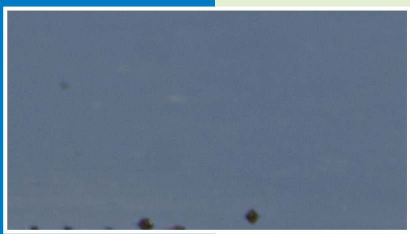
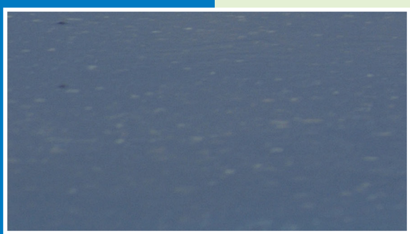
Tracking lesser black-backed and herring gulls in the Dutch Delta

Distribution, behaviour, breeding success and diet in relation to (future) offshore wind farms





N. Vanermen
R.C. Fijn
E. Bravo Rebolledo
R-J. Buijs
W. Courtens
S. Duijns
S. Lilipaly
H. Verstraete
E.W.M. Stienen

BEC
deltamilieu PROJECTEN
Bureau Waardenburg Ecology & Landscape
INSTITUUT NATUUR- EN BOSONDERZOEK
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N. Vanermen, R.C. Fijn, E. Bravo Rebolledo, R-J. Buijs, W. Courtens, S. Duijns, S. Lilipaly, M. Van de walle, H. Verstraete, E.W.M. Stienen

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Bureau Waardenburg
Ecology & Landscape

Bureau Waardenburg, Varkensmarkt 9, 4101 CK Culemborg, the Netherlands
0031 (0) 345 512 710, info@buwa.nl, www.buwa.nl

Preface and acknowledgements

The work presented here was commissioned by Rijkswaterstaat Water, Verkeer en Leefomgeving and contracted to Bureau Waardenburg, the Instituut voor Natuur- en Bosonderzoek, Deltamilieu Projecten and Buijs Eco Consult.

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Tracking of lesser black-backed gulls and herring gulls was performed under the appropriate Animal Experiment Licenses and site-specific Wet natuurbescherming licenses and exemptions, and Vogeltrekstation ringing permits.

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Summary

The main aim of this study was to gain insight in the offshore habitat use of large gulls breeding at Neeltje Jans to assess the potential impact of the wind energy area Borssele and the nearby Belgian wind farm concession zone. Therefore, 74 lesser black-backed and 25 herring gulls were tagged with GPS-loggers. To support the GPS data and to gather reference data for future comparison, we further collected data on breeding success and diet.

This study showed that herring gulls breeding at Neeltje Jans occur strongly coast-bound and thus did not show overlap with the regarded offshore wind farm (OWF) concession zones. Herring gulls recorded offshore in and around the OWFs must therefore originate from different breeding locations, most likely in the UK and Scandinavia.

Breeding lesser black-backed gulls, however, did use the OWF concession zones regularly. Targeted analyses on their distribution inside and near the wind farms could not detect meso- nor macro-avoidance responses. Importantly, this poses them with a higher collision risk than thought before. This indicates that OWFs that are nearshore and close to colonies may pose a potential threat to lesser black-backed gulls breeding in the Netherlands.

This tagging study provided crucial insight in the spatio-temporal and individual variation in habitat use of large gulls in general as well as in the gulls' occurrence in and around the regarded OWFs. As such, the collected GPS database can be used to refine collision risk modelling, and to assess the potential additional mortality at colony-level.

Despite the many knowledge gaps that have been filled in this study, some important issues do remain. The origin of herring gulls observed in the Borssele and Belgian wind energy areas for example is still of concern, as effects on these individuals may have consequences for more northern (protected) populations. Tagging studies outside our borders could shed more light on this issue. And although a better insight in the absence of meso- and macro-avoidance responses by lesser black-backed gulls is now available, estimates of micro-avoidance are still lacking. To study such behaviour the birds need to be filmed or observed directly when approaching rotating turbines. On the other hand, in combination with accelerometer data analyses, high resolution GPS data might also allow to discern micro-scale avoidance actions. Another option would therefore be to adjust the geofences of the current loggers in future years and collect for example 1 second interval data inside (part of) the wind farms.

Nederlandse samenvatting

Het hoofddoel van deze studie was om meer inzicht te verwerven in het offshore habitatgebruik van op Neeltje Jans broedende grote meeuwen, dit teneinde de potentiële impact van het windenergie-gebied Borssele (alsook het zeer nabije Belgische windparkconcessiegebied) beter te kunnen inschatten. Daartoe werden 74 kleine mantel- en 25 zilvermeeuwen voorzien van een GPS zender. Om de daaruit voortvloeiende data te ondersteunen, en om referentiemateriaal te verzamelen voor een toekomstige vergelijking, werden ook gegevens rond broedsucces en dieet verzameld.

Deze studie toonde aan dat zilvermeeuwen van Neeltje Jans sterk kust-gebonden voorkomen, en dat hun verspreiding niet overlapt met de offshore windparken. De zilvermeeuwen die daar (voornamelijk buiten het broedseizoen) worden waargenomen zijn wellicht Scandinavische en Britse broedvogels.

De gezenderde kleine mantelmeeuwen daarentegen maakten wel gebruik van de windparkgebieden. Gerichte analyses van hun verspreiding in en rond de windparken konden geen vermijdingsgedrag detecteren, noch op meso- noch op macroschaal. Dit stelt hen echter wel aan een groter aanvaringsrisico bloot dan voorheen gedacht. Windparken die dichtbij de kust of meeuwenkolonies gelegen zijn kunnen daarom een bedreiging vormen voor broedende kleine mantelmeeuwen in Nederland.

Deze studie leverde cruciale inzichten in de spatio-temporele en individuele variatie in habitatgebruik van grote meeuwen in het algemeen en in het gebruik van de Borssele en Belgische offshore windparken in het bijzonder. De opgebouwde databank van GPS gegevens kan aldus worden gebruikt ter verfijning van aanvaringsmodellen en om de potentiële additionele mortaliteit te bepalen op het niveau van de kolonie op Neeltje Jans.

Ondanks die opgebouwde kennis blijven er belangrijke kennishiaten. Het feit dat er wel degelijk zilvermeeuwen worden waargenomen in en rond de windparken doet de vraag rijzen wat de invloed is van deze parken op de betrokken populaties, en zenderstudies buiten onze landsgrenzen zouden hier een antwoord op kunnen bieden. Verder is ook nog weinig bekend over micro-vermijding van kleine mantelmeeuwen. Om dit soort gedrag te bestuderen zijn heel gedetailleerde en directe observaties, bijvoorbeeld door het gebruik van camera's, nodig. Anderzijds zou de analyse van accelerometer-data in combinatie met hoge resolutie GPS gegevens wel eens meer inzicht in microvermijdingsgedrag kunnen opleveren. Een optie voor volgend jaar zou zijn om de resolutie van de nog werkende GPS zenders uit deze studie verder te verhogen tot bijvoorbeeld 1 record per seconde binnen (een deel van) de windparken.

1 Introduction

1.1 Background

Renewable energy, and in particular the development of offshore wind farms (OWFs), is one of the key strategies of the 'Klimaatakkoord' of the Dutch government to fulfil the requirements of various agreements to combat global climate change. Upscaling of the capacity of OWFs in the Dutch North Sea is currently ongoing (Structuurvisie Wind op Zee, routekaart 2030) but given the potential negative effects of OWFs on a range of physical and biological parameters, a detailed insight in these consequences is urgently needed (Fox *et al.* 2006, Bailey *et al.* 2014, Goodale & Milman 2016, Nazir *et al.* 2020).

Lesser black-backed gulls *Larus fuscus* and herring gulls *Larus argentatus* occur throughout the Delta area. Both species have large breeding colonies on Maasvlakte, Haringvliet, Hollands Diep, Schouwen, Neeltje Jans and Sloegebied. The number of breeding pairs of herring gull declined between 1980 and 2005, after which the numbers stabilized around 14,500 breeding pairs (data Rijkswaterstaat (RWS)). The number of breeding pairs of lesser black-backed gull increased in the early 2000s, after which their numbers also remained relatively stable at about 40,000 breeding pairs (data RWS).

Lesser black-backed gulls and herring gulls are among the 18 species of sea and coastal birds identified as susceptible to collision mortality and/or avoidance due to offshore wind farms (Buij *et al.* 2018, van Kooten *et al.* 2019, Potiek *et al.* 2019). Based on previous studies (e.g. Camphuysen *et al.* 2015, Stienen *et al.* 2016, Thaxter *et al.* 2015 & 2018), it is expected that the home ranges of the birds breeding in the Dutch Delta will overlap with the wind energy area Borssele as well as with the nearby and fully operational Belgian wind farm concession zone.

In addition to direct mortality as a result of collisions, avoidance of offshore wind farms may have consequences for foraging and breeding success, or may induce indirect mortality due to decreased fitness (so-called carry-over effects, e.g. Harrison *et al.* 2011, Betini *et al.* 2013). To assess the impact of the Borssele wind farm, GPS tracking devices have been deployed to herring and lesser black-backed gulls in the colony on the artificial island of Neeltje Jans at the Oosterschelde. Based on previous studies and diet remains around the nest (e.g. Lilipaly *et al.* 2019), an unknown fraction of the individuals in this colony is known to forage in the Voordelta and thus potentially within the wind energy area Borssele.

The aim of this study is to gain insight into offshore habitat use of lesser black-backed gulls and herring gulls in a colony potentially affected by the wind energy area Borssele. As background information for further studies, we also collected data on colony size, breeding success and diet.

1.2 Research questions

The initial research questions regarding lesser black-backed gull and herring gull defined in the tender[1] were:

1. How do large gulls breeding in the Dutch Delta use the adjacent marine habitat for foraging?
2. What is the influence of offshore wind farms on the distribution and foraging behaviour of large gulls?
3. What is the relationship between foraging habitat, prey choice and breeding success?

These broad questions were translated into specific research questions which are addressed in the report at hand. These specific questions are given below with references to the chapters in which they are being treated:

- To what degree do at-sea distributions of lesser black-backed and herring gulls overlap with (planned) OWFs? (Chapter 3)
- To what degree do large gulls react to OWFs at meso- and at macro-scale? (Chapter 4)
- What are the breeding numbers and breeding success of large gulls breeding at Neeltje Jans and in the Delta region? (Chapter 5)
- What is the diet composition based on pellets found around the nests of large gulls with GPS-loggers? (Chapter 6)

These research questions aim to fill existing knowledge gaps concerning large gulls and the potential impact of OWFs on these species. These knowledge gaps, identified in the EIA process of individual OWF concession areas and the so-called KEC (Dutch: 'Kader voor Ecologie en Cumulatie', English: 'Framework for Ecology and Cumulative effects'), focus on 1) the distribution of large gulls, especially during the breeding period, and 2) avoidance of, or attraction to OWFs. Furthermore, baseline data on breeding and diet are collected as background information with respect to tagged gulls, and for future use to study potential changes.

[1] In the tender, also the sandwich tern is mentioned as study object. Results on this species are combined with another Wozep-study in a separate report (19-0138-0923 Final Report Sandwich Tern Projects).

2 Methods

2.1 Tracking

2.1.1 Trapping, ringing and tagging

In the breeding season of 2020, fifty gulls equally spread over herring and lesser black-backed gull were caught on their nest during incubation using walk-in traps. Targeted nests were marked beforehand with a numbered bamboo stick and three-egg clutches were strongly favoured. Forty birds were caught and tagged in the most south-western sub-colony of Westduinen (51.624°N 3.684°E) during two different days (20 & 28/05/2020). The ten remaining birds were caught and tagged on the 2nd of June at sub-colony Oostduinen (51.628°N 3.703°E) (Figure 2.1). Both locations were chosen based on clear indications of marine foraging habits of the gulls breeding there. After year 1 it was clear that herring gulls did not interact with the Borssele OWF at all.

In 2021 another fifty trackers were thus deployed on breeding lesser black-backed gulls only. All fifty birds were caught and tagged at Westduinen over three days (25/05, 01/06 & 02/06/2021). To avoid too much and too localized pressure on the colony, catching effort was spread along the dune strip at Westduinen (between 51.628°N 3.703°E and 51.632°N 3.695°E) in subareas called Westduinen, Noord van Slufter and Noordduinen (Figure 2.1). One bird tagged in 2020 (‘*Wouter*’) was (accidentally) recaught and subsequently retagged as the old tracker did not function anymore. Summarising, there are 99 different study birds, i.e. 25 herring gulls and 74 lesser black-backed gulls.

Figure 2.1 *Toponyms of the breeding locations of lesser black-backed and herring gull colonies on Neeltje Jans.*

Lesser black-backed gulls near walk-in trap at Westduinen (Photograph R. Fijn, Bureau Waardenburg)

Herring gull with GPS-logger at Westduinen (Photograph R. Fijn, Bureau Waardenburg)

Lesser black-backed gulls were equipped with a black-coloured Ornitela OT-15-3GCT tracker (15 g), while herring gulls received a white-coloured OT-20-3GCT tracker (20 g). Trackers were attached using a body harness of Teflon ribbon which in 2020 (but not in 2021) was internally threaded with a nylon string (Stienen *et al*. 2016). Apart from tagging, we also measured tarsus, head, bill & wing length, bill depth and mass of each bird. Birds were sexed based on biometrics, and all birds received a metal scientific ring from the Dutch Vogeltrekstation and a coloured plastic ring with an individually recognizable inscription. An overview of (part of) the metadata is given in Table 2.1.

2.1.2 Explorative analyses on the general movements and distribution of tagged gulls

The settings of the trackers vary depending on the time of day and the birds' location. In the breeding season and from dawn till dusk, the GPS fix interval was set at 900 s when inside the colony, at 180 s when outside the colony and at 20 s when inside the OWF geo-fence. This geo-fence surrounds the Borssele and Belgian wind farm concession zones and was delineated by a north-south orientated rectangle with the following coordinates: 51.828°N 2.659°E (northwest corner) and 51.464°N 3.172°E (southeast corner). From dusk till dawn, the GPS fix interval was kept at 20 s in the OWF geo-fence, but lowered to 1,800 and 900 s, respectively in- and outside the colony. Stepwise longer intervals are induced when the tracker's battery is down to 75%, 50% and 25% of its maximal capacity. After each GPS fix, three-dimensional accelerometer data are gathered for 1 s with a frequency of 20 Hz. Outside the breeding season fix intervals were extended to 1,200 s, except for the OWF geo-fence where a resolution of 20 s is maintained year-round.

To obtain manageable datasets, we performed some data selections prior to analysing. For explorative visualisations and analyses we mostly used a dataset that was resampled to a 60 min resolution, unless stated otherwise. Tracks with fix intervals higher than 100 min were deleted from the database. This strategy has several advantages, as it avoids the results being skewed towards tracks with the highest resolution and it also avoids autocorrelation between consecutive fixes (Ross-Smith *et al.* 2016, Thaxter *et al*. 2018). Depending on the scope, we also often applied a geographical selection of GPS fixes within the species-specific foraging ranges from Neeltje Jans. The latter were based on Thaxter *et al*. (2012) who report a mean maximum foraging range of 61 km for herring gull and 141 km for lesser black-backed gull.

Based on the gulls' yearly cycle we defined four periods, i.e. winter (October-February), pre-breeding season (March-April), breeding season (May-July) & post-breeding season (August-September). In case of lesser black-backed gulls, we sometimes further distinguished between territorial and non-territorial birds, which was decided based on the number of fixes inside a buffer zone of 3 km around Neeltje Jans (>200 records, resampled to 60 min) and the percentage of the fixes (>25%) spent there per month. While these cut-offs were based on birds known to have eggs and/or chicks, this strategy also includes individuals showing a comparable attachment to the colony, regardless of their known breeding status (note that in 2021 we did not have nest information of birds that were tagged in 2020).

Table 2.1 *Metadata of the tagged birds, totalling 25 herring and 74 lesser black-backed gulls.*

Tag ID	Taxon	Nickname	Deploy date	Mass	Ring ID	Sex	Location
201115	*Larus argentatus*	Torkild	20/05/2020	1,100	N-6|1	m	Westduinen
201116	*Larus argentatus*	Renaud	02/06/2020	1013	N-9|E	m	Oostduinen
201117	*Larus argentatus*	Arie	28/05/2020	919	N-8|W	m	Westduinen
201118	*Larus argentatus*	Hubert	28/05/2020	1,025	N-8|N	m	Westduinen
201119	*Larus argentatus*	Martin	28/05/2020	1,002	N-8|R	m	Westduinen
201120	*Larus argentatus*	Ann	20/05/2020	861	N-6|X	f	Westduinen
201121	*Larus argentatus*	Meta	20/05/2020	819	N-6|3	f	Westduinen
201122	*Larus argentatus*	Maarten	28/05/2020	1,012	N-8|K	m	Westduinen
201123	*Larus argentatus*	Hadewych	20/05/2020	778	N-6|Z	f	Westduinen
201124	*Larus argentatus*	Tine	20/05/2020	835	N-6|W	f	Westduinen
201125	*Larus argentatus*	Arjen	28/05/2020	946	N-8|T	m	Westduinen
201126	*Larus argentatus*	Marijke	20/05/2020	850	N-6|Y	f	Westduinen
201127	*Larus argentatus*	Jos	28/05/2020	978	N-8|M	m	Westduinen
201128	*Larus argentatus*	Mark	02/06/2020	1,067	N-9|L	m	Oostduinen
201129	*Larus argentatus*	Sander	02/06/2020	1,013	N-9|J	m	Oostduinen
201130	*Larus argentatus*	Mimi	20/05/2020	871	N-6|4	f	Westduinen
201131	*Larus argentatus*	Brechtje	28/05/2020	741	N-8|U	f	Westduinen
201132	*Larus argentatus*	Luis	02/06/2020	1,109	N-9|P	m	Oostduinen
201133	*Larus argentatus*	Marc	20/05/2020	1,028	N-6|0	m	Westduinen
201134	*Larus argentatus*	Timo	28/05/2020	1,035	N-8|L	m	Westduinen
201135	*Larus argentatus*	Floor	20/05/2020	975	N-6|2	m	Westduinen
201136	*Larus argentatus*	Pim	20/05/2020	1,030	N-6|V	m	Westduinen
201137	*Larus argentatus*	Griet	28/05/2020	863	N-8|J	f	Westduinen
201138	*Larus argentatus*	Dirk	02/06/2020	977	N-9|Z	m	Oostduinen
201139	*Larus argentatus*	Mingtje	28/05/2020	776	N-8|P	f	Westduinen
201089	*Larus fuscus*	Nicolas	20/05/2020	901	P-D9	m	Westduinen
201090	*Larus fuscus*	Hilbran	02/06/2020	892	P-H4	m	Oostduinen
201091	*Larus fuscus*	Ruben	20/05/2020	845	P-D7	m	Westduinen
201092	*Larus fuscus*	Wouter	20/05/2020	892	P-DY	?	Westduinen
201093	*Larus fuscus*	Willie	28/05/2020	973	P-G=	m	Westduinen
201094	*Larus fuscus*	Naomi	20/05/2020	626	P-D5	f	Westduinen
201095	*Larus fuscus*	Marloes	28/05/2020	730	P-G9	f	Westduinen
201096	*Larus fuscus*	Jelena	28/05/2020	737	P-DZ	f	Westduinen
201097	*Larus fuscus*	Jarno	28/05/2020	924	P-HA	m	Westduinen
201098	*Larus fuscus*	Miranda	28/05/2020	758	P-G6	f	Westduinen
201099	*Larus fuscus*	Astrid	02/06/2020	763	P-H2	f	Oostduinen
201100	*Larus fuscus*	Halina	28/05/2020	691	P-G8	f	Westduinen
201101	*Larus fuscus*	Sophie	02/06/2020	670	P-H5	f	Oostduinen
201102	*Larus fuscus*	Nora	02/06/2020	688	P-H6	f	Oostduinen
201103	*Larus fuscus*	Sjoerd	20/05/2020	940	P-D2	m	Westduinen
201104	*Larus fuscus*	Anke	02/06/2020	771	P-H3	f	Oostduinen
201105	*Larus fuscus*	Jolanda	20/05/2020	819	P-D4	f	Westduinen

Tag ID	Taxon	Nickname	Deploy date	Mass	Ring ID	Sex	Location
201106	*Larus fuscus*	Jacintha	28/05/2020	671	P-G7	f	Westduinen
201107	*Larus fuscus*	Eric	20/05/2020	977	P-D1	m	Westduinen
201108	*Larus fuscus*	Roland-Jan	20/05/2020	884	P-D6	m	Westduinen
201109	*Larus fuscus*	Wilma	20/05/2020	736	P-D0	f	Westduinen
201110	*Larus fuscus*	Maureen	28/05/2020	653	P-G+	f	Westduinen
201111	*Larus fuscus*	Kees	28/05/2020	838	P-HC	m	Westduinen
201112	*Larus fuscus*	Matias	28/05/2020	901	P-G5	m	Westduinen
201113	*Larus fuscus*	Abel	20/05/2020	821	P-D8	m	Westduinen
211275	*Larus fuscus*	Dovakhiin	25/05/2021	837	N/R-A.X	m	Westduinen
211276	*Larus fuscus*	Fréderik	02/06/2021	907	N/R-B.0	m	Westduinen
211277	*Larus fuscus*	Maarten	25/05/2021	943	B-N|4	m	Westduinen
211278	*Larus fuscus*	Djailey	02/06/2021	835	N/R-B.Y	f	Westduinen
211279	*Larus fuscus*	Emmanuel	25/05/2021	914	B-N|V	m	Westduinen
211280	*Larus fuscus*	Jip	02/06/2021	634	N/R-B.N	f	Westduinen
211281	*Larus fuscus*	Lore	01/06/2021	706	N/R-B.B	f	Westduinen
211282	*Larus fuscus*	Mirna	01/06/2021	704	N/R-B.C	f	Westduinen
211283	*Larus fuscus*	Wouter	01/06/2021	874	P-DY	m	Westduinen
211284	*Larus fuscus*	Bonita	25/05/2021	868	B-N|Z	f	Westduinen
211285	*Larus fuscus*	Sion	25/05/2021	919	B-N|S	m	Westduinen
211286	*Larus fuscus*	Alexander	01/06/2021		N/R-B.G	m	Westduinen
211287	*Larus fuscus*	Bas	25/05/2021	925	B-N|Y	m	Westduinen
211288	*Larus fuscus*	Lumi	02/06/2021	945	N/R-B.W	m	Westduinen
211289	*Larus fuscus*	Tiffany	25/05/2021	777	B-N|8	f	Westduinen
211290	*Larus fuscus*	Lien	02/06/2021	738	N/R-B.1	f	Westduinen
211291	*Larus fuscus*	Marta	25/05/2021	706	B-N|+	f	Westduinen
211292	*Larus fuscus*	Maura	02/06/2021	693	N/R-B.7	f	Westduinen
211293	*Larus fuscus*	Natacha	02/06/2021	852	N/R-B.T	f	Westduinen
211294	*Larus fuscus*	Daniël	25/05/2021	780	B-N|5	m	Westduinen
211295	*Larus fuscus*	Nathan	01/06/2021	893	N/R-B.F	m	Westduinen
211296	*Larus fuscus*	Maya	25/05/2021	706	B-N|6	f	Westduinen
211297	*Larus fuscus*	Véronique	25/05/2021	836	B-N|T	f	Westduinen
211298	*Larus fuscus*	Vincent	02/06/2021	967	N/R-B.S	m	Westduinen
211299	*Larus fuscus*	Annabelle	02/06/2021	707	N/R-B.2	f	Westduinen
211300	*Larus fuscus*	Alec	25/05/2021	868	N/R-A.W	m	Westduinen
211301	*Larus fuscus*	Elly	02/06/2021	723	N/R-B.U	f	Westduinen
211302	*Larus fuscus*	Carlin	25/05/2021	866	B-N|=	m	Westduinen
211303	*Larus fuscus*	Luc	02/06/2021	823	B-N|1	m	Westduinen
211304	*Larus fuscus*	Arvin	25/05/2021	675	B-N|3	m	Westduinen
211305	*Larus fuscus*	Monique	02/06/2021	775	N/R-B.8	f	Westduinen
211306	*Larus fuscus*	Marleny	25/05/2021		B-N|K	f	Westduinen
211307	*Larus fuscus*	Zoë	02/06/2021	735	N/R-B.X	f	Westduinen
211308	*Larus fuscus*	Lars	25/05/2021	976	B-N|7	m	Westduinen
211309	*Larus fuscus*	Joey	25/05/2021	895	B-N|W	m	Westduinen

