Monitoring the effects of soil subsidence on East Ameland

Evaluation after 18 years of gas extraction ***May 2005***

Supervisory Committee Monitoring Soil Subsidence Ameland

Based on contributions and sub-reports from: WL I Delft Hydraulics
ALTERRA
Nature Centre Ameland

Preface

The monitoring study into the effects of soil subsidence near Ameland was started 17 years ago. If we consider this study to be a life, it has now reached its midlife period. During the first years after 1987, when the study was started, seas of time lay ahead. The first interesting events developed, it was a time full of expectations. After eight years, a picture started to emerge as to what the monitoring process could produce. A first preliminary report was published. Every now and then a correction in the course was made and interesting developments prevented things from becoming a mere routine. A first serious assessment was produced in 2000, when after 12 years of research a summarising report was published. In that same year, the report was assessed by independent experts during a symposium organised by the University of Groningen. Appreciation was expressed for the work that was carried out, but there was also criticism. Hence various additions and changes were made. Now, 5 years later, in the midlife period, the new results are becoming apparent. Knowing that the soil subsidence will probably have ended around 2020, this is a suitable moment to once again take stock and think about what still needs to be done in the remaining period.

Perhaps some of the readers think that the interesting period for research has passed by now. On the contrary! During the past years, new observations were made, particularly in the field of accretion on the mudflats near Ameland and in the field of water level and vegetation developments in the wet dune slacks. A lot is going on there and new technologies have become available, enabling the collection of different and better data! Furthermore, there is still a lot of excitement with regard to plant growth on the salt meadows. To date, not a lot has changed in this respect, but will that still be the case when the soil subsides further still? Therefore, the next 15 years will be a time of harvesting, of knowledge and insights which can perhaps also be used elsewhere.

This brings me to my final points. First it can be concluded that the results of this research played a role in the political discussion as to whether or not to extract gas underneath the Wadden Sea. As a result, the research has gained in social importance which exceeds the basis for local natural compensation alone. Second, the results already provide some insights into the possible effects of the likely rise in sea-level. Both for the researchers involved and the members of the supervisory committee, it is satisfactory to know that this work has been useful. The final and also the main point of this preface is the conclusion that the supervisory committee believes that this research and the subsequent reports have been carried out adequately. The researchers have been given the time and freedom to properly fulfil their tasks. All their conclusions can be found in this summary and the background reports and their findings are in accordance with the observations made by the members of the committee during their field trips to Ameland.

I therefore submit this report to you with the greatest satisfaction.

Dr. J. de Vlas

Introduction

Introduction

Gas extractions on East Ameland started in 1986. In that same year, on the instruction of the NAM, WL|Delft Hydraulics, in conjunction with Alterra (RIN at the time), produced a forecast of the possible effects of soil subsidence, after which the monitoring process was started at the end of 1988. The first two reports are based on data up to 1994 and 1999 respectively and describe the effects covering a period of 8 and 13 years respectively after gas extraction activities commenced. This third report is based on data up to 2003/2004. For further background information reference is made to the evaluation report of March 2000 and the new 2000-2010 monitoring programme which can be found on the enclosed CD.

The soil subsidence took place in the form of a large basin with a diameter of around 15 km and could be measured as from 1987. In the subsequent period, up to around 2000, the soil in the centre of the basin subsided by approximately 1.8 cm per year. After that, as a result of the falling pressure in the field, the subsidence speed reduced somewhat to up to 1.2 cm per year. In 2003, the soil subsidence in the centre of the soil subsidence basin amounted to 27 cm. It is expected that the soil subsidence will continue to diminish up to 2020, when it will have come to a full stop.

In 2000, the results were presented during a public debate. Various improvements have since been implemented. The highlights of the past 5 years are the publication of the 2000-2010 research programme, the bird study, the extensive measurements on the mudflats and the newly developed technology of pin measurements. In addition, the new programme for the wet dune slack received ample attention with surprising results. The new prognosis of NAM has been discussed in the Committee and, as a result thereof, a new assessment of the possible consequences for the salt meadow has been made. The main improvements/changes in the programme include:

Committee and research team

Based on the comments made by Dr. Salomons, the composition of the committee and the research team has been widened. The objective thereof was to improve the (local) social embedding. The committee has been expanded with 2 members representing the Friesian province. This at the same time injected expertise into the Committee with regard to groundwater, which is important in connection with the development of the dune slacks. The research team was expanded with 3 researchers of and via Nature Centre Ameland. They are *dr.* Kersten, expert in the field of mudflat birds, *drs.* W. Molenaar, who collected the grazing data and *drs.* J. Krol, contact person and coordinator of the Nature Centre and responsible for research into the flooding of the slacks. This led to new ideas, techniques and insights.

The Committee currently consists of representatives of the National Institute for Coastal and Marine Management (RIKZ), the Directorate-General for Public Works and Water Management (RWS), the Ministry of Agriculture, Nature and Food Quality (LNV), the nature organisation It Fryske Gea, the Province of Friesland, the Dutch Petroleum Company (NAM) and the Municipality of Ameland. In addition to their representative tasks, these parties also offer specific expertise. The researchers are delegates of WL|Delft Hydraulics, Alterra (Green World Research) and Nature Centre Ameland.

Prognosis, soil subsidence measurement and morphology

Based on the comments made by professor Augustinus, a new technique has been developed to measure erosion and sedimentation on the mudflats, locally and against time, and field measurements have been carried out. His comments mainly related to the inaccuracies of routine soundings. Field measurements were carried out by means of RTK-GPS for a number of consecutive years. The measurements show a pattern of changes, but are highly laborious and can only be carried out once a year. The accuracy is expressed up to the centimetre.
The "pin measurements" are a new technique and make it possible to measure changes in surface altitude in relation to a buried anchor on a regular basis (every 2-3 months). The measuring results produce an entirely new picture of the variability in surface area, within which the soil subsidence appears to be fully compensated by measuring points outside the basin (below Ameland and above Paezumerlannen).

In 1991 and 1998, new prognoses for the soil subsidence were made. The forecasts of the effects of soil subsidence are based on prognosis calculations of the soil subsidence, based on knowledge of the reservoir, the expected reduction in pressure and the accumulation of rocks on top. In 2004, the NAM prepared a new prognosis which was published in the Ameland extraction plan. The soil reduction in the centre will amount to approx. 34 cm, at a volume that corresponds to the original estimate. However, in 2000, prognoses and land survey measurements did not form part of the discussion.

Up to around 2000, the eastside of Ameland accreted. Based on new map images, it is safe to assume that the accretion has now ended. Channel formation stopped the growth. The erosion of the salt meadow edge is a hot issue among the islanders, but photo analyses do not show a shift in trends that can be attributed to soil subsidence. This too appears to be an autonomous development.

Elsewhere, erosion of a small-scale salt meadow pool was stopped. During the creation of the location, an inlet became blocked. Slightly west thereof, a much larger salt meadow pool naturally broke through to an existing inlet and was drained, resulting in new vegetation successes.

The mudflat research results have been discussed with professor Augustinus in the interim.

Salt meadows and grazing

Comments made by dr. J. Bakker particularly relating to the absence of grazing data in the analysis. The grazing data has been collected with retroactive effect, insofar as available, and currently forms part of the standard data package. The temporarily reduced grazing intensity is believed to be the cause behind the increase of Artemisia maritima.

The soil subsidence is fully compensated at the salt meadow edge, but runs behind in the central and high salt meadow. The salt meadow measurements have been continued at a higher frequency of twice per year, in order to be in a better position to monitor the process.

Low dune slacks

The comments made by professor J. van Andel were particularly aimed at the importance assigned to the type of nature objectives. It is noted here that this relation refers to the study report by Mrs Schouten, who was bound to the instructions of her University lecturer from Utrecht. The low dune slacks did not form part of the original monitoring programme. Sea buckthorns dying off - which was also detected during similar research on

Schiermonnikoog and Terschelling - indicated drowning caused by storm tides. Calculations by Schouten pointed out that the flooding frequencies of the low dune slacks were set to increase dramatically. A separate programme was developed on the basis thereof.

Here researchers of Alterra focused on new techniques in order to determine vegetation development. Researchers of the Nature Centre focused on describing the floods. This showed that not the flooding frequency, but the groundwater level is decisive for the vegetation development instead. Due to the soil subsidence, the current position of the slacks is such that they remain submerged for longer periods of time (months instead of days). As a result, the number of sea buckthorns will reduce.

Birds

The comments made by professor R. Drent were two-tiered. On the one hand, his opinion was that it had been insufficiently demonstrated that the count data did indeed relate to birds that were dependent on the soil subsidence area. On the other, his comments were that the scientific research should not have been limited to the effects of soil subsidence alone. With regard to the latter, the committee has concluded that research into effects not related to soil subsidence – and which do not influence the effects of soil subsidence – fall outside the scope of its duties. Hence these comments could not be acted upon. Specific research has been carried out in order to answer the question as to which varieties forage within the soil subsidence outline. The tide migration has been closely monitored as well as forage behaviour and the places where this takes place. It has also been investigated how counting can be improved and whether the peak in presence differs between the east and west of Ameland.

Results of the bird study have been discussed with Dr. J. Tinbergen in the interim.

Soil subsidence

Based on contributions by

Dirk Doornhof

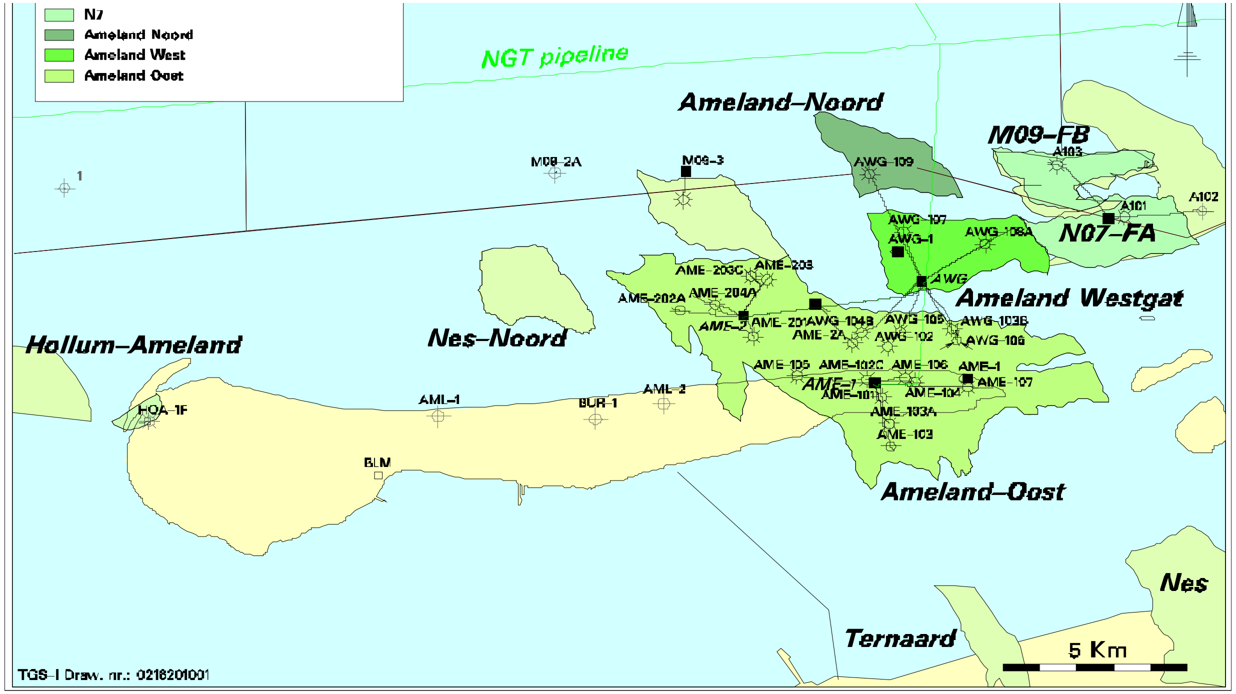
Joop Marquenie

Simon Schoustra

Wim Eysink

Soil subsidence

Soil subsidence is the result of gas extraction from sandstone layers at a depth ranging between 3300 and 3600 metres. The gas is extracted via different offshore and onshore plants. The so-called mother platform is called Ameland Westgat (AWG). Here the gas is prepared for transport (dried and compressed). Initially the gas was under a pressure of around 600 Bar. Meanwhile, only 100 Bar thereof is left. When that pressure reduces further, the gas must be compressed up to a pressure that exceeds the pressure in the transport pipeline (>80 Bar). The compressors required to that end are located at AWG. The platform is continuously manned and all required energy is generated onsite. Some water comes up with the gas. In principle, that 'production water' is led back into the ground. In the event of faults or maintenance, this water is filtered to remove oil down to below the statutory level of 40mg/l and discharged at sea. The Ameland field is vast to the extent that not the entire field can be tapped into or extracted via AWG or the onshore location. Hence there are 2 auxiliary plants from where wells have been drilled: the onshore location East Ameland (AME/1) and an offshore satellite (AME/2).



Overview of the different gas fields underneath Ameland, drilled wells and plants. The monitoring process.

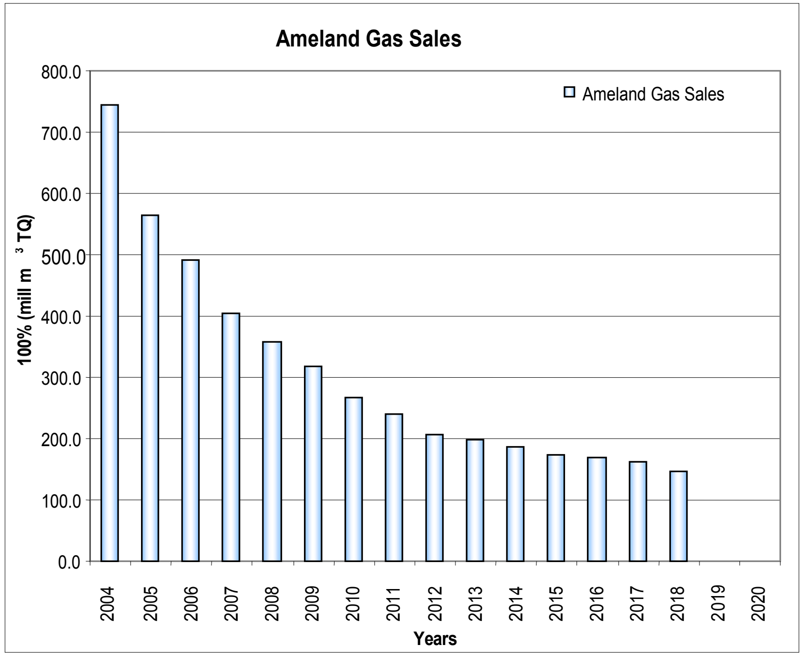
Ameland Noord	North Ameland
Ameland West	West Ameland
Ameland Oost	East Ameland

After having been treated and compressed, the gas is transported through the "North Gas Transport pipeline" (NGT) to Uithuizermeden. Slightly to the west, there is a third structure in the sea, the so-called monopile N07-FA (see map). The future plan is to link up the monopile N7 with AWG via a pipeline.

The production of Ameland gas started in 1986. The anticipated end date for production is 2020.

A lot of gas has been extracted from Ameland already. As a result, the pressure has fallen from more than 600 Bar to less than 100 Bar. As a result, the flow speed of the gas has also been strongly reduced. The current forecast of the amount of gas still to be produced is detailed in the diagram below.

The predicted gas production in the fields of East Ameland and Ameland Westgat for the period 2004 to 2020.



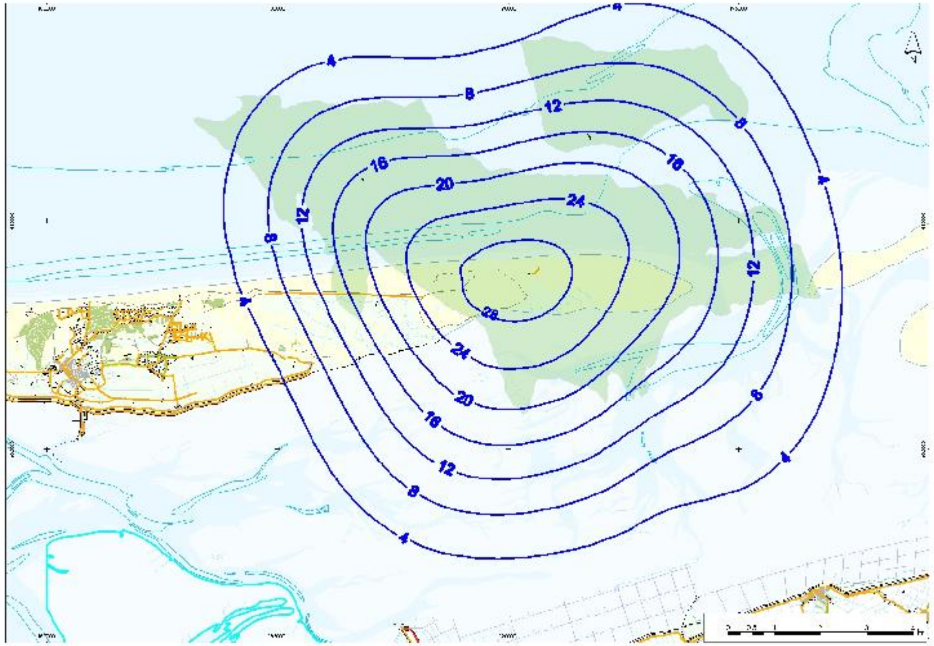
The total gas production can roughly be subdivided into a contribution of 70% from Ameland eastern part of the field and 30% from the Ameland western part. Currently, production in the Ameland northern part is yet to commence. This production form “North” will not affect the soil subsidence on Ameland. Ultimately, the total expected soil subsidence caused by gas extraction (after termination of the extraction activities in 2020) from the gas fields described in the extraction plan amounts to 34 cm in the centre of the soil subsidence basin, calculated from the start of the gas extraction activities. The error margin of the calculation is set to +/- 3 cm. Possible exploitation of new gas fields (e.g. N7) near East Ameland and Westgat and/or additional production by means of new wells and/or applying compression in existing fields that are part of Ameland East (AME/1) and Ameland Westgat (AWG) are not included in the current prognosis and can produce a different picture. Also, the possible future exploitation of gas fields located south and southeast of Ameland below the Wadden Sea (Paesens, Nes and Lauwersoog) has not been included.

