Seal monitoring and evaluation for the *Luchterduinen* offshore wind farm: 2. Tconstruction – 2014 report

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Contents

Summary

1. Two seal species live in Dutch waters: the harbour seal (*Phoca vitulina*) and the grey seal (*Halichoerus grypus*). They occupy land-based sites (haul-outs) in both the Wadden Sea and the Delta region, and move between these regions along the North Sea coastal zone. Human activities, such as construction of a wind farm in this zone, may influence movement and use of the zone by the seals.

2. Monitoring of potential impacts on seals to *Luchterduinen* construction was required in the permit to construct which was issued by the Dutch government (*Wbr* permit WV/2009-1229). The monitoring had two aims:
   I. To collect data on movement routes of the seals through the North Sea coastal zone.
   II. To detect potential responses of the seals to pile-driving and other activities related to the building and operation of the wind farm.

3. The Monitoring and Evaluation Plan (MEP) for *Luchterduinen* stated that seals were to be fitted with tracking devices only in Spring each year over three years. As a consequence, harbour seals are tracked for only several months of their pre-breeding period. For grey seals, trackers could be attached immediately after their moult, allowing a most of their annual cycle to be recorded. The three years are defined as follows: T0 prior to construction, Tc in the year of construction and T1 post construction. Further, based on the results, consideration should be given to two additional years of monitoring (T2 and T3). This is a progress report of data collected during the second year (2014), the year of construction (Tconstruction, Tc).

4. The *Luchterduinen* offshore wind farm is the third wind farm development in the Dutch North Sea coastal zone (between Den Helder and Rotterdam). Pile-driving of the turbine towers occurred between 31 July and 16 October, 2014. During this 78 day period, there were 45 pile-driving events that averaged 110 minutes per event. Pile-driving frequency increased overtime. In the first half of the period there were 13 events (av. 1 per 3 days) and in the second half there were 32 (av. 1 per day - including 2 events per day on 9 days).

5. This report assesses data up to 26 October, 10 days after the completion of pile-driving, and provides first indications from a preliminary analysis of the data on movement of seals prior to and during pile-driving.

6. In March, GSM-GPS tracking devices (SMRU Limited) were attached to 20 harbour seals (10 at the Eierlandse Gat in the Wadden Sea, and 10 at a sandbar north of Renesse in the Delta Region). In April, devices were attached to 20 grey seals (10 at the Eierlandse Gat in the Wadden Sea, and 10 at Aardappelenbult sandbar near Brouwersdam in the Delta Region).

7. The 20 harbour seals were tracked for durations of 73 to 114 days (92 ± 12 days, mean ± sd). Tracking durations were limited by device loss caused by normal hair-quality deterioration prior to seals' moult. The majority of trackers stopped in June; three continued into July with the last reaching 17 July. There was no temporal overlap between harbour seal tracking and pile-driving.

8. Up to the 26 October, the 20 grey seals had been tracked for durations of 73 to 207+ days (179 ± 34 days): 19 provided >100 days of data (5 for >200 d). On 26 October, 12 to 14 of the devices were still providing locations.

9. Five of the 20 grey seals and one of the 20 harbour seals traversed the North Sea coastal zone from one end to the other at least once.

Ten of the 20 grey seals (three from the Wadden Sea and seven from the Delta region) and no harbour seals performed foraging trips to within the North Sea coastal zone.

10. Locations of eight grey seals and one harbour seal were within a 20 km of perimeter of the *Luchterduinen* wind farm, and two of the grey seals provided locations within the wind farm; one before pile driving had commenced and one during the pile driving period, on a day when there was no pile-driving activity.

11. Six grey seals moved within the North Sea coastal zone during the pile-driving period of 31 July to 16 October. Distances of seals within the coastal zone from pile-driving events ranged from 54 to 7 km. A total of 83 exposures, defined as a tracked seal being in the coastal zone during active pile-driving, were recorded, with between 3 and 26 exposures for individuals.

12. Movement responses of seals to pile-driving could be partially interpreted from the location and dive data. Gross reactions of the grey seals to the pile driving included: stopping progress, turning away, heading into shore, travelling parallel to the incoming sound, and no apparent reaction.

13. Seals exposed to pile-driving, even at close distances of <20 km, returned to the same area on subsequent trips. This suggests the seals had a short-term incentive to go to these areas which was stronger than the potential deterring effect of the pile-driving.

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1. Introduction

1.1 Background

In the Netherlands, the greatest numbers of grey and harbour seals are observed to haul out in the Wadden Sea but both species also haul out in the Delta region (Figure 1). There could be considerable movement of seals along the Dutch North Sea coastal zone between the two regions (Reijnders et al. 2000, Brasseur & Reijnders 2001b, Aarts et al. 2013). Here, the North Sea coastal zone is defined here as being between Rotterdam and Den Helder, i.e. the area enclosed by 51.95°N to 52.94°N, and the coast to 3.73°E. Seals likely forage in the coastal zone and movement through the zone may be particularly important for the maintenance of seal numbers in the Delta region (Aarts et al. 2013). Few harbour seal pups are born in the Delta and no grey seal pup births have been recorded there to date, so seals must come from other areas. Anthropogenic developments in the coastal zone, such as wind farms, could influence movement of seals in the coastal zone (Brasseur & Reijnders 2001a, Brasseur et al. 2010, Brasseur et al. 2012, Aarts et al. 2013). This could have a number of costs for the seals, including restricting feeding habitats and constraining occupation of the Delta region.

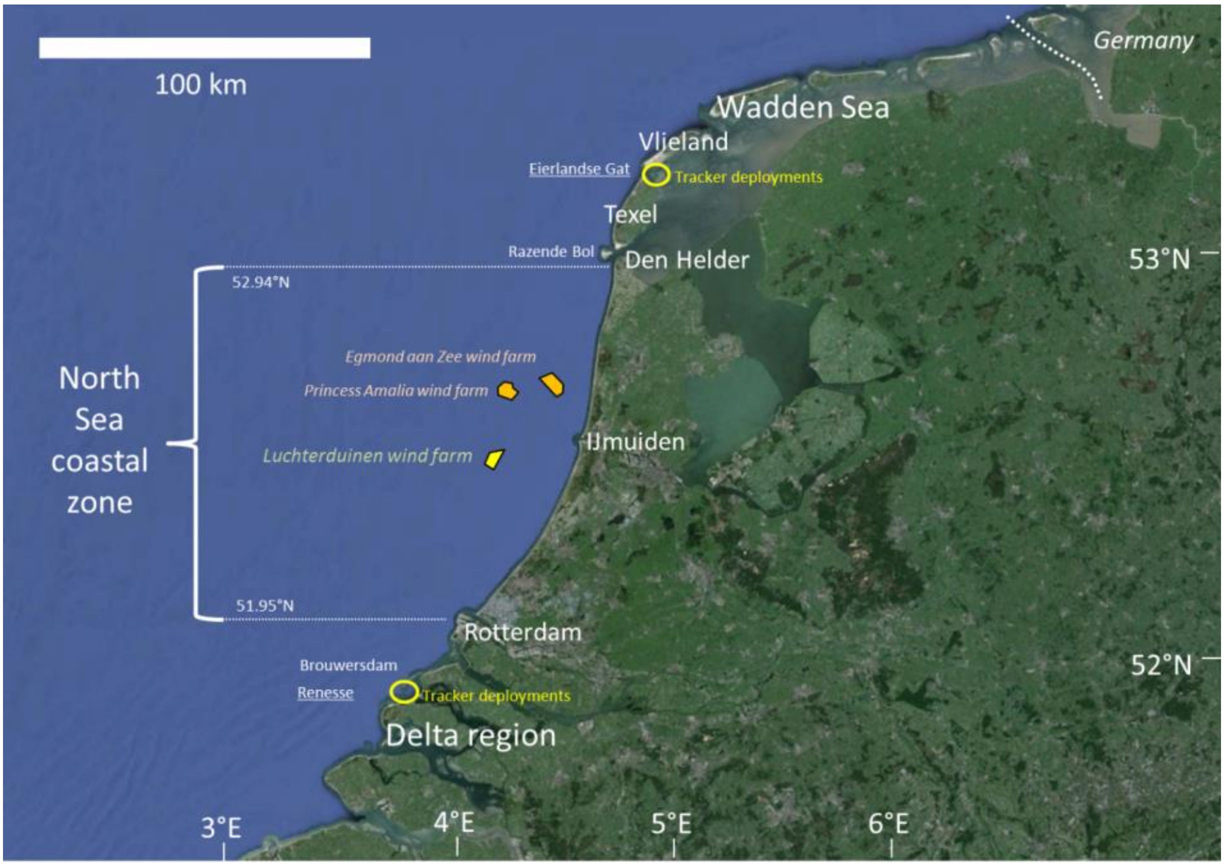


Figure 1. Location of Luchterduinen *offshore wind farm and other operating wind farms adjacent to the North Sea coastal zone of the Netherlands, and deployment sites where seals were fitted with transmitters for this study.*

In the coastal zone zone, *Clusius CV* (50% ENECO, 50% Mitsubishi Corporation – the client) is constructing the offshore wind farm *Luchterduinen* approximately 23 km off the coast of IJmuiden (Figure 1). The site is 20 km south of two existing wind farms*, Prinses Amalia windpark* (PAWP) and Offshore Windfarm Egmond aan Zee (OWEZ). Construction of *Luchterduinen* commenced in 2014, with pile-driving (piling) of the 43 turbine towers plus one operations tower in a 16 km^2 area conducted between 31 July and 16 October. The wind farm is expected to be operational in 2015.

1.2 Plan for seal monitoring

During the last decade, the Dutch government has formulated a strategy to develop a capacity of 4450 MW of energy from offshore wind farms (Social Economic Council agreement, August 2013). Construction, operation and decommissioning of offshore wind farms has the potential to negatively affect marine ecosystems (Prins et al. 2008). Therefore, development of an offshore wind farm in the Dutch Exclusive Economic Zone (EEZ) requires a '*Waterwet*' (Water Act) permit (*Wtw*-permit, until August 2013 also including the N2000 legal framework, formerly '*Wet Beheer Rijkswaterstaatwerken*' permit, *Wbr*-permit). *Rijkswaterstaat*, the management organisation of the Dutch Ministry of Infrastructure and the Environment, is the authority that issues *Wbr*/ *Wtw*-permits. Since August 2013, the Ministry of Economic Affairs became the Competent Authority in the Dutch EEZ with respect to the N2000 legal framework (*Nb Wet* [Nature Management Act], *FF Wet* [Flora and Fauna Act]). This development has, as yet, no implications for the *Luchterduinen* wind farm licence.

As part of *Clusius CV*'s application to the Ministry for Infrastructure and Environment (*Ministerie van Infrastructuur en Milieu; Rijkswaterstaat)* for a *Wbr*/ *Wtw*-permit for *Luchterduinen*, an 'Environmental Impact Assessment' and an 'Appropriate Assessment' were conducted. Based on the Assessments, the *Wbr*/ *Wtw*-permit (WV/2009-1229) for *Luchterduinen* offshore wind farm construction, released by on 18 December 2009 (Anonymous 2009, point 5, pages 65-66) included the obligation to prepare a 'Monitoring and Evaluation Plan' (MEP). The MEP contained 11 topics, including the monitoring of harbour porpoises, seabirds and seals. IMARES was contracted to undertake and evaluate seal monitoring.

This report documents seal monitoring data collected in the year of construction, 2014 (Tc). It was preceded by a desk study on grey and harbour seal spatiotemporal distribution along the Dutch North Sea coastal zone based on the existing data (Aarts et al. 2013) and a T0 report containing the results of the baseline monitoring (Kirkwood et al. 2014).

The *Wbr*/ *Wtw*-permit (Anonymous 2009, point 5, pages 65-66), provides that for seals the following monitoring was expected:

(Translated to English)
Aim of the measurement(s) is to collect data on the migration routes of harbour and grey seals.
***Required methods*:**
This research should be in line with the tagging research carried out by IMARES
Time aspects and definition of area:
The tagging research should be delineated in such a way that it could procure insight in migration routes of both species on the Dutch Continental Shelf at the height of the Voordelta and Coastal zone of Holland. This is to be scrutinised by the competent authorities. There should be continuous measurement starting one year before constructing commences until 3 years after the operational period started.
Requested accuracy:
The research should be carried out using methods that are 'state of the art'. This is to be scrutinised by the competent authorities.
Other points:
The research should be in line with other seal tagging studies.

In the MEP, it was decided that tagging of both seal species only once a year, at either longitudinal end of the coastal zone, would enable sufficient monitoring of the seals (Table 1). It was stated that the best time for the single deployment was in March-April. This period was between the moult period of grey seals (February-March) and the late pregnancy period of harbour seals (April-May) (see section 1.5).

Seal movements were to be monitored one year prior to construction (Kirkwood et al. 2014), during the year of construction (Tc – this report) and during operation of the wind farm post-construction (T1). During the Tc, when most impact of the construction phase could be expected (due to pile-driving), the sample sizes were 10 seals of each species per end of the coastal zone.

Following an evaluation of the results from T0 to T1, consideration would be given to monitoring seal movement during two years of wind farm operation (T2 and T3). This deployment protocol was approved by *Rijkswaterstaat* (Table 1).

Table 1. Deployment arrangement for the contract period and optional arrangement for additional, longer-term, monitoring.

Phase	**Harbour Seal**		**Grey Seal**	
	Wadden Sea	**Delta**	**Wadden Sea**	**Delta**
Approved (deployments):				
T0 (spring 2013)	6	6	6	6
Tconstruction (spring 2014)	10	10	10	10
T1 (spring 2015)*	6	6	6	6
Total	**22**	**22**	**22**	**22**
Possible further deployments, after evaluation:				
T2	*6*	*6*	*6*	*6*
T3	*6*	*6*	*6*	*6*

* T1 seal monitoring was shifted from spring 2016 to spring 2015

1.3 Aims of the study

The aims for seal monitoring research of the *Luchterduinen* offshore wind farm are:

1. To gain insight into grey and harbour seal movement routes along the Dutch North Sea coastal zone (between the Wadden Sea and the Delta region).

2. Investigate the impact of construction (including pile-driving) and operation of the wind farm on movements of the seals.

This will lead to 3 reports (with the possibility of further reports, if monitoring is sought for T2 and T3):

- Annual T0 report - delivered (Kirkwood et al. 2014).
- Annual Tconstruction report (this report)
- Annual T1 report – A final report with multi-year analyses and interpretation.

1.3.1 Content of Tc report

This report gives an overview of the data collected from deployments of tracking devices on seals in 2014 (data included up to 26 October). It provides a description of the movements and behaviour of the seals and a preliminary comparison pre-construction and during construction. Detailed analysis and interpretation will be conducted following the post-construction monitoring of seal movement, and will be presented in the final T1 report (to be drafted in late 2015 and released in 2016).

The responsibility of IMARES is to deliver monitoring according to the specifications in the approved Monitoring and Evaluation Plan (MEP). Although the explicit aim is to deliver monitoring that will be approved by *Rijkswaterstaat*, such approval is beyond the control of IMARES.

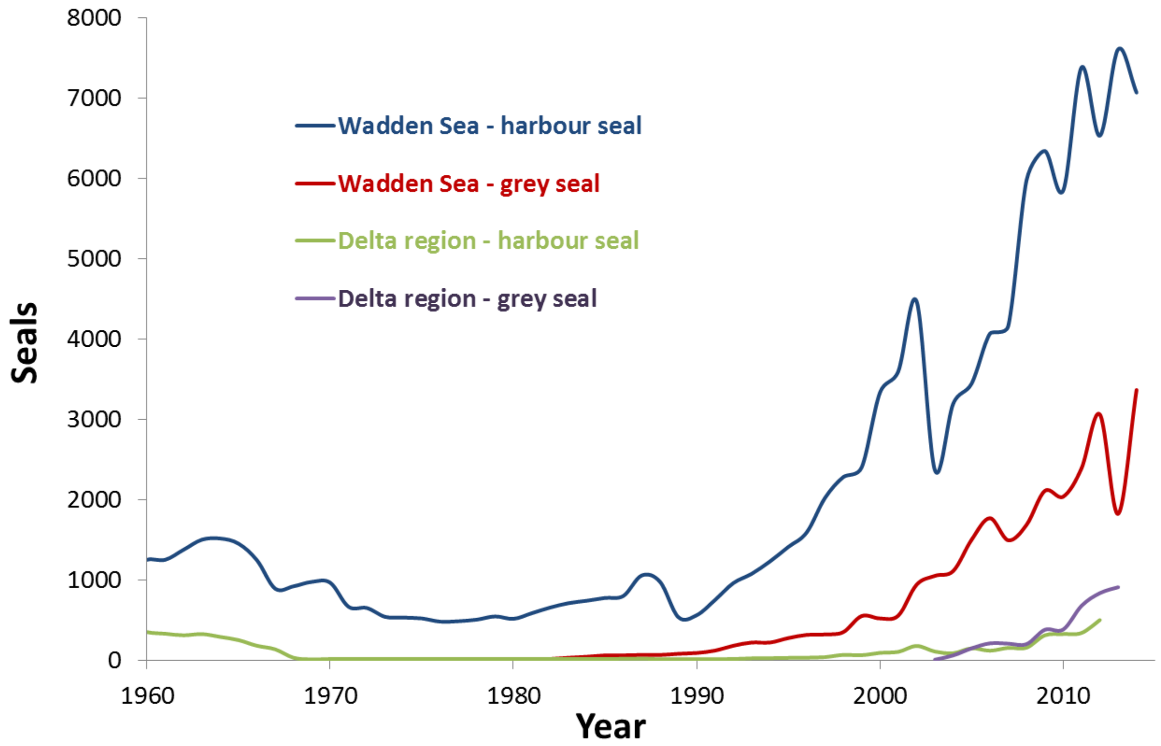
IMARES takes full responsibility for the quality of its work, but cannot be held responsible for results that are not in line with the expectations of *Clusius CV* or *Rijkswaterstaat*. The quality is assured by an internal IMARES review process and reviews by *Clusius CV* and *Rijkswaterstaat*.

1.4 Seals in Dutch waters

1.4.1 General information

Two seal species live in Dutch waters, the harbour seal, *Phoca vitulina*, and the grey seal, *Halichoerus grypus*. Both forage throughout Dutch marine waters and haul-out mainly on sandbars to rest, breed and moult (Brasseur et al. 1996). During recent decades, both seals have increased in number in the Netherlands (Figure 2). The increase is mostly a recovery following the cessation of hunting pressure (Reijnders 1985, 1994).

Seal numbers started to recover in the Wadden Sea during the 1980s and 1990s. Recoveries commenced in the Delta in the 1990s and early 2000s. The return of grey and harbour seals to the Delta region was likely to be a result of travels to the region by individuals from the Wadden Sea and elsewhere (Brasseur et al. 2010, Brasseur et al. 2012) and, particularly for harbour seals, intermittent virus epidemics, in 1988 and 2002 (Reijnders et al. 2010a).



Data from http://www.compendiumvoordeleefomgeving.nl/indicatoren/nl1231-Gewone-en-grijze-zeehond-in-Waddenzee-en-Deltagebied.html?i=19-135 , and http://www.waddensea-secretariat.org/sites/default/files/CWSS_Internal/TMAP/Marine_Mammals/grey_seal_report_2014.pdf

Figure 2. Trends in numbers of harbour and grey seals counted on the sandbanks in the Dutch Wadden Sea and Delta region.

Harbour seals in the Netherlands are part of the East Atlantic harbour seal population which has a total population of approximately 100,000 seals (Bjørge et al. 2010). In the international Wadden sea, ranging from Esbjerg in Denmark to Den Helder in the Netherlands, a total of 26,794 seals were counted in 2014.

After correcting for approximately 1/3 of the animals not seen during survey flights, because they were in the water at the time (Ries et al. 1998), this indicates that the international Wadden sea population consists of approximately 40% of the total population, about a quarter of these animals (~10% of the total population) reside in Dutch waters.

Grey seals in the Netherlands are part of the East Atlantic grey seal population, which is estimated to number approximately 115,000 seals; 90% of pups are born in the UK (SCOS 2011). The grey seal colony in the Dutch Wadden Sea is the largest on the European continental coasts, and produces approximately 1% of pups for the species. Recent studies indicate, however, that as many as 5000 animals could use the Dutch waters at least for part of the year (Brasseur et al. 2014)

1.4.2 Annual cycle

In the Netherlands, grey seals give birth in winter and moult in spring, while harbour seals give birth in early summer and moult in late summer (Figure 3). To maximise data collection and minimise the chance of adverse impacts, optimum deployment periods are influenced by taking the annual pupping and moult periods of seals into account.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Harbour seal					near term	pups		moult				
Grey seal		moult									near term	pups
Captures			optimum			captures not permitted			optimum			
Pile-driving										pile-driving permitted		

Figure 3. Comparison of annual cycles for seals in Dutch waters, timing for captures and the permitted period for pile-driving of offshore wind-turbine towers.

Although there have been no indications that capturing seals at any time in their annual cycle impacts their breeding success, this might occur and, if so, could be highest immediately prior to and during pupping. Taking this into account, government permits do not allow seal captures between 15 May and 31 August. Following this thought, capture attempts for grey seals should avoid the period between mid-November and late January. It should be noted, however, pupping periods change over time. The mean pupping date for harbour seals in the Wadden Sea crept earlier between 1974 and 2009, from 22 July to 27 June, a rate of 0.7 days/year (Reijnders et al. 2010b). Similarly, the mean date for grey seal pupping in the Netherlands crept earlier between 1985 and 2013, from 21 January to 16 December, a rate of 1.3 days/year (Brasseur et al. 2014).

Regarding moult, tracking durations are maximised if devices are attached to the hair of seals soon after they moult. Moult in seals is a staggered process with some seals completing moult before others start (Thompson & Rothery 1987). One result of this staggered process is that even during the latter part of the moult period, some seals suitable for device attachment are present at haul-out sites, although there could be some bias. For example, younger seals tend to moult earlier than older, breeding age seals.

Another consideration for when to deploy on the seals was that this project sought overlap of seal movement data with the *Luchterduinen* pile-driving. In the Netherlands, pile-driving is restricted to months between July and December. To record seal movement in those months, and recognising captures are not permitted from 15 May to 31 August, the optimum period to attach devices to grey seals is April to early May. For harbour seals, the optimum time for deployments to maximise sampling durations is September-October. However, this is after the planned pile-driving period of July-August.

A single deployment period per year was agreed to between *Clusius CV* and *Rijkswaterstaat*, and the Spring, March-April, period was selected. This provided a high likelihood of temporal overlap between grey seals and pile-driving, and it was hoped some harbour seals could retain their trackers sufficiently long to cover part of the pile-driving period.

1.4.3 Seal movement

Seals have periods at sea where they forage and traverse between areas, and periods ashore to rest, moult, socialise and breed (including to raise pups). During moulting and breeding periods, grey seals remain ashore for weeks at a time. Harbour seals come ashore for hours at a time, generally using tidal haul-outs, rather than days but come ashore more frequently during pup-support and moult periods, so remain more adjacent to haul-outs over these periods.

Due to their requirement for periods ashore, grey and harbour seals tend to perform trips to sea from one haul-out site. Periodically, they traverse to an alternative area and utilise a different haul-out site. The pattern of residency in an area and movement to another varies between individuals. This is because such movement is stimulated by, for example, individual need, previous experience, hunting strategy and prey availability. Although seals are very individualistic in their movements, more pronounced groupings of movements occur at the start and end of breeding and moulting periods (Thompson et al. 1996). Seals tend to come back to the same breeding and moulting site (these two can differ) at the same time of year, year after year (Pomeroy et al. 1994, Pomeroy et al. 2000).

Movement at sea typically involves travel out from a haul-out, feeding within an area for a period and then movement to a different area or back to the former haul-out. While at sea, the seals usually dive to the bottom, move along the bottom then return to the surface to breath. This is termed the dive-cycle. They dive to the bottom because that is where their usual prey lives, i.e. the main prey is primarily benthic dwelling. Movement along the bottom could also assist the seals with their navigation. For example, by detecting changes in substrate, the seal could maintain a direction of travel or recognise approximately where it is.

The diving behaviour of seals changes over time and examination of dive-patters can reveal changes in behaviours of the seal. For example, distinct dive-profiles can be indicative of foraging, traveling and resting, prey hunting strategies, and reactions to particular stimuli, such as changing light conditions with time of day (Thompson et al. 1991, Lesage et al. 1999, Austin et al. 2006). Responses to anthropogenic sounds may also be detected in dive profiles. For example, experimental exposure of sperm whales that were fitted with dive recorders to anthropogenic underwater sounds (seismic airguns) caused detectable changes in dive profiles (Miller et al. 2009). It is possible that harbour and grey seals that experience pile-driving events will also change their diving behaviour and that this could be detectable in recordings of dive parameters.

