Postbus 68 | 1970 AB IJmuiden

Rijkswaterstaat Water, Verkeer en Leefomgeving
T.a.v. Meik Verdonk, Martine Graafland
Postbus 2232
3500 GE Utrecht

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OUR REFERENCE
2426147.SBr.mw

POSTAL ADDRESS
Postbus 68
1970 AB IJmuiden

VISITORS' ADDRESS
Haringkade 1
1976 CP IJmuiden

INTERNET
www.wur.nl/marine-research

CoC NUMBER
09098104

HANDLED BY
Amber Jägers

TELEPHONE
+31 (0) 6 11 85 26 32

EMAIL
marine-research@wur.nl

Author(s): Sophie Brasseur & Geert Aarts

EXECUTIVE SUMMARY

Aim of the KEC

The Framework "Kader Ecologie en Cumulatie" (KEC) aims to assess the ecological and cumulative effects caused by the construction of offshore wind farms on the populations of protected species. These species include harbour and grey seals (*Phoca vitulina* and *Halichoerus grypus*, respectively). The Acceptable Limit of Impact caused by the construction of offshore wind farms is defined as follows: the populations on the Dutch Continental Shelf must be maintained at a minimum of 95% of the present level with a high degree of certainty (>95%). In other words, the probability of a population reduction of more than 5% must be smaller than 0.05 (Heinis *et al*., 2022).

Background and problem statement

The KEC assessment of the effect of sound exposure on marine mammals can be divided into two main analysis steps. Both steps are affected by the latest insights regarding the distribution and population development of seals.

In the first analysis step, the number of seal disturbance days is estimated by overlaying estimated sound exposure levels for pile driving with the modelled distribution of seals. The seal distribution maps (developed by WMR) are underpinned by a habitat model based on tracking data. This habitat model attempts to account for the fact that seal trackers were deployed opportunistically during a diverse array of projects resulting in data scattered across various regions and different time periods. However, the problem is that 90% of the transmitter data were collected prior to 2016. Only in the Delta area in the South, where a small part of the population resides, there was a tagging campaign in 2019 (Table 1). Thus from the Wadden Sea, where by far most seals haul-out, no seals have been tracked during the last eight years, apart from six (naïve) juveniles released from a rehabilitation centre. These recent data from juveniles raise questions on the validity of the existing distribution maps for juveniles, but these sparse observations also raise concerns about the validity of the maps for all other age groups. It cannot be excluded that the seals' foraging habitat may have changed as a result of natural and anthropogenic processes in the North Sea. As a result, the existing maps may no longer represent current seal distribution, let alone be representative for the future for which the KEC attempts to estimate the impact of the human activities.

In the second step of the KEC assessment, an Interim PCoD (iPCoD) model is used to estimate how the resulting seal disturbance days translate into population-level effects. In the latest KEC assessment (4.0) it was estimated that the construction of offshore wind farms would lead to approximately 140,000 disturbance days for harbour seals and approximately 79,000 disturbance days for grey seals. The iPCoD model estimated that this would not cause any change (0%) in the population size for either species.
This estimate of effect on the population-level rests on two critical assumptions, which relate to 1) the division of disturbance days among individuals, which is contingent upon the level of site fidelity of seals, and 2) the sensitivity of seals to missed foraging opportunities caused by the disturbance. New insights from population surveys (presented in the supplement) suggest that in the last 10 years, the vast majority of pups born do not appear to survive the first year, and hence. that the assumptions need to be revisited. If the (naïve) juveniles venture further offshore (as suggested by the new tracking data), some of these mortalities could be directly or indirectly caused by the recent raise in anthropogenic disturbances, including the construction of offshore windfarms.

Objective of this memo

The assignment states: “Based on expert judgement, describe to what extent the results of the KEC 5.0 based on the old maps are representative of the latest insights in the field of seals and make a proposal for improvements.”

We concentrate primarily on harbour seals in this memo. Partly due to the fact that grey seals are part of an open population, with the vast majority residing in the United Kingdom, where ~90% of the grey seal population resides. Quantifying the number of UK seals entering and leaving Dutch waters is therefore challenging, which hampers accurate population assessments. In contrast, exchange of the harbour seals between the Netherlands and the UK is limited, and within the Wadden Sea countries, we work together with Denmark and Germany to monitor the total population. Though seals are counted when they haul out in the Wadden Sea they use the North Sea to forage and travel. Another reason to concentrate on harbour seals is because the population size of harbour seals that haul-out in the international Wadden Sea has clearly decreased in recent years, which underscores the necessity of further attention.

Regarding the question to what extent the results of the KEC 5.0 based on the old maps are representative, a distinction will be made between the consequence of these latest insights for the number of disturbance days (first step of the KEC) and the consequence of these insights for the population level consequences, as estimated by iPCoD model (second step of the KEC).

Below we summarize the latest insights with regards to the distribution and health of seals. Next, we describe their consequences with respect to the KEC estimates. And finally, we provide some recommendations. More information about these latest insights and related topics are given in the chapter *Background Information* below.

Latest insights in the field of seals:

1) Recent data indicate that juvenile (naïve) harbour seals exhibit different foraging behaviour and distribution compared to the old seal tracking data used to create the distribution maps for the KEC.

To test new seal tracking devices, 6 young (naïve) harbour seals from a rescue centre were tagged in 2020-2021. In comparison to animals tagged in previous years, these animals made significantly longer trips, often lasting multiple days or even weeks, travelled a greater distance from their colony (often over 50km), and ventured further offshore. More details can be found in the *Background Information*. For other age-classes, there is a lack of recent tracking data, which means that it is not possible to determine whether older age-classes currently also distribute differently.

