Grey and harbour seal spatiotemporal distribution along the Dutch West coast

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1. Samenvatting

Het aantal gewone en grijze zeehonden in de Nederlandse Waddenzee is de laatste jaren exponentieel gegroeid. Het is te verwachten dat het gebruik van de Nederlandse kustzone door zeehonden ook sterk is toegenomen. Voor 2014 staat de constructie van het windmolenpark Luchterduinen gepland en als onderdeel van de vergunningseis dient onderzocht te worden wat de mogelijke effecten van de constructie en operationele fase zijn op zeehonden. Het doel van deze voorstudie is om bestaande data te gebruiken en een overzicht te geven van het gebruik van de kustzone door gewone en grijze zeehonden en hoe dit verandert binnen en tussen jaren, en te definiëren wat de ecologische functie is van dit gebied. Voor deze analyse wordt gebruikt gemaakt van data van vliegtuigtellingen van zeehonden op de ligplaatsen in de Waddenzee en Delta, bestaande zenderdata, scheepstellingen in de Noordzeekustzone en tellingen gecorrigeerd voor waarnemingsinspanning vanaf vaste uitkijkpunten langs de Noordzeekust.

De exponentiele groei in het aantal waargenomen grijze zeehonden langs de Nederlandse kust (16.2 % p/j) is gelijk aan de populatie groei van grijze zeehonden op de ligplaatsen in de Waddenzee (15.9%). Grijze zeehonden worden vooral gezien in de zomer (juli – augustus) en winter (december – februari). Data van gezenderde individuen (2005 – 2008) laten zien dat de dichtheid het hoogst is nabij de kust. Er zijn vanaf 2005 29 grijze zeehonden gezenderd, maar tot op heden is er geen gezenderde grijze zeehond die gebruik heeft gemaakt van het Luchterduinen gebied.

Tot 2008 was de waarnemingskans voor gewone zeehonden klein en variabel, maar in 2009 en 2010 nam het aantal waargenomen gewone zeehonden vanaf de kust toe met een factor 10, wat lijkt te suggereren dat aantallen gewone zeehonden langs de Nederlandse kust in recente jaren plotseling is toegenomen. Echter, deze toename werd in sterke mate bepaald door een aantal extreem hoge tellingen in de wintermaanden (december – februari). Data van 86 gezenderde gewone zeehonden verzameld tussen 1997 en 2008, laten ook voor de gewone zeehond zien dat dichtheden hoger zijn nabij de kust, maar dit patroon is minder prominent dan voor de grijze zeehonden. Dit patroon kan echter veranderd zijn in meer recente jaren. In totaal hebben 3 gezenderde gewone zeehonden gebruik gemaakt van het Luchterduinen gebied. Scheepstellingen in de kustzone (0-3 km van de kust) laten zien dat in december 2012 naar schatting 242 gewone zeehonden gebruikmaken van het gebied, en in januari 2013 was dit aantal 852. Deze hoge aantallen suggereren dat het belang van dit gebied (gedurende de wintermaanden) mogelijk is toegenomen.

Resultaten uit voorgaande modelstudies en data gepresenteerd in deze studie laten zien dat de Noordzeekustzone vooral fungeert als foerageerhabitat, maar ook dient als medium voor uitwisseling tussen de Waddenzee en Delta. De groei in de Delta van zowel gewone als grijze zeehonden kan niet worden verklaard door lokale reproductie en dus vindt er netto immigratie plaats. Verwacht kan worden dat een groot deel van de import in de Delta afkomstig is uit de internationale Waddenzee, omdat dit het dichtstbijzijnde gebied is met naar schatting 38 500 gewone zeehonden. De zenderdata laat inderdaad zien dat er uitwisseling plaatsvindt tussen deze gebieden. Voor grijze zeehonden is Groot-Brittannië naar verwachting de belangrijkste bron.

Zover bekend foerageren gewone en grijze zeehonden individualistisch, en dit suggereert dat ontdekking van de Delta een kansproces is. Het feit dat de Noordzeekustzone dienst doet als foerageergebied lijkt een dergelijke ontdekking te faciliteren. Menselijke activiteiten, met name heiwerkzaamheden, kunnen het gebruik van dit gebied en uitwisseling potentieel beperken.

2. Summary

Numbers of both grey and harbour seals observed at colonies in the southern North Sea have grown exponentially in the last decade. The number of seals at-sea along the Dutch West coast is expected to have increased as well. In 2014, a new offshore wind park (Luchterduinen) will be built and part of the license agreement is to investigate the potential impact of the construction and operational phase on seals. The aim of this pre-study is to use existing data to provide an overview of the use of the coastal zone by the seals and to describe how this has changed within and between years. In addition, this study will attempt to identify the ecological function of this area for the seals. To investigate the spatiotemporal distribution of both species off the West coast of the Dutch mainland, we use data from aerial haul-out counts, tracking studies of individual seals, ship-based line-transect surveys and effort-corrected surveys from ashore (sea-watches).

The exponential growth in grey seal sightings along the Dutch coast (i.e. 16.2% p/a) is similar to the population trend recorded in Wadden Sea aerial survey data (i.e. 15.9%). Grey seals are mostly present in coastal waters during summer (Jul. – Aug.) and winter (Dec. – Feb.). Individual tracking data from 2005 – 2008 show that grey seal density is highest near the coast. Currently no individually tracked grey seals have been observed to use the Luchterduinen area.

For harbour seals, sighting rates were low and infrequent prior to 2008, but in 2009 and 2010, the sighting rate increased by at least 10-fold, suggesting a sudden, more intensive use. However, the observed increase was predominantly caused by some extreme counts during the winter months (Dec. – Feb.). Individual tracking data of 86 harbour seals collected between 1997 and 2008, did not reveal such a distinct higher density near the coast compared to grey seals, but this may have changed in recent years. In total three harbour seals used the Luchterduinen area. During boat-based surveys in Dec. 2012 and Jan. 2013, an estimated 242 and 852 harbour seals, respectively, were present within the first 3km from shore, suggesting that the importance of the coastal zone in winter has increased in recent years.

Results from previous modelling studies and the data presented in this study show that the Dutch West coast acts as foraging habitat for harbour and grey seals, however it also serves as an exchange medium between the Wadden Sea and Delta region. The increase in numbers in the Delta of both harbour and grey seals cannot be explained by local reproduction, indicating a net import. The international Wadden sea is the nearest area of large seal numbers, with approximately 38 500 harbour seals. It is to be expected that a large part of the import into the Delta originates from the Wadden Sea. Individual tracking data indeed shows that seals exchange between these areas. For grey seals, the United Kingdom is probably the most important source.

Both harbour and grey seals are believed to be individualistic foragers. Therefore, discovery of the Delta region by individuals is potentially the result of individual exploration. The fact that the Dutch coastal zone acts as a foraging habitat facilitates such discoveries and exchange. Human activities, such as pile driving activities, may potentially impede the use and exchange of seals between the two areas.

3. Introduction

In Dutch waters, two pinniped species occur: grey seals (*Halichoerus grypus*) and harbour seals (*Phoca vitulina*). Numbers of both species have increased exponentially in the Dutch Wadden Sea in the past decade. Grey seals were practically absent in the Netherlands prior to 1980, but then recolonised and in 2012, 2388 were counted during moult, when numbers ashore reach an annual peak (Brasseur et al. 2012b). The pup production, expressed as the maximum number of pups counted during a seasonal survey, has grown at a rate of 19% p/a (Brasseur et al. in prep). After the most recent seal epidemic in 2002, the number of harbour seals counted during aerial surveys in the Dutch part of the Wadden Sea has grown from slightly over 2300 animals to 6800 in 2012 (Galatius et al. 2012), with an average annual growth rate of 13.7%.

Corresponding to the increase in seal numbers observed during the aerial counts at haul-outs, the density of seals offshore is expected to also have increased at a similar rate. Because both species are central-place foragers (i.e. departing and returning to and from a haul-out site), at-sea density is expected to be highest near the haul-out sites. However, tagging studies have shown that both species venture to places further afield, including the Dutch West coast where haul-out sites are absent. This region is used for foraging, but it also functions as an exchange medium or 'corridor' between the Wadden Sea in the North and the intertidal areas in the Delta region in the South (Brasseur et al. 2010, 2012a). The literature on the term corridor is contradictory because of the ambiguity in the use of the word (Rosenberg et al. 1997). However, there is much less debate about the ecological function of a corridor. Corridors facilitate movement of individuals among subpopulations and hence decrease variability in birth and death rates, increase (re-)colonization rates and increase gene flow for maintaining genetic variance and population fitness. For a corridor to be effective, first, the animal must be more likely to leave a patch through a corridor than would be expected by random movement. Second, a greater proportion of animals must successfully disperse through corridors than through alternative, less suitable habitats (Haddad 1999). Though most fundamental knowledge on the matter is typically land-based, we will use this functional definition of a corridor in this study. We define a corridor as a region in space facilitating movement of individuals between subpopulations.

Historically, the Dutch Delta region was an important stronghold for harbour seals, holding about 1/3 of all harbour seals in the Netherlands (Reijnders 1994), but after centuries of intensive hunting, seals had practically disappeared. Recently, this region has also shown an increase in seal numbers of both harbour and grey seals, although the numbers there remain low and variable compared to in the Wadden Sea (Strucker et al. 2012). The current negligible pup production in combination with an observed high mortality in the Delta suggests that growth mostly depends on immigration from other regions, such as the Wadden Sea, rather than internal growth (Brasseur and Reijnders 2001).

The increase in seal numbers off the Dutch West coast may lead to an increase in the numbers of seals that come into conflict with human activities such as offshore wind farm development, sand mining and shipping. An increase in such activities may decrease the suitability of this area as a foraging habitat. In addition, some human activities might impede the exchange of animals between the Delta and the Wadden Sea. This could reduce the number of seals that reach the Delta area.

The objective of this study is to use existing data to provide an overview of the use of the Dutch coastal zone by grey and harbour seals and to describe how this has changed within and between years. In addition, this study will attempt to identify the ecological function of the Dutch coastal zone for the seals. To achieve this, several existing data sets are amalgamated, including sea-watcher records, wildlife telemetry, ship-based line-transects and aerial surveys at the haul-out sites. This analysis should provide a better understanding of the ecological role of this region and how grey and harbour seals may potentially interact with local human activities.

4. Materials and Methods

Study region

The region of interest entails the coastal waters from the 'Maasmond (Maasvlakte)' (51.99ºN, 4.03ºE) in the South, to 'Huisduinen' (52.95º, 4.72º) in the North (Figure 1). For the analysis of the wildlife telemetry data we only use locations at least 10 km north of the 'Zuid-Maasvlakte (51.9123°N, 4.0179°E), and 10 km south of the 'Razende Bol' (52.96°N, 4.69E), thus between 52.0030°N and 52.8713°N. This is to remove telemetry locations for seals associated with the haul-out sites at those locations, which do not reflect foraging or transit behaviour. For the analysis of the sea-watcher's data, all sites between (but excluding) 'Maasmond' and 'Huisduinen' were used.

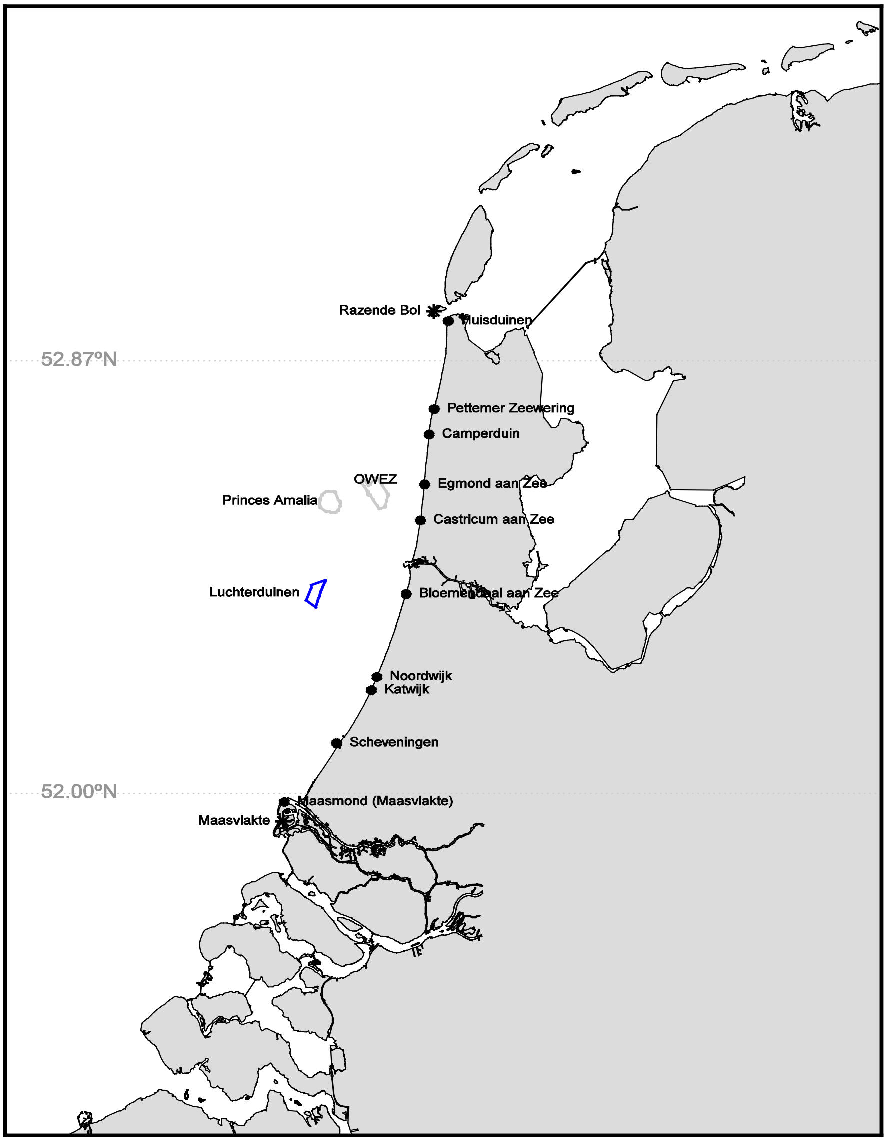


Figure 1. Map of study area, containing the three offshore wind farms (Princes Amalia, Luchterduinen, and OWEZ), all coastal sea-watcher sites and the seal colonies: de Maasvlakte in the South and Razende Bol in the North.

Wildlife telemetry data

Between 1997 and 2008, satellite tags were deployed on both harbour and grey seals on several occasions and in different areas (Table 1).

Table 1 Seals tagged between 1997 and 2008 in Dutch waters. Locations in italic are further east of the current study area (and in the Wadden Sea): seals tagged in these areas are less likely to use our area of interest. Tracking devices are distinguished as "sat" for ARGOS satellite transmitters and "phone" for GSM-GPS tags. An additional 141 harbour seals caught near the Ems estuary were equipped with a phone tag in 2009-2011. However, due to data-use restrictions, these data could not be used in this study. With the exception of the seals caught near the Ems estuary, all tagged seals using the coastal zone (see column "Coast") are incorporated in this study.

	Autumn	**Spring**	***Grand Total***	***Coast†***	***Q10****
Grey seals Totals:	**12**	**12**	***24***	*7*	***0***
sat					
Texel	(2005) 6	(2005, 2006) 7	*13*	*1*	*0*
phone					
Texel	(2008) 6	(2006, 2007) 5	*11*	*6*	*0*
Harbour seals Totals:	**43**	**43**	***86***	***22***	***3***
sat					
Lauwers	(2003) 3	(1998) 10	*15*	*0*	*0*
Maasvlakte	(1997) 4	(1998,1999) 7	*11*	*9*	*2*
Eastern Scheldt	(1998, 2000) 7	(1999, 2000) 7	*14*	*3*	*0*
Texel	(2002, 2004, 2005, 2007)13	(2003, 2007)13	*26*	*8*	*0*
Western Scheldt	(2005, 2007) 6	(2007) 6	*12*	*1*	*0*
phone					
Texel	(2007) 6		*6*	*1*	*1*
Western Scheldt	(2007) 4		*4*	*0*	*0*
Grand Total	**55**	**55**	***110***	***29***	***3***

Coast †: The area is defined according to the specification provided in the "study region" paragraph
Q10*: contains the number of seals within 5km of the central location of the Luchterduinen area

Two types of tags were used: the earlier Argos tags (called 'sat' tags, from Wildlife Computers or Sea Mammal Research Unit, SMRU) and GSM-relayed data loggers (GPS-Phone Tags, SMRU). The tags were glued to the hair on the back of the head of the animals (Fedak et al. 1983). Sensors in both tag types measured depth (pressure sensor) and whether the unit was dry or wet (conductivity sensor).The ARGOS loggers were located by satellites with a polar orbit, resulting in a 3-7 locations per day. GPS-Phone tags contained sensors that measured geographic position (FastlocTM), resulting in up to 72 locations per day. Data from this tag were relayed by the GSM network, and provide a more complete behavioural picture than the ARGOS tags.

Ship-based survey data collection

In December 2012 and January 2013, bird and marine mammal counts were conducted from the research vessel *MV* Navicula. The survey was primarily aimed at great crested grebes (*Podiceps cristatus*), but locations of seals were also recorded. The survey was conducted in the near-shore waters

(0-3 km from shore) between Hoek van Holland in the south to Den Helder in the north, along pre-defined tracks following the standardized European Seabirds At Sea (ESAS) protocol (Tasker et al. 1984, Van Franeker 1984). Distances to individuals were estimated and registered in six distance classes: A (0-50 m), B (50-100 m), C (100-200 m), D (200-300 m), E2 (300-500 m) and E1 (500-1000 m). For the density estimations in the present study, only observations within classes A-D were included. The survey took place during daylight hours, and counts were carried out by one observer on each side of the ship and a central recorder who looked straight ahead. Transects were broken up into 1-minute segments which represented approximately 200-300m (considering the survey speed was ~ 7 knts). The configuration of track-lines – a zig-zag pattern – was determined using Distance analyse software (v6.0, Thomas et al. 2009). The total track length was ~150 nm (278 km), which could be covered in 4 days. For each 1-minute segment, sea-state (Beaufort scale) was recorded. Relative abundance of schooling fish was noted on the ship's echo-sounder, as 'none', 'some', or 'many'. Species composition of fish schools in areas with high fish abundance was occasionally assessed using short, mid-water (i.e. not the sea floor), beam trawls.

Coastal observations

Primary goal of coastal sea-watches is the recording of coastal bird migration, but marine mammals (seals and cetaceans) are systematically recorded as well. Effort data and sightings of grey and harbour seals were extracted from the sea-watcher's databases (www.trektellen.nl). The analysis presented here is based on sightings collected during standardized sea-watches over a period of 16 years (1997 to 2012, *n* = 40271 hrs). The counts were conducted year-round, but with increased intensity during periods of (water bird) migration in spring (Mar. – May) and autumn (Aug. – Oct.). Sea-watches were conducted under all weather conditions. Observations were made from vantage points (dune-tops, piers, dikes), with observatories normally at a height of 5-15 m above sea level, to provide views over the near shore strip of coastal sea (up to 5-10 km distance). Seals were most often detected within 2 km from the observers. Observers recorded date, duration of the observation period (start and end time), and weather characteristics and usually logged their sightings per hour of observation. The data are expressed as "number per hour of observation" (n/h). Only the watching station Camperduin contained at least 100 hours of effort for each year and, therefore, data from this station was used to assess long-term trends. The sea-watch stations at Pettemer Zeewering, Camperduin, Huisduinen, Bloemendaal, Noordwijk, Katwijk, Scheveningen, Maasmond, Egmond and Castricum aan Zee where all used for describing seasonal patterns in recent years. See Appendix A – Table A1.

Aerial survey haul-out sites

Wadden sea method

Counts in the entire Dutch Wadden Sea were carried out for the two seal species in relation to their phenology i.e. the moult and pupping seasons (Reijnders 1978, Reijnders et al. 1997, Meesters et al. 2007): In practice, this lead to the following sampling regime: for the grey seal a minimum of 5 aerial surveys each year, 3 during the pupping period (Nov. – Jan.) and 2 during the moulting period (Mar. – Apr.); for the harbour seal a minimum of 5 aerial surveys each year, 3 during the pupping (Jun. – Jul.) and 2 during the moulting period (Aug.). The track of the flight is chosen with the aim to count all known haul-out sites. Aerial surveys were carried out from a fixed-wing, single engine aircraft, flying at approximately 500 ft (~150 m) and 150-200 km/h. Surveys were conducted within a 4-h window around low tide between 2-h before and 2-h after low tide and were aimed at low tides between 1200 and 1600 (Reijnders et al. 2003). Surveys were performed on good weather days, with daily rainfall <8.5 mm (measured from 0800 UTC the preceding day), winds below 46 km/h (25 knots, or 6 Beaufort) and good visibility. The flight route was recorded using GPS. From 2000 onwards, a digital camera was used to register the number of seals present at the haul-out sites. All environmental data, including flight path and flight conditions, were entered into a database for further analysis. Before 1995, seals were counted directly during the flight. From 1995 onwards, systematic photos were taken of all groups of seals. In the laboratory, these images where projected and all animals were counted individually.

Delta method

For the monthly aerial surveys of seals in the Delta area similar flight methods (altitude & aircraft) were used. However, flights are timed differently and only an occasional picture was taken when seal numbers exceed what could be accurately counted visually. These data were obtained from the yearly rapports of Delta Project Management, commissioned by Rijkswaterstaat Waterdienst (e.g. Strucker et al. 2012).

