



Seal monitoring and evaluation for the Gemini offshore windfarm: Tconstruction - 2015 report

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Wageningen University &
Research Report C004/18

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Report number C004/18



Wageningen Marine Research

Publication date:

January 2018

Sophie Brasseur, Roger Kirkwood, Geert Aarts, 2017. Seal monitoring and evaluation for the Gemini offshore windfarm: Tconstruction - 2015 report Wageningen, Wageningen Marine Research (University & Research centre), Wageningen Marine Research report C004/18.

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This report can be downloaded for free from <https://doi.org/10.18174/431831>
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Cover photograph: by Bert Meerstra

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Executive summary

1. Gemini offshore windfarm is located 55 km north of the island of Schiermonnikoog. The construction works for the 150 wind turbines and electrical infrastructure were carried out in 2015-2016. Pile-driving, which is generally considered to have largest expected immediate but short term impact on marine fauna, was carried out in July-October 2015. Installation of the turbines commenced in February 2016. Movements of both harbour and grey seals were studied during 2013-2014, before construction of the Gemini windfarm, a T0 period (Brasseur & Kirkwood 2015). For this study seals were tracked in 2015, the year of construction, called Tc, with the aim of studying possible effects of the construction activities on seals.

2. As stipulated in the Monitoring and Evaluation Plan the methods chosen for this study were in line with the seal tracking research carried out by IMARES (now: Wageningen Marine Research) in previous years. In April 2015 seven grey seals were deployed with trackers prior to the onset of the pile driving. In September 2015 (during constructions) nine grey seals and ten harbour seals were deployed with trackers.

3. The offshore construction activities in the Gemini windfarm area include a variety of activities such as preparation of the field, scour protection at monopile pads and cable crossings, cable installation, pile driving of monopile foundations and installation of the turbines on the monopile foundations. Data for many of these activities are presented in this report. However, the analysis concentrates on the pile driving activity for this study.

4. Out of the 26 tracked seals deployed for the Gemini Tc study, 23 trackers functioned well, collecting data for 56-208 days. The other three trackers - two on grey seals, one a harbour seal - performed only for a relative short time. Data collected in the framework of Luchterduinen windfarm is incorporated into the data analysis of this study.

Grey seals tracked following both spring and autumn deployments, remained most of the time in Dutch waters, though three visited the UK and one visited Helgoland. Most trips of the grey seals at sea were relatively close to shore (< 60 km), though four animals travelled more broadly across the North Sea. Maximum dive depth for most seals was <60 m, though in the area around Gemini most dives ranged between 20 and 35 m. There was also a clear peak at approx. 3 m.

The harbour seals (only autumn deployments) generally remained within 50 km of the coast and in the general area around Gemini. Two animals moved west, one even travelling to the Dutch delta. The harbour seals dived at depths <40 m, most ranged between 20 and 35 m, and there was a clear peak at 3 m, and also around 10 m depth.

5. While in years prior to the construction, several seals were observed within and near the Gemini area, only one grey seal was tracked through the wind park. Though this occurred in the pile driving period, there was no pile driving activity on-going. Seven harbour seals and six grey seals were tracked within 50 km of Gemini during pile driving, some individuals at multiple occasions. Three harbour seals and five grey seals were tracked within 40km of the wind farm during pile driving.

6. During pile driving seals swam significantly more often away from than towards the pile driving activity. This was the case for grey seals that were within 30 and 40 km from active pile driving site (45 events in total). Harbour seals hardly approached the pile driving thus sample size was low (12 events) and no significant effect in swimming direction could be determined. Dives during pile driving for both species were shallower.

7. Aside from to the Gemini windfarm, 10 other windfarms were built in the study area in recent years (2007-2015). The construction activities have been almost continuous. For harbour seals the usage further offshore seems to have diminished since the first tracking in the area with high-resolution GPS trackers in 2009. Also during the year of construction (2015) there was less usage further offshore (> 45km) compared to previous years.

7. Observed patterns in the seal's distribution at sea depend on the current size of the population, environmental conditions and human activities. Increasing anthropogenic developments in the North Sea

have potentially a significant effect on movement and habitat use of seals in North Sea. A study on cumulative effects based on existing data may provide for insight in underlying processes. Next to the population monitoring by aerial surveys, seal tracking (as part of regular monitoring) would provide the necessary data to monitor and eventually to understand long-term changes in the seals' behaviour, in relation to the recent windfarm development.

8. Habitat models and individual based models can be used to help understand and describe the mechanism underlying seal distribution, and have the potential to make predictions in both space and time. With these models, scenarios can be tested to predict the seal population development under changing circumstances and human activities.

In the Netherlands, the Wadden Sea is the area where most seals can be observed and two species are resident: the harbour seal, *Phoca vitulina*, and the grey seal, *Halichoerus grypus*. Previous studies show the seals that use haul out at sites in the Wadden Sea make considerable use of the adjacent waters spending almost half their time there potentially travelling hundreds of kilometres into the North Sea (Reijnders, Brasseur & Brinkman 2000; Brasseur & Reijnders 2001; Brasseur *et al.* 2011; Aarts *et al.* 2013; Kirkwood, Bos & Brasseur 2014; Brasseur & Kirkwood 2015). Seals move into the North Sea to forage and to travel to other areas. These movements can be restricted by anthropogenic developments, such as windfarms (Brasseur & Reijnders 2001; Brasseur *et al.* 2010a; Brasseur *et al.* 2011; Aarts *et al.* 2013).

Movements of both seal species were studied during 2013-2014, before construction of the Gemini windfarm, a T0 period (Brasseur & Kirkwood 2015). For this study seals were tracked in 2015, the year of construction, called Tc, with the aim of studying possible effects on seals of the construction activities.

1.2 Aims of the study

The aim of monitoring seal movement before, during and after construction of Gemini windfarm is to assess possible effects of the windfarm construction and operation (including the underwater noise from pile driving, operational turbines and the additional shipping traffic) on the seal's habitat use. However, knowledge on seal habitat use in general is limited and a study such as this one cannot be expected to provide complete understanding of these effects. Rather, the data collected during this study serves to enhance understanding of the seals' habitat use and how this is affected by human activity.

This report provides a comparison of seal movement during pre-construction (T0) and construction (Tc) monitoring, interpretations of potential seal responses to pile driving at Gemini and recommendations for future seal monitoring in relation to the Gemini windfarm.

1.3 Assignment

The Dutch government has formulated a strategy to develop a capacity of 4450 MW of energy from offshore windfarms (Social Economic Council agreement, August 2013). Construction, operation and decommissioning of offshore windfarms has the potential to negatively affect marine ecosystems (Prins *et al.* 2008). Therefore, offshore windfarm developments in the Dutch Exclusive Economic Zone (EEZ) require a 'Waterwet' permit (Water Act, Wtw-permit, until August 2013 also including the Natura2000 legal framework, formerly 'Wet Beheer Rijkswaterstaatwerken', Wbr-permit). *Rijkswaterstaat*, the management organisation of the Dutch Ministry of Infrastructure and the Environment, is the 'Competent Authority' that issues Wtw-permits. In August 2013, the Ministry of Economic Affairs became the Competent Authority with respect to the Natura2000 legal framework (*NB Wet* [Nature Management Act], *FF Wet* [Flora and Fauna Act]).

As part of the application to *Rijkswaterstaat* for Wtw-permits for Gemini (WV/2009-1138 and 1139), an 'Environmental Impact Assessment' and an 'Appropriate Assessment' were conducted on each of the two sites (Schuchardt, Storz & Todeskino 2009). Based on the results of the Assessments, the Wtw-permit included the obligation to prepare a 'Monitoring and Evaluation Plan' (MEP). In consultations between Gemini windfarm and *Rijkswaterstaat*, it was concluded that seal monitoring for Tc should include the tracking of grey seal movements following spring and autumn deployments and harbour seal movements following Autumn deployments. The sample sizes were set at 10 seals per deployment. Deployment sites were selected to maximise the chance that seals using them would move through the Gemini windfarm, i.e. sites in the central to eastern Dutch Wadden Sea were required.

Specific aims for this report are:

1. Correlate movement of the seals with pile driving times at Gemini to record potential responses to the pile driving.
2. Compare seal movement during the construction period with data from other tracking programs, including Gemini T0 in 2013-2014. IMARES (now: Wageningen Marine Research) also conducted a seal monitoring program for Luchterduinen windfarm, which was constructed approximately 200 km southeast of Gemini in 2014. Gemini and Luchterduinen have a data-sharing agreement in relation to the IMARES (now: Wageningen Marine Research) -collected seal movement data.
3. Compare seal movement data during construction with detailed data collected during pile driving.
4. Collect other construction data within the Gemini project that could aid interpretation of seal movement data.

1.4 Gemini timeframe in relation to other windfarm constructions

In the Netherlands prior to Gemini construction, three other offshore windfarms were constructed: *Offshore Windpark Egmond aan Zee* (OWEZ, operational since 2007), *Prinses Amalia Windpark* (operational since 2008) and *Luchterduinen* (operational in 2015). These three windfarms are situated in the Dutch coastal zone between the Wadden Sea and the Delta region, and within 25 km from the coast. Gemini is the first Dutch windfarm north of the Wadden Sea islands. It is not the first windfarm in the area, however, as in adjacent waters of the German Bight between 2007 and 2015, 13 windfarms were installed (858 turbines) and >50 more were under construction, authorised or planned (see Table 1). Consequently, prior to Gemini construction, the area was already busy with construction activities and an increasing number of operational windfarms.

It should therefore be noted that, although the monitoring design was timed to study possible changes between the “unaffected” pre-construction period (T0: 2013-2014) and the construction period (Tc: 2015-2016) of the Gemini windfarm, other windfarms were being constructed in the same general area which might have affect the results (Table 1). This is further discussed in chapter 4. *Long-term seal activity in and around the Gemini windfarm site.*

Table 1. Offshore windfarms north of the Wadden Sea islands (apart from Gemini, all are in German waters). Constructions that coincide with the Gemini seal monitoring period are indicated in red.

Name	Tower installation	Dist. to Gemini centre (km)	Turbines	area (km ²)	No / km ²	Depth (m)	km to land
Trianel Windpark Borkum 1	Sep 2011 - Apr 2012	32	40	23	1.7	28-33	45
Bard Offshore 1	Dec 2010 - Jul 2013	35	80	17	4.7	39-41	101
Borkum Riffgrund 1	Jan - Jul. 2014	39	77	36	2.2	23-29	55
Alfa ventus	Jun 2007 - Mar 2009	42	12	3	4.0	28-30	45
Riffgat	Jun. 2012 - Jul 2013	51	30	6	5.0	18-23	15
Global Tech I	Oct 2012 - Jan 2014	58	80	43	1.9	38-41	109
Meerwind Ost/Sud	Sep 2012 - Apr 2013	120	80	40	2.0	24-27	53
Nordsee Ost	Oct 2012 - Mar 2014	121	48	36	1.3	22-25	57
Amrumbank West	Jan 2014 - Mar 2015	126	80	36	2.2	20-25	35
Dan Tysk	Jan - Dec 2013	146	80	66	1.2	21-29	70
Butendiek	Apr - Jul. 2014	160	80	33	2.4	19-21	32
Horns Rev 1	Mar - Aug. 2002	201	80	21	3.8	6-11.	18
Horns Rev 2	May - Oct. 2008	202	91	33	2.8	9-17.	32
			858				
Gemini	Jul - Oct 2015	0	150	68	2.2	28-36	70
Nordsee One	Dec 2015 -	56	54	33	1.6	28-29	44
Gode Wind 1 & 2	May - Sep 2015	67	97	70	1.4	28-34	40
Sandbank	Jul 2015 - Feb 2016	141	160	66	2.4	25-37	90
			461				
OWP West	Authorised	13	41	14	2.9	29-31	79
Borkum Riffgrund West I	Authorised	18	45	30	1.5	29-31	53
Deutsche Bucht	Authorised	32	42	23	1.8	38-40	87
Vega Mate	Authorised	32	67	50	1.3	39-41	87
Trianel Windfarm Borkum 2	Authorised	33	40	33	1.2	28-33	45
Borkum Riffgrund 2	Authorised	36	57	45	1.3	25-29	57
Merkur Offshore	Authorised	39	80	47	1.7	27-33	57
EnBW He Dreiht	Authorised	39	80	62	1.3	37-40	85
EnBW Hohe See	Authorised	51	80	42	1.9	39-40	90
Delta Nordsee 1	Authorised	52	35	17	2.1	26-34	50
Delta Nordsee 2	Authorised	52	32	10	3.2	29-33	50
OWP Albatross	Authorised	57	79	39	2.0	39-41	105
Innogy Nordsee 2	Authorised	57	48	36	1.3	26-34	47
Innogy Nordsee 3	Authorised	61	60	29	2.1	32-34	47
Kaikas	Authorised	65	83	62	1.3	40-41	115
Gode Wind 4	Authorised	67	42	29	1.4	30-34	42
Nordicher Grund	Authorised	130	64	42	1.5	27-38	84
			975				

Data from web site <http://www.4coffshore.com/offshorewind/>, last accessed 31 March 2016.

1.5 Seal tracking in the area, prior to Tc

A summary of overlap between the Gemini windfarm areas and seal tracking data collected previously was provided in the T0 report (Brasseur & Kirkwood 2015). The data demonstrated that the majority of movement by seals in the North Sea in the vicinity of Gemini windfarm was inshore of the windfarms, and within 50 km from the Wadden Sea Island chain. However, there was considerable inter-annual variability in the distance off the coast that seals moved. For example, movement data collected for harbour seals in three consecutive autumn periods, 2009, 2010 and 2011, indicated overlap with Gemini (Figure 2). In 2011, two windfarms were constructed in the area, Trianel Windfarm Borkum 3 at 32 km east of Gemini and Bard Offshore 1 at 35 km northeast (Table 1) and underwater sound produced during

construction of these windfarms could have influenced the seals movements, i.e. limited the distance offshore that the seals foraged. The potential for natural inter-annual variability in movement offshore, however, also influences interpretations of potential responses to pile driving.

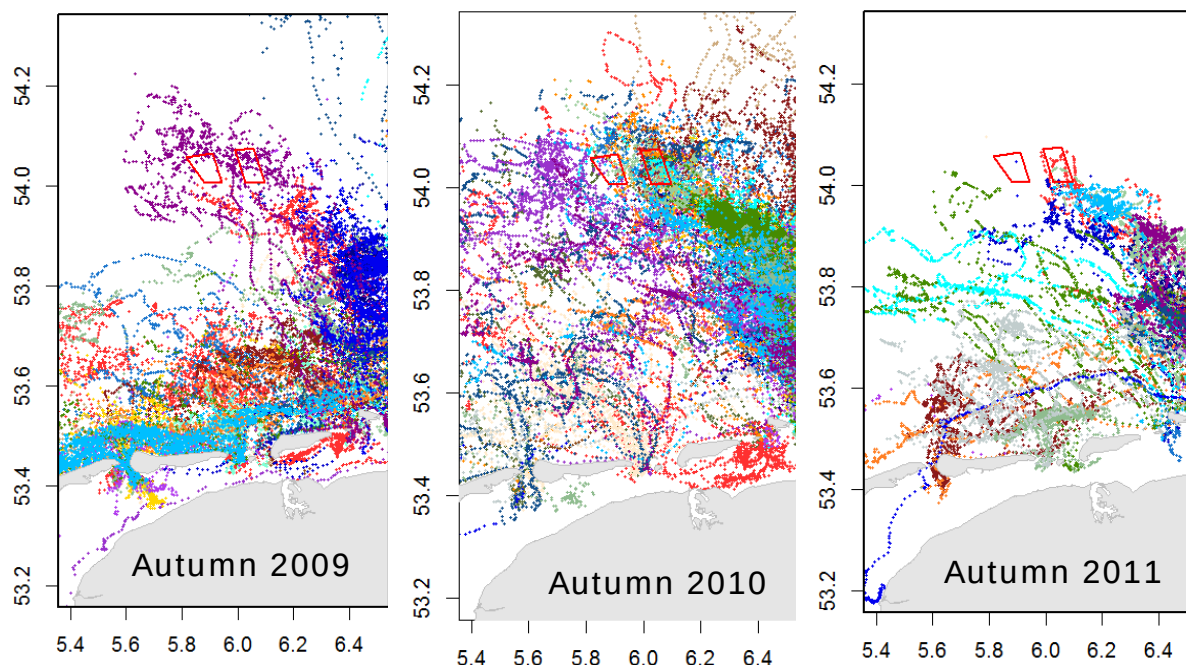


Figure 2. Overlap between Gemini windfarm area and harbour seal locations recorded in autumn during three previous years, 2009, 2010 and 2011, demonstrating inter-annual variability in overlap.

The Gemini windfarm T0 pre-construction seal-monitoring program was conducted in 2013 and 2014. The haul-out sites selected for seal captures were in the vicinity of Pinkegat in the central Dutch Wadden Sea (Figure 3). There, large numbers of harbour seals and sufficient grey seals had been hauling out in recent years (reported by Wadden Unit vessels and evident in aerial surveys conducted by IMARES (now: Wageningen Marine Research)). Seal tracking for T0 aimed for 10 individuals of each seal species at two times of the year, autumn and spring (**Error! Reference source not found.**). Due to low numbers of grey seals in the capture area, however, none were deployed in spring 2014, and in a back-up autumn sampling period in 2014, just one grey seal was available. Due to the low numbers of seals found at Pinkegat in spring 2014, a second catch area 20 km to the west, Blauwe Balg (Figure 3), was included.

Table 2. Completed seal monitoring program for Gemini windfarm in T0.

Deployments	Harbour seal		Grey seal	
	Actual	Planned	Actual	Planned
Autumn 2013	10	10	10	10
Spring 2014	10	10	0	10
Back-up autumn 2014			1	
Total	20	20	11	20



Figure 3. Location of Pinkegat, the primary seal catch area, and Blauwe Balg, a second catch area, in relation Gemini windfarms

For harbour seals, Gemini T0 tracking provided almost year-round, pre-construction movement data, for the periods September to January and March to July. The tracked harbour seals remained predominantly in Wadden Sea and North Sea within 30-50 km of the Wadden Sea islands, although one moved to the southern Dutch Delta region and several moved into German waters (Figure 4). In both tracking periods, individuals moved through the Gemini windfarm areas.

T0 tracking provided autumn-winter data for the period September to February, for grey seals. Half the grey seals moved extensively over the North Sea, while the other half remained predominantly in Dutch waters of the North Sea and within 50 km of the Wadden Sea islands (Figure 4). The only grey seal tracked in 2014 followed the latter pattern and remained near the Dutch coast of the North Sea. In 2013, several grey seals crossed through the Gemini windfarm area.

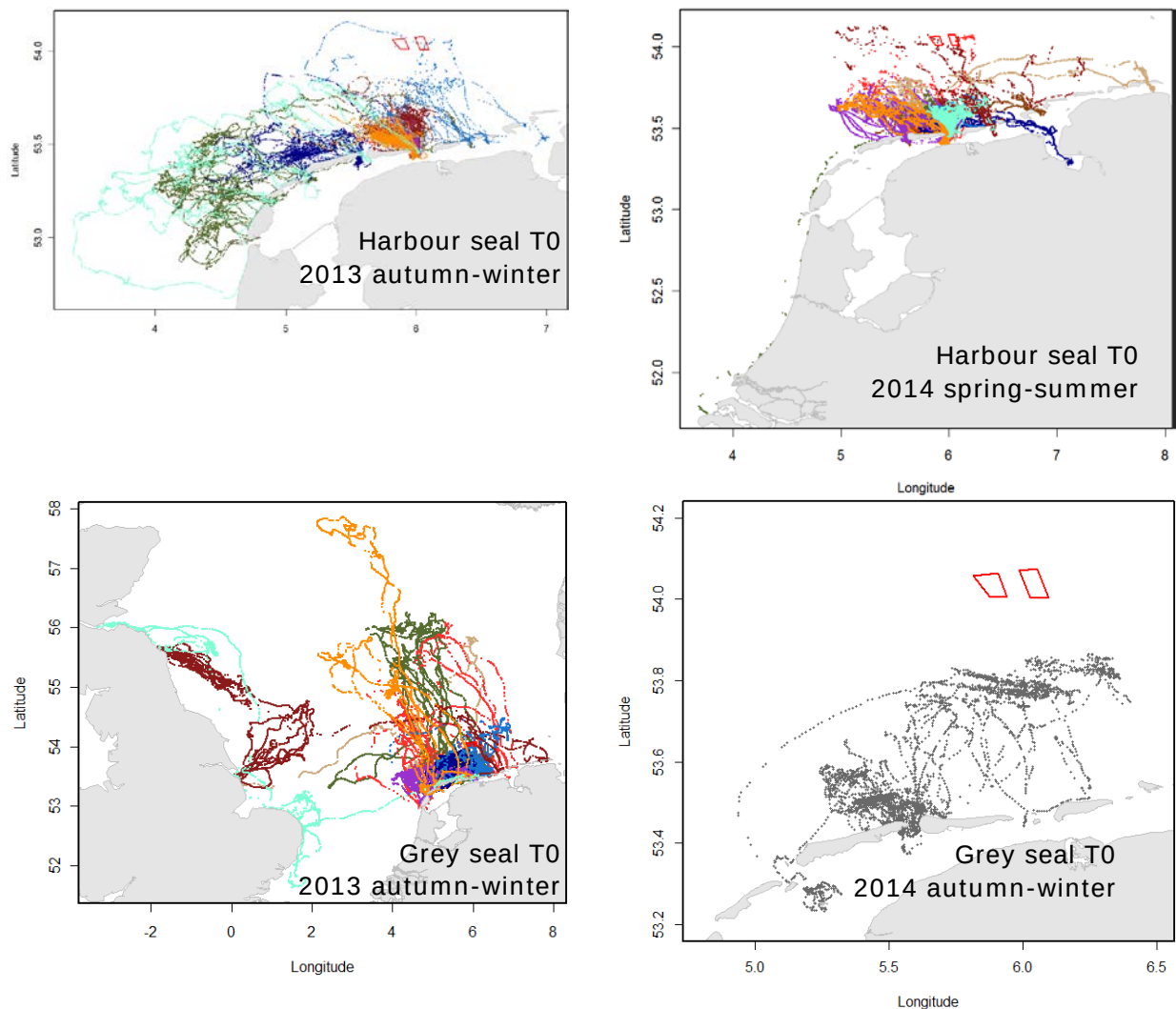


Figure 4. Gemini T0 seal tracking: locations of harbour and grey seals through 2013 autumn-winter and 2014 autumn-winter. Different colours are different seals.

In addition to data collected prior to 2013 and T0 tracking for Gemini windfarm, during 2013-2015 seals were tracked for the Luchterduinen windfarm. A data sharing agreement allowed the seal tracking data for Luchterduinen to be included in the analysis. Tracker deployment sites for Luchterduinen were in the western Wadden Sea (80 km west of Pinkegat) and the Zeeland-Delta region (250 km south-west of Pinkegat). However, a few of both grey and harbour seals from both sites did move in proximity to Gemini windfarm.

2. Materials and Methods

2.1 Seal tracking

- *Field sites*

The Gemini windfarms are located adjacent to German waters, offshore from the eastern end of the Dutch Wadden Sea. Because seals tend to rest ashore as close as practicable to their preferred marine habitats, the best place in the Netherlands to catch seals that are likely to utilise waters near Gemini is in the eastern Dutch section of the Wadden Sea. Although there are large numbers of harbour seals in the eastern Dutch Wadden Sea, grey seal numbers are relatively low. Through an assessment of all available distribution data (including IMARES -now: Wageningen Marine Research) aerial survey records, and reports from experienced crew of Wadden Unit Vessels) the area chosen for captures was in the vicinity of the island of Ameland, called Pinkegat, the same catch site as for T0 (Figure 3). In this area, harbour seals and grey seals co-occur, typically with hundreds of harbour seals and interspersed, smaller groups of grey seals. As a back-up catch site, the Blauwe Balg was selected. More grey seals appeared to be hauling out more regularly at Blauwe Balg than at Pinkegat. Although further to the west, seals at Blauwe Balg haul-out were still within striking distance from the Gemini area. At both Blauwe Balg and Pinkegat, there was the opportunity to catch both seal species in single catches/ catching trips.

