High-definition bird and marine mammal aerial survey image collection in Borssele

First-year report

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Preface

Rijkswaterstaat WVL (RWS WVL) commissioned Waardenburg Ecology and HiDef / BioConsult SH to collect and deliver digital video images of birds and marine mammals in and around the wind farm area at Borssele and the adjacent Belgian wind farms, and at a comparable area without wind farms in the Dutch North Sea, over a period of two years. The images from the first year have been analysed to determine whether differences in the species composition, numbers and distribution of seabirds and marine mammals in and around the wind farm can be detected. Images from the second year are delivered to RWS WVL and currently no analysis within the current project is planned.

As part of the first year of data collection two interim reports were produced that described the first and second halves of this period; February – July 2021 and August 2021 – February 2022 respectively (Collier *et al.* 2022a, Collier *et al*. 2022b). These reports detail the timings of the surveys, species identified and numbers and distributions of key species and species-groups. Furthermore, methods of data collection are given in Collier *et al.* 2021 as well as in these interim reports.

Fieldwork, data collection and data handling were carried out by HiDef and Waardenburg Ecology acted as coordinator between Rijkswaterstaat and all parties.

We thank the HiDef operations team for coordinating successful survey flights and for diligently informing wind farm operators prior to flights, and in turn the wind farm operators for facilitating flights over their respective wind farm areas.

We are thankful to the support and contributions from Maarten Platteeuw, Jos de Visser, Dagmar van Nieuwpoort and Ingeborg van Splunder (Rijkswaterstaat).

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Summary

Digital aerial surveys were carried out twice a month from February 2021 to January 2022 with an extra survey conducted in February 2022. Surveys were conducted in two areas in the southern North Sea, one of which encompassed offshore wind farms. The aim of the surveys was to 1) collect digital images that can later be used to develop software for analysing images; 2) to collect spatio-temporal distribution data on birds and marine mammals to determine differences between wind farm and adjacent areas; and 3) to provide information on how to investigate displacement and habituation of seabirds and marine mammals to wind farms.

A total of 56,580 birds and 1,831 marine mammals were recorded during the 25 surveys between February 2021 and February 2022. Peak numbers were recorded during winter months and lowest figures were recorded from mid-spring to early autumn. Numbers and distributions of six key seabird species (Northern Gannet, Lesser Black-backed Gull, Great Black-backed Gull, Black-legged Kittiwake, Common Guillemot and Razorbill) and a marine mammal (Harbour Porpoise) are described. Monthly density maps do not show any strong tendencies of these species to favour particular areas within the study area. This was confirmed by analyses of densities within and near offshore wind farms and in a reference area. Exceptions were Northern Gannet and Common Guillemot, which showed lower densities within the wind farm areas then just outside and in the reference area respectively.

Densities recorded during the digital aerial surveys and observer-based aerial surveys (MWTL surveys) were comparable for the key species investigated. Species identification and the proportions of individuals aged were similar between methods, but for identification this was slightly higher in the observer-based surveys and for ages this was slightly higher in the digital aerial surveys.

Digital aerial surveys offer several benefits over observer-based aerial surveys, including the higher flight height, enabling data to be collected within offshore wind farms, and a quicker flight speed, allowing more area to be covered per period. On the other hand, digital aerial survey data are currently more time consuming to analyse and as such, costs are higher. Developments in analytical software could decrease the time needed to analyse digital images.

Nederlandse samenvatting

In twee gebieden in de Nederlandse en Belgische Noordzee zijn tussen februari 2021 en januari 2022 twee keer per maand digitale vliegtuigtellingen uitgevoerd. Daarnaast is in februari 2022 een keer extra gevlogen. In één van deze gebieden staan diverse offshore windparken. Het doel van het onderzoek was om: 1) digitale afbeeldingen te verzamelen die later kunnen worden gebruikt om software te ontwikkelen voor het analyseren van beelden; 2) het verzamelen van spatio-temporele verspreidingsgegevens van vogels en zeezoogdieren om verschillen tussen windpark- en aangrenzende gebieden te bepalen; en 3) aanbevelingen te doen voor een opzet van onderzoeken van vermijding en gewenning van zeevogels en zeezoogdieren als gevolg van windparken.

In totaal zijn 56.580 vogels en 1.831 zeezoogdieren geteld tijdens de 25 tellingen. Piekaantallen werden geteld tijdens de wintermaanden en de laagste aantallen werden geteld van de lente tot de vroege herfst. De aantallen en verspreiding van zes zeevogelsoorten (jan-van-gent, kleine mantelmeeuw, grote mantelmeeuw, drieteenmeeuw, zeekoet en alk) en één zeezoogdier (bruinvis) worden beschreven. Maandelijkse dichtheidskaarten laten geen sterke voorkeur zien van deze soorten voor bepaalde gebieden binnen het studiegebied. Dit werd bevestigd door analyses van dichtheden binnen en nabij windparken op zee met het referentiegebied. Uitzonderingen waren jan-van-gent en zeekoet, waarvan bij beide lagere dichtheden binnen de windparkgebieden werden vastgesteld dan net erbuiten, en in het referentiegebied.

Dichtheden bepaald door de digitale vliegtuigtellingen en door de visuele MWTL-tellingen waren vergelijkbaar voor de belangrijkste onderzochte soorten. Soortidentificatie en de relatieve aantallen individuen die op leeftijd waren gebracht waren grotendeels vergelijkbaar tussen de methoden, alleen de identificatie van soorten was iets hoger in de MWTL-tellingen terwijl het aantal op leeftijd gebrachte dieren iets hoger was in de digitale vliegtuigtellingen.

Digitale vliegtuigtellingen bieden verschillende voordelen ten opzichte van visuele vliegtuigtellingen, waaronder de grotere vlieghoogte, waardoor gegevens kunnen worden verzameld binnen offshore windparken, en een hogere vliegsnelheid, waardoor een groter gebied per periode kan worden bestreken. Aan de andere kant zijn digitale vliegtuigtellingen momenteel arbeidsintensiever om te analyseren en daardoor zijn de kosten hoger. Ontwikkelingen in analytische software zouden de tijd, die nodig is om digitale beelden te analyseren, kunnen verkorten.

1 Introduction

1.1 Background

Offshore wind farms are known to have various effects on birds in the marine environment including displacement, leading to effective habitat loss for birds. With increasing numbers of offshore wind farm developments planned, displacement can be expected to increase, and a good understanding of the distribution and abundance of seabirds and marine mammals is needed.

The entire Dutch North Sea is currently surveyed by the large-scale MWTL-surveys (Monitoring Waterstaatkundige Toestand des Lands) that have been undertaken routinely since 1991. These aerial surveys map the numbers and distributions of seabirds and marine mammals in the Dutch North Sea, providing the fundamental data on which the effects of future offshore developments are assessed.

These aerial surveys currently use observers to count all observed birds and marine mammals along transects at a flight height of approximately 75 m (Fijn *et al.* 2022). A low flight height is necessary for the identification of species such as auks and terns yet provides difficulties for flying over wind farms and can potentially lead to the disturbance of certain species. The extent to which displacement occurs is therefore difficult to ascertain through current monitoring programmes.

Digital aerial surveys, where images are recorded with cameras, can be carried out at heights of about 550 meters, well above the tip height of current wind turbines and causing less disturbance. The recorded images are analysed after the flight and can be reviewed for quality assurance. However, flying at 550 meters above sea level requires good weather with no low cloud, conditions that can be uncommon during the winter in Dutch offshore waters. Moreover, the collected images need to be reviewed and analysed, which generally results in higher costs than for visual surveys.

A trial of digital aerial surveys in the Dutch North Sea were commissioned as part of the Dutch Governmental Offshore Wind Ecological Programme (Wozep), which is part of an assignment by the Dutch Ministry of Economic Affairs and Climate Policy to Rijkswaterstaat (RWS) to investigate the (cumulative) effects of multiple new wind farms planned in the Dutch North Sea. This integrated monitoring and research programme aims to study gaps in the knowledge relating to the impact of offshore wind farms on the North Sea ecosystem and its inhabitants. This project serves to provide insight into the practicalities of digital aerial surveys, data collection and processing, and the ability to assess the potential impacts of offshore wind farms on spatial distribution patterns. Furthermore, it is aimed that the images collected will be used for developing techniques that can automatically process digital aerial survey images in the future.

In a collaboration for the current project, Waardenburg Ecology and HiDef / BioConsult SH have collected digital video images of birds and marine mammals in and around the wind farm area near Borssele (in both the Dutch and Belgian EEZ) between February 2021 and February 2022 with the aim of being able to determine the numbers and distribution of these species in and around the wind farm. Surveys to collect digital video images will continue until January 2023, and although no analysis of these images is planned within the current project it is the intention that these images can be used to develop processes for the automisation of image analysis in the future.

1.2 Research aims and approach

The current project has three main aims:

1. To collect digital images that can be used to develop image recognition software to automatically filter, identify and count those containing birds and/or marine mammals.
2. To collect spatio-temporal distribution data of birds and marine mammals within the research area throughout the year to be able to determine differences between wind farm areas and adjacent areas.
3. To provide RWS WVL with information on how a successful digital aerial survey programme can be implemented to investigate the displacement and habituation of seabirds and marine mammals to wind farms.

These research aims and full methodology are further described in Collier *et al*. (2021, 2022a and 2022b), and further outlined in the current report.

1.3 Scope of this report

The current report describes the collection and analyses of digital aerial images in part of the Dutch North Sea between February 2021 and February 2022. This report follows on from the two interim reports, which describe the data collected during the first and second halves of the first year of surveys respectively (Collier *et al.* 2022a, Collier *et al*. 2022b).

Alongside a description of survey methods and the data collected, the spatio-temporal distribution of key seabird and marine mammal species will be described with the aim of determining any differences in abundance and distributions between wind farm areas and adjacent areas.

Furthermore, digital aerial surveys will be described and evaluated as a method for investigating the displacement and habituation of seabirds and marine mammals to wind farms.

2 Surveys and data collection

2.1 Survey area

Data presented in this report were collected from digital aerial surveys carried across two study areas in the south of the Dutch North Sea, with part of the southern area falling in the Belgian North Sea (figure 2.1).

These two survey areas each consist of seven equally spaced parallel survey transects running northwest – southeast, which is largely similar to the orientation of MWTL survey transects in this area (Fijn *et al.* 2022). The distance from shore is similar between the two areas, but the southern area is largely occupied by wind farms, whilst the northern area has none.

The offshore wind farms within the southern survey area include Borssele I, II, III, IV and V in the Dutch North Sea and (from north to south) Seamade (Mermaid), Northwester 2, Belwind, Nobelwind, Seamade (SeaStar), Northwind, Rentel, Thornton Bank phase I, II, III (also called C-Power) and Norther in the Belgian North Sea. All of the offshore wind farms in this area were operational before the start of the surveys with those in Belgian waters commissioned between 2009 and 2020 and those in the Dutch waters commissioned in 2020 and early 2021.

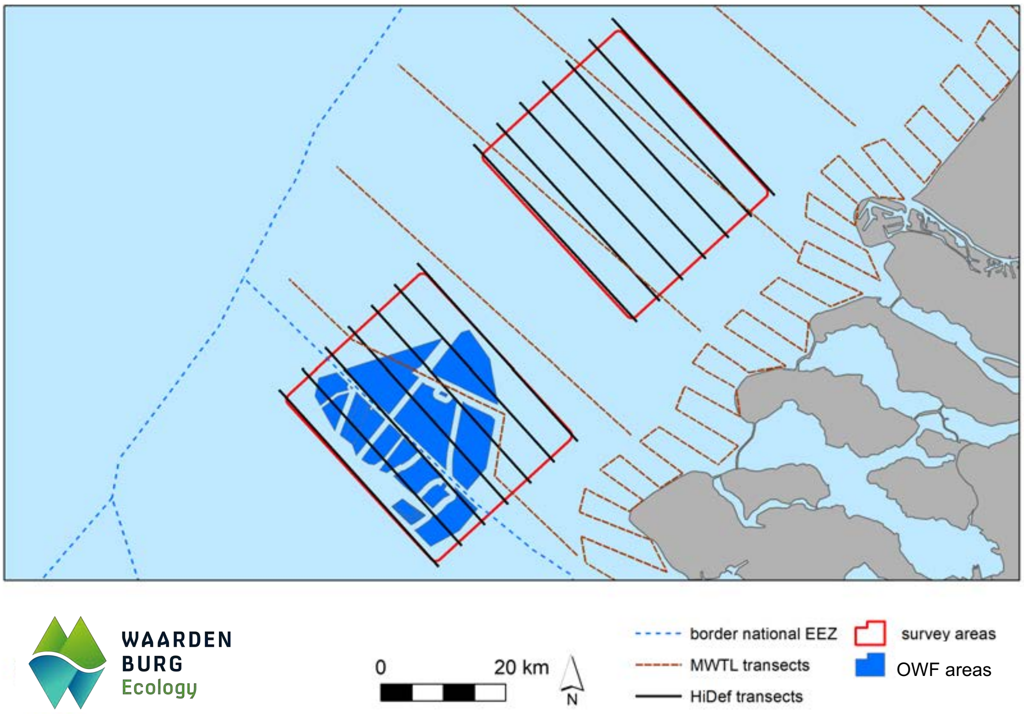

Figure 2.1 *Transect routes through the two study areas covering commissioned wind farms (along the Dutch-Belgian border) in the southern area, and the reference area in the north. Transects of the digital aerial surveys (black solid line) are in a similar orientation to the MWTL surveys (brown dashed line).*

2.2 Surveys

Surveys were coordinated and carried out by HiDef / BioConsult SH, who identified suitable weather windows and subsequently organised logistics and arranged permissions with wind farm managers prior to each survey. Surveys were flown using a Diamond DA 42 aircraft and at a height of 550 m and a speed of 220 km/h.

The HiDef / BioConsult SH custom digital video system consists of four bespoke cameras with extremely high resolution that translates to a pixel resolution of 2 cm at ground level. Combined, the four cameras cover a total strip approximately 544 m wide. Overlap between the images is prevented by leaving a gap of approximately 20 m between strips (figure 2.2).

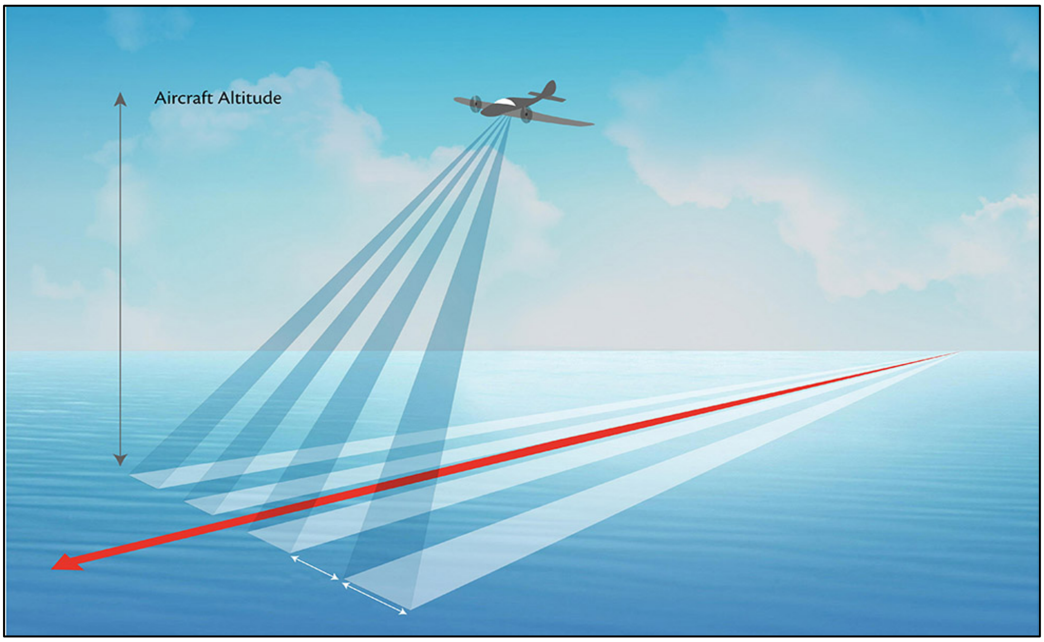

Figure 2.2 At a flight height of 550 m, coverage of the four cameras translates into a total strip width of 544 m with 20 m between each of the camera's field of view at surface level.

Surveys of the fourteen transects were undertaken twice per month between February 2021 and January 2022, with an extra survey in February 2022 being processed to compensate for a lower survey coverage in the November and December surveys. This lower coverage was due to the misalignment of one of the four cameras during these four surveys, which resulted in data being collected over a smaller total strip width than planned.

Surveys were carried out at least seven days apart and under the following conditions:

- No cloud below flying height (550 m).
- No precipitation.
- Wind speeds of less than ca. 30 km/h at sea level.
- Sea state of 6 or less.
- Not less than 1.5 hours after sunrise and not less than 1.5 hours before sunset.

These strict weather requirements resulted in the second survey from November being undertaken on 1st December. This survey is regarded as the second November survey for the purpose of this report. Transects were surveyed consecutively, either northernmost – southernmost or southernmost – northernmost) with each total survey being completed within between 2:58 and 4:10 hours (table 2.1).

Table 2.1 Dates and duration of the digital aerial survey flights during the first year of surveys.

Survey	Year	Month	Day	Time 'on survey'
1	2021	February	13	03:08
2	2021	February	20	03:22
3	2021	March	21	03:21
4	2021	March	30	03:15
5	2021	April	8	03:14
6	2021	April	22	03:09
7	2021	May	12	03:05
8	2021	May	20	02:59
9	2021	June	6	03:24
10	2021	June	23	02:58
11	2021	July	18	03:16
12	2021	July	29	03:10
13	2021	August	13	03:15
14	2021	August	29	03:10
15	2021	September	12	03:55
16	2021	September	20	03:26
17	2021	October	9	04:10
18	2021	October	23	03:09
19	2021	November	6	03:07
20	2021	November (December)	1	03:33
21	2021	December	11	03:40
22	2021	December	21	03:15
23	2022	January	6	02:59
24	2022	January	17	03:10
25	2022	February	5	03:00

During the survey, the aircraft's position is recorded at one second intervals using a Differential Global Positioning System (DGPS) device with a positional accuracy of two meters.

2.3 Data collection and processing

Digital video images collected during surveys, were analysed to identify bird and marine mammal species by experienced identification personnel at HiDef / BioConsult SH.

Digital video images were analysed using a two-stage process. Firstly, experienced staff highlight objects of potential interest within the video images by viewing these frame-by-frame on high-resolution display screens and image management software that allows the reviewer to adjust brightness and tones to facilitate the detection of an object. This stage is subject to a quality assurance step consisting of 'blind' reassessment of at least 20% of the material, of which more than 90% must be assessed equally.

The second stage involves the identification of objects identified in the first stage. For this, experienced ornithologists identify an object and where possible attach additional information such as age, sex, behaviour, etc. If necessary, additional support in identification is provided by leading seabirds and marine mammal specialists. This stage is again subject to a quality assurance step in which a separate group of expert ornithologists independently identifies objects in at least 20% of the material with the requirement of at least a 90% match.

Alongside information on birds and marine mammals, processed survey data includes ‘trip’ information such as ‘start time’, ‘strip width’, etc. and ‘positional’ information such as ‘date’, ‘glare’, ‘seastate’, etc. See table 2.3 in Collier *et al.* (2022a) for full details.

2.4 Data delivery

Data collected during digital aerial surveys were stored and analysed by HiDef / BioConsult SH and supplied to Rijkswaterstaat (Wozep datalab) with assistance from Waardenburg Ecology.

Data supplied to the Wozep datalab include processed count data, images containing features of interest and accompanying information (so-called ‘bounding boxes’ information). The delivery of these data for the first year of surveys was completed on 30 September 2022. In addition, all raw video footage recorded during the surveys is provided to the Wozep datalab, together providing fundamental material for the development of image recognition software to automatically filter, identify and count those containing birds and/or marine mammals. An example of images collected through the digital aerial surveys are presented in Appendix IV.

3 Species, numbers and distributions

The two previous half-year interim reports (Collier *et al.* 2022a and 2022b) describe the numbers of species (see for the full list Appendix I), species groups (see for grouping Appendix II) of birds and marine mammals recorded during the first year of digital aerial surveys. This is not repeated here, although figures across the entire period from February 2021 to February 2022 are summarised here and more detail is given into key seabird and marine mammal species. During November and December surveys, strip width was approximately three-quarters that during other months due to the inclusion of data from three, instead of four cameras. No correction of the figures presented here as counts has been made in this chapter except where explicitly stated (and where densities are presented). Any correction assumes that animals are evenly distributed across the surveyed transect and thus a correction factor of 1.33 has been applied (i.e. figure 3.1). For the current report, data were divided into 5 x 5 km grid cells, centred on transect lines, for presentation of density maps.

3.1 Species and numbers

Total numbers

A total of 56,580 birds and 1,831 marine mammals were recorded during the 25 surveys between February 2021 and February 2022. The average number of animals (birds and marine mammals combined) recorded per survey was 2,338, with the highest count being 8,299 on the first survey in January 2022, and the lowest count being 126 on the second survey in June 2021. See also Collier *et al.* (2022a and 2022b).

Number of birds counted were highest in February to April and again from December onwards (figure 3.1). Extrapolated figures to correct for a lower surveyed area in November and December are shown in the figure 3.1. Extrapolated numbers for the survey in February 2022 are shown as double the counted numbers in the single survey. Total monthly numbers were lowest in May to September with slightly higher figures in October and November. Numbers of marine mammals counted were highest in March, although the number of marine mammals generally remained a relatively small percentage of the total number of animals recorded; exceptions being May, June and July when marine mammals made up between 17-27% of the monthly total of animals counted.

Broadly, birds appeared to be distributed across the survey areas with no obvious concentrations evident across the year (figure 3.2).

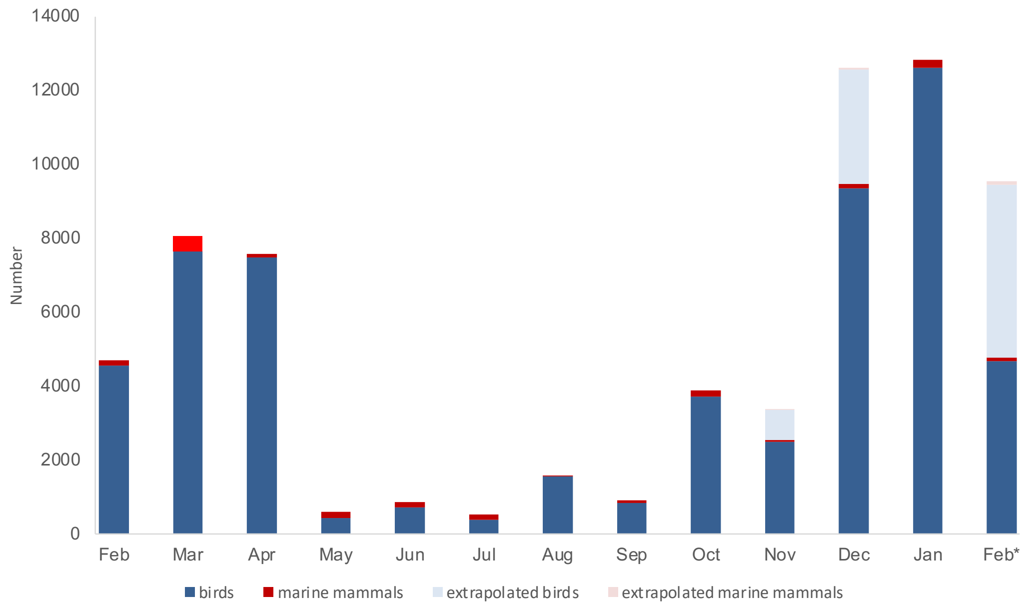

Figure 3.1 *Total numbers of birds (blue) and marine mammals (red) recorded each month, summed across the two surveys. * February 2022 total consists of one survey with extrapolated numbers for the second survey shown in light blue/red. The strip width in November and December surveys is approximately three-quarters that in other months due to the inclusion of data from three instead of four cameras. Extrapolated numbers for November and December are shown in light blue/red.*

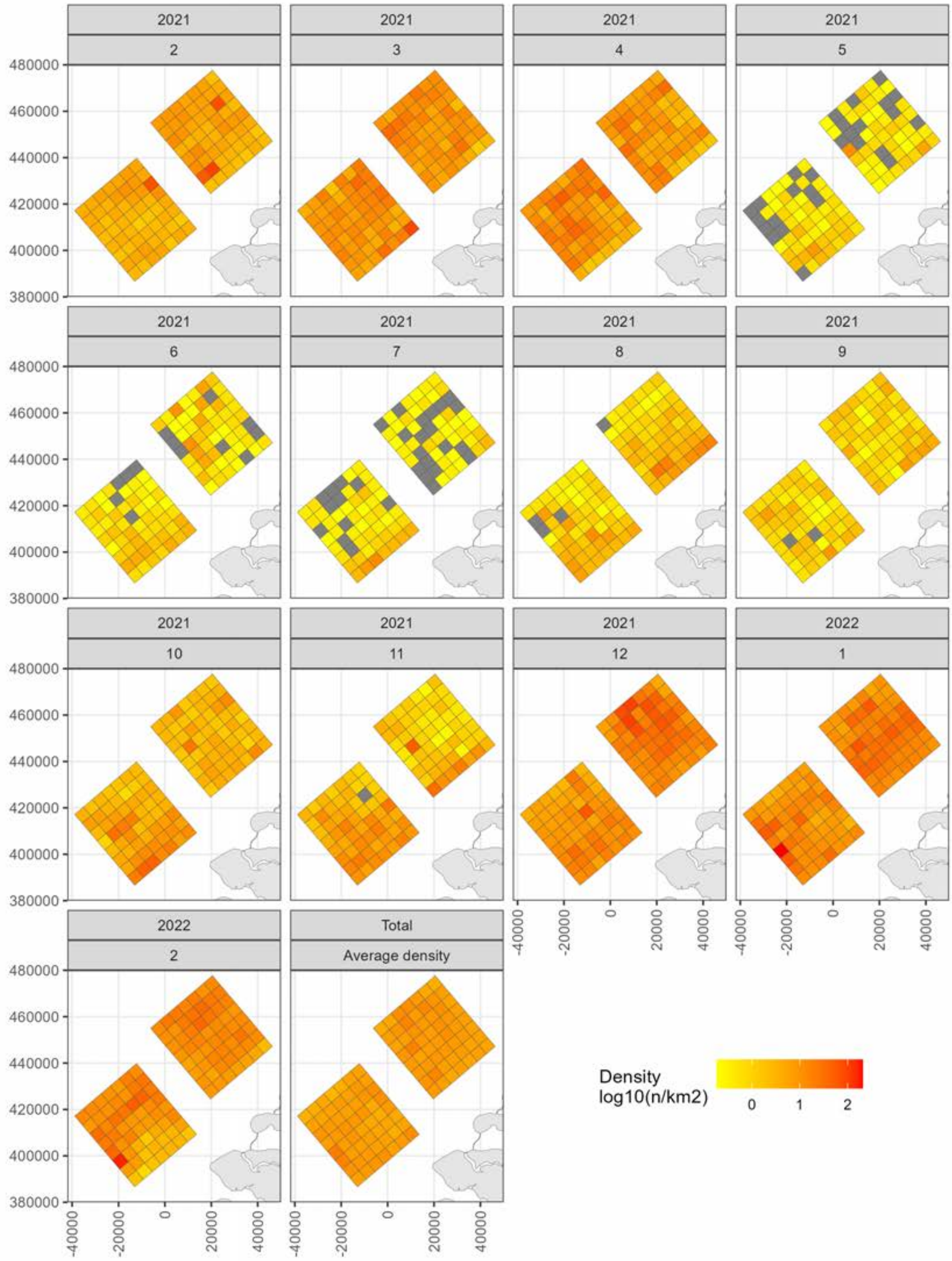

Figure 3.2 *Distribution of all birds across surveys areas and per month and averaged across all surveys as log of density (n/km²). Grey squares show zero counts.*

Species and species-groups
A total of 42 bird species, and four marine mammal species, were identified from survey data collected between February 2021 and February 2022. In addition, 26 other species-groups (23 birds and 3 marine mammals) were assigned to observations that could not be identified to species. These include amalgamations of similar species such as 'Common Guillemot/Razorbill' and 'Arctic/Common Tern' as well as wider groupings such as 'large gull' and 'unidentified diver'. For reporting, the groups 'tern/small gull' and 'fulmar/gull' are included as 'gulls', and 'seal/small cetacean' as 'pinnipeds'. For full details of the species and species-groups included in each 'reporting group' see Appendix II.