1.4.4 Movement in the North Sea coastal zone

Harbour and grey seals potentially could use the North Sea coastal zone as a foraging area or as a zone through which to move between foraging, moulting or breeding areas (Aarts et al. 2013). To distinguish between the two uses, we define complete crossings between the latitudinal boundaries of the zone as being ‘traverses’, and entrances then exits over the same latitudinal boundary as being ‘foraging trips’. Obviously these categories are not exclusive and, for example, seals on ‘traverses’ may forage along the way.

Previously, habitats in Dutch waters that are likely to be preferred foraging areas of harbour and grey were predicted based on the habitats utilised by instrumented seals (tracking devices and dive recorders) and modelling of the distribution of those habitats (Brasseur et al. 2010, Brasseur et al. 2012).

Factors used to model habitats were sediment type and water depth. The exercises predicted that the centre-section of the North Sea coastal zone (in particular) could provide suitable feeding habitat for both seal species (Figure 4). The estimate that this zone might be of importance for the seals was supported by a more recent report by Aarts et al. (2013). Habitat use is influenced by factors such as proximity to haul-outs, prey availability and population size, and is likely to change over time. Regarding proximity to haul-out, actual use of a foraging area is likely to diminish the further a seal needs to travel. Although numbers of are seals seen on the coastal zone, there are no regular haul-out sites for seals there. Seals choosing to forage in the coastal zone must base themselves at haul-outs outside the zone. *Luchterduinen* is situated on the outer edge of an area that was estimated to be potentially good habitat for the seals, adjacent to Ijmuiden in the central part of the coastal zone. A new modelling effort using recent counts and the recent, more detailed, tag results could help to redefine the current importance of the area for the seals.

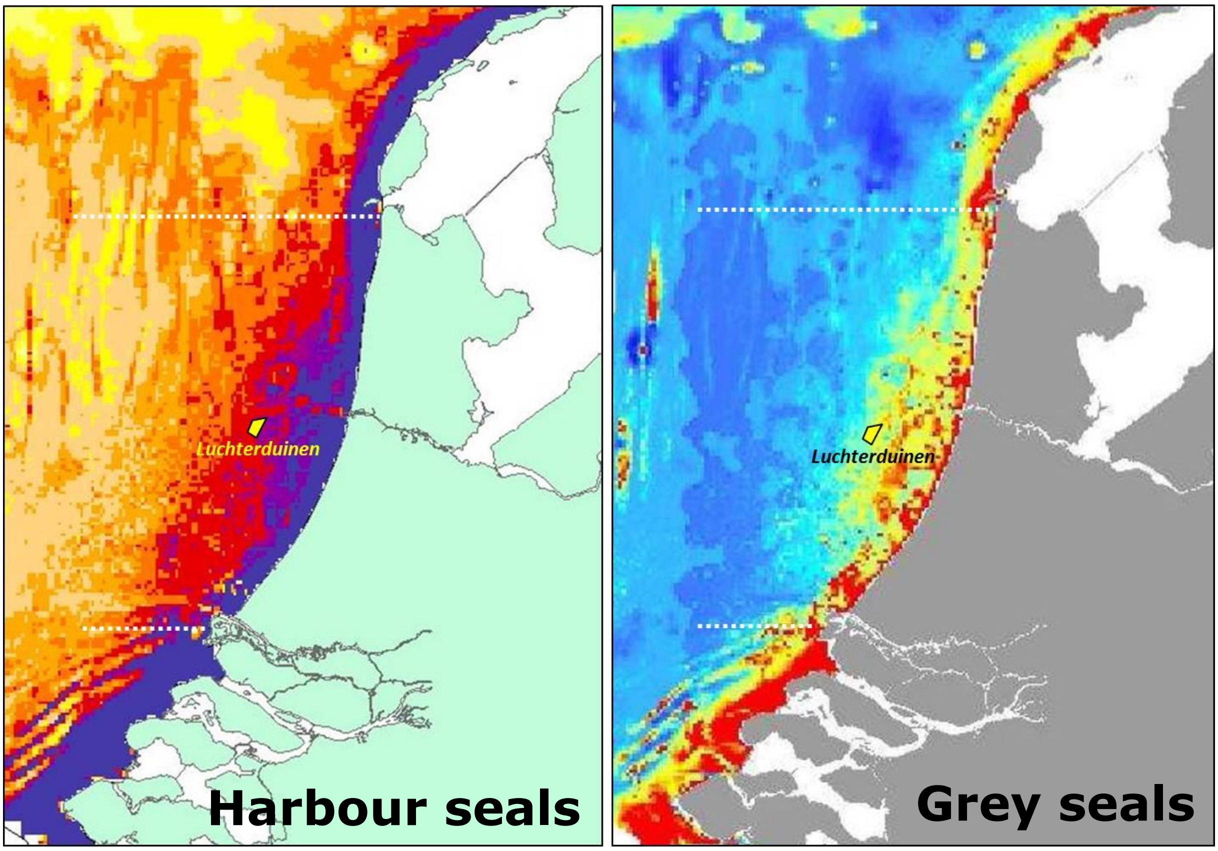


Figure 4. Extracts from modelled likely habitat preferences for harbour and grey seals in Dutch waters based on sediment type, water depth and disturbance, and derived from dive records of the seals (Brasseur et al. 2010, Brasseur et al. 2012). To explore all possible feeding grounds, the model did not take into account distance from haul-out site. Actual habitat use would depend on a range of additional factors including the location of haul-out sites and the number of seals utilising them. The figures have different scales and different colours, for harbour seals high preference is purple and low preference is yellow, for grey seals high preference is red and low preference is dark blue.

Human activities in the North Sea coastal zone are increasing and include shipping (particularly intensive on the sailing routes between the major European harbours of Antwerp, Rotterdam and Hamburg and, to a lesser extent near, Scheveningen and IJmuiden), dredging, fishing and wind farms. A concern over increasing human activities in the coastal zone is that this may affect the exchange of seals between the Wadden Sea and the Delta area (Brasseur et al. 2010, Aarts et al. 2013). Particularly, the Delta area appears to be dependent on an influx of seals from other areas, such as the Wadden Sea (Reijnders et al. 2000, Aarts et al. 2013), and this influx could be impacted by the human activities in the coastal zone.

Although seals may cross the North Sea, the majority of locations previously recorded for tracked seals within the North Sea coastal zone have been within 20 km of the coast for grey seals and within 50 km for harbour seals (Brasseur & Reijnders 2001a, Brasseur & Fedak 2003, Brasseur et al. 2010, Brasseur et al. 2012, Aarts et al. 2013, Kirkwood et al. 2014). Thus, this coastal strip appears to be of particular importance to the seals.

2. Materials and Methods

2.1 Field sites

The first aim for this study was to investigate seal movement within the North Sea coastal zone. To achieve this, deployment sites were selected on both ends of the zone (see Figure 1):

a. In the western Wadden Sea, in the inlet of the Eierlandse Gat, between Texel and Vlieland (grey seals at 53.20°N, 4.91°E, harbour seals at 53.20°N, 4.94°E).
b. In the Delta region, harbour seals were caught at a sand bar north of Renesse (51.75°N, 3.75°E) and grey seals at the Aardappelenbult sandbar to the north-east of, and parallel to, the Brouwersdam (51.79°N, 3.78°E).

2.2 Tracking devices

Devices selected to track the seals were *GPS-GSM transmitters* from the Sea Mammal Research Unit (SMRU, Scottish Oceans Institute, Scotland). These provide the accuracy of Fastloc® GPS location-determinations, dive depth, sea temperature and haul-out time measurements. Recovery of data is through the GSM mobile-phone network. As North Sea coasts have almost complete coverage by mobile phone networks, reception of records of the seals' movements are ensured.

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' to maximising location determinations based on expected dive durations (>5-minutes for most dives) and expected deployment periods. The harbour seal sample interval was set at the maximum rate of every 5-minutes, providing an estimated battery-life of 6-8 months. As grey seals were expected to retain devices for considerably longer, their sample interval was set at 15-minutes, providing an estimated battery life of 10-12 months. The Fastloc requires <1-second of air exposure to acquire the information for a location determination. However, not all 'surfacings' of the seal provide a location, because the antenna does not always break the surface.

Water temperature and transmitter depth are recorded at pre-set intervals. The intervals are set to maximise data within the memory capacity of the devices, and the estimated maximum intervals between downloads. Up to 3-months of data are stored in the memory of the transmitters and can be relayed via the GSM mobile-phone system when the seal hauls out within range of a network. This is possible at most seal haul-out and breeding sites in the Netherlands and the United Kingdom. The 3-month data storage facility is valuable in case seals remain at sea for extended periods or remain for a period at haul-outs that are not covered by the GSM network.

Transmissions drain power, so to maximise the life of each device the frequency of transmission attempts is duty cycled. The transmitters receive a reply from the network and on-board software determines if data was transmitted correctly or needs to be resent. If underwater or outside a GSM mobile network, the transmission attempt could be delayed until the next moment a network is detected.

Minimising device size is important to minimise drag, which could impair swimming efficiency (Fish 1993). Advances in battery and communications technologies have enabled device sizes to reduce over time. The latest *GPS-GSM transmitters* by SMRU weigh 330 g in air and 180 g in water, and have a volume of 150 cm^3.

2.3 Field procedures

All required permits to enter protected areas and for handling animals during field procedures were obtained from the appropriate authorities.

These included a permit under the Dutch Nature Protection Act (*Natuurbeschermings Wet*) from the provinces of Zeeland and North-Holland, a permit under the Flora and Fauna Act (*Flora en Fauna Wet*) from 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 were conducted in March for harbour seals and April for grey seals (Table 2). Seals were captured at low tide adjacent to sandbars, using a purpose-built seine-net of approximately 100 m length and 8 m depth. Seals not required were released immediately. Seals selected to carry transmitters were healthy individuals that had completed their moult. We attempted to have an even spread of males to females and subadults to adults. Selected seals were strapped into purpose-built cradles and had a *GPS-GSM transmitter* glued (epoxy resin, *Permacol*) to their pelage, at the mid-dorsal point behind the neck. While the glue set (approximately 10-15 minutes), the seals were sexed, measured (standard length) and weighed (using block-and-tackle and suspension scales). Once the glue had set, each seal was released immediately to proceed directly to the water. Further details on field techniques are provided in the T0 report (Kirkwood et al. 2014).

Table 2. Field trips for transmitter deployments in 2014.

Seal	Wadden Sea	Delta region
Harbour	17-18 March	24-25 March
Grey	14-16 April	1-4 April

2.4 Data processing

Seal location and dive data were transmitted by the tracking devices to the GSM-network and stored at SMRU, Scotland, from where they were downloaded as Access files. These data were then analysed using packages and custom written scripts in the R statistical framework (R Development Core Team).

Movement data were also compared with the *Luchterduinen* site and with a 20 km perimeter around the site. The 20 km distance was adopted to represent movement 'near-by' to *Luchterduinen*. It also coincides with a 21 km distance at which a pre-construction report predicted seals might respond by exhibiting avoidance behaviour (de Jong et al. 2013).

Potential reactions of grey seals to pile-driving could be investigated through correlations between movement and dive data of the seals with activities data (supplied by ENECO). During the pile-driving, period, potential exposures of seals in the North Sea coastal zone were noted. Exposures were defined as occasions when a seal was located within the North Sea coastal zone during an actual pile-driving event. Movements of individual seals in the 12 hour period prior to the pile-driving, during the pile-driving and in the 12 hour period post pile-driving were identified. Movements during these three periods were compared to identify potential changes in direction or speed that could have indicated detection or response to the pile-driving. Although such changes could not be attributed to the pile-driving itself, because many other variables could initiate changes to movement, they provided indications of a correlation.

Dive data for the seals during periods of exposure to pile-driving were extracted from the full dive records of the seals. There was insufficient time between receipt of pile-driving periods (pile-driving completed on 16 October) and the required report submission deadline (1 November) to enable a statistical analysis of the dive behaviour data in relation to pile-driving. These will be presented in the T1 report. Instead, graphical plots were constructed of dive-profiles and travel speeds over time periods that overlapped with pile-driving events. Patterns of change to diving behaviour that could have related to detection of pile-driving were identified in the figures.

2.5 Luchterduinen activities

The offshore construction activities in the *Luchterduinen* area include (see Figure 5):

- Preparation of the field, including unexploded ordnance clearance
- Stone dropping (scour protection at monopile pads and cable crossings)
- Pile-driving of monopile foundations
- Cable burial
- Positioning of the Offshore High Voltage Station (OHVS).

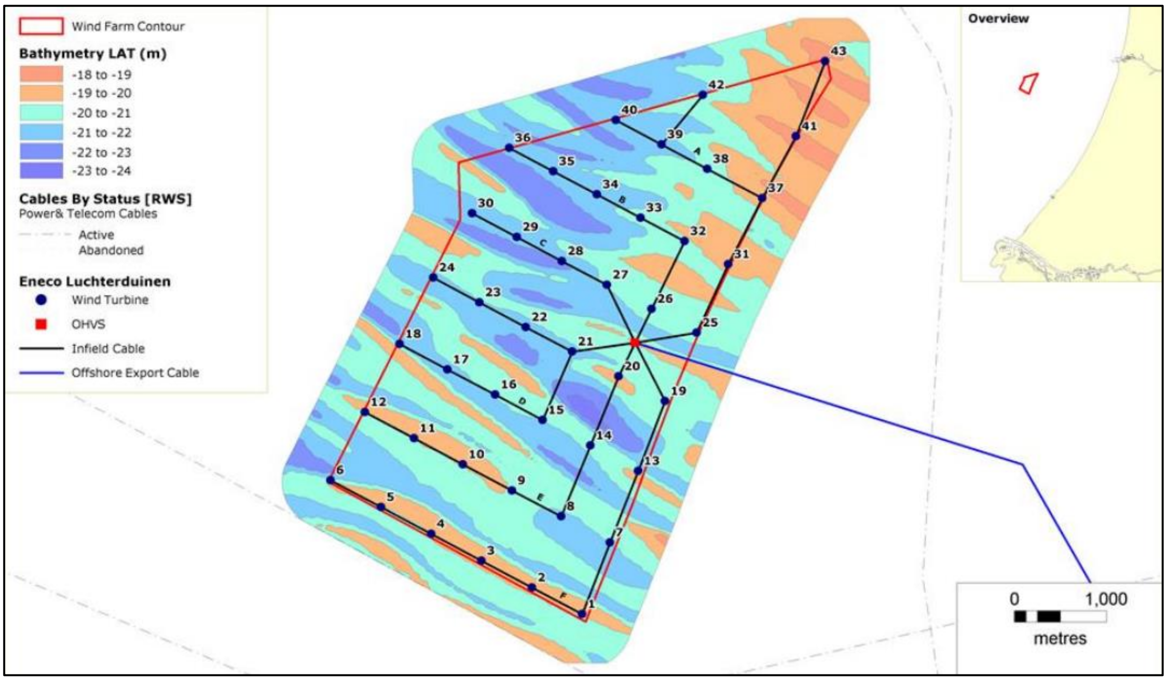


Figure 5. Locations for activities, wind-turbine and cable locations, and bathymetry at Luchterduinen *(map supplied by ENECO).*

During all activities, some kind of underwater noise was produced, and movement and light from the vessels might also have been detected by seals and influence their movement choices. The loudest underwater sound was produced by pile-driving. Other sounds are e.g. stone dropping and sonar surveys.

At the time of writing this report, data for two activities of construction at the *Luchterduinen* site were available for comparison with the movement behaviours of the seals: stone dropping and pile-driving. This report focusses on temporal overlap with the pile-driving. The data of other activities, including stone dropping, will be included in the final analysis report, after T1.

Stone-dropping was to establish scour protection pads around the base of the towers. Stone-dropping was undertaken prior to pile-driving and took place in June. Two layers of different sized stones were dropped from the *Van Oord* multipurpose support vessel *Jan Steen* (load capacity of 1824 T) to construct each scour pad. Sonar scans during stone-dropping provide accurate monitoring of the shape of the scour protection pads. Two positions are without scour protection: pile 30 and pile 42.

Pile-driving was conducted by the *Van Oord* jack-up vessel *Aeolus* in the period 31 July to 16 October.

In total 44 monopiles (mostly 4.5 m diametre) were piled: 43 turbines turbine foundation and one for the offshore high voltage station. Generally, four monopiles were loaded on board of the *Aeolus* in Vlissingen and, if weather allowed, the *Aeolus* moved to the *Luchterduinen* area. At the right position, the vessel pinned its four legs and jacked up. Before the actual 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 harbour porpoises out of 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.

Pile-driving activity increased through the pile-driving period. One tower was installed in July, 11 in August, 16 in September and 17 in the first half of October (Figure 6). Towers required an average of approximately 110 minutes to be driven in to their required depth. Longer piles at positions 30, 42 and the OHVS took longer (150 to 170 min). After completion of pile-driving, the *Faunaguard* was switched off; the vessel installed some fixtures to the tower, then jacked-down and moved to the next location. After 4 piles, *Aeolus* returned to port to load the next piles, typically resulting in a gap of 2-3 days without pile-driving. On occasions, for instance due to bad weather, *Aeolus* had to return to the port or wait in the area before continuing activities.

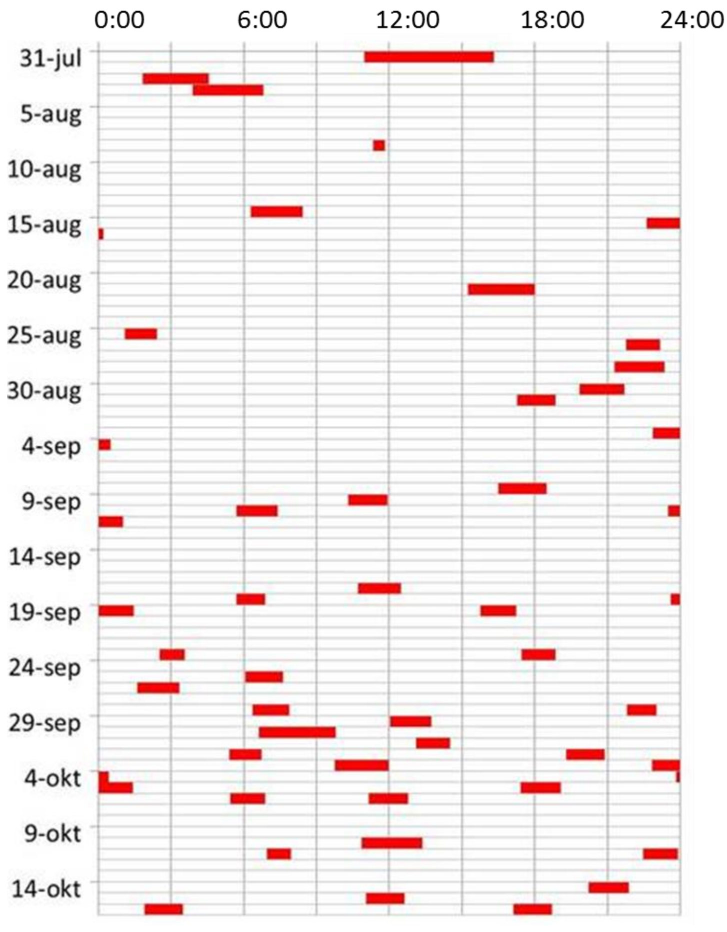


Figure 6. Date and time of day (UTC, which equalled local [CEST] time minus 2 hours) of pile-driving for Luchterduinen wind farm in 2014.

Each monopile had a unique pile-driving record (see example in Figure 7). Because the pile-driving procedure can influence the behaviour of the seals, it is important to document procedure variability.

After a tower had been stood on end and lowered to the sea-floor, the pile-driving hammer was positioned over it and hammering commenced with a ‘soft-start’, i.e. no (or light) power. This soft-start was to ensure the tower seated well and penetrated the substrate in a controlled manner. As the pile-driving progressed and the tower penetrated further into the substrate, the power was increased. Hammering was at a rate of 40-50 blows per minute. The power supplied to the hammer varied over time, as required for the individual pole. Generally, energy levels increased as the pile penetrated deeper, up to a maximum of 80% capacity, which was 1400 kJ. The maximum power supplied to a single tower varied, and this likely equated with different maximum sound levels produced for each pile-driving event. Hammering was also not continuous through a pile-driving event. Initial hammering periods were for several seconds, separated by breaks for observation/ adjustment of up to several minutes. Durations of hammering tended to increase through the event, with durations of continuous hammering in the later stages lasting 30 minutes or longer (Figure 7).

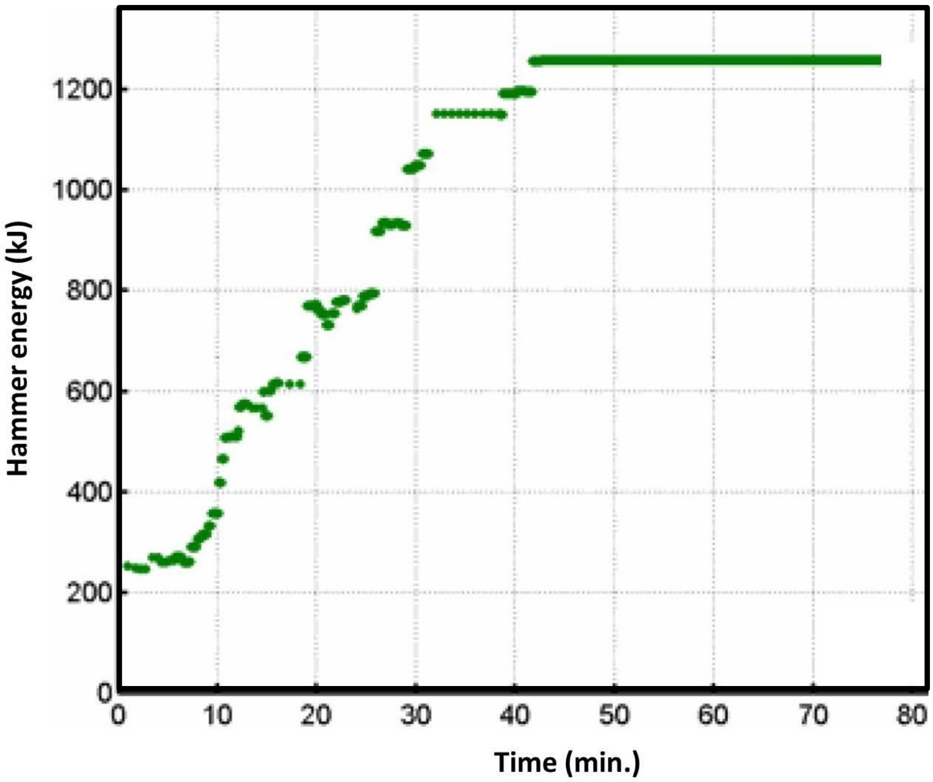


Figure 7. An example of the change in energy level and frequency of blows over time during pile-driving of a turbine tower. This is a scenario based on a total of 2500 hammer blows and a maximum energy of 90% of 1400kJ. Figure adapted from de Jong et al (2013).

3. Results

This report presents results up to 26 October 2014. Tracking continued after this date. All times in this report are presented in UTC (UTC [Coordinated Universal Time] = CEST [Central European Summer Time] - 2 hours).

3.1 Deployments

The four field trips to two study sites for the attachment of 40 GPS-GSM-transmitters to harbour seals (20) and grey seals (20) required a total of 12 field days: eight capture days, one bad-weather day and three travel days.

This report presents data up to 26 October. The 20 harbour seals were tracked for durations of 73 to 114 days (mean ± sd, 92 ± 12 days). The 20 grey seals had been tracked for durations of 73 to 207+ days (179 ± 34 days), of which 12-14 devices were still operating (Table 3, Figure 8). Seals were differentiated as adult or subadult based on length (nose to tail): adults were harbour seals >130 cm, grey seal females >140 cm and grey seal males >160 cm.

