Pupping habitat of grey seals in the Dutch Wadden Sea

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IMARES rapport C009/15

IMARES
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BO-11-011.04-015

Cover photograph by RK: A grey seal pup on Griend.

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Summary

Atlantic grey seals (*Halichoerus grypus grypus*) started recolonising Dutch coastal haul-outs in the 1950s, after practically 500 years of rarity in the Dutch coastal zone which was caused mainly by human hunting. The first pup-birth was recorded in 1985 at the Wadden Sea sandbank of Engelschhoek.

Sandbanks in the Wadden Sea may form and recede in periods of decades, but may change abruptly as a result of a single storm. These rapidly evolving places are not the perfect breeding habitat for grey seals, which exhibit long-term fidelity to breeding sites and only reluctantly shift. Little is known of the geomorphology of the currently utilised pupping sites, nor the implications of change in structure on future occupation and selection of new sites.

Now in the early 2000s, grey seals give birth to pups at five key locations in the Netherlands – all in the Wadden Sea area: Richel (67% of the pups born); Engelschhoek (14%); Griend (2% and increasing); Razende Bol (5%); and Steenplaat (4%). These are critical locations for the sustainability of the recolonisation of grey seals. There are approximately 400 grey seal pups born in the Dutch Wadden Sea each November-January. This is the most grey seal births in continental Europe and 1% of total births for the species. Most births are in the UK. The natural development of the grey seal population in the Netherlands requires key pupping locations to be adequately protected from human disturbance, particularly during pupping periods.

Conservation of grey seals in the Netherlands is managed by the Ministry of Economic Affairs in accordance with the European Commission's Habitats Directive. This directive requests Member States to undertake surveillance of, and seek a 'favourable' status for, habitats and species of 'Community Interest'. Due to a lack of knowledge on grey seals, the Ministry has sought further data on habitat quality and monitoring of population structure in the Netherlands.

This report continues research into the habitat quality and population structure of grey seals in Dutch waters (Brasseur et al. 2014). It presents new research related to:

1. *Geomorphology and vegetation of the important pupping sites of Richel, Griend and Engelschhoek.*
2. *Exchange of grey seals between the Dutch Wadden Sea and other regions.*
3. *Ameliorating potential errors in long-term monitoring of grey seal pup production.*

<u>1- Geomorphology and vegetation of important pupping sites</u>

a) Grey seals require land habitat to rest, moult, have pups and breed. The habitat utilised for pupping is the most critical land habitat for population sustainability. Selection of a pupping site by the seals and stability of the site over time is influenced by its geomorphology. Data were limited on the geomorphology of key pupping sites in the Dutch Wadden Sea.

b) Inundation at pupping sites during the pupping period can reduce pup survival. The geomorphology of a site determines among others its inundation risk.

c) The preferred pupping/ breeding habitat for grey seal in the Wadden Sea consists of sandy areas above mean high tide, with or without vegetation. These are islands and shoals with supra-tidal sandbars (not part of a N2000 habitat type), and dunes (*Embryonale duinen* [H2110], *Witte duinen* [H2120]). Limited use is made of *Zilte pionierbegroeiingen* [H1310], *Slijkgrasvelden* [H1320] and *Schorren en zilte graslanden* [H1330]. Lower areas just above mean high tide (sand flats and beaches) have easier access, whereas dunes (above +3 m NAP) offer safety during storms.

d) We surveyed the geomorphology and vegetation of the pupping sites of Engelschhoek (a bare sandbar), Richel (a partly vegetated sandbar) and Griend (a small dune and salt-marsh island), all located within the Vlie tidal basin (between Vlieland, Terschelling and the mainland).

e) The sites vary in accessibility, elevation, vegetation, and seal use. Complete flooding, which can lead to flushing of seals, happens on average more than five times per year on Engelschhoek, between two and five times on Richel, and less than once in every ten years on Griend. Griend hence offers most protection against storm events. However, Griend is the least accessible. It is surrounded by several hundred metres of shallow water whereas the others are beside deep channels and are nearer to the North Sea. Being less accessible probably influenced the later colonisation of Griend.

f) The current level of seal use does not have a significant influence on either geomorphology or vegetation of the pupping sites. This may change if seal numbers increase.

g) All study sites are dynamic, and thus the seals will have to adapt to the changing, sometimes sub-optimal, conditions of their pupping sites. Within the coming decades, Engelschhoek will most likely weld with Terschelling. In the meantime it remains an unvegetated sandbar. Richel may develop further into a 'real' island with white dunes and a salt marsh, depending on the number and intensity of storms in the coming years, and other geomorphology processes. Griend is eroding and will soon be 'nourished', i.e. artificial dumping of sediment to extend and protect the island, and create more potential nesting habitat for birds.

h) Based on the geomorphology, there are yet unused locations in the Dutch Wadden Sea suitable as pupping habitat. These include the inhabited islands, where the dunes would offer good protection during storms. Disturbance due to human use is most likely inhibiting such occupation, but given sufficient protection in places, colonies could establish. Most likely places are the dunes of the western Islands (Texel, Vlieland & Terschelling) where currently single births of grey seals are reported. Policing by local government and interest groups could provide areas with sufficient protection from human disturbance to allow females to remain and rear pups to weaning. This could be occurring adjacent to the harbour on the north-east side of Vlieland, where several females reared pups to weaning in 2014.

<u>2- Exchange between the Dutch Wadden Sea and other areas.</u>

a) Modelling of grey seal population data collected in the Netherlands confirms that a proportion of the seals, born in the UK, are incorporated into Dutch colonies (Brasseur et al. 2015). Also, a number of grey seals that breed in the UK occupy Dutch waters and coastlines outside the breeding period. The exchange between the Netherlands and the UK is evident in individual movements recorded during telemetry studies in the past decade.

b) Quantification and a better understanding of the underlying mechanisms for the migrants require a longer-term study (photo-ID plus genetics).

c) A photo-ID program was commenced in the framework of this project, in cooperation with researchers at the Sea Mammal Research Unit (SMRU, St Andrews, Scotland). SMRU researchers developed the photo-ID method for grey seals and have a data base of over 20 000 seals mostly from UK colonies. Processing and pattern matching of images in 2014 recorded one match between the Donna Nook site (UK) and Steenplaat (NL), two matches of breeding females from Griend at Steenplaat, and multiple between year matches at both Griend and at Steenplaat.

3- Ameliorating errors in monitoring of pup production.

a) Hindrances to accurate grey seal pup production monitoring in the Dutch Wadden Sea relate to site accessibility (e.g. winter pupping, the difficulty of discerning pups in vegetated areas, distances between sites, disturbance issues), and to the seal's breeding biology (e.g. asynchrony in pupping, brevity of maternal support, gregarious behaviour).

b) The current method of estimating annual pup production is to perform a series of overflights of sites during the pupping period, count observable pups, and incorporate published durations of maternal support and model counts over time to derive peak pupping data and total numbers of births. One immediate source for error in the estimate relates to pups being obscured from the aerial view, by vegetation, dune structure or other seals.

c) Visits to breeding sites of Griend and Richel, where most counting error due to obscuring likely occurs, were timed to over-lap with aerial surveys during December.

d) Comparisons between aerial and ground counts revealed that on Griend, aerial counts could miss a significant proportion of pups present – e.g. 30% missed in 2013. In 2014, due to breeding concentrating only on the north coast and staff on the island directing the aerial survey, all but one of the pups were detected.

e) On Richel, ground-based observations did not assist aerial surveys to record pup numbers because observers on land could not see into the centre of the vegetated area where aerial surveys revealed most pups were present. Greater elevation (such as using ladders) would be required to improve the accuracy of the ground counts. Counting while moving through the vegetation patch is not recommended because of the disturbance this would cause to the seals.

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1 Introduction & Methodology

1.1 Conservation status of grey seals in the Wadden Sea

The grey seal *Halichoerus grypus* is one of two species of pinniped seals that lives and breeds in the Netherlands; the other is the harbour (or common) seal *Phoca vitulina*. The greatest numbers of both species are observed at haul-out sites in the Wadden Sea region; both species also haul out at sites in the Delta region (i.e. Zeeland and part of South Holland). During recent decades, the numbers of both species have increased in both regions.

The primary level of governance for management of grey seals in the Netherlands is the Ministry of Economic Affairs (*Economische Zaken*). Under the Habitats Directive (HD), this ministry defines the conservation status of protected habitats (HD Annex I) and species (HD Annex II) and sets conservation objectives (both at a national level and at a Natura 2000 site level). The objectives strive to achieve a 'favourable' conservation status for the habitats and species at a national level.

The conservation status for a species is defined in the Habitats Directive as the sum of influences acting on the species which may affect the long-term distribution and abundance of its' populations. Status is taken as 'favourable' when:

1. population dynamics data on the species concerned indicate that it is maintaining itself on a long term basis as a viable component of its natural habitat;
2. the natural range of the species is neither being reduced nor is likely to be reduced for the foreseeable future; and
3. there is, and probably will continue to be, a sufficiently large habitat to maintain populations on a long-term basis.

For grey seals, although other components were assessed as 'favourable', the habitat quality was assessed as 'unfavourable/ inadequate' (due to sub optimal breeding conditions at pupping sites), and hence the overall assessment was 'unfavourable'. However, since the population of grey seals was growing, the Ministry did not opt for an 'improvement target' ('*verbeteropgave*'), but for a target to conserve the situation as it was when the Natura 2000 site 'North Sea Coastal Zone' ('*Noordzeekustzone*') was placed on the list of sites of Community Interest (SCI, '*behoudsopgave*'). The same conservation target was set for the Natura 2000 area 'Wadden Sea' (also '*behoudsopgave*').

In 2011, an appeal to the Dutch high court (*Raad van State*) (case 200902398/1/R2) argued that an improvement target ('*verbeteringsopgave*') was needed to shift the conservation status of grey seals to 'favourable'. In 2013, the Dutch high court rejected the appeal (case 201104368/1/A4[1]). However, the ministry and appellants did not dispute that there were knowledge gaps with respect to the status of grey seals in the Netherlands, particularly regarding pup survival and the importance of an influx of seals, mainly from the UK. This report continues a previous study (Brasseur et al. 2014) to redress these knowledge gaps.

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[1] http://www.raadvanstate.nl/uitspraken/zoeken-in-uitspraken/tekst-uitspraak.html?id=74490

The national conservation status of the grey seal in the Netherlands is described in the Natura 2000 species profile document (see web page[2], last accessed February 2015).

1.2 Project objectives

Primary objectives of this research project are to investigate:

1. Geomorphology and vegetation of key pupping sites,
2. Exchange/ immigration from other areas, *and*
3. Amelioration of potential errors in aerial-survey based, pup counts.

1.3 Methodology

Sub-project 1. Geomorphological and vegetation of key pupping sites.
The Wadden Sea is a constantly evolving environment for grey seals, with sandbars forming and submerging in periods of decades, or in some cases (i.e. during heavy storms) within days. But grey seals exhibit long-term fidelity to breeding sites and only reluctantly shift. Little is known of the implications of rapid change in breeding habitat on grey seals. So, in terms of pup survival during the pupping period, Wadden Sea sandbars are not ideal long-term pupping locations for them.

Currently, grey seals in the Netherlands rely heavily on one pupping site, the island of Richel. Two other important sites are the islands of Griend and Engelschhoek. These sites are all within the same catchment area: the Vlie, between the Islands of Vlieland and Terschelling. Only a few pups are born in other areas, such as around Texel and Ameland. There are many management implications of the reliance of grey seals on few sites. For instance, 1) stability of the sites could enhance the growth while instability could retard/ disrupt the recolonisation process of the area; 2) grey seals may alter vegetation and geomorphic processes at these islands, and 3) medium term habitat-altering processes at these sites could (in an untimely fashion) force hundreds of grey seal females to search for adjacent beaches to have their pups. As an example, if Richel were inundated by high seas in winter, as occurs occasionally, there could be 300-500 grey seal cows seeking adjacent beaches on which to pup. If the timing of the inundation is a few weeks later, hundreds of grey seal pups could be distributed on beaches around the Wadden Sea.

To assess the geomorphological and vegetation processes at key pupping sites required a combination of literature surveys and field investigations. The field investigations were undertaken in both summer and winter.

Questions

1. What are the preferred pupping/ breeding habitat for grey seal seals in the Wadden Sea (altitude, geomorphology, vegetation, area)?
2. What are the links between habitat and grey seal status at the islands of Richel, Engelschhoek and Griend?
3. Are the seals themselves modifying the habitat?

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[2] http://www.synbiosys.alterra.nl/natura2000/documenten/profielen/soorten/Profiel_soort_H1364_2014.pdf

4. How stable is the habitat at the important breeding sites of Richel, Engelschhoek and Griend? How will this habitat change in the (near) future?
5. Is periodic flushing of seals from breeding habitats in the Wadden Sea inevitable?

Sub-project 2. Estimated population exchange.

Grey seals in the Netherlands are North Atlantic grey seals which range around the UK and continental Europe from France to Norway (Härkönen et al. 2007). Part of the increase of grey seals in the Netherlands is related to temporary or permanent migration from other areas, particularly the UK where grey seal numbers are greatest (Brasseur et al. 2015). It is not known what percentage of seals in the Netherlands, breed or migrate through territories of other nations.

One effective way to examine levels of exchange between different regions is through matching the highly individual patterns on the pelage. Photography and pattern matching analysis has linked seals to different regions (see webpage[3]). The present proposal aims to utilise the established photo-ID technique with a much greater sample size. Links between areas may also be investigated through seal tracking and genetics studies.

Questions

1. What are the broader links between grey seals in the Wadden Sea and grey seals elsewhere?
2. Is population status linked to immigration, and where are immigrants coming from?
3. To what extent are migratory seals influencing growth in the number of seals that utilise the Wadden Sea?

Sub-project 3. Ameliorating potential errors in aerial survey based pup counts.

The aim of this sub-project is to better quantify how many pups could be obscured from aerial photography by vegetation and other ground features. This required simultaneous aerial-survey based pup counts and ground surveys at the key pupping habitats of Griend and Richel. The study involved field-trips to the islands during summer, when no seals were present, to map the substrate, and in winter, to monitor pup numbers and distribution.

Questions

1. How can the accuracy of grey seal pup estimates from aerial surveys be improved?
2. How can the within colony distribution of grey seals be determined accurately?

Field program

All appropriate permits for visits to the field sites were obtained and crew of the *Rijksrijderij* vessel *MV Stormvogel* provided field support (Table 1).

Table 1. Timing of visits to grey seal pupping sites of Richel, Griend and Engelschhoek in 2014.

	Richel	Griend	Engelschhoek
Summer	21 August 2014	20 August 2014	21 August 2014
Winter	30 December 2014	13-16 December 2014	

[3] http://www.isleofmaygreyseals.co.uk/?page_id=16

2 Grey seals in the Netherlands

2.1 Breeding biology

Grey seals are large mammals that have a long lifespan, delayed maturity and low rates of adult mortality (Promislow & Harvey 1990). Longevity is up to 26 years for males and 46 years for females.

Grey seals typically give birth to a single pup once a year. They are colonial breeders and gather in numbers at pupping sites that may only be utilised during the pupping period, although several are also year-round haul-out sites. Grey seals have a 16-21 day suckling period during which the mother and pup stay close by each other. Pups weigh approximately 15 kg at birth and 20 to 60 kg at weaning (Hall et al. 2008).

After weaning, grey seal pups may stay on land for a month to undergo a moult and converting fat into muscle (Boyd & Campbell 1971). Some pups will depart within a week of weaning, however, and complete undergo the moult away from the colony. Un-moulted pups from colonies in the UK occasionally cross the North Sea and come ashore on Dutch beaches. This is demonstrated by the arrival in the Netherlands of paint-marked pups from the Farne Islands, where, as part of a long-term study, all pups are painted with a dye on weaning.

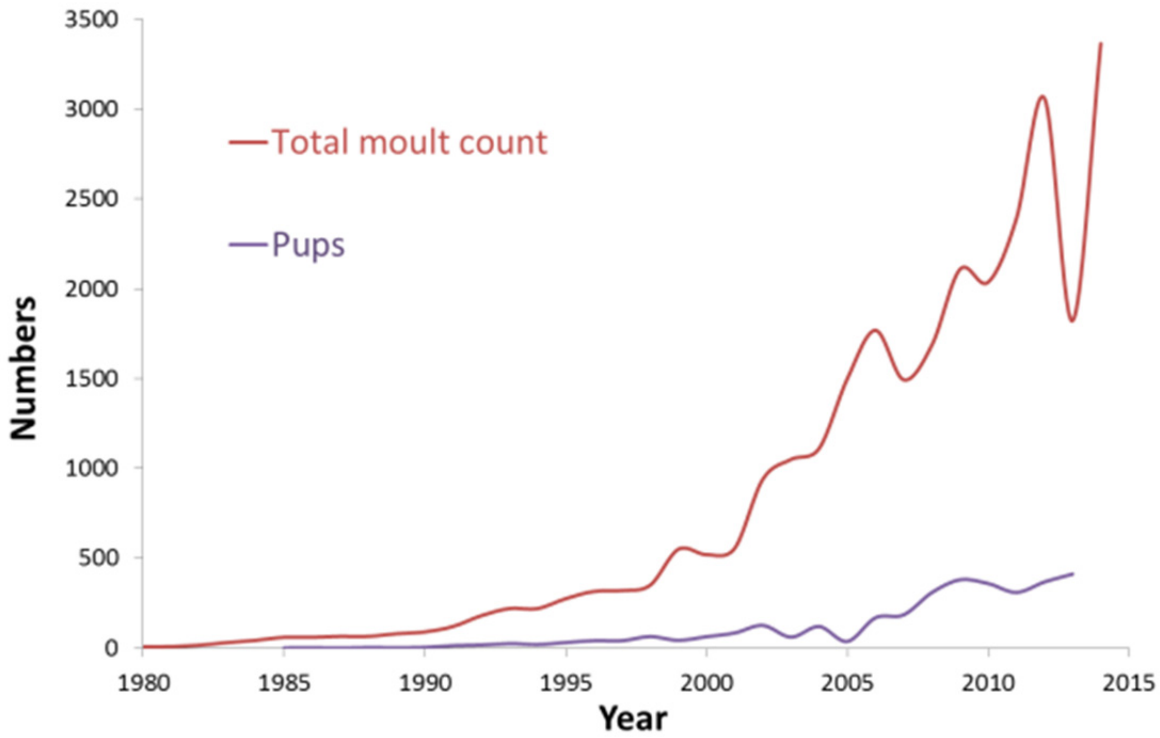
Sexual maturity in grey seal females is at 3-6 years of age (Hammill & Gosselin 1995) and thereafter, each year, 83-94% of adult females give birth to a pup (Boyd 1985). The mean age of sexual maturity in males is 6 years although they may not achieve social maturity and hold a territory until aged 8 (Hammill & Gosselin 1995).

The time of year when grey seals give birth varies between late-Summer to autumn in western and northern colonies of the UK, to winter in southern UK colonies, the Netherlands and Germany. Recently, the timing of the pupping period has crept earlier in the Netherlands. The peak was in early January in 1985 but in early December by 2010, a mean rate of change of 1.3 days per year (Brasseur et al. 2015).

2.2 Population trends

After centuries of virtual absence in the Dutch Wadden Sea, grey seals were recorded more often after the 1940s (van Haaften 1975, Reijnders et al. 1995). During the 1970s, seals were observed on sandbars between the islands of Vlieland and Terschelling, particularly at Engelschhoek (Reijnders et al. 1995). Between 1980 and 1983, annual maxima at these sandbars grew from 10 to 40. In 1985, at Engelschhoek, approximately 40 seals were present and the first pup-birth in the Netherlands was recorded (Reijnders et al. 1995).

Annual surveys of grey seals in the Netherlands cover the pupping period (November-February) and the moulting period (March-April), and have recorded increases (Figure 1). For example, pup numbers increased at a rate of 19% per year between 1985 and 2010 (Brasseur et al. 2015). This rate exceeds growth rates elsewhere, e.g. 5-7% at colonies on the North Sea coast of the United Kingdom (Thompson & Duck 2010). The rate also exceeds the estimated maximum growth possible for an isolated seal population of 11% (Härkönen et al. 2002). Reasons for the high growth rate in the Wadden Sea could be a combination of high intrinsic survival supported by immigration.



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

Figure 1. Numbers of grey seals counted during the peak of moult each year and numbers of pups counted in the Dutch Wadden Sea between 1980 and 2014.

2.3 Breeding sites in the Netherlands

Grey seals are capable of pupping along most coastlines of the Netherlands. All the larger islands and much of the coast bordering the western part of the country contain sand beaches that are comparable to sites currently occupied by grey seals in Canada and the UK (Brasseur et al. 2014). Potentially, the only areas within the Wadden Sea where there are physical barriers to occupation are those that have man-made barriers (such as dikes and harbours).

Pupping locations are predominantly sandbars in the western Wadden Sea, although births occur at other locations, including on inhabited islands (Figure 2). There are five key colony sites: Richel (67% of the pups born); Engelschhoek, Griend, Razende Bol and Steenplaat (Figure 3 and Table 2).

Figure 2. Main locations of grey seal pup births in the Dutch Wadden Sea since 1980 (Google earth map).

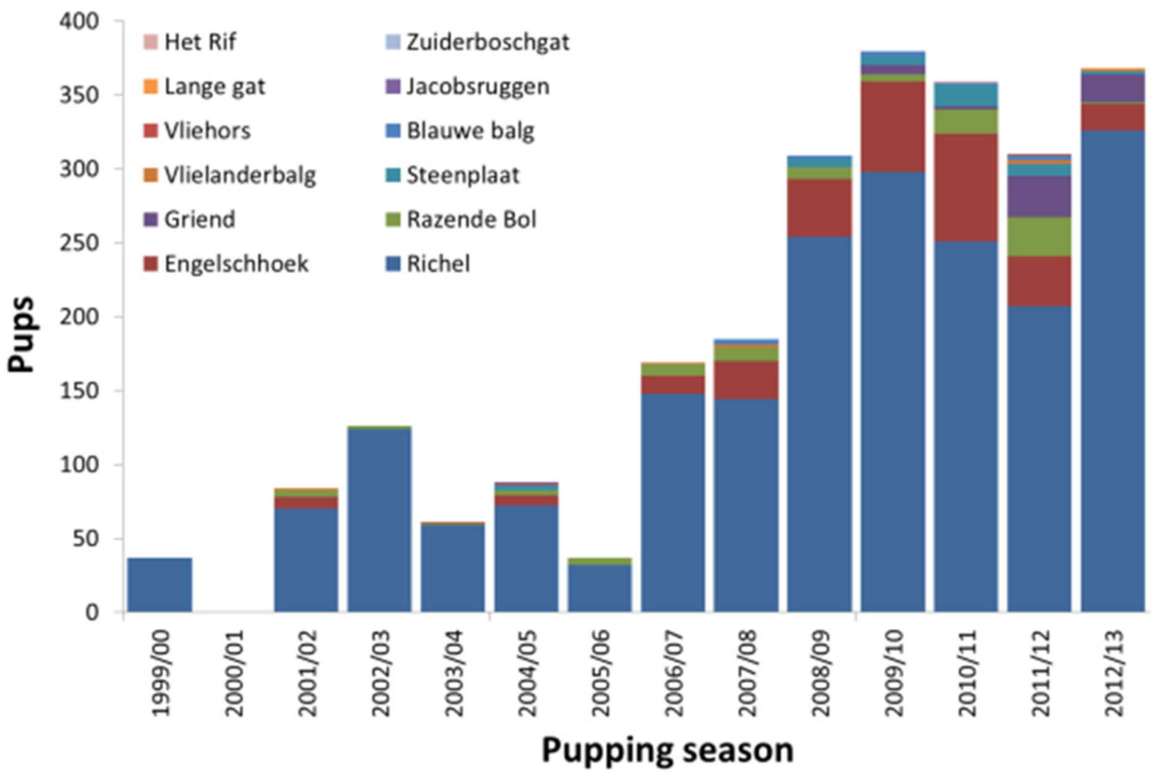


Figure 3. Locations of grey seal pups recorded during surveys in the Dutch Wadden Sea between 1999/2000 and 2012/13.

Table 2. Pup production at colonies in the Dutch Wadden Sea.

Colony	Mean percent births per year 2008 to 2012	Comment
Richel	67%	
Engelschhoek	14%	Maximum in 2010/11
Griend	2%	Growing since 2007
Razende Bol	5%	No pups in 2012/13*
Steenplaat	4%	Less in 2011

*Pupping probably was deterred at Razende Bol in 2012-13 by a high disturbance level with visitation to a stranded whale.

Richel is situated adjacent to the channel between the islands of Vlieland and Terschelling. Pup production there developed in stages. Between 1999 and 2005, an average of 66 pups was recorded (range 32 to 124, Figure 3). In the next three years there was a rapid increase to >200 pups. Between 2008 and 2012, an average of 267 pups was recorded each year (range 207 to 326).