2) *The harbour seal population is declining*

Following decades of recovery, during which time the harbour seal population had grown at an average rate of ~9% per year, the population surveys of the international Wadden Sea seal population, that uses the North Sea, revealed a sudden shift in 2013 (see supplement). The population size was then estimated to be approximately 43.000 animals. Since that year, the population growth has stagnated, average growth being less than 1% per year, despite a continuing growth in pup production. The international Wadden Sea produced approximately 13.000 pups annually in this period (23% of the total population – see *Background information*). Then, since 2021, the population began to decrease by an average of 7% per year, though the pup production remained high. The population decrease and no evidence for mass emigration to other areas outside the Wadden Sea suggests that more than the equivalent of all pups born are dying every year, which for 2021-2023, corresponds to at least 23% of the population. Thus, at least 23% + 7% = 30% of the population present in the international Wadden Sea during the summer months are expected to die each year. As the Wadden Sea population is one population, it is difficult to calculate exactly how many of these die in the Dutch Waters. From voluntary records collected along the Dutch coast we know that at least 750 individual harbour seals were found dead in 2023 (7% of the estimated Dutch part of the population). Many dead animals are lost at sea so this only represents a fraction of the total mortality.

Estimated consequences based on the available data and expert judgment

1) A more widespread distribution of naïve animals and potentially also of other age groups.

<u>Consequences for calculation of seal disturbance days</u>: The tracked (naïve) seals have a more widespread distribution. If these tracked seals are representative for other juvenile seals in the population, the current maps likely underestimate the use of the construction area by seals, since most wind farms are also located further offshore. Therefore, also the number of disturbance days would likely be underestimated. This potentially also holds for other age groups.
<u>Consequences for the estimated effect on population</u>: It is anticipated that the survival probability will decrease as the number of seal disturbance days increases. However, in the present KEC assessment, disturbance does not translate into population-level effects (now estimated as 0%). This is due to the assumptions that seals a) exhibit low foraging site fidelity, resulting in a low number of repeated exposures for individual animals, and b) are in healthy condition, such that the estimated disturbances will not affect their fitness. If the KEC assessment would include stronger foraging site-fidelity and larger variation in condition throughout the population, the estimated increase in disturbance days would likely lead to a decrease in survival.

2) Regarding the high mortality of (juvenile) harbour seals

Consequences for calculation of disturbance days: Assuming the seal distribution will stay the same (although this is unlikely given the latest tracking data), the decline in population size will result in a decline of the absolute number of seal disturbance days. However, because both change in proportion, the percentage of seals affected will not change.

Consequences for the estimated effect on population: The most likely hypothesis explaining the observed high mortality is the inability of (juvenile) seals to find sufficient food, which will first lead to lower body condition, and ultimately causing mortality. Potentially, this is preceded by a lower investment by the mother during pregnancy and suckling, although there is currently no empirical evidence for this. The vast majority of seals dying, are not found ashore. It is most likely that those in poor condition (and as result have a negative buoyancy), will die offshore and sink to the bottom. However, some indications might be found in stranded animals, but records of stranded animals are poor in the Netherlands and there is no monitoring of the animals stranded (see recommendations). Currently, the iPCoD model implicitly assumes that seals are in good condition and thus can withstand substantial levels of disturbance. However, if a substantial part of the population is in a poor condition the effect of missed foraging opportunities caused by disturbance is likely to be severely underestimated (now estimated as 0%).

Proposal for improvements: What could be done in the short term?

Recent insights suggest that when using the existing maps, the KEC 5.0 estimates of disturbance days and their effects on the population are possibly underestimated. First we will address potential improvements of the information used to assess these effects. Below we suggest research to address this.

1. To accurately assess the effect of missed foraging opportunities caused by disturbance on the animals' fitness, it is necessary to incorporate realistic estimates of body condition, taking seasonal and between-individual variation into account.

2. Integrate foraging and movement behaviours into the model in a realistic manner. This serves two purposes. First, the inclusion of movement will enable the estimation of the number of individuals approaching the construction area during piling operations. Second, it will more accurately represent the strong foraging site fidelity of the individual seals, which will lead to a higher number of repeated exposures for each individuals. This can have a substantial influence on the estimated resulting population-level consequences.

3. Account for changes in distribution with respect to their historic distribution measured using older tracking data. Changes are expected to occur as a result of natural factors, such as internal factors (age distribution, health) and external factors (for example, prey availability and distribution), as well as changes in anthropogenic activities (for example, growth in renewable energy production and marine traffic).

Research needed to obtain the information mentioned above: How?

In relation to this proposal for improvements, efforts should initially be concentrated on harbour seals, since this population is in decline (an * was added where both species could be considered). The following actions could be taken: (These are not detailed project proposals, but rather suggestions for studies to improve knowledge regarding the effects of windfarm construction) :

1) *Measure changes in distribution*
   a. Track new animals

i. Project based: Include all animals (age and sex classes) and compare to the existing data set to understand if and how recent (in the past decade) changes, caused by both natural and anthropogenic factors have changed the seals' movement and behaviour.
ii. Project based: Study the difference in behaviour (e.g. movement) between young/naïve animals and (sub) adults.
iii. Structural study: (annual monitoring) Include all animals (age and sex classes) and compare to existing data set to monitor changes in relation to ongoing environmental processes and human activities.

b. Study changes in the environment
   i. Diet and variation in diet* in relation to seasonal and annual changes.
   ii. Include human activities in IBM and habitat models. This could include an empirical study to investigate if movement and distribution is influenced by to the construction and operation of windfarm, but also shipping, sonar, mining, (installation of) cables, fishing and military activities.

2) *Measure body condition and health*
   a. Registration and investigation of stranded animals* to measure variation in health, understand causes of mortality and (changes in) population structure.
   b. Measure condition of living animals in the field*, for example using and further developing existing 3D drone technology. This could include monthly drone flights to measure seasonal and between-individual variation in body conditions in order to define critical periods when seals are nutritionally stressed.
   c. Inclusion of the existing individual-based movement component into the KEC assessment which allows to trace body condition over time.

3) *Inclusion of individual-based model to incorporate realistic movement patterns and trace how reduction in foraging opportunities impacts health and vital rate parameters*

   Further develop and improve the Individual-Based Model framework that takes seasonal, phenological and individual variation in body condition into account to appropriately capture the effect of missed foraging opportunities, but also to test various management scenarios. New tracking data could feed directly into this. This type of model could replace some elements of the iPCoD assessment and could potentially inform better which effects can be expected from human activities. This IBM could also be used to improve estimates of the number of disturbance days, by accounting for seals swimming in and out of the impact area within a day. Furthermore, it can incorporate individual-level foraging site fidelity and as a result more realistically estimate how the disturbance days are distributed over individuals.

