Harbour seal monitoring and evaluation for the Luchterduinen offshore windfarm:

Final report

Author(s): Sophie Brasseur, Jessica Schop, Jenny Cremer, Geert Aarts

Wageningen University & Research report C074/18

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Summary

Though it seems unlikely that marine mammals, including seals suffer at a large scale from direct mortality caused by the construction or operation of windfarms at sea, they are likely to be affected by disturbance and habitat alterations.
In 2014, Luchterduinen windfarm was constructed in the Dutch coastal zone south west of IJmuiden and the permit (WV/2009-1229) requested monitoring with respect to both harbour and grey seals. Two main questions were formulated:

1. How do seals use the coastal zone? The aim was to gain insight in harbour and grey seal movement routes along the Dutch North Sea coastal zone (between the Wadden Sea and the Delta region).

2. What is the impact of Luchterduinen on seals? (with a focus on the impact of piling).

This rapport discusses the results of the harbour seal studies. The initial monitoring (T0-T1; 2013-2015) based on a series of studies on the movements and habitat use of harbour seals deployed in spring (March), was timed in relation to the construction (2014) and operation of the windfarm. These studies were evaluated after T1 (in 2016). It was concluded that by limiting the study to spring deployments, the harbour seals' habitat use during a large part of the year was missing. Since harbour seals moult in summer, the trackers attached to the fur typically fell off in June –July. In this study (T2-T3) therefore, a deliberate choice was made to study the behaviour of the seals in the post moult, from September onwards. A total of 18 seals were tracked from September onwards: in 2016 (T2) 6 from the Wadden Sea area and 6 from the Delta and again 6 from the Wadden Sea area in 2017(T3).

With longer track durations of 20 to 187 days (mean 106 ± 46 days) in this last study information has been collected covering seven calendar months, six of which had not been studied before in this region. However there was large variation in behaviour, possibly but not solely as a result of the male bias in the sample (11 males, 7 females). Though the maximum and mean distance travelled by the seals was slightly less in autumn, the waters in the study area (i.e. the area off the west coast of the Netherlands enclosed by 51.95°N to 52.94°N, and from the coast offshore to 3.73°E) were used much more extensively by the seals tracked in autumn. In total the seals tracked during T2-T3 spent 27.3% of their time in the defined study area, while during spring deployments for T0-T1, this was only 1.5%. Out of the 18 seals tracked in autumn, 11 were observed in the study area. Interestingly these were animals tagged in the Wadden Sea region. During this time of the year animals are mostly feeding, which probably explains their higher presence in the study area. In contrast, during spring, mostly seals from the Delta crossed the study area en route to their breeding sites in the Wadden Sea. This probably explains the limited amount of time spent in the coastal zone. During the complete Luchterduinen study (T0-T3) comprising of 44 animals in spring and 18 in autumn, only one animal entered the Luchterduinen wind farm area. Its visits were short; which suggests it only crossed the area. Animals tracked during T2-T3 were observed more often in the vicinity of the wind farm, compared to the animals tagged during T0-T1.
Based on these studies we concluded that harbour seals use the coastal zone west of North and South Holland to migrate to breeding areas in spring/summer, and use it to feed in autumn and winter. Recently, the recovery of the harbour seals in the Wadden Sea has come to a halt. However, pup production in the Wadden Sea is still increasing, and over two thousand pups are born in the Dutch Wadden Sea each year. Since the population size no longer grows, this suggest that an equal number of individuals die each year. Possibly the population has reached a 'natural' carrying capacity. However, human use at sea could also play a role in influencing the survival of individuals and the size of the population. Like other North Sea countries, the Dutch government has shown a clear intention to intensify the use of the marine areas in the near future, for windfarms but also sand mining, traffic and aquaculture. Quite likely this will affect the way the seals use the marine area. Further studies are needed to better understand how habitat changes play a role in the survival of individual animals.

Samenvatting

Hoewel het onwaarschijnlijk is dat zeezoogdieren en dus zeehonden op grote schaal direct dodelijke gevolgen ondervinden van de bouw of ingebruikname van windparken op zee, is het hoogstwaarschijnlijk zo dat ze worden beïnvloed door de verstoring en veranderingen in hun habitat. Luchterduinen windpark werd in de Nederlandse kustzone ten zuidwesten van IJmuiden gebouwd in 2014 en de vergunning (WV/2009-1229) vereiste de monitoring van grijze en gewone zeehonden. Twee belangrijke vragen werden gesteld:

1. Hoe gebruiken zeehonden de kustzone? Het doel was om inzicht te krijgen in de routes van de gewone en de grijze zeehond gedurende hun aanwezigheid in de Nederlandse kustzone (tussen de Waddenzee en het Deltagebied).
2. Wat is de impact van Luchterduinen op de zeehonden? (met een focus op de hei-werkzaamheden)

Dit rapport bespreekt de resultaten van de studies naar de gewone zeehond. De eerste monitoring (T0-T1; 2013-2015), gebaseerd op een reeks studies van beweging en habitat gebruik van gewone zeehonden gezenderd in het voorjaar (maart), was getimed in relatie tot de constructie (2014) en ingebruikname van het park. Deze studies werden na de T1 geëvalueerd (2016). Er werd geconcludeerd dat, door de studie te beperken tot het zenderen in het voorjaar, inzicht in het habitatgebruik van de gewone zeehonden voor een belangrijk deel van het jaar ontbrak. Aangezien de dieren in de zomer verharen, verloren ze de op de vacht geplakte zenders gewoonlijk in juni-juli. In de huidige studie (T2-T3) werd daarom een bewuste keuze gemaakt om het gedrag van de gewone zeehonden na de verharing te bestuderen, vanaf september. In totaal werden 18 zeehonden in het najaar gezenderd: in 2016 (T2) 6 in het waddengebied en 6 in het Deltagebied en het jaar erna, in 2017(T3) 6 in het waddengebied.
Gemiddeld was de tijd dat de dieren gevolgd werden langer dan in de eerdere studies namelijk 20 tot 187 dagen (gem. 106 ± 46 dagen). In deze studie werd bovendien informatie verzameld over een periode van zeven maanden waarvan één maand overlap vertoonde met de eerder studies
Er was een grote variatie in gedrag tussen de dieren, mogelijk speelde o.a. de scheve geslachtsverhouding van de gezenderde zeehonden hierbij een rol; er werden 11 mannetjes en 7 vrouwtjes gezenderd. Hoewel de gemiddelde en de maximale afstand die de dieren zwommen in de herfst iets lager was, gebruikten de zeehonden in deze periode het studiegebied (ten westen van de westkust van Nederland begrensd door 51.95°N en 52.94°N, en van de kust af tot 3.73°E) veel intensiever. De zeehonden gezenderd in het najaar tijdens T2-T3 besteedden 27.3% van hun tijd in dit gebied, terwijl de dieren gezenderd in het voorjaar voor T0-T1 maar 1.5% van hun tijd hier doorbrachten. Van de 18 zeehonden gezenderd in de herfst werden er 11 in het gebied gezien. Interessant is wel, dat al deze dieren in het waddengebied waren gezenderd. In deze periode van het jaar zijn de dieren vooral aan het foerageren, wat mogelijk deze verspreiding verklaart. In tegenstelling daarmee, waren het vooral de in de Delta gezenderde dieren die in de lente het gebied doorkruisten op weg naar het waddengebied waar ze zich voortplanten. Dit verklaart mogelijk de beperkte tijd dat de dieren in het studiegebied gezien werden. Tijdens de gehele Luchterduinen-studie (T0-T3) met 44 dieren gezenderd in de lente en 18 in de herfst werd er maar één dier in het park zelf gezien. Gezien de korte verblijfsperiode in het park is het waarschijnlijk dat het dier het gebied alleen doorkruist heeft. Tijdens T2-T3 werden er meer dieren in de buurt van het windpark dan tijdens T0-T1.
Gebaseerd op deze studies concluderen we dat gewone zeehonden het gebied ten westen van de Noord- en Zuid-Hollandse kust in de lente en zomer vooral gebruiken om te migreren naar de voortplantingsgebieden, en in de herfst en winter om te foerageren. De laatste jaren zijn de getelde aantallen gewone zeehonden in de Waddenzee min of meer gelijk gebleven, terwijl het aantal pups nog steeds groeit. Er worden tegenwoordig jaarlijks meer dan 2000 pups geboren. Aangezien er geen groei is suggereert dit dat er even zoveel dieren jaarlijks sterven. Mogelijk heeft de populatie de "natuurlijke" draagkracht bereikt. Echter menselijk gebruik van de zee zou ook een rol kunnen spelen en de overleving van individuen en de populatiegrootte kunnen beïnvloeden. Net als andere Noordzeelanden heeft de Nederlandse regering

een duidelijke intentie getoond om in de nabije toekomst het gebruik van de zee te willen intensiveren voor windparken, en daarnaast ook voor zandwinning, vaarbewegingen en aquacultuur. Het is aannemelijk dat dit de manier waarop de zeehonden de zee gebruiken zal beïnvloeden. Verdere studies zijn nodig om te begrijpen hoe verandering van het habitat van de zeehonden een rol kan spelen op de overleving van individuele dieren.

1 Introduction

Marine mammals, including seals can potentially be affected in numerous ways by human activities in their environment. In the past decade, the developments of offshore windfarms have taken large leaps following the urge to ultimately diminish the human dependency on fossil fuels. While it seems unlikely that this development will cause direct large scale mortality to marine mammals, indirect effects caused by disturbance or habitat changes affecting individuals, may occur,. These effects are much more difficult to quantify. Especially as we still lack general understanding how marine animals are distributed in the waters and what drives them to specific areas. This also holds for seals, even though out of the marine mammals, individual movement and habitat use this species group is best understood. Luchterduinen is the third offshore windfarm built in the Netherlands, whilst in the near future, windfarms are planned in a much larger scale in the Dutch North Sea waters. The permit requirements for the construction and operation of Luchterduinen included monitoring of harbour and grey seals. Here the final study on harbour seals is presented.

1.1 Aims of this study

In the 2009 MEP two main questions were formulated:

1. How do seals use the coastal zone? Aim is to gain insight in harbour and grey seal movement routes along the Dutch North Sea coastal zone (between the Wadden Sea and the Delta region).

2. What is the impact of Luchterduinen on seals? (with a focus on the impact of piling).

The monitoring was timed in relation to the construction and operation of the windfarm and a series of studies on the movements and habitat use of seals and the effects of construction and operation of the windfarms were carried out. This included :

1. A study based on existing data of grey and harbour seal spatiotemporal distribution along the Dutch North Sea coastal zone (Aarts *et al.* 2013),
2. A T0 report containing results of the baseline monitoring (Kirkwood *et al.* 2014),
3. A $T_{construction}$ report describing movements of seals in the year of pile-driving (Kirkwood *et al.* 2015),
4. A T1 report describing movements of seals in the year after pile-driving and including an evaluation to define the final monitoring reported here (Kirkwood *et al.* 2016).

After T_1, the monitoring was evaluated to ensure optimal collection of information (Kirkwood et al. 2016), The evaluation resulted in a revision of the MEP (Brasseur *et al.* 2016). The following two studies were proposed:
1. The behavioural response of grey seals to pile-driving based on the available data on grey seals during $T_{consruction}$ pile-driving – of both Luchterduinen and Gemini windfarms (reported in Aarts *et al.* 2018).
2. Study the movement of *harbour* seals in the Dutch coastal zone. As during T0-T1, harbour seals were only tagged in spring, and they lose their tags in summer, there was insufficient information on harbour seals movements in the coastal zone during autumn and winter. This should be fulfilled through the collection of information on the movement and behaviour of harbour seals with tracker deployments in autumn.

In this final report, the results of the autumn tracking (T2/T3) are presented.

1.1.1 Content of final report

The current report covers the distribution of harbour seals in autumn (T2-T3), and relates this to the previous spring deployments (T0-T1). It documents the autumn-based tracking study of harbour seals from the western Wadden Sea and Delta region, on both ends of the coastal zone along the western shoreline of the Netherlands in 2016 (T2), and the autumn tracking from the western Wadden Sea in

the North in 2017 (T3). These deployments provide data on the movement and behaviour of harbour seals in autumn and winter, which was lacking in the T0, $T_{construction}$ and T1 studies. The availability of year-round data, will allow for a more complete study of the harbour seals movements and behaviour in the North Sea coastal zone.
The rapport includes a background and introduction to seals in Dutch waters, descriptions of methods and pile-driving activities. Presentation of the T0 and $T_{construction}$ data and comparison with T1 data are provided in the results and discussion. Where appropriate, results are compared to those of previous studies (Aarts et al. 2013, Brasseur *et al.* 2011, Brasseur *et al.* 2010a, Brasseur *et al.* 2009, Brasseur & Kirkwood 2015, Brasseur & Kirkwood 2016, Brasseur & Reijnders 2001, Kirkwood et al. 2015, Kirkwood et al. 2016, Kirkwood et al. 2014, Reijnders *et al.* 2000).

1.2 Background

During the early 2000s, the Dutch government formulated a strategy to develop a capacity of 4450 MW of energy from offshore windfarms (Social Economic Council agreement, August 2013). Because construction, operation and decommissioning of offshore windfarms has the potential to negatively affect marine ecosystems (Prins *et al.* 2008), their development in the Dutch Exclusive Economic Zone (EEZ) requires a '*Waterwet*' permit (*Wtw*-permit, formerly '*Wet Beheer Rijkswaterstaatwerken*', *Wbr*-permit). These permits are issued by *Rijkswaterstaat*, the management organisation of the Dutch Ministry of Infrastructure and the Environment.

In 2014, Luchterduinen windfarm was constructed in the Dutch coastal zone by *Clusius CV* (50% ENECO, 50% Mitsubishi Corporation). Prior to construction, *Clusius CV* conducted an 'Environmental Impact Assessment' and an 'Appropriate Assessment', and applied for a *Wbr*/*Wtw* permit. The permit (WV/2009-1229) was issued on 18 December 2009 (Anonymous 2009, point 5, pages 65-66). With respect to seals, the *Wbr*/ *Wtw*-permit requested the following monitoring.

> Aim of the measurement(s) is to collect data on the migration routes of harbour 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 into 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.

The *Wbr*/*Wtw*-permit included the obligation to prepare a 'Monitoring and Evaluation Plan' (MEP). In the 2009 MEP it was stipulated that, rather than monitoring year-round, which necessitated tagging seals on two occasions per year, tagging once a year would be sufficient. It was determined that the best time for the single yearly deployment was in April-May (later revised to March-April). The sampling regime aimed to maximise recording of seal movement over the time of year that pile-driving of turbine towers was permitted, July-December, because pile-driving produces a high level of underwater sound that can impact on marine mammals (Madsen *et al.* 2006). Also, it was decided that deployments should be split between in the Wadden Sea and in the Delta region, at either end of the coastal zone.

Upon finalising the T0, $T_{construction}$ and T1 a workshop was held to evaluate the findings (Kirkwood *et al.* 2016). Here it was concluded that to form a complete picture of the harbour seals' movement and behaviour the study should include autumn. A new MEP was drafted in 2016 (Brasseur *et al.* 2016), defining a tracking schedule for the T2 and T3 phase (Table 1).