Like most sandbars in the Wadden Sea, most of Richel is inundated when water-levels achieve >2 m above NAP (Amsterdam Ordnance Datum) (see also chapter 3.6). This occurs 2-5 times a year. Between 1987 and 2007, 18 inundations coincided with the November to January pupping period: three in November, nine in December and six in January. There were only six pupping seasons when the Richel was not flooded. Storms in December and January are of more consequence for pup survival because then, many un-weaned and post-weaned pups are present, and vulnerable to premature separation from mothers and drowning. It is difficult to determine the exact loss of pups as a result of inundations. Many undoubtedly survive and remain associated with Richel. For example, on a visit to Richel on 16 December 2013, 10 days after a complete inundation on 6 December, several hundred pups were present.

Despite the on-going inundations and associated loss of pups, grey seals have not abandoned Richel. In fact, the number of females that pup there continues to grow. Either alternative sites are not apparent to them or the flooding is not a strong mechanism to trigger a change in pupping site. Since around 2006, a patch of vegetation has established on Richel and the majority of pups are now born in this patch (Figure 4).

Figure 4. Aerial view of Richel 15 September 2014. The dark patch on the sandbank is vegetation that developed since 2006 and is where the majority of grey seal pup births in the Netherlands now occurs photo by RK).

Engelschhoek is 4 km north of Richel and also beside the channel between the islands of Vlieland and Terschelling. Unlike the Richel, Engelschhoek extends partially into the North Sea. It is where the first grey seal births in the Dutch Wadden Sea were recorded. By the early 2000s, however, Richel had replaced Engelschhoek as the most important pupping site. Then, between 2002-04, Engelschhoek was submerged, so no pup births could take place there for 2-years. After re-emergence, grey seals returned to pup at Engelschhoek. The number of pups born there has fluctuated up to a maximum of 73 in 2010-11 (20% of pups born in the Netherlands that year).

Griend is a small (1 x 0.5 km), vegetated, island within the Wadden Sea. It is associated with the same channel network as Richel and Engelschhoek. The first record of grey seal births on Griend was 'six pups present' on 14 December 2007 (in hut log-book). This pre-dated the first winter aerial surveys of Griend in 2009/10, when six pups were identified in aerial photographs. In 2012, Griend become the second most important pupping site for grey seals in the Netherlands, surpassed only by Richel.

Razende Bol and Steenplaat are also important pupping sites that are on sandbars beside channels entrances to the Wadden Sea. Both are south-west of Richel and Engelschhoek.

Other sites within the Wadden Sea where grey seal pup births have been recorded represent incidental or occasional pupping locations. Some of these sites could, if minimally disturbed, develop into colonies in the future, particularly if the breeding group in the Netherlands continues to increase in size. Occasionally, grey seals have given birth on main islands (such as Texel, Vlieland and Terschelling, eg Figure 5).

Figure 5. Grey seal cow giving birth in a coastal field on the island of Vlieland in November 2014 (photo © Staatsbosbeheer, Vlieland, accessed from www.waarneming.nl).

2.4 Background for this report

Grey seals are an on-going management issue for authorities. They are charismatic marine mammals that are highly visible and stimulate great public emotion. Sections of the community wish to offer seals greater protection. Other sections view seals as competitors for limited resources. All management decisions over seals are likely to be controversial. Critical to competent management-decision making is adequate and robust data on habitat quality and use, population structure and trends.

Due to the international protection laws, management impetus is towards protection and conservation of grey seals. However, the population is growing, partly due to immigration and partly intrinsic growth (Brasseur et al. 2014b). With increased numbers, more breeding sites are likely to be colonised, reducing the present vulnerability of having the vast majority of births at one site (Richel). Levels of interaction with human activities, e.g. recreation and fisheries, are likely to increase.

As noted in the introduction, all current pupping sites of grey seals in the Netherlands are flooded by extreme high tides and by high storm surges. Because grey seal pups usually do not swim until 3-7 weeks after birth (3-weeks of maternal support and up to 4-week of post-weaning period), flooding at the current sites poses a risk to them, causing drowning and separation of mothers from pups. Because of the vulnerability to inundation, current pupping sites can be considered sub-optimal for pup survival (Brasseur et al. 2014a).

Within the Netherlands, alternative habitats for the seals to colonise are available, including coastal beaches and adjacent dunes of the mainland and Wadden Sea islands. At such places, the seals may stay dry for as long as needed. Grey seals have not colonised these sites yet, most likely in part due to human disturbance as well as fidelity to other sites once breeding had established at them. Future colonisation of such sites might occur provided disturbance is minimised, particularly during the first years of colonisation.

Chapter 3 of this report deals with the geomorphology of key breeding sites. Continued growth and distribution of grey seal pupping in the Netherlands will be influenced by geomorphological developments at the current breeding sites. For example, the current growth of pioneer vegetation on Richel suggests that the sandbar is getting higher and potentially more stable. On the other hand, erosion is currently reducing the size of Griend and thereby reducing the pupping capacity that could be achieved there. The geomorphology of current breeding habitats in the Wadden Sea is an important factor influencing the long-term sustainability of a viable breeding group in the Netherlands.

Chapter 4 of the report continues investigations of the structure of the group of grey seals that occupies the Dutch Wadden Sea. Modelling of grey seal population data collected in the Netherlands confirms that a proportion of the seals, born in the UK, are incorporated into Dutch colonies (Brasseur et al. 2015). Approximately 35% of the one-year-old grey seals in the Wadden Sea are estimated to come from the UK. Also, grey seals that breed in the UK occupy Dutch waters and coastlines outside the breeding period. The exchange between the Netherlands and the UK is evident in recent telemetry studies.

Quantification and a better understanding of the underlying mechanisms for movements require a long-term study, such as photo-ID plus genetics. This is of importance to further understand the inter-dependency of the colonies in the North Sea. A photo-ID program commenced in the framework of this project in 2013, in cooperation with researchers at the Sea Mammal Research Unit (SMRU, St Andrews, Scotland). SMRU researchers developed the photo-ID method for grey seals and have a data base of over 20 000 seals mostly from UK colonies.

Chapter 5 of the report further investigates means for maintaining accurate estimates of grey seal pup production. The growth in pup numbers at the vegetated sites of Griend and Richel, are increasingly difficult to accurately count using aerial surveys alone. Due to the undulation in the substrate, density of seals and moving vegetation, an unknown and variable proportion of pups could be obscured from aerial photography. Also, protraction of the pupping period means that some pups will leave (wean or die) prior to the birth of other pups, so multiple aerial flights are required and actual estimates require modelling of turn-over rates. The grey seal pup counts form the basis of monitoring of grey seals in the Netherlands. More knowledge of the sites and better methods of obtaining accurate pup counts are required.

3 Geomorphology and vegetation of important pupping sites

3.1 Study sites

As the largest proportion of grey seal pups are born in the Vlie tidal basin between the islands of Vlieland and Terschelling, three pupping sites in this area were studied in detail: Engelschhoek, Richel and Griend (Figure 6). Engelschhoek is an unvegetated sandbar in the ebb-tidal delta. Though only a small proportion of pups are born here, the site is the most important moulting site (more than 2000 animals) and it is used throughout the year. Richel is a sandbar just inside the back-barrier area on which a vegetated embryonic dune field has developed recently. Here by far most pups are born, but during the rest of the year the site is most often vacated. Griend is a remnant of a previously much larger island which is now eroding and has been nourished twice. Griend is fully vegetated. The site is only used during pupping by a relatively small number of seals. In addition to differences in grey seal colonisation, the locations differ in habitat characteristics and dynamics. This chapter deals with the geomorphology and vegetation of the three locations, to assess habitat suitability and stability.

In this chapter, we first provide background information on the formation of shoals and islands in the Wadden Sea. Then, we detail the methods used in this study. Results and discussion are presented for the Vlie tidal basin as a whole, then the pupping sites in the order of colonisation by the grey seals: first Engelschhoek, then Richel and finally Griend. This coincides with, but is most probably not related to, the age of the sites (young to old) and to which degree they are vegetated (bare to vegetated). A final discussion is presented on pupping habitat characteristics.

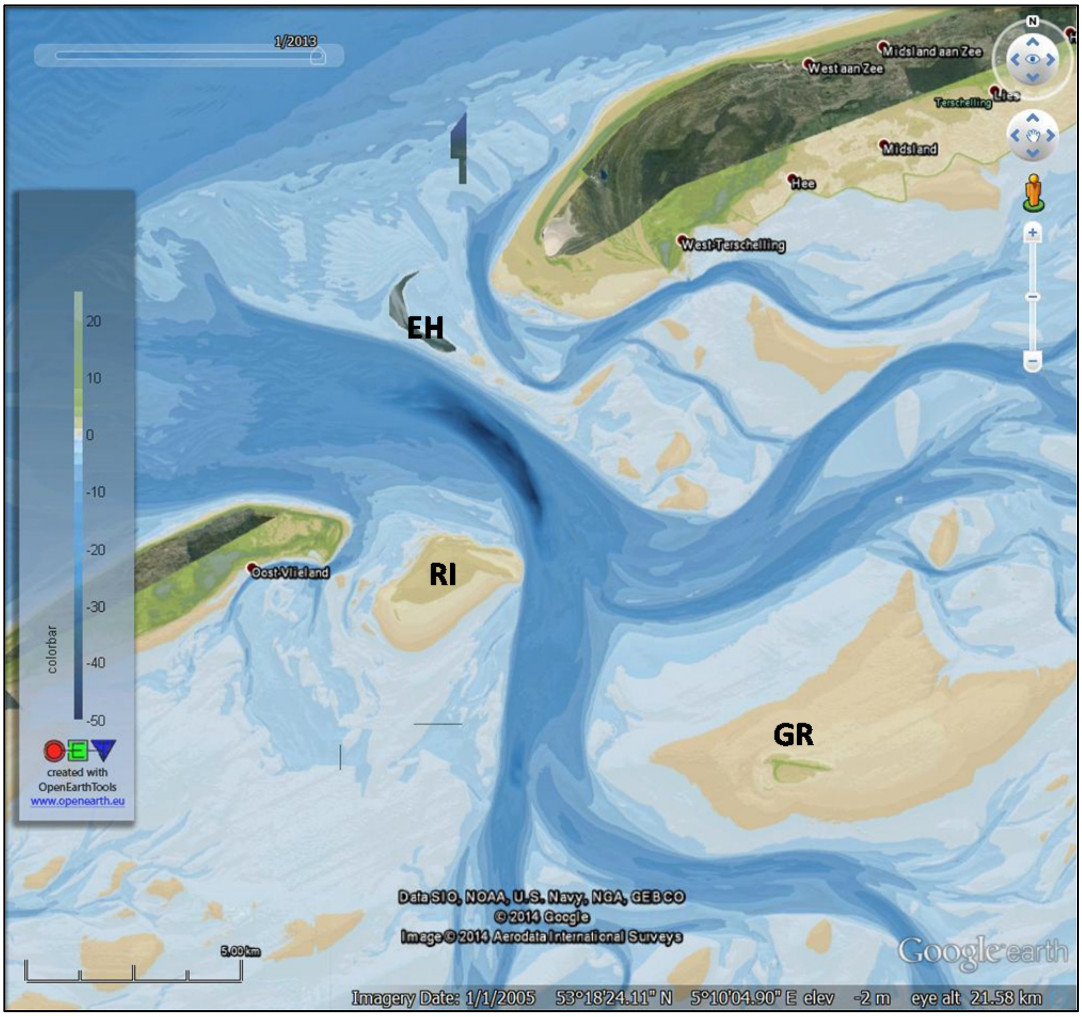


Figure 6. Bathymetry of the Vlie tidal inlet, with Engelschhoek (EH), Richel (RI) and Griend (GR). Legend in m + NAP. (Data: RWS/Open Earth/Google).

3.2 Wadden-Sea islands and sandbars

3.2.1 *Wadden Sea*

The Wadden Sea is a dynamic area where sandbars, shoals, channels and intertidal flats constantly change under the influence of waves, wind and tides (Wang et al. 2012, Oost et al. 2014). The Wadden Islands (also known as the Frisian Islands) form the barrier between the open North Sea and the enclosed Wadden Sea (Figure 7). Between the islands, deep channels form inlets where, twice a day, large masses of water and sediment flow in and out of the Wadden Sea. On the North-Sea side of each inlet, there is an ebb-tidal delta: a large complex of deep channels (up to 30 m), sandbars and shoals (Van Veen et al. 2005, De Swart & Zimmerman 2009). Part of these sandbars can be supra-tidal, i.e. only get flooded under storm surge conditions, and these are particularly suited for grey seals during pupping or moulting.

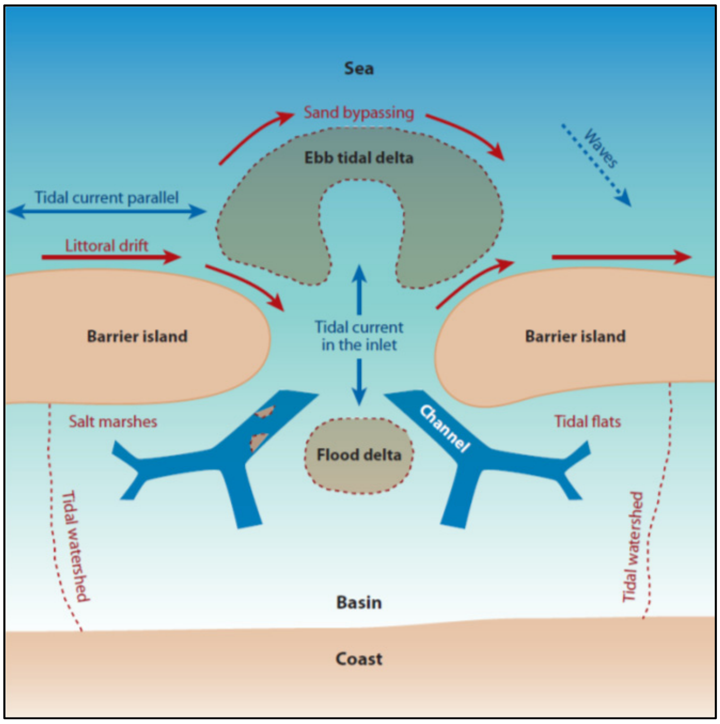


Figure 7. Schematic overview of the geomorphic elements of the Wadden Sea system (De Swart & Zimmerman 2009).

Ebb-tidal deltas function as wave breakers and (probably) as sources of sand for the Wadden Sea (Elias et al. 2012). The system of sandbars and channels tends to move in a clockwise direction over a period of several decades, after which the old main channel fills in and a new one develops on the 'up-drift' side. The up-drift side is the direction from which the dominant water and sediment transport comes, which is the (south)west in the case of the Dutch Wadden Sea. Through this semi-cyclic behaviour of an ebb-tidal delta, sandbars periodically weld to the barrier islands. This leads to a large 'head' on the up-drift side of the Wadden Sea islands. The sand is then gradually transported along the North Sea coasts of the island to the down-drift side of the island, where it forms an elongated island tail (Oost et al. 2012).

The back-barrier area, i.e. the area between the islands and the mainland coast, consists of channels, intertidal flats, sandbars and salt marshes. The channels branch away from the inlets and form a dendritic network of diminishing size towards the end of the tidal basins. Close to the inlets, the sediment is mainly sandy and can even contains gravel. The further into the back-barrier area, the lower the hydrodynamics and the muddier the sediment. The sediment budget of the back-barrier area is positive, whereas the ebb-tidal delta and coasts of the adjacent islands show a net loss of sediment (Elias et al. 2012).

Human activities (dredging and dyke developments, shipping) also influence geomorphological processes in the Wadden Sea. For instance, the Vlie tidal basin, like elsewhere in the Wadden Sea, continues to adapt to the change in hydrodynamic conditions following the closure in the 1930s of the Zuiderzee, by the Afsluitdijk. The tidal channels are diminishing in size and part of the intertidal area is accreting (Cleveringa & Grasmeijer 2010, Terwisscha van Scheltinga 2012, Wang et al. 2012).

For the geomorphology and dynamics of the Wadden Sea, so-called "ecosystem engineers" are very important (De Groot et al. 2014). These are organisms that actively influence their environment (Jones et al. 1994). In the Wadden Sea, abundant shellfish fauna filter the seawater and by that alter sediment properties such that more mud is retained within the Wadden Sea. Mussels and oysters build reefs that consolidate and raise the sediment, and increase the stability of the bed. Above surface ecosystem engineers are also present and, in regard to grey seal habitat, dune grasses are the most important ecosystem engineer. Their action is described in this chapter.

The highly dynamic nature of the Wadden Sea means that grey seals must adapt their pupping places to the available topography, on a year-by-year basis.

3.2.2 *Island development*

Sandbars (also called shoals or sand flats) are unvegetated, flat sand structures that develop under the influence of currents and waves. The Wadden Sea harbours many sandbars, ranging from those that are submerged every high tide to those that are flooded only during storm surges. A sandbar develops into an island when it is high enough that vegetated dunes can develop. Aeolian dynamics and vegetation establishment are hence key processes in island formation.

Dunes are important features on Wadden Sea islands as they provide elevation above sea level for flora and fauna and shelter for salt marshes to develop. Here we distinguish between the following types of dunes:

- Free ephemeral, low dunes: without vegetation, in the form of proto-dunes, barchans or barchanoid ridges. These develop on beaches and beach plains during moderate winds to storms, and can grow up to 1.5 m in height. They may form around an obstruction such as drift-line material. As there is no vegetation to anchor them, they are easily washed or blown away.
- Embryonic dunes [also called incipient fore-dunes, (Hesp 2002)]: vegetated hummocky dunes of 1 to 2 m in height and one to several metres in width.
- White dunes (or established fore dunes): dune ridges of over 3 m height and vegetated with Marram grass and other dune grasses. The name originates from the whitish appearance of the sand surface, as the soil has not formed yet.
- Grey dunes: older dunes that are vegetated with a variety of herbaceous vegetation or shrubs. As the soil is developing and organic matter is accumulating, the soil looks more greyish.

The development from bare sand flat or beach plain into an island has recently been described for island tails, which mainly differ from the sandbars in this report in that they are connected to a barrier island (De Groot et al. 2015). However similarities with the developments on Richel and other vegetated sandbars in the Wadden Sea (Hellwig & Stock 2014), justify using the model described to explain possible developments of the seals' breeding sites. Such development follows the steps of bio-geomorphological succession (Corenblit et al. 2007, De Groot et al. 2015) (Figure 8).

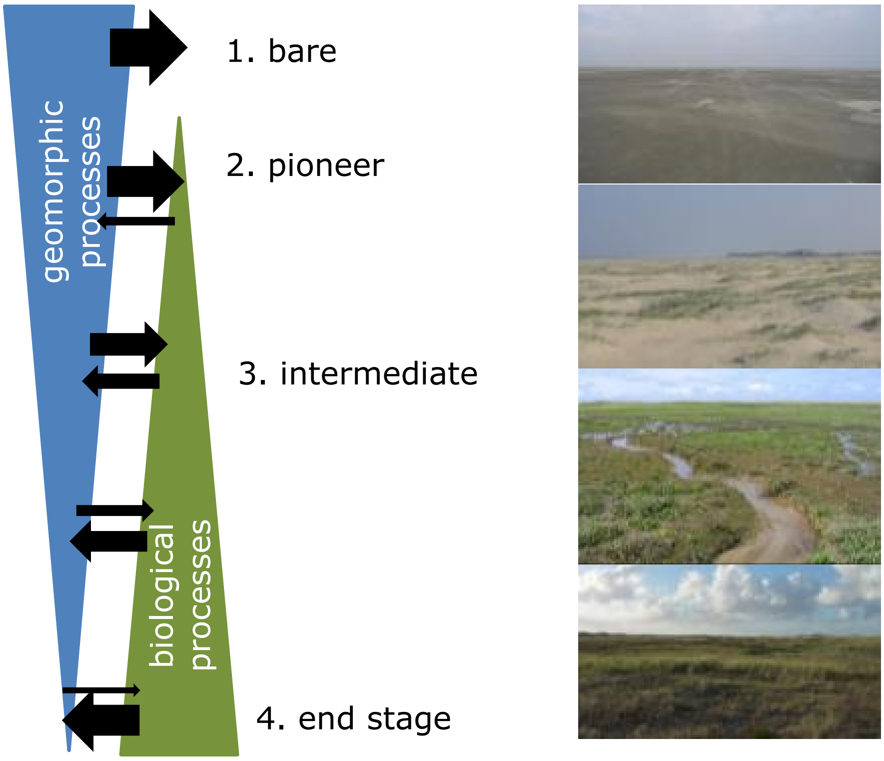


Figure 8. Phases in biogeomorphological succession of islands in the Wadden Sea (after Corenblit et al. 2007, De Groot et al. 2015). Arrow size indicates the relative strength of the processes. (Photos: Alma de Groot)

The development of an island in the Wadden Sea barrier starts with a phase in which vegetation is absent and the geomorphic processes dominate. The area is then a bare sandbar.

In the second phase, pioneer dune vegetation establishes and catches wind-blown sand. This leads to the development of embryonic dunes. Sand couch *(Elytrigia juncea* / *Elymus farctus* / biestarwegras) plays a key role in this phase trapping and binding of the sand (Figure 9). Other species, such as *Cakile maritima* (European sea-rocket/ *zeeraket*) may aid the formation of embryonic dunes.

Figure 9. Vegetation stabilising an embryonic dune on Richel: Elytrigia juncea *and* Cakile maritima *(in flower) (August 2014, photo by SB).*

The third phase of island formation commences when the embryonic dunes have trapped sufficient sand to be elevated above most floods. At this stage the sandbar has also formed a small, sub-surface, freshwater lens. In the Dutch Wadden Sea, phase three coincides with a dune height of approximately +3 m NAP. Then, *Ammophila arenaria* (marram grass/helm) can establish. This grass is more efficient at catching and binding sand than *Elytrigia juncea*, and also has a greater tolerance for burial. When enough sand is available, dunes with *A. arenaria* may grow up to 1 m in height per year (Huiskes 1979). In the shelter of the dunes, green beaches and salt marshes develop. A green beach is a mostly sandy area, somewhat more exposed than a salt marsh, which consists of a patchwork of dune, dune-slack and salt-marsh species. It is often (but not always) a transitional feature with a relatively high number of ‘red-list’ species. On the salt-marsh, the plants further reduce currents and waves so that mud can settle. Their roots bind and consolidate the deposited sediment, leading to a vertical growth of approximately 0.5 to 1 cm/year. A dendritic creek network develops as the salt marsh grows. In this phase, the geomorphic and biological processes are both responsible for shaping the landscape.

In the fourth phase, the vegetation cover has become strong enough to withstand most geomorphic processes, and the development of the island is dominated by the biological processes. The dunes grow further, the salt marshes and dunes undergo vegetation succession, and the green beaches transform into salt marsh or primary dune slack.

On the long term, channel migration and sediment transport and availability on a large scale determine the fate of an island: whether it will continue to grow or will undergo erosion.

The Natura 2000 habitat types associated with developing islands are those of the mudflats and sandflats not covered by seawater at low tide (H1140), salt marshes (H1310 – H1330) and coastal sand dunes (H2110 – H2190). Supra-tidal sandbars, often used by grey seals as breeding haul-outs in the Wadden Sea, are formally not defined as a protected habitat type. Literature and observations suggest that all of the described phases of island formation are potentially suitable for grey-seal use (section 2.3).

3.3 Methods

The development and geomorphology (dynamics/ stability, elevation) of the three study sites are described based on literature, existing data and data collected during field visits. The same is done for the habitats and vegetation. As the characteristics of the three study locations differ, the exact data and analyses also differ between the islands.

3.3.1 *Pupping locations*

During aerial monitoring of seals by IMARES, oblique pictures are taken of seal haul-outs and pupping sites (Brasseur et al. 2015). The flights take place several times per year and have been on-going since 2001. The coordinates of the plane from which the photos were taken are recorded, but, in lack of reference points, ground coordinates of the photos are not reconstructed.

Additionally, seal locations on Griend were mapped during field visits to the island in December 2013 (Brasseur et al. 2014) and December 2014 (see Figure 35, Chapter 5).

3.3.2 *Geomorphology*

3.3.2.1 Long-term development

The description of the long-term development of the sites is mainly based on literature, of which a recent analysis of the Vlie tidal inlet (Terwisscha van Scheltinga 2012) is a key study. Further, bathymetry maps from *Rijkswaterstaat* (RWS, available through https://publicwiki.deltares.nl/display/OET/OpenEarth) and georeferenced aerial photos were used (source: Alterra).

3.3.2.2 Elevation and location

Field visits to Engelschhoek, Richel and Griend to monitor the geomorphology and vegetation were conducted on 20 and 21 August, 2014. This was timed to be outside the breeding seasons for both birds and seals, to minimize disturbance. Visits were limited to the period around local low tide to avoid disturbing birds during their high tide resting. The procedure to minimise disturbance limited the duration of visits and thus the amount of observations that could be made.