Analysis tagging data

All ARGOS animal tracks were first run through a location filter to remove erroneous locations (see Brasseur et al. 2012a). Similarly from the GPS tracking data, all locations representing unrealistic travel speeds (i.e. V_MASK = 20 dm/s or <0) where removed. All remaining locations inside the study region were plotted. Actual transits between the Delta and Wadden region were analysed in more detail.
We also provide a description of the variation in density as function of distance to the coast, to highlight the potential existence of transit corridors. This was achieved by first calculating for each location the average of the time to the previous and next location, and next summing these times for each distance class. Such results are expressed as seal days.

Population analysis grey and harbour seal population size

The population trend for Wadden Sea and Delta was defined for grey seal pups (Dec./ Jan.), total number of grey seal (moult; Mar./Apr.), harbour seal pups (May. – Jul.) and total numbers of harbour seals (moult; Jul./Aug.). We modelled the counts as a function of the year since 1985 (following Brasseur et al. in prep) and assumed these counts to follow a (quasi-) Poisson distribution with a log-link. Using these count data (N), both the estimated initial population size in 1985 (N_0, i.e. the exponent of the intercept β_0), and population growth rate (λ) were estimated by fitting a Generalized Linear Model (McCullagh and Nelder 1989). The expected count was therefore modelled as:
$N_t = e^{\beta_0+\beta_1(t-t_0)} = e^{\beta_0} e^{\beta_1(t-t_0)}$, where $e^{\beta_0} = N_0$ and $e^{\beta_1} = \lambda$,

where $t_0 = 1985$, and linearized using a log function:
$\log(N_t) = \beta_0 + \beta_1(t - t_0)$

To test for differences in growth rates observed between the population counts and sea-watch data, the interaction between data source (i.e. aerial count or sea-watch) and year was included in the model. The standard error and *p*-value of the interaction signifies the difference between the observed growth in the data sets.
Finally, we estimate the absolute growth for the Delta for each year based on (maximum) moult counts, and relate this to observed numbers of pups counted in the previous year. If the growth exceeds the pup production, this indicates a substantial immigration from other regions, e.g. the Wadden Sea or the United Kingdom. This provides a conservative estimate of immigration, since it assumes no pup mortality.

At-sea density estimation based on ship-based survey

Total numbers of grey and harbour seals present in the area were estimated using the distance-sampling method (Thomas et al. 2010) based on line-transect surveys. Data analysis incorporated two steps.

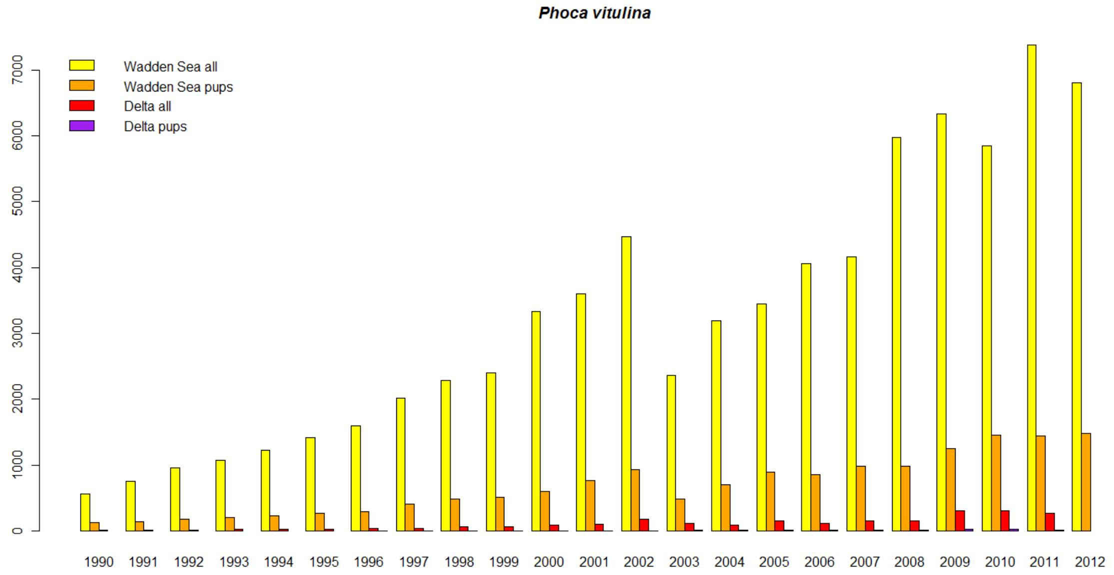
1. Estimation of the effective strip-width (ESW, i.e. the total one-sided strip width of 300 m multiplied by the estimated sighting probability). This was based on the distribution of perpendicular distances to the observed seals.
2. Estimation of mean density based on counts per unit area.

Four detection functions were fitted to the counts per distance class (*y*) using the program Distance (Version 6.0, Thomas et al. 2009, 2010). These functions included the hazard-rate key detection function ($1-\exp\left(-\left(y/s\right)^{-b}\right)$) and half-normal detection function ($1-\exp\left(-y^2/2s^2\right)$), where *b* and *s* are parameters and, for both functions, *s* was either a fixed value or was allowed to vary as a function of sea state category (i.e. cat. A: 0-2 bft, and cat. B: 3-5bft). AIC was used to select the best function. These detection curves were then used to estimate the effective strip width. We assumed that the sighting probability for grey and harbour seals were equivalent and, hence, all seal sightings including the unidentified seals were used to estimate the ESW. Next, an intercept-only, log-linear model was fitted to the number of sightings within each segment (differentiating between species). The log of the product of the ESW and segment length was included as the offset. To transfer the uncertainty in the estimation of the ESW into the estimated seal density, 1000 estimates of the ESW were generated by randomly sampling from the parameter distribution (i.e. mean and standard error) of the detection curve. The corrected mean density estimate was multiplied by the total area of the survey block (i.e. 373 km^2), to arrive at an estimated total. This implicitly assumes that the survey representatively covers the study region, which is a safe assumption given that the effective coverage of the survey is ~ 167 km^2 (some of which are partly overlapping segments), while the total survey region is 373 km^2.

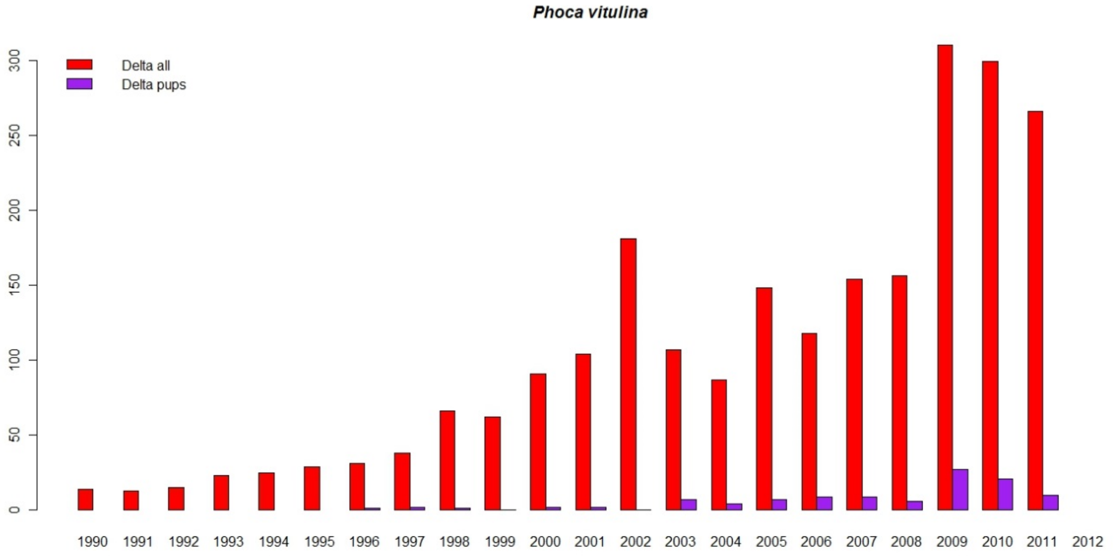
5. Results

Growth rates based on haul-out counts and sea-watching sighting rates

Haul-out count results for harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*) were available from 1990 (Figure 2 and 3, respectively).



a.



b.

Figure 2. Maximum count (in one survey season) of the number of a) harbour seals (*Phoca vitulina*) (moult; Jul./Aug.) for the Wadden Sea (yellow) and Delta (red), and b) harbour seal pups (Jun. – Jul.) for the Wadden Sea (orange) and Delta (purple). For the Delta, no data was available for 2012. Note different in y-axis scales (Data: IMARES Wageningen UR, RWS and Province of Zeeland).

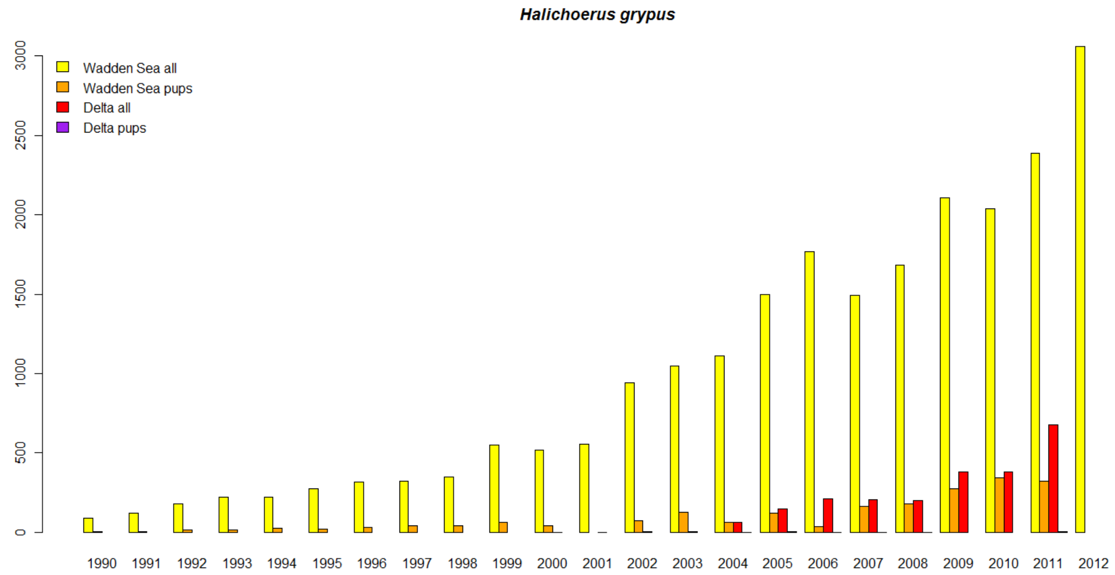


Figure 3. Maximum count (in one survey season) of the number of grey seals (moult; Mar./Apr.) for the Wadden Sea (yellow) and Delta (red), and grey seal pups (Dec./ Jan.) for the Wadden sea (orange) and Delta (purple). For the Delta, no data is yet available for 2012. Grey seal pup counts are extremely low in the Delta region, with only 0-3 pups p/a. (Data: IMARES Wageningen UR, RWS and Province of Zeeland)

The growth rate in grey seal numbers counted during the moult (1990-2012) in the Wadden Sea is estimated at 16.2 % per year (95% CI = 15.11 to 17.37, see Table 2.). For further details, see also Brasseur et al. (in prep). The growth rate in grey seal numbers in the Delta is estimated at 42.0 % (39.63 - 44.47), which is significantly higher than the Wadden Sea rate (Likelihood-ratio statistics = 1310.2, p <0.001). Annual increase in the number of grey seals counted during coastal sea-watching counts from Camperduin (52.72ºN, the only site with long term records of grey and harbour seals, see also Appendix A – Table A1) is estimated at 15.92% (95% CI; 10.65 – 21.44), which does not significantly differ from the Wadden Sea growth in moult counts (LR = 0.025, p = 0.87). Coastal sighting rate at Camperduin is significantly different from the increase in grey seal numbers in the Delta area (LR = 18.72, p <0.001).

For harbour seals, the growth rate since 2002, based on moult counts in the Wadden Sea, is estimated at 12.73% (95% CI = 10.19 to 15.32), and for the Delta the growth rate is 16.54 (95% CI = 10.95 – 22.42) . These growth rates are significantly different (LR = 11.56, p = 0.0007).

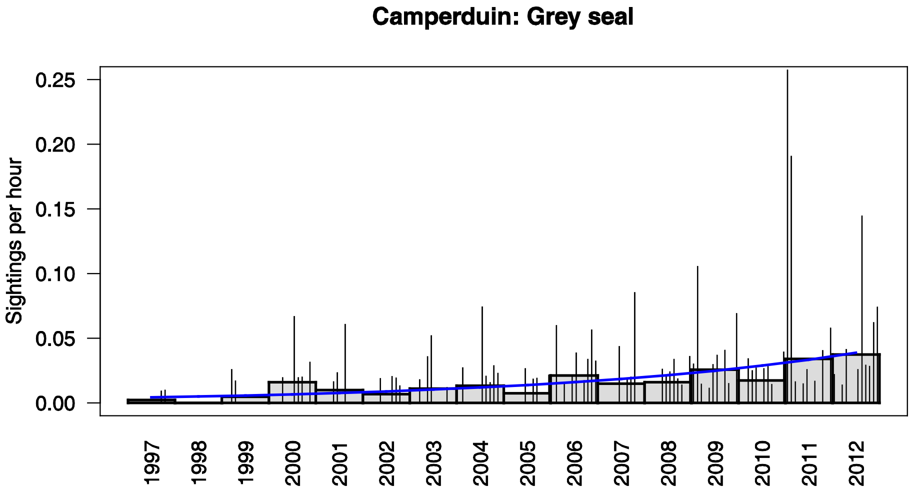
The yearly increase in coastal sightings of harbour seals observed from Camperduin is 30.15% (95% CI = 15.40 to 46.78, Fig. 4). However, this rate was calculated assuming a continuous exponential growth for the coastal sightings from Camperduin, which may not be a good representation of the observed temporal changes (see Fig. 4b). The harbour seal sighting rate was relatively low up to 2008, but in 2009 and 2010, there was a ten-fold increase, followed by a drop in 2011. This pattern was mostly caused by high sighting rates during the winter months of 2009 and 2010. When the winter data (December to March) is excluded, the estimated annual increase was 16% (95% CI = 1.2 to 33, Fig. 4c).

The average annual sighting rate for harbour and grey seals over the last 5 years of the time series (2008-2012) was 0.042 and 0.018 seals/h, respectively (Fig. 4). Therefore, the ratio harbour seal / grey seal sighting rate was 2.3.

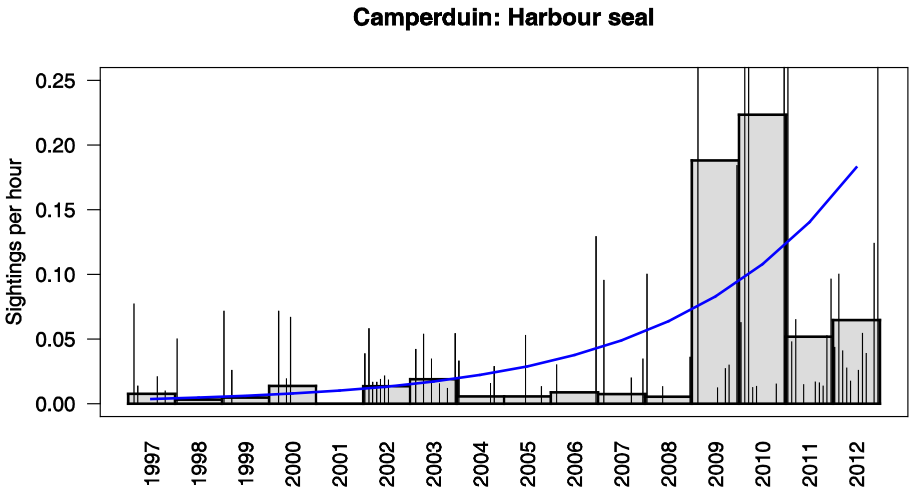
In summary, the coastal sighting rate and population size increase of grey seals in the Wadden Sea are not significantly different, but the Delta growth is significantly larger. For harbour seals, the growth of the harbour seal numbers in the Delta is also larger. Also the annual increase in the coastal sighting rate along the Dutch coast is larger than the growth in the Wadden Sea. This is, however, mostly influenced by some extreme (incidental) coastal counts during the winter months. During most of these counts (e.g. Camperduin 4-2-2009: 78 harbour seals/day 14-2-2010: 42/day and 14-2-2009: 38/day), all individuals were travelling either North or South.

Table 2 Population growth rate parameters of grey seals (1990 – 2012) and harbour seals (2002 – 2012) based on aerial survey haul-out counts and sea-watches from Camperduin (1997 – 2012).

Species	Data series	Slope (SE)	Growth in % (95% CI)
Grey seal	Aerial moult counts Wad	0.150 (0.00496)	16.23% (15.11 -17.37)
	Aerial moult counts Delta	0.3508 (0.00869)	42.02 (39.63 - 44.47)
	Camperduin sighting rate	0.148 (0.0237)	15.92 (10.65 - 21.44)
Harbour seal	Aerial - moult Wad	0.120 (0.0116)	12.73 (10.19 - 15.32)
	Aerial – moult Delta	0.153 (0.0251)	16.54 (10.95 - 22.42)
	Camperduin sighting rate increase	0.264 (0.0613)	30.15 (15.40 - 46.78)
	Camperduin sighting rate Apr.-Nov.	0.149 (0.070)	16.09 (1.16 - 33.21)



a.



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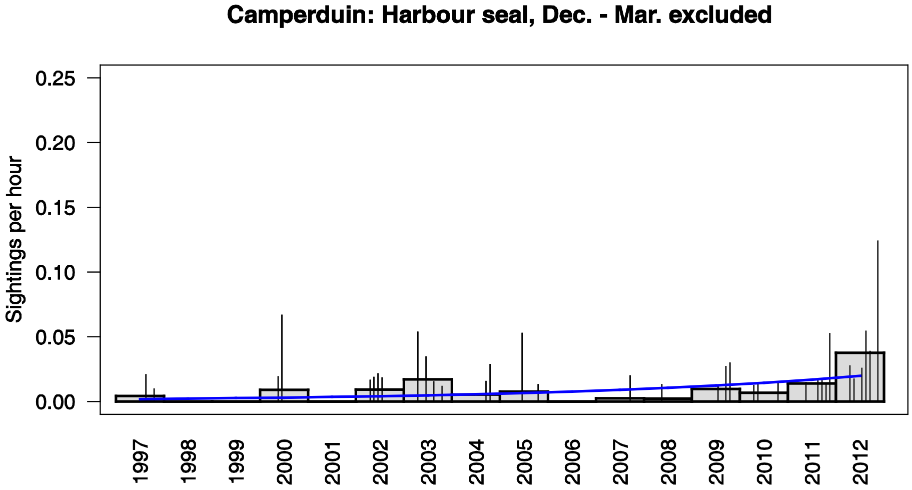
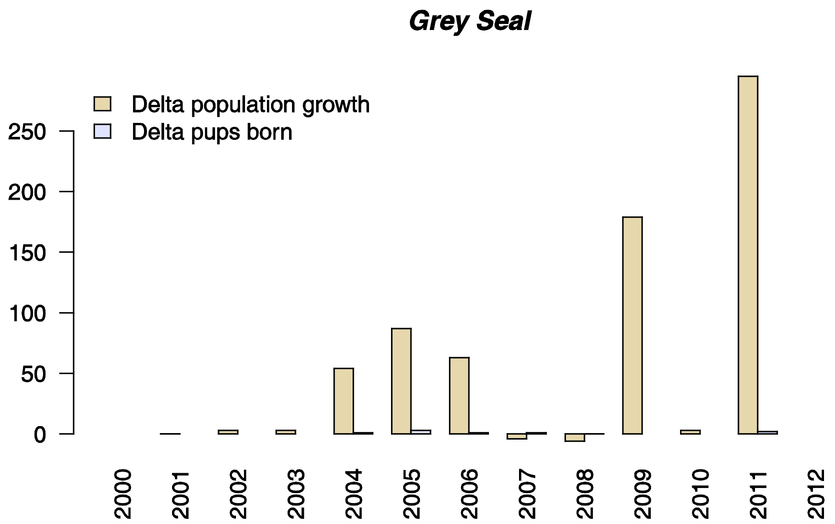


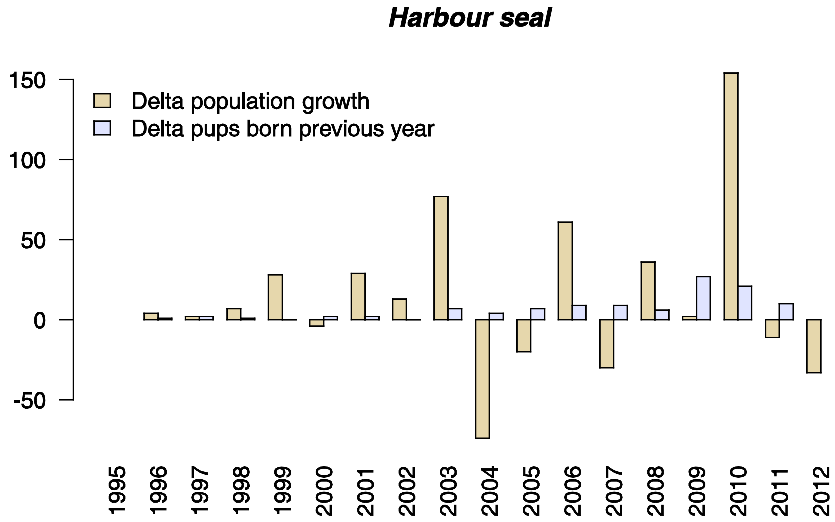
c.