Recommendations: What could be done on the long term?

In the aforementioned recommendations, we focussed on harbour seals and improving the current KEC estimates related to the impact of the construction of offshore wind parks. We acknowledge that these short-term recommendations fail to consider other processes, such as the international exchange of populations and potential confounding factors that could affect seal survival (e.g., changes in prey availability), also grey seals are disregarded. For example, recent grey seal population survey data also indicates lower pup production in the Dutch waters in recent years. This might be an indication of change also occurring in the grey seal populations. This could be the result of local (Dutch) changes, but could also be a general (international) trend. Either within other current or future research projects, these issues require further attention.

BACKGROUND INFORMATION

a: Current maps

The Framework Ecology and Cumulation (KEC) focuses on possible cumulative effects on the populations of protected species during the construction and operation of offshore wind farms. For impact assessments, like the KEC, it is important to have an estimate of the spatial distribution of all seals, both grey and harbour using the (Dutch) North Sea. The maps of Aarts (2021), show an estimate of the monthly distribution of the of grey and harbour seals at sea based on the available count and tracking data when they were made i.e. data from 2007-2019 (Fig 1.). The KEC 4.0, used these maps though they were summarised in the KEC 4.0 to differentiate in four seasons, intended to capture the variation in seal distribution following their phenological cycle.
The maps represent an estimate of the distribution of seals at sea at any given moment. These can therefore be used to calculate the average number of disturbance days for single exposures.

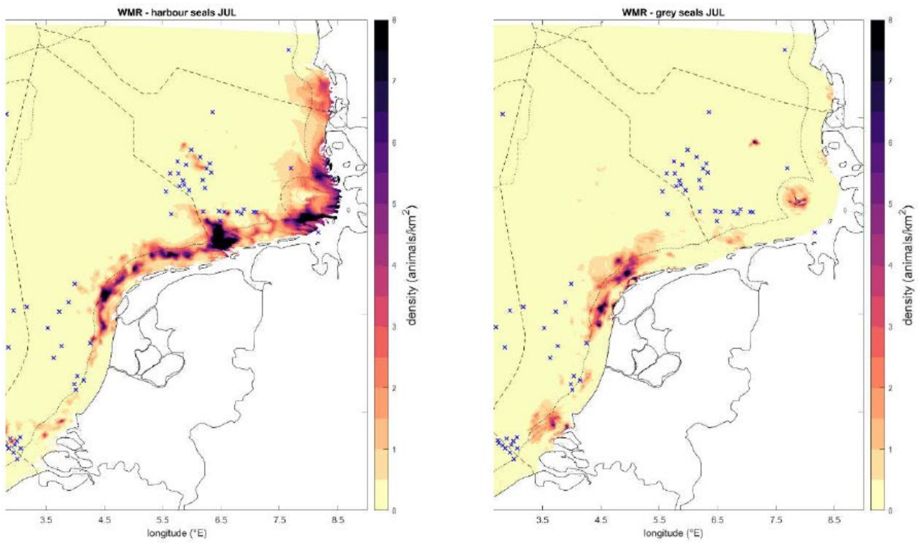


Figure 1. Maps of harbour and grey seal distribution used in KEC 4.0. Estimate of the mean density at sea of harbour seals (left) and grey seals (right) in July (Aarts, 2021). Blue crosses: the selected sites in each wind farm/wind energy area for which calculations were made. For more information, see https://www.noordzeeloket.nl/publish/pages/198641/kec-4-0-cumulative-effects-underwater-noise.pdf.

These maps were used in the KEC 4.0 to calculate the number of “animal disturbance days” that would occur as a result of piledriving (Heinis *et al.*, 2022), and then to estimate the potential population-level reduction using the iPcoD model, which is based on expert elicitation (Heinis *et al.*, 2019). The iPCoD model in the KEC 4.0 based on these maps predicted that the construction of future offshore wind parks would result in numerous animal disturbance days (~140,000 for harbour seals and 79,000 for grey seals), but despite this, the model estimated that there would be a negligible change (0%) in the population size.
However, the maps cannot be used to properly estimate cumulative effects (i.e. multiple piledriving moments during construction of a wind farm, and additional shipping). Seals are highly mobile and the number of individuals using an area, can be much higher than the number observed there at any given moment. During the construction period, spanning multiple days, the individual animals could move in and out of the estimated disturbed areas. As a result, the number of individual seals exposed will likely be underestimated in the KEC and also seals could be subjected to

multiple disturbances throughout their distribution. Currently the calculation in the KEC does not appropriately capture individual movement processes, such as individual foraging site-fidelity as revealed by the tracking data. The importance of taking animal movement into consideration is for example shown in Aarts *et al.* (2016).

b: Tracking data

Since most marine mammals, including seals, spend most of their time below the surface, and they are not seen readily from the air, tracking is the best available method to monitor their distribution at sea. Tracking data provide information about movements of individuals in space and time, but also provide additional information about their diving behaviour and when they are hauled-out. Wildlife tracking gives an unbiased estimate of the distribution of those individuals tracked. However, in the Netherlands, tracking has always been on project-by-project basis. As a result, more seals were tracked in some regions (e.g., the Ems Estuary) compared to other regions. Consequently, simple density estimates of the tracking data cannot be used to infer their population distribution. However, the tracking data is used to investigate which types of habitats they use, and combined with haul-out counts, these habitat association estimates can be used to estimate the distribution of the whole population of seals, resulting in the maps mentioned above.