- *Tracking devices*

Devices selected to track the seals were *GPS Phone transmitters* from the Sea Mammal Research Unit (SMRU, Scottish Oceans Institute, Scotland). These provide the accuracy of Fastloc® GPS location-determinations, dive depth and sea temperature data, and haul-out time measurements. Recovery of data is through the GSM mobile-phone network with a very high data bandwidth, which is ideal for data transfer around the North Sea, because North Sea coasts have almost complete coverage by mobile phone networks. That ensures the reception of records of the seals' movements and behaviour. This would not be the case for other location-transmitters available. The choice for GPS-GSM devices was based on the ethical principal to maximise the return from seal captures.

The Fastloc® GPS in the transmitter attempts to determine a location after a pre-set time and when the antenna is next exposed. The time is 'user-defined' based on exceeding expected dive durations (i.e. ≥ 5 -minutes for most seals), maximising location determinations and ensuring battery life for the expected deployment period. Devices placed on seals just after their moult (i.e. grey seals in spring and harbour seals in autumn) could have stayed on the seals for 10-11 months. To ensure batteries in the tracking devices lasted this long, the sampling rate for location determinations was set at 15-minute intervals. Devices placed on grey seals in autumn (~4 months prior to their annual moult) were expected to be retained for 3-4 months so could be given a faster sampling rate, set at 5-minute intervals, to increase the frequency of location determinations. Less than 1-second of air exposure is sufficient to acquire the information for a location determination. However, not all 'surfacing' of the seal provide a location, because the antenna does not always break the surface.

Up to 3-months of data can be stored in the memory of the transmitters and can be relayed once in reach of the GSM mobile-phone system. The 3-month data storage capacity is valuable in case seals remain at sea for extended periods or travel to a haul-out not covered by the GSM network.

Transmissions drain a considerable amount of power, so to maximise the life of each device the frequency of transmission attempts was duty cycled. The transmitters in this study attempted to send their data every 19 hours. If underwater or outside a GSM mobile network, the transmission attempt was

delayed until the next moment a network could be detected. The transmitters receive a reply from the network to determine if the data was transmitted correctly and, if not, continued to store the data.

Minimising device size is important as seals have hydrodynamic shapes and rely on low drag to maximise swimming efficiency (Fish 1993). Advances in battery and communications technologies have enabled device sizes to reduce over time. The latest GPS-Phone transmitters by SMRU weigh 330 g in air and 180 g in water, and have a volume of 150 cubic cm³. The weight is 25% less than the previous transmitters due to a reduction of the battery from a D-cell to a C-cell.

- *Field procedures*

All permits required to enter protected areas and handle seals during field procedures were obtained from the appropriate authorities. These included a permit under the Dutch Nature Protection Act (*Natuurbeschermingswet*) given by the provinces of Friesland, a permit under the Flora and Fauna Act (*Flora en Fauna Wet*) given by the Dutch government and protocols approved by an animal ethics committee (*Dier Ethische Commissie*, DEC) of the Royal Netherlands Academy of Science (*Koninklijke Nederlandse Academie voor Wetenschappen*, KNAW).

Field trips require a day to transport staff and equipment (vessels etc.) to the initial departure port (Lauwersoog for Pinkegat or Holwerd for Blauwe Balg), then 1-3 days of captures, returning to port at the end of each day.

Deployment periods were 14-15 April 2015 for grey seals in spring, and 22-24 September 2015 for grey seals and harbour seals in autumn. Field captures required calm sea conditions and a low tide near the middle of the day. Low tide was needed as most seals are on the sandbank at that time, water depths adjacent to sandbanks were shallowest which meant the lead line of the net reached the bottom, and there was slack water so the catch-net was not dragged away by water currents. The low tide needed to coincide with near the middle of the day so there were sufficient daylight hours to set-up, catch seals and deploy the trackers on them, and return to the transport vessels. During captures, staff were assigned specific roles to maximise efficiency and minimise handling times.

Seals were captured at low tide adjacent to sandbars where they rested, using a specifically designed seine-net of approximately 100 m length. A GPS phone transmitter was glued (epoxy resin, *Permacol*) to the pelage of each seal, at the mid-dorsal point immediately behind the neck. Animals were measured and weighed. Once the glue on an individual seal's transmitter had set, the seal was released and the seal proceeded directly to the water.

Initially, in each sample of 10 seals for each species, it was planned to include at least three adult females, three adult males and three sub-adults. This was to standardise representation from the different age-sex classes. In the field, however, because the capture technique randomised which seals were caught, age-sex age classes were not caught in a standard ratio. Retaining the pre-determined structure would have required additional catch attempts which would have increased the disturbance to the seals and extended the field time. It was considered more appropriate to attach transmitters to suitably healthy individuals from each capture. This resulted in different ratios for the age-sex classes.

- *Data storage*

Seal location and dive data were downloaded via the GSM network to a computer at the SMRU in Scotland. The data were downloaded from there for storage and analysis. (R statistical Package, version 3.3.0, R Foundation for Statistical Computing, Vienna). Individual and grouped seal tracks were plotted using R programs to visualise movements.

Preliminary analysis provides an indication of usage by the seal species of the North Sea waters adjacent to the eastern Dutch Wadden Sea. This included spatial use, based on location data, and benthic habitat use, based on diving-depth data.

- *Additional seal tracking data*

In addition to data collected prior to 2013 and T0 tracking for Gemini windfarm, during 2013-2015 seals were tracked for the Luchterduinen windfarm, owned by ENECO. A data sharing agreement between Gemini windfarms and ENECO, allowed the seal tracking data for Luchterduinen to be included in the analysis. Tracker deployment sites for Luchterduinen were distant from the deployment sites Gemini, being in the western Wadden Sea (80 km west of Pinkegat) and the Delta region (250 km south-west of Pinkegat). However, a number of both grey (10 animals) and harbour seals (14) from both sites did move in proximity to Gemini windfarm.

2.2 Data for construction activities

Besides pile driving, other construction activities may affect the seals behaviour. During all activities related to the construction of the windfarm, if either underwater noise is produced, or movement and light from the vessels might be detected by seals, behaviour and movement of the animals could be influenced. Gemini provided records of activities related to the construction, this included:

- Preparation of the field, including unexploded ordnance clearance
- Stone dropping (scour protection at monopile pads and cable crossings)
- Pile driving of monopile foundations
- Installation of the turbines on the monopile foundations
- Cable installation

- *Preparation of the field for construction*

During preparation of the field in which a windfarm is to be installed, there is increased shipping and survey work in order to determine exact bathymetries and sediment types. There are also surveys to locate potential hazards on the sea floor. For windfarm construction in the Netherlands, the loudest underwater sounds produced are explosions to remove unexploded ordnance. Thousands of ordnance were dumped into the North Sea during and after the Second World War and continue to be recovered. During windfarm construction, the sea floor was surveyed for unexploded ordnance and those discovered were detonated on site using explosives.

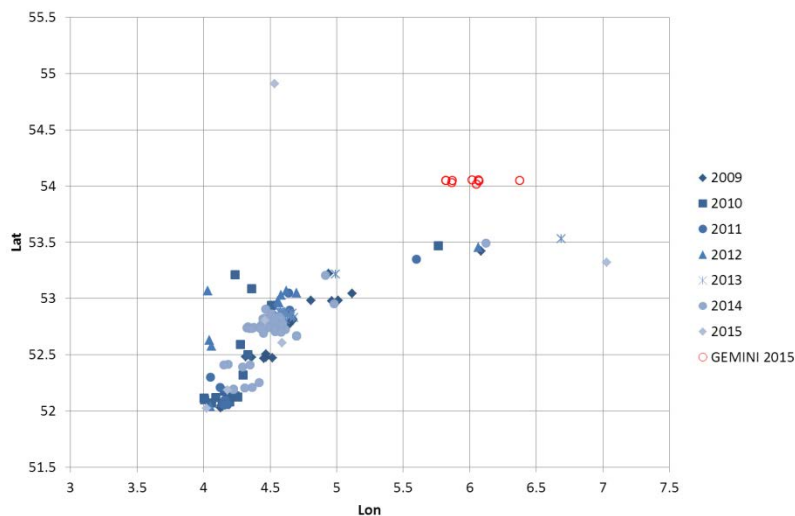


Figure 5. Timing and location of explosive clearance of recovered WW2 ordnance 2009-2015.

In May-June 2015, nine underwater explosions were required to clear ordnance that was located within the windfarm areas (Figure 5; Table 3, for details). These were the only explosions in this area between 2009 and 2015.

Table 3. Explosive clearance of recovered WW2 ordnance for Gemini windfarm in 2015 (data courtesy of the Coast Guard, supplied by Gemini windfarms).

Date	Time (GMT)	Lat.	Long	Explosive (kg)
11-5-2015	11:56 AM	54.045	6.07	25
13-5-2015	7:51 AM	54.0572	6.0652	25
22-5-2015	4:31 PM	54.0523	6.3726	5
23-5-2015	4:45 PM	54.0528	6.0167	5
25-5-2015	6:43 PM	54.05	5.8667	3
26-5-2015	4:28 PM	54.0167	6.05	26 (US MK 25)
7-6-2015	7:47 AM	54.0518	5.8204	<1
8-6-2015	5:51 PM	54.0307	5.8627	42
25-6-2015	6:24 AM	54.0518	5.8204	Ground-mine UK A mk6

- *Stone dropping*

To inhibit scouring by water movement around the base of monopiles, layers of stones are dropped to form pads on the sea floor prior to installation of the foundations. The stone-dropping vessel positions over the site and stones are steadily pushed overboard. Sonar scans during stone-dropping provide accurate monitoring of the shape of the scour protection pads on the sea bottom. Two layers of stones are dropped for each scour-protection pad, a so called armour layer and a filter layer. Both layers were installed between mid-February and early September 2015. These activities were carried out synchronously in both east and west sides of the park. Though starting earlier, activities overlap with piledriving.

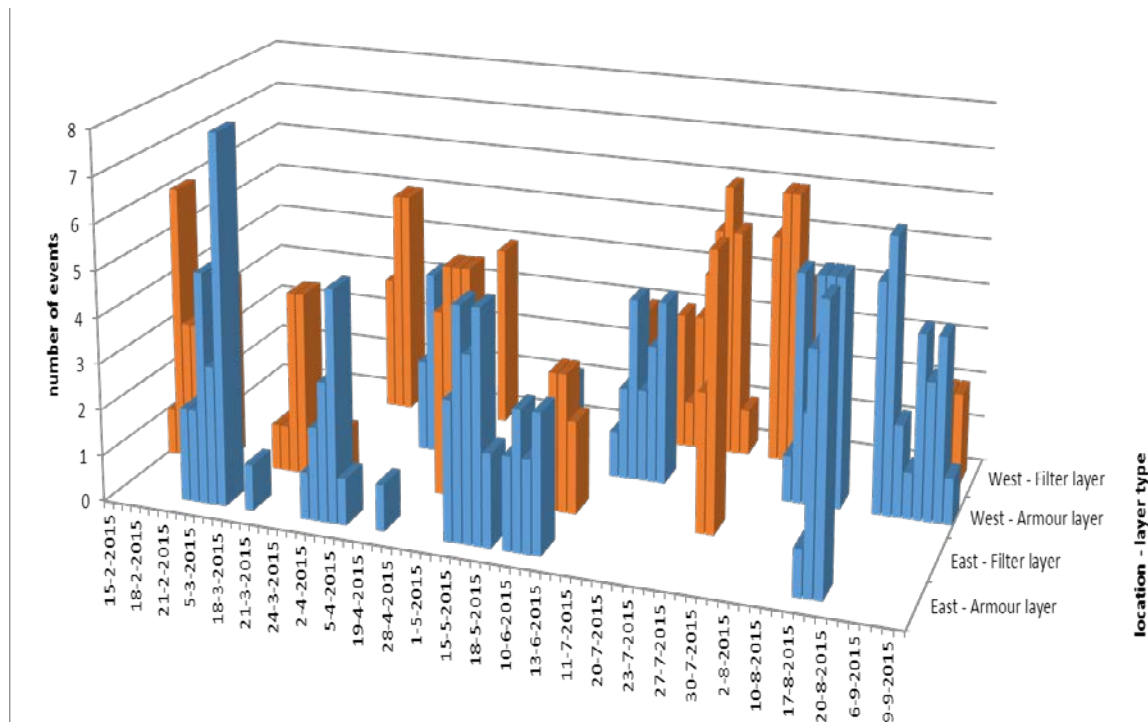


Figure 6. Intensity of stone dropping events separated between the eastern (East) and western part (West) of the wind park defined as number of events i.e. days during which stones were dropped on a site certain site. Blue: armour layer; Orange: filter layer

- *Pile driving of monopile foundations*

For Gemini windfarms, pile driving was conducted by two jack-up vessels in the period 1 July to 17 October 2015. The vessels operated out of Eemshaven. In total there 150 monopile foundations for the turbines and eight piles for the foundations of the two Offshore High Voltage Stations (OHVSs). Generally, three monopiles were loaded on board of a vessel and, if weather allowed, the vessel moved to the Gemini area. At the right position, the vessel lowered its' four legs to the seafloor and jacked up. A monopile was craned over the side of the vessel, positioned into a holding frame and lowered to the seafloor. Once in place, the hammer mechanism was placed on top of the monopile.

The foundations required an average of approximately 79 minutes (57-110 min) to be driven in to their required depth, and 127 minutes (76-254 min) between the start of piling and the final blow. When a pause of >60 min was taken, the pile driving was considered to be two separate events. In total, including the two OHVSs there were 152 pile driving locations. However, 14 pile driving events were considered multiple events as more than an hour break was taken within them, resulting in a total of 166 pile driving events (Figure 7).

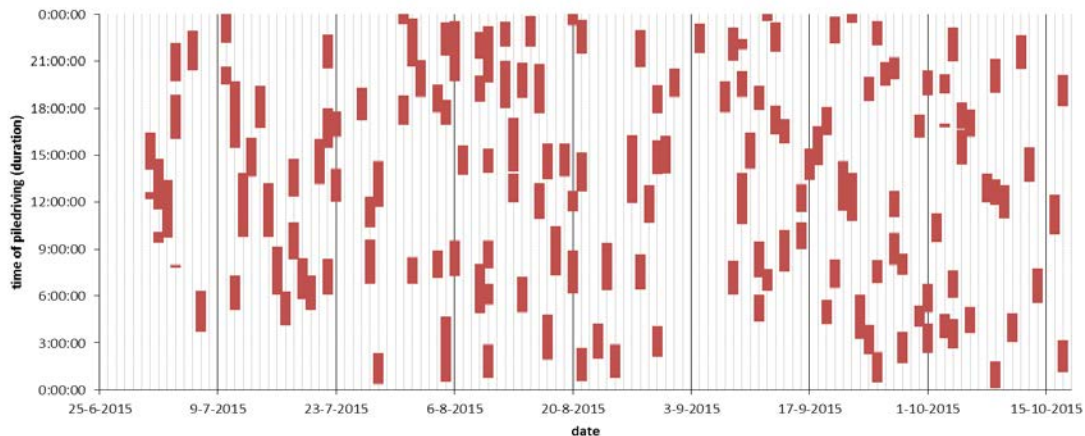


Figure 7. Gemini pile driving activity. Line height indicates duration of pile driving.

Before piling started, a *Faunaguard* (an acoustic porpoise deterrent, SEAMARCO Ltd) was switched on. This device produced sounds at ultra-sonic frequencies (60-150 kHz), which were higher than could be detected by seals, whose frequency range for best hearing is 0.5 to 40 kHz (Kastelein *et al.* 2009). The *Faunaguard's* aim was to drive away harbour porpoises from the immediate vicinity prior to the commencement of pile driving, so as to reducing potential injuries to them from the underwater sound produced by the pile driving. Only after completion of the pile driving, the *Faunaguard* was switched off.

Each monopile had a unique pile driving record. Typically, hammering commenced with a 'soft-start', i.e. no (or light) power. This was to ensure the monopile seated well and penetrated the substrate in a controlled manner. As the monopile penetrated further into the substrate, the power to the hammer and blow frequency generally increased. Hammering was at a rate of 40-50 blows per minute. Energy levels reached up to a maximum of 80% capacity, which was approximately 1400 kJ. Hammering was not continuous through a pile driving event. Initial hammering was for periods of several seconds, followed by breaks in hammering of up to several minutes for observation and adjustment. Durations of hammering tended to increase through each pile driving event up to durations of continuous hammering in the later stages lasting 30 minutes or longer. Underwater noise during pile driving was measured at two different monopiles (foundation structure of the wind turbines) and one pin-pile (jacket foundation of the Offshore High Voltage Station), at four distances (MP1 to MP4 at 750 m to approx. 60 km) to the source (Remmers & Bellmann 2016).

Upon achieving a required depth, the hammer was removed from the monopile, fixtures (e.g. platform) were attached, and the vessel jacked-down and moved to the next location. After all monopiles had been installed (or bad weather delayed installation), the vessel returned to Eemshaven to restock before returning to install further foundations. This resulted in a gap in pile driving by that vessel of 2-3 days. Installation of the turbines commenced in February 2016.

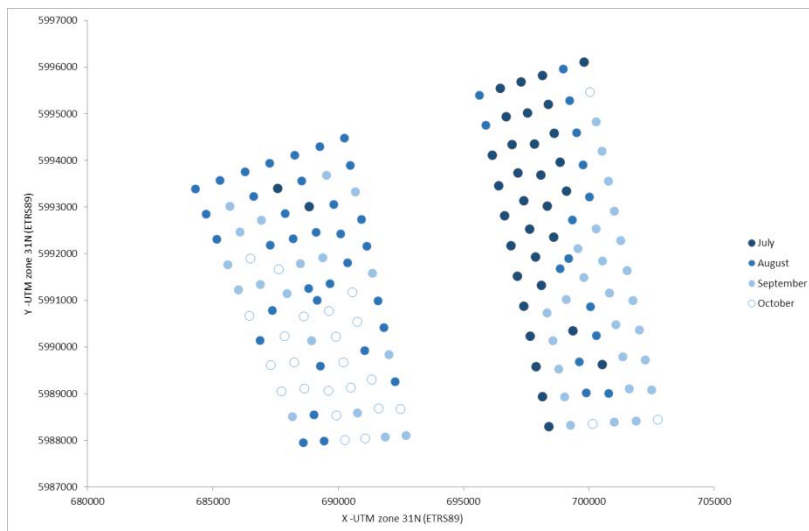


Figure 8. Geographical sequence of pile driving events by month.

- *Cable laying*

The export cables connecting the wind farm to a facility on shore at Eemshaven were installed during 2015. The timing of these activities is presented in Figure 9.

- *Other windfarms*

In addition to the construction of Gemini in 2015, other windfarms in the German Bight were in various stages of construction (see Figure 1, Table 1). While information on the periods in which pile driving took place for these can be extracted from web pages (<http://www.4coffshore.com/offshorewind/>), exact pile driving time schedules and information on timing of other activities were not available for inclusion in this report.

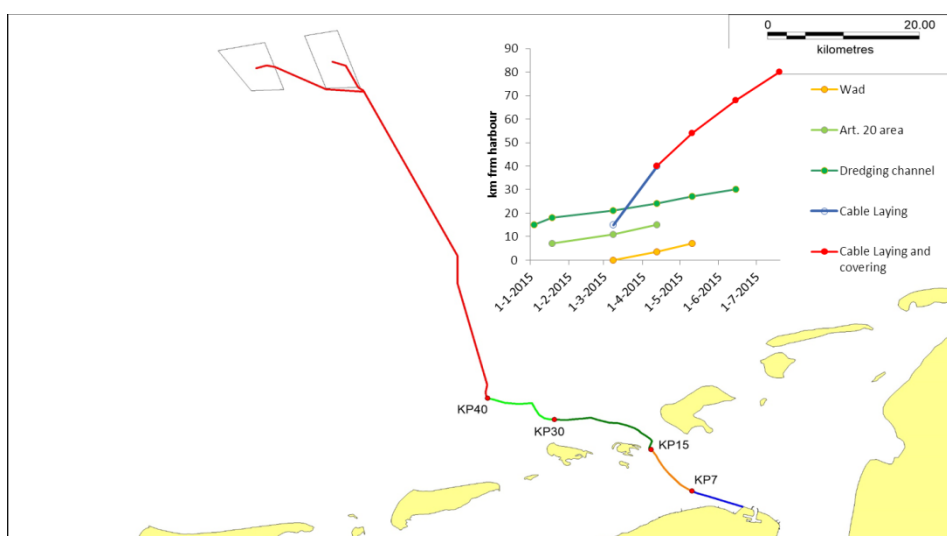


Figure 9. Map of cable laying activities. Inserted graph indicates the timing of activities.

2.3 Data analysis

- *Seal distribution in relation to the coast*

Based on the distribution of seal GPS locations, the seal usage or spatial density as a function of distance to the coast was estimated. In order to focus on the general Gemini region, only locations between 5-7°E were used. Ideally, locations fixes are obtained at regular interval and each location fix could then represent an equal amount of time spent in an area. However, different types of behaviour (e.g. travelling or foraging) may lead to a different location-fix rate. Using locations alone could add bias to the interpretation of where seals spent most of their time. To correct for this, each GPS location received a weight equal to half the time to the previous and next location (with a maximum of 6 hours). Finally, the time spent (i.e. an estimate of usage) was estimated for each 1-km distance-to-coast class.

- *Distribution of dive depths.*

For the overview of the dive depths, all dive records of individual seals were summarised by dividing the sum of the time spent in dives to a certain maximum depth, by the total sum of time spent diving. Thus, times spent at the surface or hauled out were excluded.

- *Effect of pile driving on seals*

As pile driving is generally assumed to affect marine animals most, this was considered as the focus of our effect studies. Sound from pile driving may affect the behaviour of seals in a variety of ways. Here, we investigate whether pile driving leads to seals evading the area during pile driving. For each seal the closest distance compared to the location of pile driving at the moment of pile driving but also the last location prior to and first location after pile driving were determined. In some cases, there were no locations recorded during pile driving, then the closest in a window of 6 hrs was taken. First, within 50 km of the pile driving for each pile driving event, and for each seal recorded, a map was made showing the track one day prior to pile driving (green), during pile driving (red) and one day after pile driving (orange). Next, the direction of travel during pile driving was estimated based on the last-location prior to pile driving and the first location after pile driving. Assuming pile driving has a deterring effect, it could be expected that the direction of travel would be, on average, away from the sound source, particularly for those locations in the near vicinity (i.e. <30 or 40 km). To test deviations from uniformity a Rayleigh test was carried out.

3. Results

3.1 Deployments

During all catching periods, suitable weather windows were available to undertake field operations.

Table 4. Seals tracked in 2015 for Gemini windfarm monitoring (F=female, M=male, a=adult, sa=sub-adult).

	Seal	Sex	Age	Length (cm)	Weight (kg)	Deployed	Last	Days
HG46G								
Blauwe Balg	13077	M	sa	139	38	14-apr-15	08-nov-15	208
Blauwe Balg	13112	M	sa	146	63	15-apr-15	12-sep-15	150
Blauwe Balg	13113	M	sa	136	60	15-apr-15	03-sep-15	141
Blauwe Balg	13114	F	sa	112	32	14-apr-15	08-nov-15	208
Blauwe Balg	13116	M	sa	145	73	15-apr-15	21-okt-15	189
Blauwe Balg	13119	F	a	168	90	14-apr-15	01-nov-15	201
Blauwe Balg	13317	M	sa	111	35	14-apr-15	21-jul-15	98
HG51								
Blauwe Balg	14110	F	a	166	141.2	23-sep-15	05-okt-15	12
Blauwe Balg	14112	M	sa	134	44.5	23-sep-15	31-jan-16	130
Blauwe Balg	14113	M	a	184	169.4	23-sep-15	10-feb-16	140
Blauwe Balg	14121	F	sa	123	40.6	23-sep-15	02-feb-16	132
Blauwe Balg	14130	M	sa	129	46.8	23-sep-15	29-sep-15	6
Pinkegat	14132	M	sa	146	75.4	22-sep-15	12-jan-16	112
Pinkegat	14133	M	sa	132	52.4	22-sep-15	03-dec-15	72
Pinkegat	14136	F	a	157	85.2	22-sep-15	31-dec-15	100
Blauwe Balg	14144	M	sa	135	47.2	23-sep-15	24-dec-15	92
PV61								
Pinkegat	14115	M	a	146	35.8	22-sep-15	10-okt-15	18
Pinkegat	13117	M	sa	98	41.0	22-sep-15	19-jan-16	119
Pinkegat	13118	M	sa	127	42.2	22-sep-15	30-dec-15	99
Blauwe Balg	14119	M	a	149	53.4	23-sep-15	13-dec-15	81
Blauwe Balg	14123	M	a	143	71.0	23-sep-15	15-dec-15	83
Pinkegat	14134	F	a	133	61.4	24-sep-15	30-dec-15	97
Pinkegat	14135	F	sa	107	26.6	24-sep-15	30-dec-15	97
Blauwe Balg	14137	M	a	148	65.8	23-sep-15	18-nov-15	56
Pinkegat	14145	M	a	145	65.0	22-sep-15	03-dec-15	72
Pinkegat	14147	F	a	134	67.0	24-sep-15	03-jan-16	101

Seven grey seals were deployed in April 2015, and in September 2015 nine grey seals. Although the intention was to track 10 grey seals for each deployment, fewer were tracked due to the low numbers of grey seals in the catch areas. Taking into consideration the effort and costs required to complete the samples and negating further disturbance to seals at haul-outs, it was decided to limit the number of catches once a majority of the animals were deployed. The intended sample of 10 harbour seals in autumn was completed.