Especially during pupping, seals need to haul out on dry land. Therefore the elevation of a site relative to water level is of major importance to define the quality of an area. For Griend, LiDAR data from 2010 were available (source: RWS). The data consists of one measurement per square metre, averaged into grid-cells of 5 x 5 m^2. The vertical uncertainty is most probably in the order of that of AHN2 (www.ahn.nl), thus amounting to 1 sigma systematic error of 5 cm and stochastic error of 5 cm. Elevation is given with respect to local ordnance datum NAP, which is approximately equal to mean sea level.

During the field visits, elevation on Engelschhoek and Richel was measured using a Real-Time Kinematic (RTK) GPS (Global Positioning System), which provides precise recordings of elevation and locations (in Dutch RD coordinates). The GPS receiver was a Trimble R6 Model 3, combined with a Trimble TSC3 controller using the Trimble Access Field Software version 2013.00 (4617). The RTK was mounted on short pole with a wheel so that profiles could be made while walking. In this mode, vertical accuracy of the measurements is within a few cm. Every effort was made to keep the pole vertical, however, slight dipping from vertically while walking may have led to an underestimation of the elevation of up to a few cm. At selected locations, stationary measurements were made. There, vertical accuracy was within 1.5 cm and horizontal accuracy within 1 cm. On Richel, the RTK was also used to delineate the outline of the embryonic dune field. On Griend, GSM reception (necessary for correction of the satellite data) was too poor to measure elevation reliably.

Elevation data were compared to local tide characteristics from the nearby tide stations of Vlieland Haven and West-Terschelling (www.rws.nl).

3.3.2.3 Groundwater

On Richel, groundwater conductivity and salinity were measured using a handheld EC meter, at the locations of vegetation relevés (see below). Using an auger, a hole was made to the depth of the groundwater. The EC meter was lowered into the hole and into the groundwater. A recording was made when the reading was stable.

3.3.3 *Vegetation*

3.3.3.1 Vegetation maps Griend

Vegetation maps of Griend are available from *Rijkswaterstaat* for 1991, 1995, 1999, 2006 and 2012. Grey seals started using the site as a pupping site in about 2006.

3.3.3.2 Oblique aerial photos (Engelschhoek and Richel)

Vegetation maps for Engelschhoek and Richel are not available. Oblique aerial photos from regular seal counts, several times per year since 2001, include parts of Engelschhoek and Richel. Though not ideal for documenting establishment and changes in vegetation, they allow for partial, qualitative reconstruction of the development of the vegetation. From these photos, the presence or absence of vegetation was noted. From the moment the vegetation field on Richel became apparent, it became subject of an ‘overview’ photo and gives a reasonable overview of recent development.
In the aerial photos, there was the potential to confuse patches of tide-washed seaweed with patches of terrestrial vegetation (such as *Elytrigia juncea*). To differentiate between these, a set of guidelines was followed based on field experience at other locations in the Wadden Sea:

- small dune with tail or hummocky area: grass
- vertical green structure: grass
- flat: seaweed/ wreck
- in a wet area in an arc of the shoal, or along a previous waterline: seaweed
- when bright green: seaweed or algae
- when totally covering an area and not hummocky: most probably seaweed or algae.

Some variation between years is expected, as the visibility of the vegetation strongly depends on lighting conditions, viewing angle, time of year, and sand dynamics (burial or deflation of plants).

3.3.3.3 Aerial ortho-photos

Georeferenced aerial (ortho)photos of Richel were available for 2003, 2006, 2008 and 2010 through the Geodesk of Wageningen UR (data (Kadaster/Cyclomedia 2010) and Copyright Eurosense B.V. 2008). The vegetation was not well enough visible to reliably reconstruct the vegetation outline: a patch of *Elytrigia juncea* can be clearly seen when viewed from the side, but not always when viewed from straight above.

3.3.3.4 Species list (Richel)

To our knowledge, vegetation composition on Richel had not been formally described prior to our field visit. During the first exploration of the vegetated area on Richel, a list was made of all higher plant species encountered. This list may not be exhaustive due to time limitations. The coordinates of every first encounter of a plant species (going from west to east) were recorded using GPS.

3.3.3.5 Outline of embryonic dune field (Richel)

The outline of the embryonic dune field, and hence the vegetation, on Richel was mapped with the RTK. Tracks around the field were made in 2011, 2012 and 2013 by Eelke Dijkstra (*Rijksrederij*, from *MV Stormvogel*), and were made available for this report.

3.3.3.6 Relevés (Richel and Griend)

Vegetation relevés were made at Griend (on 20 August 2014), at places where seals were observed in December 2013, and on the vegetated area of Richel (on 21 August 2014). The relevés serve as characterisation of the seal pupping locations and as reference for possible future developments (i.e. they can be revisited and may be used as permanent quadrats. The relevés were positioned semi-randomly, in homogenous vegetation.

The vegetation relevés on Griend were 2 x 2 m in size. Only the three dominant species were scored, following the same scale as on Richel.

On Richel, relevés were 5 x 5 m^2. This is larger than mostly used in the Wadden Sea, and was chosen because of the patchy nature of the cover of *E. juncea*. Every 125 m along the southern edge of the vegetation patch, two relevés were made perpendicular into the vegetation, one 25 m in and a second 65 m in. Two additional relevés were positioned to provide further examples of inter-species association; one on the eastern edge of the vegetation patch and the other in an observed species-rich location. Locations can be found in Appendix D. To obtain a representative elevation, four RTK measurements were made per relevé. All species in each relevé were score, following the scale 'Londo (2) verkort' (Hennekens 2009) (Appendix C). Additionally, information was recorded on total cover, vegetation height, traces of birds, geomorphology and sediment type.

3.4 Large-scale dynamics in the Vlie tidal basin

The long-term sedimentation/erosion map of the Vlie tidal basin shows the dominant movement of the major channels (Figure 10), indicated by the red (strong sedimentation) areas next to blue (strong erosion). The area around Engelschhoek has accreted strongly during the past 80 years, which is a result of the strong dynamics in the ebb-tidal delta. The area around Richel, especially to the east, has shown net accretion. The area around Griend is stable although the island itself is eroding. These changes are also visible when observing the subsequent aerial photographs.

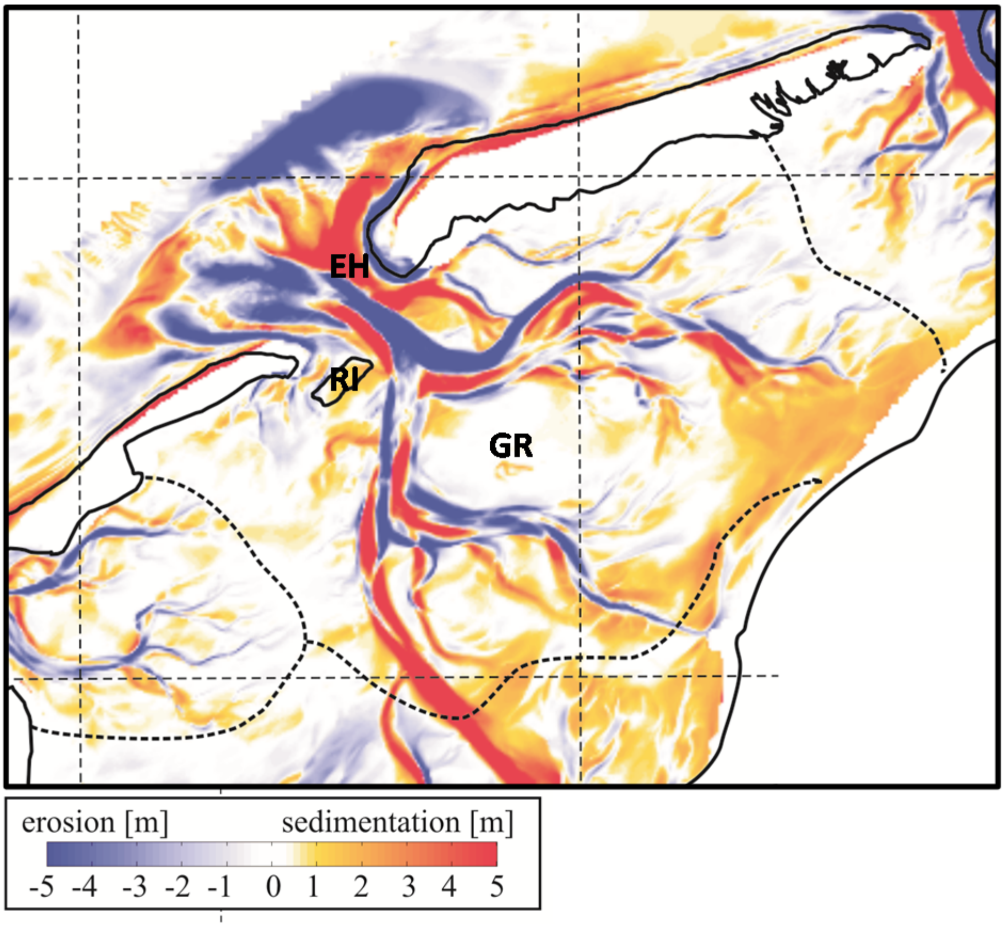


Figure 10. Sedimentation/erosion map of the Vlie tidal basin between 1927/1935 and 2005, with the study sites indicated (EH = Engelschhoek, RI = Richel, GR = Griend). Grid is 25 km. (detail from (Elias et al. 2012)). Dotted lines represent the tidal divides between the tidal basins.

3.5 Engelschhoek

Engelschhoek is a bare, supra-tidal sandbar between Terschelling and Vlieland (Figure 11). It is part of the ebb-tidal delta of the Vlie inlet. The area is very dynamic with shifting channels and shoals (Terwisscha van Scheltinga 2012). A deep channel, the Vliestroom, is located at the western side, with depths exceeding 35 m and a steep slope towards Engelschhoek.

Figure 11. Aerial view of Engelschhoek looking towards the northeast (photo taken in 2011, https://beeldbank.rws.nl, Rijkswaterstaat / Joop van Houdt).

Engelschhoek was evident as a sandbar throughout the 1900s, then submerged to be sub-tidal for two years between 2004 and 2006. Seals were forced to disperse to other sandbars. Since re-emerging, it has grown as the result of sand bypassing in the ebb-tidal delta and shifted eastwards (Terwisscha van Scheltinga 2012). The channel east of it, the Boomkensdiep, has also shifted eastwards and become narrower (Terwisscha van Scheltinga 2012) (Figure 12). Based on historical behaviour of similar channels in the Wadden Sea, such as on Schiermonnikoog, it is expected that the Boomkensdiep will continue to move eastwards and silt in. Engelschhoek will most probably follow that movement and weld to the Noordsvaarder on Terschelling within a couple of decades. However, the dynamics in the ebb-tidal delta of the Vlie are so strong, that it is not certain that Engelschhoek will keep its current form during the eastward migration: lowering or accretion are both possible, as are changes in shape and the development of channels that cut through the bar.

Engelschhoek is the most exposed to the open North Sea of the three study sites. The morphology of the northern and western sides of Engelschhoek show signs of strong wave influence. Under storm conditions, it is expected that, even though part of the North Sea waves are broken by sub-tidal sandbars further to the north and west, significant wave action reaches and dissipates on Engelschhoek.

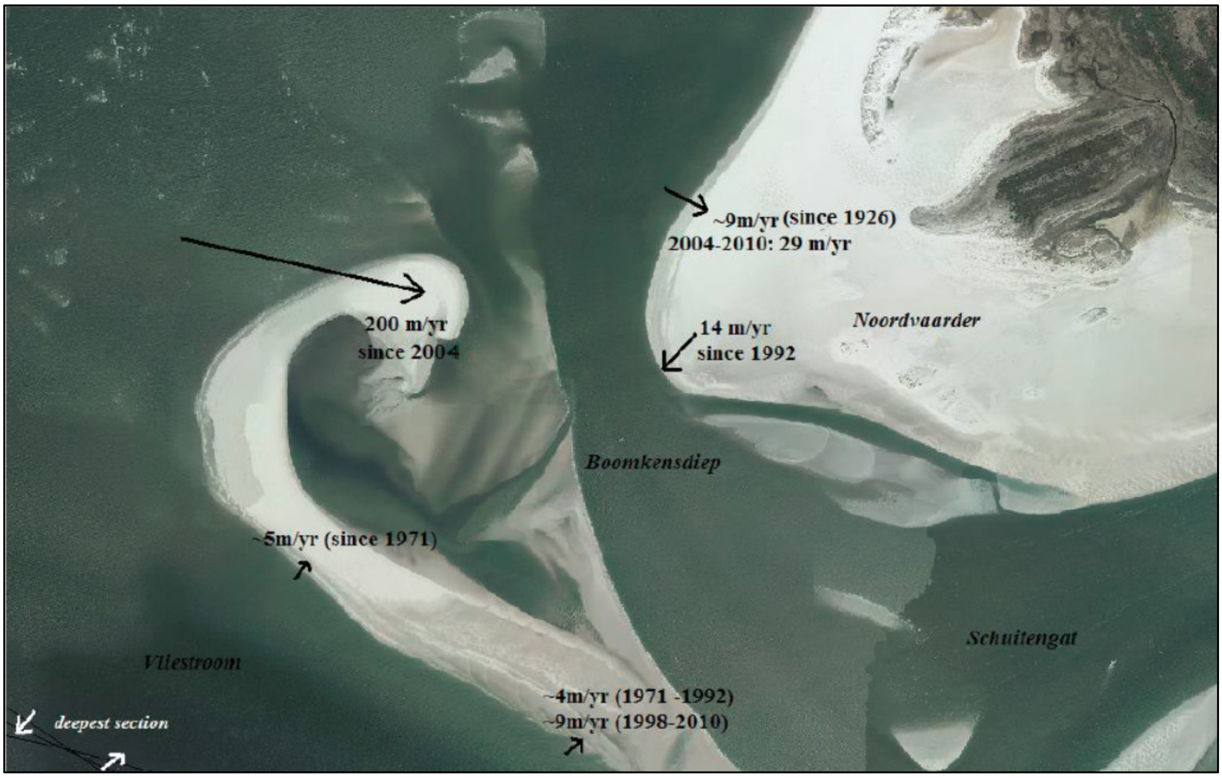


Figure 12. Migration rates for Engelschhoek and its surroundings (Terwisscha van Scheltinga 2012).

Elevation was measured at the approximate pupping location on Engelschhoek (in the northwestern 'hook' visible in Figure 11 and Figure 12). During fieldwork, grey seals were hauled-out further east, on the end of the hook, adjacent to Boomkensdiep, and harbour seals were hauled-out further south on the eastern bank of the southern arm. To avoid disturbing the seals, these areas were not visited. The highest measured elevation was +1.37 m NAP. Most of the sandbar measured was lower than +1.0 m NAP (Figure 13). When compared to historical water levels of Vlieland and Terschelling (www.rws.nl), this means that the highest point is flooded on average more than five times per year, and that the rest of the area is flooded more often.

No vegetation was found on the oblique aerial photos nor during the field visit to Engelschhoek. Occasionally, individual plants of *E. juncea* have been seen on Engelschhoek (E. Dijkstra, MV Stormvogel, pers. comm.). Significant vegetation development on Engelschhoek is not expected in the near future due to its highly dynamic surface. Sandbars on ebb-tidal deltas generally do not become vegetated unless they are welded to an island head, due to the high hydrodynamics.

In terms of Natura2000, the pupping habitat on Engelschhoek below Mean High Water (approximately +0.8 m NAP) consists of H1140_B 'Slik- en zandplaten' (Noordzeekustzone), and the part above MHW does not belong to any N2000 habitat type.

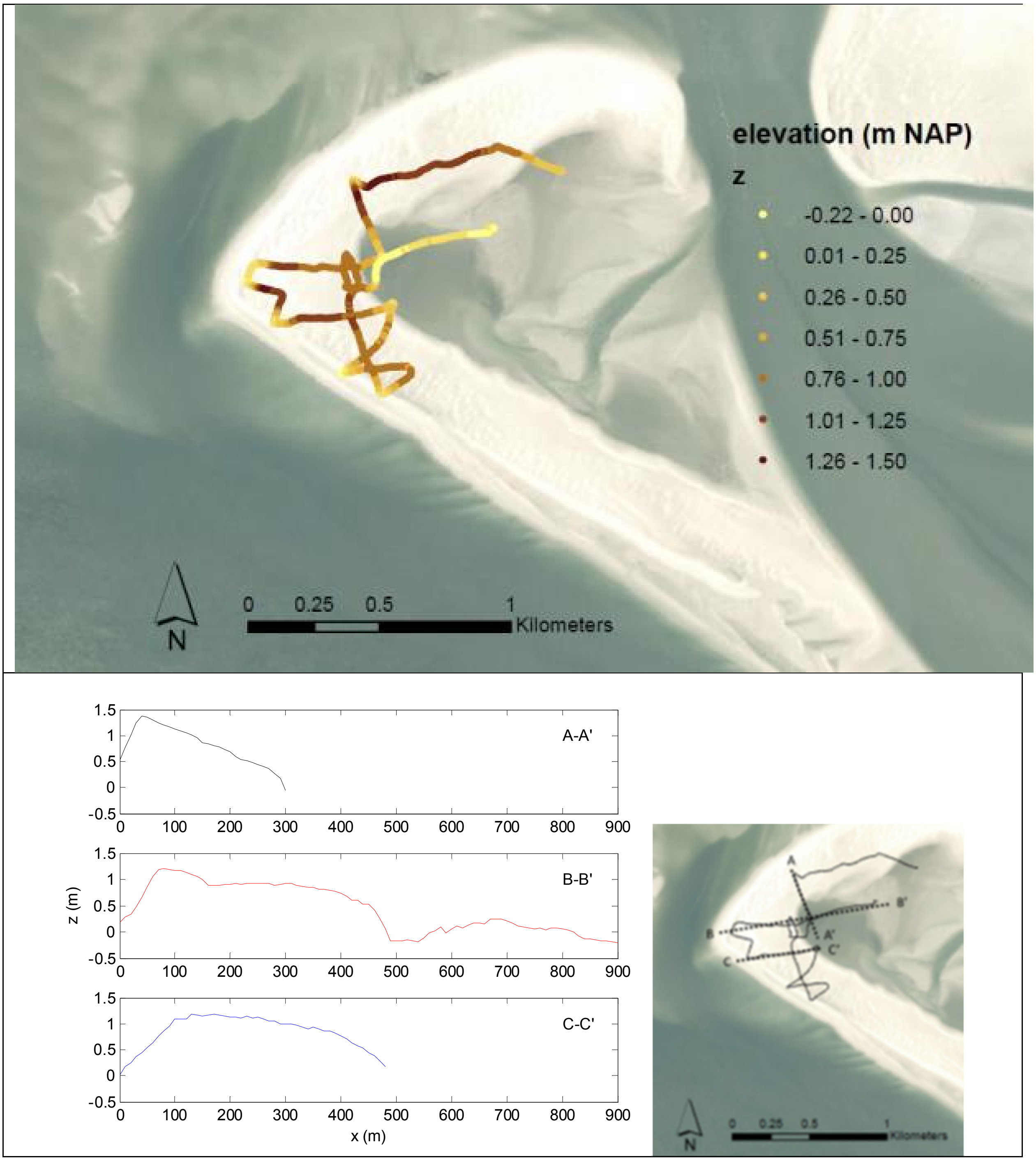


Figure 13. Elevation (relative to NAP) of the grey seal pupping site on Engelschhoek, August 2014. Upper panel: map of RTK measurements. Colours indicate elevation. Background aerial photograph from 2014 (http://pdokviewer.pdok.nl/). Lower panel: cross-sections of elevation on three transects.

3.6 Richel

3.6.1 *Geomorphology*

The Richel sandbar is known from maps drawn as early as 1796. The sandbar has changed shape over time, slowly building toward the east (Lofvers 2014). North and east of Richel is the 15+ m deep Vliestroom channel, with a steep edge towards Richel. Channel dynamics of the Vliestroom may cause future erosion or expansion of Richel. As long-term movement of the Vliestroom is towards the west, this would lead to erosion of (part of) Richel. On the north-western side, Richel is bordered by the channel Vliesloot. Vliesloot is currently decreasing in depth and the tidal shoals around it are increasing in height and expanding (Terwisscha van Scheltinga 2012).

3.6.2 *Development of the embryonic dune field*

A significant recent development on Richel has been the establishment of an embryonic dune field (Figure 14 and Figure 15). This is now where the majority of grey seal pups are born.

In 2003, Richel was bare and the highest area (showing up light in the photo of Figure 14) was largely outside where the current embryonic dune field has established. In 2006 and 2007, no vegetation was evident, although dark patches in some photos are thought to be eroding, wet, ephemeral dunes without vegetation. Some pictures show green patches, but these appeared to be tide-washed seaweed. In 2008, the first embryonic dunes were present in the NW of the current dune field. In 2009, vegetation had clearly established and was visible as green patches in dry sand. The remainder of the patch exhibited signs of aeolian activity, in the form of protodunes and linguoid dunes (both free-moving, ephemeral sand dunes of several decimetres (protodunes) to 1.5 m (linguoid dunes) high and often with a wave-like shape).

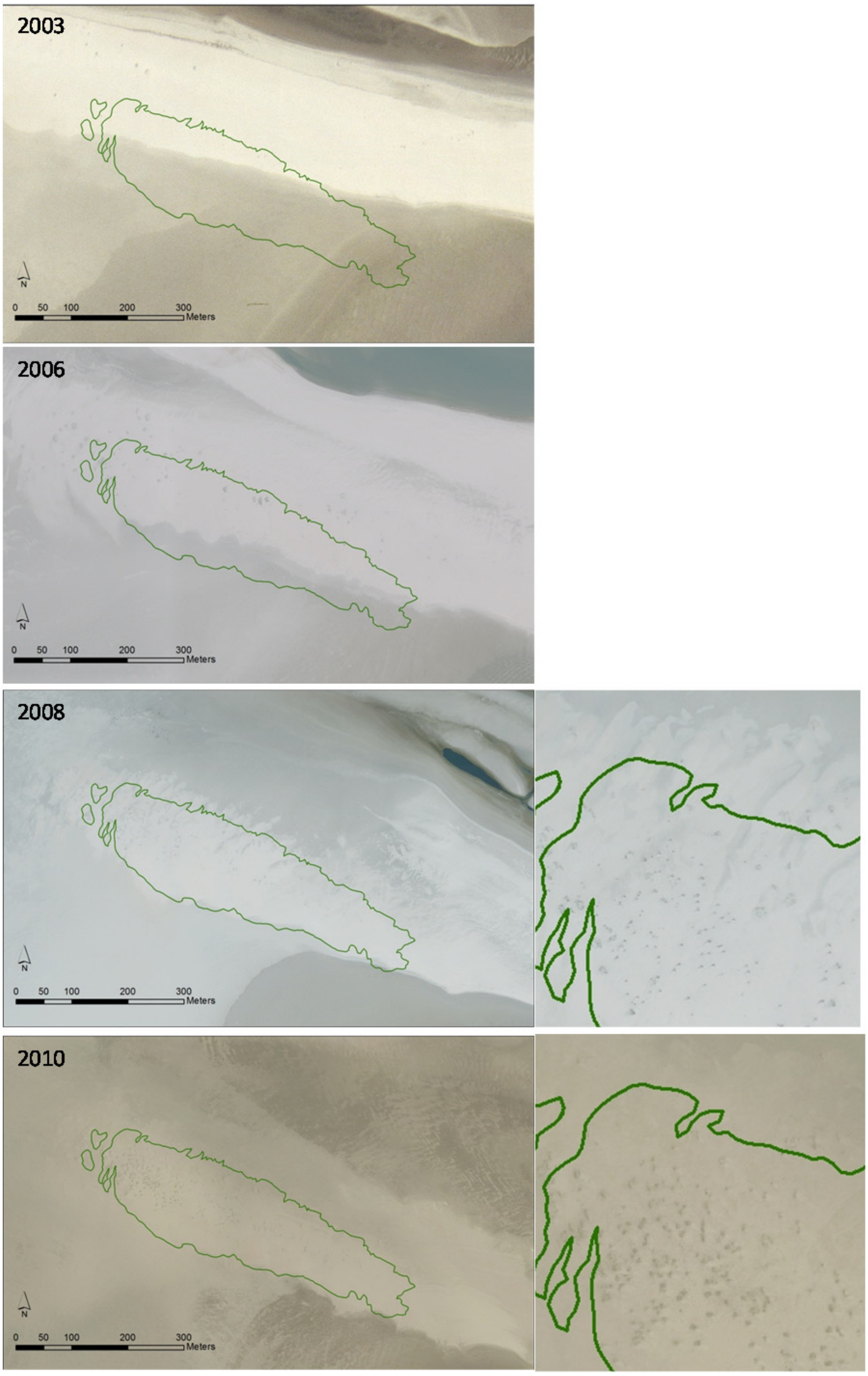


Figure 14. Development of embryonic dune field on Richel from orthophotos. The outline of the dune field of 2014 is given as reference. (Copyright 2008 image Eurosense B.V. and 2010 image Kadaster/Cyclomedia).