Tag ID	Taxon	Nickname	Deploy date	Mass	Ring ID	Sex	Location
211310	*Larus fuscus*	Tristan	01/06/2021	860	N/R-B.E	m	Westduinen
211311	*Larus fuscus*	Virgile	02/06/2021	885	N/R-B.3	m	Westduinen
211312	*Larus fuscus*	Carine	01/06/2021	715	N/R-B.A	f	Westduinen
211313	*Larus fuscus*	Atlas	02/06/2021	709	N/R-B.P	m	Westduinen
211314	*Larus fuscus*	Gipsy	02/06/2021	883	N/R-B.V	m	Westduinen
211315	*Larus fuscus*	Rutger	02/06/2021	819	N/R-B.6	m	Westduinen
211316	*Larus fuscus*	Joseph	01/06/2021	883	N/R-B.D	m	Westduinen
211317	*Larus fuscus*	Francisca	02/06/2021	835	N/R-B.4	f	Westduinen
211318	*Larus fuscus*	Job	01/06/2021	743	P-HE	f	Westduinen
211319	*Larus fuscus*	Dimi	25/05/2021	862	B-N|X	m	Westduinen
211320	*Larus fuscus*	Mare	01/06/2021	775	N/R-B.H	f	Westduinen
211321	*Larus fuscus*	Eline	01/06/2021	747	N/R-B.J	f	Westduinen
211322	*Larus fuscus*	Garfield	02/06/2021	907	N/R-B.Z	m	Westduinen
211323	*Larus fuscus*	Yoram	25/05/2021	780	B-N|2	m	Westduinen
211324	*Larus fuscus*	Boris	02/06/2021	917	N/R-B.5	m	Westduinen

2.1.3 Targeted case studies on the use of the OWF concession zones by lesser black-backed gulls

Temporal variation in the use of the OWF concession zones

In this chapter we explore the temporal variation in the number of tagged lesser black-backed gulls present inside the OWF concession zone of Borssele and the adjacent Belgian OWFs. We used a GPS dataset that was resampled to a resolution of 3 min (discarding tracks with a fix interval higher than 4 min) and further selected data of the months of June and July, as this time of year generated 88% of all GPS fixes inside the concession zones. Finally, only data from the year 2021 were included since the Borssele wind farm was only fully operational from the beginning of that year onwards.

For each hour of the regarded period (June-July 2021) we determined (1) the number of tagged individuals present inside the OWF concession zones and (2) the number of individuals present in the wider offshore area, yet still within 141 km distance from Neeltje Jans (this distance being used as proxy for the gulls' foraging range). We further added the hourly averages of wind direction, wind speed and tidal height as potential covariates to the dataset. These parameters were measured at the monitoring location on the Westhinder sand bank and the data were downloaded from Meetnet Vlaamse Banken (www.meetnetvlaamsebanken.be).

The number of different individuals present (N_{area}) either inside the wind farms or in the offshore area was then modelled in function of thin plate regression splines of wind speed (m/s), tidal height (cm) and time of day (h), a factor variable weekend (TRUE/FALSE) and a factor variable area (OWF/Offshore). We allowed interaction effects between the factor variable area and the four former covariates. To avoid overfitting, the number of knots in the splines was kept at a maximum of six, and for time of day we applied a cyclic spline.

An offset variable was included in the model to account for the number of individuals present within 141 km from Neeltje Jans (N_{total}), thus also including terrestrial GPS fixes. We tested two distributions (Poisson & negative binomial) and four random structures, i.e. (1) no random effects, (2) a random intercept for month, (3) random intercepts for month and wind direction and (4) a random intercept for month and a random slope for wind direction over wind speed. Based on the AIC (Akaike 1974) a Poisson model with random intercepts for month and wind direction was selected. Through backward model selection, only the interaction between the factor variables area and weekend was discarded and, thus, the resulting (fixed part of the) model was of the following structure:

$$N_{area} \sim offset(N_{total}) + Area + Weekend + s(Hour,\ by{=}Area) + s(WindSpeed,\ by{=}Area) + s(TidalHeight,\ by{=}Area)$$

Meso-avoidance: case study Borssele OWF

In this case study we analyse whether distance to the nearest turbine is explanatory for the distribution of lesser black-backed gulls within an offshore wind farm, thus looking for meso-avoidance patterns. We used all GPS data (resampled to 3 min, discarding tracks with a fix interval higher than 4 min) located inside the Borssele wind farm (defined by a 300 m wide buffer area around the outer turbines), again only retaining data from 2021. We distinguished between 'flying' and 'non-flying' records based on a moving speed cut-off of 4 m/s (Baert *et al*. 2018), resulting in two separate datasets. Within both datasets, we only retained individuals with a minimum of 40 records to reduce the number of random effect levels.

For each GPS fix in both datasets, we randomly generated 6 pseudo-absences within the wind farm boundaries (Aarts *et al*. 2008, Langley *et al*. 2021). Next, we determined the distance to the nearest turbine as well as to the colony for each record.

A logistic regression was performed with presence/absence as the response variable and thin-plate smoothers (maximum number of knots set at six) of the two distance variables as explanatory variables. We tested two different random structures: no random effects and a random slope for individual over distance to the nearest turbine. Based on the AIC (Akaike 1974) we selected the latter random structure for the 'non-flying' dataset, and we continued with a model without random effects for the 'flying' dataset.

Macro-avoidance: case study Norther OWF

In Vanermen *et al*. (2021), a BACI study was performed to assess the effect of the construction of the Norther OWF (in the most south-eastern part of the Belgian wind farm concession zone) on the distribution of GPS-tagged lesser black-backed gulls. The relatively recent installation of this wind farm offered the opportunity to compare the distribution of tracked gulls in and around this particular site, before and after the construction of the turbines. To this end, one impact and two equally sized control areas were delineated as illustrated in Figure 2.2. The data used originated from lesser black-backed gulls caught and tagged in the colonies of Zeebrugge, Ostend & Vlissingen, using UvA-BiTS trackers (Stienen *et al*. 2016). As tagging effort in these colonies decreased over the last few years, a general decrease in the number of GPS records also occurred in the study area. Though easily accounted for by the model, more post-construction records clearly would build a stronger case. We therefore included GPS data from individuals tagged with Ornitela trackers in the Dutch colony of Neeltje Jans, the foraging range of which has been shown to overlap with the study area. In this chapter a comparable BACI analysis is thus performed by cumulating GPS data from all 4 colonies.

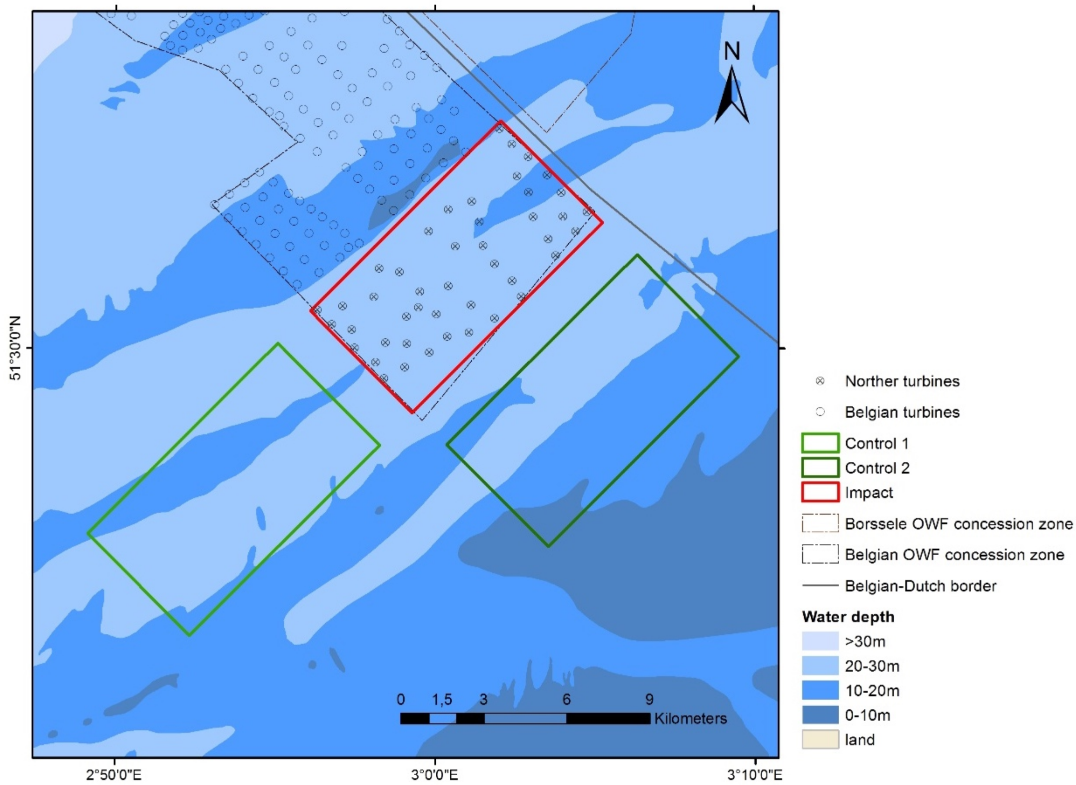

Figure 2.2 *BACI set up to study the impact of the construction of the Norther OWF on the distribution of tagged lesser black-backed gulls.*

Data of both logger types were resampled to a 60 min resolution (discarding tracks with a fix interval above 70 min, thus applying a more stringent cut-off compared to the explorative analyses in §2.1.2) to obtain an unbiased dataset. Based on the project timeline (www.norther.be/#timings), we defined the different periods for application in the BACI analysis as follows:

- Pre-construction period: 01/01/2016 – 30/06/2018
- Post-construction period: 01/09/2019 – present

Further overlaying the GPS data with the BACI polygons as shown in Figure 2.2 resulted in 2,707 records distributed per period and per origin as shown in Table 2.2.

Table 2.2 *Number of GPS fixes per period and per origin.*

	UvA-BiTS	Ornitela
Pre-construction period	1,526	0
Post-construction period	182	999

The response variable in our BACI model is the number of GPS records per day per area. We only considered days between the 1st of March and the 31st of August. Number of lesser black-backed gulls outside this time frame are much lower in general and those present probably originate from different sub-populations. With 490 and 368 days of sampling, respectively in the pre- and post-construction period, and three areas considered, the database holds 2,574 unique day-area combinations. As covariates we included the factor variables month, weekend (TRUE/FALSE), area and period, allowing interaction between the two latter. The estimated coefficient of the interaction between the area factor level 'impact' and the period factor level 'post-construction' is a measure of the (indirect) effect of the wind farm on the gulls' presence. We tested 4 distributions, i.e. Poisson, negative binomial, zero-inflated Poisson and zero-inflated negative binomial, and selected the negative binomial distribution based on the resulting AIC value (Akaike 1974).

Data processing and analyses

All data processing and analyses were performed in R version 4.1.1 (R Core Team 2021) using RStudio (RStudio Team 2021) making use of the following packages (in alphabetical order): data.table (Dowle & Srinivasan 2021), dplyr (Wickham *et al*. 2021), ggplot2 (Wickham 2016), htmlwidgets (Vaidyanathan *et al*. 2021), leaflet (Cheng *et al*. 2021), lubridate (Grolemund & Wickham 2011), MASS (Venables & Ripley 2002), mgcv (Wood 2017), pscl (Zeileis *et al*. 2008), reshape2 (Wickham 2007), rgdal (Bivand *et al*. 2021), rgeos (Bivand & Rundel 2021), sp (Pebesma & Bivand 2005), spatialEco (Evans 2021), tidyverse (Wickham *et al*. 2019).

2.2 Monitoring of breeding colonies

Beginning in April, suitable study areas were selected within the gull colony of Neeltje Jans. Besides the presence of a high density of breeding gulls, the possibility of constructing an enclosure around the nest was important for this selection. During May, suitable nests were marked individually with a labelled bamboo stick for visual recognition.

Inside these sub-colonies, data loggers were attached to part of the breeding adults (only one individual per nest, also see §2.1.1), and breeding success was monitored. Within a few days after catching and tagging, still active nests were enclosed with a 50 cm high chicken wire, resulting in enclosures with a diameter of about 4 m. The enclosures provided sufficient space for chick movement. In open locations with little shelter, PVC pipes were placed inside the enclosure to provide protection against predation or harsh weather conditions.

The enclosures were checked two to three times a week to register the number of eggs and/or chicks per nest. New-born chicks were aged and marked individually with coloured plastic tape around the tarsus, and body mass and head size of all chicks present were measured during each visit. Later in the breeding season, when the chicks were large enough, the tapes were replaced by a metal scientific ring from the Dutch Vogeltrekstation and a coloured plastic ring with an individually recognizable inscription. In all occupied enclosures we searched for regurgitated food and pellets, which were collected and stored in a freezer (see §2.3).

A reference colony was selected in the Oostduinen, where no data loggers were deployed. There, breeding success was monitored in a large enclosure set up in 2019 by Buijs Eco Consult and Het Zeeuwse Landschap. Within this enclosure, chicks could walk around freely, and could not be related to specific nests.

At the end of breeding season, end of July 2020 and 2021, all nearly fledged juveniles were counted in areas with a known total number of nests, both at Neeltje Jans as well as in the rest of the Delta. In small colonies mostly the entire colony was monitored, while in larger colonies subsamples were taken and only selected plots, for which the exact number of breeding pairs was known, were counted. In mixed colonies where it was difficult to acquire a good estimate of the number of juvenile lesser black-backed gulls and herring gulls, the proportion of adult birds present was used to determine the number of chicks per species. High vegetation in particular hampers the identification of chicks.

The gull colony at Westduinen with enclosures (Photograph R. Fijn, Bureau Waardenburg)

Herring gull breeding in an enclosure at Westduinen (Photograph R. Fijn, Bureau Waardenburg)

Herring gull at a marked nest at Westduinen (Photograph R. Fijn, Bureau Waardenburg)

2.3 Diet sampling and collection

The gull colony at Neeltje Jans is one of the few colonies in the Dutch Delta with a relatively large proportion of gulls (more specifically lesser black-backed gulls) that have marine feeding habits. Other colonies with a similar marine orientation are those in the Meeuwenduinen near Burgh-Haamstede and at the Maasvlakte.

In the enclosures of birds with GPS-loggers, pellets were collected for diet analysis. In total pellets were collected from 45 enclosures in 2020 and 2021. This concerned 6 herring gull enclosures in 2020 from which 20 pellets were collected and 39 lesser black-backed gull enclosures in 2020 and 2021 combined from which 86 pellets were collected (Appendix I). In general pellets are only produced by adults and not by (growing) chicks. Chicks only regurgitate when handled. So, it is fair to assume that all pellets originate from adult birds.

The pellets were individually collected in plastic bags and then stored in the freezer at minus 20°C until further processing. Pellets containing a lot of soft prey residues (meat, fat, liquid, etc.) were put in mesh bags (separate bags per pellet), made of nylon gauze, and washed following the method described by Bravo Rebolledo *et al.* (2013). These washed samples were then air-dried and checked for prey residue. In total, 70 of the 88 pellets were washed following this method, while the other pellets could be checked for prey remains immediately.

Vegetable matter was not included in the diet composition, as this was probably included during pellet collection and mainly concerned types of plants growing in dune areas. Natural prey remains were divided into 11 categories; fish, mussel, crab, bird (own feathers excluded), marine mammal, starfish, *Nereis*, *Sepia*, earthworm, seaweed and shrimp. Human-related material consisted of kitchen food and plastic waste or litter. To identify the species of ingested fish, the collected otoliths were identified.

Sorting diet samples in the lab (Photograph N. Ampe, Bureau Waardenburg)

3 Results: General movement and distribution

3.1 Herring gull

The 25 tagged herring gulls show a relatively limited geographical distribution (Figure 3.1), mainly concentrated around Neeltje Jans in the breeding season (May-July) and extending south to an area just north of Paris outside the breeding season. The latter most southern cluster of fixes is due to 1 specific bird in 2 consecutive winters. Interestingly, none of the tagged herring gulls ventured more than 30 km north of their breeding colony and throughout the year none entered the OWF concession zone Borssele. Due to their migratory behaviour, there is a strong seasonal pattern in the birds' average distance to Neeltje Jans (Figure 3.2). This distance is highest during mid-winter in December (126 km) and reaches its minimum in May (8 km).

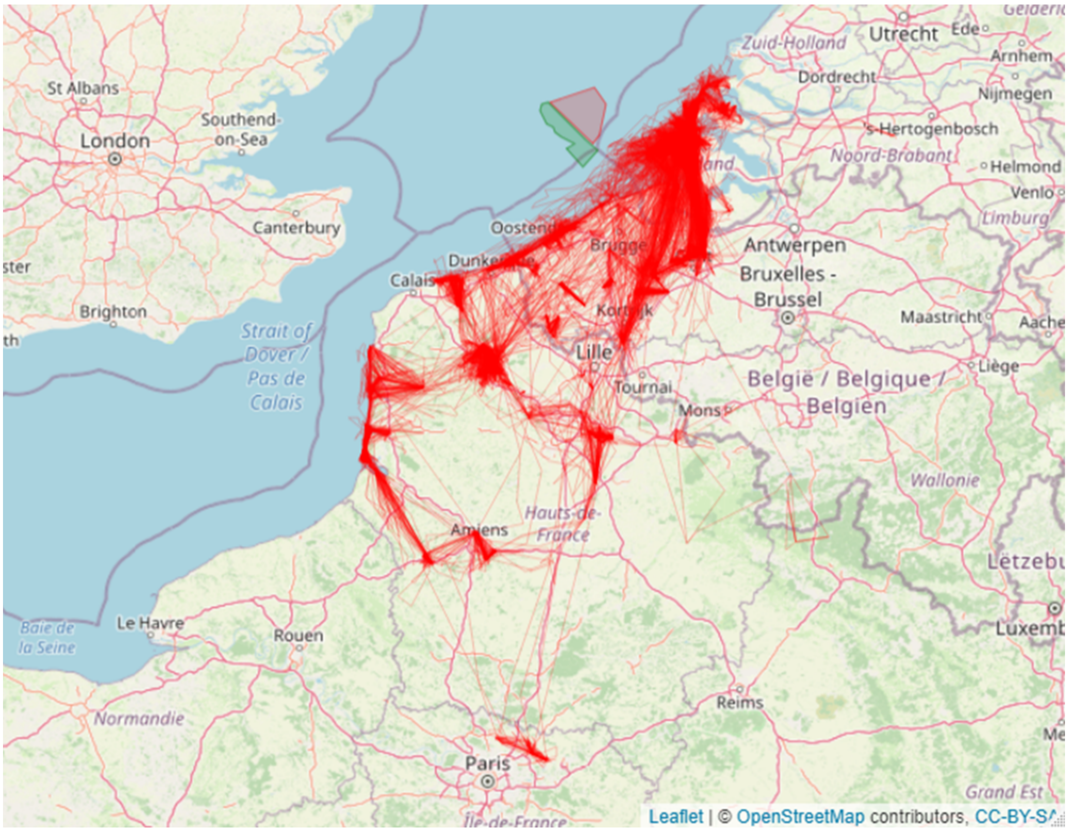

Figure 3.1 Year-round distribution range of the 25 herring gulls caught and tagged in their breeding colony at Neeltje Jans.

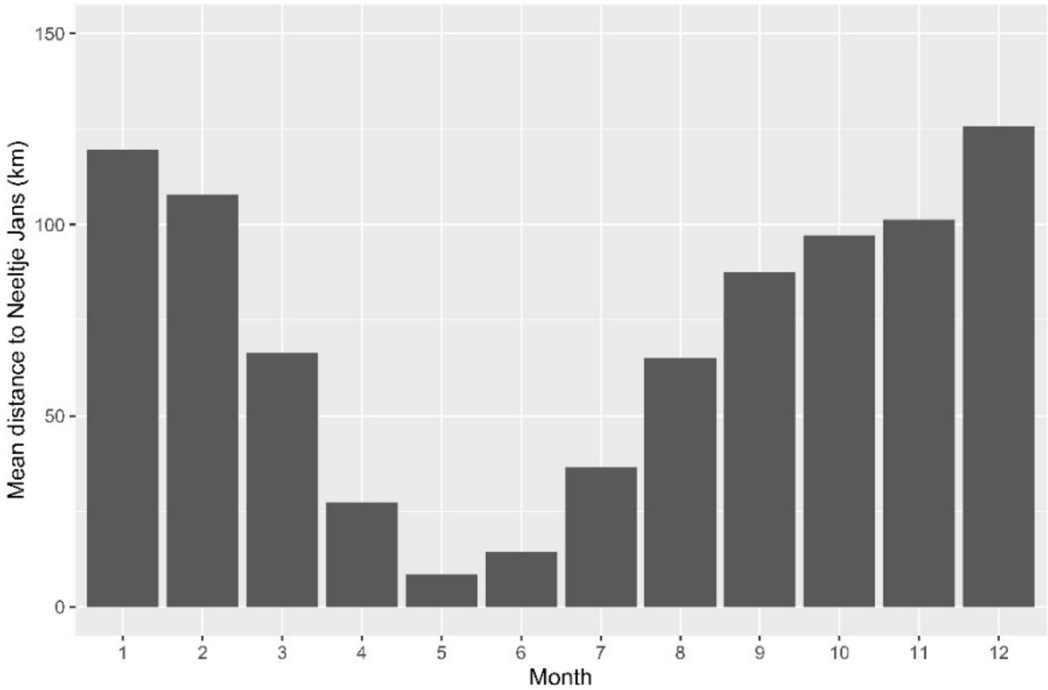

Figure 3.2 *Monthly variation in the mean distance of herring gull GPS fixes to Neeltje Jans (based on data resampled to 60 min - first averaged per individual per month and then per month).*

Figure 3.3 to Figure 3.6 zoom in more closely to the northern part of the birds' range and illustrate the seasonal variation in the distribution of tagged herring gulls.