Key species
A total of six bird species and one marine mammal species have been selected for further analyses in this report. These are: Northern Gannet, Lesser Black-backed Gull, Great Black-backed Gull, Black-legged Kittiwake, Common Guillemot, Razorbill and Harbour Porpoise. Raw distribution maps for the key species are given in Appendix III.

Apportioning unidentified species
Figures given in the following section are for individuals identified to species only. We have not to apportioned unidentified species to species. This is to provide transparency of the results of the digital aerial survey methods and provide insight into the data collected. Apportioning of large gulls is discussed in section 3.5, and the apportioning of auks is discussed in section 3.9. In section 5.3, densities of unapportioned visual and digital aerial surveys are compared. This is again to allow comparisons of methods.
If using digital aerial survey data to calculate absolute densities, apportioning of unidentified groups to species can be applied. This is best done per survey to take into account any seasonal variation in identification, and if a geographical bias for the identification of species is expected also at a geographical level. Although the former may apply for species such as large gulls (where the presence of similar plumages may be seasonal), the latter may only be applicable in certain situations where survey conditions or local phenomena may influence identification.

3.2 Northern Gannet

A total of 2,025 Northern Gannets were recorded during the 25 surveys between February 2021 and February 2022. The peak count of 258 was recorded in the first survey in April. Northern Gannets were recorded in every survey. At the start of the survey year, numbers rose to peak in April before dropping dramatically in the same month and remaining low until into August. Numbers per survey then fluctuated, but totals per month showed a rise to peak again in January (figure 3.3).

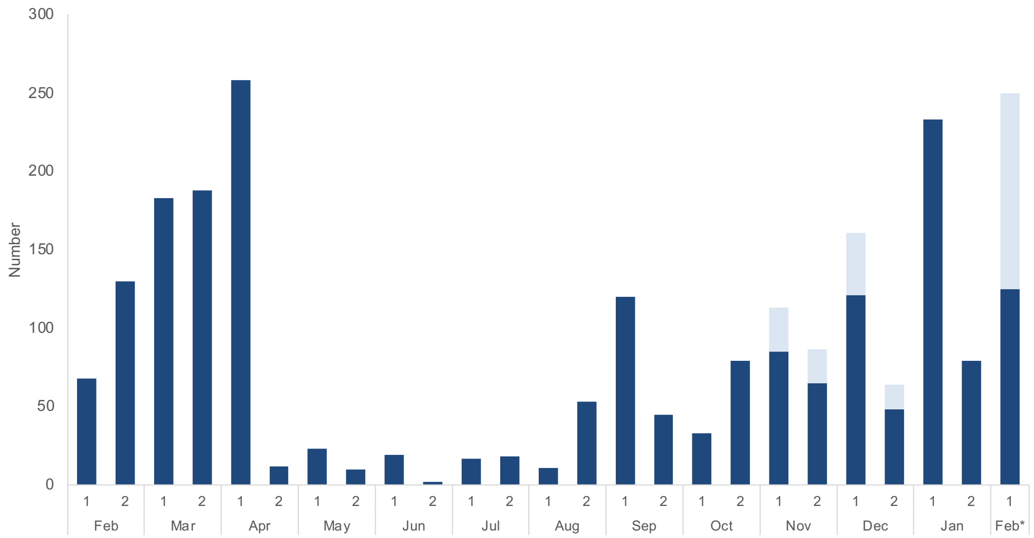

Figure 3.3 *Total numbers of Northern Gannet recorded each survey. Note that the surveyed strip width in November and December surveys is approximately three-quarters that in other months due to the inclusion of data from three instead of four cameras as in other months. Extrapolated numbers for November and December are shown in light blue. * February 2022 total consists of one survey with extrapolated numbers for the second survey shown in light blue.*

Throughout all surveys, 58% of the Northern Gannets recorded were aged. Ages were defined as either immature or adult. The percentage of immature birds recorded each month varied between 0% and 73% (figure 3.4). Immature birds were recorded in greatest proportions between May and October, and from June to September outnumbered adults.

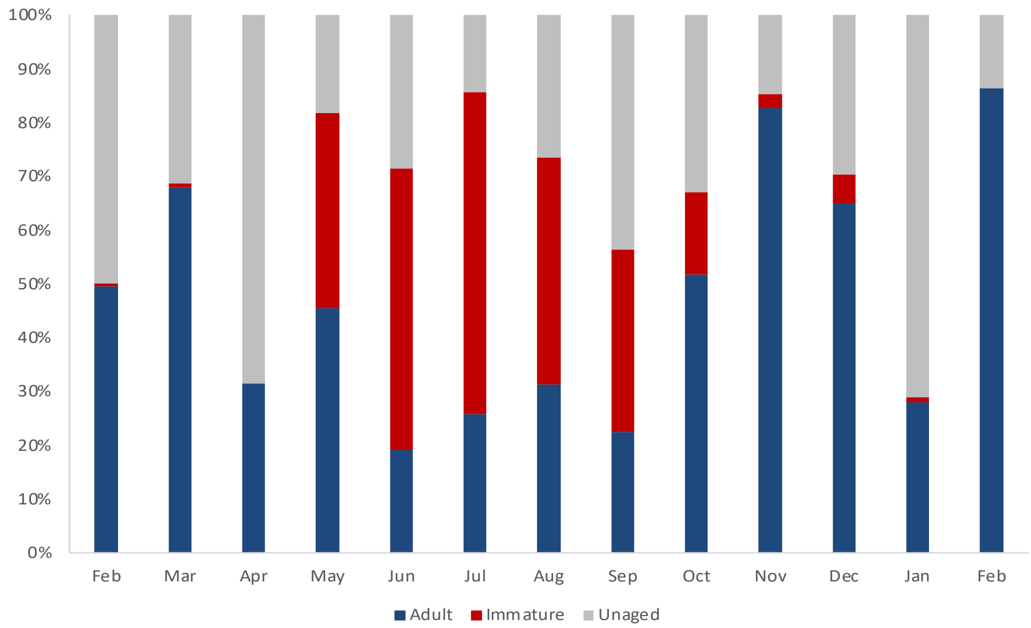

Figure 3.4 *Percentages of adult, immature and unaged Northern Gannets recorded each month.*

The monthly distribution of Northern Gannets is shown in figure 3.5. At this scale, concentrations between the two study areas seem similar. In January a high concentration was recorded in the northern study area, which can also be seen in the annual average. The annual figure possibly shows a slight decrease in densities towards the coast in both the northern and southern study areas, but this is not striking.

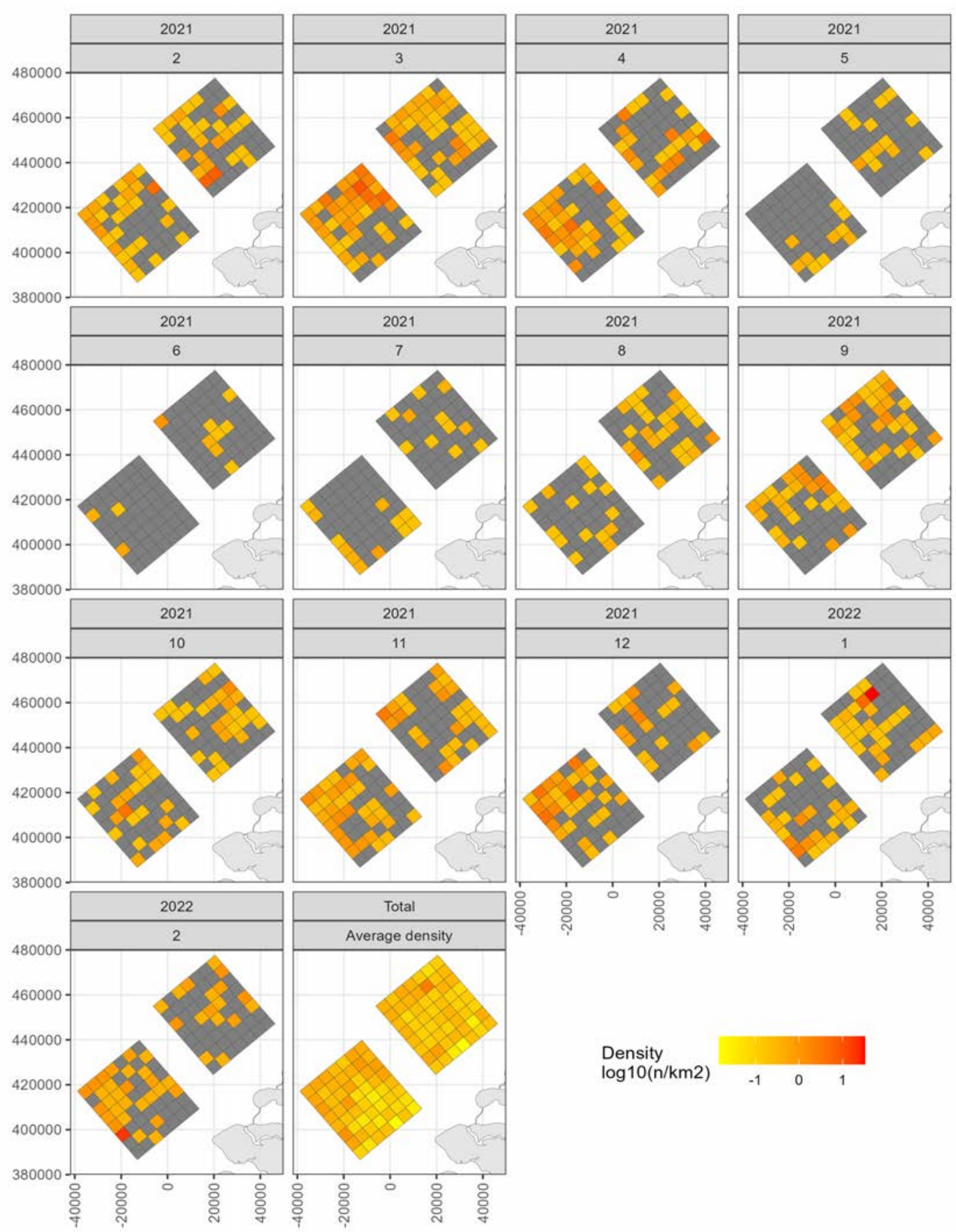

Figure 3.5 *Distribution of Northern Gannet across surveys areas and per month and averaged across all surveys as log of density (n/km^2). Densities based on identified individuals only and no apportioning of unidentified groups is applied. Grey squares show zero counts.*

3.3 Lesser Black-backed Gull

Lesser Black-backed Gulls were recorded in all surveys and totalled 3,235 across the year. Numbers peaked at 408 in the second survey in March, although a second peak of 400 was recorded in the first June survey. The general pattern throughout the year was an increase in numbers from February to March before a drop in May. After the second peak numbers per survey fluctuated but, except in September, remained above 200 through until December when numbers fell (figure 3.6).

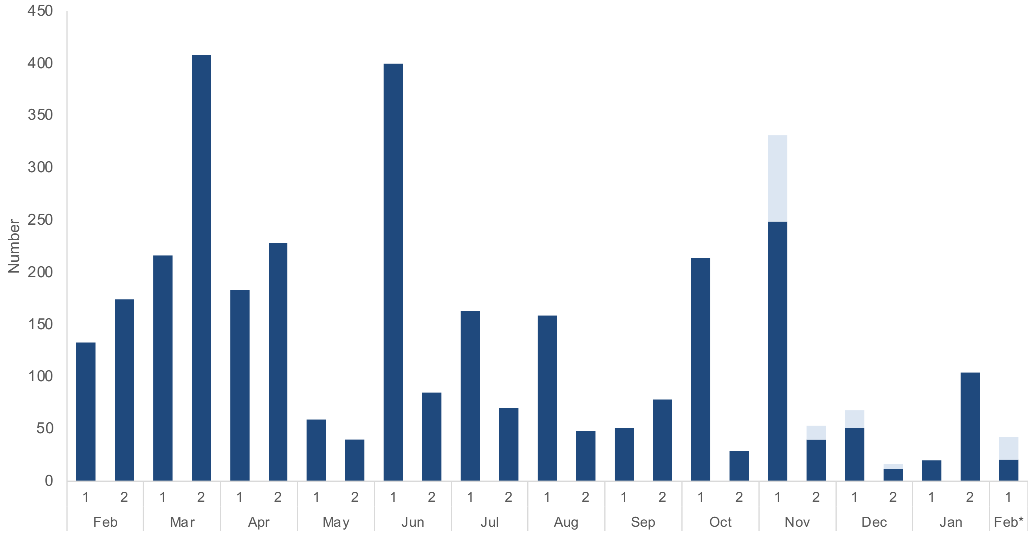

Figure 3.6 *Total numbers of Lesser Black-backed Gull recorded each survey. Note that the surveyed strip width in November and December surveys is approximately three-quarters that in other months due to the inclusion of data from three instead of four cameras as in other months. Extrapolated numbers for November and December are shown in light blue. * February 2022 total consists of one survey with extrapolated numbers for the second survey shown in light blue.*

Throughout all surveys, 51% of Lesser Black-backed Gulls recorded were aged. Ages were defined as either immature or adult. The proportion of unaged birds per month ranged between 13% to 88%, with relatively fewest being aged in December and January. The percentage of immature birds recorded each month varied between 4% and 45% (figure 3.7). Immature birds were recorded in greatest proportions in May, September and October although never outnumbering adults.

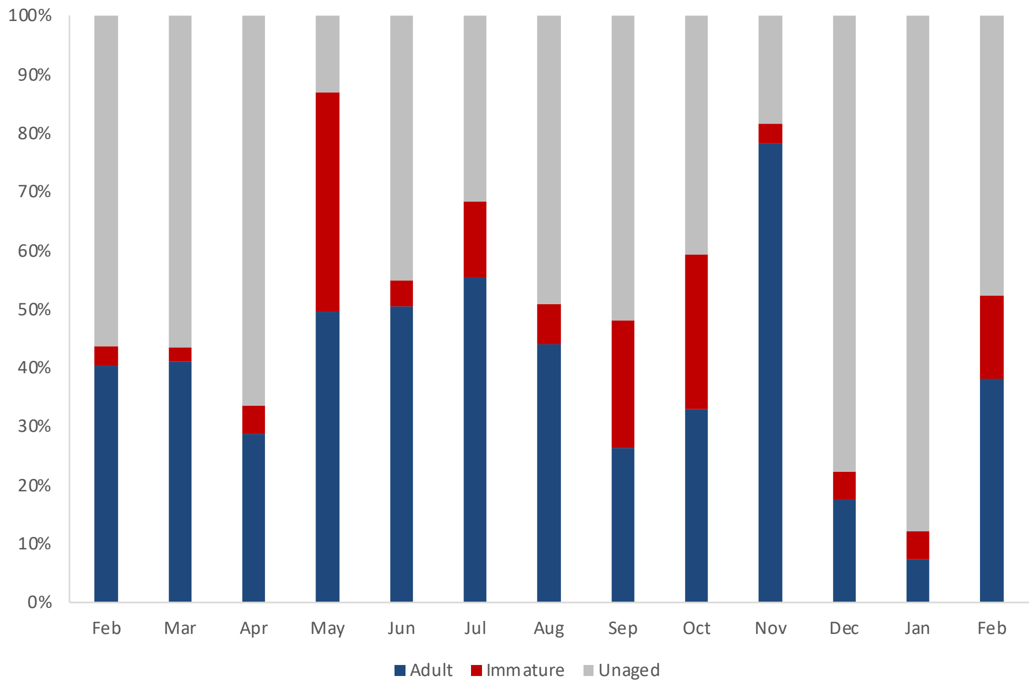

Figure 3.7 Percentages of adult, immature and unaged Lesser Black-backed Gull recorded each month.

Overall distributions of Lesser Black-backed Gulls appear fairly uniform, with only slight variation in concentrations evident in the northern study area (figure 3.8). Within months, densities in the northern and southern study areas again seem fairly similar, except in November and December when more are present in the southern study area.

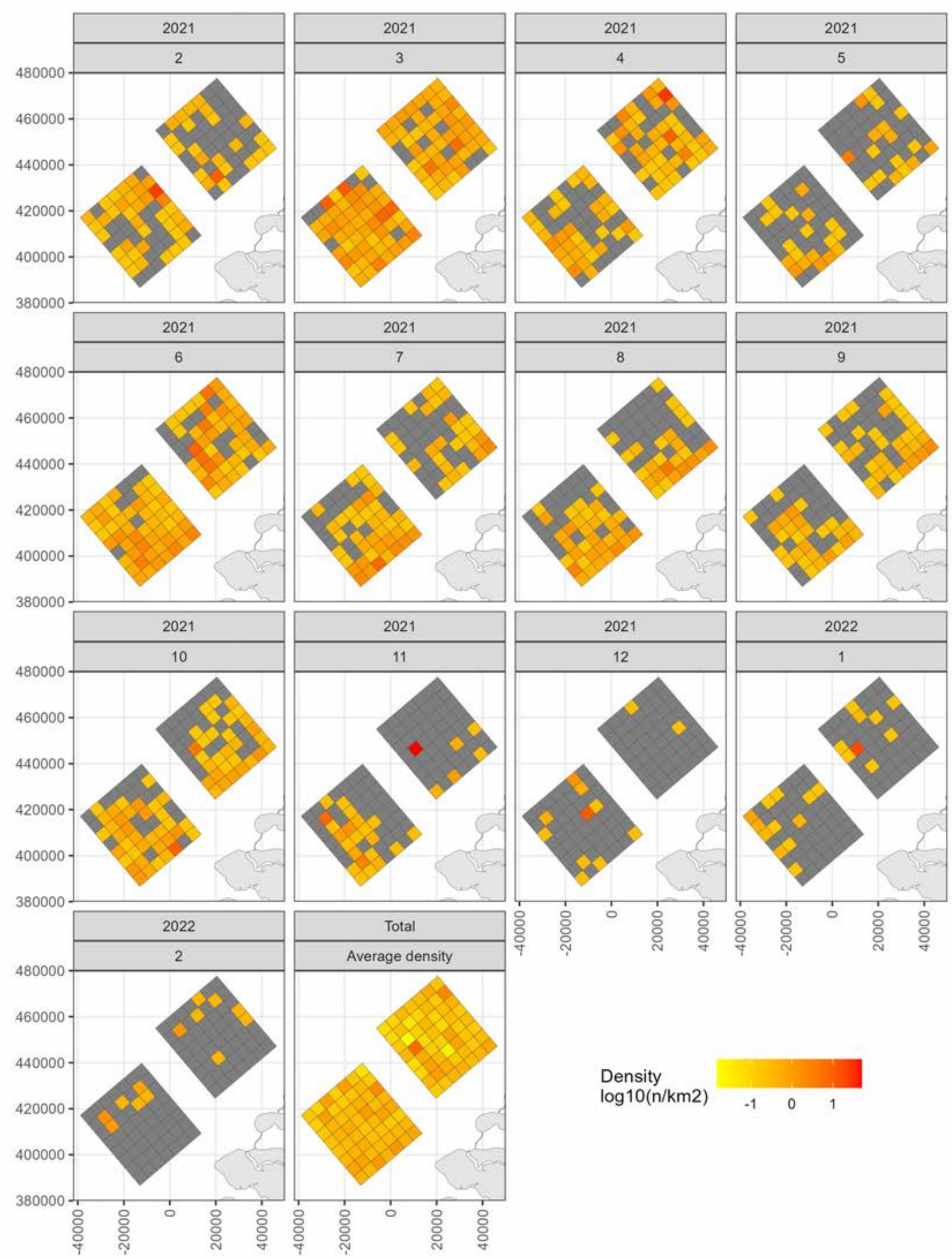

Figure 3.8 *Distribution of Lesser Black-backed Gulls across surveys areas and per month and averaged across all surveys as log of density (n/km²). Densities based on identified individuals only and no apportioning of unidentified groups is applied. Grey squares show zero counts.*

3.4 Great Black-backed Gull

Great Black-backed Gulls totalled 1,273 across the year. Numbers per survey fell after the initial survey and remained low or absent until rising again from August onwards. Numbers were highest in December through to February 2022 with a peak count of 253 in the first January survey (figure 3.9).

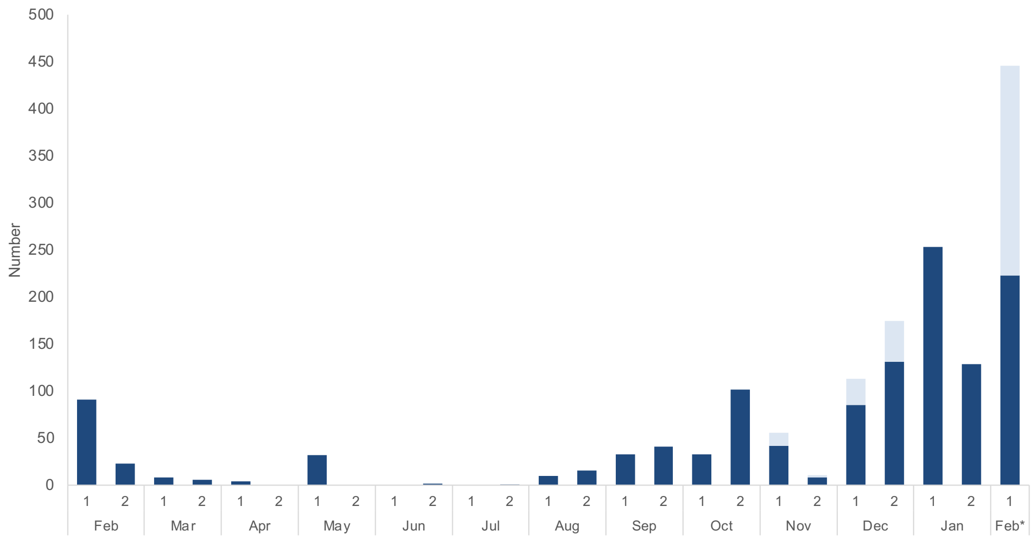

Figure 3.9 *Total numbers of Great Black-backed Gull recorded each survey. Note that the surveyed strip width in November and December surveys is approximately three-quarters that in other months due to the inclusion of data from three instead of four cameras as in other months. Extrapolated numbers for November and December are shown in light blue. * February 2022 total consists of one survey with extrapolated numbers for the second survey shown in light blue.*

Across all months, a total of 44% of Great Black-backed Gulls were aged. Birds were aged as either immature or adult. The proportion of immature birds varied between 15% and 42% in months with counts greater than 100 birds (figure 3.10). The high proportions of immature or adult birds between March and September can be explained by low totals (average counts of 10 per month) in those months.

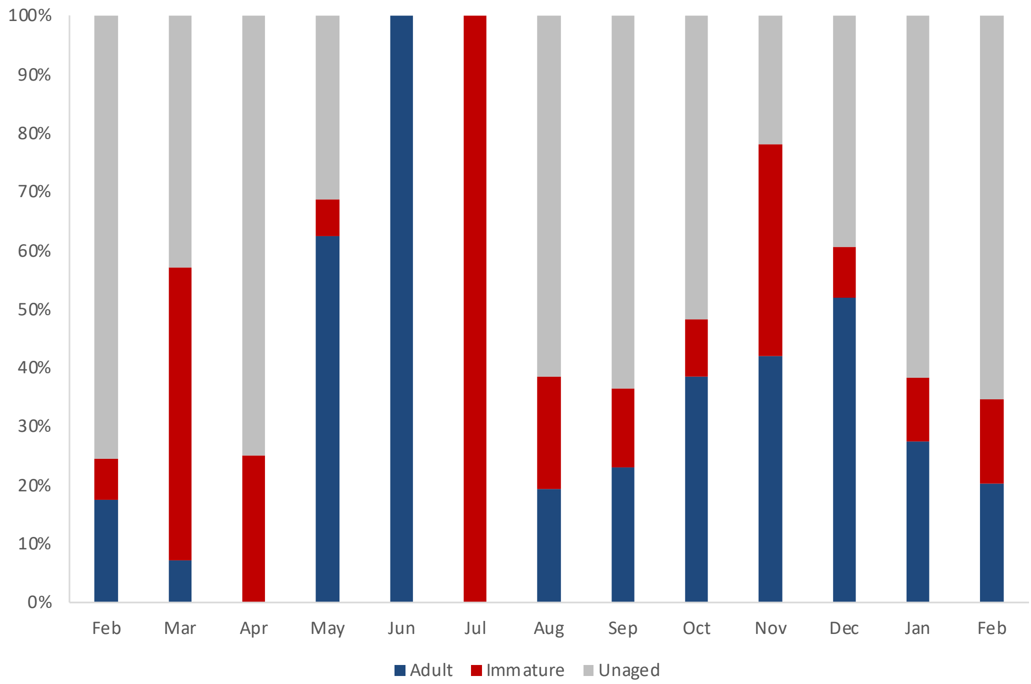

Figure 3.10 *Percentages of adult, immature and unaged Great Black-backed Gull recorded each month.*

Overall figures for Great Black-backed Gull between the northern and southern study areas appear fairly similar (figure 3.11). Within months, the distribution between these areas is again similar with no striking differences in the overall densities between areas. Exceptions are August, September, October and November when more appear to be present in the southern area.

