

Habitat preferences of harbour seals in the Dutch coastal area: analysis and estimate of effects of offshore wind farms

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Rapport: OWEZ R 252 T1 20120130
C043-10



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Publication Date: 30-01-2012

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Summary

This study describes the abundance and distribution of harbour seals, *Phoca vitulina*, in the Netherlands in relation to environmental factors (both natural and human related), and considers the effects of the Offshore Wind farm Egmond aan Zee (OWEZ).

Harbour seals are common in Dutch waters. They are a relatively well studied species, but information on the seals' habitat use (preference) and on which factors influence their distribution (both natural and anthropogenic) is lacking. In the current study, we utilise data on the movements, and therefore the behaviour, of harbour seals via satellite telemetry. We collected data in the framework of this study, tracking seals to the north and south of the wind farm. Next to this, we have also included data collected in earlier studies, thus the total data set used includes the tracking of 89 individual animals between 1997 and 2008.

This extensive amount of data (almost 29.000 locations after filtering) allowed us to develop a habitat preference model. With regard to the environmental conditions, the study demonstrates that seals in Dutch North Sea waters show a preference for the following:

1. *Areas close to the haul out sites*
2. *Relatively shallow areas*
3. *Sediments with low mud content*

It is estimated that the preference observed is not only governed by the factors themselves but most probably also by the preference of the seals' prey for these environmental factors.

Dive data collected during tracking was used to discriminate between foraging and other behaviour. Locations identified in periods when animals were assumed to be foraging, were used to model preferential foraging habitat.

Both models (habitat preference model and preferential foraging habitat model) were applied to estimate the relative abundance of harbour seals within the NCP (Dutch Continental Shelf). This was done by combining these habitat models and numbers counted during aerial surveys. This resulted in two maps: one describing relative abundance, the second describing preferential foraging grounds.

The original design, was not specifically suited to study the effect of the wind farm as the distance to the closest haul-out was over 40 km's and the probability of tagged seals roaming from the haul out to the wind farm was slim. Furthermore, only one wind farm area was studied. Also, the study did not include the construction period, thus it was not designed with the intention to measure the effects of construction on the seals. Despite this, we have found indications that the seals' habitat use is influenced by this type of human activities. These should be studied in more detail when planning new wind farms in the seals' aquatic habitat:

1. *Seals are less abundant near shipping activity.*
Only large shipping vessel were investigated, however, the seals on average, are less abundant in the direct proximity of the large shipping routes.
2. *Pile driving activities could have influenced the seals distribution,*
Pile driving for OWEZ and then Prinses Amalia Wind Park took up almost a year. The seals tracked during these constructions did not visit the area, thus effects cannot be excluded. This ranges up to at least 40 km's north of the wind farm, and over 1-00 km south of it.
3. *The effect of the wind farms in operation could not clearly be defined in this study,*
Both in the periods before and after construction, tagged seals extend their distribution towards the wind farms.

Acknowledgement

This project was carried out on behalf of The Offshore Wind Farm Egmond aan Zee with a subsidy of the Ministry of Economic Affairs under the CO2 Reduction Scheme of the Netherlands. We would like to thank the Dutch Ministry of Agriculture, Nature and Food Quality for their assistance in the field and all who participated in the project.

1 Assignment

Dutch government policy aims at realising sustainable energy production in the Netherlands. One possibility explored is offshore wind power. As an initiative, the government has given permission for the construction of OWEZ (Offshore Wind farm Egmond aan Zee) as a demonstration project, used for assessing both technological and environmental challenges in relation to construction and operation. From an ecological perspective, a number of studies were procured by The Nuon-Shell consortium “NoordzeeWind” exploiting the wind farm, giving insight into the possible effects of the wind farm. This incorporated among others, studies on marine mammals that could be affected by underwater noise. This study includes harbour seals, representing seals in general. Figure 1 delineates the overview of this particular study. The study on seals is mainly aimed at estimating distribution and abundance in the area, and defining how the wind farm can influence this. The effects of the wind farms on harbour porpoises are presented in a separate report.

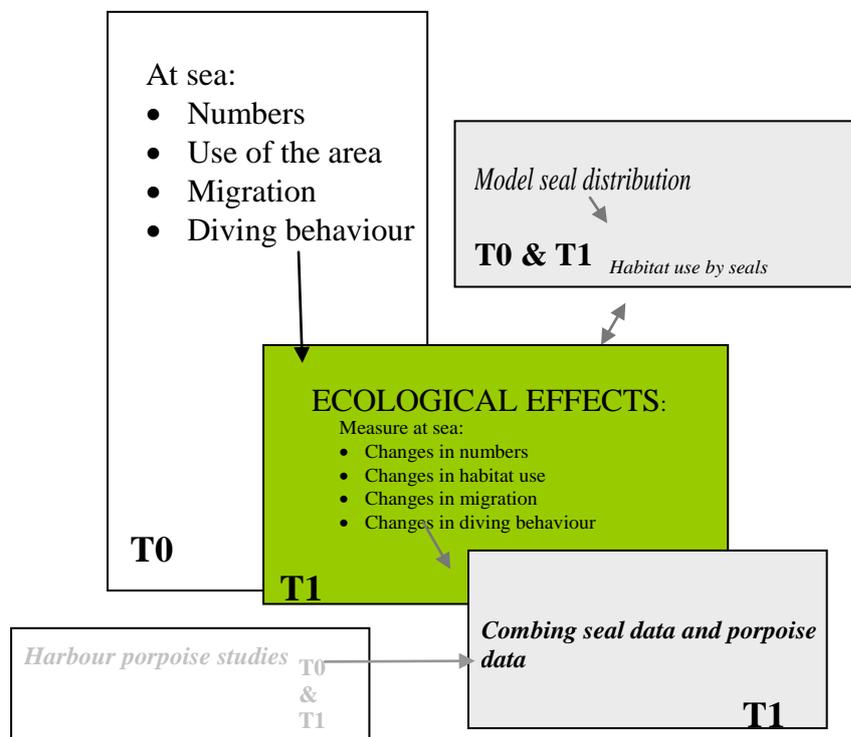


Figure 1 Scheme of the proposed seal study in relation to the building and operation of OWEZ.

First, in order to evaluate environmental impacts on seals from an offshore wind farm it was necessary to carry out a baseline study, which provided additional information needed for a thorough description of the ecological reference situation. The study was carried out in the autumn and winter of 2005/2006. The wind farm was built between April 2006 and December 2006. An effect study (T1) was carried out in 2007.

At interim, reports on both studies were presented: OWEZ_R_252_T0_20061010 and OWEZ_R_252_T1_20080303. The reports gave an overview of the procured results of the work

executed in preparation of this final report evaluating possible effects of the building and presence of the wind farm at its location just east of Egmond aan Zee.

The Offshore Wind farm Egmond aan Zee (OWEZ) is intended to be a demonstration project, and therefore the assessment of possible effects will have a greater scope than only this study. Results should also yield a more general insight on the interaction between the seals and intended wind farms. Therefore, the ultimate goal of the complete project includes, in addition to the impact study, the modelling of the use of the Dutch coast by seals, providing information on the relative importance of specific areas for the species.

In this report, we present the results of the complete study. It includes the data collected in the framework of this study and those used in the interim reports and describes the spatial distribution, activity and migration of the harbour seals that haul out both north of the OWEZ area (Wadden Sea) and south of the area (Delta area). In addition, data collected in the framework of other studies along the Dutch coast is used to define the more general habitat preference of the seals. This is then used to interpret possible effects of OWEZ but also to assess in Dutch waters, which areas may play an important role.

2 Introduction

2.1 Effect of human activity on seals: wind farms

2.1.1 Disturbance of marine mammals

Extensive research has shown that human activity, even the sheer presence, has a potential to negatively affect wildlife. The response of wildlife depends on a number of factors, both stimulus related and inherent to the animal, and the effects vary from short term e.g. fleeing an area, through to long-term e.g. permanent physical damage or even death. In the case of marine mammals, only a few cases of direct deaths have been recorded (Jepson et al., 2003). Many examples can be found on human activities affecting, through disturbance (noise or other), the behaviour of animals. For example, a study on bottlenose dolphins (*Tursiops truncatus*) found that an increase in the number of tourist boats resulted in a decrease in resting behaviour (Constantine et al., 2004). In seals, comparable results were found in experiments manipulating the extent of human disturbance (Reijnders et al., 2000; Brasseur & Reijnders, 2001). Despite these studies, and a large number of others (Hayward et al., 2005; McMahon et al., 2005; Nordstrom, 2002; van Polanen Petel et al., 2006), disturbance by underwater noise or other factors is seldom quantified such that effects on the population can be measured or estimated. Moreover, for obvious reasons, disturbance on land is understood much better than disturbance underwater. When at sea, that is, not hauled out, seals and marine mammals in general have the potential to be affected by underwater noise, as well as underwater structures and the presence of boats.

Human activity in Dutch waters is obvious and evident. Shipping traffic is heavy, in some areas as many as 70,000 shipping hours/year (MARIN Wageningen), with a number of large international ports along the Dutch coast. Commercial fisheries operate in the area seeking a variety of species and recreational boating is popular. The coast itself is popular for recreation and activities such as beach nourishment occur almost constantly. There are also two operational wind farms 8-18 km and 24-30 km off shore. In the near future, human activity in Dutch waters will increase substantially, with the construction and operation of a large number of new wind farms. Additionally, the harbour of Rotterdam will be enlarged and large-scale sand mining in coastal waters is planned. All of these activities have the potential to negatively affect both the quality of the marine ecosystem and the wildlife that inhabits it.

2.1.2 Expected effects

The construction and operation of wind farms at sea has the potential to affect marine life in and around the area. The construction phase often includes profiling, shipping, driving of heavy steel piles into the seabed, trenching and dredging (Nedwell et al., 2004). All of these activities generate noise of varying intensity, duration and frequency, with pile-driving producing powerful shock waves. The operational phase generates mechanical noise transmission from moving parts and blade beat frequencies, next to boating activity related mainly to maintenance. The physical presence of the turbines also has the potential to affect marine life. In general it is agreed that in the construction of a wind farm, pile-driving, is the activity most likely to affect marine mammals (Koschinski et al., 2003; Madsen et al., 2006; Thomsen et al., 2006). Although of relatively short duration, this generates intense impulses that are likely to induce hearing impairment at close range, and to disturb the behaviour of marine mammals at ranges of many kilometres. As harbour seals are relatively sensitive at low frequency, and sounds of low frequency travel relatively well in seawater, it is to be expected that these animals may be aware of such an intense sound at very large distances. In Madsen et al. (2006) the modelled ranges indicate that pile-driving sounds should be audible to marine mammals at very long ranges of more than 100 km.

Operating wind turbines commonly generates low sound levels, unlikely to impair hearing in marine mammals. Despite this, it is still possible that wind turbines affect animals, for example by causing changes in foraging behaviour. More importantly in this particular case, it could influence the movement pattern of the seals and thereby limit the number of animals migrating south towards the heavily depleted harbour seal population in the Dutch Delta area.

Another effect that is often stated is the possible amelioration of feeding possibilities for marine mammals as the piles of the turbines could serve as substrate for growth of animals and plants, thereby attracting fish (it is intended to forbid commercial fisheries in the wind parks). In the Dutch case, however, where seal populations are growing at exponential rates, it is unlikely that food availability is limiting population growth.

2.1.3 Studied effects

Research on the effects of wind farm construction and operation on marine mammals is limited, with much of the literature in the form of reports (Edrén et al., 2004; Tougaard et al., 2006). For example, a study on harbour seals, 10 km from the Nysted wind farm, at Rødsand seal sanctuary using remote video monitoring, showed that there was no change in disturbance rates during the construction period (thought to be due to boat regulations), but that during ramming periods the number of seals on land decreased significantly (between 31 and 61%) (Edrén et al., 2004). Fewer seals were observed in the wind farm and in the immediate surroundings during the construction period which was attributed to the high levels of underwater noise generated by pile driving operations (Edrén et al., 2004). Similarly, a study by Teilmann *et al.* (2006) found indications of disturbance to harbour seals (& grey seals) from pile driving at two Danish wind farms (i.e. reduced numbers observed on land during pile driving). In their study, Teilmann *et al.* (2006) do state that no changes in abundances were observed during construction at (Horns Rev) and that no effects were documented from the operation of the wind farms. In a different study, (but on one of the same wind farms (Horns rev) and on the same species), Tougaard *et al.* (2006) state that they were unable to determine whether there were any effects of the wind farm on harbour seals. This was attributed to the limitations of the methods used. However they did observe and record via satellite telemetry that seals were in the wind farm area during operation and based on this stated that it is unlikely that the operation of the wind farm would have significant effects on the seals. .

It is obvious from the above studies that harbour seals reacted to wind farm related activity, albeit with a short-term response in the case of pile driving. However, it is unclear as to whether these have negative effects and if so to the what level of impact, i.e. to the individual animal or to the population level. Moreover, cumulative effects and long term consequences in terms of population changes and even regional species composition is unknown.

2.2 Harbour seals

2.2.1 Status

Harbour seals (*Phoca vitulina*) are protected under several conventions and treaties. The harbour seal is listed as an Appendix III species under the Bern Convention, and the subpopulations in the Baltic and Wadden Seas are listed as an Appendix II species under the Bonn Convention. The species is also listed as a protected species under Annex II and Annex V of the European Community's Habitats Directive, and several important sites for the harbour seal have been proposed in EC member countries as Special Areas of Conservation.

The harbour seal is a relatively small coastal phocid that is found along practically all temperate and Arctic marine coastlines of the Northern hemisphere. It is common in Dutch waters where there are numerous established breeding sites (Brasseur & Reijnders 1997). Harbour seals are found in all Dutch coastal waters, with the largest numbers found in the Wadden Sea (<http://www.milieuennatuurcompendium.nl/indicatoren/nl1231>). Despite two virus epizootics in which approximately half of the population was lost, annual counts show that the population has been increasing since surveys were initiated in the 1960s (Figure 2). At the last count in 2008, close to six thousand individuals were counted in the Dutch Wadden Sea during the moult. This is over a quarter of the total Wadden Sea population totalling more than 20,000 animals, which ranges from Esbjerg in Denmark to Den Helder in the Netherlands (TSEG, 2008). The true number of harbour seals is actually approximately 45% higher as part of the population remains unseen (underwater or at sea) during surveys. In the southern Dutch Delta area, growth has been much less prosperous with counts of approximately 200 harbour seals during the moult.

Though surveys are carried out during low tide when most seals are hauled out on sandy tidal flats in the Wadden Sea or Delta area, their habitat clearly extends to the Dutch North Sea. This area, predominantly the coastal area, is a known foraging area, but also a migration route between the Wadden Sea and the Delta area, or to other colonies in neighbouring countries, and vice versa (Brasseur et al., in press; Brasseur et al., 2004; Brasseur et al., 2001a; Brasseur et al., 2001b). As numbers in the Delta area are low, lacking sufficient births and bearing a relatively high mortality rate, preservation of the seal colonies largely depends on the influx from elsewhere, notably the Wadden Sea as it is the closest (Reijnders et al 2000).

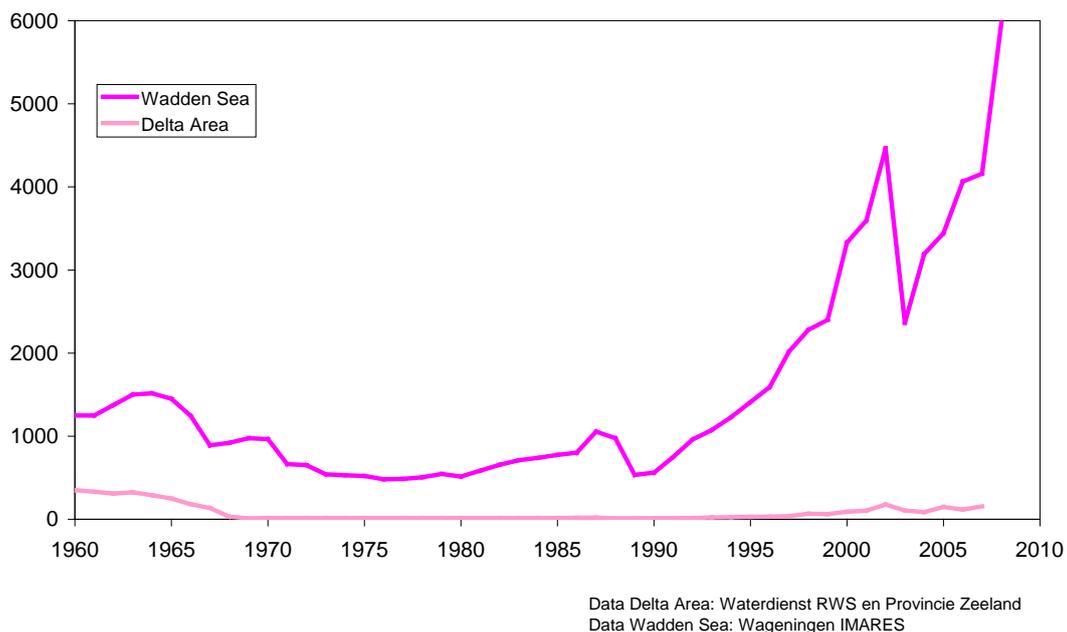


Figure 2. Numbers of seals counted in Dutch Waters

2.2.2 Habitat use

Satellite tracking studies have shown that seals travel 50-100 km offshore, 200 km between haul-out sites, with home ranges greater than 1,500 km² (Lowry et al., 2001; Thompson, 1993). They have also shown that some animals exhibit seasonal migrations of 65-520 km, hereby suggesting that not all harbour seals are sedentary (Lesage et al., 2004). In the Netherlands, research shows that harbour seals tend to travel along the coast (within a few tens of kilometres) but also travel up to a few hundred

kilometres from the coast. They easily migrate up to several hundreds of kilometres between colonies, e.g. research shows that the seals migrate from the southern Delta area north to the Wadden Sea and back (>300 km). Pregnant females, for example, were found to leave the Delta area before parturition to give birth in the Wadden Sea (Brasseur et al., in press; Brasseur et al., 2004; Brasseur et al., 2001a; Brasseur et al., 2001b). However, harbour seals are still commonly referred to as being sedentary, exhibiting breeding philopatry and strong fidelity to summering and wintering haul-out sites (Bjorge et al., 2002b; Lesage et al., 2004). They have been reported to spend the majority of their time within 50 km of their haul-out and are generally considered to feed in shallow, near shore waters (Suryan et al., 1998; Thompson, 1993).

The actual size of the harbour seals' home range and how they use the area is dependent on a number of factors including; abiotic factors such as sediment type, depth and distance to haul-out, and biotic factors such as food resources and potentially the level of human activity and man-made structures in the area (Bjorge, 2001; Bjorge et al., 2002a; Lesage et al., 2004). The influence of these factors on harbour seals, both on an individual level and on a population level, is not only variable but also difficult to determine. Seals live in a 3-dimensional world above and under water. This makes accurately tracking an animal difficult. As a consequence establishing cause and effect relationships is both problematic and challenging, particularly with respect to human activity.

2.3 Aims of the study

In this study the distribution of individually tagged seals in the Netherlands, both in the framework of the wind farm and within earlier studies, is used to define the seals' preference for specific habitat characteristics of both abiotic factors, for example depth, and distance to shore, and human related factors such as shipping. This data is used to estimate seal density in Dutch waters. In addition, the effect of wind farming on the seals' distribution is considered and, despite limited data, the construction phase of the wind farm is additionally investigated.

Given that the satellite tags we used recorded dive information as well as movement, an attempt is made to distinguish between different behaviours such as foraging, migration and resting. In this way we can gain insight into which areas of the North Sea can be defined as preferred habitat for (harbour) seals, and why these areas are important (i.e. feeding, migration, rest). In order to achieve these aims the following aspects of the study have been combined:

1. Define, based on tracking data for each seal, a general habitat preference for environmental factors (physical and human).
2. Use dive data to distinguish between types of behaviour (e.g. foraging, migration, resting)
3. Use aerial survey data (counts) of haul outs, in combination with the results of 1. and 2. to predict seal distribution and abundance.