Table 1. *Harbour seal deployment arrangement for the contract period and additional T2 T3 monitoring.*

Phase	Spring deployments (March)		Autumn deployments (September)	
	Wadden Sea	**Delta**	**Wadden Sea**	**Delta**
T0 (2013)	6	6	-	-
$T_{construction}$ (2014)	10	10	-	-
T1 (2015)	6	6	-	-
T2 (2016)	-	-	*6*	*6*
T3 (2017)	-	-	*6*	-
Total	**22**	**22**	**12**	**6**

The responsibility of WMR is to deliver a report of the monitoring according to the specifications in the MEP, commissioned by *Clusius CV*. Although the explicit aim is to deliver monitoring that will be approved by *Rijkswaterstaat*, such approval is beyond the control of WMR. WMR takes responsibility for the quality of its work, but cannot be responsible for results that are not in line with the expectations of *Clusius CV* or *Rijkswaterstaat*. The quality is managed through an internal review process and reviews by *Clusius CV* and *Rijkswaterstaat*.

1.3 Harbour Seals in Dutch waters

1.3.1 General information

Two seal species live in Dutch waters; the harbour seal, *Phoca vitulina* and the grey seal, *Halichoerus grypus.* The grey seal only recently recolonised the area during the early 1990's (Brasseur *et al.* 2015). Both species forage throughout Dutch marine waters and haul-out mainly on sandbars to rest, breed and moult (Brasseur *et al.* 1996). Most do so in the Wadden Sea but substantial numbers also haul-out in the Delta region. Around 1960 harbour seal numbers in the Netherlands were low and declined further due to hunting pressure, pollution and disturbance (Reijnders 1985, Reijnders 1994). In the 1970s only a few hundred were seen in the Wadden sea and they had practically disappeared from the Delta region (Figure 1).

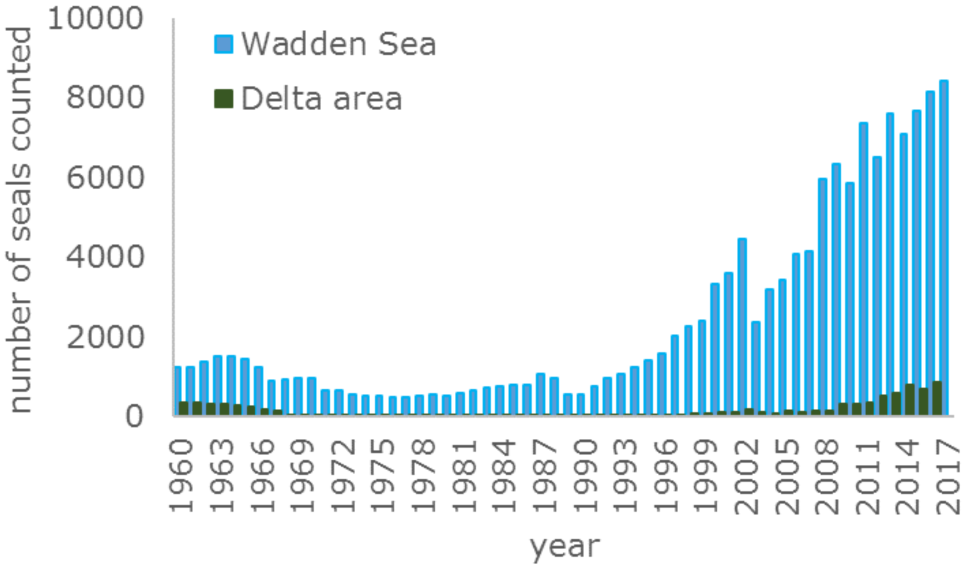


Figure 1. *Trends in numbers of harbour seals counted on the sandbanks in the Dutch Wadden Sea and Delta region.* *Data from http://www.clo.nl/indicatoren/nl1231-gewone-en-grijze-zeehond-in-waddenzee-en-deltagebied*

Seal hunting ended in 1960 in the Netherlands, but continued in the German and Danish Wadden Sea until the 1970s. During the 1980s and 1990s harbour seals started to recover. Though the recovery of harbour seals in the Delta region only became apparent during the late 1990s when the construction of the "Delta works" ended.
Harbour seals in the Netherlands are East Atlantic harbour seals of which there are a total of approximately 100,000 seals (Bjørge *et al.* 2010). The approximately 10,000 Dutch seals are part of the Wadden Sea population which has a total size of almost 40,000 animals (Galatius *et al.* 2017).

Harbour seals are protected in the Netherlands under the habitat guidelines of the EU, annex II and V and are included within several Dutch protection laws. Although on an overall scale both species are increasing in numbers in the Netherlands, there is some concern over their sustainability in the Delta area (Aarts et al. 2013). Specific conservation aims for harbour seals in the Delta were set in the 1990's, when very few harbour seals were observed there, at attaining a population of 200 animals. Though numbers have overgrown this, the apparent growth of harbour seals in the Delta can only be the consequence of large scale temporary migration to the area. The numbers likely developed through the arrival of individuals travelling from the Wadden Sea and elsewhere (Brasseur *et al.* 2012, Brasseur *et al.* 2010b). Few pups are born there (Figure 2). Moreover, for harbour seals, recorded mortality (which is a fraction of the actual mortality) has been varying between two to three times the number of births (Aarts et al. 2013, Brasseur 2018).

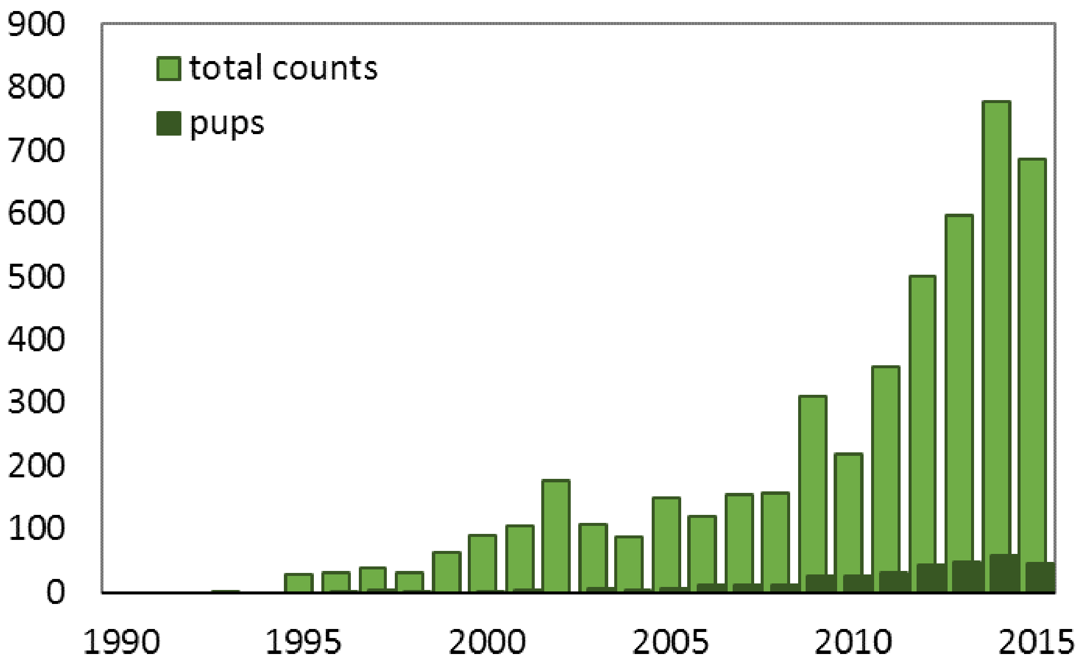


Figure 2. *Number of harbour seals and pups in the Delta area data from (Brasseur 2018).*

1.3.2 Seal movement

Seals spend periods at sea foraging and traversing between haul-out and foraging areas, and periods ashore, resting, moulting, socialising and breeding. Harbour seals breed and moult during different periods than many other seal species, they breed in June-July and moult in July-August. During their breeding and moult, adult harbour seals often remain more in inshore areas and come ashore for hours at a time, generally using tidal haul-outs.

Seals also perform trips to sea from one haul-out site, then periodically traverse to an alternative area and utilise a different haul-out. The pattern of residency in an area and movement to another varies between individuals, and is stimulated by individual need, previous experience, hunting strategy, prey availability and disturbance. Seals tend to return, however, to the same breeding sites year after year

(Härkönen *et al.* 1999), and pups seem to show natal philopatry i.e. the tendency to return to the natal site (Brasseur *et al.* 2018).

Movement at sea typically involves travel out from a haul-out, feeding within an area for a period and then movement back to the same haul-out or to a different area. While at sea, the seals usually dive to the bottom, move along the bottom to hunt, and then return to the surface to breath.
The diving behaviour of seals changes over time. Distinct dive-profiles can indicate foraging (generally dives with a high descent and ascent rate and relatively long bottom time) traveling and resting (respectively shorter and longer dives with relatively low descent and ascent rates), and reactions to particular stimuli, such as changing light conditions with time of day (Lesage *et al.* 1999, Austin *et al.* 2006, Thompson *et al.* 1991). Responses to anthropogenic sounds may also be detected in dive profiles (Miller *et al.* 2009). Recent studies show that seals may alter their behaviour at very large distances as a result of loud underwater sounds such as pile-driving (Aarts *et al.* 2018). The question how this might affect populations ultimately remains unanswered. Potentially, the sound might cause animals to spend more energy in for example feeding behaviour or drive the animals to other locations. In the end leading to changes in reproduction capacity, survival rates or emigration. Given the longevity and site faithfulness of the seals effects cannot be expected to be measurable on the short term but rather on the longer term.

1.3.3 Movement in the North Sea coastal zone

As in previous reports, the *study area* in the North Sea coastal zone is defined as being between Rotterdam and Den Helder, i.e. the area enclosed by 51.95°N to 52.94°N, and from the coast offshore to 3.73°E (Figure 3). The area encloses the Luchterduinen windfarm comprising of a 16 km^2 area situated approximately 23 km off the coast of IJmuiden and 20 km south of two existing windfarms*, Princes Amalia Windpark* (PAWP) and Offshore Windfarm Egmond aan Zee (OWEZ), and contains 43 turbine towers.

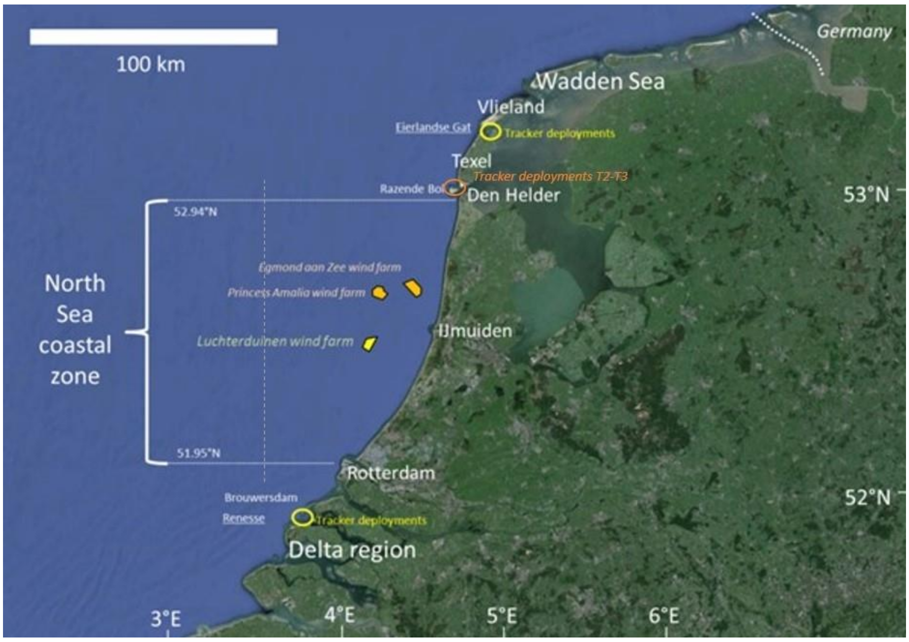


Figure 3. *Location of the* study area (North Sea Coastal Zone) *and Luchterduinen offshore windfarm and other operating windfarms in the vicinity of the west coast of the Netherlands, and deployment sites where seals were fitted with transmitters for this study (in orange the new site: Razende Bol) .*

Harbour seals potentially use the North Sea coastal zone as a foraging area and as a zone through which to move between foraging, moulting or breeding areas (Aarts et al. 2013). The continued occupation of the Delta is dependent upon an influx of seals from other areas, such as the Wadden Sea (Reijnders et al. 2000, Aarts et al. 2013). Movement through the coastal zone between the Delta and Wadden Sea has probably been critical to the reestablishment and preservation of seals in the Delta region. Especially as few harbour seal pups have been born in the Delta (Brasseur 2018).

There are likely to be seasonal patterns in the density of seals in the coastal zone, which would vary depending on the seals changing needs through their annual cycles. Monthly sea-watch data collected by an observer net-work at stations along the coast and recorded in an on-line database (www.trektellen.nl) demonstrated harbour seal numbers peak in winter and are relatively low throughout the rest of the year (Aarts et al. 2013). Tracking data from previous studies indicate there might be a marked difference between spring and autumn tracking. This can be expected, as in autumn harbour seals recovering from the breeding and moult in summer are more focused on feeding than in spring when they have regained weight and prepare for breeding. This is based however, mostly on seals tracked to study behaviour around the Wadden Sea, rather than the North Sea coastal zone.