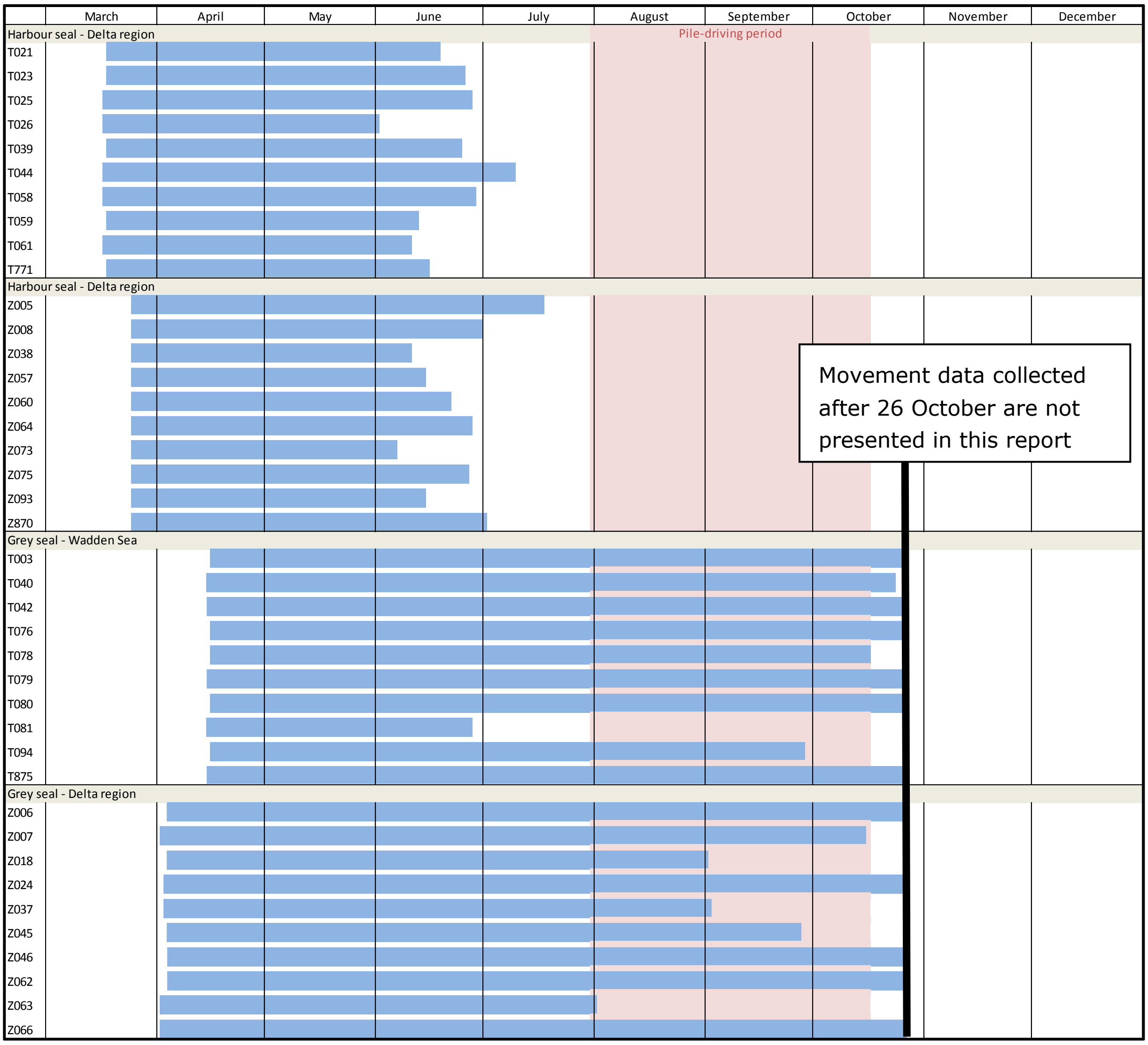


Figure 8. Durations that seals were tracked during 2014, in relation to the Luchterduinen *pile-driving period of 31 July to 16 October (data up to 26 October).*

Table 3. Seals tracked in 2014 (data up to 26 October – asterisks indicate tracking continued past this date).

Seal number	Sex	Age group	Date out	Last location from seal	Days tracked
Harbour seal – Wadden Sea					
T021	M	adult	18 March	18 June	92
T023	M	adult	18 March	25 June	99
T025	F	subadult	17 March	27 June	102
T026	M	adult	17 March	1 June	76
T039	M	subadult	18 March	24 June	98
T044	F	adult	17 March	9 July	114
T058	F	adult	17 March	28 June	103
T059	M	adult	18 March	12 June	86
T061	F	adult	17 March	10 June	85
T771	F	subadult	18 March	15 June	89
Harbour Seal – Delta region					
Z005	M	adult	25 March	17 July	114
Z008	F	adult	25 March	30 June	97
Z038	M	adult	25 March	10 June	77
Z057	M	adult	25 March	14 June	81
Z060	M	adult	25 March	21 June	88
Z064	F	adult	25 March	27 June	94
Z073	F	subadult	25 March	6 June	73
Z075	M	subadult	25 March	26 June	93
Z093	M	adult	25 March	14 June	81
Z870	M	subadult	25 March	1 July	98
Grey seal – Wadden Sea					
T003	F	adult	16 April	26 October*	193
T040	F	adult	15 April	23 October*	191
T042	F	subadult	15 April	26 October*	194
T076	F	adult	16 April	25 October*	192
T078	M	adult	16 April	16 October*	183
T079	M	adult	15 April	26 October*	194
T080	M	subadult	16 April	26 October*	193
T081	M	subadult	15 April	27 June	73
T094	M	subadult	16 April	28 September	165
T875	F	adult	15 April	26 October*	194
Grey seal – Delta region					
Z006	F	adult	4 April	25 October*	204
Z007	F	subadult	2 April	15 October	196
Z018	F	adult	4 April	1 September	150
Z024	F	adult	3 April	26 October*	206
Z037	M	adult	3 April	2 September	152
Z045	M	adult	4 April	22 September	171
Z046	F	adult	4 April	26 October*	205
Z062	F	adult	4 April	26 October*	205
Z063	F	subadult	2 April	1 August	121
Z066	M	adult	2 April	26 October*	207

During tracking, locations were recorded frequently, though not always at the set interval of 5 min for harbour seals or 15 for grey seals. For example, 9% of locations for grey seals were not within one hour of the preceding location (Figure 9). This can be the result of the animal being hauled out, and the tracker switching to a power saving mode when dry for more than 10min. Another cause can be that as the animal surfaces to breath, the tracker does not come out of the water enough to fix a location.

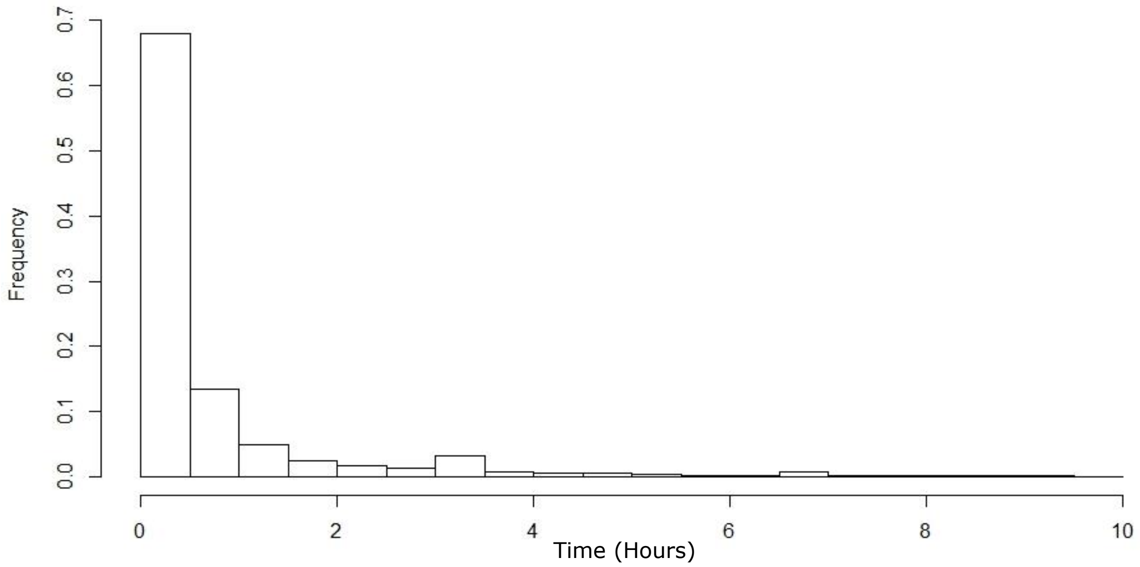


Figure 9. Frequency of occurrence of time periods between successive location determinations for grey seals during tracking in 2014 (n = 49,357 periods between locations, data up to 26 October).

3.2 Seal movement

Data collection for this report goes up to 26 October 2014, when 12-14 of the grey seal transmitters were still providing data. Data from these after 26 October 2014 will be incorporated into the T1 report. There was great variation in the degree of movement of individual grey seals, as has been found in previous studies in the Netherlands (Brasseur et al. 2010, Brasseur et al. 2012). For example, one seal (T003) remained within 30 km its' capture location throughout the 193 days it was tracked, while eight of the 20 seals (five from the Delta and three from the Wadden Sea) crossed the North Sea to the UK coast. Two Wadden Sea seals (T080 and T875) travelled >800 km to the Orkney Islands, Scotland. The maximum distance from capture site was 860 km. The longest movements by Delta region seals were of approximately 350 km, by both Z037 - through the English Channel to southern England - and Z066 - to the eastern Wadden Sea.

Overall, harbour seals ranged less than did grey seals (Figure 10 and Figure 11). One harbour seal and seven grey seals crossed the North Sea to the UK. Within Dutch waters, most movement by the seals was in the North Sea rather than the Wadden Sea or Delta channels, however, one grey seal (Z006) remained predominantly within the Oosterschelde.

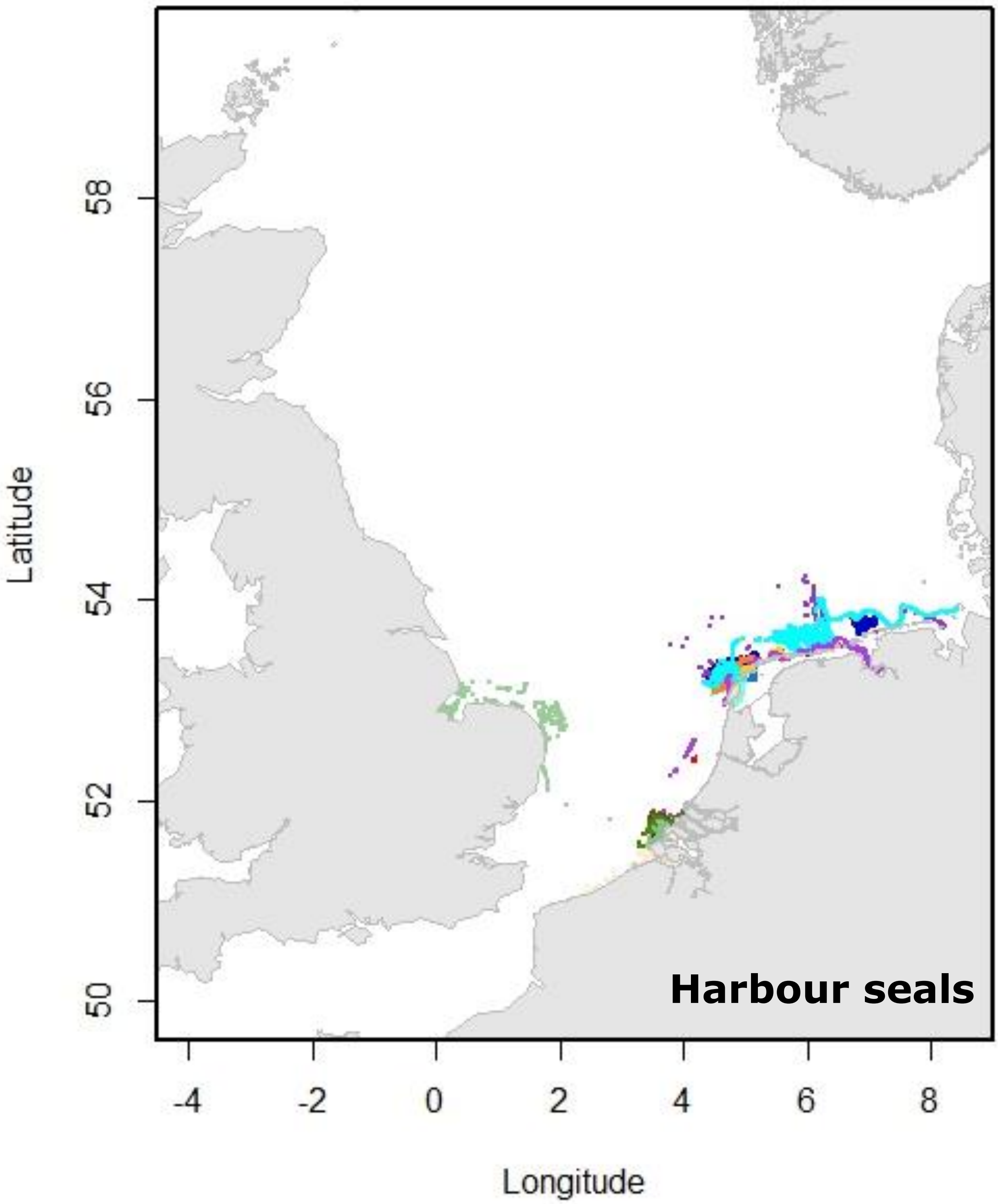


Figure 10. Locations recorded for 20 harbour seals during 2014 (data up to 26 October). Different colours are different seals.

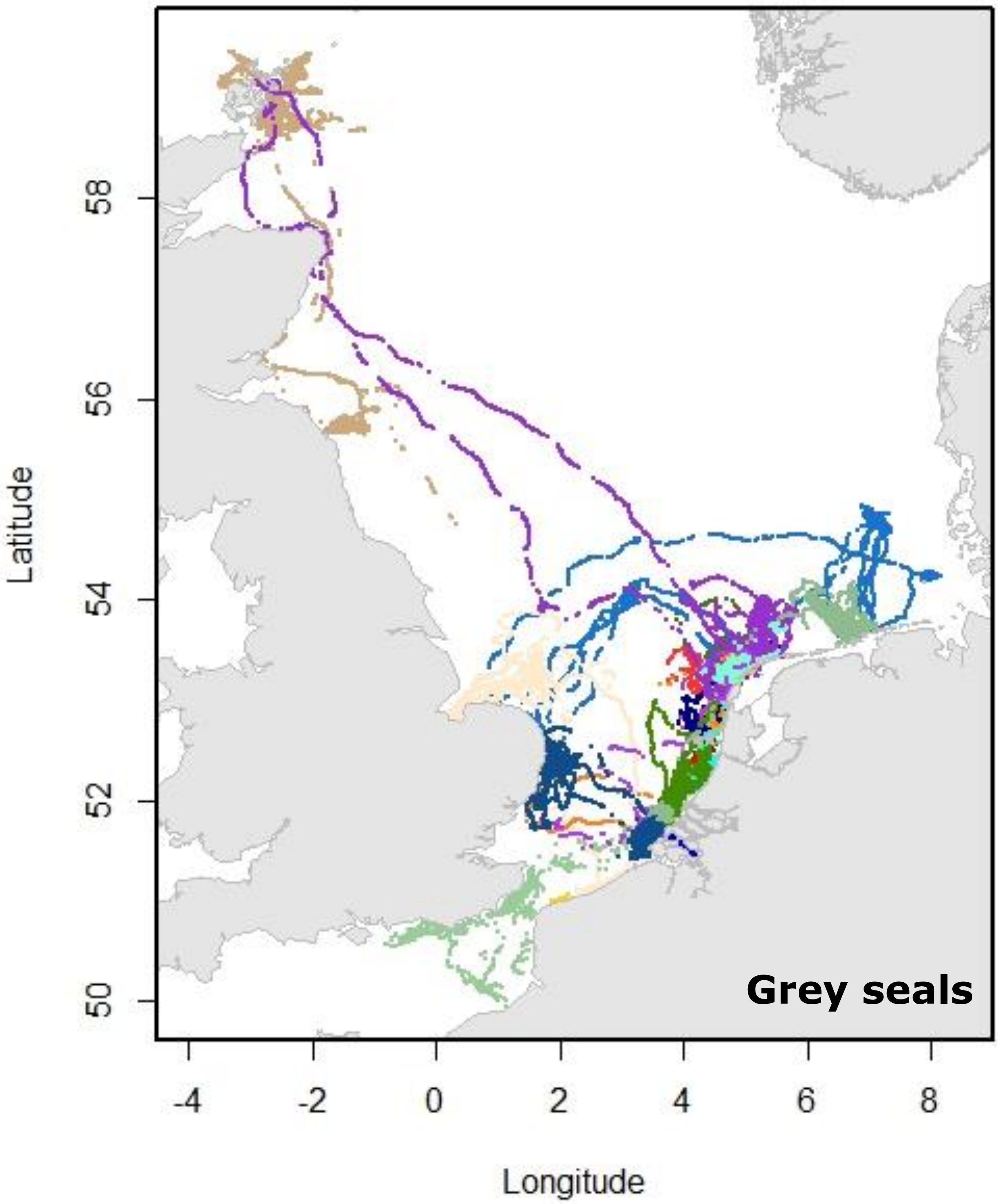


Figure 11. Locations recorded for 20 grey seals during 2014 (data up to 26 October). Different colours are different seals.

3.3 Use of the North Sea coastal zone

Ten grey seals and one harbour seal moved within the North Sea coastal zone (Figure 12), eight of these (including the only harbour seal) were tracked from the Delta area. Hence, movement of just three of the 10 grey seals and no harbour seals captured in the Wadden Sea was recorded within the coastal zone.

One of the Wadden Sea grey seals (T079) relocated to the Delta and performed trips into the coastal zone from there. Consequently, most of the movement into the coastal zone was from the south.

Five grey seals and one harbour seal traversed the North Sea coastal zone from one end to the other. Three of the grey seals performed return trips and one of those performed two return trips (Table 4). Furthermore, 10 seals and no harbour seals performed foraging trips into the coastal zone (Table 5).

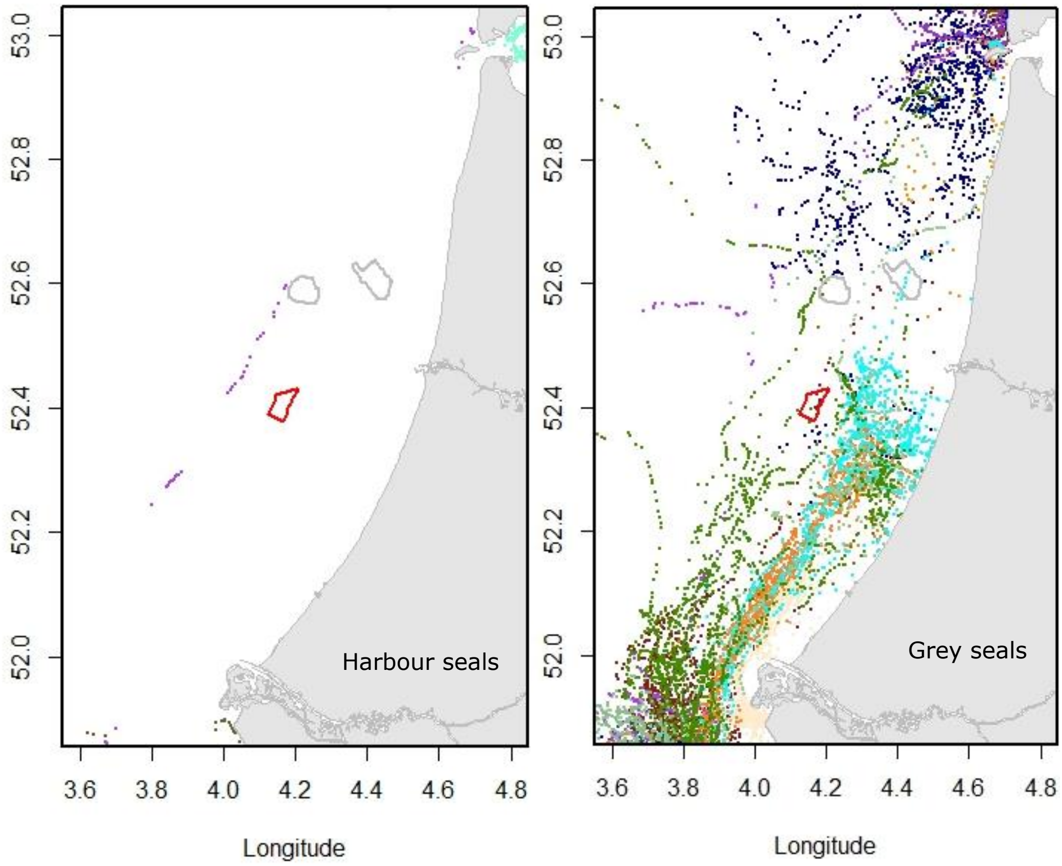


Figure 12. Locations adjacent to the Dutch coastal zone recorded for grey and harbour seals during 2014 (data up to 26 October). Wind farms, red shape = Luchterduinen*, grey shapes = OWEZ and PAWP.*

Table 4. Grey seals and a harbour seal tracked in 2014 that performed traverses of the North Sea coastal zone (data up to 26 October).

Species	**Seal**	**Sex**	**Age**	**Capture area**	**Coming from**	**Return trip recorded**
Grey	T079	M	adult	Wadden Sea	North	no
Grey	Z037	M	adult	Delta region	South	yes
Grey	Z045	M	adult	Delta region	South	yes (twice)
Grey	Z046	F	adult	Delta region	South	yes
Grey	Z066	M	adult	Delta region	South	no
Harbour	Z064	F	adult	Delta region	South	no

Table 5. Grey seals tracked in 2014 that performed foraging trips along the Dutch coastal zone, between the Wadden Sea and Delta region (to 26 October). No harbour seals did this.

Species	Seal	Sex	Age	Capture area	Coming from	Trips up to 26 Oct
Grey	T076	F	adult	Wadden Sea	North	26
Grey	T079	M	adult	Wadden Sea	South	7
Grey	T080	M	subadult	Wadden Sea	North	1
Grey	T081	M	subadult	Wadden Sea	North	14
Grey	Z007	F	adult	Delta region	South	22
Grey	Z024	F	adult	Delta region	South	23
Grey	Z037	M	adult	Delta region	South	8
Grey	Z045	M	adult	Delta region	South	14
Grey	Z046	F	adult	Delta region	South	1
Grey	Z063	F	subadult	Delta region	South	19

The only harbour seal that utilised the Dutch coastal zone (adult female Z064) was transmitted at Renesse sandbar in the Delta on 2 April and traversed the coastal zone (~20-30 km from the shore) between the 23 and 26 May (Figure 13). It continued east and arrived in the Eems Estuary on 3 June. Based on its movements thereafter, this female gave birth and raised her pup in the Eems Dollard in late June. Shortly after this, the transmitter came off the seal; it is unknown if the seal returned to the Delta area after its pup had weaned.

Figure 13. Movements of harbour seal female Z064, the only harbour seal tracked for Luchterduinen *in 2014 that passed within 20 km of* Luchterduinen*. This seal was caught in the Delta region in March, traversed north in late May and probably had a pup in the Eems Dollard in June.*

3.4 Movement in the vicinity of *Luchterduinen*

Eight grey seals and one harbour seal provided locations within 20 km of *Luchterduinen* wind farm (Figure 14, Table 6). The majority of locations were inshore from the wind farm. Before the pile driving started, seven of the seals were tracked when they entered the area within 20 km of the wind farm multiple times (68 in total) (Table 6). Two seals came within 5 km of the centre point of the wind farm in this period. After pile driving started, three seals continued to use the area. A fourth (T079) came within 20 km of *Luchterduinen* on a single foraging trip, and actually entered the wind farm area on that trip, the only seal to enter *Luchterduinen* during the pile-driving period (i.e. after July 31), although this did not coincide with a pile driving event. In total, after the beginning of pile driving, 22 visits into the 20 km perimeter area were recorded. During the whole recording period, three grey seals provided locations within 5 km of the *Luchterduinen* wind farm site. Four Delta region seals (Z024, Z035, Z045 and Z063) spent >10% of the duration they were tracked within 20 km of the wind farm (Table 6).