Table 1. Number of grey and harbour seals tracked in the Netherlands using GPS/GSM trackers. For harbour seals tracking during the fall would include post- moult animals and potentially more young of the year; spring tracking represents pre breeding. In grey seals this is the opposite. Number of presumed young of the year harbour seals are indicated between brackets. In orange shading the rehabilitated ones.*

			2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2019	2020	2021	2022	2023	Total
Grey seals	**Outer**	*fall*													10 (1)					10
	Delta	*spring*								**6 (1)**	**10 (2)**	**6 (1)**								**22**
	Texel	*fall*			6															12
		spring	4	5						9	10	6								42
	Ameland	*fall*								10 (2)	1	9								20
		spring										7(2)								7
	Total		**4**	**5**	**6**	**0**	**0**	**0**	**0**	**25(3)**	**21(2)**	**28(3)**	**0**	**0**	**10 (1)**	**0**	**0**	**0**	**0**	**99**
Harbour seals	**Outer**	*fall*											6 (1)		10 (2)					16 (3)
	Delta	*spring*								6 (2)	10	6								22 (2)
	Westersch	*fall*		4																4
	elde	*spring*		6																6
	Texel	*fall*											6 (1)	6 (2)		1 (1)		5 (5)		18 (8)
		spring		6						6 (1)	10	6								28 (1)
	Ameland	*fall*								10 (1)		10 (2)								20 (3)
		spring									**10**									**10**
	Eems	*fall*				25 (1)	24 (2)	24												73 (3)
		spring				21	24	24												69
	Total		**0**	**16**	**0**	**46 (1)**	**48(2)**	**48**	**0**	**22 (4)**	**30**	**22(2)**	**12(2)**	**6(2)**	**10(2)**	**1(1)**	**0**	**5(5)**	**0**	**260**

*The tracking data mentioned in this table are the product of numerous studies reported earlier in: (Brasseur *et al.*, 2006; Brasseur *et al.*, 2009a; Brasseur *et al.*, 2009b; Brasseur *et al.*, 2010a; Brasseur *et al.*, 2010b; Brasseur *et al.*, 2010c; Brasseur *et al.*, 2011a; Brasseur *et al.*, 2011b; Brasseur *et al.*, 2012; Kirkwood *et al.*, 2014; Brasseur and Kirkwood, 2015; Kirkwood *et al.*, 2015; Brasseur *et al.*, 2016; Brasseur and Kirkwood, 2016; Kirkwood *et al.*, 2016; Brasseur *et al.*, 2018a; Brasseur *et al.*, 2018b; Brasseur *et al.*, 2022; Aarts and Brasseur, 2023).

The tags used to produce the habitat maps are so called GPS/GSM tags, allowing for accurate location data and complete dive records. Table 1 shows the number of seals tracked using these trackers (Figure 2). Prior to this, 1989-1998, short-ranged VHF trackers (84 harbour seals) and then, 1997-2007, ARGOS trackers were used (14 grey seals and 79 harbour seals). Though the range for ARGOS trackers was larger than for VHF trackers, the accuracy and amount of data received was limited. We therefore concentrate on the tracks obtained using the recent GPS tags.

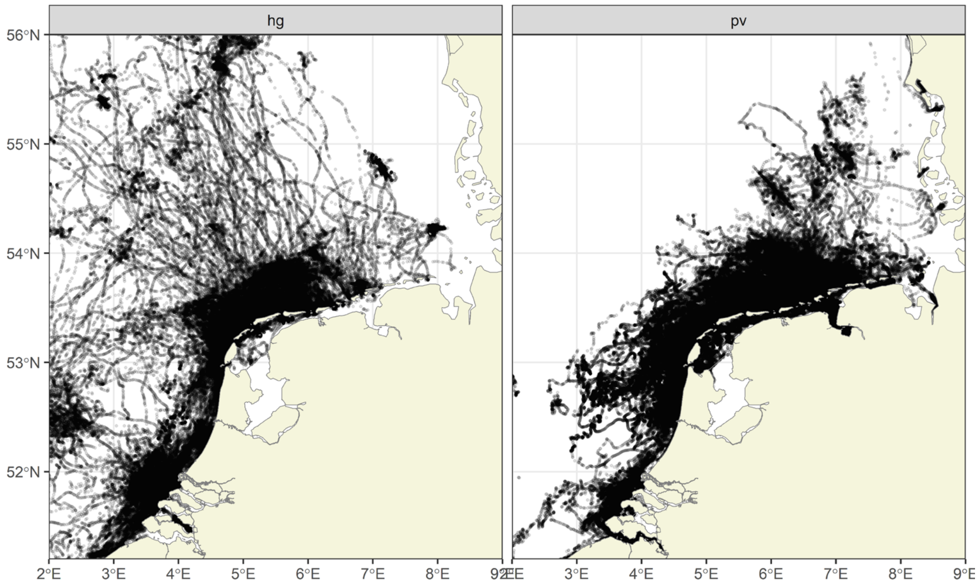


Figure 2. Distribution of all tracked grey seals (Halichoerus grypus-hg) left and harbour seals (Phoca vitulina-pv) right. See also Table 1.

c. Underrepresentation of young of the year in the KEC4.0 maps

Ideally, to produce the KEC maps, tracking data should have been collected systematically assuring a good temporal and spatial distribution. However, the data available (Table 1) originate from a diversity of projects carried out by WMR throughout the years in variable locations, hence the numbers varying over space and time. By far most data on wild seals (90%) were collected up to 2015, though one project was carried out in the Delta area in 2019 (Brasseur *et al.*, 2022), and captive seals were released with trackers in 2020-2022 (Aarts and Brasseur, 2024). Also, most data (>70%) are available on harbour seals.
For each project however, care was taken to use similar methods and tag seals from different age and sex groups. We generally aimed to collect data on equal amounts of adult males, adult females and subadults. In many studies, seals are grouped in these three different age/sex classes and tracking of very small seals i.e. young of the year was often avoided to limit the burden of the tracking experiment. *Figure 3* shows the size distribution of the tracked seals with the estimated size reached in the first year (Hauksson, 2007; Harding *et al.*, 2018)

In 2020 and 2022 young of the year harbour seals from Ecomare, a rehabilitation centre, were tracked (Aarts and Brasseur, 2024). Though the objective of the study was to develop new tags, it also allowed us to study the movements of these animals (Table 2).