During the pre-breeding season (March-April), tagged herring gulls already start to concentrate near the breeding colony, yet with many dispersed fixes still to the south and inland, across Flanders (Figure 3.3). Compared to the other seasons, the distribution pattern shows a distinctive marine 'plume' of fixes, originating at Neeltje Jans and extending about 10 km offshore.

As expected, the distribution of our study birds is most strongly concentrated near and mainly just south of the breeding colony at Neeltje Jans in the breeding season (May-July - Figure 3.4). As such, 82% of all GPS fixes are located within 22 km from the colony, with a particularly high concentration along the north-western coast of Walcheren. Offshore fixes are relatively scarce and all within 20 km from the coast. Shortly after the breeding season (August-September), the birds already occur much more dispersed (Figure 3.5). Distribution during that time of year is distinctly coastal with relatively few inland fixes (except for a cluster in the port of Ghent).

During the winter season, only 20% of all fixes are still located within a distance of 22 km from Neeltje Jans. More south, quite some inland clusters occur across Flanders and northern France, and a particularly strong concentration is found along and just in front of the coast between Ostend and Dunkerque. As in the rest of the year, the study birds do not venture far at sea, with no fixes further than 15 km offshore (Figure 3.6).

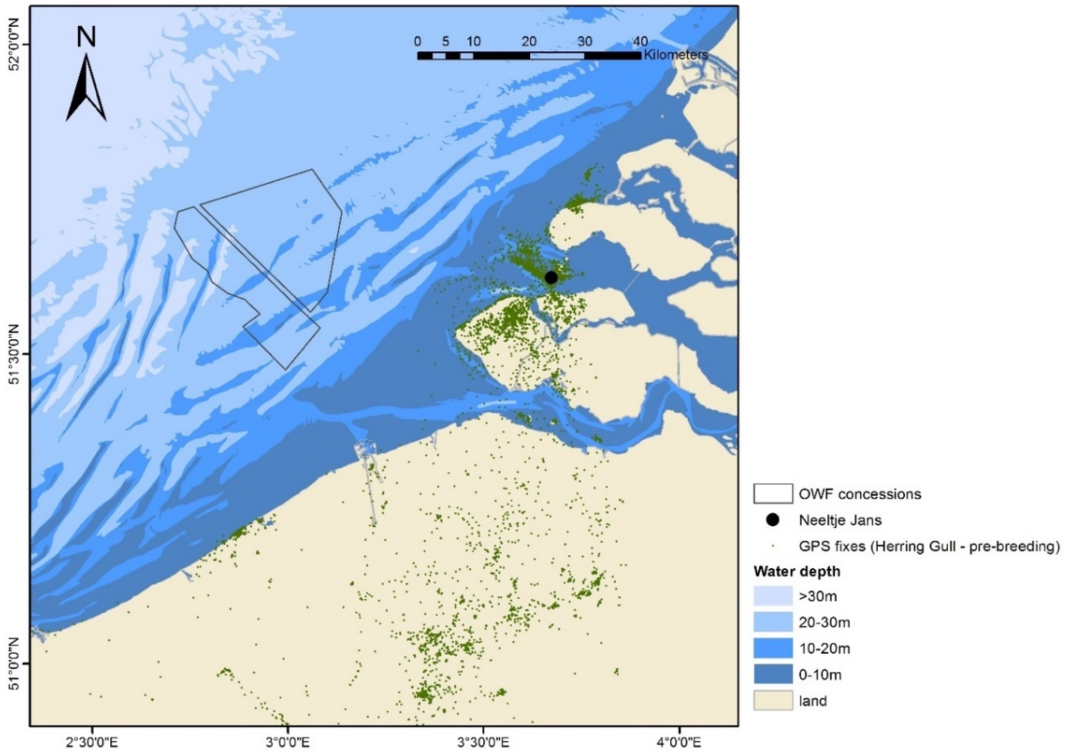

Figure 3.3 GPS fixes of herring gulls in the pre-breeding season (based on data resampled to 60 min).

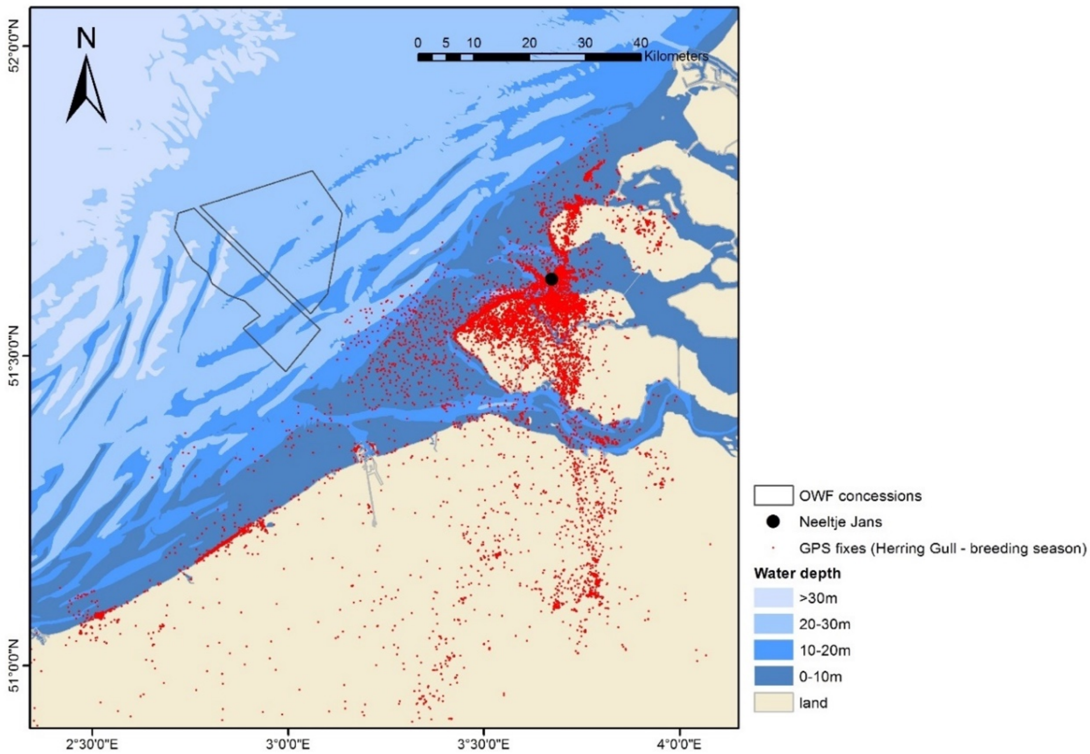

Figure 3.4 GPS fixes of herring gulls in the breeding season (based on data resampled to 60 min).

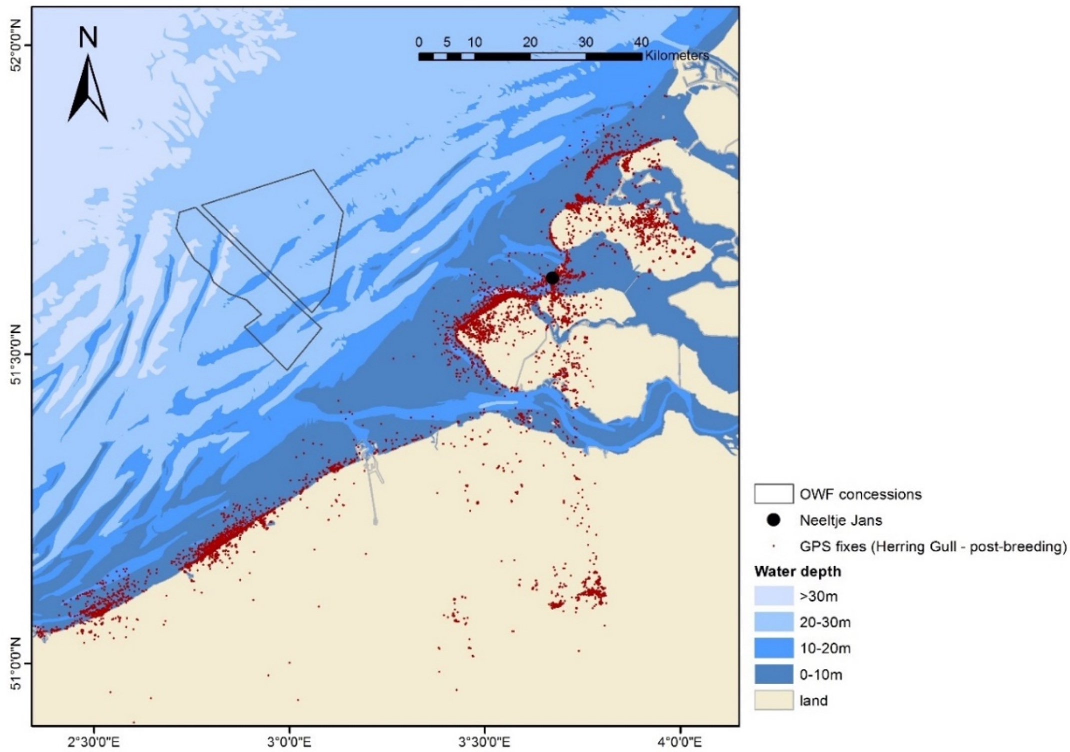

Figure 3.5 *GPS fixes of herring gulls in the post-breeding season (based on data resampled to 60 min).*

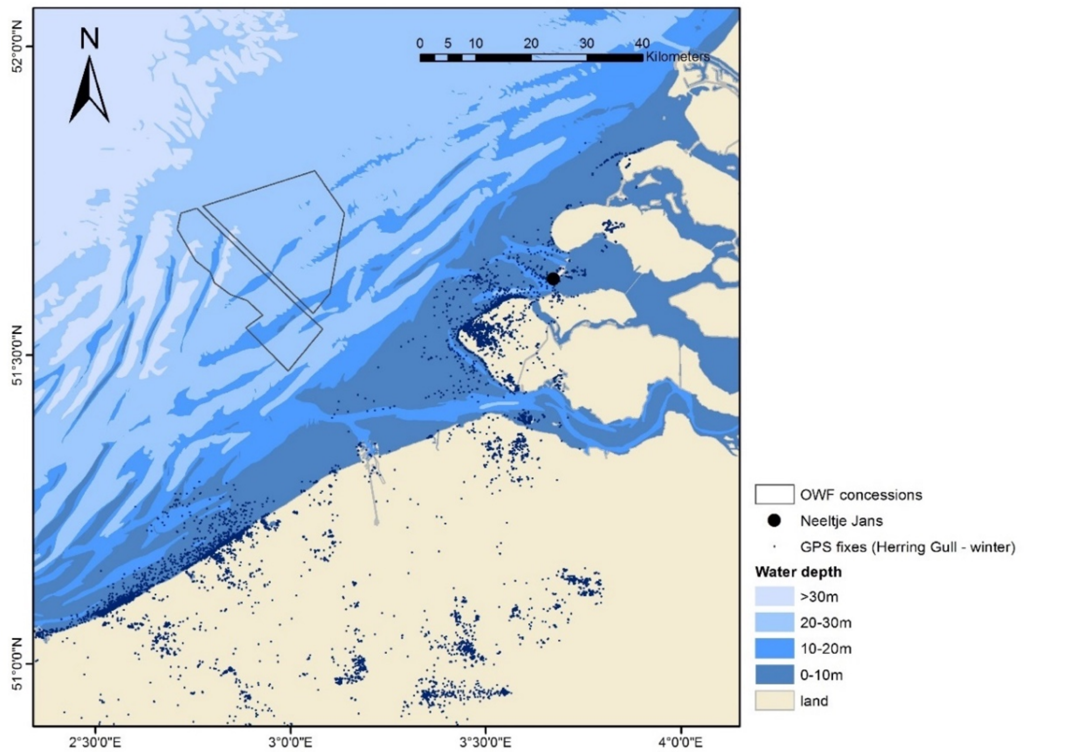

Figure 3.6 *GPS fixes of herring gulls in the winter season (based on data resampled to 60 min).*

When considering habitat use around the breeding colony (i.e. for herring gulls within 61 km distance), the tagged herring gulls indeed appear to spend very little time offshore (Figure 3.7). The percentage of offshore fixes ranges from 1.1% in the post-breeding months (August-September) to a maximum of 3.9% in the pre-breeding season (March-April, also see Figure 3.3). It should be noted that 'offshore' in this case is defined as more than 3 km outside the coastline to exclude the frequent use of intertidal areas for foraging and resting. Thus, the percentages given here are an underestimation of the actual time spent at sea. Importantly, due to this coast-bound distribution, no GPS fixes occur inside the OWF concession zone boundaries, which is why no more herring gulls were tagged in the breeding season of 2021.

Figure 3.7 further illustrates the seasonal variation in attachment to the colony, with especially high percentages of fixes (49.4 and 56.2%) in the direct vicinity (within 3 km) of the colony in the pre-breeding and breeding seasons respectively.

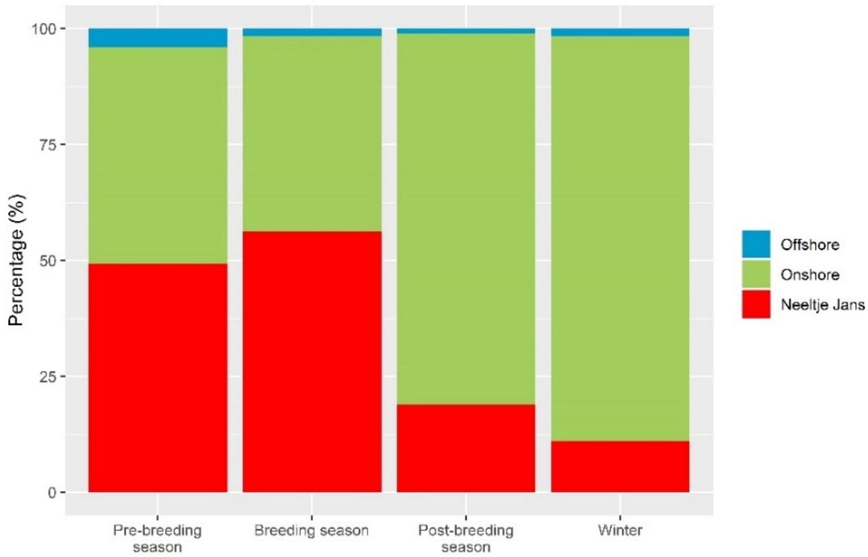

Figure 3.7 *Seasonal variation in the proportion of time spent offshore, onshore and near the colony by tagged herring gulls (based on data resampled to 60 min and located inside a buffer zone of 61 km around the colony).*

Overlaying our herring gull GPS fixes with the 'Corine Land Cover 2018' map (Copernicus Land Monitoring Service 2021) results in the pattern shown in Figure 3.8. This was based on data located within 3 to 61 km distance from the colony, thus excluding the time birds spend on the nest.

The percentage of time spent at sea, ranging between 13 and 28%, here is much higher compared to the percentages shown in Figure 3.7. The large difference in percentages between both figures concern birds within 3 km outside the coastline and is further amplified by the exclusion of time spent near the colony. Interestingly, a major part of these 'marine water' records includes birds resting and feeding on breakwaters. A significant part of the tagged gulls' time is further spent in 'industrial, commercial and transport units' (12-26%), ‘maritime wetlands’ (5-20%, mostly ‘intertidal flats’), ‘arable land’ (11-25%), and ‘open spaces with little to no vegetation’ (1-12%, mostly ‘beaches, dunes, sands’).

During the breeding season, most time is spent in coastal habitats (44%) and agricultural lands (36%), with comparatively little time in artificial urbanized or industrial sites (17%). Coastal habitats are used most often in August-September, with 59% of all fixes located there (see also Figure 3.5).

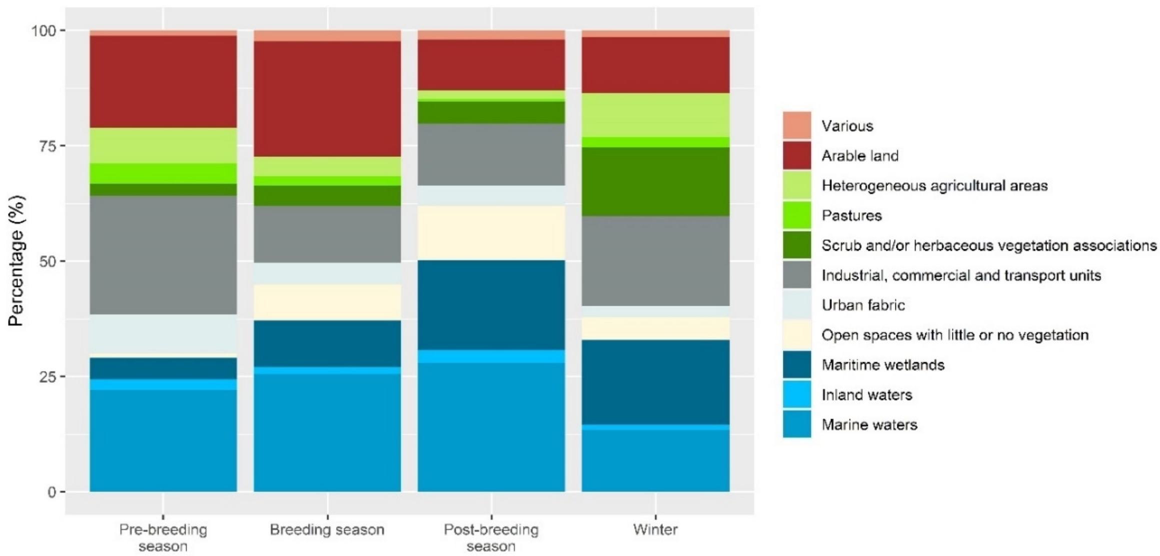

Figure 3.8 Seasonal variation in habitat use by herring gull applying the Corine land cover classification (based on data resampled to 60 min and located 3 to 61 km away from the colony).

Figure 3.9 illustrates the very strong individual variation in habitat use during the breeding season. The use of ‘marine waters’ for example varies from 0.5 to 71.7%, and the use of ‘arable land’ from 0.6 to 98.2%. The distribution of some distinctive individuals is displayed in Figure 3.10. Herring gull *Arie* (201117) for example spent 65% of his time in industrial areas, focusing on waste disposal sites just north of Ghent, about 60 km south of the breeding colony. The other three birds all had much more limited foraging ranges. *Hubert* (201118) rarely flew further than 5 km south of the colony and mainly focused on nearby arable land (89% of his time), while *Mark* (201128) mostly flew to the north, where he spent 55% of his time on a camping site in Renesse, from where he commuted back and forth to intertidal flats right in front of the coast (23%). Lastly, herring gull *Timo* (201134) appears to be a truly coastal bird, since he spent 77% of his time in coastal habitats. Yet this individual mainly focused his efforts on one single beach head in front of Domburg.