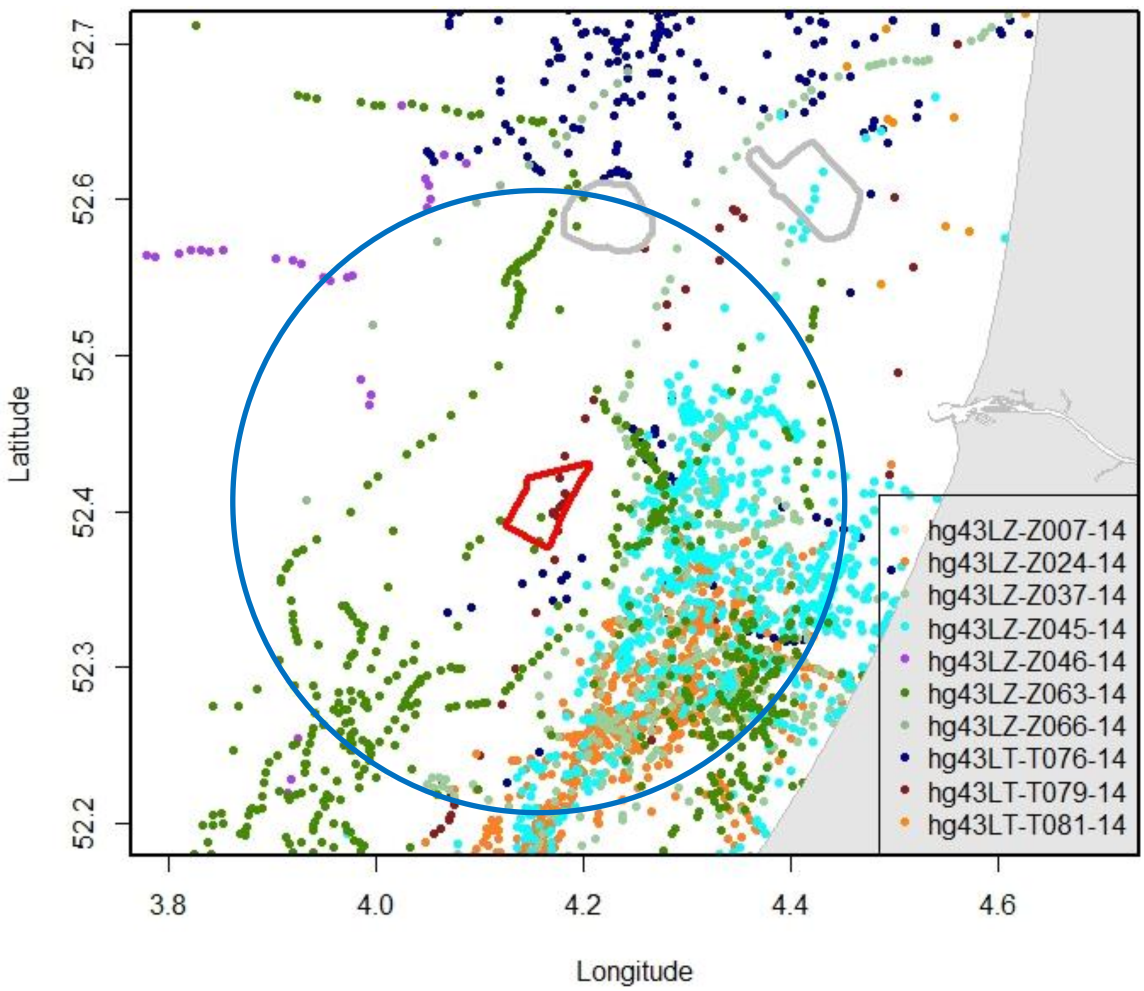


Figure 14. Locations of grey seals in the vicinity of Luchterduinen *wind farm site (red) and operational wind farms (grey). Blue circle is 20 km distance from* Luchterduinen *(data up to 26 October).*

Table 6. Percentage of time seals spent within 20 km of Luchterduinen *and within* Luchterduinen *before and after the pile-driving period commenced, on 31 July 2014 (data up to 26 October 2014, n = number of visits).*

Seals	**Days tracked**		**% of time <20 km**				**% of time in *Luchterduinen***			
	Before 31 July	**31 July and after**	**Before**	**n**	**After**	**n**	**Before**	**n**	**After**	**n**
Harbour seals										
pv54L-Z064-14	94	0	0.5	1	0	0	0	0	0	0
Grey seals										
hg43L-T076-14	106	86	3.3	2	0	0	<0.1	1	0	0
hg43L-T079-14	107	87	0	0	2.1	2	0	0	0.4	1
hg43L-Z007-14	120	76	<0.1	1?	0	0	0	0	0	0
hg43L-Z024-14	119	87	39.2	14	33.2	13	0	0	0	0
hg43L-Z037-14	119	33	1.8	6	29.2	9	0	0	0	0
hg43L-Z045-14	118	53	20.9	22	41.3	12	0	0	0	0
hg43L-Z046-14	118	87	0.1	1	0	0	0	0	0	0
hg43L-Z063-14	120	1	10.7	22	0	0	0.4	4	0	0
hg43L-Z066-14	120	87	0.2	1	0	0	0	0	0	0
Visits by grey seal				**68**		**26**		**5**		**1**

Single locations in the potential windfarm area were recorded twice for seal Z063: on 19 April at 16:39 UTC and 6 July 13:24 (before pile-driving), and a series of locations was provided by seal T079 between 12 August 21:42 and 13 August at 3:13 (see Appendix A). When seal Z063 passed through the site on the 6 July, this followed two stone-dropping events that occurred on the 5 and 6 July, when the seal was within 10 km. Seal T079 passed through the site for 6.1 hours, 4-days after the third tower had been installed and spent several hours in the vicinity of the new tower.

Locations within an operational wind farm were recorded for two grey seals. Seal Z045 was assumed to have crossed through the centre of Offshore windpark *Egmond aan Zee* (OWEZ) between 1:30 and 3:00 am on 12 May 2014. Although the seal was recorded on several other occasions in the neighbourhood, there were no locations recorded in the wind farm. Seal Z063 crossed the western edge of Princess Amalia windpark (PAWP) between 1:30 and 2:00 am on 11 April. These crossings have not been compared with weather conditions or activity of the wind turbines.

3.5 Movement in the vicinity of pile-driving at *Luchterduinen*

Movements of six grey seals were recorded within the North Sea coastal zone during the pile-driving period of 31 July to 16 October. A seventh grey seal (Z063) departed the coastal zone on 31 July, prior to pile-driving on that day (and no locations for this seal were provided thereafter).

A comparison of seal locations recorded prior to the pile-driving period with locations recorded during the pile-driving period indicates fewer locations offshore during pile driving (Figure 15). It is clear that these data are largely influenced by the single seal Z063 (green in Figure 15) which moved frequently in the offshore waters prior to pile-driving and whose tracker provided no further locations after the day pile-driving commenced (see data for individual seals in Appendix B).

Comparisons of the movement by individual seals prior to and during pile-driving indicate different areas were utilised by seals over time (Appendix B).

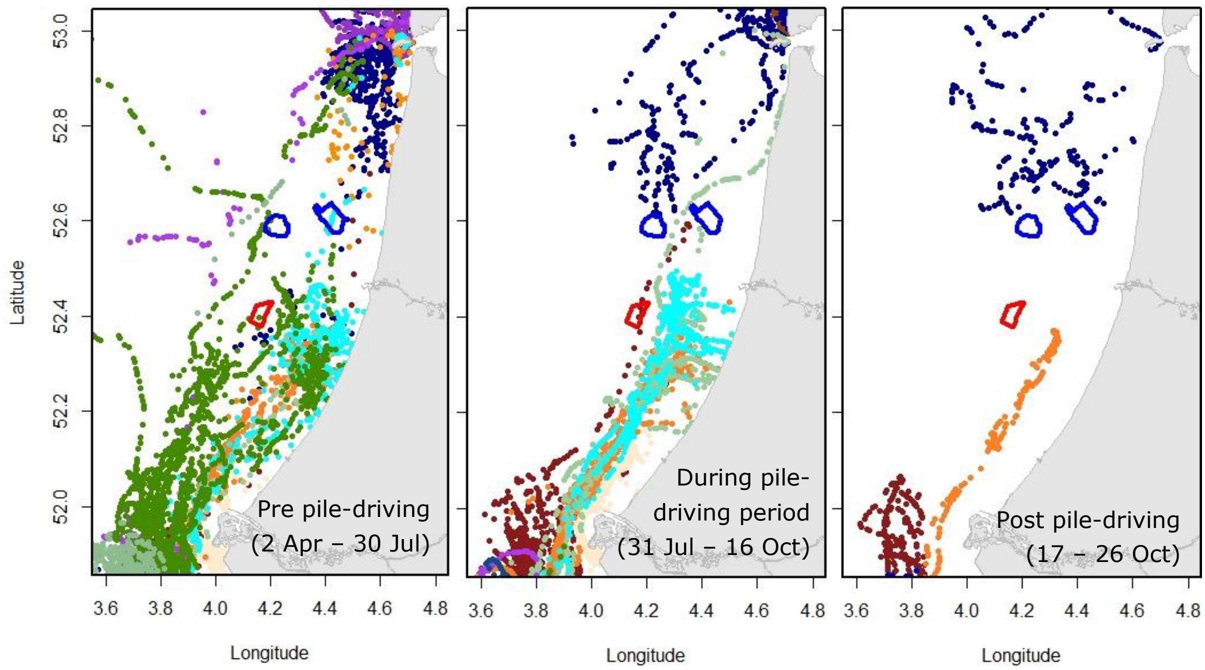


Figure 15. Locations recorded for grey seals in the North Sea coastal zone prior to pile-driving, during the pile-driving period and post pile-driving (data up to 26 October).

Although seals outside of the North Sea coastal zone may have detected pile-driving at *Luchterduinen*, here we define possible overlap as 'exposures' of seals that were in the North Sea coastal zone at the time of a pile-driving event. Thus, the maximum distance a seal could have been from a pile-driving event and be included, was 55 km to the south or 69 km to the north. Accordingly, there were 83 exposures of grey seals to pile-driving events. The distances from events ranged between 7 and 54 km (see details in Appendix B). The number of exposures recorded for individual seals ranged from 4 to 26 (Table 7).

Table 7. Number of potential exposures to pile-driving events based on seal locations within the North Sea coastal zone from the location of pile-driving within Luchterduinen*.*

Distance between pile-driving event and closest location recorded for the seal at the time	**T076**	**T079**	**Z007**	**Z024**	**Z037**	**Z045**	**Total**
0 ≤ 10 km				2	1	1	4
10 ≤ 20 km		1		15	4	9	29
20 ≤ 30 km	2	1	3	4	1	5	16
30 ≤ 40 km			19			1	20
40 ≤ 50km	3	2	2	3		1	11
50 ≤ 55km	1			2			3
Total	**6**	**4**	**24**	**26**	**6**	**17**	**83**

On 45 (54%) exposures of a seal to a pile-driving event, no locations were recorded for the seal (Table 8). On the remaining 38 exposures, at least one location of the seal was recorded. Comparisons between the locations of the seal prior to and during pile-driving suggested no change in trajectory on 25 occasions, potential aversion (i.e. the seal stopped or moved away but it cannot be confirmed if this was due to the sound or another factor) on 10 occasions and potential approach (i.e. the seal moved closer but it cannot be confirmed if this was due to the sound or another factor) on three occasions. Amongst the potential aversion movements, three were evident for seals positioned closer than 20 km.

During exposures to pile-driving at distances <20 km, no locations were recorded 19 times, and the seal remained in the area or continued on its incoming trajectory on 11 occasions.

Table 8. Recorded movement of seals that were present in the North Sea coastal zone <u>during</u> pile-driving at Luchterduinen *(n = 83), data summarised from Appendix B.*

Seal movement during pile-driving event	Potential interpretation	Frequency	Distances between pile-driving and the seal*
No locations recorded during event		45	9 – 51 km
Locations recorded during event indicated the seal:			
- Continued on trajectory	Change not evident	11	13 – 51 km
- Remained in area	Change not evident	14	7 – 34 km
- Moved away	Aversion	6	11 – 46 km
- Stopped	Aversion	1	18 km
- Moved inshore	Aversion	2	16 – 29 km
- Moved offshore	Aversion?	1	54 km
- Moved closer	Approach	3	28 – 45 km

*Seal location is nearest location recorded during or within an one hour of pile-driving, or if none available, the location closest in time to the event.

Based on comparisons of trajectories of seals prior to and post exposures to pile-driving events, no alteration to movement direction was evident on 53 (64%) of the 83 occasions, potential aversion was evident on 27 (33%) occasions and potential approach on 5 (6%) occasions (Table 9).

Table 9. Recorded movement of seals present in the North Sea coastal zone <u>after</u> a pile-driving event at Luchterduinen *(n = 83), data summarised from Appendix B.*

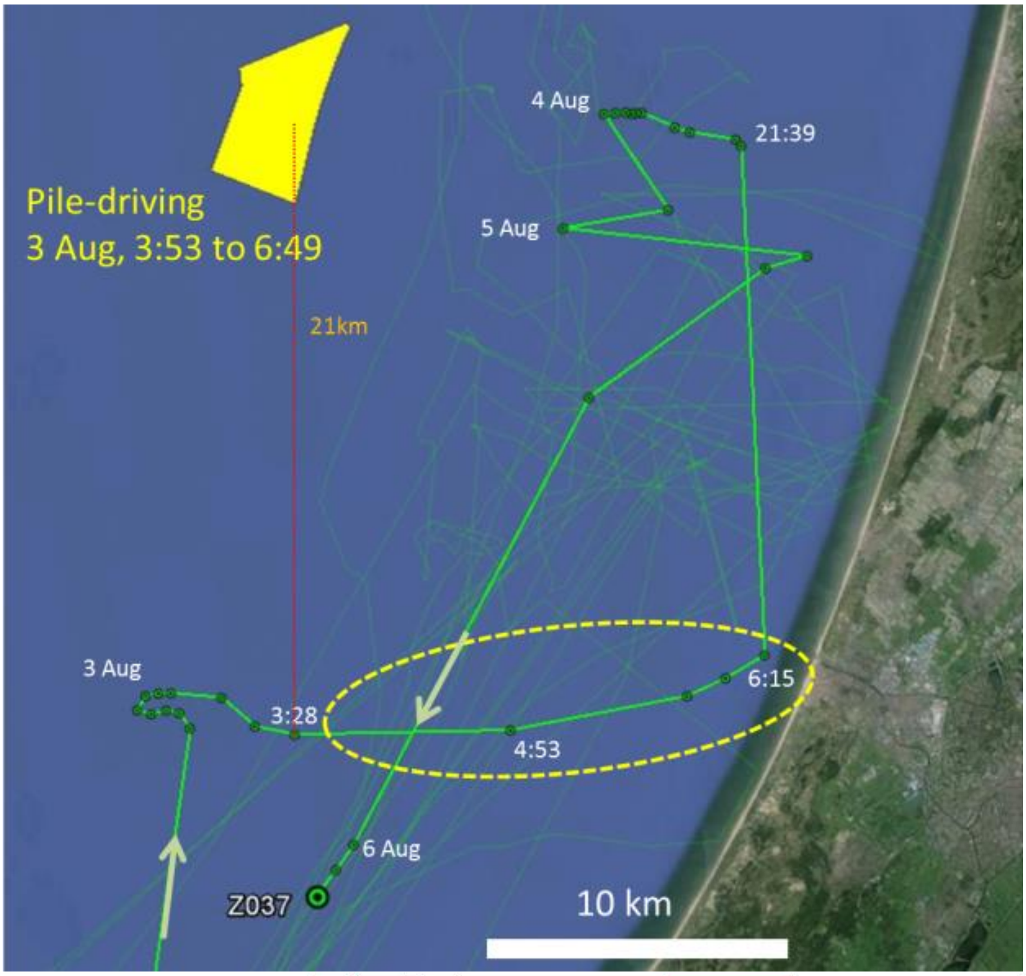
Seal movement post pile-driving	Potential interpretation	Frequency	Distances between pile-driving and the seal*
Continued on trajectory	Change not evident	24	10 – 51 km
Remained in area	Change not evident	28	9 – 34 km
Moved parallel with *Luchterduinen*	Change not evident	3	7 – 24 km
Moved away	Aversion	15	14 – 49 km
Moved inshore	Aversion	8	13 – 41 km
Moved closer	Approach	5	15 - 54 km

*Seal location taken as the nearest location recorded within an hour of pile-driving, or if none available, the location closest in time to the event.

3.6 Diving behaviour during pile-driving

Dive data provides a means of further investigation into potential changes in movement of the grey seals in response to pile-driving activity. Numerous detailed responses were recorded (see example in Figure 16).

For seals at proximities of closer than 25 km, visually detectable changes to the dive patterns near in time to the commencement of pile-driving were evident in 16 of 42 exposures (see Figure 16, Figure 17 and further examples in Appendix D). Occasionally, changes to dive patterns preceded pile-driving (see example in Figure 17). Changes also were evident during pile-driving and at the completion of pile-driving events (see for example Z045 on 2014-09-18, in Appendix D).



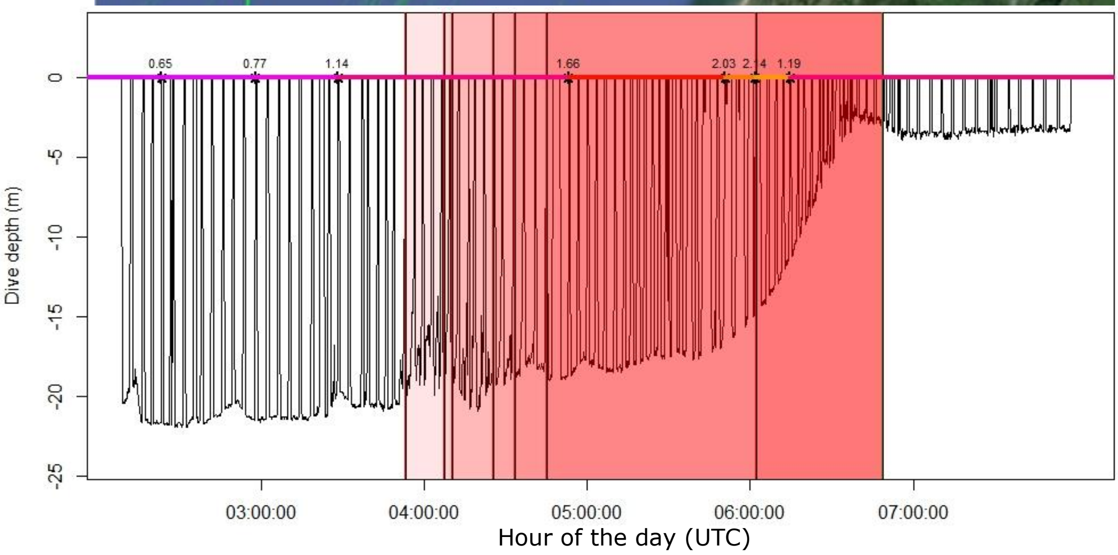


Figure 16. An example of movement by a grey seal (Z037) before, during and after a pile-driving event, for which a full log of the pile-driving was available. Wind speed in the area at the time of the pile-driving was 10-15 knots, south-westerly. The top map provides locations of the seal (connected by interpolated lines) and proximity to Luchterduinen*, with the yellow oval indicates position during the pile-driving. The bottom figure indicates dive depth against time of day. Black lines show diving behaviour of the seal, typically from the surface to the bottom (which shallows over time from 22 m to <5 m after 6:30). The pink area is the pile-driving period, separated into stages of increased energy input. The numbering and colour scale on the 0 m (surface) line represent horizontal speed of the seal in metres per second. During the pile-driving the seal increases speed and enters shallower water.*

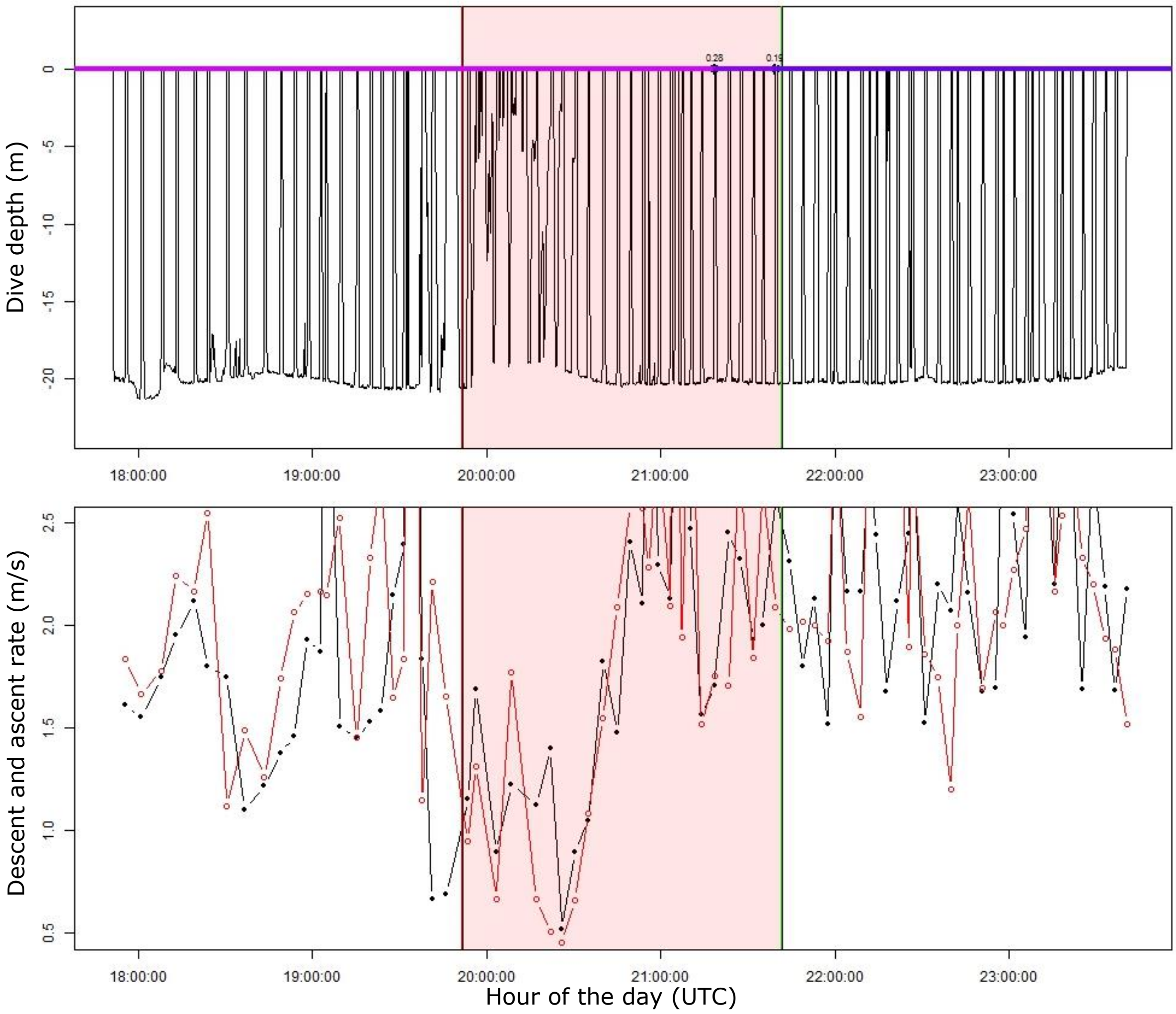


Figure 17. Dive records from grey seal Z037 when it was approximately 13 km from a pile-driving event (pink area) at Luchterduinen *on 30 August 2014. The top figure provides dive-depth over time; the bottom figure indicates the seals descent (black) and ascent (red) rates. Note the seal almost always dives to the sea floor at about 20 m depth. At the start of pile-driving, the dive profiles change with more spiked, and shallow, dives compared to the flat-bottom dives before and after the start of pile-driving. Seal descent and ascent rates slow down for the first 30 minutes of pile-driving, then speed up.*

4. Discussion

4.1 Overview

In the framework of the *Luchterduinen* wind farm project, seal monitoring for Tconstruction, 2014, was based on deployments in March and April, on harbour and grey seals and at either end of the coastal zone. The monitoring had two aims:

1. To monitor seal movement and behaviour in the coastal zone between the Wadden Sea and the Delta region.
   - In spring 2014, 40 seals were fitted with a GSM-GPS tracking device. These provided individual seal location data for periods ranging between 73 to >200 days. One of the 20 harbour seals and 11 of the 20 grey seals provided movement data within the coastal zone, where *Luchterduinen* is being constructed.
2. To monitor seal movement and behaviour in the vicinity of *Luchterduinen* wind farm during the July-August period, when pile-driving was anticipated.
   - Pile-driving was conducted from 31 July to 16 October. Six grey seals were tracked in the North Sea coastal zone during that period, and 83 exposures to pile-driving events (defined as occurrences when a tracked seal was within the North Sea coastal zone during pile-driving activity) were recorded at distances ranging between 7 and 54 km.