Figure 4. Trend in sightings per hour for (a) grey and (b) harbour seal based on sea-watches from Camperduin (1997 – 2012). Fig. 4c shows the harbour seal sightings excluding winter data (December to March). Grey shaded areas are the annual averages and black vertical lines are monthly averages. The blue solid line is the estimated exponential growth rate.

Absolute growth in the numbers of grey and harbour seals in the Delta based on moult counts was compared to the number of pups observed in the previous year (Fig. 5). The absolute growth in moult counts exceeds the pup production. This is particularly true for grey seals, and this implies that the observed growth (Fig. 3a, 5a) is almost entirely the result of immigration.



a.

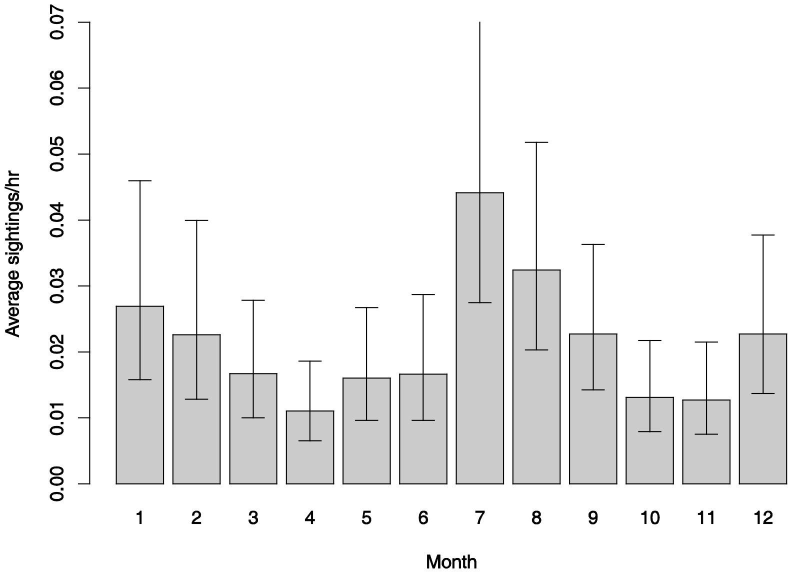


b.

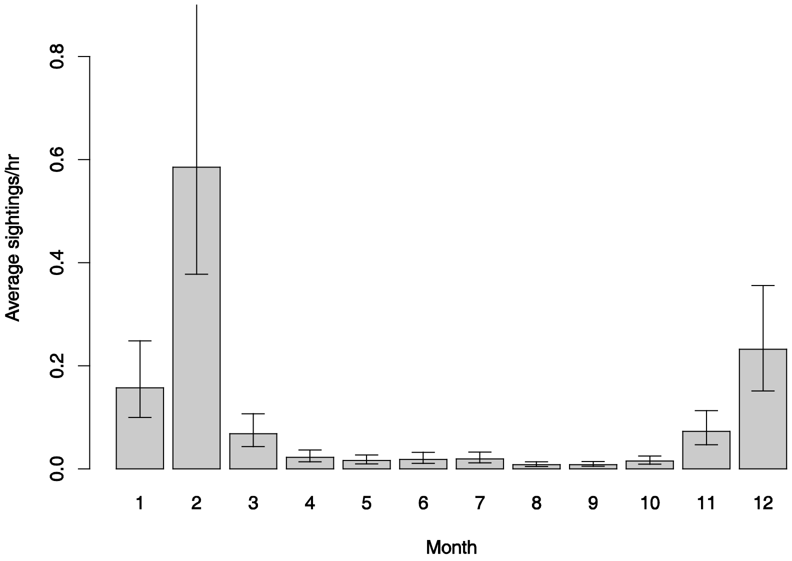
Figure 5. Absolute growth in the numbers of (a) grey and (b) harbour seals in the Delta, compared to the number of pups counted in the preceding year. The low pup values compared with population values for the following year imply that the population growth cannot be accounted for by intrinsic growth alone so must be result from immigration from other regions.

Seasonal variation

Monthly sea-watch data were analysed per hour to correct for variable effort. Effort increased during spring (Mar. – May) and autumn (Aug. – Oct.), when birds are migrating (Fig. A2 in Appendix A). The hourly sighting rate of grey seals reveals two peaks, in Jul. – Sep. and in the winter months (Dec. – Feb.; Fig. 6a). The harbour seals peaked in late winter (February). The low sighting rate in summer (May to Sep.) coincides with the reproduction and moult periods.



a.

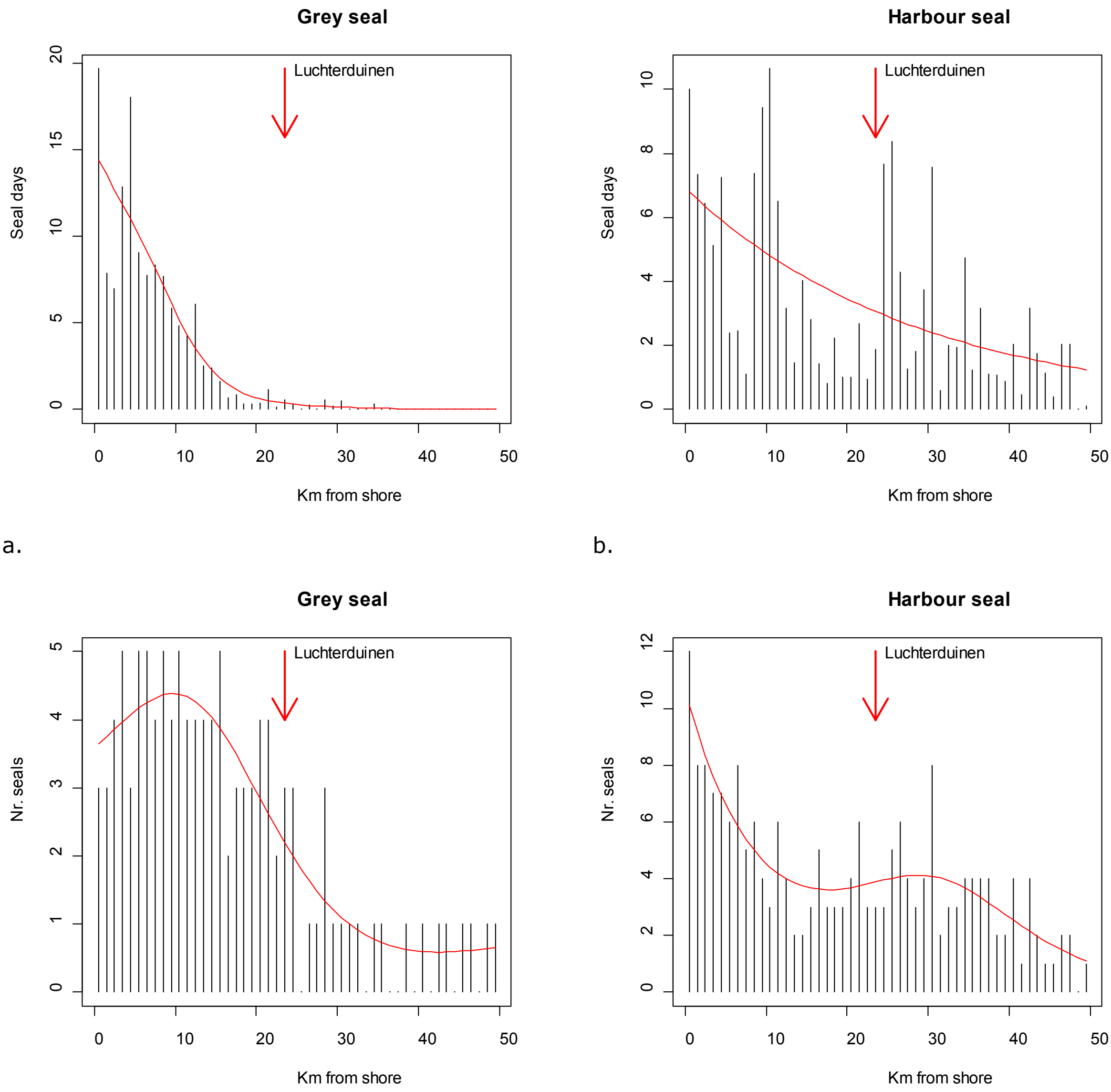


b.

Figure 6. Monthly pattern of number of (a) grey and (b) harbour seals observed per hour (i.e. corrected for effort) during the sea-watches along the Dutch coast, 2009-2012.

Spatial distribution

Based on the tracking data, grey seals occur closer to the Dutch shore than do harbour seals (Figures 7 and 8). The data on grey seals was mostly collected from 2005 to 2008 and that for harbour seals from 1997 to 2008. From ship-based sightings, in December 2012, harbour seals were found along the entire Dutch coast, but with highest densities near the Delta (Fig. 9). In January 2013, a high density occurred again near the Delta region, but by far the highest density was near ‘Egmond aan Zee’.



a.

b.

c.

d.

Figure 7. Density of seal telemetry locations along the entire Dutch West coast, weighted by time and expressed as seal days (see methods) as a function of the distance to the coast for grey seal (a) and harbour seal (b). Number of grey seals (c) and harbour seals (d) observed within each distance class. Luchterduinen is located at 23km from the coast. Data are based on 7 grey seals and 22 harbour seals.

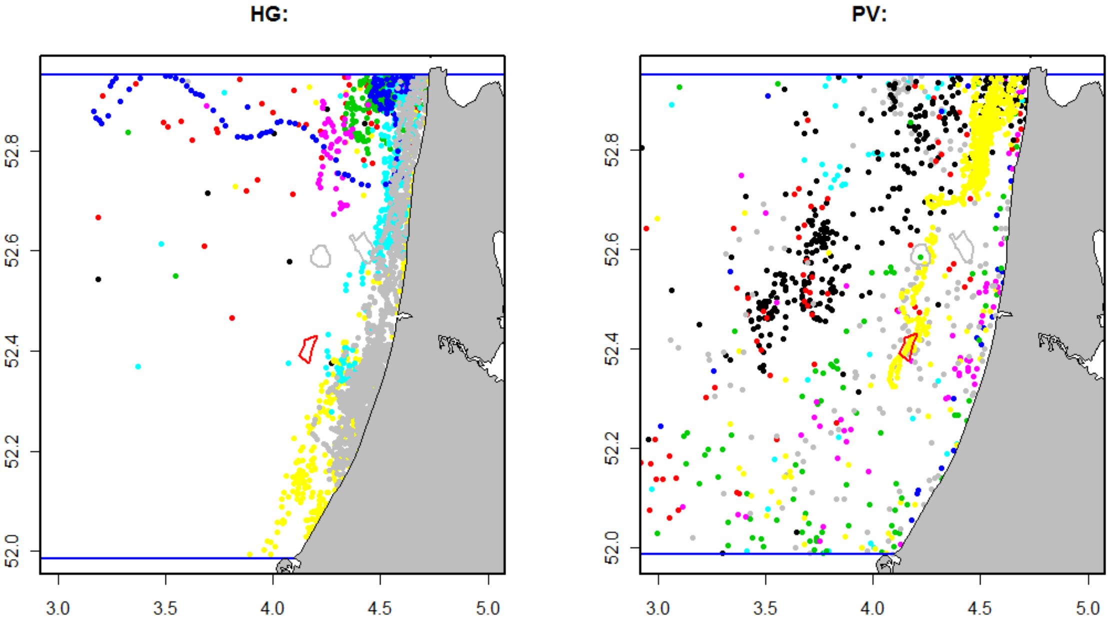


Figure 8. Distribution of grey seal (HG) and harbour seal (PV) locations within the study region of interest. Seal locations are collected by GPS FastLoc and ARGOS data loggers. The latter provide only a few location fixes per day. Each colours represent a different individual. Tracks from each individual seal are shown in Supplement S1.

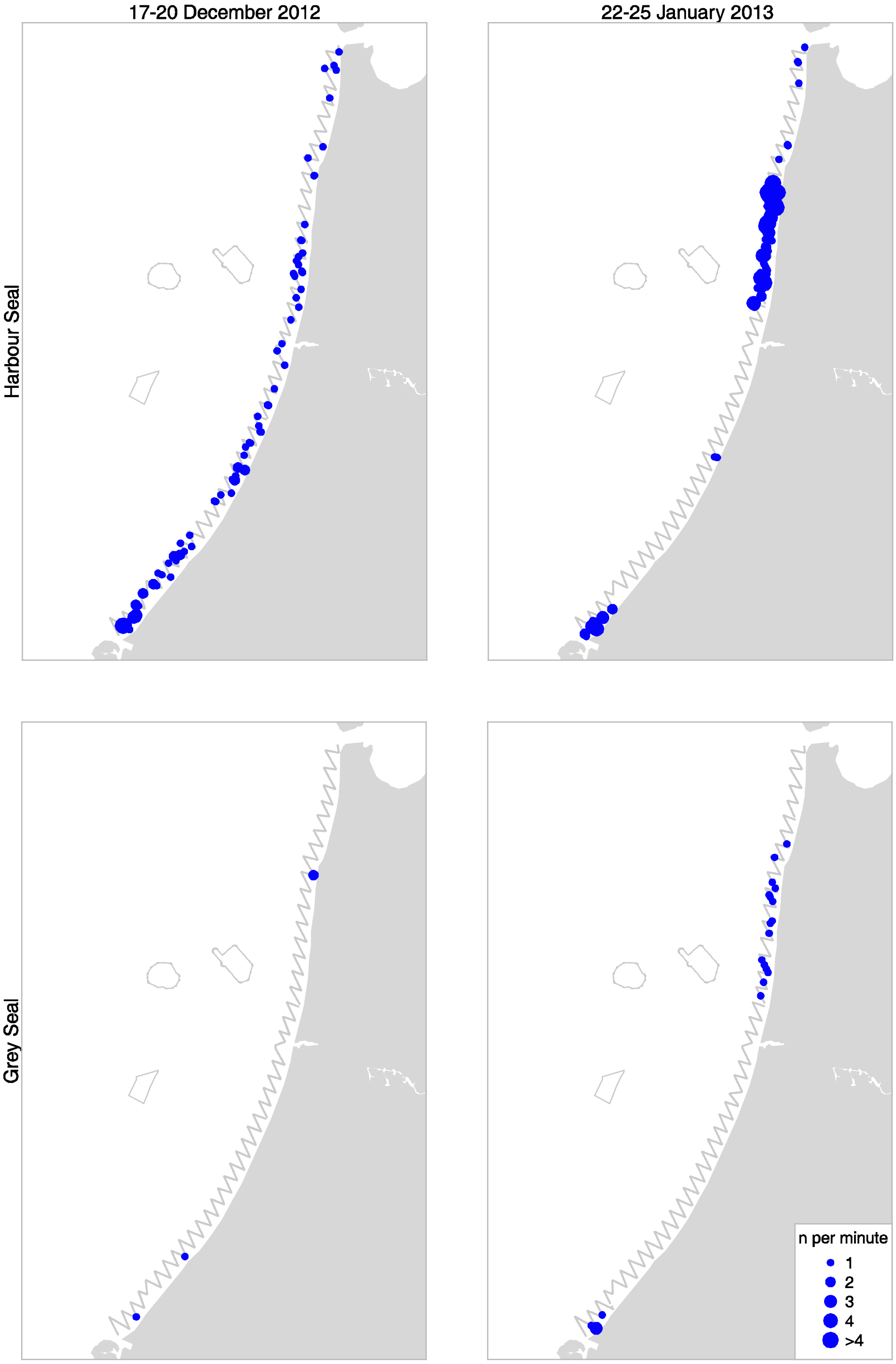


Figure 9. Distribution of grey (bottom) and harbour seals (top), as recorded from ship-based surveys 17-20 December 2012 and 22-25 January 2013

Table 3 and 4 present all known transits between the Delta and the Wadden Sea based on tracking data. In total 7 individuals travelled from the Delta to the Wadden Sea, all of which were harbour seals. The average transit duration was 2.7 days (min = 0.94 and max = 7.77 days). In total 4 individuals (3 harbour seals and one grey seal) transited from the Wadden Sea to the Delta. Average transit duration was 2.28 days (min=1.30 and max=5.472). Some individuals (15OS, 19OS, and pv21b-I-07) travelled back and forth between the Delta and Wadden Sea at least once, and one individual (i.e. 19OS) even twice. The tracking data shows more individuals moving from the Delta northwards to the Wadden Sea than the other way around. This is probably because there is a larger probability of catching "exchanging" individuals in the Delta. The "captive bred" individuals were individuals born on Texel (Ecomare) and released in the Delta.

Table 3. Northwards migrations from the Delta to Wadden Sea. PV= harbour seal, A = Adult, and S = Subadult.

Seal-id	Spec.	year	arrival date (m/d/y)	sex	age	release location	type of animal	transit duration (d)
15OS	PV	2000	5/16/2000	F	A	O'schelde	wild	2.12
19OS	PV	2000	3/26/2000	M	A	O'schelde	wild	2.61
19OS	PV	2000	5/26/2000	M	A	O'schelde	wild	1.98
1BM	PV	1997	9/30/1997	M	S	Brielse	captive bred	5.47
2BM	PV	1997	10/10/1997	M	S	Brielse	captive bred	1.69
3B3	PV	1999	5/4/1999	F	S	Brielse	captive bred	1.71
pv21b-I-07	PV	2007	4/29/2007	M	A	Hansweert	wild	1.30

Table 4. Southwards migrations from the Wadden Sea to the Delta. PV= harbour seal, and HG=grey seal.

Seal-id	Spec	year	arrival date (m/d/y)	sex	age	release location	type of animal	transit duration (d)
15OS	PV	2000	7/10/2000	F	A	O'schelde	wild	1.91
19OS	PV	2000	4/29/2000	M	A	O'schelde	wild	2.05
pv21b-I-07	PV	2007	5/13/2007	M	A	Hansweert	wild	1.64
hg21g-792-07	HG	2008	10/22/2008	M	A	noorderhaaks	wild	2.63

At-sea coastal absolute density estimation

Based on a half-normal detection function with sea state category as a covariate, the estimated half strip width was 284 m during sea state 0-2 bft, and 205 m during sea state 3-5 bft. The sighting probability is assumed to be equal for grey and harbour seals. This results in estimated densities for harbour seals of 0.65 km^{-2}, and for grey seals of 0.03 km^{-2} for Dec. 2012 and 2.29 km^{-2} and 0.14 km^{-2}, respectively for Jan. 2013 (Table 5). This does not take into account the number of seals submerged at the time of observation and is thus most probably an underestimate. The total area of coverage (i.e. the study area in which the survey takes place) is 372.7 km^2. Multiplying the average density by the total survey area results in a total abundance of 11.1 and 242 for grey and harbour seals in Dec. 2012, and 54, and 852 respectively for Jan. 2013.

Table 5. Density and abundance estimation of grey and harbour seals within 3 km off the Dutch Westcoast, based on the ship-based survey (see Fig. 7). The estimate for all seals also incorporates unidentified seals.

Species	Date	# sightings	density (95% CI)	Total abundance (95% CI)
Harbour seal	17-20 Dec. 2012	92	0.65 (0.49 - 0.93)	242 (183 - 345)
	22-25 Jan. 2013	357	2.29 (1.76 - 3.02)	852 (655 - 1126)
Grey seal	17-20 Dec. 2012	4	0.030 (0.008 - 0.132)	11.1 (2.99 - 49.1)
	22-25 Jan. 2013	22	0.14 (0.091 - 0.23)	53.9 (33.8 - 86.2)
All seals	17-20 Dec. 2012	99	0.70 (0.54 -1.01)	261 (200 – 378)
	22-25 Jan. 2013	379	2.43 (1.89 - 3.17)	905 (704 - 1182)

6. Discussion

Growth of the Wadden Sea and Delta population size

Numbers of both grey and harbour seals in the Wadden Sea have grown at an annual rate of 16.2 and 12.7%, respectively in the past decade. Assuming the individual specific proportion of time spent on land has not changed drastically, this should lead to a parallel development in the density at sea, thus also along the Dutch West coast. For grey seals, the growth rate based on moult counts is relative similar to coastal sightings rate (15.9%) from Camperduin (the only site with long term records of harbour and grey seals, and situated ~30 km from the Wadden Sea). In contrast, the pattern in the coastal sighting rate of harbour seals appears different from the population growth observed on the colonies. Sighting rates along the coast were low up to 2008, and increased rapidly thereafter. The years 2009 and 2010 appear to be exceptional, given the lower rates in 2011 and 2012, albeit being higher compared to the pattern up to 2008. This pattern is predominantly driven by some high counts during the winter months. E.g. on Feb. 13, 2010 from Egmond and Feb. 14, 2010, from Camperduin a total of 36 and 42 individuals where seen in 2 and 3 hours, respectively. This could indicate a rare event, or a new phenomenon in this area. When looking at the increase in sighting rate based on sea-watching data collected between April and November, this rapid increase since 2009 is not present.

Seasonal variability

The monthly coastal sighting rates reveal a clear pattern. For harbour seals, the hourly sighting rate is highest from December to March, with a peak in February. The latter is to some extent driven by the two extreme counts in Feb. 2010 from Egmond aan Zee and Camperduin. The post Huisduinen (excluded from the seasonal analysis due to its proximity to the Razende Bol haul-out site), shows a similar seasonal pattern with the highest sighting rate in Nov. – Feb. (see Appendix C). The seasonal pattern, with highest densities in the winter months, roughly mirrors the harbour seals annual cycle of pupping (Apr. – Jul.) and moult (Jun. – Jul. for juveniles, Jul. - Aug. for adults), during which the animals are expected to stay at or near their breeding and moult sites in the Wadden Sea (and to a lesser extend the Delta).