Figure 15. Development of embryonic dune field on Richel from oblique pictures taken during the aerial seal-counts (photos by Sophie Brasseur, IMARES). Larger versions can be found in Appendix A.

In 2010, the vegetation tussocks of 2008 persisted. The number of embryonic dunes had increased since 2009 and displayed streamlined tails. In aerial photos from www.bing.com/maps (with an estimated date of 2010, see Appendix A), an elongated field of scattered embryonic dunes is evident, running from WNW (more dense patches) to ESE (scattered patches).

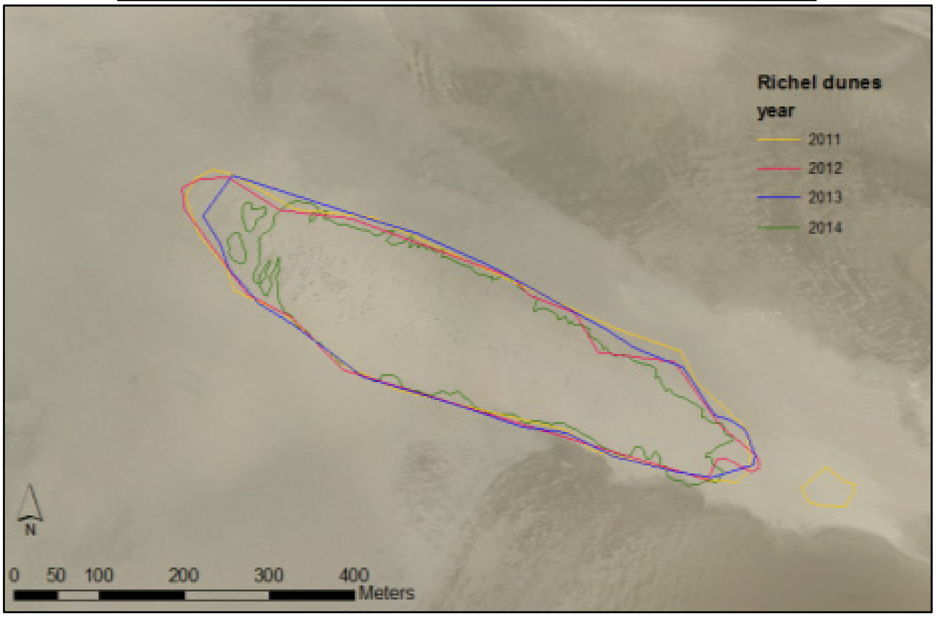


Figure 16. Outline of the vegetated embryonic dune area on Richel, top as overview of entire Richel and bottom development from 2011 to 2014 (data for 2011– 2013 from Eelke Dijkstra, MV Stormvogel and for 21 August 2014 by IMARES. Aerial photographs Kadaster/Cyclomedia 2010).

In 2011, the area with vegetation had extended and the vegetation was denser. It was elongated in shape and at least several hundred metres long, extending WNW to ESE. Some vegetation patches were close together, others more spread. Between 2011 and 2014, the outline of the vegetated area stayed mostly the same, apart from some erosion at the north-western end (Figure 16). However, vegetation became much denser.

In summary, based on the available aerial photographs, *E. juncea* tussocks had established on Richel by 2008. As it takes several years for *E. juncea* to grow into tussocks (Van der Stege 1965), the establishment of individual plants most probably took place a few years earlier (possibly around 2006). The embryonic dune field had established by 2009. Since then the overall size has changed little but the vegetation has become more dense.

3.6.3 *Dune types and sediment composition*

The focus of the field visit to Richel was on the vegetated dune area. All dunes were classified as embryonic dunes. Their elevation (see next section) did not exceed + 3 m NAP and the dominant plant species was *E. juncea*. Some of the tussocks on the southern side showed evidence of erosion by waves. Although vegetation cover was patchy, there were no real wash-over structures. There was one depression in the dune field that had very shallow standing water, but it did not bisect the dune field from one side to the other.

The soil consisted of sand with shells. No fine-grained sediment (mud) was found. East of the dune field was a small, unvegetated ridge with shells and sand, and south of the dune field, areas with shell lag were present. A considerable amount of drift-line material, consisting of e.g. *Ulva lactuca* and anthropogenic litter (mainly plastic), was scattered all over the area. Furthermore, as the field visit was in late summer, recent use by colonies of lesser black-backed gull (*Larus fuscus*) and herring gull (*Larus argentatus*) was evident: droppings, dead and dying birds (mostly fledglings) and regurgitated pellets full of shells.

3.6.4 *Elevation and flooding frequency*

An elevation map of the vegetated patch and surrounding sandbar was prepared based on RTK measurements taken on 21 August 2014 (Figure 17). The embryonic dune field was the highest part of Richel. The elevation at the circumference of the vegetation patch was between +1.04 m and +1.72 m NAP, and was on average +1.30 m NAP. Consequently, the edge of the vegetation would be flooded more than five times per year (based on flooding frequencies for the Vlieland tidal gauge, www.rws.nl).

The higher parts of the patch were above +1.50 m NAP, which would be flooded around five tides per year. The highest elevation in the patch was +2.39 m NAP. These would be flooded every 1 – 2 years. Most storms are in autumn and winter in The Netherlands which coincides with the grey seal pupping period.

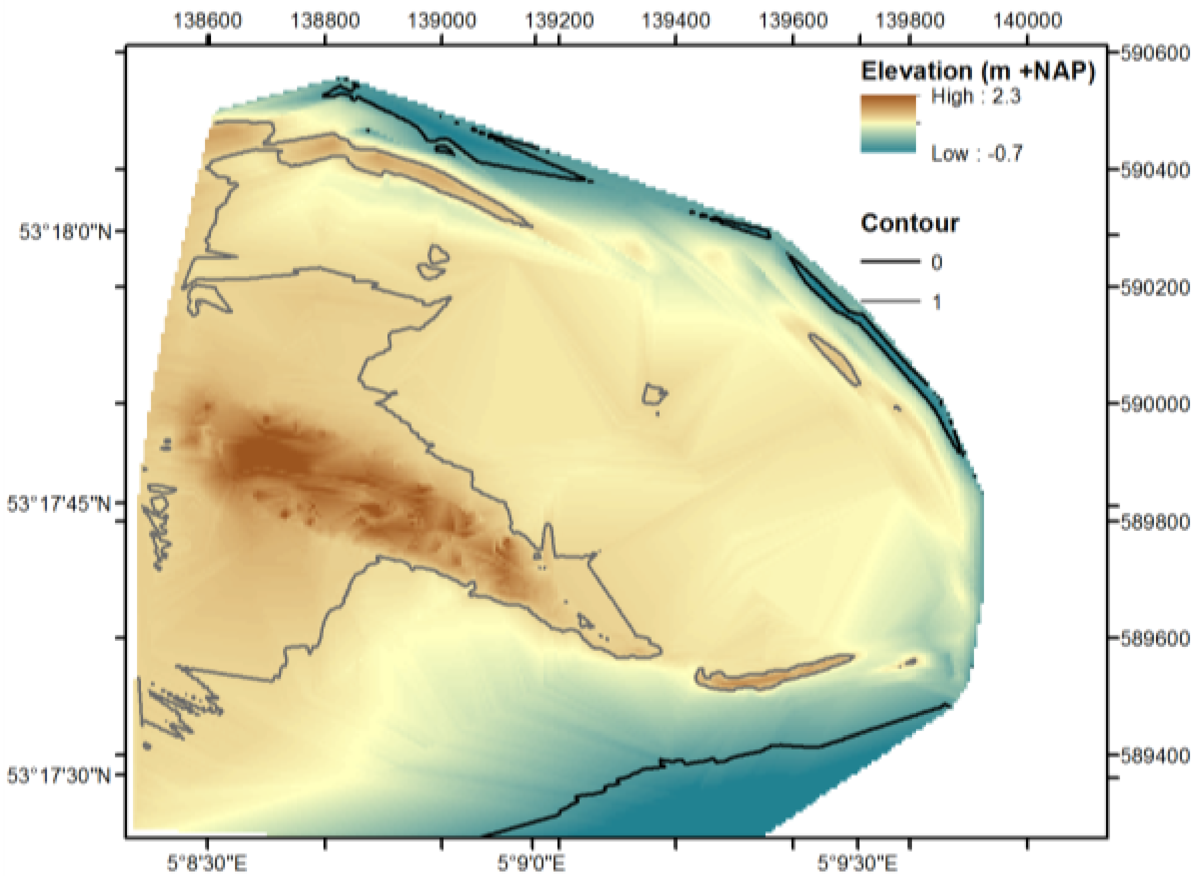


Figure 17. Elevation map of the studied part of Richel, based on RTK measurements of 21 August 2014. The contours of 0 and +1 m NAP are given for reference.

While the majority of grey seal pups is born in the vegetated patch, a number are born elsewhere on the Richel, such beside the Vliestroom channel (evident in Figure 17). In 2014, a ridge beside the channel had an elevation of around +1 m NAP, just above Mean High Water Spring. It would be safe for small pups during normal conditions, but would flood during even mild storms that occur several times per year.

Groundwater was found mostly circa 50 -70 cm below the soil surface. Measured groundwater salinity ranged between 0.1 and 5.1 promille (= ‰), indicating it was fresh to brackish (Figure 18 and Appendix D). Thus, the embryonic dunes had grown large enough for the development of a (near) freshwater lens.

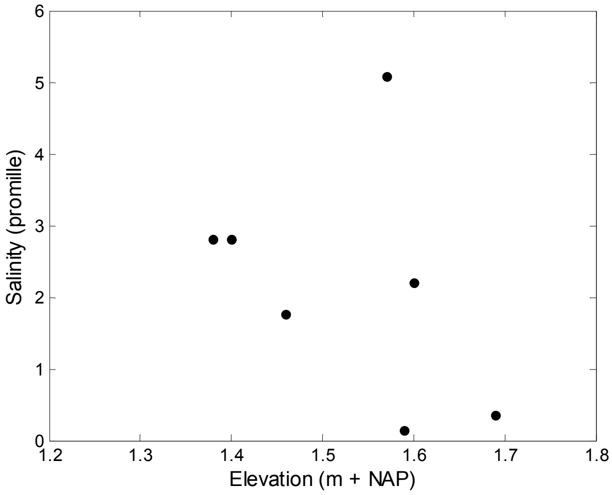


Figure 18. Salinity of the groundwater and surface elevation on Richel, for seven relevés.

Figure 19. Oblique aerial photograph of a section of the vegetation patch at Richel, taken in August 2014 by IMARES during the fieldwork for this report, indicating the size and density of vegetation clumps (photo Jenny Cremer).

3.6.5 *Vegetation*

Richel harboured at least 19 different higher plant species, a relatively large diversity for such a young system (see Appendix B). The vegetation cover was dominated by *Elytrigia juncea*, in various growth forms (Figure 20). The dominance of *E. juncea* means that the entire vegetated area, including the relevés, belongs to the Natura 2000 habitat type H2110 'Embryonic shifting dunes'. Total vegetation cover was around 75%, which is high compared to other embryonic dune fields in the Dutch Wadden Sea. The next most often occurring species was *Cakile maritima*, a typical drift-line species, often associated with *E. juncea* (Figure 9). Also, *Senecio vulgaris* was abundant, with many seedlings. The other species present were regular species of dunes, green beaches and salt marshes that exhibit a degree of salt tolerance:

- Drift-line species: *Cakile maritima, Salsola kali, Tripleurospermum maritimum, Honckenya peploides, Crambe maritima;*
- Salt-marsh species: *Salicornia spp., Suaeda maritima, Atriplex prostrata, Puccinellia maritima, Plantago maritima, Polygonum aviculare, Cirsium arvense;*
- Dune species: *Elytrigia juncea, Ammophila arenaria, Senecio vulgaris, Sonchus arvensis, Hippophae rhamnoides.*

A rare species was *Tetragonia tetragonioides (Pallos) Kuntze*, a non-endemic vegetable garden plant. Given the species present, *Agrostis stolonifera*, *Atriplex glabriuscula*, or other *Atriplex* species were expected but were not identified during our visit. It is possible that these were missed during the inventory or were misidentified.

The large species list demonstrates that seeds (or other propagules) can reach Richel easily. This rapid dispersal is in line with studies on salt-marsh dispersal (Huiskes et al. 1995). Further vegetation development will probably not be limited by dispersal.

Figure 20. View on the embryonic dune field of Richel, August 2014 (photo SB).

In August 2014, we found only a few tussocks of *Ammophila arenaria*. This dune grass normally follows *E. juncea* in the succession as it is less salt-tolerant. It is much more effective in trapping sand, though. Hence, if *A. arenaria* cover increases, the area can grow into white dunes within a few years. By 2014, this threshold had not been reached.

South and east of the current embryonic dune field, a band with a very low density of *E. juncea* tillers was found (Figure 21). This was a flat area without dune formation. After the establishment of *E. juncea*, it takes 3 – 4 years before it reaches its maximum sand-catching capacity (Van der Stege 1965). Providing there are no storm surges that wipe away these tillers, the area may develop into embryonic dune field within a couple of years. As Richel is an exposed area, though, such expansion of the dune field is not certain (Van der Stege 1965).

Figure 21. Elytrigia juncea tillers (left) extending south from the embryonic dune field (right) on Richel, August 2014 (photo AdG).

3.6.6 *Animal presence*

In August 2014, the embryonic dune field contained clear signs of recent use by birds: nest-sites, trampling, grazing, droppings and carcases, attributed to herring gulls and lesser black-backed gulls. Geese (species unknown) also visit the vegetation patch, as evidenced by their droppings and evident grazing on plants. Due to the high out-put and nutrient load of bird droppings, and the timing of their deposition with the summer 'plant-growth' period, the birds likely have some influence on the vegetation. Trampling, grazing and nest construction by the birds may inhibit growth locally and temporarily.

There were no grey seals on Richel in August 2014. During their breeding season in November-January, the grey seals use both the bare, supra-tidal sand flat and the vegetated embryonic dune field (Figure 22). In the last week of December 2014 when the area was visited again, the great majority of mother-pup pairs were within the dune field. This enabled a circumnavigation of the dune field without excessive disturbance to mother-pup pairs. This contrasted with the situation in December 2013, when the mother-pup pairs were spread over much of the Richel, although with the greatest density in the dune field. The spread of the seals restricted our movement and, so as not to disturb the seals excessively, we did not circumnavigate the dune field. In both 2013 and 2014, male grey seals and weaned pups were distributed over and around the vegetated patch.

Figure 22. Grey seals (dark shapes, but difficult to distinguish in the vegetation) on Richel, 3 December 2014. Seal tracks towards the vegetation are visible on the lower left of the picture (photo Jenny Cremer).

3.6.7 *Seal influence on vegetation*

Aerial observations indicate that in the dune field, most seals lay between the grass tussocks rather on top of them. Ground observations indicate there is also considerably movement over the vegetation.

The above-ground parts of *Elytrigia juncea* die off during winter, but the roots and rhizomes keep binding the sand into embryonic dunes. That means that when the grey seals use the area for pupping, vegetation density is lower than in summer, when the vegetation recordings were made. Disturbance by the seals in winter probably will damage the vegetation much less than if they would use the area in summer.

It would be difficult to recognise any influence of the grey seals on vegetation at Richel for a number of reasons:

1) the density of seals could be too low;
2) the August field trip to investigate the vegetation was conducted 7 months after seal occupation;

3) much of the area would have been inundated by high-tides since the seals' occupation;
4) summer growth in vegetation would have masked impacts the seals might have had during their winter occupation; and
5) summer-breeding birds had just vacated the island and their presence would have further masked changes to vegetation caused by the seals.

During the field visit in August, however, the following signs of possible seal influence on the vegetation and geomorphology were searched for:

- *Plants that are indicators for high nutrient status*: the high abiotic dynamics make that the area was not in the stage yet where nutrient levels determine vegetation composition. The density of *E. juncea* was higher than observed on embryonic dunes on Ameland, Schiermonnikoog or Texel, but whether this has any relation with nutrient inputs cannot be said. There was ubiquitous evidence of bird use: droppings, dead birds, old nests.
- *Seal nutrient import – scats and carcasses*: no scats found (and none expected due to eight months of degradation and potential flooding since seal occupation), two seal-carcasses found were highly decomposed.
- *Seal tracks*: none found (and none expected due to the 7-month gap since occupation, potential flooding since occupation and summer vegetation growth).
- *Bare patches potentially caused by seal trampling*: many bare patches were evident, but all were characteristic for embryonic dune fields and could not be attributed to seals. Vegetation density was higher than expected based on experience in other Wadden Sea areas, possibly facilitated by the absence of hares and rabbits, absence of trampling in the growing season and nutrient input from birds.
- *Accumulations of sand*: none found other than those related to vegetation. When seals are hauling out under windy conditions, windblown sand may pile up around them and form dunes of up to 0.5 m high (Figure 23). When the seals move away, however, the sand is easily blown or washed away. Sand accumulation will only lead to permanent dune formation if it is captured by vegetation.

Figure 23. Aerial photograph of seals on a sandbar in the Wadden Sea showing an accumulation of wind-blown sand (lighter colour) around them (photo RK).

3.6.8 *Future*

The current growth of pioneer vegetation on Richel suggests that the sandbar is getting higher and potentially more stable. The dune field is now in the second phase of biogeomorphic succession and the question remains if it will stay there, be eroded back to a bare sandbar, or make the transition to the phase in which white dunes, salt-marsh and green beach develop. As the area with embryonic dunes seems to be fairly stable, despite the 5-6 December storm of 2013, and there is a freshwater lens building underneath, it is expected that the further establishment of *A. arenaria* is only a matter of time and a few years without important storm surges. Ultimate resilience of the vegetation patch might be influenced more by broad-scale geomorphological processes, such as meandering of the Vliestroom channel.

Richel is one of a series of small, dynamic islands in the international Wadden Sea (Hellwig & Stock 2014). It shows for instance similarities to Engelsmanplaat, now a sandbar between Ameland and Schiermonnikoog. Some decades ago Engelsmanplaat was vegetated as Richel is now, with embryonic dunes dominated by *E. juncea*. After lowering of the entire bar, the vegetation disappeared (Mes et al. 1980). Engelsmanplaat is more dynamic in shape than Richel, so the chances for survival of the dunes on Richel may be higher.

The Kachelotplate in Germany, albeit more dynamic in shape, is in the same stage of development as Richel, with embryonic dunes covered with *E. juncea* (Wehrmann et al. 2014). On the highest part of the dunes *Leymus arenarius* has established, which was not present in 2014 on Richel. Given favourable conditions, the development of both islands is expected to continue similarly to that of Norderoogsand (Germany), where dunes have developed further and salt-marsh vegetation recently established (Padlat 2014). It is also similar to Mellum (Germany), which became vegetated around 1880 and now consists of low dunes and a salt marsh (Kleyer et al. 2014).

If Richel develops further toward a typical Wadden Sea small-island, it could grow in importance for the seals. The typical high dynamics of this type of small islands will not necessarily inhibit use by seals, as Rottumerplaat (NL), Rottumeroog (NL) and Norderoogsand (D) show that despite regular erosion and new vegetation colonisation, the total volume of the islands is preserved (Padlat 2014, Van Rooijen & Oost 2014).

3.7 Griend

3.7.1 *Geomorphology*

Of the three study locations, Griend lies furthest into the back-barrier area. It is a remnant of a much larger island, that has been eroding for centuries (Simons 2014). The remnant island receives legislative protection largely due to its importance as a summer breeding location for seabirds.

Griend would have eroded away completely had it not been for two 'sand nourishments', the last of which was in 1988 (Figure 24). A protective 'hook' was extended from the north-west corner to form a complete outer barrier of the western coast. Also, a straight-line barrier, approximately 1.6 km long and 100 m wide, was constructed along the northern coast.

Figure 24. Griend in 1988 following the sand nourishment and vegetation program, looking to the east (photo ©GCN, Terschelling – accessed from http://www.ecomare.nl/en/encyclopedia/regions/wadden-sea-region/dutch-wadden-region/terschelling/terschelling-nature/griend/). The red oval indicates approximately the remnant island prior to the replenishment.

By 2014, virtually no trace of the western 'hook' remained (Figure 25). The northern barrier was present but had eroded considerably. To preserve Griend as a breeding area for birds, there are plans for a new nourishment to be conducted within the next five years (pers. comm. *Rijkswaterstaat*, *Natuurmonumenten*, *Arcadis*). At the time of preparing this report and in planning the nourishment programme, a detailed analysis on the morphological development of Griend was being prepared for *Natuurmonumenten* and *Rijkswaterstaat* (by *Arcadis*).

Figure 25. Griend in September 2014, indicating erosion of the dune areas and expansion of the salt-marsh since the 1988 nourishment, looking to the west (photo RK).

In December 2014, the geomorphology of Griend was dominated by sand dikes along the northern and western sides (Figure 26, Figure 27). The maximum elevation of the sand dikes in 2010 was approximately 3.6 m. Erosion had produced cliffs and ramps along seaward side of these sand dikes. The sand dikes protect a salt marsh with a dendritic creek pattern that drains to the southeast. Offshore to the west of the island, the 'hook' shaped barrier that was constructed in 1988 was evidenced only by an unvegetated sandbar. At some places, remnants of man-made structures such as wooden groins can be found.

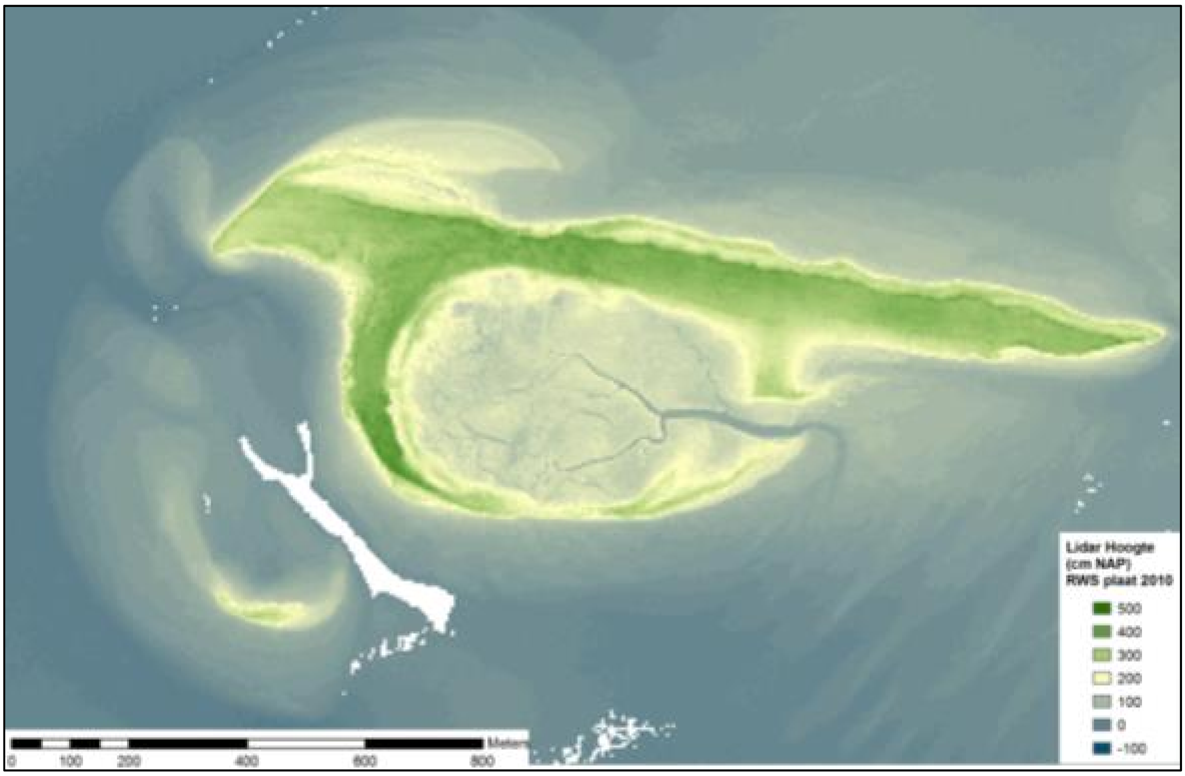


Figure 26. Elevation of Griend [source: Cleveringa (concept 2014), Rijkswaterstaat].