However, the estimate of 34 cm (maximum 37 cm) already exceeds the original estimate of soil subsidence in 1985, which amounted to 26 cm +/- 6 cm. The bandwidths of both calculations partly overlap. The estimates regarding the scope and depth of the soil subsidence basin have been adjusted multiple times. As part of this process, the subsidence at its deepest level, which was originally estimated at 21 to 31 cm, has ultimately been adjusted upwards to 31 to 37 cm. However, the sand shortage that will arise in the Wadden Sea has been adjusted downwards, from 22.5 to 14 million m^3. Thus the pit becomes deeper, but approximately 38% smaller in volume.

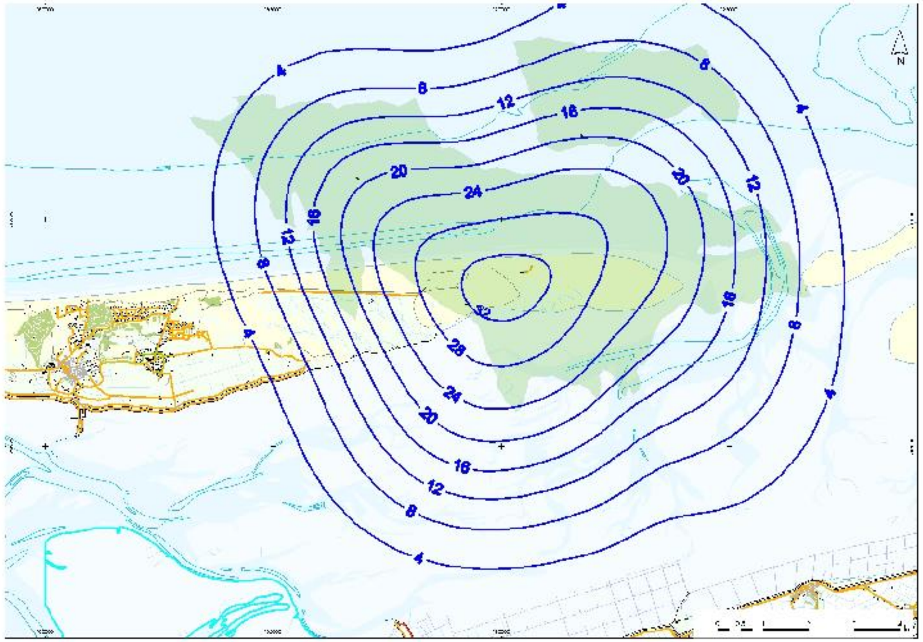
Prognosis	Depth in cm	Scope ($10^6 m^3$)	Contribution to the sand shortage ($10^6 m^3$)
1985	21-31 (26)	28	22.5
1991	14-22 (18)	18	14.5
1998	28-32 (28)	14-18	10
2003	31-37 (34)	22	14

Estimate of the contribution by the ultimate soil subsidence to the sand shortage.

Since the forecast of the effects, on the basis of which the Committee started its work, was based on 26 cm soil subsidence, the Committee has requested an additional forecast of the possible effects on the salt meadow in relation to the extra soil subsidence. To this end, it was important to distinguish between the period up to 2010 and after 2010 up to 2020. Particularly important here are the end value and the reduction in soil subsidence speed on the salt meadows. In addition, the total scope of the soil subsidence on the mudflat and in the coastal zone is important.



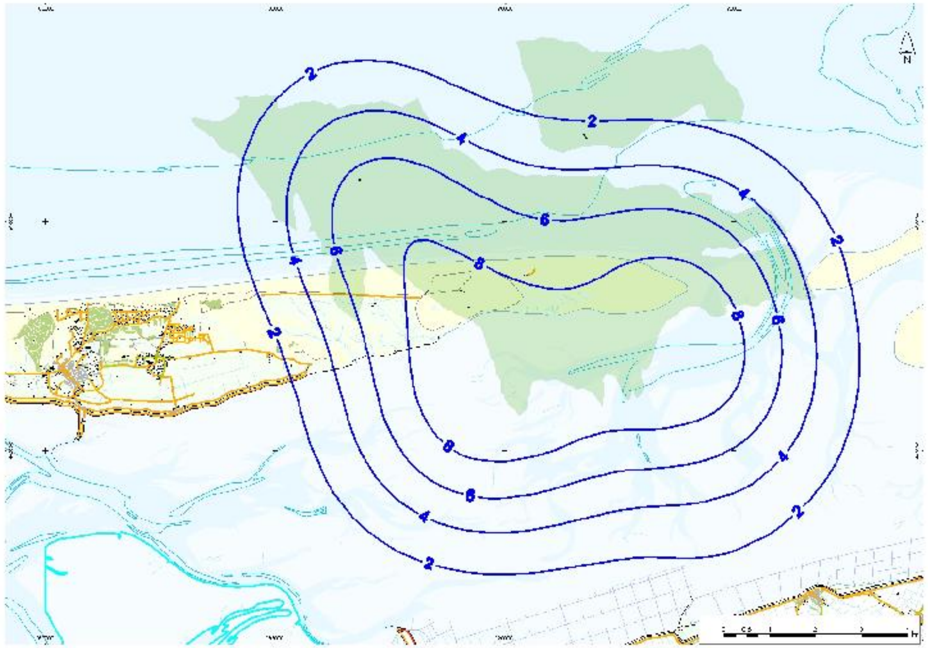
Soil subsidence prior to **2010** for both parts of the gas field (indicated in green). The effect of silting has not been included for the subsidence in the region. The average soil subsidence speed in the centre for the period 2003-2010 amounts to 0.7 cm per year. The outline borders indicate the soil subsidence in cm.



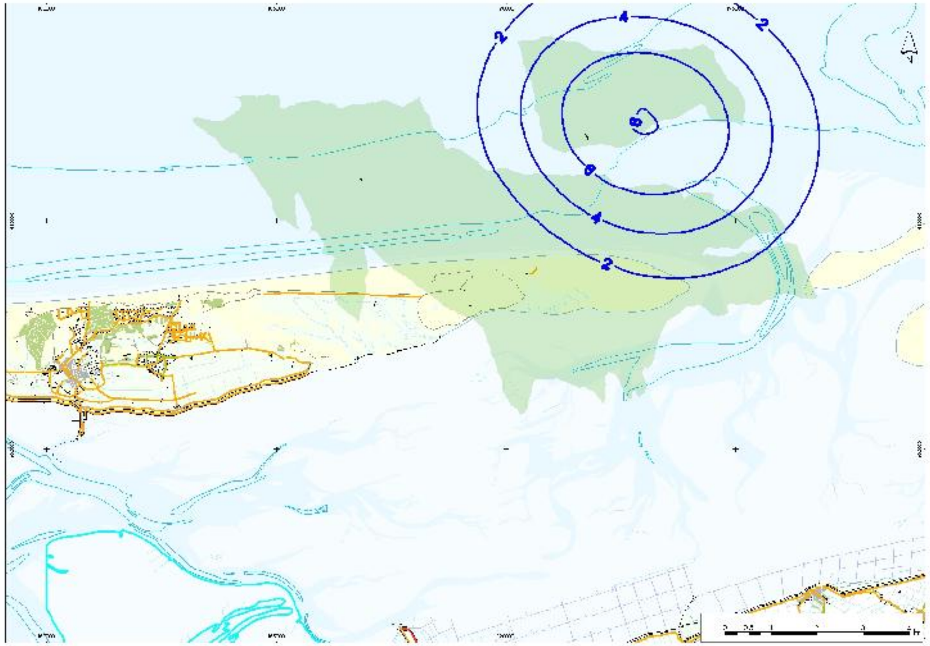
Soil subsidence prior to **2020** for both parts of the gas field (in green). The effect of silting has not been included for the subsidence in the region. The remaining average soil subsidence speed in the centre after 2010 amounts to 0.4 cm per year. The outline borders indicate the soil subsidence in cm.

In order to further refine the monitoring process in the years to come, it is important to know how much soil subsidence is still to follow and whether the shape of the soil subsidence basin will change. Hence the illustrations below indicate the anticipated soil subsidence between 2003 and 2020, distinguishing between the fields East Ameland and Ameland Westgat. The method used creates a transparent image for both the whole of the subsidence as well as for the different elements.

Noticeable in this analysis is that the further deepening of the basin will follow a very gradual and level pattern with a relatively large and flat area showing a subsidence of 8-10 cm. New drillings and developments on Ameland Westgat do not have direct consequences for the salt meadows on Ameland or the mudflats, but do of course form part of the total sand balance.



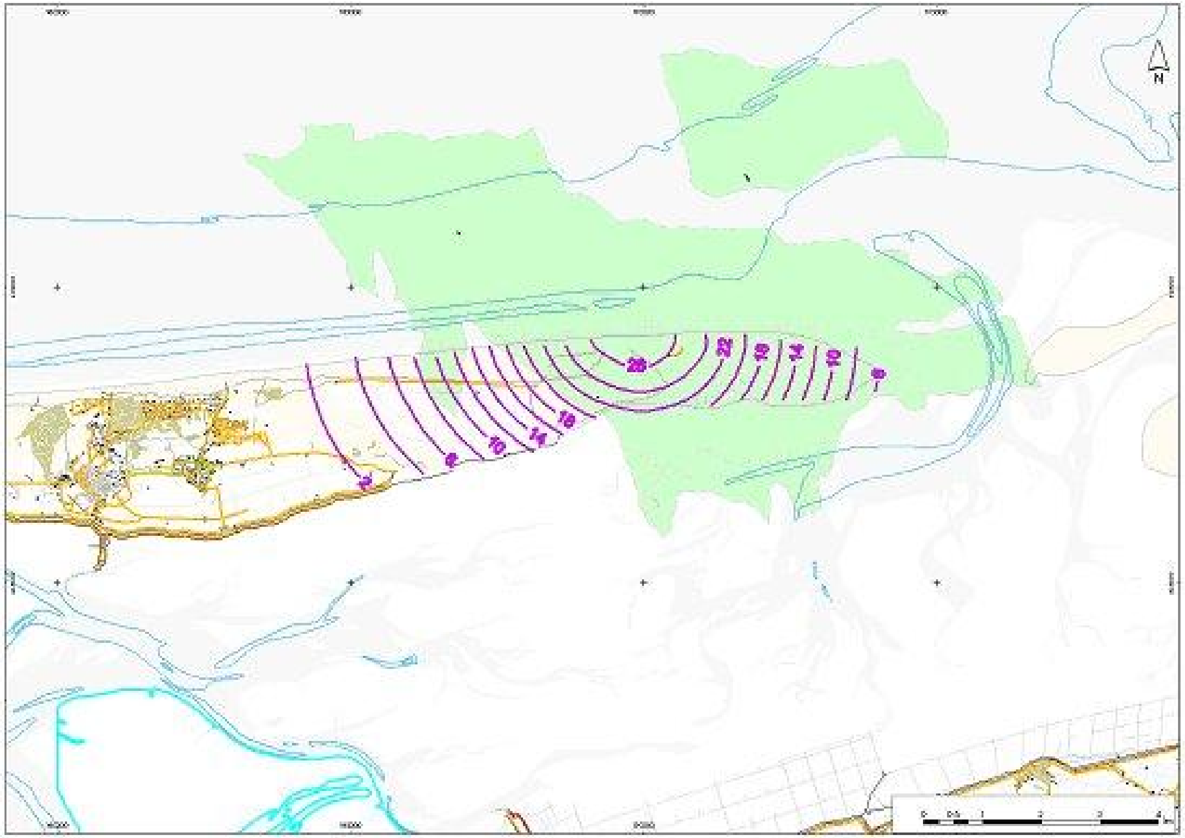
Anticipated soil subsidence (2003-2020) for the appearance of East Ameland. The still to be expected soil subsidence amounts to approximately 10 cm at the deepest point.



Anticipated soil subsidence (2003-2020) for the appearance of Ameland Westgat. The still to be expected soil subsidence amounts to approximately 8 cm at the deepest point.

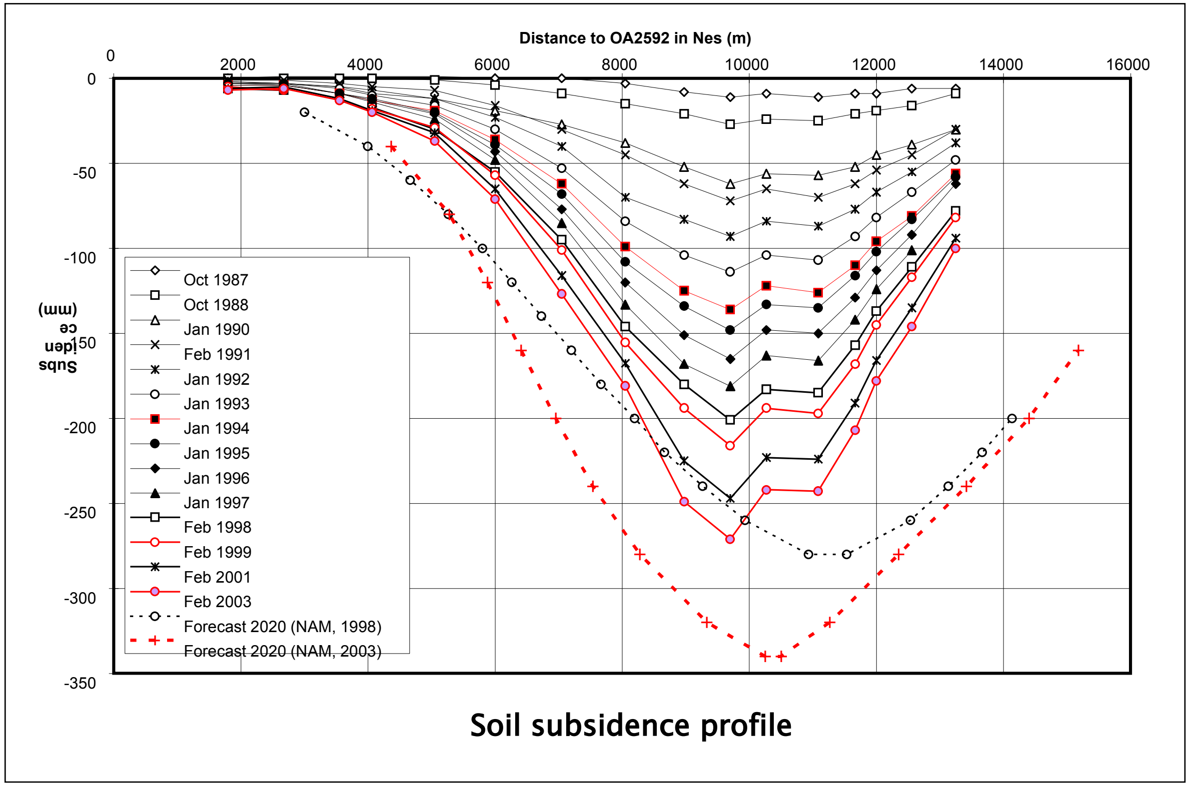
Monitoring the soil subsidence

Each year, on the instruction of the NAM and after zero measurement at the points of an extensive measuring network on East Ameland in March 1986, accuracy levelling was carried out on East Ameland up to February 1999. At the time, it was decided to no longer carry out the accuracy water levelling on an annual basis, as, on the basis of the available data, extrapolation enabled the execution of an accurate forecast of further subsidence for short periods of one to two years. The final accuracy levelling exercises were carried out in February 2001 and February 2003.



Soil subsidence outlines based on the measurement of February 2003.

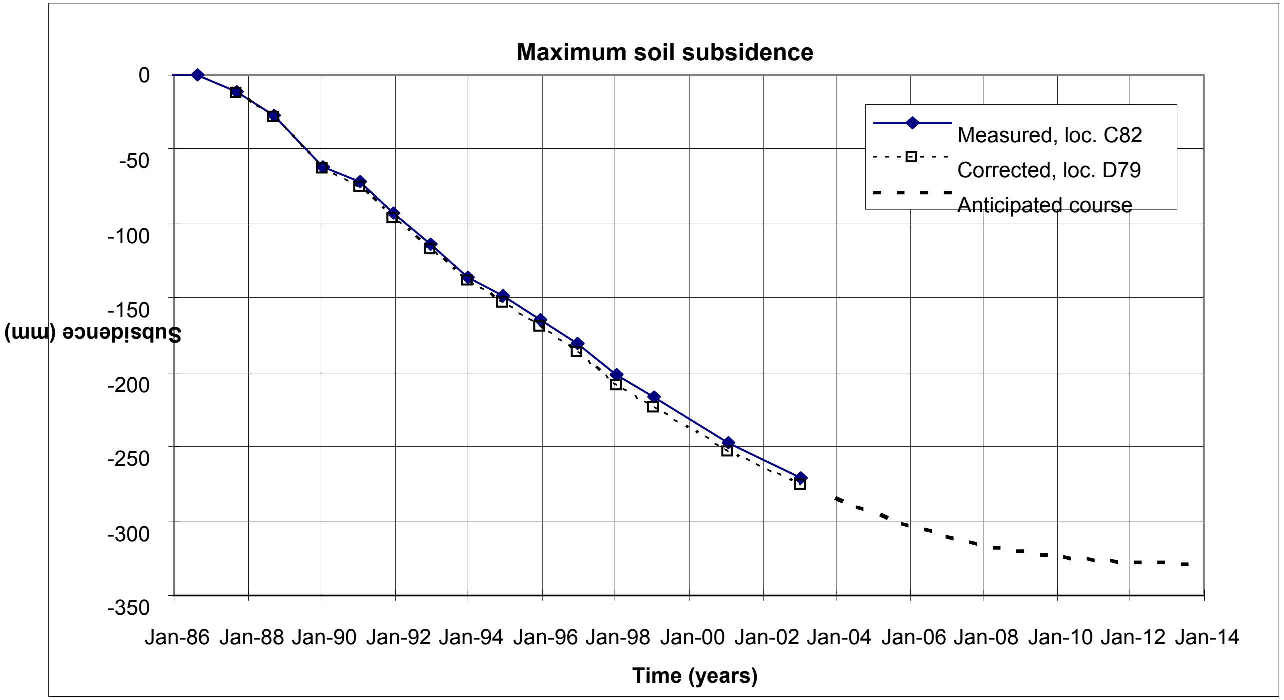
The measurements can also be shown in the form of a longitudinal section running from Nes to the eastern point of Ameland. This shows that the NAM location (measuring point is within the small building), probably unjust, appears to subside less than the nearest measuring points. The most likely subsidence at this location can be easily estimated by sketching a logical subsidence profile.