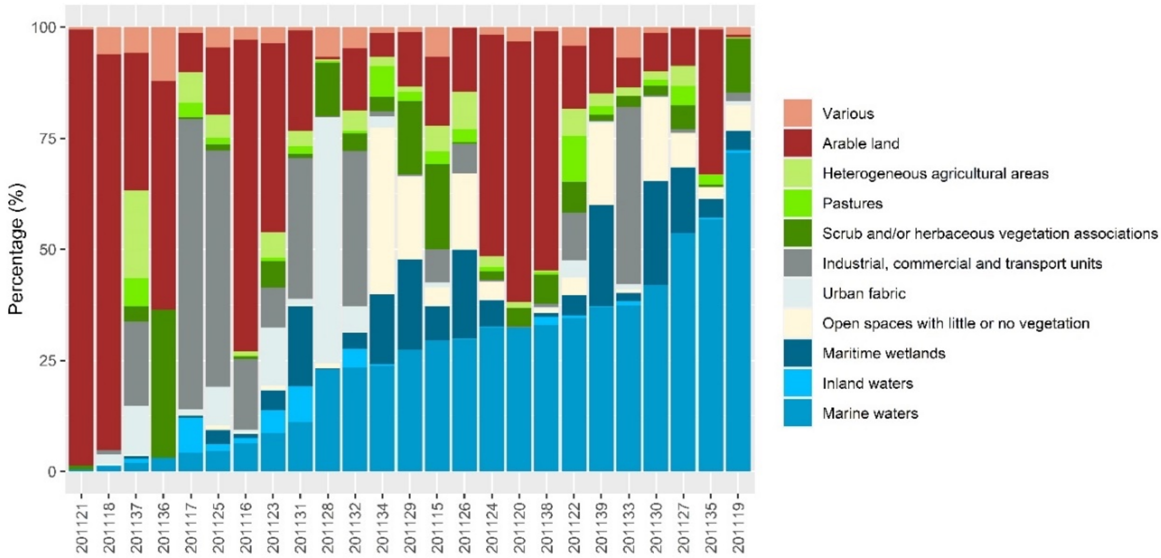

Figure 3.9 *Individual variation in habitat use by herring gull during the breeding season applying the Corine land cover classification (based on data resampled to 60 min and located 3 to 61 km away from the colony).*

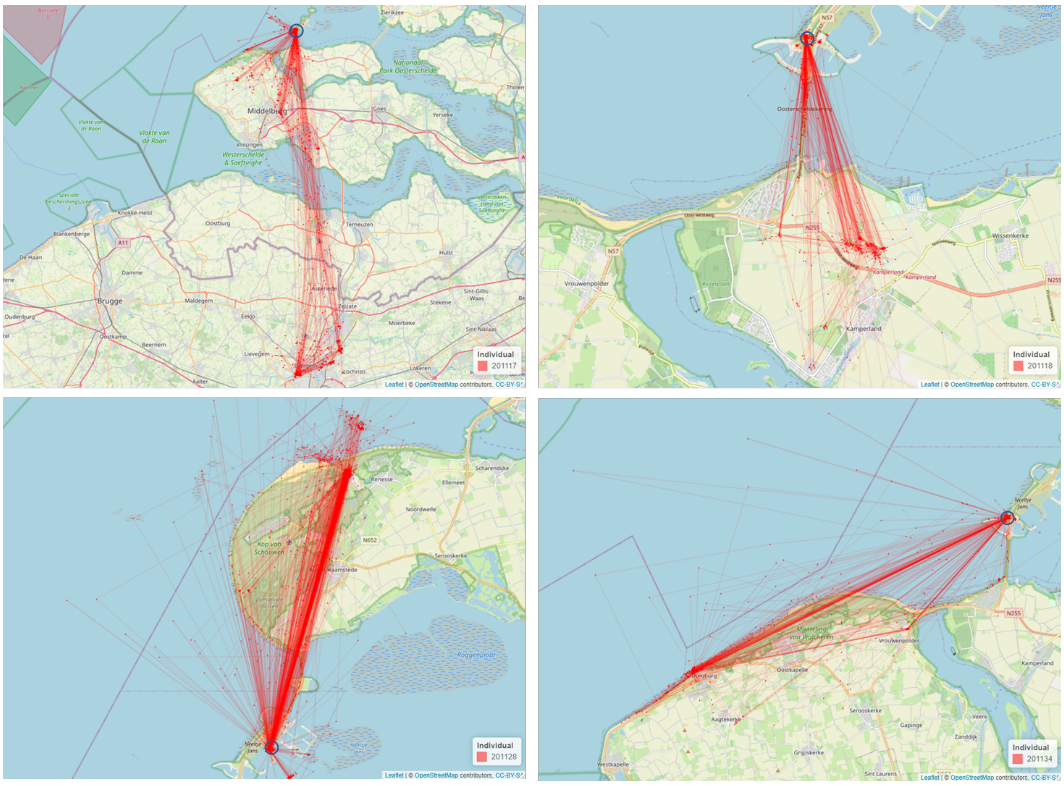

Figure 3.10 *Individual variation in foraging range and habitat use in 4 herring gulls (the blue circle shows the colony location) (based on data resampled to 60 min).*

3.2 Lesser black-backed gull

Lesser black-backed gulls are true migratory birds and have a much wider distribution range compared to herring gulls (Figure 3.11). Even within our small sample of 74 birds breeding close to each other, there is a striking range in migratory strategies, with birds wintering in northern France, the UK, Spain, Algeria, Morocco and Western Sahara. Figure 3.12 displays the seasonal variation in the birds' average distance to Neeltje Jans, which is highest during mid-winter in January (1,648 km) and reaches its minimum in May (21 km). From September to March the average distance is consistently above 750 km, far above the average midwinter distance of 126 km as seen in herring gull (Figure 3.2).

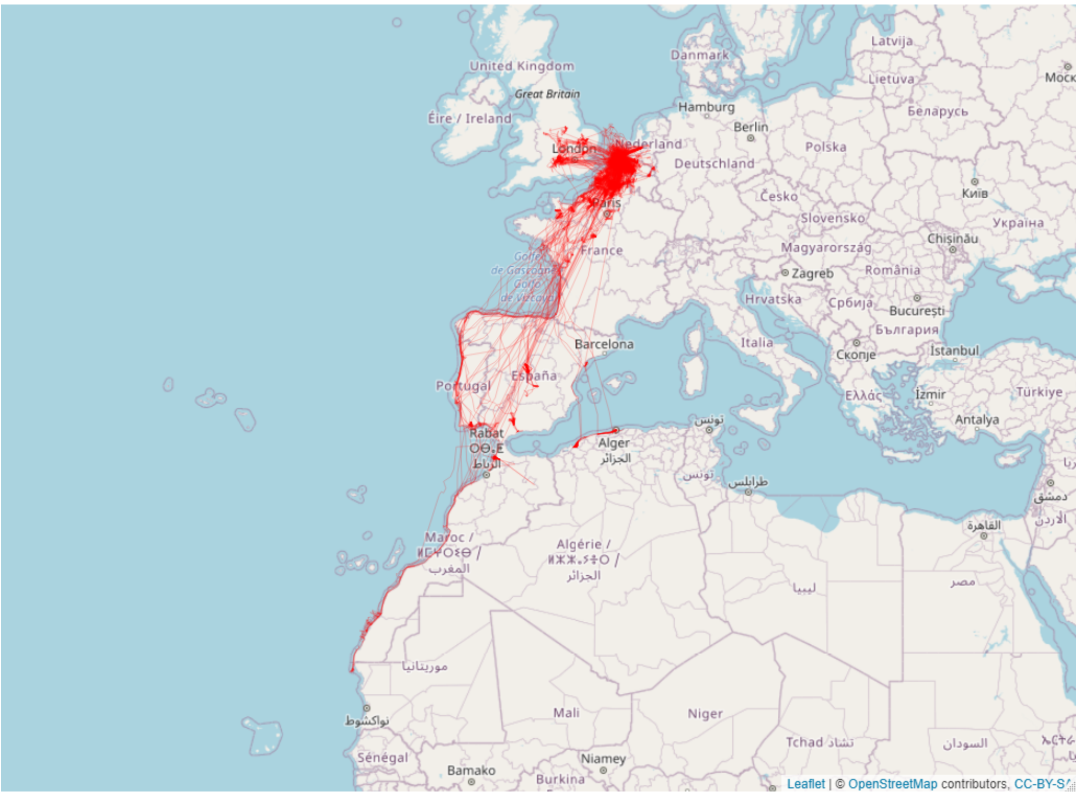

Figure 3.11 Year-round distribution range of the 74 lesser black-backed gulls caught and tagged in their breeding colony at Neeltje Jans.

Figure 3.13 to Figure 3.15 zoom in more closely and illustrate the seasonal variation in distribution near the tagged birds' colony.

For the months of March and April, Figure 3.13 shows relatively few fixes, most of which are located just northwest and south of Neeltje Jans. Of all pre-breeding fixes, 39% is located within 141 km around Neeltje Jans, the latter representing the birds' assumed foraging range. In contrast, during the breeding season 82% of all fixes occur within 141 km from the colony (Figure 3.14). That time of year the gulls mainly concentrate around the colony and at Walcheren. Meanwhile, many fixes are found offshore, mainly in the waters west of Walcheren, resulting in an overlap between lesser black-backed gull distribution and the OWF concession areas. The overall spatial pattern of GPS records, however, seems to suggest avoidance of the OWF concession zones (but see §4.3). There further seem to be clear offshore concentrations of GPS fixes, as for example in the gullies surrounding the Gootebank in Belgian waters (just southwest of the concession zone) and the clear cluster of fixes 40 km off Neeltje Jans.

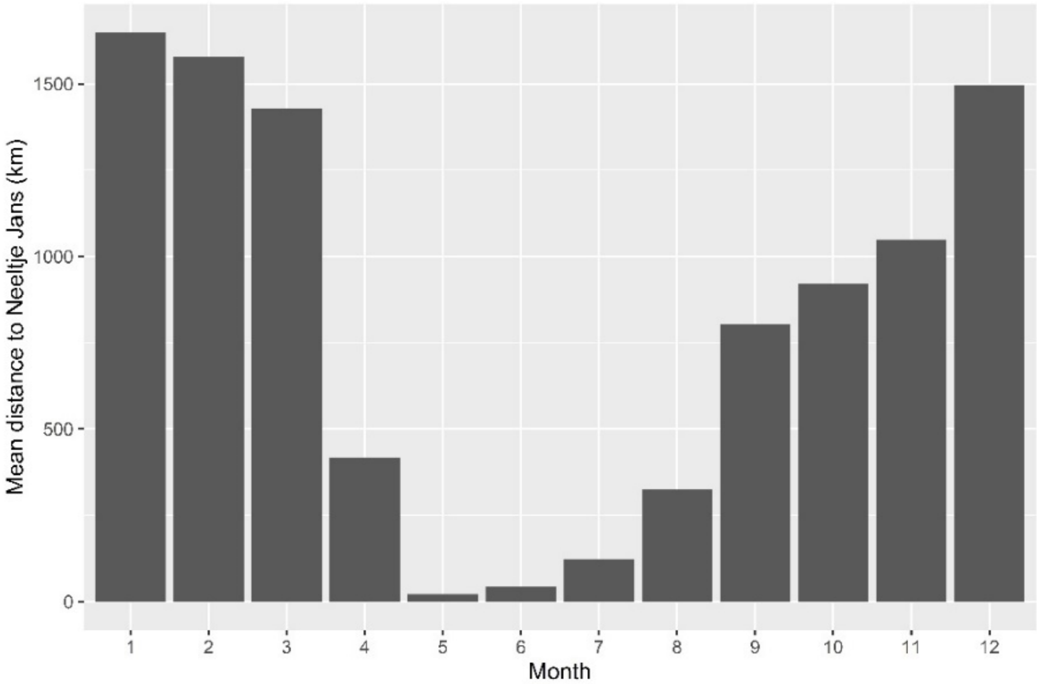

Figure 3.12 *Monthly variation in the mean distance of lesser black-backed gull GPS fixes to Neeltje Jans (based on data resampled to 60 min - first averaged per individual per month and then per month).*

In the post-breeding months (August-September) most birds have left the area (only 25% of the fixes remaining within 141 km from Neeltje Jans – see Figure 3.15). Interestingly, the same cluster of fixes located 40 km off Neeltje Jans still stands out. While one could suspect that such a cluster represents an interesting foraging area where multiple individuals aggregate, the opposite is true as this is due to a single individual (gull *Wouter*) frequenting this area in both study years (almost daily in the months of June and July). A comparable cluster visible in all three maps is found 27 km off Ostend and again is the result of a single individual returning to the same patch of sea day after day (gull *Nicolas*).

N/R-B.E ('Tristan') on a refuge dump near Bordeaux (Photograph T. Chansac)

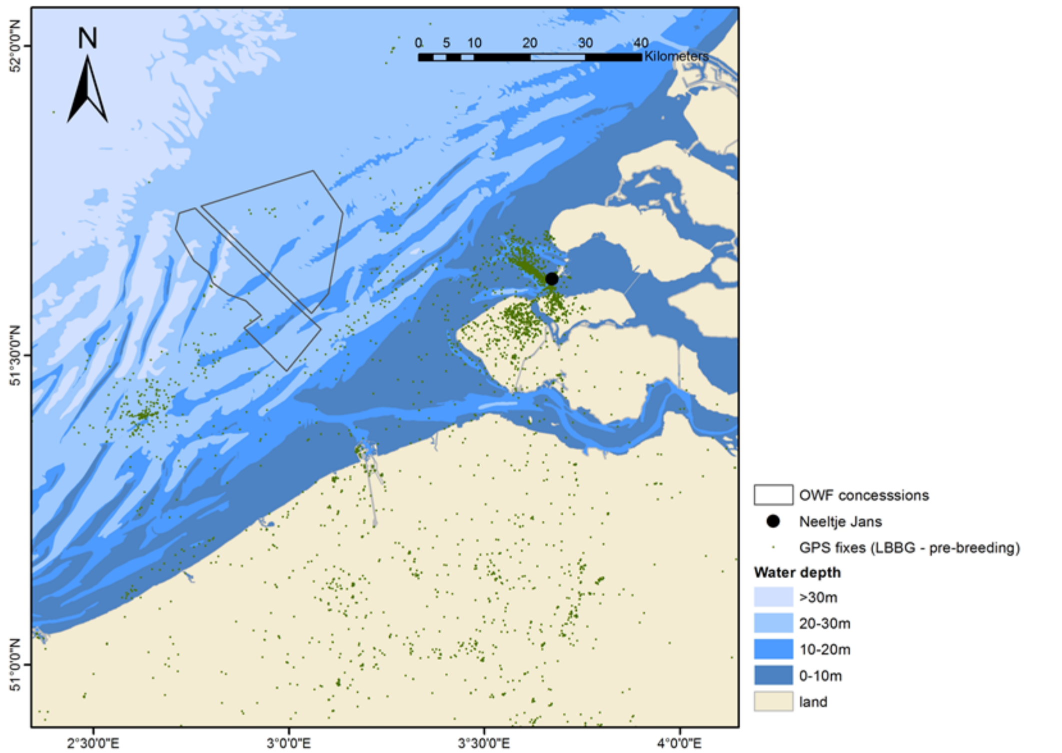

Figure 3.13 *GPS fixes of lesser black-backed gulls in the pre-breeding season (based on data resampled to 60 min).*

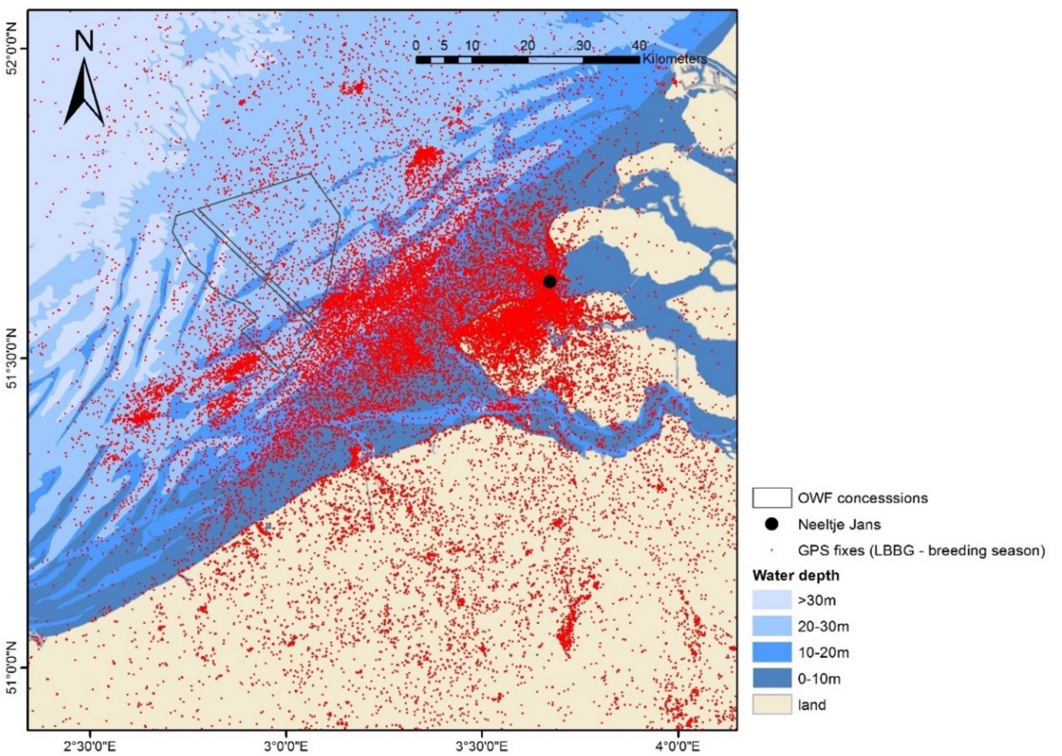

Figure 3.14 *GPS fixes of lesser black-backed gulls in the breeding season (based on data resampled to 60 min).*

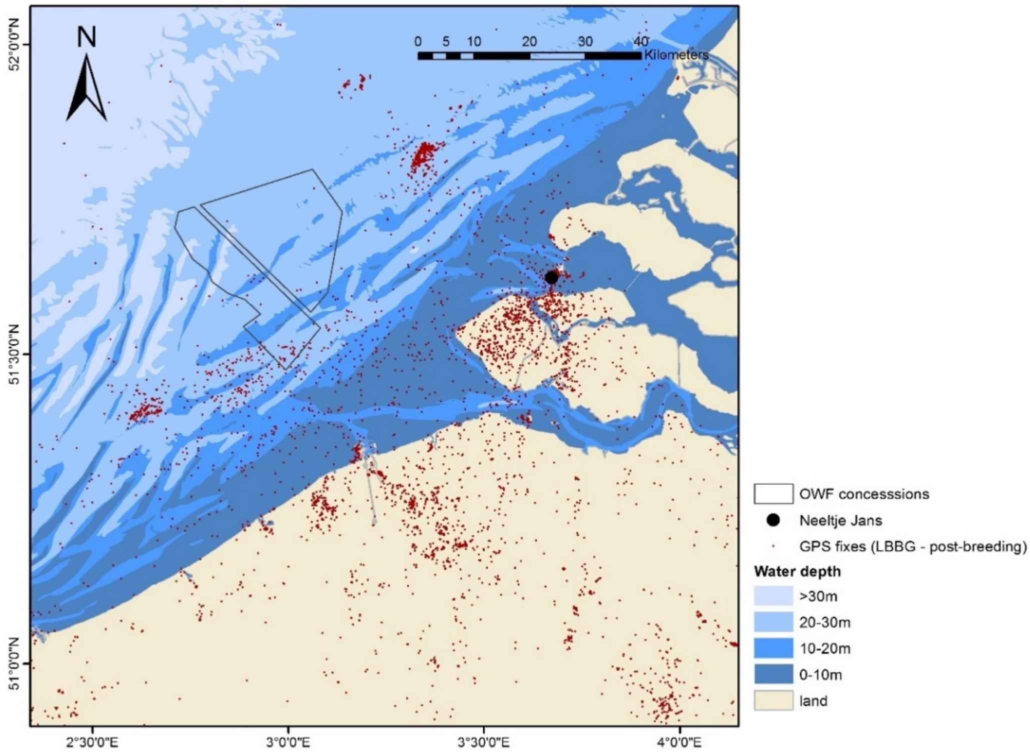

Figure 3.15 *GPS fixes of lesser black-backed gulls in the post-breeding season (based on data resampled to 60 min).*

Figure 3.16 shows the percentages of fixes located inside 3 different polygons within the forementioned buffer zone of 141 km around the colony, distinguishing between ‘offshore’ (further than 3 km from the coastline), ‘onshore’ (on land or within 3 km from the coastline) and ‘Neeltje Jans’ (within 3 km from the colony). In the pre-breeding season, the tagged gulls already spent 43% of their time near or inside the colony, a percentage that further increases to 49% in the breeding season, at least for territorial birds. Non-territorial birds appear to spend only 19% near or inside the colony.

Compared to herring gull, lesser black-backed gulls spend much more time offshore, with proportions ranging from 11 to 18% in case of our tagged gulls. The preference for offshore waters is highest during the breeding season and for territorial birds.

Calculating the percentage of time spent in each of the habitat types defined by the ‘Corine Land Cover 2018’ map (Copernicus Land Monitoring Service 2021) results in the pattern shown in Figure 3.17. This overlay was based on data located within 3 to 141 km distance from the colony, thus excluding the time birds spend on the nest or near the colony.

Compared to other seasons and non-territorial birds, territorial lesser black-backed gulls spent more time offshore (39.5%). This figure is higher compared to the 18% offshore use mentioned before (see Figure 3.16), due the fact that the percentage here excludes time spent in the colony and includes birds close to the coastline (< 3 km). Territorial birds in the breeding season further spend 40.4% of their time in agricultural habitats and only 11.3% in areas classified as ‘industrial, commercial and transport units’.

The use of agricultural areas varies between 36.7% in the post-breeding and 49.8% in the pre-breeding season, while the use of ‘industrial, commercial and transport units’ is highest during post-breeding (37.0%).

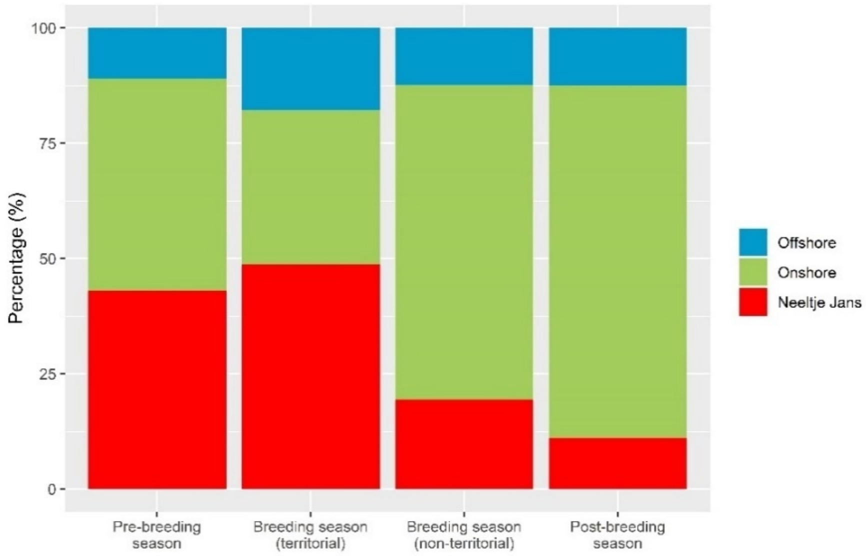

Figure 3.16 *Seasonal variation in the proportion of time spent offshore, onshore and near the colony by tagged lesser black-backed gulls (based on data resampled to 60 min and located inside a buffer zone of 141 km around the colony).*

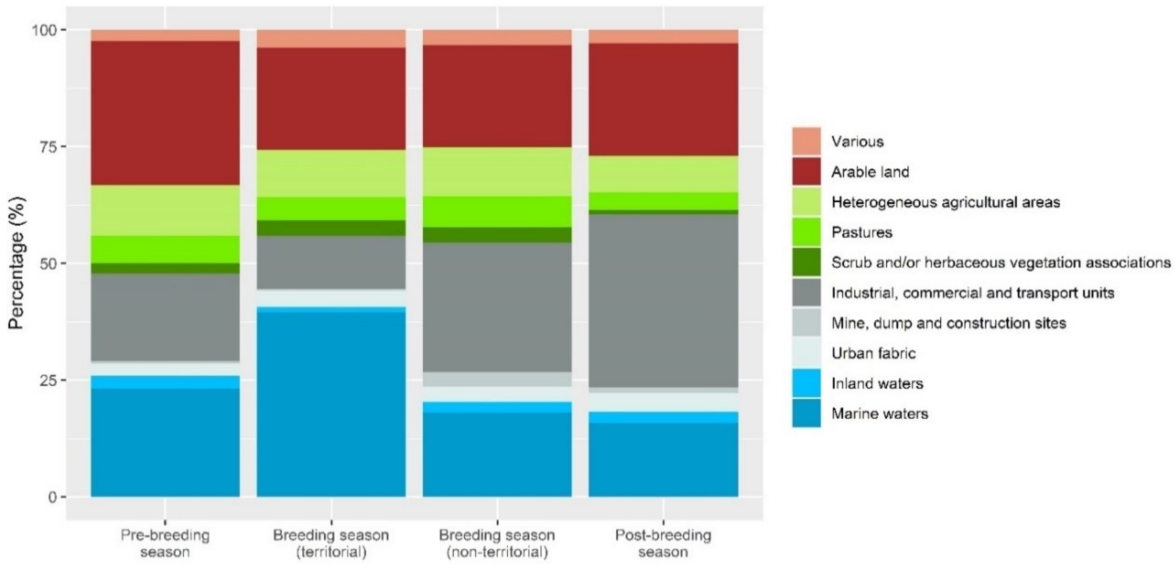

Figure 3.17 *Seasonal variation in habitat use by lesser black-backed gull applying the Corine land cover classification (based on data resampled to 60 min and located 3 to 141 km away from the colony).*

Performing the same overlay for the breeding season and further selecting for territorial individuals with over 1,000 fixes results in Figure 3.18 displaying the huge individual variation in habitat use and foraging strategies. Most striking is the variation in the use of ‘marine waters’ varying between 2.5 and 96.2%, while the use of agricultural land ranges from 2.6 to 81.8%. Lifting out some distinct personalities further illustrates this strong individual variation (Figure 3.19). *Abel* (201113) is on the far left extreme of Figure 3.18 and only rarely heads out for sea. This individual appears to have a very limited foraging range as it mostly visits agricultural fields at Walcheren located about 10 km from the colony. Gull *Monique* (211305) is on the other extreme regarding foraging range, flying back and forth to industrial sites at Vilvoorde (Belgium) about 100 km away from the colony, where it frequents a waste disposal plant and gelatine factory. *Wouter* (201092 / 211283) is on the far right of Figure 3.18 and a strongly marine-oriented bird. Indeed, this bird commutes daily to the same patch of sea 40 km northwest of Neeltje Jans, creating the cluster of offshore fixes that was already discussed above (Figure 3.14). Comparatively, gull *Dimi* (211319) is a far more flexible individual and can be regarded as a generalist, visiting the coasts of Walcheren and Schouwen-Duiveland, agricultural fields at Walcheren and near Damme in Belgium, but also regularly heading out at sea.