To put this study into context, prior to discussion the findings, we present a review of knowledge on possible effects of pile-driving sound on grey and harbour seals.

4.1.1 Possible effects of pile driving sound

While little is known about the long term effects of offshore wind farms, the largest immediate impact on marine fauna is assumed to be caused by pile-driving (Madsen et al. 2006). Pile-driving into the sediment of wind turbine towers (monopiles) produces a series of high-impact, broad-band pulses of noise and pressure-waves, over several hours. The sound levels produced by pile-driving and the distances they travel vary depending on the equipment used (vessel, hammer type, tower design) and location (e.g. inshore shallow vs offshore). The sound exposure levels (SEL) received by a seal depend on a range of factors, including: distance from the event, the amount of other (ambient) noise and whether the animal is positioned on the surface or at depth. If unobstructed, the sound of pile-driving may be detected by marine mammals over distances of hundreds of kilometres (Madsen et al. 2006).

Several studies have collected some data and modelled the sound levels that could be received at certain distances from pile-driving. In a study of Thompson et al. (2013), modelled peak to peak sound levels at 10 km and 50 km from pile-driving were approximately 170 and 140 dB re 1 μPa, respectively. Sound exposure levels predicted for pile-driving of towers at *Luchterduinen* ranged up to 140 dB re 1$\mu Pa^2 s$ at 10 km distance and 120 dB re 1 $\mu Pa^2 s$ at 50 km distance (de Jong et al. 2013) (see Figure 18). Most energy of such pile driving occurs at frequencies around 0.25-1 kHz.

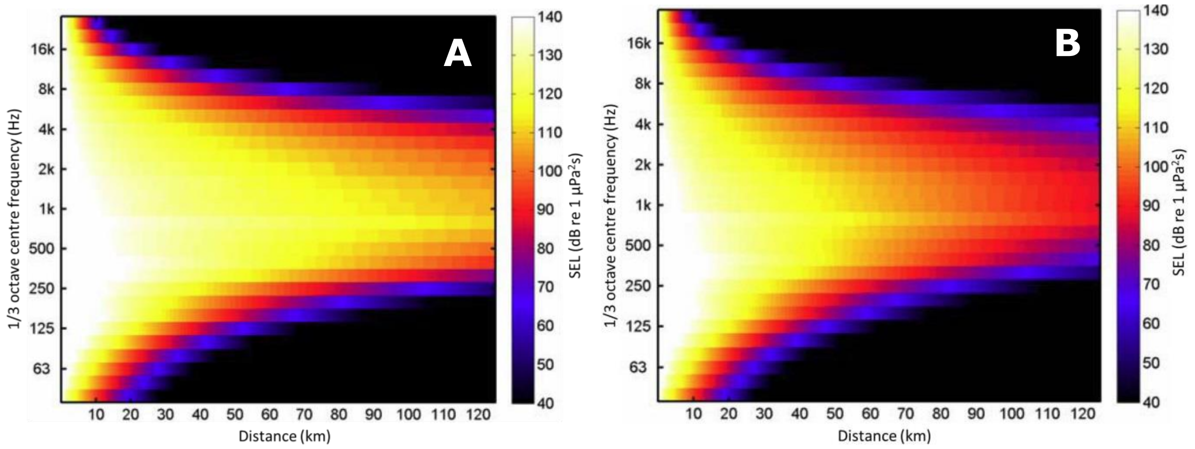


Figure 18. Predicted 1/3 octave band spectrum of the sound exposure level (SEL) at 1-m above the seabed, as a function of distance from Luchterduinen *tower 28, during a single pile-drive at an energy level of 1400 kJ: A) with no wind interference; B) with wind at 6-8 m/s, creating noise on the surface that reduces sound propagation. Figure taken from de Jong et al. (2013).*

When no data are available for species in the wild, but such data are required to apply reasonable management decisions, data for other 'similar' species, or captive-experimental data are often applied. This has been done to predict seal responses to pile-driving. An example of use of data from other species is a 2013 environmental impact assessment of pile-driving on harbour seal populations in Moray Firth, Scotland (Thompson et al. 2013). That study used published responses of harbour porpoises, *Phocoena phocoena*, (from Brandt et al. 2011) and 'expert judgement', to model possible impacts on harbour seals.

Seals have been considered to be less sensitive to underwater sound than are cetaceans (Southall et al. 2007). This may not be the case, however: recent studies have demonstrated seals are highly sensitive to sounds underwater. In an experimental situation, two captive/ trained harbour seals detected play-backs of pile-driving (recorded for similar tower sizes to those at *Luchterduinen* during pile-driving at the OWEZ windfarm, near to *Luchterduinen*) at SELs of 39-43 dB re 1μPa^{2}s (Kastelein et al. 2013b). Other captive studies have shown that harbour seals have a maximum sensitivity over a broad frequency range, 0.5 to 40 kHz (Kastelein et al. 2009), and that grey seals can detect frequencies up to at least 69 kHz (Stansbury et al. 2014). A recent field study (Götz & Janik 2015) showed pulse noise at a frequency of ~1 kHz (a frequency produced during pile-driving that is propagated over a great distance, see Figure 18, from de Jong et al. 2013), displaced harbour seals while harbour porpoise seemed unaffected. Peak sound frequencies produced by pile-driving, in fact are at lower frequencies – 125 to 500 Hz – where harbour seals hear well but harbour porpoises do not. Thus, harbour and grey seals should be considered as highly sensitive to underwater sounds produced by pile-driving, and potentially more sensitive than harbour porpoises.

Moving on from detection, the exposure levels at which marine mammals may be injured by anthropogenic underwater sound varies between species, individuals within species and timing of the exposure in relation to what the individual is doing (Nowacek et al. 2007, Southall et al. 2007, Weilgart 2007). Research on captive harbour seals has indicated that the duration of exposure to pile-driving, not just the received sound levels, influences the time required for individuals to recover from a temporary threshold shift (TTS) in their hearing ability (Kastelein et al. 2013a, Kastelein et al. 2013b). Two harbour seals were inadvertently and for 60 minutes, subjected to play-backs of pile-driving sounds at an SEL of 199 dB re 1μPa^{2}s; considerably higher than a level known to initiate a TTS, approximately 169 to 177 dB re 1μPa (Kastelein et al. 2013a, Kastelein et al. 2013b). The seals had the option to leave the water or remain in the tank. One of the seals left the water while the other remained in the tank throughout the exposure. The seal that remained in the tank received a TTS that lasted for 4-days.

This experiment with two captive seals highlights their potential to remain in an area, despite receiving sound SELs that could be damaging to their long-term hearing.

Based on modelled propagation scenarios for anticipated sound levels produced by pile-driving at *Luchterduinen,* and assumptions on seal behaviour, based on an interpretation of the experimental results from two captive harbour seals (Kastelein et al. 2010, Kastelein et al. 2013b), predictions were made of potential distances at which 'seals' could be influenced by pile-driving (de Jong et al. 2013) (see Table 10). According to this model, when there was no masking from wind sounds, seals within 21 km would avoid the pile-driving, seals within 13 km might receive some level of TTS and those within 100 m might receive a PTS to their hearing ability. If there was some masking of the pile-driving due to wind and wave activity, the distances were predicted to be less. It was concluded that very few seals would suffer any effect from the pile-driving activities.

Table 10. Distances from pile-driving at Luchterduinen *at which data from data from de Jong et al. (2013) predicted seals would 1) avoid, 2) receive temporary threshold shift (TTS) or 3) receive permanent threshold shift (PTS), based on experimental results with two captive harbour seals and modelled sound propagations.*

Distance for:	**Scenario 1 wind speed 6-8 m/s (12-16 knots)**	**Scenario 2 wind speed 0 m/s**
- avoidance at 1 m above the sea-floor	15 km	21 km
- avoidance at 1 m below the sea-surface	5 km	7 km
- TTS onset	8 km	13 km
- PTS onset	0.1 km	0.1 km

In making the determinations of impacts on seals, however, several assumptions about seal behaviour might have been unrealistic. That seals might choose to avoid the area ignores the high level of site fidelity of many seals. They might not leave if motivated for some reason to remain, despite being exposed to high levels of sound. Moreover, it was assumed that those present would swim away with a speed of 5 m/s. This over-estimates the maximum sustainable speed of a seal, which would be closer to 2 m/s. Finally, seals were assumed to be less sensitive to pile-driving sound than porpoises, thus the thresholds at which avoidance would be expected were assumed to be higher. As discussed above, though, at lower frequencies this might not be the case.

Avoidance distances by seals positioned near the surface were predicted to be considerably less than those for seals positioned near the sea-floor. However, individual grey and harbour seals continually dive to the sea-floor during their time spent at sea (Thompson et al. 1991, Goulet et al. 2001, Beck et al. 2003, Eguchi & Harvey 2005), so the maximum exposure levels, those at the sea-floor, should be assumed.

As demonstrated by the captive seal that allowed itself to be exposed to pile-driving, playback sounds, that gave it a TTS which lasted for 4-days, behaviours of seals can influence the sound energy levels they are exposed to. In the wild, seals may not have the option to haul-out and avoid underwater sounds, or they may choose to remain exposed rather than move away, despite possible discomfort from a certain level of sound exposure. The captive seals exposed to sounds knew they would be fed, irrespective of whether or not they remained in the water. A hungry wild seal might be more likely to remain in an area where it is catching prey, despite also receiving discomforting (potentially even damaging) sound levels. The fear or pain mechanisms that could initiate avoidance or flight responses, and override a need to feed (or perform other behaviours) are poorly understood. On the other hand, seals that do not necessarily have to visit the area, might avoid it from a much greater distance, even tens of km.

The strength of behavioural responses of an individual wild seal to underwater sound will be influenced by factors in addition to received sound spectra and potential interests in maintaining an activity such as foraging. For example, response level can be influenced by patterns in the sound (altering sound levels could appear to the seal as if it were being approached), previous experience with pile-driving and behavioural considerations (such as fidelity to a foraging site).

4.2 Harbour seal movements in Tc

Like in 2013, harbour seals were tracked during the pre-breeding period only. Movement records of harbour seals during the tracking period of 2014 was comparable to movement recorded during 2013. Due to the expected pre-moult tracker loss in June-July, and the later than expected commencement of pile-driving, there was no temporal overlap between harbour seal movement and pile-driving for *Luchterduinen*. Three harbour seals continued to provide location data into July, with the longest lasting, 114 days, ending on 17 July (adult male Z005).

Most trips to sea by harbour seals did not go further than 30 km from the haul-out site. However, six of ten seals from the Wadden Sea performed one or more longer movements, mainly from the western to the eastern Wadden Sea (80- 250 km). Also, four of ten seals from the Delta travelled larger distances on one or more trips. There was the one female that had her pup in the Eems region (360 km), two other harbour seals went south to the Westerschelde and the French coast (120 km), and one adult male (Z060) in late May crossed the North Sea to England and went to The Wash (300 km). This is a known harbour seal haul-out and pupping site and is 300 km from the seal's capture site. Previous tracking of harbour seals from the Delta region has also recorded this link with The Wash (Brasseur & Fedak 2003).

4.3 Grey seal movements in Tc

As with harbour seals, movement data recorded for grey seals in 2014 was comparable with the data collected in 2013. However, considerably more data were collected. The deployment procedure had been adjusted compared to 2013. In 2014, deployments were conducted in April rather than March. This was to reduce captures of pre-moult seals. In 2013, nine of the 15 deployments potentially were on seals that had not completed their moult (possibly due to a late moult that year); none of those devices tracked seals for periods >26 days. A tenth tracker, also failed early, possibly due to an electronics fault. The remaining five trackers each provided >100 days of data, and two provided >200 days (Kirkwood et al. 2014). In 2014, the first tracker to fail was after 73 days. The remaining 19 each provided >100 days of data, and 13 provided >200 days. Therefore, although the milder weather in 2014 might have allowed for earlier deployments, the adjusted procedure, of conducting grey seal deployments in April rather than March, probably assisted in a more successful tracking program.

On average the grey seals were tracked for a much longer period than the harbour seals and in another period with respect to their phenology, so more variation in their behaviour can be expected. For a large part of the study, many of the grey seals performed similar to the harbour seals, traveling less than 50 km away from the initial tagging site, with only occasional trips further away. Others switched haul-out site (to >100 km's away) and then remained close to those sites for the duration of the study. These transitions could in part be related to the animals returning to their breeding site.

In these transitions, the strong link between grey seals in the Netherlands and the UK was emphasised in the high number of seal movements to the UK that were recorded in 2014. Dutch populations of grey seals have increased in number since the 1980s, partially due to immigrations from the UK (Brasseur et al. 2014). Moreover, grey seals that breed in the UK are observed in Dutch waters, especially during the (Dutch) moulting period in March-April and in the summer they are assumed to forage frequently in Dutch waters (Brasseur et al. 2014).

Seals tracked in 2014 that went to the UK visited known colony sites, including Blakeney Point, Donna Nook, Farne Islands, Fastcastle and locations in the Orkney Islands. Other areas utilised by grey seals tracked in 2014 included Helgoland in Germany and the coasts of Belgium and northern France. These data support previous findings (Brasseur et al. 2010, Brasseur et al. 2014) grey seals travel extensively throughout the North Sea region.

4.4 Harbour seal overlap with the North Sea coastal zone and *Luchterduinen*

From the capture site in the west of the Wadden Sea, harbour seals tended to remain in the area or travel to the east rather than down the coast toward the Delta region. This has been found in previous studies (Brasseur et al. 2011, Brasseur et al. 2012), including the 2013 monitoring for *Luchterduinen* (Kirkwood et al. 2014). Movements by harbour seals from the Wadden Sea into the coastal zone have been recorded, though, including one of six harbour seals from 2013, an adult male, which perform several trips down the coast, coming to within 20 km of *Luchterduinen*. Moreover, in March 2014 an adult male harbour seal tracked from the central Wadden Sea for *Gemini* wind park (see pv54G-A002, in Appendix C) travelled to the Delta and back.

One harbour seal tracked from the Delta region in 2014 entered the North Sea coastal zone. That seal, an adult female (Z064), traversed from south to north and continued to the Eems Delta in the eastern Dutch Wadden Sea, where the movement and dive data obtained suggested she had a pup. She was one of two adult females in the Delta sample; the other (Z008) gave no indications in the recorded movement or diving data of breeding behaviour. Movement by adult female harbour seals up the Dutch coast from the Delta to the Wadden Sea immediately prior to the in June-July pupping period has been recorded previously (Reijnders et al. 2000, Brasseur & Reijnders 2001a, b, Kirkwood et al. 2014).

From the Delta region, the movement of just one of 10 harbour seals through the coastal zone in 2014 is less than the tracking of four of six harbour seals through the zone in 2013 (Kirkwood et al. 2014). The difference might reflect inter-annual variability in movement, but more likely reflects variability in the relative composition of the samples of seals. The one seal that crossed in 2014 was one of three females in the sample of 10. In 2013, three of four seals that crossed were three of the four females in the sample of six. Potentially, female harbour seals are more likely than males to move from the Delta region to the Wadden Sea, at least at the time of year when tracking was undertaken, i.e. the the pre-breeding period. The females could return to the Delta region after weaning their pup, i.e. in July or later, but data has not been collected to demonstrate this.

Combining data within year, the movement of harbour seals through the coastal zone was less in 2014 (one of 20) than in 2013 (five of 12 seals, Kirkwood et al. 2014). The between-year difference could not be attributed to an avoidance of pile-driving at *Luchterduinen* because all data for harbour seals were collected prior to pile-driving.

4.5 Grey seal overlap with the North Sea coastal zone and *Luchterduinen*

Eleven of the tracked grey seals entered the coastal zone during the period they were tracked, including seven from the Delta region. The three Delta region seals that did not enter the coastal zone included one that foraged almost exclusively in the Oosterschelde (Z006), another that moved to the French coast near Calais (Z018) and a third that travelled west, offshore from the Delta (rather than north of it) including several crossings of the North Sea to England (Z062). Three of the Delta grey seals (Z024, Z045, Z063) foraged almost exclusively in the coastal zone, two others (Z007, Z037) performed the majority of their foraging trips to the coastal zone but also foraged elsewhere and two more (Z046, Z066) transited through the coastal zone.

The use of the coastal zone by grey seals from haul-outs in the Delta region was higher than recorded previously (summarised in Aarts et al. 2013, Kirkwood et al. 2014). This was likely influenced by the large amount of data obtained in 2014 compared with data collected previously on grey seal movement from the Delta region. The results confirm the proposal by Aarts et al. (2013) that the North Sea coastal zone is both a transit zone and a foraging region for grey seals. Furthermore, movements recorded in 2014 support the observation that much of the movement by grey seals is within 20 km of the shore.

Eight grey seals and one harbour seal provided locations within 20 km of *Luchterduinen*, with the majority of locations being inshore. Four Delta region seals (Z024, Z035, Z045 and Z063) performed numerous trips to this area. In 2013, one of three grey seals tracked for >30 days, T034 (which was captured in the Wadden Sea), relocated to the Delta region in late July and then performed trips to the same area inshore from *Luchterduinen* (Kirkwood et al. 2014). The apparent multi-year use of this area and use by four of 10 grey seals tracked from the Delta region in 2014 signal it to be an important foraging area for grey seals (Figure 19). That the section of the North Sea coastal zone inshore from *Luchterduinen* could be a preferred foraging area for seals was predicted in habitat-modelling exercises conducted for both seal species which predicted habitat quality (Brasseur et al. 2012).

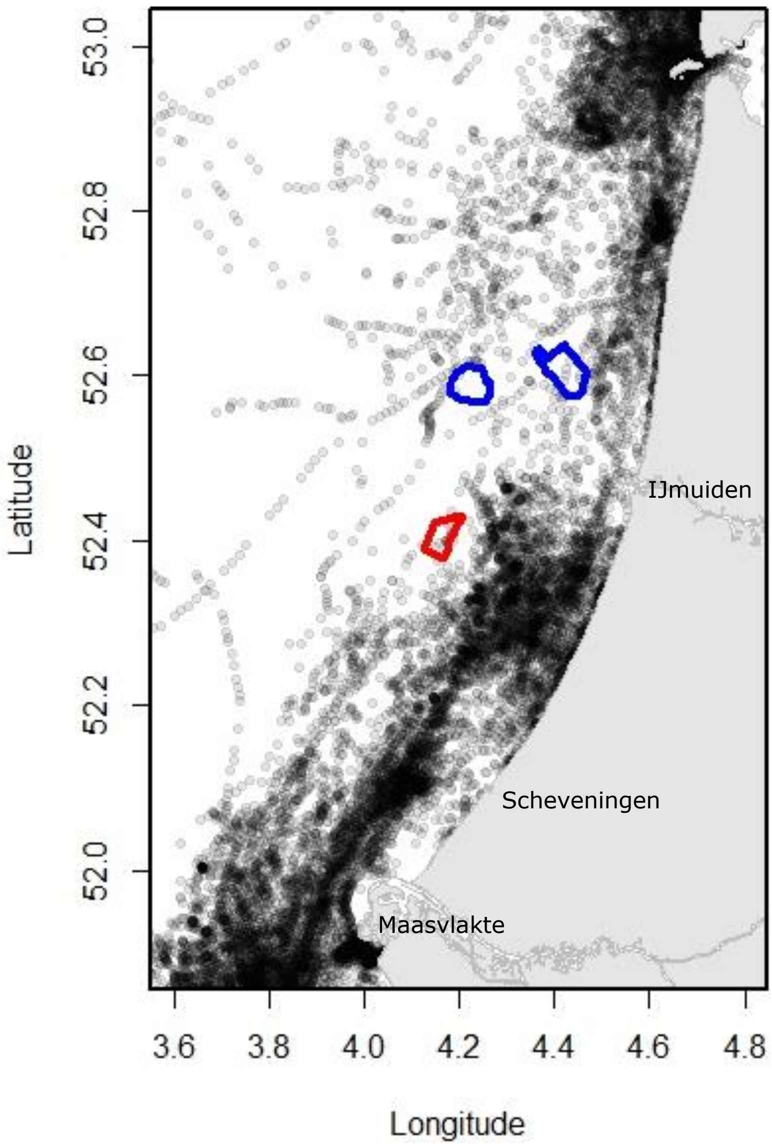


*Figure 19. All locations recorded for grey seals tracked by IMARES between 2005 and 26 Oct. 2014 (n=67 seals) in the North Sea coastal zone (*Luchterduinen *wind farm in red, operational wind farms in blue). Note, at the Maasvlakte, seals go around recent extensions of the coast that are not shown in the map.*

Other patterns of movement by grey seals in the coastal zone in 2014 were in accord with patterns evident in previous data (Brasseur et al. 2010, Aarts et al. 2013, Kirkwood et al. 2014). North of IJmuiden, much of the movement was within 0-10 kilometres of the shore. There is a gap in location data in the vicinity of Ijmuiden. This might reflect avoidance due to disturbance from shipping activity in that area, as IJmuiden is an important port, the adjacent anchor area's and the presence of the windfarms NSW and PAWP. There is, however, to a lesser extent a comparable absence of location data along the coasts of Scheveningen or Maasvlakte, also important shipping channels.

South of IJmuiden to Scheveningen, including the coastal area inshore from *Luchterduinen*, as mentioned, appears to be used frequently by grey seals. Between Scheveningen and Maasvlakte, however, few locations have been recorded in the near-shore, 0-8 km, although there is a band of activity, potentially a foraging and/or transit band, at 10-15 km from shore.

4.6 Overlap between grey seal movement and pile-driving

Comparisons of the areas of movement of individual seals before and during the pile-driving period indicate changes over time. It could not be determined if areas of visitation were influenced or not by pile-driving alone. For example, seals Z007 and Z037 moved over greater distances in the months prior to pile-driving, than they did in the months during pile-driving, when both remained predominantly in the area between the Delta region and inshore from *Luchterduinen* (see Appendix B). Seal Z024 remained in the same area, between the Delta region and Luchterduinen prior to and during the pile-driving periods, except for a 6-day trip to the UK during late pile-driving, 1-7 October. The changes in movement patterns likely were influenced by each individual seal's foraging success rates, requirements and knowledge of other areas, as well as potential seasonal effects, such as prey availability and annual cycle (e.g. related to breeding). Seasonal movement patterns of seals within the North Sea coastal zone and other areas could become more apparent with a larger data and this will be investigated following 2015 data collections, in the T1 report.

A step toward determining if the grey seals were responding to pile-driving is to recognise in the data potential changes to individual seal behaviour that could indicate it was detecting the pile-driving. One possible indication that seals were detecting and reacting to the pile-driving was that no location data were recorded for seals during 54% of the 46 x 110 minute pile-driving periods. Considering 81% of successive locations recorded for grey seals were <1-hour apart (see Figure 9), the high proportion of times that no locations were recorded suggests seals altered their behaviour at the surface (when links to satellites are made).

At present, it is not known how such surfacing is achieved, or what energetic cost to the seals could be involved. These seals obviously were surfacing to breath during the pile-driving events, but not in a way that brought the antenna of their tracking device out of the water and allowing it to receive a sufficient number of satellite transmissions to predict a location. It is common for locations to not be recorded every 15 minutes or so, but the high frequency of no-location data coinciding with 110 minute pile-driving periods was abnormal, and suggests seals were surfacing in a different fashion than they did normally. Without observational data, we can only speculate on how this could occur. Potentially, such a result could be seen if the seals were keeping most of their head and neck (and ear apertures) underwater when they were breathing at the surface. It is not known why they might do this.

That seals detected and reacted to the pile-driving was also evident in the seals' dive profiles. The data were not consistent, however. On occasions a change in dive pattern was evident coinciding with, particularly, the commencement of pile-driving, while on other occasions a reaction to the pile-driving was not evident in the dive profiles, or not exactly synchronised with the activities. Potentially, confounding factors could have influenced the reactions of the seals.

For example, sounds could be masked at times (e.g. by strong wind or another sound source) or a seal that is familiar with the sounds of pile-driving may continue with a behaviour pattern without an evident change to its dive-profiles. Seals may also receive a pre-warning of pre-pile-driving, by detecting sounds produced when the vessel is being jacked up, or the monopile being lowered into position, which influenced their response to the commencement of pile-driving. With data available on all activities at *Luchterduinen*, including the logs of pile-driving activity, investigations of changes in behaviour by individual seals to the minute of actual activities can be further investigated (it is planned to present this further in the T1 report).