3 Materials and Methods

3.1 Project plan

Figure 3 gives an overview of the different elements presented in this study. Due to site choice for the wind farm, there were no expectations of direct effects on the known haul-out sites of the seals, thus, research effort was concentrated on understanding the distribution of the seals at sea. Seals are very cryptic animals; only needing to emerge their nostrils to breath and therefore they are seldom observed at sea. The only way to quantify their use of the aquatic environment is to track individual animals with telemetry devices (referred to as tagging). In order to quantify the possible exchange between haul out sites to the north and south of the wind farm, tagging was to be carried out concurrently in both areas (Figure 4).

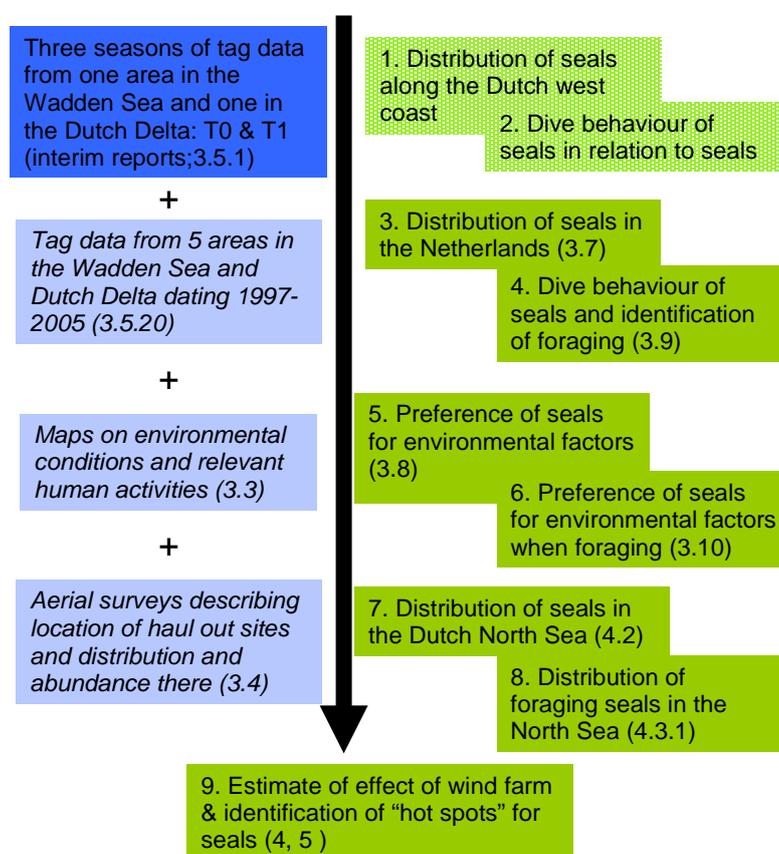


Figure 3. Scheme of the work plan for this study, including data collected (blue) and results (green). Dark blue: data collected in the framework of this study, light green results presented in earlier reports. Numbers between brackets refer to chapters in this report

With this data, that specifically describes the seals movement in the target area, but also with the data of seals tagged throughout the Netherlands between 1997 and 2005, the movements of seals and preference for particular environmental conditions could be described.

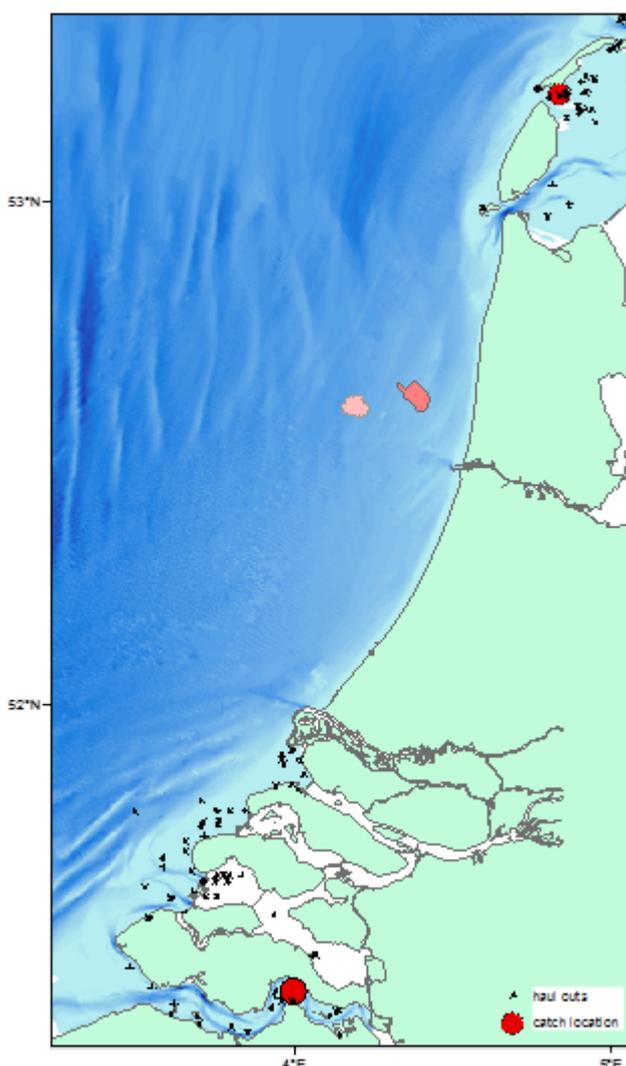
Using this knowledge, the number of seals counted during low tide in the framework of the monitoring of the population (contracted by the ministry of Agriculture, Nature and Food Quality, LNV) in the model. As a result maps are created defining the probability of seal presence.

Parallel to this, dive data procured by the tags was used to analyse behaviour. In most tags, dive data was recorded in 6 hr. histograms, containing either dive depth, dive duration or time spent at certain depths. By comparing these histograms to the detailed time-depth recording collected for one individual an analysis is made to identify those periods in which the seals are assumed to feed. By mapping this, data areas where most probably feeding occurs, are identified.

Finally, the possible effects of the wind farm in operation on these preference is explored and a tentative is made to evaluate, despite the sparse data, the effect of wind farm construction on the seals.

3.2 Study Area

The Dutch North Sea coastal zone is known to play an important role as a foraging area, but also as a migration route between the Wadden Sea and the Delta area, and vice versa. OWEZ (North Sea coast off Egmond aan Zee) is located 8-18 km offshore with an approximately surface area of 40 km².



There are 36 wind turbines with a hub height of 70 meters above median sea level (MSL), each producing 3 MW. Construction began in April 2006 with all the turbines standing by August 2006 (pile driving period). The official opening of the wind farm was in April 2007.

Slightly west of the wind farm studied, Prinses Amalia Wind Park is located 23 kilometres off the coast of IJmuiden. The total area of this wind farm is 14 km². There are 60 2MW turbines with a hub height of 59 meters. Construction of the wind farm began in October 2006 with the laying of the foundations (i.e. pile driving). This activity ceased in April 2007. Further construction continued until April 2008 (non-pile driving activity) with the official opening occurring in June 2008.

Although seals are occasionally seen hauled out on the beach near Egmond, the area is relatively far from their major haul out sites (Figure 4).

Figure 4. Map of the research area, including catch locations North and South in bright red. Also showing the location of OWEZ (dark pink) and Prinses Amalia Wind Park (light pink) haul-out sites of the seals.

3.3 Maps on environmental conditions

A large quantity of spatial data has been collected on environmental conditions, including anthropogenic activities and man-made structures throughout the North Sea. Some spatial data, such as sediment type, is based on a different classification scheme, consequently, data from different countries cannot easily be merged. Therefore we were limited in our efforts to the Dutch Continental Shelf (NCP). Figure 5, Figure 6 and Figure 7 show maps of the different data used. The motivation for using distance to their haul-out site is that seals are central-place foragers, hence usage is expected to be higher in proximity to these sites. Harbour seals spent a large amount of time foraging at or near the sea bottom, feeding on benthic prey species. Since most benthic species have a preference for both sediment type and depth, these variables most likely also influence the distribution of their predator (i.e. harbour seals). Also distance to land could be included as a potential explanatory variable. However, it is highly correlated with depth and although it may act as a proxy for other biological processes (e.g. depth, current speed, etc.), we consider it unlikely to influence seal distribution directly. Therefore, this variable was not included in the analysis. For the habitat analysis, only the telemetry data from within the NCP will (and can) be used. The data used in this study are shown in Table 1.

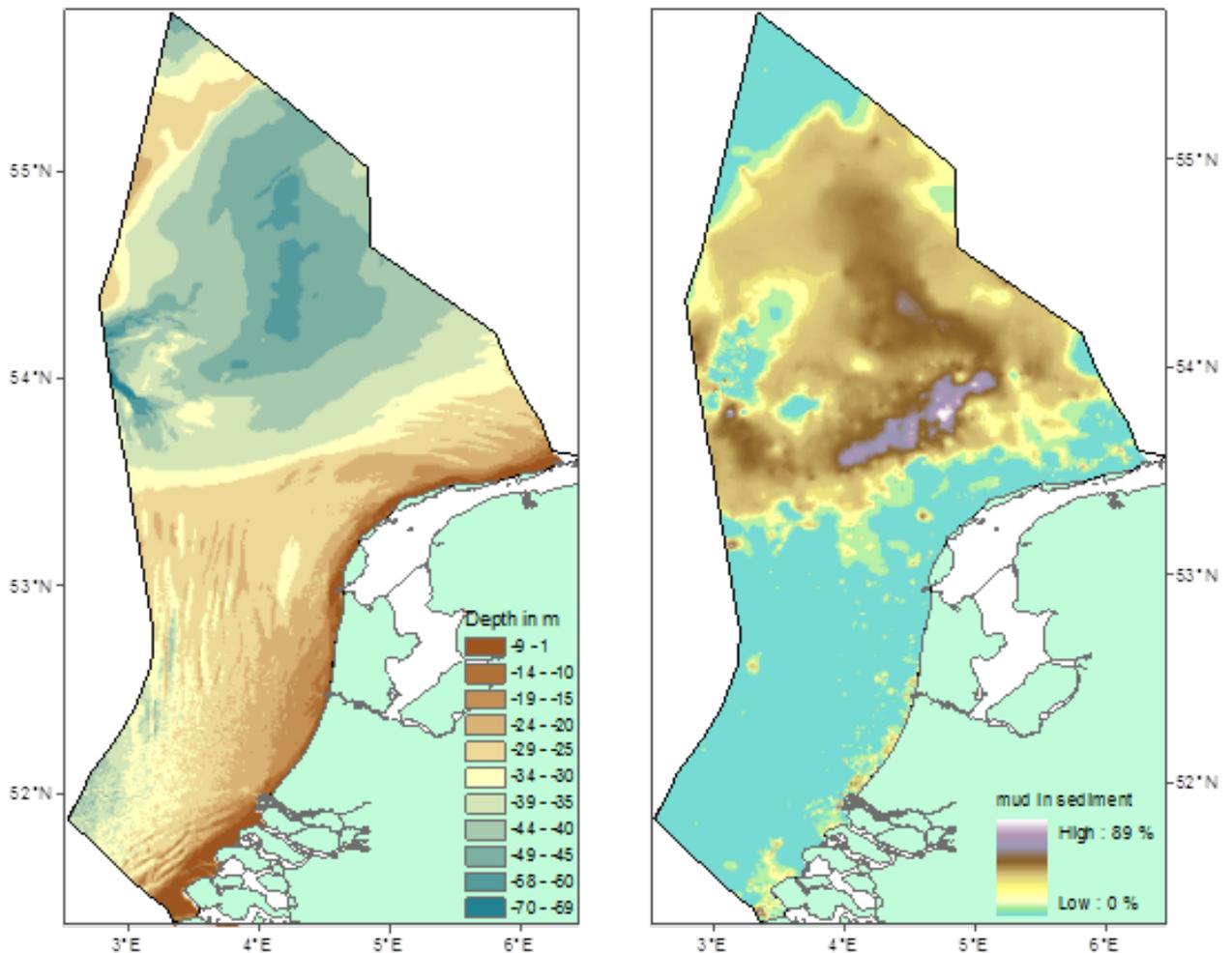


Figure 5. Depth (left) and sediment map (right) used in the modelling and explanation of the seals' distribution.

Table 1. Overview of maps used.

	Type of data	extent	Author/owner/
Depth	Depth grid in cm	NCP	TNO & RIKZ (now Waterdienst)
Sediment type	Gridded percentage mud based on point measurements of particle size	NCP	TNO
Shipping activity	Number of ship hours per 5x5 km grid, based on the Automatic Identification System (AIS) carried by all vessels >300Gt	NCP	MARIN (Wageningen),
Location of OWEZ	1x1 km grid of distance to OWEZ	NCP	
Location of haul-out site	Coordinates based on the Aerial surveys	The Netherlands, UK, Niedersachsen (Germany)	IMARES, Waterdienst (min. of Public Works), National Park Wattenmeer
At-sea distance to all haul out sites	1x1 km grid of shortest at-sea (i.e. not crossing land features) distance to each individual haul-out site	North Sea	IMARES

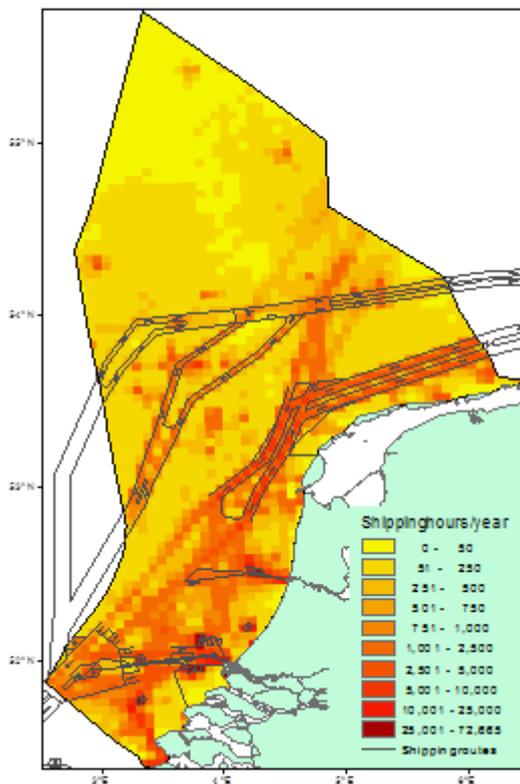


Figure 6. Shipping activity, number of ship hours per 5x5 km grid, based on the Automatic Identification System (AIS) carried by all vessels >300Gt (MARIN (Wageningen)).

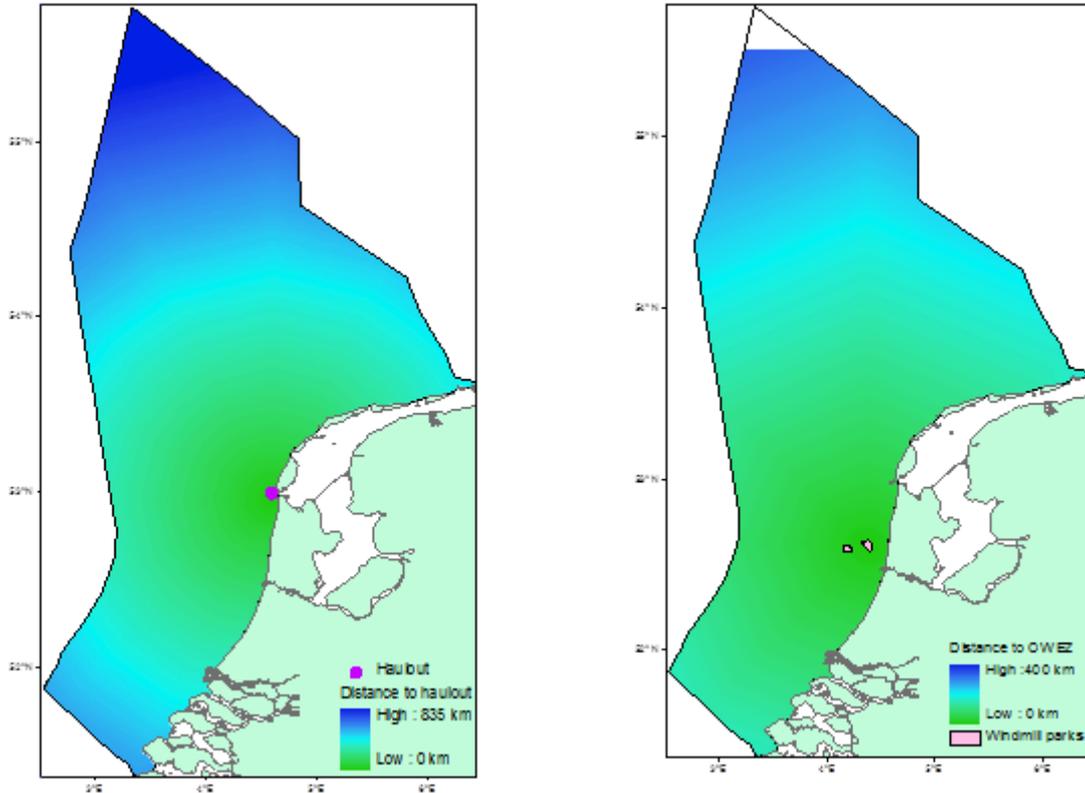


Figure 7. Example of cosdistance (left) and distance to OWEZ (right) used in the modelling and explanation of the seals' distribution.

3.4 Aerial Surveys

Harbour seals are usually counted during aerial surveys at low tide, when the maximum number of haul-out sites are available. Harbour seals are counted in the Wadden Sea during pupping and the moult (June and August respectively). This has been occurring since 1959, and from 1974 onwards by the authors (IMARES), contracted by the Ministry of Agriculture, Nature and Food Quality. Multiple counts (5-8 counts per year) in this period provide the necessary accuracy for long term monitoring and population studies (Meesters et al., 2007; Reijnders, 1978; Reijnders, 1997). The data also provides information on the spatial distribution of the seals and their pups whilst hauled out (http://www.zeezoogdieren.alterra.wur.nl/pla1_zeehondentelling.htm). In the southern Netherlands (Delta area) seals are counted during a monthly count (Biologisch Monitoring Programma Zoute Rijkswateren van het RIKZ, Rijksinstituut voor Kust en Zee, now Waterdienst).

3.5 Tracking of individual seals

3.5.1 Seals studied in the framework of the OWEZ wind farm project

As previously mentioned, former studies have shown that seals easily migrate up to several hundreds of km to other colonies or swim tens of km, apparently to feed (Brasseur et al., in press; Brasseur et al., 2004; Brasseur et al., 2001b). In order to define the use of the area by the seals, 12 seals were tagged with satellite tags before the wind farm was built in the autumn of 2005 Table 2. As there are no haul-out

sites in the immediate vicinity of the study area, six animals were tagged to the north (Steenplaat, near Texel) and six animals were tagged to the south (Hansweert, in the Western Scheldt; Figure 4). During the operational phase, 2 x 6 seals from the same areas were tagged, this time in the spring of 2007 and again in the autumn of 2007. During the last period, due to technical problems only 4 seals were tagged in the south.

Seals were caught on the haul out areas with a large seine net, and tagged directly on location. The tags were glued to the fur on the neck using two component quick setting epoxy (Fedak et al., 1982). Captured seals were weighed and measured before release. Tags are lost as the seals moult in late summer. This project was given approval by the Dutch Animal Ethics Committee of the Royal Netherlands Academy of Sciences, and licences were obtained under the Flora en Faunawet & Natuurbeschermingswet.

Table 2 Overview of the seals tagged in the framework of the OWEZ wind farm project, in Hansweert (western Scheldt) and Steenplaat (north of Texel).

	<i>age group</i> <i>location</i>	<i>Female</i>		<i>Male</i>		<i>Total</i>
		<i>adult</i>	<i>sub-ad</i>	<i>adult</i>	<i>sub-ad</i>	
baseline (autumn 2005)	Hansweert	2	3		1	6
	Steenplaat		1	4	1	6
T1-a (spring 2007)	Hansweert				6	6
	Steenplaat		2	2	2	6
T1-b (autumn 2007)	Hansweert			4		4
	Steenplaat	1		2	3	6
Total		3	6	12	13	34

3.5.2 Seals studied in the framework of other projects in the Netherlands

During the period between 1997 and 2004 a number of studies were conducted to study seals in specific areas (Table 3). This data is used as an addition to the data mentioned above. Seals were caught and tagged as in the current study. The total number of seals tagged amounts to 89 animals.