Table 2. Overview of data on tracked rehabilitated seals

Name	sex	Date of rescue	App age at rescue (months)	Date of release	App age at release (months)	Weight at release	Duration of tracking
Snow white	m	22/10/2019	4	15/01/2020	7	40.7	161
Jet*	f	11/03/2022	9	06/05/2022	11		47
Malaika	f	28/6/2022	1	01/09/2022	3		104
Eddie	m	21/10/2022	4	01/12/2022	6	23.5	141
Jack	m	27/9/2022	3	01/12/2022	6	25.3	162

Emma	f	9/10/2022	4	01/12/2022	6	26.9	136

* This was a second rescue: was rescued and released in 2021

These animals were taken into rescue as young pups, thus had only experienced the wild for a very short time. Though some young seals had been tracked in the wild, this was the first time such naive young of the year were monitored using the detailed GPS/GSM trackers (Table 1). The tracks of these seals demonstrated a significant disparity in the distribution and duration of trips, when compared to the behaviour of previously tracked animals. The inexperienced animals spread over a larger area and made longer trips, utilising the outer edges of the known foraging distribution more extensively. This can increase the risk of being exposed to the activities around offshore wind parks (i.e., construction and operation) that are currently built at some tens of kilometres offshore. As the data had not been analysed yet, it was done for this memo. Analysis and results are presented below.

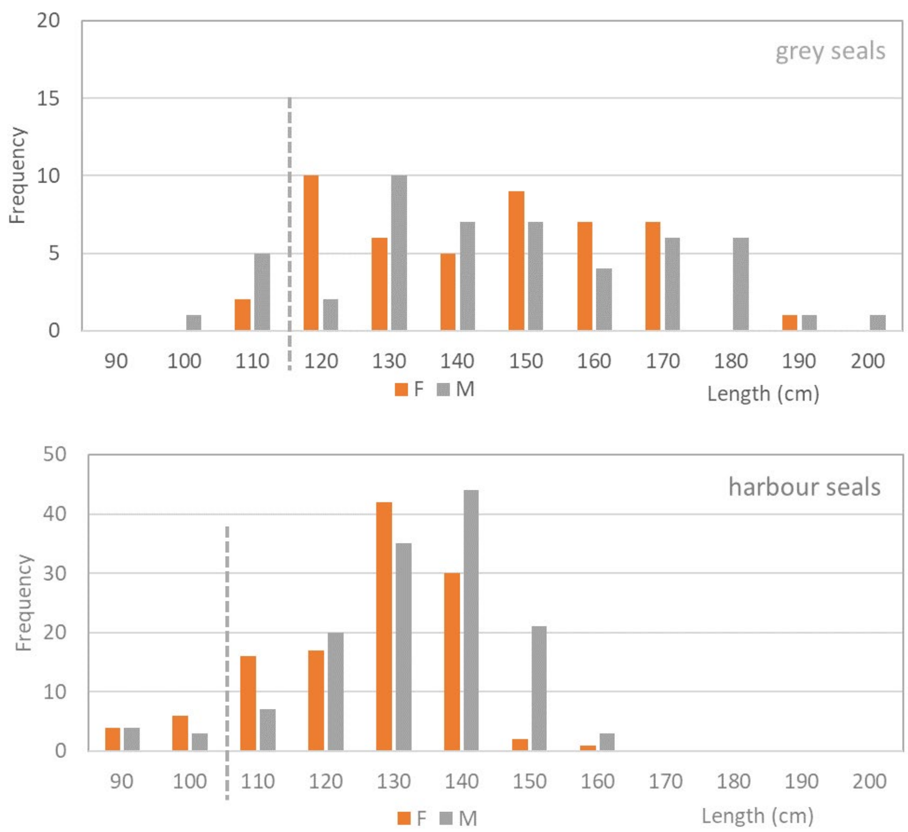


Figure 3. Length (standard length) distribution of wild seals tracked using GPS/GSM tags. Dotted vertical line indicates the approximate size of the seals in their first year (Hauksson, 2007; Harding et al., 2018).

Data processing and analysis – Like for the existing tracking data only GPS tracking data collected between the release of the animal and the loss of the tracker by the animal were utilised. The trip duration and distance were calculated based on the haul-out data, which refers to periods when the tracking device was dry for more than 10 minutes. The trip began when the tracker was wet for over 10 minutes and ended when the tracker was dry for over 10 minutes. Each trip's maximum distance was calculated as the straight-line distance between the GPS location and the average haul-out event location as during a haul out bout seals can move on the sandbank.

As mentioned above, in the Netherlands, so far, very few young of the year have been tracked (15 in total; Table 1; Figure 5). Until now, these tracking data have not been considered separately. If applicable, they were included into the category "sub adult" (Brasseur *et al.*, 2011c; Kirkwood *et al.*, 2016; Brasseur *et al.*, 2018a; Brasseur *et al.*, 2022).

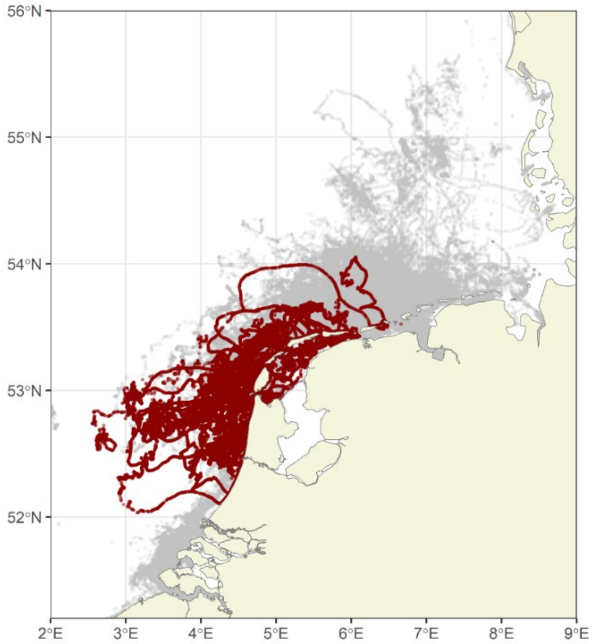


Figure 4. Distribution of the 6 juvenile harbour seals from the rehabilitation centre EcoMare (dark red) plotted on top of all harbour seal locations (light grey).