In contrast, grey seals reproduce in winter (Nov. – Jan.) and moult in March. They are expected to forage at sea during the remainder of the year, which might explain the highest number of grey seals seen along the coast from July to September. However, unexpectedly also relative large number of grey seals are seen along the Dutch West coast between December and February, which overlaps with the breeding season. Some of them might be misidentified harbour seals, or individuals that do not reproduce (e.g. sub-adults). Also just after the moult (Apr. – Jun.), grey seals are expected to spend more time foraging at sea, but this is not reflected in the coastal sighting rate. We would even expect a higher sighting rate in early spring, compared to July to September, since many species of demersal fish, the preferred prey type of grey seals, tend to move to deeper waters further offshore during the summer months (Teal et al. 2012).

Spatial distribution along the Dutch West coast

Overall, the distribution along the coast appears extremely variable. During the December boat survey (Fig. 9), harbour seals were sighted along the entire coast, with most sightings near the Delta region. In contrast, during the January survey, most sightings occurred between Castricum and Petten, and in the most southern part of the coastal zone. Because the survey was only carried out up to 3km from shore, we cannot state whether this phenomenon of a high sighting rate also occurred further offshore.

The telemetry data (collected between 1997 and 2008) shows that seal density is highest near the haul-out sites in the North and South of the Dutch coast, and density is lowest in-between these sites (see also Fig. 14 in Brasseur et al. 2012a). On average, the telemetry data of harbour seals suggest that the density of seals decreases as a function of distance to the coast, but this decline is much less steep compared to grey seals (Fig. 7).

The apparent increase in coastal sightings off Camperduin during the winter months in the most recent years could suggest a new local phenomenon is taken place. During the ship-based survey in January 2013 when a large number of seals were observed, a temperature cold front was detected, showing a drop in temperature of about 2ºC. This could be cold Wadden Sea water moving south-wards with the ebb tidal current. Most sightings occurred just south of this front. The new seal GPS-GSM tags also collect accurate temperature profile data. Therefore, such new telemetry data could be used to understand the underlying mechanism and to find out whether the high density of seals near the coast in winter is a local event, or whether it occurs further offshore as well. However, in the proposed monitoring plan for Luchterduinen, there is no tagging effort just after the harbour seal moult in September, and hence no data will be available to further address this.

The distribution of grey seals based on the boat survey reveals a similar pattern to that of harbour seals, although densities are much lower. Given the occurrence of the breeding season in winter, this is to be expected. The telemetry data on grey seals (collected from 2004 to 2009), reveal a distinct decaying function relative to the coast (based on data from 7 individuals). These data suggest that density of grey seals is very low beyond 20km, and no tagged grey seal has ventured into the Luchterduinen area (Fig.7 and 8).

Exchange between the Delta and other areas

By the late 1980's the Delta region was practically devoid of seals. In 1987 approximately 20 animals were counted, and after the PDV epidemic of 1988 only 12 animals. No grey seals were reported. Parallel to the recovery from the disease in the Wadden Sea, numbers started to grow in the Delta. In 2011 moult counts yielded a maximum number of 266 harbour seals. Interestingly, this could not be a result of local reproduction as numbers born were too low. Moreover, several tens of animals (~30 harbour seals and 10 grey seals p/a, unpublished data) were found dead in the Delta area, indicating a relatively high mortality.

Therefore, the observed growth has to be the result of animals originating from other areas and hauling out in the Delta. It is however unclear what the origin of these animals is. Given the relatively large numbers of harbour seals in the Wadden Sea (~ 38 500 animals in 2012 in the entire international Wadden Sea (Galatius et al. 2012); about 25% of these are counted in the Dutch part), the Wadden Sea population is the most likely candidate. Many animals could have come from there, but seals from other colonies could have attributed as well. In the Wash and other English colonies, total number of harbour seals were estimated at 4000 animals (SCOS 2010), approximately 2800 reside in the Wash, which is ~ 275 km from the Delta. In France (Hassani et al. 2010), harbour seal numbers were growing in the same period attaining a total of almost 300 animals in 2008.

Most likely this process of exchange is not a result of an inherent migration cycle, but rather individual movement, 'discovering' the Delta area underway. Once the existence of the Delta sites is known to these individuals, they may occasionally perform more direct transits. This seems to be the case for the majority of animals presented in table 3 and 4 (i.e. relative short transit times and direct routes). The contrasting seasonal peaks in numbers in the Wadden Sea and Delta and the lack of exact correlation between the growth of the different areas and that of the Delta, seems to suggest that the majority of seals use the Delta as a central base from which forage trips are undertaken. More data is needed to understand why and when seals exchange between the Delta and other sites.

For grey seals, a similar process could explain the growth in the area, though here it is more likely that many animals come from the UK were the numbers heavily outweigh those in other areas like the Wadden Sea. In total, along the North Sea coast of the UK, pup production in 2009 was estimated at 7637 pups (SCOS 2010), whilst in the Dutch Wadden Sea only some 300 pups were observed. Recent tag data show that a large proportion of the grey seals tagged in spring in the Baie de Somme (Northern France) do actually transit to the Dutch waters, but also the UK North Sea coasts and back (unpublished data, Université de La Rochelle / CNRS, Parc naturel marin d'Iroise, Océanopolis, Picardie Nature, Région Bretagne, Région Poitou-Charentes).

Despite the fact that more than 100 seals were tagged, only few seals were recorded to actually show an exchange between the areas. This is probably due to the small probability of tagging animals actually undertaking this trip. For example in 2007 respectively 12 harbour seals and 6 grey seals were tagged in the Wadden Sea (0.2% and 0.3% of the population) whilst only one grey seal was actually being seen to go to the Delta area. Chances of tagging exactly those individuals that are going to the Delta area are extremely low. Despite this, there are some records of exchanges. When we exclude the captive bred animals, the *observed* exchange between the Delta and Wadden Sea in north- and southward direction was equal (i.e. four individuals, see table 3 and 4), even though more animals were tagged in the Wadden sea. This does not mean that there is a net absolute north-ward migration. In fact, the growth of the Delta population cannot be explained by local reproduction, and hence we expect a net south-ward migration. However, because the *proportion* of "exchanging individuals" is much higher in the Delta, the probability of tagging an "exchanging individual" is larger as well. This phenomenon is known as source-sink dynamics, where the Wadden Sea is the source population and the Delta is the sink population.

— Zooals bekend is, houden zich in het Brielsche zeegat, zoowel als in het Goereesche, altijd veel zeehonden op, hetgeen veroorzaakt wordt door de vele zandbanken aldaar. Want in den Rotterdamschen Waterweg, alzoo vlak in de nabijheid, vertoont zich zelden of nooit een zeehond.

In verband met het voordurend wisselen der zandbanken, haar tijdelijk aangroeien of afnemen, veranderen ook de hoofdverblijfplaatsen der zeehonden. Thans heeft zich in het Brielsche zeegat een ware kolonie gevestigd, en als men weet, dat een volwassen zeehond 5 K.G. visch noodig heeft voor zijn dagelijksch voedsel, kan men nagaan hoe moordend de aanwezigheid van zulk een

groot aantal dier beesten voor de visscher
is. Daartegen wordt thans zoo goed als nie
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den op geduchte wijze in aantal vermeerdere
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Wenschelijk zou het zijn, zegt een berich
gever in het „N. v. d. D.", dat ook van hoog
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premie op een gedooden zeehond — maa
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krachtig te bestrijden.

Figure 10 Article from "Texelse Courant" of 3-11-1898

The ecological role of the Dutch coastal zone

During the boat survey in January 2013, 852 harbour seals were estimated to be present along the Dutch West coast within 3km from shore. Telemetry data (collected between 1997 and 2008) show that harbour seals are also present further offshore. Although some observed seals may come from individuals transiting between the Wadden Sea and the Delta, most individuals are expected to forage in this period and region. This is also reflected in the individual tracking data. From a total of 29 individuals using the coastal zone, 7 (3 of which were captive bred animals) actually crossed-over between the Wadden Sea and Delta, with an average duration of ~2 days (see Table 3 and 4).
It is currently unclear which ecological processes attract grey and harbour seals to this region. Particularly, the large increase in harbour seals in the coastal area in 2009 and 2010 (Leopold et al, in prep.). During the grebe survey in Dec. 2012 and Jan. 2013, large quantities of pelagic fish were observed on the fish echo-sounder. During two mid-water beam trawls in December, the most caught species where gobies (*Pomatoschistus spec.*), dab (*Limanda limanda*), a sprat (*Sprattus sprattus*), whiting (*Merlangius merlangus*), juvenile cod (*Gadus morhua*), hooknose (*Agonus cataphractus*) and European smelt (*Osmerus eperlanus*). During the January 2013 survey the catch consisted mostly of sprat and herring. The stomach of a single fresh harbour seal which was found dead nearby ('Schoorl aan Zee') on January 24, contained two sprat and 2 herring otoliths. Despite the fact that seals are known to forage benthically, the relatively shallow coastal waters and large wintering clupeid stocks could permit them to access the more pelagic sprat and herring.
The large count in January, as well as the extreme land-based counts during the winter months occurred when the temperature was below 0 ºC. The ship-based survey observed the highest density of seals just south of a cold water front generated by outgoing colder water from the Wadden Sea. This phenomenon could explain the aggregation of prey and predator.

Studied effects of off shore wind farms – a review

Despite the intention to implement offshore wind farming at a relatively large scale throughout the (western) world, only few studies have been carried out to study the possible effects on marine life. In only four occasions in Europe, seals were monitored in relation to the construction of wind farms at sea. These include two wind farms in Denmark (Horns Rev and Nysted), one in England (Scoby Sands) and one in the Netherlands (OWEZ). The most elaborate studies concentrated on the number of seals on land. Results show that on a relative short term of 2 years after construction, the numbers of harbour seals remained low near Scoby sands (Skeate et al. 2012), while the observed numbers at Nysted recovered (Edrén et al. 2010). However, these results could be confounded by the general recovery of the harbour seal population after the virus epidemic in 2002 (Härkönen et al. 2006).
It is expected that underwater noise resulting from pile driving during the construction of the wind farm will have the most effect (Edrén et al. 2004, 2010, Tougaard et al. 2009, Brasseur et al. 2010, Bailey et al. 2010, Skeate et al. 2012). Most effort is put in understanding the thresholds of hearing and hearing damage (Kastak et al. 2005, Tougaard et al. 2009, Bailey et al. 2010, Kastelein et al. 2011). Modelling results are variable depending on the methods used. In particular, considerable discussion exists on frequency dependent sound weighing and how to incorporate the duration of sound exposure (Southall et al. 2007, De Jong and Ainslie 2008). For the Moray Firth (Scotland), Bailey et al. (2010) suggests that permanent and temporal hearing damage will only occur within respectively 20 and 40m. This however, was an estimate for a single blow. Southall et al. (2007) suggest that the cumulative exposure to multiple pulse sounds during a longer period may lead to temporal or even permanent threshold shifts at much larger distances. However, these estimates were based on the summation of single peak pressure levels, and do not account for possible (inter-pulse) recovery (Kastelein et al. 2012). For moving animals, it is therefore difficult to estimate the exact distance at which hearing damage would occur.

In contrast, the audibility range for pile driving would lie much further: Up to approximately 70 km, the sound can be detectable above background noise (i.e. measured with all engines switched off and during Beaufort sea state 3 or less, Bailey et al. 2010). For wind turbines in operation audibility for harbour seals ranged from less than 100 m to several kilometres (Tougaard et al. 2009), but these estimates are site specific and also dependent on the level of background noise. At these distances, however, animals should be aware of the activities and might change their behaviour accordingly. Although traditionally most research has focused on the estimation of the effect of sound on PTS and TTS levels, recently more emphasis is put on studying the short and long-term effect of sound on behaviour (Art Popper, pers. Comm.). Partly, because behavioural responses may be induced by lower SEL levels, and consequently may impact more individuals at an increasing rate. For example, Götz and Janik (2011) show that repeated sound exposure and subsequent elicitation of the acoustic startle reflex leads to sensitisation (rather than habitation) in subsequent avoidance behaviour, and hence they show that it induces long-term fear conditioning.

One would expect the studies including tagged animals to show this. However, none of the studies above provided conclusive evidence for effects. In studies in Denmark and the Netherlands (Dietz et al. 2003, Brasseur et al. 2010, 2012a) significant effects were neither detected, nor unambiguously proven. This could be a sign of no effect (Lindeboom et al. 2011), or it could be the result of limited sampling size (i.e. number of animals tagged) during the construction period (Brasseur et al. 2012a), or lack of spatiotemporal accuracy of the transmitters (Teilmann et al. 2006). Moreover the understanding of the mechanisms that might be set off by the noise or disturbance in general, causing a longer term effect is limited, especially in the light of the large individual variation.

Monitoring of seals, in relation to the building and operation of an extra wind farm in the Dutch coastal area is planned. Currently, the accuracy of the telemetry data has ameliorated markedly (i.e. locations every 5-15 min, location error <20 m and continuous data on diving behaviour). Furthermore, the aberrant behaviour resulting from anthropogenic noise may only be detectable, under certain natural conditions (e.g. when other environmental conditions, such as absolute food availability, are less stringent - Aarts et al. 2013). Ultimately, more insight is required in how and why seals use the Dutch West coast, how they react to offshore operations, and how this may influence the foraging behaviour and exchange between regions in the short and long term. In particular, simultaneous estimates or measurements of received sound levels resulting from pile driving and behavioural measurements by the improved data loggers, may allow us to estimate the short and long term consequences of these activities.

A short review of the current monitoring plan

The current proposed monitoring plan to investigate the spatiotemporal use of the Dutch West coast (and in particular the Luchterduinen area) by both grey seal and harbour seal is provided in table 6 .

Table 6. Overview monitoring plan. PV=Harbour seal, HG = Grey seal.

Phase	**Period**	**PV**	**HG**	**Ntotal**	**N catch days**	
T0	March	12 (6 W'Sea, 6 Delta)	12 (6 W'Sea, 6 Delta)	24	4	
Tconstr	March	20 (10 W'Sea, 10 Delta)	20 (10 W'Sea, 10 Delta)	40	6	
T1	March	12 (6 W'Sea, 6 Delta)	12 (6 W'Sea, 6 Delta)	24	4	
T2	March	*12* (6 W'Sea, 6 Delta)	*12* (6 W'Sea, 6 Delta)	*24*	*4*	*after evaluation*
T3	March	*12* (6 W'Sea, 6 Delta)	*12* (6 W'Sea, 6 Delta)	*24*	*4*	*after evaluation*
		68	68	136	20 or 22	

On March 12 (2013), transmitters were deployed on 5 grey seals and one harbour seal caught near the Steenplaat and on March 13 (2013) the remaining transmitters were deployed on 5 harbour seals and 1 grey seal caught near the same location. In the Delta, transmitters were deployed on March 19 on 6 harbour seals ("Renesse") and on March 21 on 6 grey seals ("Aardappelbol"). To date (27-3-2013), one grey seal was observed to transit from Texel to the Delta and continued to the United Kingdom. One grey seal caught in the Delta travelled towards the Delta.

Grey seals moult in March and April, and the current tagging scheme should result in a near year-round coverage for this species. Grey seal numbers observed from the land-based sea-watching sites are highest in July and August, and this species will be the most likely candidate to measure short-term effects of pile-driving on their behaviour, if the study will be accompanied by measurements or estimates of received sound levels.

However, harbour seals finish their moult in August. Consequently probably no data will be available from August onwards. This report shows that harbour seals are most abundant near the coast in the winter months from November to March (Fig. 6b). Harbour seal activities from September onwards, including the high densities, such as observed during the ship-based surveys in Dec. 2012 and Jan. 2013, will not be recorded.

7. Conclusion

As seal populations grow in the southern North Sea, this report shows that the density of seals along the Dutch West coast has increased exponentially in recent years, and individuals venture far away from their known haul-outs. There are clear differences between the behaviour of the grey seals and harbour seals which can partially be explained by their biological cycle. Harbour seals give birth and moult in summer, and feed more intensively in late autumn and winter. Grey seals should show an almost mirror image as in the Netherlands they breed in winter and moult in spring. However, the seasonal pattern for this species is less distinct.

In the past, the Delta area has been quite important, at least for harbour seals in Dutch waters (Reijnders 1994; and see also Fig. 10 for some historic anecdotal evidence). Currently the number of grey and harbour seals observed in the Delta are relative small, and it is clear that nowadays neither harbour nor grey seals found there form a separate viable population, and numbers are dependent on the influx from elsewhere. This hypothesis is supported by the low number of births and the apparent high mortality.

This study shows that at least periodically, a relative large proportion (~10% of the Dutch Wadden Sea) of the harbour seal population is present along the Dutch West coast, demonstrating that this area has an intrinsic value as foraging area. This was also determined and modelled based on the diving behaviour and environmental factors by Brasseur et al. (2012a). The current study also shows that at least some individuals, particularly harbour seals, travel between the Wadden Sea and Delta, contributing to the observed net growth in the Delta. However, so far no dedicated seal tracking study has looked at the effect of pile-driving for the construction of offshore wind farms on the short and long term population dynamics of the Delta and feeding behaviour near the Dutch West coast.

8. Acknowledgements

Seal tagging was carried out by a large number of people, specifically Piet-Wim van Leeuwen, Andre Meijboom, Hans Verdaat and the crew of the "Wadden Unit" ships of the ministry of Economic affairs. Sea-watches were conducted by hundreds of volunteers, often organised in local bird clubs. The grebe surveys were conducted by Steve Geelhoed, Rob van Bemmelen, Mardik Leopold, Hans Verdaat, Jenny Cremer, and Elisa Bravo Rebolledo, and the crew of the MV Navicula (Bram Fey, Ewout Adriaans, Hein de Vries and Klaas Jan Daalder). Erica Koning assisted with the logistics and Bram Couperus advised on the use of the echo-sounder and fish sampling. Much of the aerial survey data in the Wadden Sea has been collected thanks to our pilot Aad Droog and recorded in an intelligible database by Jenny Cremer and Elze Dijkman. Finally we thank Peter Reijnders, Jakob Asjes, Roger Kirkwood, Suzanne Lubbe, Martine Graafland and Joop Bakker for their constructive comments.

9. Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2013 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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Justification

Rapportnumber: C103/13
Project Number: 4306121301

The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of IMARES.

Approved: Peter Reijnders
Hoogleraar

Signature:

Date: 25-2-2013

Approved: Jakob Asjes
Hoofd afdeling Ecosystemen

Signature:

Date: 18 juni 2013

10. Appendix A. Seasonal and annual variation in Sea-watching effort.

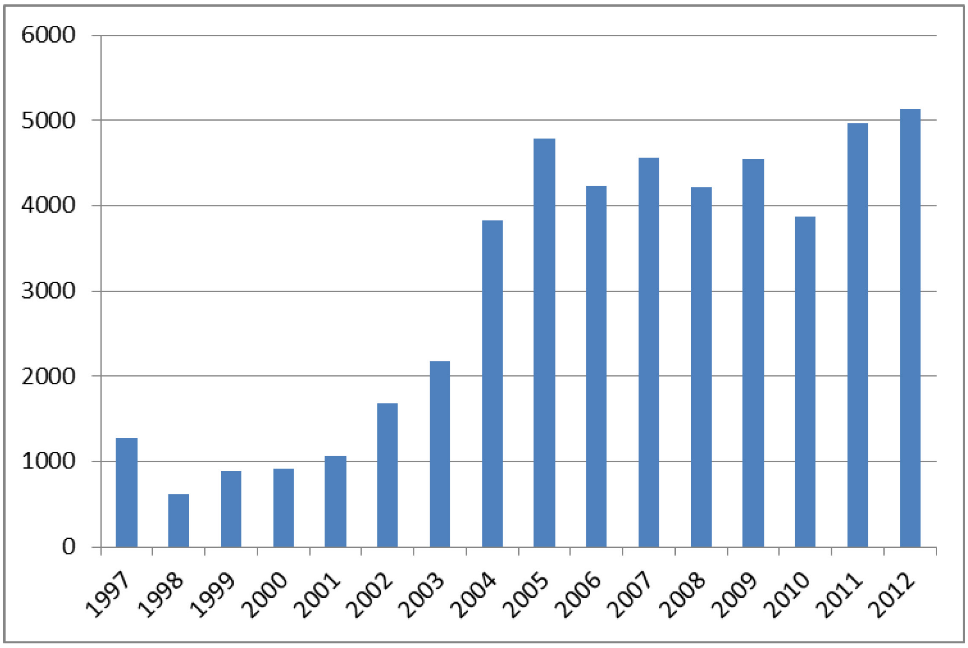


Figure A1. Observation effort sea-watches per year, 1997-2012 in hours (n = 48742).

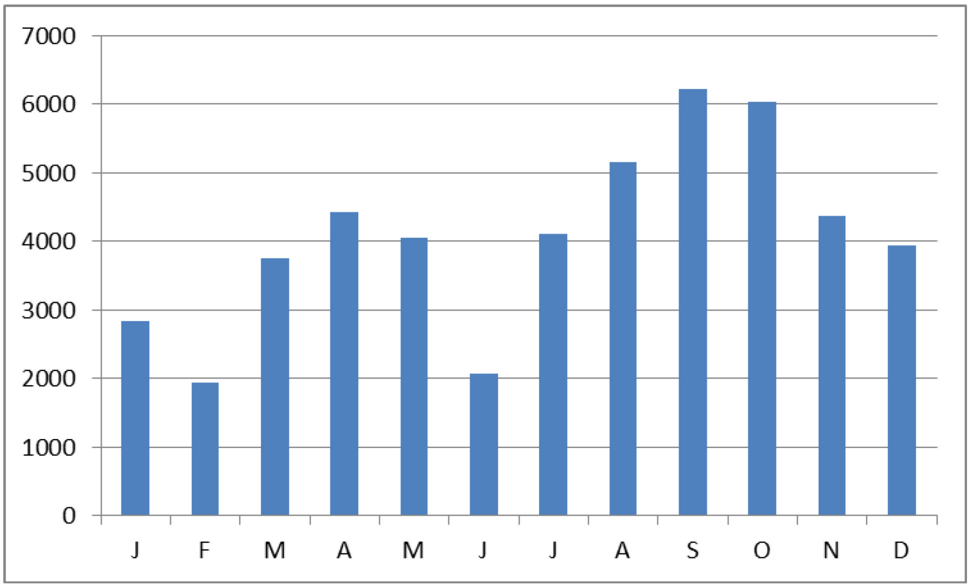


Figure A2. Seasonal distribution observation effort sea-watches, 1997-2012 in hours (n = 48742).