Table 3. Overview of seals tagged on earlier occasions along the Dutch coast (1997-2004).

location	age group	Female		Male		Total
		adult	sub-ad	adult	sub-ad	
year						
Brielse	1997		2		2	4
	1998		2		2	4
	1999		2		1	3
Lauwerswal	1998	6		2	2	10
	2004	1	1	3		5
O'schelde	1998	1	1	1		3
	1999	1		2		3
	2000	2	2	2	3	9
Texel	2002		2		2	4
	2003		3		4	7
	2004		1	2		3
Total		11	16	12	16	55

3.6 Telemetry Systems

Several types of tags were used in this study. Tags differed either in the way data was summarised and presented or in the transmission of the data or in how location data was obtained (table 4).

Table 4. Overview of tag used in the analysis

	Dive data collected	Location and frequency	Data transmission	Periods in use
SDR 16	6 hrs. histograms	ARGOS (Doppler); average 7 loc/day	ARGOS	1997-2005
Dead reckoning device	5 sec info on e.g. depth, orientation	none	upon retrieving floating tag	2004
SDRL	6 hrs. summary data individual + dive records	ARGOS (Doppler); average 7 loc/day	ARGOS	2005-2007 (T0, T1a)
GPS phone tag	6 hrs. summary data individual + dive records	GPS; up to 1 loc/20 min	GSM (phone)	2007-now (T1b)

3.6.1 Collected dive data

In earlier studies, before 2005, the SDR 16 (wildlife computers) was used. The dive data is collected by sensors to measure depth, temperature, and wet/dry periods (to determine surfacing; (adapted from <http://www.wildlifecomputers.com>). During deployment, depth data is collected, analysed, summarized, and compressed for transmission through the Argos satellites. This tag returns data presented in histograms. These are offered as follows:

- *Dive duration histograms*: Number of dives within the specified dive duration ranges.

- *Maximum dive depth histograms*: Number of dives whose maximum depth is within the specified depth ranges.
- *Time-at-depth histograms*: Time spent within the specified depth ranges.
- *20-minute timelines*: Each 24 hour period is divided into 20-minute increments. Each increment is marked with as to whether it was generally deeper than a configurable depth, or was dry.

In 2004-2005, in another study preceding this project, three different tags were used: two seals were tagged in the area of Lauwerswal using an SDR 16, the other six (3 in the same area and 3 near Texel) were tagged with the SRDLs (discussed below). One of the seals was also equipped with a “dead-reckoning–system” (Mitani et al., 2003; Wilson et al., 2007). This archival tag recorded, at 5 second intervals, depth, pitch (a measure for the seal’s position proportionate to its length axis, nose up or down), and roll (whether the seal was more on its left side or right side). This tag was equipped with a floating device and a self-release mechanism.

Both the SDRL and the GPS phone tag used, were constructed by the Sea Mammal Research Unit (SMRU). Data from a depth sensor (0.5 m resolution) and a submergence sensor were used to determine the activity of the seal: “diving” (deeper than 0 m for at least 4 s), “at surface” (no dives for 180 s) or “hauled out” (continuously dry for at least 600 s, stops when submerged after 40 s). Individual dive records include maximum dive depth, duration and previous surface interval durations. Dives were divided into shallow dives (<10m) and deep dives. From the deep dives, the shape was also recorded: four points per dive using dive characterisation algorithm, i.e. depth and time was recorded on four most significant flexing points in the dive.

3.6.2 Location data and transmission

In 2005 and in spring 2007, satellite relayed data recorders (SRDLs) were used. The location of these tags is determined using the ARGOS-system (<http://www.cls.fr/>). Argos locations are calculated by measuring the Doppler shift on the transmitter signals. Doppler shift is the change in frequency of a wave when a source of transmission and an observer are in motion relative to each other. When the satellite “approaches” a transmitter, the frequency of the transmitted signal measured by the on-board receiver is higher than the actual transmitted frequency, and lower when it moves away.

Table 5. Location quality of the different classes of locations determined by ARGOS (<http://www.cls.fr/>).

Location Quality Class	Type	Estimated error	Number of messages received per satellite pass
3	Argos	error < 250m	4 messages or more
2	Argos	250m < error < 500m	4 messages or more
1	Argos	500m < error < 1500m	4 messages or more
0	Argos	error > 1500m	4 messages or more
A	Argos	No accuracy estimation	3 messages
B	Argos	No accuracy estimation	2 messages
Z	Argos	Invalid location (available only for Service Plus/Auxiliary Location Processing)	

Each time the satellite instrument receives a message from a transmitter, it measures the frequency and time-tags the arrival. The Argos processing centres computes the locus of possible positions for the transmitter, a cone defined by:

- a vertex at the position of the satellite when it received the message,
- the angle at the vertex, a function of the difference between the frequency measured on board the satellite and the transmitter frequency.

The accuracy at which the location is estimated depends on many factors such as the geometry of the satellite relative to transmitter, the number of uplinks received and the stability of the frequency. To

indicate the level of accuracy, Argos supplements each location with a so called Location Quality (LQ). (Table 5). The average daily uplink rate of the ARGOS-tags is seven (ranging from 2 to 12). In order to prolong battery life, the tag switches to an energy saving mode after 5 hrs. when transmissions are continuous due to the seal being hauled out.

During the second series in T1, improved technology had become available and the tags were equipped with Fastloc (GPS) and data was relayed through GSM. These tags were constructed by the Sea Mammal Research Unit (SMRU) and consisted of a data logger, like the SRDLs, however now relayed to a GPS. Detailed dive behaviour, and location information is collected and transmitted via GSM. The Fastloc tag is set to collect and store a location every 20 min. When in contact with a phone base, it sends the data as a text message. Data can be stored up to 3 months before being sent and received.

3.7 Data Processing, locations

3.7.1 Animal tracking filtering procedure for ARGOS data

Most of the tracking devices used in this analysis relies on the Argos satellite system. In contrast to GPS locations, the Argos locations, as mentioned above, cannot estimate the exact location of the animal, i.e. the Argos estimates are known to have considerable errors (Table 5). Consequently, in heterogeneous environments, such as coastal regions, some locations at-sea will appear to be on land. Traditionally, those locations are excluded from further analysis. This implies that locations close to the shore, are more likely to fall on land and will thus be removed, compared to those that are far from shore. This can lead to strong biases in estimates of spatial distribution of the species and their habitat preference, towards offshore. This is more problematic in coastal species such as the harbour seal.

In this project, we developed a method that overcomes this problem by repositioning the Argos telemetry observations. The framework not only includes information on land-features, it also incorporates information on the magnitude of Argos error associated with each telemetry observation, and speed with which animals travel. We applied the algorithm to data from harbour seals (*Phoca vitulina*) in the Dutch Wadden Sea, an area with a complex topography. Below we outline how this filtering algorithm works.

In the past, studies have been conducted to get estimates of the magnitude of the error for each location class (Vincent et al., 2002). Given these error estimates it is now possible to generate any random location in space relative to the inaccurate Argos location, and calculate how likely it is that the animal was actually at that random location. When this random location falls on land, we know with some certainty that this is not correct. Finally, if the distance to the previous and next Argos location implies a travel speed beyond the animals' physiological capabilities, then we know that this is a random location and not the true position. By repeatedly generating random locations, it is possible to find the location that is most likely to be the true animals' position. The final product of this algorithm is a new set of animal positions that are always at-sea and within the individuals' travel speed capabilities. All ARGOS tracks presented in this report were subjected to this treatment.

3.7.2 Analysis of trips

Definition of trips -To predict the spatial distribution of the entire population using the counts at the haul-out sites, it is essential to model the spatial distribution of individual tracked seals conditional on leaving from a known haul-out site. Therefore, each telemetry location should be part of a trip with a known start and end point, a haul-out site. Defining whether a seal actually uses a haul-out is not straightforward, because the locations obtained through the Argos satellite system are not exact and there are a large number of haul-out sites in close proximity to one another. If we obtain an Argos

location near a known haul-out site, the seal may in fact be swimming or lying several kilometres away from that site.

The Wildlife Computer (WC) SRDL, provides for each 20 minute period, information on whether it was mostly (>10 minutes) wet or dry. The SMRU SRDL defines haul-out events, which consist of the start and end time of the period where the transmitter is dry for at least 10 minutes. If a Argos location falls within such a haul-out event, the seal is assumed to be on land and is given a value of 1.

For this study it was assumed that individual harbour seals would only use a limited number of sites to rest, instead of potentially all sites they might approach. High quality Argos locations ($LQ \geq 2$) and information from the wet-dry sensor were used to determine for each individual seal, which particular haul-out sites were used. Subsequently, all other haul-out sites were disregarded for that particular animal. On the other hand, all haul-out periods, even if only bad quality locations were recorded, were allocated to one of the selected haul-out sites if it was within 5 km of such an individuals' specific used haul-out site. For the much more precise GPS locations, every location within 200 m of any known haul-out site is treated as a haul-out event. A trip starts at the mid-point in time between the last location inside, and the first location outside this haul-out zone (5 km and 200 m, respectively). Similarly, a trip ends at the midpoint between the last location outside and the first location inside this haul-out zone. For transitory trips, all locations obtained in the first and second half of the trip belong to the start and end haul-out respectively.

3.8 Spatial Modelling

The spatial habitat analysis consist of two phases. First the seals preference for environmental variables is investigated, which results in a habitat preference model. To do this, an empirical model is fitted to the data. An advantage of this type of model is that little prior knowledge is required. Particularly for marine mammals, information on the environmental processes that influence their spatial distribution is often limited. However, a disadvantage is that the resulting model is based on the correlation between the distribution of a species and several environmental variables. Also correlations between these environmental variables often exists. This is known as multi-collinearity. The presence of multi-collinearity means that it can be difficult to disentangle which of two or more correlated environmental variables explains the distribution of seals best. Next this model and information on the number of seals on the haul out sites can be used to estimate the spatial distribution of the entire population. Details can be found in Aarts et al. (2008).

3.8.1 Defining the habitat preference function

First we consider the estimation of the preference function. If all habitats are equally available, the seal will use habitats proportional to its preference (w) for those habitats. The preference can be any complex function of the environmental variables. For example, one could assume that the log of preference is a linear function of the environmental variables x_1, \dots, x_k

$$w = e^\eta = e^{\beta_0 + \beta_1 x_1 + \dots + \beta_k x_k} \quad [eq. 1.]$$

However, animals often respond in a non-linear way to environmental variables, e.g. they might have a peak preference for a particular type of sediment. This non-linearity can be included in the model by including smooth functions of x

$$\eta = \beta_0 + s(x_1) \dots s(x_k) \quad [eq. 2.]$$

Here we use b-spline smoothers consisting of four basic functions, each being a different cubic polynomial of the original explanatory variable x (function `bs()` within the R library 'splines') (de Boor 1978).

The wildlife telemetry locations come from different individuals, and most likely those individuals will differ in their preference for environmental conditions. Treating all telemetry locations as an independent sample of the entire population would therefore be inappropriate. To capture the hierarchical structure in the data (animal location \rightarrow individual \rightarrow (sub-)population) and to capture the non-independence in the observations within an individual, we used mixed-effect models. The idea is that each parameter in eq. 2 is treated as a random normally distributed variable (Pinheiro et al., 2000)

$$b_{j,m} = \beta_{j,0} + v_j \quad [eq. 3],$$

where m refers to the m^{th} individual and v_j is the random effect which is assumed to have a joint multivariate normal distribution with a mean of zero and a variance-covariance matrix Ψ , representing within-class variability (Pinheiro and Bates., 2000).

The inclusion of individual specific random effects and b-spline smoothers means that it is not only possible to detect whether different individuals are affected by particular covariates but, also, whether the functional form of this relationship differs between individuals.

3.8.2 Accounting for unequal habitat availability

When all habitats are equally available, the observed use $f^u(x)$ of the different types of habitat is equal to preference $w(x)$. In nature, this is never the case. As a consequence it is most likely to observe seals at those environmental conditions that are most abundant. In mathematical notation

$$f^u(x) = w(x)f^a(x) \quad [eq. 4].$$

For example, it is unlikely to observe harbour seals from the Dutch Wadden Sea in deep conditions (e.g. $> 80m$), simply because such depths do not exist in this region. Not only total availability, but also the accessibility (i.e. the proximity to the haul out site), influences the observed use of the different environmental conditions. To correct for the effect of habitat availability, it is necessary to compare the use of environmental conditions with those that are available to the study animal. To do this, two approaches can be used. The first is to select random points in space according to some null-model of usage. This null-model could be defined as a decaying function of distance relative to the central place. In that case preference becomes

$$\begin{aligned} w &= g(dist) \cdot \exp(\beta_0 + s(dist) + s(x_1) \cdots s(x_k)) \\ &= g(dist) \cdot \exp(s(dist)) \cdot \exp(\beta_0 + s(x_1) \cdots s(x_k)) \end{aligned} \quad [eq. 5],$$

where $g(dist)$ represents the null-model of movement. The remaining component; $\exp(s(dist)) \cdot \exp(\beta_0 + s(x_1) \cdots s(x_k))$, will quantify the difference between the observed distribution of the species and the distribution defined by the null-model of usage. If the null-model incorrectly describes how seals use the North Sea as a function of distance, the model will estimate $s(dist)$ such that it best quantifies this discrepancy.

The second approach is to select random points uniformly in space (but within the NCP). Most likely the difference between this null-model of usage (i.e. uniform use) and the actual distribution will be larger. The effect of distance is estimated as follows

$$\exp(s_2(dist)) = g(dist) \exp(s_1(dist)) \text{ [eq. 6]},$$

where s_1 and s_2 represent the smooth of distance estimated according to the first method (null-model of usage) and second method (uniform in space), respectively. Now as long as the smooth functions are allowed to be flexible enough and g is defined as a function of distance, both methods will produce the same results. Because the method which selects the random points according to some null-model of usage (which incorporates accessibility), will only concentrate on those regions that can be used, it tends to be more computationally efficient. But in lack of a proper null model, we chose for the second (less) efficient method, defined in eq. 6.

The habitat availability is approximated by placing random points uniformly in space and to extract for each point the environmental conditions. One of those environmental conditions is the at-sea distance to the trip haul-out (3.3) which may differ for each seal location. Therefore each seal location is matched with a set (20 in our case) of such random points. Below is outlined how both the seal locations and the 'control' locations are used to estimate the parameters of the preference function.

3.8.3 Likelihood function and parameter estimation

The previous section specifies the preference function. To estimate the parameters (β) of this function, the model needs to be linked to the data (the seal location and control points reflecting habitat availability), using a so-called likelihood function.

The likelihood of observing one animal observation at a point in space (Lele & Keim 2006) is

$$L(Y | \theta, X) = \prod_{i=1}^N \frac{w(X | \theta)}{\int_{\text{all } X} w(X | \theta) f^a(X)} = \prod_{i=1}^N \frac{w(X | \theta)}{M^{-1} \sum w(X^* | \theta)} \text{ [eq. 7]},$$

where N is the total number of animal observations, $f^a(X)$ is the relative availability of the environmental conditions in the study area, X^* are the values of the environmental variable of a point randomly selected from space, and M is the total number of random points. In this study, for each telemetry locations, 20 random locations were selected, such that $M > 100.000$ random points. Similarly, the log-likelihood can be defined as

$$\ell(Y | \theta, X) = \sum_{i=1}^N (\log(w(X | \theta)) - N \log(M^{-1} \sum w(X^* | \theta))) \text{ [eq. 8]}.$$

Minimizing the negative of the log-likelihood function, leads to the maximum likelihood estimates of the parameters. To assess the robustness of the estimation procedure, different starting values for the parameters were chosen. Parameter estimation is done using Random Effects module of the Automatic Differentiation Model Builder (ADMB-RE, Skaug 2002; Skaug & Fournier 2003; Otter 2004).

3.8.4 Spatial prediction of usage and preference

The estimated function $w(x)$, quantifies the strength of the seals preference for the different environmental conditions. Although we may not observe seals in all areas throughout their North Sea range, there are maps of the environmental variables for the entire NCP (figure 5). Using those maps and the preference function it is possible to estimate the spatial usage for this entire region. In addition, haul-out counts are available (Figure 1). For each haul-out site the expected distribution of one individual can be predicted and multiplied by the total seal count at that site. This can be repeated for all sites to estimate the total at-sea distribution.

Because seals are central-place foragers, the at-sea distribution is largely influenced by the distance to the haul-out site, which is included as a variable in the model. Using the preference function, and excluding this variable (i.e. assuming that it is 1 for all points in space) when making spatial predictions, results in the expected distribution of seals when they would move independent from their haul-out site.

3.9 Behavioural data

During the same time span as the spatial data, the tags used also give insight into the diving behaviour of individual animals. Potentially, the location of feeding, and resting and the migration routes along which the seals commute between these areas can thus be identified. Here the methods to discern these different behavioural stages are described.

Because of the high temporal resolution, and the extra information on the position of the seal, the data procured from the single ‘dead-reckoning’ device was used as a reference for the dive data that had been summarised in the other tags. This data was even more valuable, as the tag had been deployed simultaneously with a SDR 16 (Wildlife Computers), providing a possibility for direct comparison.

The SDR 16 was used in most of the studies, before 2006 (see also 3.6). This tag records diving behaviour as number of dives within bins of fixed duration, depth, and time spent at depth. This allows the construction of histograms showing the distribution of the number of dives within six hour periods (see Figure 8).

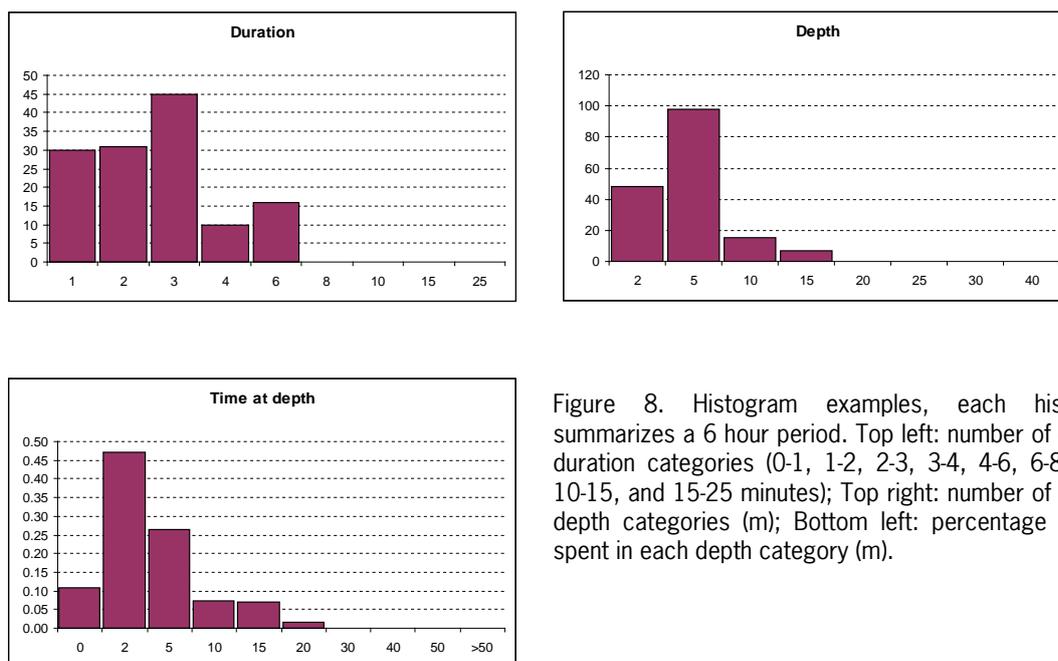


Figure 8. Histogram examples, each histogram summarizes a 6 hour period. Top left: number of dives in duration categories (0-1, 1-2, 2-3, 3-4, 4-6, 6-8, 8-10, 10-15, and 15-25 minutes); Top right: number of dives in depth categories (m); Bottom left: percentage of time spent in each depth category (m).