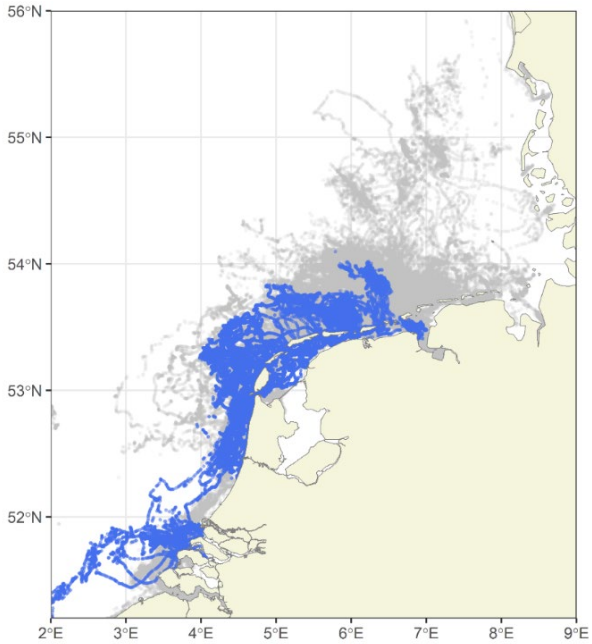


Figure 5. Distribution of the other juvenile harbour seals tagged in the wild smaller than 110cm (blue) plotted on top of all older harbour seal locations (light grey).

Despite the small sample size, it appears that compared to the older wild seals, the naïve rehabilitated seals exhibit a more extensive at sea distribution (Figure 4). To demonstrate this, Figure 6 shows nine examples of the distribution of six seals, randomly selected from all tracked animals, matching the number of seals tagged from Ecomare as shown in Figure 4. Clearly long-distance trips are less common among these individuals than among the captive juvenile seals. Furthermore, it seems that this is also the case for juvenile harbour seals that were tracked in the wild, although this is less pronounced (Figure 5).

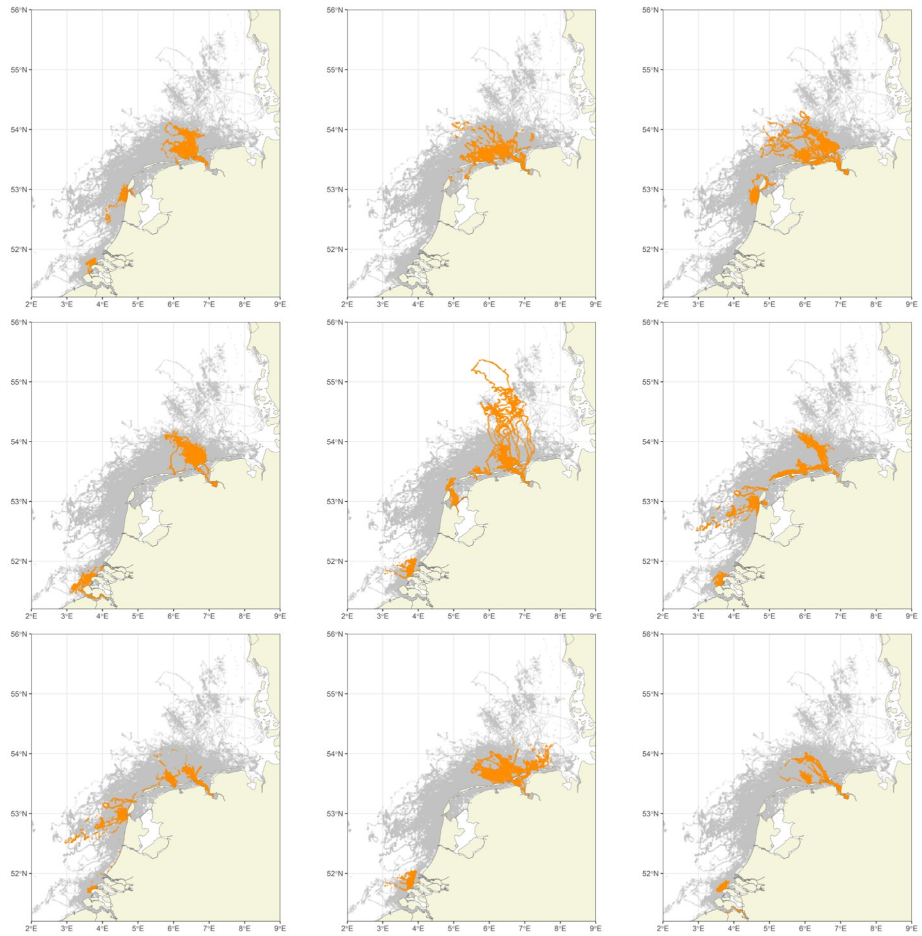
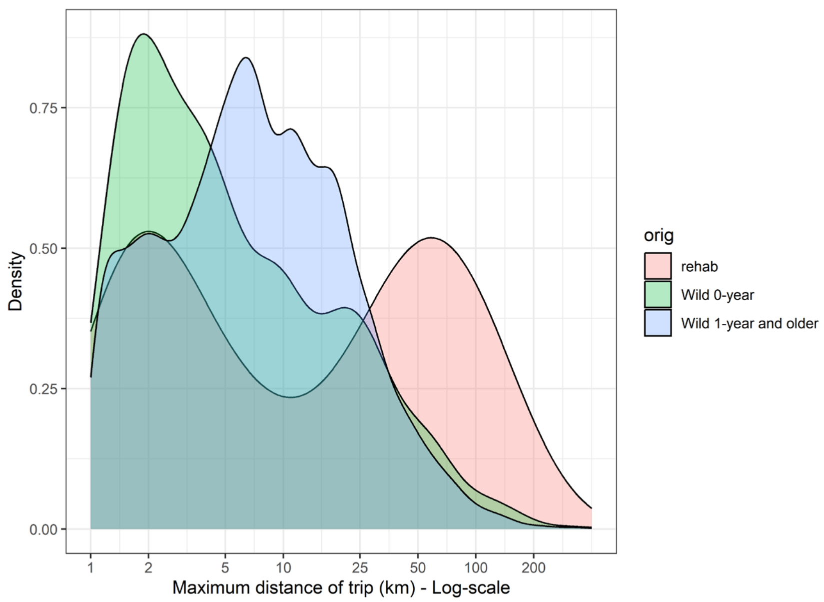


Figure 6. Nine distribution maps with each 6 randomly selected seals (orange) from all wild tracked seals (grey) to allow for comparison with the naive young of the year seals from the rehabilitation centre.