Cross-section of the soil subsidence basin of Nes via NAM location to eastern point of Ameland.

The figure above shows that the actual soil subsidence takes place within a slightly smaller area than predicted in 1998. Taking into account the corrected maximum soil subsidence, it further becomes clear that the most likely maximum soil subsidence of 28 cm anticipated in 1998 was reached as early as 2003.

The course of the soil subsidence at the deepest point of the basin against time is also shown (see below). This figure shows that, since 1994, the annual subsidence has been decreasing. The course of the subsidence is shown as a natural continuation into the future. From this it becomes clear that a further subsidence of approximately 33 cm in the 2010 – 2012 period must be taken into account. Thereafter, the anticipated subsidence speed is very limited. According to the latest prognosis, the ultimate subsidence, originally set to 26 cm, can reach approximately 34 cm (maximum 37 cm) in 2020.



Course of soil subsidence on East Ameland.

This data forms an important point of departure for the remaining aspects of this study.

Morphology

Based on contributions by

Wim Eysink

Johan Krol

Marcel Kersten

Pieter Slim

Marlies Sanders

Ruut Wegman

Water levels, rain and evaporation

In addition to soil subsidence, a number of abiotic factors play a role in the morphological and/or ecological developments in and around the Wadden Sea. These include:

- water levels
- precipitation and evaporation
- groundwater level in the dunes and
- groundwater quality in the dunes

Hence data of these variables has also been collected and processed.

Water levels

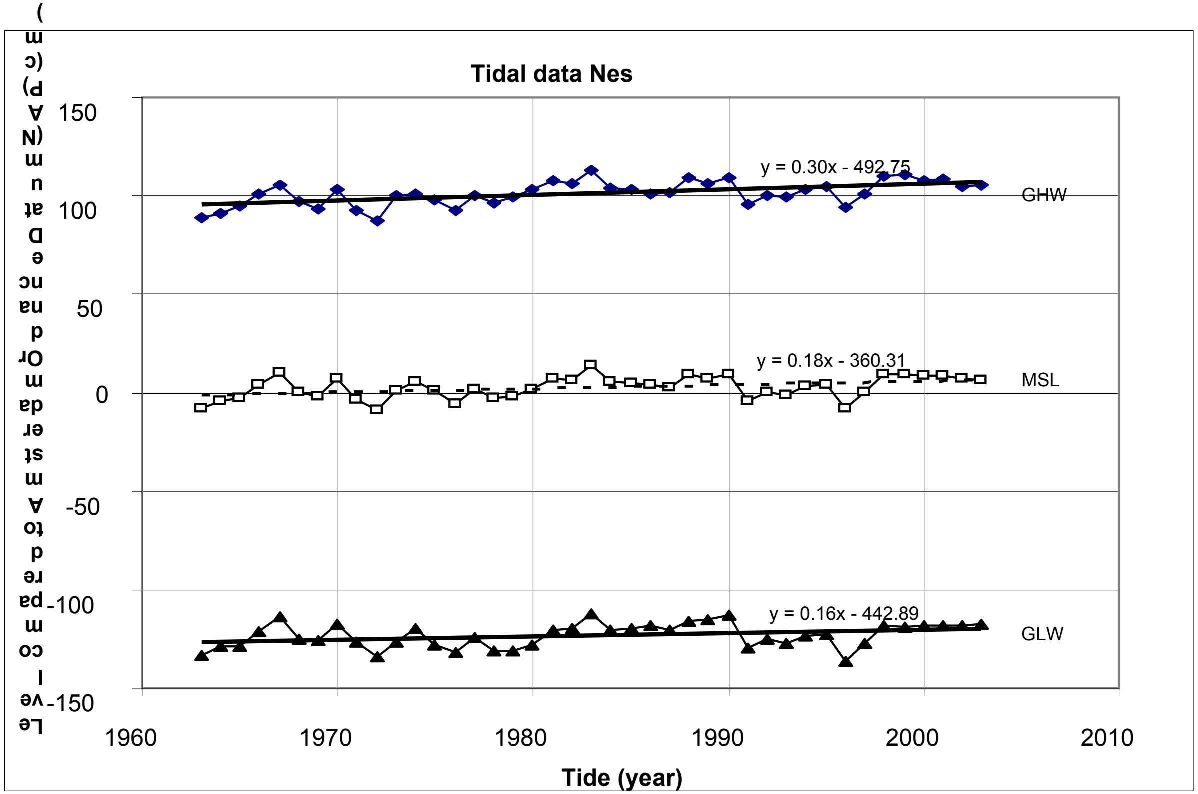
Water levels and water level changes play an important role in the morphology and the ecology in and around the Wadden Sea. The previous report detailed an extensive overview of the causes of changes in the water level, i.e.:

- astronomic tide
- set-up and draw-off by wind
- long-term changes in the average sea level due to climate change

Studying the different tidal stations in the Wadden Sea shows that station Nes at the pier, in front of the ferryboat, is most representative for the salt meadows Nieuwlandsrijd and to a slightly lesser extent for De Hon on East Ameland (see Eysink et al, 1995, 2000). During a storm, the salt meadow on De Hon and the low dune slacks west of the NAM location are flooded from two directions, viz., by seawater via the storm surge channels through the dunes east of the NAM location and via the low side, at the Wadden Sea flank. Station Wierumergronden produces good results for these locations.

The water penetrates via the storm surge channels, as a result of an increased water level at the North Sea flank caused by (wave) set-up surrounding the high water. However, the capacity of the narrow storm surge channels with a relatively high sill is limited. It is expected that most water comes in via the mudflat side slightly later, after the high water has drawn around the eastern point. The level of the high water near De Hon will not have resonated that far as yet and, on average, be slightly lower compared to that at Nieuwlandsrijd (ranging between 0.05 – 0.1 m). Due to differences in set-up, this difference can further increase or decrease under storm conditions. All in all, here too station Nes produces a reasonable indication for the risk of flooding of De Hon.

Particularly fluctuations in the annual mean high water level (GHW) and in the number of extreme high waters, during which salt meadows and low dune slacks are flooded, are important to explain the developments in vegetation in these areas. Hence the courses of the mean high water level (GHW), the mean sea level (MSL) and the mean low water level (GLW) of station Nes are shown in the figure below since observations started in 1963, while the high water transgression data is summarised in the high water transgression table.



Courses of average high water, average sea level and average low water (survey station Nes).

The tidal range in Nes ranges between approximately 2.20 m and 2.30 m and clearly shows the effect of the astronomic tidal component with a cycle of 18.36 years and amplitude of around 5 cm. The average tidal range for the entire period is 224.5 cm and seems to have increased in the period under review. According to the linear trend line, the average increase amounts to approximately 1.4 mm per year. However, this trend is not reliable, since the total period does not coincide with a full number of cycles of 18.6 years and, furthermore, comprises only two cycles. With a view to the influence of other, random disturbances, this is not much. It is certainly possible that the average tidal range has not changed.

In the previous report, the transgression data of 1981-1998 was presented together with long-term average transgressions. In this report, the data has been updated up to 2005. The table below shows that the number of extreme storm surges in the 1999-2004 period has been limited. In 1999, the level of Amsterdam Ordnance Datum (NAP) + 2.5 m was exceeded four times and the NAP+3.0 m level was not exceeded once. In 2000, the level of NAP+2.5 m was exceeded only once, however, a level of NAP+3.0 to 3.1 m was reached during that year. In other years during that period, the level of NAP+2.7 m was never exceeded. This type of storm surge level can cause flooding of the low dune slacks.

During this period, the level of NAP+2.0 m was exceeded below the average number, except in 1999. This also applies to the level of NAP+1.5 m, during which the lower parts of the salt meadows are flooded. However, in terms of percentage, the difference here is significantly smaller than at the level of NAP+2.0 m. This means that the salt meadows were flooded slightly less frequently and that, on average, the flooded area and the water depth per flood were below the average. As a result, the annual accretion on the salt meadows during this period could have been below the average.

Niveau	Aantal HW-overschrijdingen per jaar																									
(m + NAP)	1941-1980		1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	1981-2003
	Gem.	1)																								Gem.
3.5			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
3.4			0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.04
3.3			0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.09
3.2			0	0	1	0	0	0	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0.17
3.1			1	0	1	0	0	0	0	0	0	2	0	0	1	1	0	0	0	0	0	0	0	0	0	0.26
3	0.2	0.25	2	0	1	0	0	0	0	0	0	3	0	0	1	3	1	0	0	0	0	1	0	0	0	0.52
2.9	0.3	0.35	2	1	1	0	0	0	0	0	0	3	1	0	1	3	1	0	0	0	1	1	0	0	0	0.65
2.8	0.4	0.50	2	1	1	1	0	0	0	0	1	3	1	0	4	3	1	0	0	0	2	1	0	0	0	0.91
2.7	0.6	0.75	2	1	2	2	0	1	0	0	1	4	1	0	4	3	1	0	0	0	2	1	0	0	0	1.1
2.6	0.9	1.1	3	1	4	2	0	1	1	1	1	5	1	0	4	4	1	1	0	1	2	1	0	1	1	1.6
2.5	1.3	1.6	4	2	4	3	2	1	1	1	1	10	3	0	5	4	2	1	0	1	4	1	1	2	1	2.3
2.4	1.9	2.2	5	5	4	6	3	1	1	3	2	12	3	0	9	4	4	1	0	3	6	2	1	2	2	3.4
2.3	2.7	3.2	9	7	4	10	3	1	2	4	2	13	5	2	10	5	6	1	1	5	7	4	2	3	2	4.7
2.2	3.7	4.4	9	9	6	14	4	3	3	5	2	17	6	3	12	5	8	4	1	6	12	7	2	4	3	6.3
2.1	5.2	6.1	14	12	7	15	5	3	4	7	4	19	8	3	15	7	10	4	3	11	14	8	2	5	6	8.1
2	7.2	8.3	19	15	16	19	7	12	7	12	5	29	13	8	17	10	17	4	3	14	14	11	5	6	11	11.9
1.9	10.0	12.0	25	15	26	22	9	18	7	23	7	34	17	12	21	14	19	4	6	20	18	15	8	11	13	15.8
1.8	14.3	17.0	34	22	31	29	15	27	11	31	12	43	21	17	28	16	22	6	12	28	25	21	18	17	16	21.8
1.7	20.5	25.0	43	34	46	33	20	36	19	41	23	56	29	19	34	28	31	13	19	36	33	23	24	26	29	30.2
1.6	30.5	36.0	53	45	70	50	32	45	35	74	35	63	36	30	43	38	44	25	35	58	50	36	39	42	38	44.2
1.5	44.0	52.0	74	65	99	65	47	57	53	92	63	90	49	45	55	53	60	32	50	76	69	50	58	58	55	61.5
1.4	65.0	78.0	99	93	136	87	71	89	76	127	97	119	63	75	76	86	95	49	65	114	105	81	89	84	75	89.2
1.3	95.0	116.0	133	134	184	119	103	134	122	175	143	151	90	99	103	129	142	82	91	153	148	124	152	124	125	128.7
1.2	141.0	172.0	187	200	256	179	166	191	182	235	208	216	135	162	147	194	194	124	153	234	227	199	229	184	195	191.2
1.1	212.0	259.0	280	280	348	267	249	265	274	319	294	295	193	237	200	275	267	191	234	311	321	303	307	290	280	273.0
1	321.0	350.0	385	377	441	365	363	344	365	407	396	375	273	372	294	361	363	289	347	407	417	416	409	407	386	372.1
0.9	400.0	455.0	487	473	521	445	469	431	452	496	474	468	352	432	393	440	450	402	451	511	516	521	509	485	477	463.3
0.8	495.0	530.0	565	559	589	515	545	499	530	571	559	551	462	529	499	531	547	501	536	582	591	603	593	565	543	546.3
0.7	565.0	600.0	624	605	634	587	617	567	592	624	625	610	551	587	583	608	613	563	599	635	645	642	643	616	614	608.0
0.6	622.0	640.0	666	652	664	641	660	610	635	658	664	650	622	639	626	649	651	615	656	670	674	671	681	643	660	650.3
0.5	660.0	670.0	687	682	678	668	681	657	666	670	682	677	652	668	668	669	671	644	675	687	690	688	693	661	687	674.0
0.4	681.0	686.0	694	697	692	683	691	673	681	683	694	689	674	690	679	684	683	660	687	698	694	700	698	684	699	687.3
0.3	691.0	694.0	696	702	699	695	696	687	686	700	699	697	689	700	687	693	693	674	694	703	698	703	703	692	703	695.2
0.2	698.0	700.0	699	705	702	702	701	697	693	703	703	702	696	704	694	699	698	687	696	704	701	704	705	700	704	700.0
0.1	701.0	702.5	701	705	703	705	703	701	698	704	705	703	697	705	699	701	701	697	701	704	702	705	705	702	705	702.3
0	703.0	704.0	703	706	704	706	704	703	699	705	705	704	699	705	702	702	704	701	702	705	704	706	706	703	706	703.7
Aantal HW's / jaar	705.8		705	706	705	707	705	706	705	707	706	705	705	707	706	705	706	707	706	706	705	707	706	705	706	705.8

Gegevens van RWS-DGW

1) Gecorrigeerd voor zeespiegelrijzing van 1960 tot 1990

High water transgression data NES (blue indicates the highest water level attained).

Niveau Level

Aantal HW-overschrijdingen per jaar

Number of High Water transgressions per year

Gem. Average

Aantal HW's / jaar

Number of High Waters / year

Gegevens van RWS-DGW

Data of Directorate General for Public Works and Water Management-DGW

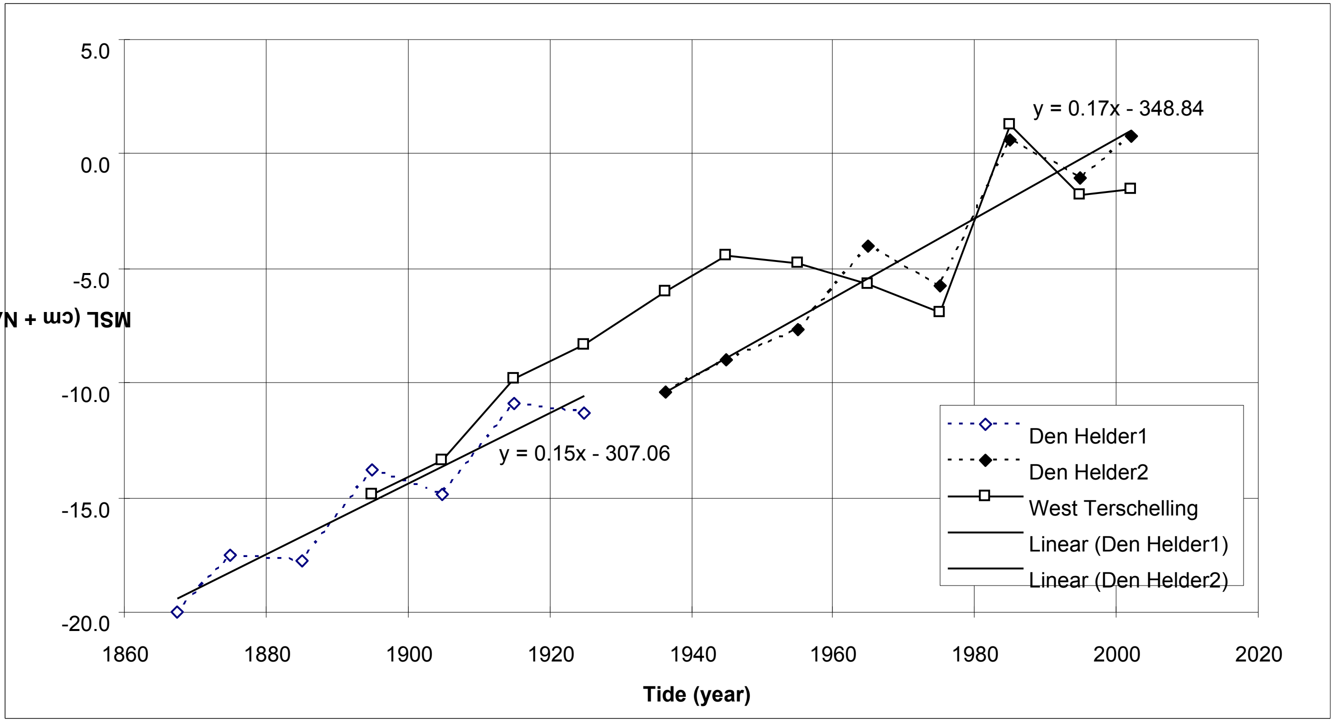
1)Gecorrigeerd voor zeespiegelrijzing van 1960 tot 1990

1) Corrected for sea level rise from 1960 to 1990

Based on the tidal data of Nes, it can be concluded that, since 1963, the average sea level near Ameland has gradually increased by approximately

1.5 mm per year. This corresponds to other measurement series. The tidal station of Den Helder (Naval port) has a long-term observation period (starting in 1865) and has been least affected by the developments in the Wadden Sea. Hence this station is deemed the most representative for assessing the long-term changes in sea level rising, albeit that a potential influence has been generated due to closing off the Zuiderzee. Hence a distinction has been made between the 1865 -1930 period and 1935 to date. The station of Terschelling shows the same trends as station Den Helder, albeit that the measurement series at Terschelling may possibly have been affected by channel developments.