Due to the fact that Dutch coastal waters, where the seals are active, are generally shallow, depth is not considered to be limiting or a good denominator for behavioural categories. In other studies (Baechler et al., 2002), U-shaped dives are often judged typical of foraging dives. Here the seal would make a relatively quick descent, spend some time at the bottom, then ascend relatively quickly. In so-called V-shaped dives all dive time is spent descending and ascending. In shallow waters seals would reach the bottom and follow this, creating a u-shaped dive. Because of the shallow depth, U-shaped dives can be made anywhere and at any time, and most probably cannot be used to define behavioural categories. Therefore, we chose to focus on the duration of the dives and the number of pitch changes (only determined in the dead-reckoning tag) within each dive. Consequently, only histograms on dive duration were used.

Data consists of two groups. The first group contains the data from the SDR 16 sensor of 48 animals which consists of only six-hour histograms. The second group of data consists of detailed data from the dead reckoning sensor that, apart from depth information, also measures pitch and roll of the animal at 5 second intervals.

3.9.1 Relating histogram information to diving behaviour, general approach

The detailed data collected from the one single animal was used to determine a model by which all dive duration histograms can be related to predominantly foraging or other behaviour. This data had been collected in the framework of another study, it was not an option to enlarge the sample. For this study we hypothesised that this presumed feeding behaviour was so general that the behaviour of one seal would be clear enough, within the very extensive sampling of >1.000.000 records, to extract a general rule applicable to the other seals. We assumed that observed sudden change in pitch (angle) were indicative of the animal foraging. In Figure 9 we show this behaviour.

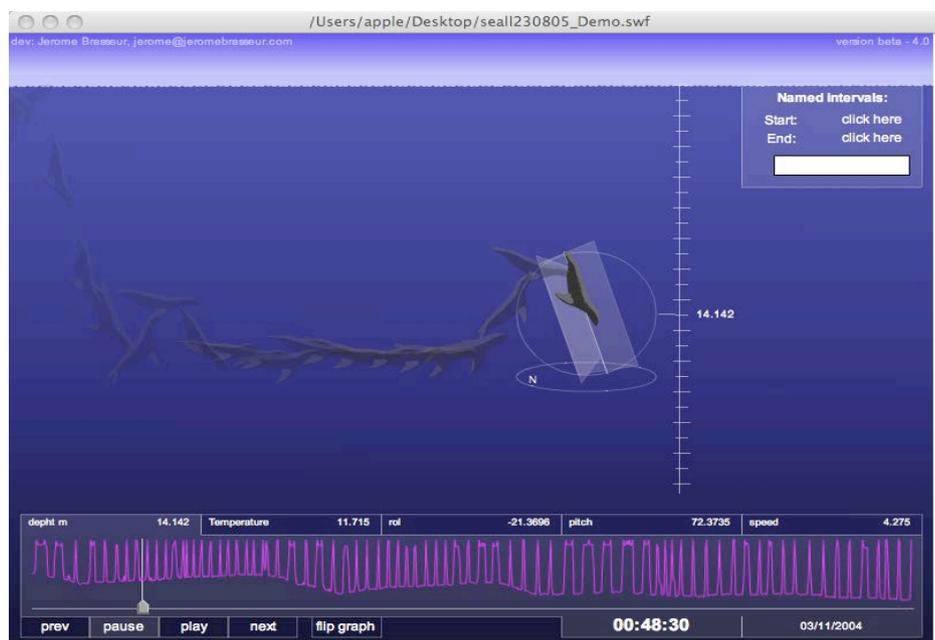


Figure 9. Screen capture of application built to visualize diving behaviour showing a suspected foraging event in the white circle (© Jerome Brasseur).

The animal is swimming along the bottom and shows no pitch changes. Suddenly (within the white circle) the animal shows a pitch change. It is assumed that when an animal is searching for prey, it will, now and then, make sudden movements to decrease its speed and try to catch prey. Because it has a forward speed, this causes the animal to lift its lower body. The sensor on the dead-reckoning device, along with depth, measures pitch changes. Changes in the roll of the animal, also measured, are less

clear and not considered to be related to feeding behaviour. For each dive recorded, these sudden pitch changes are registered (but only for this one animal).

From the detailed dive information (dead reckoning) histograms were constructed, similar to the ones that are generated by the SDR 16 sensors. These histograms thus contain dive information, summed over six hour periods. Moreover, because of the additional data on the angle of the animal the data also includes the number of sudden pitches changes in each dive within 6 hour periods. Periods containing many dives in which these events occurred were assumed to be periods with mainly foraging behaviour. By searching for similar patterns in the histograms of the other animals (for which no pitch information was available), it is possible to infer, for these animals, possible foraging periods. As we have an estimate of the position of all of the animals, it is possible to link periods in which the animals are foraging to geographic positions (locations).

3.9.2 Data processing of dead-reckoning device

The data from the detailed tag recorder measured depth, pitch and roll every 5 seconds. This information was translated into dive behaviour through a number of data processing steps:

1. Depth gauge correction;
 2. Distinguishing dives;
 3. Detecting pitch changes and deriving other dive information;
 4. Aggregating data into 6 hour histograms.
1. *Depth gauge correction.* The depth gauge changed slightly during deployment (appendices Fig. 1). By calculating the minimum depth every 20 minutes and assuming that the animal would at least surface once every 20 minutes we calculated a zero depth value for every 20 minutes. This was then used to correct all depth readings.
 2. *Distinguishing dives.* A dive started if the depth reading at time zero (t_0) was less or equal to 0.5m and the following 2 depth recordings (at $t_1=t_0+5$ and $t_2=t_1+5$ seconds) were deeper than 0.5 m and depth at t_2 (Dt_2) was deeper than depth at t_1 . Furthermore, depth at t_1 , should be at least 10% deeper than Dt_0 or Dt_1 should be more than 5 times as deep as depth at t_0 . The moment depth decreased again and the animal crossed the 0.5 m depth the dive was considered complete. The deepest point was the maximum depth reached during the dive. At depth measurements within 10% of this value and below 1m and not increasing or decreasing by more than 5%, the animal was considered to be following the bottom.
 3. *Calculating pitch changes and other dive information.* For each point in time the angle of the seal was recorded on a relative scale from -100 to 100 being equal to respectively 90 degrees up and 90 degrees down. This was transformed to degrees by multiplying by 0.9. By adding 90 degrees to each angle, values were translated to mainly positive values with 0 being vertically up and 180 being vertically down. For each point, the degree of change compared to the previous point was calculated. Degree pitch changes were then assigned to categories of change: (minimum, -90), (-90, 0), (0, 20), (20, 40), (40, 90), (90, maximum). For each dive we then calculated duration, mean depth, maximum depth, and number of pitch changes of more than 20 degrees while being at the bottom.
 4. *Aggregating data into 6-hour periods to generate histograms.* All dive data from the TDR tag were aggregated into six-hour periods to make histograms of dive duration comparable to histogram data that were available from the Wildlife tags (for example of the histograms in Figure 8).

3.9.3 Data analysis

The analysis is based on multivariate methods. These methods are characterised by the fact that they base their comparisons on two (or more) samples on the extent to which these samples share particular characteristics. The samples in this case are the histograms and the characteristics of multiple variables, the different duration categories of the histograms, in total 9. In theory each category represents an axis and each histogram can be plotted as a point on a graph. However, the dive duration histograms have 9 categories, thus, we would need 9 dimensions to be able to plot every histogram at its unique position. The amount of sharing of these characteristics can fortunately also be expressed as a similarity coefficient, calculated between every pair of histograms. Often this is expressed as the amount of non-sharing or dissimilarity, because this can mathematically be better expressed as a distance. After calculating the dissimilarity between all histograms, specialised software routines attempt to plot these differences between histograms. This is represented in less dimensions than the total number of categories (mostly 2 or 3) as an ordination plot of points in two or three dimensions or as a tree-like structure (called a clustering dendrogram). This is done in such a way that the distances between pairs of histograms best reflect the relative dissimilarity between histograms. The histograms can be compared using Euclidean distance, which is one type of dissimilarity coefficient that is most well suited to compare this type of data. The smaller the distance in multivariate space between two histograms, the more similar they are and the smaller the Euclidean distance. The duration categories are used as variables that form the axes in multi-dimensional Euclidean space. A (triangular) similarity matrix of all pair-wise histogram comparisons was calculated based on Euclidean distance.

This matrix was then analysed by agglomerative hierarchical cluster analysis using average linkage (Legendre & Legendre 1998). This is a technique that links samples into hierarchical groups based on some definition of any distance measure between each clusters and displays the results in a dendrogram, a tree that connects samples (here histograms) in such a way that groups are formed of similar looking histograms samples. The number of groups required, is a partly subjective choice. We used two methods. The first method uses permutation to detect groups that show no significant difference with other groups, the so-called 'similarity profiles' technique (Clarke et al., 2008); further called the SimProf routine. Commonly, a dendrogram is sliced at one level and all remaining branches are the resulting clusters. The SimProf routine allows splitting the dendrogram at different levels depending on within cluster homogeneity of similarity values. The SIMPROF SimProf routine used within the cluster analysis allows for the detection of clusters that have no significant heterogeneity. We used a value of 1% because this gives fewer clusters and is thus more conservative than the generally accepted 5%. Furthermore, as testing involves multiple tests it is probably better to increase the p-value at which to classify a group as a significant cluster. Additionally, we found that more groups gave no better discrimination in foraging or no-foraging.

The other technique uses a combination of slicing the dendrogram at one distance level and non-Metric Multi Dimensional Scaling (MDS). MDS attempts to place samples on a "map", usually in 2 dimensions, in such a way that the rank order of the distances between samples on the map exactly agrees with the rank order of the matching (dis)similarities. Thus (relative) distance between samples on the map is very close to distances between samples in the dissimilarity matrix. By comparing the groups that originated from different levels of slicing on MDS plots the best number of groups was chosen. To choose between the two methods, the groups that resulted from the SimProf routine were also visualised using an MDS plot.

Resulting clusters were then analysed in order to determine which clusters were most likely involved in foraging; generally those containing many dives with pitch changes. Each histogram in a cluster has a number of (average) characteristics based on the detailed dive information of all the dives in that histogram (covering a 6 hour period). These are for example the mean of the total number of pitch changes per dive, the total number of pitch changes in a 6 hour period, the mean of the average depth

of each dive, the mean of the duration of all the dives in a histogram and so on. The method that gave the best representation of the underlying grouping and of which the clusters were clearly separated in terms of 'foraging'-activity was then chosen for further analysis. The next step in the analysis consisted of determining how the final clustering could best be achieved based only on dive duration categories. This was necessary because for all SDR 16 tags this is the only information available. Classification tree analysis (Breiman et al. 1984) was used to determine classification rules based only on dive duration that could be used on the SDR 16 histograms, assigning each to a cluster that contained either foraging or non-foraging histograms. Thereafter, the corresponding location was determined by combining the time that the histogram information was collected with the most likely position of the animal in that period of six hours (see next chapter). This allowed us to identify areas where the animals were presumed to be foraging.

Data processing and analyses were performed using R (R Development Core Team, 2008). Cluster analyses using similarity profiles (Clarke et al., 2008) were carried out using PRIMER software package (Plymouth Routines In Multivariate Ecological Research, version 6, Clarke and Gorley, 2006).

3.10 Spatial prediction of foraging areas

Section 3.8 describes how the animal observations can be used to estimate the seals preference for environmental conditions and to use the resulting model to predict the distribution of the entire population. All locations at-sea are used in the analysis. At some of the Argos or GPS locations, the seal may be foraging, while at others it may be resting or travelling. Each type of behaviour may be related differently to the environmental variables. To quantify the seals habitat preference while foraging, we repeated the analysis described in section 3.8, but only using the foraging locations as defined in chapter 3.9.3.

4 Results

4.1 Tracking results; filtered data

Prior to modelling, the collected data was filtered and plotted. Results, amounting to almost 29.000 locations, are discussed below. The study was not designed to track seals during the construction of the wind farm. When designing the study it was not known that Prinses Amalia Wind Park would be built during the study period. Data collected in that period was thus collected unintentionally. As a consequence seals were only tracked briefly in this period, just as OWEZ commenced construction and at the end of the construction of Prinses Amalia Wind Park. The two wind farms together ensured that there was pile driving activity between April 2006 and May 2007.

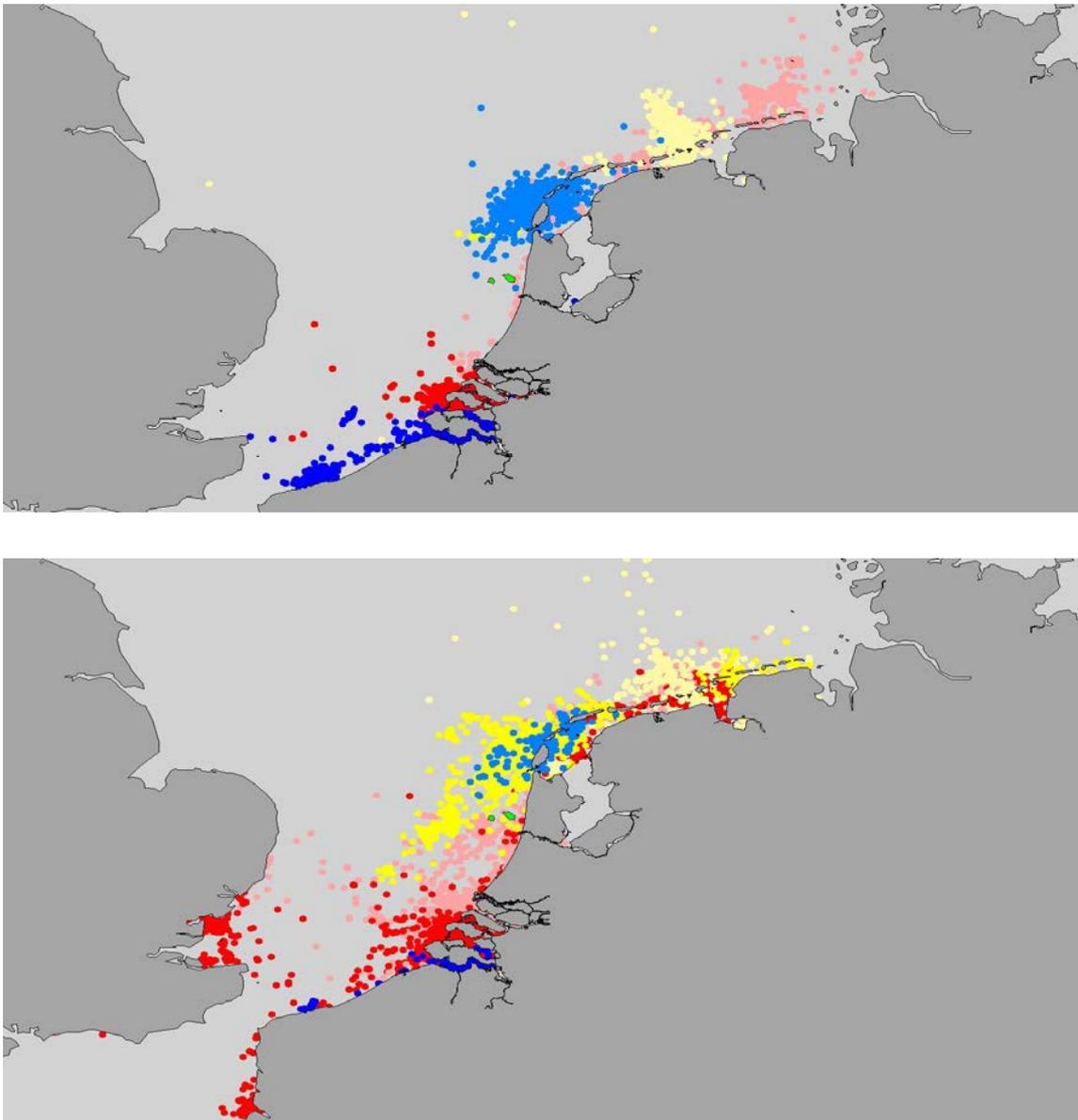


Figure 10 Overview of tracking results of seals tagged before the wind farm was built (1997-2007). Above: winter observations (N=38 seals), below: summer observations (N=51 seals). The wind farm areas are plotted in green. Seal locations are coloured in accordance with tagging site: Red: Eastern Scheldt; Pink: Maasvlakte; Bright Yellow: Texel; Light yellow: Rottum; Blue data collected in the frame of the T₀ OWEZ (see also Figure 11): Northern Texel; Dark blue: Western Scheldt

After filtering the ARGOS data, the OWEZ tag data was separated into five periods for visual inspection (Table 6). Figure 10: 1997 – April 2006: All data collected before the wind farm was built. The T0 (OWEZ) data is also presented separately in Figure 11: October 2005- April 2006. Figure 12: April 2006 - May 2007: construction period of subsequently OWEZ and Prinses Amalia Wind Park; only summer data of 2006 and 2007 was collected. Figure 13: May 2007 - June 2008: both wind farms operational summer and winter.

These figures show that the distribution of seals has changed over time. Prior to any wind farm activity seals were tracked in the wind farm area in the years 1997-2007 (Figures 10 and 11). During the short time that there was overlap between construction and tagging of seals (Figure 12) observations are limited to summer data. The seals' distribution is more restricted than during t_0 , (prior to construction). Phrased differently, the area around the wind farm largely void of seals is greater than before. Once construction was completed and the wind farms were operational, seals commenced using the area, but appeared to swim westwards around the wind farm and not along the coast between the wind farm and the mainland (Figure 13). Lack of data prevented statistical analysis comparing the different periods.

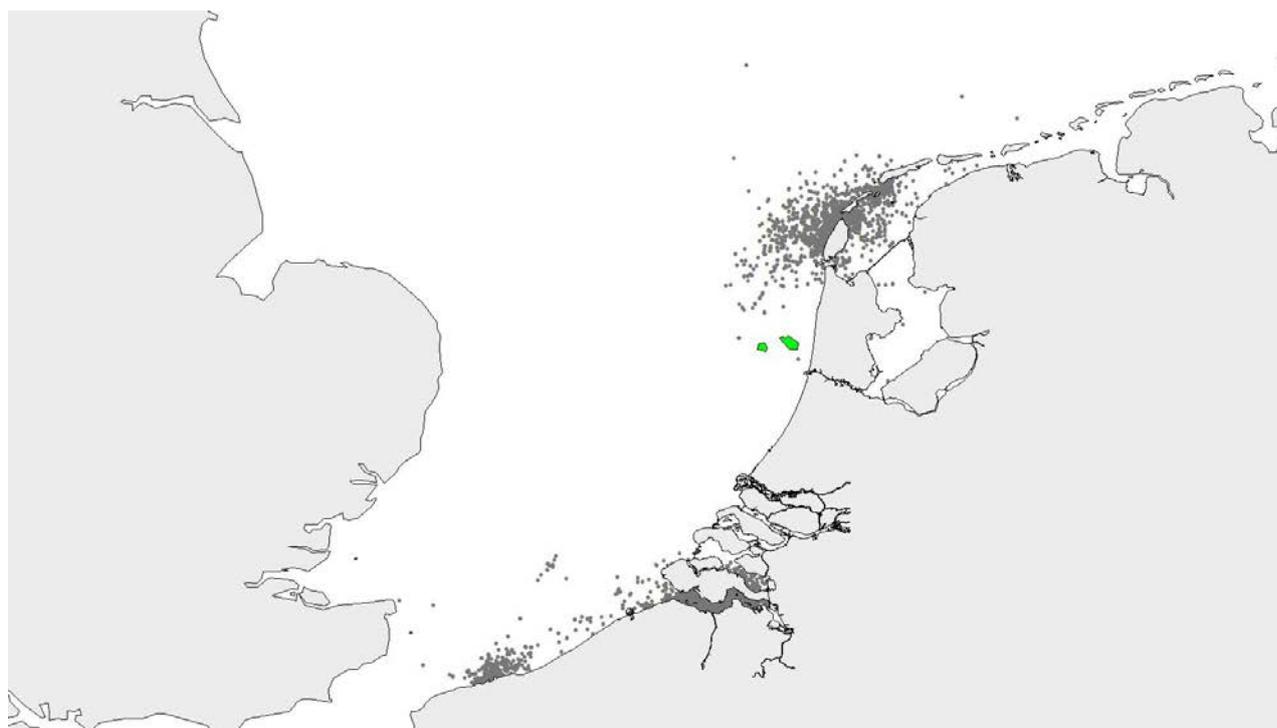


Figure 11 Overview of tracking results of seals tagged specifically for the T0 of OWEZ before the wind farm was built (2005-2006).

