	54.966101 54.966235	-3.0480281 -3.0324116	Goosander	4
15 February 2021	08:00	River Esk (NY3364 and NY3464)	54.966101 54.966235	-3.0480281 -3.0324116	Goldeneye	33
15 February 2021	15:30	River Eden (NY3361 and NY3461)	54.939147 54.939281	-3.0473268 -3.0317207	Goosander	5

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