Table A1. Yearly distribution of observation effort by location, 1997-2012 in hours.

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Westkapelle	105	41	10	29	156	280	459	628	500	272	375	325	137	252	353	204
Langevelderslag (zeetrek)	0	0	0	0	0	303	276	456	358	214	79	56	10	0	0	0
Huisduinen (zeetrek)	0	0	0	0	0	0	158	1044	1017	1064	1068	904	803	647	794	796
Scheveningen	14	14	0	0	3	24	0	474	1024	886	961	926	554	458	572	387
Noordwijk	74	90	60	50	76	154	210	218	494	453	459	425	475	415	408	478
Katwijk - Savoy (zeetrek)	17	10	101	14	12	24	100	134	190	204	245	181	223	238	389	326
Terschelling, Paal 18	20	14	10	22	3	1	0	10	36	35	81	53	71	41	80	86
Maasmond (Maasvlakte)	0	0	74	90	0	0	36	75	79	94	108	106	119	79	75	45
Egmond aan Zee	39	24	16	4	26	38	24	13	180	232	228	261	389	270	299	393
Ameland, Nes (zeetrek)	0	0	0	0	0	0	0	0	68	78	134	57	48	31	33	36
Bloemendaal aan Zee	90	108	182	260	282	261	262	238	254	74	199	132	72	112	212	198
Vlieland - Pad van Zes	0	0	0	0	0	0	0	0	8	2	1	39	30	26	40	28
Vuurtoren Ouddorp	0	0	0	0	0	0	0	0	14	15	29	96	48	42	114	77
De Bloedberg (zeetrek), Monster	0	0	0	0	0	0	4	9	13	14	25	48	39	22	12	10
Camperduin	916	316	432	441	512	594	640	531	539	569	538	564	702	577	676	697
Westerslag, Texel	0	0	0	0	0	0	0	0	0	19	22	36	27	11	30	6
Castricum aan Zee (zeetrek)	0	0	0	0	0	0	0	0	0	1	4	13	24	39	158	190
de Marlijn - Schiermonnikoog	0	0	0	0	0	0	0	0	9	0	0	0	11	13	12	10
Pettemer Zeewering	0	0	2	6	0	0	0	0	0	0	0	0	758	606	566	765
Nieuw-Haamstede (zeetrek)	0	0	0	0	0	0	0	0	0	0	2	0	0	0	39	12
Vlieland - Noordzeekust Dam 30	0	0	0	0	0	0	0	0	4	2	2	0	0	0	6	8
Neeltje Jans	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0
Texel, Hoornderslag-Paal 9 (zeetrek)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	82	380

11. APPENDIX B. Distance sampling results

Table B1. Model selection of detection curve. The term "sea state cat." indicates that the detection curve parameter varies as function of sea state category A (0-2 Bft.) and B (3-5 Bft.).

Model	n. par.	Delta AIC	AIC	ESW	D*	D CV†
Half-Normal	1	0.7749634	1015.371	275.1431	855.2907	6.357501E-02
Half-Normal sea state cat.	**2**	**0**	**1014.596**	**274.1783**	**890.0473**	**2.776341E-02**
Hazard rate sea state cat.	3	5.026978	1019.623	274.2616	859.3077	2.737748E-02
Hazard rate	2	3.020996	1017.617	272.2923	865.0812	0.0873796

* D = Deviance

† D CV = Deviance Cross validation

Table B2. Parameter estimates of half normal detection curve which varies by sea state category (cat. A = 0-2 bft., and B = 3-5 bft.).

```
Effort        :    1.000000
# samples     :    1
Width         :    300.0000
Left          :    0.0000000
# observations:    370

Model
   Half-normal key, k(y) = Exp(-y**2/(2*s**2))

   y = Distance to observer
   s = A(1) * Exp(fcn(A(2)))
   Parameter A(1) is the intercept of the scale parameter s.
   Parameter A(2) is the coefficient of level HIGH of factor covariate SSCAT.


             Point        Standard    Percent Coef.        95 Percent
 Parameter   Estimate       Error      of Variation     Confidence Interval
 ---------  -----------  -----------  --------------  ----------------------
   A( 1)      515.3        47.21
   A( 2)     -1.043       0.6219
   f(0)     0.36473E-02  0.61330E-04       1.68      0.35286E-02  0.37699E-02
   p        0.91393      0.15368E-01       1.68      0.88420      0.94465
```

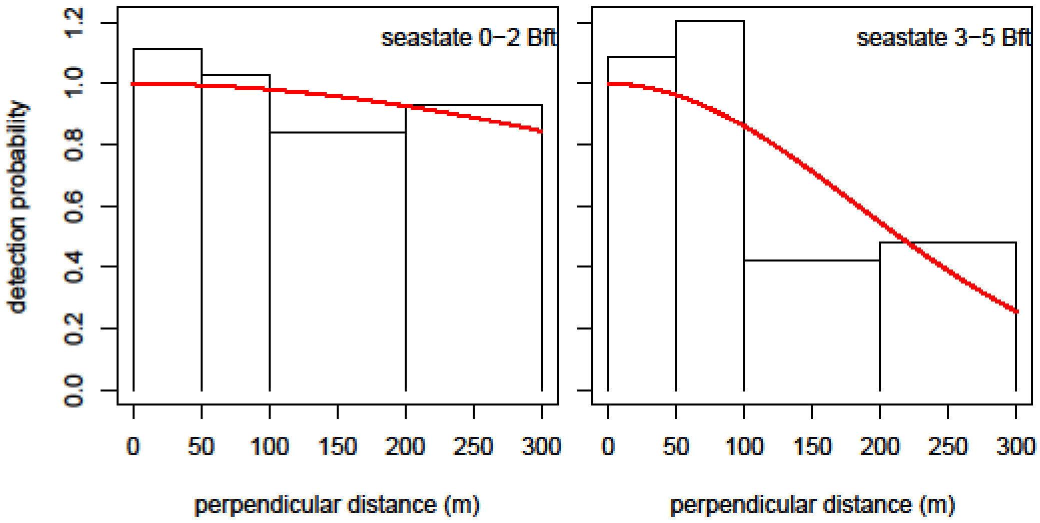


Figure B3. Half normal detection curve for sea state 0-2Bft and 3-5 Bft

12. APPENDIX C Coastal sightings Huisduinen

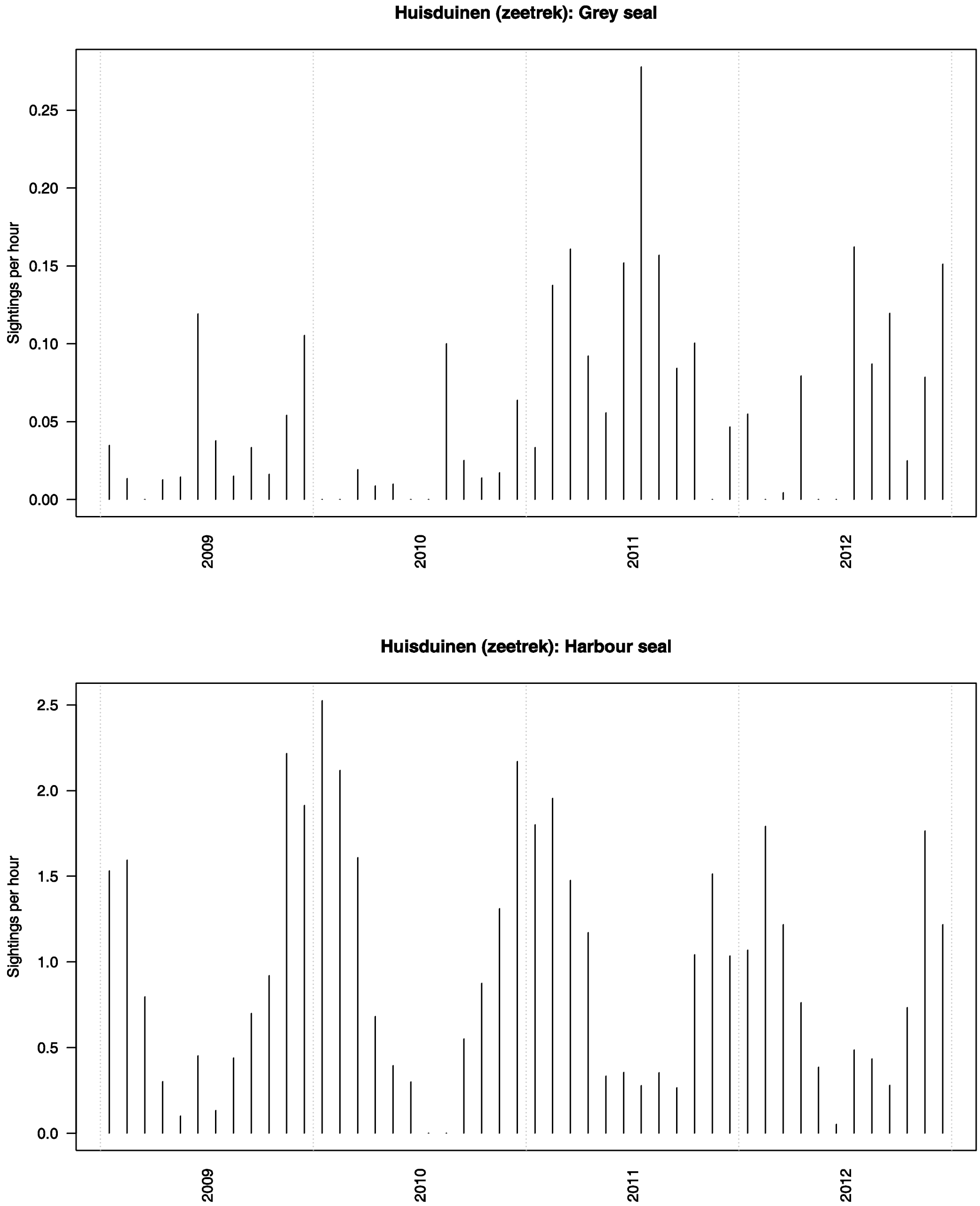
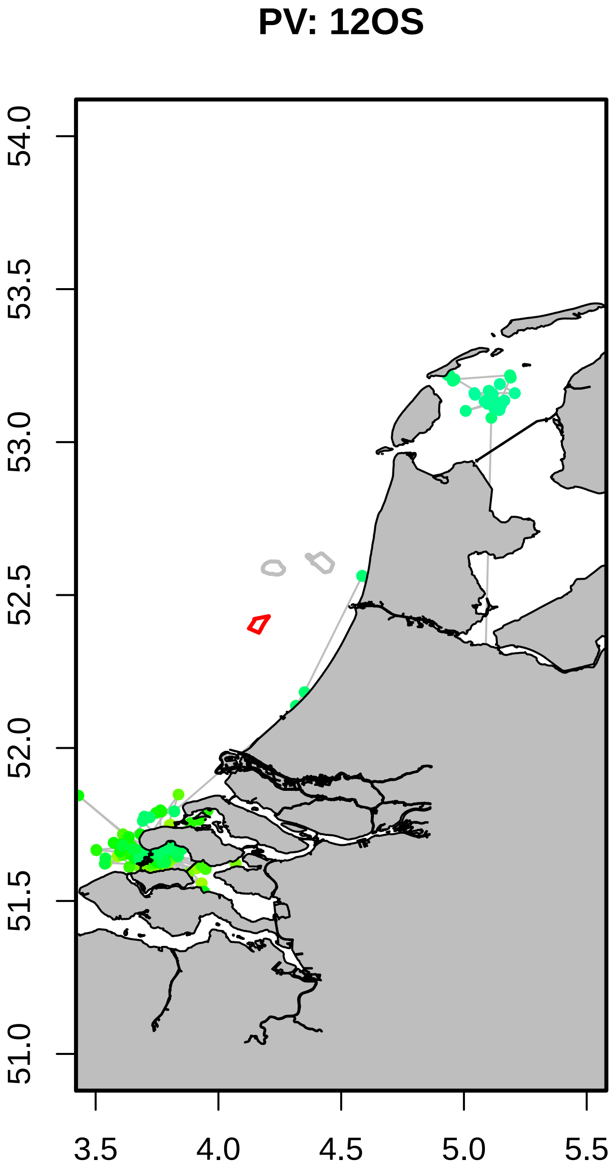
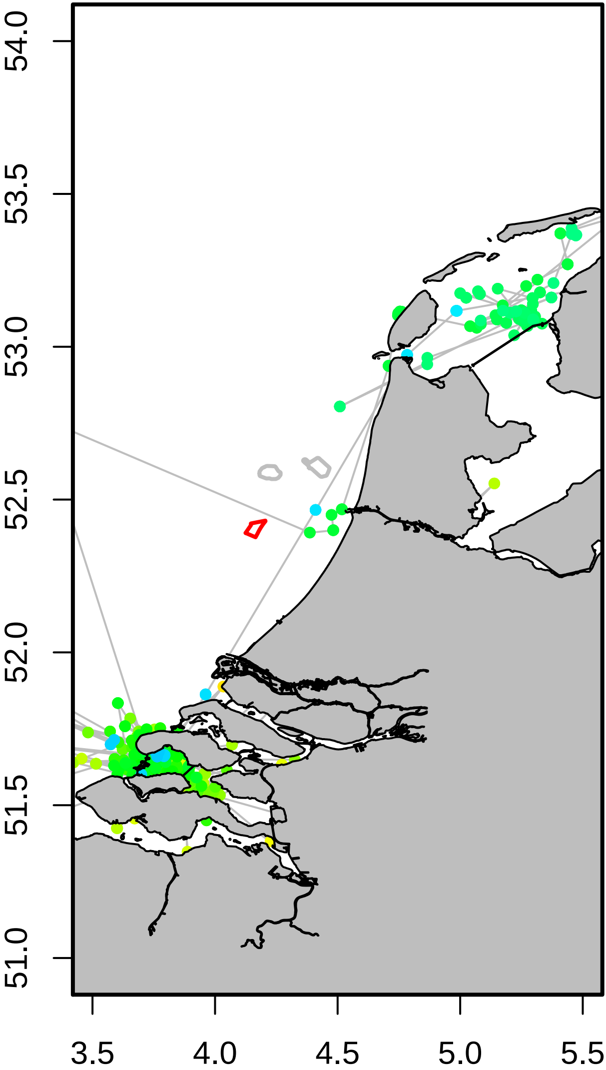


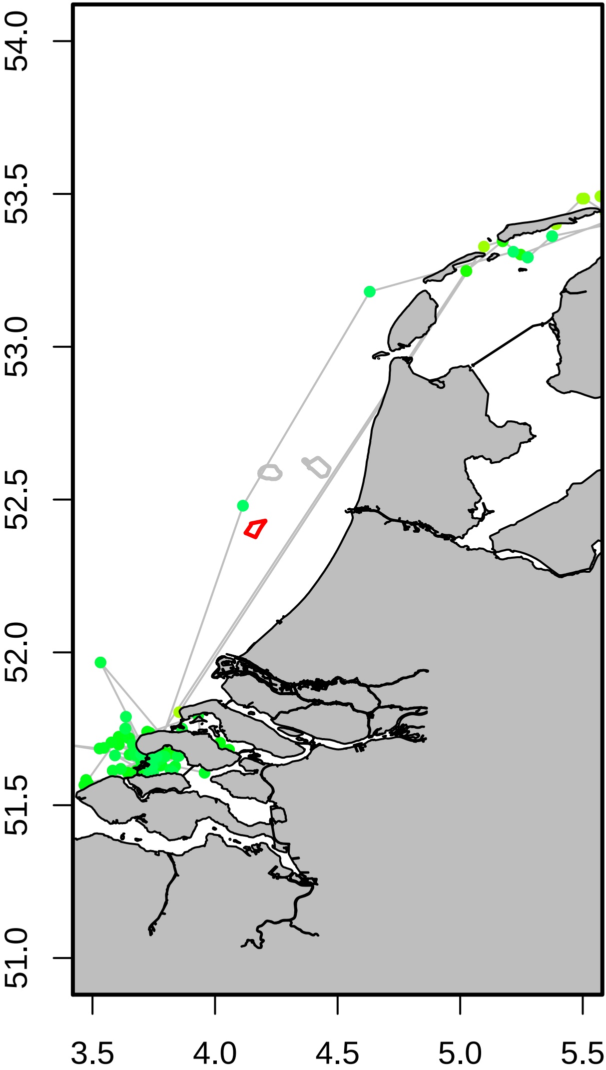
Figure C1. Coastal sightings of harbour seals (a) and grey seals (b) from 2009 – 2012 from Huisduinen.