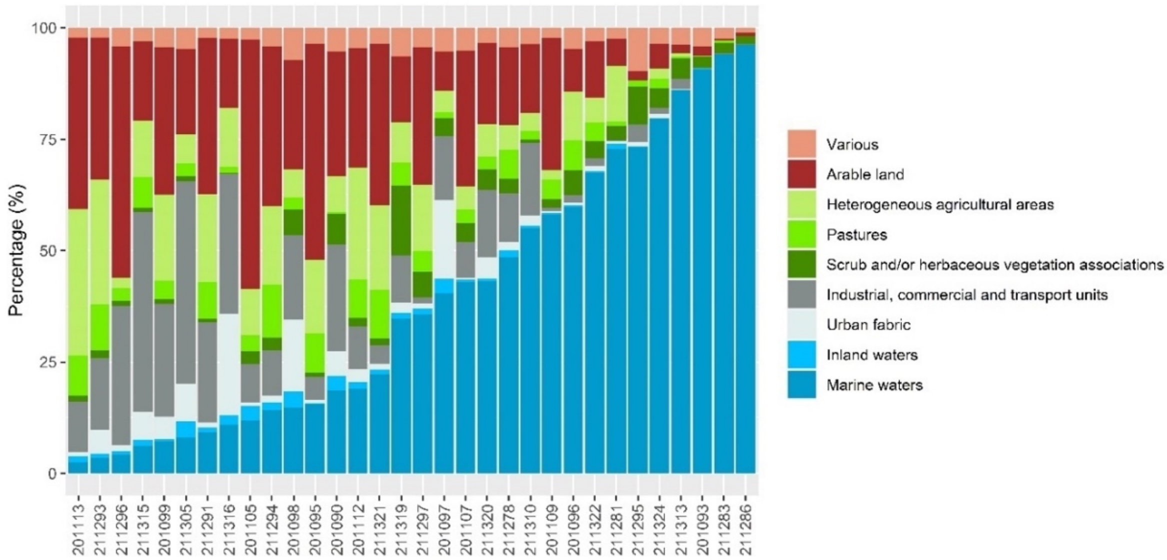

Figure 3.18 *Individual variation in habitat use by lesser black-backed gull during the breeding season applying the Corine land cover classification (based on data resampled to 60 min and located 3 to 141 km away from the colony).*

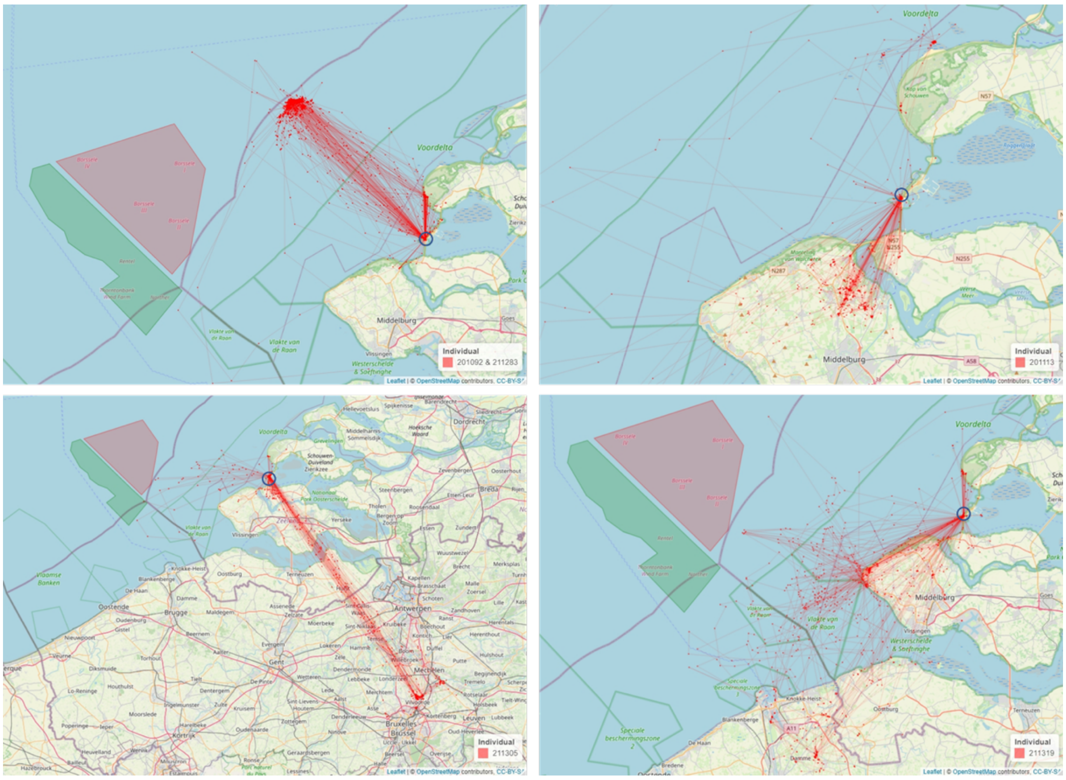

Figure 3.19 *Individual variation in foraging range and habitat use in 4 lesser black-backed gulls (the blue circle shows the colony location) (based on data resampled to 60 min).*

Only small percentages of the GPS fixes appear to be located inside the OWF concession zones (Figure 3.20). The overlap is strongest in case of territorial birds, that spent 0.86% of their time during the breeding season inside the OWF concession boundaries, with 0.37 and 0.49% respectively in the Belgian and Borssele wind energy areas. Note that these percentages account for 2021 only, as the Borssele wind farm is only operational since the beginning of that year. In the pre- and post-breeding seasons less than 0.15% of the birds' time was spent inside the wind farm boundaries. These percentages may seem to be very low but note that both concession zones combined make up for about 0.95% of the 141 km buffer zone considered here.

Applying a cut-off for 'flying' records of 14.4 km/h (Baert *et al*. 2018), the mean flying speed inside the OWFs measured 35.1 km/h (see Figure 3.21), which is slightly higher compared to the flying speed in the offshore area in general (32.6 km/h). With a standard deviation of 98 m, altitude measurements unfortunately were far too inaccurate to be applied in comparative analyses. Nevertheless, it is interesting to note that the median flying altitude was considerably higher inside the wind farm concession zones (40.5 m) than in the wider offshore area (29.1 m).

Regarding night-time activity, in the 2021 breeding season the proportion of 'flying' fixes was three times higher during daylight compared to night-time hours (34 versus 11%). Yet, considering the diurnal pattern in presence of tagged gulls inside the wind farms (see §4.1), the overall number of flight movements drops with 80% during the night.

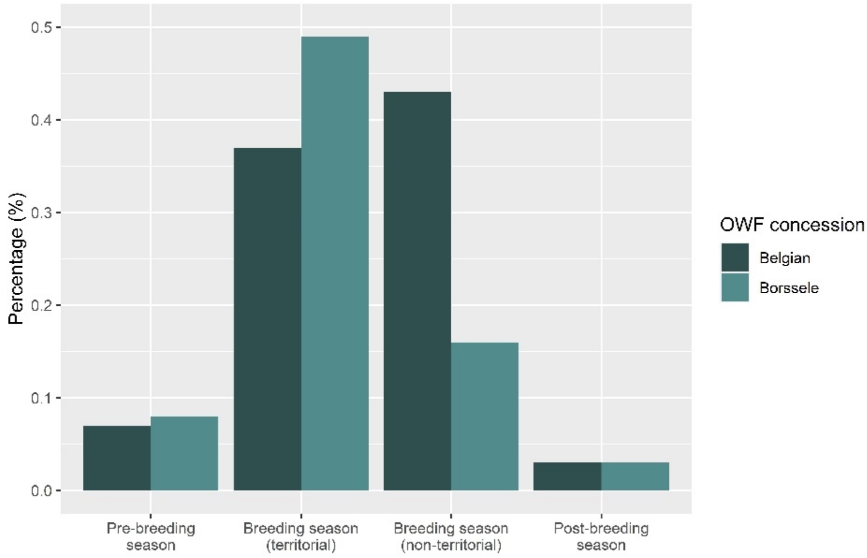

Figure 3.20 *Seasonal variation in the proportion of time spent inside the OWF concession zones by lesser black-backed gull (based on data resampled to 60 min and located inside a buffer zone of 141 km around the colony – only 2021 data).*

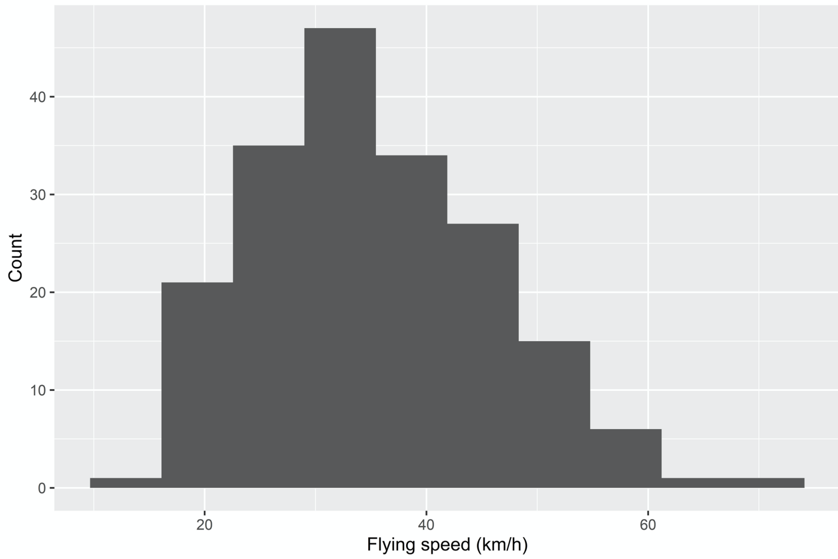

Figure 3.21 *Histogram of the flying speed of tagged lesser black-backed gulls inside the OWF concession zones (based on data resampled to 60 min – only breeding season and 2021 data).*

4 Results: Targeted case studies on the use of the OWF concession zones by lesser black-backed gulls

4.1 Temporal variation in the use of the OWF concession zones

Of all 74 tagged lesser black-backed gulls, 49 individuals were recorded at least once in the Belgian and Borssele concession zones. The frequency per individual varied from only one (*Hilbran*) up to 1,518 records (*Jarno*) (based on a GPS dataset resampled to 3 min).

Figure 4.1 illustrates the distribution of the GPS records inside and near the concession zones. This close-up again reveals the high concentrations of fixes just outside the concession zone boundaries to the east and to the southwest of the wind farms.

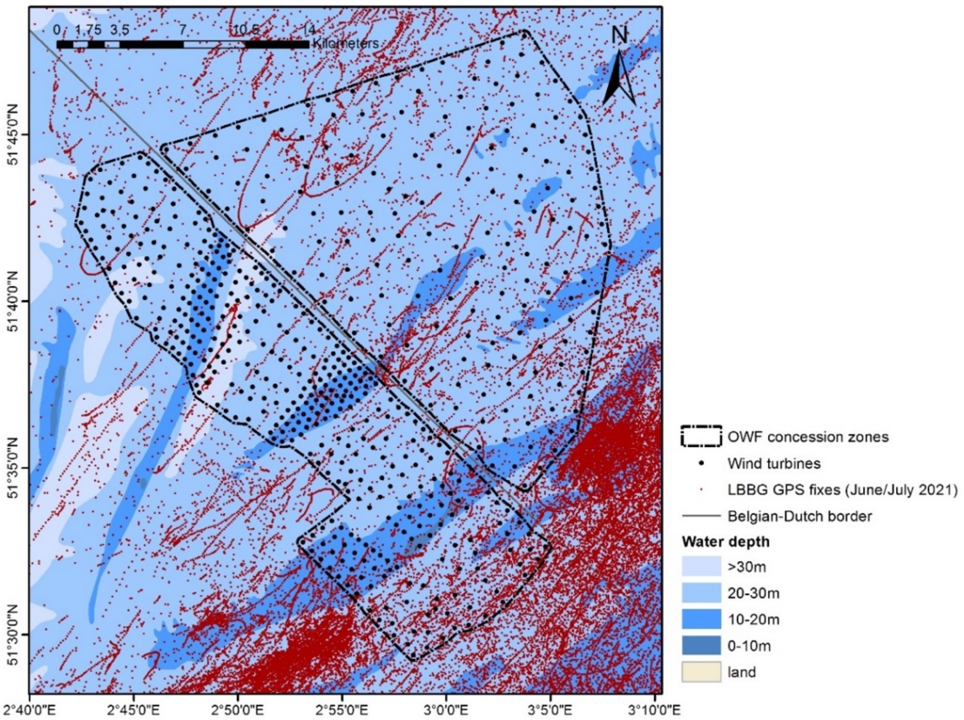

Figure 4.1 *The distribution of GPS fixes inside and near the Belgian and Borssele OWF concession zones in June and July 2021 (GPS data resampled to a 3 min resolution).*

The number of different individuals present inside the OWF concession zones (the response variable of the applied model) ranged from 0 to 7 individuals per hour, as opposed to 0 to 26 different individuals present offshore and within 141 km from Neeltje Jans. After backward model selection we retained the smoothers for time of day, wind speed and tidal height and the factor variables area and weekend, including interactions between the factor area and all three smoothers (see the model structure in §2.1.3). The resulting model predictions are displayed in Figure 4.2.

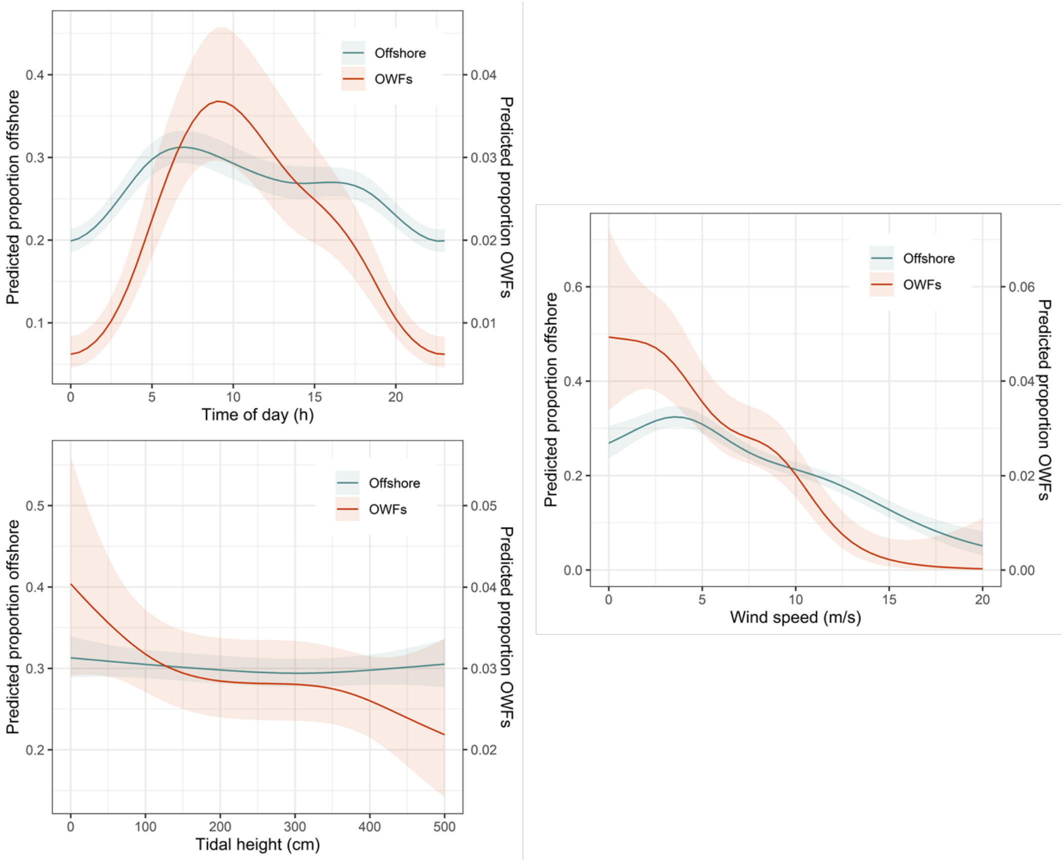

Figure 4.2 *Model results displaying the expected proportions of tagged birds, present either offshore (left axis) or in the OWF concession zones (right axis), in relation to time of day, tidal height and wind speed – to obtain model predictions the parameters were alternatively set at 8h (time of day), 5 m/s (wind speed), 50 cm (tidal height) and FALSE (weekend).*

In optimal conditions the proportion of tagged individuals present offshore is expected to be around 30%, at least for the regarded period (June-July 2021). This proportion, however, is likely to drop to 20% or less during the night and at wind speeds of more than 10 m/s. While the factor variable weekend was found to be significant, its effect appears to be rather moderate (a decrease with a factor 0.89 during weekends), while tidal height has virtually no influence on the number of individuals offshore.

Interestingly, the patterns for the OWF concession zones are distinctly different. Overall, no more than 5% of all tagged individuals is expected to be present inside the concession zones during one and the same hour. The diurnal pattern peaks around 9 am UTC and takes a drop of more than 80% around midnight, resulting in a much more extreme pattern compared to the offshore smoother. For wind speed too variability is stronger inside the concession zones as the proportion of individuals inside the wind farms will be comparatively higher at wind speeds below 5 m/s, yet distinctly lower at wind speeds over 10 m/s, almost reaching zero above 15 m/s. Lastly, while there is little effect of the tide on the number of individuals offshore, the number inside the wind farm is expected to be 50% lower at high versus low tide.

4.2 Meso-avoidance: case study Borssele OWF

Figure 4.3 and Figure 4.4 display the distribution of the GPS fixes used for this analysis, distinguishing between ‘flying’ and ‘non-flying’ fixes (based on a 14.4 km/h moving speed cut-off). The ‘flying’ GPS records are surprisingly homogeneously distributed, yet with a clear SE-NW gradient in the density of fixes (Figure 4.3). The ‘non-flying’ fixes are distributed more erratically, with dense tracks of floating individuals and clusters on top of turbine locations (Figure 4.4). Overall, 34% of all fixes inside the OWF were assigned as ‘flying’, which is highly comparable to the 36% proportion of ‘flying’ fixes in the surrounding area, i.e. the OWF geofence (see §2.1.3).

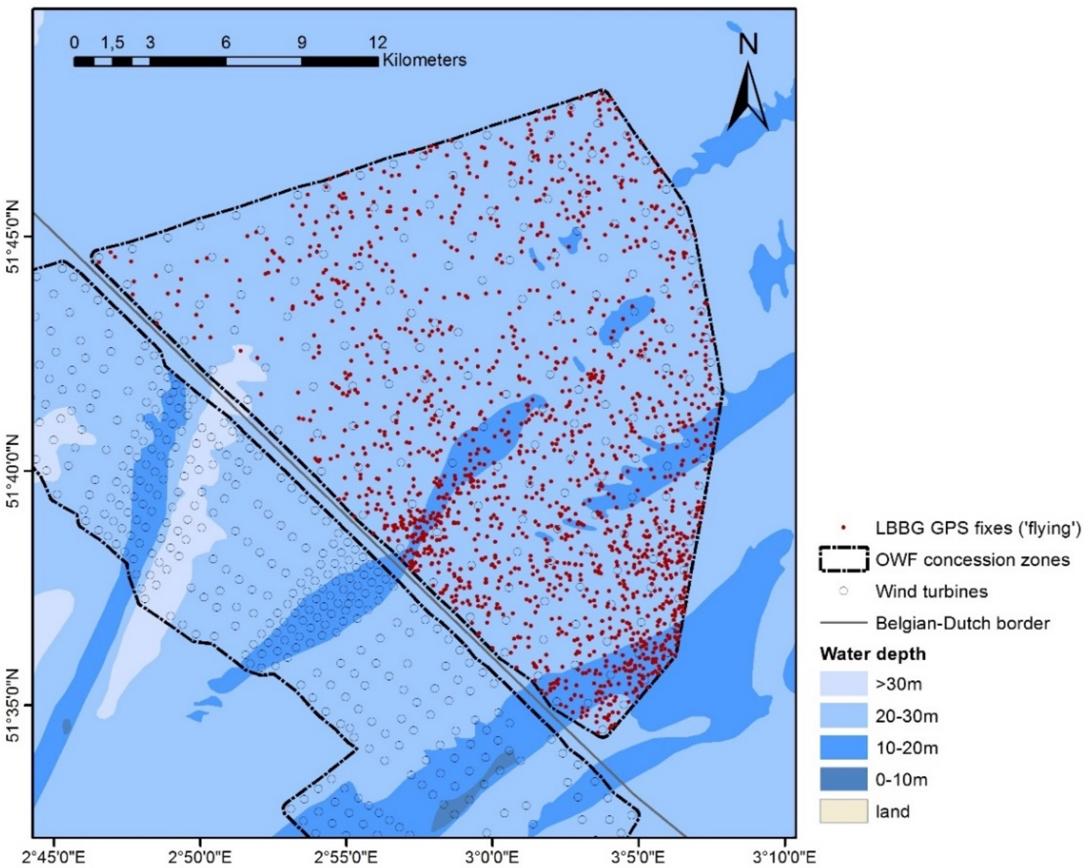

Figure 4.3 Distribution of ‘flying’ GPS fixes in the Borssele OWF concession zones in 2021 (GPS data resampled to a 3 min resolution).