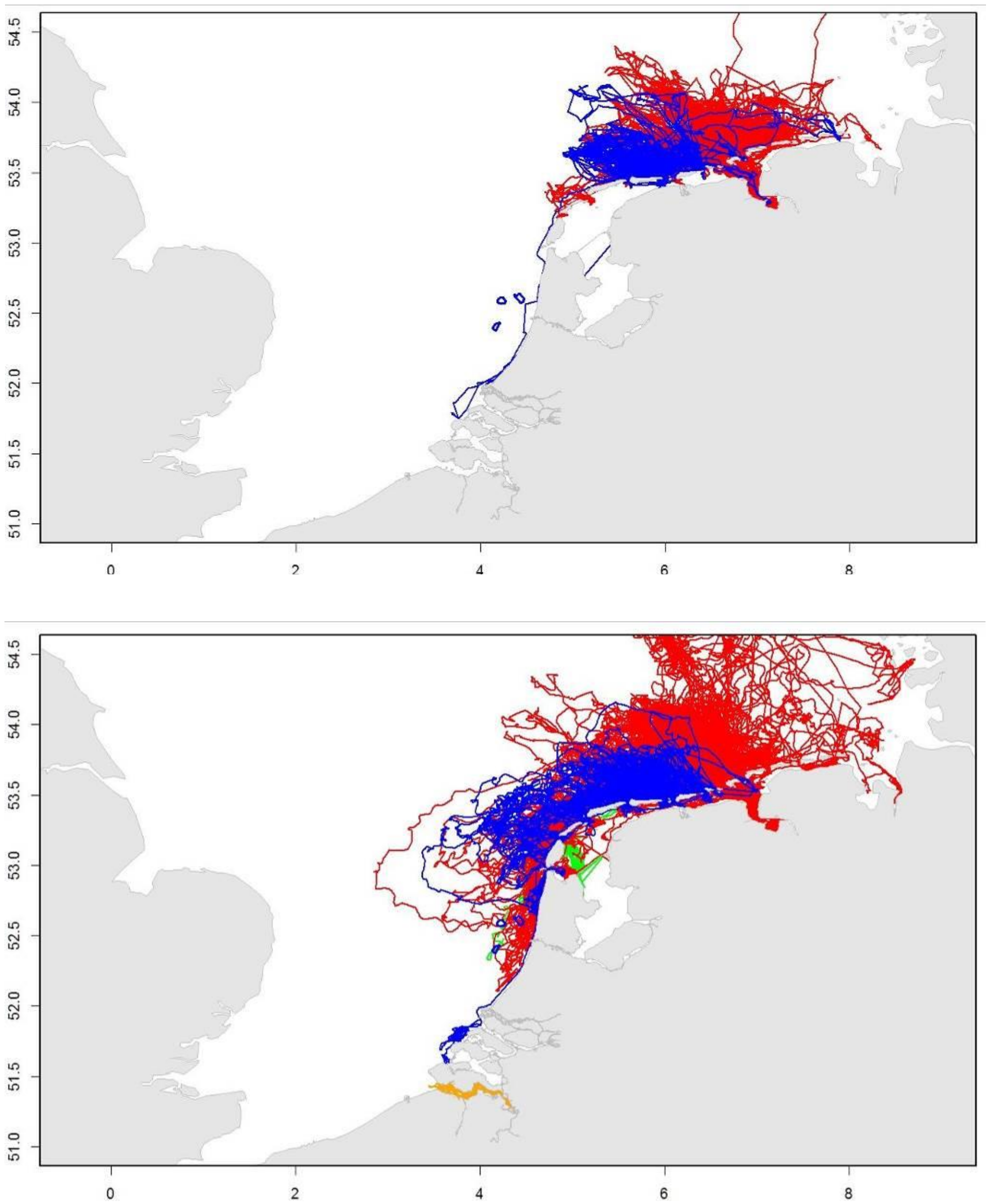


Figure 4. *Distribution of harbour seals tracked using GSM trackers excluding the Luchterduinen study (2004-2015). Top represents tracking in spring (n=92) bottom in autumn (n=119). Colours correspond to area of deployment: Red= Eems area, Blue=central Wadden Sea; green=western Wadden Sea; orange = Delta area (Aarts et al. 2013, Brasseur et al. 2011, Brasseur et al. 2010a, Brasseur et al. 2009, Brasseur & Kirkwood 2015, Brasseur & Kirkwood 2016, Brasseur & Reijnders 2001, Kirkwood et al. 2015, Kirkwood et al. 2016, Kirkwood et al. 2014).*

Tracking data also indicated that many individuals likely forage within the coastal zone (Aarts et al. 2013, Aarts *et al.* 2016, Brasseur *et al.* 2010c, Kirkwood et al. 2015). Modelling of seal habitat preference in Dutch waters, based on the movements of tracked seals up to 2010 predicted that, in particular, the centre-section of the study area in North Sea coastal zone is suitable feeding habitat for both grey and harbour seals (Brasseur et al. 2010c). More detailed monthly models show that the distribution of seals at sea is also seasonal, with on average higher densities further away from the haul-out sites, than in spring (Aarts *et al.* 2016). As an example Figure 5 shows the results for January and May. Seals choosing to forage in the coastal zone must haul-out near the Wadden Sea or Delta, as at present there are no stable haul-out locations within the zone. The majority of locations recorded for tracked seals within the coastal zone prior to 2013 were within 20 km and within 50 km of the coast for grey and harbour seals, respectively (Brasseur & Reijnders 2001, Brasseur & Fedak 2003, Brasseur et al. 2010c, Aarts et al. 2013, Kirkwood et al. 2014). Thus, our study area, the strip of several tens of km's along the Dutch west coast has the potential to be a profitable foraging area for the seals.

Human activities in the Dutch coastal zone are increasing and include shipping (particularly intensive on the main shipping channels to the harbours of Antwerp and Rotterdam and, to a lesser extent near, Scheveningen and IJmuiden), dredging, fishing, sediment extraction (sand and gravel), underwater explosions and windfarms. A concern over increasing human activities is that these may influence seal movements through the area (Aarts et al. 2013, Brasseur et al. 2010c). Particularly, they could reduce the exchange of seals between the Wadden Sea and the Delta area causing a decline in numbers in the Delta.

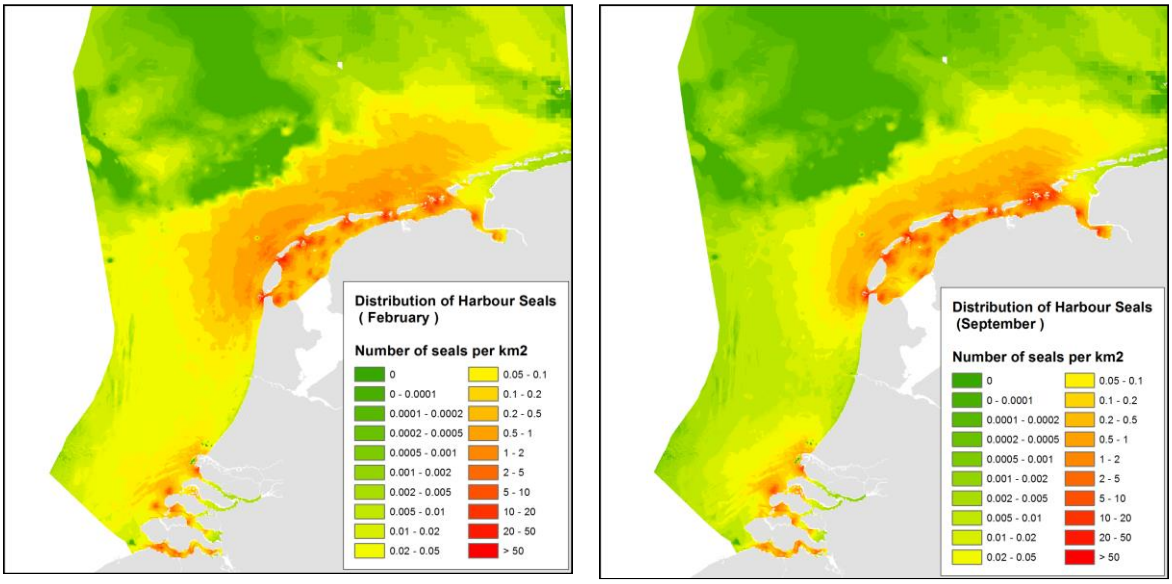


Figure 5. *Maps of predicted distribution of harbour seals making trips from haul-out sites located in the Netherlands for February (left) and September (right). Values represent number of seals per km2. (Aarts et al. 2016)*

1.3.4 Luchterduinen activities

Prior to Luchterduinen two other windfarms were built in the coastal zone. OWEZ was constructed in 2006 and has been operational since April 2007. For PAWP construction began in 2006 and was finalised in 2007. This windfarm is operational since June 2008. Both windfarms are situated approximately 20 km north of Luchterduinen (*Figure 3*)

During construction of Luchterduinen, underwater noise produced by the activities as well as visual cues, such as movement of vessels or construction activities, increased light at the surface at night and changes to water turbidity during dredging, stone-dropping, or due to the piles would have been detected by seals in the area and possibly influenced their movement choices and behaviour. The offshore construction activities in the Luchterduinen area included:

In 2013:

- Increased shipping.
- Sonar surveys of depth profiles, sub-surface features.

In 2014

- Increased shipping including residence of ships and lighting.
- Sonar surveys of depth profiles.
- Preparation of the field, including searching for and exploding World War 2 ordnance (19 April-2 May, 9-13 July, 23-25 August).
- Stone dropping plus sonar surveys - scour protection at monopole pads and cable crossings (28 April – 31 July).
- Jacking up &down of construction vessel and pile-driving of monopoles (31 July to 16 October).
- Preparations for cable landing at Noordwijk (22 August).
- Cable laying and burial between towers (3 September – 3 December).
- Export cable installation (16 October to 9 November).
- Jacking up of vessel and attachment of towers, turbine heads and blades.

In 2015:

- Jacking up of vessel and attachment of towers, turbine heads and blades.
- Placement of High Voltage station (OHVS) - 18 February.
- First test of turbine - 22 May.
- First power production - 26 June.

Though the increased activity in and around the windfarm is continuous and will be of much longer duration, pile-driving was expected to represent the loudest underwater sound emitted during offshore windfarm construction (Madsen *et al.* 2006) and to affect the largest area. At Luchterduinen 44 monopoles were pile-driven into the seafloor, comprising 43 turbine foundations and one Offshore High Voltage Station (OHVS) foundation. Pile-driving activity increased through the pile-driving period in 2014. One tower was installed on 31 July, 11 in August, 16 in September and 17 in the first half of October.

1.3.5 Monitoring movement of seals during T0, $T_{construction}$ and T1

The seal monitoring for Luchterduinen during the construction phase (2013- T0; 2014- $T_{construction}$; and 2015- T1) specifically sought overlap between seal movement and pile-driving and to have control data for the year's pre- and post- pile-driving (Kirkwood et al. 2015, Kirkwood et al. 2016, Kirkwood et al. 2014). Pile-driving was anticipated to commence in July 2014 and last several months. Therefore, it was decided that tracking devices to monitor the effects had to be deployed prior to July.

The time of year when the seals breed and moult influences data collection from trackers that are attached to the fur. Seal fur is weakest shortly before the moult as it deteriorates through the year, becoming more frayed and brittle, until the moult, when all the fur is shed. In the Netherlands, harbour seals give birth in early summer and moult in late summer (Figure 6). During moult, any trackers potentially still attached are also shed. As a consequence, the longest tracking periods possible come from tracker deployments on harbour seals in September, i.e. the tracking of T2-T3.

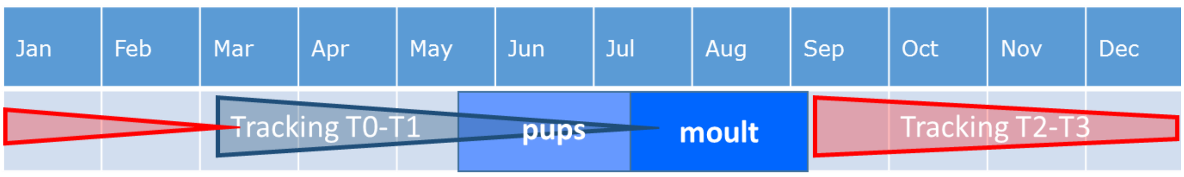


Figure 6. *Comparison of annual cycles of harbour seals, against periods of tracking data for Luchterduinen T0-T1 in 2013 – 2015, and the period of tracking data for T2-T3 in 2016-2018. Tracking data in T0-T1 was reduced over time from deployment as trackers are shed prior to the annual moult.*

As a consequence of tagging in March, many trackers deployed on the harbour seals are lost in the course of May and June during the (pre-)breeding period. There was initial hope that harbour seals fitted with trackers in spring would also retain their trackers sufficiently long to cover part of the pile-driving period. In effect, though, pile-driving did not commence until 31 July and the longest lasting device on a harbour seal stopped transmitting on 17 July (Kirkwood et al. 2015). While no recording of response to pile-driving was possible, movement within the coastal zone prior to pile-driving could be investigated.

By limiting the study in T0-T1 to spring deployments, the seals' habitat use, and thus the consequences of the offshore windfarms for the seals will have been under estimated. In this study (T2-T3) a deliberate choice was made to study the behaviour of the seals in the post moult, from September onwards is observed.

2 Materials and Methods

2.1 Tracking

2.1.1 Tracking devices

During the whole study (2013-2017) devices used to track the seals were *GPS-GSM transmitters* from the Sea Mammal Research Unit (SMRU, Scottish Oceans Institute, Scotland). This allowed us to generate comparable data throughout the study. Minimising device size is important to minimise drag, which could impair swimming efficiency(Fish *et al.* 2009). 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. The trackers provide the accuracy of Fastloc® GPS location-determinations, dive depth, water temperature and haul-out time measurements.

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. In the T0-T1 studies (2013-2015) the sample interval was set at the maximum rate of every 5-minutes, providing an estimated battery-life of 6-8 months. As during the T2-T3 (2016-2017) the seals were expected to retain devices for considerably longer, the 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, though the tracker is glued just below the neck, not all 'surfacings' of the seal provide a location, because the antenna does not always break the surface.

Transmitter depth is recorded at pre-set intervals, yielding some 20 points per dive, from which the diving pattern can be observed. Up to 48 temperature profiles can be collected by the tracker, these data were not used in this study. The intervals were set to maximise data within the memory capacity of the devices.

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. However the data collection is not "live", as the data is relayed via the GSM mobile-phone system when the seal hauls out within range of a network. Up to 3-months of data can be stored in the memory of the transmitters. Data transmission is possible at most seal haul-out and breeding sites in the North Sea. 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.

2.1.2 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).

To investigate seal movement within the study area in North Sea coastal zone, deployment sites were selected on both ends of the zone:

a. During T0-T1 seals were captured in the western Wadden Sea, in the inlet of the Eierlandse Gat, between Texel and Vlieland (at 53.20°N, 4.94°E). In that period, seals were known to haul out at Razende Bol, which is 30 km closer to the study area. However, this is a very changeable environment, and in 2013, 2014 and 2015, waves, as well as shallows and strong currents adjacent to where the seals were hauling out, were anticipated to make captures there difficult.
   As the sandbar changed shape, it was possible to capture animals on the Razende Bol (at 52.58°N, 4.42°E) in 2016 and 2017. Potentially this would yield a better coverage of the coastal area,. since on average seals are expected to minimize travel costs and, seals using the study area are likely to haul-out on the Razende Bol.

b. In the Delta region, harbour seals were caught at a sand bar north of Renesse (51.75°N, 3.75°E). Analogue to the situation in the north, seals also haul-out at a small sandbank immediately south of the Maasvlakte (Rotterdam), which is about 20 km closer to the study site, but the site is difficult to access for seal catching.

An overview of the field trips for T2 T3 is presented in
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 selected to carry transmitters were healthy individuals that had completed their moult. Seals were differentiated between adult and subadult based on their length (nose to tail): all harbour seals >130 cm, were defined as adults. We attempted to have an even spread of males to females and subadults to adults. This aim was balanced against minimising the number of catches, however, as each catch disturbs the colonies. Therefore, we accepted seals captured rather than rejecting them and requiring additional catches just to get the even spread between sex-age classes. 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 sex of the seal was determined, the seal was measured (standard length) and weighed (using block-and-tackle and suspension scales). In addition a standard set of blood and tissue samples are collected. These are made available to scientists interested in wild animals and limits the necessity to capture animals only for samples. 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). All seals were released within 90 minutes of their capture. Seals not selected to carry transmitters were released immediately after the selection of seals to be tracked.

Table 2. *Field trips for transmitter deployments in T2-T3.*

year	No of trackers per area	Date	Region
2016 (T2)	6	8-9-2016	Wadden Sea (Razende Bol)
2016 (T2)	6	7-9-2016	Delta region (Renesse)
2017 (T3)	6	25-9-2017	Wadden Sea (Razende Bol)
Total No of trackers	18		

2.2 Data processing

Seal location and dive data were transmitted by the tracking devices to the GSM-network and stored on computer 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).