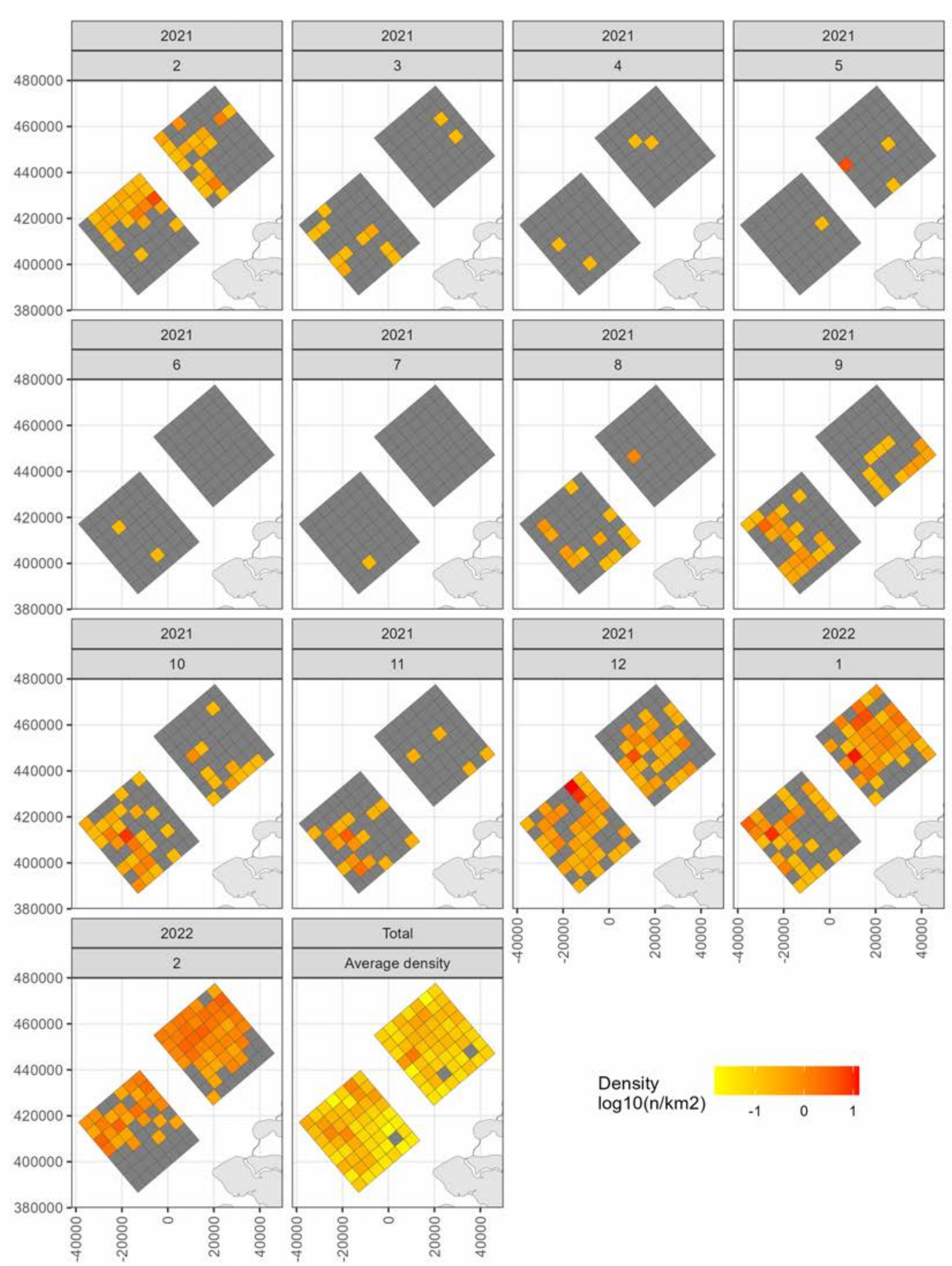

Figure 3.11 *Distribution of Great Black-backed Gulls across surveys areas and per month and averaged across all surveys as log of density (n/km^2). Densities based on identified individuals only and no apportioning of unidentified groups is applied. Grey squares show zero counts.*

3.5 Unidentified Lesser and Great Black-backed Gulls

For individuals that cannot be identified to species, a grouping is assigned. For Lesser and Great Black-backed Gulls, these may be assigned to the 'groups': 'unidentified large gulls', 'unidentified Larus gull', 'Great/Lesser Black-backed Gull' and 'unidentified gull'.

A total of 1,192 birds were recorded in these four 'unidentified' groupings, compared to 4,508 recorded to species level (either Lesser or Great Black-backed Gull). Unidentified birds were apportioned based on the survey-specific proportions of Lesser and Great Black-backed Gull recorded relevant to the constituent species of unidentified groupings.

Apportioned unidentified gulls accounted for between 57% and 0.5% of total Lesser Black-backed Gulls (figure 3.12). For Great Black-backed Gulls, apportioned unidentified gulls accounted for between 43% and 0% of post-apportioned figures (figure 3.13). Proportionally, apportioned unidentified gulls accounted for greatest numbers in July and October, and lowest numbers in February, March, May and June.

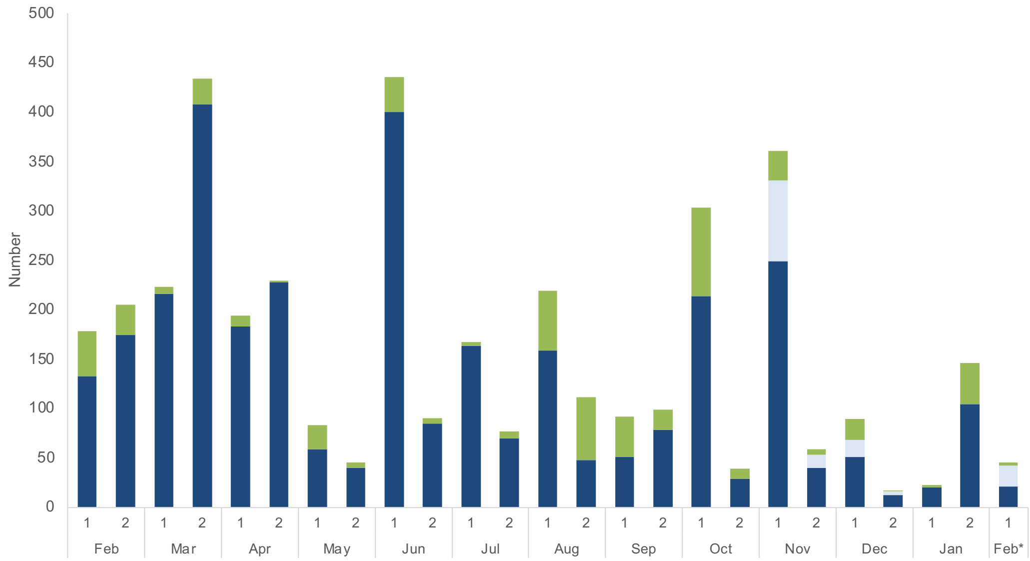

Figure 3.12 *Total numbers of Lesser Black-backed Gulls including apportioned 'unidentified large gulls', 'unidentified Larus gull', 'Great/Lesser Black-backed Gull' and 'unidentified gull' recorded each survey (green). Compare figure 3.6 which shows numbers of identified Lesser Black-backed Gulls only. Extrapolated numbers for November and December are shown in light blue. * February 2022 total consists of one survey with extrapolated numbers for the second survey shown in light blue.*

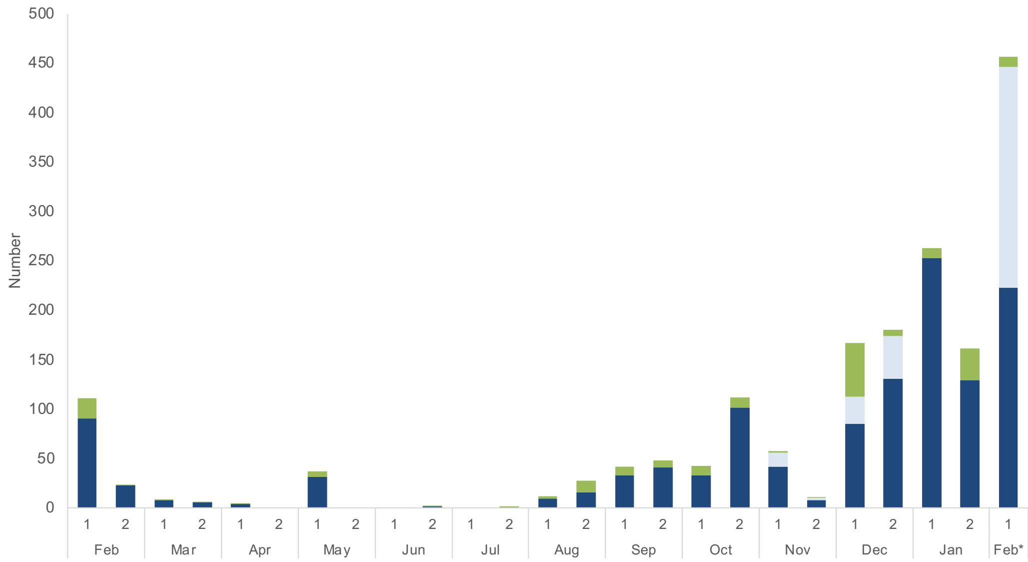

Figure 3.13 *Total numbers of Great Black-backed Gulls including apportioned 'unidentified large gulls', 'unidentified Larus gull', 'Great/Lesser Black-backed Gull' and 'unidentified gull' recorded each survey (green). Compare figure 3.9 which shows numbers of identified Great Black-backed Gulls only. Extrapolated numbers for November and December are shown in light blue. * February 2022 total consists of one survey with extrapolated numbers for the second survey shown in light blue.*

3.6 Black-legged Kittiwake

Black-legged Kittiwakes show a highly seasonal variation in abundance during surveys. A total of 9,852 were recorded throughout the year with a peak of 2,457 in the first January Survey. Early in the survey year, numbers per survey remained between 185-700 until the second April survey when numbers dropped to just 17. The species was then only recorded in low numbers or was absent in surveys until the second survey in October. Numbers recorded per survey then rose throughout the winter until into January (figure 3.14).

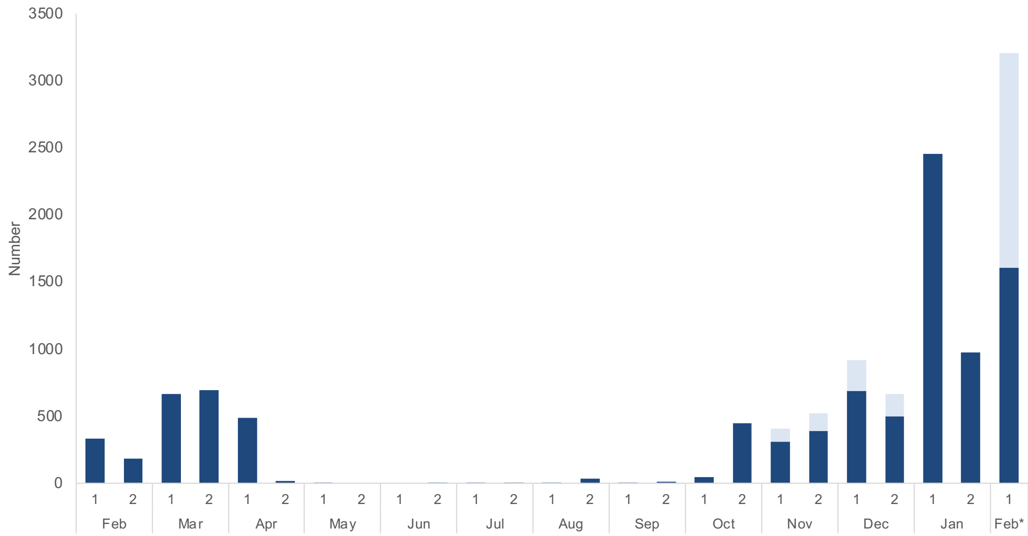

Figure 3.14 *Total numbers of Black-legged Kittiwake recorded each survey. Note that the surveyed strip width in November and December surveys is approximately three-quarters that in other months due to the inclusion of data from three instead of four cameras as in other months. Extrapolated numbers for November and December are shown in light blue. * February 2022 total consists of one survey with extrapolated numbers for the second survey shown in light blue.*

Throughout the year, a total of 46% of Black-legged Kittiwakes were aged. Birds were aged as either immature or adult. The proportion of immature birds never reached above 50% in any single month, with the highest ratios in May and September (figure 3.15). No immatures were recorded in June or July, but only one and five Black-legged Kittiwakes were recorded in these months respectively.

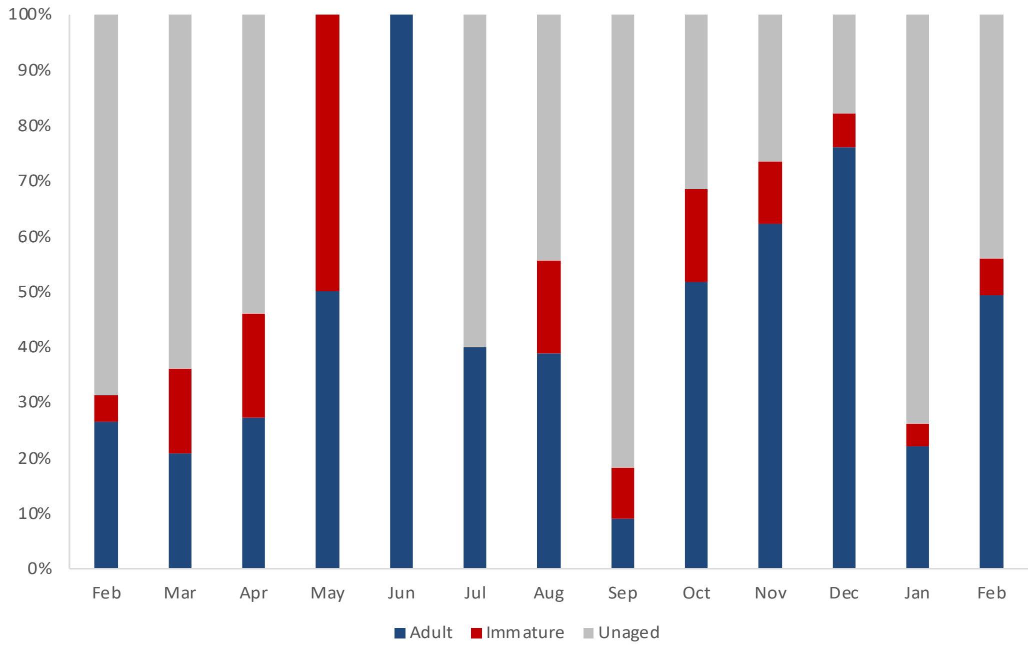

Figure 3.15 *Percentages of adult, immature and unaged Black-legged Kittiwake recorded each month.*

In general, the distributions of Black-legged Kittiwakes were fairly similar between study areas, although the overall average showed slightly higher densities in the southern part of the southern area (figure 3.16). This was particularly evident in January. In some months, such as February, March, April and February 2022, numbers appear higher further from the coast, but in other months such as October and November this pattern is reversed.

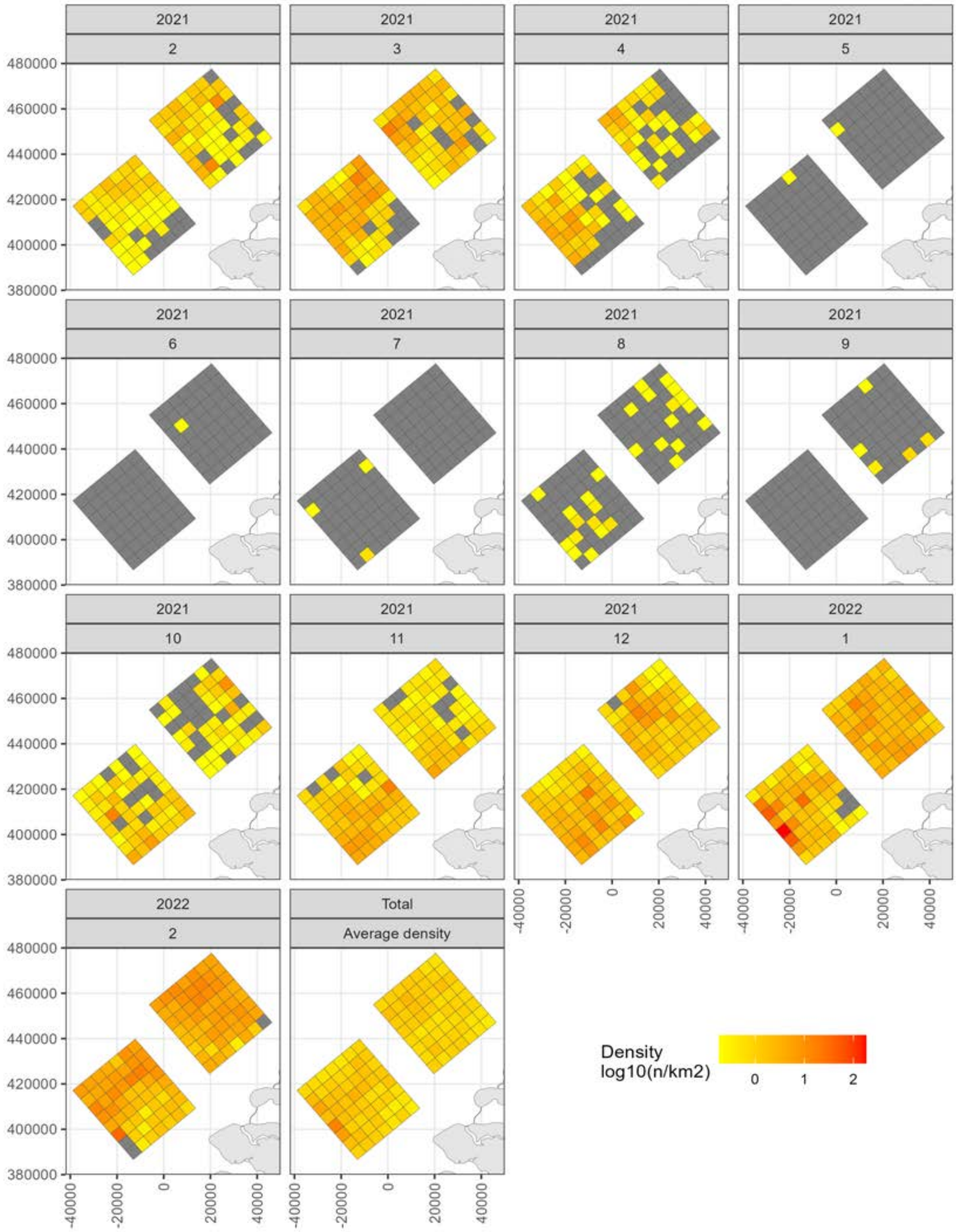

Figure 3.16 *Distribution of Black-legged Kittiwakes across surveys areas and per month and averaged across all surveys as log of density (n/km^2). Densities based on identified individuals only and no apportioning of unidentified groups is applied. Grey squares show zero counts.*

3.7 Common Guillemot

A total of 15,331 Common Guillemots were recorded during the year. Common Guillemot numbers increased at a regular rate during the initial five surveys before falling sharply. Numbers recorded then remained low before until increasing only slightly to triple figures in October and early December. It was from the second survey in December onwards that numbers recorded rose into the thousands, with a gradual decrease in numbers following the peak count of 4,395 in the second survey in December (figure 3.17). Only one Common Guillemot was aged, this was an immature bird.

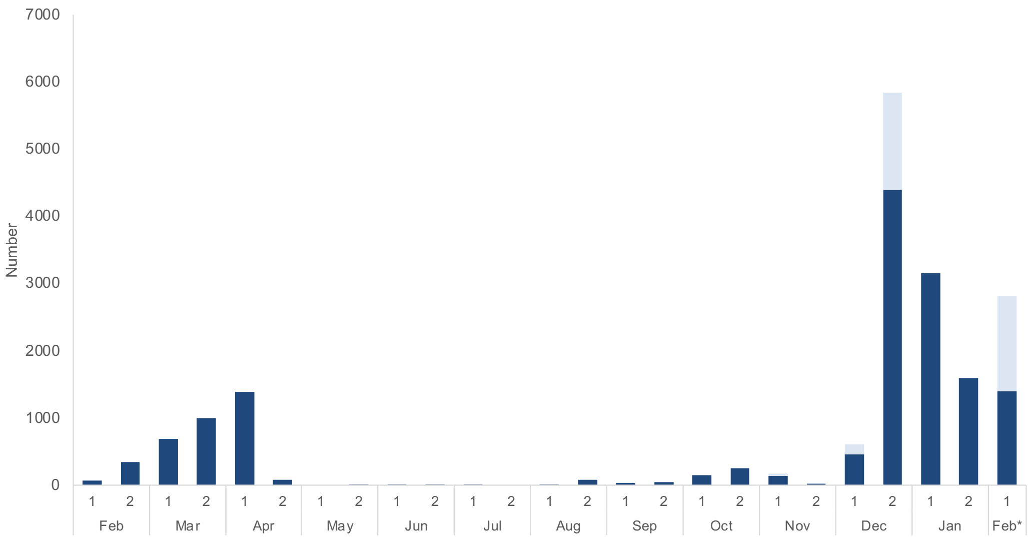

Figure 3.17 *Total numbers of Common Guillemot recorded each survey. Note that the surveyed strip width in November and December surveys is approximately three-quarters that in other months due to the inclusion of data from three instead of four cameras as in other months. Extrapolated numbers for November and December are shown in light blue. * February 2022 total consists of one survey with extrapolated numbers for the second survey shown in light blue.*

Overall, densities of Common Guillemots were slightly higher in the northern area and further from the coast (figure 3.18). This pattern is perhaps most evident in December, January and February 2022. In other months, such as March, this pattern is reversed with highest densities in the southern area.

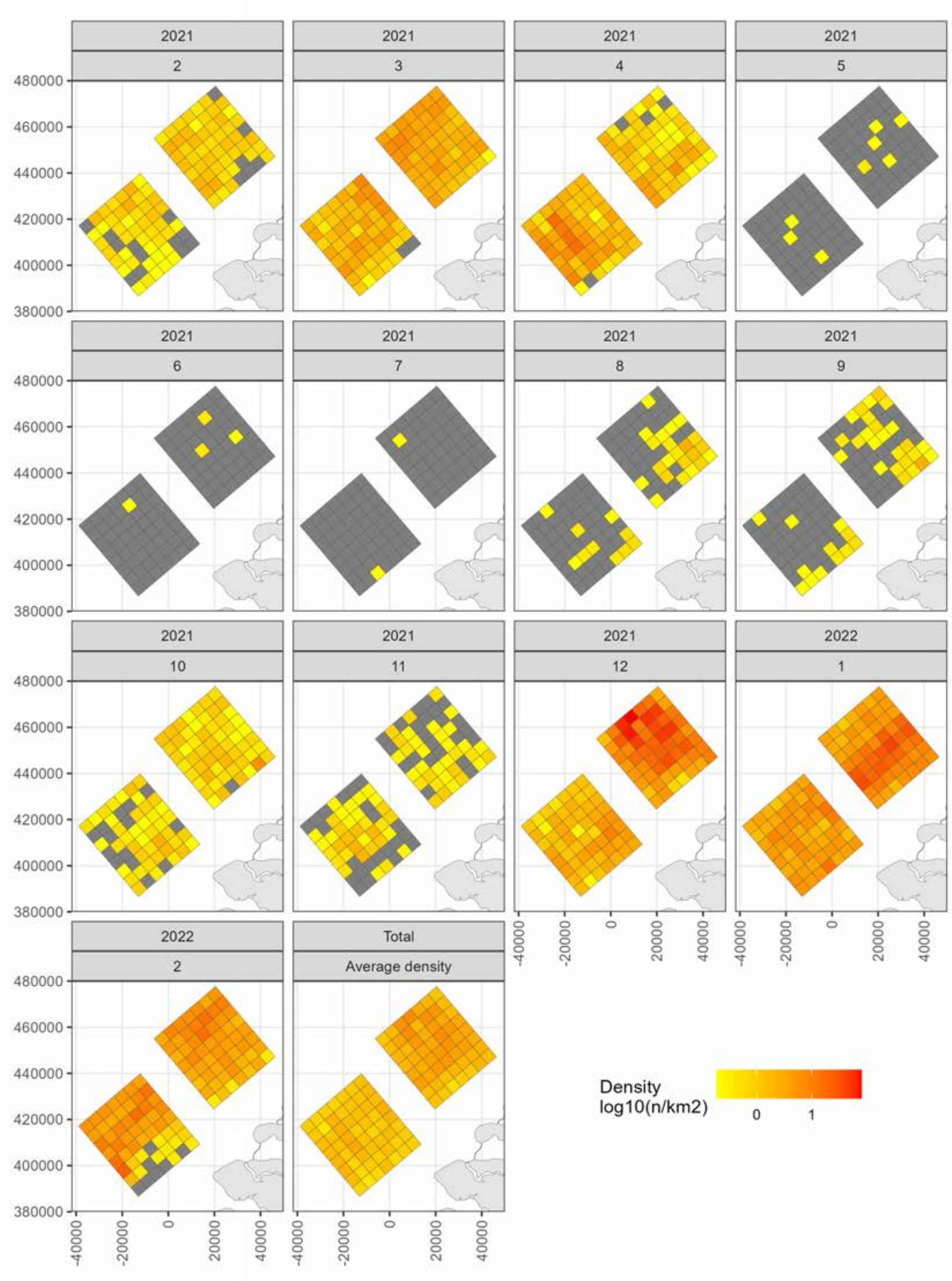

Figure 3.18 *Distribution of Common Guillemots across surveys areas and per month and averaged across all surveys as log of density (n/km^2). Densities based on identified individuals only and no apportioning of unidentified groups is applied. Grey squares show zero counts.*

3.8 Razorbill

A total of 7,371 Razorbills were recorded throughout the year. A peak count of 1,094 in the second February survey was followed by three counts in the three-hundreds. Numbers then fell, with just ten birds being recorded in the 11 surveys from late April to September. In the October surveys numbers indicate a mass return of birds with monthly totals increasing to peak at 1,750 in January (figure 3.19). No Razorbills were aged.