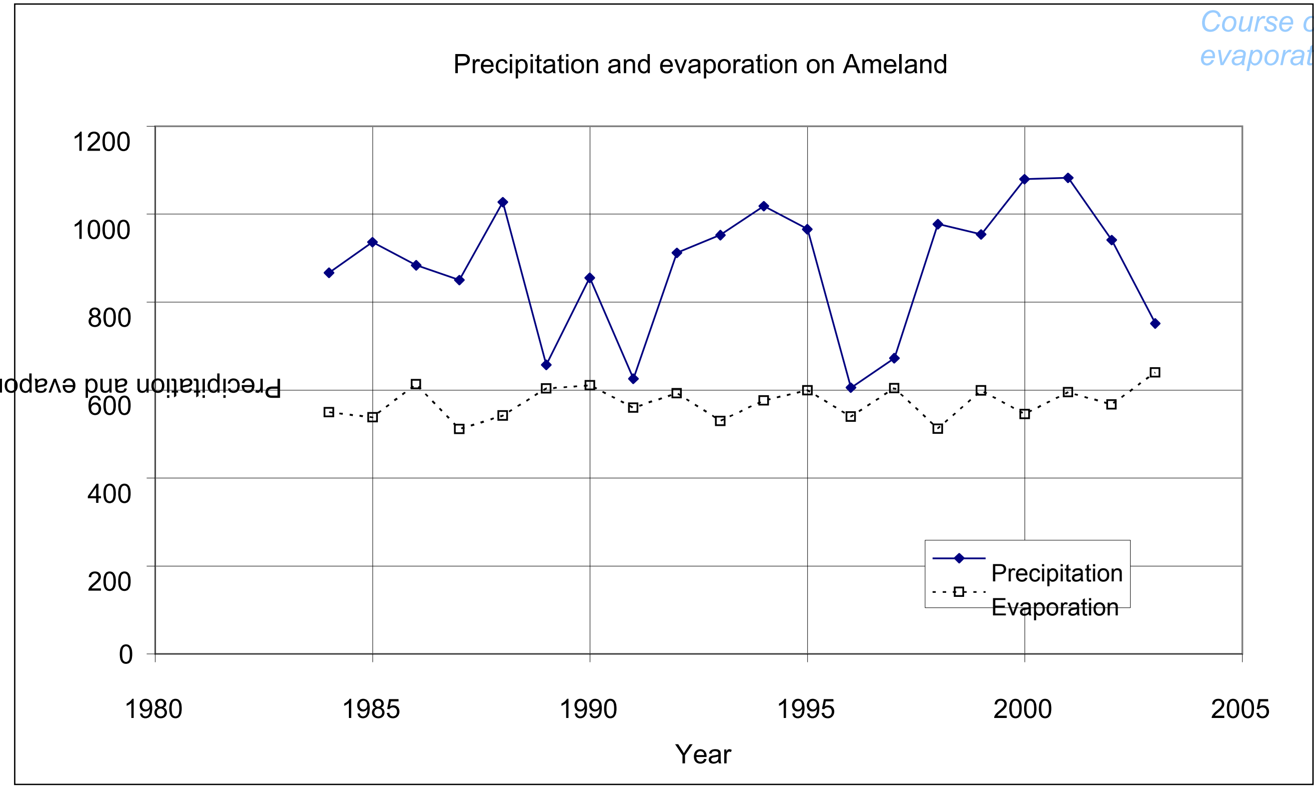
To date, the data of the tidal stations around the Wadden Sea does not show an accelerated rise in the sea level since the past decades. *Therefore, the effects of the soil subsidence must be judged within the framework of the current autonomous rise in sea level.*



Course of average sea level in Den Helder and West Terschelling.

Precipitation and evaporation

The average precipitation in Nes during the 1984-2003 period amounted to 880.8 mm/year, which was 86.9 mm higher than the long-term average of 1951-1980. In addition, it further rose by over 20 mm compared to the average for the 1984-1998 period. This can be explained by the wet years during the 1999-2002 period, with 2000 and 2001 being extremely wet years. These years were even wetter than 1993-1994, when the hawthorn and elderberry bush in the dune slacks started to die off. The year 2003 was rather dry, with a precipitation figure of 751.5 mm. The evaporation figures for Ameland during the 1999-2003 period provided by the Royal Netherlands Meteorological Institute (KNMI), all concern evapotranspiration figures according to Makkink for the location Lauwersoog. This location is representative for the evaporation on Ameland. The average evaporation for the 1984-2003 period amounts to 571.4 mm, which is only slightly below the average of 579.0 mm in Den Helder for the 1965-1986 period. The evaporation on Ameland in the 1999-2002 period did not deviate much from the average evaporation figure. Only in the rather dry year of 2003, evaporation was also relatively extreme measuring at a value of 639.6 mm. The precipitation excess in that year was nearly just as insignificant as the limited precipitation excess during the years 1989, 1991, 1996 and 1997.



Course of annual precipitation and evaporation on Ameland.

Groundwater levels

The previous report amply discussed groundwater measurements in the Kooiduinen, Het Oerd and the Oerderduinen on East Ameland. This clearly showed that the groundwater level fluctuates according to the season. During the summer season, the groundwater level is 75 to 100 cm lower compared to the winter season. This is caused by the seasonal variation in precipitation and the average sea level, among other things. At some locations, the penetration of sea water due to flooding in the winter period plays a role. In dune slacks with a sill or in a dune hollows, the groundwater can reach ground level, causing pool formation. This does of course not occur near high dune ridges.

Standard lines of direction for PQ surveys.

In accordance with the report of April 2000, additional surveys of the groundwater quality have been carried out in order to verify whether any shifts have taken place as a result of environmental changes. Compared to previous observations made in 1990/91, this appeared not to be the case (see dune slacks).

Conclusions abiotic factors

In general, the conclusion that an accelerated rise in sea level cannot be measured seems to be justified. Therefore, the effects of soil subsidence caused by gas extraction to date are not amplified.

The water level data of tidal station Nes and the high water data in particular, is representative for the water levels near the salt meadows Nieuwlandsrijd and also De Hon. Particularly the behaviour of the average high water compared to the salt meadow level and the level of low dune slacks is important. The number of external storm surges in the 1999-2004 period was limited. In 1999 and 2000, the level of 2.90 m above Amsterdam Ordnance Datum was exceeded only once and during the years after 2000 the highest storm surge remained below 2.70 m above Amsterdam Ordnance Datum. However, due to soil subsidence, the chance of salt meadows and low dune slacks being flooded, which are directly linked to the Wadden Sea, has increased.

Precipitation and evaporation figures are important for the interpretation of changes in vegetation. With regard to Ameland, the precipitation data of station Nes is requested from the KNMI. Evaporation figures are not measured in Nes. Therefore, this data is requested for the nearest station where they *are* measured. Meanwhile, a lot of information and insight has been gained in the behaviour of the groundwater level on East Ameland. This provides a proper basis for the interpretation of the observed changes in the dune and salt meadow vegetation on the island. As a result of seasonal changes in the precipitation/evaporation and the average sea level, the groundwater level shows large fluctuations across the year (ranging between 0.5 to 1 m). High values are reached during winter and low values during the summer season. As a result, low, closed dune slacks can become flooded during an extremely wet year. As expected, soil subsidence causes the groundwater level to lay closer to ground level and thus the abovementioned phenomenon could occur more frequently.

Since 1990, the quality of the groundwater has remained unchanged.

The effects of soil subsidence on morphology

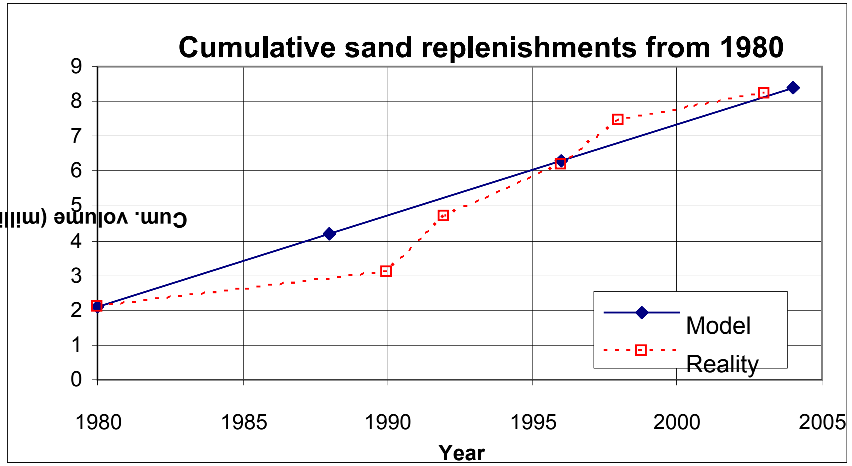
North Sea coast

In 1987, by means of a coastline model, a forecast was made of the behaviour of the North Sea coast between km direction sign 7 and km direction sign 25. The forecast predicted the calculated change in position of the average high water line (GHW line) compared to 1980. The calculations were carried out for the situation with and without soil subsidence. Either case allowed for beach replenishment of 2.1 m^3 between km 10 and km 17 every other eight years, starting in 1980.

Since 1990, the government policy has been that the coastal position of 1990 will be maintained. Near the North Sea coast of Ameland, the coastal position up to km direction sign 23 is maintained through coastal replenishments. Up to 1998, the replenishments were carried out in the foredunes and on the beach. As from 1998, the coastal replenishments have been carried out as shoreface replenishments, taking into account that only 50% of the sand volume added effectively contributes to the improvement of the position of the coastline. Since 1980, six coastal replenishment exercises have been carried out on the North Sea beach of Ameland.

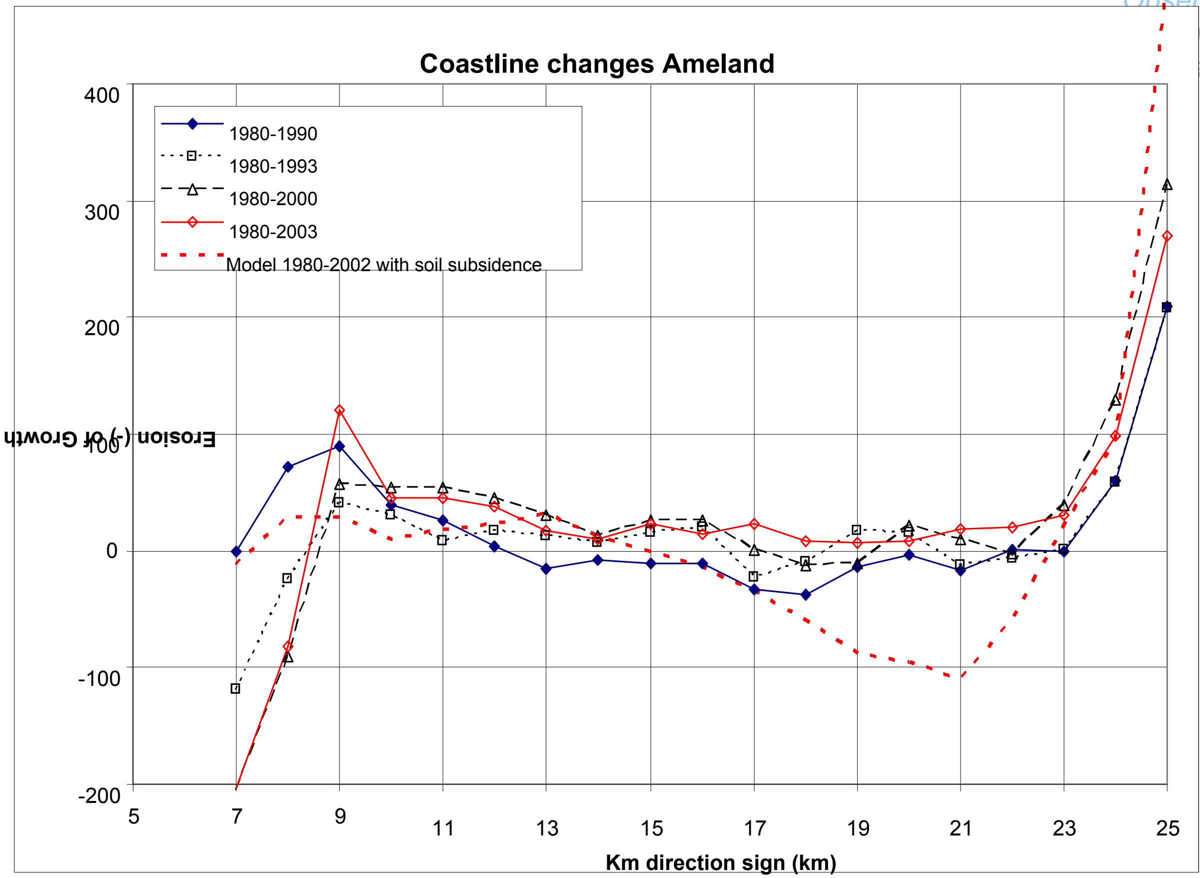
Year	Volume (10^6 m^3)	Cum. effective vol.(10^6 m^3)	Location (km-direction sign)	Comments
1980	2.1	2.1	10 – 17	foredunes/beach
1990	1.0	3.1	12 – 17	foredunes
1992	1.6	4.7	12 – 20	beach: repair basic coastline
1996	1.5	6.2	7 – 11	beach: retention basic coastline
1998	2.5	7.45	11 – 18	shoreface NAP – 6 m (50 % effective)
2003	1.5	8.2	10 – 14	shoreface NAP – 6 m (50 % effective)

Coastal replenishments at the North Sea coast of Ameland between km direction sign 7 and km direction sign 20.



Total effective volume of the coastal replenishments on the North Sea beach of Ameland.

Although the actual coastal replenishments deviated from the theoretic coastal replenishments in the coastline model in terms of time and location, the accumulated, effective volume of the replenishments matches the model well. The results from monitoring the actual coastal changes of the North Sea coast of Ameland from 1980 further show that, in 2003, the coast between km direction sign 9 and km direction sign 25 is positioned on the seaward side in relation to the coastline of 1990. In the interim, the coastline has occasionally and locally eroded past the coastline of 1990. The predicted effect of the soil subsidence caused by gas extraction between km direction sign 16 and km direction sign 23, viz., a receding coast between posts 17 and 23, did not materialise; the position of the coastline of 1990 between km direction sign 9 and km direction sign 23 remained unchanged, despite the soil subsidence.

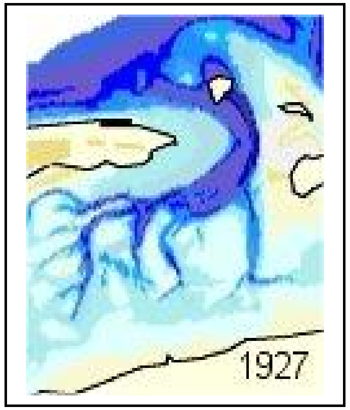


Observed and calculated coastline ...es to the North Sea beach of ...and, after 1980.

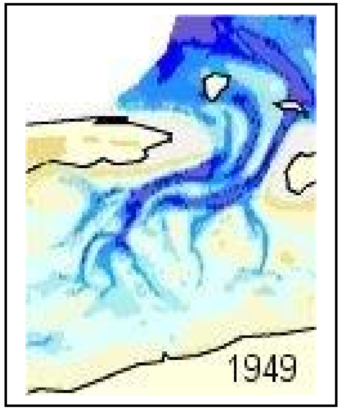
The conclusion that the soil subsidence caused by gas extraction has not had a noticeable effect on the development of the North Sea coast is justified. This was partly established as a result of the government policy to retain the 1990 coastline and the sand replenishment exercises carried out within that framework.

Friesche Zeegat and De Hon

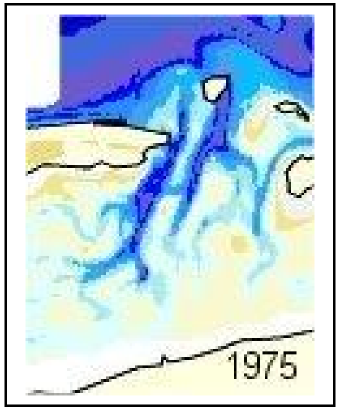
Studying the available sounding charts of the Friesche Zeegat in relation to the growth and erosion of the eastern point of Ameland shows that the behaviour of De Hon is strongly determined by the channel behaviour in the flood basin of the Pinkegat and in the coastal inlet. Around 1910, De Hon was less than approximately 1 km long starting at the Oerderduinen. Subsequently, a strong growth towards the east took place, possible fuelled by the construction of the Kooi-Oerdstuifdijk in the 1880-1893 period. The gauge map from 1927 shows that the main channels on the mudflat more or less run from west to east and only bear off north at a large distance of De Hon. As a result, the run-off of the water to the sea forms a minimum obstruction to the growth of De Hon. In addition, there are no flood channels on the North Sea side of De Hon and thus the flood current does not attack De Hon either. Therefore, the circumstances for growth are ideal. Around 1940-1950, De Hon expanded east to a maximum extent. The gauge maps from 1949 and 1975 show that the main channel on the mudflat has split in two and that the northern branch has gradually turned north, moving closer below Ameland. During that period, strong erosion at the eastern point of Ameland could be seen. From 1975 to 1979, the Holwerderbalg moved back east again, as a result of which the attack on De Hon reduced from the inside. However, a new flood channel was formed on the north side of De Hon which, for the time being, prevented growth. From 1979 to 1987, the Holwerderbalg in the Wadden Sea continued to move eastward and the circumstances for growth of De Hon were becoming favourable again (situation 1927 looks like that of 1927). After 1987, a situation similar to that of 1975 developed up to 2000. Due to this channel development, the attack on De Hon has once again started.