Mean tracking durations for seals (Figure 10) were: grey seals caught in April 2015, 171 ± 42 days ($n = 7$, range 98 to 208); grey seals caught in September 2015, 88 ± 50 days ($n = 9$, range 6 to 132); and harbour seals caught in September 2015, 82 ± 29 days ($n = 10$, range 18 to 119).

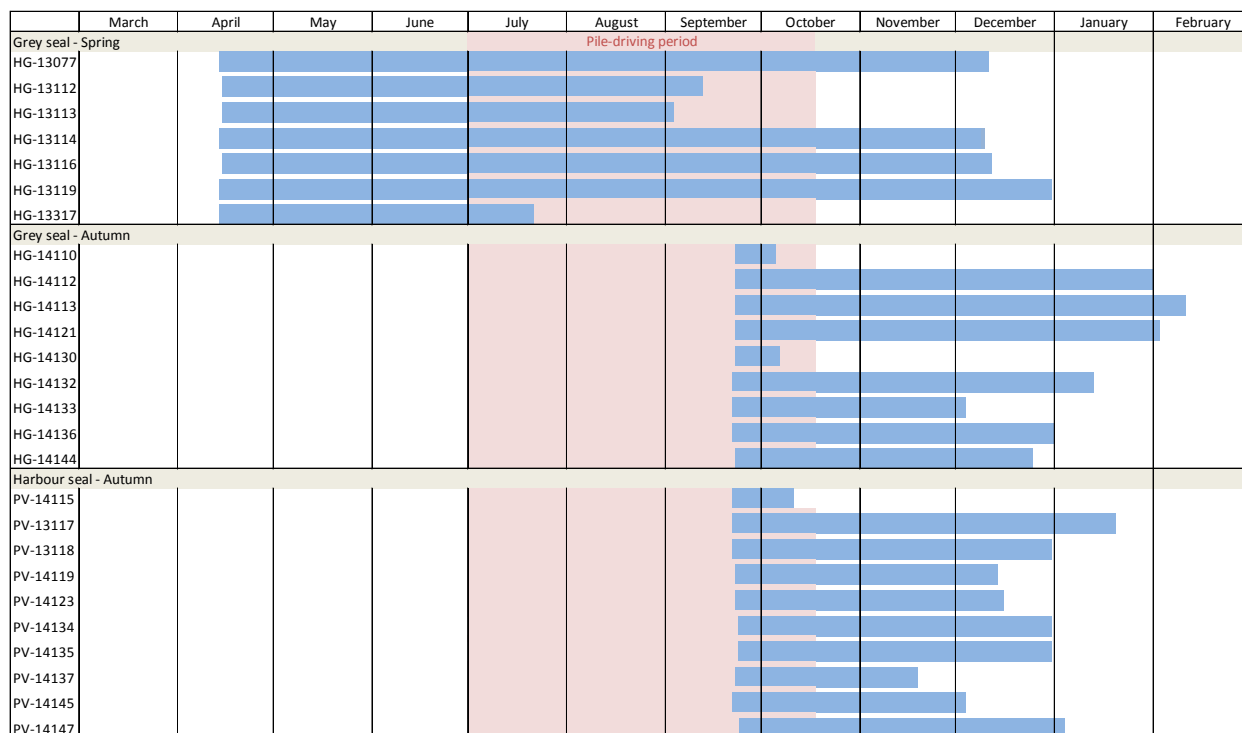


Figure 10. Durations that seals were tracked in 2015-16, indicating overlap with the pile driving period.

In the seal monitoring for Gemini T0 and Tc combined, 57 animals were tracked (Table 5). This included for both species, adult and sub-adult males and females. However, biases in the proportions of these age and sex classes included few adult male grey seals, few sub-adult female grey seals and few adult female harbour seals. The catching effort and resulting disturbance was limited to a minimum, resulting in an uneven sample size of males and females.

Table 5. Overview of seals tagged and deployment schedule for the seal monitoring program for Gemini.

	Grey seals (Hg)			Hg Total	Harbour seals (Pv)			Pv Total	Total
	2013	2014	2015		2013	2014	2015		
Adults									
F	5	1	3	9	1	4	2	7	16
M	1		1	2	3	6	5	14	16
Sub-Adults									
F	1		2	3	3		1	4	7
M	3		10	13	3		2	5	18
Total	10	1	16	27	10	10	10	30	57

In addition to the tracking for the Gemini windfarm seal monitoring program, seals tracked in the framework of Luchterduinen windfarm seal monitoring in the same period (2013-2015) that moved to the central Wadden Sea (i.e. east of 5.5°E, which was east of the island of Terschelling) could be

incorporated into the data analysis in this study. This added 25 seals to the data set, 10 grey seals and 15 harbour seals (Table 6).

Table 6. Overview of Luchterduinen seal monitoring, including in brackets seals that moved to the central Wadden Sea (i.e. east of 5.5°E). Movement of these seals could be included in the Gemini windfarm analysis.

	Grey seals (Hg)			Hg Total	Harbour seals (Pv)			Pv Total	Total
	2013	2014	2015		2013	2014	2015		
Delta									
Adults									
F	2	5(1)	0	7(1)	1	1	2(1)	4(1)	11(2)
M	3	3(1)	3(1)	9(2)	1(1)	5	2(1)	8(2)	17(4)
Sub-Adults									
F	1	2	1	5	2	2(1)	1	5(1)	10(1)
M	1		2	3	2	2	1	5	8(0)
Wadden									
Adults									
F	4	4(1)	2	10 (1)	0	3(3)	1(1)	14(4)	24(5)
M	1(1)	2(1)	3(1)	6(3)	3(2)	4(1)	3(1)	10(4)	16(7)
Sub-Adults									
F	4	1	1(1)	6(1)	2(1)	2(1)	0	4(2)	10(3)
M	0	3(2)	1	3(2)	1(1)	1	2	4(1)	7(3)
Total	15	20	12	47(10)	10	10	10	44(15)	91(25)

3.2 General seal movement and behaviour 2015

- *Grey seals*

Within the samples of grey seals tracked following both spring and autumn deployments some seals remained in Dutch waters and others travelled more broadly across the North Sea (Figure 11).

Following the spring deployments on grey seals, two sub-adult males visited the UK coast, one travelling to the Blakeney Point colony, the other visiting the Farne Islands and performing five return trips out of these islands. A third sub-adult male visited the Island of Helgoland in the German Bight and performed four return trips out of there. The remaining seals all continued to use Wadden Sea haul-outs and conduct foraging trips north into the North Sea, during the period they were tracked. The only adult female undertook three trips northwards up to 300 km off the Dutch Wadden Sea coast, then from August 2015 onwards switched to an area within 45 km of the coast. The three other seals, two sub-adult males and a sub-adult female, remained relatively close to shore, <60 km. From June on-wards, coinciding with when pile driving for Gemini commenced, they remained even closer to shore, <30 km.

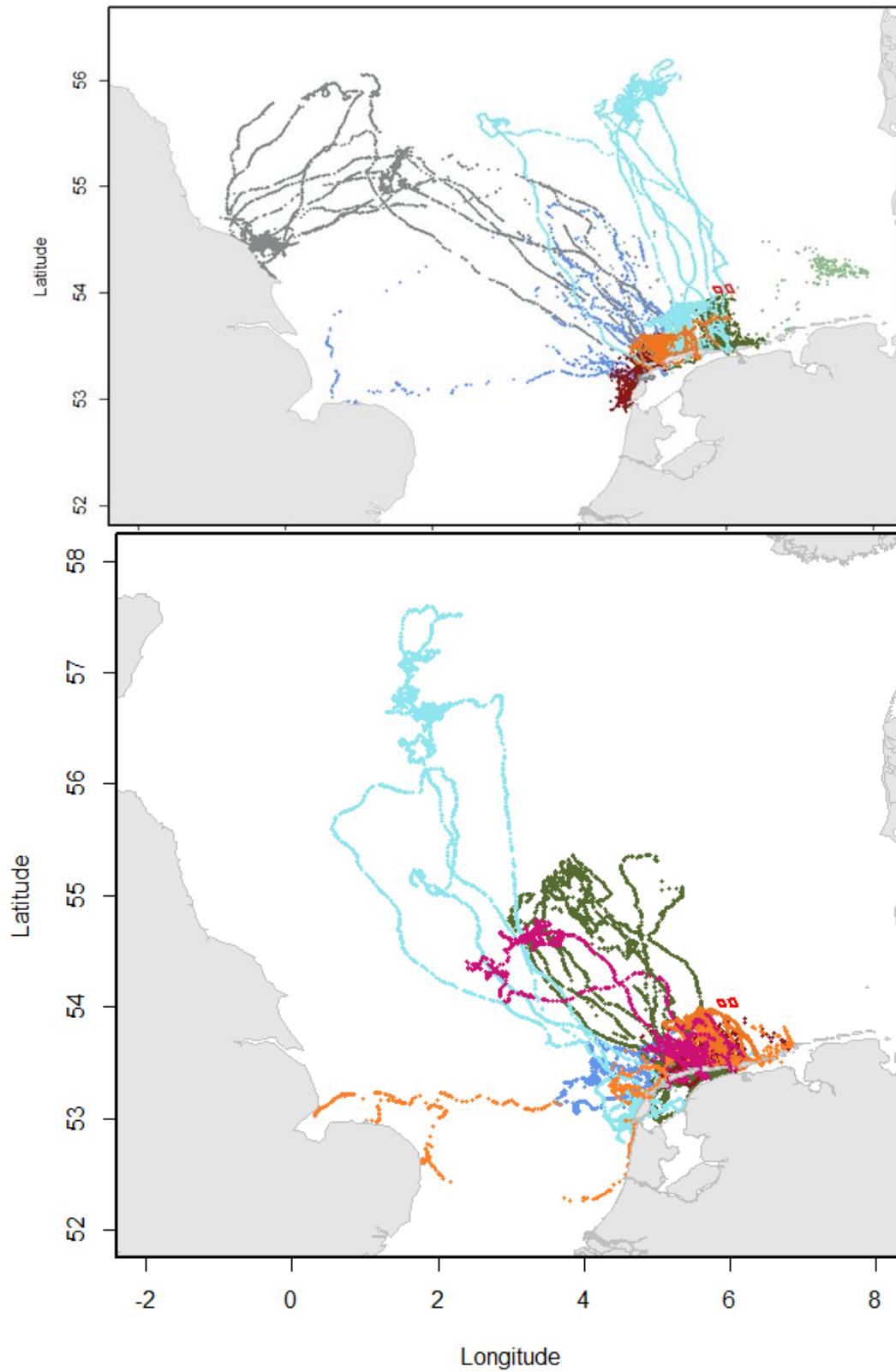


Figure 11. Locations recorded for grey seals tracked following tracker deployments in spring (top) and autumn (bottom) 2015.

Dive depth records from most grey seals tracked from spring (Figure 12 shows the data collected between 5° and 7° east) indicated a peak in dives to very shallow depths (<3 m). Overall maximum

depths achieved were approximately 60 m, although the two sub-adults that traversed to the UK occasionally dived deeper (max. approximately 90 m). Within the roughly similar depth ranges utilised, however, there was considerable individual variation in the depth most frequently visited, this also was the case in the vicinity of the windfarm (note the range of depths for the different coloured peaks in Figure 12).

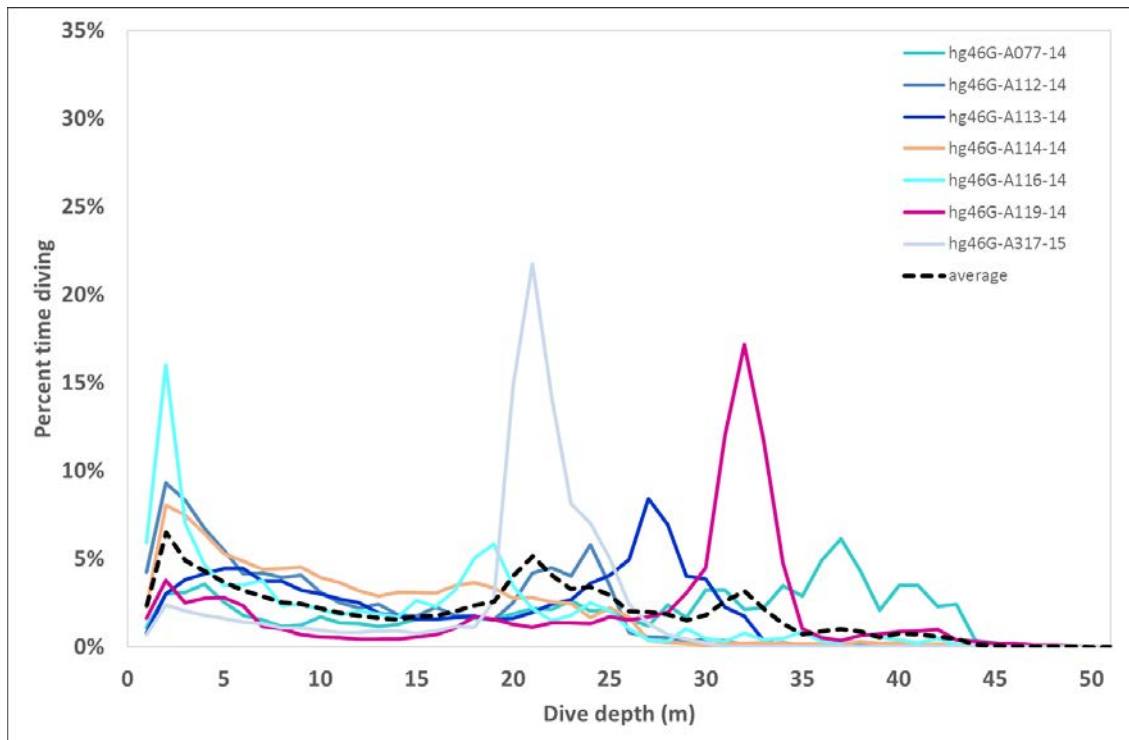


Figure 12. Percentage of dive-time spent diving between 5° and 7° east to a particular depth for individual grey seals tracked between April and November. Red tones indicate females; blue tones males (for details on individual seals see Table 4).

Of the nine grey seals tracked from autumn 2015, only one animal visited the coast of the UK, being one of the two adult females. During her single trip to the UK, this seal visited the breeding sites of Donna Nook and Blakeney Point, and a haul-out site close to Great Yarmouth. After returning to the Netherlands, this seal visited several breeding sites along the Wadden Sea, including the Cachalot Platte near Borkum. The second adult female could only be tracked for a short period before her transmitter failed. In that period, she remained close to shore. The only adult male tracked initially made three trips to approximately 230 km off shore, then, coinciding with the breeding period (Nov-Jan), remained not far from the Wadden Sea. Thereafter, it returned to its pattern of long-distance trips.

For the duration they were tracked, most of the sub-adults tracked from autumn remained within 70 km of the coast of the Wadden Sea, and west of Gemini. The only sub-adult female initially remained close to shore <20 km, then from mid-October onwards (coinciding with the end of pile driving) undertook slightly larger trips, out to approximately 50 km. One sub-adult male regularly approached Gemini feeding at approximately 60 km off the coast, while two others remained further west. Most impressive were two long trips conducted by one of these seals (14132), traveling >500 km out into the northern North Sea on trips that lasted 34 and 21 days. Sub-adult male *Seal 14144* was sighted on Blauwe Balg entangled in fishing material on 22 October 2015; after several capture attempts it was caught and the material removed on 25 January 2016 (Appendix A. Individual movement case study – entangled seal).

Despite being entangled, the seal undertook numerous foraging trips into the North Sea, including one to >200 km offshore that lasted 31 days.

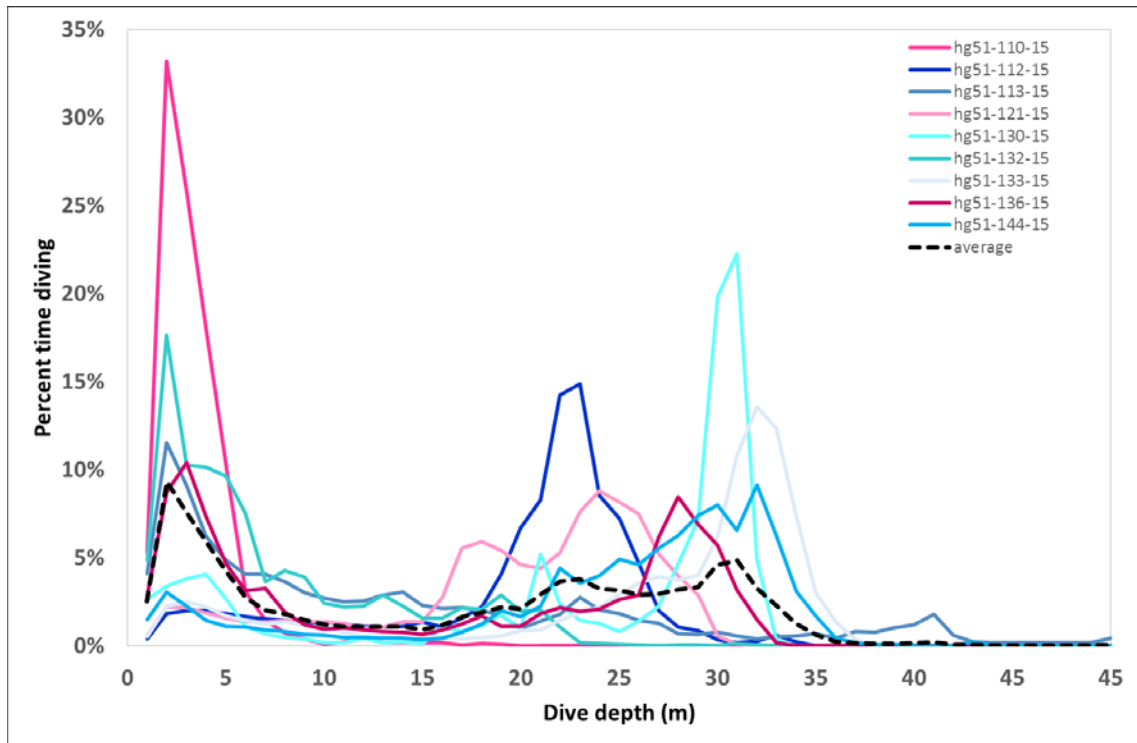


Figure 13. Percentage of dive-time spent diving between 5° and 7° east to a particular depth for individual grey seals tracked between September 2015 and February 2016. Red tones indicate females; blue tones males (for details on individual seals see Table 4).

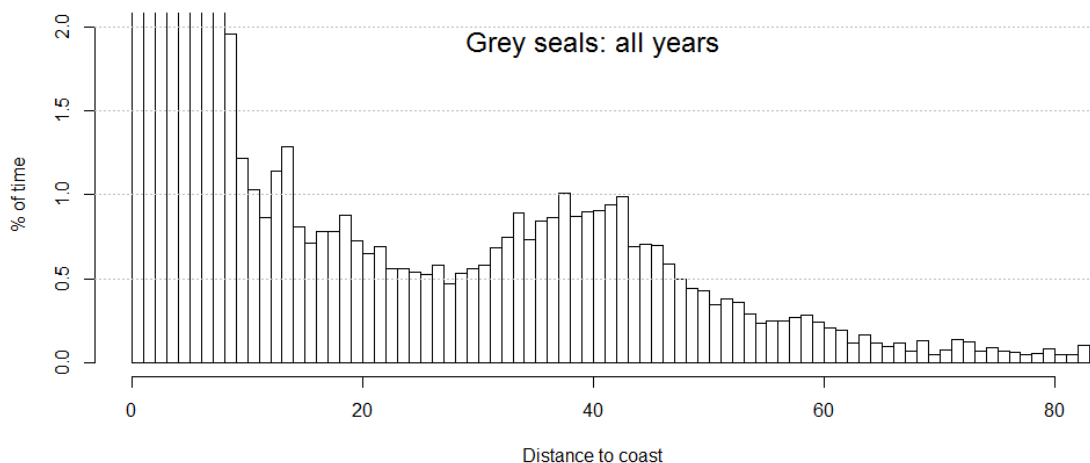


Figure 14. Distance to coast of the tracked grey seals (based on all GPS locations of all years, located between 5 – 7°E)

In the dive-depth records of grey seals tracked from autumn (Figure 13 shows the data collected between 5° and 7° east), again, most seals showed a peak at very shallow depths (<3 m). Individual

variation was also clear.. The sub-adult male that travelled to >500 km into the North Sea (14132) spent a considerable amount of time diving at depths of up to 100 m (west of 5° east, so not in the figure).

An investigation of the distances offshore that were most frequented by grey seals (all GPS tracking data combined, time spent at sea i.e. not haul-out on land) indicated that the vast majority of time was spent within 10 km of the coast (Figure 14). While seals ranged broadly out into the North Sea, there was a definite peak in utilisation of waters between 30 and 50 km from the coast.

- *Harbour Seals*

The harbour seals tracked from the Pinkegat and Blauwe Balg following autumn deployments provided movement data for the period September to December with two trackers also continuing into January (Figure 11). The two adult females stayed relatively close to shore, within 20 km, during the entire period they were tracked (Figure 15). One female left the area moving to a haul-out close to Den Helder and feeding off the coastal zone north of Egmond aan Zee windfarm (35 km to the south). Except for one adult male that moved to the Zeeland Delta area not long after the deployments, most adult male harbour seals remained in the area around Ameland and regularly travelled north-west up to 50 km off the coast. This overlapped quite a lot with the tracks of the sub-adult animals, although the two sub-adult males remained within 35 km of the coast.

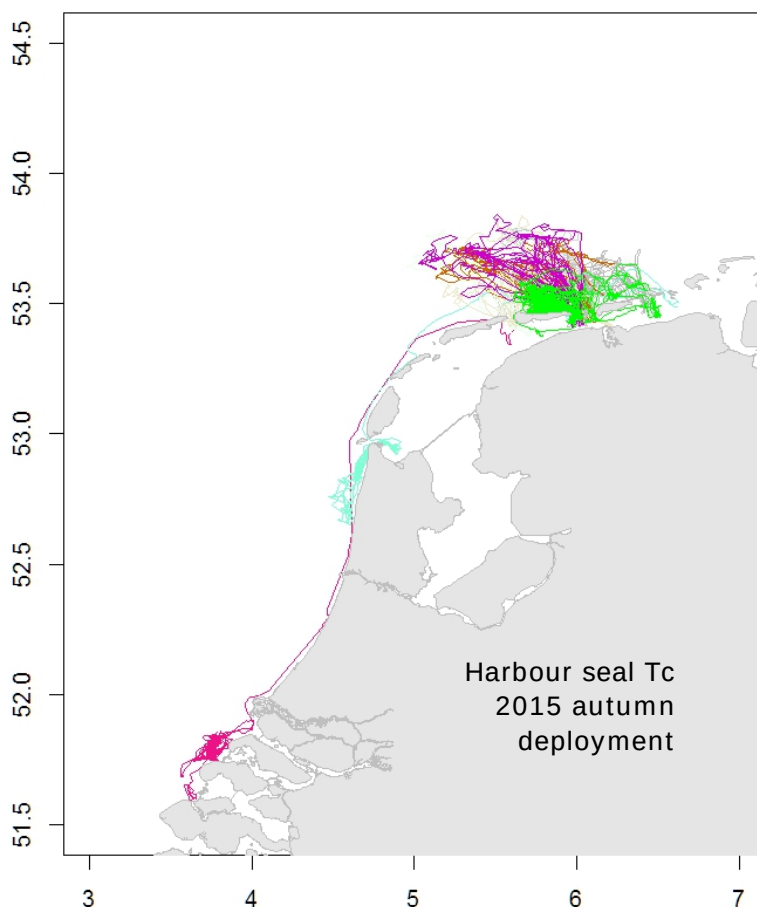


Figure 15. Locations recorded for harbour seals tracked following tracker deployments in autumn 2015.