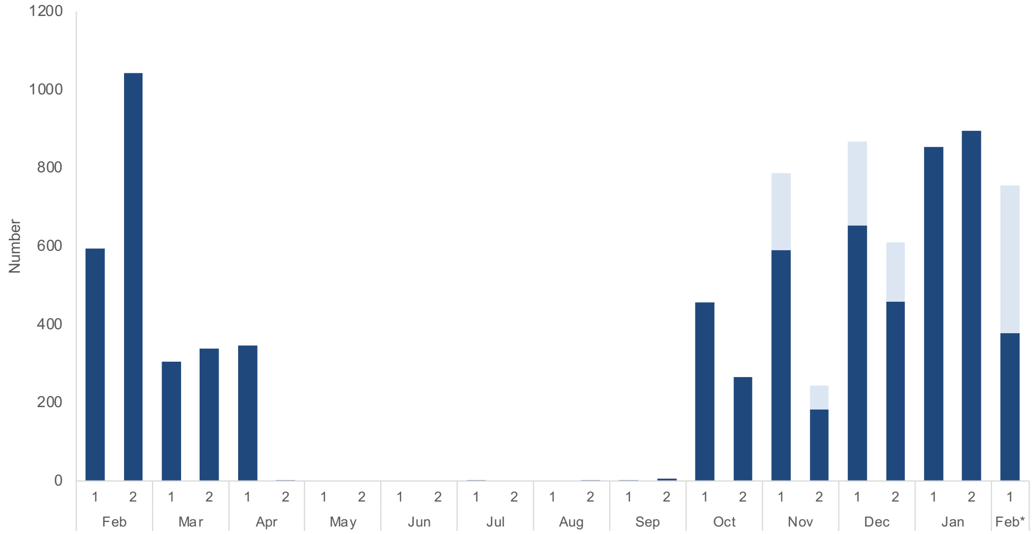

Figure 3.19 *Total numbers of Razorbill recorded each survey. Note that the surveyed strip width in November and December surveys is approximately three-quarters that in other months due to the inclusion of data from three instead of four cameras as in other months. Extrapolated numbers for November and December are shown in light blue. * February 2022 total consists of one survey with extrapolated numbers for the second survey shown in light blue.*

Overall, highest densities of Razorbills were seen nearer the coast, both in the northern and southern areas (figure 3.20). This pattern is not strongly evident in any one month, perhaps except in October, November and December. In February, concentrations can be found in the northern area, but this is not evident in other months.

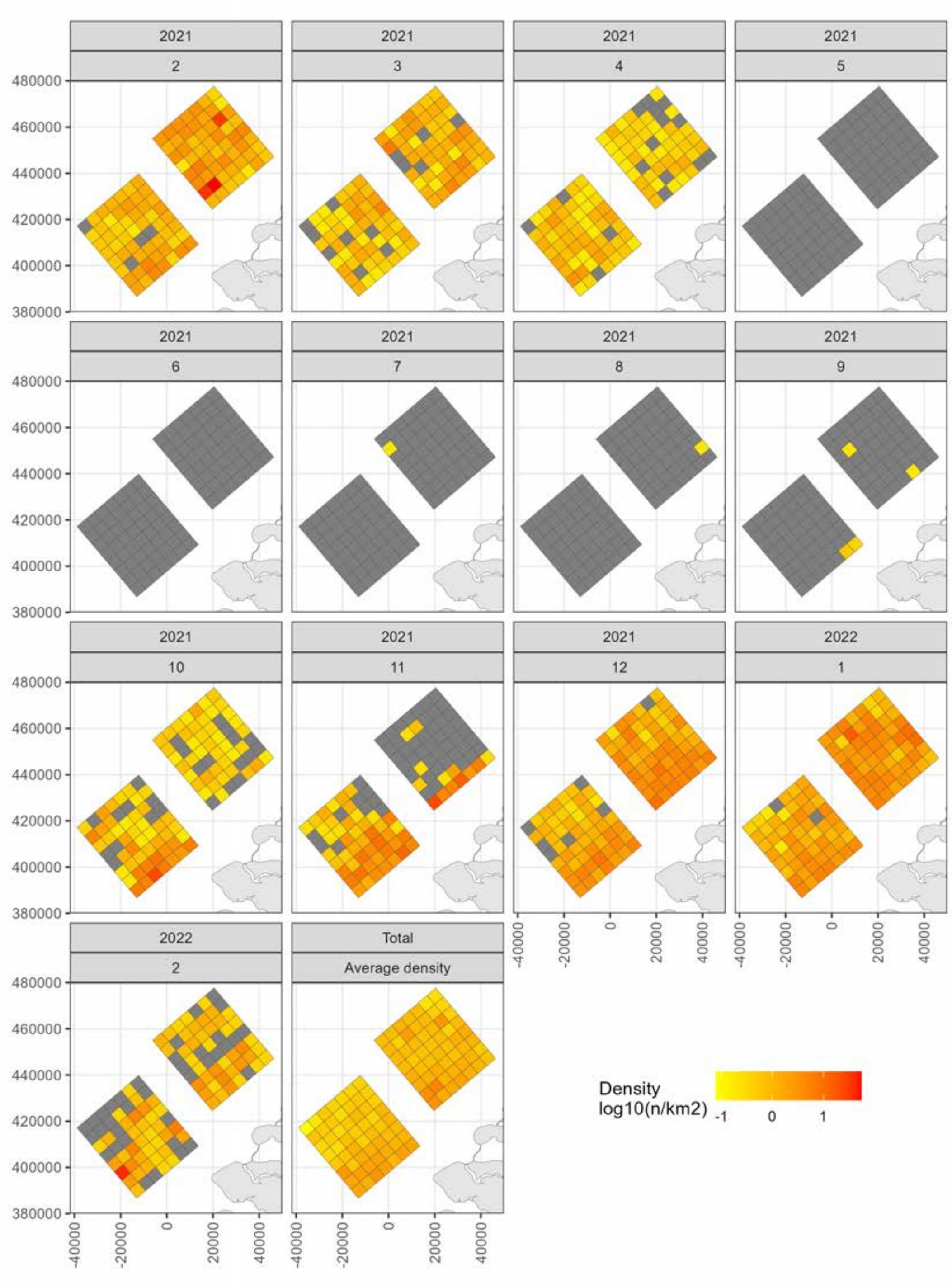

Figure 3.20 *Distribution of Razorbills across surveys areas and per month and averaged across all surveys as log of density (n/km²). Densities based on identified individuals only and no apportioning of unidentified groups is applied. Grey squares show zero counts.*

3.9 Unidentified Common Guillemot and Razorbill

Individuals of similar species, a prime example being Common Guillemot and Razorbill, cannot always be differentiated to species during surveys. As such, it is common to pool such individuals into a group consisting of these species. For example, the grouping 'Common Guillemot/Razorbill' contains individuals that are certainly one of these species but cannot be identified further. This grouping is separate to that of 'unidentified auks', which also contains individuals that can only be identified at auks and not even as either Common Guillemot or Razorbill. This grouping will inevitably also contain some Common Guillemots and Razorbills but also (in the current surveys) Atlantic Puffins and Little Auks, albeit most likely in low numbers.

Due to these limitations with identification species such as Common Guillemot may be assigned to one of several groups: i.e. 'Common Guillemot' or 'Common Guillemot/Razorbill' or 'unidentified auk' or even in some cases 'unidentified bird'.

During analyses of these species, it is important to consider the numbers of individuals that could not be identified to species. In the case of Common Guillemot and Razorbill the likelihood of an individual being assigned to the group 'Common Guillemot/Razorbill' can be considered equal for both species. As such, this group is often apportioned to the species based on the ratios of identified Common Guillemots to Razorbills in each survey (e.g. Fijn *et al.* 2022).

During the 25 surveys between February 2021 and February 2022, a total of 4,733 birds were assigned to the group 'Common Guillemot/Razorbill'. Across the year, this constituted 17% of all Common Guillemots and Razorbills (assigned to species or the two-species grouping). In addition, a total of 118 birds were assigned as 'unidentified auk'. This constitutes less than 0.5% of all Common Guillemots and Razorbills, and as such, along with the likelihood that this group most likely contains other auk species (particularly as Common Guillemot and Razorbill are most likely assigned to the 'Common Guillemot/Razorbill' grouping), we do not include these birds in the following analysis.

The proportion of Common Guillemots or Razorbills that could not be identified to species varied between 12% and 28% in months in which over 100 birds were counted (figure 3.21). In several months the number of unidentified Common Guillemot/Razorbills outnumbered either Common Guillemots or Razorbills, however, in no months did the number of unidentified Common Guillemot/Razorbill outnumber the sum of identified Common Guillemots and Razorbills combined.

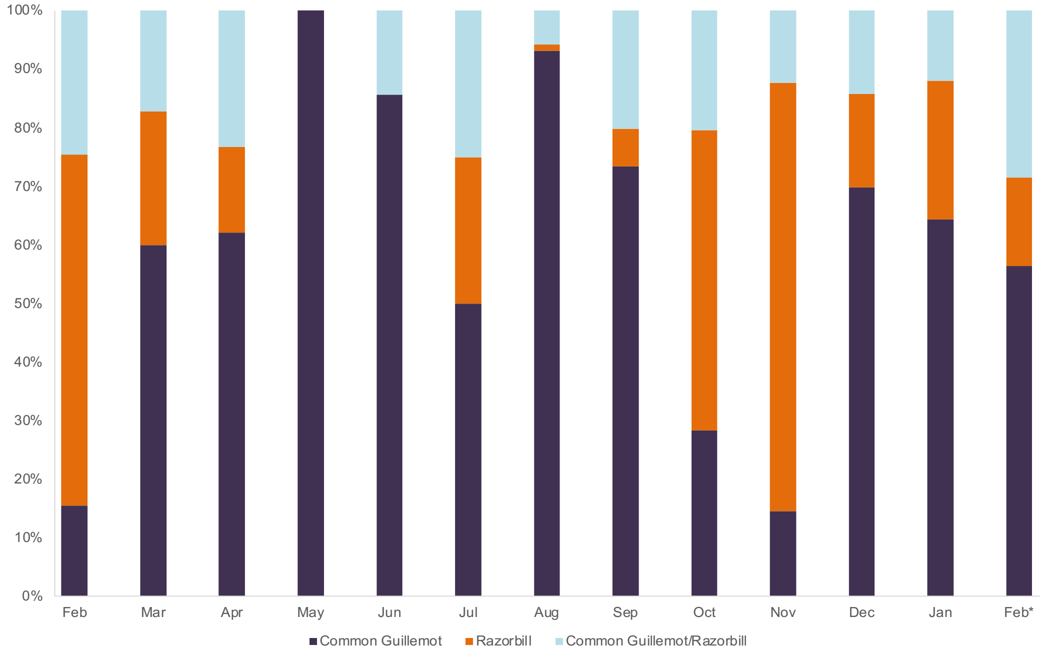

Figure 3.21 *Percentages of Common Guillemot, Razorbill and unidentified 'Common Guillemot/Razorbill' recorded each month.*

When apportioning unidentified Common Guillemot/Razorbills to the respective species, the general pattern of abundance across surveys remains unchanged (figures 3.22 and 3.23, cf. figures 3.17 and 3.19). The only slight change for Common Guillemot is a slight relative increase in numbers in the February 2022 survey. For Razorbill, a slight relative decrease can be seen in the same survey. This results from a relatively high proportion of Common Guillemots and Razorbills being unidentified to species and the relatively high proportion of Common Guillemot to Razorbill in this survey.

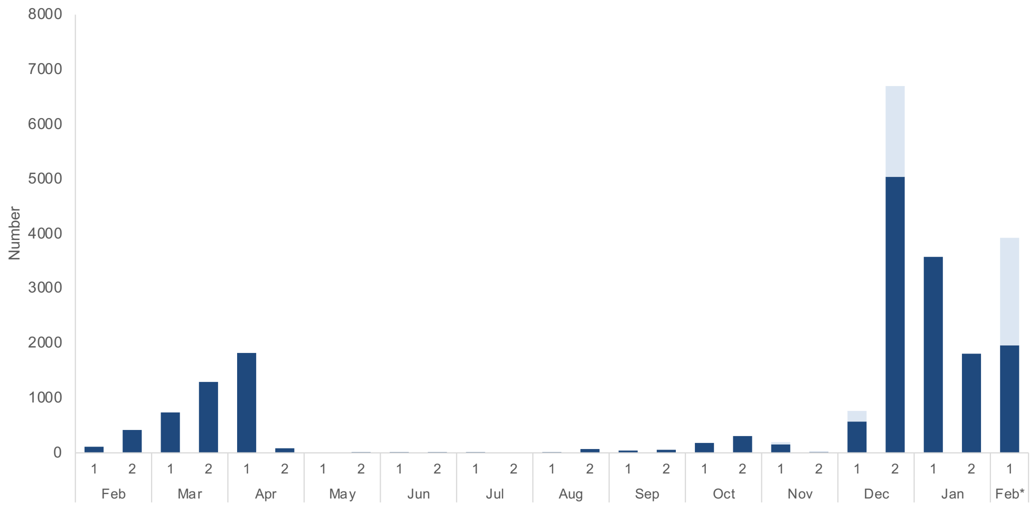

Figure 3.22 *Total numbers of Common Guillemot including apportioned unidentified 'Common Guillemot/Razorbill' recorded each survey. Compare figure 3.17 which shows numbers of identified Common Guillemot only. Extrapolated numbers for November and December are shown in light blue. * February 2022 total consists of one survey with extrapolated numbers for the second survey shown in light blue.*

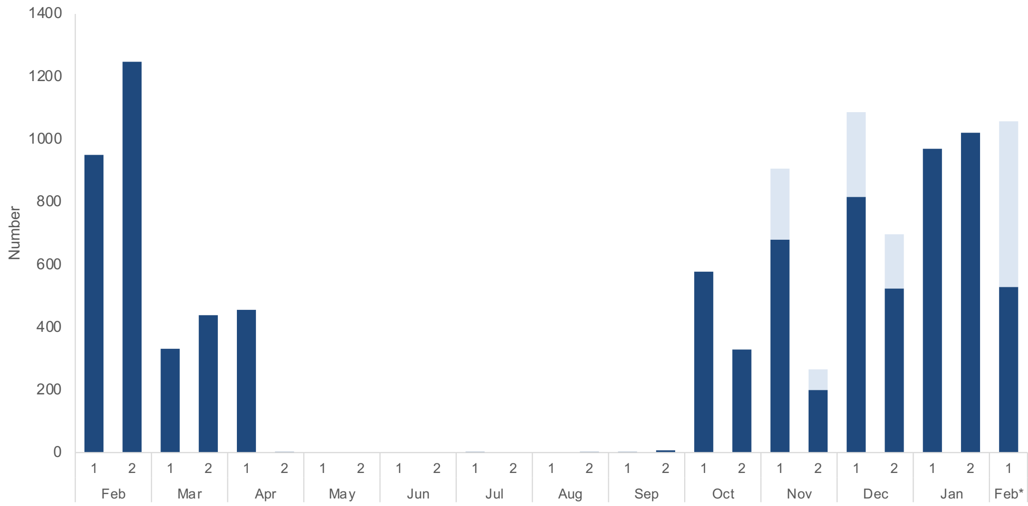

Figure 3.23 *Total numbers of Razorbill including apportioned unidentified 'Common Guillemot/Razorbill' recorded each survey. Compare figure 3.19 which shows numbers of identified Common Guillemot only. Extrapolated numbers for November and December are shown in light blue. * February 2022 total consists of one survey with extrapolated numbers for the second survey shown in light blue.*

The monthly distribution of Common Guillemot, Razorbill and Common Guillemot/Razorbill is shown in figure 3.24. At this scale, annual concentrations between the two study areas seem to be slightly higher in the northern area. This is certainly evident in February, December and January, although in April and November is reversed. In December particularly high densities were recorded in the seaward part of the northern area, yet in November concentrations appear to be higher nearer the coast.

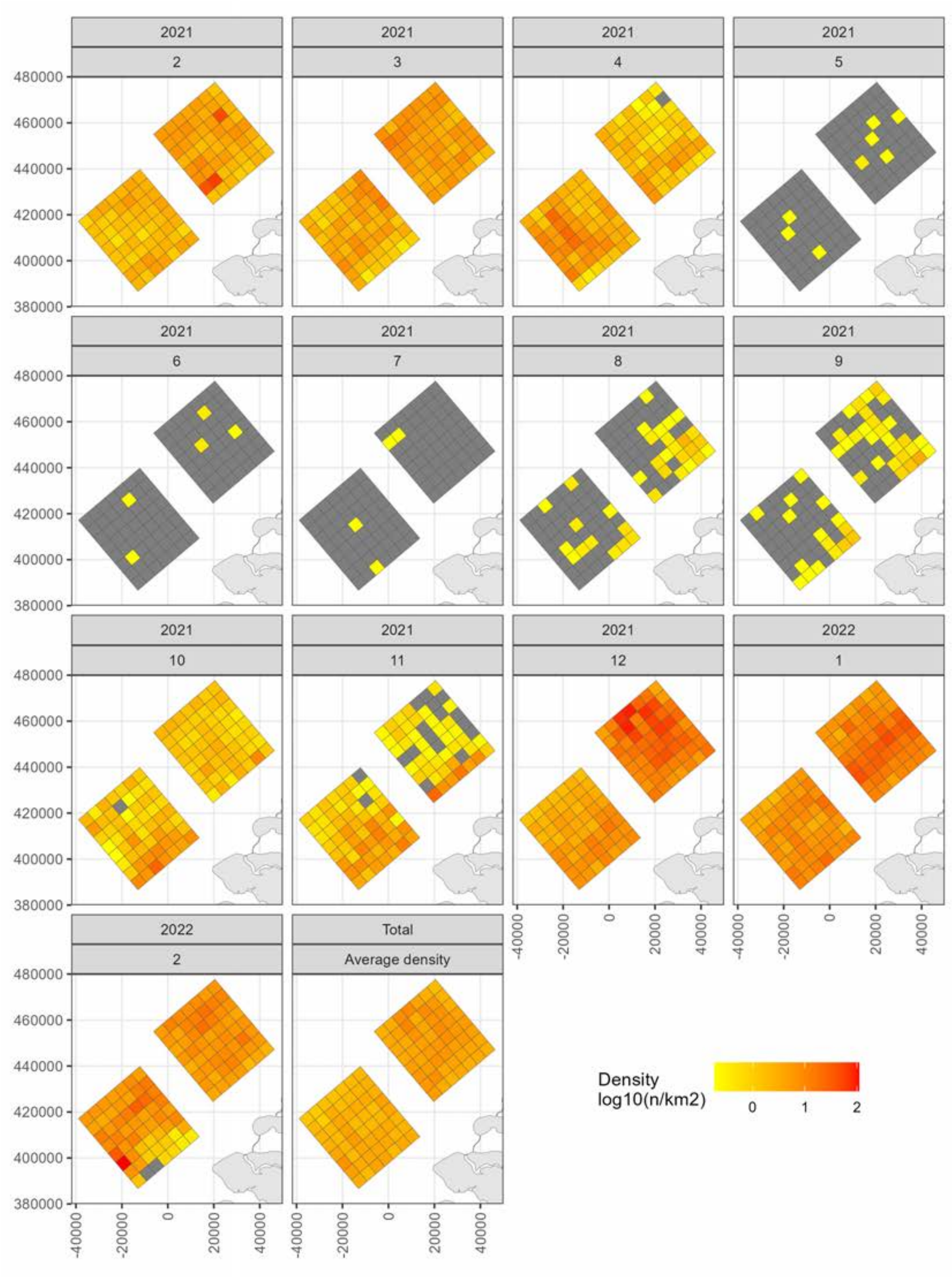

Figure 3.24 *Distribution of Common Guillemot, Razorbills and Common Guillemot/Razorbills across surveys areas and per month and averaged across all surveys as log of density (n/km^2). Densities based on identified individuals only and no apportioning of unidentified groups is applied. Grey squares show zero counts.*

3.10 Harbour Porpoise

A total of 1,551 Harbour Porpoises were counted during the 25 surveys. Numbers per survey varied throughout the year with a peak of 361 during the second survey in February and fewest recorded (8) in the second survey in July, although monthly totals remained between 24 (August) and 369 (March) (figure 3.25).

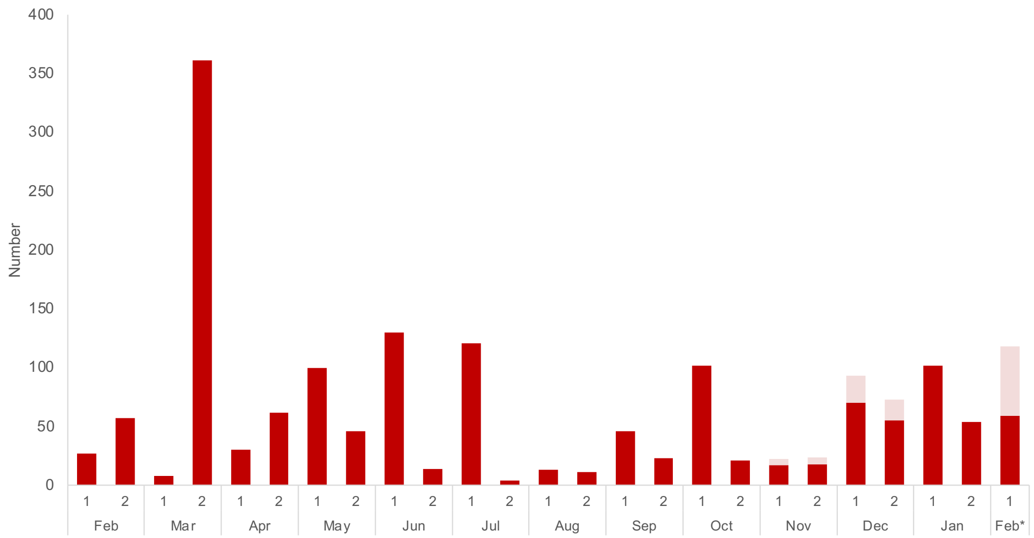

Figure 3.25 *Total numbers of Harbour Porpoise recorded each survey. Note that the surveyed strip width in November and December surveys is approximately three-quarters that in other months due to the inclusion of data from three instead of four cameras as in other months. Extrapolated numbers for November and December are shown in light red. * February 2022 total consists of one survey with extrapolated numbers for the second survey shown in light red.*

Across all surveys, 65% of Harbour Porpoises were aged. The majority of these were adults with the percentage of immatures only being above 10% in June and October (figure 3.26). Young Harbour Porpoises remain with the mother for between eight to ten months and most immatures are aged alongside an adult (Camphuysen & Krop 2011). With peak calving in the southern North Sea being in June and July, this most likely explains the difficulty in ageing animals as immatures in spring.

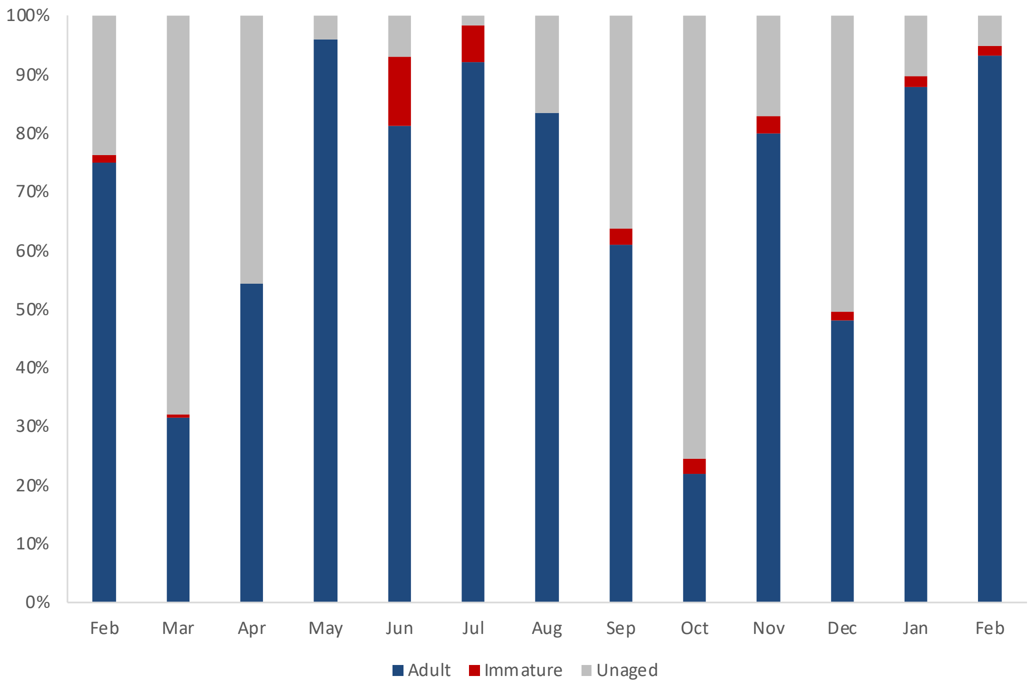

Figure 3.26 *Percentages of adult, immature and unaged Harbour Porpoise recorded each month.*

The monthly distribution for Harbour Porpoise is shown in figure 3.27. Overall, densities seem to be fairly similar between areas, although appear slightly higher in the southern area. Monthly patterns show a similar pattern, with no striking differences between the northern and southern areas.