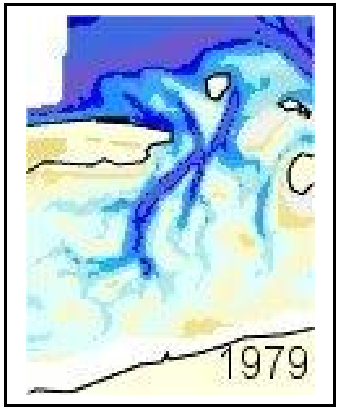
Pinkegat 1927



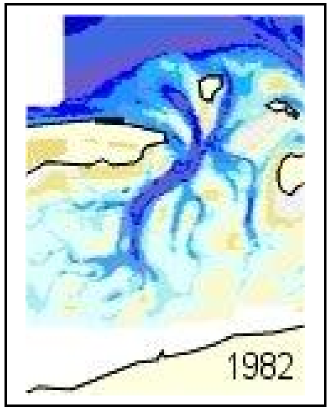
Pinkegat 1949



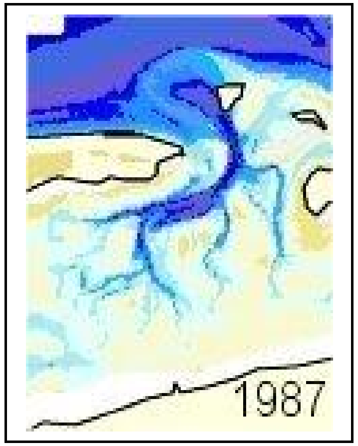
Pinkegat 1975



Pinkegat 1979



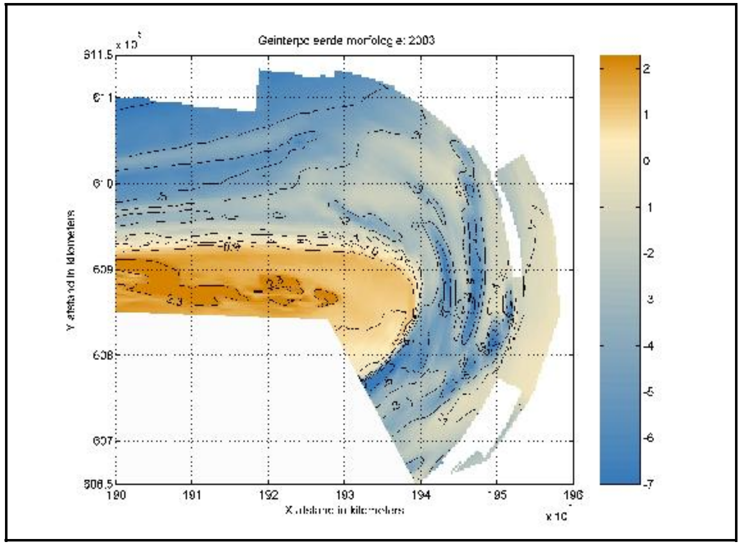
Pinkegat 1982



Pinkegat 1987

Pinkegat 1994

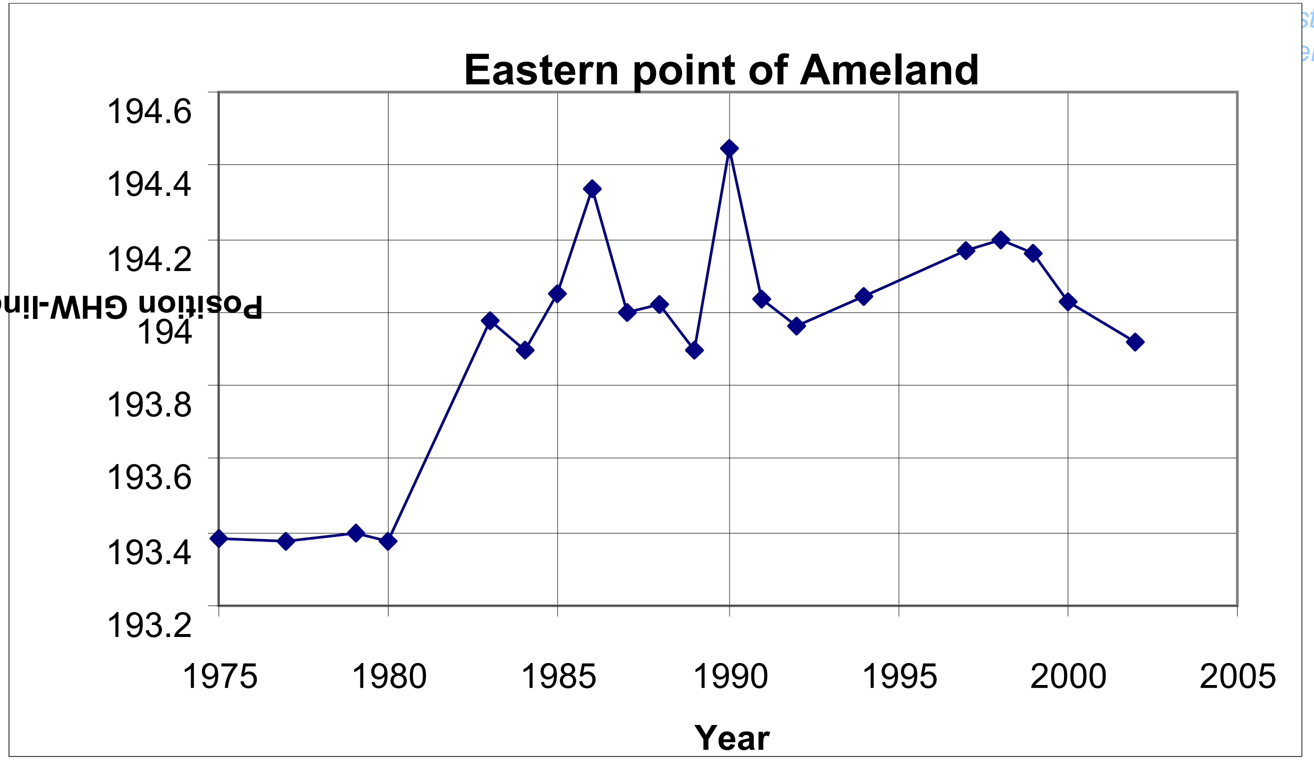
Pinkegat 2000



Pinkegat 2003

Geinterpoleerde morfologie 2003
Y afstand in kilometers
X afstand in kilometers

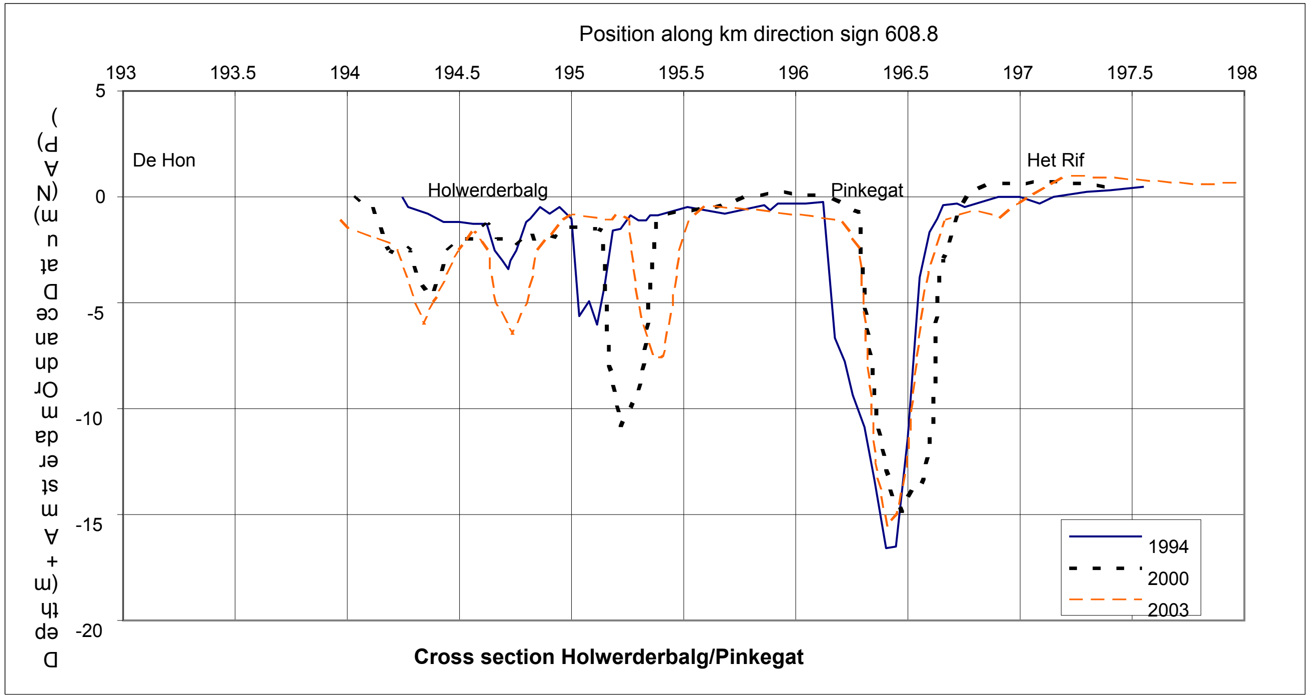
Interpolated morphology 2003
Y distance in kilometres
X distance in kilometres



...t-East migration of the eastern point of ...eland (increase = growth).

As from 1980, based on idealised cyclic channel behaviour in the Friesche Zeegat for a period of 70 to 75 years, De Hon was expected to grow in northern and eastern directions, up to 2010. Growth of more than 2 km was forecast (same position as in 1940) up to even 4 km, minus a reduction of approximately 375 m as a result of loss of sand due to soil subsidence in the Wadden Sea. To date, the actual growth since 1980 has only been around 0.6 to 1 km and it looks as if the erosion phase at the eastern point of De Hon started as early as 2000. The development was kick-started by the channel developments on the mudflat side of the coastal inlet. Currently the attack on the eastern point of Ameland is in full swing, as is clear from the channel developments in the coastal inlet. The latter shows a substantial shift of the low water line to the west.

Soil subsidence playing a role in the reduced growth and the accelerated erosion cannot be excluded, but it is also possible that the channel behaviour is autonomous to the extent that the observed development is hardly or not affected by soil subsidence. This latter possibility is deemed the most likely (see also the main report). With regard to the future, it can be assumed that the erosion process at the eastern point of De Hon, as it could develop from this moment on, can hardly or not be influenced by the additional soil subsidence, since most of soil subsidence caused by gas extraction has already taken place.



Developments in the costal inlet Holwerderbalg/Pinkegat during the period 1994 - 2003

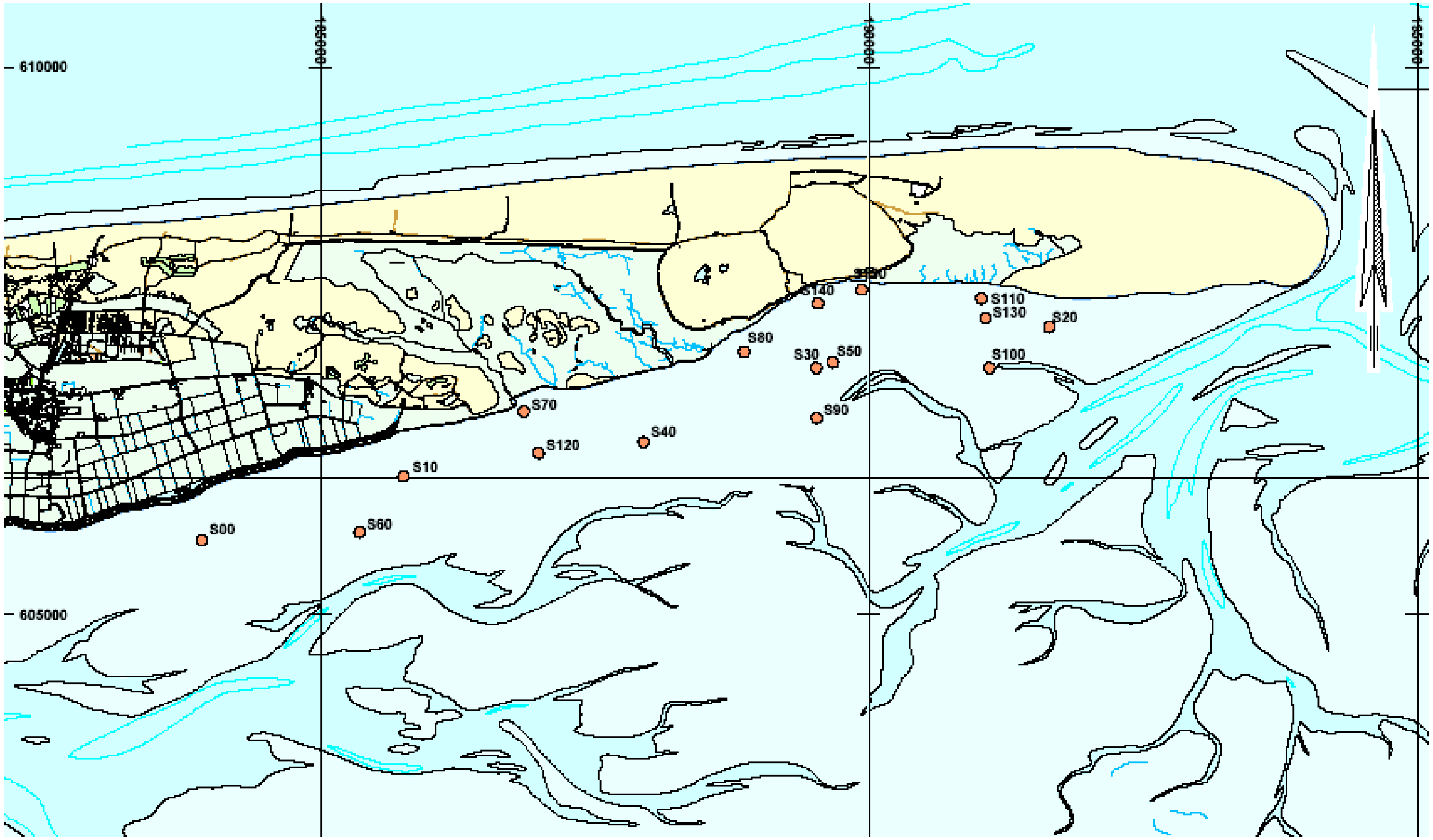
Erosion of the salt meadow edge

After 1998, the Supervisory Committee decided that levelling of the salt meadow on De Hon was no longer needed. As such, the south side of De Hon has not been included in a routine programme of the Directorate-General for Public Works and Water Management (RWS). The available information consists of visual observations and regular aerial pictures of the Ordnance Survey (Emmen). These aerial photos are used to determine the erosion speed of the salt meadow edge near the Oerderduinen. This is because during the past years, on the eastside of the Oerderduinen, near direction sign VIII, cliff erosion was detected. Slightly more to the east, halfway direction sign VIII and IX, this erosion shows a rather abrupt transition to a rather stable part of De Hon. Here a wide pioneer zone can be found and, from as early as 1986, a beautifully developed salt meadow with new inlets, alluvial ridges and basins.

The research carried out into this has been extended to the west, up to the mouth of the Oerdsloot and to the east up to the stable part. The results will be discussed in the next chapter.

Wadden Sea

The main Wadden Sea region which will subside due to soil subsidence is located on the Pinkewad directly below De Hon, the Oerderduinen and the Nieuwlandsrijd. The report of 2000 already showed that it is impossible to visualise the soil subsidence basin in the Wadden Sea on the basis of gauge maps, as a result of compensation of the soil subsidence following additional sedimentation. In August 2000, in order to gain more information in this respect, Nature Centre Ameland started measuring relative changes in the plate level of the Pinkewad below East Ameland caused by sedimentation or erosion.



Sedimentation measuring points on the plates of the Pinkewad.

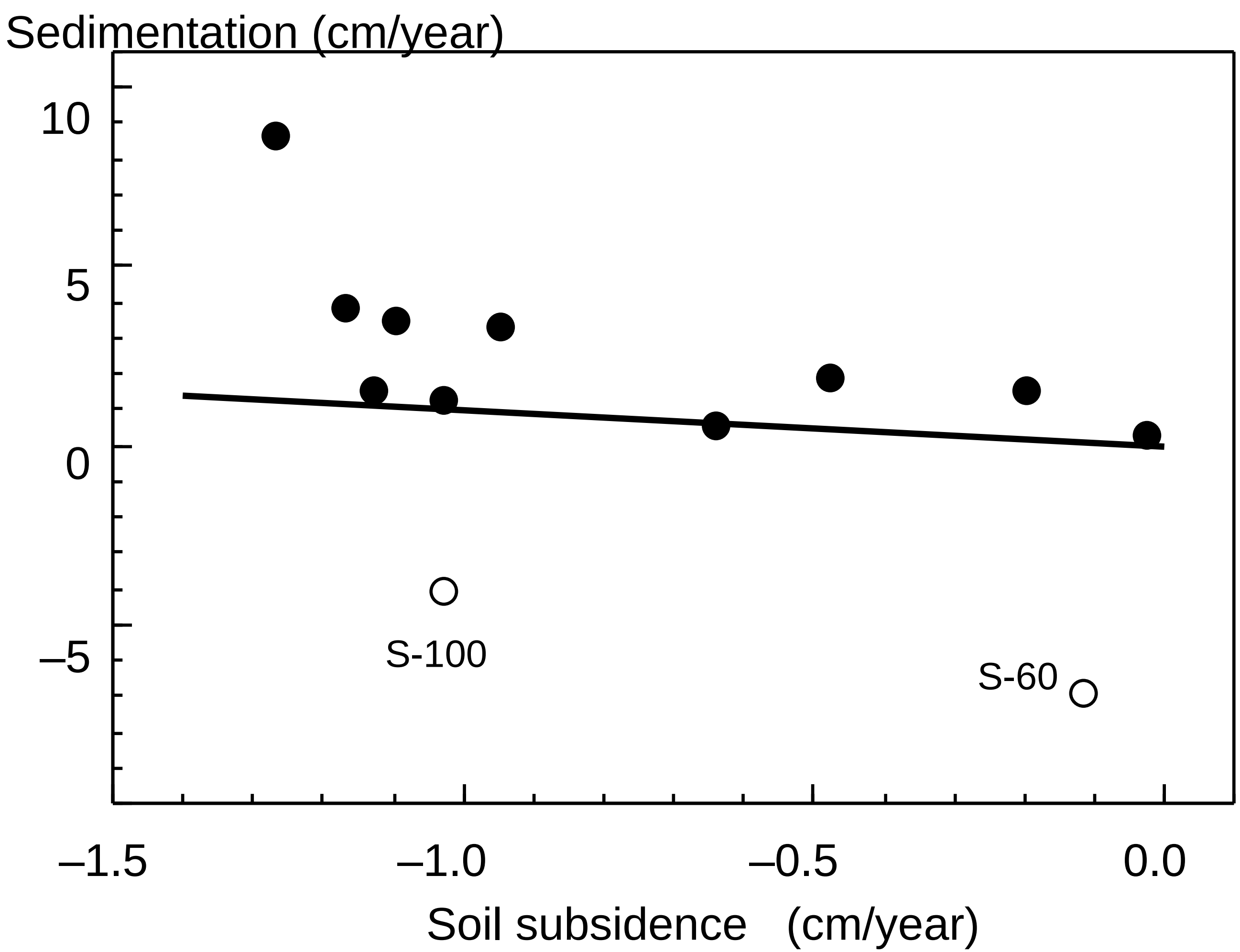
To this end, initially five measuring points were installed in the mudflat areas affected by soil subsidence. One of these points (S00) serves as a reference point for the undisturbed mudflat and has been installed near the discharge sluice of the Buurdergrie polder. At this point, the ultimately expected soil subsidence caused by soil subsidence will amount to less than 2 cm. The other points are located south of the Kooigrie/Kooiduinen, the Nieuwlandsrijd, Het Oerd and De Hon. All points lie at distance of approximately 1 km from the coast. Later on, the measurement network in the areas was gradually expanded to up to 16 points.