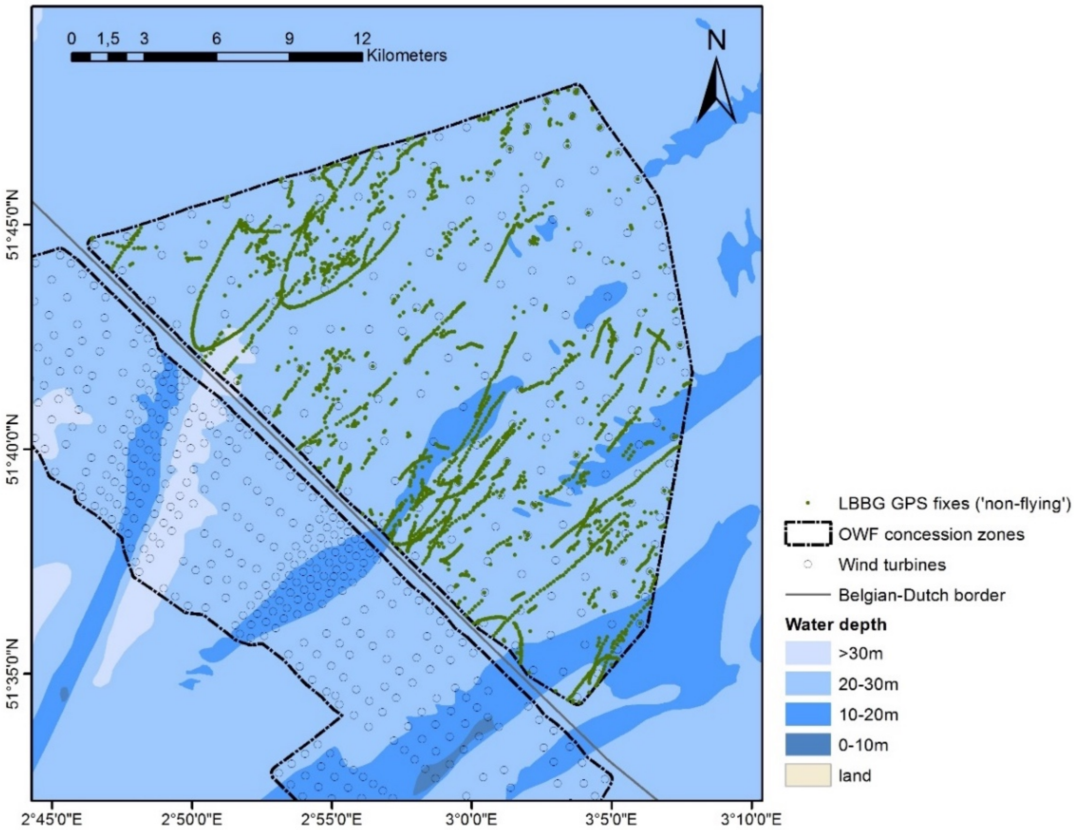

Figure 4.4 *Distribution of 'non-flying' GPS fixes in the Borssele OWF concession zones in 2021 (GPS data resampled to a 3 min resolution).*

Figure 4.5 illustrates the distinct preference of 'non-flying' birds to turbine locations, as 14% of all fixes are located within 100 m distance from the nearest turbine. Note that the peaks in frequencies at 500 m ('flying' fixes) and 600 m ('non-flying' fixes) cannot be interpreted as actual preferences as the frequencies are not normalised according to the surface available. This is further illustrated in the modelling results in Figure 4.6, displaying a strongly significant smoother for 'non-flying' fixes, with the expected peak in occurrence near the turbines opposed to a relatively constant probability of presence between 200 and 1,000 m distance. For 'flying' fixes the effect of distance to the nearest turbine was only borderline significant (P=0.023) and the curve of the smoother is indeed relatively constant at an occurrence probability of about 14%, in line with the induced odds of presence (6 simulated absences for each presence, see §2.1.3).

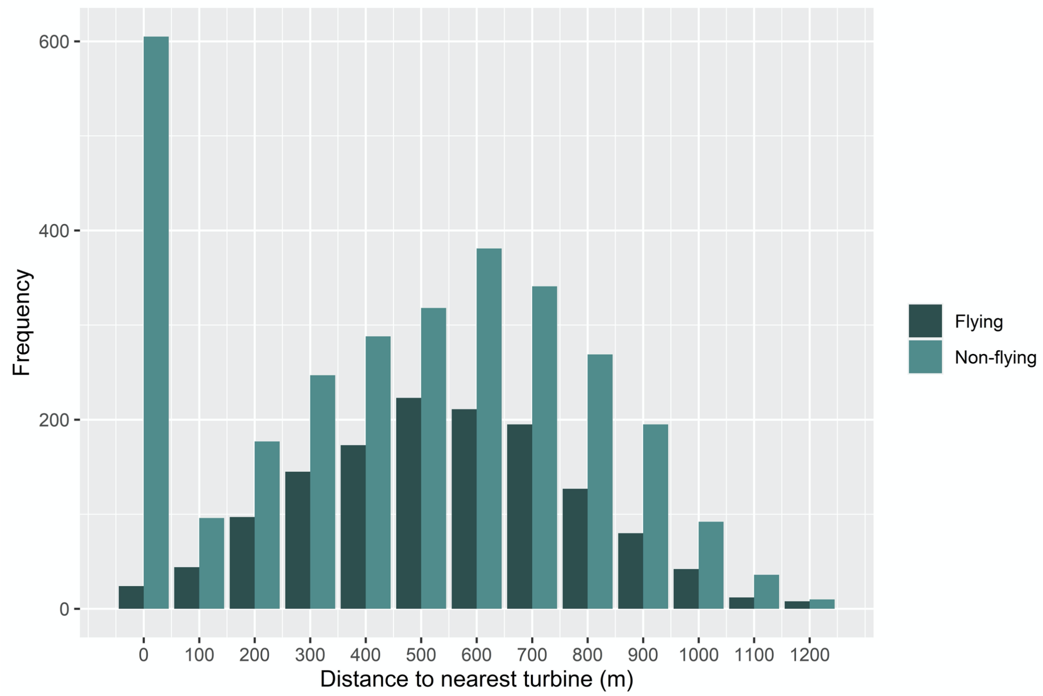

Figure 4.5 *Frequency plot of flying and non-flying GPS fixes in relation to distance to the nearest turbine.*

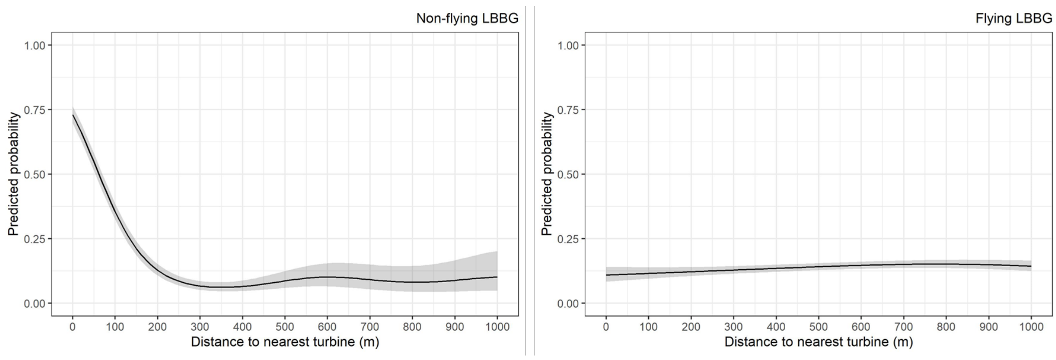

Figure 4.6 *Modelling results of the effect of distance to the nearest turbine on the probability of presence of tagged lesser black-backed gulls inside the Borssele OWF.*

4.3 Macro-avoidance: case study Norther OWF

The two maps shown in Figure 4.7 and Figure 4.8 illustrate the overlap in distribution between the birds from Ostend, Zeebrugge and Vlissingen on the one hand and birds from Neeltje Jans on the other hand. Close to the colony this overlap is generally low, but particularly around the southern borders of the Belgian and Borssele concession zones there is a remarkable similarity in habitat use. A particularly interesting feature is the fact that the gully between the sandbanks just west of the BACI polygons appears to be a favoured area in both figures, showing that the preference for this area has been a constant over the past 5 years and across different colonies. Due to this overlap in offshore distribution, cumulating the data for this specific analysis is not expected to pose any methodological problems.

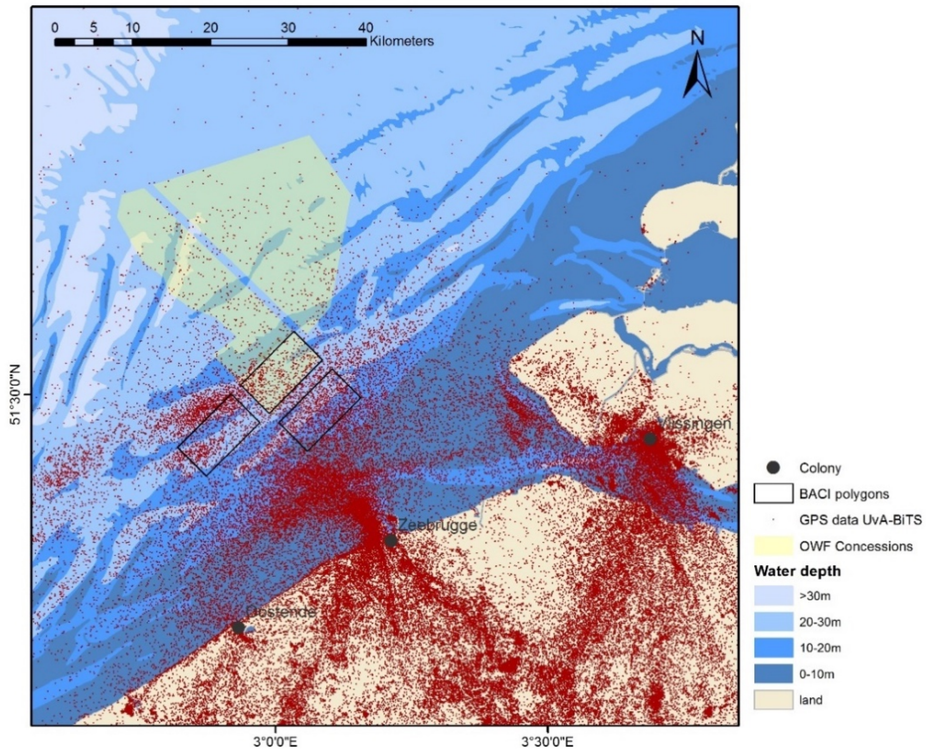

Figure 4.7 UvA-BiTS GPS records of birds from Ostend, Zeebrugge and Vlissingen included in our macro-avoidance BACI analysis (GPS data resampled to 60 min).

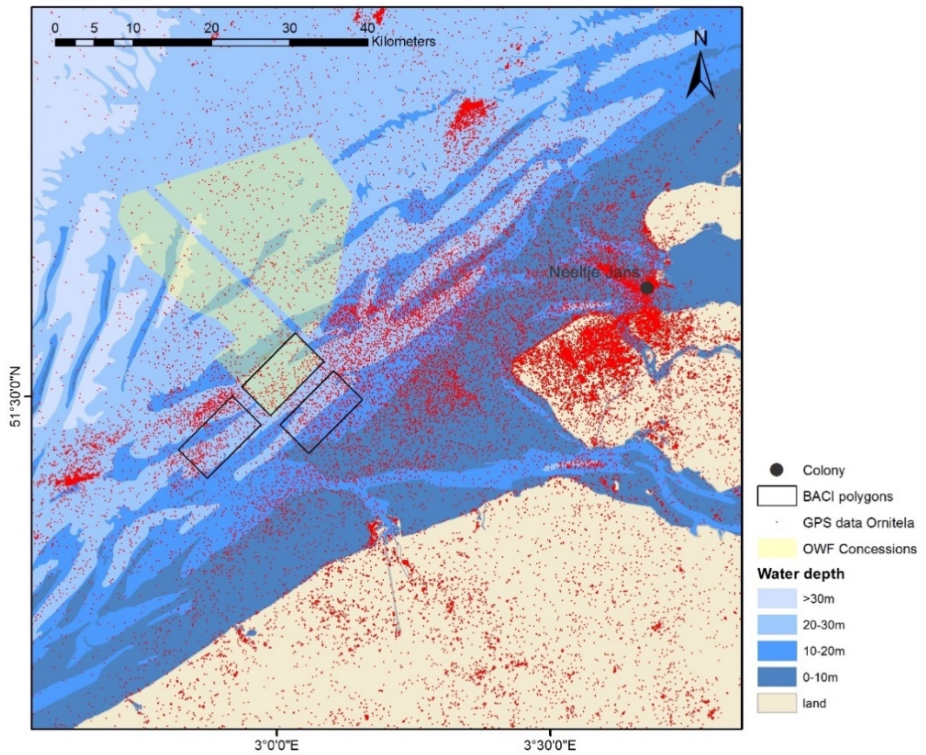

Figure 4.8 Ornitela GPS records of birds from Neeltje Jans included in our macro-avoidance BACI analysis (GPS data resampled to 60 min).

The proportions of GPS records inside the three different polygons are shown in Figure 4.9, displaying high comparability between the two periods. In both periods, about 25% of all records is located inside the impact polygon, which is slightly lower than expected based on a homogeneous distribution across all three polygons. Comparing Figure 4.10 and Figure 4.11 indeed shows a slightly lower density of records in the impact area for both the pre- and post-construction periods. Based on visual interpretation there do not appear to be any intense shifts in distribution caused by the wind farm, apart from some apparent clusters of post-construction records on top of turbine locations.

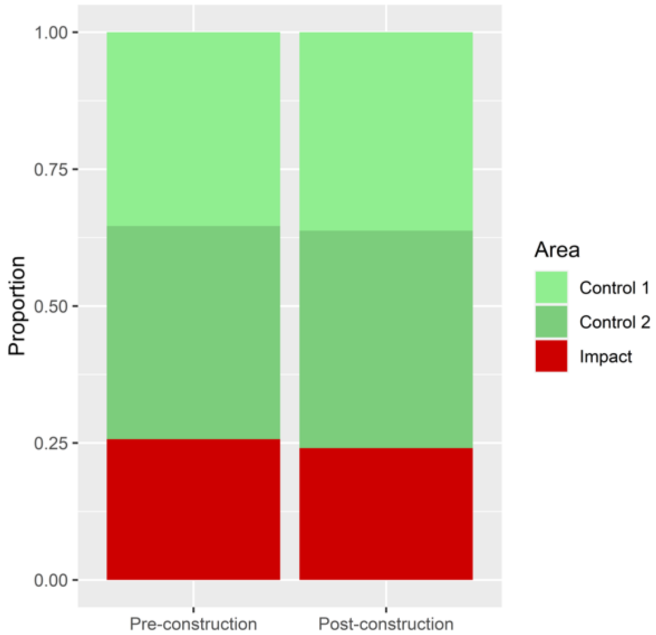

Figure 4.9 Proportion of GPS records located in the different BACI polygons during the pre- and post-construction periods.

The BACI model summary is shown in Table 4.1. The 'WeekendTRUE' factor appeared strongly and significantly negative, implying a much lower number of records in the study area during weekends, related to a decrease in fishery activities. The variable 'AreaControl2' was significantly positive, to be interpreted as a consistently higher number of records inside control area 2 compared to control area 1, likely due to its location closer to the colonies. Importantly, the interaction 'PeriodAfter:AreaControl2' was not significant, in line with the basic assumption that the trend in the number of records in control area 2 should not be any different from that in control area 1.

Lastly, and of particular interest here, the interaction 'PeriodAfter:AreaImpact' (assumed to estimate the wind farm effect) is slightly negative yet not significant. The coefficient value of -0.26 implies a factorial decrease in records of 0.77. This confirms our visual interpretation of Figure 4.9 to Figure 4.11 that lack any obvious sign of macro-avoidance, but is in contrast to the results reported by Vanermen *et al*. (2021), who found a significantly negative wind farm coefficient of -1.252 (i.e. a factorial decrease of 0.29).

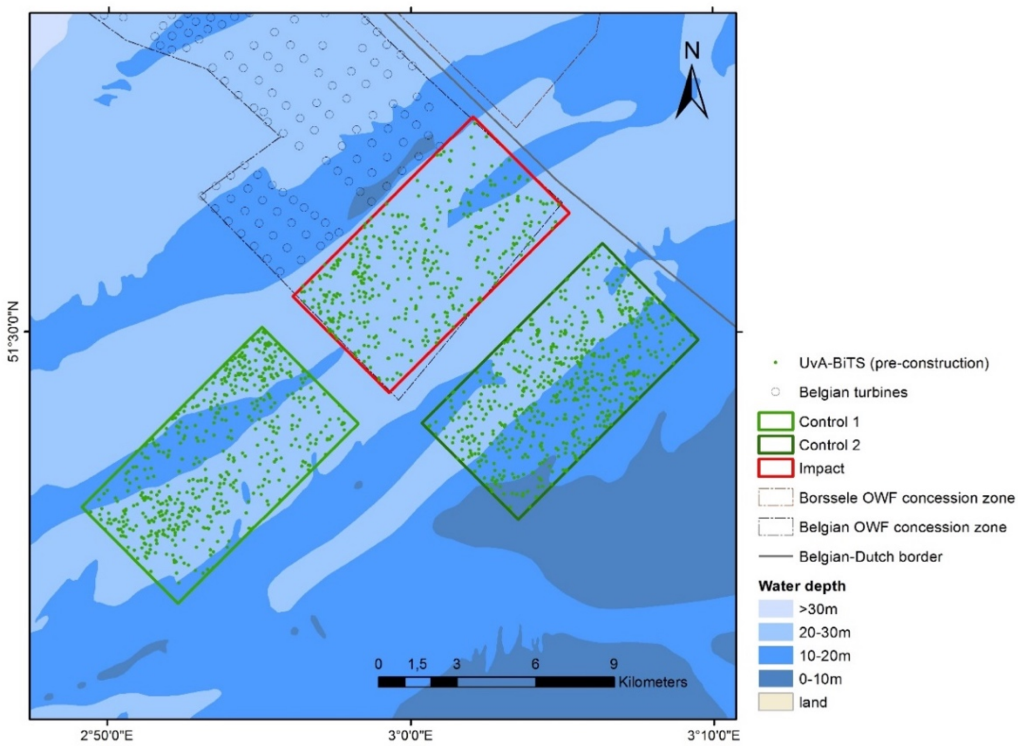

Figure 4.10 *GPS records inside the BACI polygons during pre-construction (GPS data resampled to 60 min).*

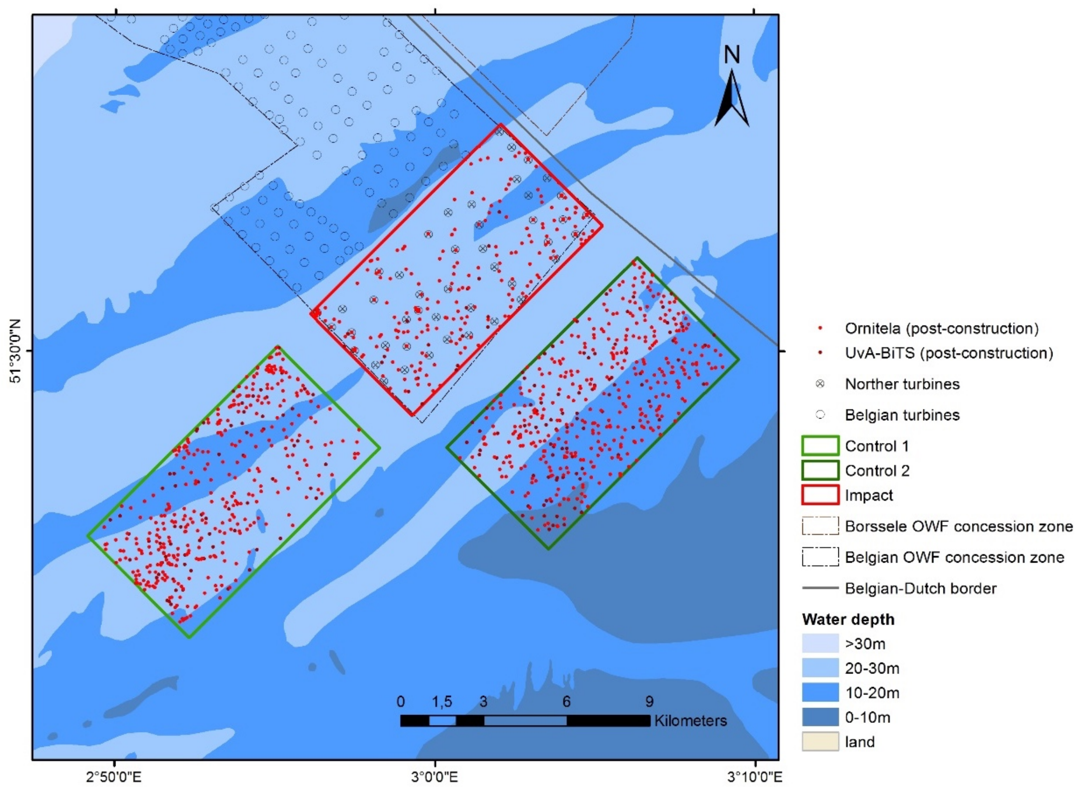

Figure 4.11 *GPS records inside the BACI polygons after construction of the turbines (GPS data resampled to 60 min).*

Table 4.1 BACI model summary, showing all coefficient estimates and associated standard errors, z & P-values.