The harbour seals' movements were reflected in their diving behaviour (Figure 16). Generally, they did not exploit water depths >40 m. The two adult females mostly dived to shallow depths, peaking at about 10 m, while the sub-adult female and the adult males that travelled further offshore dived slightly deeper, peaking between 20 and 35 m.

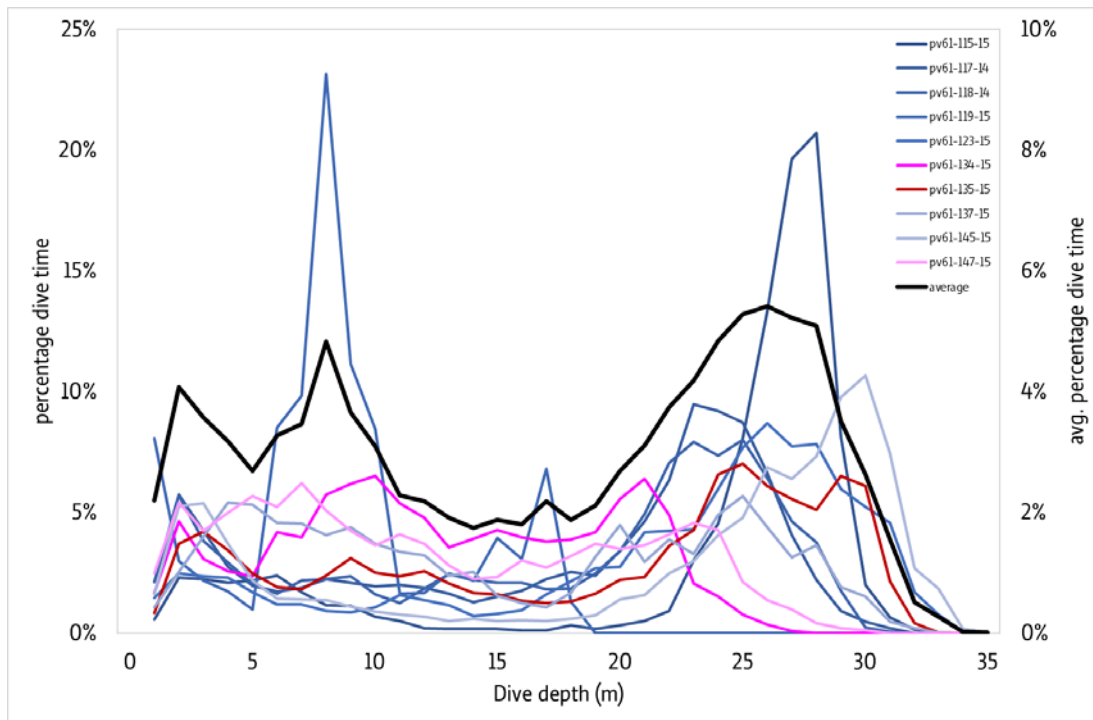


Figure 16. Percentage of dive-time spent diving between 5° and 7° east to a particular depth for individual harbour seals tracked between Sept. 2015 and Jan. 2016. Red tones indicate females; blue tones males (for details on individual seals see Table 4).

As with the grey seals, the majority of the harbour seals' time at sea was within 10 km of the coast (Figure 17). Beyond 10 km there was no apparent peak in time spent at a particular distance from the coast. Rather, there was a steady decline in utilisation with distance offshore.

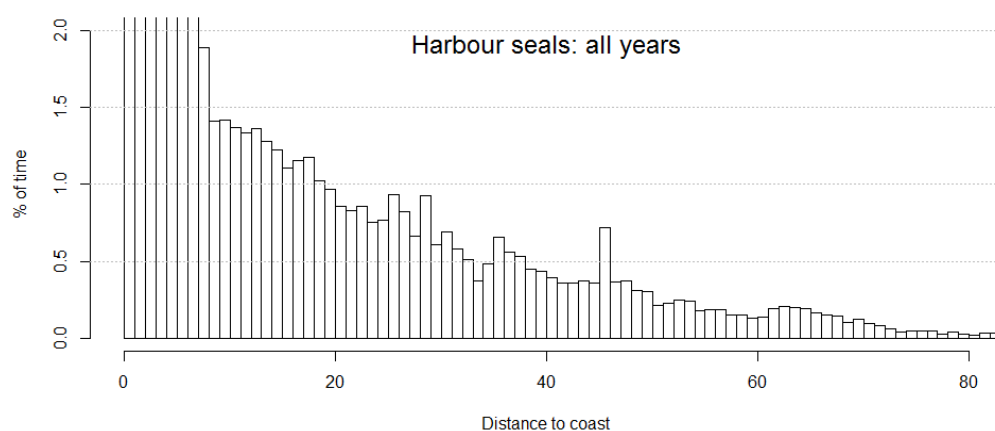


Figure 17. Distance to coast of the tracked harbour seals (based on all GPS locations of all years, located between 5 – 7 degrees Longitude).

3.3 Movement in relation to Gemini activities

The locations of tracked seals within years 2013, 2014 and 2015 (to highlight before during and after Gemini construction) are presented in Figures 13-15 for harbour seals and Figures 16-18 for grey seals.

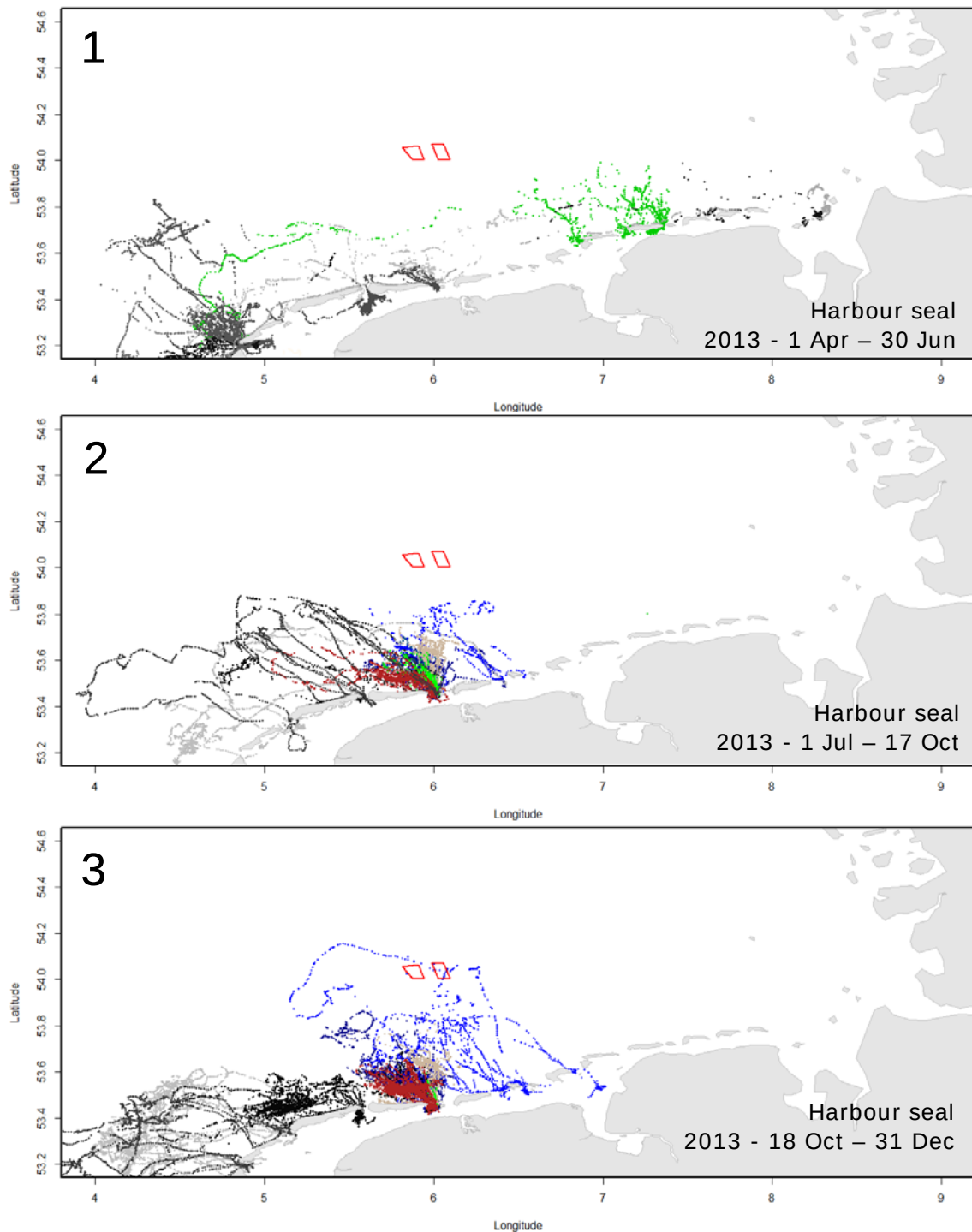


Figure 18. Harbour seal locations in 2013 separated into periods of the year, 1) prior to, 2) during and 3) after, the time of year when pile driving for li windfarm took place in 2015. Combined tracking data for Gemini and Luchterduinen windfarms.

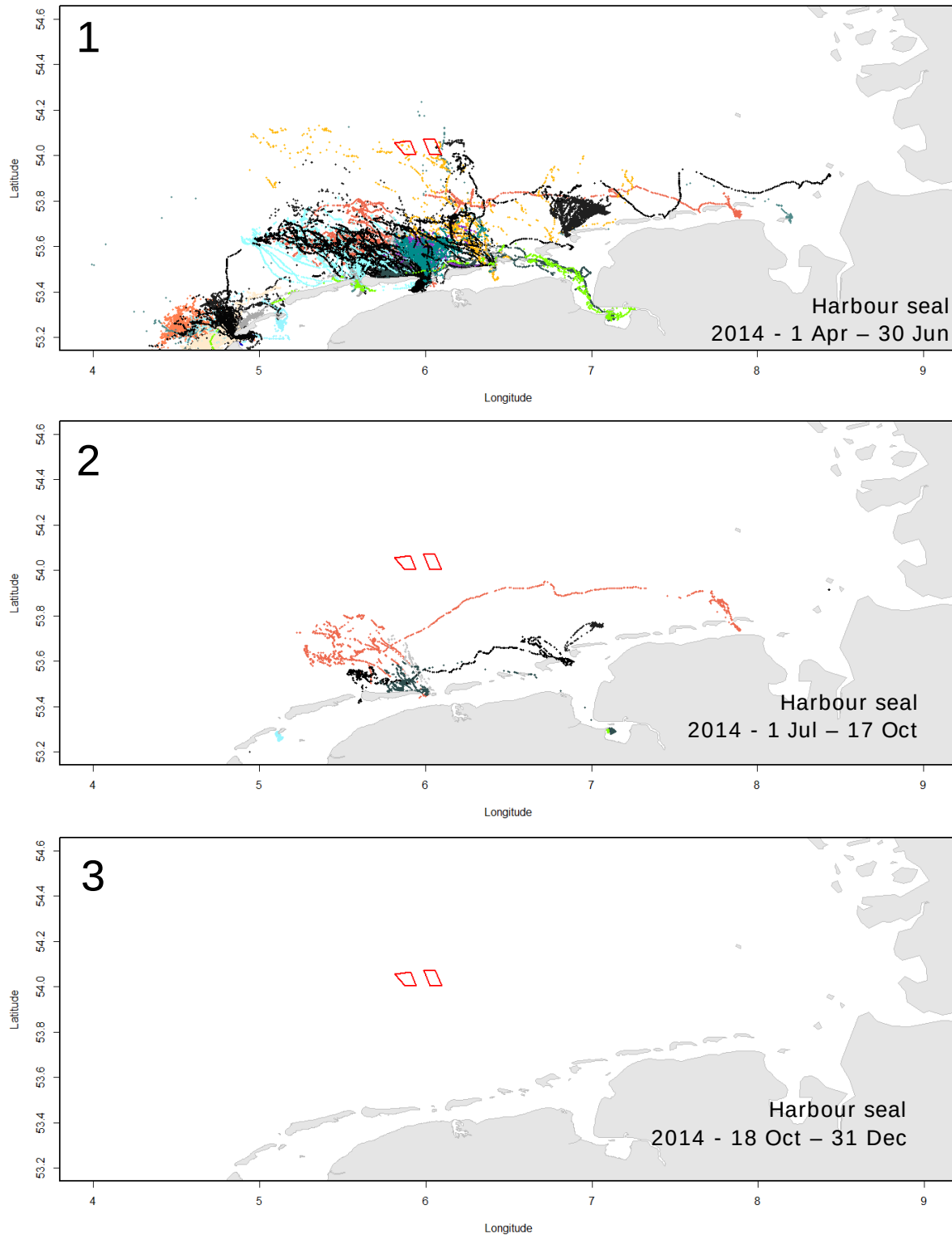


Figure 19. *Harbour seal locations in 2014 separated into periods of the year, 1) prior to, 2) during and 3) after, the time of year when pile driving for Gemini windfarm took place in 2015. Combined tracking data for Gemini and Luchterduinen windfarms.*

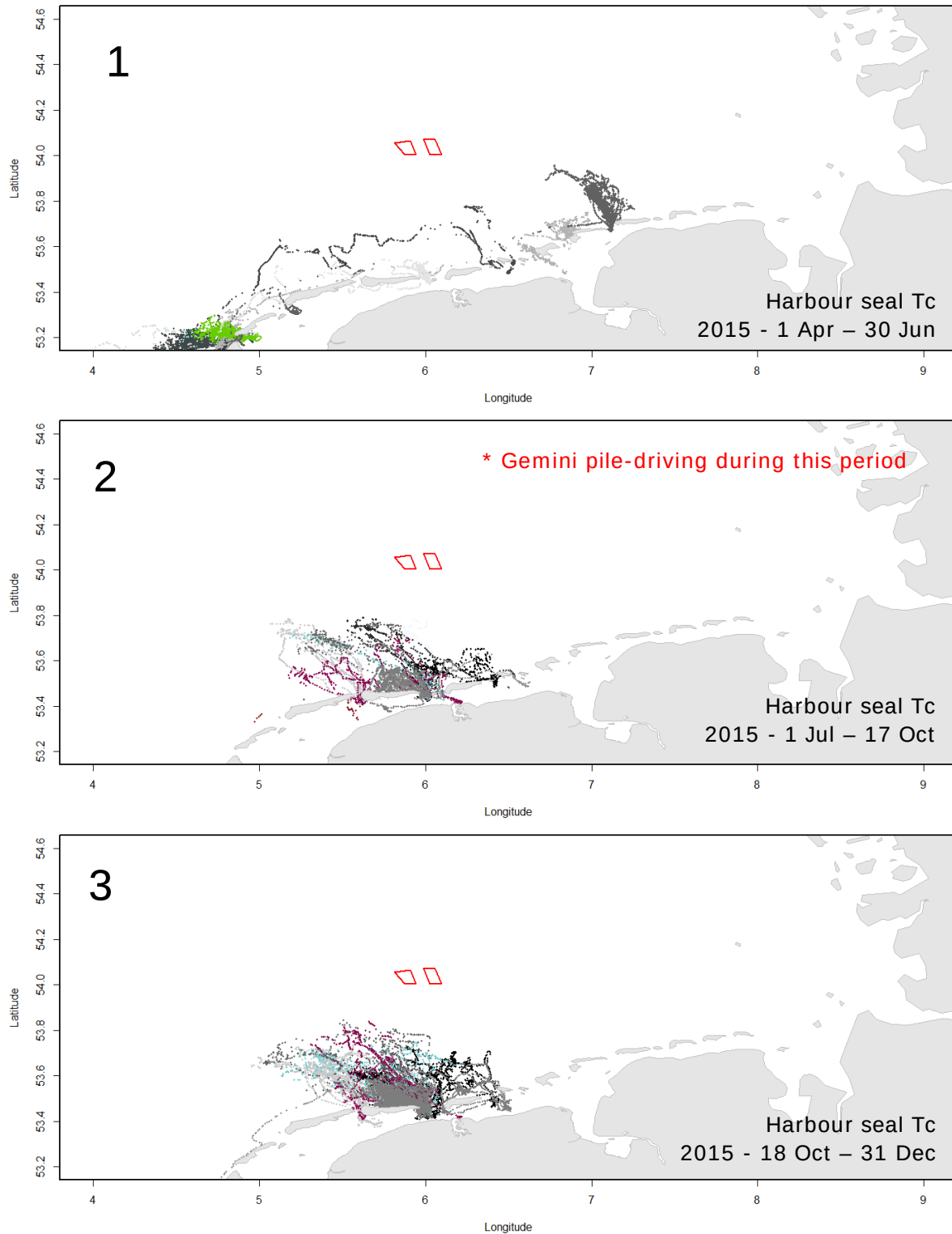


Figure 20. Harbour seal locations in 2015 separated into periods of the year, 1) prior to, 2) during and 3) after, the time of year when pile driving for Gemini windfarm took place in 2015. Combined tracking data for Gemini and Luchterduinen windfarms.

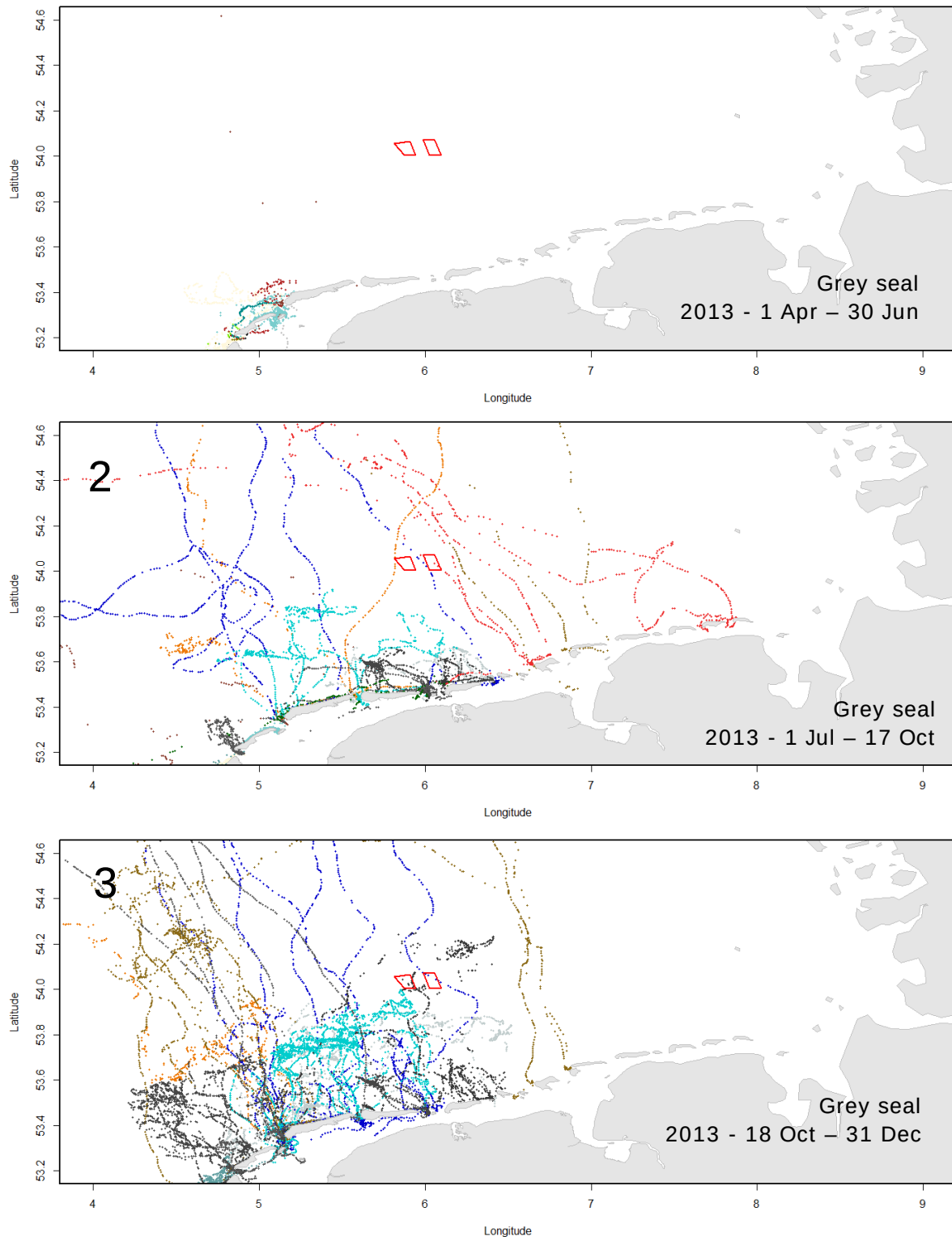


Figure 21. Grey seal locations in 2013 separated into periods of the year, 1) prior to, 2) during and 3) after, the time of year when pile driving for Gemini windfarm took place in 2015. Combined tracking data for Gemini and Luchterduinen windfarms.

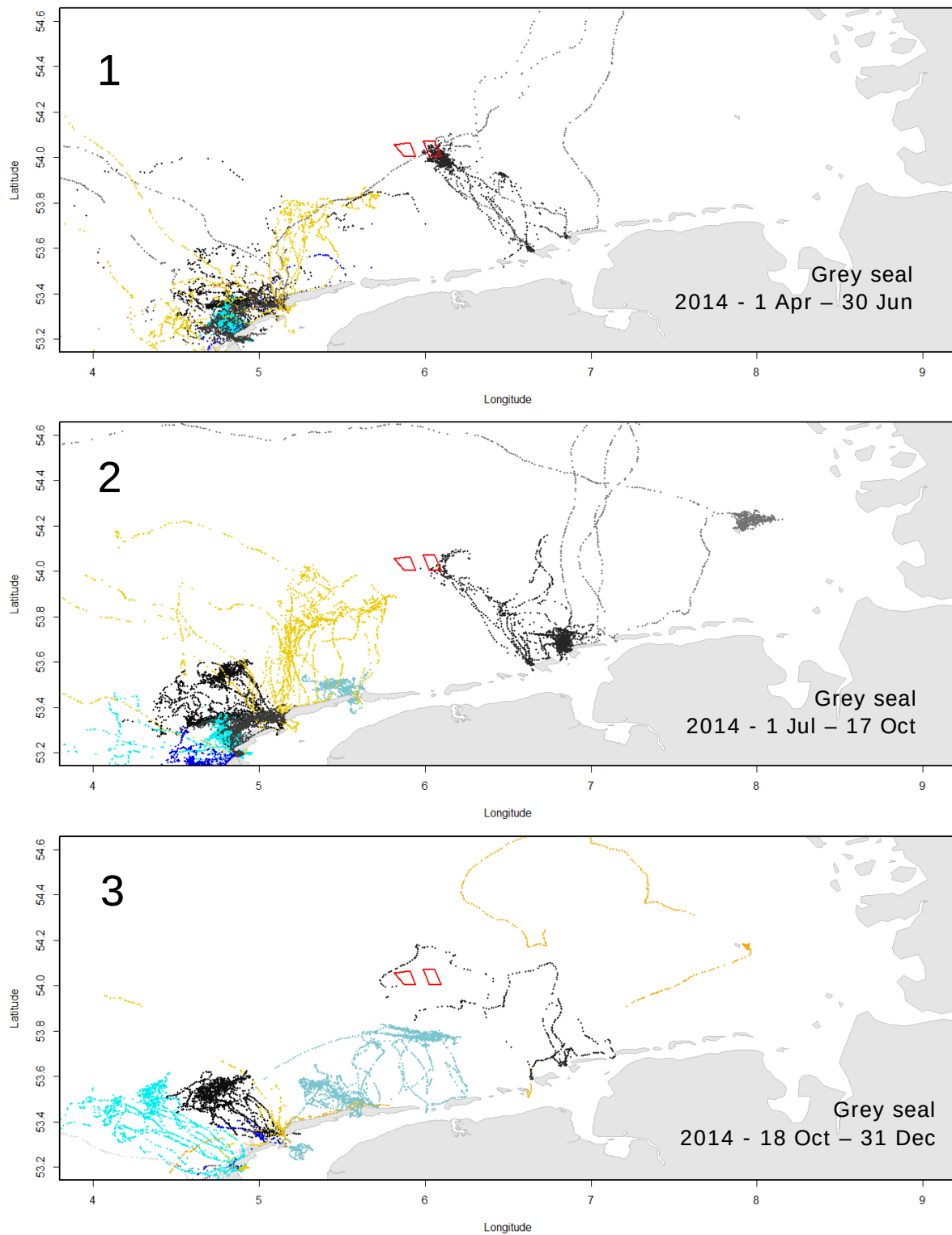


Figure 22. Grey seal locations in 2014 separated into periods of the year, 1) prior to, 2) during and 3) after, the time of year when pile driving for Gemini windfarm took place in 2015. Combined tracking data for Gemini and Luchterduinen windfarms.