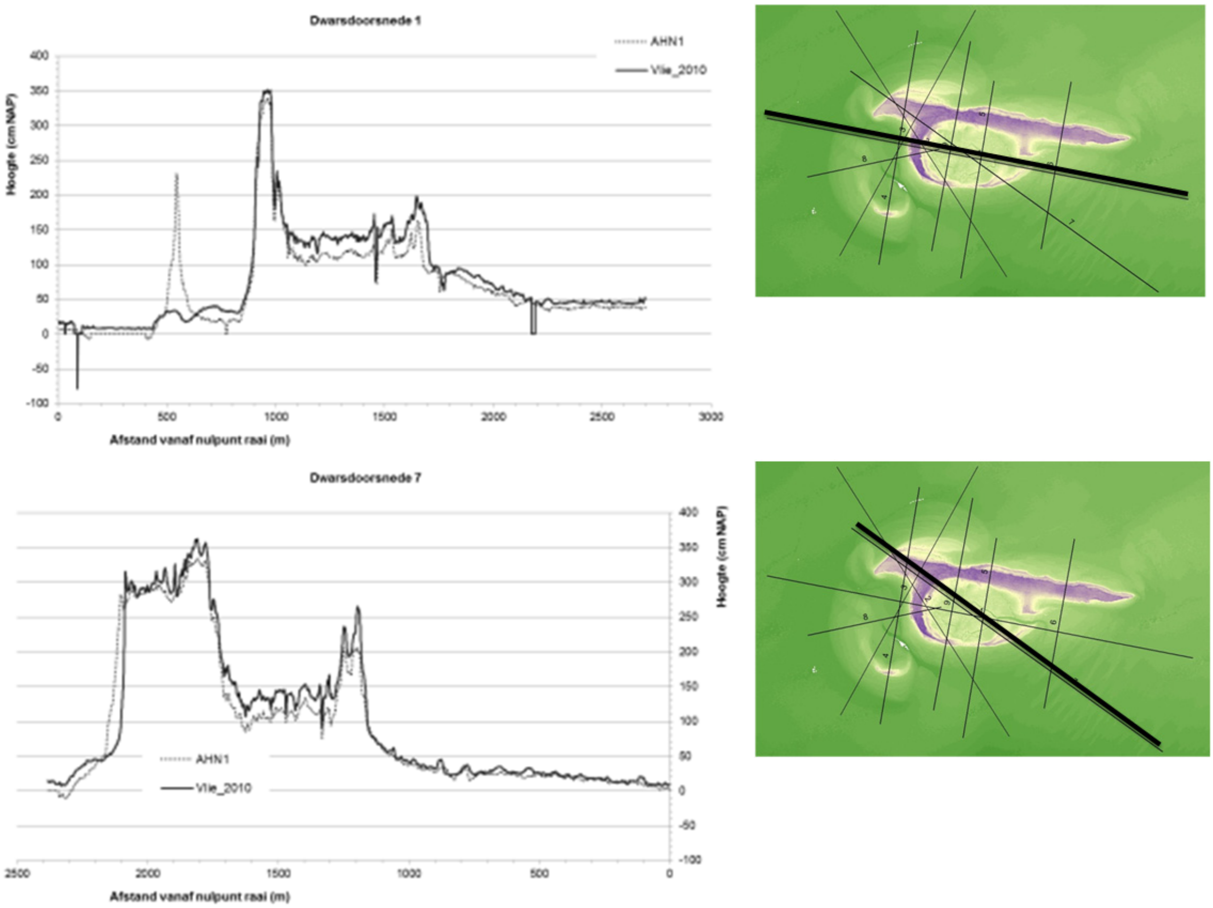


Figure 27. Cross-sections of Griend on two example locations [source: Cleveringa (concept 2014)].

Griend lies halfway between the tidal gauges of Harlingen on the landward side of the Vlie basin and Vlieland Haven/West-Terschelling on the seaward side. The exceedance water levels will therefore be, in first approximation, the average of these two locations. Accordingly, parts of the island above +2.6 m NAP will not be flooded yearly. Areas higher than +3.0 m NAP are likely to be flooded once every 5 years or less, and the seals should be more or less safe in a 1:10 year storm above +3.3 m NAP. Waves will raise the water levels somewhat compared to these values. From the laser-altimetry data of Figure 26 can be seen that there is ample area along the top of the sand-drift dike that lies above +3.3 m NAP, so that grey seals will be able to find places to escape storm floods that occur once every 10 years, and can find a safe place during any storms that occur more often.

3.7.2 *Seal pupping habitat*

The vegetation of Griend consists of dune and salt-marsh vegetation dominated by grasses and herbs (Figure 28), with only a few shrubs. In contrast to the loss of dune area between 1988 and 2014, the salt marsh had extended. Some vegetation patterns reflect now-eroded morphology, for example some salt-intolerant species found close to the waterline - probably kept alive by the freshwater lens. Several areas were eutrophicated through intensive (breeding) bird use (field observations and Simons (2014)).

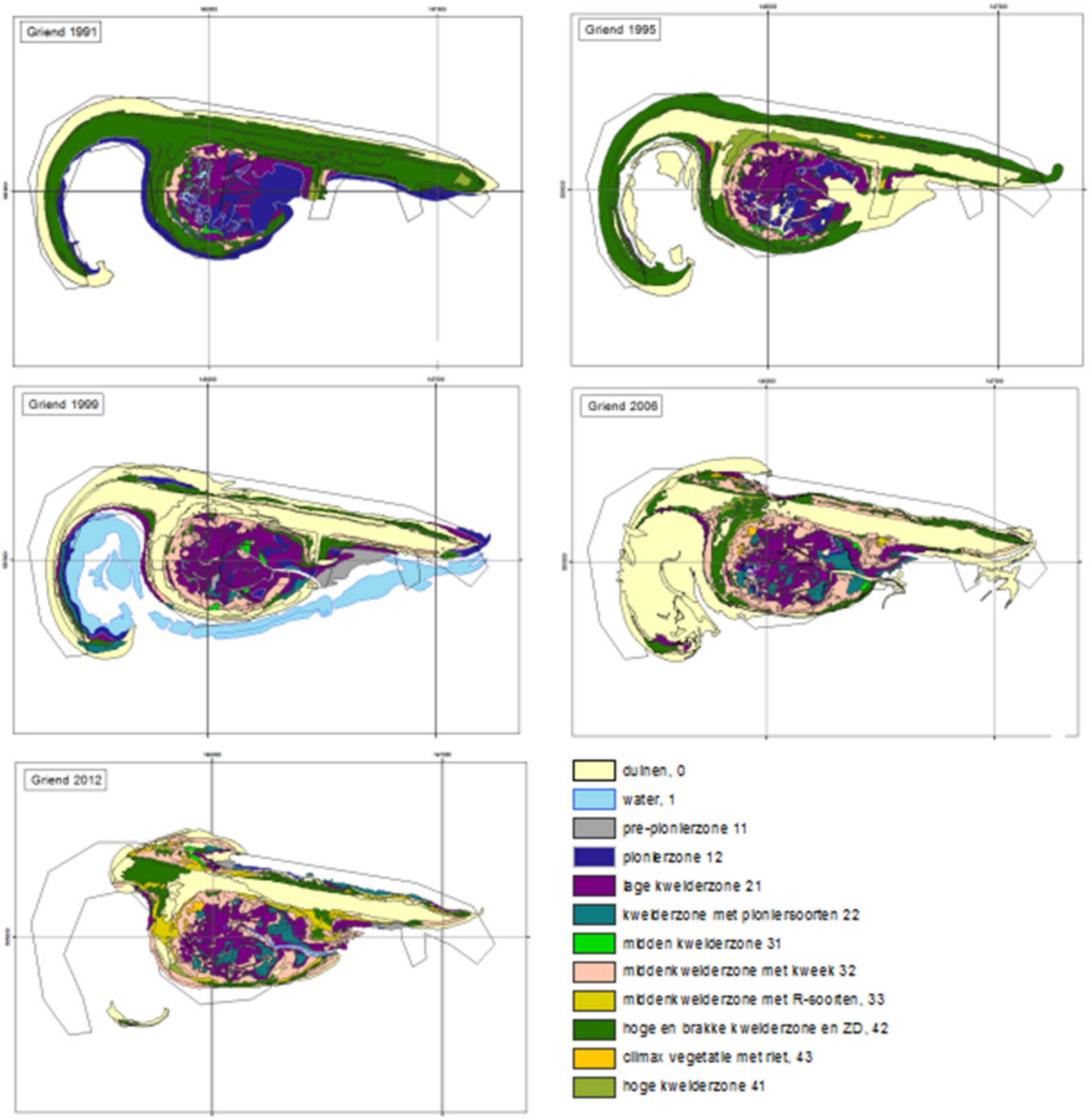


Figure 28. Vegetation maps for Griend from 1991 to 2012, based on the vegetation classification SALT97. Source: RWS VEGWAD.

Combining the observed seal locations from 2013 (see chapter 5, Figure 35) with the vegetation map (Figure 28) and the relevés (Appendix E), shows that seals occupied the beach, various grassy dune habitats and high salt-marsh vegetation. Several seals were found around depressions that were filled with water in winter, but were dry in August. Also the small stretch of salt-marsh vegetation in the north of Griend was used. Tracks of flattened vegetation indicated where individuals had crossed the island, but there was no evidence of extended occupation of the larger salt-marsh area. The seals could access the entire island, which had no thickets or trees to inhibit the seal movement. The small coastal cliff appeared not to be a barrier to seal movement inland.

An example of grey seal use of Griend is given in Figure 29. Some seals lay on and around vegetation on the supra-tidal part of the beach (lower part of the image) and a weaned pup lies within the vegetation above the erosion face.

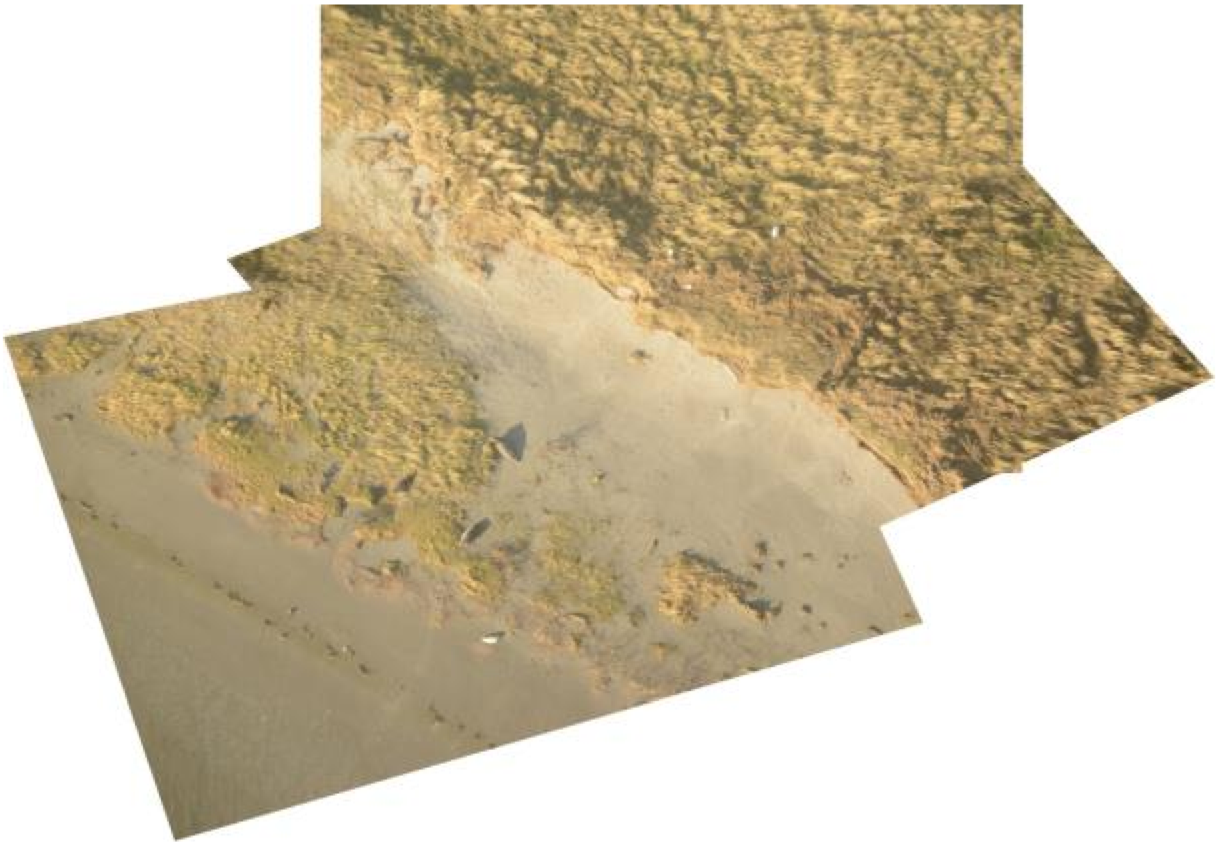


Figure 29. Oblique photo mosaic of grey seals on the south-eastern 'tail' of Griend, December 2013. The shore-line is to the lower left, a 0.5 to 1-m erosion face runs through the middle, and upper right are dunes (photo Jenny Cremer).

3.7.3 *Seal influence on vegetation*

As with Richel, the field visit to Griend was conducted in August, seven months after the seals had left the island, and following summer growth of vegetation and utilisation as a breeding site by colonial nesting birds. All of these likely concealed any short-term impacts the seals could have caused on vegetation and geomorphology. The density of seals on Griend is also considerably less than on Richel. However, during the field visit to Griend, we searched for the following signs of possible seal influence on the vegetation and geomorphology:

- *Plants that are indicators for high nutrient status*: Various nitrophilous vegetation types were present (Simons 2014). These were always associated with evidence of recent bird use, such as droppings, dead birds, feathers and old nests. Consequently, birds most likely were responsible for the eutrophication of these areas (Simons 2014). Drift-line material is likely to have contributed additional nutrients.
- *Seal nutrient import – scats and carcasses*: no scats found (and none expected due to anticipated degradation since seal occupation), one carcass found in the intertidal area – possibly a harbour seal.

- *Seal 'paths'/tracks* (which were visible in December 2013): no seal paths/tracks were evident.
- *Bare patches around seal locations from December 2013, or patches with different vegetation*: no bare patches found other than could be expected in normal dune habitat. Some patchiness in vegetation was found in the north-west and attributed to small-scale variations in hydrology.
- *Enhanced accumulation of sand*: not expected (see 3.6.7), and moreover, Griend is presently eroding.

In conclusion, the influence of the <100 grey seals breeding on Griend in winter was not evident in the vegetation and geomorphology viewed 8-months later in late summer. However, there were potential effects that could not be well quantified. For example, in the north-west of Griend, red-list vegetation types occur in the area used by seals, and the effects on those were not investigated.

3.7.4 *Future*

In 2014, Griend had been eroding for decades. Without intervention, it would likely transform into an unvegetated sandbar within decades and, consequently, become less suitable for grey seal breeding. To preserve the island as important bird habitat, sand nourishments are being considered by management authorities. Building up of the island would enhance the likelihood of longer-term occupation by breeding grey seals.

3.8 Discussion - habitat characteristics

3.8.1 *Suitability for seals*

The pupping habitats investigated are all dynamic areas and may show yearly changes in area, vegetation and elevation. As they change shape, the availability and quality of pupping habitat also changes. This is inherent to the Wadden Sea. The morphological developments in inlets are hard to predict, which also holds for the study areas. Moreover, the geomorphology of the south-western Wadden Sea is still adapting to the closure of the Zuiderzee in the 1930s.

Based on the studied locations currently being the three most important pupping sites within the Wadden Sea region, grey seals seem to prefer pupping sites with reasonable access through a deep channel, sandy substrate and bare ground or low, grassy vegetation. When the ground is undulating, the seals seem to prefer depressions between ridges. This may be for comfort, e.g. to remain sheltered from the wind, or social reasons, e.g. to reduce visibility to itinerant males. However, the available landscape types on the study sites are limited and do not include e.g. higher dunes, dune slacks or blowouts. During periods of high-water levels, higher dunes will offer more protection, but these may not be used during normal conditions.

The absence of grey seal pupping from beaches of the mainland (Holland coast) and inhabited islands of the Wadden Sea, which based on occupation of similar sites elsewhere are likely to be suitable, suggests that an important factor regulating site selection within the Netherlands is human disturbance. Given suitable protection from human disturbance pupping sites could eventually develop on island or mainland beaches. The concentration of grey seals on Richel suggests the seals are also driven by intrinsic factors, such as prior experience and site fidelity, as has been observed in other areas.

Based on the geomorphology of the Wadden Sea and the habitats already used by grey seals in the Wadden Sea and elsewhere, there are more potential pupping sites than are currently in use. These include islands and shoals adjacent to tidal inlets and up to approximately halfway into the tidal basins, such as:

- Marsdiep tidal basin,
    - Beaches and dunes of Den Helder and Texel
    - Razende Bol (currently a pupping site)
- Eierlandse gat tidal basin,
    - Beaches and dunes of Texel and Vlieland
    - Steenplaat
    - Vliehors (partly): where dunes are close enough to open water
- Vlie tidal basin,
    - Includes the established sites of Richel, Engelshhoek and Griend
    - Beaches and dunes of Vlieland (see section 2.3). This is a key site to monitor as it is adjacent to Richel and its establishment as a pupping site could be enhanced by overflow from Richel.
    - Beaches of the Noordsvaarder, Terschelling
- Amelandergat tidal basin,
    - Beaches and dunes of Terschelling, Cupidopolder
    - Beaches and dunes of Ameland (including embryonic dune field)
    - Blauwe Balg
- Pinkegat/Friesche Zeegat tidal basin,
    - Beaches and dunes of De Hon, Ameland (including the embryonic dune field)
    - Het Rif and Engelsmanplaat (not high enough to be safe during storms)
    - Beaches and dunes of Schiermonnikoog, including green beach with embryonic dunes
- Eilanderbalg/Lauwers/Schild basin,
    - Rottumerplaat
    - Rottumeroog, Zuiderduin

3.8.2 *Future developments on Richel and Griend*

The natural dynamics of the study sites may lead to an increase or decrease of suitable pupping habitat, through geomorphological changes or natural vegetation succession.

On Richel, the development of the geomorphology and vegetation is by no means certain, but there is the distinct possibility that the dunes will grow in size and that a salt marsh may develop in their shelter. Given our observations, grey seals use any type of grassy vegetation on a sandy soil and avoid the fine-grained (i.e. clayey) salt marsh. The development of a salt marsh may therefore diminish the area that is preferred by the grey seal. The growth of the dunes, however, will mean an increase in habitat quality (i.e. more shelter during storms) and quantity (if the dune area grows). If the dunes become sufficiently high and continuous, high grassy herb vegetation with shrubs may establish that could hinder the movement of the seals. Comparing Richel to the vegetation of Griend (on which the vegetation has established for a longer time), this is not expected to happen within the coming decades.

On Richel, management measures that will be taken the coming years will greatly influence the vegetation and morphology. Given the general negative sediment budget, considerable dune development is not expected, and sod-cutting is expected to remove the existing shrubs. Hence, ample short grassy vegetation and bare sand is expected to be available for the seals.

3.8.3 *Influence of seals on their pupping habitat*

At the moment, there are insufficient data to assess the impact grey seals may have on the vegetation and geomorphology. However, the current relatively low number and density of grey seals at breeding sites in the Dutch Wadden Sea in winter is unlikely to be greatly modifying the habitats. Potentially, the seals could disturb the vegetation at Richel and Griend by moving over it. On Richel, vegetation cover has increased recently, indicating current seal use is not limiting vegetation development. The seals could have more of an impact if they occupied the site during the spring-summer when most plant growth takes place. In winter, the above-ground biomass of *E. juncea* and *L. arenarius* dies off. The introduction of nutrients through faeces was not quantified in the current study, but could play a role in adding nutrients which may promote plant growth (Hellwig & Stock 2014). *Ammophila arenaria* responds to fertilizer by earlier maturation and a higher biomass production, potentially leading to increased sand accumulation (Van der Stege 1965). However, added nutrients are easily washed away from the sandy soil of embryonic dunes during inundation with sea water (Van der Stege 1965). The effect on red-list species on Griend was not quantified, as that would require more detailed study taking other environmental and ecological factors into account.

3.8.4 *Knowledge gaps*

Seal impacts may only be visible on a longer term. On Griend, time will allow the comparison of vegetation maps from before and after seal colonisation. This is not possible at Richel, where the seals colonised the establishing vegetation patch – so there was never a ‘before seals’ situation. At present, in fact, there are no vegetation maps for Richel. The construction of such a map and inclusion into the RWS VEGWAD programme would be advisable. Data gathered for this report may form input for a first vegetation map. Continuing to do full species inventories will give further insight into the development of the area. Regular measurements of elevation (preferably LiDAR) of the three locations are needed to assess the development.

Inventories of seal use should continue. For example, observations of seal use of the embryonic dune field at Richel should be monitored. If seal numbers keep rising at these sites, there is the possibility that the higher densities of seals could influence vegetation, through trampling or increased nutrient input. To better monitor the potential for nutrient loading, measurements of nutrients in the sediment on Richel and Griend should be made before and after the pupping season. Additionally, the composition and decomposition rate of seal faeces could be assessed, and be compared to the contribution by birds.

4 Exchange of grey seals with other areas

4.1 Introduction

Grey seals in the Netherlands belong to the east Atlantic stock that ranges from France to the Kola Peninsula in Russia. Genetics studies demonstrate this population to be distinct from the west Atlantic and the Baltic grey seal populations (Boskovic et al. 1996, Graves et al. 2009, Cammen et al. 2011, Klimova et al. 2014). Approximately 90% of east Atlantic grey seal pups are born in the UK where the majority of pup births occur in Scotland. There is evidence that grey seals on the North Sea coast of the UK represents a sub-population that is distinct from those on the Atlantic coast. For example, the colony at North Rona (Outer Hebrides) is genetically distinct from the colony at Isle of May (Firth of Forth, on the North Sea coast) (Allen et al. 1995). After the UK, the next largest area of pup production by the east Atlantic grey seal is in the Dutch Wadden Sea.

Grey seals in Dutch waters include those associated with local pup production (forming the local breeding group) and visitors that are not associated with local pup production (Brasseur et al. 2015). This is based on the observation of many more seals than can be expected from breeding in Dutch waters alone. Levels of isolation and overlap between these components are difficult to assess, and to do this is important for understanding the identity and sustainability of grey seals in the Netherlands.

The group of grey seals associated with pup production in Dutch waters (the local breeding group) has been growing annually and in 2013 comprised an estimated 2000 animals producing approximately 400 pups (Brasseur et al. 2015). Growth rate of the group is estimated at approximately 19% per year, which is higher than could be expected for a closed population; at least one-third of the annual growth is likely to be through immigration of young animals that eventually breed in the Netherlands (Brasseur et al. 2015).

In addition to the local breeding population and immigrants into this, at least 200 and potentially more than 1000 other grey seals from the UK visit the Wadden Sea each year as temporary visitors (Brasseur et al. 2015). These seals potentially feed in Dutch waters and haul out on the Dutch coasts for part of the year and likely return to UK colonies to give birth to pups/ participate in breeding. Individuals that migrate to or visit the Wadden Sea from the UK most likely come from the 'North Sea' cluster of colonies (see Figure 30).

Based on tracking data and occasional sightings of marked individuals, immigration and visitation of grey seals to the Netherlands is most likely from the grey seal colonies on the North Sea coast of the UK (Brasseur et al. 2014, Brasseur et al. 2015). Like in the Wadden Sea, grey seal numbers at these UK colonies have grown exponentially in recent decades (Duck 2010).

This part of the study aims to establish and better quantify grey seal connectivity between Dutch waters and other locations, and to determine the sites most likely to be contributing to growth and visitation of grey seals to Dutch waters. Three techniques are used: 1) movement of individual seals, 2) photo-ID and 3) genetic studies. Individual movement studies on grey seals have been undertaking by IMARES since 2005 (Brasseur et al. 2010, Brasseur et al. 2014, Kirkwood et al. 2014), the photo-ID program commenced in 2013 as part of an investigation into habitat quality of grey seals in the Netherlands (Brasseur et al. 2014) and the genetic component is a new initiative.

Figure 30. Grey seal colonies and haul-out sites in the UK, clustered by area. Figure from UK Special Committee on Seals (SCOS) 2013 report, which is based on data collected by the Sea Mammal Research Unit (SMRU) http://www.smru.st-and.ac.uk/documents/1803.pdf

4.2 Methods

4.2.1 *Movement data*

Between 2005 and 2014, IMARES tracked a total of 75 grey seals (Table 3). Data collected for each seal included sex, status - adult versus subadult (adult taken as nose to tail length of >140 cm for females and >150 cm for males) and mass in kilograms – IMARES unpublished data).

In the movement analysis, we excluded seals that had <50 days of movement data, in order to not bias data with seals that were tracked for short periods. This reduced the sample size to 62 seals (Table 3).