Locations from the GPS tracking data that represented unrealistic travel speeds (i.e. 20 km/s, comprising <0.01% of locations) where removed. All remaining locations inside the study region were plotted. The ranges and maximum distances from capture haul-outs achieved on individual and multiple trips were calculated. To define the usage of the North Sea coastal area and investigated the potential existence of high-use corridors, seal presence at distance from the coastline were considered. For this only the data from the North Sea coastal area (i.e. the area enclosed by 51.95°N to 52.94°N, and from the coast offshore to 3.73°E (Figure 3). was used. The analysis was achieved by first calculating for each location the half-time to the previous location and half-time to the next location, and attributing those times to the location. Seal numbers and time periods within 1-km distance categories from the coast were then summed. The results were expressed in seal days per distance category. They show the number of individual animals observed in a certain category. To express the relative importance of the different distance categories, we also looked at the percent time spent, 100% being the total time spent in the North Sea coastal area.

A similar analysis was done for the presence of seals in the vicinity of Luchterduinen windfarm to show the number of individual animals observed in a certain category and the relative importance of the different distance categories, expressed as the percent of time compared to the total time spent in the North Sea coastal area.

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

3 Results

All times in this report are presented in UTC (Universal Time Coordinated [UTC] = Central European Time [CET] - 1 hour, and Central European Summer Time [CEST] – 2 hours).

3.1 Deployments

In 2016, three field trips were required to deploy the 12 GPS-GSM-transmitters on harbour seals at two study sites: six at each site. In 2017, the deployment of six transmitters at the Razende Bol was achieved in one trip (Table 3).
The 18 harbour seals in T2-T3 were tracked for durations of 20 to 187 days (106 ± 46 days, mean ± sd). In 2017 one tracker malfunctioned and did produce dive data however, there was no location data (*Table 3*). In total 11 males and 7 females were tracked. This is discussed in more detail in 3.1.1.

Table 3. *Seals tracked from March deployments in 2016 and 2017. *In 2017 one tracker did produce dive data however, there was no location data.*

Seal number	**sex**	**age group**	**date out**	**last location date**	**days tracked**
Delta area		**2016**			
pv-Z146	M	adult	6-9-2016	12-3-2017	187
pv-Z149	F	subadult	6-9-2016	20-12-2016	105
pv-Z192	F	subadult	6-9-2016	16-12-2016	101
pv-Z138	F	subadult	7-9-2016	10-2-2017	156
pv-Z143	M	adult	7-9-2016	6-1-2017	121
pv-Z148	F	subadult	7-9-2016	4-1-2017	119
Wadden Sea area		**2016**			
pv-T065	M	subadult	8-9-2016	18-12-2016	101
pv-T193	F	adult	8-9-2016	11-11-2016	64
pv-T194	F	subadult	8-9-2016	24-11-2016	77
pv-T195	M	subadult	8-9-2016	1-1-2017	115
pv-T196	F	subadult	8-9-2016	5-11-2016	58
pv-T209	M	adult	8-9-2016	5-11-2016	58
Wadden Sea area		**2017**			
pv-1	M	subadult	25-9-2017	28-11-2017	64
pv-2	M	adult	25-9-2017	15-10-2017	20
pv-3	M	adult	25-9-2017	15-3-2018	171
pv-4	M	subadult	25-9-2017	20-3-2018	176
pv-5	M	adult	25-9-2017	*13-10-2017**	-
pv-6	M	adult	25-9-2017	20-1-2018	117

3.1.1 Comparison with T0, $T_{construction}$ and T1 deployments

Prior, during and just after the construction of Luchterduinen (T0 in 2013, $T_{construction}$ in 2014 and T1 in 2015) 44 harbour seals were fitted with GPS-GSM transmitters. They were tracked for periods of 49 to 114 days, covering a maximum of five calendar months from March onwards, up to July (Kirkwood *et al.* 2016). Because harbour seals moult in summer, most trackers were lost in June. Tracking durations for harbour seals in the pre-moult season did not differ between these years and averaged 89 ± 15 days (ANOVA, $F_{2,41}$ = 1.02, p=0.37).

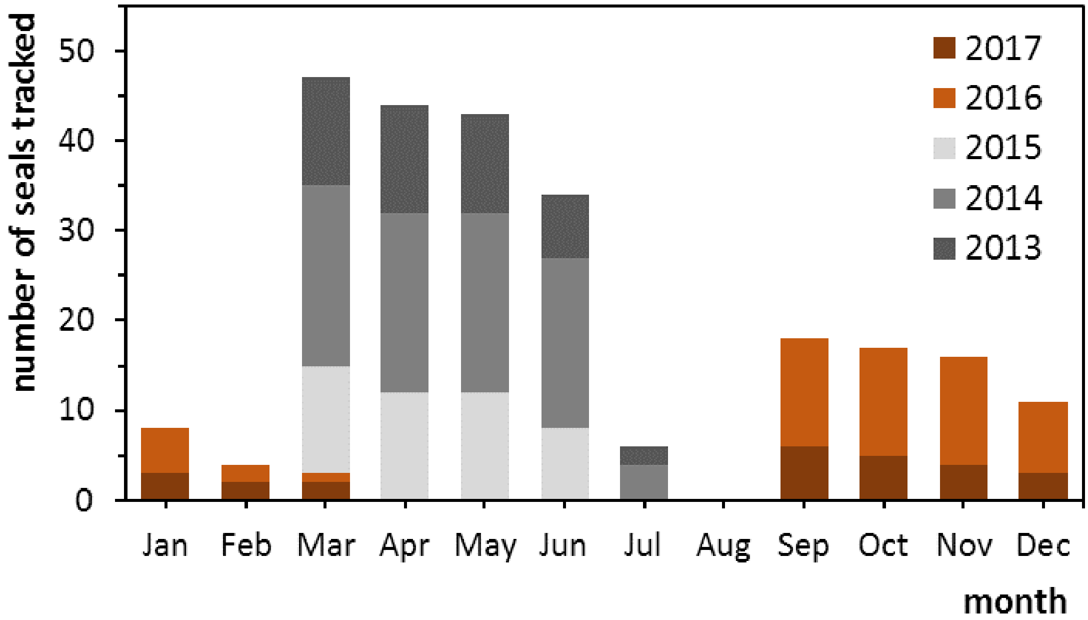


Figure 7. *Numbers of harbour seals tracked per month over five years of deployments during monitoring of Luchterduinen. Colours correspond to the deployment years.*

As explained earlier, after evaluation it was decided to change the tracking scheme and in the post-construction phase to monitoring the seals during the post-moult period i.e. from September onwards. By doing so, information has been collected covering seven calendar months, six of which had not been studied before in this region (Figure 7). During the months of February and March only few trackers were still attached to seals (respectively 4 and 3 animals). Potentially, more overlap in data between the different monitoring schemes would have been helpful to better understand how to associate the different tracking periods. This would have been the case if the trackers had continued to perform through March and April (i.e. overlapping with spring deployments). As expected, compared to the previous years' tracking, durations of tracking were longer though quite variable (Figure 8).

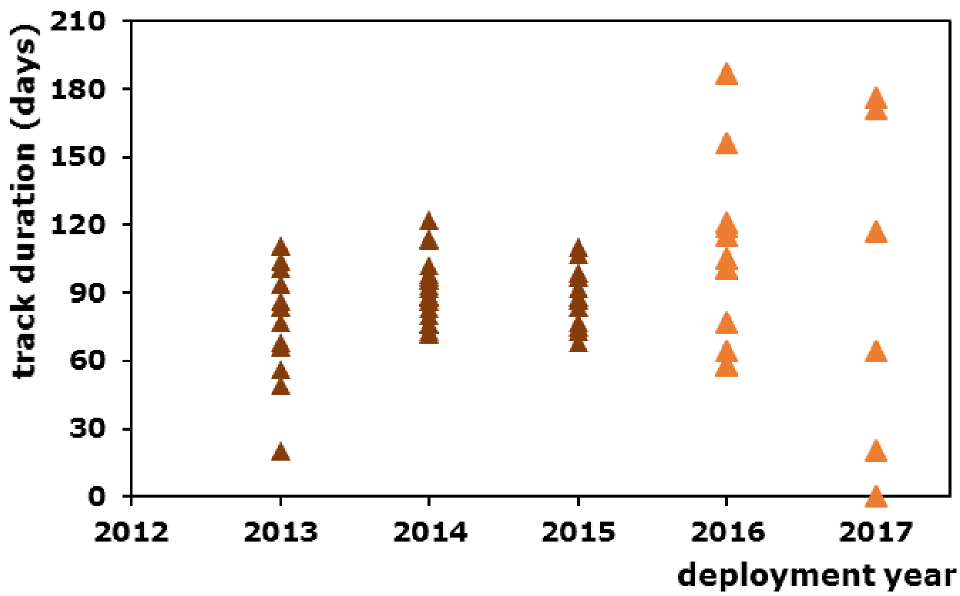


Figure 8. *Comparison of harbour seal track duration over five years of deployments during monitoring of Luchterduinen. Brown indicating the spring deployments T0-T1, orange the T2-T3 autumn deployments.*

Despite efforts to collect even amounts of animals from the different age and sex groups, females (mostly adult females) were still under-represented in the 2016 en 2017 deployments, especially from the Wadden Sea. Overall earlier samples were better balanced: 127 females vs. 136 males (Table 4). It was not always possible to catch the requested age and sex ratio, and for ethical reasons (i.e. not disturbing more seals by do an additional catch) trackers were deployed on the seals available.

Table 4*. Numbers of tracked seals classed as females and males, subadults and adults, by location and by year.*

Area	Female			Male			Total
year	Subadult	Adult	Total	Subadult	Adult	Total	
Delta							
2013	2	1	3	2	1	3	***6***
2014	1	2	3		7	7	***10***
2015	1	2	3	1	2	3	***6***
2016	4		4		2	2	***6***
Total	8	5	13	3	12	15	
Wadden							
2013	2		2	1	3	4	***6***
2014	2	3	5	1	4	5	***10***
2015		1	1	1	4	5	***6***
2016	2	1	3	2	1	3	***6***
2017				2	4	6	***6***
Total	6	5	11	7	16	23	
Grand Total	***14***	***10***	***24***	***10***	***28***	***38***	***62***

3.2 Harbour seal movement in 2016-2018

The autumn tracking in 2016 and 2017 shows mostly usage of the North Sea area within the North Sea Coastal zone including our study area (i.e. 51.95°N to 52.94°N, and from the coast offshore to 3.73°E; Figure 3), with relatively little exchange towards the Wadden Sea or other areas (Figure 9).

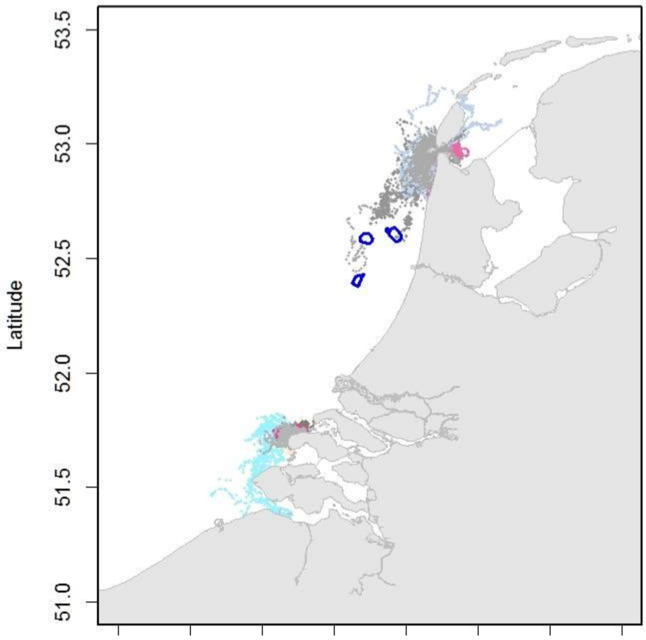


Figure 9a. *Movements of individual harbour seals tracked in autumn and winter of 2016 (six animals tracked from the Wadden and six from the Delta) Colours show different seals.*

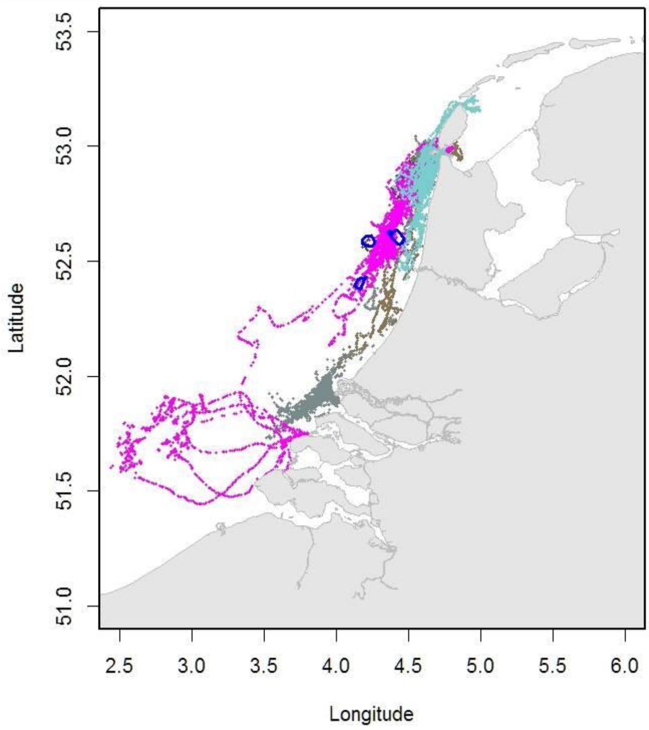


Figure 9b. *Movements of individual harbour seals tracked in autumn and winter of 2017 (six animals from the Wadden). Colours show different seals.*

The seals caught in the Delta area show relatively small ranges, whilst from the Razende Bol in the north, especially animals tracked in autumn 2017, travel more extensively southwards along the North Sea coastal zone, two of which move to the Delta area. Like in earlier studies there is large individual variation which could partially be related to the age or sex (Figure 10).