Using the distance to the wind farms, the data is also represented graphically in Figure 14. Though the results for the construction are only indicative as they were collected unintentionally and sample size is small, we explored differences between the seals in the different periods. During the T0-pre OWEZ, the density of seals in the area directly south of the wind farm is generally less than directly north of it, in some occasions the seals come relatively close to the wind farm (up to 5km's ; but the average/day was less as the seal was moving from north to south). During T0_OWEZ, the seals remain at

approximately 20 km away from the wind farm; only one seal came up to 9 km. The same pattern is observable in the T₁. This coincides with the location of the seal haul-out sites.

Table 6. For each period the minimum distance to OWEZ for the individual seals and Overview of the data presented in Figure 11 - Figure 13. In the table T_c was split in two groups 2006 and 2007. The data is so sparse that this was not possible in the figures.

Categories: <i>minimum distance away from OWEZ (km)</i>	<i>Number of seals in different periods with minimum distance</i>					
	T_pre OWEZ	T_0 OWEZ	T_c 2006	T_c 2007	T_1	T_1b
Description & period	Summer & Winter 1997 - 2005	Seals tagged for baseline autumn 2005 - spring 2006	Same seals as T ₀ OWEZ that were still working when construction started spring 2006	Same seals as T ₁ , PAWP was still being built spring 2007	Seal tagged after constr. of OWEZ, spring 2007- Summer 2007	Seal tagged after constr. of OWEZ, autumn 2007-spring 2008
0 - 10	4	1				1
10 - 20	6			1	2	1
20 - 30	6					
30 - 40	1					1
40 - 50	3	3			1	1
50 - 60	1	3	2	1		
60 - 70	2		1	2	1	4
70 - 80	2			1	1	
80 - 90	2			1		1
90 - 100	4		1		2	
100 - 110	4	1			3	
110 - 120	1	1				
120 - 130	1	3	2	4		
130 - 140	2			2		1
140 - 150	3					
150 - 160	1				1	
160 - 170	4					
170 -	1				1	
Total number of seals tagged	48	12	6	12	12	10
average no. of days/seal (range)	81.33 (3-201)	113.25 (49-172)	24.33 (8-51)	17.92 (8-29)	54.00 (21-79)	87.80 (2-219)

During T_c, the pile driving period, the seals were almost totally absent from the area, up to 40 kilometres away to the North. Only one seal was observed closer by, during one study day the seal was at an average distance of 28km (range:18-44 km) away from the building site. Towards the south the average distances are larger: seals generally stayed away at distances beyond 125km south of the wind farm. After construction was finalised, most seals that were tagged during construction of Prinses Amalia Wind Park (T₁), remain at some distance (>40 km), though a few come closer, up to 25 km, in average for a day, but a few are tracked closer to the wind farm, up to 11km's. During the second season, T_{1b}, the seals approach the wind farm more often (2 seal days: see Figure 14), one animal is tracked 6 km away from the farm. Most often the seals remain at 10 km's away.

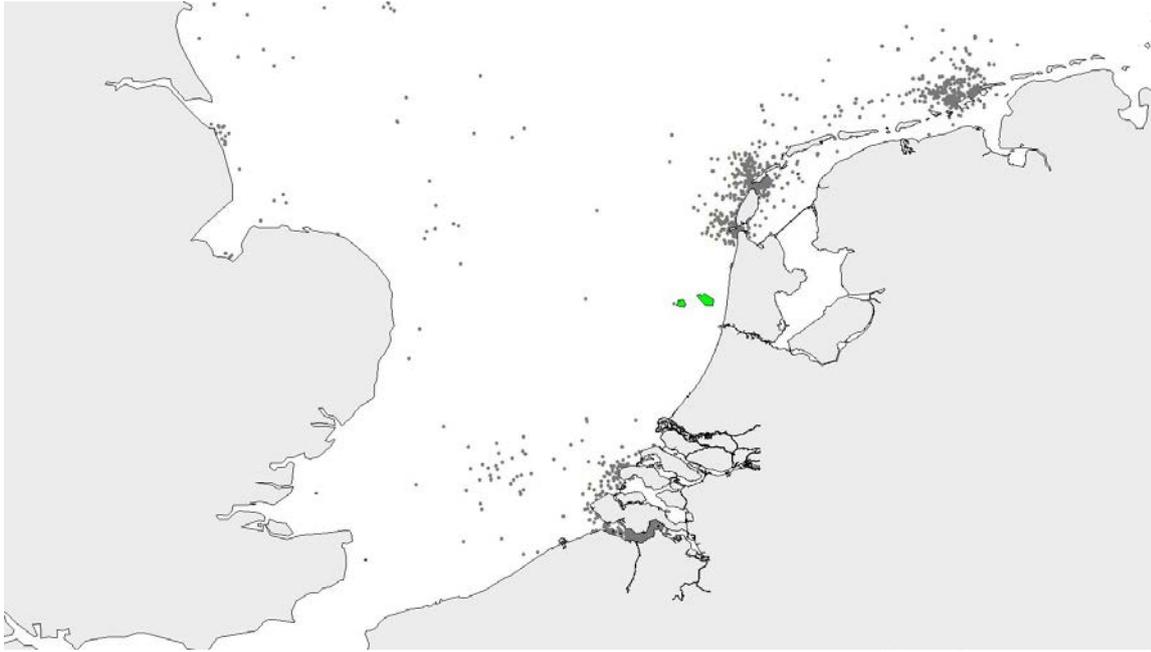


Figure 12 Overview of tracking results of seals tagged during the construction phase April 2006 - May 2007.

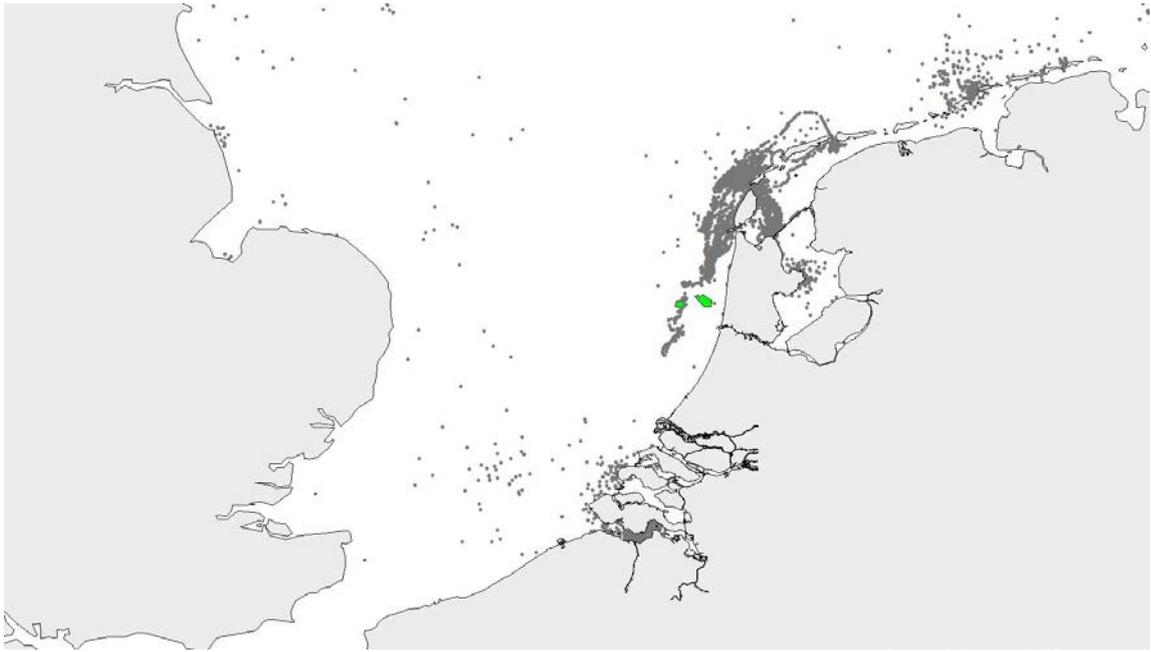


Figure 13. Overview of tracking results of seals tagged after the wind farm was built (May-2007).

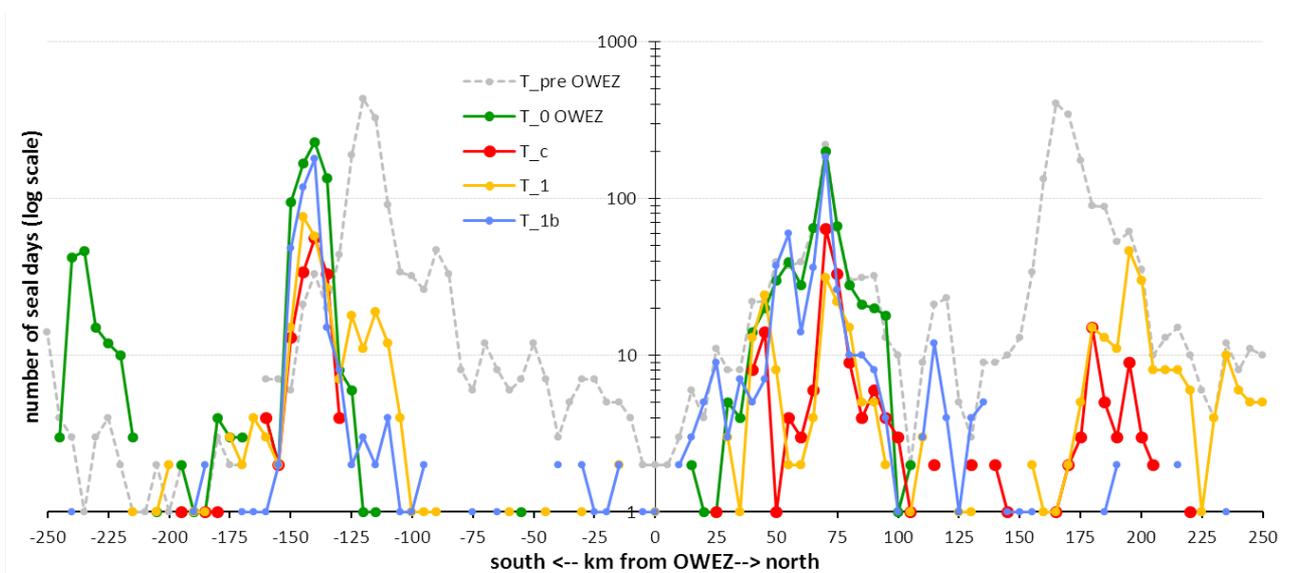


Figure 14. Distribution of tagged seals in respect to the wind farm OWEZ. For each day, for the individual seal, an average location was determined and attributed to the corresponding 5 km distance class. Data is presented separated in different periods. Coloured lines are data of tagged seals in the OWEZ monitoring, grey lines represent older data. See also Table 6.

4.2 Habitat modelling

The analysis of the habitat preference for depth, percentage mud in the sediment, distance to haul-out site, and shipping activity is shown in Figure 15. It is not possible to plot the effect of a single explanatory variable relative to the spatial distribution of the seals. This is because the absolute effect of one variable directly depends, non-linearly, on the other explanatory variables (see eq. 1). Therefore, preference is represented as relative preference.

The graphs show that the harbour seals in this study have a slight preference for shallow waters (a), whilst a high mud fraction is avoided. As could be expected, the seals tend to prefer areas close to haul out sites (c) and slightly dislike shipping lanes, though large individual variations in their preference is observed.

Initially we also included the distance to the pile driving activity as a covariate in the model. This would show whether seals were influenced by these activities. However, there was too little telemetry data in the proximity of the wind farm. Because of this the resulting preference curve was therefore predominantly influenced by data points from seals north of the Wadden Islands. These seals were so far away that they probably experienced no or little effect of pile driving activity (Figure 15). Therefore, the results were considered not to be robust and hence are excluded in the final calculations.

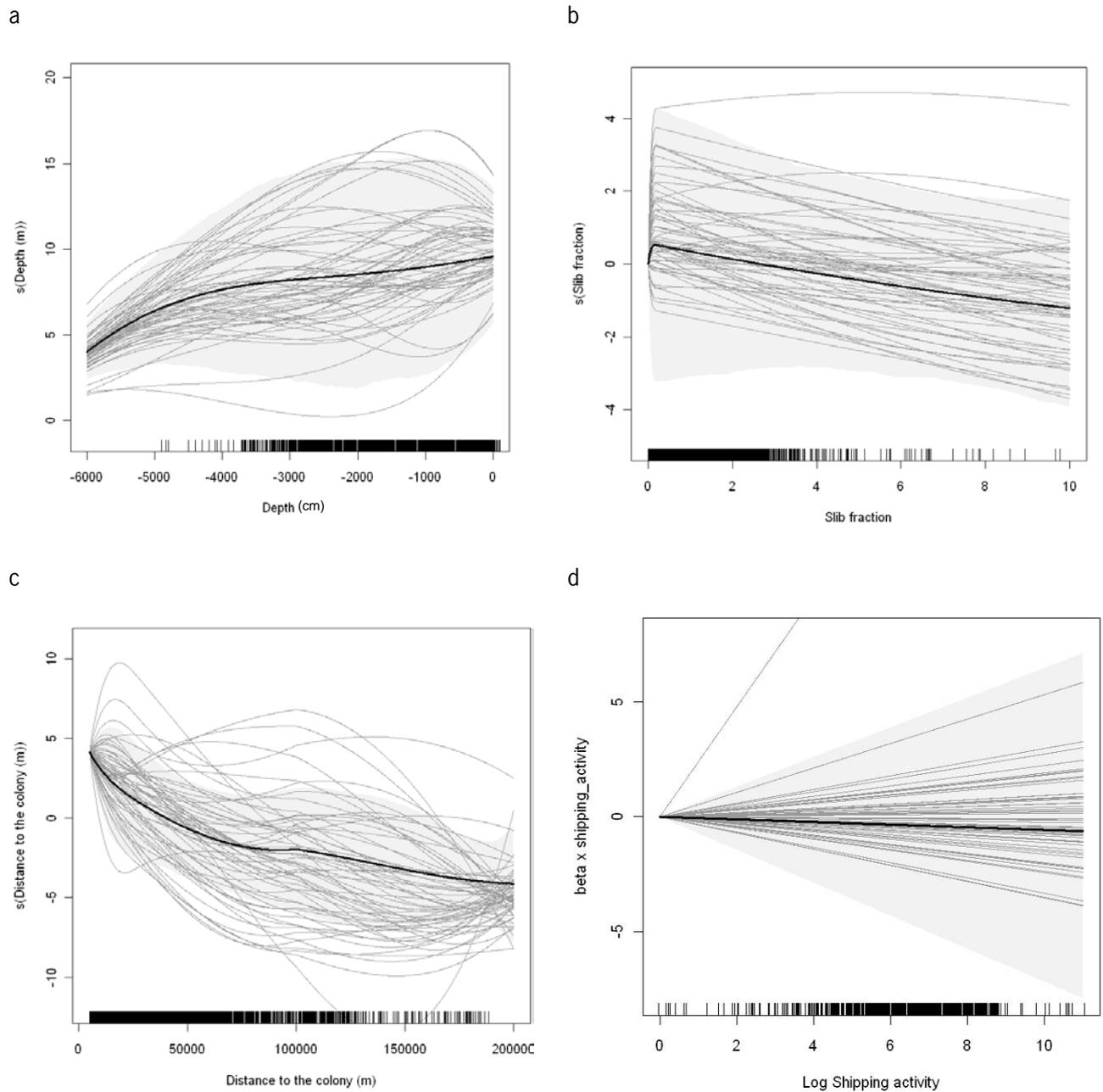


Figure 15. The relative preference for (a) depth, (b) %mud in the sediment, (c) distance to the haul out, (d) shipping activity. The y-axis, represents preference. High and low values, represent preference and avoidance, respectively (see also eq. 1). The black line describes the mean population response; the grey lines the individual estimates for each seal and the grey area represent the 95% confidence limits for the entire population. On the x-axis a measure for the intensity of the environmental conditions at which seals were observed (i.e. the telemetry data) is given.

The functions obtained in the analysis for the seals' preference for the different environmental conditions described in Figure 15 are now used to predict the distribution of the Dutch seal population at sea (Figure 16). This is done by predicting distribution for every seal counted during an aerial survey of the haul out areas, and then summing the results. Consequently, the seal density is modelled. As predicted, the at-sea distribution is largely influenced by the distance to haul-out site, which is included as a variable in the model. The amount of data to model the effect of the wind farm is too limited, and therefore not included.

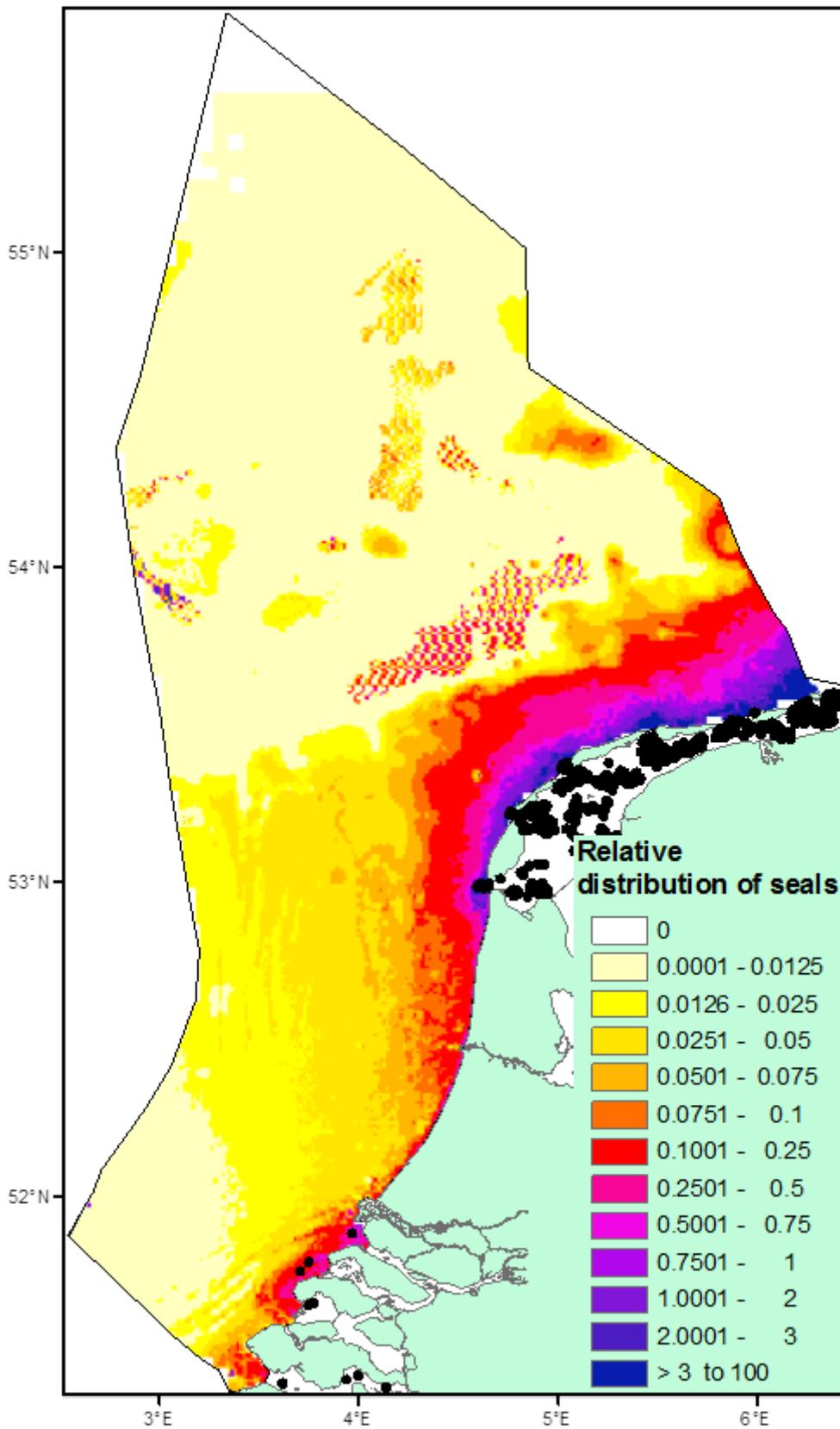


Figure 16. Modelled predicted seal density using the preferences for the various environmental characteristics described in Figure 15 , combined with the numbers of seals counted during the aerial surveys. (black dots indicate Haul out sites.