Each measurement location is marked by a post. Around this post, at a distance of one metre, four non-shrinkable plastic wires are anchored in the ground half a metre below the surface area. The wires stick approximately half a meter out of the mud flat ground and have an aluminium plate attached at the end. During each measurement, the distance of the plate to the surface area is measured. Each time, the average change for the four measurements is calculated compared to the first measurement, per measuring location. This way, regular measurements generate a reliable picture of the local change in altitude of the plate due to erosion or sedimentation. Together with the soil subsidence caused by gas extraction, this indicates the true change in plate altitude above Amsterdam Ordnance Datum.

In 2001, it was decided to install duplicate locations at a distance of approximately 10 m north of the measurement locations in order to reduce the risk of gaps in a measurement series due to loss of measurements as a result of human activity (fishing, vandalism) or natural causes (storm, ice run). Later on the measurement network was expanded further still.

The measurements generally indicate that the plates on the Pinkewad tend to rise in altitude in combination with regression due to erosion (see points S00 and S130). The average increase in plate altitude ranges between 0.5 to 2 cm/year for points with measuring series of more than two years. For points with measurement series shorter than two years (points S120-S150) values are measured ranging between 3cm/year to 7cm/year. This growth due to sedimentation appears to be occurring reasonably gradually. The largest increase due to sedimentation took place in the points below Het Oerd and Nieuwlandsrijd. During the winter of 2001/2002, regression in the sedimentation was observed in all sampled points. In November 2001, at point S10, below Het Oerd, this was caused by cockle fishing (regression approx. 4.5 cm), after which recovery from the erosion was swift. At point S40, below Nieuwlandsrijd, the same picture was seen (regression approx. 4cm), probably caused by cockle fishing. At other points, the temporary regression was much less (around 1.5 cm) and possibly caused by storms. This can indicate a seasonal influence on the sedimentation on the plates. On balance, most locations showed substantial sedimentation that exceeded the figure needed to compensate for the soil subsidence.

Points S90 and S100 generated a different picture. Around November 2002, both points showed a shift in trend, in which sedimentation changed into erosion (S90) or vice versa (S100). In all probability, this is caused by in the influence of a small channel migrating to or from the measuring point.



The average sedimentation speed on the measuring points on the Pinkewad compared to the speed of the soil subsidence. The line indicates the balance at which the plate altitude remains unchanged. Thus in most locations, sedimentation exceeds soil subsidence.

Measuring point	Soil subsidence	Sedimentation (cm/j)		Total	Observation period	Comments
	(cm/year)	A	B	(cm/year)	(month)	
S00	-0.03	0.86	0.63	0.6 to 0.83	49	
S10	-0.20	1.71	1.39	1.19 to 1.51	48.5	Flighty course
S20	-1.03	0.63	1.13	-0.4 to 0.1	48.5	
S30	-1.13	1.39	0.88	-0.25 to 0.26	48.5	
S40	-0.64	1.56	0.69	0.05 to 0.92	48.5	
S50	-1.17	1.58	1.84	0.41 to 0.67	41	
S60	-0.12	1.28	0.44	0.32 to 1.16	29	
S70	-0.48	2.52	1.71	1.23 to 2.04	29	
S80	-1.10	1.68	1.76	0.58 to 0.66	29	
S90	-0.95	6.9	6.1	5.15 to 5.95	29	Up to Nov 2002
		-2.8	-2.85	-3.75 to -3.8		After Nov 2002
S100	-1.03	-8.85	-7.50	-8.53 to -9.88	29	Up to Nov 2002
		0.88	1.60	-0.15 to 0.57		After Nov 2002
S110	-1.27	1.84	0.35	-0.92 to 0.57	29	Flighty course
S120	-0.40	4.06	2.99	1.59 to 3.66	17	
S130	-1.20	4.64	3.43	2.23 to 3.44	17	
S140	-1.25	3.91	4.11	2.66 to 2.86	5	
S150	-1.3	7.10	6.64	5.34 to 5.8	5	

Observed changes in plate altitude on the Pinkewad below East Ameland.

Explanatory notes to the table

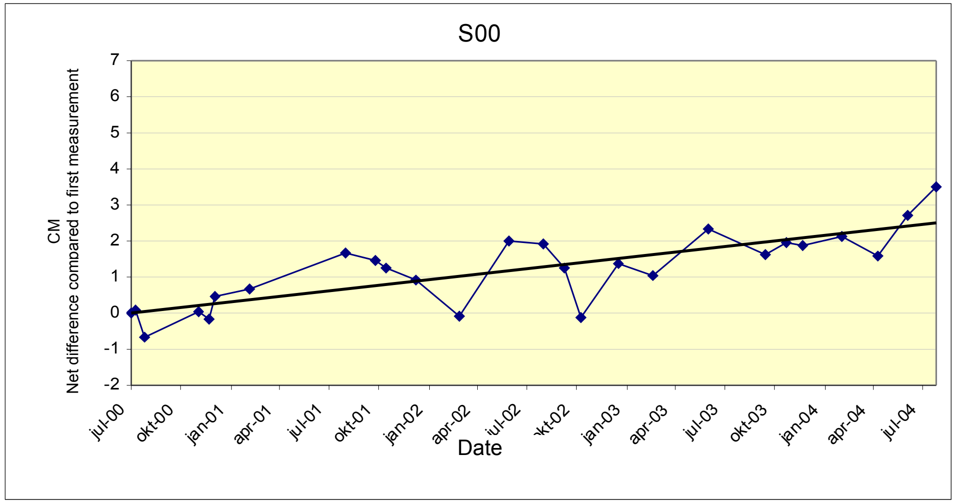
Points S90 and S100 are located closely to a channel; erosion was caused during the phase that the channel approached the measuring point, whereas sedimentation took place when the channel was stable or moving away.

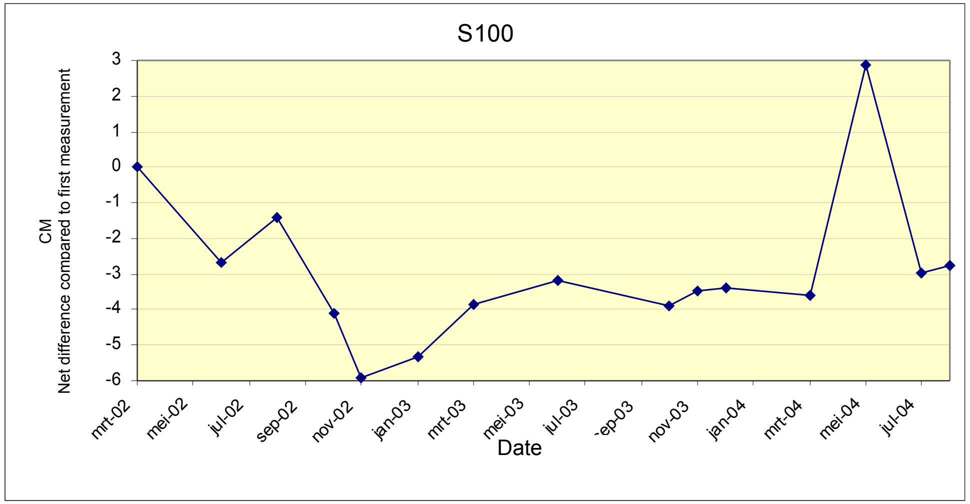
A: average change in altitude calculated from the observed altitude change at the end of the observation period, divided by the duration of the period.

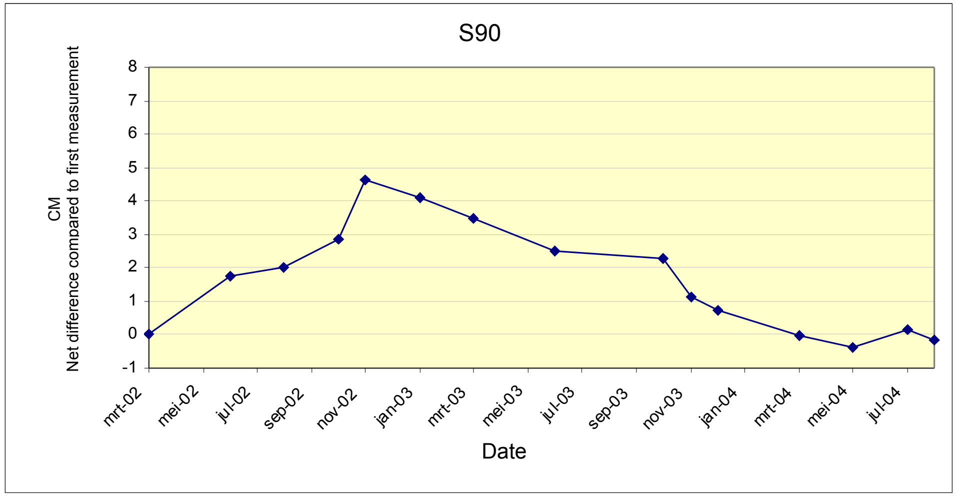
B: trend in the sedimentation on the plate based on linear regression.

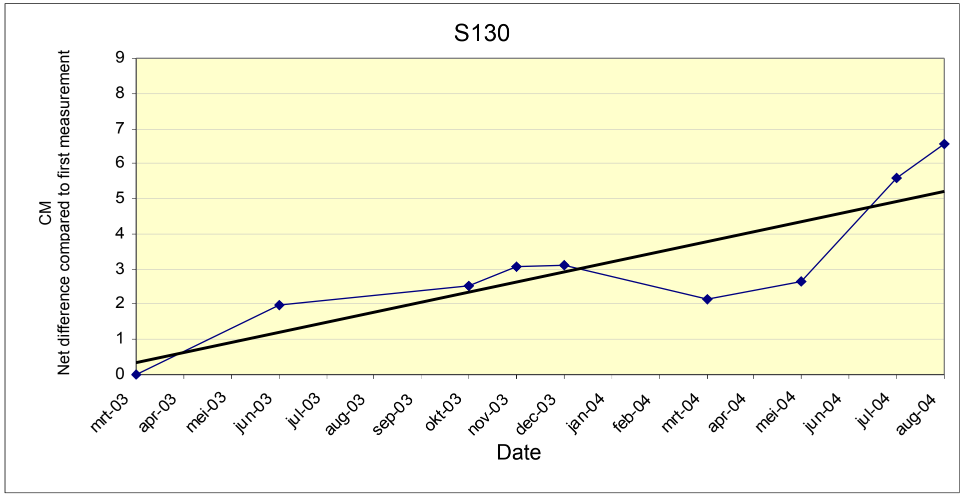
The high sedimentation in points S120-S150 is probably caused by the short measuring period.

The auxiliary tools used during a so-called pin measurement. The wire is anchored in the sediment by means of a large stud bolt which is screwed into the sediment up to a depth of approximately 60 cm. Sedimentation and erosion are determined in relation to this depth-anchored point by measuring the length of the wire above the sediment









Sedimentation/erosion on the Pinkewad observed by Nature Centre Ameland (examples).

In general, the average sedimentation exceeds the soil subsidence speed caused by gas extraction. Only in areas with high levels of soil subsistence, just below the Oerderduinen and De Hon, no full compensation will have occurred on average. Therefore, the conclusion can be drawn that, in any case, the effect by soil subsidence on the plates of the Pinkegat are largely, yet often fully compensated by sedimentation and that, in general, the plates even increase in altitude. This sedimentation suits the natural growth of De Hon and the migration of the area where tidal currents meet, which have been taken place since around 1980.
Within that context, the current sedimentation must be considers a natural process that on locations with soil subsidence caused by gas extraction will have somewhat intensified, resulting in some compensation for the relative loss in altitude due to soil subsidence. In due course, as a result of the additional sedimentation, the soil subsidence caused by gas extraction will be compensated throughout.

Salts meadows Nieuwlandsrijd and De Hon

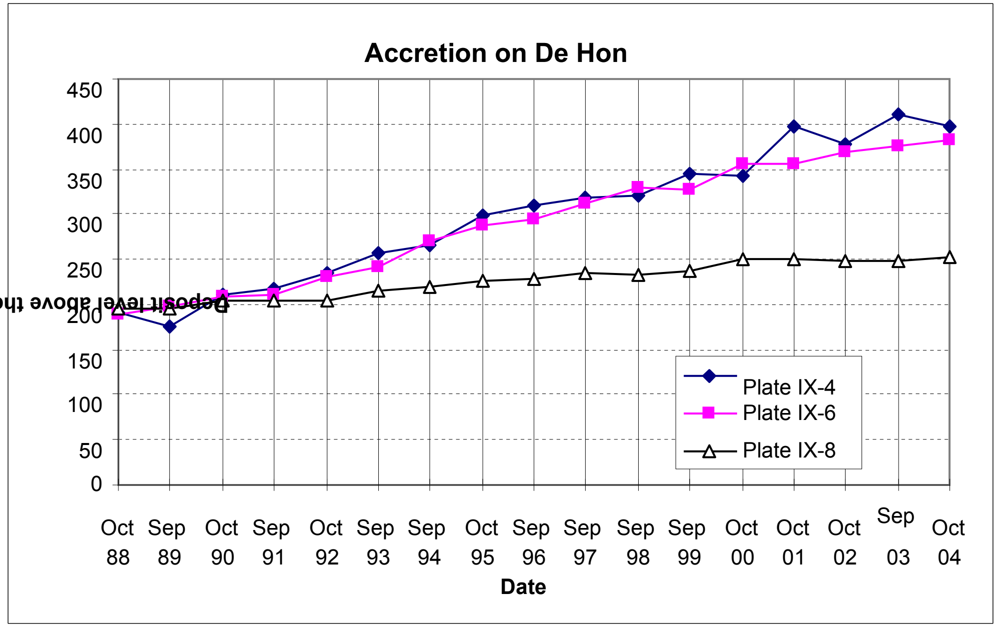
In February 2004, the soil subsidence caused by gas extraction below Nieuwlandsrijd (without compensation as a result of accretion) amounted to approximately 19 cm on the eastern side of the salt meadow to around 4 cm on the western side. This is approximately 85 and 45 per cent respectively of the original soil subsidence forecast (1985).

The main influence of soil subsidence on the Nieuwlandsrijd is an increase in frequency and scope of flooding due to storm surges. This is partly compensated by additional silt deposit as a result of extra flooding. This phenomenon also applies to the natural salt meadow on De Hon, where, in February 2004, soil subsidence caused by gas extraction ranged between 29 cm at the NAM location in the west to around 10 at the eastern point. This is more than 100 and 50 per cent respectively of the original soil subsidence forecast (1985).

The salt meadow edge of the Nieuwlandsrijd (for which bank protection measures have been implemented) amply exceeds the mean high water level (GHW) throughout, thus above the level at which salt meadow loss could occur due to soil subsidence. The salt meadow edge of De Hon is lower, as a result of which soil subsidence can cause the salt meadow to be reduced here, due to a northern shift of the GHW line on the mudflat side. However, when soil subsidence would be compensated as a result of accretion, De Hon need not be subject to salt meadow loss. Thus the resulting effect of soil subsidence caused by gas extraction on the topography of the salt meadows can only be calculated when information on compensation by silting is available. In October 1988, in order to find out more about this, stainless steel plates were dug in at nine selected PQs, at around 20 cm below ground level. Ever since, a pricker is used to determine the ground level in these locations in relation to this plate. During this procedure, the pricker is used to find the edges of the plate first, after which the measurement takes place from the centre of the plate. In principle, the first reading serves as a basis to calculate the accretion. Due to settlement in the excavated ground above the plate, the measured accretion for the first years can be less reliable. This is mostly confirmed by the limited cover, measured one year later on.

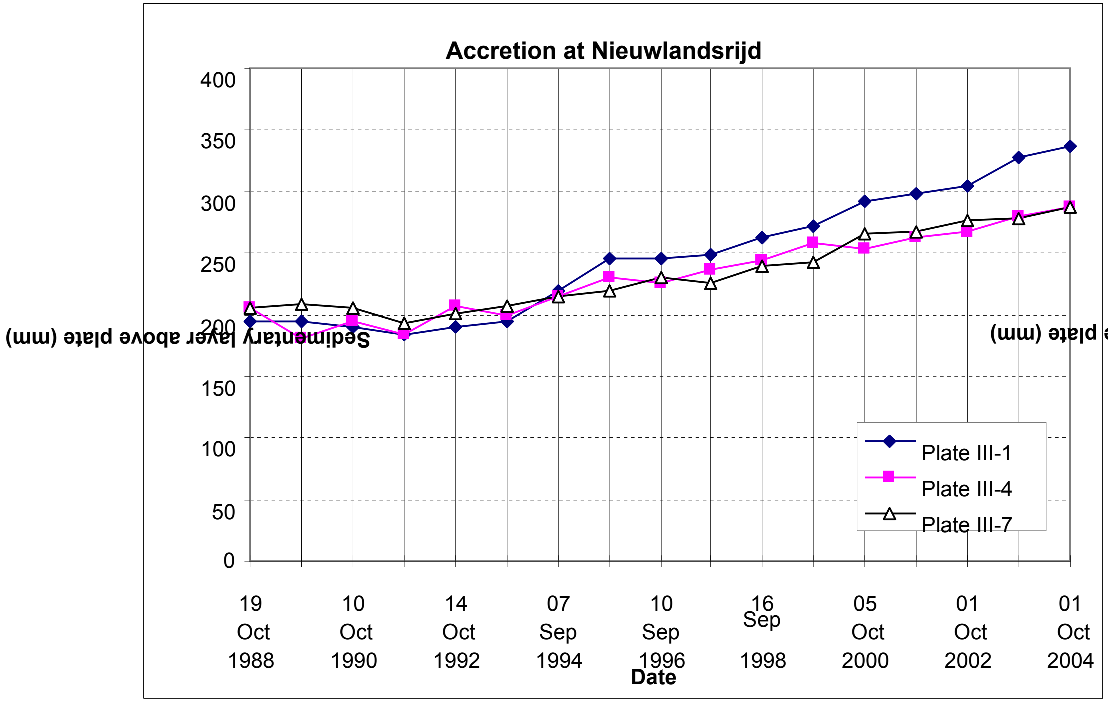
As from 1989, the course of accretion on De Hon at three selected locations is reasonably steady, yet on Nieuwlandsrijd this is much less the case as a result of the soil being tread down by grazing cows or local erosion due to a damaged turf. As a result, point 17 is fully unreliable as a representative accretion location (see locations) and in the remaining points the picture up to September 1991 is distorted.