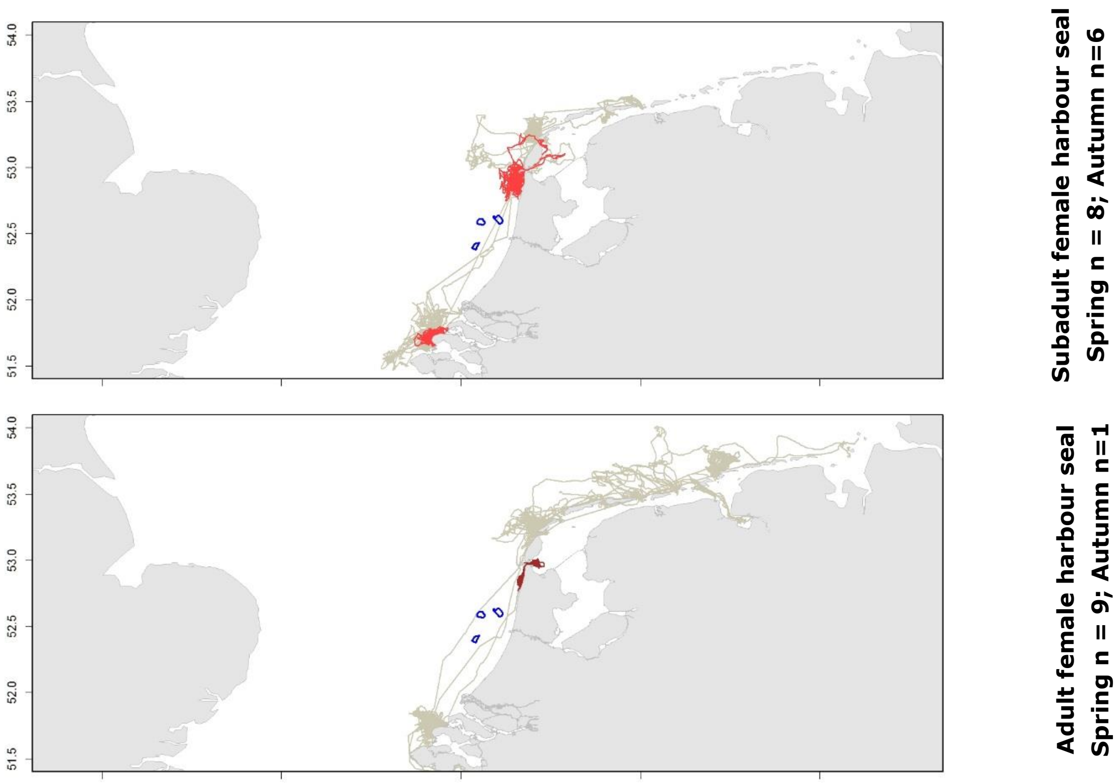


Figure 10a. *Distribution of all harbour seal females tracked during the Luchterduinen project. Top panel shows the sub adult females, and bottom panel the adult females. Grey tracks represent females tracked during the previous Luchterduinen spring deployments (i.e. T1-2013, $T_{construction}$-2014 and T1-2015) and red colours represent females tracked in autumn during T2-2016 and T3-2017 Blue polygons are Luchterduinen and adjacent windfarms).*

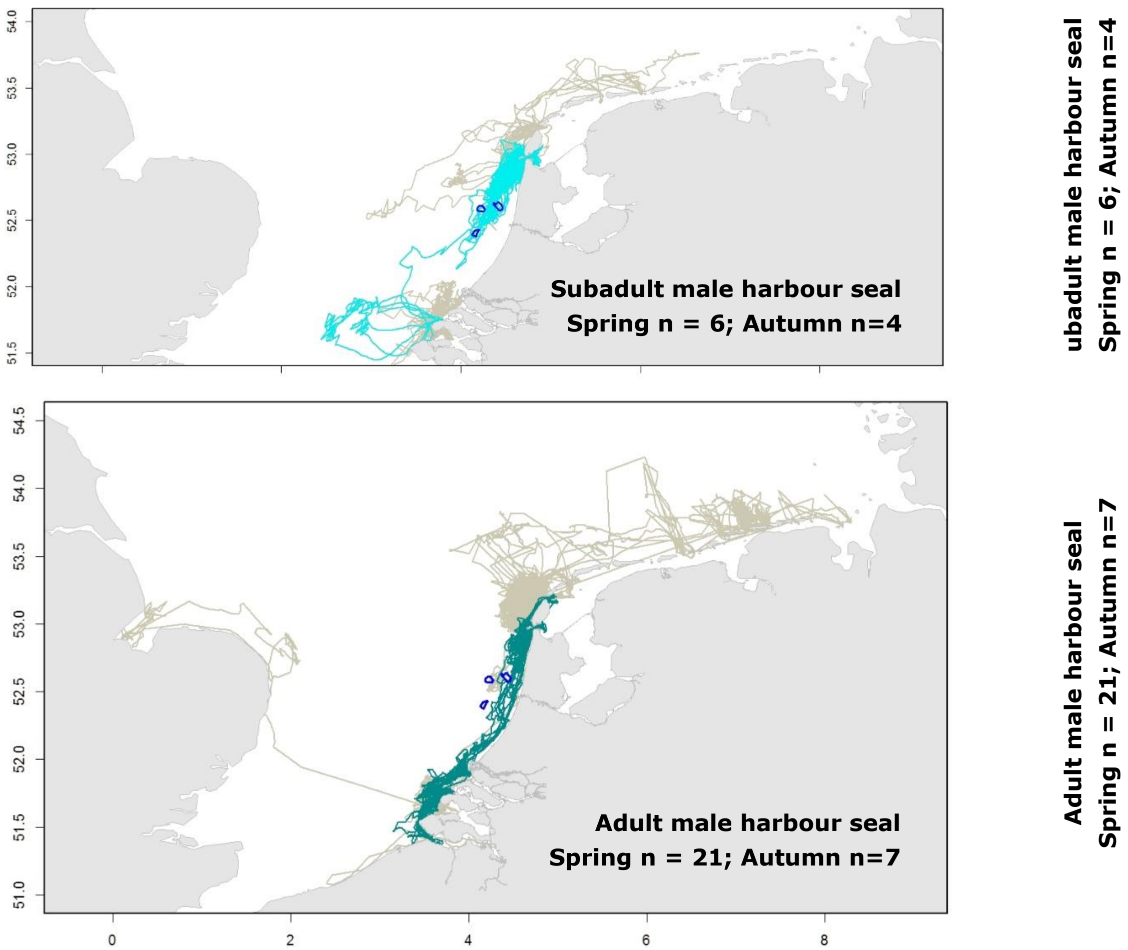


Figure 10b. *Distribution of all harbour seal males tracked during the Luchterduinen project. Top panel shows the sub adult males, and bottom panel the adult males. Grey tracks represent males tracked during the previous Luchterduinen spring deployments (i.e. T1-2013, $T_{construction}$-2014 and T1-2015) and red colours represent males tracked in autumn during T2-2016 and T3-2017 Blue polygons are Luchterduinen and adjacent windfarms).*

Compared to earlier years when tracking was done in spring, in autumn the changes in area used by the seals is quite striking; while none of the Delta animals relocated to the Wadden Sea, some seals caught in the North, relocated to the Delta. This is clear for males of all age groups and cannot be stated for adult females as only one female was tracked in this study leaving little possibility of comparison between seasons. During spring several Delta seals had relocated to the Wadden Sea. The Delta animals with trackers deployed in autumn 2016 stayed relatively close to their catching site throughout the study (Figure 9).

3.3 Spatial use in study area

After the moult in August-September, harbour seals haul out less as the breeding and moulting season is over. They are mostly focussed on feeding to replenish reserves lost through summer. The seals in the Netherlands feed predominantly in the North Sea rather than in the Wadden Sea or Delta. Most animals tracked in 2016-2018 made foraging trips from the sites they were captured, though two relocated from the Razende Bol to sites in the Delta area. The tracked seals in the autumn/winter seasons of 2016-2018 also occur more in the North Sea Coastal zone compared to the animals that were tracked in spring/summer 2013-2015 (Figure 11). The current data shows multiple travels through the area, most often seals return to their initial haul out after having travelled (possibly feeding) at sea. Despite the larger amount of animals, in T0-T1 spring/summer studies the number of times harbour seals travelled through the North Sea Coastal zone were so low that each crossing could be discussed individually (Kirkwood et al. 2015, Kirkwood et al. 2016, Kirkwood et al. 2014). In the more recent (autumn) studies the use of the area is much more continuous. The deployments in

2013-2015 (44 animals tracked) yielded a total of 3392.8 days of tracking, the cumulative time spent within our study area was 49.7 days , or 1.5% of the time. In contrast, the autumn deployments in 2016-2018 (17 animals tracked) yielded 1653.5 days of tracking of which 451.5 days (27.3%) in this study area. This is clear in Figure 11 where the tracks in spring are compared to those in autumn.

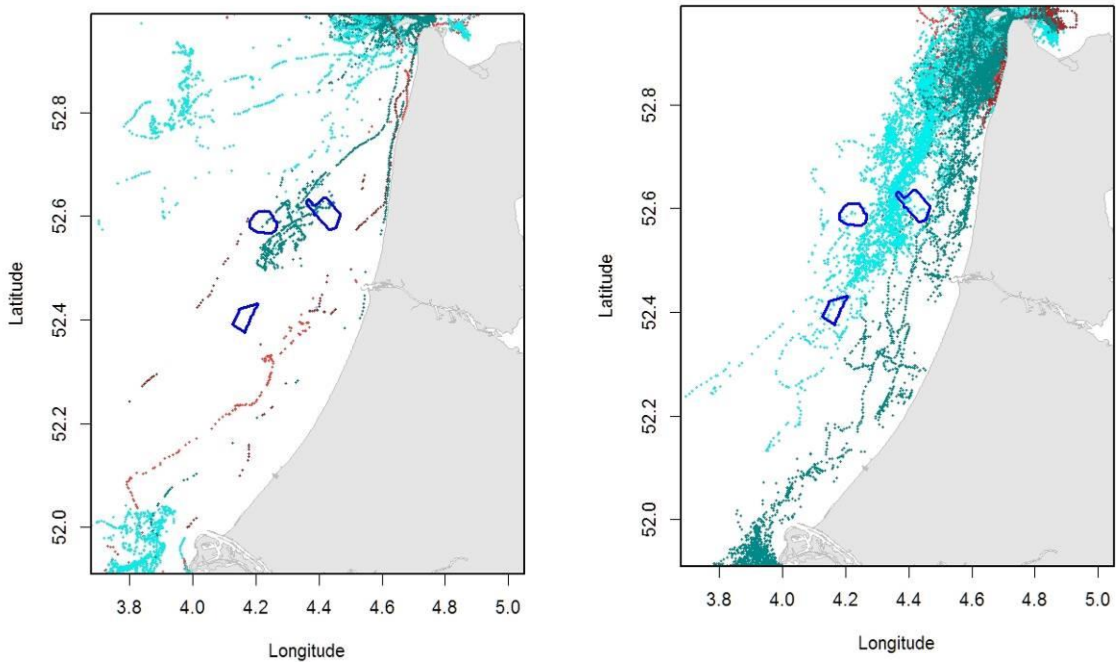


Figure 11*. Comparison of harbour seal locations in the study area between spring deployments (left; 2013-2015, N=44) and autumn deployments (right; 2016-2018, N=18). Colours coincide with age/sex groups as in Figure 10.*

3.3.1 Distance to haul outs

In spring (May/June, even July), adults, mostly adult females often make very long migratory trips towards their breeding areas, often located in Dutch or German Wadden Sea (Brasseur 2017). Seals included in the Luchterduinen studies were seen making trips of 200 to almost 400 km (Kirkwood et al. 2016). When tagging seals in autumn, we expect most seals to have returned to the haul-outs near their preferred feeding areas, and trips would be shorter compared to those longer migratory trips. Indeed, compared to the spring, our results show that seals spent relatively more time in one area to haul out and travel to and from feeding areas offshore. Figure 11 (right) clearly shows a higher usage of the North Sea coastal zone.

Table 5. *Usual ranges and long-distance movements of the tracked seals.*

	Females adults			**Female sub-adults**			**Male adults**			**Male sub-adults**		
period	**No. of individuals**	**Avg.distance (SD)**	**Max.distance (SD)**	**No. of individuals**	**Avg.distance (SD)**	**Max.distance (SD)**	**No. of individuals**	**Avg.distance (SD)**	**Max.distance (SD)**	**No. of individuals**	**Avg.distance (SD)**	**Max.distance (SD)**
North - Steenplaat												
2013		-	-	2	41(3)	70(11)	3	76(58)	163(76)	1	50(-)	130(-)
2014	3	70(51)	169(64)	2	6(1)	48(42)	4	29(35)	81(96)	1	7(-)	36(-)
2015	1	47(-)	148(-)		-	-	4	21(11)	55(40)	1	44(-)	154(-)
North - Razende Bol												
2016	1	13(-)	24(-)	2	16(5)	46(16)	1	13(-)	47(-)	2	12(6)	59(16)
2017		-	-		-	-	3	45(34)	113(49)	2	37(37)	139(110)
South - Renesse												
2013	1	18(-)	387(-)	2	45(19)	184(4)	1	9(-)	33(-)	2	8(2)	68(54)
2014	2	74(98)	157(195)	1	10(-)	21(-)	7	12(10)	76(91)			
2015	2	43(49)	149(143)	1	14(-)	54(-)	2	156(206)	179(211)	1	9(-)	48(-)
2016		-	-	4	3(1)	16(4)	2	9(6)	33(29)			
Deployment season												
Spring	***9***	***57(51)***	***184(119)***	***8***	***26(20)***	***85(65)***	***21***	***40(68)***	***93(95)***	***6***	***21(20)***	***84(53)***
Autumn	***1***	***13***	***24***	***6***	***7(7)***	***26(18)***	***6***	***28(29)***	***75(53)***	***4***	***24(26)***	***99(79)***
Total	***10***	***52(50)***	***168(123)***	***14***	***18(18)***	***60(58)***	***28***	***37(61)***	***89(87)***	***10***	***22 (22)***	***90(61)***

The apparent breeding migration might explain that both the average (or usual) distance from the haulouts and the maximum distance recorded in autumn being less than in spring. However, there are large individual differences including differences in age and sex groups. In the Delta, seals seemed to travel very little in 2016. Observed differences could also be partly the result of annual changes or deployment location (Table 5).

3.3.2 Seal density as a function of distance to the coast and Luchterduinen windpark

In earlier reports we demonstrated how the tracked seals were distributed compared to the coast in an attempt to identify the areas that might be of significance to them (Kirkwood et al. 2016, Kirkwood et al. 2015, Kirkwood et al. 2014). During the deployments in 2013-2015, 14 out of the 44 (32%) animals were actually observed in the study area (Figure 11). In the GPS-tracking data set collected during different research projects (2007-2018), the number of seals and time they spent at different distances from the coast were investigated as well (Figure 12). Although the data may be biased because the tracking periods were not evenly spaced through time, they gave an indication of the distribution of seal activity in the North Sea coastal zone. The majority of the seals' time in the study area, 82%, was spent within 20 km of the shore and, thus, inshore from Luchterduinen (located 23 km offshore). The tracking data of harbour seals in autumn (2016-2018) changed the image considerably. Out of the 17 seals that had a functional tag in 2016-2018 11 (65%) were seen in the study area. Almost all the time spent there was within the 20 km, thus inshore from the distance at which Luchterduinen was built (Figure 12).