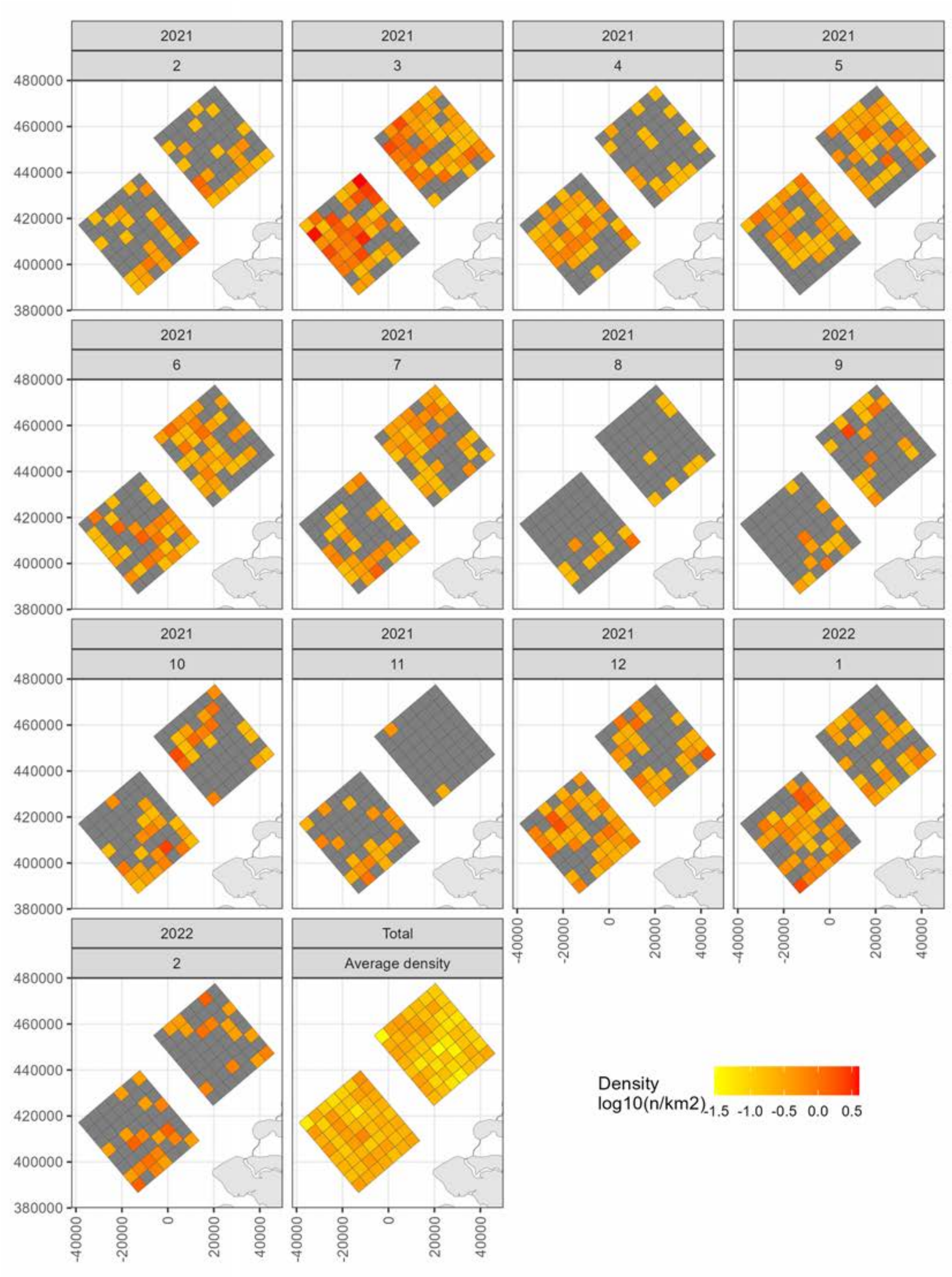

Figure 3.27 *Distribution of Harbour Porpoises across surveys areas and per month and averaged across all surveys as log of density (n/km^2). Densities based on identified individuals only and no apportioning of unidentified groups is applied. Grey squares show zero counts.*

4 Seabird and porpoise densities in and around the wind farm

A key objective of the current study is to investigate the distribution of key seabird species in and around the wind farms. Digital aerial surveys, unlike the observer-based aerial surveys, are conducted at a height above the tip of wind turbines. This allows numbers and distributions within wind farms to be recorded.

Here we investigate whether densities of key species differ within and near to the wind farms, and within the reference area using a robust method. In addition, we present figures from ship-based surveys conducted in Belgian offshore wind farms within the same period.

4.1 Methods and data section

For the general methods of the digital aerial surveys, see chapter 2. The survey data were divided into 5x5 km grid cells covering 2.5 km either side of the transect lines and from start to finish of the transects. This resulted in a total of 112 5x5 km grid cells (56 in each of the two study areas). Each grid cell was assigned to one of three classes based on its proximity to an offshore wind farm: 1) grid cells of the southern area with the midpoint within an offshore wind farm; 2) grid cells of the southern area with the midpoint outside the offshore wind farms; and 3) grid cells of the northern reference area (figure 4.1).

Data from the six key seabird species and Harbour Porpoise were selected from the digital aerial surveys data from February 2021 to February 2022. In addition, two species groups were analysed: 1) all bird species combined (including all species, not only the key species); and 2) Common Guillemot and Razorbill (plus ‘Common Guillemot/Razorbill’) combined (table 4.1). For each species and species group, only surveys with more than 25 sightings were included in the analysis.

Table 4.1 Species and species groups included in the analyses with number of surveys and number of individuals included.

Species/group	Number of surveys	Number of individuals
All birds	25	56,580
Northern Gannet	17	1,913
Lesser Black-backed Gull	22	3,182
Great Black-backed Gull	12	1,195
Black-legged Kittiwake	15	9,815
Common Guillemot	17	15,289
Razorbill	14	7,361
Common Guillemot/Razorbill	18	27,409
Harbour Porpoise	16	1,422

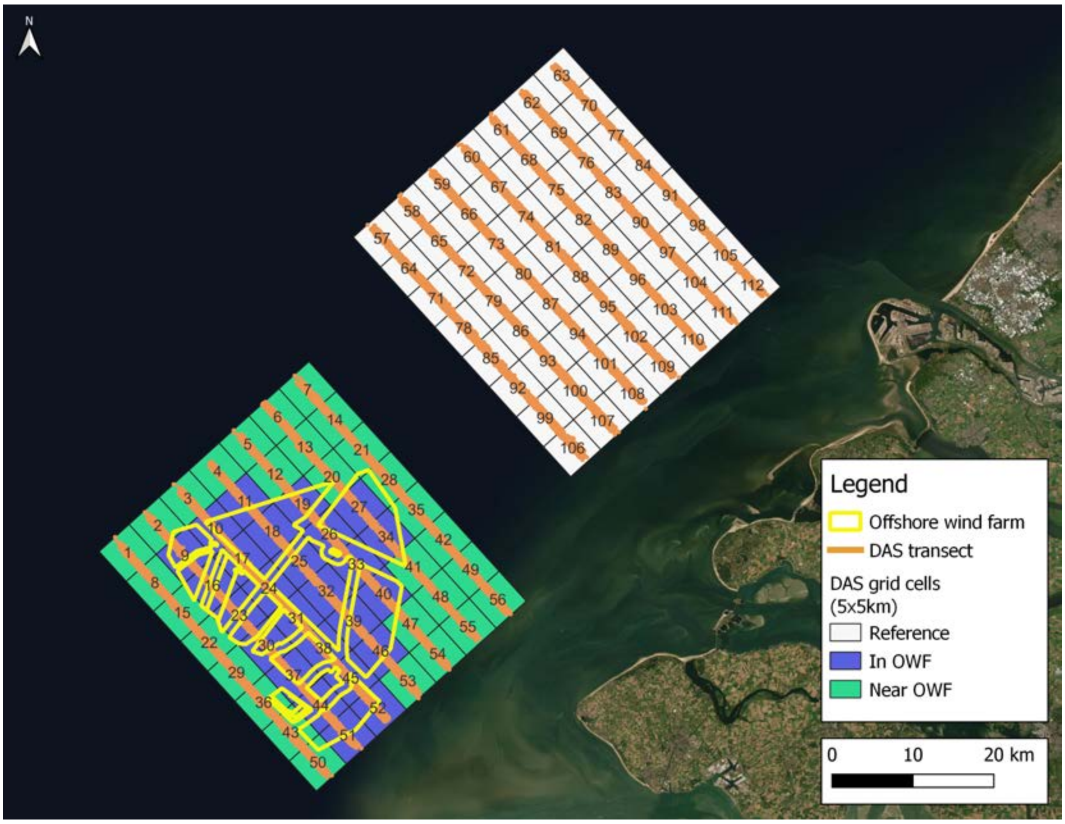

Figure 4.1 *Study area showing the separation of the three areas: within the offshore wind farms (In OWF), near the offshore wind farms (Near OWF), and the reference area (Reference).*

4.2 Statistical analysis

Bayesian Generalized Linear Mixed Models (GLMMs) were constructed for each species and species group, with number per transect (5 km) segment as the response variable with a negative binomial distribution, area (with three levels: 1) inside the offshore wind farm; 2) outside the offshore wind farm; or 3) in the northern reference area) as a fixed effect. In addition, random slopes of the effect of area were included per ‘survey’ and random intercepts were included per ‘survey’. The natural log of the surveyed area per segment was included as an offset. Models were fitted using the brms package (Bürkner 2017, 2022) in R version 4.1.2 (R Core Team 2021), which provides a frontend to the Stan platform for statistical modelling and high-performance statistical computation. We used default uninformative priors, 4 chains of 6,000 iterations, a burn-in of 1,000 iterations, and a thinning-interval of 3 iterations. Model convergence was checked by visual inspecting of the chains, posterior predictive checks, and whether the potential scale reduction factor R-hat was within 0.01 of 1.

4.3 Results

Model-derived estimates of densities in and near the offshore wind farms, and in the reference area for the key species are given in table 4.2.

Table 4.2 Model-derived estimates of densities in and near the offshore wind farms (OWFs) and in the reference area.

Species	In OWF	Near OWF	Reference area
all bird species	4.22 (2.47 - 7.1)	4.04 (3.34 - 4.9)	3.68 (2.64 - 5.19)
Northern Gannet	0.19 (0.11 - 0.34)	0.38 (0.22 - 0.67)	0.26 (0.12 - 0.57)
Lesser Black-backed Gull	0.39 (0.26 - 0.58)	0.25 (0.13 - 0.46)	0.26 (0.13 - 0.5)
Great Black-backed Gull	0.32 (0.15 - 0.66)	0.15 (0.05 - 0.41)	0.16 (0.05 - 0.49)
Black-legged Kittiwake	1.64 (0.82 - 3.33)	1.42 (0.96 - 2.13)	1.12 (0.65 - 1.95)
Common Guillemot	0.77 (0.32 - 1.86)	0.89 (0.68 - 1.18)	1.34 (0.77 - 2.34)
Razorbill	1.56 (1.11 - 2.17)	1.52 (1.22 - 1.89)	1.23 (0.49 - 3.01)
Common Guillemot / Razorbill	1.93 (0.83 - 4.49)	2.23 (1.81 - 2.79)	2.46 (1.3 - 4.6)
Harbour Porpoise	0.27 (0.18 - 0.42)	0.27 (0.21 - 0.35)	0.20 (0.15 - 0.28)

For almost all species or species groups examined, posterior probabilities of the difference in bird densities within the offshore wind farms versus both directly outside the offshore wind farm and the northern reference area, overlapped with 0, meaning there was no strong support for differences in densities in the three areas (figure 4.2). Two exceptions were Northern Gannet, which was more numerous outside the offshore wind farm in the southern area than within the offshore wind farm (beta = 0.676, 95% CrI = 0.112 - 1.230), and Common Guillemot, which was more numerous in the northern reference area than within the offshore wind farm (beta = 0.553, 95% CrI = 0.003 - 1.108).

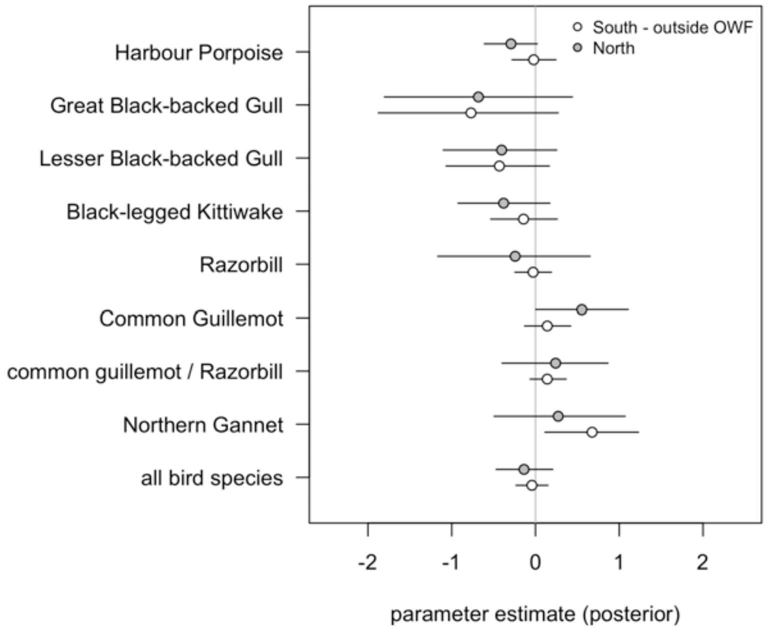

Figure 4.2 Parameter estimates of the difference between densities of key species within the offshore wind farm compared to the area surrounding it (white-filled circles) and the northern reference area (grey-filled circles). Error bars are 95% credible intervals. Deviations of estimates away from zero indicate a stronger effect. The position of 0 within the 95% credible intervals indicates the amount of support for an effect: if 0 falls outside the 95% credible interval there is strong support for an effect. The parameters are relative to the baseline, which is the area within the offshore wind farms. Thus, positive values indicate lower densities within the offshore wind farms compared to outside in the southern area, thus suggesting avoidance, whereas negative values indicate higher densities within the offshore wind farms compared to outside in the southern area, thus suggesting attraction.

4.4 Discussion

In general, for the species investigated we found little support for differences in densities within the offshore wind farm as compared to the area directly surrounding it and a more northern reference area. For only two species did we find strong evidence for different densities compared to the offshore wind farm: Northern Gannet, with higher densities in the areas directly surrounding the offshore wind farm, and Common Guillemot, with higher densities in the northern reference area. For both species, the comparison with the other area also suggested lower densities outside the offshore wind farm, but with posterior probabilities overlapping with 0, so these were inconclusive. However, for both species, lower densities within the offshore wind farm would be in line with earlier studies in other (Dutch) offshore wind farms (Krijgsveld *et al.* 2011, Leopold *et al.* 2013, Cook *et al.* 2018).

Although for most species we did not find conclusive evidence of a response to the offshore wind farm, it is interesting to note the direction of parameters. For example, the results suggest higher densities of Great Black-backed Gull, Lesser Black-backed Gull and Black-legged Kittiwake within the offshore wind farm. For the two former species, these results are in line with several studies reporting mixed effects. Lesser Black-backed Gulls have been reported to show avoidance (n=1), indifference (n=1) and attraction (n=1; see Vanermen *et al.* (2019)) in response to offshore wind farms (Cook *et al.* 2018), whereas Great Black-backed Gull showed avoidance (n=1) or indifference (n=4) (Cook *et al.* 2018).

The result for Black-legged Kittiwake, however, is more surprising, given that earlier studies reported avoidance (n=3) or indifference (n=4), but no attraction to offshore wind farms (Cook *et al.* 2018). The indifference toward the offshore wind farm suggested for Razorbill is surprising in the light of previous studies that report significant avoidance rates for alcids (Krijgsveld *et al.* 2011, Leopold *et al.* 2013).

For Harbour Porpoise, most studies have focused on the construction phase of offshore wind farms and found strong avoidance especially during periods of pile driving (Carstensen *et al.* 2006, Brandt *et al.* 2010). During the operational phase, studies report Harbour Porpoises to be indifferent to the present of an offshore wind farm (Vallejo *et al.* 2017), in line with our results.

For many of the study species, no conclusive support for either avoidance or attraction was found. Many of the parameters were associated with wide credible intervals, which can hopefully be reduced by the additional data that will be collected during 2022-2023.

4.5 Evidence from ship-based surveys

In addition to the digital aerial surveys, ship-based surveys have been conducted in and around some of the Belgian offshore wind farms in the south of the current survey area (Vanermen *pers. comm*. figure 4.3). Within the current survey period, ship-based surveys were only undertaken during two days in February 2021. These data have been collected by INBO who have kindly made summary information available for this report. Although these data were not appropriate for a full analysis, we present a summary here (table 4.3).

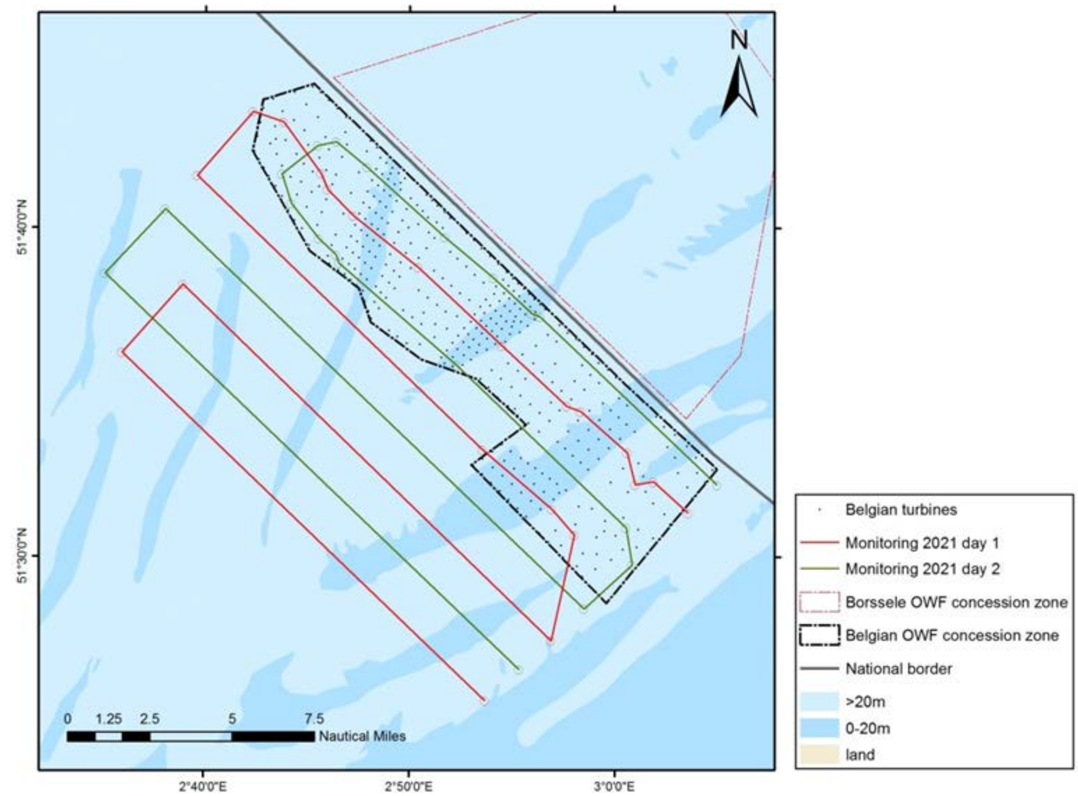

Figure 4.3 Transect route of ship-based surveys undertaken in February 2021 (from Vanermen pers. comm.).

A simple comparison of densities of key species inside and outside wind farms, as recorded during ship-based surveys, suggests higher densities of Lesser Black-backed Gulls outside the wind farms than inside. Whether this is partly caused by fishing activity (which can influence particularly numbers of gulls) outside the wind farms is unknown. Furthermore, numbers of Razorbills were almost double inside the wind farms than outside. Again, any reason for this, such as a particular concentration during this two-day survey is unknown.

Table 4.3 Summary densities (birds/km^2) of key species inside and outside wind farm areas during Belgian ship-based surveys in February 2021 (Vanermen pers. comm.)

Species	Inside	Outside
Northern Gannet	0.29	0.80
Lesser Black-backed Gull	0.43	14.27
Great Black-backed Gull	0.00	0.11
Common Guillemot	1.18	1.03
Razorbill	4.59	2.36

5 Comparison with observer-based aerial surveys

Currently, monitoring of Dutch offshore waters is undertaken through an observer-based aerial survey programme as part of the national MWTL programme (Fijn *et al.* 2022). The transects for this survey cover the entire Dutch North Sea, and several of these transect lines occur in and around the survey areas where the digital aerial surveys took place (see figure 2.1). These MWTL surveys use a line transect methodology where observations are assigned to one of six distance bands away from the transect line. Data are analysed using Distance analysis (Buckland *et al.* 1993). Unlike the digital aerial survey strip transect method, line transects rely on the use of detection curves to estimate the total number of each species in the total transect area.

Other differences between the observer based MWTL aerial surveys and the current digital aerial surveys include the height and speed at which the survey is flown. The MWTL surveys are flown at a height of 75 m above sea level and a speed of approximately 185 km/h with surveys in August, November, January, February, April and June. The current digital aerial surveys are flown at a height of 550 m above sea level and a speed of approximately 220 km/h.

Due to the spatial and temporal differences in the two surveys, a direct comparison of the species recorded and their densities, would yield limited useful information on the ability of each method to detect and identify species. Instead, we make a brief comparison of the numbers of selected key species identified to species and species-group level, and the ages recorded, in each survey. Although this does not act as an absolute measure of the ability of each method to identify species and ages this should provide a useful overview when considering the benefits of each method.

Data from the current digital aerial surveys were compared with observer based aerial MWTL surveys from the same year. MWTL surveys were available from February, April, June and August 2021, and January and February 2022, and only data from the base transects on the EEZ only were used and not the short coastal transects or from Brown Bank or Frisian Front (see Fijn *et al.* 2022).

5.1 Species identification

During aerial surveys, both visual and digital, not all individuals can be identified to species. Groupings are used for individuals that cannot be identified to species with certainty. These groupings can be to various levels, encompassing numerous species (‘unidentified gull’) or two species (e.g. ‘Great/Lesser Black-backed Gull’). To provide insight into the ability of each method to identify species, a comparison of the proportion of three sample species groups identified to species and to group is made. For this comparison we have selected large gulls, small gulls and two auks.

Large gulls

A total of 7,333 large gulls were recorded during the digital aerial surveys and 17,124 during MWTL surveys in the same period. Species included in this grouping are Common Gull, Lesser Black-backed Gull, Herring Gull and Great Black-backed Gull, and groupings include fulmar/gull, Great/Lesser Black-backed Gull, unidentified *Larus*, unidentified large gull and unidentified gull. Common Gull is included here in large gulls because of the grouping Common/Herring Gull used by the digital aerial survey method and visual similarity to Herring Gull in the images.

Across the year, 84% were identified to species during the digital aerial surveys (figure 5.1) and 98% during the MWTL surveys (figure 5.2). Identification during MWTL surveys was lowest in January (89%) but around 99% in most other surveys. Total numbers in January were not lower than in other periods, with numbers counted being highest in August and lowest in February 2022. Many individuals identified to group level were recorded at fishing vessels when large numbers of birds may limit the recording of supplementary data. Percentages identified during the digital aerial surveys ranged between 60-96%. Again, identification doesn't appear to be linked to numbers recorded. Assignment of individuals to group level during MWTL surveys most frequently occurs with large groups, such as at fishing vessels. The wider transect coverage of the MWTL methodology, particularly for grouping such as 'gulls' together with high numbers at fishing vessels likely explains the seasonal differences when comparing these groups.

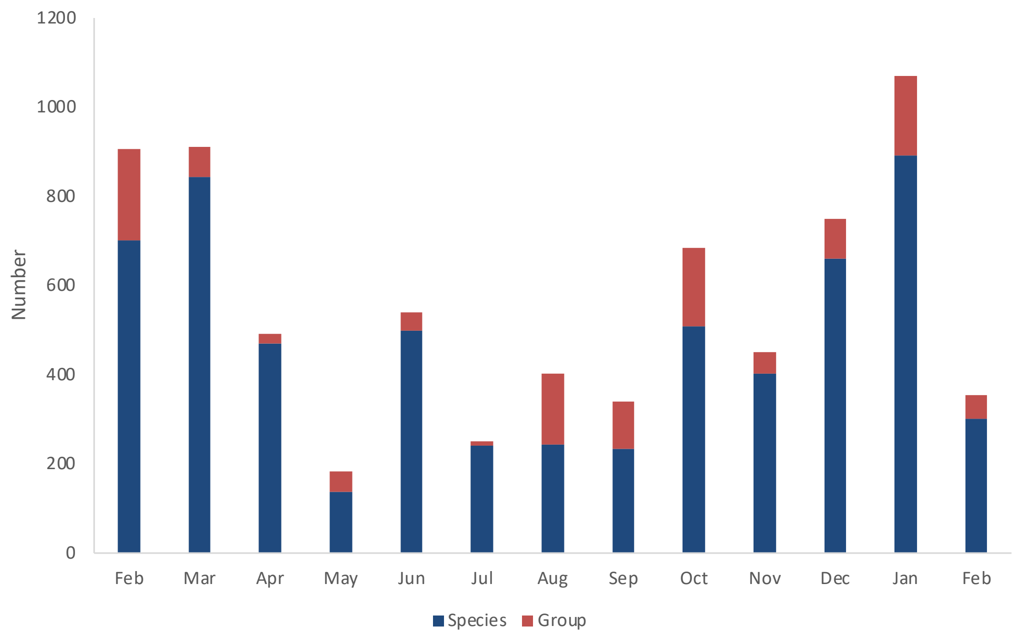

Figure 5.1 *Numbers of large gulls identified to species and assigned to group ('unidentified gull', 'unidentified large gull', 'unidentified Larus', 'Great/Lesser Black-backed Gull' and 'fulmar/gull') during digital aerial surveys between February 2021 and February 2022.*

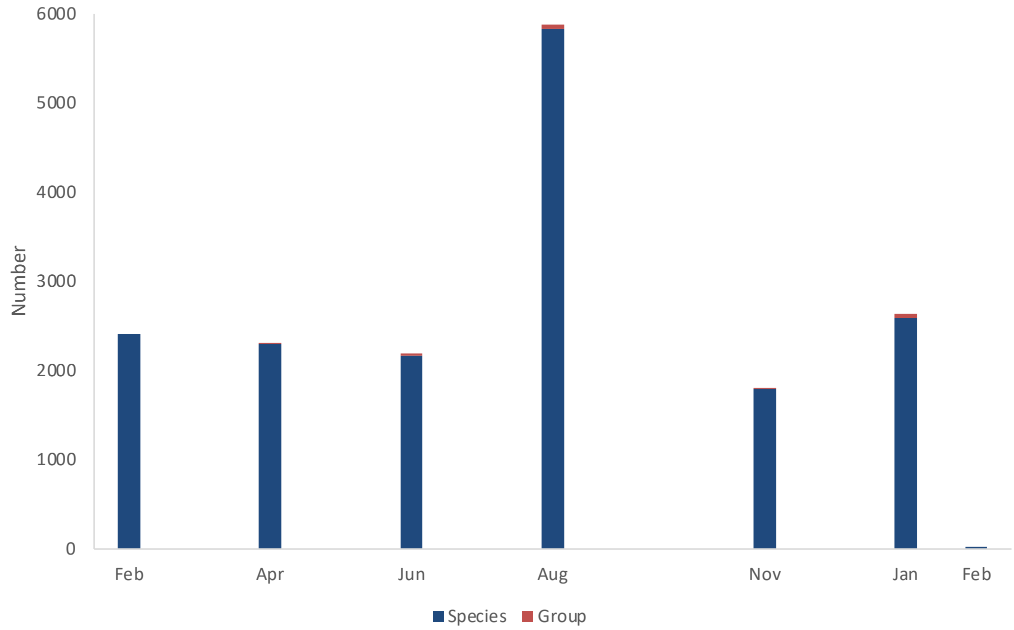

Figure 5.2 *Numbers of large gulls identified to species and assigned to group ('unidentified gull', 'unidentified large gull', 'unidentified Larus', 'Great/Lesser Black-backed Gull' and 'fulmar/gull') during MWTL surveys between February 2021 and February 2022.*

Small gulls

A total of 15,583 small gulls were recorded during the digital aerial surveys and 26,451 during the same period with MWTL surveys. Species included in this grouping are Mediterranean Gull, Little Gull, Black-headed Gull, Sabine's Gull, and Black-legged Kittiwake, and groupings are unidentified small gull, tern/small gull. Note that Common Gull is not included here in small gulls because of the grouping Common/Herring Gull used by the digital aerial survey method and visual similarity to Herring Gull in the images.