PV: 12OS
54.0
53.5
53.0
52.5
52.0
51.5
51.0
3.5
4.0
4.5
5.0
5.5

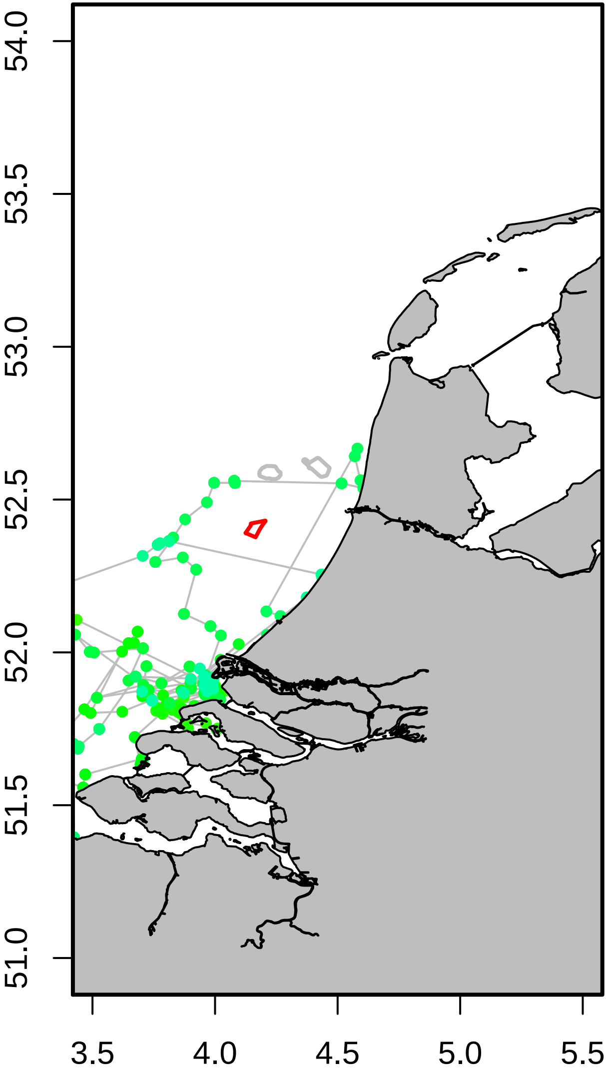
PV: 15OS

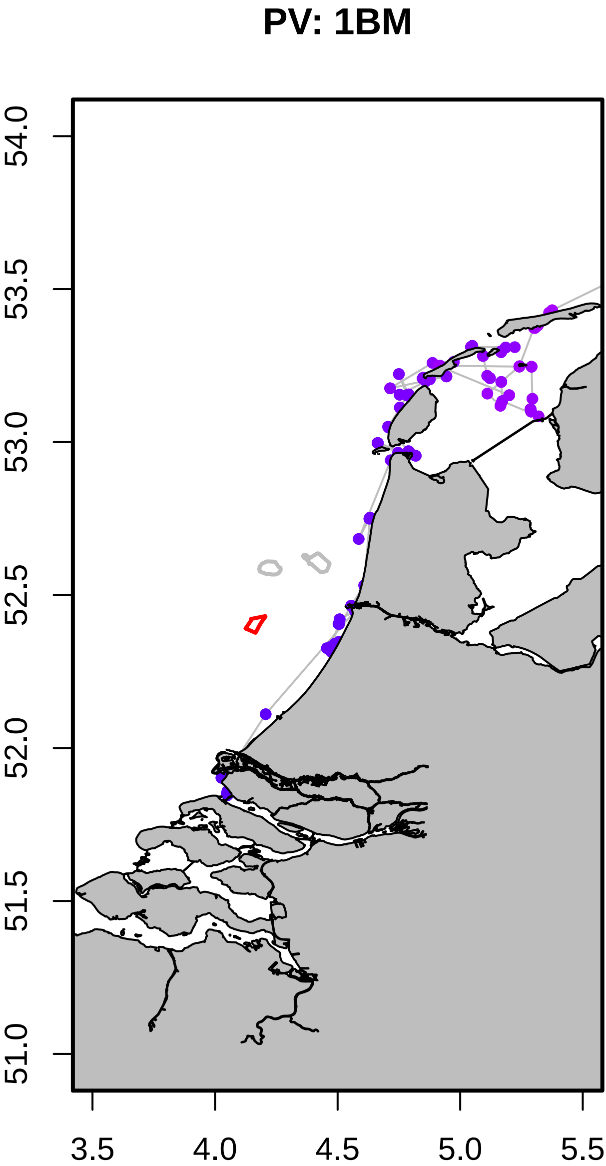


PV: 19OS

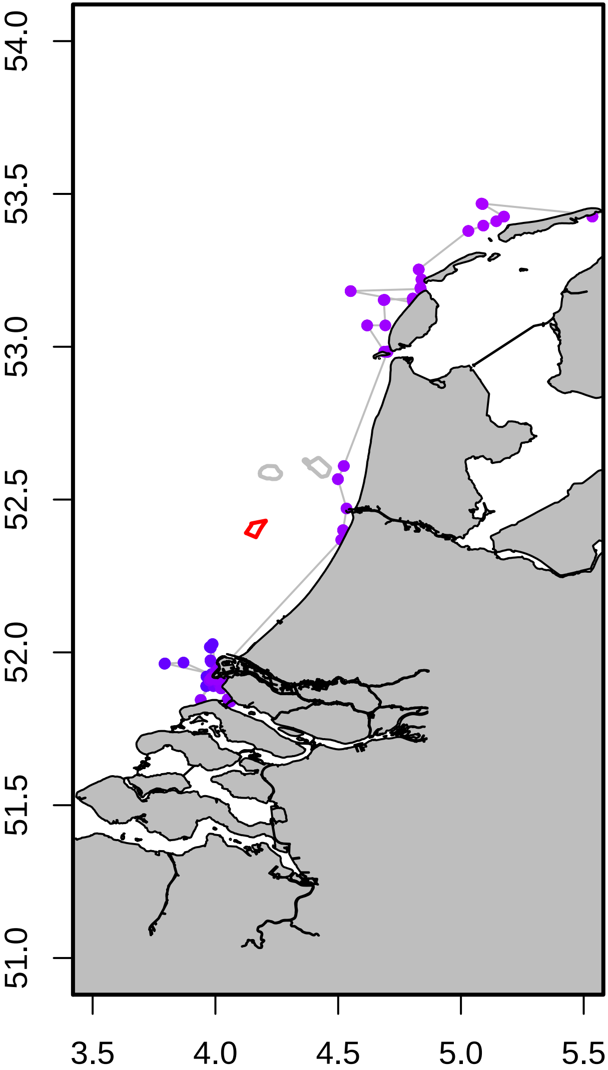


PV: 1B3

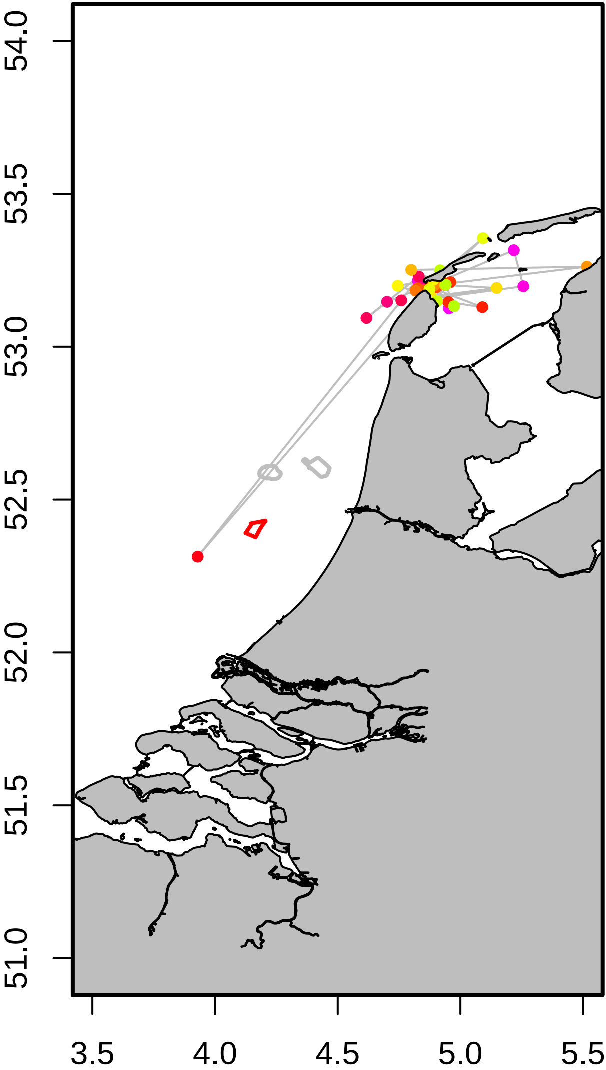



PV: 1BM
54.0
53.5
53.0
52.5
52.0
51.5
51.0
3.5
4.0
4.5
5.0
5.5

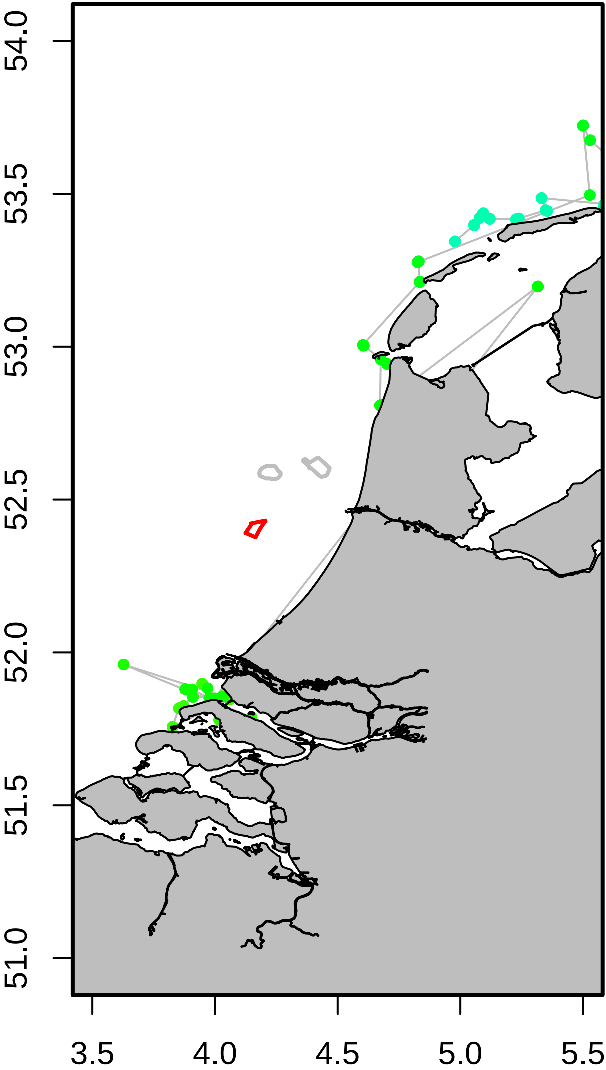
PV: 2BM



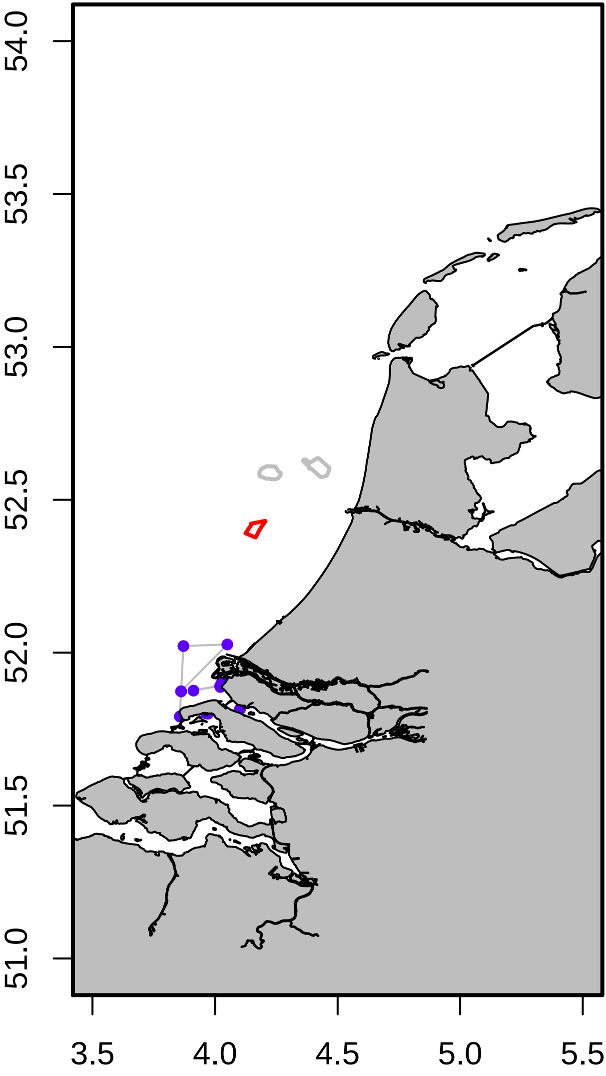
PV: 37



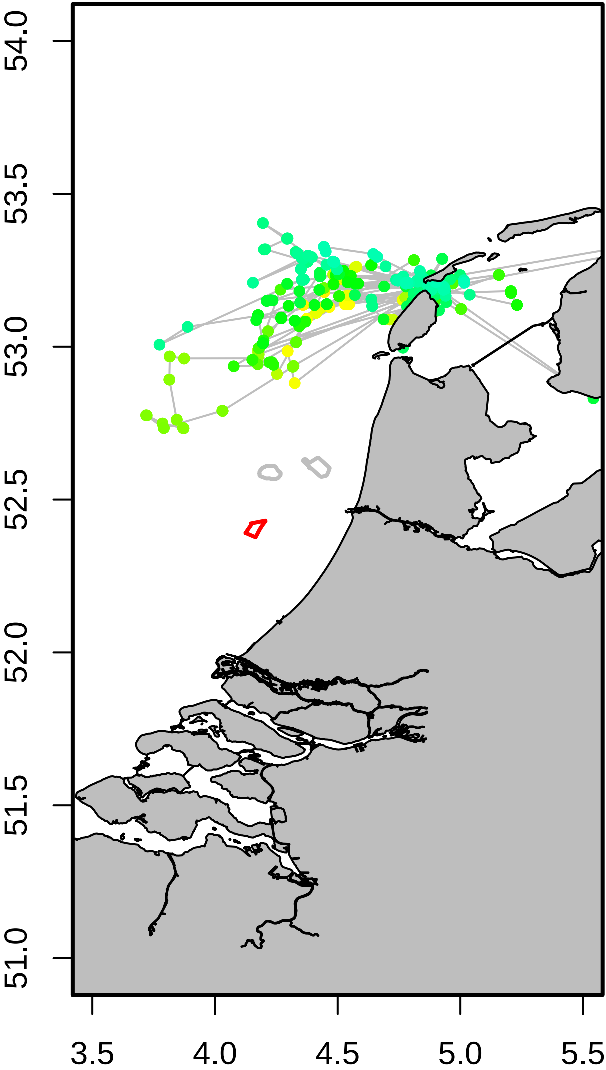
PV: 3B3

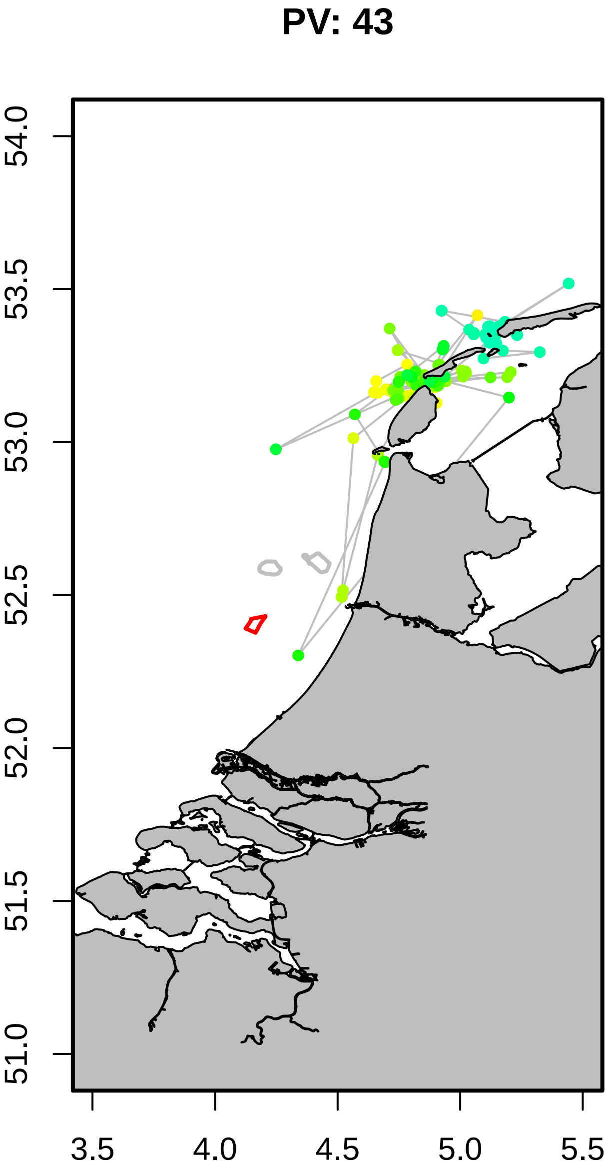


PV: 3BF

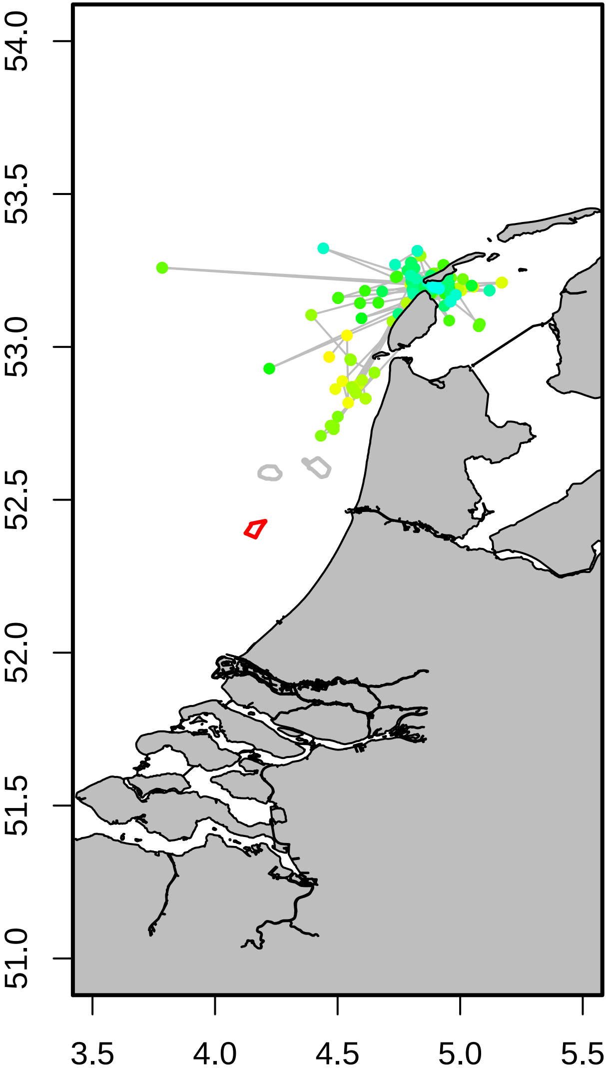


PV: 42

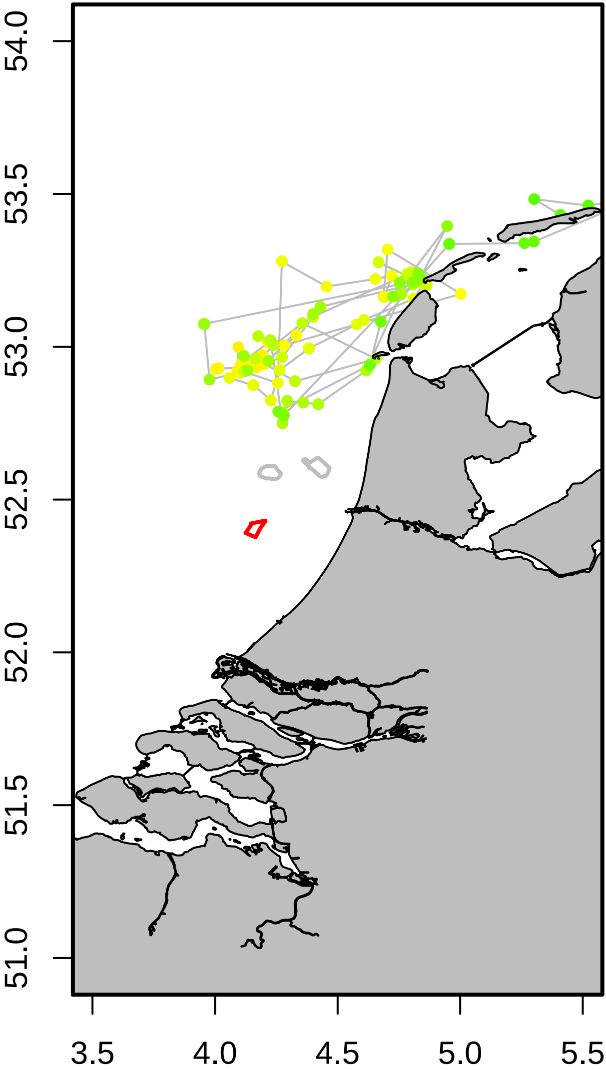



PV: 43
54.0
53.5
53.0
52.5
52.0
51.5
51.0
3.5
4.0
4.5
5.0
5.5

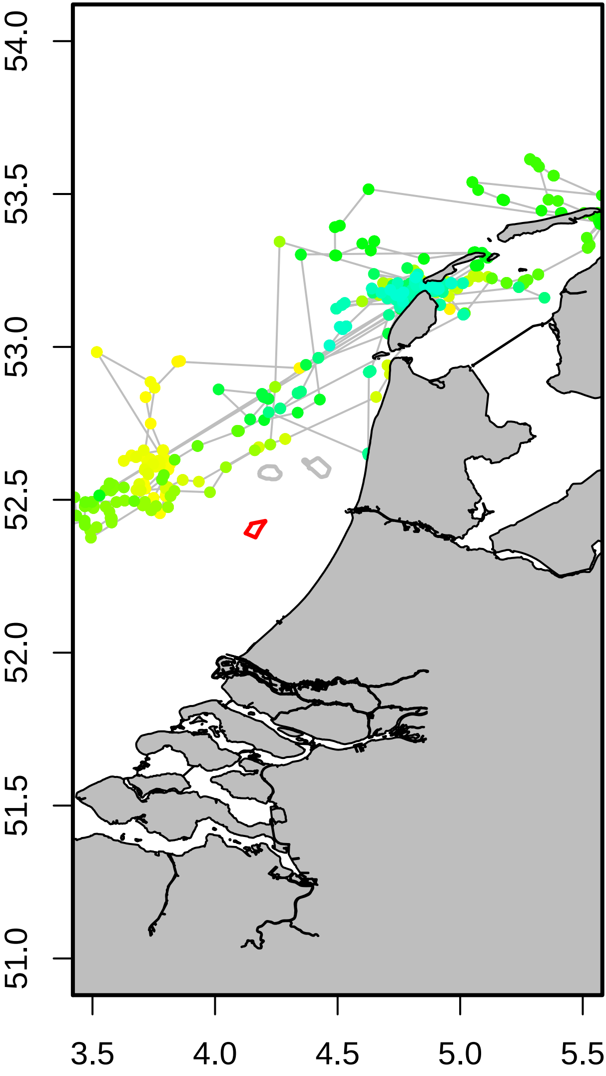
PV: 44



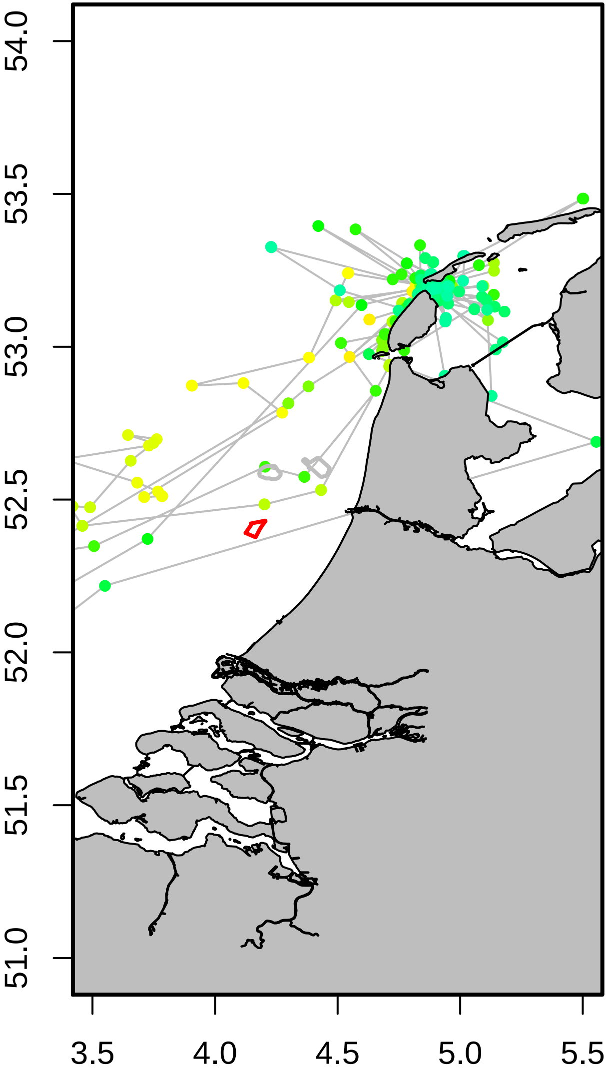