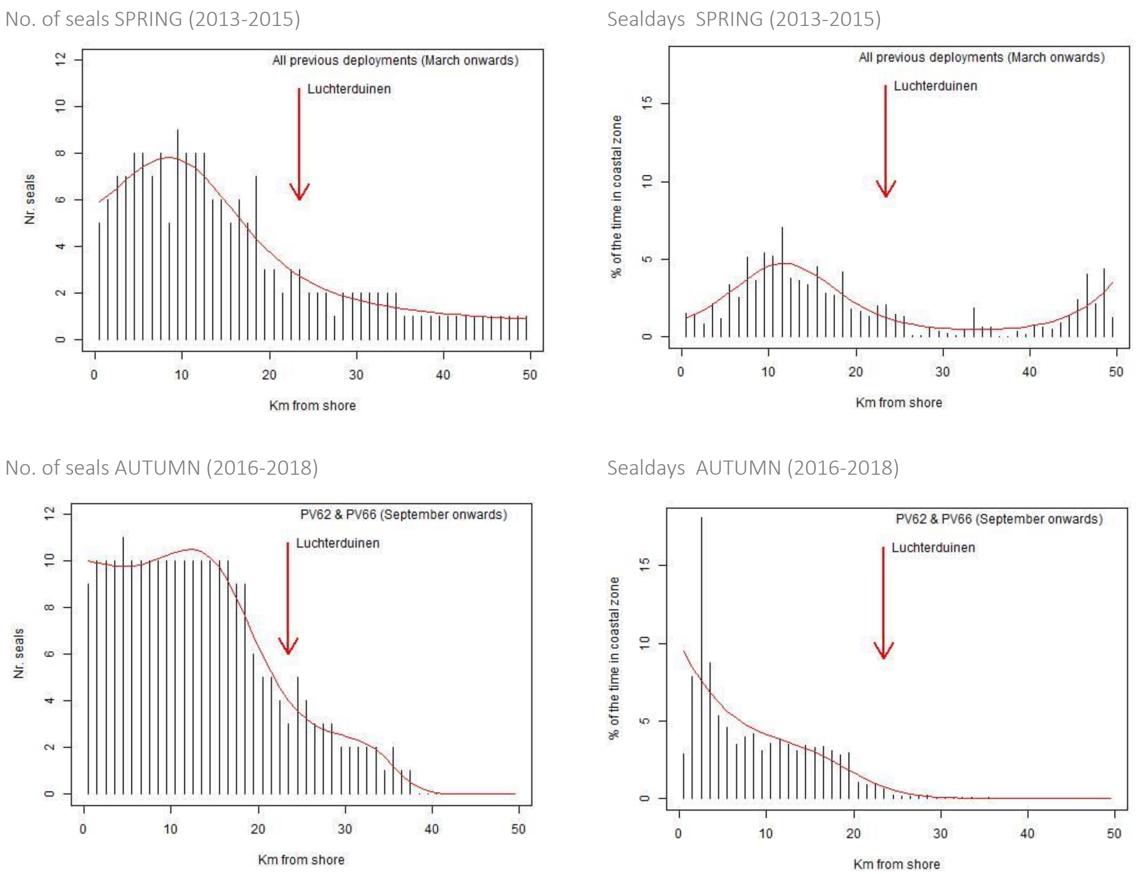


Figure 12. *Harbour seal distance from the coast within the coastal zone expressed as numbers of seals (total number of individuals that provided a location at a certain distance) and as days spent by seals (time summed for all seals) within 1-km distance categories from the shore. Top panel shows the distribution based on tracking data from all previous deployments (T0-T1; seals were tagged in March). Lower panel represents the distribution based on deployments during T2 (PV62) and T3 (PV66), when seals were tagged in September.*

Interestingly, in the latest tracking with 11 seals using the area, we see that from 2 km up until 20 km offshore at least 10 of the individuals were observed at each distance category. In the earlier tracking at most 9 out of 14 animals using the area were observed at a certain distance from the coast, possibly indicating a more opportunistic use of the area (i.e. travelling through). Compared to the patterns presented in Aarts *et al.* (2013) the emphasis on movement within 20 km of the shore was better expressed in the updated figures because they were now supported by more data and better covering autumn months, missing from previous studies. During these autumn deployments 2016-2018 the seals are seen to spend a larger proportion of their time relatively closer inshore.

Relative importance of the area near Luchterduinen

As the animals used more the North Sea coastal area, the animals tracked in autumn were also more in the vicinity of the windfarms, including Luchterduinen (Figure 13). Three individuals are seen to approach the windfarm at less than 10 km, one animal also entering the park (
Figure **14**).

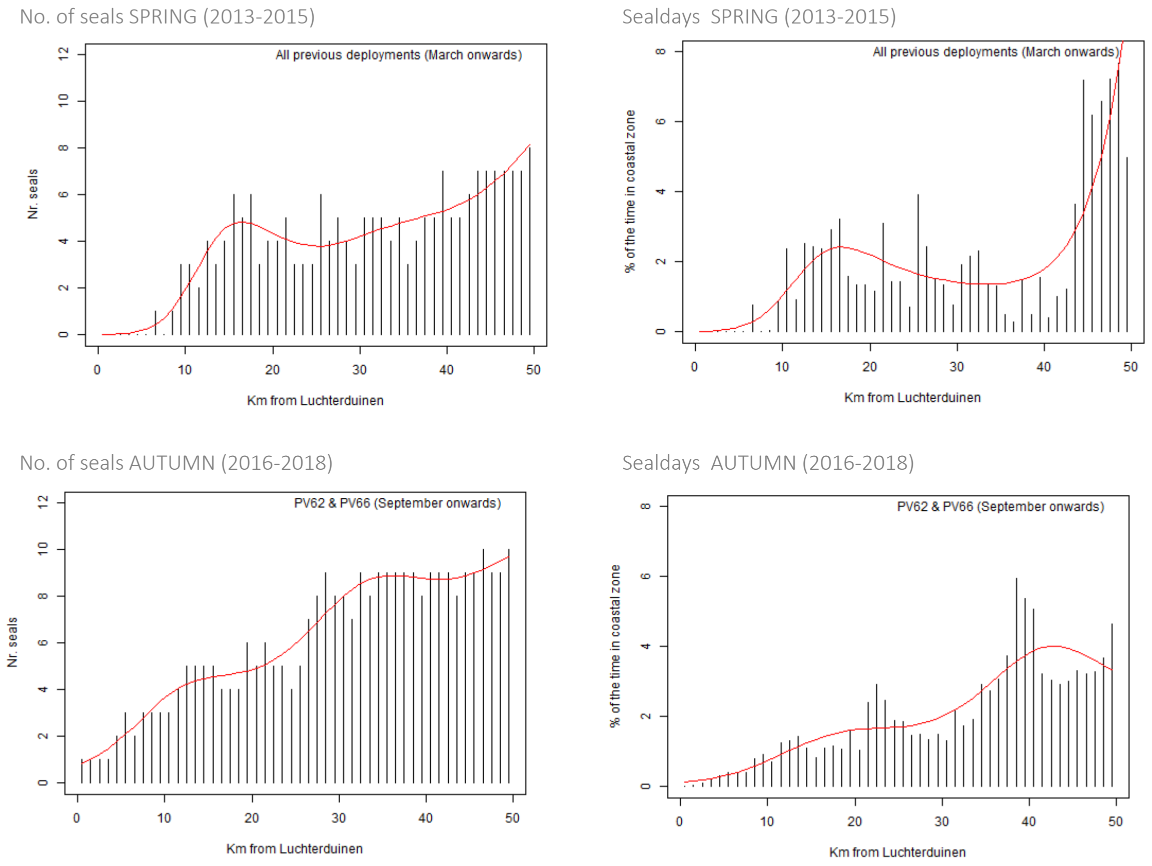


Figure 13. *Harbour seal distance from the Luchterduinen windfarm expressed as numbers of seals (total number of individuals that provided a location at a certain distance) and as days spent by seals (time summed for all seals) within 1-km distance categories from the shore. Top panel shows the distribution based on tracking data from all previous deployments (T0-T1; seals were tagged in March). Lower panel represents the distribution based on deployments during T2 (PV62) and T3 (PV66), when seals were tagged in September.*

Despite higher usage in the North Sea coastal zone in autumn and winter, only one sub adult male harbour seal moved through the Luchterduinen windfarm (
Figure **14**). Diving behaviour on these occasions is shown in the Appendix. This individual made four visits , which were relatively short, 10-77 minutes, either crossing the area (tracks 1, 4, and 6 in Figure **14**) or a short entry and exit (track 3). The short duration of the visits, seems to suggest that the individual seal is not feeding extensively in the area. The diving behaviour of the seal during these periods are shown in appendix 1. During the first crossing (track 1) the seal seems to spend longer periods surfacing when in the park. However, this behaviour is not replicated during the following crossings.

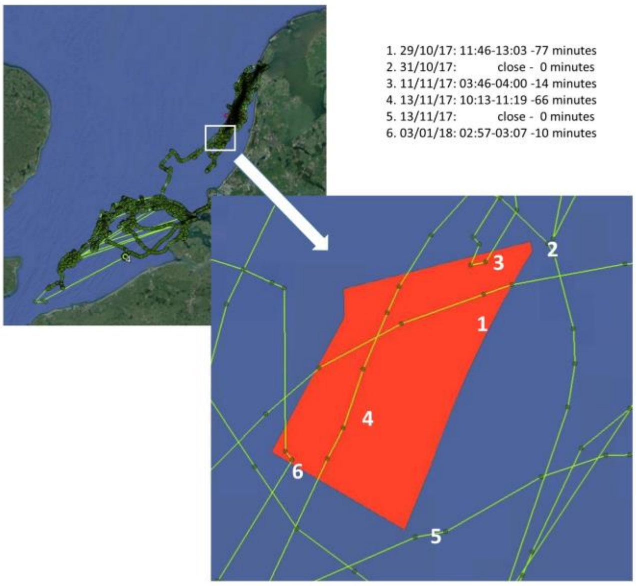


Figure 14. *One sub adult male harbour seal visited the Luchterduinen windfarm on several occasions briefly. Here details of the tracks are given*

3.3.3 Distribution and occurrence between spring (T0-T1) and autumn (T2-T3)

In the previous sections general differences were discussed between deployments in spring and autumn. Including the data collected for this part of the project (2016-2018) allows us to show an almost year round usage of the North Sea coastal zone by individual seals. Figure 15 depicts a monthly view of movements of tracked harbour seals compiling all data collected with GSM trackers. As these periods represent different times in the seals' phenology, use of the area and exchange between north and south are expected to differ. However, caution will be needed in the interpretation as sample sizes are still relatively small, especially when considering possible annual differences or differences between age/ sex groups.

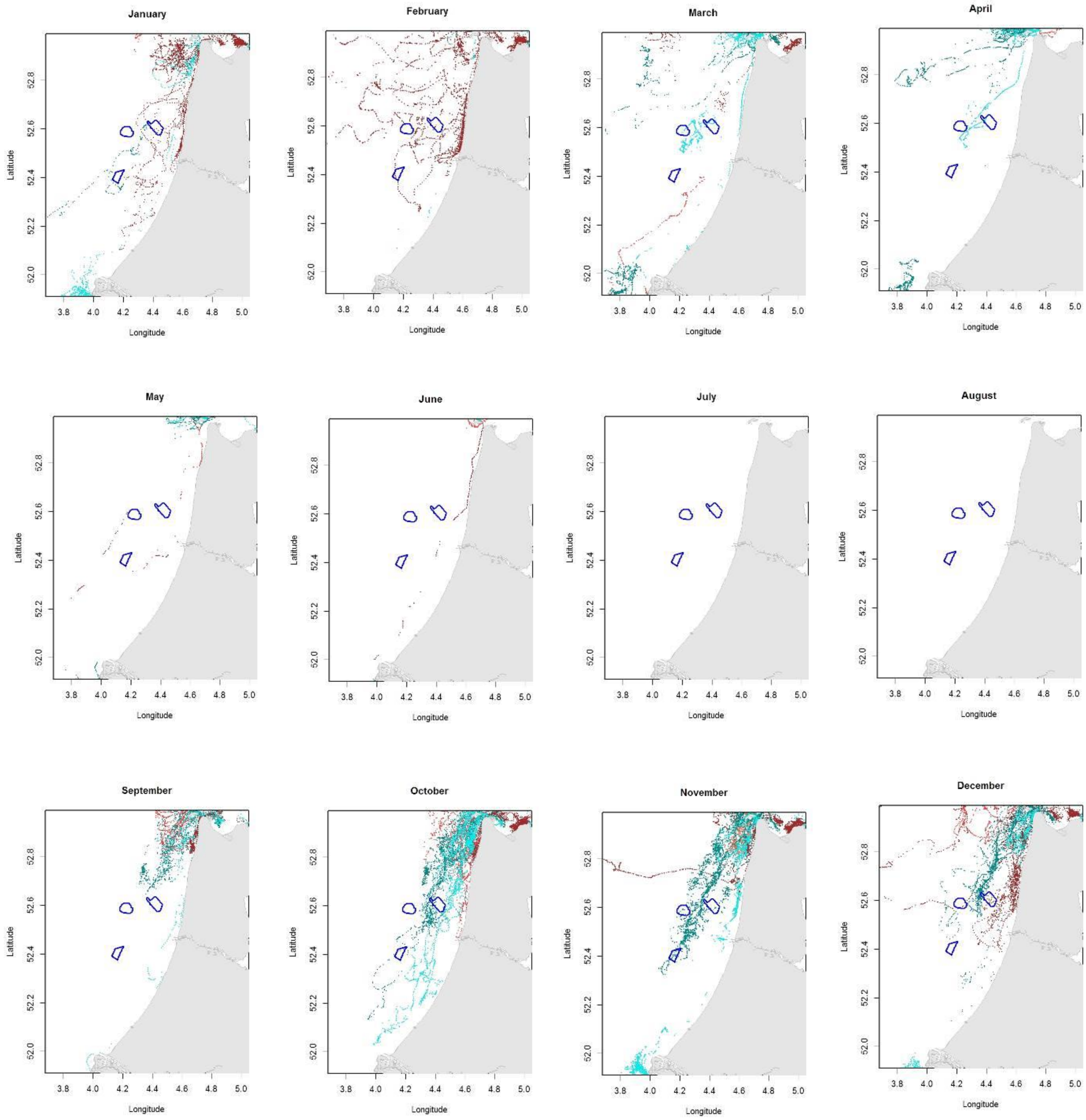


Figure 15. Harbour seal movement in the coastal zone by month: combined T0 (2013), $T_{construction}$ (2014), T1 (2015), T2 (2016-17) and T3 (2017-18). Colours indicate different age/sex, n = number of seals being tracking in the month (blue shapes = Luchterduinen, blue shapes = other windfarms). No locations in the coastal zone were recorded in July and August. *Colours coincide with age/sex groups as in Figure 10*

3.4 Diving behaviour

3.4.1 Depth range of the seals

The harbour seals’ movements discussed above were reflected in their diving behaviour (Figure 16), and like the movements, the diving behaviour varies quite a lot in time and between individuals. Generally, the seals using the study area remained in water depths <30 m. It is difficult however to pinpoint a general preference for specific dive depths when comparing the 5 deployment periods. There might be a dip in usage between 10 and 20 m though it doesn’t seem to be fixed for all animals.