4.3 Behavioural data

As defined above, in 3.9 data from the animal with the dead-reckoning device (detailed TDR sensor) was analysed to differentiate between all dives made with respect to the activities of the seals. This resulted in a set of 14,174 dives. An example of the dive pattern of dives No. 32 to 36 is shown in Figure 17.

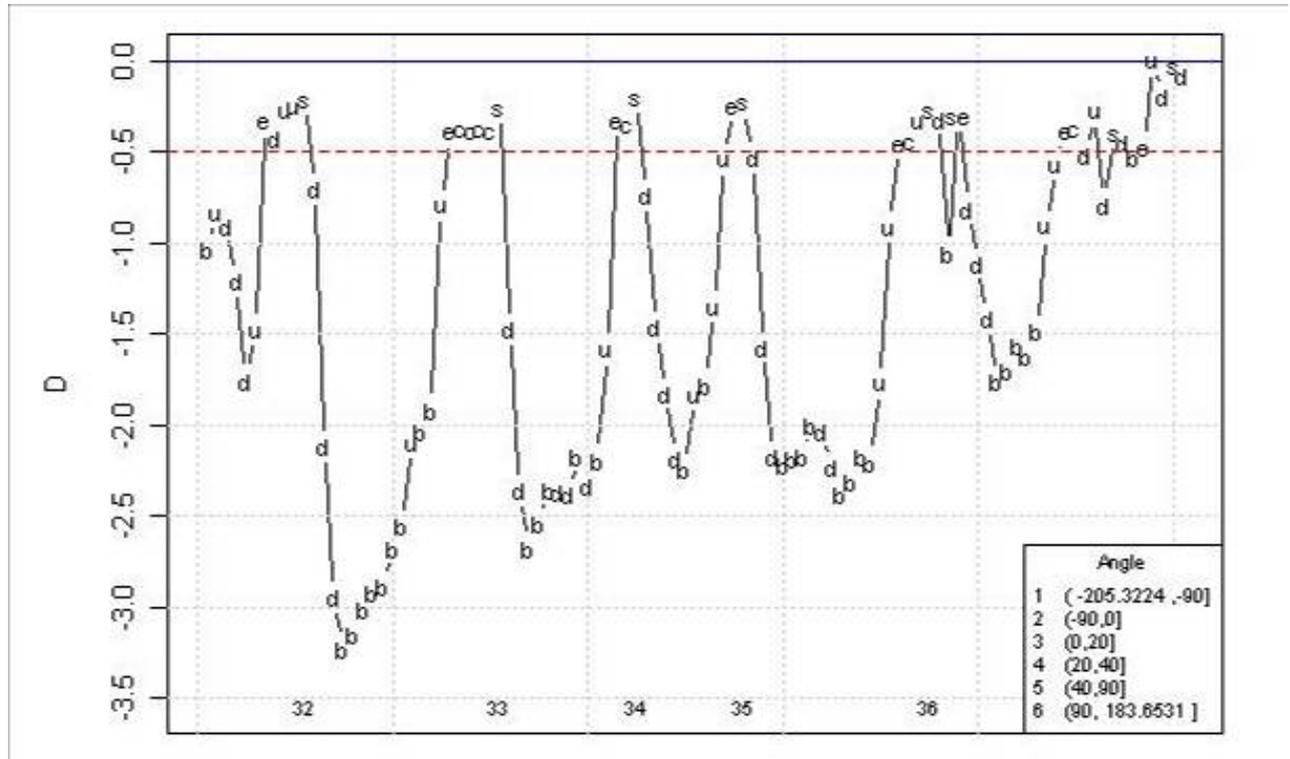


Figure 17. Dive patterns of dives No. 32 to 36. Each point that was registered by the TDR tag is shown at the recorded depth and denoted by a letter which describes the dive pattern. The y-axis gives the depth in meters and the x-axis is the index number of each observation (not shown), but observations are 5 seconds apart. Letters: s = start of dive; d = diving down; u = going up; b = bottom; e = end of dive; c = cruising; se = end and start of next dive. Dive number is shown on the bottom line.

In Figure 18 pitch changes of the animal are shown for the same dives as seen in Figure 17. Depth and pitch of the animal were recorded every 5 seconds. Thus, points in Figure 17 and Figure 18 are all 5 seconds apart and for each dive we know the angle and depth of the animal every 5 seconds. With this information, the change in pitch with regard to the previous point was recorded and assigned to different categories of pitch change. A pitch change of 20 degrees or more when following the bottom was assumed to indicate that the animal was showing behaviour resembling foraging (e.g. searching for and stopping to catch prey).

Around 50% of all dives do not show pitch changes larger than 20 degrees and are therefore not indicative of foraging behaviour (Figure 19). In the other 50 percent, most dives show one to four pitch changes. An overview of pitch changes in all dives for this animal is given in Figure 20. The darker the colour, the more pitch changes the animal has made during a dive. Clearly, there is more activity between approximately 9 a.m. and 3 p.m. and most dives are around 3 minutes long.

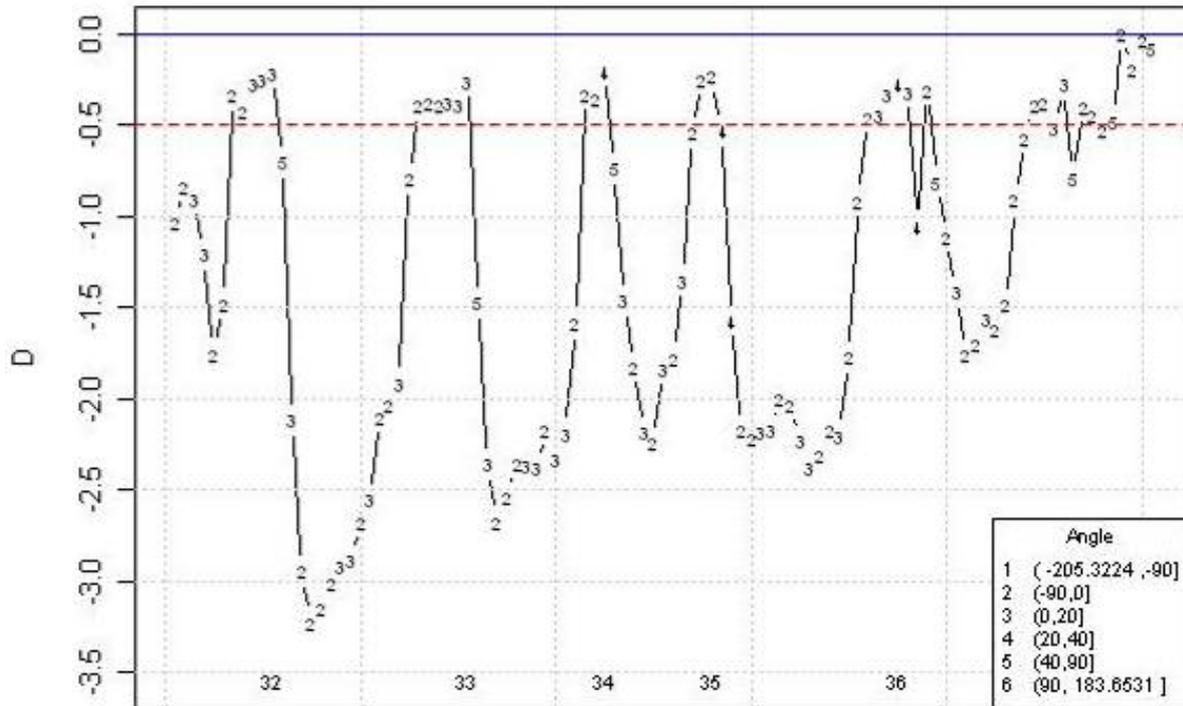


Figure 18. Dive patterns and pitch changes of dives No. 32 to 36. Axis are the same as in Figure 17. Here the numbers in the dive pattern denote a category of change in the angle of the animal compared to the previous position. Pitch changes of categories 3, 4, and 5 are assumed to be indicative of foraging behaviour.

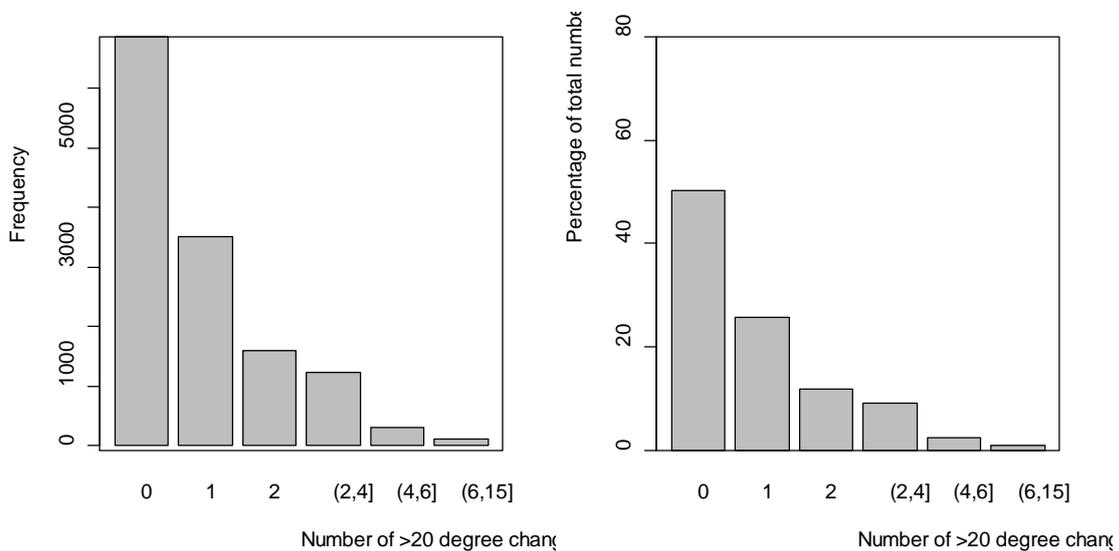


Figure 19. Total number (left) and percentage (right) of dives with different number of pitch changes of more than 20 degrees.

The separate dives were combined into 6 hour periods and for each period a histogram of the number of dives in certain duration categories (e.g. Figure 8) was calculated. This generated 124 histograms that were compared with each other using Euclidean distance. This generated a matrix of dissimilarities (distance) of all pair wise comparisons ($n=7,626$); the smaller the distance or dissimilarity between two

histograms the more similar they are. For example, two identical histograms will have a distance/dissimilarity of 0. Some histograms contain very few dives compared to the others and thus histograms with less than 20 dives were excluded.

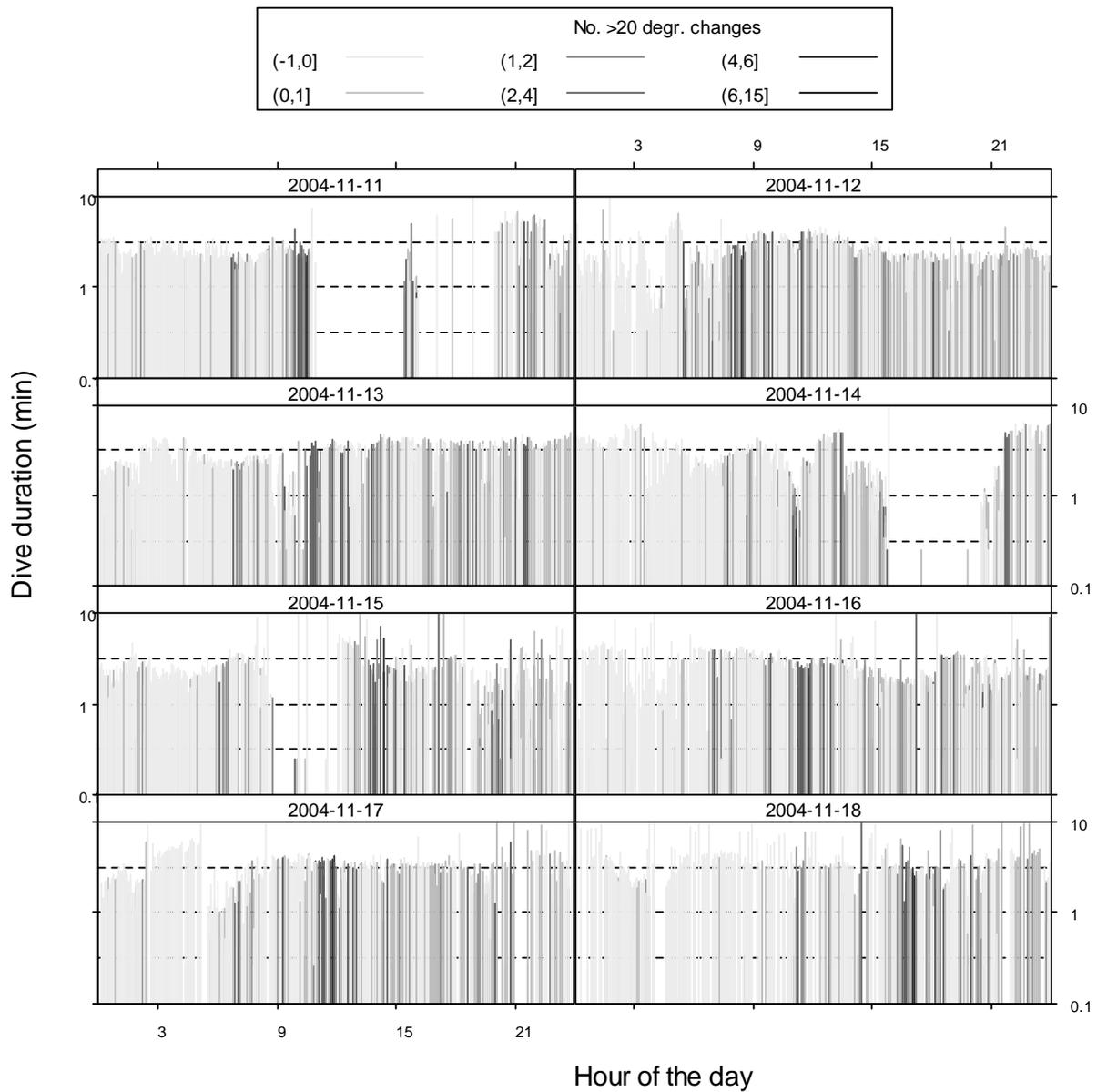


Figure 20. Example of dive patterns and pitch changes recorded by the use of the detailed TDR over a period of 8 days. Every dive is drawn as a vertical bar with length equal to the duration of the dive (note logarithmic scale). Darkness of each bar is a measure for the number of pitch changes in the dive.

Cluster analysis. The distance matrix was then analysed by hierarchical clustering using average linkage (see Materials and Methods) with the resulting tree shown in Figure 21. This dendrogram shows the grouping of the histograms in clusters that are not significantly different using the SimProf routine.

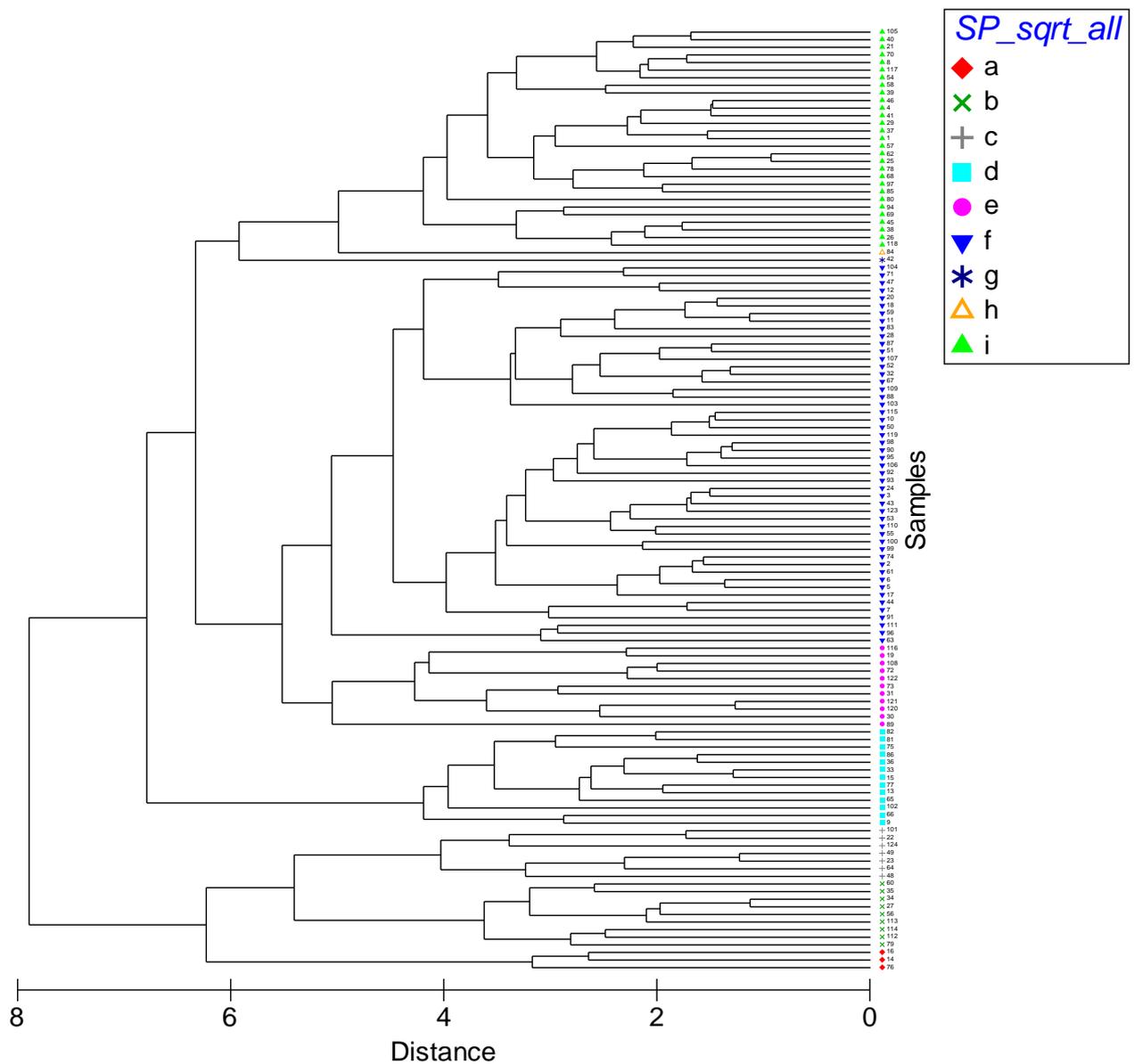


Figure 21. Cluster dendrogram showing the clustering of histograms on dive duration using Euclidean distance and average linkage. Dendrogram branches with the same symbols are not significantly different from each other (SimProf test using 1% significance). This results in 9 significantly different clusters. Numbers refer to histogram id and symbols, c.q. letters, to the cluster groups as defined by the SimProf routine.

Another grouping technique, more commonly used, is the cutting of the tree at a fixed level. Preferably this would be at a level that is at least as high as the SimProf routine indicates. We tried several levels and assessed the resulting grouping using non-Metric Multi Dimensional Scaling (MDS). MDS gives an optimal representation of a distance matrix in two dimensions. We decided, based on the separation of histograms at different distance levels of the dendrogram of Figure 21, visualization of the resulting grouping in MDSs, and the characteristics of the resulting clusters (e.g. number of pitch changes), that a grouping into 9 groups as given by the SimProf routine in Figure 21 gave the best separation of the histograms into meaningful groups (Figure 22). Of these 9 groups only 6 contained a substantial amount of histograms. Groups *g* and *h* only had 1 histogram and group *a* contained 3 histograms.