PV: 45



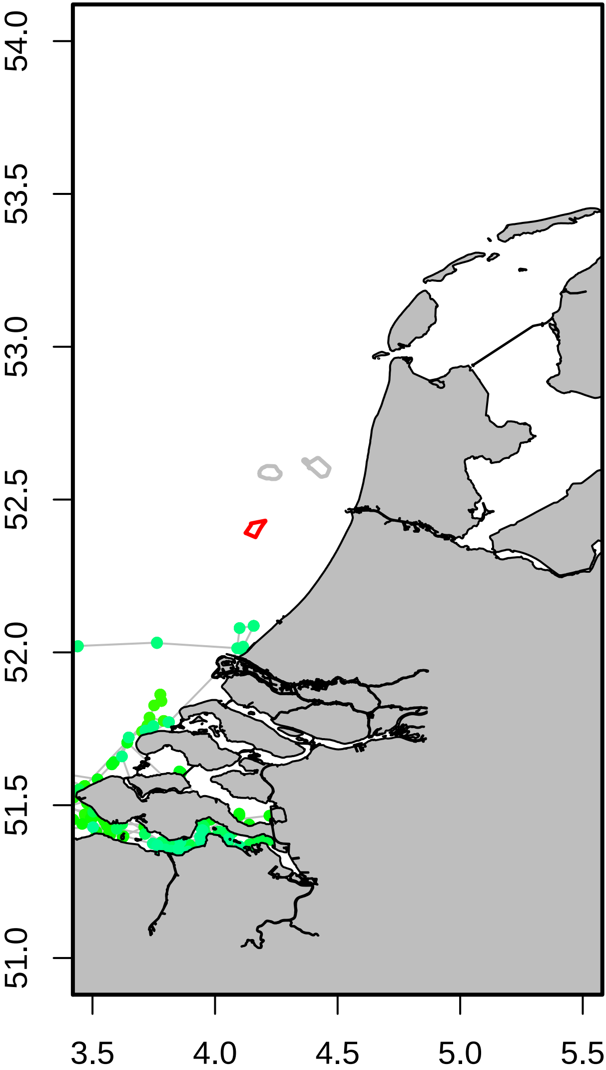
PV: 46



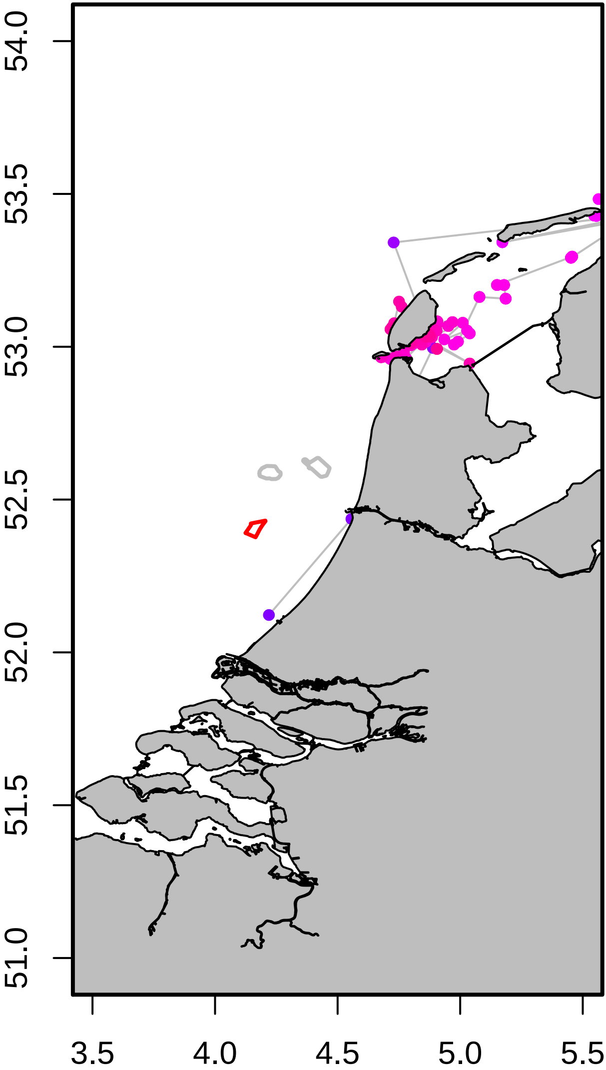
PV: 47



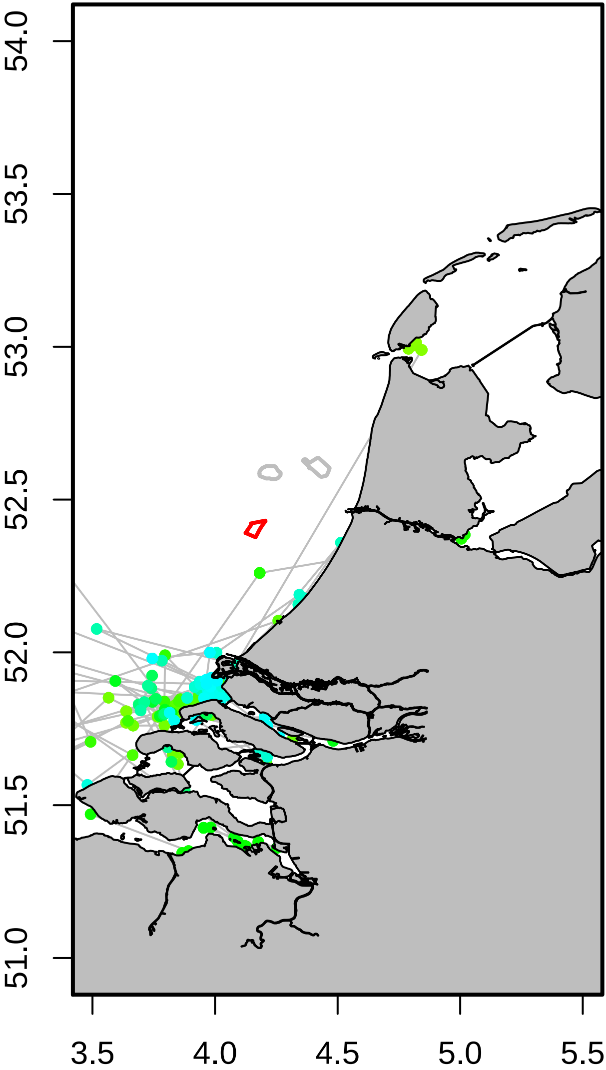
PV: 4B3



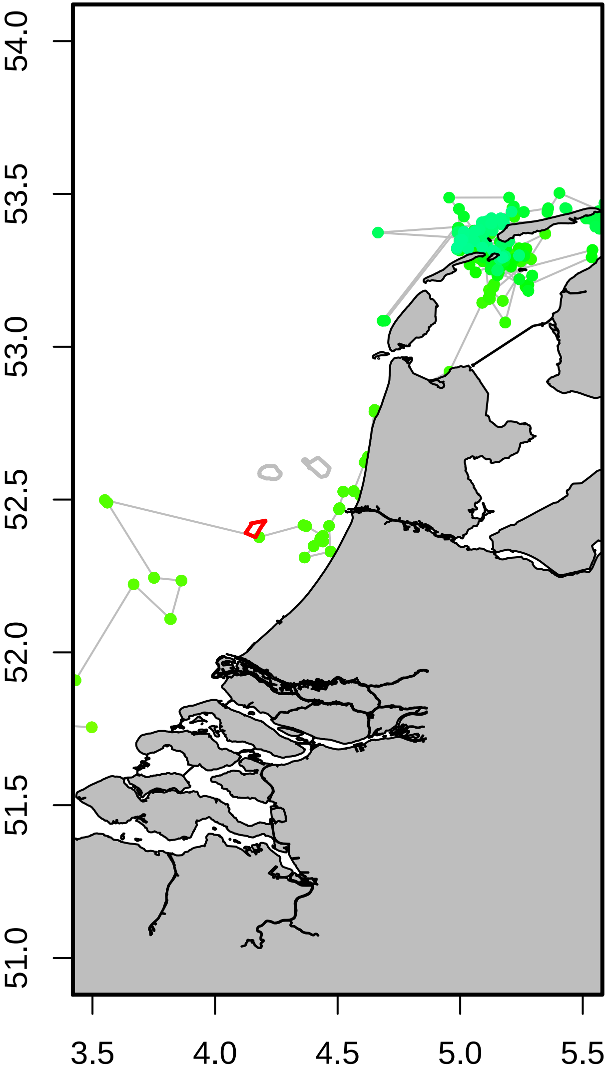
PV: 4BF

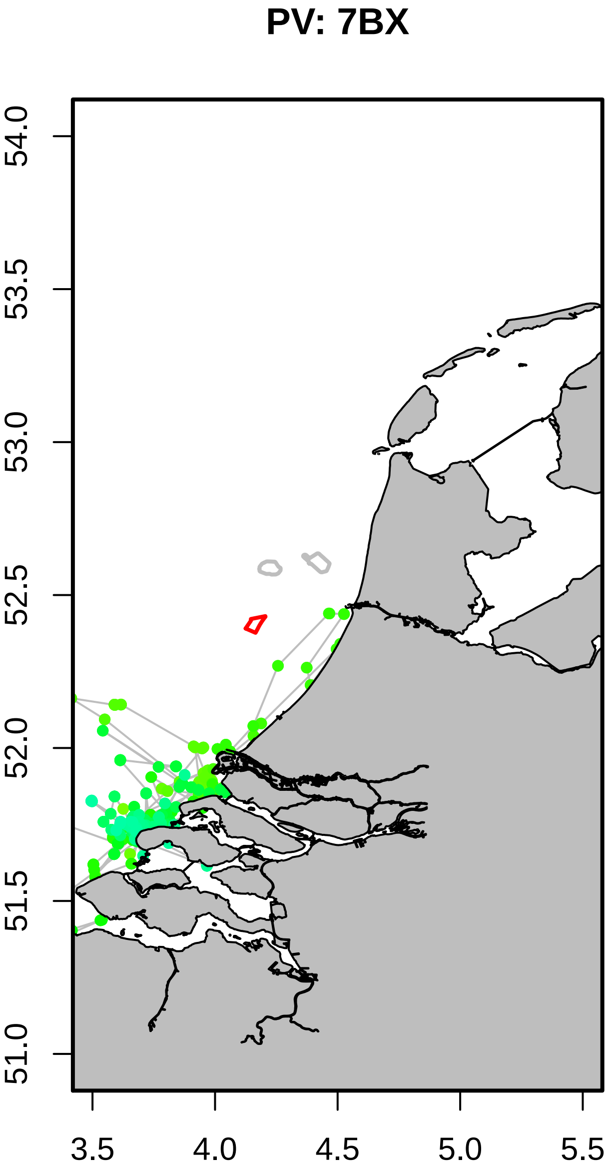


PV: 5BX

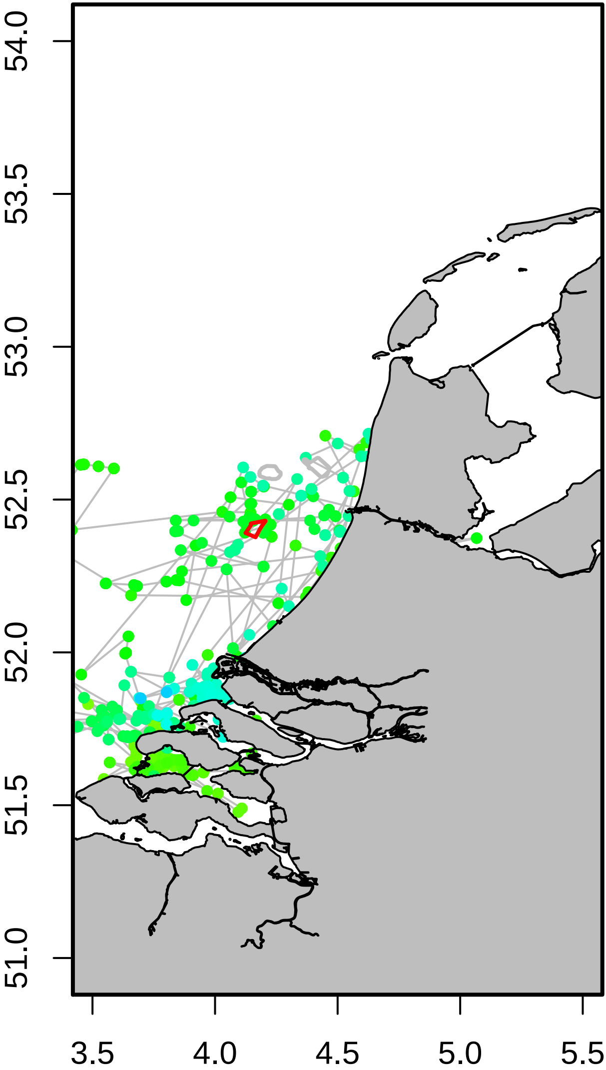


PV: 6BX

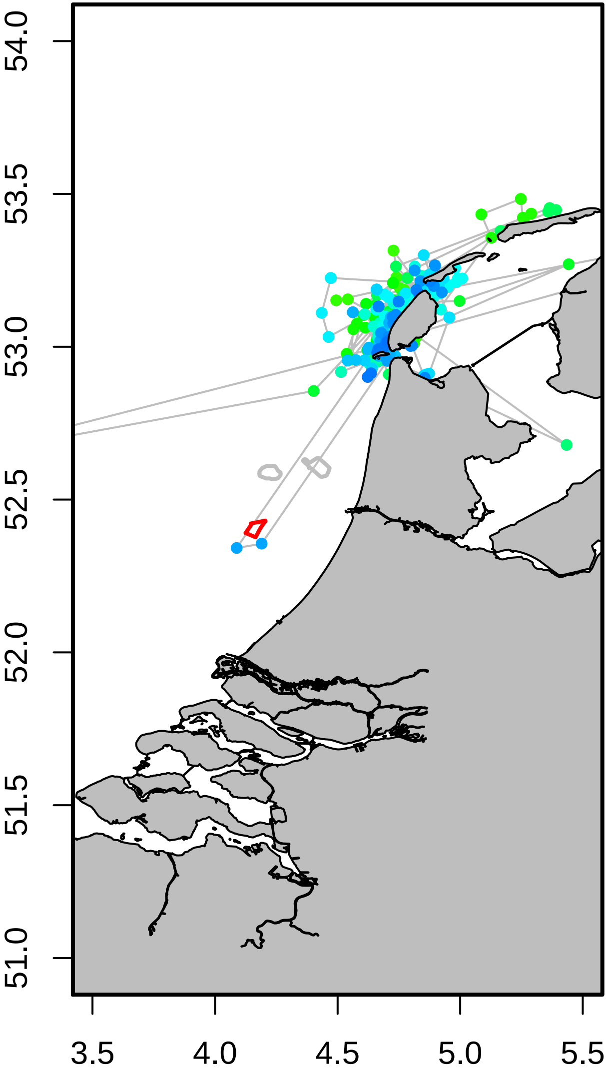



PV: 7BX
54.0
53.5
53.0
52.5
52.0
51.5
51.0
3.5
4.0
4.5
5.0
5.5

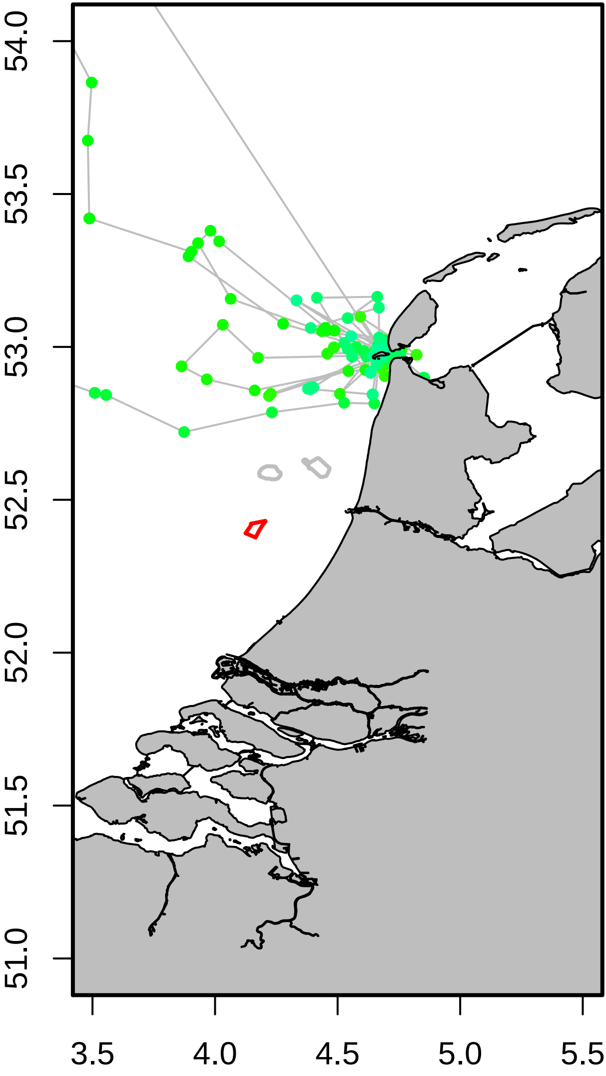
PV: 8BX



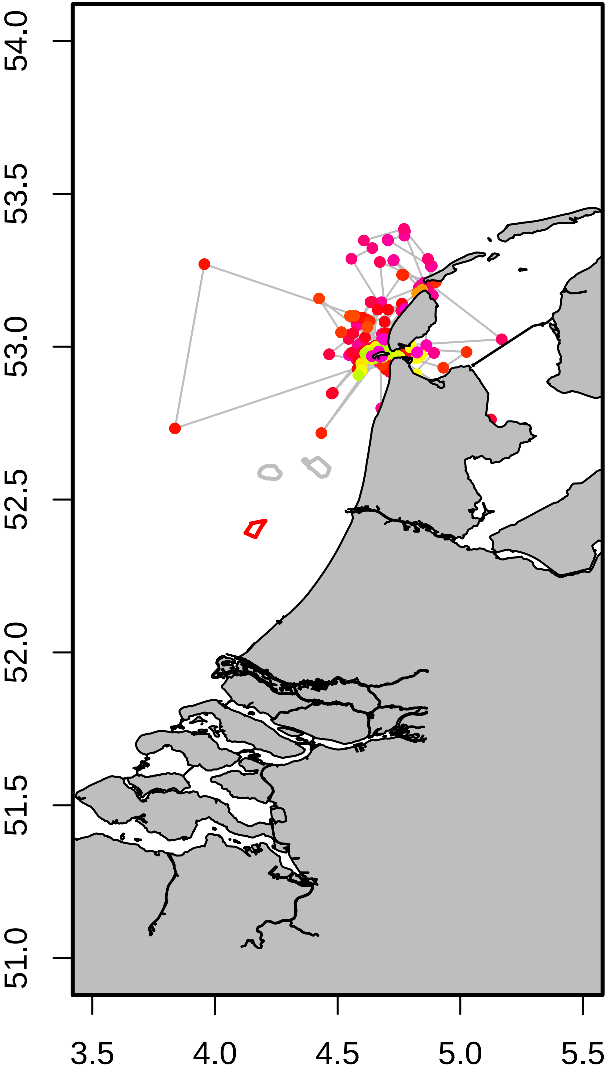
HG: hg10_12145_05

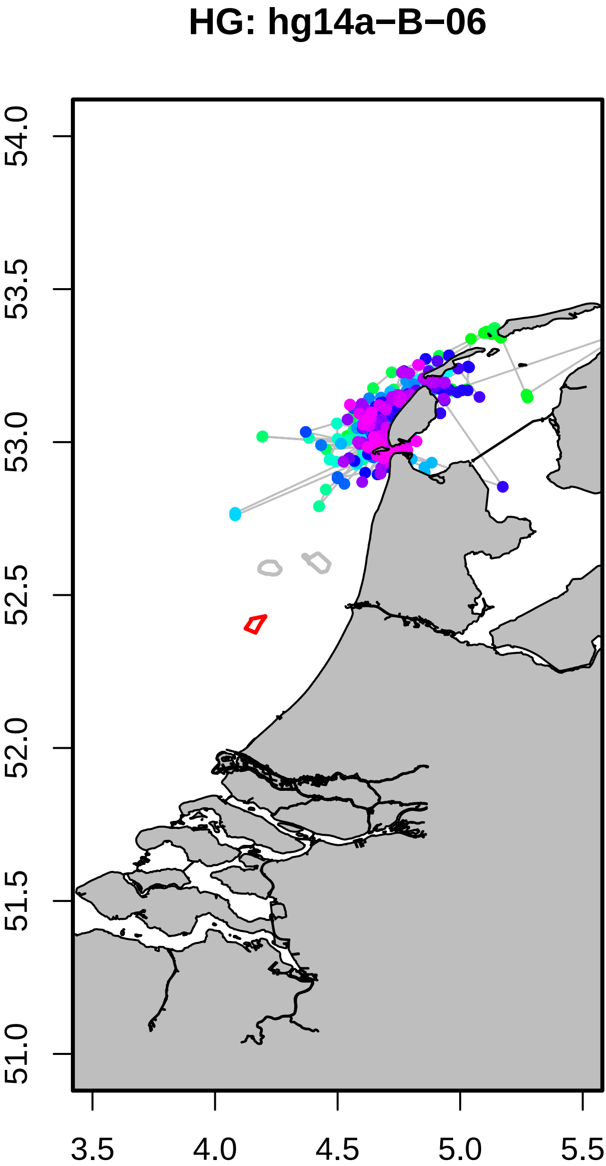


HG: hg10_12147_05



HG: hg12−E−05





HG: hg14a−B−06
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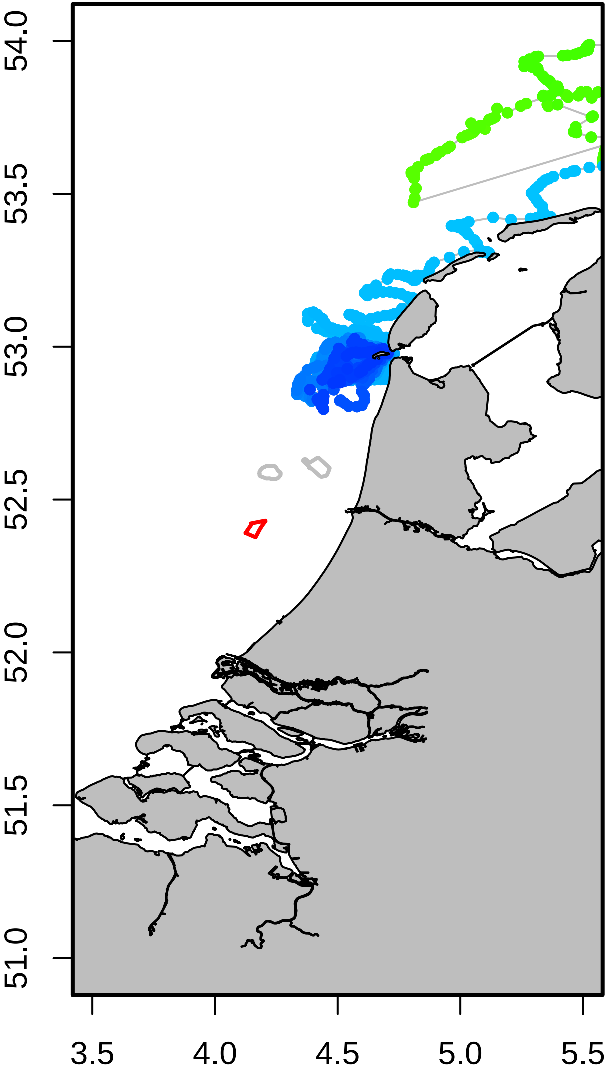
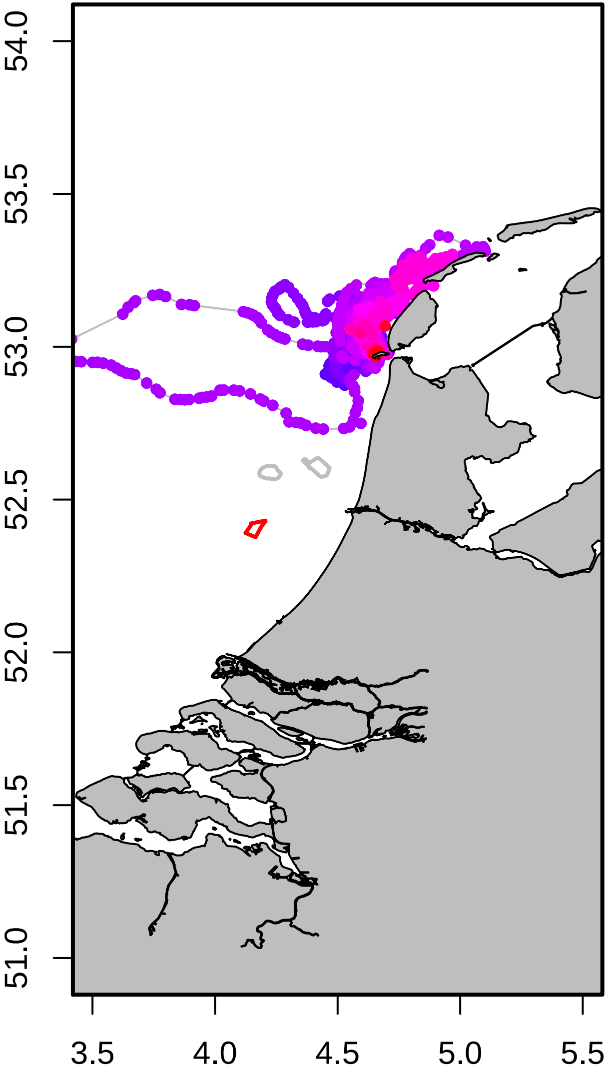