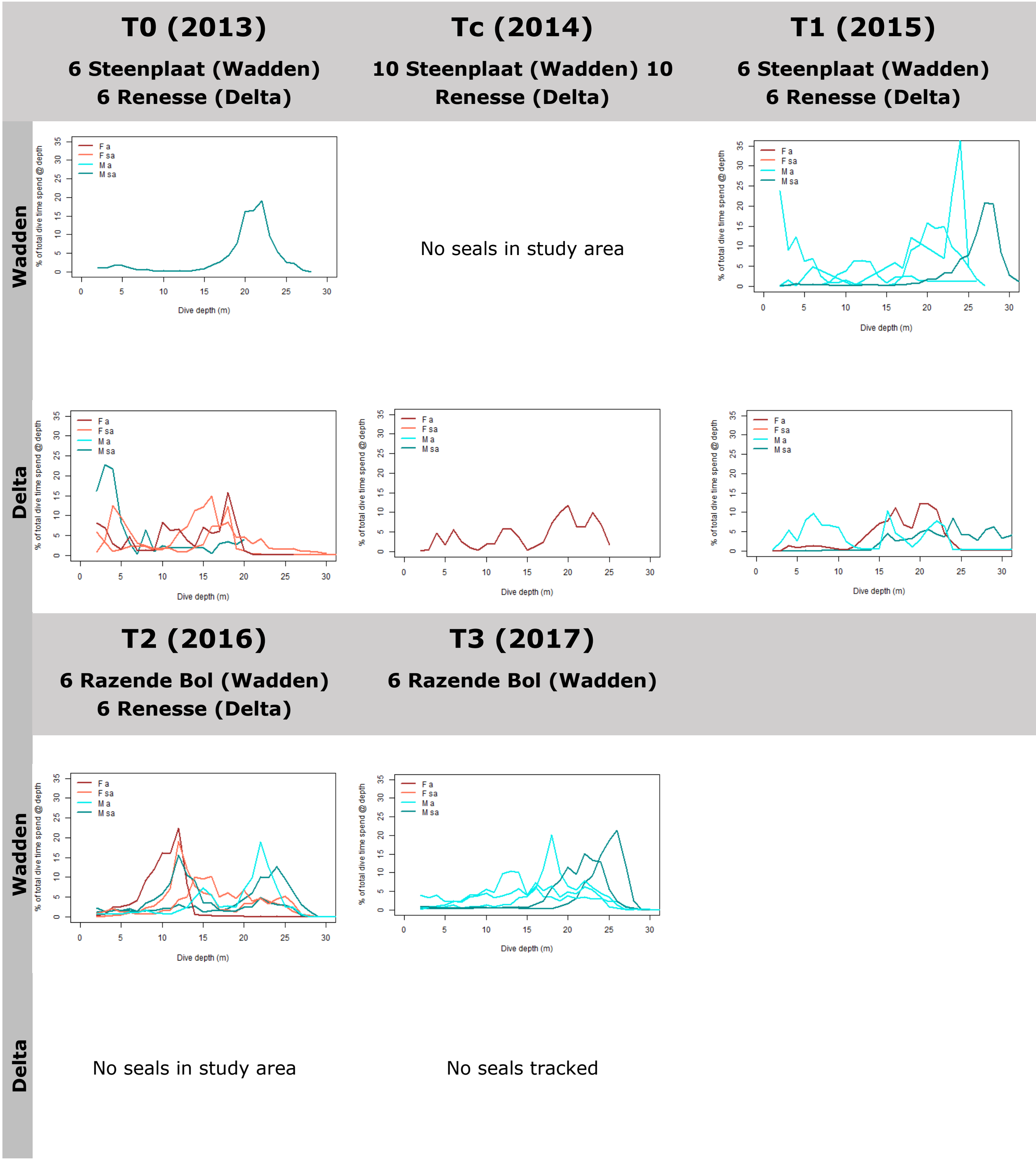


Figure 16. Harbour seal dive depth in the study area by deployment: T0 (2013), $T_{construction}$ (2014), T1 (2015), T2 (2016-17) and T3 (2017-18). Colours indicate different age/sex. Number of seals tracked is indicated above the figures. Note that in some periods no seals used the study area.

4 Discussion

Between 2013 and 2018 harbour seals were tracked from haulouts in the North and South as close to the Luchterduinen windpark as was feasible (Kirkwood et al. 2016, Kirkwood et al. 2015, Kirkwood et al. 2014). The aim was to gain insight into seal movement and behaviour along the Dutch North Sea coastal zone (between the Wadden Sea and the Delta region) and to investigate possible effects of construction and operation of the Luchterduinen windfarm (particularly pile-driving) on their movement and behaviour. Initially tracking was commissioned in spring with the intent to record behaviour when pile-driving commenced. In 2016, after finalising T0-T1 it was decided to continue monitoring harbour seals in the study area, but this time in autumn since tracking data was lacking for this period, and land-based observations suggested that the coastal zone (near Luchterduinen) might be used more during the winter months. The choice of deployments (twice in the north and once in the south was made aiming at maximising information within the (financial) limits of the project.

The autumn deployment indeed yielded valuable additional data from both north and south of the study area, providing information on harbour seal distribution in six of the seven months that were not covered in the previous deployments. Furthermore, since tracking was not limited by the loss of the trackers during the moult, the seals could be tracked longer with a maximum tracking of 187 days, while spring tracking was limited to approximately 120 days.

Despite not having deployed trackers in the Delta in 2017, the movement of two animals from the Razende Bol to the Delta provided some fortuitous information about the use of the Delta area in that year.

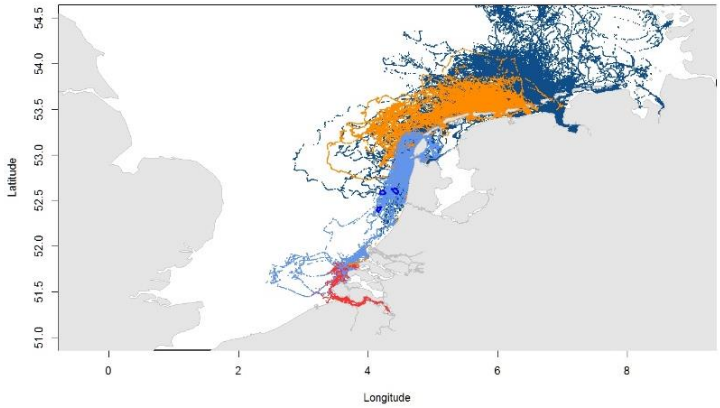
While the primary aim of the autumn deployment was to fill the gaps in harbours seal distribution data in the winter months in the coastal zone, an unavoidable consequence was that there is little overlap between the spring and autumn data, and therefore, it is difficult to directly compare the data collected recently to the data from the previous Luchterduinen projects T0-T1. Therefore, we could not test whether the higher usage of the study area was a year effect (more usage in recent year) or a seasonal effect (more usage in winter). Not only the time of year when seals were tagged changed, also the catching location: from Steenplaat to Razende Bol. Again, the primary aim was to study the seals in the study area (the North Sea coastal zone) and as the Razende Bol is closer to this region, it became the preferred catching site. While all these decisions most likely resulted in better coverage of the coastal zone, it does limit comparison with previous deployments.

There are some notes however, including the spread in sex and age and the comparison with earlier data. In the tracking efforts for Luchterduinen, the females were underrepresented, and even more so in the recent autumn samples. This holds especially for adult females as only one adult female could be caught. Although this could have simply be caused by chance, it might also be an indication less females were present at those sites, maybe still recovering from weight loss from breeding, and as a consequence, spending less time on land compared to males and subadults. Another possibility is that spatial segregation occurs in harbour seals with specific sites sometimes used by one age or sex group more than the other. There is however no clear evidence for the latter. When looking at all the animals captured between 1997 and 2017 (426 individuals), where efforts were made to distribute captures over adult females males and subadults evenly, there seems to be a slight bias towards adult males (*Table 6*).

Table 6. *Overview of age and sex of all harbour seals tracked with satellite telemetry or GPS trackers covering 1997-2017*

	Females			**Males**			**Grand Total**
	Sub adult	**Adult**	**Total**	**Sub adult**	**Adult**	**Total**	
autumn	20	51	**71**	24	60	**84**	**155**
spring	25	53	**78**	24	65	**89**	**167**
Total	**45**	**104**	**149**	**48**	**125**	**173**	**322**

Figure 17 shows for all tracking data in the Netherlands (including that of this project) how animals in the autumn and winter generally tend to travel more to and from of the haul outs where they were captured, whilst in spring many animals travel to different areas, potentially to moult and breed. As a result, there seems to be much more mixing of animals in the spring data.



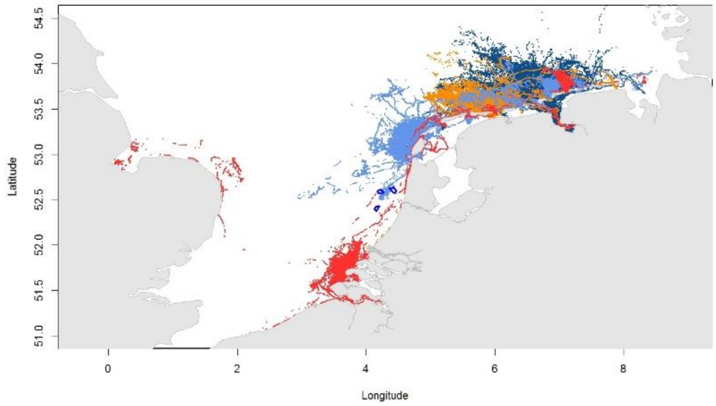


Figure 17. *Compilation of all harbour seal tracking data in the Netherlands (2007-2018). Top represents the seals deployed in autumn (N=120), bottom: in spring (N=123). Colours represent different tagging areas: red = Delta, light blue = Texel, orange central Wadden Sea, dark blue + Ems/Dollart area.*

In this respect, the T2-T3 tracking results, are comparable to the autumn and winter tracking in other areas. However, since the North Sea coastal zone has no suitable haul out sites; seals are required to travel to either the northern or southern end to haul out. Though these data were not available when the habitat model was made (Aarts et al. 2016), the habitat model also predicts that the seals use the coastal zone more intensively in the autumn and winter. Future research should show if more seals move from the Wadden Sea to the Delta in the period after the moult, similar to the two seals we observed in 2017-2018. This could partially explain the growth in numbers observed in the Delta area as pupping is currently too low even to compensate for the number of animals found dead in the area.

In autumn the movement radius of the seals (average and maximum distances; Table 5) is not very different from spring, the seals seem much more focused to assumingly feed in the coastal zone. At the moment however it is not possible to discern with certainty if the animals are foraging or "simply" diving.

The more intensive use of the coastal area is also clear when looking at the distance to the coast: out of the 44 animals tracked in spring only 14 were seen in the North Sea coastal zone, where they generally spent only a short while traversing the area, or where they mostly carried out a single feeding trip. Only 1.5% of the time of all tracked animals was spent in the North Sea coastal zone. This would coincide well with a direct travel, or migration to the breeding areas in summer. The movements of the adult females were studied in more detail (Brasseur 2017), from which it appears that the seals are faithful to their breeding site in the Wadden Sea area, and many may switch to other feeding grounds after breeding. This might also explain the limited total time the seals tracked in spring used the area during compared to the autumn deployments.

Interestingly, only seals tracked from the Delta traversed the area in spring while foraging trips where mostly made by animals from the Wadden Sea. We see in the autumn data that all Delta seals stay around the capture site, while Wadden Sea seals are the ones feeding along the North Sea coastal zone, two of them even switched to the Delta area. Possibly, the Delta area is richer and provides for enough food for the seals while the Wadden Sea is more depleted or anyway more seals feed there. In 2016-2018 11 out of 17 seals (this includes all animals of the Wadden Sea) feed in the coastal zone. 27.3% of all the time the seals were tracked is spent in the study area in the North Sea coastal zone.

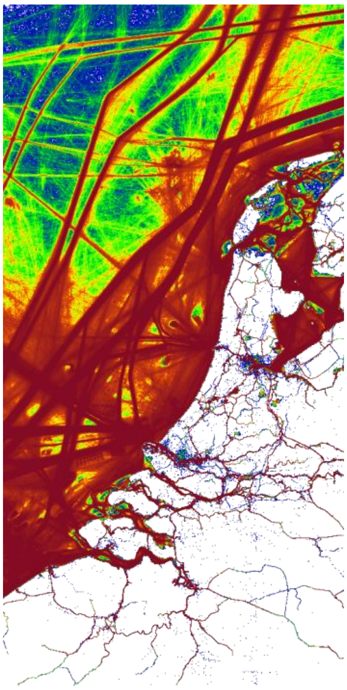


Figure 18. *Image of boat traffic density in the western Dutch coastal zone. The relative scaling is from 1(blue) to 70(light orange)to >300 (purple –dark purple)*

https://www.marinetraffic.com/en/ais/home/centerx:3.6/centery:52.5/zoom:8

Compared to the 2013-2015 data, the seals tracked in 2016-2018 seem to prefer the more inshore area, spending most of their time within 20 km off the coast rather than moving further out to sometimes >50 km's offshore. This comparison is however complicated as the total time spent in the area is also much lower in the spring deployments and as the data is limited, caution is needed for the interpretation of the use of the area. The habitat model (Aarts et al. 2016) shows that around the Wadden Sea seals are more inshore during the summer months, thus contrary to these observations. This could be driven by the distribution of the seals' prey, but human use of the area might also encourage the animals to remain within the boundaries of the very heavy boat traffic along the coast (Figure 18), or the animals might be attracted to other aspects of the area. More detailed study of the data, including possible prey abundance and human activities might provide more information on the matter.

During T2 and T3 relatively more seals were seen in the vicinity of Luchterduinen, however only one actually entered the park. Based on the short visits it is likely that the park was traversed, rather than visited to feed. There are no clear behavioural clues found in the dive data of the animal indicating specific behaviour in the park (Appendix 1.). However, more detailed inspection of all visits of windfarms by seals in other studies might provide additional details on how seals behave in windfarms in general.

5 Conclusions and recommendations

In the 2009 MEP (Wbr permit WV/2009-1229) two main questions were formulated:

1. How do seals use the coastal zone? Aim is to gain insight in harbour and grey seal movement routes along the Dutch North Sea coastal zone (between the Wadden Sea and the Delta region).
2. What is the impact of Luchterduinen on seals? (with a focus on the impact of piling).

The Luchterduinen seal monitoring generated between 2013 and 2015 a large amount of data on the movement of seals tracked north and south of the North Sea coastal zone in spring. In this period, 44 harbour seals were tracked from March onwards. For harbour seals in this period, insight into movement routes along the Dutch North Sea coastal zone (between the Wadden Sea and the Delta region) was gained. However though, in spring few trips were recorded into the North Sea coast zone. By far most trips were associated with a migration towards breeding areas in the Wadden Sea. The majority of movement by harbour seals in the area was within 20 km of the coast.

As the trackers were shed with the moult, most data was collected until June, and in a few cases July. As pile-driving commenced in July, there was no overlap between harbour seal movement and pile-driving. Thus the second question from the MEP was addressed using grey seal data (Aarts *et al*. 2018). Moreover, there was a lack of information on harbour seals movements in the coastal zone during autumn and winter. It was therefore concluded that priority should be given to tracking harbour seals from autumn, from both sides of the coastal zone. The most recent deployments 2016-2018 on harbour seals provided as expected a first insight in the movement and behaviour of the harbour seals in autumn and winter in this area.

By tracking the harbour seals in autumn and winter it was possible to demonstrate that indeed the animals are much more active in the North Sea coastal zone in this period compared to spring and summer. Overall, these seals spent 27.3 % (451.5 of 1653.5 days of tracking) of their time in the focus area of the coastal zone compared to 1.5% in spring and summer. The current data shows that mostly males venture in the coastal zone. However, sample sizes are relatively small and biased towards males. In addition, annual differences and individual behaviour might affect the findings. More over the study sample was biased in the favour of males. Future studies in the area would also profit from tracking in both seasons to overcome issues to discern between annual and seasonal effects.

For harbour seals there was no overlap in this study with the pile-driving activities and only one seal entered the Luchterduinen windfarm. This limited our means to study the effect of the operational windfarm. However, the area in the vicinity of the windfarm was visited more regularly in autumn than in spring. It seems that the unique animal traversed the area without actively feeding. To investigate the impact of operation of the windfarm on movements and behaviour of seals which was another aim of the monitoring required in the permit issued by the Dutch government more studies need to be carried out. As a start, data of different studies could be pooled to compare the behaviour of the animals in and around the windfarms. Moreover, studying harbour seals during construction and operation of a windfarm located closer to a haul out would enhance the chance of actually observing seals' reaction. The planned construction of Borsele not for from the haul outs in the Delta area would be an ideal occasion to do so.