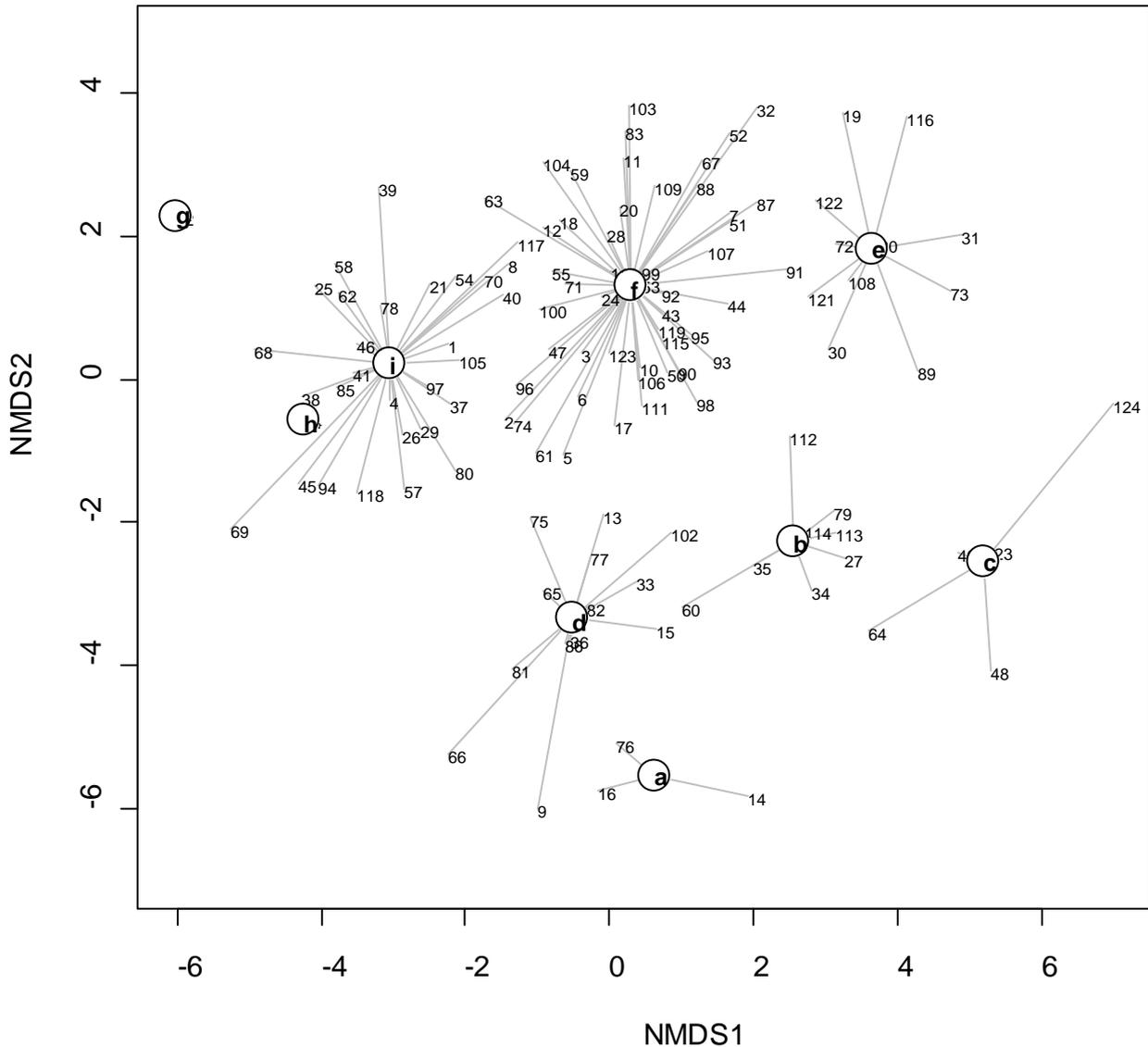


Figure 22. MDS results with superposed cluster results of the 1% significant SimProf clusters as 'spider' graphs. Each number in the graphs depicts a histogram, thus a block of 6hrs dive data. Histograms that are more similar are closer to each other. Figure 21

Figure 23 shows the mean histograms for this clustering. Clusters *g* and *h* are not very important, however, their structure is quite distinct from the other mean histograms. We also assessed the percentage of dives in each cluster that had at least 1 pitch change, assuming these are indicative of foraging dives. From these percentages it appears that clusters *e*, *f* and *i* have more foraging dives than the other clusters.

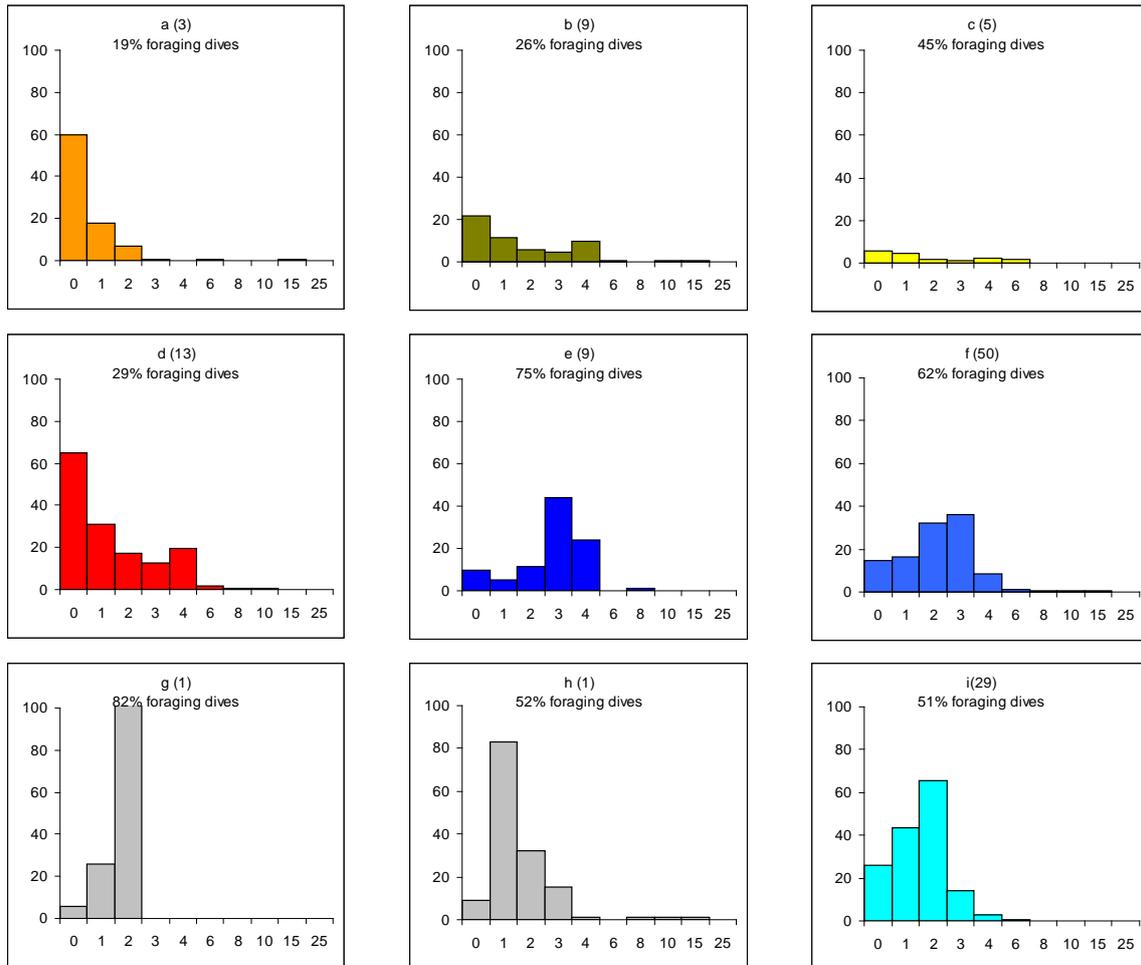


Figure 23. Mean histograms of number of dive period in different dive duration categories over a 6 hour period for the 9 clusters shown in Figure 22. The cluster number (a-i) is shown on the top of each graph and between brackets, the number of histograms in each cluster. Below this is the percentage of dives that have at least one pitch change, and thus considered foraging dives. Histograms g and h are only represented by one histogram, and are therefore grey.

4.3.1 Clustering the remaining data

Next we analysed the clusters to see which contained clear signs of foraging and which were less indicative of foraging. A first indication of foraging is presented in the figure above (Figure 23) by the percentage of foraging dives in each clusters. We also looked at the total number of pitch changes in each period (i.e. histogram), the average number of pitch changes per dive in each period, the average dive duration and mean depth (Figure 24). From the graphs, we tentatively conclude that clusters *e*, *f*, and *i* are foraging clusters and cluster *a*, *b*, *c* and *d* are not. This choice is based first of all on the fact that over 50% of the dives show pitch changes, which are assumed to be related to feeding. Generally, diving depth is higher in foraging clusters. Mean dive duration is not very different between clusters.

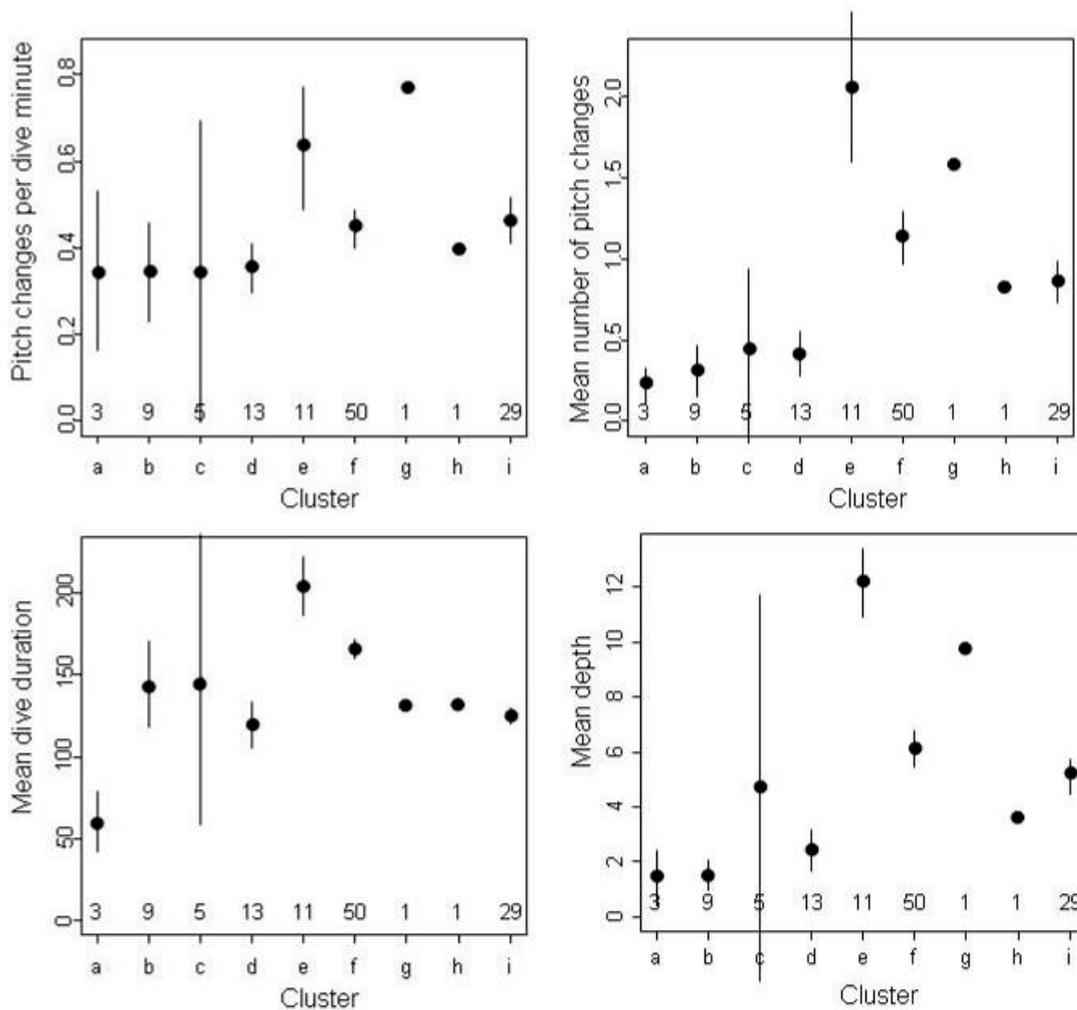


Figure 24. Clusters further analysed by calculation of mean values per cluster (including 95% confidence limits) on (clockwise from top to bottom) pitch changes per dive minute, mean number of pitch per dive per period, mean dive duration per period, and mean depth per dive per period. Number of histograms in the clusters is indicated below in the graphs.

Using the clusters a classification tree analysis was completed to determine with which settings, of the duration categories, the histograms could be assigned to clusters in such a way that the cluster grouping can be best achieved. The final result of this analysis is shown in Figure 25. Clusters *g* and *h* had too few histograms for the software to be able to generate detection rules. The other histograms, on the other hand, were classified with 95% accuracy to the correct cluster. The tree should be read as follows: if the third bin *d2* (containing the number of dives between 2 and 3 minutes) is smaller than 7.106 (square root transformed number of dives) go left, otherwise go right. Then the left branch is split on the criterion of *d2* being smaller or larger or equal to 5.05, etc. Apparently, only the first 4 bins (*d0*, *d1*, *d2*, *d3*) are enough to give the best classification since these are the only ones being used in the classification tree. This was expected as the other bins contained only a limited number of dives (see Figure 23).

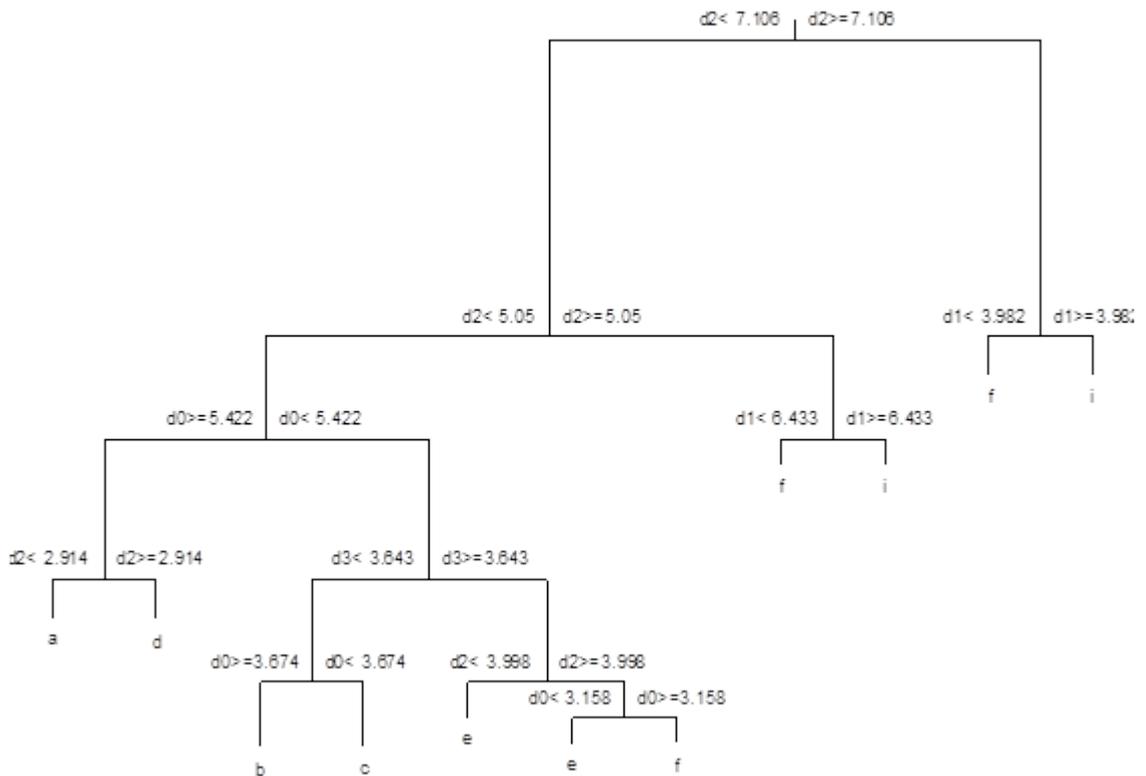


Figure 25. Classification tree representing the splitting of the detailed tag histograms into 4 clusters. Clusters *g* and *h* had too few histograms to allow classification by the tree into separate clusters. At the tree nodes the decision rule is given: for example the first split means that if the square root of the second duration category is less than 7.106 follow the left branch, otherwise follow the right branch. Abbreviations: *d0*, duration interval from 0 to 1 minute; *d1*, from 1 to 2; *d2*, from 2 to 3 minutes. The letter below the branches in the chart relates to the clusters also defined in the histograms shown in Figure 23.

The classification rules thus obtained from the tree analysis were applied to the whole set of histograms from all seals which generated a classification of the histograms in clusters *a*, *b*, *c*, *d*, *e*, *f*, and *i*. Of the 10,492 histograms of dives made during 6-hour periods, 24% were assigned to cluster *a*, 10% to cluster *b*, 13% to cluster *c*, 20% to cluster *d*, 5% to cluster *e*, 19% to cluster *f* and 9% to cluster *i*. As the two clusters could not be defined due to the small sample, no histograms were assigned to clusters *g* and *h*. Next, the positions were calculated for each period and the periods plotted to find areas where the animals show foraging behaviour.

4.4 Identifying areas of importance for feeding

Once the activity clusters were defined, dive depth histograms of the other seals were assigned to one of the cluster types by the detection rules from the classification tree analysis. These could then be allotted to the location data (Figure 26). The analysis of the habitat preference was then repeated for those locations defined as feeding locations. The results can be observed in Figure 27, for (a) depth, (b) %mud in the sediment, and (c) shipping activity.

As was done earlier, these habitat preferences can then be used to model the seals' distribution. This time defining preferred foraging areas. As determined earlier, being central-place foragers, the seals' at-sea distribution is estimated to be largely influenced by distance to haul-out site, which is included as a variable in the first model shown in Figure 16. In Figure 28 the preference function was used, only excluding this distance to haul-out in order to define good potential feeding habitat, irrespective of the current distribution on haul-outs.