Movements of these seals were investigated to determine if individuals crossed into other national waters, then if so, in which months of the year they did this and whether or not they hauled-out at sites in other countries. In particular, movement during the breeding period (November to December) of adult animals was investigated, because these could indicate that the individuals bred at the sites they visited. Adult females that resided at a breeding colony for >10 days during the pupping period likely gave birth to a pup and had the possibility of rearing the pup to weaning.

Table 3. Grey seals fitted with satellite tracking devices (Argos or GPS) in the Netherlands by IMARES.

Year	Area	Number	Tracked for >50 days
2005	Wadden Sea	12	12
2006	Wadden Sea	6	3
2007	Wadden Sea	5	5
2008	Wadden Sea	6	5
2013	Wadden Sea	19	14
	Zeeland	6	2
2014	Wadden Sea	11	11
	Zeeland	10	10
Total		**75**	**62**

4.2.2 *Photo-ID*

Being able to recognise an individual over time enables interpretations of life-history traits and movement behaviour. For example, information can be gathered on where the individual travels and how frequently or for how long it rests at one place. It also has applications for estimations of population size, by applying a mark-recapture (recognise-resight) technique. Standard techniques for enabling identification of individuals include tagging and branding. Such techniques require the animal to be captured, however, which can be difficult and invasive and give rise to ethical discussions.

The Sea Mammal Research Unit (SMRU) in Scotland has developed a photo-ID technique for grey seals and have collated images of grey seals from across the United Kingdom and France since the 1990s (Hiby & Lovell 1990, Vincent et al. 2001, Hiby et al. 2007, Hiby et al. 2012, Paterson et al. 2013). This project is supervised by Dr Paddy Pomeroy of SMRU.

The photo-ID technique takes advantage of the unique markings on each seals' fur. Pattern-matching software enables the re-sighting of individuals. In grey seals, pattern-matching of individuals comes from photographs taken on land of the head, neck and flank, and at sea of the head and neck (Hiby et al. 2012, Paterson et al. 2013).

Not all grey seals are useful candidates for photo-ID. For instance, recognising individual adult males is difficult because the pelage of males darkens considerably with age and scares gained through fighting alter the patterns. Most females, but not all, can be traced through their lives by individual patterns in their pelage (Paterson et al. 2013). Some darkening of female pelage with age serves to strengthen the contrast between dark and light areas, making identification by pelage recognition easier as animals get older (Vincent et al. 2001). Some females have a uniform colouration, though, with minimal patterning. These females are unsuitable for photo-ID.

In 2013, a grey seal photo-identification (photo-ID) program was established in the Netherlands in collaboration with Dr Paddy Pomeroy at SMRU (Brasseur et al. 2014). The ultimate aim of the project in the Netherlands is to understand the proportions of seals that are resident, those that are seasonal visitors and those that are immigrants. Additional aims are to gain information on immigration rates and routes, record movements of individual females that are pupping in the Netherlands and record turn-over rates at haul-out sites (to estimate numbers utilising sites).

Photographs of grey seals were taken during 2013 and 2014 on visits to haul-out and breeding sites of grey seals in the Netherlands, and during opportunistic visits to two breeding sites in the UK Where practical, to assist with recognising individuals in separate photos, an overview of all the seals present was constructed by stitching together a selection of images. The photo-ID photographs were collated and supplied to SMRU for further processing.

At SMRU, unsuitable photographs were removed. Unsuitable photographs comprised blurry shots (poor focus or excessive movement), repeat photographs, photographs of only harbour seals, or photographs in which the pelage of the grey seals present was not clear (poor lighting, poor angle of view, only males with unclear patterns etc). In suitable photographs, photo-ID images were extracted of the head, neck and flank, and of the left and right sides, of each seal (Figure 31). Extraction involved processing the 3-dimensional shape of the seals' body into a 2-dimensional map of the patterns of light and dark patches, which are unique to each seal. This resulted in up to six photo-ID extracts for each seal, although usually less because both sides of a seal were rarely available. The extracts were added to the photo-ID database held at SMRU, using the computer-aided matching software package '*ExtractCompare*', and were compared with all extracts in the data base. The software produced the most likely matches and these were checked visually to identify exact matches.

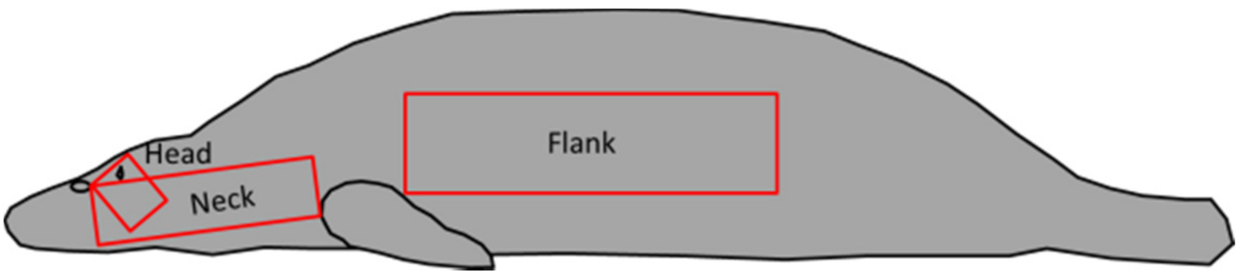


Figure 31. Positioning of the three extracts of pelage pattern for photo-ID on the left side of the seal

4.2.3 *Genetics*

The genetic structure within a population is influenced by species behaviours (such as breeding strategies and movement) as well as historical and current events. The genetic composition of grey seals in the Netherlands is the product of original expansion in diversity following the last glacial maximum to 10000 years before present, potentially a genetic bottle-neck caused by >1000 years of hunting pressure which restrained population size and range, and expansions in size and range in the last 100 years. It is not known if colonisation and on-going immigration were from one or more sites.

The grey seal's high level of philopatry and breeding site fidelity will likely enhance genetic structure (Pomeroy et al. 1994, Twiss et al. 1994, Pomeroy et al. 2000a, Pomeroy et al. 2000b). To be structured means to have separation between the genetic composition of groups that reside in different areas. However, the seals' strong dispersal capabilities is likely to disrupt structure. It is not known if separate colonies in the North Sea can be distinguished by their genetic composition. Consequently, it is also not known if source colonies for grey seals migrating to the Netherlands can be determined genetically.

The genetic analysis in this study represents a pilot study to determine primers and extract genetic sequences that might allow differentiation between extant colonies in the North Sea. Following on from this study, a preliminary assessment of genetic diversity between the Netherlands and colonies in the UK is planned. Processing will be by 'restriction aided digestion' (RAD) sequencing to determine diagnostic outlier 'single nucleotide polymorphisms' (SNPs). The RAD analyses will isolate gene sequences that contain polymorphism and for which further sequencing can focus in order to isolate colony-specific markers.

Skin biopsy samples have been collected from all seals handled during other research projects by IMARES. Twenty of these were selected to provide a spread of samples across age/sex-classes and areas within the Netherlands. During the seal breeding periods of spring-summer 2014, further skin-tissue samples were collected, mostly from dead pups, at colonies in the UK (Blakeney Point, Donna Nook and Isle of May). Samples were stored in a DMSO solution and will be analysed by 'restriction aided digestion' (RAD) sequencing in the Genetics Laboratory at University of Groningen, during 2015.

4.3 Results

4.3.1 *Movement data*

Up to 2014, IMARES had attached tracking devices to 75 grey seals, of which 62 were tracked for periods >50 days. The mean duration of recorded movement for each seal was 165 ± 61 d (range 51 to 300 d). During the period they were tracked, 27 of the 62 seals (44%) moved through waters of other countries (Figure 32, and see Appendix F). The majority of those, 21 of the 27, moved through UK waters and 18 hauled-out at least once at a known haul-out or colony site in the UK. Sites most frequented were in England: Blakeney Point (10 seals), Donna Nook (7 seals), Horsey (6 seals) and Farne Islands (6 seals). Five of the 21 seals also visited places in Scotland, including the Orkney Islands (visited by 3 seals).

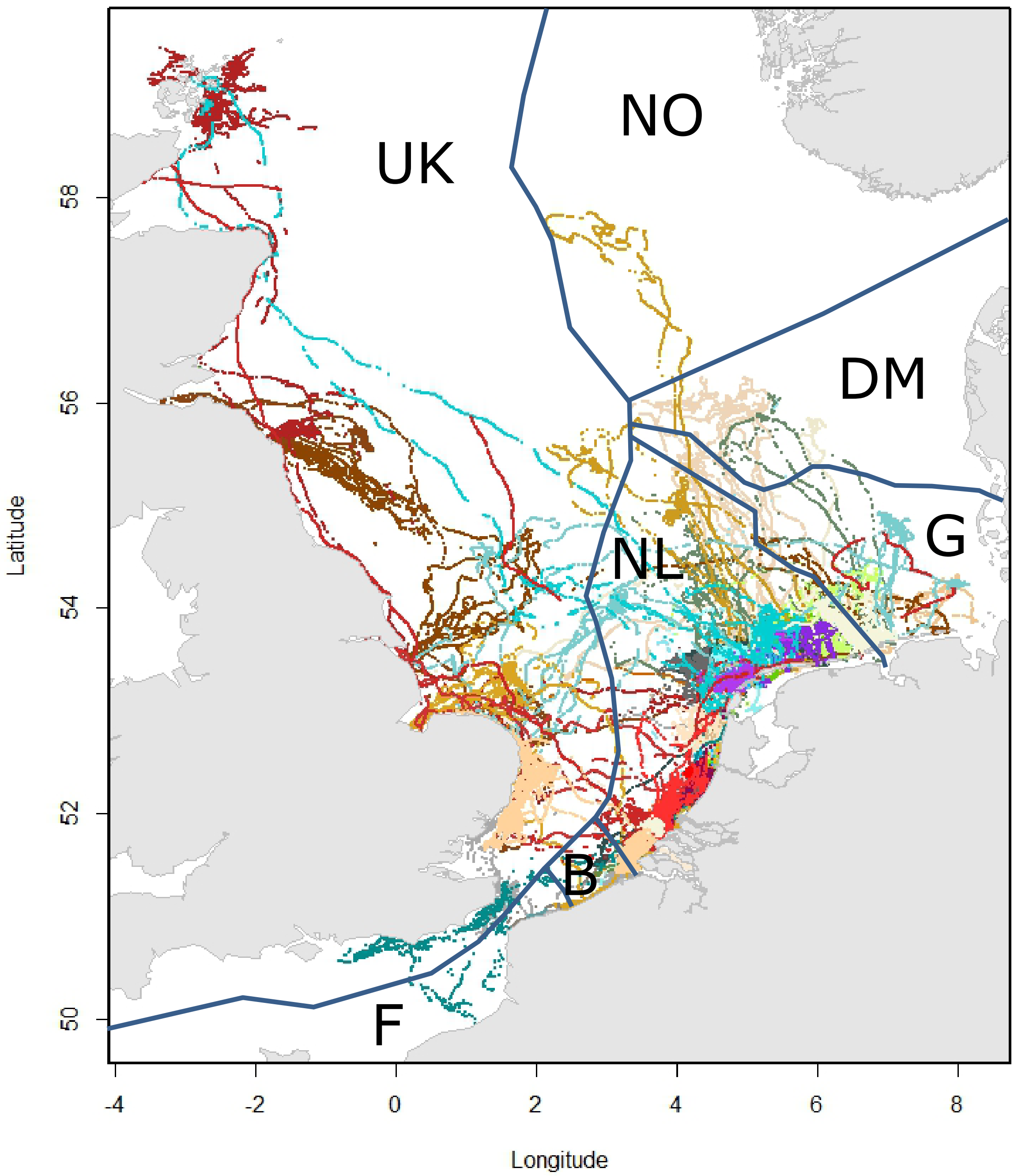


Figure 32. Locations of grey seals tracked from sites in the Netherlands up to 2014 - colours indicate individual seals (n = 75). Boundaries of national Exclusive Economic Zones in the North Sea are indicated.

In addition to visits to the UK, the seals were tracked to Exclusive Economic Zones (EEZs) of Germany (by nine seals, including haul-outs at the islands of Helgoland and Borkum), France (five seals, several visited known haul-out sites), Belgium (eight seals), Denmark (three seals) and Norway (one seal). No haul outs on land were made by the seals in Belgium, Denmark or Norway.

Of the 62 seals tracked, 15 were adult males (>150 cm) and 23 were adult females (>140 cm). Seven of the adult males were tracked during the seals' winter pupping period and six of these went to breeding sites. Three moved between breeding sites several times, in such a way that it was unlikely for them to have held a territory at any one. Of the three males that resided at single sites for several weeks at least, so could have held breeding territories, one remained in the Netherlands at Razende Bol, and two went to the UK, one to Donna Nook and the other to Horsey.

Fourteen of the adult females were tracked during a winter pupping period. Thirteen of these resided at a colony sufficiently long to have raised a pup. Five of the females that could have raised pups did so in the Netherlands, four at Richel and one at Griend. Seven females likely raised pups at colonies in the UK, six at Blakeney Point and one at Fastcastle. The remaining female likely raised a pup at Helgoland in Germany. The 14th seal visited Engelschhoek (NL) several times during the pupping period, but remained for less than 2-days during each visit. She might have had a pup there, but likely did not remain long enough to suckle a pup to weaning.

Table 4. Adult female grey seals tracked during a pupping period indicating the location where they appeared to raise a pup (up to December 2014).

											N'lands		UK		Germany
Year	**Area**	**Site**	**Seal**	**Length**	**Mass**	**Start**	**End**	**Period**	**Pup**	**Month**	**Richel**	**Griend**	**Blakeney Pt**	**Fastcastle**	**Helgoland**
2013	Wadden	Steenplaat	737	175	96	mar	dec	281	1	11			1		
2013	Wadden	Pinkegat	862	154	114	sep	feb	159	no						
2013	Wadden	Pinkegat	874	134	139	sep	feb	153	1	12	1				
2013	Wadden	Pinkegat	897	162	117	sep	feb	153	1	12	1				
2013	Wadden	Pinkegat	906	169	169	sep	jan	125	1	12	1				
2013	Wadden	Pinkegat	911	154	130	sep	jan	132	1	12				1	
2014	Wadden	Steenplaat	T003	155	74	apr	dec	235	1	11			1		
2014	Wadden	Steenplaat	T040	152	97	apr	dec	236	1	12	1				
2014	Wadden	Steenplaat	T076	179	101	apr	dec	235	1	11	1				
2014	Wadden	Steenplaat	T875	159	108	apr	dec	236	1	12			1		
2014	Zeeland	Aardappelbult	Z006	170	121	apr	dec	248	1	12			1		
2014	Zeeland	Aardappelbult	Z024	149	82	apr	dec	248	?	12			1		
2014	Zeeland	Aardappelbult	Z046	168	194	apr	dec	251	1	12					1
2014	Zeeland	Aardappelbult	Z062	165	86	apr	dec	247	1	12			1		
2014	Wadden	Blauwe Balg	A074	178	166	sep	dec	94	1	12		1			
									13		**5**	**1**	**6**	**1**	

4.3.2 *Photo-ID*

In 2013, 2449 images taken during seven visits to seal haul-out sites were processed (Table 5). Not all images were useful for photo-ID as they were of males, did not provide clear views of pelage or were repeat photos of the same seal. Photo-ID images were extracted for a total of 145 female seals. There were no matches with data in the SMRU data set.

Table 5. Grey seal photography for photo-ID pattern matching during 2013 and 2014.

Area	Location	Date	Photographs	Processed
Wadden Sea	Steenplaat	2013-03-12	339	yes
Wadden Sea	Steenplaat	2013-03-13	502	yes
Delta region	Renesse	2013-03-19	74	yes
Delta region	Aardappelbult	2013-03-21	593	yes
Wadden Sea	Steenplaat	2013-04-29	230	yes
Zeeland	Aardappelbult	2013-05-15	289	yes
Wadden Sea	Steenplaat	2013-05-23	422	yes
Wadden Sea	Steenplaat	2013-08-17	1176	yes
Wadden Sea	Steenplaat	2013-08-27	137	yes
Wadden Sea	Pinkegat	2013-09-17	91	yes
Wadden Sea	Pinkegat	2013-09-18	184	yes
Wadden Sea	Pinkegat	2013-09-19	97	yes
Wadden Sea	Steenplaat	2013-09-25	307	yes
UK North Sea	Farne Islands	2013-11-05	350	yes
Wadden Sea	Griend	2013-12-14	122	yes
Wadden Sea	Griend	2013-12-15	67	yes
Wadden Sea	Griend	2013-12-16	149	yes
Wadden Sea	Richel	2013-12-17	157	yes
Wadden Sea	Griend	2013-12-20	13	yes
Wadden Sea	Steenplaat	2014-08-20	394	yes
Wadden Sea	Steenplaat	2014-08-24	392	yes
Wadden Sea	Steenplaat	2014-08-27	378	yes
Wadden Sea	Steenplaat	2014-08-31	420	yes
Wadden Sea	Steenplaat	2014-09-20	241	yes
UK North Sea	Fastcastle	2013-11-08	406	no
Zeeland	Aardappelbult	2014-04-04	15	no
Wadden Sea	Razende Bol	2014-08-14	12	no
Wadden Sea	Griend	2014-12-13	1110	no
Wadden Sea	Griend	2014-12-14	572	no
Wadden Sea	Griend	2014-12-15	389	no
Wadden Sea	Griend	2014-12-16	933	no
Wadden Sea	Richel	2014-12-30	1489	no
			12050	

In 2014, photographs from 17 sampling days were processed (Table 6). Photographs from a further eight sampling days, including visits to the breeding colonies of Richel and Griend during the pupping period of December 2014, remain to be processed.

From a total of 897 individuals detected, there were 2569 photo-ID extracts made and compared with records in the data base, to look for matches. For Steenplaat samples, only the neck extracts have been pattern-matched with the data base.

Table 6. Processing outcomes of grey seal photo-ID images taken in the Netherlands.

Location	Date	Suitable images	Individuals	Extracts (Neck)	Extracts (Head)	Extracts (Flank)	Total Extracts
Ameland	2013-09-17	25	2	2	2	2	6
Ameland	2013-09-18	36	4	5	7	3	15
Ameland	2013-09-19	59	5	6	8	3	17
Farnes	2013-11-05	135	72	101	48	86	235
Griend	2013-12-14	93	20	28	16	22	66
Griend	2013-12-15	63	11	19	18	7	44
Griend	2013-12-16	142	9	43	39	23	105
Richel	2013-12-17	123	59	99	70	75	244
Griend	2013-12-20	13	5	8	8	6	22
Steenplaat	2013-08-17	294	122	168	121	115	404
Steenplaat	2013-08-27	115	106	122	89	61	272
Steenplaat	2013-09-25	141	121	167	99	74	340
Steenplaat	2014-08-20	116	103	89	66	54	209
Steenplaat	2014-08-24	135	98	92	96	47	235
Steenplaat	2014-08-27	95	69	66	54	36	156
Steenplaat	2014-08-31	68	61	49	41	31	121
Steenplaat	2014-09-20	53	30	34	32	12	78
	Total	**1706**	**897**	**1098**	**814**	**657**	**2569**

One seal photographed at Donna Nook (UK) in early 2013 was re-sighted at Steenplaat (Netherlands) on 17 August 2013. Three movements within the Netherlands were recorded - two seals at Steenplaat in August 2013 (one of these was seen on two occasions) subsequently had pups at Griend in December 2013. A further resighting was made within the UK – a seal photographed at the Isle of May in Scotland was resighted at the Farne Islands during our visit there, on 5 November 2013. Additionally, there were 13 individuals were photographed at Steenplaat in both 2013 and 2014.

As well as the photo-ID matches between Steenplaat and Isle of May, one female at Steenplaat had a readable flipper tag which identified it as having been caught at the Isle of May, Scotland (data on actual dates have not been processed).

4.3.3 *Genetics*

To analyse possible exchange between the different pupping sites in the North Sea, DNA from the areas were collected. The genetics study will be presented in a later report.

4.4 Discussion

4.4.1 *Movement data*

The link between grey seals in Dutch waters and colonies on the North Sea coast of the UK is evident in the tracking data. The movement of seals tracked from the Netherlands demonstrates that many (and potentially the majority) grey seals that haul-out on sandbars in Dutch waters frequent other national waters. During the period that seals were tracked, which averaged approximately 165 days, 44% of seals caught at Dutch sandbars visited other waters, including 34% to UK waters. It could be anticipated that the percentage of seals to travel internationally would be higher than that recorded, because some seals that remained in Dutch waters during the half year they were tracked, could have moved out of Dutch waters in the period of year they were not tracked, or in other years. Accordingly, as has been highlighted previously (Brasseur et al. 2015), the grey seals in the Netherlands cannot be considered a discrete sub-population or even a single management unit.

While tracking of grey seals from the Netherlands indicates considerable exchange with the UK, few of the seals tracked from the UK visited Dutch waters (Figure 33). The apparent discrepancy is in line with the expectation that a small percentage (<2%) of young UK seals migrate annually into the Dutch breeding population and a similar proportion of adult seals from UK colonies would visit Dutch waters annually (Brasseur et al. 2015). The chances of tagging exactly those seals in the UK are rather slim. On the other hand, the small percentage of UK seals migrating into the Dutch breeding population represents an annual influx of at least 33% and practically all 'visitors' originate from the UK and seals from both groups are likely to revisit the UK.

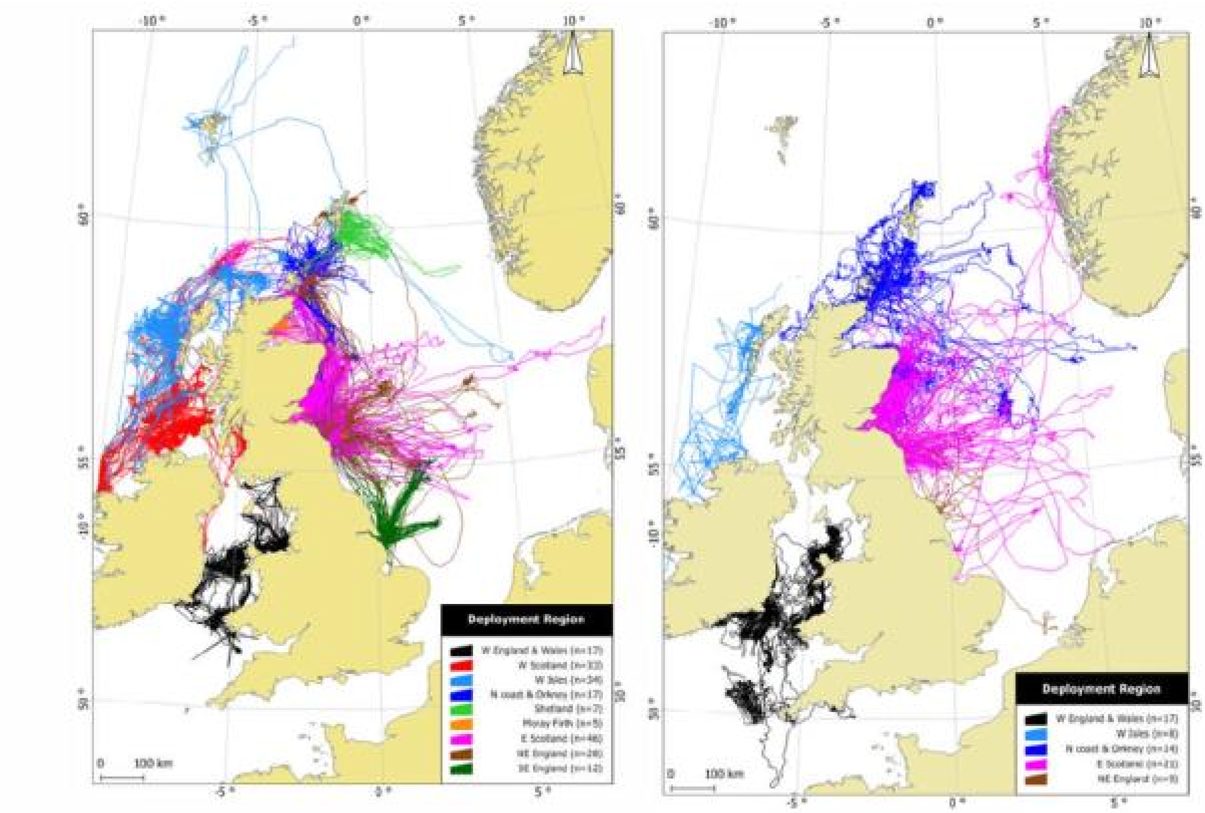


Figure 33. Tracks of grey seal (a) adults and (B) pups tracked from sites in the UK, coloured by deployment region. Figure from UK Special Committee on Seals (SCOS) 2013 report, which is based on data collected by the Sea Mammal Research Unit (SMRU) http://www.smru.st-and.ac.uk/documents/1803.pdf

4.4.2 *Photo-ID*

The matching of an adult female between Donna Nook in the UK and Steenplaat in the Netherlands represents the first photo-ID confirmation of movement between these two countries. It establishes a link between the two sites of Donna Nook and Steenplaat, which until now has been evident only in tracking data. More such links could be expected in the future as the photo-ID data base grows, helping to better quantify overlap in movement by individuals from the UK and the Netherlands.