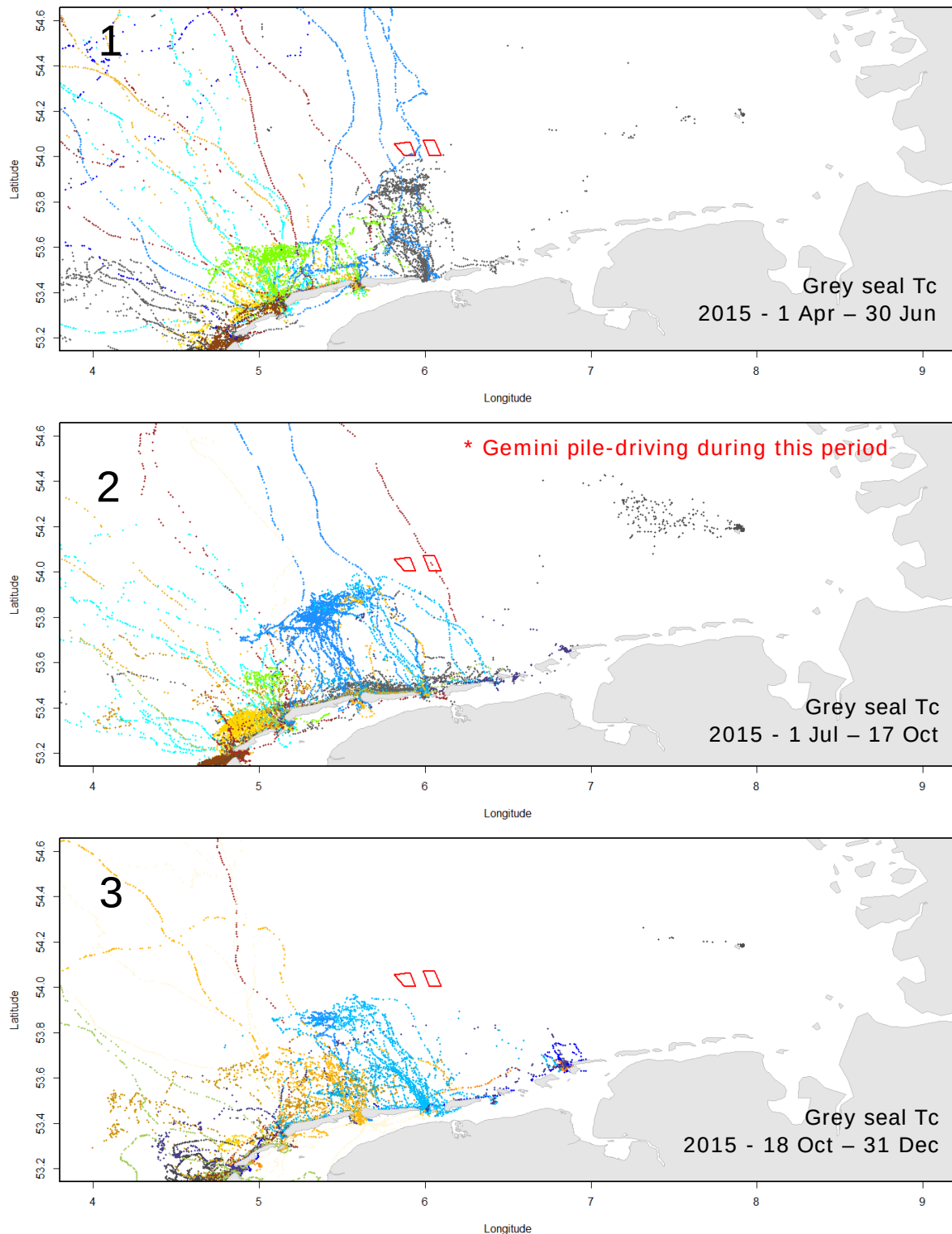


Figure 23. Grey seal locations in 2015 separated into periods of the year, 1) prior to, 2) during and 3) after, the time of year when pile driving for Gemini windfarm took place in 2015. Combined tracking data for Gemini and Luchterduinen windfarms.

3.4 Direct response of seals to pile driving

During the pile driving events, there were 184 records of a seal (either harbour or grey) being within 50 km of the pile driving, defined in this study as an encounter (Table 7). 59 encounters were within 40 km from the pile driving site, when pile driving was active. These encounters occurred during 70 (42% of all pile driving) pile driving events and during the remaining 96 (58%) pile driving events no tracked seals were within a range of <50 km.



Figure 24. Track of grey seal hg46-13119 during exposure to 42 piling events at <50 km, 16 of which at <40 km.

In total, twelve seals were exposed to pile driving within 50 km, comprising six harbour seals and six grey seals (Table 7). Eight of these seals were also within 40 km of active pile driving: two harbour seals and six grey seals.

Table 7. Encounters: Seals exposed to Gemini pile driving at <50 km and <40 km from the pile driving site.

Species	Individual	Exposures at <50 km	Exposures at <40 km
Grey seal	hg46-13113	2	2
Grey seal	hg46-13119	42	16
Grey seal	hg51-14121	2	
Grey seal	hg51-14133	23	17
Grey seal	hg51-14136	6	3
Grey seal	hg51-14144	13	7
Harbour seal	pv61-14115	16	7
Harbour seal	pv61-13117	7	5
Harbour seal	pv61-13118	1	
Harbour seal	pv61-123-15	1	
Harbour seal	pv61-14135	1	
Harbour seal	pv61-14137	1	
Harbour seal	pv61-14145	10	2
Total encounters		125	59

Most exposures were received by one grey seal: hg46-13119 (Figure 24). This seal spent most of its time at sea during the pile driving period in an area 35 to 55 km offshore from the Wadden Sea and 25 to 80 km south-west of Gemini. It received 42 exposures to pile driving events at distances <50 km, including 16 at distances <40 km.

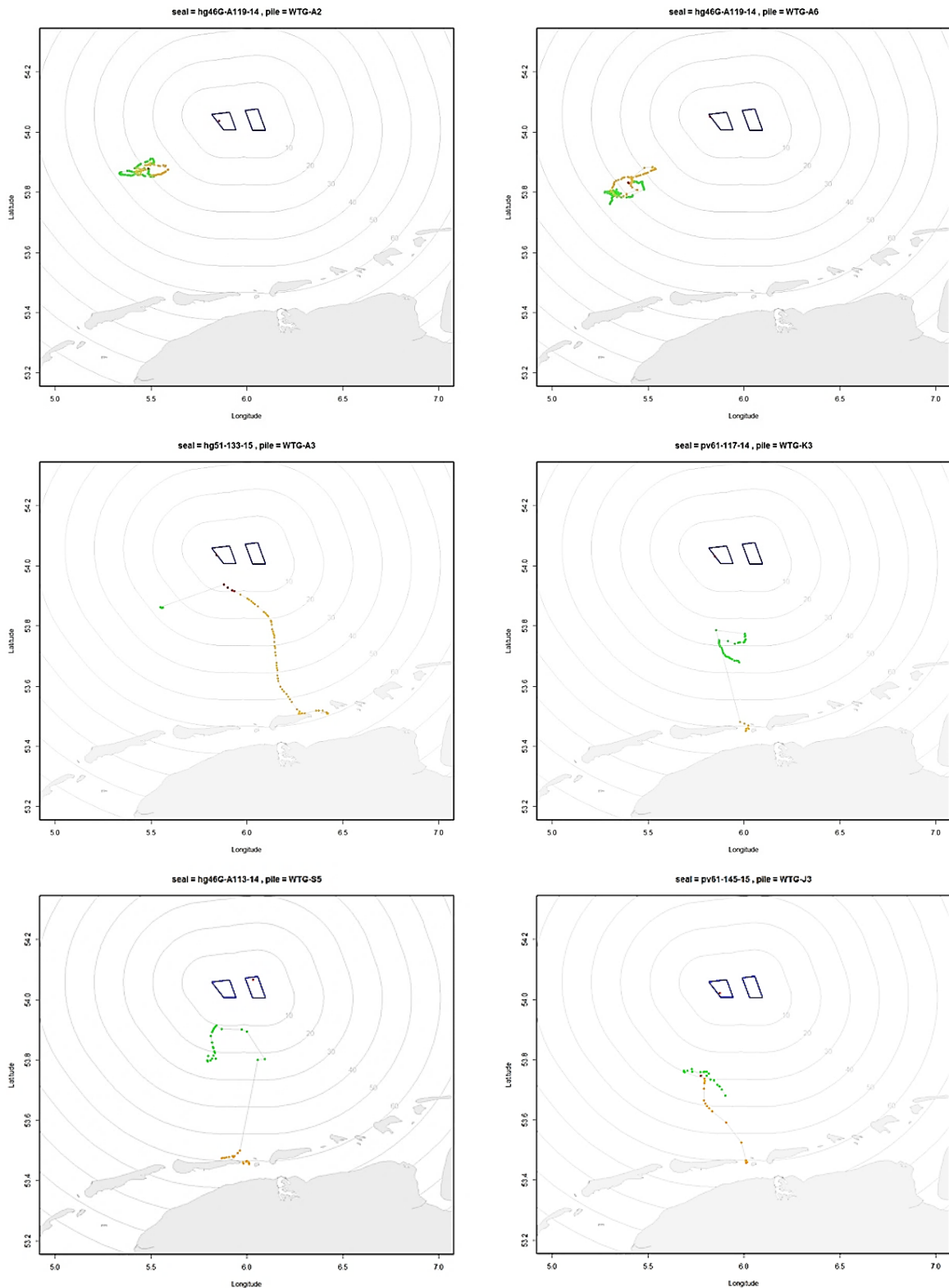


Figure 25. Examples of six seal tracks prior to (24 h, green), during (red) and post (24 h, orange) pile driving. The top two indicate no apparent response to the pile driving while the bottom four could indicate flight from the sound of the pile driving.

For each seal and each pile driving event a map was made showing the seals track prior to (24 h), during and post (24h) pile driving (Figure 25). Some seals showed no clear avoidance of the pile driving site,

remaining in the same general area (top 2 figures), while others appeared to flee in response to the pile driving towards the Frisian Islands during or after pile driving (bottom 4 figures).

To summarize these results, the swimming direction from the last point before piling (the last green dot in Fig. 25) to first point after piling (i.e. the first orange point in Fig. 25) was determined to observe if changes would occur (Figure 26). Several grey seals were in relative close proximity (<30 km) during pile driving. Again, large individual variability was apparent with some seals swimming away from the pile driving site, while others swim parallel to the windfarm. Few tracked harbour seals were near the Gemini windfarm during pile driving events, all beyond 20km.

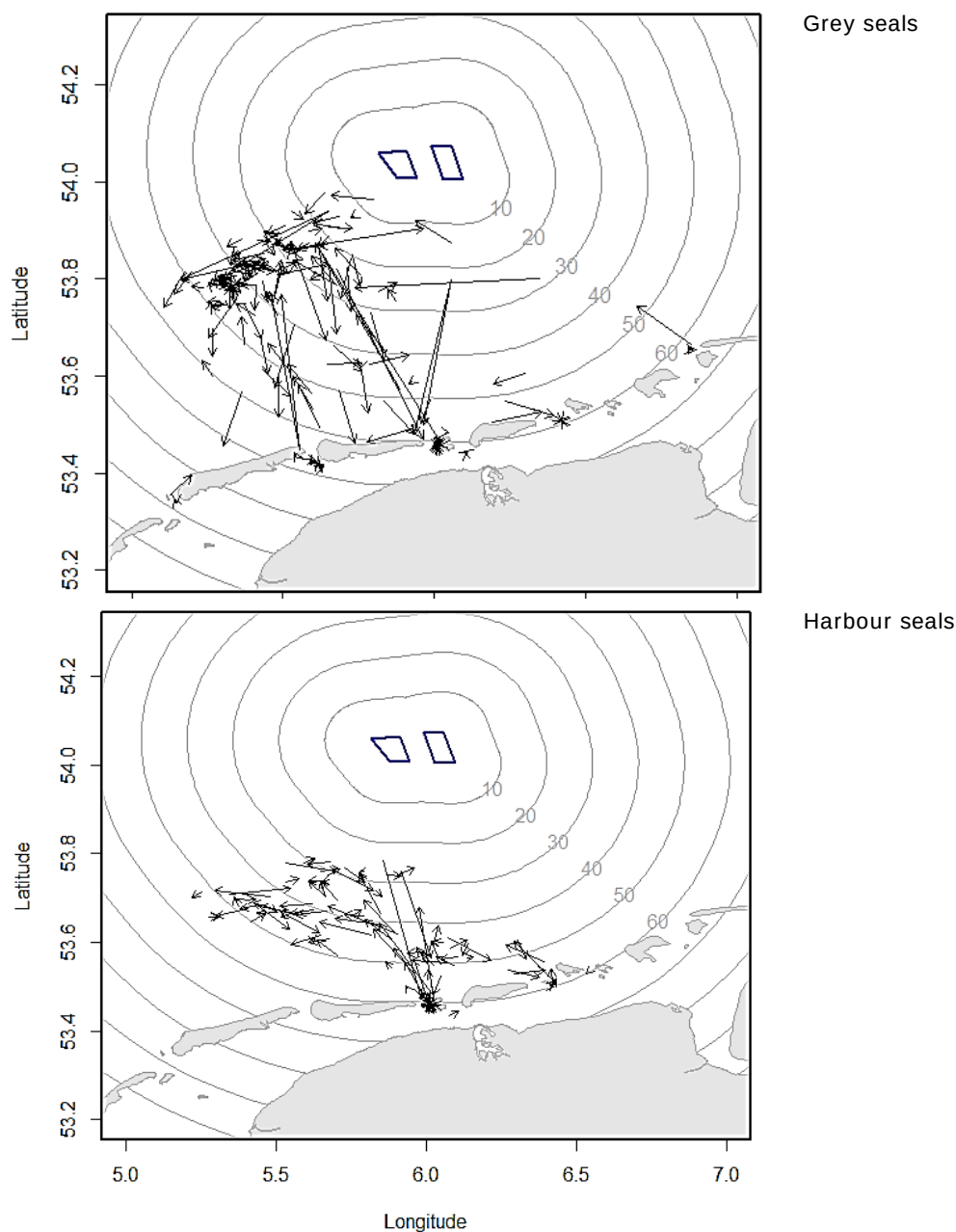


Figure 26 Direction of movement of grey (top) and harbour (bottom) seals in relation to pile driving events of Gemini windfarm.

Figure 27 shows the direction of travel of seals in the vicinity of the Gemini windfarm, when pile driving is active. On the circles, “0” indicates the seal swam towards the active pile driving site, “180” indicates the seal swam in the opposite direction. Particularly for grey seals within 30km, there is an overall tendency to swim away from the pile driving activity (Rayleigh test of Uniformity, $z=0.5403$, $p=0.0015$).

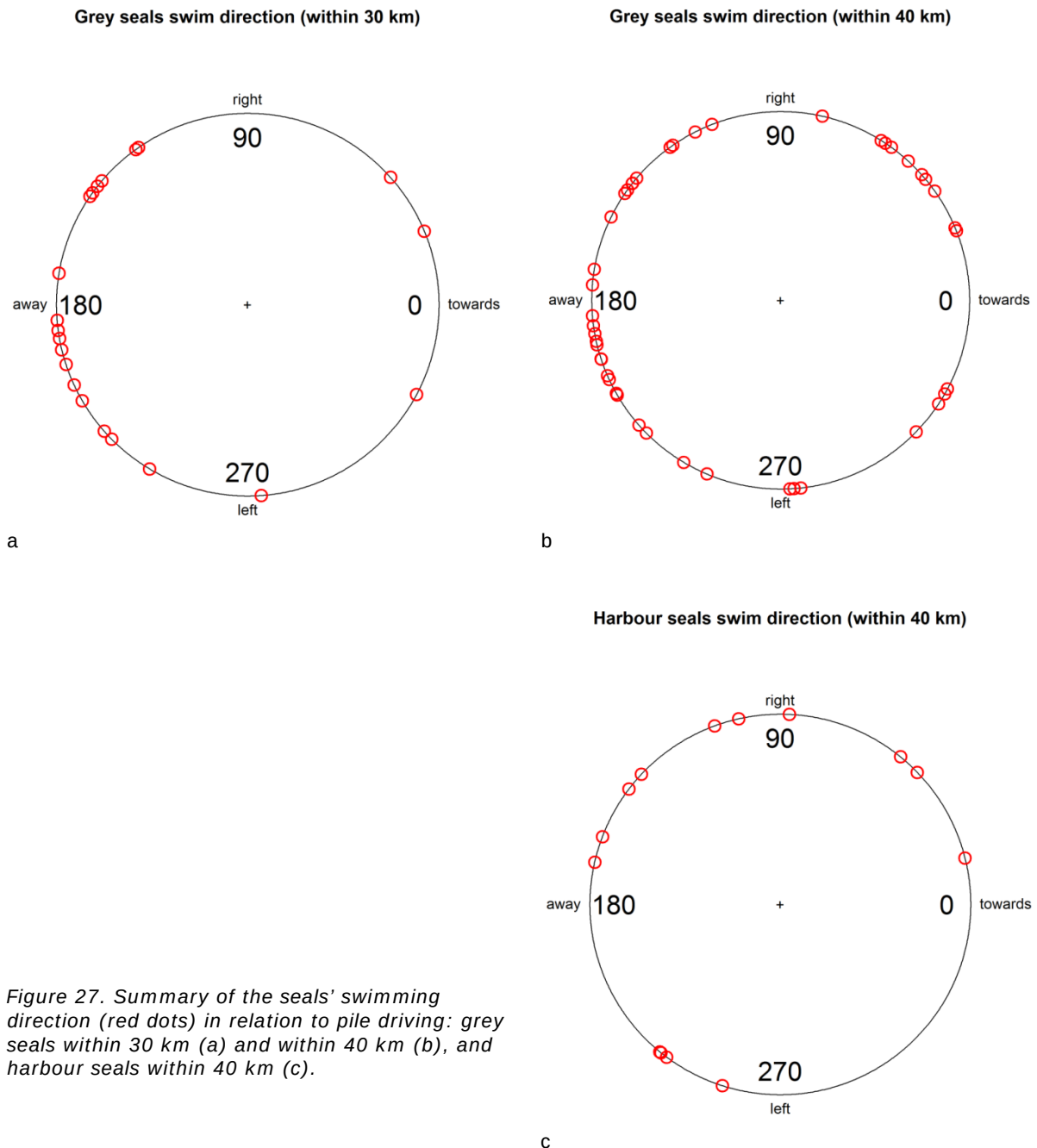


Figure 27. Summary of the seals' swimming direction (red dots) in relation to pile driving: grey seals within 30 km (a) and within 40 km (b), and harbour seals within 40 km (c).

The circle diagrams show the direction of travel relative to the Gemini windpark (Figure 27). For at least grey seals exposed within 30km distance of the pile driving site, an indication of avoidance (i.e. more swim directions clustered around 180 degrees away from the source) appears present. This was tested using a Rayleigh Test of Uniformity (Jammalamadaka et al. 2001). Results show that for grey seals both within 40 km and 30 km the seals swam significantly more often away from the pile driving (respectively, 40 km: test statistic 0.2691; P-value 0.0375, N=45, and 30 km: test statistic 0.54; P-value: 0.0015, N=21). For harbour seals this was not significant (at <40 km; test statistic 0.3537; P-

value: 0.1749, N=14). It should be noted that the sample size for harbour seals was low, since few harbour seals were in the vicinity, and this reduced the power for a statistically significant change to be recorded.

One seal that was tracked as part of the monitoring program for Luchterduinen windfarm traversed through one of the Gemini windfarms during the pile driving period (Figure 28). However, it did so during a period when no pile driving took place. Pile driving events occurred during the seals approach toward Gemini, when it was 320 km north and 170 km north, and after the seal had haul-out at a sandbar in the Wadden Sea.

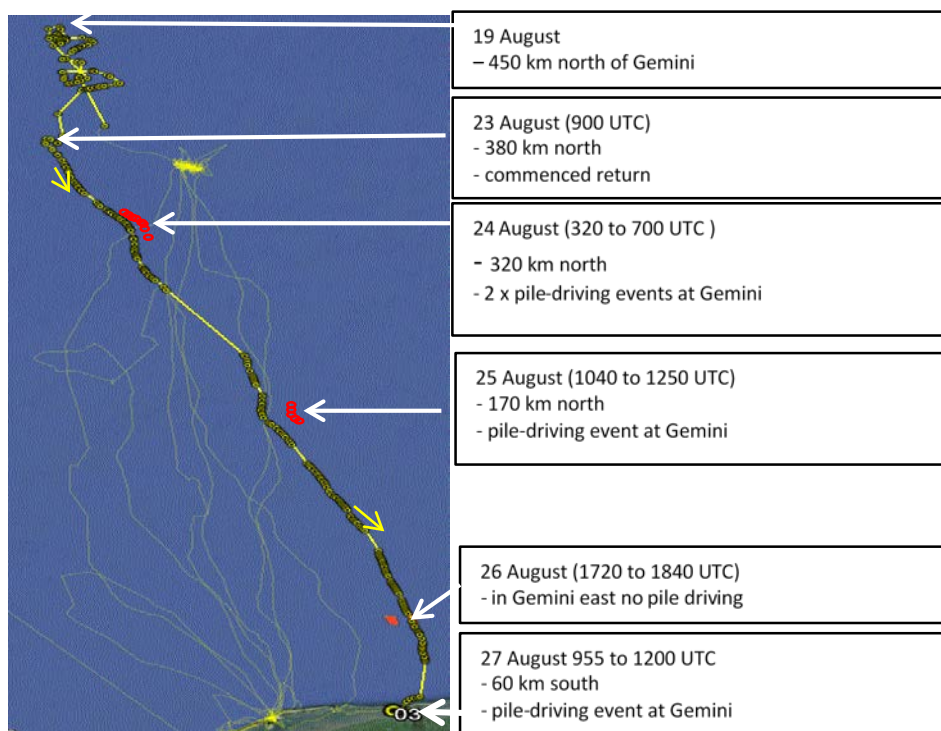


Figure 28. Passage of grey seal hg43L-03 (sub-adult female – tracked for Luchterduinen) returning to the Wadden Sea in August and passing through Gemini windfarm.

3.5 Diving activity in relation to pile driving

As described above, the group of grey seals tracked from spring were followed before pile driving started and then during pile driving, and two seals continued to be tracked in the area following the cessation of Gemini pile driving. Hence, there was the potential to record the initial reactions and adaptations in behaviour in response to the pile driving at Gemini for these seals. In contrast, the grey and harbour seals tracked from autumn deployments may have adapted their movement to the pile driving activities prior to the tracking. These seals were followed during the last month of pile driving and then for some time after pile driving had ceased. To further investigate diving behaviour in proximity to Gemini, i.e. between 5-7°E, in relation to pile driving, the dive records were split into before pile driving, during pile driving and after pile driving.