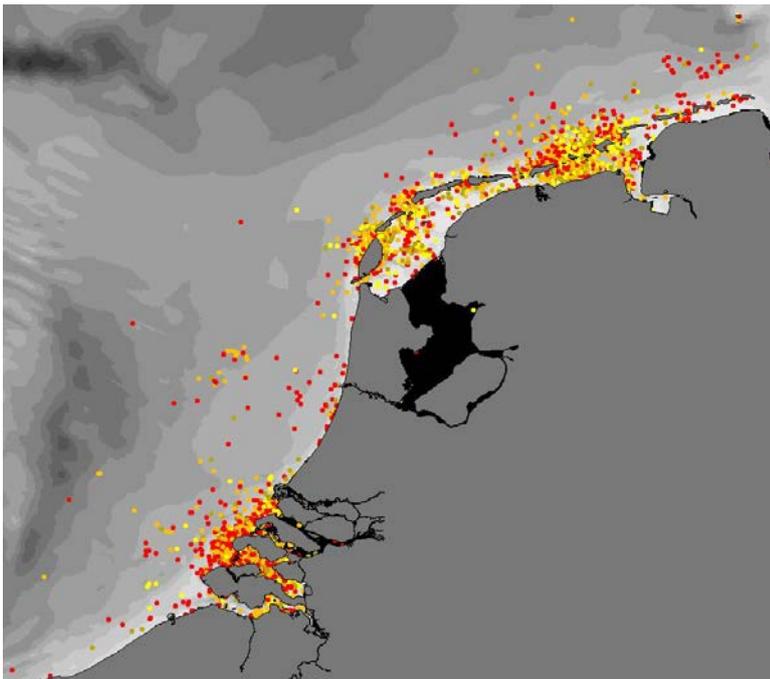
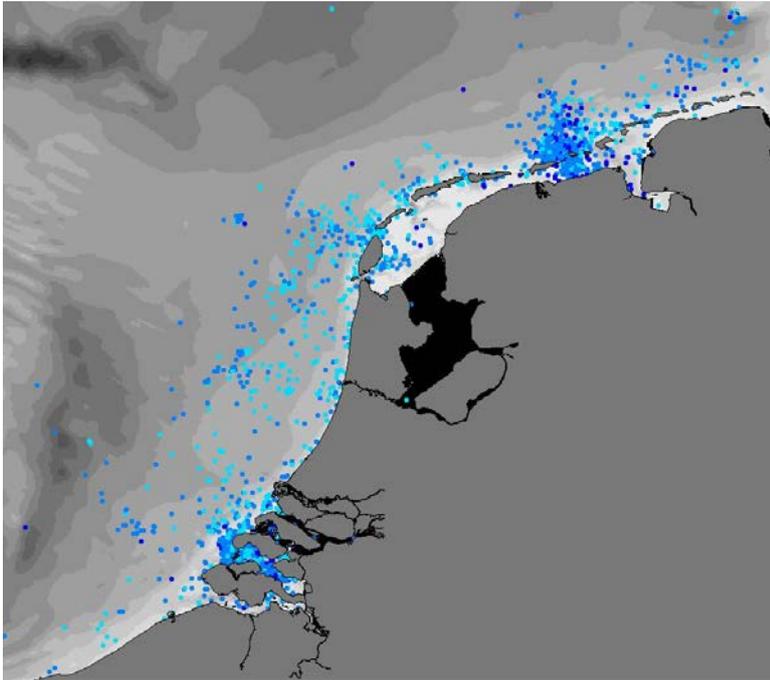
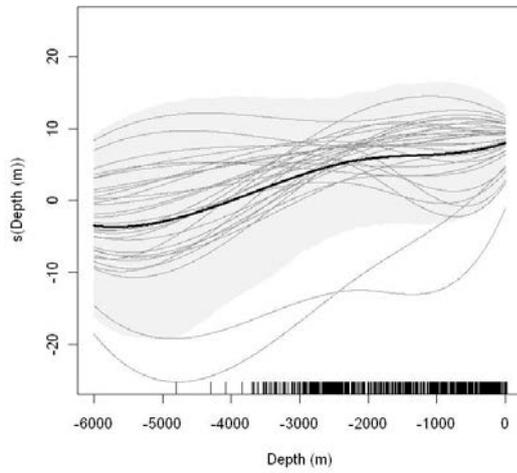
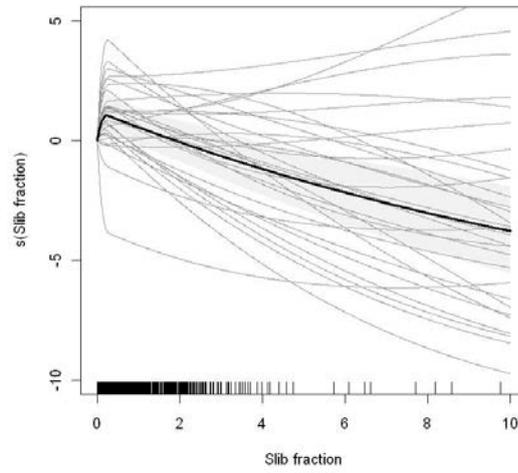


Figure 26. Top: Distribution of the seal locations identified as feeding, by clustering dive histograms (4.3). Here the locations corresponding to clusters **e**, **f** and **i** are presented. Bottom: Distribution of the seal locations identified as non-(or less) feeding, by clustering dive histograms (4.3). Here the locations corresponding to clusters **a**, **b**, **c** and **d** are presented. Colours used coincide with those of the histograms defined in Figure 25.

a



b



c

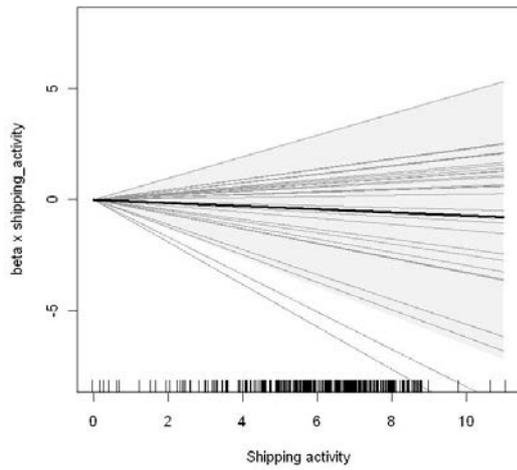


Figure 27. The relative preference for (a) depth, (b) %mud in the sediment, and (c) shipping activity. The black line describes the mean population response, the grey lines the individual estimates for each seal and the grey area represent the 95% confidence limits for the entire population.

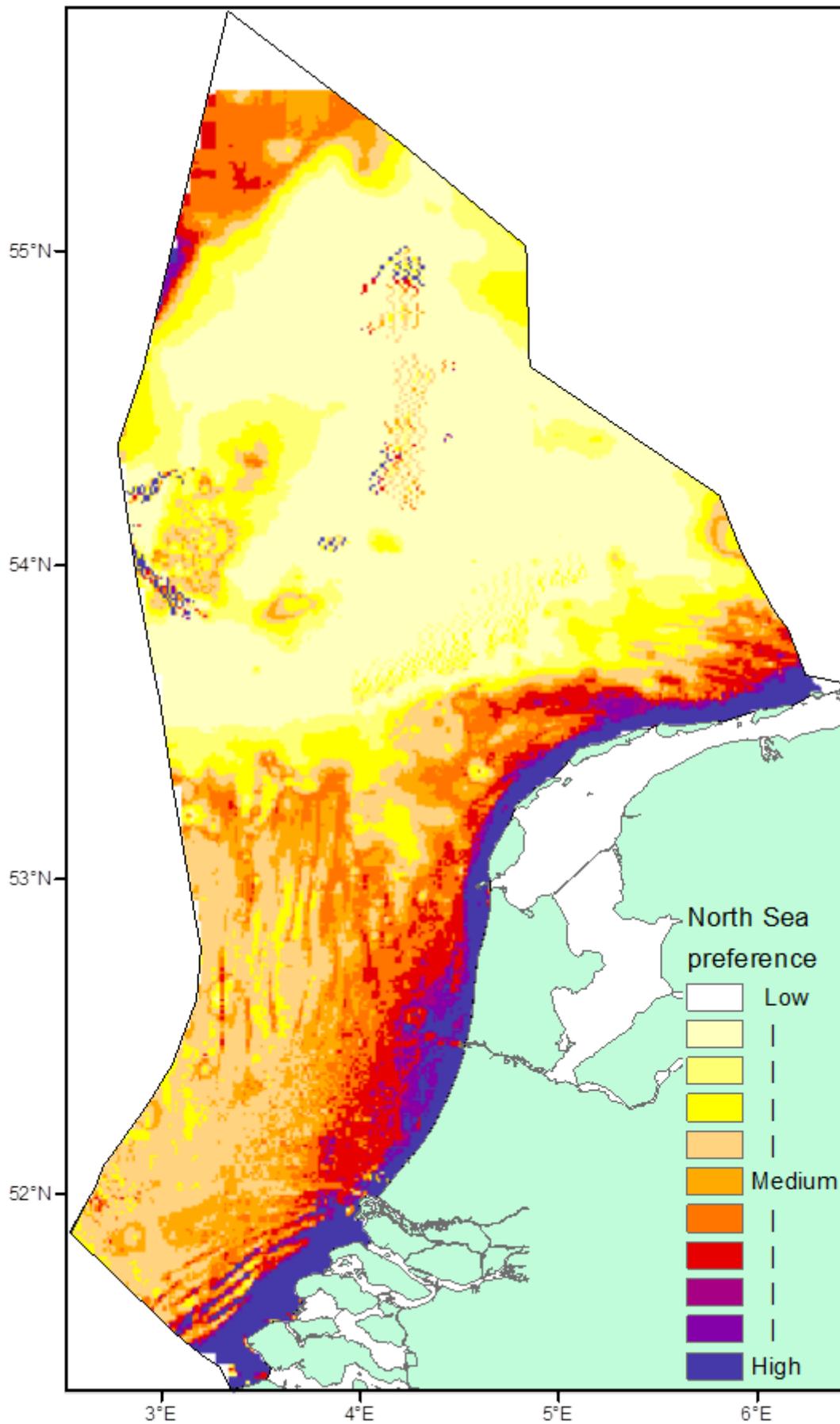


Figure 28. Predicted relative preference of seals for foraging. The preference function used for this map does not include the distance to haul-out in order to define good potential feeding habitat, irrespective of the current distribution of haul-outs.

5 Conclusions and Discussion

5.1 General conclusion

Quantifying the effects of human activity on wildlife is both challenging and difficult because of the many factors, both inherent to the animal and to the stimulus, that influence how an animal will react, let alone how these will affect a population or a species in general. In the case of harbour seals in Dutch waters, identifying a cause and effect relationship between the wind farm (construction and operation) and the well-being of the seals requires detailed knowledge of the life history and behaviour of the seals. This in turn requires an understanding of the 'normal' behaviour, i.e. habitat use, of the seals and the ability to accurately track individuals in their 3-dimensional environment. Additionally, it is necessary to understand if and how these 'normal' behaviours change in the presence of the wind farm. In fact to determine how the wind farm affects the influence of natural environmental factors.

Compared to many other marine mammal species, we have a relatively good understanding of harbour seals in Dutch waters, i.e. numbers, haul-out patterns, and phenology (e.g. recently reviewed in Brasseur et al., 2008). This also holds true for our knowledge on the seals' distribution at sea, although this has been somewhat hampered by the large individual variation seen in these animals. Despite this knowledge, we only now have more detailed information (this report) on the seals' habitat use (preference) and on which factors (both natural and human) influence their distribution. Using this information, we can begin to understand the potential effects of offshore wind farming on harbour seals in Dutch waters.

Rather than being primarily an impact study about the effect of the OWEZ wind farm on seals, the ultimate goal of the project, as defined in paragraph 1, includes the modelling of the use of the Dutch coast by seals, providing information on the relative importance of specific areas for this species. Only with this knowledge can we start to define the possible effect of human activity, like wind farming on seals.

5.2 Seal distribution and abundance

The model data in section 4.2 is, given the available data, the best estimate of the seals' distribution in the offshore area possible, defining an estimate of local abundance. Our studies on environmental conditions demonstrate that seals in Dutch waters show a preference for the following:

1. *Areas close to the haul out,*
2. *Relatively shallow areas*
3. *Sediments with low mud content*

The preference for areas relatively close to the haul-out sites, could suggest that seals, in addition to other factors, may select haul-out sites in proximity to good foraging areas. Nevertheless, the seals in this study were seen to (easily) range out to areas >100 km from their haul out sites. Figure 16 shows that in general, given the current use of haul out sites the seals can be expected in relatively high densities around the Dutch Wadden Sea coast. Despite the very small numbers, this is also the case in the areas around the Dutch Delta area. Unlike earlier studies (i.e. Brasseur et al 2004), the expected densities are not homogenously distributed around the haul out sites. The pattern is partially determined by the abiotic factors included (depth and sediment type). The model in fact predicts relatively high densities (0.1-0.25 animals/ km²) in the area directly surrounding the OWEZ.

In this study we have attempted to link environmental parameters to the seals' distribution based on harbour seal data. One may argue that seals, ultimately distribute themselves according to the distribution of their prey. Currently, data on the distribution of fish species at a sufficient spatial and temporal resolution is not available to examine this. However, many fish species will also reveal a preference for physical covariates, such as depth and sediment. For example Wright et al. (2000) and Holland et al. (2005) illustrate that sandeel, a major food source for grey seals, have a strong preference for coarse substrate.

So the variables used in this study, sediment type and depth, may act as a proxy for the seals' hunting grounds thus indirectly the fish distribution. Secondly, also the sediment type may influence seal distribution directly. Grey seals, for example, have been observed to use their nose to dig through sediment, causing fish to appear. Such bioturbation may be more complicated in finer, muddy substrate (Aarts et al. 2008). We expect similar relations between harbour seals and their prey.

Dive data was used to distinguish areas where seals were likely to feed (see paragraph 4.3 and 4.3.1). Here we chose to identify potential feeding grounds rather than actual ones that are restricted by the current haul-out areas, defined among other things by human activity. Interestingly, when modelling preferred foraging habitat, without taking into account the location of haul-out sites, it becomes clear that the entire Dutch coast consists of preferential feeding habitat, stretching well beyond the intended wind farm expansions (Figure 28). Even more impressive is the identification of the coasts of the Dutch Delta area as having a very high foraging potential. This supports well with historical data, showing that in former times there were much larger numbers of seals in that area (Mees et al., 1994; Reijnders, 1985). The absence of seals in these areas could be a result of the intensive human use of the coastal area, preventing the seals from feeding within the Delta area and hauling out in the vicinity of these good feeding grounds.

Except for haul-out possibility, it is unlikely that the seals directly prefer these abiotic factors, .i.e. shallow waters and sediment with low mud content *per se*. As mentioned before it is more likely that the seals are simply searching the areas for prey that inhabit such environments. In fact, the prey themselves could be limited by abiotic conditions. Understanding prey behaviour is outside the scope of this study. Likewise it should be considered that the influenced of anthropogenic factors on prey could, indirectly, influence the distribution of harbour seals.

5.3 Effect of OWEZ on the seals' distribution and abundance

When designing the study, it was not expected to determine a significant effect of the wind farm on seals, since the size or area of the wind farm itself compared to the total habitat of the seals is small, and the distance to any major haul out site is large. Furthermore the study included only a Tpre-construction and a T1 (after construction) and, tagging had specifically not been commissioned during the pile driving. This would be the period when the sound production is most likely to affect the marine environment.

Except for comparing the habitat use of the seals before and after the wind farm was built, this study was not designed to study the effect of human activity on the seals *per se*. As only one site was studied and there was no recording of the possible environmental changes (i.e. prey distribution), it is difficult, if not impossible to isolate the effect of the wind farm on the seals. Despite this, we have identified a number of factors that indicate that the seals are influenced by human activity that need to be mentioned, and should be considered when planning more activities in the seals' aquatic habitat:

1. *Seals are less abundant near shipping activity.*

In lack of other data, only large shipping vessel (>300GT) were investigated. The results indicate that the seals on average, have a tendency to be less abundant in the direct proximity of the large shipping routes. There seems to be very large individual variability in their response (Figure 15).

2. *Pile driving activities could have influenced the seals' distribution;*

It appears that, except for a handful of locations of one seal, none of the tagged seals approached the area during construction (from April 2006 to May 2007, including the pile driving of OWEZ and Prinses Amalia Wind Park; Figure 12). As there was only a limited amount of data, effects of pile driving on the harbour seals cannot be excluded. The grey seals tagged in the same period, show similar behaviour (Brasseur et al 2010).

3. *The effect of the wind farms in operation could not clearly be defined in this study;*

Especially in the periods before but also after construction, the tagged seals extend their distribution towards the study area. Effects of the operational wind farm or the lack thereof could not be determined in this study.

Ad 2. In this study the seals north of the construction site, remain largely beyond a 40 km range from the pile driving activity. This does not concur completely with the findings of Kastelein et al (2006), who expected the seals to react to pile driving at 80 km. However in the northern range, a large sand bank extends into the North Sea (called the Razende Bol). It might be the case that the Razende Bol, could influence the seals behaviour by forming a sound barrier. Further studies of the propagation of sounds audible to seals and the effect of underwater structures on the might show if this is a correct hypothesis. Animals to the south stay much farther away (~120km).

Based on this study there are indications that human activities at sea could affect the distribution and habitat use of harbour seals. Additional studies are needed to investigate this in more detail, before drawing conclusions on the effects on populations. In particular, the cumulative effects of several forms of human activity in the same area and/or time period need to be understood.

5.4 Discussions on the methods used

ARGOS

We chose to invest extensively in the filtering of the ARGOS data. The inaccuracy of this system, though state of the art in the period we use it, is, we believe, too high to engage in very detailed, examination of individual locations. Despite filtering it remains possible that some locations are faulty. Because of the small scale of the wind farm compared to the "open" sea around it, it is much more difficult to prove an animal was in or close to the wind farm than it is to prove that it was away from it. The new method using the GPS system is much more appropriate for this species as day to day movements can occur on a very fine scale.

Data limitations

The modelled distribution presented here was based only on Dutch data, using a limited set of environmental factors (depth, sediment and boating). The fact that other data could not be used or did not prove significant was at least partly due to the fact that either the international data was not compatible with the Dutch data or the scale at which it was collected was not adequate. For example, in an earlier study an attempt was made to relate seal distribution to fish data (Brasseur et al 2004). However, most fish data is collected only once a year; an impractical scale to compare to the daily movements of seal. In the same way we attempted to relate the seal distribution to temperature data collected by satellite. Here too, the scaling of the data hampered proper analysis.

Although the number of seals included in this study was unprecedented, the number still represents only a very small sample of the Dutch harbour seal population. Individual variation, typical to these animals, creates the need for greater numbers if finer detail is required. For this reason, we could not determine the influence of seasonality, sex or age related effects. Further development of the model, and the collection of additional data, will enable such studies in the near future.

In this study, the lack of tagged seals occurring in proximity of the wind farm could be the result of the fact that they were caught too far from the targeted wind farm area.

Habitat modelling

One of the main objectives of this study is to estimate the at-sea distribution of harbour seals. Using the telemetry observations directly would be inappropriate, because it ignores the fact that seals are only caught at a few distinct haul-out sites. Instead, by quantifying the seal's preference for environmental conditions, the expected distribution of seals departing from each haul-out site can be predicted. These estimates can be scaled using the seal counts on the haul-out sites. This potentially allows for an unbiased estimate of the at-sea distribution of all harbour seals in Dutch waters. The major aim of this study was to investigate the feasibility of this method, and apply it in order to determine areas at sea where harbour seals are more likely to aggregate .

Since it is currently impossible to observe all seals at sea, we believe habitat analysis to be the only viable alternative to estimate the distribution of the population. This study provides a proof of concept, but many improvements can certainly be implemented. In this study, the distribution and habitat preference is considered to be constant among seasons and types of individuals. Due to the phenology and variability in prey abundance and distribution, the seal distribution will probably differ between seasons. Also the individual characteristics (e.g. sex, age, size) may influence where and when they forage at sea. This seasonal and phenological variability should receive more attention.

Finally, and perhaps most importantly, the at-sea distribution may change inter-annually. For the at-sea estimates to be used in management and offshore planning, one needs to be able to make future predictions or illustrate that there is some inter-annual consistency in their distribution. In other words, are the model estimates reliable and what is their predictive power? These aspects should be considered in future studies.

Underwater sound propagation

Moreover, using distance as a measure for aversion towards wind farming activities is only beneficial/useful for animals that, at the moment of the activity, could be aware of it. In lieu of this information, i.e. exact measures of the distance at which the seals could hear or otherwise perceive wind farming activities, all data was included. In the near future, modelling of sound, specific to the area will aid to ameliorate our understanding of the seals' reactions. This also holds true for the sound produced by shipping.

Dive analysis

The dive data collected in 6 hrs. histograms is bound to often be a mixture of different behaviours, including feeding and resting. We attempted to separate the different periods, identifying those in which it was more likely that the seals were feeding. Though this might be seen as state of the art, much work has yet to be done in understanding when, where and how these animals actually feed.

Identification and quantification of population effects of wind farms on marine mammals

In this study it has been shown that human activities can affect the seals' distribution. However we can only postulate on possible effects on the population. It is not possible to quantify what the actual effect is on survival, growth and reproduction from these results alone. In our calculations for the habitat

model we chose to use counted seal numbers instead of estimated population numbers. It should be noted that the density of seals at specific locations are therefore an underestimate.

6 Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 57846-2009-AQ-NLD-RvA). This certificate is valid until 15 December 2012. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Environmental Division has NEN-AND-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2013 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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Justification

Rapport OWEZ R 252 T1 20120130/ C043-10

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

Approved: Martine van den Heuvel-Greve
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Number of copies: ~number~
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