On average, naive young of the year from Ecomare embark on foraging trips that are considerably longer in duration and occur at greater distances from the haul-out sites (Figure 7). Furthermore, the trip duration of the seals that have been tracked thus far is highly correlated with the tidal cycle, averaging 7 hours, 19 hours, or 43 hours. A 7-hour trip occurs when seals depart the haul-out locations several hours prior to high tide and re-enter a few hours after the sandbank re-emerges before low tide. The 19- and 43-hour trips skip one or three low tides, respectively. The juveniles from Ecomare do not exhibit such a pronounced cyclic haul-out pattern, except for the seven-hour at-sea periods during which they enter the water around the high-water period, presumably when the sand banks are submerged.

The data available for the young of the year seals tracked from captivity suggests that those seals (who are probably more naïve about current prey distributions) disperse more widely, extensively using the periphery of their known foraging distribution. Also, trip durations appear longer, with several trips lasting more than a week. Occasionally, long trips were observed in tracking of the wild seals in former years, but this was much less common. Other studies have also shown that juvenile seals in general undertake longer trips to more remote regions than adults. For example, grey seal pups tracked from the UK exhibit more random searching and wider movement patterns compared to adults (Carter *et al.*, 2017)



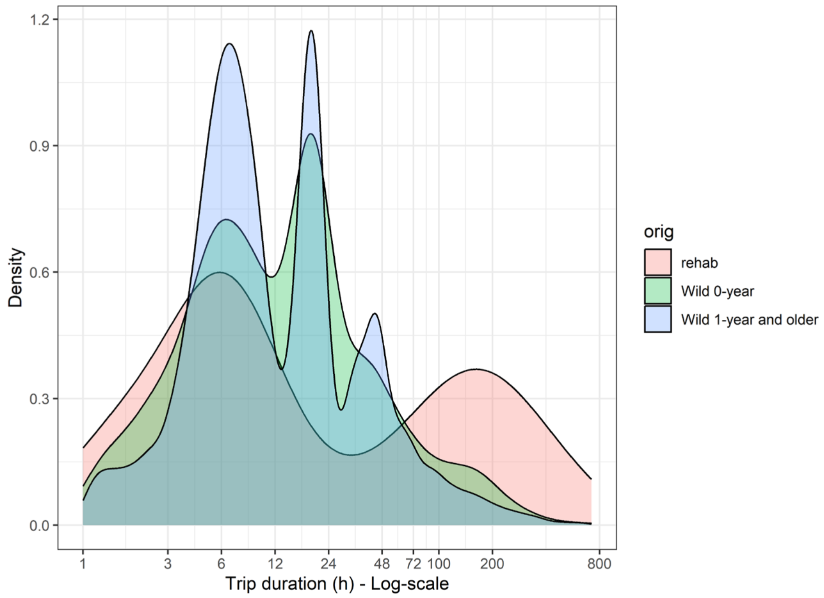


Figure 7. Frequency distribution of the distance of the furthest point relative to the haul-out (top) and trip duration (bottom).

Given the lack of other/recent tracking data from wild animals, it is unclear whether this behaviour is specifically applicable to young seals (naive rehabilitated juveniles), or whether this is a recent phenomenon and performed by all age classes as a result of the changing environment. A recent tracking study in the UK also revealed that harbour seals (tagged in the Wash) appear to use the remote Dogger Bank region more frequently compared to the animals they tracked earlier (Russell, pers. com.) This could indicate a change of all animals, however, the dataset available (with data scattered in time and location and lack of recent data) is not appropriate to test if these differences are only seen in young of the year or whether this is a general change in behaviour due to external changes (i.e. disturbance). We conclude that the distribution of harbour seals in peripheral areas of the existing habitat model might have been underestimated. To obtain correct maps for the KEC new tracking data should be collected from all animals but especially from young of the year.

d. Health and Population development

Recent population monitoring and wildlife tracking data have indicated that the survival, behaviour and distribution, of especially young seals, appears different from other age-classes. Such differences might also influence the impact of offshore wind farms on the seal populations.
In the KEC, an *Acceptable Level of Impact* during the construction of offshore wind farms was determined and was stated as follows: the populations on the Dutch Continental Shelf must be maintained at a minimum of 95% of the present level with a high degree of certainty (>95%). In other words, the probability of a population reduction ≥ 5% must be ≤ 5% (Heinis *et al.*, 2022). Above we have argued why some of the model assumptions do not match the latest field observations, and as a consequence both the mean and uncertainty of the estimated population level effects are probably incorrect. Population trajectories are driven by survival, reproduction and migration. Data on these vital rate parameters are imperative to support all models estimating population effects such as the IBMs, but also the iPCod used in the KEC so far, ensuring that the estimates and predictions are correct.
To estimate the population level consequences of disturbance, a series of steps are taken in the KEC 4.0-report (Heinis *et al.*, 2022). The step from days of exposure to estimating the impact on survival and reproduction is crucial. In the KEC 4.0-report (and those that preceded it), it is assumed that all seals can equally endure a significant amount of disturbance, before this will impact their survival. This resilience will however heavily depend on the condition of seals. Indeed, as capital breeders, seals can accumulate reserves to cope with periods of food deprivation, while breeding. However, we would like to stress that not all seals always high reserves at *all times*. Any of the seals might have a period with less reserves but especially young animals, with less experience finding food, are potentially more sensitive to environmental (natural or anthropogenic) changes. This might account for the current high mortality observed in harbour seals discussed below. Therefore, it should be considered, that even minor levels of disturbances and consequential missed foraging opportunities may push, mostly these young animals, over the edge.