The use of photo-ID to record movements of seals becomes exponentially of greater value as more years of data are collected. The few matches so far made is understandable considering the short duration of the study and the small proportion of seals in the total population for which photo-ID extracts have been obtained.

In addition to the increasing data from photo-ID in the Netherlands during 2014, photo-ID programs in the UK are also growing. In 2014, and partly stimulated by the research in the Netherlands, photographs were taken of adult females at more of the large breeding colonies along the North Sea coast of the UK, including Blakeney Point, Donna Nook, Fast Castle and the Isle of May (P. Pomeroy, pers. comm).

In 2014, the photo-ID project focused on seals utilising the haul-out site of Steenplaat and on breeding females at the colonies of Griend and Richel. The Steenplaat is one of the most accessible haul-out sites in the Netherlands because a tourist vessel visits there frequently between May and September. Regular sampling there provides an important opportunity to record visitations of individuals from the UK. Monitoring of breeding females at the colonies of Richel and Griend focusses on recording potential immigrants into the Dutch breeding group.

In addition to the data that will come in proportions of grey seals resident, visiting and immigrating, photo-ID provides the opportunity to better understand habitat use and breeding behaviour of the grey seals in the Netherlands. Studies at Steenplaat can investigate durations of haul-outs and total numbers of seals utilising the haul-out (based on analyses of mark-resight and 'survival' at a haul-out).

At Richel and particularly at Griend (because each breeding female there can be recorded), pupping rates, pupping success, site fidelity, and longevity are amongst the studies that can benefit from a long-term photo-ID program. Opportunities for extending the application of the photo-ID technique could be investigated in the future. These projects provide the means to monitor structure and sustainability of the breeding group in the Netherlands.

4.4.3 *Genetics*

RAD analysis and determination diagnostic outlier 'single nucleotide polymorphisms' (SNPs) will isolate gene sections suitable for amplification and aid in determination of sample-sizes required for genetics studies on relatedness of grey seals between regions. Further genetics studies will be based on the results of this analysis.

4.5 Conclusions

In the UK in the last decades, grey seal numbers have undergone considerable growth (Figure 34). Since 2005, sites on the southern North Sea coast, such as Donna Nook and Blakeney Point, have grown at faster rates than colonies elsewhere. This rate matches the growth in pup production in the Dutch Wadden Sea, suggesting the same processes are affecting grey seal numbers on both east and west coasts of the southern North Sea. However, the number of pups born on the UK coast of the southern North Sea is 10 times that in the Dutch Wadden Sea.

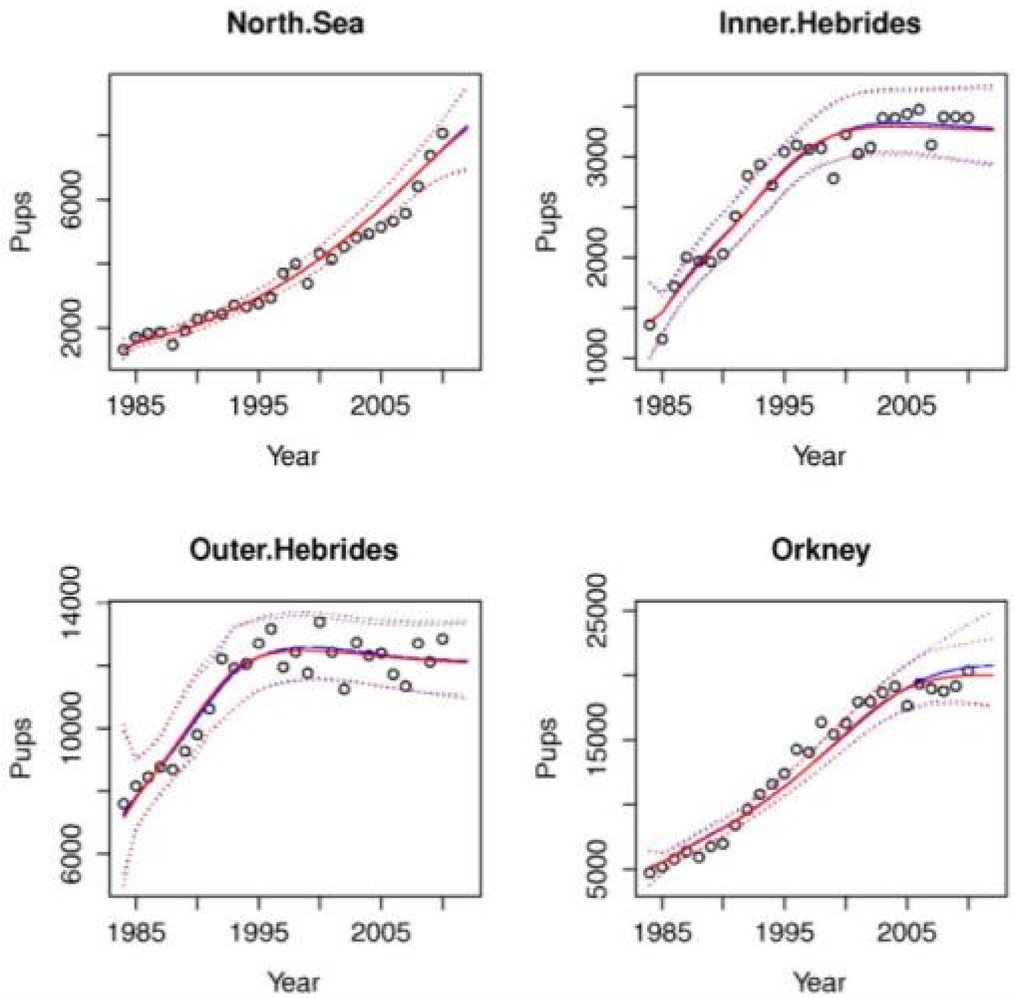


Figure 34. Mean estimates of pup production and 95% confidence intervals from a model of grey seal population dynamics fit to pup production estimates from 1984 to 2010. Data from UK Special Committee on Seals (SCOS) 2013 report, which is based on data collected by the Sea Mammal Research Unit (SMRU) http://www.smru.st-and.ac.uk/documents/1803.pdf

Based on the tracking data collected by IMARES since 2006, the first photo-ID record of a Donna Nook seal resighted in Steenplaat, and the apparent influx based on the growth in numbers in the Wadden Sea (Brasseur et al. 2015), it is clear that many female grey seals that breed in the UK visit Dutch waters to forage – and some potentially remain in Dutch waters for the majority of the year. Between foraging trips, they haul-out at sites in Zeeland and the Wadden Sea. Based on the animals tracked so far, this is certainly the case for seals from Blakeney Point and Donna Nook. Further monitoring should focus on this link and collaborative projects with researchers at Blakeney Point should be fostered; what occurs there will undoubtedly influence the numbers and distribution of grey seals visiting Dutch waters.

Despite being a source for visitors to Dutch waters, Blakeney Point and Donna Nook may not be the source sites for seals immigrating into the Dutch breeding group. Blakeney Point currently has an annual growth rate of approximately 30% which itself can only be attained through a high level of immigration. It is highly likely that immigrants into breeding groups at Blakeney Point, Donna Nook and the Dutch Wadden Sea (i.e. the southern North Sea area) are coming from the northern North Sea, such as from the Farne Islands and sites in Scotland – including the Isle of May, Fastcastle, the Forth of Firth and the Orkney Islands. At the Orkneys, for example, total pup production is twice that of the North Sea and populations are no longer growing ‘locally’ (Figure 34). They could be supporting growth elsewhere.

Some emigration of seals from the Hebrides could also occur. However, there are few records of tracked seals crossing north of Scotland between the Hebrides and Orkney Island groups. Clarification of likely sources of immigrants into the Dutch breeding group could come through future genetics studies.

In summary, tracking studies and long-term monitoring data provide us with the most information to date on the movement of seals around the North Sea. Photo-ID and more targeted genetics studies are likely to enhance this data in coming years, at relatively low costs provided monitoring is maintained. Based on tracking data, grey seals that temporarily visit Dutch waters each year are likely to come from sites in the UK, particularly southern North Sea sites like Blakeney Point and Donna Nook. Grey seals that immigrate into the breeding group in Dutch waters are likely to be the same source that is boosting growth at sites in southern England, such as at Blakeney Point, Donna Nook and Horsey. Potentially, most emigration is from sites in northern UK, including the Orkney Islands. Genetics studies are likely to provide the best means for ultimately determining the source of migrants into the Dutch Wadden Sea.

Better quantification of the national and international movement of individuals will come through additional tracking studies, and the long-term data from the photo-ID project and genetics studies. Future cooperation within the North Sea in exchanging information, samples and photo-id data would probably be the best way to further develop the management of the North Sea grey seals.

5 Ameliorating errors in monitoring of pup production

5.1 Introduction

Counts of grey seal pups each winter breeding period form a basis for monitoring the status of the grey seal population in the Netherlands. The number of seal pups born correlates with the total number of seals present (Bowen et al. 2007, Duck and Thompson 2007) or at least forming the breeding population (Brasseur et al. 2015). The correlation is not static, however. Changes in population growth rate, demography, reproductive rates and exchanges with other populations nearby affects the number of seals present in a way which is not deducible from pup counts alone (Härkönen & Harding 2001, Brasseur et al. 2015). These sources for variability in the relationship between pup numbers present and total population can be modelled to improve the accuracy of population estimates (Brasseur et al. 2015).

Underpinning all pinniped population modelling based on pup count data is that counts of pups are as accurate as possible and that all sources for error are accounted for in variability estimates. In this regard, two important limitations need to be taken into account. Firstly, at each point in time during the period of pup births, not all pups will be present. Some pups may be yet to be born, while others may have already left the colony, or died (Bowen et al. 2007). Accordingly, a single pup survey will not record all pups born in a breeding season, even if it coincides with the maximum number of pups is present. Solving this limitation requires that more than one survey be undertaken through the pupping period, and data be modelled based on numbers recorded and known pup-support durations. The second limitation is a more basic one, that pups present need to be recorded accurately or that the proportion missed can be quantified. The present study addresses this second limitation.

Grey seal pups are born in winter when short day-light periods and bad weather often hamper complete monitoring of all possible pupping sites. Low levels of incident light and overcast conditions also reduce the quality of photographs, making it difficult at times to distinguish pups, especially lone weaned/ moulted pups, from older grey seals, and even harbour seals or marine debris. At times, considerable scrutiny and comparisons between photographs is required to provide the best estimates of pup numbers.

A compounding source for error in aerial counts that has increased in recent years is that an unknown proportion of pups could be obscured from view. They may be hidden behind other seals in undulating and vegetated substrates. This issue is particularly relevant at the sites of Richel, where by far the majority of pups is born, and Griend, where numbers are increasing and the vegetation is thick (see chapter 3).

The aim of this part of the study was to overlap routine aerial survey techniques with alternative survey techniques at the key pupping habitats of Richel and Griend, to better quantify how many pups could be obscured from aerial photography by vegetation and topography.

5.2 Materials and methods

5.2.1 *Comparison of aerial and ground counts of grey seal pups at Griend*

On 14 December 2013 and 16 December 2014, ground and aerial-photography based counts were made of grey seal pups on the island of Griend.

Ground counts were undertaken by a team of two to three people who circumnavigated the island searching for and tallying dependant and weaned pups. Maps were constructed of the distributions of the seals present.

The survey technique of grey seal pups in the Dutch Wadden Sea has evolved over time as numbers of seals increased, new technologies become available. Between 1985 and 2001, pups were counted from warden boats of the ministry during tours around the known pupping sites. Seal numbers present were scored directly. Boat-based surveys become increasingly difficult, however, due to the increasing distribution of the seals. From December 2001 onwards, aerial surveys replaced the boat surveys. As the range grew further, the aerial surveys expanded and by 2007 they covered the entire Dutch Wadden Sea. Coinciding with the commencement of aerial surveys, a digital camera linked to a GPS, to record locations of photos and the flight path, was introduced. Counts were based on projections of the digital images. The estimate of annual pup numbers involves at least three survey days within each breeding period to accommodate for the length of the pupping period, approximately 6 weeks, and the duration of maternal support for each pup, approximately 2-3 weeks.

Aerial surveys were conducted from a fixed wing, single engine aircraft, flying at approximately 150 m (500 ft) at a speed of 160-200 km/h. Surveys were timed around low tide, 2-hours before to 2-hours after, on days when low tide was between 10:00 and 16:00 local time (Reijnders et al. 2003). Flights were only undertaken on good weather days: clear visibility, winds <25 knots (Beaufort 6) and no or minimal rainfall.

Photographs of the coastal areas likely to be occupied by seals were taken with a hand-held, digital, Nikon Camera fitted with a 75-400 mm zoom lens. A second observer in the aircraft recorded data on frame numbers and locations. At Griend and Richel, two full circuits of the islands were made.

Digital images were downloaded and projected on to a screen. The clearest images were selected and counts of visible seals, pups and adults, were made from these.

In 2013, the aerial survey was undertaken with no knowledge from ground surveys of where the pups could be. In 2014, the ground team had searched the island prior to the survey day and were able to advise the aerial team where pups were distributed (thus there was a greater discrepancy between the pups counted in 2013 than in 2014).

On 5-6 December 2013, prior to the 2013 survey, a severe storm caused water levels at Vlieland harbour (2 km from Richel) to reach +2.70 m above NAP. All of Richel and about 50% of Griend would have been inundated by surging waves during at least two high-tide periods in that storm. On Griend, 2-m high banks of shredded grass and marine debris on the north and west coasts indicated where the high water had been held back partially by lines of higher sand dunes (approximately the dark-green lines on Figure 35). Patches of compressed vegetation on higher grounds indicated where groups of seals had gone to avoid the storm surges. Undoubtedly, the storm re-distributed the seals prior to the survey date. On 11-12 December 2014, high-tides reached the edges of the vegetation around the island (light green in Figure 35). This storm was clearly less severe: three tides had highest water levels over +1.70 m NAP (highest tide was +1.82 m NAP). Unlike in 2013, there was no indication that grey seal breeding groups on Griend had resided far inland.

5.2.2 *Comparison of aerial and ground counts of grey seal pups at Richel.*

On 16 December 2013, aided by binoculars and from the elevation of the top deck a Wadden Unit vessel (approximately 7 m above sea level) passing adjacent to Richel, a count was made of the grey seal pups present. This could be compared with aerial counts on 14 December 2013. During ground visits to Richel on 16 December 2013 and 30 December 2014, attempts to count pups while walking around the sand bar were abandoned as it was evident that too many pups within the vegetated area were obscured from view. Additional aerial surveys to monitor changes in pup numbers were conducted: in 2013 on 28 November and 28 December, and in 2014 on 3, 16 and 29 December.

5.2.3 *Alternative survey techniques*

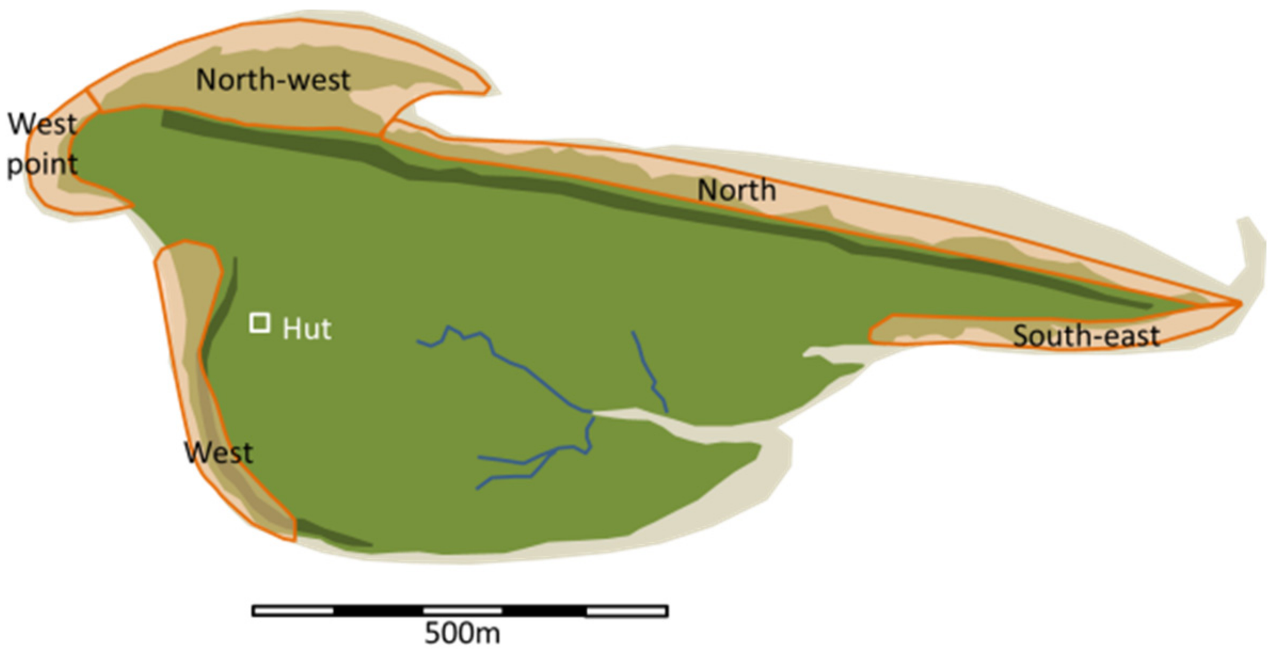
Other methods to record grey seals during the pupping season were explored. As a trial, the Dutch coast guard photographed grey seals on the Richel and Griend using Infra-red cameras and conventional photography during flights on 17 and 30 December 2014.

5.3 Results

5.3.1 *Comparison of aerial and ground counts of grey seal pups at Griend*

In 2013, grey seal breeding groups and pups were spread around much of the coast of Griend with concentrations on the north-west headland and the south-east coast (Figure 35). Ground counts recorded a total of 31 dependant pups and 8 weaned pups while 24 pups were recorded in the aerial photographs. The aerial photography missed the 8 weaned pups, which were not associated with adults, plus the group of seals on the south coast that contained 3 pups, and the one on the central north coast, which had 1 pup, and missed 3 pups hidden in vegetation in the north-west headland.

In 2014, the breeding groups were confined to west point and the north coast. In the west point and north-west areas there were 26 of the 30 (87%) dependant pups and 7 of the 8 weaned pups (Figure 35). Ground counts recorded 38 pups, whilst the aerial survey conducted on the same day and just after the ground counts, recorded 37 pups, missing one pup in the North area.



	14 December 2013				16 December 2014			
Area	**Aerial**	**Ground**			**Aerial**	**Ground**		
	Total	**Suckled**	**Weaned**	**Total**	**Total**	**Suckled**	**Weaned**	**Total**
West	0	3	1	4	0	0	0	0
West point	4	4	1	5	8	7	1	8
North-west	10	13*	2	15	25	19	6	25
North	1	2	2	2	4	4	1	5
South-east	9	9	2	11	0	0	0	0
Total	**24**	**31***	**8**	**39***	**37**	**30**	**8**	**38**

*Figure 35. Areas on Griend occupied by grey seals, and aerial and ground counts of still-suckled and weaned pups, in 2013 and 2014. *Two days after the 2013 survey date, an additional pup was recorded in the north-west (possibly new born), raising the season total from 39 to 40.*

Ground and aerial count data record the increase in pup numbers since 2007 (Figure 36).

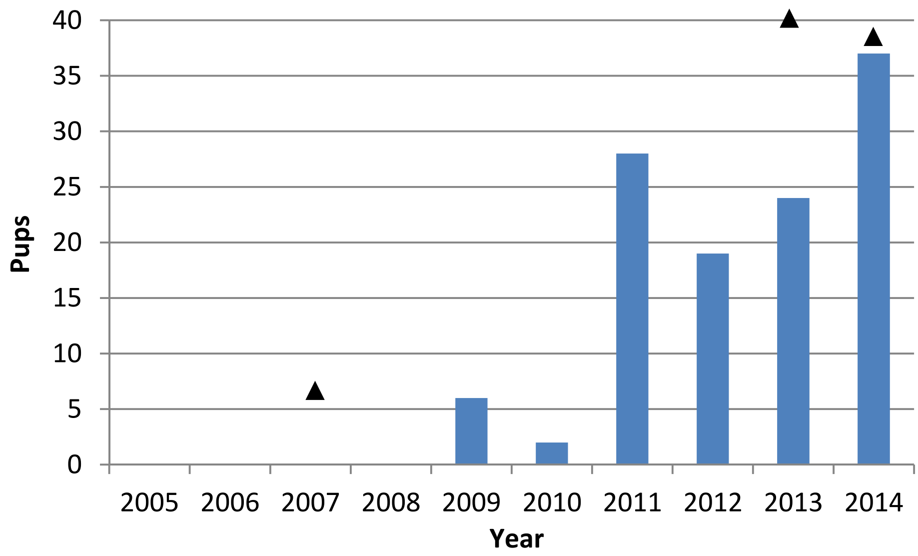


Figure 36. Grey seal pups on Griend recorded from aerial (bars) and ground (triangles) counts.

5.3.2 *Comparison of aerial and ground counts of grey seal pups at Richel*

On 16 December 2013, aided by binoculars and from the elevation of a Wadden Unit vessel passing adjacent to Richel, a total of 200 pups was recorded, which was less than half of the 457 recorded in aerial photographs taken two days earlier.

Ground-based pup counting was not feasible at Richel. The elevation of the observer was too low to accurately count seals beyond the outer edge of the vegetated area. Observers did not move through the vegetated area due to the high level of potentially unnecessary disturbance this could cause to the seals.

5.3.3 *Alternative survey techniques*

Photography from the Coast Guard provided additional information on the structure of the islands (Figure 37) but did not enhance estimates of pup numbers. Infra-red photographs provided insufficient resolution to identify individual seals.

Figure 37. Aerial photographs of the vegetated patch on Richel taken by the Coast Guard on 30 December 2014.

5.4 Discussion

Ground-based counts aided estimates of pup numbers at Griend but not at Richel. At Griend, if only aerial surveys are possible (without ground truthing), it should be assumed that seals could be present at any point on the island, and all flanks of the island should be clearly photographed. The study has assisted in recognising where errors in counts due to obscuring of pups in vegetation are most likely to occur.

6 Conclusions & recommendations

6.1 Geomorphology of key pupping sites

Current pupping/ breeding habitat for grey seal seals in the Wadden Sea is on islands and shoals with supra-tidal sandbars. All sites are dynamic. Within decades, for example, the ebb-tidal sandbar of Engelschhoek will most likely move towards Terschelling and weld to the Noordsvaarder (part of Terschelling). Even though Engelschhoek is not as important at Richel for pupping, it is the single most intensively used site by grey seals, with over 2000 animals present during moult, so its movement will have important implications for the grey seal population. Vegetated dune formation is not expected on this sandbar. Richel is in an accretionary phase and may develop into a 'real' island with white dunes and a salt marsh. Whether this happens will be influenced by the number and intensity of storms in the coming years, which could erode surface features (i.e. dunes, vegetation). Griend is eroding. Within a few years, though, a replenishment program will be carried out to prevent it from turning into a sand flat. For all three sites, movements of adjacent channels and large-scale processes (e.g. sediment supply) will determine development on the longer term. The high dynamics of small islands and sandbars in the Wadden Sea means that the grey seals will continually be adapting their pupping places to the available topography.

As in former years, periodic flushing of seals from the current breeding habitats in the Wadden Sea is likely to continue, given that grey seals exhibit a high fidelity to current, low-lying, pupping sites. However, if the seals start colonising areas with dunes higher than approximately + 4 m NAP, such as the main barrier islands, the proportion of pups born that are flushed from sites would be reduced.

Current pupping sites of sand beaches and shoals with supra-tidal sandbars are not part of a N2000 habitat type, however, dune habitats currently utilised are N2000 listed. These include *Embryonic shifting dunes* [H2110] and *White dunes* [H2120]. Limited use is made of other N2000 habitats in the Wadden Sea, like *Salicornia and other annuals colonizing mud and sand* [H1310], *Spartina swards* [H1320] and *Atlantic salt meadows* [H1330].

At the moment, the seals do not seem to substantially modify the geomorphology or vegetation of their pupping habitats. On Richel, the vegetation is present for too short a time to see effects, and on Griend there are too few grey seals for significant effects. If there is an effect on Richel and Griend, it is likely obscured by periodic sea-water flushing and effects of occupation by birds. In the Wadden Sea, the grey seals seem to use existing habitats and adapt to changes in that, rather than affecting these habitats, i.e. they cannot be considered 'ecosystem engineers'. If seal numbers would increase, impact may become visible, particularly on the dune field on Richel, should that also develop further.