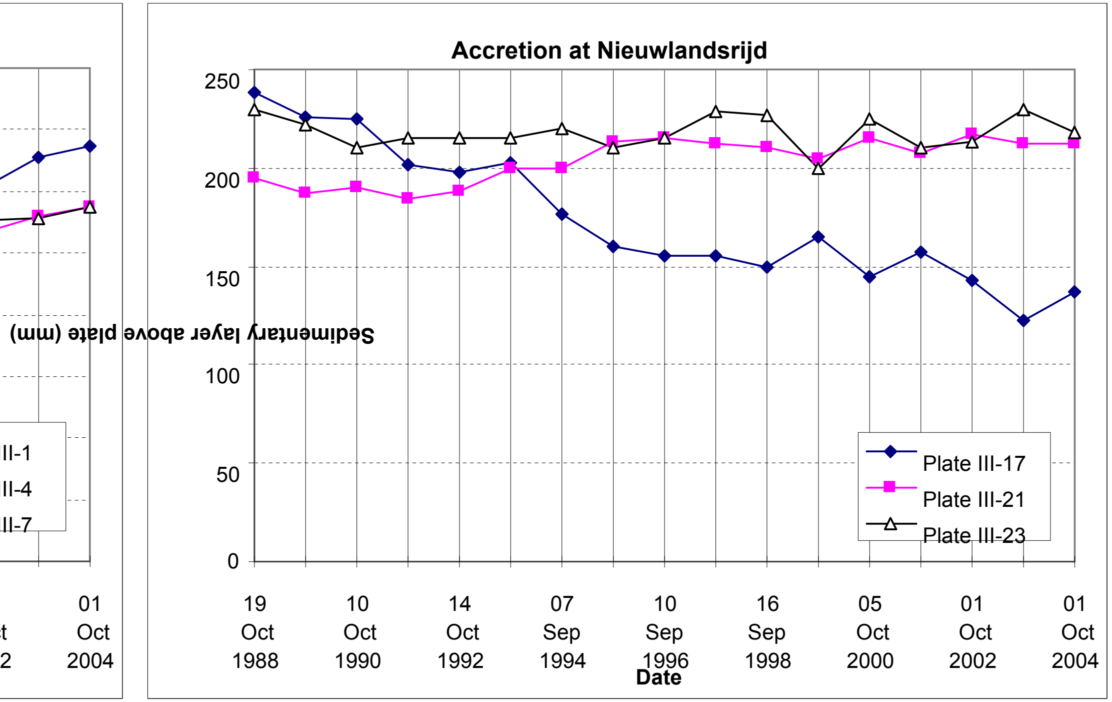
Damaged turf at PQ III-17.



Accretion data of salt meadow De Hon.

The points on De Hon are located at an increasing distance from the Wadden Sea and at an increasing site level. The points IX-4 and IX-6 are rather close to each other on the low salt meadow and are of around the same elevation. Hence the course of the sedimentation at these points is closer to each other, showing a total accretion of 208 mm and 195 mm respectively in October 2004. In 2001, the sedimentation course at point IX-4 shows a jump, whereas the course at point IX-6 remains steady. The sedimentation at point IX-8, which is located further away from the Wadden Sea and higher, is clearly less than the other two points and has stagnated since October 2000. In September 2004, the total accretion at that point amounted to 57 mm. During the period October 2000 to October 2004, at point IX-6, which is located lower, sedimentation does not stagnate, but the sedimentation speed is lower than in the previous period. It is thought that the low frequency of high storm surges in this period plays a role. In general, it appears that the soil subsidence on the salt meadow on De Hon is compensated by accretion. On the lower parts of the salt meadow, near the Wadden Sea, the compensation is equal or even exceeds the soil subsidence caused by gas extraction. Subsequently, the soil subsidence caused by gas extraction does not result in regression of the salt meadow edge. Towards higher parts of the salt meadow and further away from the Wadden Sea, compensation by accretion decreases, as the inundation frequency and depth falls together with the salt meadow level. In addition, the silt content in the water reduces with the distance to the sea due to sedimentation.





Accretion data of salt meadow Niewlandsrijd.

The sediment that deposits at the measuring points on Nieuwlandsrijd is mainly fed via the Oerdersloot. The accretion on the salt meadow appears to reduce as the salt meadow level increases and the distance to the mouth of a main inlet and the distance to the main inlet increases. Since September 1991, for instance, the total accretion appears to be highest at point III-1, near the mouth of the Oerdersloot (153 mm). The total accretion at point III-7, which is of the same altitude and at a larger distance from the mouth along the Oerdersloot, amounted to 94 mm. The accretion at point III-4, of a lower altitude and at some distance from the Oerdersloot near point III-1, amounted to 103 mm. Since September 1991, the total accretion at points III-21 and III-23, which are located far away from the Wadden Sea, very near the Kooioerdstuifdijk and relatively high, amounted to only 28 mm and 3 mm respectively. Thus here too, accretion makes an important contribution towards compensating soil subsidence on the low salt meadow. This decreases as the distance to the Wadden Sea and the main inlets decreases and as the salt meadow level increases.

At a later stage of the monitoring process, Alterra started to measure the sedimentation/erosion on all PQs on the salt meadows by means of the SEB method. The reason was to obtain reliable sedimentation data at each location prior to the vegetation study, to ensure a proper interpretation of the changes found in vegetation. With regard to the results, which confirm the picture described above, reference is made to the appendix of Alterra.

Dune areas

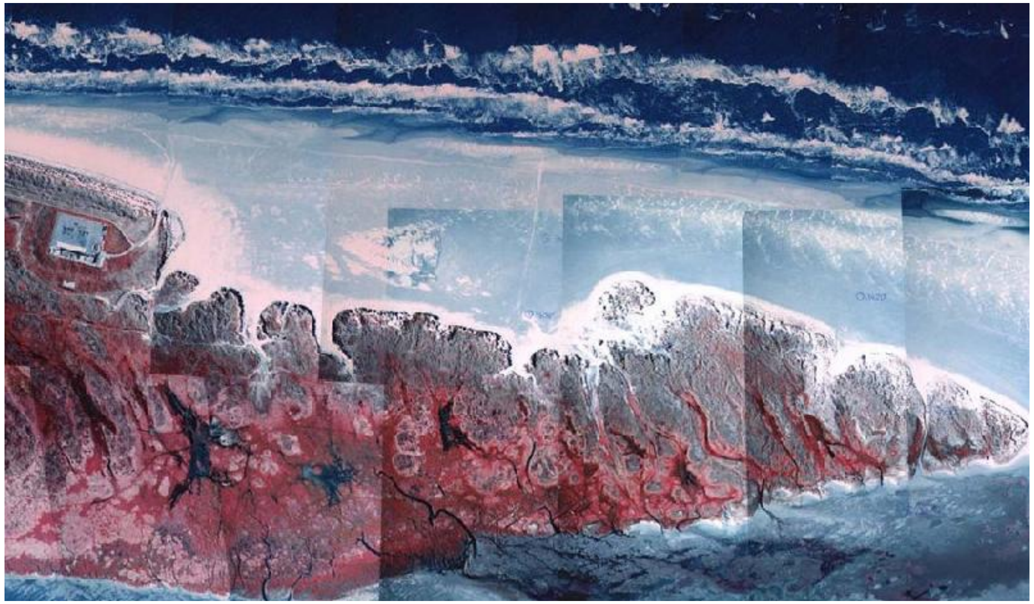
The previous report included an extensive description of the dune areas within the scope of influence of the soil subsidence basin caused by gas extraction. The conclusions of the previous report remain in full force, i.e.:

- The foredunes and the young dunes on De Hon are relatively dynamic and here the effects of soil subsidence are fully subordinate to the dynamics of nature.
- The vegetation study in the dunes focused mainly on the older, inactive dunes with strong vegetation. Here sand transportation is hardly present, so that soil subsidence caused by gas extraction will be practically equal to the ground level subsidence. Thus, in principle, the soil subsidence will lead to a permanent subsidence of the dune landscape.

The sea level gradually increases somewhat as a result of the relative rise in sea level (approx. 2 mm/year) and also the chance of wintry precipitation will sooner increase than decrease. As a result, the flooding frequency and flooding duration of low, open dune slacks will increase and low, closed dune slacks will become wetter.

Strom surge channels on De Hon

East of the NAM location, the foredunes are lower compared to those from the NAM location westwards. In addition, the foredunes on the northern side of De Hon are interrupted by storm surge channels in multiple places. They are shallow passages through the dunes with a sill in the foredunes of NAP + 2 m. As a result, sea water flows from the North Sea to the Wadden Sea during high storm surges and high tide.



Storm surge channels east of the NAM location at km direction sign 23.

Storm surge channel slightly further east near Het Baken.

This is limited to only a number of times per year and the amount of water flowing to the salt meadow via this route is thought to be limited with a view to the limited dimensions of these passages and the relatively high level of the sills. To date, the impression is that the reduction of the sills and the high beach due to soil subsidence are fully compensated by sand banking up. This impression is based on the data of the beach and the dunes from the JARKUS file and on a careful comparison of the annual photo panoramas taken on De Hon.

Up to now, now that the soil subsidence has nearly reached its anticipated maximum, signs of any scouring of these surge storm channels, leading to an increase of these channels, can still not be seen, nor is this expected for the future. There is a bigger chance of these storm surge channels becoming smaller due to sand drifting in and the foredunes closing up as part of a natural process.

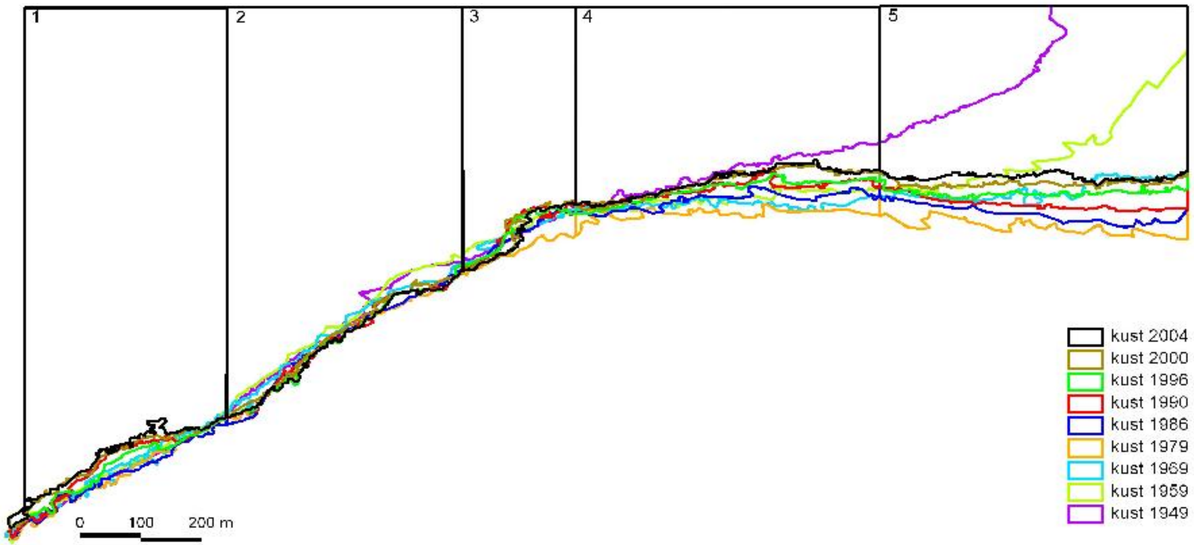
Coastal erosion of salt meadow edge

The vegetation of the coastal strip south of Het Oerd and the Oerderduinen is characterised by a large diversity in varieties and, as a result of fresh-salt gradients, unique in the composition of its varieties. The combination of halophytes and nutrient-poor grassland with carnation sedges makes the presence of Red List variations considerable. This coastal strip in particular is sensitive to erosion, consequently endangering the natural value. In order to find out whether gas extraction and soil subsidence accelerates the erosion, the accretion and erosion of the coast has been quantified by interpreting aerial photographs of the coastline for the past 55 years. Photograph comparison showed that accretion of the coast took place until around 1979. Afterwards, erosion mainly dominated. Therefore, coastal erosion started amply in advance of the start of gas extraction in 1986. The erosion speed can rise to more than 3 m per year.

Cliff edge erosion on the Westside of the coastal strip below Het Oerd, managed by the 'De Vennoot' (August 2004). Photo: R.M.A. Wegman.

The consequences for vegetation were determined by comparing vegetation surveys of permanent test areas (PQs) from 1986 with those of 1999 and 2004. This mainly indicated vegetation succession (regression). During this period, the vegetation in part of the PQs on the mudflat side eroded and in the adjacent PQs less salt-indicating plant species were found. The diversity in species is also falling. A number of vegetation zones is shifting towards the land and collapses at the toe of the dune with marram, which offers less and less room from an ecological and physical point of view.

Conclusion is that the regression of vegetation between 1986 and 2004 (in approximately half of the PQs) is caused mainly by coastal erosion and, in addition, by soil subsidence as a result of a reduction in the ground level and increased flooding. To date, the course of the coastal erosion appears to run parallel to the natural dynamics of the coast.



Behaviour of the Oerderduinen salt meadow edge 1949 -2004.

Kust Coast

Luchtfotointerpretatie kustlijn ten zuiden van de Oerderduinen, Ameland 2004

Aerial photo interpretation of the coastline south of the Oerderduinen, Ameland 2004

Metres

Salt Meadows

Based on contributions by

Kees Dijkema

Willem Molenaar

Han van Dobben

As from 1986, the effects of soil erosion caused by gas extraction on the salt meadows of East Ameland have been monitored in transects. These lines of direction are situated on the part with practically the largest soil subsidence, per salt meadow. In 2003, transect III, on Nieuwlandsrijd, subsided by 14 cm (8 mm/yr on average). In that same year, transect IX on De Hon subsided by 20 cm (12 mm/yr on average). With a view to the position, the permanent test areas (PQs) in the transects describe the maximum effects of soil subsidence.

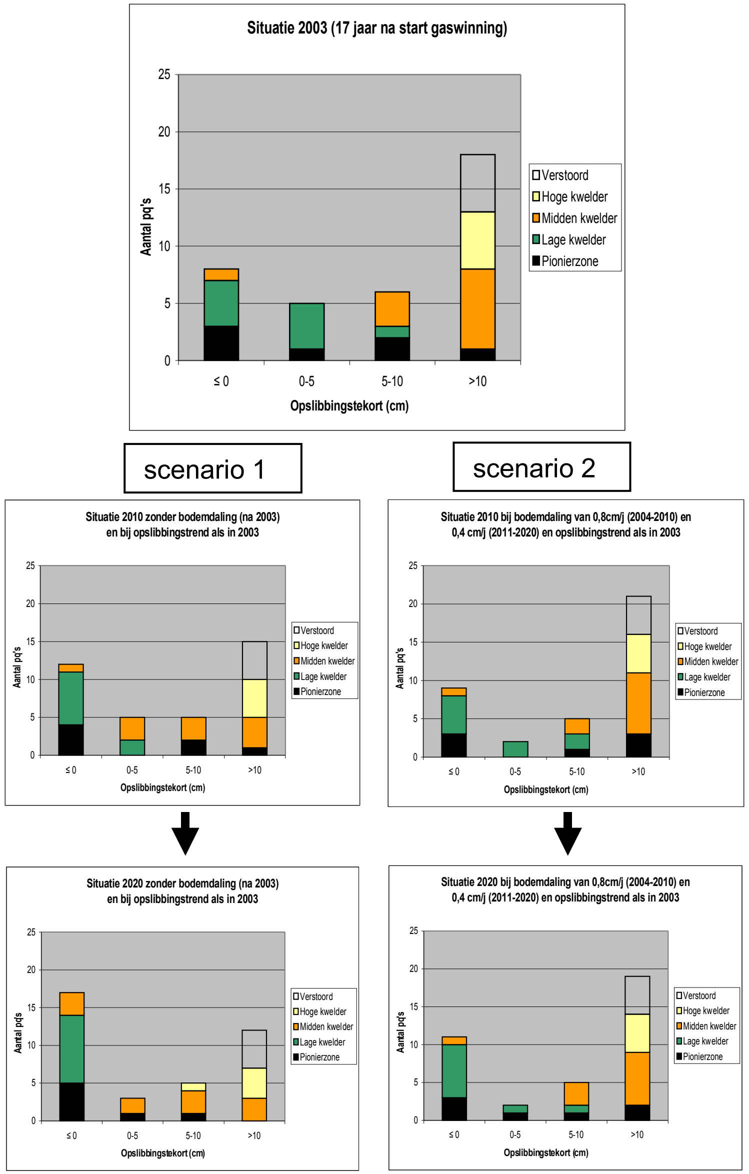
The 1987 forecast of the effects is based on the zone hypothesis: reduction in the ground level can be directly translated to a change in the salt meadow vegetation. In 1987, a considerable regression of the vegetation was forecast. **Regression** means that vegetation returns to plant species of a lower or younger salt meadow zone. In the specific case that ageing is reversed (e.g. disappearance of Elymus athericus or the recovery of vegetation that includes sea lavender, regression is called **rejuvenation**. **Succession** means that vegetation develops to plant species of a higher or older salt meadow zone. In the specific case that mono cultures of Halimione portulacoides, Elymus athericus or Coach are formed, succession is called **ageing**.