In the majority of exposures of tracked seals to pile-driving events (45 of 83) no locations were recorded during the pile-driving period. When location data indicated the direction of movement of the seal during pile-driving, on 25 of 38 occasions (66%) the seals appeared to continue in the directions they had adopted prior to the pile-driving. On 10 occasions (26%) potential aversion was evident and on three occasions (8%) potential approaches were recorded. It is not known if the seals were able to detect/ determine the direction of the pile-driving that they were exposed to. Nor is it known if the seals could comprehend that the sound source (pile-driving) was not moving. For example, a ramp-up in pile-driving energy might be perceived by the seal as something approaching it, which could make some seals increase speed or head towards perceived safety areas (shallow or deeper water), and others attempt to determine the direction of the approach. Prior experience with the pile-driving in the area is likely to greatly influence the directional response of the seal during a current exposure, because they could have a better idea of the direction to the pile-driving, its potential duration, and what they can do to minimise disturbance from it while maximising prey acquisition.

Comparing movement trajectories of the seals prior to and post a pile-driving event, in 52 of 83 exposures (66%), the seal apparently returned to the movement it was undertaking prior to the pile-driving. Potential aversions (n = 23, 28%) and approaches (n = 5, 6%) were also observed. As with the reactions during pile-driving, these responses are open to interpretation, because the motivations of the seal or its understanding of the pile-driving are unknown. Also, longer time gaps in the location data could mean that shorter-term changes in direction were not apparent. Further, the gap in time between pile-driving and when locations were recorded varied between situations, so movements indicated were not recorded over the same temporal scales.

If a seal detects a pile-driving event, its response will vary depending on other motivations. For example, the motivation to feed is strong and could over-ride apprehensions about a potential danger. A seal might chose to tolerate pile-driving rather than take the risk of leaving a known foraging area to seek prey elsewhere. Also, the seal cannot predict when a pile-driving event might occur, so even if it might prefer to do so, it could not adjust its program of foraging at sea and returning to land around pile-driving events.

Seals continued to return to the vicinity of the pile-driving at *Luchterduinen* following exposures at distances of <20 km, including three seals that performed numerous trips to the area inshore of *Luchterduinen* prior to the commencement of pile-driving (Z024, Z037 and Z045). They continued to do so during the pile-driving period. This suggests a motivation to move into the region irrespective of the potential deterrence that a close approach to pile-driving could cause. Potentially, the motivation to frequent the area was that it contained prey resources which the seal perceived to be more available to it, than were prey resources elsewhere.

An important consideration for the interpretation of these data is that information is not available on the prior experience of individual seals to pile-driving. In recent years, there has been considerable pile-driving activity in the North Sea including in close proximity to the Dutch coastal zone. Twenty kilometres north of *Luchterduinen*, 36 towers were installed at OWEZ wind farm in 2006 and 60 were installed at PAWP in 2007.

Also since 2008, 181 towers have been installed at three Belgian wind farms, 60-70 km south west of our seal capture sites in the Delta, and 415 have been installed at three UK wind farms, within 170 km of the Dutch Delta region. Potentially, all the grey seals we tracked had heard at least one pile-driving event previously. They could have been aware that a pile-driving event would last a particular duration (e.g. 2 hours) and then stop for a duration (e.g. 12 to 24 hours). The varying degrees of prior experience of the tracked seals with pile-driving (potential habituation for some individuals) could have mitigated reactions to *Luchterduinen* pile-driving events.

In addition, while pile-driving at *Luchterduinen* would have been one source for sound on the Dutch coastal zone in 2014, other sources include shipping activity, dredging, and naval explosions. Data on these activities are not related to seal movements here, but responses to sounds from these sources could mask potential responses to the pile-driving at *Luchterduinen*, and complicate interpretations.

Hence, there are multiple reasons why detection of actual changes in seal behaviour coinciding with pile-driving at *Luchterduinen* could be difficult, especially because all data come from back-mounted tracking devices. That the data, particularly the dive-profiles and speed data, frequently indicate changes in behaviour that overlap in time with pile-driving is of interest and requires further investigation. This represents the first study to record overlap between movement of individually tracked grey seals and pile-driving, and the results have relevance to future pile-driving activities in the Netherlands and elsewhere. Further investigation of the diving behaviour data will be presented in the T1 report, which allows time for a more comprehensive analysis and interpretation of the data.

One important result is that several grey seals returned to an area where they are likely to have anticipated more pile-driving activity would occur. Assuming, based on captive studies with harbour seals (Kastelein et al. 2012, Kastelein et al. 2013a, Kastelein et al. 2013b), the grey seals could detect the pile-driving and that it might have caused them some discomfort, why might they continue to return?

On land, seals show a high fidelity to breeding sites (Pomeroy et al. 1994, Twiss et al. 1994, Pomeroy et al. 2000), and probably also to moulting and resting sites (Härkönen & Harding 2001, Karlsson et al. 2005). At sea, there are also indications of local preferences and site-fidelities (Oksanen et al. 2014), although long term data is scarce. Seals operate in an open environment through which they continually balance the metabolic costs and gains of remaining in an area with the metabolic costs and gains of moving elsewhere. The motivation to shift is typically less than the motivation to remain, because shifting exposes the seal to unpredictable variables (such as prey, predators, disturbance and conspecific competition). This is a known phenomenon that complicates simplified optimal foraging theories (Kamil et al. 1993), because it appears as if the animal is not foraging optimally. For the three grey seals Z024, Z037 and Z045, which frequently moved into the area inshore from *Luchterduinen* before and during pile-driving, the costs they recognised they were receiving from visiting the area probably did not exceed the benefits of the prey resources there, and induce them to forage elsewhere.

Seals exposed to a disturbance in an area in one year, could persist at the time, because of the cost of moving at a critical period (such as the lead up to breeding), but due to memory of the disturbance they could alter foraging areas in subsequent years. Accordingly, the knowledge that pile-driving occurred in the vicinity of *Luchterduinen* might influence foraging area selection by a seal in following years. However, detecting such a reaction could require tracking of the same individual in later years, and knowledge of inter-annual variability in foraging ranges of individuals.

There was an indication that seals might have avoided deeper waters offshore from *Luchterduinen* during the pile-driving period. Numerous locations were recorded offshore from the wind farm prior to pile-driving and none during. However, this observation was largely influenced by the one seal (Z063), which frequently moved in the waters offshore from *Luchterduinen* prior to the commencement of pile-driving, but then did not supply data during the pile-driving period.

It is known, though, that sound propagation, especially at lower frequencies, is higher in energy closer to the bottom and is minimised in shallower waters (de Jong et al. 2013). The potential that water depth could influence movement patterns of grey seals during pile-driving events requires further investigation, and will be looked at in more detail in the T1 report.

5. Conclusions and recommendations

5.1 Outcome of recommendations in the T0 *Luchterduinen* seal monitoring report

The T0 report contained five recommendations:

1. Retain the capture sites selected for seal captures in 2013.

This recommendation was adopted in 2014 and the sites again proved to be suitable for seal captures. There was considerable use of the coastal zone by grey seals captured at both the Zeeland and Wadden Sea sites. In contrast, minimal use of the coastal zone was recorded for harbour seals caught at these sites in 2014, which also contrasted with a higher use recorded for harbour seals in 2013. It is not known if this represented an inter-annual variability or simply a result of sample size and high levels of individual variability amongst the seals.

2. In future years, have separate-species field trips, targeting harbour seals in March and grey seals in April.

This recommendation was adopted and was financially supported by *Clusius CV*. It resulted in twice the number of field trips than would otherwise have been undertaken. The change was successful with all devices remaining on grey seals for at least 70 days. Substantially more data were obtained for grey seals in 2014 than in 2013 (as mentioned in the discussion).

3. Consider shifting T1 deployments from March-April 2016 to March-April 2015.

This recommendation was supported by *Clusius CV* and agreed to by *Rijkswaterstaad*.

4. Consider undertaking September deployments on harbour seals in 2014 and 2015, to maximise the potential to monitor response and recovery by this species to the pile-driving.

This recommendation was considered but not adopted.

5. Investigate/ establish protocols for the sharing of seal tracking data between projects.

This recommendation was supported by *Clusius CV.* Through a request from IMARES, project managers for the two wind farms currently under constructions in the Netherlands, *Luchterduinen* and *Gemini*, both of which have seal monitoring programs, discussed and agreed to the sharing of data between projects. This greatly increases the data available for analysis for each project. The wind farms are being constructed in different regions of the Dutch Continental Shelf, *Luchterduinen* in the North Sea coastal zone and *Gemini* offshore of the eastern Wadden Sea, and seal captures are specific to region. However, individual seals can travel great distances and overlaps were recorded in the 2014 data sets. One of the biggest inter-project overlaps was by grey seal Z066, caught in Zeeland for *Luchterduinen*, which provide the highest spatial overlap by an individual seal with the *Gemini* windpark. Z066 repositioned to a haul-out site in the German Wadden Sea. Between 12 May and 13 September 2014, this seal spent 1008 hours during nine separate trips within 20 km of Gemini, including 190 hours during 17 separate visits within the windpark area. In the reverse, in 2014 more harbour seal movement in the North Sea Coastal zone was recorded from seals tracked for the *Gemini* program than for seals tracked for the *Luchterduinen* program.

5.2 Tc conclusions

Movement data for 20 harbour seals and 20 grey seals from Dutch waters were obtained during 2014 and movements of six grey seals in the North Sea coastal zone were recorded during pile-driving events for *Luchterduinen*.

As the choice was made to deploy trackers only in Spring and the seals have contrasting annual cycles, moulting and breeding at alternate times of the year, their movement and behaviours cannot be directly compared. Data from harbour seals were limited to a few months immediately prior to breeding and might not represent year-round behaviour of these animals, while that for grey seals covered an 8-9 month period from moult through to breeding. Results should be interpreted accordingly.

Data recorded from the grey seals exposed to pile-driving events indicated that they had detected the events. This was evidenced in the lack of location data during pile-driving events, suggesting the seals had altered there surface behaviours, and was apparent in altered dive-profiles and speeds. It is not known if seals could determine the direction of the pile-driving. During and immediately after the exposures, seals did not display strong avoidance; the most common reaction observable was to continue gross directions of movement that were evident prior to the pile-driving event.

Individual grey seals that were exposed to pile-driving, continued to returned to the North Sea coastal zone on subsequent trips, such that individuals received multiple exposures. For example, seal Z024 received 26 exposures to pile-driving events at distances ranging from 7 to 51 km. Reasons for the return to the coastal zone despite exposure to pile-driving, likely relate to the seals' fidelity to (or short-term/ seasonal bond with) a particular foraging area, which in the case of Z024 was the area inshore from *Luchterduinen*. Such a motivation could over-ride the consequences it "perceived" it was receiving from the exposure to underwater sounds from pile-driving.

A further conclusion of this study is that data on responses of captive harbour seals to underwater sound cannot be directly extrapolated to predict what seals might do in the wild. Captive animal studies do provide important indications and insights into what individuals might do in the wild, particularly where wild animals are elusive and difficult to study. However, if taken out of context, the results can be incorrect. For example, speculation that seals might evacuate a 15-21 km perimetre around pile-driving based on the responses of a captive harbour seal to pile-driving play-back sounds (de Jong et al. 2013) is in contrast with the multiple recordings of grey seals remaining within 20 km of *Luchterduinen* during complete pile-driving periods. There are likely inter-species differences in behaviour (i.e. seasonal requirements of the animals) as well as the different requirements of captive versus wild animals, particularly that of being fed versus sourcing prey, as well as adaptations to a daily routine that are made by captive animals versus the less predictable wild situation.

Data collected in 2014 support the observation of earlier studies that much of the movement by seals along the coastal zone is within 20 km of the shore.

A more comprehensive investigation of seal diving patterns before, during and after pile-driving events is required. The large data-set of 3D movement by grey seals overlapping spatially and temporally with pile-driving activity represents a unique data set of international relevance. The analysis should incorporate all data available in pile-driving logs (such as times of hammering, gaps in hammering and power levels) and vessel activities (such as times of jacking procedures). Interpretations of the data could be improved if data were also available on all activities within the *Luchterduinen* site, and potentially elsewhere in the coastal region, that could have been detected by the seals.

5.3 Tc Recommendations for T1

1. Maintain plan to deploy trackers on both seal species at the selected sites at both ends of the North Sea coastal zone.

2. If additional trackers were available, consider additional deployments on grey seals in the Delta region – to maximise data for comparison with grey seal movement during pile-driving.

3. If the opportunity arises, re-track a seal for which intensive data are available (the seals can be recognised by individual flipper tags), to investigate inter-annual variability and development through life in foraging behaviours.

5.4 Tc Recommendations for future seal research

1. Consider future tracking of harbour seals from September onwards, to provide the potential to record overlap of this species with pile-driving in the Netherlands. Harbour seals were not tracked in September in this study as pile-driving was expected to be completed in July-August, when harbour seals are moulting. However, pile-driving for *Luchterduinen* continued into September and October, thus overlap with tracking data from harbour seals could have been possible. By tracking in September also help clarify if/ when post-breeding females return to the Delta region.

2. Collate/ examine data on seal numbers at haul-outs in the Delta region as a means of further identifying change in numbers/ composition that could be induced by human activities in the North Sea coastal region. Enhanced monitoring might be required to detect changes?

3. Undertake additional studies to determine the source/s for seals into the Delta region (e.g. genetics studies).

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7. Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2017 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

8. Justification

Report: C152/14
Project Number: 4306122501

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

Approved: Prof. dr. ir. P.J.H. Reijnders
Researcher

Signature:

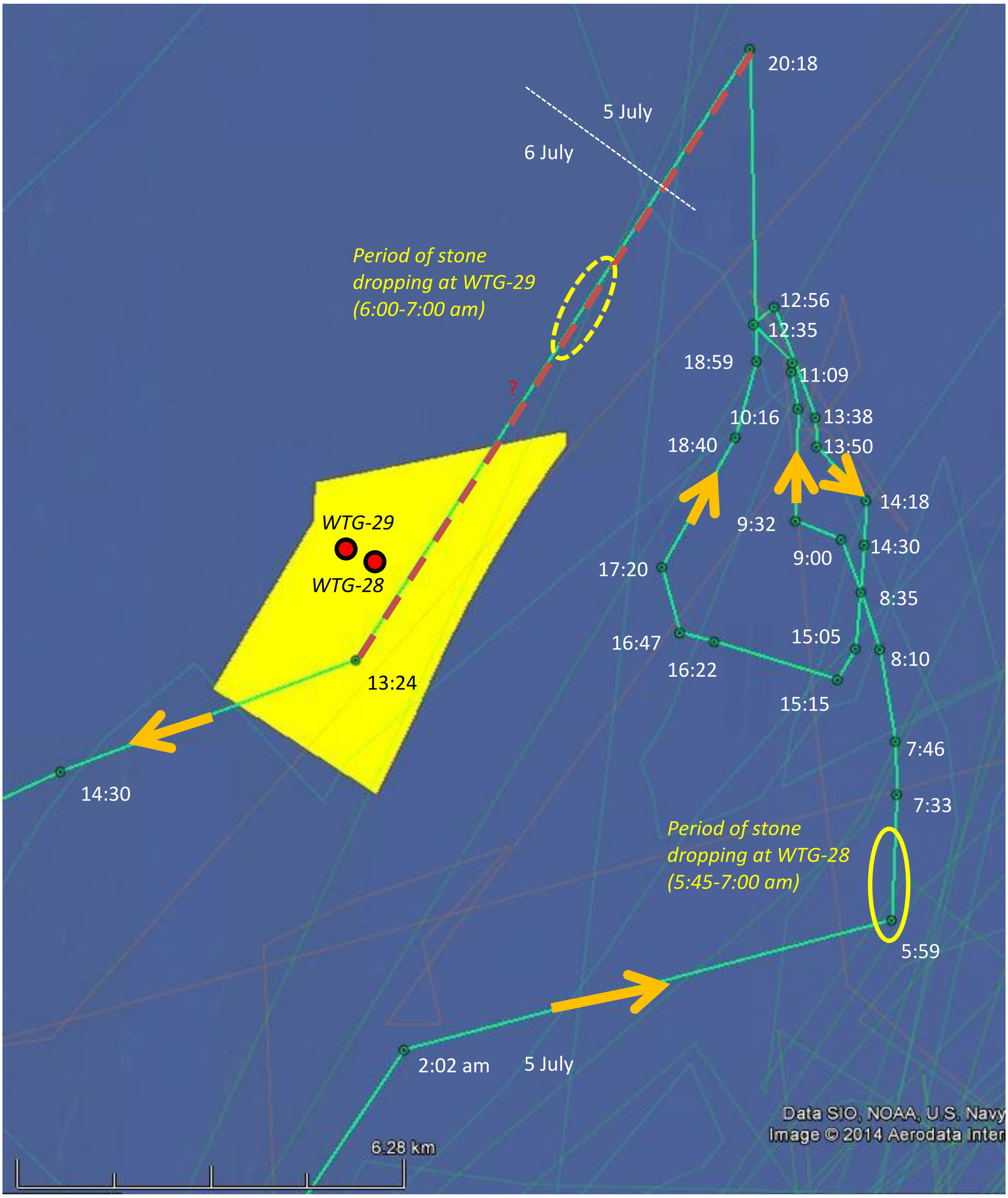
Date: 29 April 2015

Approved: Drs. J. Asjes
Head Ecosystems Department

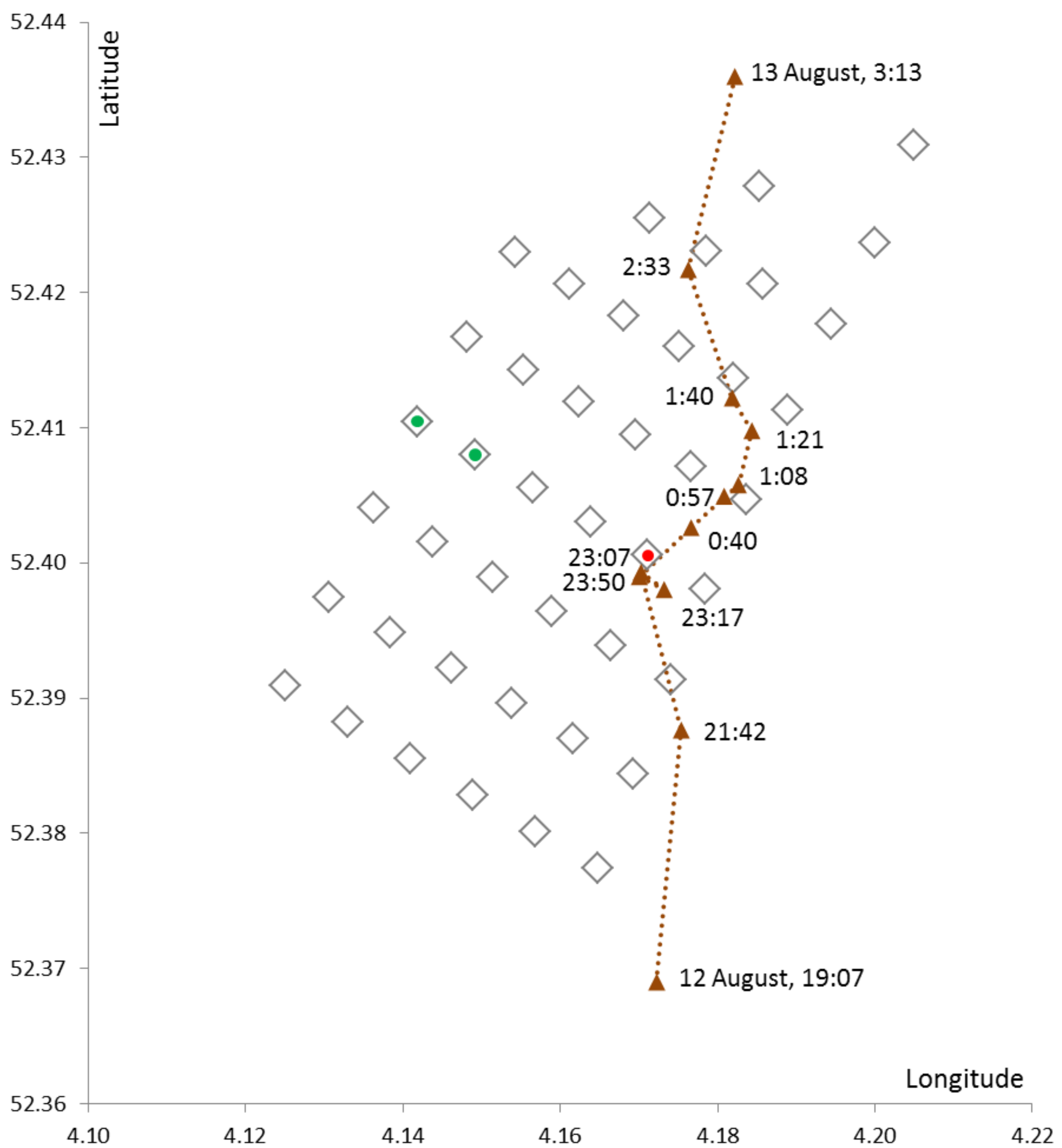
Signature:

Date: 29 April 2015

Appendix A. Locations of seals within *Luchterduinen* in relation to activities.



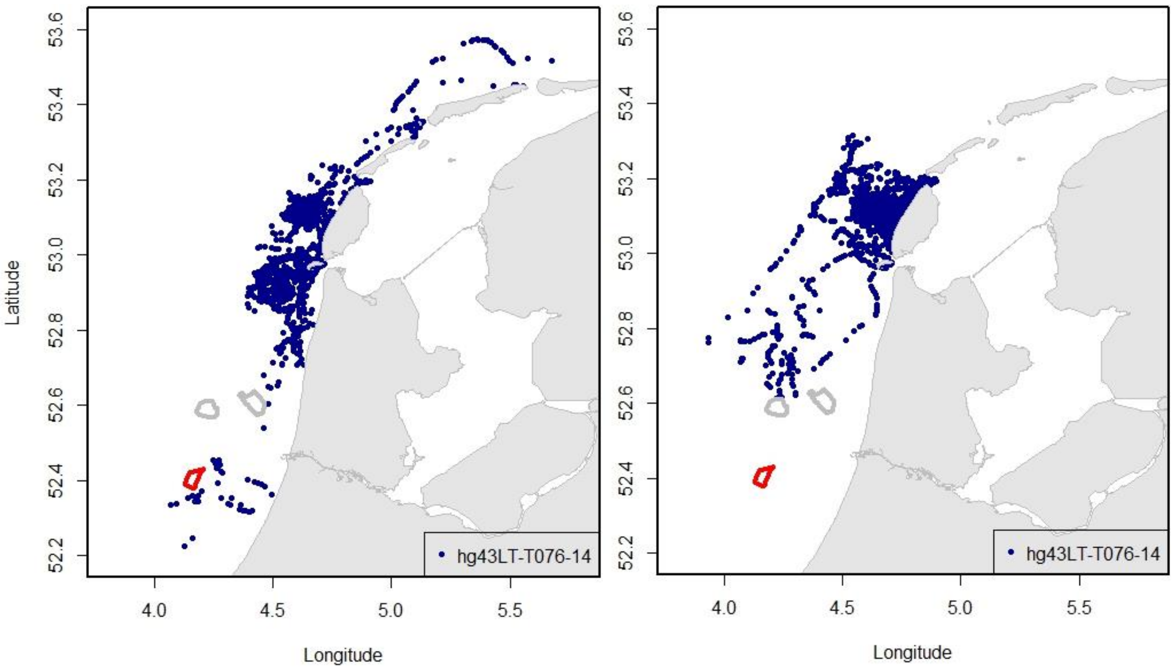
Appendix A: Figure 1. Locations and interpolated lines connecting the locations to represent movement of grey seal Z063 in the vicinity of Luchterduinen wind farm during 5-6 July, a period when stone dropping for scour protection of the tower-bases was being undertaken. The red dashed line indicates a 17-hour period when no location data were obtained.