Translation of the estimates of effects of disturbance into population health are often inaccurate, since lack of field data prevents to actually reflect natural variation in health of individuals in the population. Moreover, vital rate parameters under natural conditions are generally unknown. This certainly hold for seals in the Netherlands. Based on the precautionary principle, potential individual variation in health status of the seals should have been taken into consideration in the iPCoD model. Depending on the environment, a varying proportion of the population may be in a poorer condition than was assumed. A healthy seal at the start of the breeding season may be able to endure a certain level of disturbance, while after the moult or for a malnourished or sick seal the disturbance might directly affect its survival. This might be one of the most important causes of underestimation of the effects when using iPCoD. In this respect, current changes in the environment are expected to affect density dependent processes, either due to reduction of available habitat - disturbance- or growth of competing species, including the focal species itself. Density dependent processes ideally should be included in the iPCoD model for seals, to approach a realistic translation to population level consequences.

In Dutch waters, annual counts are carried out to follow the trajectory of the two seal populations. Below we discuss their trajectory. The results are published annually (https://www.waddensea-worldheritage.org/seals). Also, results of counts in other areas can be used to assess whether immigration from our coast to other areas might occur (ICES_WGMME, 2022). In some cases, studies that were originally designed for different purposes can help us make sense of changes in count results. These ad hoc studies can provide valuable insights and support our understanding and interpretation of changes observed in the count results. A good example are the various tracking studies done under various contracts throughout the years (see b: Tracking data).

The harbour seal population has been monitored annually since the last century and aerial counts are coordinated trilaterally (Denmark, Germany and the Netherlands) to obtain one count for the population (Brasseur *et al.*, 2018c; Galatius *et al.*, 2023). Albeit interrupted twice by a virus (PDV) epidemic, the population appeared to grow exponentially at an average rate of 8.9% until 2012 (Brasseur *et al.*, 2018c), after which a sudden change in the growth trend occurred and growth seemed to have ceased. Moreover, since 2021, the population is clearly decreasing (Galatius *et al.*, 2023). In 2021 a decline of 5% was registered, followed by a decline of 12% in 2022 and of 4% in 2023. Interestingly, when the population trend changed, the number of pups born continued to grow. At least, until recent years (blue line in Figure 8).

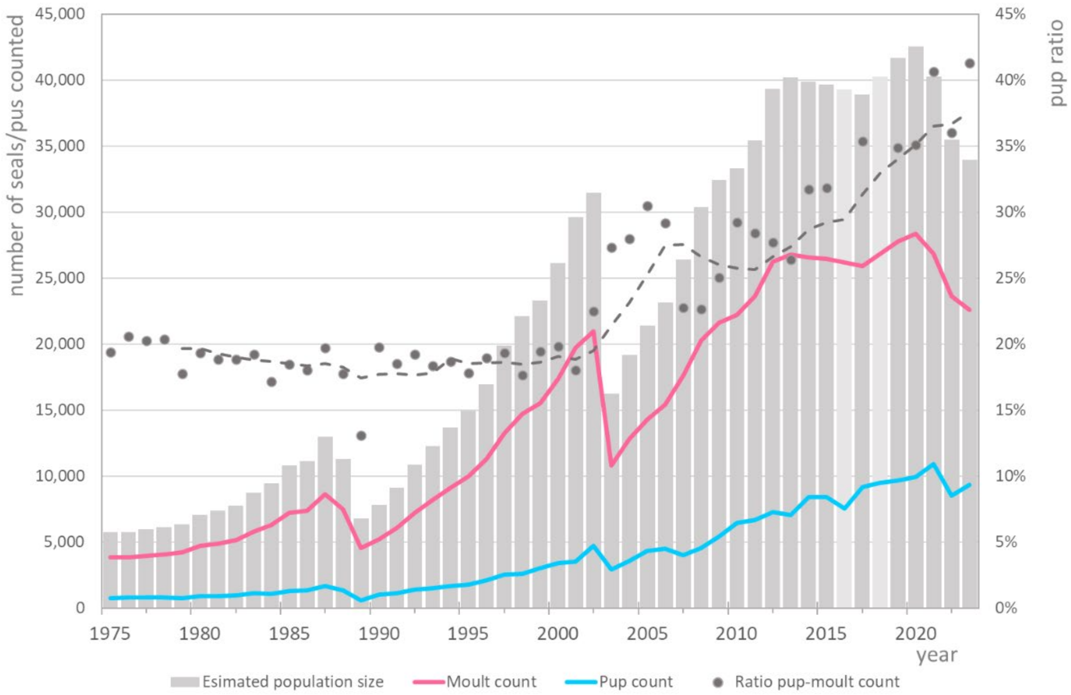


Figure 8. Seal counts in the international Wadden Sea during the moult (pink line), pup counts (blue line) and the pup ratio (pups/moult; dots and dashed line) 1975-2023 (data based on trilateral data collected at the Common Wadden Sea Secretariate, CWSS). Light bars indicate that population size was estimated based on incomplete moult counts see (Galatius et al., 2017; Galatius et al., 2019).

The observed population trajectory shows a clear trend change around 2013, and a recent drop in moult counts from 2021 onwards (Figure 8). The number of pups, in contrast, continued to increase after 2013, both in absolute and relative numbers (i.e. in 2023 40% compared to the adult counts during the moult; black dots in Figure 8). This growth in pup production indicates that rather than adult mortality or fecundity, the pup mortality, is the main cause for the trend change. This seems to be corroborated by the observation that after a period of stagnant growth (2013-2021) the population has started to decline. This could be explained by the lack of recruitment of young animals into the adult population. However, the exact mechanisms at play aren't still fully understood because there haven't been enough studies beyond annual counting. More research is needed to clarify the causes of the changes observed.

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Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. The organisation has been certified since 27 February 2001. The certification was issued by DNV.

Justification

Project Number: 4315100223

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

Approved: Dr. J.M. Ransijn
Researcher

Signature: Signed by:
5A8FF9F55DA6445...

Date: 4 november 2024

Approved: Maarten Mouissie
Business Manager

Signature: Signed by:
291E7A4CA7DB419...

Date: 4 november 2024