Dive data for the grey seals tracked from spring (before, during and after pile driving) are presented in **Error! Reference source not found.**, and seals monitored from autumn (during and after pile driving) are presented in **Error! Reference source not found.** for grey seals and Figure 30 for harbour seals.

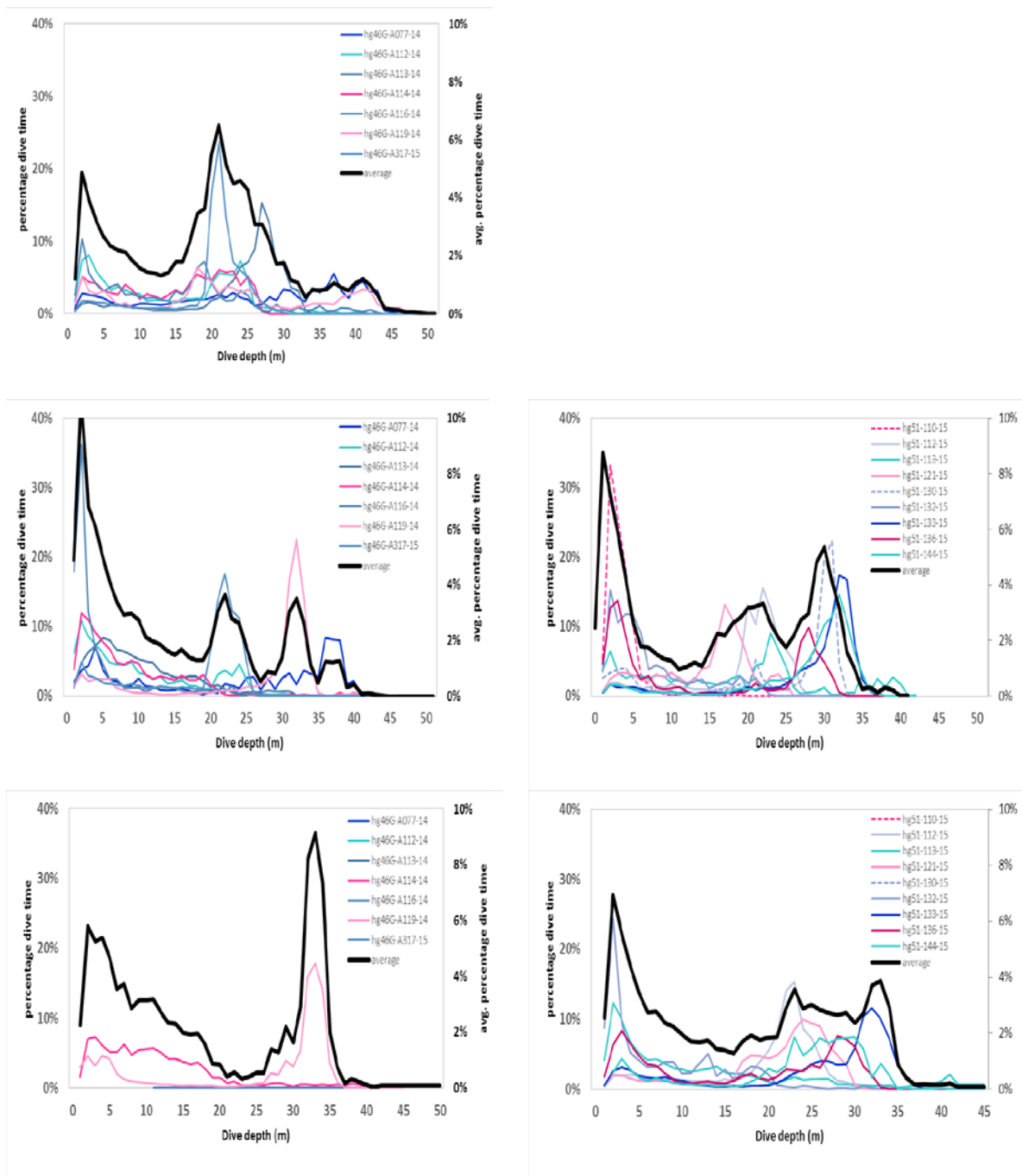


Figure 29. Percentage of dive-time spent going to a particular depths for individual grey seals tracked in the vicinity of Gemini (i.e. between 5-7°). Left column: between April and November, right column: between September and December. Data are distinguished between before (top), during (middle) and after (bottom) pile driving period for Gemini. Black line indicates the average (right axis). Red tones indicate females; blue tones males (for details on individual seals see Table 4). Trackers that stopped functioning before the end of a period, were given a dashed line.

Numerous patterns and conflicting behaviours are evident in the presentations of the dive depths utilised in the vicinity of Gemini before, during and after pile driving. Perhaps the strongest uniform pattern is that for harbour seals which, during pile driving indicated a spread of patterns with a range of depths that were most frequented, between 8 and 30 metres. Both species seem to show a greater tendency for

shallower dives during pile driving. After pile driving had ceased, there was greater uniformity in the patterns, with the most frequented depths for virtually all harbour seals being between 22 and 30 m.

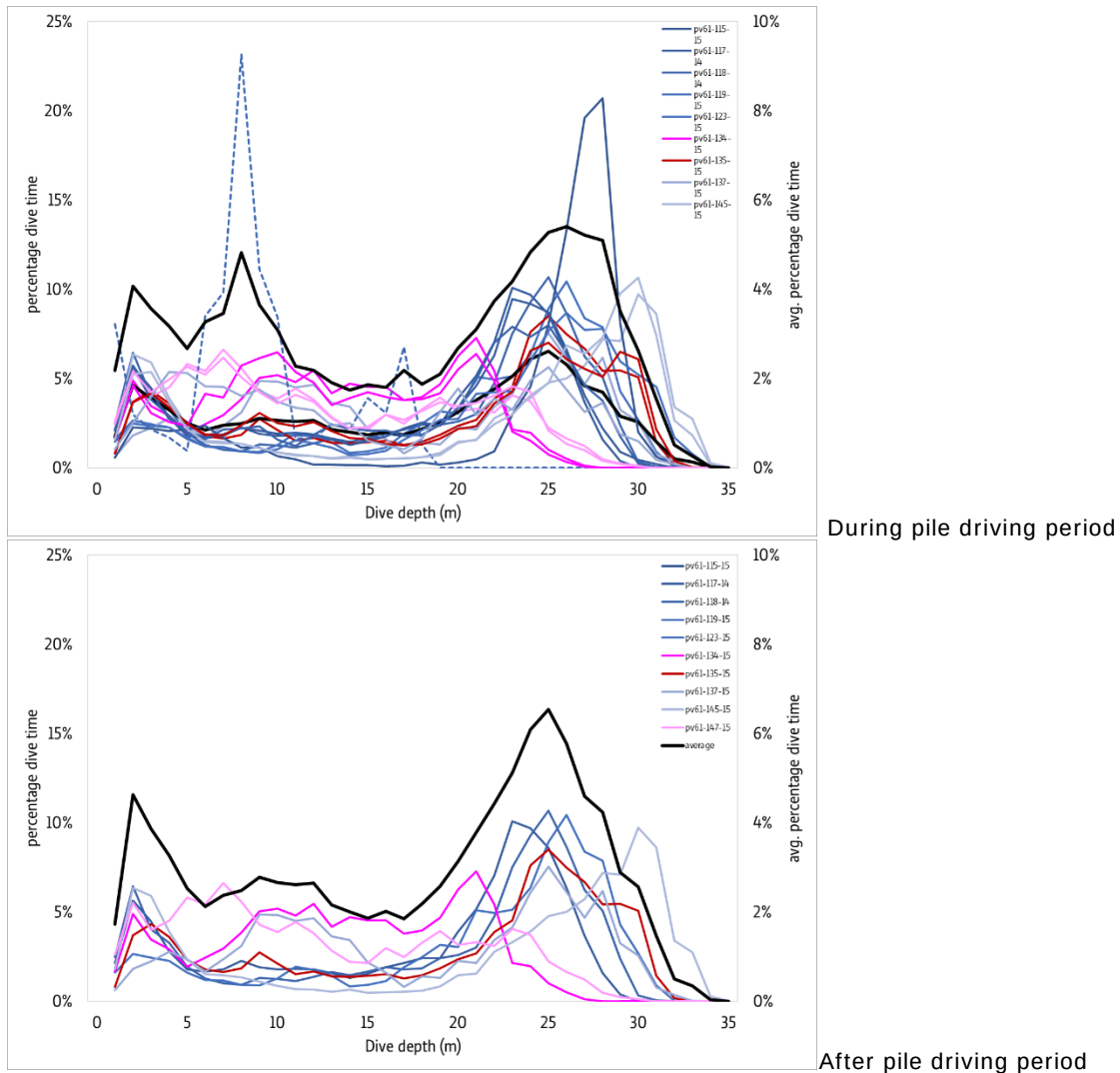


Figure 30. Percentage of dive-time spent going to a particular depths for individual harbour seals tracked between September and December in the vicinity of Gemini (i.e. between 5-7°). Red tones indicate females; blue tones males (for details on individual seals see Table 4). Data are distinguished between during (top) and after (bottom) pile driving for Gemini. Trackers that stopped functioning before the end of pile driving, were given a dashed line.

4. Long-term seal activity in and around the Gemini windfarm site

Since 2008, many seals of both species were tracked in the framework of different projects in the Netherlands. Few data were collected in a period without windfarm construction or operational activity (Figure 31). It is most likely that the seals experienced and potentially responded to some extent to these activities during the tracking. Figure 1 and Table 1 show the locations and specifics of these activities. Figure 31 shows for example that during T0 two other windfarms were being built less than 100km away from Gemini and during the Gemini pile driving and shortly after, again two windfarms were in construction. It goes beyond the scope of this rapport to analyse the effect of all the other sites in detail. Therefore, we concentrated on the Gemini piling events. However, if the aim is to understand the effect of the windfarms on the seals' habitat use it will be necessary to study the (cumulative) effect of all these activities.

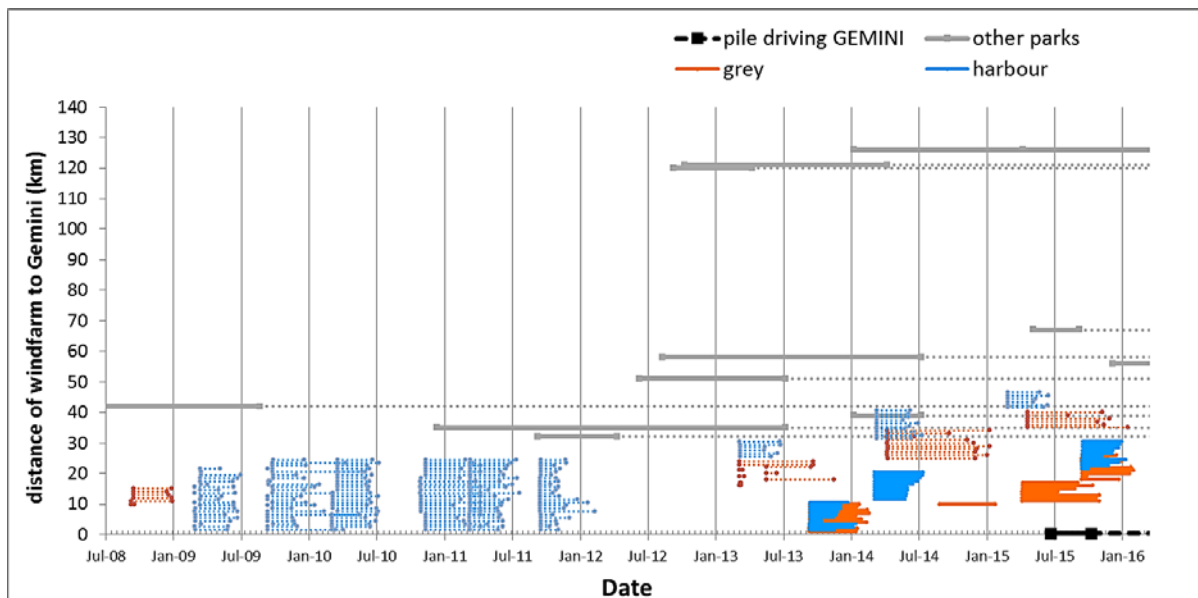


Figure 31. Temporal overlap of all seals tracked 2008-2016 and windfarm construction in the area around Gemini. Construction period: solid grey line. Post construction: dashed grey line. Gemini in black. Y-axis shows the distance of the windfarms to Gemini site. Seal tracking effort is represented in red lines (grey seals) and blue lines (harbour seals). For seals, each line represents one animal; the y axis is not relevant, solid lines represent seals tagged for the Gemini project dashed lines, other projects.

Locations recorded for all seals tracked in the vicinity of Gemini windfarm were collated (Figure 32). Gemini appears to be at the northern boundary of an area of the North Sea, adjacent to the Wadden Sea that was frequented by both species.

By far, the most data on seal movement in the vicinity of Gemini windfarm are available for harbour seals. We therefore further analysed the distribution of the harbour seals with respect to their distance to the coast in different years (Figure 33). Movement data for the harbour seals during the year of Gemini pile driving differs from all other years in that the seals did not utilise waters at distances >50 km from the coast. It is difficult to conclusively assign the reason for this as being a response to pile driving for Gemini, however. Possibly, responses to other human activities in the area along with inter-annual variability in habitat use also influenced inter-annual variability in the distances offshore in which the harbour seals spent their time.

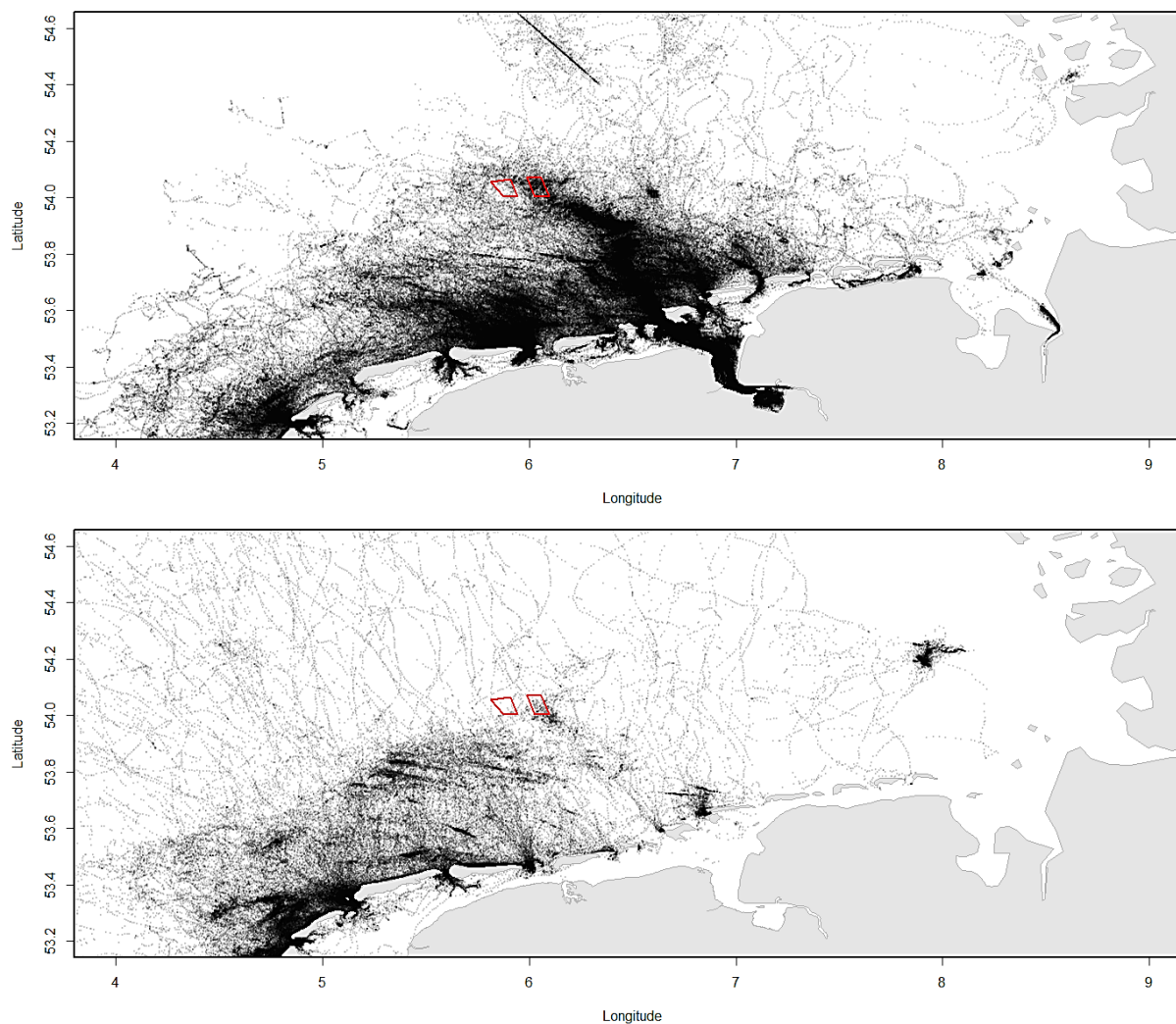


Figure 32. Locations in the vicinity of Gemini windfarm that have been recorded for 1) harbour seals, 2) grey seals, during GPS tracking of seals since 2007.

As mentioned in the introduction, Gemini was not the first windfarm to be constructed in the German Bight. Ten other windfarms were constructed in adjacent German waters between 2007 and 2015. To investigate the potential that these could have influenced the movements of harbour seals that were tracked for Gemini windfarm seal monitoring, as well as previous harbour seal tracking studies, locations recorded for these seals in the documented construction period for the ten other windfarms (Table 1) were compared (Figure 34). Determinations from these presentations would be enhanced if more information were available on the actual days/ times within the published foundation installation periods, pile driving occurred. However, overall a degree of avoidance of the areas where windfarms were installed during the installation periods is apparent.

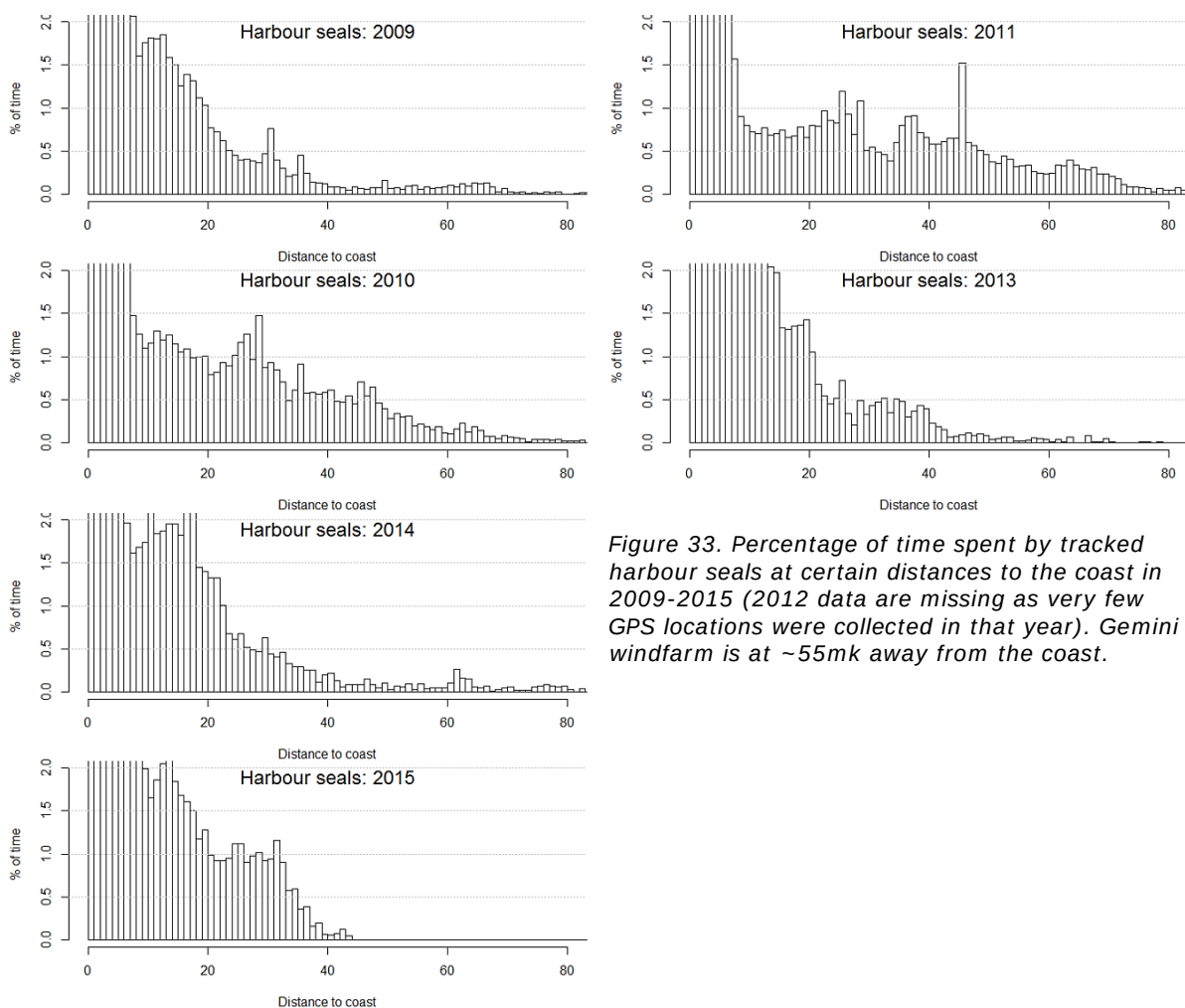


Figure 33. Percentage of time spent by tracked harbour seals at certain distances to the coast in 2009-2015 (2012 data are missing as very few GPS locations were collected in that year). Gemini windfarm is at ~55mk away from the coast.

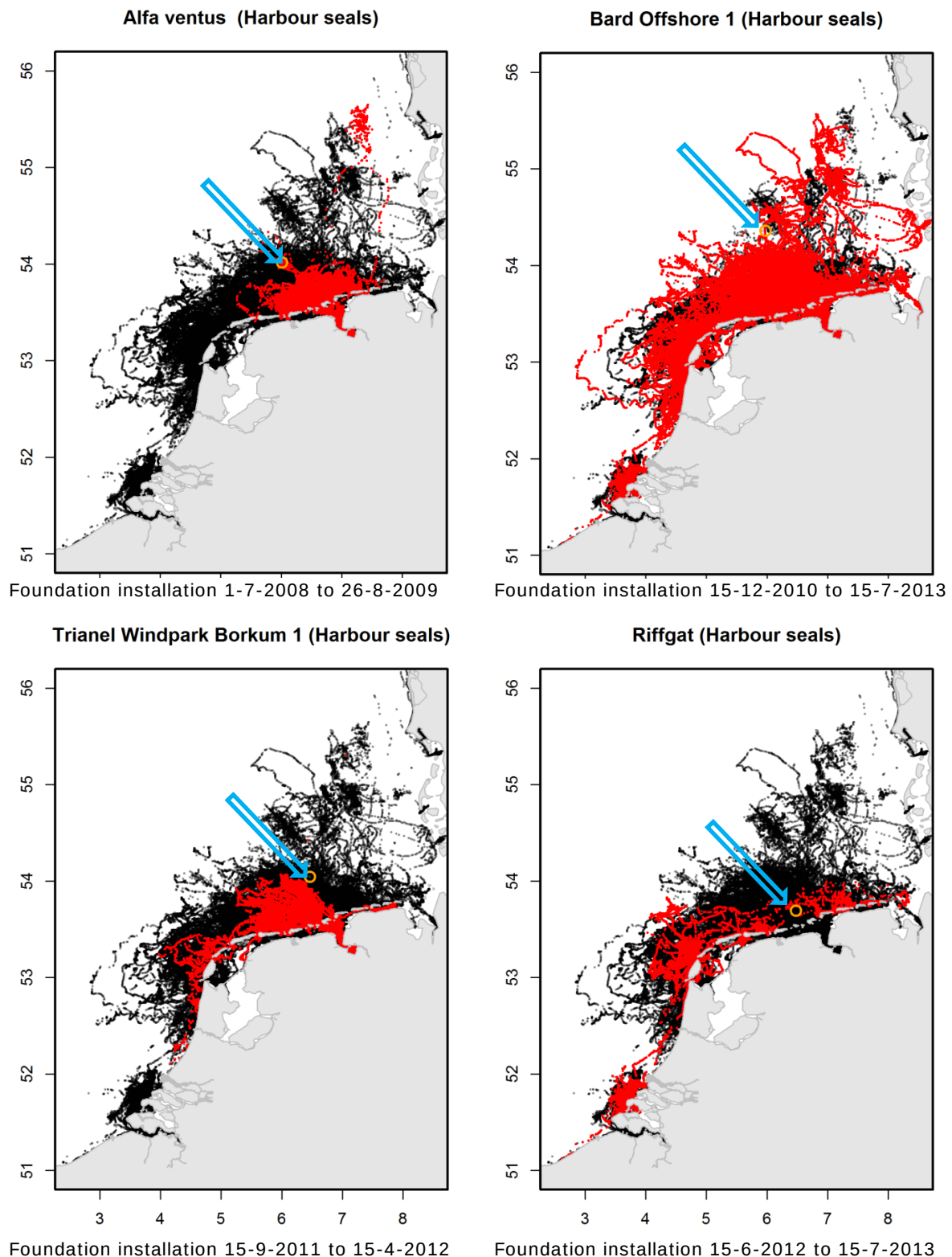


Figure 34. Maps showing all locations collected using GPS trackers for harbour seals (black) and locations during the foundation installation period of a windfarm (red). The windfarm location is the orange circle, indicated by the blue arrow.