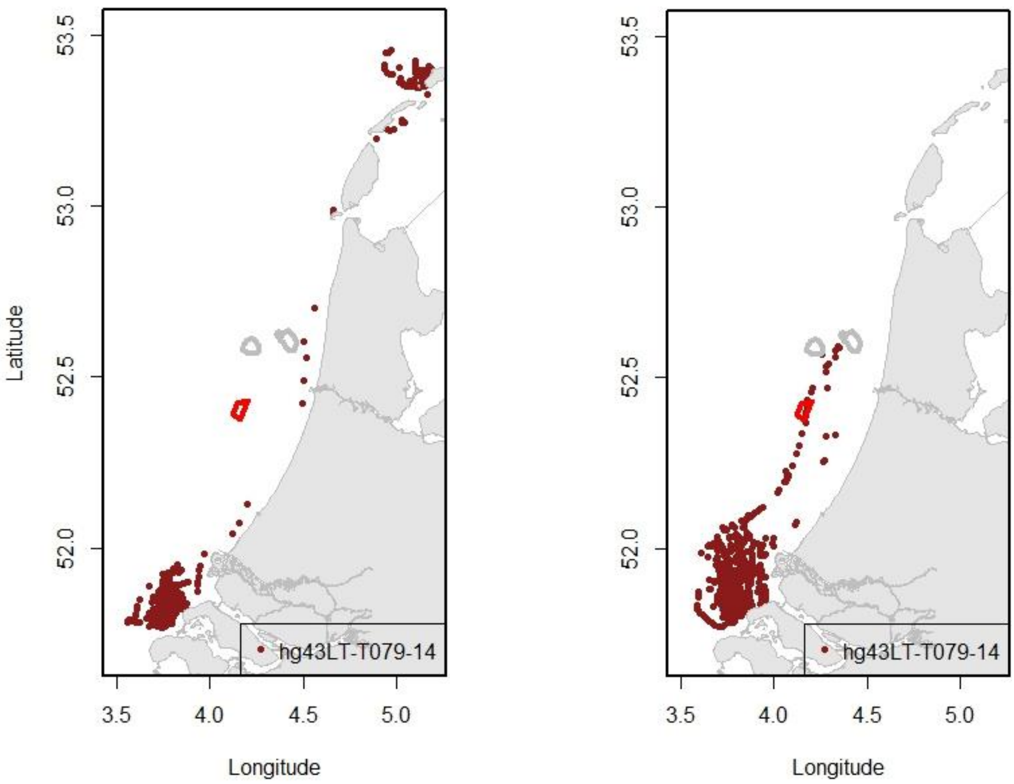
Appendix A: Figure 2. Movement of grey seal T079 through Luchterduinen wind farm overnight on 12-13 August 2014 (time in UTC, + 2 h = CEST). Brown triangles are locations of the seal, connected by an interpolated track (brown dots). Grey squares are stone pads for scour-protection, green circles are installed turbine towers, and the red circle is the most recently installed tower – completed on 8 August, 4-days prior to the seals arrival. The seal likely remained near the recent tower for several hours.

Appendix B. Grey seal locations prior to and during the *Luchterduinen* pile-driving period.

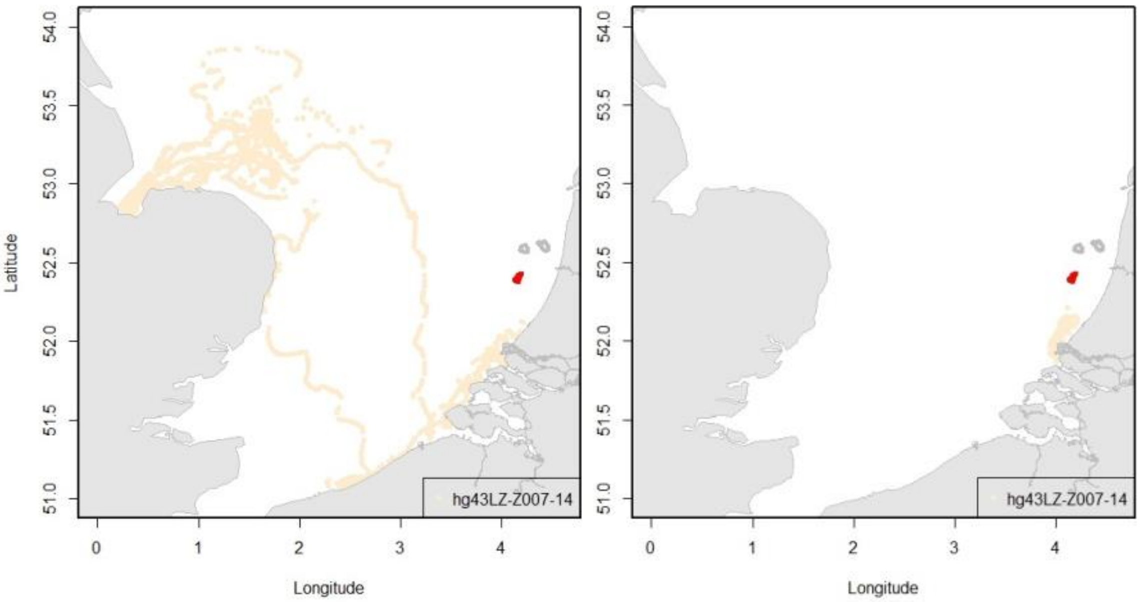
(Only for grey seals tracked in 2014 that utilised the coastal zone during the pile-driving period)



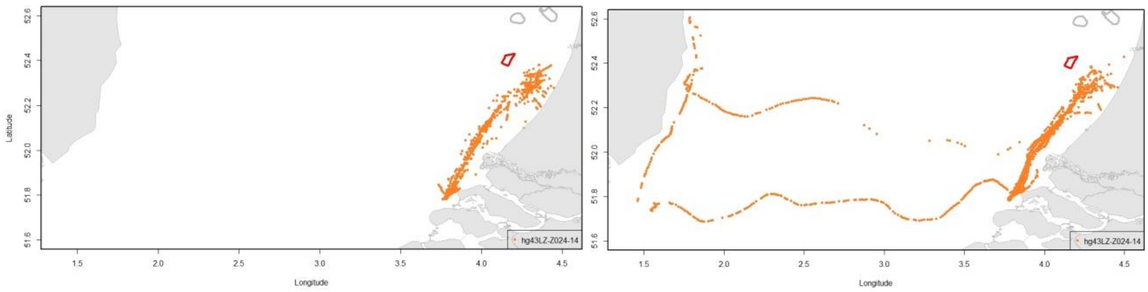
1. T076 - Prior to pile-driving, 2 April – 30 July During pile-driving, 31 July – 16 October



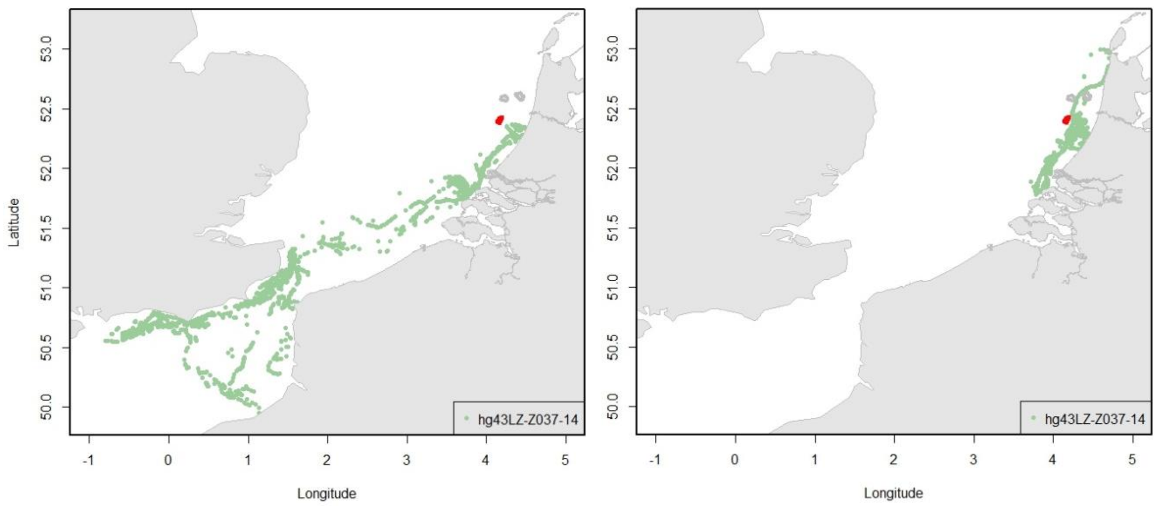
2. T079 - Prior to pile-driving, 2 April – 30 July During pile-driving, 31 July – 16 October



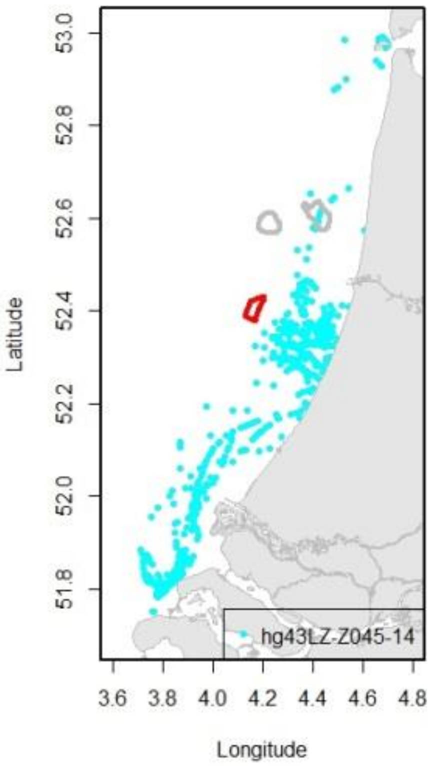
3. Z007 - Prior to pile-driving, 2 April – 30 July During pile-driving, 31 July – 16 October

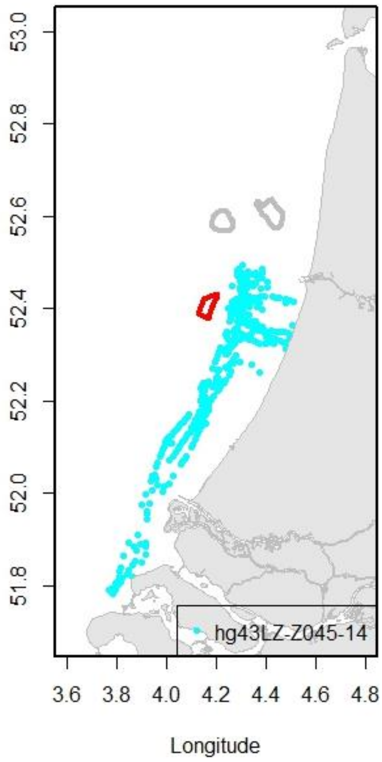


4. Z024 - Prior to pile-driving, 2 April – 30 July During pile-driving, 31 July – 16 October

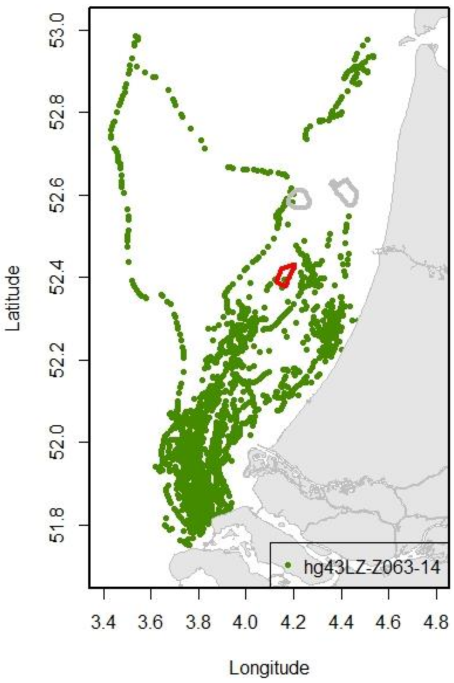


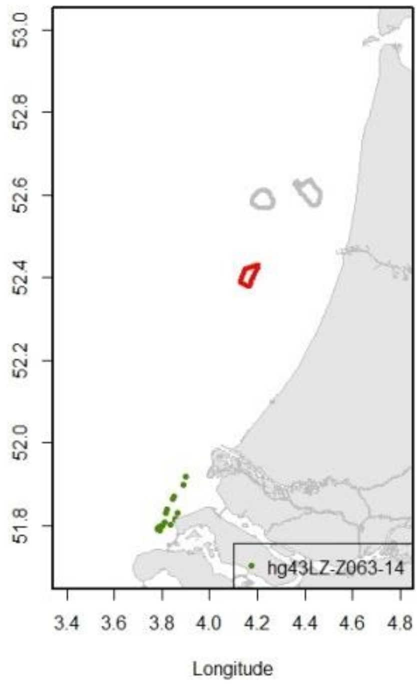
5. Z037 - Prior to pile-driving, 2 April – 30 July During pile-driving, 31 July – 16 October





6. Z045 - Prior to pile-driving, 2 April – 30 July During pile-driving, 31 July – 16 October





7. Z063 - Prior to pile-driving, 2 April – 30 July During pile-driving, 31 July – 16 October

Appendix C. Gross movement patterns of grey seals in the North Sea coastal zone during a pile-driving event for *Luchterduinen* wind farm in 2014.

To estimate distance from a pile-driving location, seal location was taken as the nearest location recorded within an hour of pile-driving, or if none recorded in that period, the location closest in time to the event.

1. T076 - Coming south from Razende Bol.

Day	Tower	Distance	Pre exposure	During	Post exposure
10 Oct	7	28	North of PAWP	Moved closer	Moved away
11 Oct	1	46	North of PAWP	Moved away	Moved closer
11 Oct	2	29	Moving closer toward PAWP	Moved inshore	Moved away and inshore
14 Oct	3	54	Moving closer	Moved slightly offshore	Moved closer
15 Oct	4	46	North of PAWP	Moved away	Moved closer
16 Oct	5	45	North of PAWP	Moved closer	Moved away and inshore

2. T079 - Coming north from Aardappelenbult.

Day	Tower	Distance	Pre exposure	During	Post exposure
14 Aug	22	24	North near OWEZ	No locations	Moved closer, inshore then away
15 Aug	21	14	Moving south, parallel	Continued	Continued away
25 Aug	14	49	Near Maasvlakte	No locations	Moved away
26 Aug	8	41	Near Maasvlakte	No locations	Moved away

3. Z007 - Coming north from a haul-out south of Maasvlakte.

Day	Tower	Distance	Pre exposure	During	Post exposure
2 Aug	23	41	Moving closer	No locations	Moved inshore then away
8 Aug	20	34	Moving closer	Remained in area	Remained in area
15 Aug	21	34	Moving away	No locations	Continued away
21 Aug	OHVS	35	In area	Moved away	Moved away
25 Aug	14	35	Moving closer	No locations	Continued closer
28 Aug	15	31	In area	Remained in area	Remained in area
30 Aug	16	34	Moving closer	Remained in area	Remained in area
31 Aug	17	34	In area	No locations	Moved away
3 Sep	27	32	In area	Moved away	Remained in area
10 Sep	11	29	Moving closer	Remained in area	Remained in area
10 Sep	12	27	In area	No locations	Remained in area
17 Sep	31	32	Arrived in area	Remained in area	Remained in area
18 Sep	37	32	In area	Remained in area	Remained in area

Day	Tower	Distance	Pre exposure	During	Post exposure
18 Sep	41	32	In area	Remained in area	Remained in area
19 Sep	43	32	In area	No locations	Remained in area
25 Sep	40	29	In area	Moved closer	Remained in area
26 Sep	42	32	In area	No locations	Remained in area
1 Oct	18	33	Arrived in area	No locations	Remained in area
2 Oct	32	33	In area	Moved away	Remained in area
2 Oct	33	32	In area	No locations	Remained in area
3 Oct	34	44	Moving away	Continued	Continued away
6 Oct	13	37	Moving closer	Continued	Continued closer
6 Oct	19	32	Arrived in area	No locations	Remained in area
10 Oct	7	33	In area	No locations	Moved away

4. Z024 - Coming north from Aardappelenbult.

Day	Tower	Distance	Pre exposure	During	Post exposure
2 Aug	23	50	Moving closer	No locations	Continued closer
3 Aug	20	16	Moving closer	No locations	Moved inshore then north, parallel to Luchterduinen
8 Aug	20	23	Moving inshore	No locations	Moved away
14 Aug	22	16	Arrived in area	No locations	Remained in area
15 Aug	21	14	In area	No locations	Moved away
21 Aug	OHVS	12	In area	No locations	Remained in area
25 Aug	14	30	Moving away	No locations	Continued away
28 Aug	15	18	Moving closer	Stopped	Moved away
31 Aug	17	51	Moving closer	Continued	Continued closer
3 Sep	27	13	In area	Remained in area	Remained in area
9 Sep	10	44	Moving closer	No locations	Continued closer
10 Sep	11	15	Moving closer	No locations	Continued closer
10 Sep	12	10	In area	No locations	Remained in area
17 Sep	31	17	Arrived in area	Remained in area	Remained in area
18 Sep	37	14	Moving parallel nth	No locations	Remained in area
18 Sep	41	7	Moving parallel nth	Remained in area	Moved parallel south
19 Sep	43	14	In area	Remained in area	Moved parallel south
23 Sep	39	51	Moving closer	No locations	Continued closer
25 Sep	40	16	Arrived in area	Moved slightly inshore	Moved away
26 Sep	42	19	In area	Remained in area	Moved away
30 Sep	30	22	Moving closer	No locations	Remained in area
1 Oct	18	49	Moving away, to UK	Continued	Continued away
10 Oct	7	20	Moving closer	Remained in area	Continued closer
11 Oct	1	16	In area	No locations	Moved inshore?
11 Oct	2	16	In area	No locations	Remained in area
14 Oct	3	30	Moving away	Continued	Continued away

5. Z037 - Coming north from Aardappelenbult.

Day	Tower	Distance	Pre exposure	During	Post exposure
3 Aug	20	21	Moving inshore	Continued	Moved inshore up coast
15 Aug	21	10	Moving south beside Lucht	No locations	Continued away
25 Aug	14	13	Beside Lucht	No locations	Moved to coast
26 Aug	8	13	Moving south beside Lucht	Continued	Continued south then inshore
30 Aug	16	13	Moving closer	Remained in area	Moved to coast
31 Aug	17	17	Moving closer from coast	Continued	Moved away

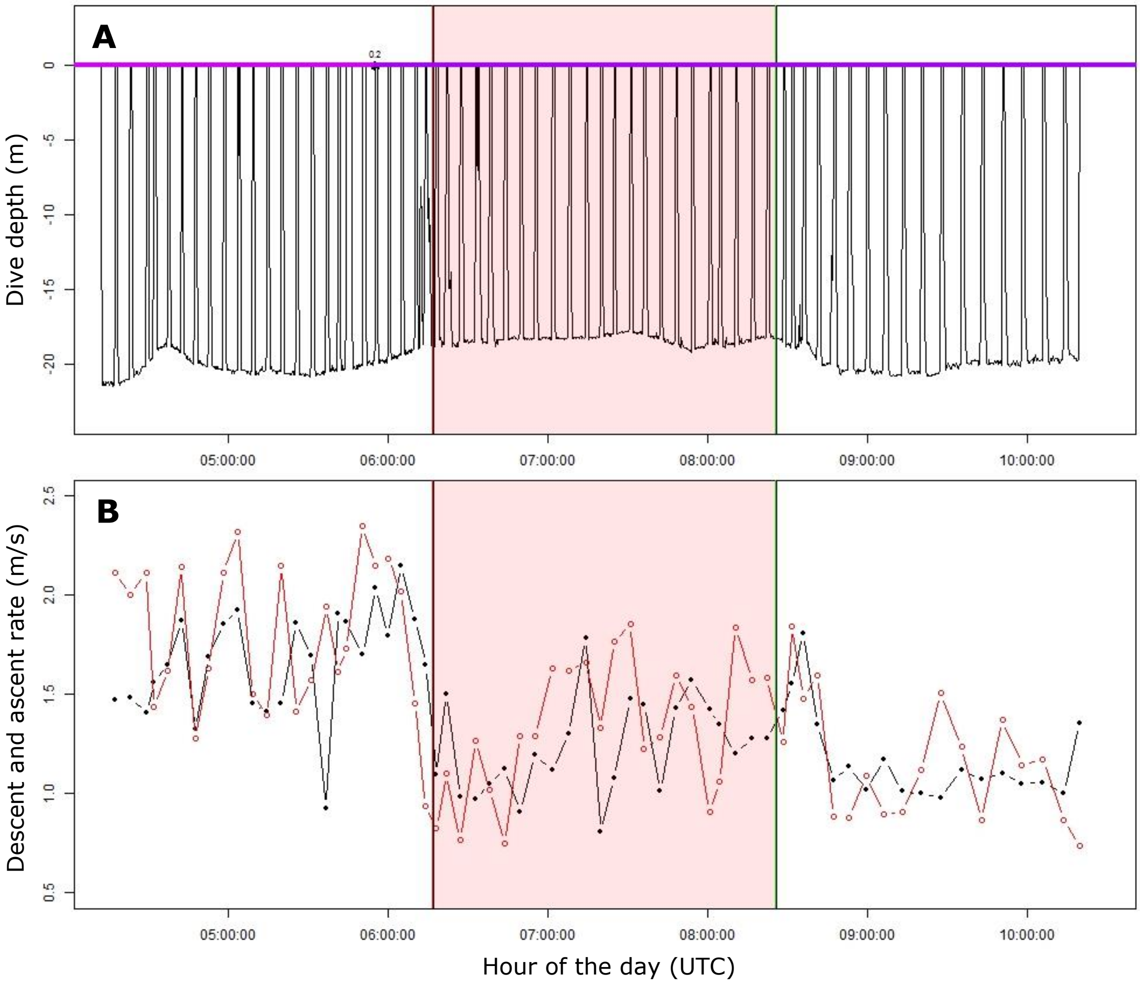
6. Z045 - Coming north from Aardappelenbult.

Day	Tower	Distance	Pre exposure	During	Post exposure
31 Jul	24	18	Moving south	No locations	Continued away
8 Aug	20	23	Beside Lucht Moving inshore	No locations	Continued inshore
15 Aug	21	34	Moving closer	Continued	Continued closer
21 Aug	OHVS	18	Moving away	Continued	Continued away
25 Aug	14	45	Moving closer	No locations	Continued closer
26 Aug	8	9	In area	No locations	Remained in area
28 Aug	15	15	In area	No locations	Moved closer
30 Aug	16	24	In area	No locations	Moved closer
31 Aug	17	12	Heading closer	No locations	Continued closer
8 Sep	9	11	In area	No locations	Remained in area
9 Sep	10	11	In area	Moved away	Remained in area
10 Sep	11	11	In area	No locations	Remained in area
10 Sep	12	24	Moving away	No locations	Continued away
17 Sep	31	24	In area	No locations	Moved to coast
18 Sep	37	24	Moving closer	No locations	Moved to coast
18 Sep	41	18	In area	No locations	Moved away
19 Sep	43	20	Moving away	No locations	Moved away

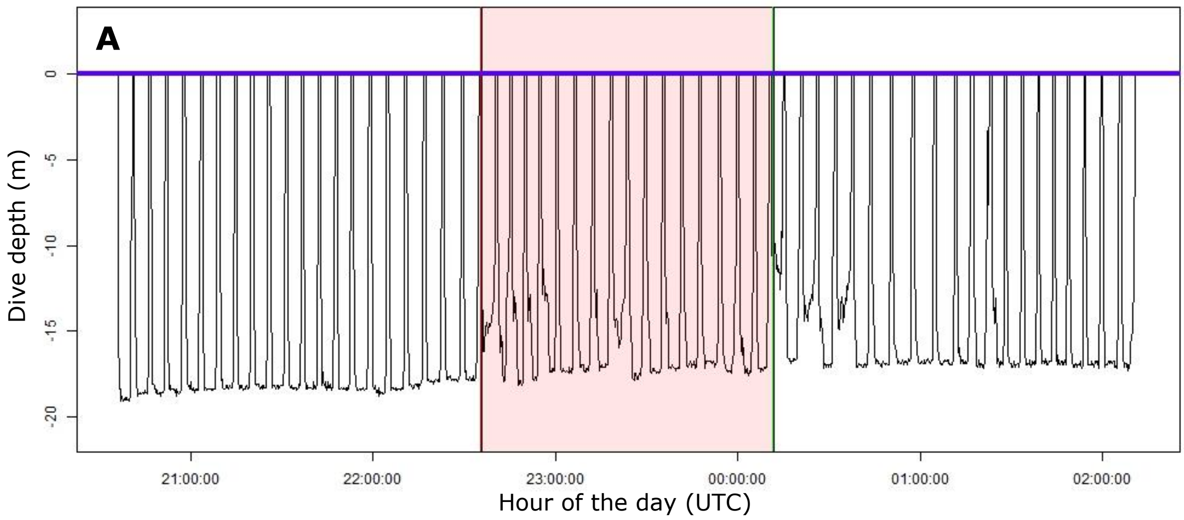
Appendix D. Dive-profiles, and descent and ascent rates of grey seals in the North Sea coastal zone during pile-driving events for *Luchterduinen* wind farm.

Figures are: A) seal depth, and B) seal descent (black) and ascent (red) rates.