4.5
5.0
5.5

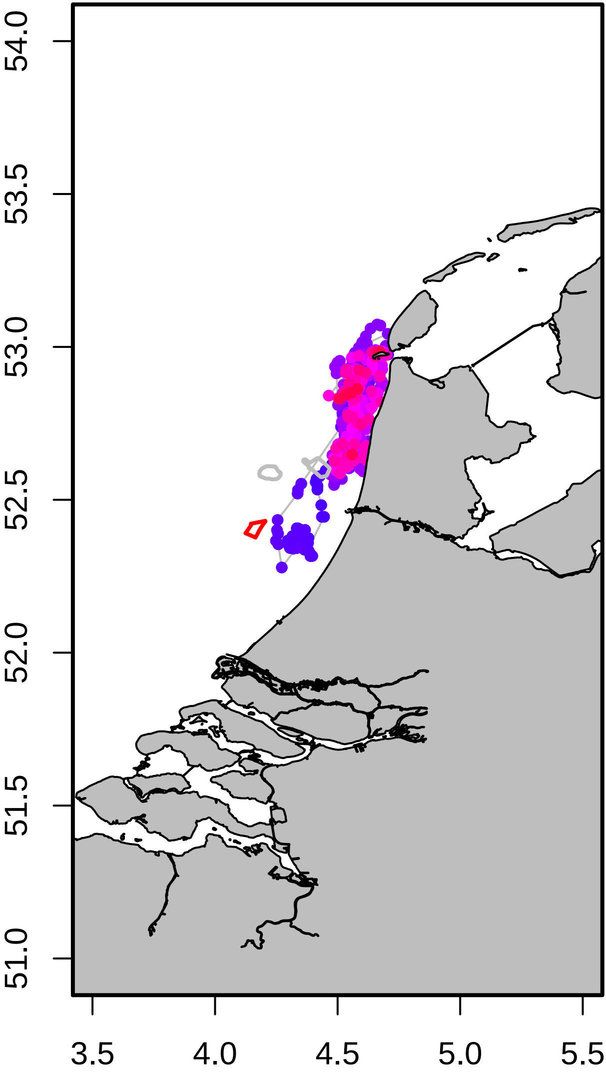
HG: hg16g−F5−07



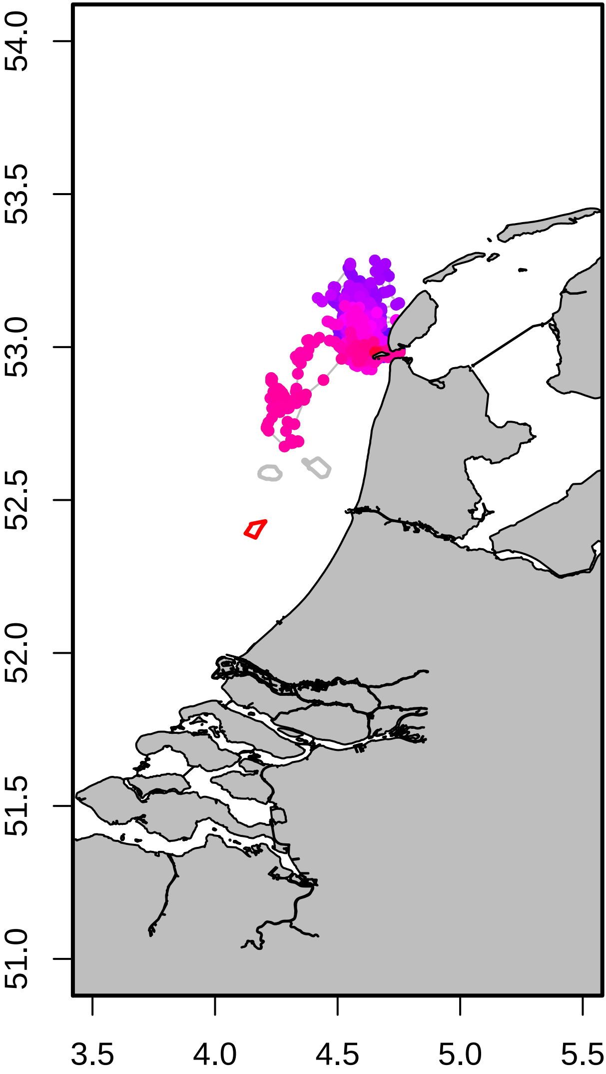
HG: hg21g−717−07

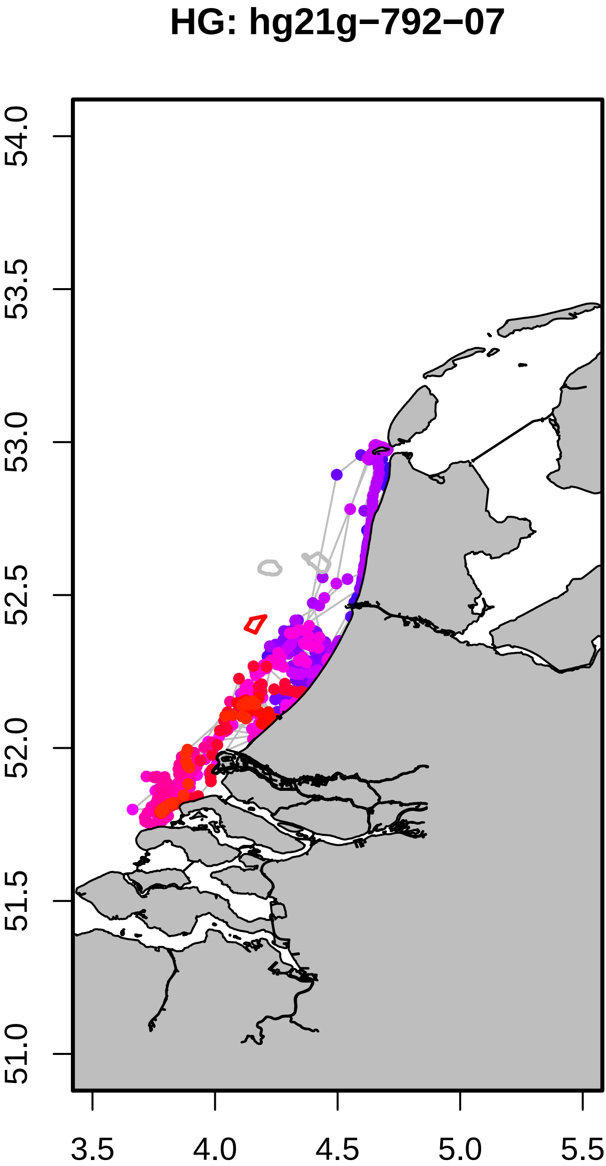


HG: hg21g−769−07



HG: hg21g−785−07




HG: hg21g−792−07
54.0
53.5
53.0
52.5
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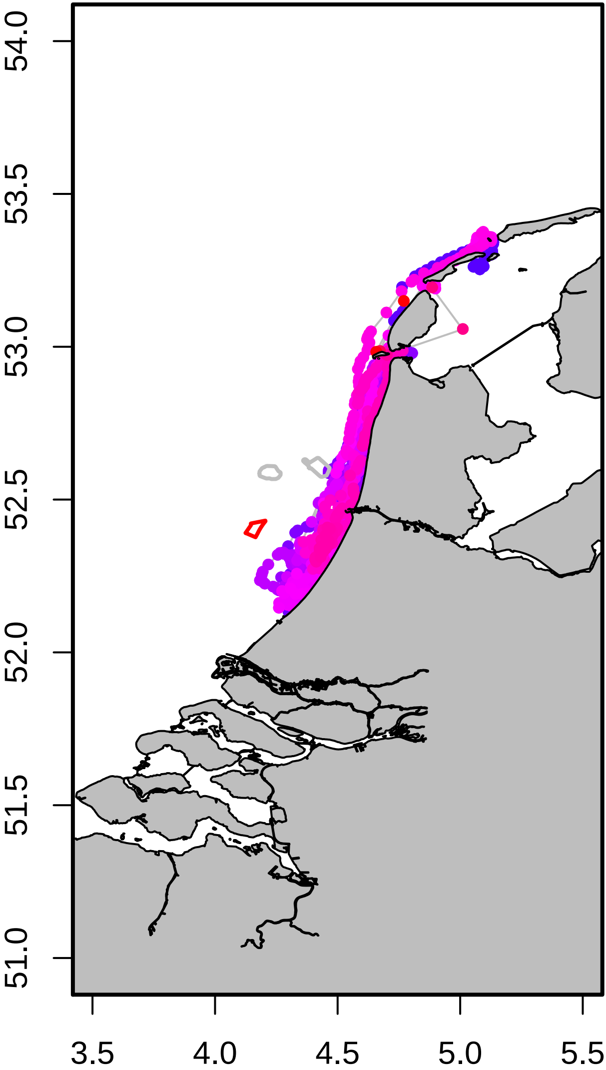
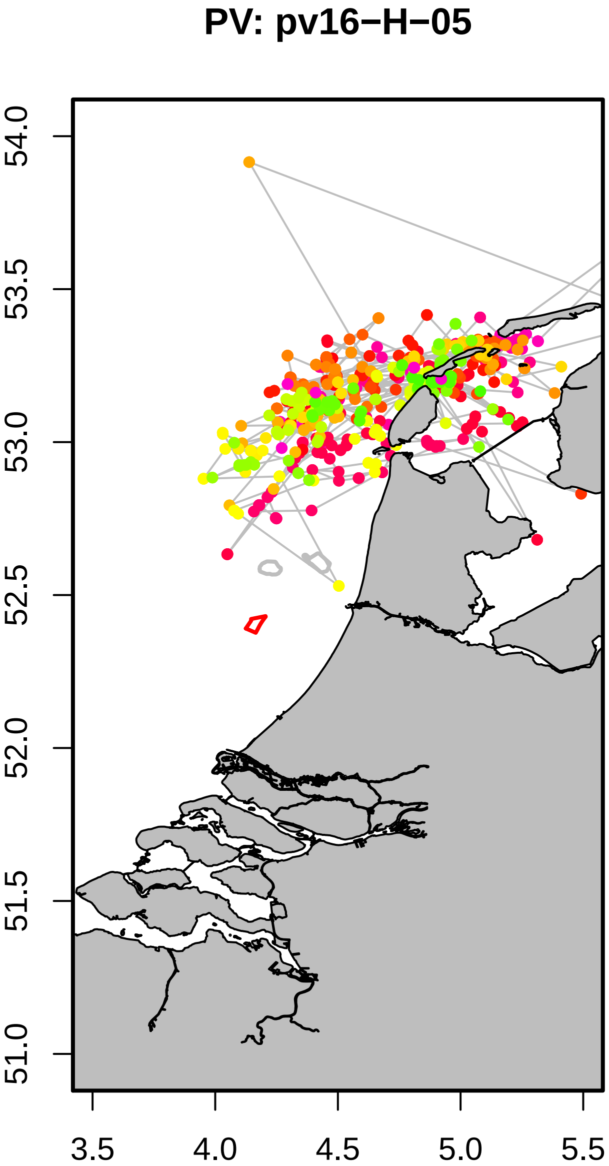
51.5
51.0
3.5
4.0
4.5
5.0
5.5

HG: hg21g−804−07




PV: pv16−H−05
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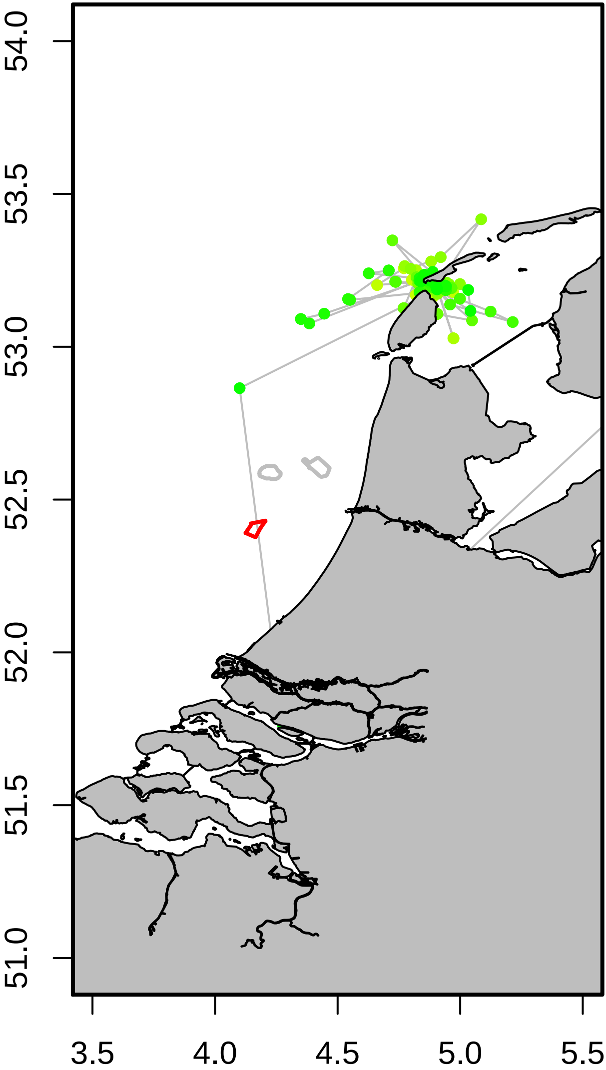
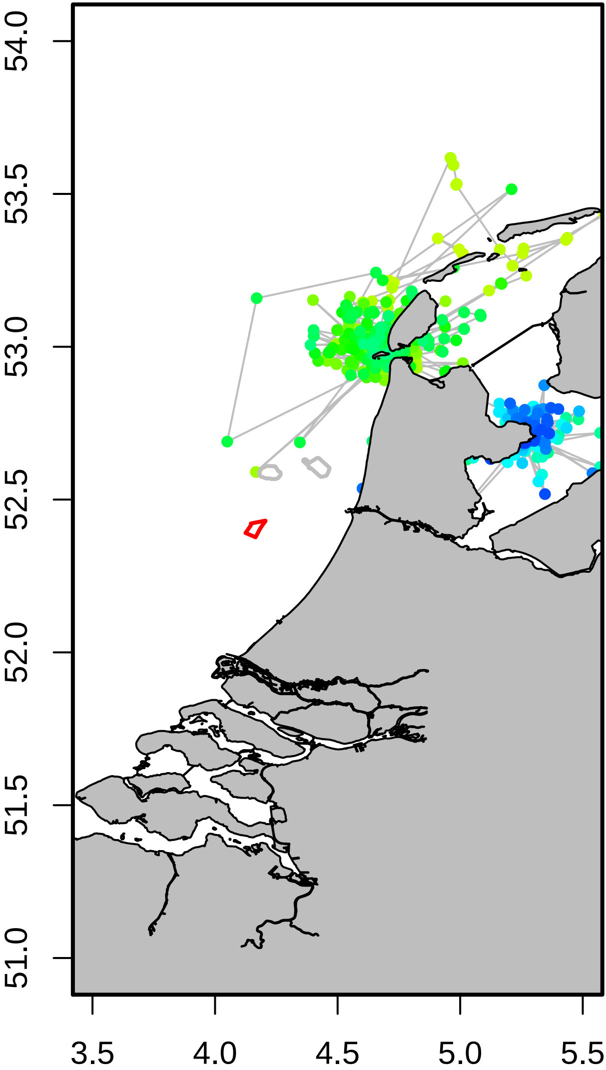
53.5
53.0
52.5
52.0
51.5
51.0
3.5
4.0
4.5
5.0
5.5

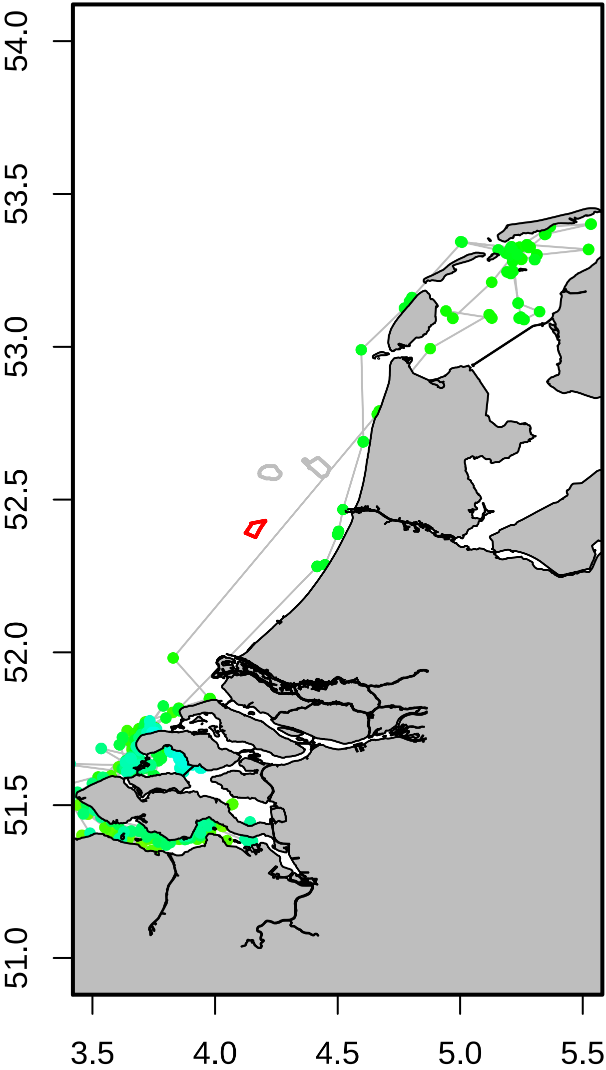
PV: pv21−C−07



PV: pv21−F−07



PV: pv21b−I−07



PV: pv22g−F15−07