Across the year, 92% were identified to species during the digital aerial surveys (figure 5.3) and 99.99% during the MWTL surveys (figure 5.4). Identification during MWTL surveys was near 100% in all months. Percentages identified during the digital aerial surveys ranged between 81-98% in months with counts of 500 or more 'small gulls'. Apart from in March (81%), identification of small gulls to species was in the 90% range. Only in months with low counts, below 150 'small gulls' were the percentages identified under 35%.

As with large gulls, a different seasonal pattern can be noted between MWTL and digital aerial surveys. This is likely a result of the broader survey transects of the MWTL methodology and comparison of specie-groups (here 'small gulls') which are often detected in greater numbers and across a wider area with the MWTL methodology, particularly in relation to fishing vessels.

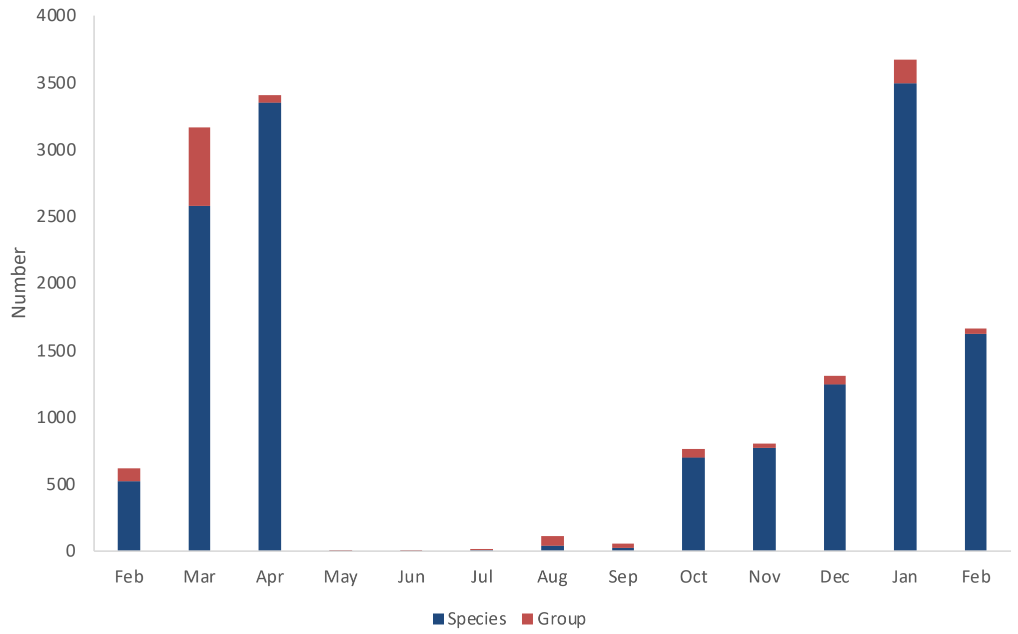

Figure 5.3 *Numbers of small gulls identified to species and assigned to group ('unidentified small gull' and 'tern/small gull') during digital aerial surveys between February 2021 and February 2022.*

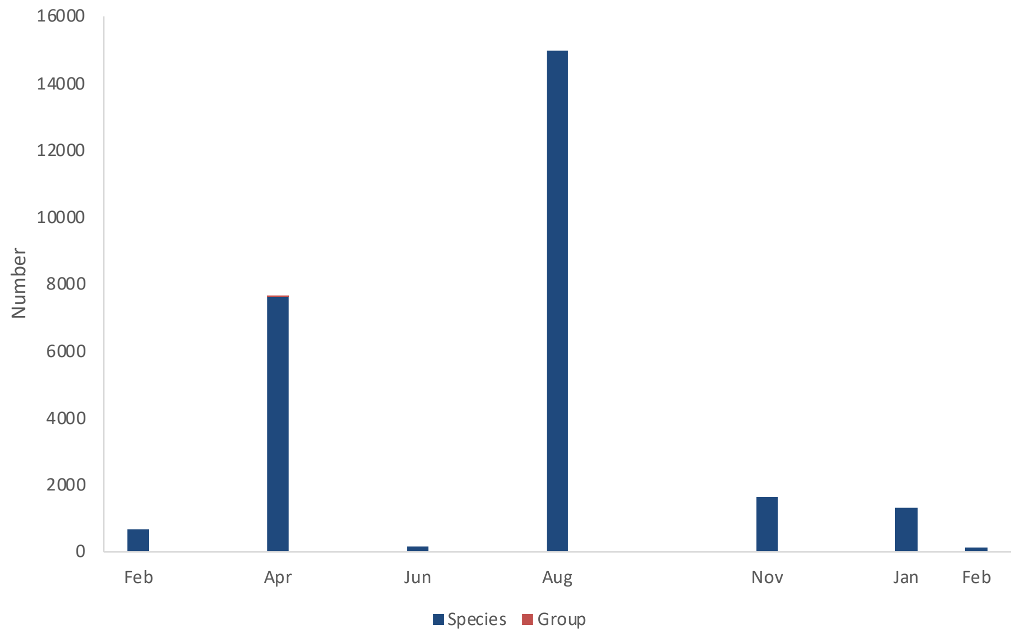

Figure 5.4 *Numbers of small gulls identified to species and assigned to group ('unidentified small gull' and 'tern/small gull') during MWTL surveys between February 2021 and February 2022.*

Common Guillemot and Razorbill

Common Guillemot and Razorbill are often challenging to separate during aerial surveys. It is therefore common practice to assign unidentified individuals of these species into the grouping 'Common Guillemot/Razorbill'. Some Common Guillemot or Razorbill may be assigned to the group 'unidentified auks', yet for this comparison we exclude this grouping as relatively few 'unidentified auks' were recorded and focussing the comparison to Common Guillemot and Razorbill will give insight into the identification of this at times problematic group.

A total of 27,435 Common Guillemot, Razorbill and Common Guillemot/Razorbill were recorded during the digital aerial surveys and 16,622 during the same period with MWTL surveys. Across the year, 83% were identified to species during the digital aerial surveys (figure 5.5) and 99% during the MWTL surveys (figure 5.6). Identification during digital aerial surveys varied between 72-88% in months with more than 100 birds. In MWTL surveys identification was between 98-100% for the same period.

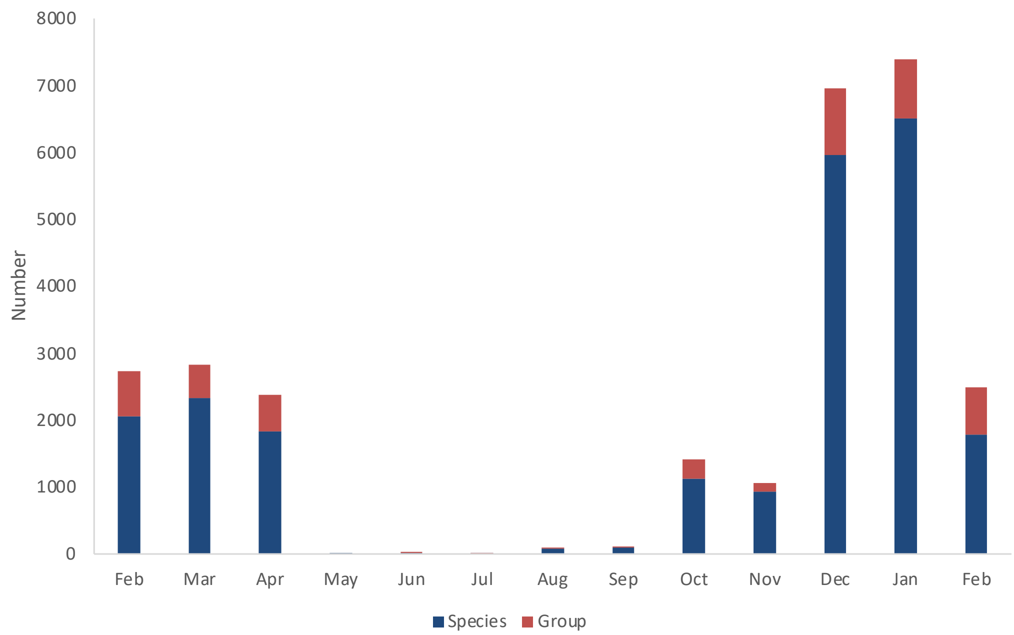

Figure 5.5 *Numbers of Common Guillemots and Razorbill identified to species and individuals assigned to group ('Common Guillemot/Razorbill') during digital aerial surveys between February 2021 and February 2022.*

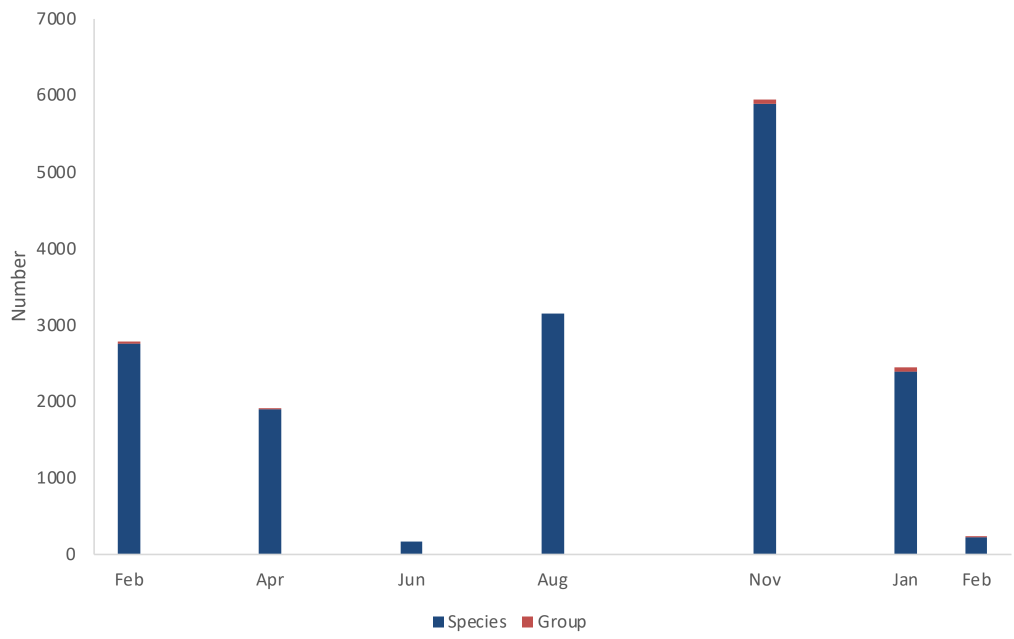

Figure 5.6 *Numbers of Common Guillemots and Razorbill identified to species and individuals assigned to group ('Common Guillemot/Razorbill') during MWTL surveys between February 2021 and February 2022.*

5.2 Age determination

Ages of Northern Gannet and Black-legged Kittiwake, at least to immature or adult, are relatively straightforward to determine. The following comparison for these two species of numbers aged and left unaged in the digital aerial surveys and MWTL surveys should provide some indication of the ability of each method to determine ages of seabirds during surveys.

Northern Gannet

During digital aerial surveys, a total of 2,025 Northern Gannet were recorded, of which 58% were aged (figure 5.7). During the MWTL surveys, 2,500 were counted, among which age was determined for 45% (figure 5.8). Per month, the percentage of Northern Gannets aged on digital aerial surveys varied between 29-86% for periods in which more than 100 birds were recorded. During MWTL surveys 33-58% were aged, and when fewer than 100 Northern Gannets were counted, this figure rose to 96%. Ageing of Northern Gannets is achievable with the MWTL methodology, but some birds are left unaged during periods of high numbers or due to complacency. For both methods it is possible that the percentage of birds aged may increase were this given more emphasis in specific project aims.

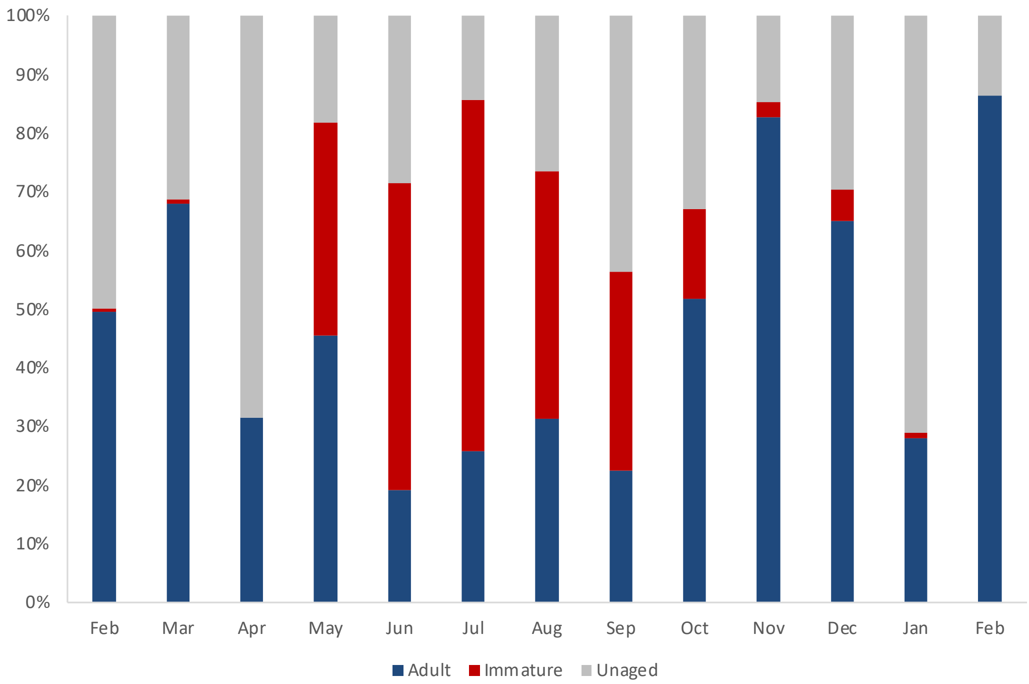

Figure 5.7 *Percentages of adult, immature and unaged Northern Gannet recorded during digital aerial surveys between February 2021 and February 2022.*

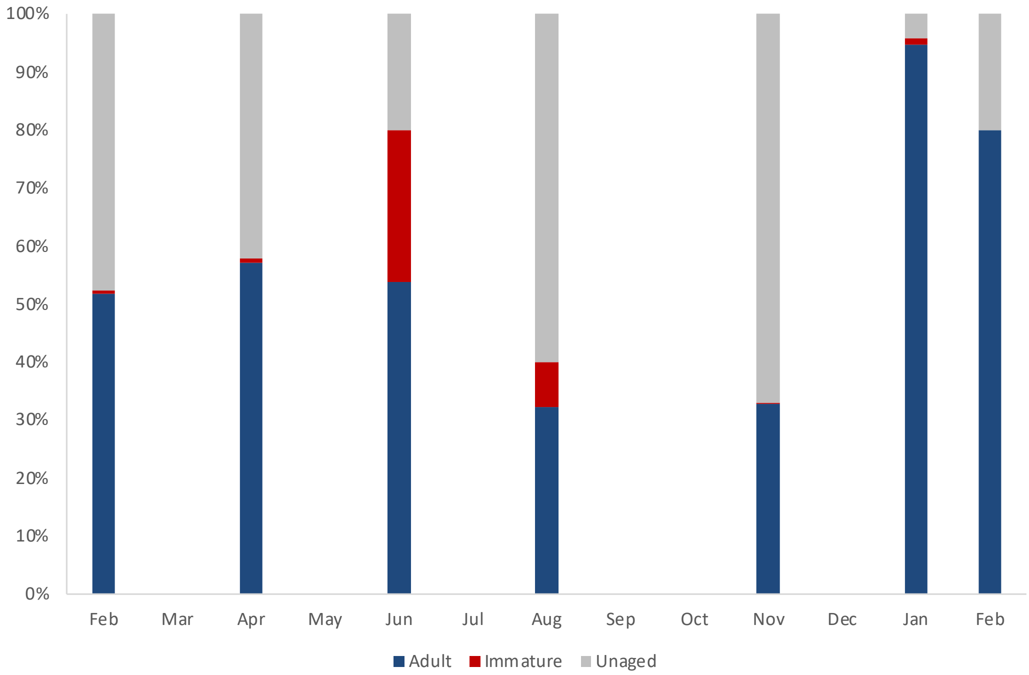

Figure 5.8 *Percentages of adult, immature and unaged Northern Gannet recorded during MWTL surveys between February 2021 and February 2022.*

Black-legged Kittiwake

During the digital aerial surveys, a total of 46% of the 9,852 Black-legged Kittiwake recorded were aged (figure 5.9). This compares to 44% during the MWTL surveys, when 5,198 were recorded (figure 5.10). The percentage aged per month varied between 26-82% during the digital aerial surveys and between 23-79% during the MWTL surveys, for months in which at least 100 birds were counted.

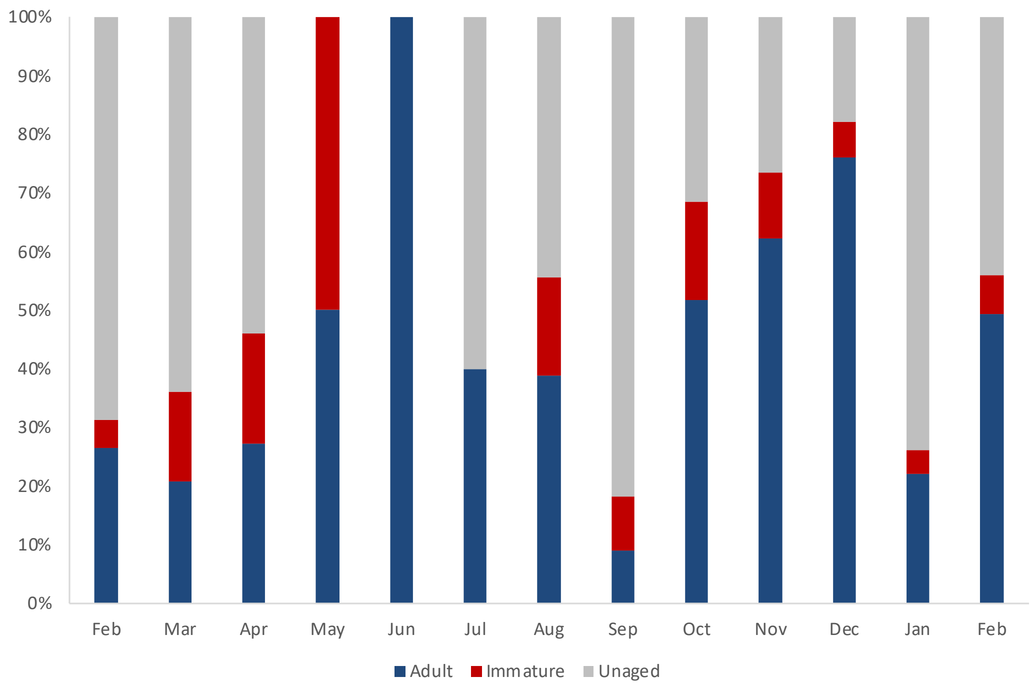

Figure 5.9 *Percentages of adult, immature and unaged Black-legged Kittiwakes recorded during digital aerial surveys between February 2021 and February 2022.*

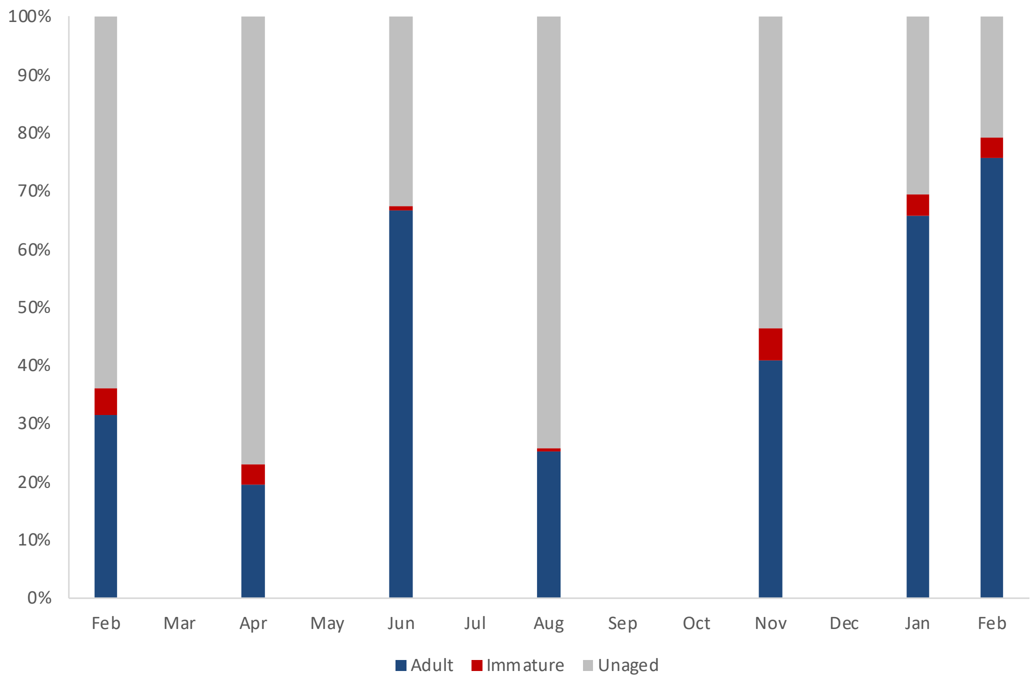

Figure 5.10 *Percentages of adult, immature and unaged Black-legged Kittiwakes recorded during MWTL surveys between February 2021 and February 2022.*

5.3 Densities

The third objective of this report is to provide information on how a successful digital aerial survey programme can be implemented to investigate the displacement and habituation of seabirds and marine mammals to wind farms. Within this objective, we compare here seabird densities recorded by the digital aerial surveys to the observer-based aerial surveys.

5.3.1 Data selection

MWTL surveys followed a line-transect (distance) survey setup. See Fijn *et al.* (2022) for an extensive description of the methodology. Four MWTL transects intersect the two digital aerial survey (DAS) areas in the current study (figure 5.11). MWTL transects completely falling outside the digital aerial survey study areas were excluded. Both MWTL and digital aerial survey data were aggregated to segments of 5 km. Data from the digital aerial surveys were linked to the nearest MWTL data, by determining the closest MWTL transect to the midpoints of each digital aerial survey segment and in time (table 5.1). For the MWTL data, the effectively surveyed area, corrected for imperfect detection of animals, was calculated by multiplying the segment length by the effective strip width, which was retrieved for each species from the most recent MWTL distance analyses (Fijn *et al.* 2022). For the analysis of all species together, the median effective strip width across all species was taken. For the digital aerial survey data, the surveyed area was calculated from the segment length and the width of the video stills. The natural log of the surveyed area was then calculated to be used as an offset in the statistical model (see below).

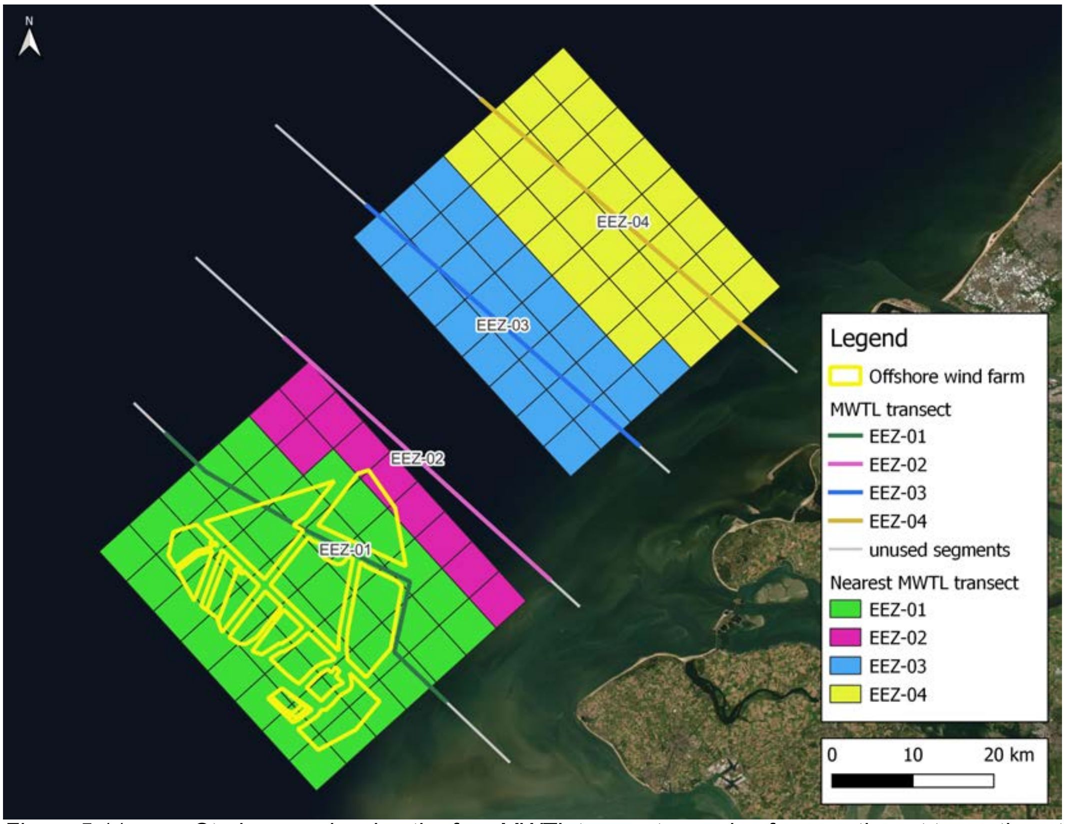

Figure 5.11 Study area showing the four MWTL transects running from northwest to southeast and the two digital aerial survey (DAS) study areas. Colours show corresponding digital aerial surveys grid cells and MWTL transect lines.