	Estimate	Std. Error	Z value	Pr (>|z|)
(Intercept)	-0.88661	0.14791	-5.994	2.04e-09 ***
as.factor(Month)4	1.07514	0.15447	6.960	3.39e-12 ***
as.factor(Month)5	0.49789	0.15883	3.135	0.001720 **
as.factor(Month)6	1.78044	0.15061	11.822	< 2e-16 ***
as.factor(Month)7	1.72453	0.15749	10.950	< 2e-16 ***
as.factor(Month)8	0.58278	0.16693	3.491	0.000481 ***
WeekendTRUE	-0.50444	0.09874	-5.109	3.24e-07 ***
PeriodAfter	-0.08339	0.15069	-0.553	0.580011
AreaControl2	0.27939	0.13666	2.044	0.040912 *
AreaImpact	-0.15042	0.14013	-1.073	0.283077
PeriodAfter:AreaControl2	-0.26100	0.21128	-1.235	0.216706
PeriodAfter:AreaImpact	-0.25539	0.21741	-1.175	0.240134

5 Results: Colony size and breeding success of lesser black-backed and herring gulls at Neeltje Jans and in the Delta.

5.1 Breeding numbers

Lesser black-backed gulls and herring gulls breed throughout the entire Delta area. Large colonies of both species are found on Maasvlakte, in Haringvliet, Hollands Diep, Schouwen, Neeltje Jans and Sloegebied. The number of breeding lesser black-backed gulls increased substantially up until 2000, after which numbers stabilized on a population level of approximately 40,000 pairs (data RWS). In contrast, the number of breeding pairs of herring gull decreased between 1980 and 2005, after which the numbers stabilized to a population of approximately 14,500 breeding pairs (data RWS). Since 2019 population levels of both species are decreasing again, probably due to the increased presence of ground predators such as red fox *Vulpes vulpes* in a number of breeding colonies.

Total counts of the breeding colonies on Neeltje Jans indicated 2,835 breeding pairs of lesser black-backed gull and 1,439 breeding pairs of herring gull in 2020. In 2021 these species totalled 3,571 and 1,323 respectively. Fluctuations of breeding numbers occur regularly due to intercolonial movements of gulls to and from nearby colonies such as Meeuwenduinen and the southern coast of Schouwen. The average breeding numbers of both species at Neeltje Jans over the past 10 years is 3,205 pairs of lesser black-backed gull and 1,835 pairs of herring gull (data RWS).

5.2 Breeding success: study colonies at Neeltje Jans

5.2.1 Lesser black-backed gull

A total of 23 enclosures with nests of lesser black-backed gull were monitored in 2020 (Table 5.1), the majority of which was located in Westduinen. Unfortunately, at the end of May many nests were predated by conspecifics. Eventually, seven juveniles fledged resulting in a fledging success of 0.30 young per pair. Out of the 16 nests in the reference colony in Oostduinen, almost all eggs hatched, yet eventually only three young fledged due to a high level of predation in this specific part of the colony.

In 2021 a total of 51 enclosures with nests of the lesser black-backed gull were monitored (Table 5.1), including 1 bird tagged in 2020 and 50 birds from 2021. Ten of these were deserted shortly after tagging, and in nine nests eggs did not hatch. Out of the 151 eggs, 77 chicks were born and hatching success was thus 51%. Only 17 chicks eventually managed to fledge, and as such reproductive success measured 0.33 chicks per pair.

Table 5.1 *Breeding results of (GPS-tagged) lesser black-backed gulls in the study colonies in 2020 and 2021; hatching success is the fraction of hatched eggs (total number of eggs in brackets), fledgling success is the number of fledged chicks per nest.*

2020	Number of nests	Hatching success	Fledging success
Westduinen	18	0.38 (n=47)	0.22 (n=4)
Oostduinen	5	0.57 (n=14)	0.60 (n=3)
Without GPS	12	0.70 (n=20)	Unknown
Reference colony	16	0.97 (n=36)	0.19 (n=3)
2021			
Westduinen	51	0.51 (n=151)	0.33 (n=17)

5.2.2 Herring gull

A total of 22 enclosures with nests of tagged herring gulls were monitored in 2020 (Table 5.2), of which the majority was located in Westduinen (n=17). The nests of 5 herring gulls were predated or abandoned shortly after catching, while from the other nests most eggs hatched. Overall, hatching success was over 70%, which was similar to the other monitored sites. With 6 chicks fledged, the breeding success of the GPS-tagged individuals was 0.27 young per pair.

Table 5.2 *Breeding results of (GPS-tagged) herring gulls in the study colonies in 2020; hatching success is the fraction of hatched eggs (total number of eggs in brackets), fledgling success is the number of fledged chicks per nest.*

	Number of nests	Hatching success	Fledging success
Westduinen	17	0.78 (n=32)	0.18 (n=3)
Oostduinen	5	0.71 (n=14)	0,60 (n=3)
Noordduinen	1	Unknown	Unknown
Without GPS	6	0.40 (n=25)	Unknown
Reference colony	5	0.66 (n=15)	0.40 (n=2)

5.3 Breeding success compared to Neeltje Jans

In order to put these numbers into a larger context, we compared the breeding results in the enclosures with the rest of the colony, since the breeding success of both gull species was measured in a number of sub-areas on Neeltje Jans.

5.3.1 Lesser black-backed gull

The overall breeding success of tagged lesser black-backed gulls (0.30 young per pair) in 2020 was in accordance with the average breeding success on other parts of Neeltje Jans that same year (0.23 juveniles per pair). There were large differences in breeding success between areas due to local predation. The western side of Neeltje Jans (with a relatively large number of marine-oriented breeding birds) had better breeding success than the eastern part of Neeltje Jans (0.35 versus 0.21 juveniles per pair).

Table 5.3 Breeding results of lesser black-backed gulls at Neeltje Jans in 2020; breeding success is the number of fledged chicks per nest.

Subarea	Side of Neeltje Jans	Number of breeding pair	Breeding success
Noordland	west	143	0.68
Westduinen	west	155	0.34
Noordduinen	west	243	0.17
Poolvoet	west	89	0.26
Haak	oost	216	0.36
Noord van Slufter	west	123	0.11
Oostduinen	oost	480	0.19
Rondom Slufter oost	oost	75	0.54
Werkeiland Roggenplaat	oost	189	0.03

In 2021 it proved difficult to make a reliable estimate for the different sub-colonies at Neeltje Jans, due to the extensive vegetation at most places. This made it very hard to locate nearly fledged chicks. We therefore chose to wait for the moment when fledged chicks gathered at the edges and/or outside the colony. Places where almost all locally fledged chicks gather are in the Mattenhaven (for birds from the eastern dune area), the Slufter in the eastern dune area, and the North Sea beach for birds from the western dunes. A total count on 28 July 2021 showed 798 fledged lesser black-backed gulls which would equal to 0.22 young per pair, very similar to the figure for 2020.

5.3.2 Herring gull

The breeding success in the enclosures of tagged herring gulls in 2020 (0.27 juveniles per pair) was slightly lower than the average of other areas on Neeltje Jans where breeding success was recorded (0.31 juveniles per pair). There were large differences between the different parts on Neeltje Jans. The breeding success was particularly high on the plain of Noordland (Table 5.4). The impression in the field was that there was no shortage of food in the area and that the large differences in breeding success are to be contributed to local presence of ground predators such as rats and polecats. This low breeding success in herring gull was also observed on Neeltje Jans in 2018 and 2019 (unpubl. data R.J. Buijs).

Table 5.4 Breeding results of herring gulls at Neeltje Jans in 2020; breeding success is the number of fledged chicks per nest.

Subarea	Number of breeding pairs	Breeding success
Noordland	99	1.12
Westduinen	62	0.22
Noordduinen	65	0.73
Poolvoet	36	0.29
Haak	216	0.35
Noord van Slufter	56	0.11
Oostduinen	185	0.16
Rondom Slufter oost	54	0.54
Werkeiland Roggenplaat	241	0.08

For herring gull too it proved difficult to make a reliable estimate for the different sub-colonies in 2021 due to the extensive vegetation at most places. Also for this species we waited until the end of the season to perform a total chick count of the entire island of Neeltje Jans. A total count on 28 July 2021 produced 706 fledged herring gulls which would equal to 0.53 young per pair, almost twice the figure for 2020.

5.4 Breeding success compared to Delta population

5.4.1 Lesser black-backed gull

In 2020 we collected breeding success data from 20 lesser black-backed gull colonies with more than 20 breeding pairs (Figure 5.1). A breeding success of more than 1 juvenile per pair was observed in the colonies in Ouwerkerkse Inlagen and on Krammersche Slikken. The breeding success on Sassenplaat (0.48 juveniles per pair) in Hollands Diep and in Meeuwenduinen (0.45 juveniles per pair) on Schouwen was also above average. The mean breeding success of all colonies in 2020 was 0.34 juveniles per pair compared to an average of 0.33 in 2019 (Lilipaly *et al*. 2019).

In 2021 we collected breeding success data from 28 colonies with more than 20 breeding pairs. The average number of fledged young in the Delta was 0.55 juveniles per pair, slightly higher than the two previous years. Colonies with the highest breeding success were located in the eastern part of the Delta. At Sassenplaat about 6,000 chicks fledged (1.55 young per pair). Other successful colonies were located at Slikken of Flakkee (2.24 young per pair) and Krammersche Slikken (1.49 young per pair). In the largest colony of the Delta, Europoort (Rotterdam Harbour), breeding success was reasonably high (0.60 young per pair) and at least 7,500 juveniles fledged. Further down at Maasvlakte, fox predation resulted in a total of 200 fledged young on 3,700 breeding pairs (0.05 young per pair). Also in other colonies foxes were active, leading to very low breeding success in e.g. Thermphos (0.01 young per pair), Quarleshaven (0.01 young per pair) and Van Cittershaven (0.02 young per pair). In a number of areas, there was no clear sign of a cause for the low breeding success: Werkeiland Roggenplaat (0), Meeuwenduinen (0.09 young per pair, Dwars in de Weg (0.13 young per pair) and Veermansplaten (0.15 young per pair).

5.4.2 Herring gull

Data on breeding success were collected in 2020 at 27 colonies with more than 20 breeding pairs (Figure 5.2). The highest breeding success (> 1 juveniles / pair) in the Delta area was registered in Ouwerkerkse Inlagen and Krammersche Slikken. Colonies with no or very low breeding success in 2020 included Middelplaat, Quarleshaven, Van Cittershaven and Haringvreter. Fox predation was found in all of these areas. The mean breeding success of all colonies in the Delta was 0.31 juveniles per pair compared to 0.34 juveniles per pair in 2019 (Lilipaly *et al*. 2019).

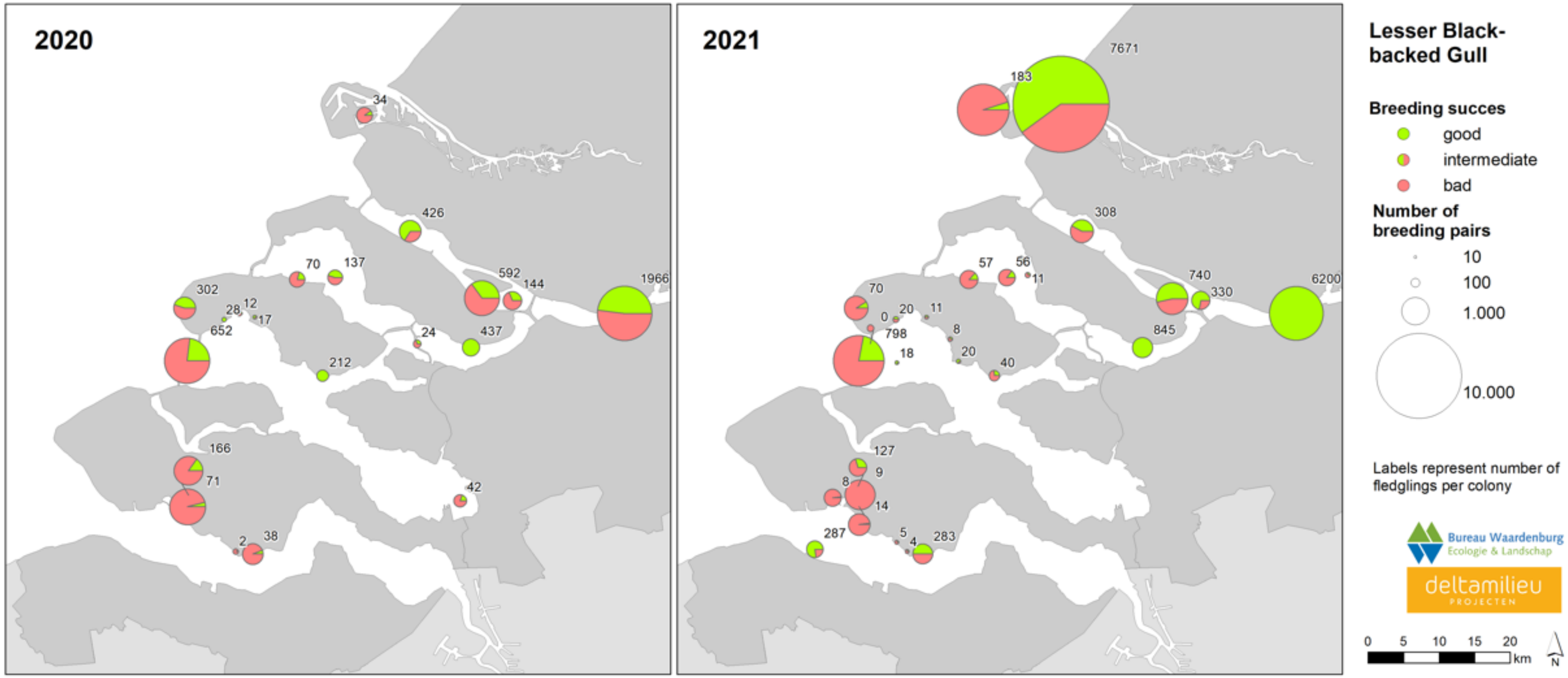

Figure 5.1 *Breeding success of lesser black-backed gulls in a selection of Delta colonies in 2020 and 2021.*

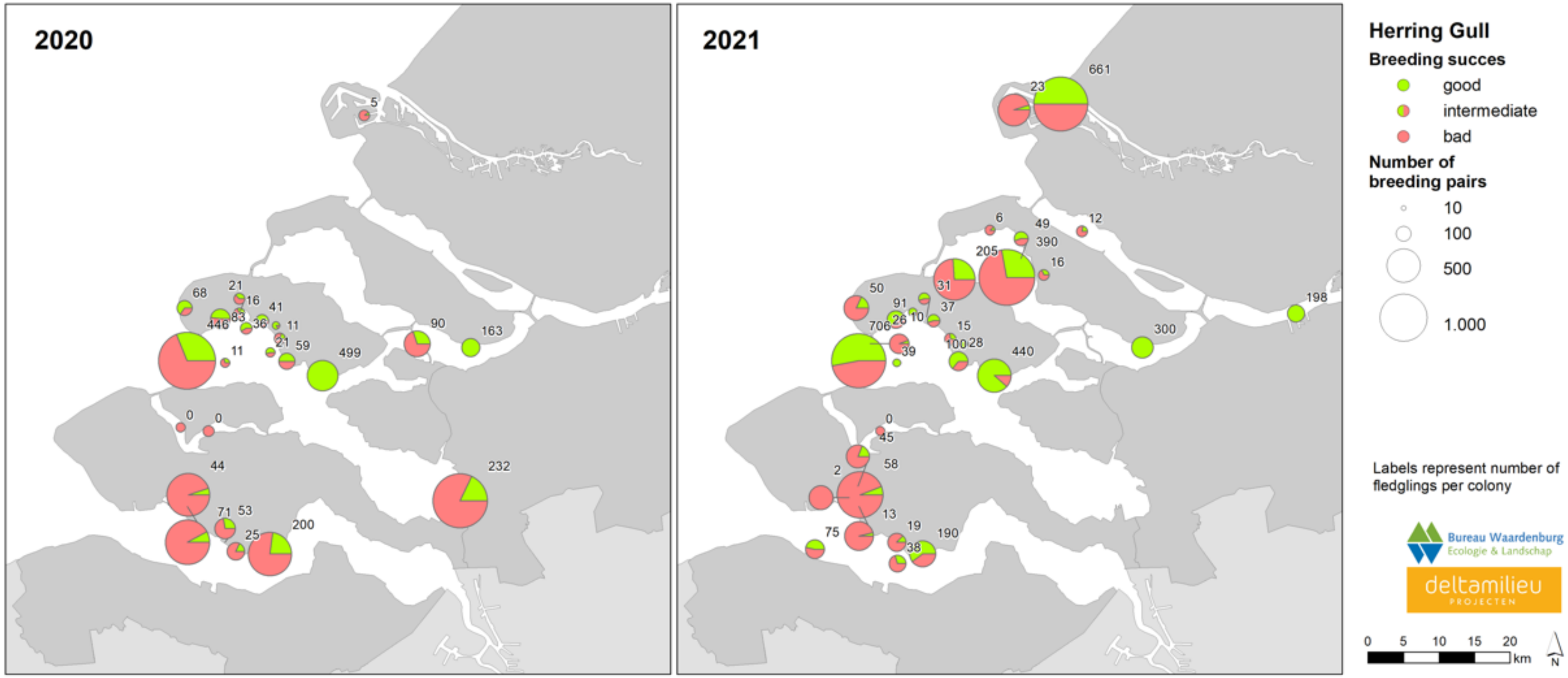

Figure 5.2 *Breeding success of herring gulls in a selection of Delta colonies in 2020 and 2021.*

In 2021 a total of 31 colonies with more than 20 pairs were monitored on breeding success. On average the breeding success was 0.38 young per pair in the Delta. There were large differences between colonies. Some of the successful colonies included Sassenplaat (1.55 young per pair), Krammersche Slikken (1.49 young per pair) and the shell-dump at Neeltje Jans-plaat (1.5 young per pair). Predation by foxes was a huge problem for a number of colonies and although juveniles were observed in all colonies, breeding success was particularly low at Maasvlakte (0.05 young per pair), Thermphos (0.01 young per pair), Van Cittershaven (0.04 young per pair) and Quarleshaven (0.06 young per pair).

6 Results: Diet of chick-feeding lesser black-backed and herring gulls at Neeltje Jans.

6.1 Lesser black-backed gull

A total of 29 pellets were collected from 12 different enclosures in 2020, and all contained food items from marine origin (Appendix 1). In 2021, 57 pellets were collected from 27 different enclosures. At five out of 27 nests only pellets with terrestrial food items were found, at four nests a mix and the remaining 18 nests only had pellets from marine origin.

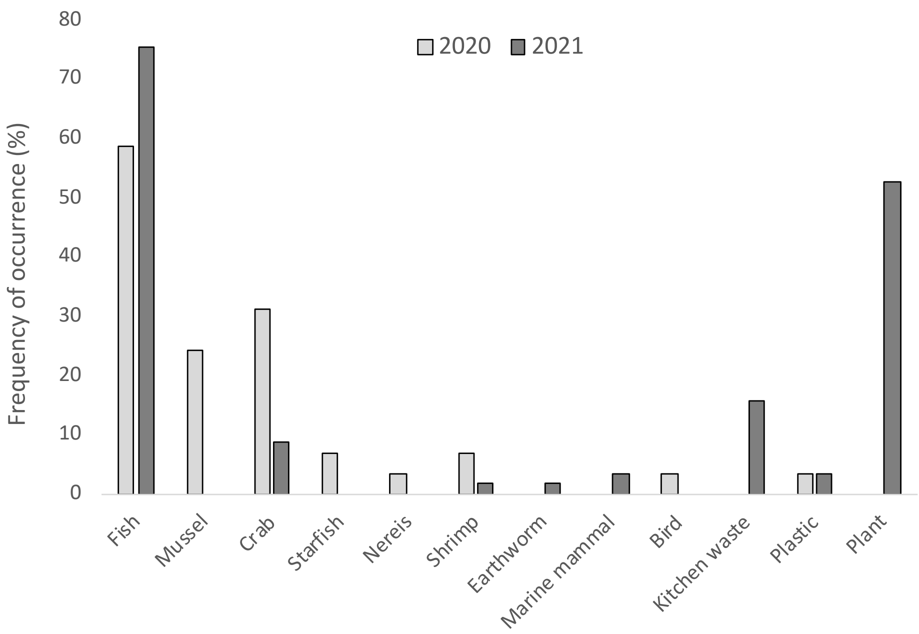

Figure 6.1 *Frequency of occurrence of prey items in pellets of lesser black-backed gulls in enclosures of birds with GPS-loggers at Neeltje Jans in 2020 and 2021.*

The majority of food remains found in the pellets were attributable to fish, mussel, crab and kitchen food (Figure 6.1). Overall, fish remains were found in 59 pellets and 27 pellets contained identifiable fish parts, which were otoliths of 12 whiting *Merlangius merlangus*, 13 sandeels *Ammodytidae*, 3 cod *Gadus morhua*, 1 goby *Gobiidae*, 1 plaice *Pleuronectes platessa*, 1 herring *Clupea harengus*, 3 flounder *Platichthys flesus,* 1 hooknose *Agonus cataphractus,* 1 sand-smelt *Atherina presbyter,* 2 dab *Limanda limanda*, 5 sprat *Sprattus sprattus*, 1 plaice *Pleuronectes platessa*, 1 mackerel *Scomber scombrus*, and 1 pout *Trisopterus luscus*. Remarkable was the large year-to-year variation in the occurrence of sandeel remains, with 12 sandeels in the smaller sample of pellets in 2020, to only 1 in many more pellets in 2021. In addition to the otoliths of 2 flounders, a whole flounder has also been found (Figure 6.2).

In addition to the most common prey item fish, we found several sources of other marine food items including crab, mussels, starfish, sepia, seaweed and marine mammal (from scavenging) (Figure 6.1). In 16 pellets, crab remains were found, mainly shields and scissors. Remarkable was the occurrence of mussels in lesser black-backed gull pellets in 2020. Generally, this species does not consume mussels. Whether these pellets are from herring gulls and accidentally deposited in lesser black-backed enclosures is unknown. Two pellets contained remains of starfish: one common brittle star *Ophiothrix fragilis* and one common starfish *Asterias rubens*. Jaws of *Nereis* have been identified in one pellet. The same pellet also contained otoliths of plaice and whiting, which suggests that the *Nereis* jaws were secondary prey items and ingested by plaice or whiting. Three pellets contained shrimps *Crangon crangon*, which were likely secondary prey items as well, as otoliths of whiting and cod were founds in these same pellets. One regurgitate contained remains of a harbour porpoise: a piece of blubber (Figure 6.3). An unidentifiable bird was found in one pellet in 2020, an unidentified rodent in 2021. Nine pellets contained kitchen food in 2021, to none in 2020. These include bones from chicken and spare-ribs, pasta and minced meat. Two pellets contained earthworms. Almost all pellets in 2021 contained plant material, mainly grass and dune vegetation which was most likely taken accidentally during the collection of the pellets. Only seaweed is probably part of the gulls' diet.