Harbour seals have recently recovered from near extinction due to centuries of overhunting but may well have currently reached the carrying capacity of the area. This is assumed based on the relatively stable numbers in the past years counts in the international Wadden Sea. It is as of now unclear which factor determines the height of the carrying capacity and how human use could play a role in defining the size of the population. Like other North Sea countries, the Dutch government has shown a clear intention to intensify the use of the coastal areas in the near future, for windfarms but also sand mining, traffic and aquaculture. In the study area, human pressure is already extremely high, not the least due to the severe boat traffic in line with the presence of large harbours such as Amsterdam, Rotterdam and Antwerp. Undoubtedly this in conjunction with other human use (i.e. sand mining, tourism, fisheries, military activities), affects or at least influences the way the seals may use the coastal area and possibly play a role in the ultimate survival of animals. Still knowledge lacks to predict if and how this might affect the seal population and whether for example the numbers of seals in the Delta colonies will remain, as they are lacking births and thus dependent on exchange with the Wadden Sea area.

Future studies should concentrate on understanding how seal movement and behaviour is driven by both natural (annual & seasonal) changes in the environment and human activities, to better predict how the populations could be influenced. This also includes studying how and where animals acquire their food. One of the great challenges in this respect is understanding the link between the available fish stocks and the seals. Studies on diet composition are still fragmented.

In addition to annual counts, it would be advisable to monitor on a more continuous basis changes in the use of the North Sea by the harbour seals. An annual tracking scheme should give insight in how the seals cope with the changes in their environment, and record direct effects of specific changes such as the construction of wind farms. Moreover, the data will help to understand which population parameter is likely to change, i.e. reproduction , survival or migration. With the current survey data, as growth hardly occurs, one could assume annual mortality is the equivalent of the annual pup production in the International Wadden Sea i.e. 30%-35% of the population (Galatius *et al.* 2018). However, other mechanisms affecting the surveys could also play a role such as the change in haul out patterns. The possible involvement of the increasing human use of the seals' habitat should be investigated.

6 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. This certificate is valid until 15 December 2021. The organisation has been certified since 27 February 2001. The certification was issued by DNV GL.

7 References

Aarts, G., S. Brasseur, S. Geelhoed, R. Van Bemmelen and M. Leopold. 2013. Grey and harbour seal spatiotemporal distribution along the Dutch West coast. C103/13 IMARES Wageningen UR. 63 pp.

Aarts, G., S. Brasseur and R. Kirkwood. 2018. Behavioural response of grey seals to pile-driving. C006/18 Wageningen Marine Research. 54 pp.

Aarts, G., J. Cremer, R. Kirkwood, J. T. V. D. Wal, J. Matthiopoulos and S. Brasseur. 2016. Spatial distribution and habitat preference of harbour seals (Phoca vitulina) in the Dutch North Sea. Wageningen Marine Research rapport, 1566-7197 ; C118/16. Wageningen Marine Research, Den Helder :.

Anonymous. 2009. Beschikking: Besluit inzake aanvraag Wbr-vergunning offshore windturbinepark 'Q10'. Ministrie van Verkeer en Waterstaat. 147 pp.

Austin, D., W. D. Bowen, J. I. Mcmillan and S. J. Iverson. 2006. Linking predator movement, diving, and habitat to foraging success in a large marine predator. Ecology 87:3095-3108.

Bjørge, A., G. Desportes, G. T. Waring and A. Rosing-Asvid. 2010. Introduction: the harbour seal (*Phoca vitulina*) - a global perspective. NAMMCO Sci. Publ. 8:7-14.

Brasseur, S. 2018. Stranding and Rehabilitation in Numbers: Population development and stranding data on the Dutch coasts 1990-2016; Analysis of new data from a public database. . Wageningen Marine Research report 36 pp.

Brasseur, S., G. Aarts, E. Meesters, T. Van Polanen Petel, E. Dijkman, J. Cremer and P. Reijnders. 2012. Habitat preferences of harbour seals in the Dutch coastal area: analysis and estimate of effects of offshore wind farms. pp.

Brasseur, S., J. Creuwels, B. Van Der Werf and P. Reijnders. 1996. Deprivation indicates necessity for haul-out in harbor seals. Marine Mammal Science 12.

Brasseur, S., R. Kirkwood and G. Aarts. 2016. Monitoring and Evaluation Program (MEP) for seals during Luchterduinen windfarm operation. Tender document 16.43034. pp.

Brasseur, S., P. Reijnders, E. Meesters, G. Aarts and J. Cremer. 2011. Harbour seals, *Phoca vitulina*, in relation to the wind farm site OWEZ, in the Netherlands. IMARES for Noordzeewind. pp.

Brasseur, S., T. Van Polanen-Petel, S. Geelhoed, G. Aarts and H. Meesters. 2010a. Zeezoogdieren in de Eems 2009: overzicht van de verkregen data. IMARES. pp.

Brasseur, S., T. Van Polanen Petel, G. Aarts, E. Meesters, E. Dijkman and P. Reijnders. 2010b. Grey seals (*Halichoerus grypus*) in the Dutch North Sea: population ecology and effects of wind farms. pp.

Brasseur, S. M., T. V. Polanen Petel, M. Scheidat, H. Meesters, J. Verdaat, J. Cremer and E. Dijkman. 2009. Zeezoogdieren in de Eems: evaluatie van de vliegtuigtellingen van zeezoogdieren tussen oktober 2007 en september 2008. Wageningen IMARES. pp.

Brasseur, S. M. J. M. 2017. Seals in motion. Wageningen University, Wageningen.

Brasseur, S. M. J. M., G. M. Aarts, H. W. G. Meesters, T. V. Polanen-Petel, E. M. Dijkman, J. S. M. Cremer and P. J. H. Reijnders. 2010c. Habitat preferences of harbour seals in the Dutch coastal area: analysis and estimate of effects of offshore wind farms. IMARES. pp.

Brasseur, S. M. J. M. and M. Fedak. 2003. Habitat Use of Harbour Seals in Relation to Recreation, Fisheries, and Large Infra-structural Works. *Wadden Sea Ecosystem.*

Brasseur, S. M. J. M. and R. J. Kirkwood. 2015. Seal monitoring and evaluation for the Gemini offshore windpark: Pre-construction, T0 - 2014 report. IMARES. 52 pp.

Brasseur, S. M. J. M. and R. J. Kirkwood. 2016. Seal monitoring and evaluation for the Gemini offshore windpark: T-construction - 2015 report. IMARES, C043/16. 52 pp.

Brasseur, S. M. J. M. and P. J. H. Reijnders. 2001. Zeehonden in de Oosterschelde, fase 2; effecten van extra doorvaart door de Oliegeul. Alterra. pp.

Brasseur, S. M. J. M., P. J. H. Reijnders, J. Cremer, E. Meesters, R. Kirkwood, L. F. Jensen, A. Jeβ, A. Galatius, J. Teilmann and G. Aarts. 2018. Echoes from the past: Regional variations in recovery within a harbour seal population. PLoS ONE 13:e0189674.

Brasseur, S. M. J. M., T. D. Van Polanen Petel, T. Gerrodette, E. H. W. G. Meesters, P. J. H. Reijnders and G. Aarts. 2015. Rapid recovery of Dutch grey seal colonies fueled by immigration. Marine Mammal Science 31:405-426.

Fish, F. E., B. Würsig and J. G. M. Thewissen. 2009. Streamlining A2 - Perrin, William F. Pages 1123-1127 *Encyclopedia of Marine Mammals (Second Edition).* Academic Press, London.

Galatius, A., S. Brasseur, J. Cremer, R. Czeck, L. F. Jensen, J. Armin, P. Körber, R. Pund, U. Siebert, J. Teilmann and S. Klöpper. 2018. Trilateral Seal Expert Group (TSEG). Aerial surveys of Harbour Seals in the Wadden Sea in 2018. Another record year for pups. http://www.waddenseasecretariat.org/sites/default/files/downloads/TMAP_downloads/Seals/2018_harbour_seal_report.pdf . CWSS, Willemshaven.

Galatius, A., S. M. J. M. Brasseur, R. Czeck, J. Armin, P. Körber, P. Ralf, U. Siebert, J. Teilman and S. Klöpper. 2017. Trilateral Seal Expert Group (TSEG). Aerial surveys of Harbour Seals in the Wadden Sea in 2017.Population counts still in stagnation, but more pups than ever. Common Wadden Sea Secretariate (CWSS). .

Härkönen, T., K. C. Harding and S. G. Lunneryd. 1999. Age- and sex-specific behaviour in harbour seals *Phoca vitulina* leads to biased estimates of vital population parameters. Journal of Applied Ecology 36:825-841.

Kirkwood, R. J., G. M. Aarts and S. M. J. M. Brasseur. 2015. Seal monitoring and evaluation for the Luchterduinen offshore wind farm: 2. T-construction - 2014 report. IMARES. 65 pp.

Kirkwood, R. J., G. M. Aarts and S. M. J. M. Brasseur. 2016. Seal monitoring and evaluation for the Luchterduinen offshore wind farm: 3. T1 – 2015 report. WMR. 83 pp.

Kirkwood, R. J., O. G. Bos and S. M. J. M. Brasseur. 2014. Seal monitoring and evaluation for the Luchterduinen offshore wind farm 1. T0 - 2013 report. IMARES. 47 pp.

Lesage, V., M. O. Hammill and K. M. Kovacs. 1999. Functional classification of harbor seal (Phoca vitulina) dives using depth profiles, swimming velocity, and an index of foraging success. Canadian Journal of Zoology-Revue Canadienne De Zoologie 77:74-87.

Madsen, P. T., M. Wahlberg, J. Tougaard, K. Lucke and P. Tyack. 2006. Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs. Marine Ecology Progress Series 309:279-295.

Miller, P. J. O., M. P. Johnson, P. T. Madsen, N. Biassoni, M. Querob and P. L. Tyack. 2009. Using at-sea experiments to study the effects of airguns on the foraging behavior of sperm whales in the Gulf of Mexico. Deep-Sea Research 56:1168-1181.

Prins, T. C., F. Twisk, M. J. Van Den Heuvel-Greve, T. Troost and J. K. L. Van Beek. 2008. Development of a framework for Appropriate Assessments of Dutch offshore windfarms. Deltares. pp.

Reijnders, P. J. H. 1985. On the extinction of the southern Dutch harbor seal population. Biological Conservation 31:75-84.

Reijnders, P. J. H. 1994. Historical population size of the harbor seal, *Phoca vitulina*, in the Delta area, The Netherlands. Hydrobiologia 283:557-560.

Reijnders, P. J. H., S. M. J. M. Brasseur and A. G. Brinkman. 2000. Habitatgebruik en aantalsontwikkelingen van gewone zeehonden in de Oosterschelde en het overige Deltagebied. Alterra, Research Instituut voor de Groene Ruimte, 078. 56 pp.

Thompson, D., P. S. Hammond, K. S. Nicholas and M. A. Fedak. 1991. Movements, diving and foraging behaviour of grey seals (*Halichoerus grypus*). Journal of Zoology 224:223-232.

Justification

Report C074/18
Project Number: 4312100043

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

Approved: Steve Geelhoed
Researcher

Signature:

Date: 18 February 2019

Approved: Tammo Bult
Director

Signature:

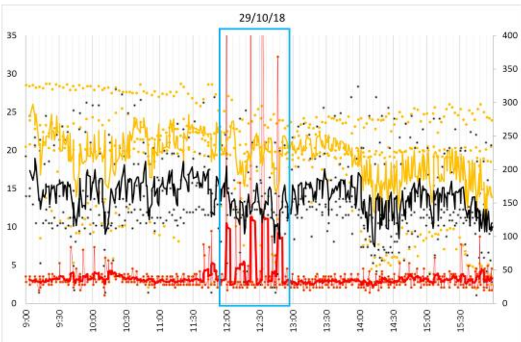
Date: 18 February 2019

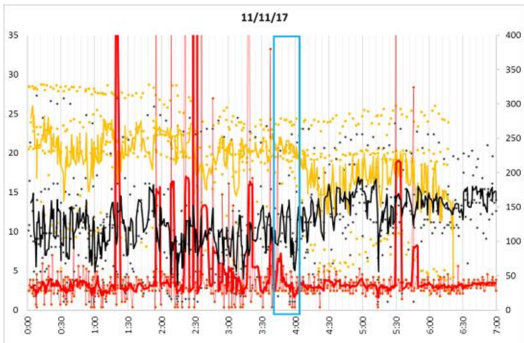
Appendix 1.

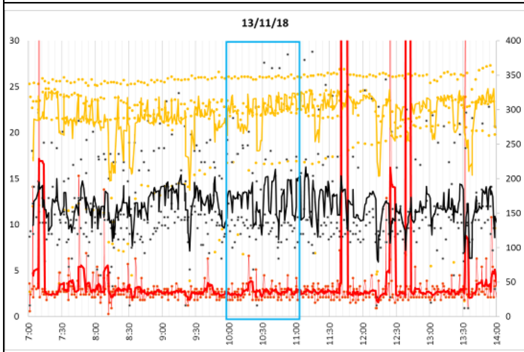
Dive data PV66-04

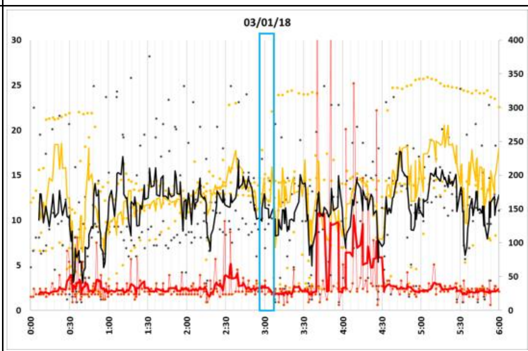
Seal PV66-04 traversed Luchterduinen on several occasions. For each occasion dive depth (m; yellow, left axis) surface duration (seconds; red, right axis), dive duration (seconds; black, right axis). Individual data points are shown indicating the variation; thick lines represent the moving average (5 dives). Blue square indicates the time between the first and last location in the park.

1. 29/10/17: 11:46-13:03 -77 minutes
2. 31/10/17: close - 0 minutes
3. 11/11/17: 03:46-04:00 -14 minutes
4. 13/11/17: 10:13-11:19 -66 minutes
5. 13/11/17: close - 0 minutes
6. 03/01/18: 02:57-03:07 -10 minutes









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Wageningen Marine Research is the Netherlands research institute established to provide the scientific support that is essential for developing policies and innovation in respect of the marine environment, fishery activities, aquaculture and the maritime sector.

Wageningen University & Research:
is specialised in the domain of healthy food and living environment.

The Wageningen Marine Research vision
'To explore the potential of marine nature to improve the quality of life'

The Wageningen Marine Research mission
- To conduct research with the aim of acquiring knowledge and offering advice on the sustainable management and use of marine and coastal areas.
- Wageningen Marine Research is an independent, leading scientific research institute

Wageningen Marine Research is part of the international knowledge organisation Wageningen UR (University & Research centre). Within Wageningen UR, nine specialised research institutes of the Stichting Wageningen Research Foundation have joined forces with Wageningen University to help answer the most important questions in the domain of healthy food and living environment.