6.2 Exchange of grey seals between Dutch waters and other areas

Recent modelling of grey seal count data collected in the Netherlands since the 1980s provides insight into the exchange of grey seals between Dutch waters and other areas (Brasseur et al. 2015). Grey seal numbers in the Wadden Sea have increased at an exponential rate of 19%. Because maximum intrinsic growth rates for pinniped populations are approximately 11% (Härkönen et al. 2002), immigration must be contributing substantially to the growth in seal numbers. Through modelling, it was estimated that first-year survival of seals born in the Wadden Sea was likely to be low (~56%) and that at least 35% of the 1-year old animals in the Wadden Sea were immigrants, most likely from the UK east coast (Brasseur et al. 2015). Additionally high seal numbers during the moult and in summer leads to the hypothesis that, next to the breeding colonies, there are considerable numbers of grey seals that breed in the UK but use the Dutch waters outside the breeding period. Potentially, this number is much larger than the 200-250 animals which can be directly accounted for in the counts.

Tracking of grey seals has demonstrated the movements of individuals over large distances, and the strong links between grey seals on the east coast of the UK and those in the Wadden Sea. In 2014, grey seals tracked as part of monitoring programs for offshore wind farm projects collected further data on links between sites around the North Sea. For example, five adult females tracked from Zeeland and the Wadden Sea had their pups at the Blakeney Point colony in England, which is now the largest colony on mainland UK and one of the closest to the Netherlands.

To obtain further quantifiable information on the magnitude of the exchanges (permanent and temporary migrants) and to better understand the underlying mechanisms, a photo-ID program commenced in the Netherlands during 2013, in the framework of this project (Brasseur et al. 2014). This was in collaboration with the Sea Mammal Research Unit, Scotland, where a photo-ID technique for grey seals was established in the 1990s and a data-base of over 20,000 animals from different breeding sites in the UK is maintained.

Initial processing and pattern matching of images in 2013 represented a pilot study for the photo-ID technique. In 2014, the project expanded with photography at pupping sites and further photography at the Steenplaat haul-out. In response to implementation in the Netherlands, in the UK, efforts were increased to collect photo-ID records at additional colonies on the east coast. For example, records were collected at Blakeney Point for the first time. The first photo-ID re-sighting of a seal from the UK to the Netherlands was made, a seal was recorded at Donna Nook colony, England, and later at Steenplaat haul-out in the Wadden Sea.

In 2014, a genetics study of grey seals in the North Sea was initiated. Collaborators plan to collect tissue samples from dead pups at colony sites in the UK, for comparison with samples from seals in the Netherlands. It is planned to expand the sample collection and undertake analysis in 2015, in collaboration with the Centre for Ecological and Evolutionary Studies, University of Groningen.

6.3 Ameliorating errors in monitoring of pup production

Ground-based counts aided estimates of pup numbers at Griend but are not realistic at Richel, where they require excessive disturbance to the seals or else provide underestimates. Further tests with infra-red techniques, for example, will be needed if the grey seal pupping will continue in more vegetated areas where pups can be obscured.

6.4 Recommendations

- Maintain monitoring of grey seal numbers during their pupping and moult periods by means of aerial surveys.

- Evaluate if adequate protection is given from disturbance by unregulated human visitation to currently important sites in the Wadden Sea. Particularly those for pupping, such as Richel (the most important), Griend, Engelschhoek, Razende Bol, Steenplaat and Blauwe Balg. The evaluation should include haul out sites outside of the breeding period when by far most grey seals (up to 70%

of all grey seals in NL) haul out on the Engelsehoek. Disturbances outside of the breeding period could affect the distribution during the pupping season.

- Establish a monitoring program on the potential colonisation by grey seals of the coasts of Texel, Vlieland and Terschelling.

- Establish a program to routinely monitor vegetation and elevation on Richel and Griend, to assess the chance of flushing of pups and possible long-term impacts of grey seals on the habitats, possibly in combination with projects dedicated to other developments of these areas (such as rejuvenation plans at Griend).

- Maintain photo-ID program to provide data on immigration rates and exchange of ‘Dutch’ grey seals with the UK population. Seek to also cooperate with groups in Germany and France. Augment this with a genetics study.

- Data are required on the demographics, breeding success, survival rates and site fidelity of seals at the Dutch pupping sites.

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8 Acknowledgements

We gratefully acknowledge the assistance of the following:

- Ernst Lofvers (*Rijkswaterstaat* Noord-Nederland) provided valuable information and discussion on the morphological development of the area.
- The crew of the *Rijksrijderij* vessel *MV Stormvogel*, Eelke Dijkstra, Theo van Malsen and Nico Laros, provided assistance in the field and historical data they had collected on the vegetation development on Richel.
- The grey seal photo-ID project is conducted in collaboration with Dr Paddy Pomeroy, Sea Mammal Research Unit, Scotland. We thank Tobias Rosas de Costa Oliver for training with the photo-ID program and to Toby and Lex Hiby for assistance with the program.
- The genetics project is a collaboration with Dr Per Palsbøll of the University of Groningen and Dr Paddy Pomeroy of the Sea Mammal Research Unit.

9 Quality Assurance

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

10 Justification

Rapport number: C009/15
Project Number: BO-11-011.04-015

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

Approved: Steve Geelhoed
Researcher

Signature:

Date: 04/11/2015

Approved: Drs Jakob Asjes
Head of IMARES Ecosystems Department

Signature:

Date: 04/11/2015

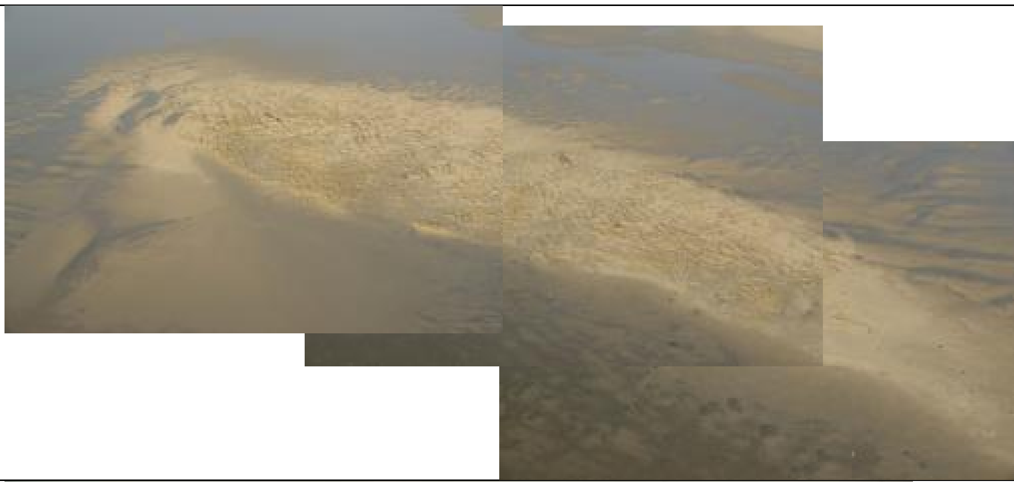
11 Appendix A. Development embryonic dune field on Richel

Oblique aerial photos were taken during seal counts from a plane. Per year, the clearest picture from, if possible, the growth season was used. As the pictures of the vegetation are only a side-product of the aerial surveys that focus on seal counting, the direction in which they were taken varied between years. All photos by IMARES (mostly SB), except when indicated otherwise.

Year/ view	**Information**
2006	No photos with vegetation (vegetation either non-existent or not captured)
2007	No photos with vegetation (vegetation either non-existent or not captured)
2008	No photos with vegetation (vegetation either non-existent or not captured)
August 2009 (view to appr. SE)	
June 2010	

appr. 2010 (Bing maps)		
August 2011 (view to appr. S)		
June 2012 (view to appr. E, S and E, respectively)		

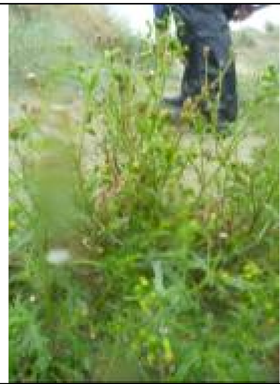
	 	
2013 (view to appr. NE)		

16 December 2013 (view appr. N)	
August 2014 (view to appr. SE and S, respectively)	 

12 Appendix B. Vegetation species list for Richel – August 2014

All photos by AdG, RK and SB. Species identified by Alma de Groot, checked by Willem van Duin. If few plants were seen, ID specimens were not collected.

Scientific name	Dutch name	RD_X (m)	RD_Y (m)	Cover or # of individuals	Comments on classification	Photograph on Richel
Elytrigia juncea	Biestarwegras	139147	589699	99% of total cover	certain. Many growth forms	
Cakile maritima	Zeeraket	138667	589901	1% of total cover	certain	

Senecio vulgaris	Klein kruiskruid	138677	589930	> 50 individuals	from photo	
Salsola kali	Loogkruid	138691	589921	~ 3 individuals	certain	
Atriplex prostrata	Spiesmelde	138668	589901	> 50 individuals	certain	

Soncus arvensis	Akkermelkdistel	138667	589894	< 15 individuals	certain	
Tripleurospermum maritimum	Reukeloze kamille	138672	589894	< 15 individuals	certain	
Puccinellia maritima	Gewoon kweldergras	138672	589895	~ 2 tussocks	certain	
Juncus gerardii	Zilte rus	138705	589895	~ 2 tussocks	probable	no photo available

Ammophila arenaria	Helm	138733	589929	~ 2 tussocks	from photo and specimen	
Plantago maritima	Zeeweegbree	138733	589925	1 individuals	certain	
Suaeda maritima	Klein Schorrenkruid	139078	589758	~ 3 individuals	certain	

Honckenya peploides	Zeepostelein	139099	589726	1 tussock	certain	
Polygonum aviculare	Gewoon varkensgras	138877	589791	1 individual	certain	
Tetragonia tetragonioides (Pallos) Kuntze	Nieuw-Zeelandse spinazie	138876	589833	1 individual	from photo	

Crambe maritima	Zeekool	138822	589818	1 individual	probable	
Cirsium arvense	Akkerdistel	138739	589841	~ 3 individuals	certain	
Salicornia spp.	Zeekraal			unknown, outside main dune area. at least 2 individuals	from photos	

Hippophae rhamnoides	Duindoorn			1 individual	from photo, not entirely certain	

Possibly missed due to classification difficulties: *Agrostis stolonifera* and *Atriplex glabriuscula*.

13 Appendix C. Vegetation scoring table

"Londo (2) verkort" (Turboveg-opnameschaal '09') (Hennekens 2009) (.http://www.telmee.nl/servoces/fielditems.php?fldid=58londo_2_verkort)

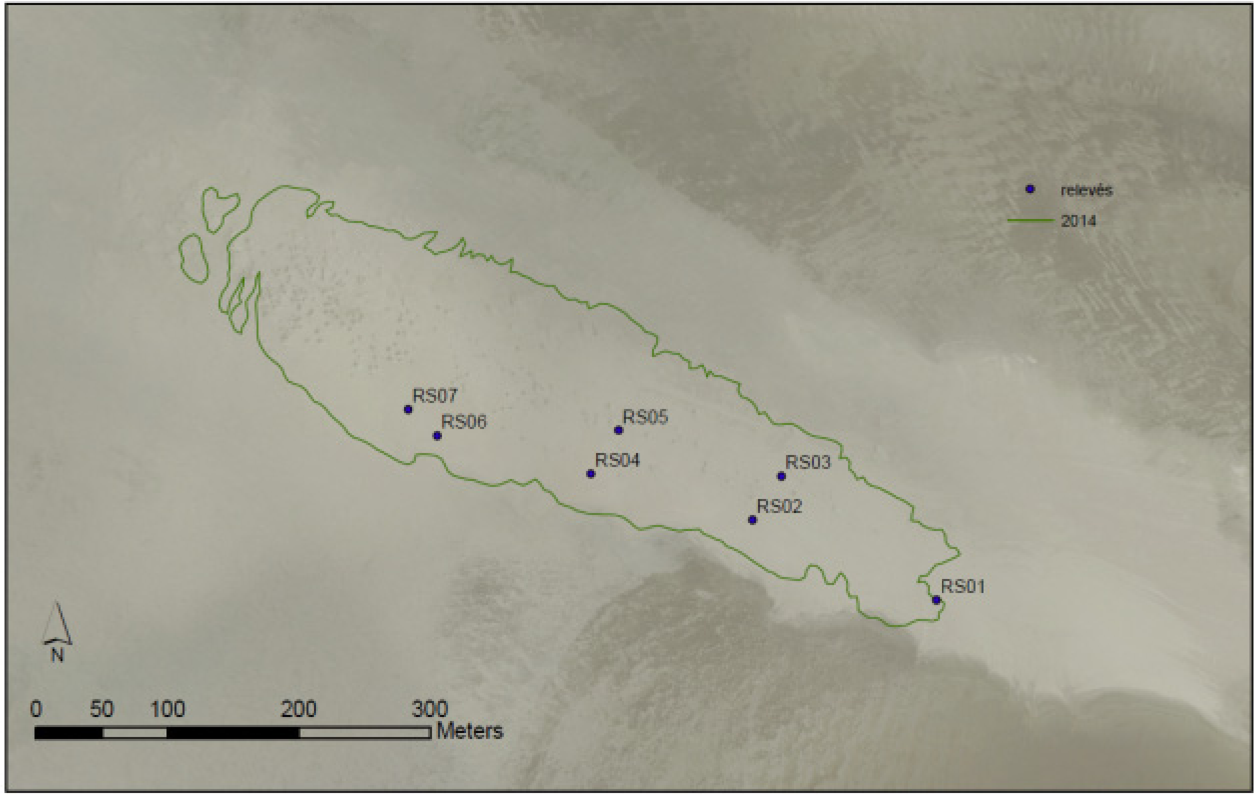
r	sporadisch	<5%
p	weinig talrijk	<5%
a	talrijk	<5%
m	zeer talrijk	<5%
1	willekeurig	5-15%
2	willekeurig	15-25%
3	willekeurig	25-35%
4	willekeurig	35-45%
5	willekeurig	45-55%
6	willekeurig	55-65%
7	willekeurig	65-75%
8	willekeurig	75-85%
9	willekeurig	85-95%
10	willekeurig	95-100%

14 Appendix D. Vegetation relevés on Richel – August 2014

The vegetation relevés on Richel were 5 m x 5 m in size, because of the patchy nature of the vegetation. All species in each relevé were scored, following the scale in Appendix B. RTK measurements were done later, so coordinates have an uncertainty of 0.5 – 1 m. Given the topography within the relevés, elevation is an average value. Date of recordings: 21 August 2014. The location of the relevés is given below.

	RS01	**RS02**	**RS03**	**RS04**	**RS05**	**RS06**	**RS07**
RD_X_GPS	139142	139002	139024	138879	138900	138762	138740
RD_Y_GPS	589695	589756	589789	589791	589824	589820	589840
waypoint GPS	123	124	125	126	127	128	129
RD_X_RTK	139142	138999	139022	138876	138897	138762	138738
RD_Y_RTK	589687	589753	589787	589791	589826	589822	589843
elevation (m + NAP)	1.40	1.38	1.60	1.69	1.59	1.57	1.46
time	15:00	15:30	15:45	15:57	16:08	16:28	16:43
size relevé	5x5	5x5	5x5	5x5	5x5	5x5	5x5
total cover	1	6	5	5	4	5	8
dead material	r	a (~1%)	~1%	<1%	<1%	<1%	<1%
vegetation height (cm)	30	70	60	50	50	50	30
damage	flowers grasses sometimes gone	0	0	part flat, small growth form	0	0	0
bird droppings etc.	0	old geese droppings	skeleton, old geese droppings	shell remains, geese	old geese droppings	dead bird (juvenile)	few
herbivory	little	0	0	little	0	0	0
drainage	good	good	good	good	good	good	good/reasonable
sediment	fine/medium	sand	sand	sand, few	sand	sand	sand

	RS01	RS02	RS03	RS04	RS05	RS06	RS07
	sand + shells			shells			
shells (%)	5%	<1%	1%	2%	2%	0%	0%
morphology	eastern end of embryonic dune field	embryonic dune	embryonic dune + depression	embryonic dune + depression	embryonic dune + depression	embryonic dune	dune, relatively flat and high
drift-line	1 + algae + plastic	0	some ulva	few	crabs	few	few
seal scats	0	0	0	0	0	0	0
salinity groundwater (‰)	2.81	2.81	2.2	0.35	0.14	5.09	1.77
conductivity groundwater (uSv/cm)	4360	4350	3480	597	251	7690	2820
temperature (°C)	16.6	16.5	16.8	16.9	16.3	17.1	16.8
comments	begin vegetation	next to Cakile		Cakile in surroundings		close to depression with low vegetation around rim	aim: have species-rich relevé
Elytrigia juncea	1	6	5	5	4	5	8
Polygonum aviculare				r			
Cakile maritima					r	p	p
Senecio vulgaris						p	
Cirsium arvense							p
Sonchus arvensis							a



relevés
2014
RS07
RS06
RS05
RS04
RS03
RS02
RS01
N
0 50 100 200 300
Meters

Photographs of relevés on Richel – August 2014

(photos by RK)

RS01

RS02

RS03

RS04

RS05

RS06

RS07

15 Appendix E. Vegetation relevés on Griend – August 2014

The vegetation relevés on Griend were 2 m x 2 m in size. Only the three dominant species were scored, following the scale in Appendix B. GS01 – GS05. Locations of the relevés were chosen based on known seal locations from December 2013. Date of recordings: 20 August 2014.

Griend	GS01	GS02	GS03	GS04	GS05	GS06	GS07	GS08	GS09	GS10
RD_X	145812	145818	145828	145844	145856	145744	145778	145813	145917	146892
RD_Y	584855	584862	584869	584879	584886	585358	585358	585403	585315	585068
size relevé	2x2	2x2	2x2	2x2	2x2	2x2	2x2	2x2	2x2	2x2
photo (Alma cam)	12:00		12:14	12:23	12:30	13:40	13:50	14:03	14:16	15:15
total cover	10	8	9	9	10	10	10	3	10	7
vegetation height (cm)	70	30	20	25	25	35	45	20	70	30
vegetation in surroundings	same	Leymus + kaal	same	same	same	same, also agrostis stolonifera	same, also odontites vernus, potentilla anserina	among phragmites , Leymus, Artri, distel	same, + more phragmites , agrostis, festuca	same
damage	0	0	signs of breeding birds	drift-line	drift-line	0	0	0	sort of path	0
evidence of birds	many dead birds	dead birds	dead birds, breeding spots, hummocks	0	0	0	0	0	0	droppings
herbivory	0	0	0	0	0	0	0	0	0	0

Griend	GS01	GS02	GS03	GS04	GS05	GS06	GS07	GS08	GS09	GS10
drainage	prob. good	good	prob. good	prob. good	reasonably good	prob. good	prob. good, in winter ponds	high and dry	wet, close to pond	good
soil/sediment	sand	sand	organic layer on sand	org. matter on sand	sand + org (perhaps bit clayey?)	0	sand	sand + shells	organic + sand	sand
shells	0	0	yes, prob. brought in by birds	0	0	0	0	50%	deeper in soil	0
morphology	slope against cliff	next to cliff on seaward side	landwards of cliff top	slope	last dune ridge	sort valley between two dune ridges	depression between two dune ridges	on top of seaward ridge	depression between two dune ridges	slope of dune ridge
cliff	yes	yes	yes, ca 10 m away	further away	further away	more like a ramp ca 30 m away		ramp	0	small one
drift-line	0	yes	lots	little	little	0	0	0	0	little
seal scats	0	0	0	0	0	0	0	0	0	0
comments			much Ely is dead, disturbed by birds		part of veg dead					
Leymus arenarius	10	5	1					2		6

Griend	GS01	GS02	GS03	GS04	GS05	GS06	GS07	GS08	GS09	GS10
Atriplex littoralis	p	1								
Cakile maritima	p	2								
Elytrigia atherica			8	9	10	2	2		5	1
Urtica dioica			a							
Stellaria media				r						
unkown (perhaps Sonchus arvensis, no leaves on picture)				r						
Festuca rubra						6	6			
Phragmites australis						4	3		4	
Elytrigia juncea								1		
Elytrigia repens								p		
Bolboschoenus maritimus									1	
Agrostis stolonifera										1

Photographs of relevés on Griend – August 2014

(photos by RK)

GS01

GS02

GS03

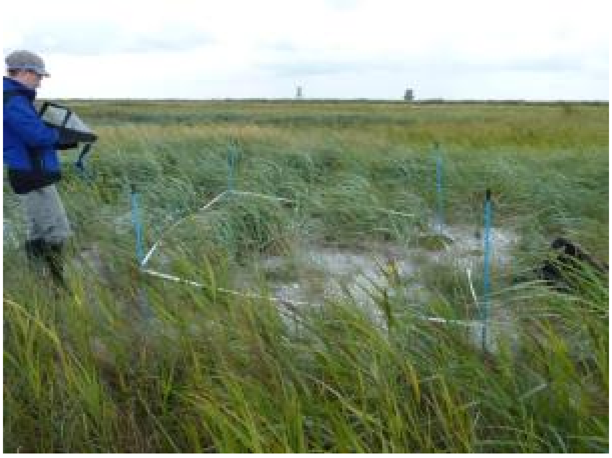
GS04

GS05

GS06

GS07

GS08



GS09

GS10

16 Appendix F. Seals tracked from the Netherlands to other places

Seals tracked from the Netherlands that have crossed into other national waters, including specific locations in the UK where seals hauled-out.

Year	Area	Site	Seal	sex	Age class	Length	Mass	Months	UK	Hauled-out	Had a pup	Goodwin Sands	Harwich Sands	Scoby Sands	Horsey	Blakeney Point	The Wash	Donna Nook	Farne	Fastcastle	Inchkeith	Isle of May	Helmsdale & Berriedale	Orkneys		BELGIUM	FRANCE	GERMANY	DENMARK	NORWAY
2005	Wadden	Razende Bol	5163	M	a	163	120	6-10,	1	1									1											
2005	Wadden	Steenplaat	A	M	a	168	111	12	1	1						1														
2005	Wadden	Razende Bol	12146	M	a	158	92	5-12,	1	1													1	1						
2005	Wadden	Razende Bol	12147	F	a	154	68	7,8	1	1									1				1	1						
2005	Wadden	Razende Bol	5162	F	a	158	62	4-12,	1	1		1	1													1	1			
2006	Wadden	Steenplaat	A	M	a	156	66	5-9,	1	no																				
2013	Wadden	Pinkegat	866	M	sa	116	39	10-1,	1	no																		1	1	
2013	Wadden	Pinkegat	860	M	a	190	246	11	1	no								1										1	1	
2013	Wadden	Pinkegat	900	M	sa	147	34	10-2,	1	1								1	1									1		
2013	Wadden	Pinkegat	911	F	a	154	130	9-2,	1	1	1			1	1	1		1	1	1	1									
2013	Wadden	Steenplaat	737	F	a	175	96	4-5,11	1	1	1	1	1	1	1	1										1	1			
2014	Wadden	Steenplaat	T080	M	sa	142	60	5	1	1																				
2014	Wadden	Steenplaat	T003	F	a	155	74	11	1	1	1					1														
2014	Zeeland	Renesse	Z037	M	a	176	99	4-7,	1	1		1															1			
2014	Zeeland	Renesse	Z046	F	a	168	101	11-12,	1	1	?							1	1				1					1		
2014	Zeeland	Renesse	Z007	F	sa	117	37	4-6,	1	1					1	1	1									1	1			
2014	Wadden	Steenplaat	T078	M	a	158	80	4-5,10-11	1	1				1	1	1		1										1		
2014	Wadden	Steenplaat	T875	F	a	159	108	5-12,	1	1	1			1	1	1		1	1	1		1		1						
2014	Zeeland	Renesse	Z062	F	a	165	86	12	1	1	1					1														

2014	Zeeland	Renesse	Z006	F	a	170	121	12	1	1	1					1		1												
2014	Zeeland	Renesse	Z024	F	a	149	82	10,12	1	1	1			1	1	1														
									21	18	7	3	2	5	6	10	1	7	6	2	1	1	3	3						
2007	Wadden	Steenplaat	F5	F	sa	123	46	6-7,		1																		1		
2013	Wadden	Pinkegat	874	F	a	134	139	12		no																				1
2013	Wadden	Pinkegat	897	F	a	162	117	9-2,		1																		1		
2013	Wadden	Pinkegat	867	M	sa	116	42	10-11,		no																		1	1	
2014	Zeeland	Renesse	Z018	F	a	165	100	4-10,		1																	1			
2014	Zeeland	Renesse	Z066	M	a	152	70	5-11,		1																		1		
																										3	5	9	3	1