Data from six seabird species and Harbour Porpoise were selected from both the digital aerial surveys and from the MWTL programme. Only records identified to species were included and no apportioning of unidentified groups was included. In addition, two combined species groups were analysed: 1) all bird species combined; and 2) Common Guillemot and Razorbill combined (table 5.1). MWTL surveys with less than 25 sightings were excluded, because surveys with such low abundance are unlikely to contribute to the robust estimation of the difference between the two survey methods, and they add disproportionally to the proportion of zeros in the data, which cause zero-inflation. Removing these surveys left 5-10 MWTL surveys to compare to digital aerial surveys (table 5.2).

Table 5.1 Aggregation of digital aerial surveys and MWTL surveys based on date as used in the analysis.

Aggregation	Digital aerial survey	MWTL survey
1	13 February 2021 20 February 2021	21 February 2021
2	21 March 2021 30 March 2021 8 April 2021 22 April 2021	13 April 2021
3	12 May 2021 20 May 2021 6 June 2021 23 June 2021	08 June 2021
4	18 July 2021 29 July 2021 13 August 2021 29 August 2021 12 September 2021 20 September 2021	25 August 2021
5	9 October 2021 23 October 2021 6 November 2021 1 November (December) 2021 11 December 2021 21 December 2021	16 November 2021
6	6 January 2022 17 January 2022 5 February 2022	30 January 2022

Table 5.2 Species considered in the analysis, with the number of surveys and number of observed individuals during digital aerial surveys (DAS) and MWTL surveys.

Species	n surveys DAS	n birds DAS	n surveys MWTL	n birds MWTL
all bird species	25	56,580	10	4,961
Northern Gannet	25	2,025	9	350
Lesser Black-backed Gull	25	3,235	8	2,094
Great Black-backed Gull	21	1,255	8	203
Black-legged Kittiwake	21	9,849	8	552
Common Guillemot	21	15,316	7	482
Razorbill	15	7,362	5	152
Common Guillemot/Razorbill	21	27,419	7	684
Harbour Porpoise	25	1,551	6	117

5.3.2 Statistical analysis

Bayesian Generalized Linear Mixed Models were constructed for each species, with number per segment as the response variable with a negative binomial distribution, method (DAS or MWTL) as a fixed effect and random intercepts for 'survey' and MWTL transect. The log of the surveyed area per segment was included as an offset. Models were fitted using the brms package (Bürkner 2017, 2022) in R version 4.1.2 (R Core Team 2021), which provides a frontend to the Stan platform for statistical modelling and high-performance statistical computation. We used default uninformative priors, 4 chains of 4,000 iterations, a burn-in of 1,000 iterations, and a thinning-interval of 4 iterations. Model convergence was checked by visual inspecting of the chains, posterior predictive checks, and whether the potential scale reduction factor $\hat{R}$ was within 0.01 of 1. Posterior distributions of the parameters and the degree to which 0 was within their distribution were then inspected to infer the evidence for differences in seabird densities between the two methods.

5.3.3 Results

Across surveys, there was a strong positive relation between the density of seabirds during digital aerial surveys and MWTL surveys (β = 0.9, 95% CrI[1] = 0.45 - 1.39; figure 5.12). Considering sightings of all bird species, the percentage of 5 km segments with no sightings was 3.3% for MWTL and 15.5% for digital aerial surveys, despite the broader strip width of the digital aerial surveys (500 m).

Plots of the raw data suggest that seabird densities based on MWTL surveys were similar to those based on the digital aerial surveys (figures 5.13 and 5.14). Indeed, our models, accounting for dependency over time (MWTL surveys) and space (transects), as well as different surface areas covered, confirm the similar densities derived from the two methods (figure 5.15). For all species and species groups, model results lend no support for differences between the two methods in densities, considering that all 95% CrIs[1] overlap with 0 (meaning the absence of an effect of survey method cannot be excluded) (figure 5.16).

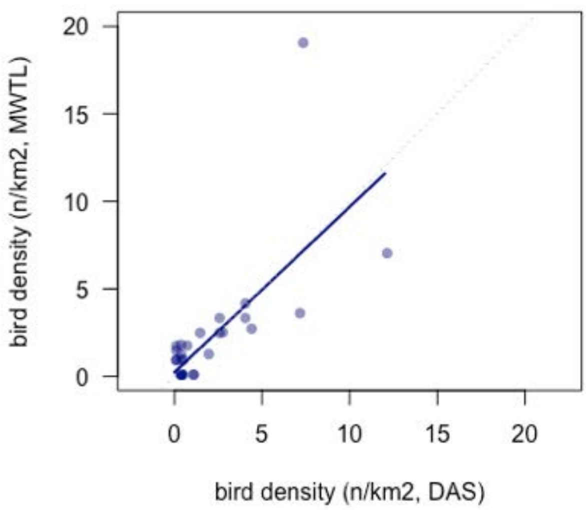

Figure 5.12 *Mean bird density per survey per species compared between the two survey methods: digital aerial surveys (DAS) and MWTL. The blue line is the estimated regression line, the grey dotted line is x=y.*

[1] Credible Interval (CrI) is an output equivalent to Confident Interval (CI) from Bayesian statistics.

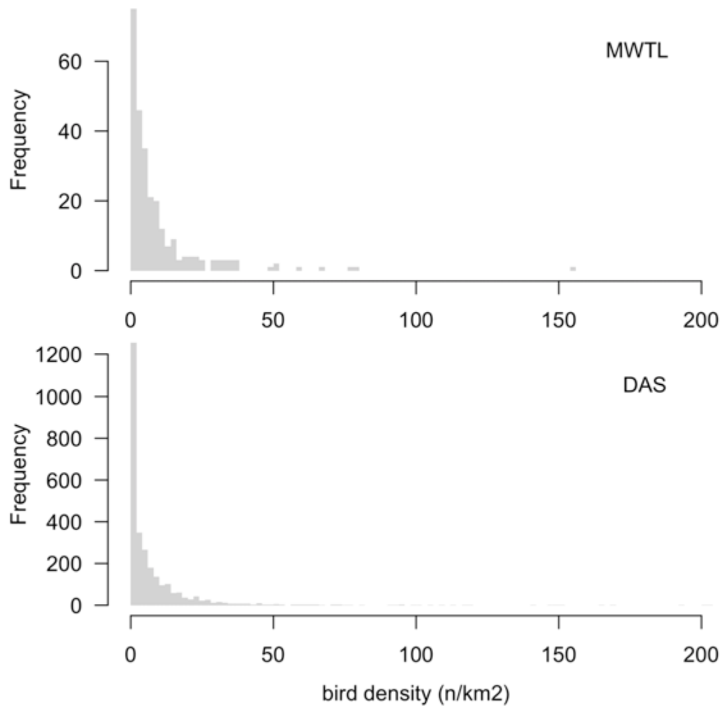

Figure 5.13 *Histograms showing distribution of density per transect segment for MWTL (upper figure) and digital aerial surveys (DAS) (lower figure). To show more details in the lower ranges, the x-axes have been truncated at 200; there was one more extreme value for MWTL of 1,079 birds/km^2.*

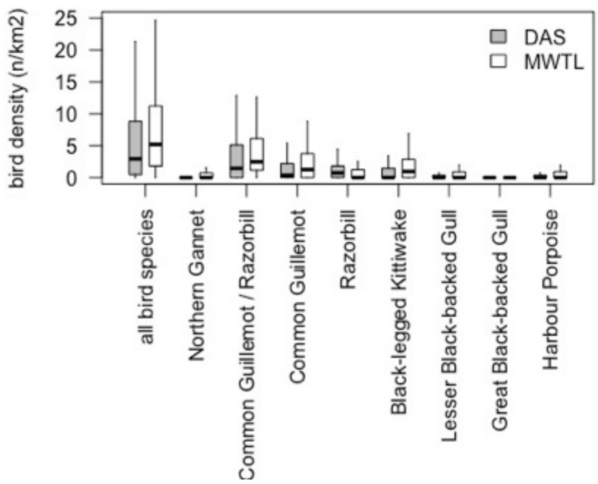

Figure 5.14 *Distribution of densities per segment based on digital aerial surveys (DAS) (grey) and MWTL (white) for the nine species and species groups.*

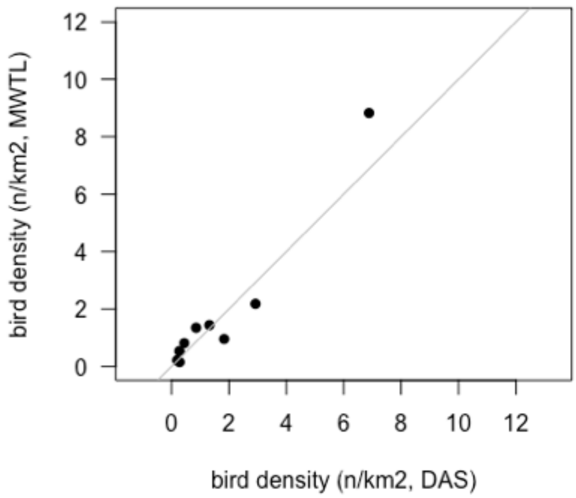

Figure 5.15 *Comparison between densities obtained from model parameters on the response scale, for digital aerial surveys (DAS) (x-axis) and MWTL surveys (y-axis). The diagonal line shows x=y.*

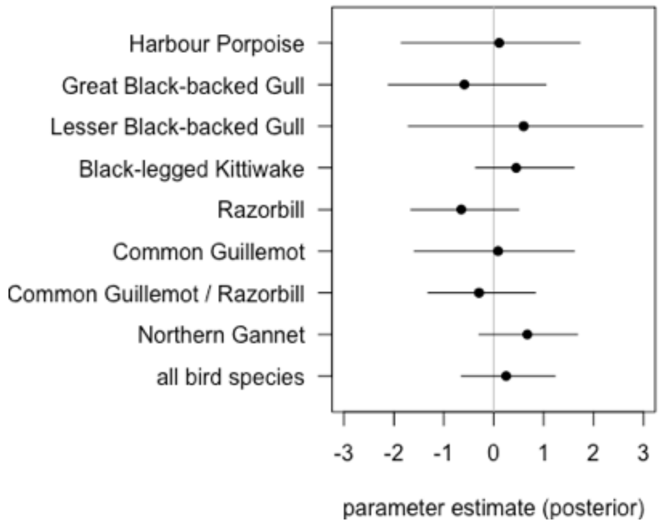

Figure 5.16 *Model parameter estimates (on the scale of the linear predictor) with 95% credible intervals of the difference between digital aerial surveys (DAS) and MWTL surveys. Positive values mean densities based on MWTL surveys were higher than those based on digital aerial surveys (DAS).*

5.4 Discussion

Species identification and supplementary information

Based on the comparisons of proportions of large gulls, small gulls and Common Guillemot and Razorbill identified to species, observer-based surveys would appear to be better for species identification. However, this is difficult to test fully, as observer-based data cannot be analysed for accuracy, and identification may vary between observers. Digital aerial survey data have the advantage of being available for re-analysis. Furthermore, the difference in the proportions identified to species may not be important for specific studies.

Plus, it can be expected that the identification of digital aerial methods may increase as technology develops further.

It was noted that greater numbers of auks (Common Guillemot, Razorbill and Common Guillemot/Razorbill) were recorded during the current digital aerial surveys compared to the MWTL surveys, despite the latter surveying a larger area (transect width and length). This suggests that the digital aerial surveys are better at detecting these species of auks, possibly as the higher flight height results in lower disturbance.

Based on the two species examined, digital aerial surveys appeared to be slightly better in identifying ages of the species assessed. This may be a result of the speed at which data is recorded during aerial surveys, during which observers must sometime prioritise key data at the detriment of supplementary data. Digital aerial survey data allows more time for the data to be examined (and if needed re-examined) where more supplementary data like age can be recorded.

These comparisons are based on a small amount of data and the differences are not considerable. Emphasis on the aim of the surveys, may result in more individuals being aged or identified to species. So, there is no strong evidence that one method is better than the other for species identification or recording supplementary data such as age.

Density estimates

Bird densities correlated well between the two survey methods, with no support for differences in estimated densities at the species level. There are several earlier comparisons between observer-based and digital image aerial seabird surveys in the peer-reviewed literature. A comparison of the methods in the Mediterranean yielded more sightings of seabirds using human observers as compared to digital imagery (García-Garín et *al.* 2020). Another comparison, in the North Sea, indicated underestimation of numbers of Common Scooters by observer-based surveys as compared to the digital image method, possibly largely driven by lower disturbance rates by the latter method (Buckland *et al.* 2012). Similar results were found for Red-throated Divers in a study comparing visual observers and digital still images (Skov *et al.* 2016). Finally, digital aerial surveys yielded higher seabird densities than the observer-based surveys for all species except Common Eider in an extensive comparison between the two methods carried out in the southern Baltic Sea (Žydelis *et al.* 2019). However, sample sizes for some of the species, such as alcids, were low. Nevertheless, our results differ from the cited literature in that we did not find support for differences in seabird densities for any species or species group.

6 Recommendations

6.1 Overview of key difference of digital and observer based aerial surveys

A brief overview of the differences between digital aerial surveys and the observer based MWTL surveys is given in table 6.1.

Table 6.1 Key differences in survey conditions and methods between the current digital aerial surveys and MWTL surveys.

	Digital aerial surveys	MWTL surveys
Method	Strip	Line transect
Count within surveyed area	Absolute	Estimate with Distance
Flight speed (km/h)	220	185
Flight height (m)	550	75
Weather requirements:		
max. wind speed (km/h)	30	40
max. sea state	6	5-6
rain	none	Not more than light rain
visibility	No clouds or mist below 550 m	No clouds or mist below 75 m

Digital aerial surveys offer several benefits over observer-based aerial surveys, including the higher flight height (and thus less disturbance and improved safety for staff), enabling data to be collected within offshore wind farms, and a quicker flight speed, allowing more area to be covered per period. Furthermore, the possibility to re-analyse a survey is a great benefit of digital aerial surveys. On the other hand, digital aerial survey data are currently more time consuming to analyse and as such, costs are higher. Furthermore, the occurrence of fishing vessels further away from the transect line, that can heavily influence the number of birds in an area, cannot be recorded during digital aerial surveys. Developments in analytical software could decrease the time needed to analyse digital images, providing this does not compromise species identification or other supplementary data such as age. Automisation of image analyses also facilitates the possibility of re-analyses of data and application of statistical techniques for estimating densities. Digital aerial surveys also employ a strip transect rather than line transect methodology. Strip transects potentially provide more certainty around population estimates due to the lack of detection variability that is found in line transect methodology.

6.2 Detecting displacement and attraction in offshore wind farms

Digital aerial surveys potentially provide a method to collect data for investigating displacement and attraction at offshore wind farms. The height at which digital aerial surveys can be carried out means that data can be collected within offshore wind farms. In addition, this height and the speed of the aircraft could be expected to provoke less consequence of disturbance in the survey data (i.e. potential for fewer diving birds to be overlooked).

Any study using aerial survey data to investigate displacement or attraction at offshore wind farms should ensure sufficient spatial coverage within the wind farm and of the surrounding area to be able to detect change whilst also taking into account covariates determining distributions. As a rough recommendation, 50% coverage of the wind farm area and similar coverage of an area outside the wind farm should be aimed for. A contiguous area outside of the wind farm could be deemed better than a separate reference area for detecting differences at varying distance from the wind farm. Ideally, a before-after-control-impact (BACI) design should be used. The temporal coverage of two surveys per month was deemed sufficient for the current analysis, but survey frequency could depend on numbers and variability per area and species.

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Appendix I Numbers recorded per month

*Table I.1 Numbers of each species/identification group (italics) recorded each month, summed number across the twice-monthly surveys between February 2021 and February 2022. *February 2022 total consists of one survey. +The strip width in November and December surveys is approximately three-quarters that in other months due to the inclusion of data from three instead of four cameras.*

Identification group / Species	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov+	Dec+	Jan	Feb*
Red-throated Diver		15	16				1	1	3	2	51	10	6
Black-throated Diver	1										2	1	
unidentified diver	*2*		*1*					*1*		*1*	*5*	*2*	
unidentified grebe												*1*	
Northern Fulmar		5	13	3	3			1		1	2	5	6
Manx Shearwater											2		
Northern Gannet	198	371	270	33	21	35	64	165	112	150	169	312	125
Great Cormorant	3	12	1		1			5	2		6		1
Great Cormorant/European Shag											*1*		
Grey Heron									1				
Brent Goose		25											
Eurasian Wigeon											12		
Northern Shoveler		4									3		
Common Eider								9					
Common Scoter	2		7						6	8			
Common Goldeneye									3				
Red-breasted Merganser												1	
Goosander											1		
unidentified duck									*3*				
Eurasian Marsh Harrier							1						
Eurasian Sparrowhawk			1						2				
Common Kestrel						1							
Eurasian Oystercatcher							3						
European Golden Plover						1	1						
Northern Lapwing	2												
Bar-tailed Godwit								13					
Eurasian Curlew			10					6					
unidentified wader									*35*				
Arctic Skua		1											
Long-tailed Skua								1					
Great Skua					2	1	4		1	2	2	3	
unidentified skua							*1*						
Mediterranean Gull											1	2	
Little Gull	6	1187	2842				2	6	153	66	45	57	14
Black-headed Gull	3	34				1		7	50	5	10	1	

Identification group / Species	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov+	Dec+	Jan	Feb*
Common Gull	130	154	29	5	2	1	2	13	80	11	321	196	27
unidentified small gull	*94*	*549*	*19*	*1*	*4*	*4*	*1*	*13*	*61*	*33*	*59*	*180*	*40*
Lesser Black-backed Gull	307	624	411	99	485	233	207	129	243	289	63	124	21
Herring Gull	151	52	25	2	10	5	7	17	51	52	60	189	30
Common/Herring Gull	*3*	*1*	*1*						*1*		*9*	*3*	
Great Black-backed Gull	114	14	4	32	2	1	26	74	135	50	216	382	223
unidentified large gull	*76*	*14*	*10*	*25*	*19*	*7*	*67*	*61*	*74*	*26*	*18*	*80*	*27*
Great/Lesser Black-backed Gull	*23*	*13*	*3*	*16*	*3*	*1*	*50*	*33*	*81*	*14*	*9*	*65*	*10*
unidentified Larus gull	*5*						*1*				*47*	*1*	
Black-legged Kittiwake	516	1358	505	2	1	5	36	11	494	699	1190	3431	1604
fulmar/gull			*1*	*1*							*3*	*1*	*5*
unidentified gull	*101*	*40*	*9*	*2*	*19*	*3*	*42*	*13*	*21*	*9*	*13*	*31*	*10*
Sandwich Tern		167	739	122	87	65	291	10	2		1	3	
Common/Arctic Tern		*2*	*126*	*10*	*44*	*4*	*257*	*81*	*2*	*1*			
tern/small gull		*39*	*41*	*6*	*3*	*6*	*69*	*16*	*1*				
unidentified tern		*9*	*4*	*39*	*11*	*11*	*333*	*38*	*1*				
Common Guillemot	422	1689	1474	9	6	2	81	80	397	154	4855	4758	1404
Common Guillemot/Razorbill	*670*	*486*	*553*		*1*	*1*	*5*	*22*	*286*	*130*	*986*	*884*	*709*
Razorbill	1637	643	348			1	1	7	721	774	1111	1750	378
Atlantic Puffin										1	1		
unidentified auk	*26*	*31*	*6*	*5*					*8*	*7*	*23*	*7*	*5*
Feral Pigeon				30	1								
Common Wood Pigeon		3							3				
unidentified dove/pigeon	*1*												
Common Swift		1											
Fieldfare									14		6		
unidentified thrush									*45*				
unidentified crow	*1*												
unidentified bird	*42*	*74*	*24*	*5*	*7*	*5*	*9*	*17*	*153*	*18*	*26*	*139*	*43*
unidentified songbird	*30*	*37*							*485*		*13*		
seal/small cetacean	*8*	*25*	*1*	*2*	*1*	*1*	*5*	*1*	*4*	*3*	*1*	*5*	*3*
unidentified dolphin										*1*			
White-beaked Dolphin										1			2
Harbour Porpoise	84	369	92	146	144	125	24	69	123	35	125	156	59
unidentified pinniped (Grey/Harbour Seal)	*33*	*18*	*4*	*10*	*5*	*13*	*5*	*7*	*23*	*2*	*6*	*40*	*17*
Grey Seal	2	1	1	1		4		2	6			3	
Harbour Seal	1	1		1	2	2	1		1		2		2

Appendix II Grouping used for reporting

Table II.1 Groupings used for reporting in this interim report and their constituent identification groups.

Reporting group	Identification group
Divers	Red-throated Diver
	Black-throated Diver
	unidentified diver
Grebes	unidentified grebe
Fulmars	Northern Fulmar
	Manx Shearwater
	Northern Gannet
Cormorants	Great Cormorant
	Great Cormorant/European Shag
Herons	Grey Heron
Wildfowl	Brent Goose
	Eurasian Wigeon
	Northern Shoveler
	Common Eider
	Common Scoter
	Common Goldeneye
	Red-breasted Merganser
	Goosander
	unidentified duck
Raptors	Eurasian Marsh Harrier
	Eurasian Sparrowhawk
	Common Kestrel
Waders	Eurasian Oystercatcher
	European Golden Plover
	Northern Lapwing
	Bar-tailed Godwit
	Eurasian Curlew
	unidentified wader
Skuas	Arctic Skua
	Long-tailed Skua
	Great Skua
	unidentified skua
Small gulls	Mediterranean Gull
	Little Gull
	Black-headed Gull
	unidentified small gull
	Black-legged Kittiwake
	tern/small gull
Large gulls	Common Gull
	Lesser Black-backed Gull
	Herring Gull
	Common/Herring Gull
	Great Black-backed Gull

	unidentified large gull
	Great/Lesser Black-backed Gull
	unidentified Larus gull
	fulmar/gull
	unidentified gull
Gulls	Mediterranean Gull
	Little Gull
	Black-headed Gull
	Common Gull
	unidentified small gull
	Lesser Black-backed Gull
	Herring Gull
	Common/Herring Gull
	Great Black-backed Gull
	unidentified large gull
	Great/Lesser Black-backed Gull
	unidentified Larus gull
	Black-legged Kittiwake
	fulmar/gull
	unidentified gull
	tern/small gull
Terns	Sandwich Tern
	Common/Arctic Tern
	unidentified tern
Auks	Common Guillemot
	Common Guillemot/Razorbill
	Razorbill
	Atlantic Puffin
	unidentified auk
Passerines and near-passerines	Feral Pigeon
	Common Wood Pigeon
	unidentified dove/pigeon
	Common Swift
	Fieldfare
	unidentified thrush
	unidentified crow
	unidentified bird
	unidentified songbird
Cetaceans	unidentified dolphin
	White-beaked Dolphin
	Harbour Porpoise
Pinnipeds	seal/small cetacean
	unidentified pinniped (Grey/Harbour Seal)
	Grey Seal
	Harbour Seal

Appendix III Raw distribution maps

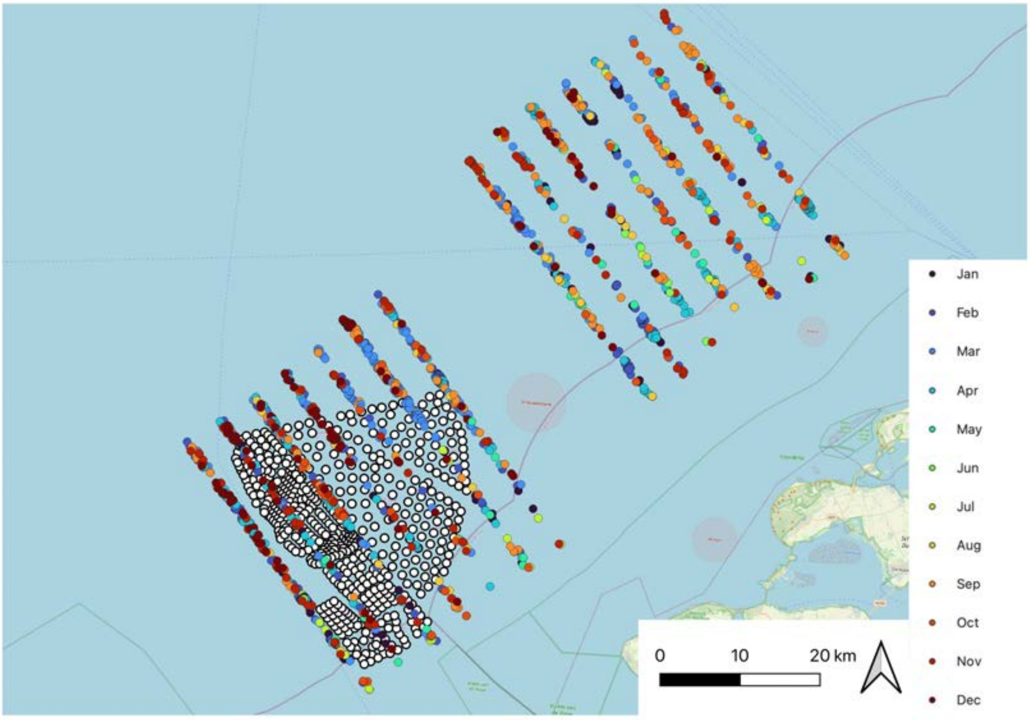


Figure AIIIa. Raw distribution data for Northern Gannet from all surveys between February 2021 and February 2022.