Figure 6.2 Complete flounder found in an enclosure of a lesser black-backed gull.

Figure 6.3 *Remains of harbour porpoise blubber from an enclosure of a lesser black-backed gull.*

6.2 Herring gull

A total of 20 pellets were collected from 6 different enclosures (Appendix I) in 2020. Food remains of fish, mussels, crabs and birds have been found. In addition, kitchen waste and plastic were found in the pellets (Figure 6.4).

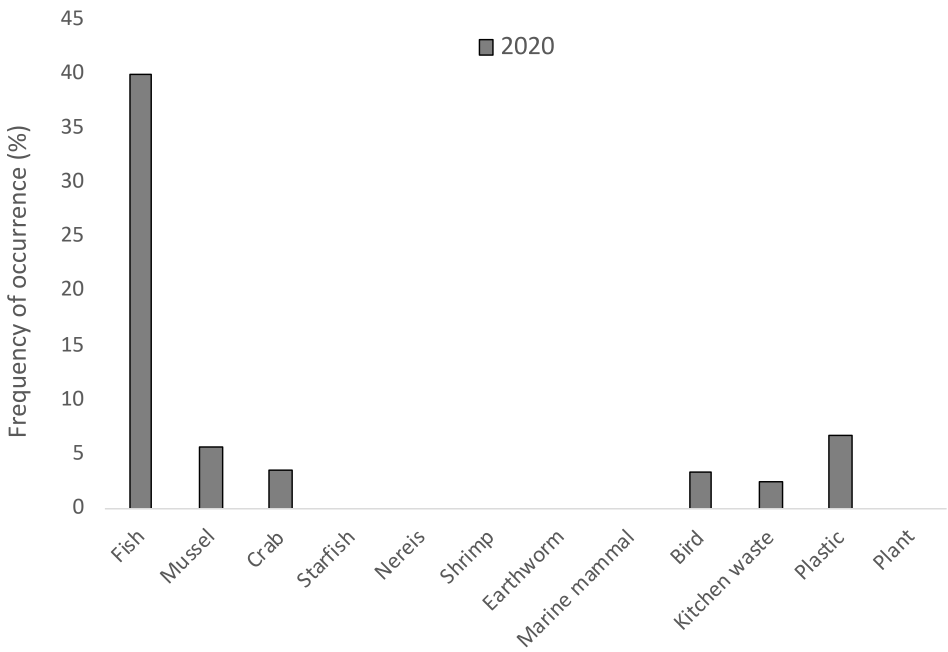

Figure 6.4 *Frequency of occurrence of prey items in pellets of herring gulls in enclosures of birds with GPS-loggers at Neeltje Jans in 2020.*

The most common prey species in pellets of herring gulls were fish and mussels, followed by crab and (song)birds. Fish were found in 8 pellets and three pellets contained identifiable fish parts. These were the body of a mackerel *Scomber scombrus* (Figure 6.5) otoliths from 1 whiting and otoliths from 3 herring. Crab remains were found in 9 pellets, which were mainly shields and scissors. The remains of birds have been found in pellets from 3 nests and consisted of remains of a blackbird *Turdus merula,* a robin *Erithacus rubecula*, unidentifiable songbird bones and the leg of an unidentified duck. Remarkably, no remains of starfish, *Nereis* or shrimp have been found in the pellets of herring gulls on Neeltje Jans. Kitchen waste was found in two pellets, which were leftovers of spareribs, lamb chops and chicken bones (Figure 6.6). Plastic waste was found in 4 of the 20 pellets.

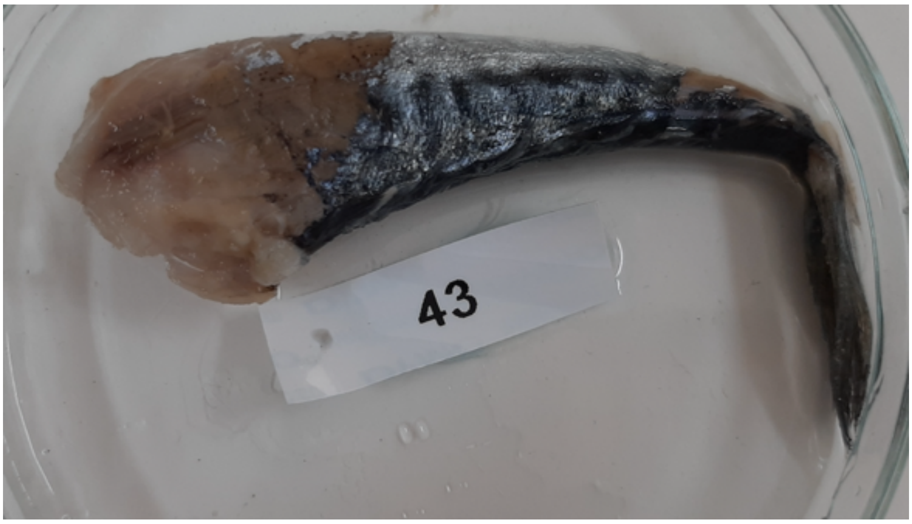

Figure 6.5 Remains of mackerel found in a pellet of a herring gull.

Figure 6.6 Remains of kitchen waste in a pellet of herring gull.

7 Discussion and conclusions

7.1 Which knowledge gaps have been filled?

The research in this report aims to fill existing knowledge gaps concerning large gulls and the potential impact of OWFs on these species. These knowledge gaps, identified in the EIA process of individual OWF concession areas and the so-called KEC (Dutch: 'Kader voor Ecologie en Cumulatie' translated Framework for Ecology and Cumulative effects), focus on 1) the distribution of large gulls, especially during the breeding period, and 2) avoidance of, or attraction to OWFs. Furthermore, baseline data on breeding and diet have been collected as background data with respect to tagged gulls, and for future use to study potential changes.

7.1.1 Distribution of gulls and overlap with OWF

In order to get better insight in the effects of offshore wind farms (OWFs) in general and the Borssele OWF in particular, the habitat use and distribution of 25 individual herring gulls *Larus argentatus* and 74 lesser black-backed gulls *Larus fuscus* breeding on Neeltje Jans were studied using GPS-loggers.

The results in this report showed that the tagged herring gulls were mostly bound to terrestrial and coastal habitats and largely avoided the offshore area. Offshore waters were used most often in the pre-breeding season, with about 4% of the records located further than 3 km offshore, yet no GPS fixes at all occurred inside the OWF concession zones during the study period (May 2020 – November 2021). This is in line with the results obtained through GPS data of herring gulls breeding in the nearby colonies of Zeebrugge and Ostend, that never ventured far enough offshore to reach the Belgian OWFs in place at that time (Stienen *et al*. 2016, Vanermen *et al*. 2018). Nevertheless, during ship-based surveys, herring gulls were encountered frequently inside the Belgian OWF concession zone, especially in midwinter, and were even shown to be attracted to the Belgian Blighbank and Thorntonbank OWFs (Vanermen *et al*. 2019a, 2020). Again, based on ship-based data, the proportion of adult birds inside the Belgian OWF concession zone was found to be 62%. All this seems to suggest that these adult herring gulls originate from different, probably more northern populations that spend the winter in the southern North Sea. A study on the origin of offshore resighted colour-ringed herring gulls revealed that birds in the surroundings of OWF Borssele were coming from the UK, Norway and Finland (Duijns *et al.* 2020). As we only tagged adult herring gulls, it remains unknown whether the immature birds encountered offshore and inside the OWF concessions do have more local provenance. Tagging of local juveniles and/or gulls from northerly breeding sites such as in Denmark and Norway could shed more light on this.

In contrast, lesser black-backed gulls were often recorded inside the OWF concession zones, in line with their generally much more offshore-oriented distribution. During the breeding season, territorial birds spend up to 18% of their time offshore (>3 km from the coast), and 0.86% of the records fell within the regarded OWF boundaries. Note that while this may sound like a low percentage, the concession zones make up for only 0.95% of the birds' assumed foraging range, i.e. within 141 km distance from the breeding colony at Neeltje Jans. Of all 74 tagged gulls, 49 individuals were recorded at least once inside the concession zones, but generally less than 5% of the tagged individuals was present at the same time. Our analyses further illustrated the huge individual variation in habitat use and tendency to head offshore, explaining why some individuals were never observed inside the wind farms, while others were recorded frequently. The use of the wind farms by these latter individuals appeared subject to strong temporal variation. The gulls were less inclined to enter the wind farms at high wind speeds (>10 m/s), compared to their overall offshore occurrence, while they were present in higher than expected numbers at wind speeds below 5 m/s. A comparable pattern was found for tagged lesser black-backed gulls in and around the Belgian Thorntonbank OWF (Vanermen *et al*. 2018), leading to believe that the level of visual disturbance induced by wind turbines increases with the turning speed of their blades. While the tidal cycle seemed to have little effect on the presence of lesser black-backed gulls in offshore waters, the OWFs were favoured during low tide, and meanwhile avoided during high tides. At low tide, the birds might be attracted to the wind farm as the exposed hard substrates offer additional foraging possibilities. It is, however, not clear what food would then attract the gulls, because most epibenthos growing on the hard substrates (shellfish) is only consumed by herring gulls and not by lesser black-backed gulls.

7.1.2 Avoidance of, or attraction to OWF?

When looking at the birds' spatial distribution (e.g. Figure 3.14 and Figure 4.1), one might expect macro-avoidance of the wind farms due to the intense concentration of fixes just outside the concession zone boundaries. The areas to the northeast and southwest of the Belgian Norther wind farm in particular stand out. However, when performing a BACI analysis for the Norther OWF by cumulating GPS data of birds from four different colonies collected over the period 2016-2021, we could not find a statistically significant avoidance effect, due to a similar distribution pattern prior to the construction of the wind farm. Indeed, the concentration of fixes to the southwest of the Norther OWF and located in the gully between the Thorntonbank and Gootebank is also visible in the UvA-BiTS records (Figure 4.7), most of which originate from the pre-construction period. Due to the specific location between two sandbanks and its consistency across time and colonies, this concentration could well be related to fishery activities. The fact that the weekend factor contributed significantly to our BACI model is another indication of the effect of fishery activity on the presence of tagged lesser black-backed gulls in our study area (Tyson *et al*. 2015). Taking in consideration the strong attraction effect of fishing activities makes it very hard to interpret distribution patterns of gulls in and around OWFs, as apparent avoidance may be the result of attraction of nearby trawling and/or the exclusion of fisheries from the impact footprint, rather than the result of disturbance by the turbines.

So, in contrast to what was reported by Vanermen *et al*. (2021), the current analysis did not find indications for macro-avoidance of the Norther OWF by lesser black-backed gulls during the breeding season. Results on OWF avoidance by gulls are indeed often inconsistent (Vanermen & Stienen 2019), highlighting the need for a case-by-case approach when aiming to assess the impact of OWFs on seabirds.

Next, we zoomed in to the gulls' distribution within the Borssele wind farm footprint area to look for meso-scale response patterns (Thaxter *et al*. 2018). We hypothesised that gulls, when suffering from visual disturbance by the turbines, are expected to move between the turbine corridors rather than randomly crossing the wind farm. This in turn would lead to a higher probability of occurrence further away from the turbines. As lesser black-backed gulls are also known to favour turbines for roosting (Vanermen *et al*. 2019b), we performed separate analyses for flying and non-flying birds. Based on the model results, however, flying gulls did not seem to display any preference regarding distance to the nearest turbine, thus implying random movements across the wind farm and lack of meso-scale avoidance. The only meso-scale distribution pattern is due to gull roosting behaviour on the turbine foundations. The non-flying birds indeed showed strongly increased presence close to the turbines, yet a comparably flat curve further away. Note that, while macro-avoidance patterns may partly be related to the location of the wind farm relative to colonies and/or favoured foraging areas, the lack of meso-avoidance more likely reflects a true species-specific response (or the lack thereof).

The lack of indications of avoidance, both on a macro- and meso-scale, as found in this study has clear implications for the expected collision risk. Birds that do not tend to avoid turbines, or that are even attracted to them, clearly are at higher risk of collision. Unfortunately, last-min avoidance actions, often referred to as micro-avoidance, could not be assessed in this study, even when considering the high-resolution GPS data (20 s) recorded inside the OWF geofence. To study such behaviour the birds need to be filmed or observed directly when approaching rotating turbines (see for example Skov *et al*. 2018) or the resolution of the GPS data needs to be improved.

7.1.3 Breeding success

Averaged over the two study years, the reproductive success of the GPS tagged lesser black-backed gulls was 0.32 chicks per pair. Reproductive success of the entire colony at Neeltje Jans was 0.23 chicks per pair. In order to compensate for annual mortality, lesser black-backed gulls should raise 0.63 chicks per pair, and reproduction at Neeltje Jans in the study year thus ran short. In the SW Delta area as a whole, lesser black-backed gulls reached an average breeding success of 0.55 chicks per pair in 2010-2019 (Schekkerman *et al.* 2021). During the study period, the mean breeding success of all colonies monitored in the Delta was 0.34 juveniles per pair in 2020 and 0.55 juveniles per pair in 2021.

Disturbance due to the catching and monitoring activities will undoubtedly have contributed to egg predation and the relatively low hatching success, although also in other related colonies a remarkable amount of egg loss was observed. In 2020, the persistent drought in May might have played a role, as this leads to increased absence of adult birds, making nests vulnerable to predation. Lastly, it should be noted that breeding success in the reference enclosure (where no birds were caught nor tagged) was even lower (0.19 young per pair). As such there are no reasons to assume that the tagging and monitoring activities have directly impacted the overall breeding success.

On a wider scale, the breeding success of all important coastal colonies in the Delta area (Vlissingen-Oost, Neeltje Jans, Meeuwenduinen and Maasvlakte) in 2020 and 2021 was too low to maintain a viable population. On the other hand, more terrestrial oriented colonies in the eastern part of the Delta had a much better breeding success, i.e. the colonies in Hollands Diep, Haringvliet and Krammer-Volkerak. In these areas, the number of breeding pairs has doubled over the past decade, whereas coastal colonies have shown a decline in numbers. In case of a continuing trend this implies that the number of offshore foraging lesser black-backed gulls is likely to decrease as well, which may in part limit or mitigate the impact of offshore wind farms on the Dutch breeding population.

The breeding success of the GPS-tagged herring gulls was 0.27 young per pair. This too can be regarded as a poor breeding success, as herring gulls should raise 1.1 chicks per pair to maintain a viable population. For comparison, in the SW Delta area as a whole herring gulls had an average breeding success of 0.63 fledglings per pair in 2010-2019 (Schekkerman *et al.* 2021). The mean breeding success of all monitored colonies in the Delta was 0.31 juveniles per pair in 2020, and 0.38 young per pair in 2021.

The large variability in habitat use of lesser black-backed gulls prevents a clear separation between gulls using OWFs and those that do not. There is even not a clear separation between terrestrial and marine gulls, since most of them show mixed habitat use. Therefor it is difficult to compare the breeding success of “OWF-gulls” and “non-OWF-gulls”. Given the fact that there is a limited number of successful nests anyway, even advanced statistics will likely not result in meaningful conclusions. The results of this analysis would be biased towards the few successful couples and their individual habitat use. Furthermore, habitat use of the other (untagged) parent cannot be quantified, leading to a missing explanatory variable, i.e. the habitat use of the untagged parent. All this, makes it impossible to reliably model breeding success or chick growth based on habitat use and/or use of the wind farm areas. However, the data collected these two years will function as baseline data on breeding success and chick growth, which can be used in future studies focused on potential changes due to the construction of OWFs.

7.1.4 Diet

Based on pellets found in the enclosures, the diet of chick-rearing lesser black-backed gulls was mainly of marine origin, as 30 out of 39 enclosures exclusively held pellets containing marine prey items such as fish, crab, mussels, starfish, sepia and seaweed. Unfortunately, several issues hampered the possibility to link diet and habitat use. First of all, as only one of two birds per breeding pair were tagged, there will always be a very important yet missing explanatory variable, i.e. the habitat use of the untagged parent. Because of the same reason, diet results cannot be linked directly to a tagged bird. Therefor it is currently impossible to reliably link diet to habitat use and/or use of the wind farm areas. However, the data collected these two years will function as baseline data on the diet of gulls at

Neeltje Jans, which can be used in future studies focused on potential changes due to the construction of OWFs.

7.2 Summary: how vulnerable are lesser black-backed and herring gulls to OWF developments?

To conclude, the tagging of gulls at Neeltje Jans provided crucial insight in the spatio-temporal and individual variation in the gulls' occurrence in and around the regarded offshore wind farms. As such, the GPS database can be used to refine collision risk modelling, and to assess the potential additional mortality at colony-level.

In summary, breeding herring gulls 1) did not venture far offshore and 2) thus did not show overlap with OWF concession zones. The herrings gulls recorded offshore in and around the OWF concession zones, especially outside the breeding season, must originate from different breeding locations and the most likely origins are breeding sites in Scandinavia and the UK.

Breeding lesser black-backed gulls 1) did use the OWF concession zones, 2) and did not show meso- and macro-avoidance, which 3) poses them with a higher collision risk than thought before. The amount of micro-scale avoidance is, however, unknown.

All this indicates that OWFs that are nearshore and close to colonies pose a potential threat to lesser black-backed gulls, but not to herring gulls breeding in the Netherlands.

7.3 Future studies

Despite the many knowledge gaps that have been filled in this study, some important issues remain. Although a better insight in the absence of meso- and macro-avoidance is now available, estimates of micro-avoidance are still lacking. To study such behaviour the birds need to be filmed or observed directly when approaching rotating turbines. On the other hand, in combination with accelerometer data analyses, high resolution GPS data might also allow to discern micro-scale avoidance actions. Another option would therefore be to adjust the geofences of the current loggers in future years and collect for example 1 second interval data inside (part of) the wind farms.

The current study set-up and current sampling size did not allow to link breeding success of lesser black-backed gulls with offshore habitat use and/or the use of the offshore wind farm areas. Continued tagging efforts of both parent birds and/or genetic sampling in a colony with a higher guaranteed breeding success could meet these concerns.

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Appendix I Overview pellet content

Table I.1 *Overview of number of collected pellets per nest and date for lesser black-backed gull in 2020 (12 nests, 29 pellets) and 2021 (27 nests, 61 pellets), where + indicates whether this type of prey item was found in the pellet.*

2020										
Date	Nest nr.	Fish	Mussel	Crab	Bird	Starfish	Nereis	Shrimp	Kitchen Waste	Plastic
02-06-20	2	+						+		
19-06-20	2		+	+						
27-06-20	2		+							
30-06-20	2		+							
03-07-20	2		+	+		+				
09-07-20	2		+	+						
19-06-20	7	+								
03-07-20	7	+						+		
19-06-20	9	+	+	+						+
23-06-20	9		+							
28-05-20	14	+					+			
20-05-20	23	+								
20-05-20	28	+								
20-05-20	38	+								
29-06-20	44	+								
28-05-20	68	+								
20-05-20	15	+								
02-06-20	15					+				
30-06-20	15			+						
09-07-20	15			+						
19-06-20	49	+								
23-06-20	49			+						
06-07-20	49			+						
09-07-20	49			+	+					
28-05-20	54	+								
23-06-20	54	+								
30-06-20	54	+								
03-07-20	54	+								
13-07-20	54	+								
Total		**17**	**7**	**9**	**1**	**2**	**1**	**2**	**0**	**1**

2021										
Date	Nest nr.	Fish	Crab	Shrimp	Sepia	(Marine) mammal	Earth-worm	Sea weed	Kitchen waste	Plastic
23-06-21	104	+								
25-06-21	104						+			
02-06-21	105								+	
07-06-21	105	+								
09-06-21	105	+								
16-06-21	105	+								
18-06-21	105								+	
25-06-21	105								+	
25-06-21	105								+	
23-06-21	111	+	+							
14-06-21	119	+								
18-06-21	119		+							
11-06-21	127	+								
16-06-21	127	+								
07-06-21	202	+	+							
11-06-21	202	+								
11-07-21	202								+	
19-07-21	202								+	
18-06-21	204								+	
07-06-21	205	+								
09-06-21	205	+								
16-06-21	205	+								
18-06-21	207	+								
14-06-21	209	+						+		
21-06-21	215						+			
09-06-21	227	+								
11-06-21	227	+								
23-06-21	227	+		+						
05-06-21	228								+	
25-06-21	229	+								
11-06-21	230	+								
11-06-21	301							+		
11-06-21	305	+	+							

2021										
Date	Nest nr.	Fish	Crab	Shrimp	Sepia	(Marine) mammal	Earth-worm	Sea weed	Kitchen waste	Plastic
07-06-21	307	+								
16-06-21	307	+								
11-07-21	307	+								
02-06-21	328	+								
25-06-21	328	+								
11-07-21	328	+								
13-07-21	328	+								
16-07-21	328								+	+
23-06-21	329	+								
25-06-21	329	+								
11-07-21	405	+						+		
13-07-21	405	+								
19-07-21	405	+								
11-06-21	406								+	+
05-06-21	407	+								
07-06-21	407	+	+							
09-06-21	407	+								
25-06-21	407	+								
19-07-21	407	+								
19-07-21	407	+								
09-06-21	408					+				
18-06-21	411	+								
21-06-21	412	+								
14-06-20	420	+								
Total		**42**	**7**	**1**	**1**	**2**	**2**	**3**	**9**	**3**

Table II.2 *Overview of number of collected pellets per nest and date for herring gull, where + indicates whether this type of prey item was found in the pellet.*

Date	Nest	Fish	Mussel	Crab	Bird	Starfish	Nereis	Shrimp	Kitchen waste	Plastic
19-06-20	6			+						
06-07-20	6									
09-07-20	6				+					
28-07-20	6								+	
30-07-20	6	+	+	+	+					
19-06-20	11		+		+					+
30-06-20	11		+							+
28-07-20	11		+							
19-06-20	5		+	+						
03-07-20	35								+	+
19-06-20	8		+	+	+					
23-06-20	8		+							
30-06-20	8		+							
20-05-20	43	+								
19-06-20	43	+								
23-06-20	43	+								
27-06-20	43	+								+
30-06-20	43	+								
30-06-20	43	+	+							
03-07-20	43	+								
Total	**20**	**8**	**9**	**5**	**4**	**0**	**0**	**0**	**2**	**4**

Bureau Waardenburg
Ecology & Landscape

Varkensmarkt 9, 4101 CK Culemborg, The Netherlands
Tel. +31 345 51 27 10
www.buwa.nl, info@buwa.nl