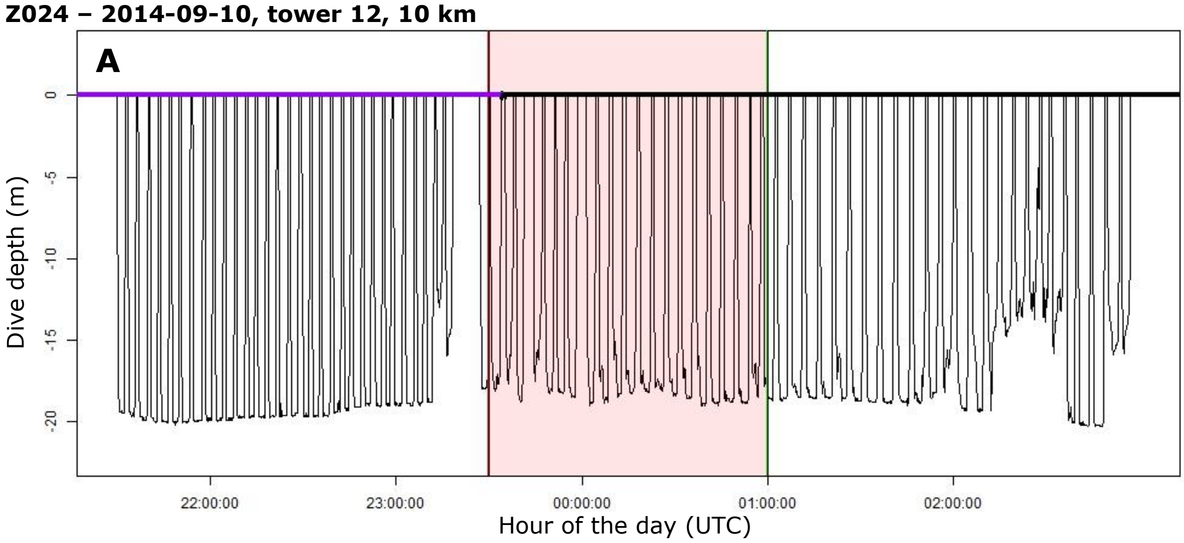
T079 – 2014-08-14, tower 22, 24 km



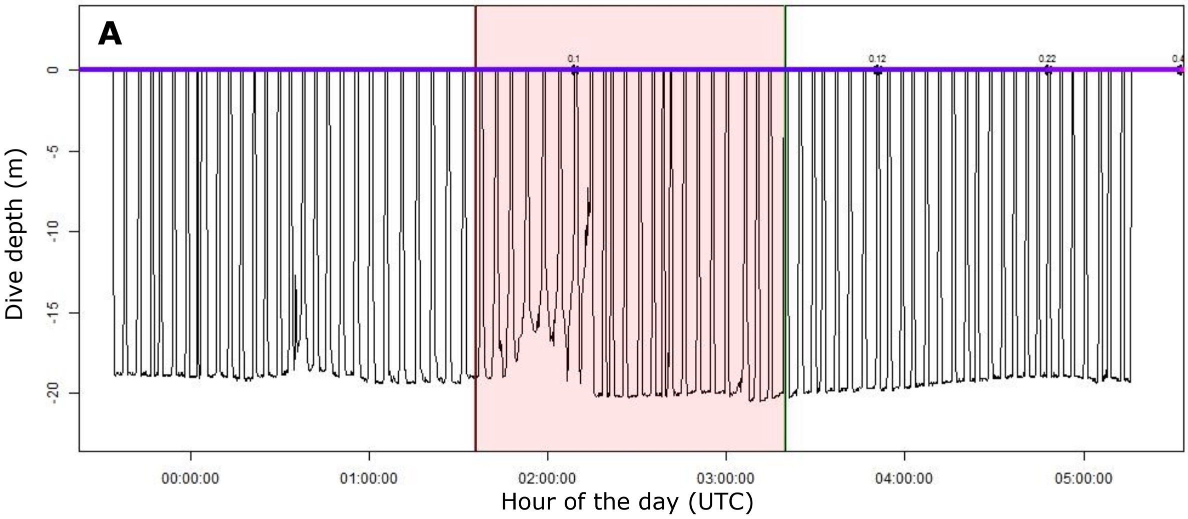
Z024 – 2014-08-15, tower 21, 14 km



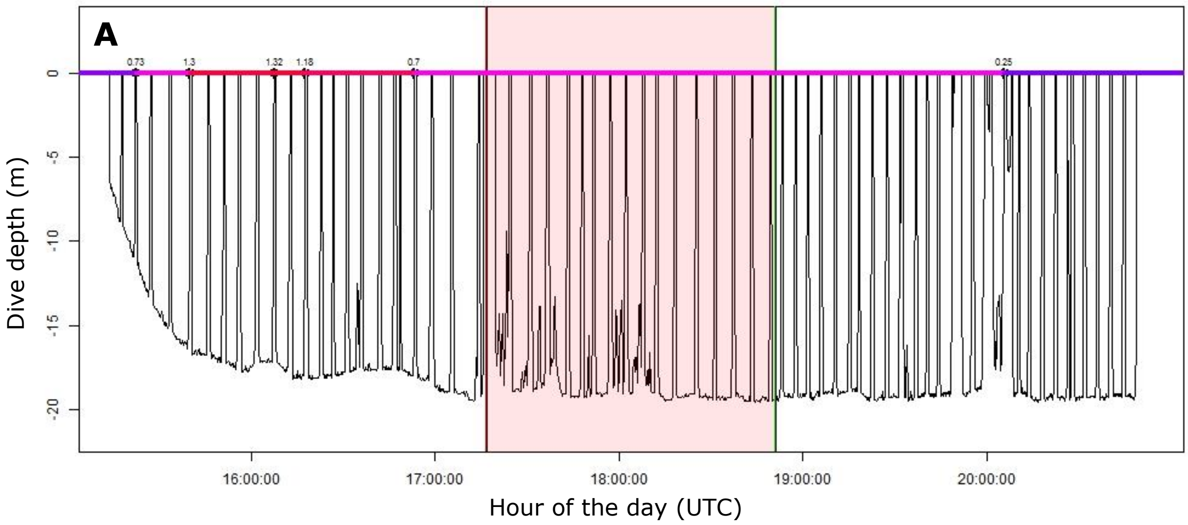
Z024 – 2014-09-10, tower 12, 10 km



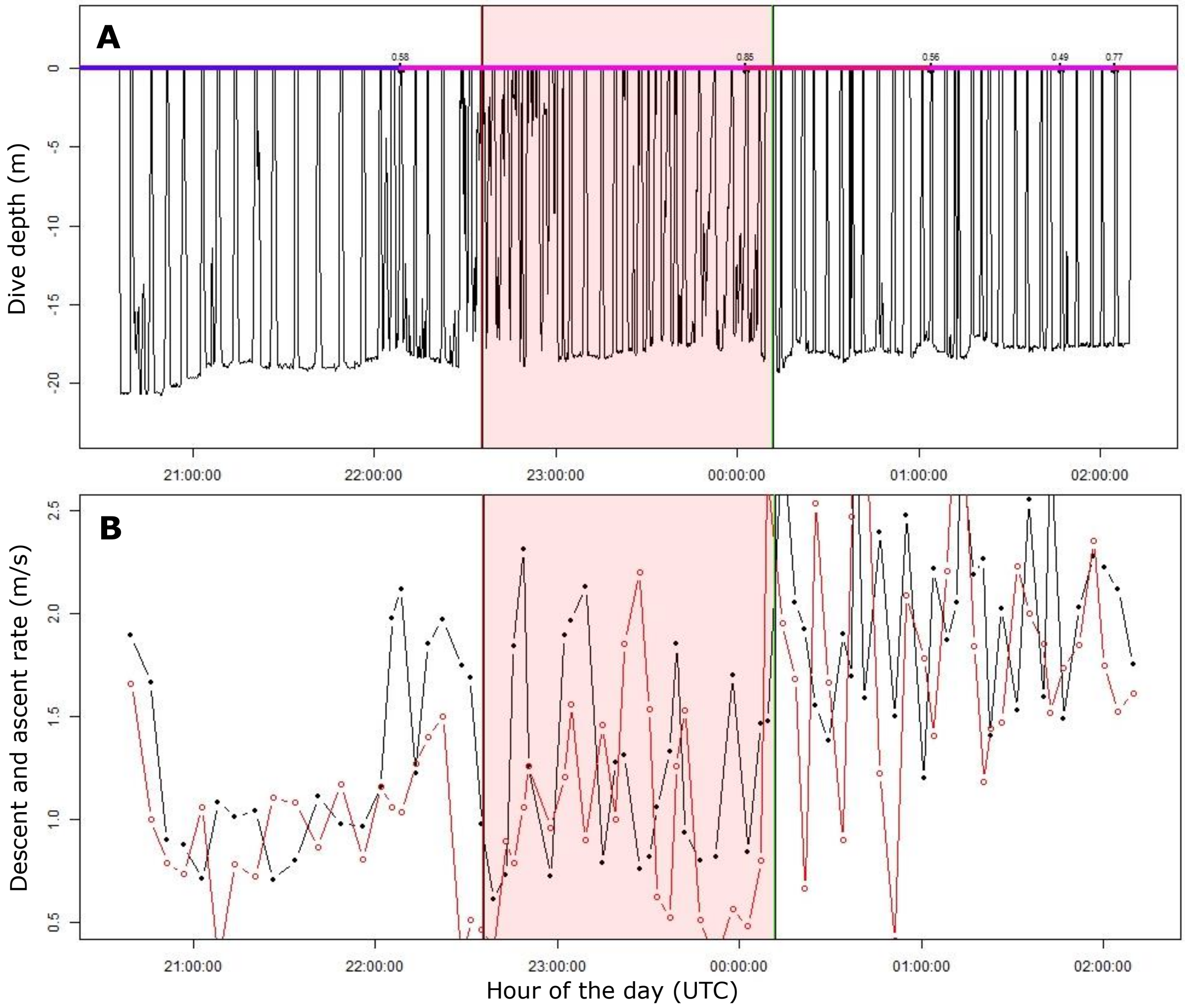
Z037 – 2014-09-26, tower 42, 19 km



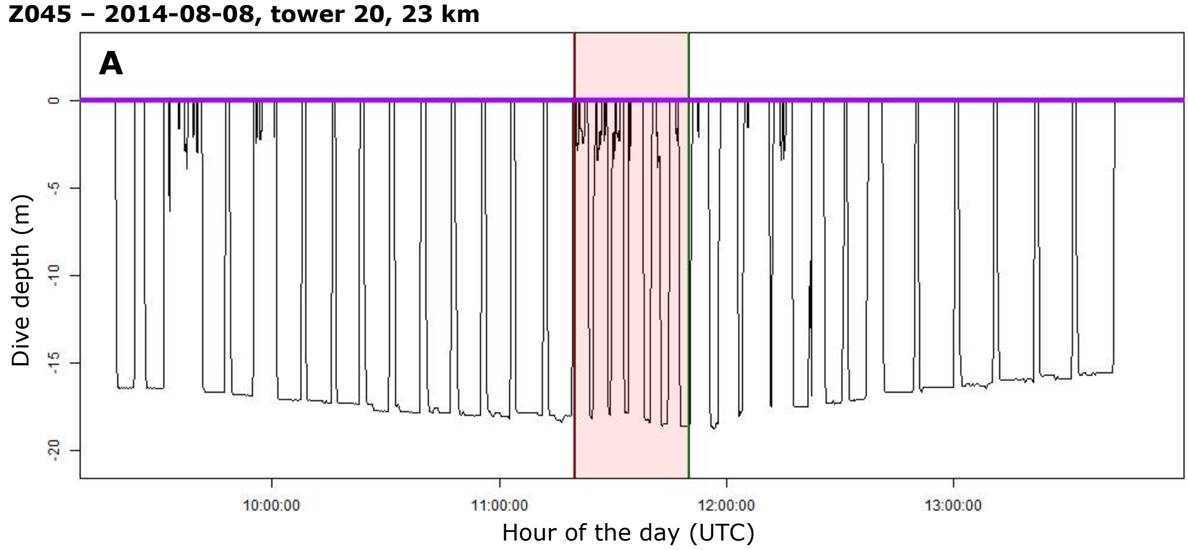
Z037 – 2014-08-31, tower 17, 17 km



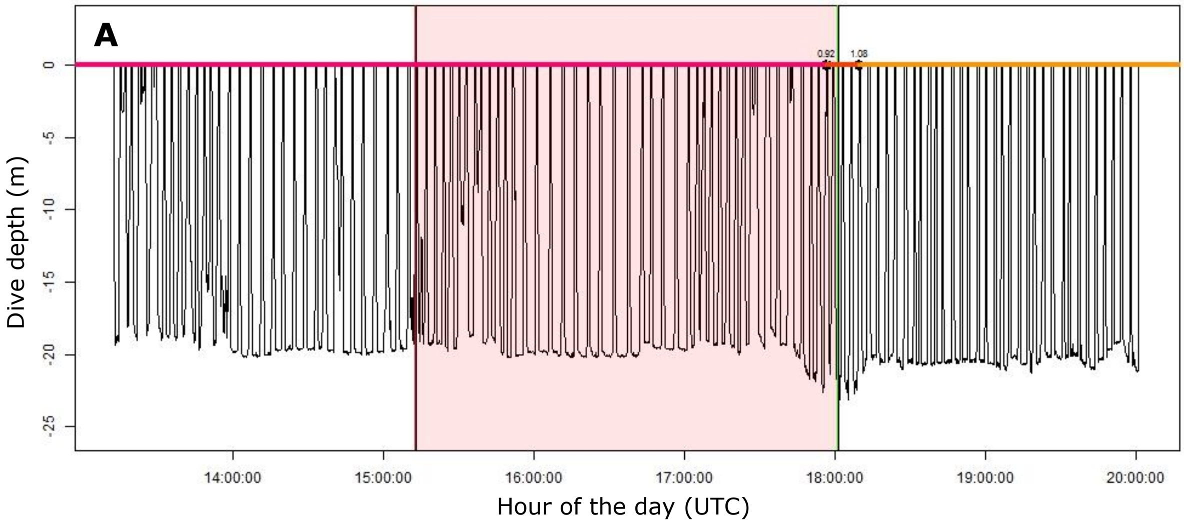
Z037 – 2014-08-15, tower 21, 10 km



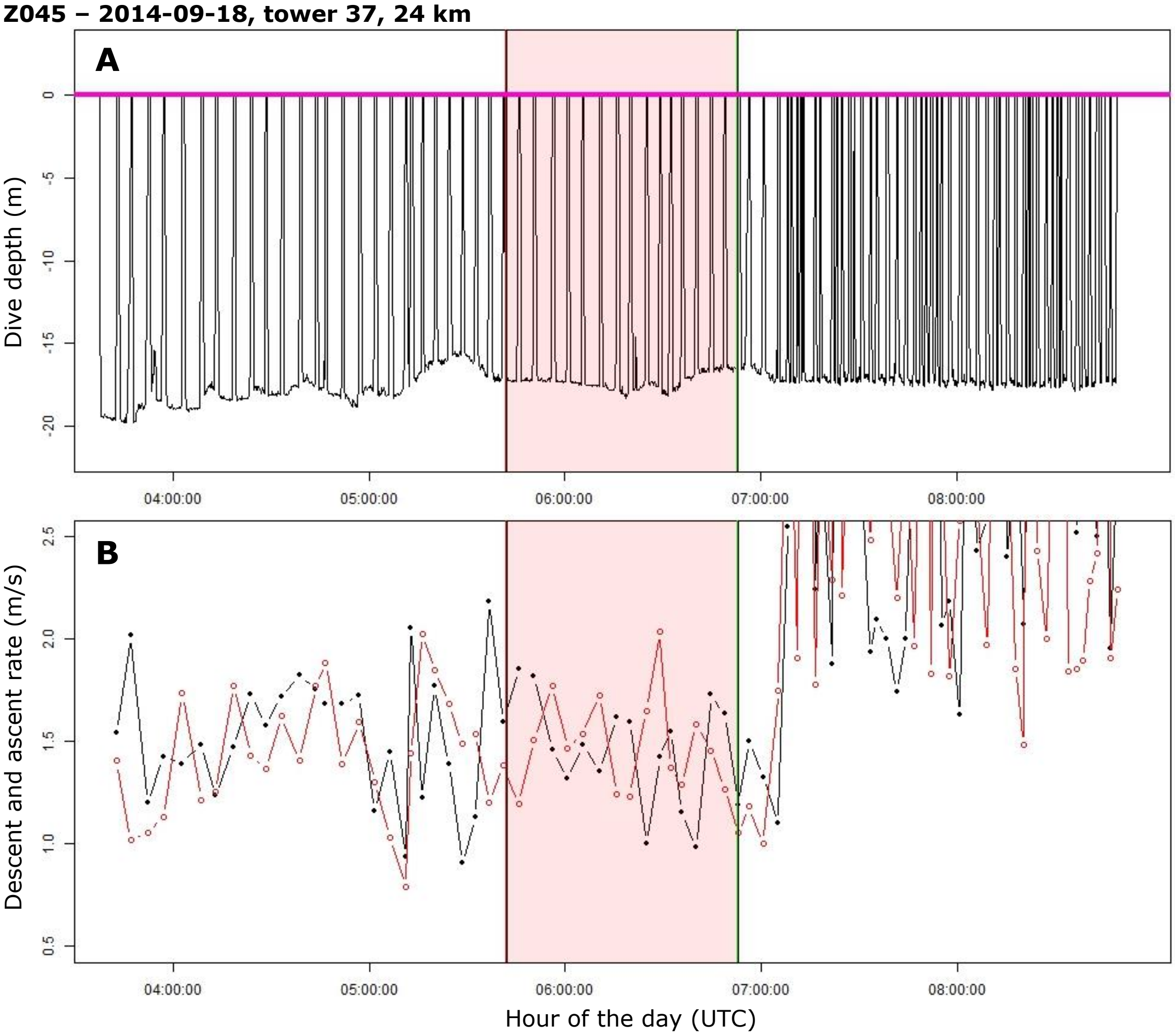
Z045 – 2014-08-08, tower 20, 23 km



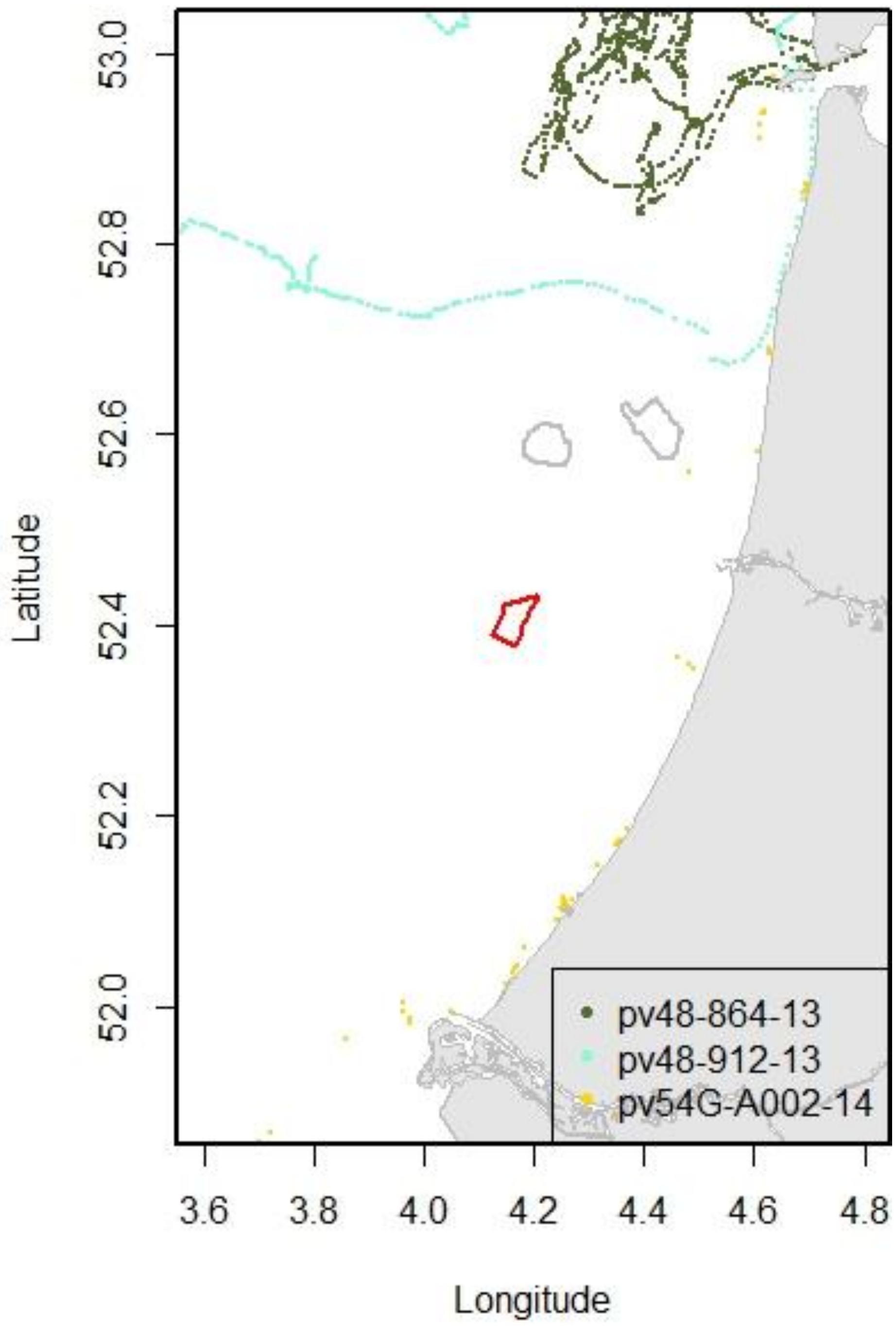
Z045 – 2014-08-21, tower OHVS, 18 km



Z045 – 2014-09-18, tower 37, 24 km



Appendix E. Use of the coastal zone by seals tracked for Gemini wind farm.



Appendix C. Figure 1. Locations of seals tracked as part of monitoring for pre-construction of Gemini wind park north of the Wadden Sea, which utilised the North Sea coastal zone, all were harbour seals (two in 2013 and one in 2014).

Appendix F. Definitions

Term	Explanation
Central place foraging	Foraging trips of seals out of one or several adjacent haul-out sites
Competent Authority	Authority responsible for the management of the Dutch part of the North Sea, including for issuing permits for off shore wind farm .The authority is *Rijkswaterstaat* (www.rws.nl) (RWS) *Zee en delta*
DEC	Animal ethics committee (*Dier Ethische Commissie*)
Devices (=transmitters)	Seal tracking devices (GPS Phone transmitters)
FF Wet	Flora and Fauna Act
MEP	Monitoring and Evaluation Program
Movement vs migration	The *Wbr*/ *Wtw*-permit and MEP for *Luchterduinen* stipulate that data be collected on the migration routes of harbour and grey seals. Migration is a term that fits well for the seasonal, mass movement, of species such as seabirds and cetaceans. However, it is not an appropriate term for movements of seals. At certain times of the year, seals do exhibit co-ordinated movements (such as to breeding areas) but they do so as individuals, not in species specific groups. Use of the term migration also limits the study to explicit group movements when individual foraging and exploratory trip movements are equally important in terms of habitat use within the North Sea coastal zone.
Natura 2000	European network of protected areas under the Habitat Directive (SACs) and/or Bird Directive (SPAs)
Nb Wet	Nature Management Act
North Sea coastal zone	Defined in this report as being between Rotterdam and Den Helder
OWEZ	Offshore windfarm Egmond aan Zee
PAWP	Prinses Amalia windpark
SMRU	Sea Mammal Research Unit (http://www.smru.st-andrews.ac.uk/)
Transmitters (=devices)	Seal tracking devices (GPS Phone transmitters)
Traverses vs foraging trips	Traverses are defined as complete crossings between both latitudinal boundaries of the North Sea coastal zone, whereas foraging trips involve an entrance and exit over the same latitudinal boundary. On traverses, seals are relocating to seek better foraging grounds, avoid disturbance where they had been or for a biological imperative, such as to pup. On foraging trips seals go to sea primarily to foraging, but potentially also to avoid conditions on land (high tides, disturbance, and weather).
T0	Pre-construction period
Tc, Tconstruction	Construction period
T1	First sampling period in a year of post-construction
Wtw-permit (formerly Wbr)	'*Water Wet*' permit (*Wtw*-permit, *Water Wet Act*, until August 2013 also including the N2000 legal framework, formerly '*Wet Beheer Rijkswaterstaatwerken*' - *Wbr*).