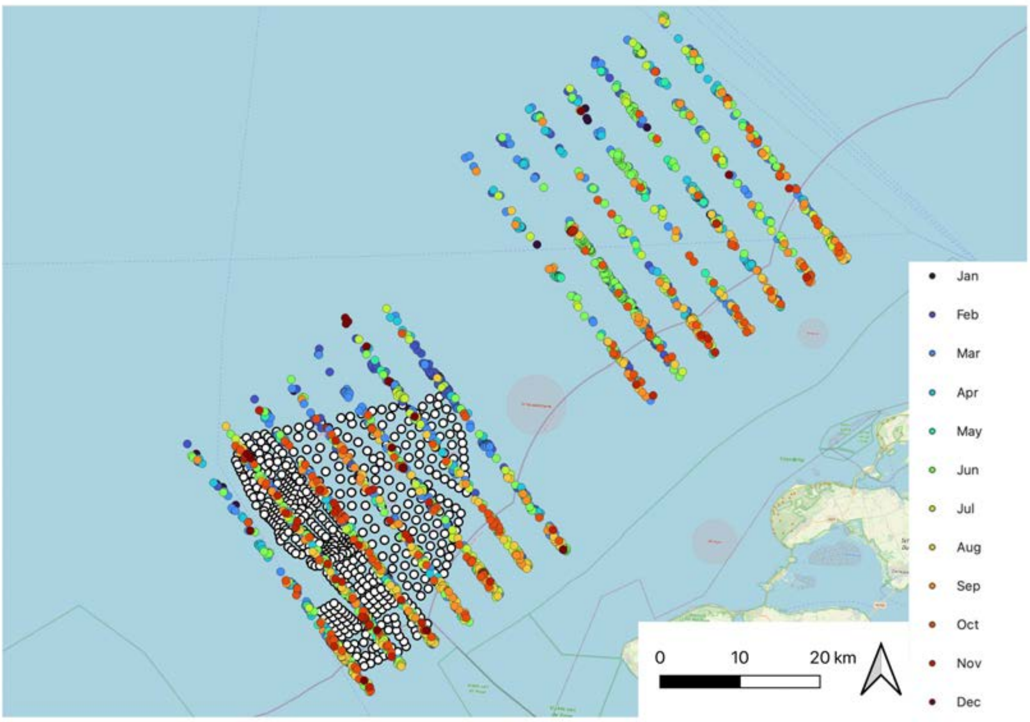


Figure AIIIb. Raw distribution data for Lesser Black-backed Gull from all surveys between February 2021 and February 2022.

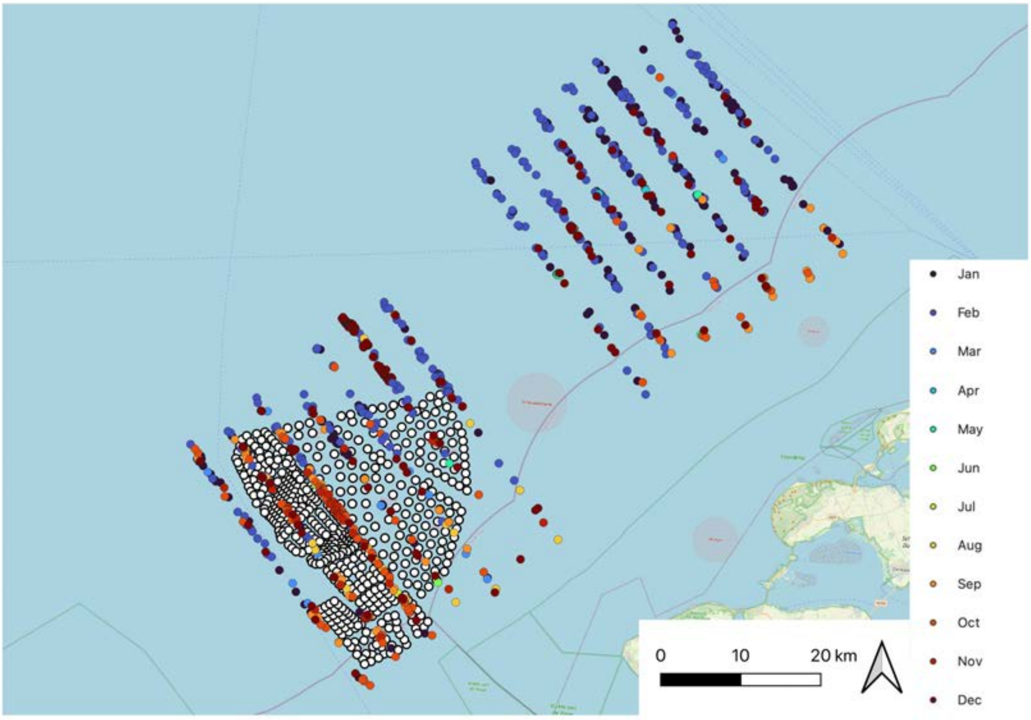


Figure AIIIc. Raw distribution data for Great Black-backed Gull from all surveys between February 2021 and February 2022.

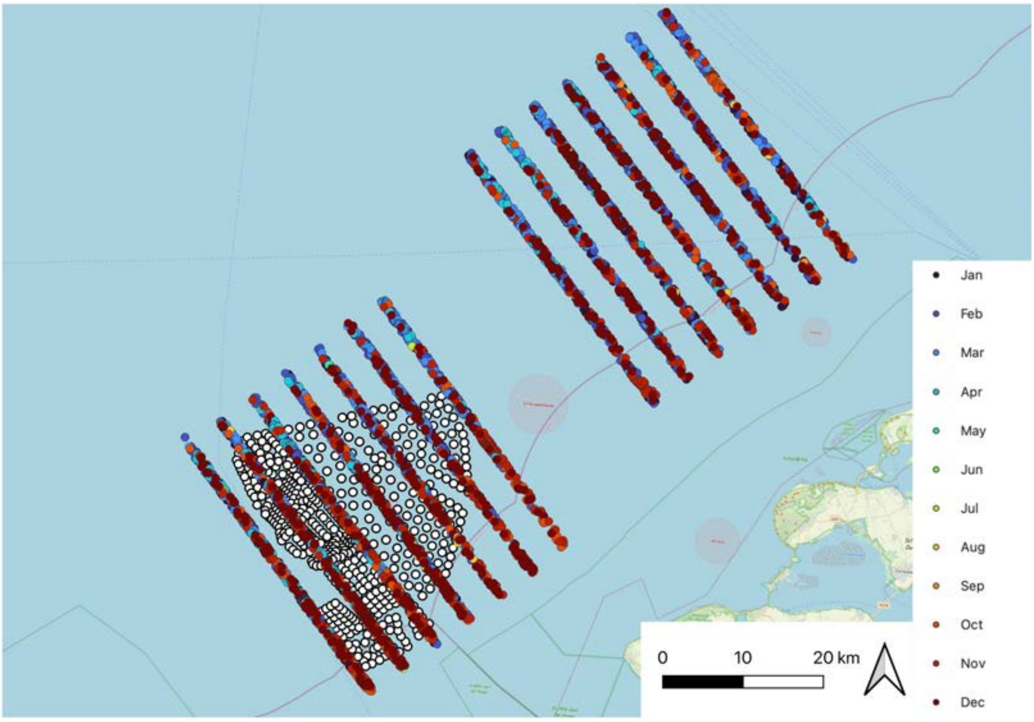


Figure AIIId. Raw distribution data for Black-legged Kittiwake from all surveys between February 2021 and February 2022.

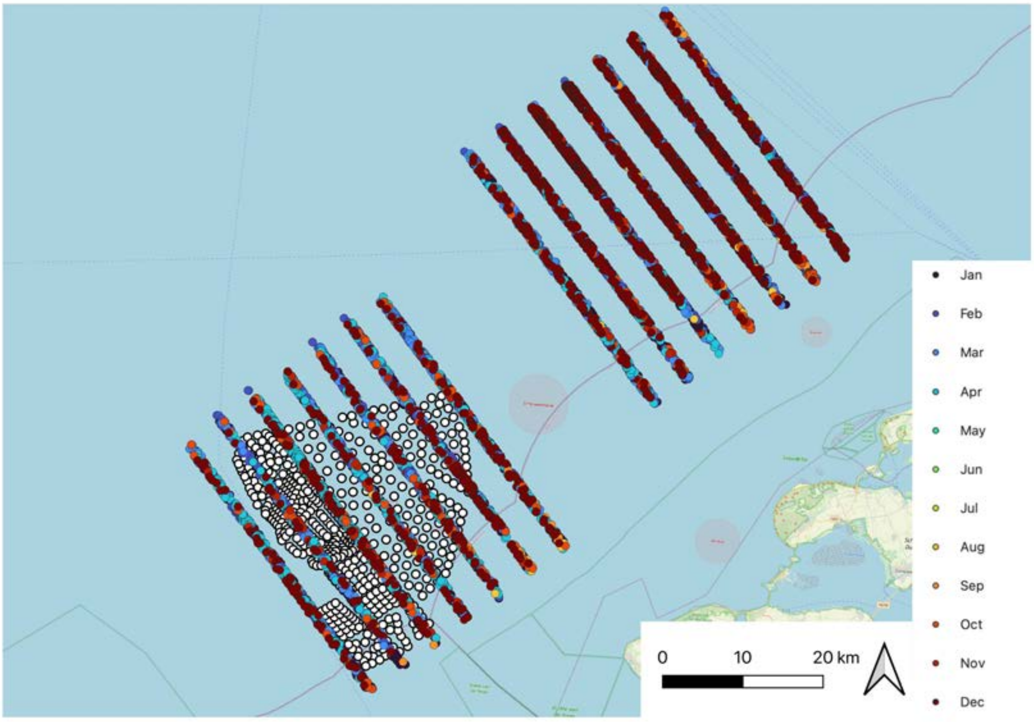


Figure AIIIe. *Raw distribution data for Common Guillemot from all surveys between February 2021 and February 2022.*

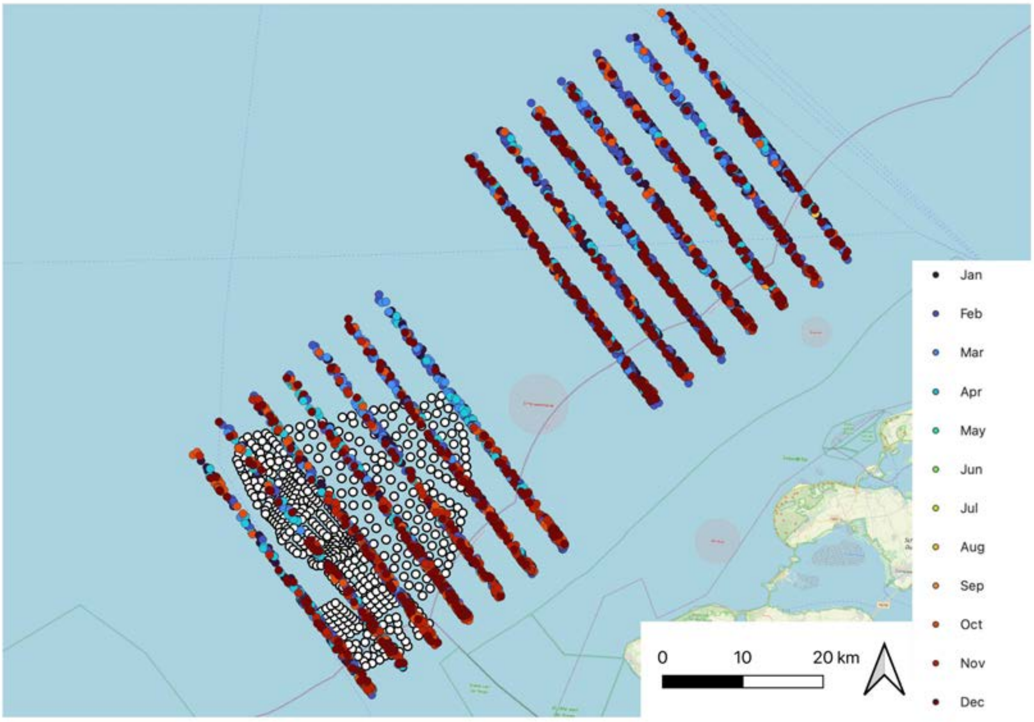


Figure AIIIf. *Raw distribution data for Razorbill from all surveys between February 2021 and February 2022.*

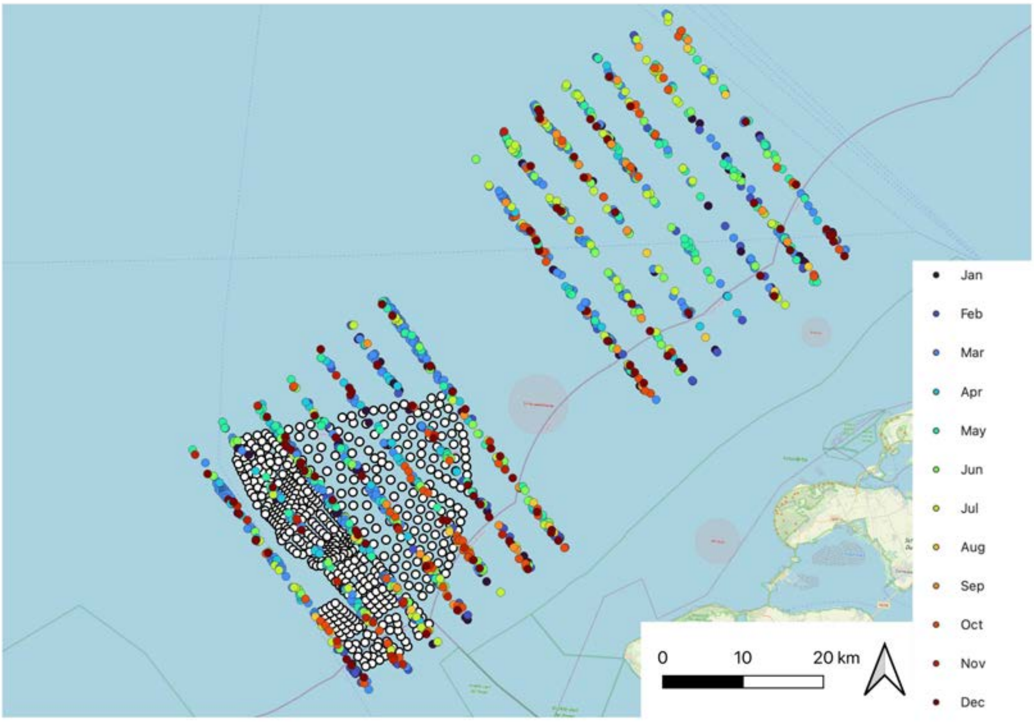
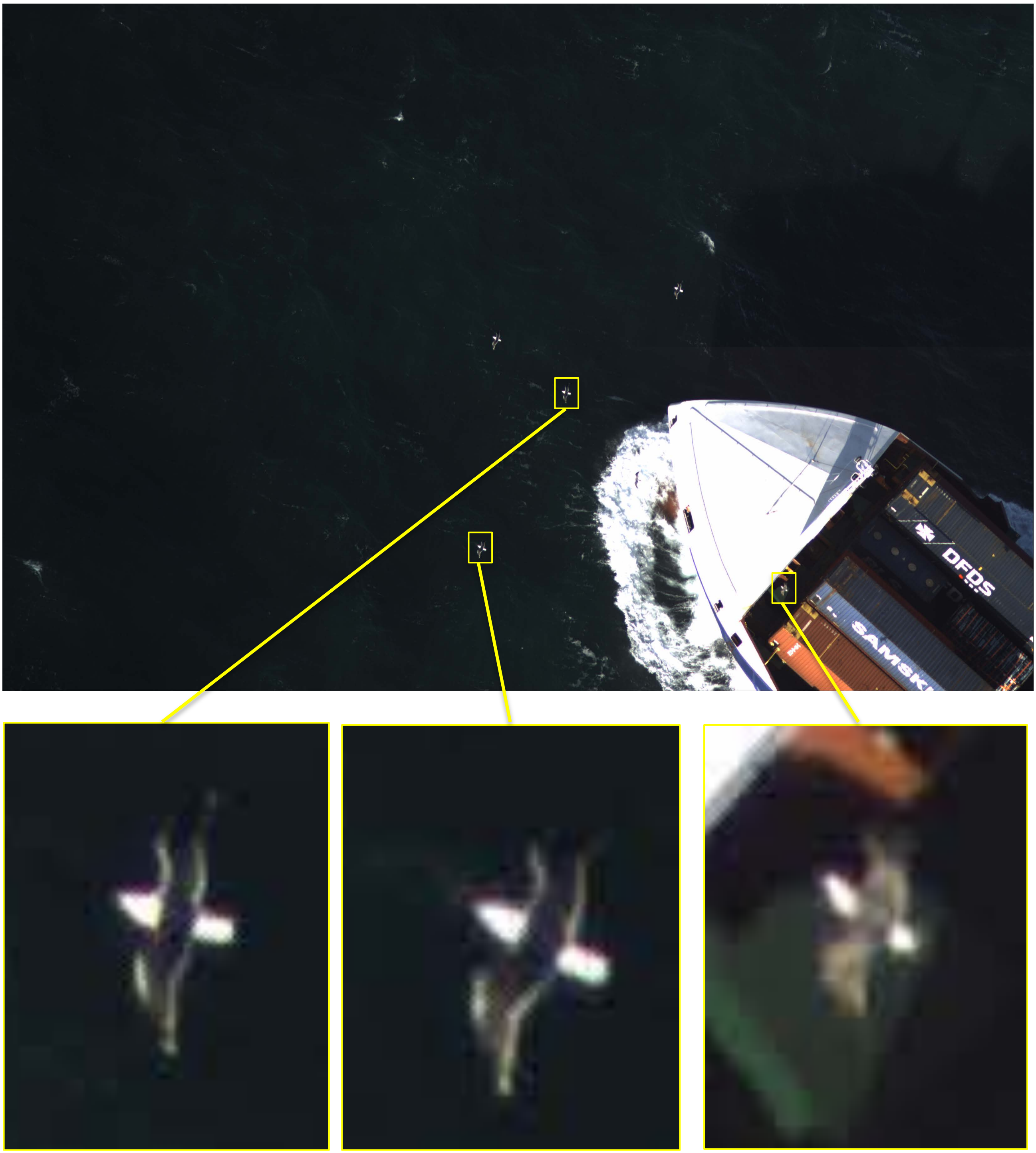


Figure AIIIg. Raw distribution data for Harbour Porpoise from all surveys between February 2021 and February 2022.

Appendix IV Example images

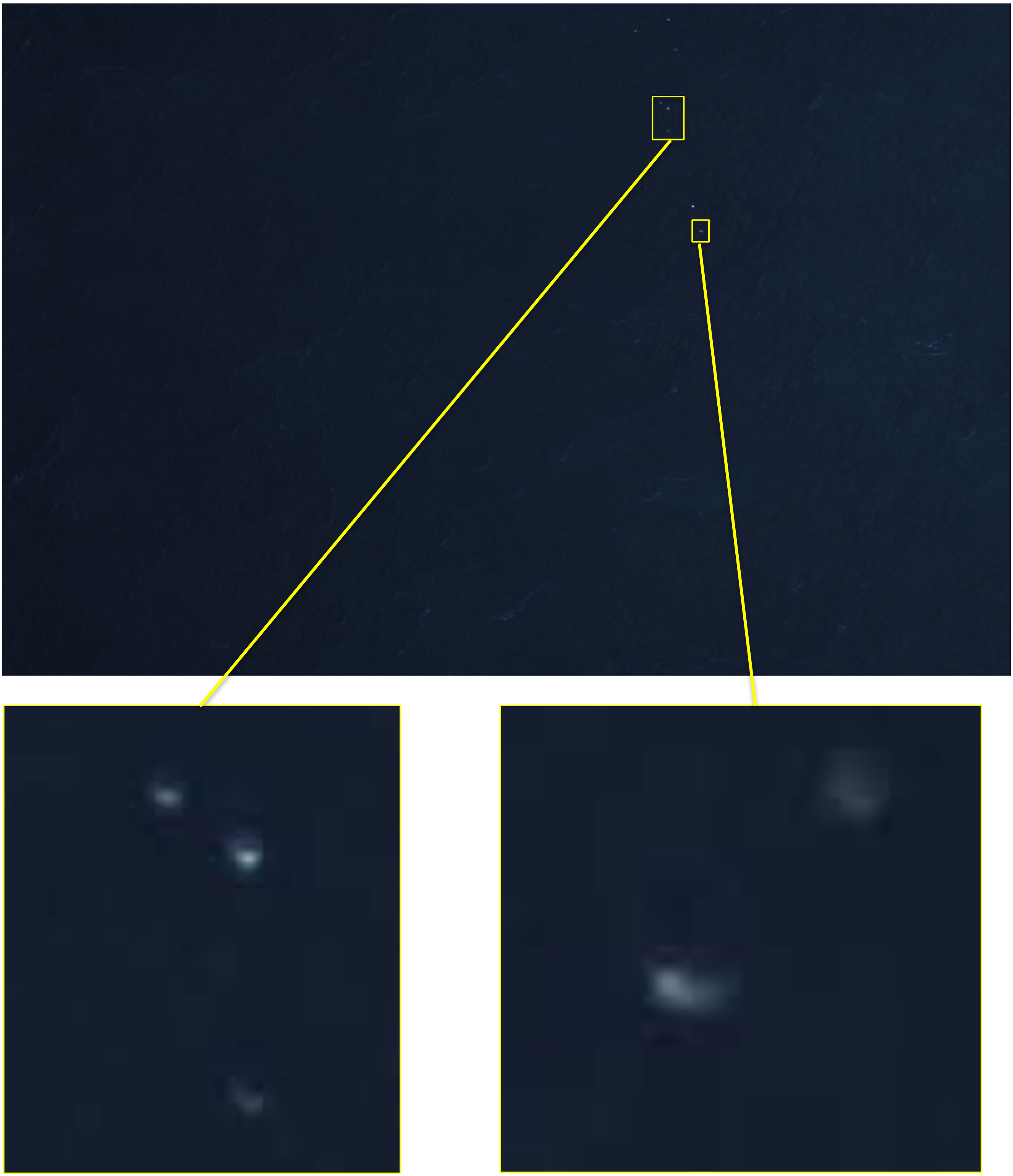
a) Razorbill b) Northern Gannet c) Black-legged Kittiwake

Figure AIVa. Example of a single digital aerial survey video frame from the second survey in January 2022. Highlighted are a single Razorbill (a), Northern Gannet (b), and Black-legged Kittiwake (c). Further Northern Gannet (2), Black-legged Kittiwake (2), Razorbill (6) and Common Guillemot/Razorbill (1) are present in the image but not highlighted.



a) Lesser Black-backed Gull   b) Lesser Black-backed Gull   c) Lesser Black-backed Gull

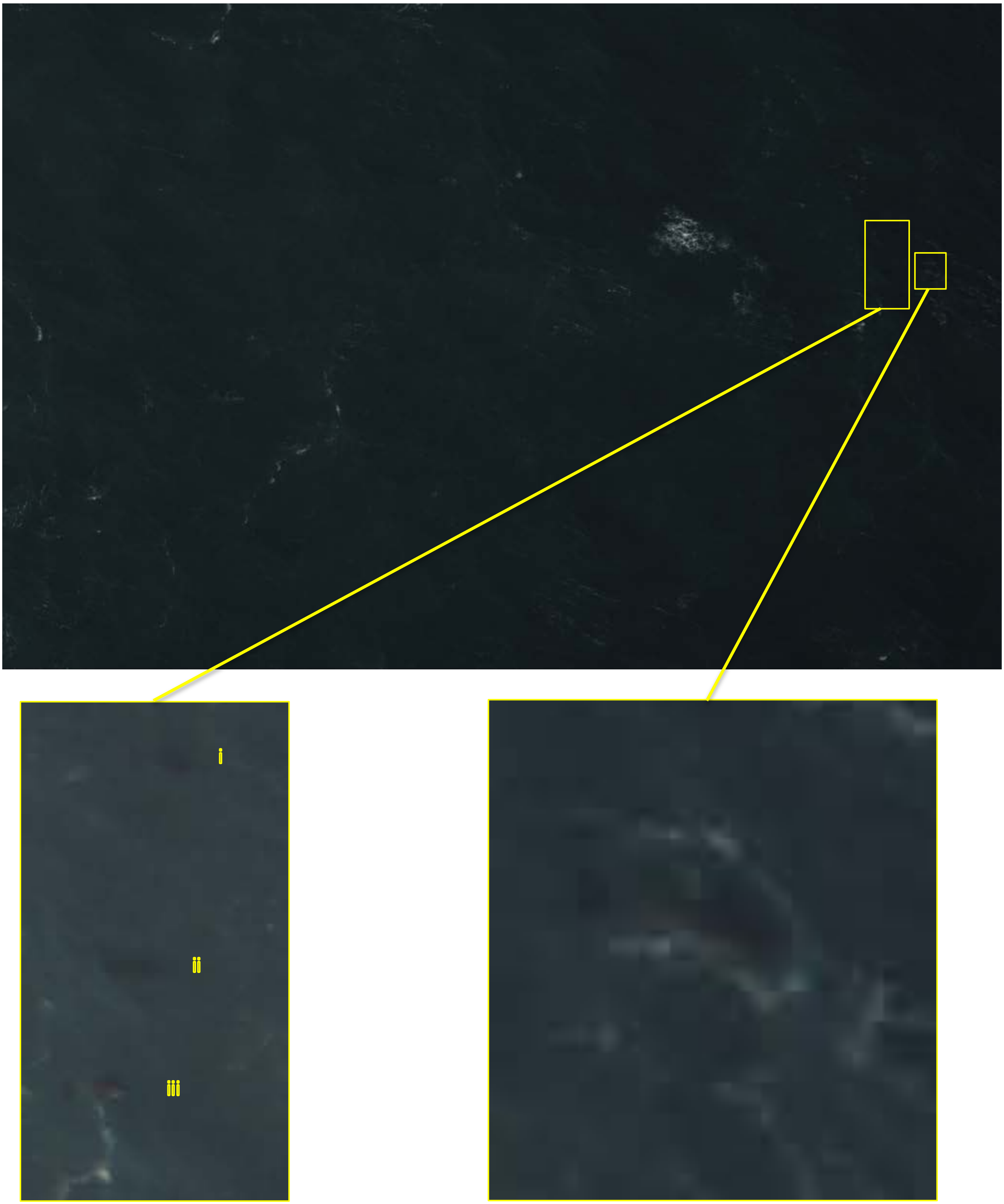
Figure AIVb. Example of a single digital aerial survey video frame from the first survey in February 2022. Highlighted are a single Lesser Black-backed Gulls (a-c). Further Lesser Black-backed Gulls (3) and unidentified large gulls (1) are present in the image but not highlighted.



a) Common Guillemots

b) Common Guillemots

Figure AIVc. Example of a single digital aerial survey video frame from the first survey in January 2022. Highlighted are groups of three (a) and two (b) Common Guillemots. Further Common Guillemot (4) are present in the image but not highlighted.



a) Three Harbour Porpoises (i – iii) b) Harbour Porpoise

Figure AIVd. Example of a single digital aerial survey video frame from the second survey in January 2022. Highlighted are four Harbour Porpoises (a-b). Cropped images have been adjusted for contrast and brightness.