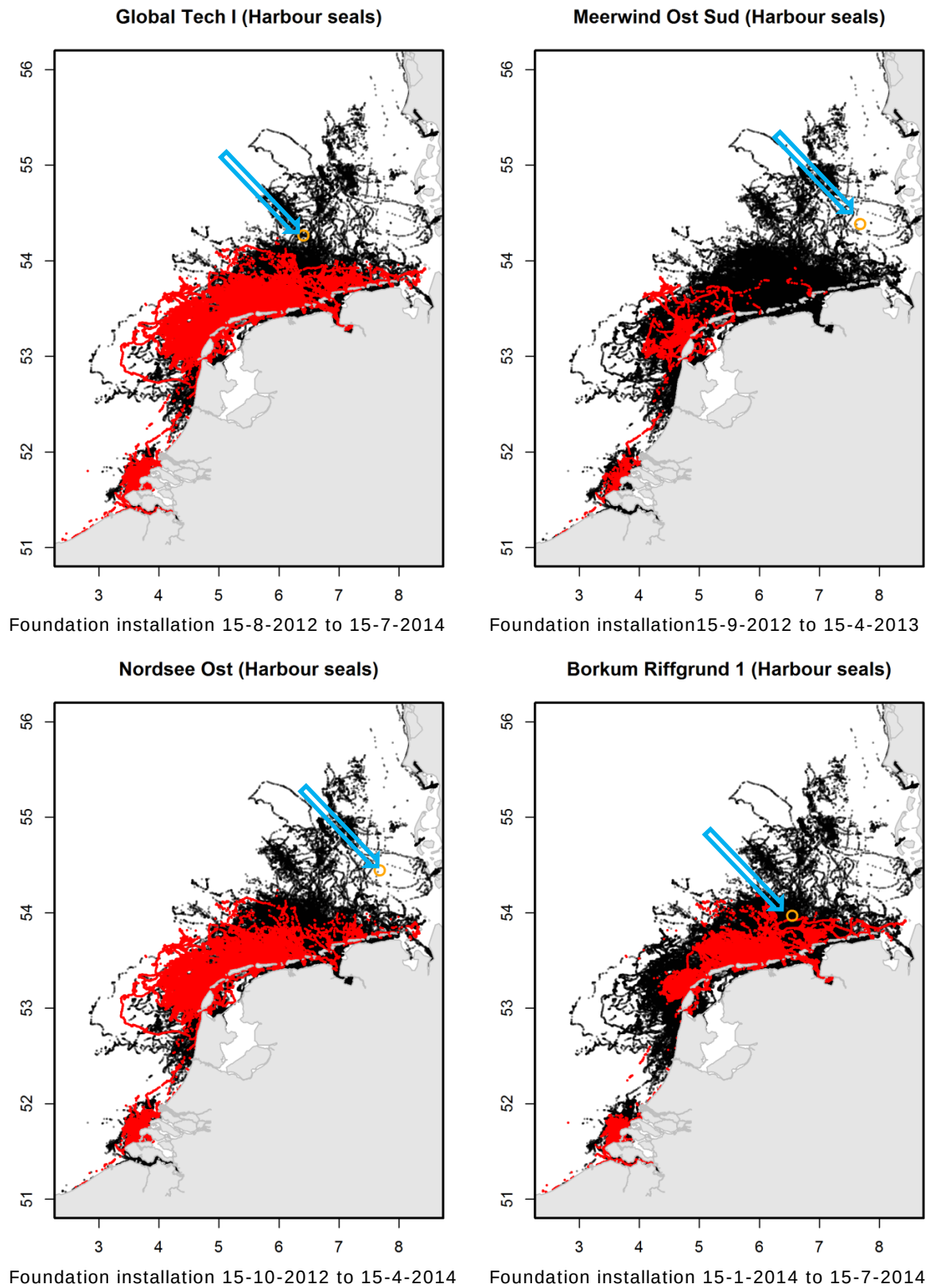
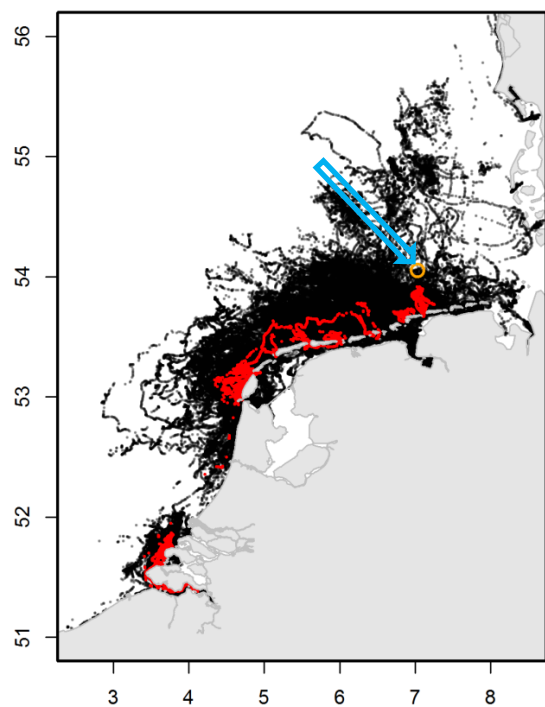


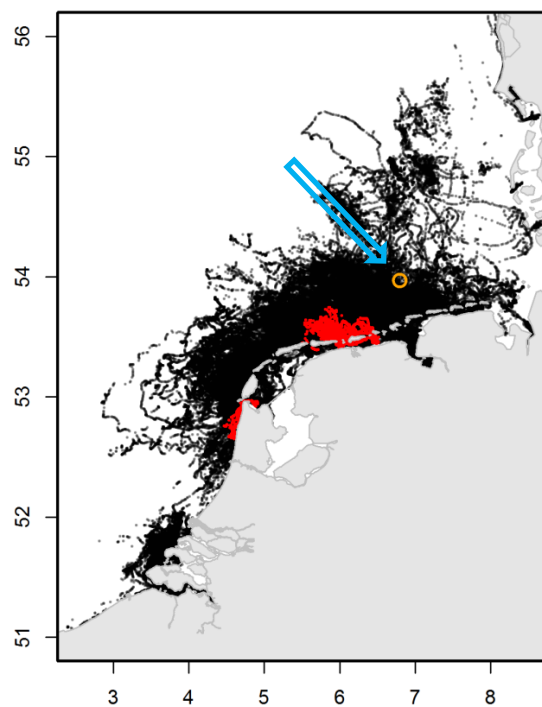
Figure 34 (continued). Maps showing all locations collected using GPS trackers for harbour seals (black) and locations during the foundation installation period of a windfarm (red). The windfarm location is the orange circle, indicated by the blue arrow.

Gode Wind 1 & 2 (Harbour seals)



Foundation installation 15-5-2015 to 15-9-2015

Nordsee One (Harbour seals)



Foundation installation 15-12-2015 to 15-6-2016

Figure 34 (continued). Maps showing all locations collected using GPS trackers for harbour seals (black) and locations during the foundation installation period of a windfarm (red). The windfarm location is the orange circle, indicated by the blue arrow.

5. Discussion

5.1 Overview

In the framework of the Gemini windfarm project off the coast of the eastern Dutch Wadden Sea, grey and harbour seal movement and behaviour was monitored in the vicinity of the Gemini windfarms, prior to foundation installations (T0, in 2013 and 2014 – reported in (Brasseur & Kirkwood 2015)) and during the period of foundation installations (Tc – this report).

For T0, in 2013 and 2014, 31 seals (11 grey and 20 harbour) were fitted with a GPS tracking device. While this represented 'base-line' movement and behaviour data against which data collected during pile driving and other construction activities could be compared, it is recognised that human activities in the region, including pile driving at adjacent windfarm sites continued during this period, and potentially influenced movement choices of the seals that were tracked.

For Tc, in spring 2015, 7 grey seals were fitted with GPS tracking devices, and in autumn 2015, 19 seals (9 grey seals and 10 harbour seals).

For grey seals tracking results were generally similar to the T0 tracks, showing large individual variation. Most animals stayed close to the coast (within 50 km) while some undertook long trips to open sea, or to other haul-out areas in the UK for example. None of the autumn animals visited Gemini windfarm. Dive depth was generally shallower than in the T0-period, only few seals undertook dives exceeding 40 m, and more time was spent diving at depths <5m.

Harbour seal trackers were deployed only in autumn during the pile driving period, and generally the seals stayed more inshore compared to T0, remaining at about 50 km away from the site. Accordingly, the dive depths recorded showed a higher peak at shallow depths, below 10m.

All of the grey seals tracked in spring were still followed when pile driving started on the July 1, 2015, and 8 animals were within 100 km of Gemini when there was pile driving. Only two were tracked within 40 km of the piling. Pile driving had already begun when the trackers were deployed in autumn. During pile driving three grey seals and three harbour seals ventured within 40 km of the site.

5.2 Grey seal movements

The data on grey seals collected for the Gemini windfarm represents an impressive data set for this species on movement and habitat use in this sector of the Dutch North Sea. For Gemini a total of almost 3500 days of movement data were obtained, of which 2000 days in this last Tc study. Other studies in the Netherlands deployed trackers on grey seals either in the western Wadden Sea or in the Zeeland/Delta region of the southern Netherlands (Brasseur *et al.* 2010b; Kirkwood, Bos & Brasseur 2014; Kirkwood, Aarts & Brasseur 2015), provide for an extra 9300 days. The previous studies mostly recorded movement offshore from the western Wadden Sea, the Dutch coastal zone and the Delta region, as well as several tracks to the UK. Only ten of these grey seals tracked in other studies ventured into the study area (Table 6).

Similar to the observations during the T0, grey seals were seen to adopt three different strategies in their movements. The first comprised relatively short trips up to 100 km into the North Sea (more often seals remained even closer; well within 40 km away from shore). The second was to conduct less frequent but longer foraging trips to 100-300 km into the North Sea, and the third was to undertake long-distance movements, such as to UK waters. In the last case the seals shift their haul out area. In

this part of the study, we concentrated on the seals that would stay in the study area or at least come back regularly. However, we should be aware that the grey seals that were tracked only represent a small part either of the animals potentially using the area to forage occasionally or as they shift to the haul-outs in the central Wadden Sea. This was demonstrated by the visits of the ten grey seals tracked in the framework of Luchterduinen (Kirkwood et al in prep).

Despite the striking long-distance tracks that were recorded for grey seals out into the North Sea, (Figure 12), the analysis demonstrates that north of the Dutch Wadden Sea, for most of the time, the grey seals operated at less than 60 km off the coast, and most of the time were even closer, i.e. within 20 km. Furthermore, in the vicinity of Gemini wind farms, i.e. between 5-7°E, the grey seals typically tended to dive to depths shallower than 50 m, most often even shallower than 10 m, reflecting their predominantly near-shore activity.

After pile driving commenced and in the post-pile driving period that was monitored, none of the seals tracked for Gemini Tc seal monitoring provided locations in the windfarms and just once did a seal move within 10 km of the site. One grey seal tracked for the Luchterduinen seal monitoring program, did travel through one of the windfarms, but likely did so at a moment no pile driving was occurring. While in the T₀ regular visits to the Gemini area were made, the near absence of locations close to the Gemini windfarms by tracked grey seals during and after pile driving was noteworthy. If this were a consequence of the construction activities, given the large number of grey seals in the North Sea, many seals potentially would have been displaced during this period.

5.3 Harbour seal movements

The 2015 Gemini study provided data for 30 harbour seals and over 800 days of tracking data. These data could be augmented by almost 18.000 h of previous and contemporary GPS tracking studies mostly from the Eems Dollard (Brasseur *et al.* 2010a; Brasseur *et al.* 2011; Kirkwood, Bos & Brasseur 2014; Brasseur & Kirkwood 2015; Kirkwood, Aarts & Brasseur 2015). Studies conducted from the western and southern Dutch coasts as part of the Luchterduinen windfarm monitoring program provided additional data on 15 seals that utilised the North Sea area offshore from the eastern Dutch Wadden Sea within the Gemini construction period.

Comparable to grey seals harbour seals also adopt different strategies in their movements: these include long trips to open sea extending >100 km offshore (these were usually less frequently and less far than for the grey seals), more coastal behaviour as has been displayed within the Gemini study, and long trips moving to new areas, often longing the coast. Within the Gemini Tc study, and comparing 2015 data with data from previous years, it was apparent that in 2015, there was less movement in waters >50 km from the coast. Although other anthropogenic or environmental factors could have been involved in this difference in range of movement, it is also possible that pile driving for Gemini reduced the movement of harbour seals into these waters further offshore.

In the Wadden Sea, harbour seals greatly outnumber grey seals. Therefore, although fewer tracked harbour seals than tracked grey seals (in both T₀ and Tc monitoring) moved >50 km offshore, and thus came within close proximity to Gemini, this does not indicate that fewer individual harbour seals could be present in the offshore waters. In previous studies, harbour seals have travelled further out to sea than has been recorded in the Gemini monitoring. For example, long-distance movements to the UK or up into Danish waters have been recorded (Brasseur *et al.* 2010c, Brasseur *et al.* 2011b). Most of the Wadden Sea data was collected from animals from within the Eems, the use of the North Sea by harbour seals might even have been underestimated in our studies. Potentially, had seals been tracked from the outer Wadden sea haul-outs, as were the 30 animals in the Gemini seal monitoring program, more use of the

North Sea could have been recorded at the time. Accordingly, the contrast between relatively high use of waters >50 km from the coast seen in previous years and the low use seen in 2015 may have been even stronger.

The distance analysis shows that the tracked animals of both seal species spend considerable time within 50 km from the coast, especially at less than 10 km. However, were the harbour seals seem to spend gradually less time in areas further away, grey seals, show a slight peak between 30 and 50 km away. This could be an artefact of the low number of grey seals tracked in the area. This could also be a result of differences in habitat preference or spatial segregation between harbour and grey seals due to competition.

Possibly, the smaller body size of harbour seals compared with grey seals influences a general difference in choices of movement and foraging ranges. This could provide individual grey seals an advantage over harbour seals to capitalise on prey resources further offshore. Being larger in body size also comes with a disadvantage, though, in that more resources are required. Potentially, the smaller bodied harbour seals, being more numerous and require fewer prey-per-day than the average grey seal, could outcompete grey seals for prey resources in nearshore waters. Further habitat modelling of time-in-area by both species would help to clarify this situation.

5.4 Seals during pile driving at Gemini

For this rapport, we concentrated on the overlap between pile driving and the seal tracks. Depending on the time trackers were deployed and how well they functioned, seals were followed either before and during pile driving or during and after pile driving, and, in two cases (hg46-13114 and hg46-13119), before, during and after pile driving.

Seals may be impacted by pile driving in several ways. Seals may be unable to anticipate upcoming piling events, and once pile driving starts, show an immediate behaviour response, by escaping the area. Alternatively, when pile driving is ongoing for several months, seals might be aware of the approximate location of the activity and avoid the region. Another possibility if seals are not capable of fleeing the area (if the animals are dependant of the area for food, for example) is a change in behaviour within the area. This could include diving less or shallower avoiding the underwater sounds.

Of the 26 seals tracked, 15 (eight harbour seals and six grey seals) provided locations within 50 km of the activity, including eight individuals (three harbour seals, five grey seals) that provided locations within 40 km. We defined these events as being potential 'exposures' to a pile driving event. There was a large variation in the number of times individual seals were exposed: one grey seal (hg46-13119) was within 40 km of pile driving 16 times (42 times <50 km), while other seals were exposed only once at 50 km (e.g. pv61-14147) or not at all. Likewise, immediate reactions to the exposures varied considerably, likely due to individual variability between and a variable distance to the pile driving.

In general, individual grey seals were exposed at closer distances than were harbour seals. Comparing their locations before and after the pile driving event, the grey seals moved away from the activity significantly more frequently than was their movement in any other direction in relation to the windfarm. For harbour seals, the movement direction was less clear, possibly due to the smaller sample size of overlaps and the distance at which they were at the moment of the pile diving. Future analysis of the direction of movement by seals would benefit from a larger data set, potentially including seal responses to pile driving at the German windfarms (if data were available on the times of these) and in response to pile driving elsewhere, such as for Luchterduinen and for windfarms in UK and Belgian waters. An analysis could then investigate factors such effects of individual variation of movement direction in

response to pile driving activity. Possibly, also general avoidance of the area by individual seals influenced by pile driving affects the results of the current analysis.

The grey seals tracked from April, changed their diving behaviour to shallower depths when pile driving started. During September, both grey seals and harbour seals were fitted with trackers at a time when pile driving at Gemini had been ongoing for several months. Most trackers lasted until well after pile driving had stopped. The pattern observed in the dive behaviours of the seals once pile driving ceased showed less variation between individuals in preferred dive depths than during pile driving. Harbour seals, also showed a tendency to dive deeper more frequently after pile driving ceased. This could be interpreted as a recovery from avoidance of deeper waters during the pile driving period, but might also be the result of seasonal changes in foraging behaviour.

It should be noted that the seals might also react to construction activities other than pile driving. Analysis of seal location and diving data during other activities may help elucidate how and how strongly the seals could be responding to the pile driving alone, as well as indicate if other activities could be influencing the seals movement choices. In further studies, environmental variables should also be taken into consideration. As an example, wind speed during the Gemini pile driving period varied considerably, with maxima exceeding 70 km/h and minima approaching wind still conditions (Figure 35). The higher the wind speed, may cause pile driving sound to be (partly) masked. Hence, the ability to detect pile driving and therefore movements of the seals in response to pile driving are likely to be influenced by the prevailing wind speed.

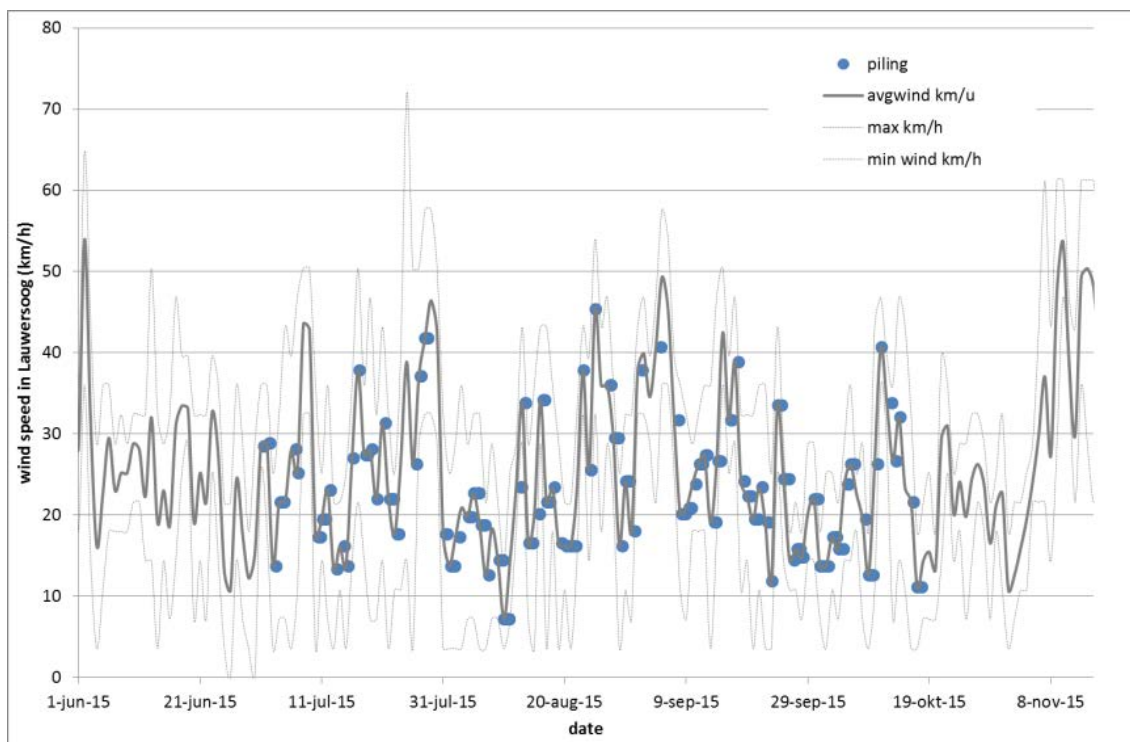


Figure 35. Wind speed (km/h) at Lauwersoog during the pile driving period. Individual piling events are plotted as blue dots in the graph.

5.5 Other windfarm construction activity- accumulation of effects

Since 2008, many seals of both species were tracked in the framework of different projects in the Netherlands. When plotting the tracking periods against the construction activities of windfarms north of the Wadden Sea, it is clear that there is considerable overlap. This provides, especially for the harbour seals, for a unique dataset, with seals fortuitously being recorded during the construction of at least ten different windfarms (Figure 31, Figure 1 and Table 1 show details of the windfarms).

Although it was not possible to perform an in-depth analysis of all these overlaps within the scope of this study and furthermore details on timing of the activities were not available, the preliminary investigation (chapter 4) using harbour seal data suggested valuable results could be obtained. Potentially, a significant contribution to understanding the long-term responses of harbour seals to wind farm construction, and possibly operation could be made (like for example in Russell et al. 2016).

5.6 Methods and short comings

As seals operate individually rather than in groups, consequently large individual variability occurs and often hampers simple generalizations regarding seal behaviour, particularly when sample size is small. However, by tracking seals under different research projects, and applying similar methods throughout our studies (Brasseur *et al.* 2010a; Brasseur *et al.* 2011; Kirkwood, Bos & Brasseur 2014; Brasseur & Kirkwood 2015; Kirkwood, Aarts & Brasseur 2015), the sample size increases, which on the long run allows conclusions to be drawn at the population level (Brasseur *et al.* 2010b; Brasseur *et al.* 2012; Aarts *et al.* 2013). In a similar way, the low density in which the seals appear to occur at sea hampers short-term observations that are sufficiently robust to define changes with certainty. To improve this situation, it is imperative to design studies with large enough sample sizes.

When studying the effects of a human activity on wildlife, in general, but especially with the difficulties to observe the seals a minimum of detail is needed on the activity itself. Here we show that for the pile driving in Gemini, for which data on exact times of hammer blows were available, we could analyse the seals' reactions in detail (providing there was temporal and spatial overlap). It would certainly be worthwhile to research multiple impacts, incorporating for example pile driving, ordnance clearance, shipping lanes etc. The coarser data on start and end times for construction of other windfarms in the German bight (prior to Gemini) provided just a broad qualitative perspective of potential impacts. More detailed data are needed to better understanding individual and cumulative effects of windfarm construction on seal habitat use in the North Sea.

Further, many current studies are aimed at monitoring individual human activities much could be learned from using the data collected in these frameworks to study in more detail the biology and behaviour of the animals to better understand the mechanisms that influences this and anticipate on possible effect of in the near future

5.7 Consequences windfarms on conservation status of grey and harbour seals.

Current conservation and management of harbour seals and grey seals in the Netherlands is underpinned by the Natura2000 programme, the key instrument to protect biodiversity in the European Union. Natura2000 is an ecological network of protected areas set up to ensure the survival of Europe's most valuable species and habitats. Both harbour seals and grey seals have been designated as protected species under the Natura2000 law (harbour seal, *Phoca vitulina* – H1365, and grey seal, *Halichoerus grypus* – H1364).

The national conservation objective for the harbour seal is to 'maintain distribution, expand size and improve quality of the habitat to expand the population', whilst for grey seals it is to 'maintain distribution, size and quality of habitat to maintain the population'¹. This rapport indicates that the pile driving activities affect seal's habitat use and therefore the habitat quality. Further studies are needed to determine if this has ultimately population-level consequences.

Both seal species reside in sites included by the Natura2000 Habitats Directive. In the Netherlands, these include, the Wadden Sea (*Waddenzee* – site NL9801001), Delta region (*Voordelta* – site NL4000017), North Holland coastal zone (*Noordzeekustzone* – site NL9802001) and the Eems-Dollard (site NL2007001). The seals are also present in Natura2000 sites of neighbouring countries. Of note is the Borkum-Riffgrund Natura2000 site (DE2104301) in German waters that border the Gemini windfarm area.

Although grey and harbour seals in the Netherlands utilise sand bars as places to haul-out for resting, breeding and moulting, the majority of their time is spent foraging mostly in the North Sea. In addition to individuals holding a fidelity to specific haul out sites, they can also exhibit a high degree of fidelity to particular areas at sea (see also Oksanen *et al.* 2014). Over the years, seals may have acquired detailed information on the patchy distribution of prey in that region, and when disturbed, the cost of relocating to unexplored territory may be high.

Given the location of the Gemini area, the use by grey and harbour seals is low compared to the more inshore habitats. Yet, seals use it and it represents a fraction of the foraging grounds available to the seals. Possibly as an effect of the growing anthropogenic use, including the recent development of multiple windfarms, our data show that in recent years, the harbour seals have been moving less far offshore. Due to the relatively small area compared to the seals total habitat, it might be challenging to measure a population-level effect of a single windfarm on the seal population. Possibly, the accumulation of several activities in an area might lead to measurable effects. However, this kind of study is further complicated because of multiple processes are taking place, both anthropogenic and natural (Wright & Kyhn 2014).

For example, between 1960 and 2014, both seal species were recovering from severe over-hunting which had been banned (Reijnders 1983; Reijnders, van Dijk & Kuiper 1995). Impacts of current human activities on trajectories of the seal population may not be detectable against the background these recoveries.

In addition, the numbers of seals in an area will be influenced by the available resources. This could be either prey resources, or necessary habitat to breed or rest. If a necessary resource is limited, so is the population size that is attainable. A key to identifying population level consequences is to identify what resources are necessary, how available they are and what could limit their availability. Current investigations of individual movement and, habitat use by seals in Dutch waters, including the long-term changes herein, can be considered an approach, to understand the underlying mechanisms. In combination with annual population surveys (see for example Brasseur *et al.* 2013), changes at an individual level could be extrapolated to a population scale change.

In depth data-analysis of existing tracking data and further collection of new data would be required to disentangle the longer-term impacts of offshore human activities from natural processes, and to anticipate how this might affect the national conservation objectives for grey and harbour seals, with regard the Natura2000 aims.

¹ See webpage <http://www.synbiosys.alterra.nl/natura2000/documenten/profielen/soorten>

6. Conclusions

- Aside from to the Gemini windfarm, 10 other windfarms were built in the study area in recent years (2007-2015). The construction activities have been almost continuous.
- Though large variation was observed, seals of both species utilised waters in the general vicinity of the Gemini windfarm, though more time is spent closer to shore.
- For harbour seals that were tracked more often in the study area than greys, the usage further offshore seems to have diminished since the first tracking with high resolution GPS trackers in 2009 in the area. During the year of construction (2015) there was less usage further offshore (> 45km), compared to previous years. As in that year the harbour seals were tracked when construction was well underway, they were not naive to the activity.
- For grey seals, this study shows that seals move away from the pile driving caused when they were closer than 40 km from the site. The numbers of harbour seals in the vicinity of the pile driving was too low to determine an effect conclusively.
- Both species utilize shallower depths during pile driving. Many individuals were seen to go more often to deeper waters when the pile driving had ceased
- Understanding whether seals avoid the regions further offshore because of the pile driving or because of other human processes (including activities at other windfarms), would require detailed data on these processes. For this, however accurate data for the windfarms, and other human activities would be required. These data are not readily available when this rapport was produced.
- The long-term effects of windfarms requires long-term studies of the movement and behaviour of the seals, including several years of the operational phase. For the area north of the Dutch Wadden Sea we demonstrate that potentially there is high quality seal data from 2008 onwards, which would allow for such analysis of the early German windfarms. In this respect, additional tracking efforts in the area would be a very valuable addition to observe long-term changes in relation to offshore windfarms.
- Given the ongoing human activities at sea, and large variability in natural ecosystem processes, a baseline measure cannot be attained. Instead, multivariate habitat models fitted to data on seal behaviour, distribution and abundance can be used to estimate the effect of human activities on marine biota. Such models may ultimately have some predictive abilities, they are most reliable when fitted to recent data.

7. Recommendations for further research

- Observed patterns in the seal's distribution at sea depend on the current size of the population, environmental conditions and human activities. When one or more of these variables change, so may the seal distribution. Hence, for both species, tracking in the near future will be necessary in order to monitor and eventually to understand long-term changes in the seals' behaviour, in relation to the recent windfarm development.
- Habitat models and individual based models can be used to help understand and describe the mechanism underlying seal distribution, and have the potential to make predictions in both space and time. However, there is currently no marine species (including harbour and grey seals) where the processes driving their distribution are sufficiently well understood, and hence data are continuously needed to develop and validate these models. Therefore, in parallel to model development and updating, continuous seal tracking (as part of regular monitoring) and aerial surveys are needed to collect the necessary data to understand long-term changes. The recent increasing anthropogenic developments in the North Sea have potentially a significant effect on movement and habitat use of seals in North Sea. Without monitoring at sea, it will be challenging to explain the observed population changes.
- In depth analysis of existing data and overlap with past construction activities. The large telemetry dataset and high overlap with historic windfarm developments (Figure 31), provides a unique opportunity to study the potential effects of windfarms at sea.

8. Acknowledgements

We acknowledge the valuable and on-going assistance and support of the Wadden Unit staff, including the effort Bert Meerstra and Arjen Dijkstra, put in to release the tracked seal from the net. Piet Wim van Leeuwen provided great support to the field work, as well as Jessica Schop, Elisa Bravo Rebolledo and Santiago Álvarez Fernandez. In addition, the skilled and professional approach of all the members of the IMARES seal monitoring field team is greatly appreciated.

9. References

- Aarts, G., Brasseur, S., Geelhoed, S., van Bemmelen, R. & Leopold, M. (2013) *Grey and harbour seal spatiotemporal distribution along the Dutch West coast*. IMARES Wageningen UR, IJmuiden [etc.].
- Brasseur, S., Aarts, G., Meesters, E., Polanen Petel, T.v., Dijkman, E., Cremer, J. & Reijnders, P. (2012) Habitat preferences of harbour seals in the Dutch coastal area: analysis and estimate of effects of offshore wind farms.
- Brasseur, S.M.J.M., Aarts, G.M., Bravo Rebolledo, E., Cremer, J.S.M., Fey-Hofstede, F.E., Geelhoed, S.C.V., Lindeboom, H.J., Lucke, K., Machiels, M.A.M., Meesters, H.W.G., Scholl, M.M., Teal, L.R. & Witte, R.H. (2011) Zeezoogdieren in de Eems: studie naar de effecten van bouwactiviteiten van GSP, RWE en NUON in de Eemshaven in 2010. pp. 212. IMARES, Den Burg.
- Brasseur, S.M.J.M., Cremer, J.S.M., Dijkman, E.M. & Verdaat, J.P. (2013) Monitoring van gewone en grijze zeehonden in de Nederlandse Waddenzee 2002-2012. pp. 31. Wettelijke Onderzoekstaken Natuur & Milieu, Wageningen.
- Brasseur, S.M.J.M. & Kirkwood, R.J. (2015) Seal monitoring and evaluation for the Gemini offshore windpark: Pre-construction, T0 - 2014 report. pp. 52. IMARES, Den Burg.
- Brasseur, S.M.J.M., Polanen-Petel, T.v., Geelhoed, S.C.V., Aarts, G.M. & Meesters, H.W.G. (2010a) Zeezoogdieren in de Eems; studie naar de effecten van bouwactiviteiten van GSP, RWE en NUON in de Eemshaven in 2009. pp. 110. IMARES, Texel.
- Brasseur, S.M.J.M., Polanen Petel, T.v., Aarts, G.M., Meesters, H.W.G., Dijkman, E.M. & Reijnders, P.J.H. (2010b) Grey seals (*Halichoerus grypus*) in the Dutch North sea: population ecology and effects of wind farms. pp. 72. IMARES, Den Burg.
- Brasseur, S.M.J.M. & Reijnders, P.J.H. (2001) Zeehonden in de Oosterschelde, fase 2; effecten van extra doorvaart door de Oliegeul. Alterra, Wageningen.
- Fish, F.E. (1993) Influence of hydrodynamic design and propulsive mode on mammalian swimming energetics. *Australian Journal of Zoology*, **42**, 79-101.
- Kastelein, R.A., Wensveen, P.J., Hoek, L., Verboom, W.C. & Terhune, J.M. (2009) Underwater detection of tonal signals between 0.125 and 100 kHz by harbor seals (*Phoca vitulina*). *The Journal of the Acoustical Society of America*, **125**, 1222.
- Kirkwood, R.J., Aarts, G.M. & Brasseur, S.M.J.M. (2015) Seal monitoring and evaluation for the Luchterduinen offshore wind farm: 2. T-construction - 2014 report. pp. 65. IMARES, Den Helder.
- Kirkwood, R.J., Bos, O.G. & Brasseur, S.M.J.M. (2014) Seal monitoring and evaluation for the Luchterduinen offshore wind farm 1. T0 - 2013 report. pp. 47. IMARES, Den Helder.
- Madsen, P.T., Wahlberg, M., Tougaard, J., Lucke, K. & Tyack, P. (2006) Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs. *Marine Ecology-Progress Series*, **309**, 279-295.
- Oksanen, S.M., Ahola, M.P., Lehtonen, E. & Kunasranta, M. (2014) Using movement data of Baltic grey seals to examine foraging-site fidelity: implications for seal-fishery conflict mitigation. *Marine Ecology Progress Series*, **507**, 297-308.
- Prins, T.C., Twisk, F., van den Heuvel-Greve, M.J., Troost, T. & van Beek, J.K.L. (2008) Development of a framework for Appropriate Assessments of Dutch offshore windfarms. Z4513, Deltares, Delft.
- Reijnders, P.J.H. (1983) The effect of seal hunting in Germany on the further existence of a harbor seal population in the dutch Wadden Sea. *ZEITSCHRIFT FUR SAUGETIERKUNDE-INTERNATIONAL JOURNAL OF MAMMALIAN BIOLOGY*, **48**, 50-54.

- Reijnders, P.J.H., Brasseur, S.M.J.M. & Brinkman, A.G. (2000) Habitatgebruik en aantalsontwikkelingen van gewone zeehonden in de Oosterschelde en het overige Deltagebied. *Alterra-rapport*, pp. 56. Alterra, Research Instituut voor de Groene Ruimte, Wageningen.
- Reijnders, P.J.H., van Dijk, J. & Kuiper, D. (1995) Recolonization of the dutch Wadden Sea by the grey seal *Halichoerus grypus*. *Biological Conservation*, **71**, 231-235.
- Remmers, P. & Bellmann, M.A. (2016) Offshore Wind Farm Gemini. Ecological monitoring of underwater noise during piling at Offshore Wind Farm Gemini. Version 4. (ed. i.G.I.o.t.a.a. physics).
- Russell, D.J.F., Hastie, G.D., Thompson, D., Janik, V.M., Hammond, P.S., Scott-Hayward, L.A.S., Matthiopoulos, J., Jones, E.L. & McConnell, B.J. (2016) Avoidance of wind farms by harbour seals is limited to pile driving activities. *Journal of Applied Ecology*.
- Schuchardt, B., Storz, G. & Todeskino, D. (2009) Offshore windpark 'BARD Offshore NL 1': milieueffectrapport. Planungsgemeinschaft Umweltplanung Offshore Windpark, for BARD Engineering GmbH, Emden.
- Wright, A.J. & Kyhn, L.A. (2014) Practical management of cumulative anthropogenic impacts with working marine examples. *Conservation Biology*, **DOI: 10.1111/cobi.12425**.

10. Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2008 certified quality management system (certificate number: 187378-2015-AQ-NLD-RvA). This certificate is valid until 15 September 2018. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V.

Furthermore, the chemical laboratory at IJmuiden has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2021 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation. The chemical laboratory at IJmuiden has thus demonstrated its ability to provide valid results according to a technically competent manner and to work according to the ISO 17025 standard. The scope (L097) of the accredited analytical methods can be found at the website of the Council for Accreditation (www.rva.nl).

On the basis of this accreditation, the quality characteristic Q is awarded to the results of those components which are incorporated in the scope, provided they comply with all quality requirements. The quality characteristic Q is stated in the tables with the results. If, the quality characteristic Q is not mentioned, the reason why is explained.

The quality of the test methods is ensured in various ways. The accuracy of the analysis is regularly assessed by participation in inter-laboratory performance studies including those organized by QUASIMEME. If no inter-laboratory study is available, a second-level control is performed. In addition, a first-level control is performed for each series of measurements.

In addition to the line controls the following general quality controls are carried out:

- Blank research.
- Recovery.
- Internal standard
- Injection standard.
- Sensitivity.

The above controls are described in Wageningen Marine Research working instruction ISW 2.10.2.105. If desired, information regarding the performance characteristics of the analytical methods is available at the chemical laboratory at IJmuiden.

If the quality cannot be guaranteed, appropriate measures are taken.

The responsibility of IMARES (now:Wageningen Marine Research) in this specific study was to deliver monitoring according to the specifications in the approved MEP. Although the explicit aim was to deliver monitoring that would be approved by *Rijkswaterstaat*, such approval is beyond the control of Wageningen Marine Research. Wageningen Marine Research takes full responsibility for the quality of its work and this quality is assured by an internal review process and through review by the client and *Rijkswaterstaat*

11. Justification

Report: C004/18
Project Number: 4312100007

The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research.

Approved: SCV Geelhoed
Researcher

Signature:



Date: January 2018

Approved: Drs. J. Asjes
Management team Wageningen Marine Research

Signature:



Date: January 2018

Appendix A. Individual movement case study – entangled seal

Sub-adult male *Seal 14144* was caught on Blauwe Balg on 23 September 2015. At the time, it weighed 47.2 kg. for the next month, it performed single and multi-day trips into the North Sea up to 50 km from Blauwe Balg. Then, on 22 October 2015, it was sighted on Blauwe Balg entangled in monofilament fishing net. Several capture attempts were made, then on 31 December the seal was sighted with additional entanglement debris, appearing to be rope. The seal was caught and all the material was removed on 25 January 2016. The tracker had stopped working on 24 December. The seal was released in situ: it had a cut on the back of its neck but was considered to be in sufficiently good condition to survive. Despite being entangled, the seal undertook numerous foraging trips into the North Sea, including one to >200 km offshore that lasted 31 days.

Table A1. Timing of events for grey seal 14144.

Date	Comment
2015-09-23	Tracker attached
2015-10-22	First sighted entangled – monofilament fishing net
2015-10-26	First catch attempt
2015-10-28	Second catch attempt
2015-11-05	Third catch attempt
2015-12-24	Last locations from tracker
2015-12-31	Re-sighted – now entangled in rope as well as monofilament net
2016-01-26	Caught, material removed, seal released in situ

Being to our knowledge, the first grey seal tracked with a known entanglement, it was interesting to note both the extensive movement and the diving capabilities of this seal, despite carrying the debris. From these data, the strongest indication that it was not normal was the increased time the seal spent cruising rather than diving while at sea.

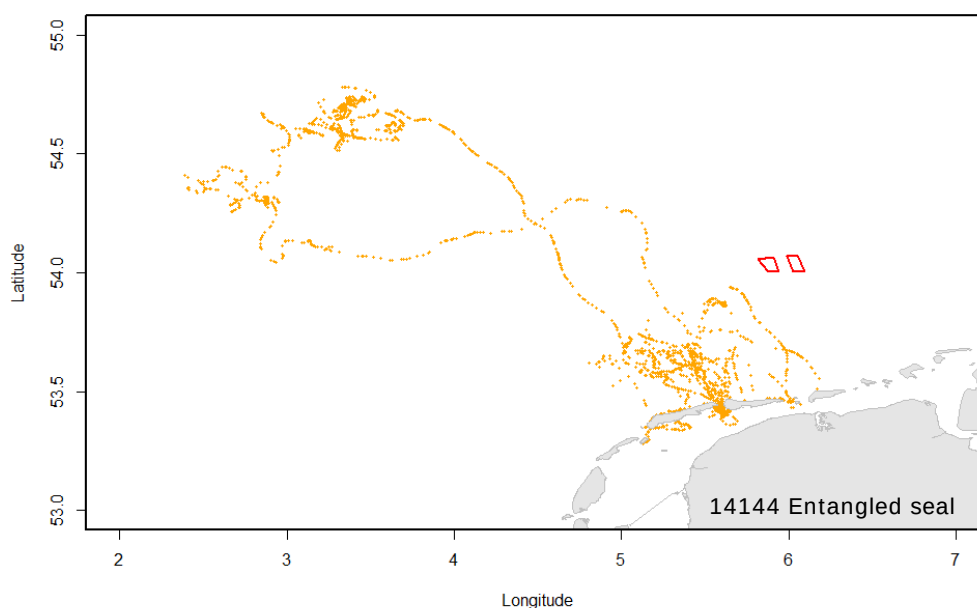


Figure A1. Locations recorded for grey seal 14144.

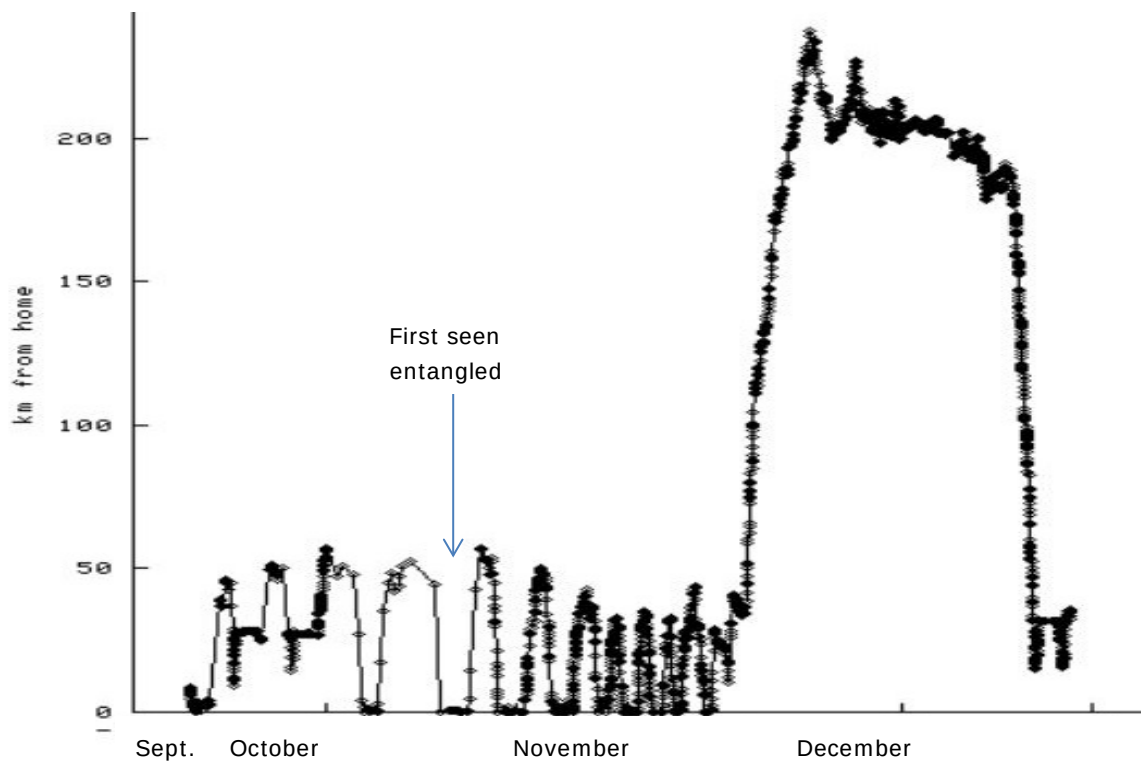


Figure A2. Distances from Blauwe Balg recorded for grey seal 14144.

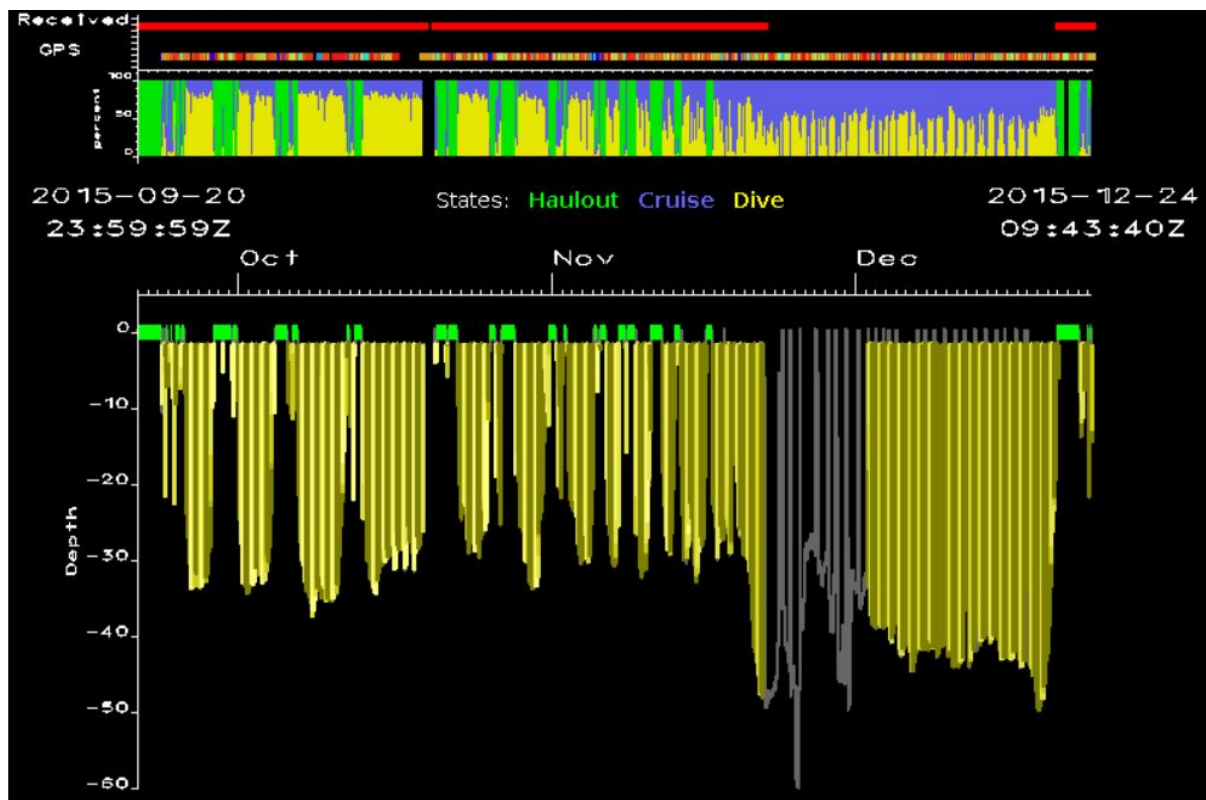


Figure A3. Diving profile over time for grey seal 14144.



31 December

Photo by Bert
Meestra (Wadden
Unit)



25 January

Photo by Arjen Dijkstra(Wadden Unit)



Figure A4. Photographs of grey seal 14144.

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- To conduct research with the aim of acquiring knowledge and offering advice on the sustainable management and use of marine and coastal areas.
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