Accretion balance measured during the 1986-2003 period:

- Monitoring the contour profile across the transects shows a high level of accretion near the mudflats and at alluvial ridges near inlets (9 mm/yr on average) and a low level of accretion further away from the mudflat, in the basins and higher up the salt meadow (2 mm/yr on average). Both values are normal for islands. In the centre of salt meadow De Hon, accretion is much less than the soil subsidence. By way of comparison: accretion on onshore salt meadows is around 10-20 mm/year.
- Despite a negative accretion balance, ground level near the mudflats is subsiding, often not below the lower limit of the relevant vegetation zone on the lower parts of the salt meadow and on the high salt meadow.
- On the central salt meadow and within the group of disturbed PQs, ground level does subside below the lower limit of the relevant vegetation zone in ¾ of the cases.
- Based on the zone hypothesis and the creation balance, changes in vegetation are to be expected for PQs 9.7 and 9.8 in the central basin of De Hon.

Forecast of the effect up to 2020 on the basis of the new prognosis:

In terms of assessing the consequences of the additional soil subsidence, 2 situations can be distinguished. Scenario 1 assumes no further soil subsidence after 2003 and describes the recovery as it were up to 2020. This corresponds to a maximum soil subsidence of approx. 26 cm as originally forecast and reached in 2003. Scenario 2 describes the possible effect of a continuation of soil subsidence in accordance with the current forecast of 34 cm in 2020.



Conclusions zone approach Scenario 1 period 2003-2020:

- *De Hon: all three PQs (9.10, p.11 and 9.12) disturbed due to inlet blockages subside from vegetation zones higher up to erosion-sensitive zones.*

Conclusions zone approach Scenario 2 period 2003-2020:

- *Nieuwlandsrijd: in 2020, PQ 3.9 has subsided to the pre-low salt meadow. The PQ does not border onto mudflat or a salt meadow pool.*
- *De Hon: three PQs of the central salt meadow (9.7, 9.8 and 9.9) subside to the pre-low salt meadow due to a lack of accretion. The PQs are located centrally on De Hon. PQ 9.9 is positioned in a vulnerable location near a salt meadow pool.*
- *Disturbed PQs: PQs on Nieuwlandsrijd and De Hon disturbed due to creation of wetland habitat or crushing appear to be vulnerable and all subside to a lower vegetation zone.*

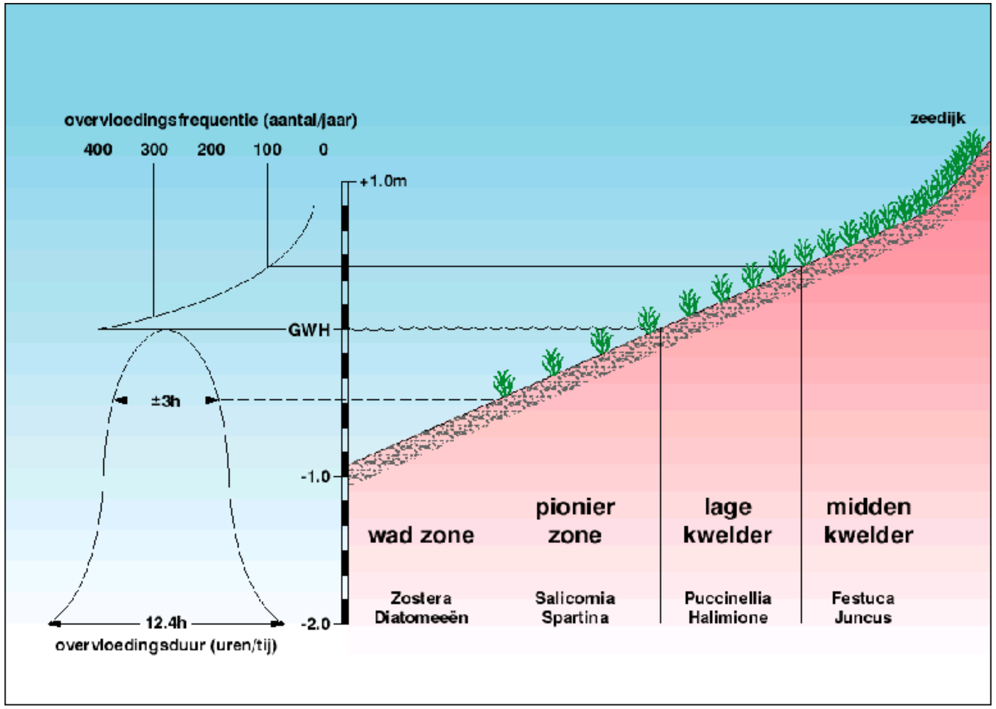
Situatie 2003 (17 jaar na start gaswinning - Situation in 2003 (17 years after the start of gas extraction activities)
Aantal pq's - Number of PQs
Opslibbingstekort (cm) - Accretion shortage (cm)
Verstoord - disturbed
Hoge kwelder - High salt meadow
Midden kwelder - Central salt meadow
Lage kwelder - Low salt meadow
Pionierzone - Pioneer zone
Situatie 2010 zonder bodemdaling (na 2003) en bij opslibbingstrend als in 2003 - Situation in 2010 without soil subsidence (after 2003) and with accretion trend as in 2003
Situatie 2010 bij bodemdaling van 0,8 cm/j (2004-2010) en 0,4 cm/j (2011-2020) en opslibbingtrend als in 2003 - Situation in 2010 with soil subsidence of 0.8 cm/yr (2004-2010) and 0.4 cm/yr (2011-2020) and accretion trend as in 2003
Situatie 2020 zonder …. - Situation in 2020 …. (as above)
Situatie 2020 bij … - Situation in 2020 ….. (as above)

Scenario results of calculations in respect of anticipated soil subsidence and accretion on salt meadows.

Since the subsidence for De Hon and the east side of the Nieuwlandsrijd is expected to be bigger than in 1987, new predictions have been made of the anticipated effects. The scenario calculations show that in the future, the focus should be on PQs 9.7 - 9.9, which are representative for the central basin of De Hon between the salt meadow edge that is subject to a great extent of accretion, and the salt meadow pools without accretion. The comparison of vegetation maps 1988-2003 of that area also points to a low salt meadow. The ground level is not much higher than the mean high water level, i.e. approx. 15 to 25 cm, which is just above the lower limit of the low salt meadow. This zone is home to a lot of Halimione portulacoides, Atriplex prostrate and, occasionally, Suaeda maritima. The vegetation looks sprightly. The entire upper section of transect IX (PQs 9.7 - 9.14) is subject to a negative accretion balance, which is set to grow in the future. Based on the zone hypothesis (which has emerged to be unreliable), the vegetation changes into that of a lower salt meadow zone. In the case of scenario 1, PQs 9.7 and 9.8 of the central salt meadow - south of the salt meadow pools - change to the pre-low salt meadow. In the case of scenario 2, PQ 9.9 also changes to the pre-low salt meadow. These PQs are vulnerable to erosion due to their location near the salt meadow pool. De Hon as a whole is not in danger, as the pools are located far from the erosion-susceptible edges (the mudflat and the North Sea). The salt meadow pool can both grow in size and connect to an inlet. In the latter case, the pool will soon be covered in vegetation of the young salt meadow, as occurred recently with a 2.5 ha salt meadow pool in the centre of the soil subsidence on De Hon. There is no reason for salt meadow erosion from the sea side as predicted in 1987.

In brief, the main future effects of soil subsidence on the salt meadow vegetation of Ameland are a slowdown of succession/ageing and possibly an expansion of the salt meadow pools in the centre of De Hon. The creation of the pools could be regarded as unwanted regression, as the area of salt meadow vegetation is affected. Another view is that the salt meadow pools form a valuable part of the salt meadow eco system. The condition is that the pools do not grow to the extent that the banks will be subjected to continued erosion caused by waves.

Nieuwlandsrijd: summary of the measurements and the prognosis until 2020	De Hon: summary of the measurements and the prognosis until 2020	Zoning and mineralisation
Based on the monitoring process so far and two hypothetical soil subsidence scenarios, no actual effects are expected for the Nieuwlandsrijd salt meadow vegetation in transect III until 2020. The succession of the vegetation will start autonomously virtually everywhere in 2004, while the changes that were predicted in 1986 have not materialised. Perhaps the vegetation succession has slowed down due to the soil subsidence, causing the salt meadow vegetation to age slower than it would without accretion. With a view to the ageing process on many salt meadows, delayed succession is seen as positive.	A pool has formed at a distance from the mudflat in transect IX on De Hon. The pool is the result of a blocked inlet. The pool is an outlet of an existing pool measuring 0.6 ha west of transect IX. The soil subsidence scenarios until 2020 predict a soil subsidence effect immediately south of this pool: in the case of scenario 1, PQs 9.7 and 9.8 of the central salt meadow will change to the pre-low salt meadow. In the case of scenario 2, PQ 9.9 also changes to the pre-low salt meadow. The salt meadow pool can both grow in size and connect to an inlet. In the latter case, the pool will soon be covered in vegetation of the young salt meadow, as occurred recently with a 2.5 ha salt meadow pool in the centre of the soil subsidence on De Hon. There is no reason for salt meadow erosion from the sea side as predicted in 1987.	In the event of normal accretion and the corresponding succession of vegetation, the salt meadow will grow in altitude and become drier, organic matter will mineralise and vegetation will age. In the East Scheldt, this process is accelerated due to falling tidal levels. The reverse also seems to be true: the possibility of soil subsidence indirectly stopping ageing (e.g. through Elymus athericus) by slowing down mineralisation in the soil. In general, the soil maturity process is regarded as irreversible, but the processes on Ameland and in the East Scheldt point to a larger role of both increasing and decreasing soil aeration.



Overvloedingsfrequentie (aantal/jaar)	flooding frequency (quantity/year)
Zeedijk	sea dike
Overvloedingsduur (uren/tij)	duration of flooding (hours/tide)

Example of zoning and inundation frequency.

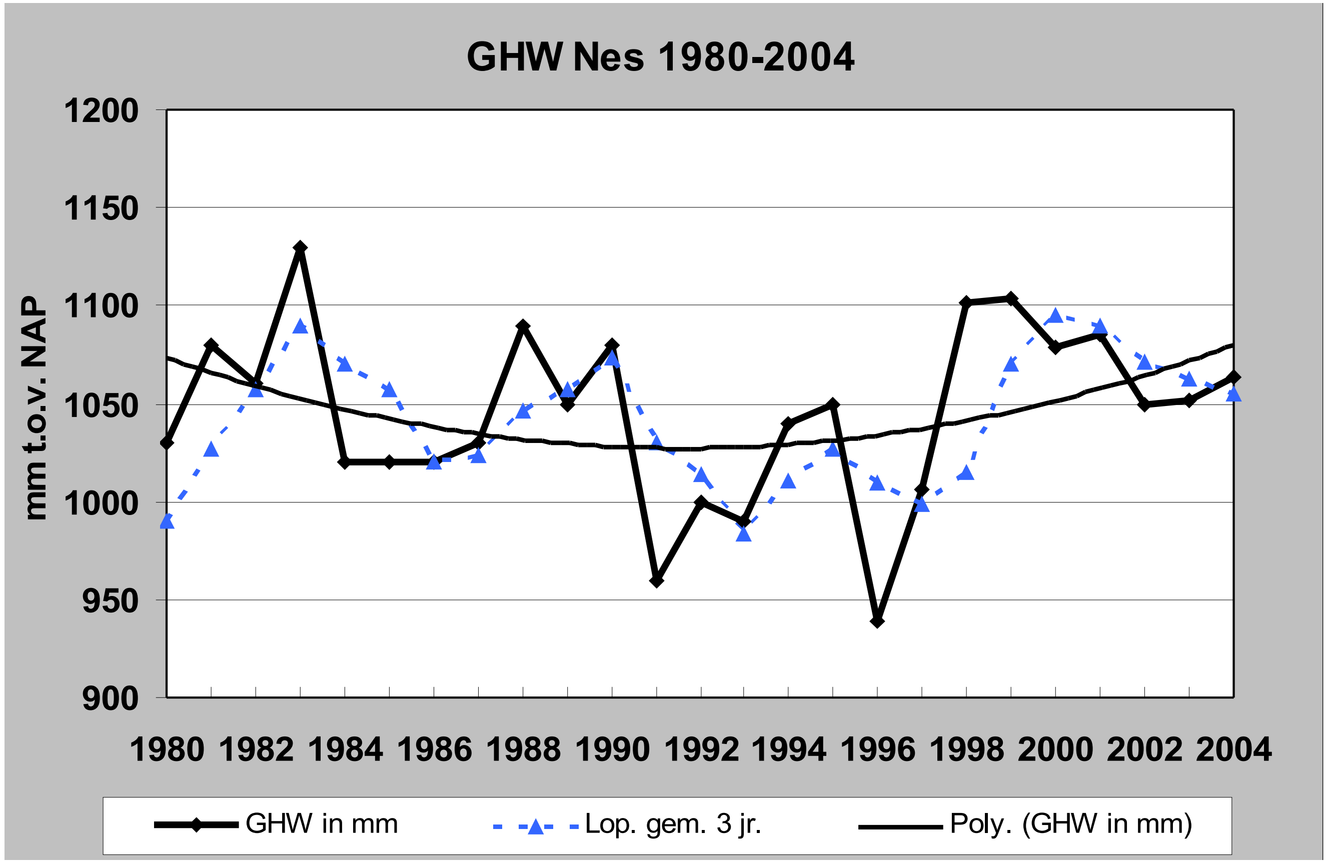
The Nieuwlandsrijd and De Hon salt meadows are experiencing developments that are similar to other island salt meadows behind sand-drift dikes (Bakker, 1997). These salt meadows are developing on a high sand flat with an altitude gradient from the mudflat to isolated low dunes. In contrast to mainland salt meadows, this gradient is not a reflection of succession - it is already present when the sand flat is created. They are "salt meadows behind artificial sand-drift dikes", characterised by a fast succession process (Westhoff et al. 1998). Due to the big age difference, both salt meadows have a simple classification of clay density. Nieuwlandsrijd is old and has a layer of clay that is relatively thick. De Hon is young and has a thin layer of clay. The salt meadow system of East Ameland can be divided into three:

- ***Nieuwlandsrijd** was formed after the sand-drift dike between the Kooi Dunes and Het Oerd was completed in **1893**; the sand flat was already covered in low dunes dating from the 1800-1880 period. In 1995, the clay density in transect III is between 50-30 cm on the mudflat side and 15-10 cm on the dune side.*
- *In **1962**, **De Hon** was nothing more than a bare sand flat; young dunes started to form along the northern edge. Here too, the construction of a sand-drift dike caused a salt meadow to develop rapidly. The sand-drift dike is not closed (anymore). In 1995, the clay density in transect IX is between 18-19 cm near an inlet on the mudflat side and 7-11 cm at the foot of the low dunes.*
- *A young salt meadow (PQs 9.1-9.5 in transect IX) can be found near transect IX, on the **mudflat side of De Hon**. During the **1986-2004** period, a young salt meadow experienced a process of virtually complete succession, from thin pioneer vegetation, Pucinellia maritima and Halimione portulacoides to Elymus athericus. The current zoning still reflects the succession process of the past 20 years. It wouldn't look better in a salt meadow manual. The thickness of the clay layer goes from 0 cm in 1995 in the pioneer zone, to 13 cm near the inlet.*

Wad zone	mudflat zone
Pionier zone	pioneer zone
Lage kwelder	low salt meadow
Midden kwelder	central salt meadow
Zostera Diatomeeën	Zostera Diatoms

Changes in flood frequency 1986-2003:

- During the 1986-1197 period, the drop in annual average high tides largely compensated the possible effects of soil subsidence on the salt meadow vegetation via a stable flood frequency.
- During the 1997-2003 period, the increase in annual average high tides enhanced the possible effects of soil subsidence on the salt meadow vegetation via an increase of the flood frequency on 60% of the PQs.



Progress of annual average high tides (mean high water level) at the Nes survey station.

GHW	mean high water level
mm t.o.v. NAP	mm compared to Amsterdam Ordnance Datum
GHW in mm	mean high water level in mm
Lop. gem. 3 jr	running average 3 yrs
Poly.	Polygon

Salt meadow vegetation measured during the 1986-2003 period:

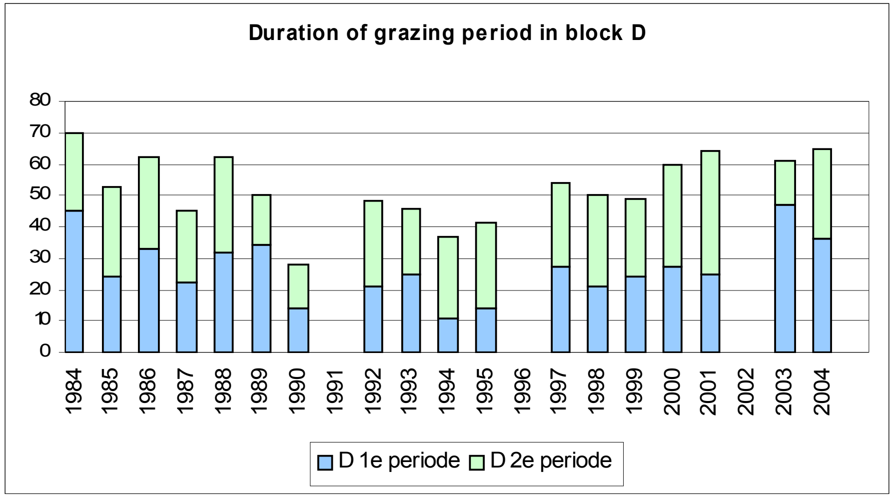
- Half of the PQs show autonomous succession, 22% of which shows ageing into climax vegetation (e.g. Elymus athericus) and 28% of all PQs shows succession from vegetation to a higher salt meadow zone (e.g. Artemisia maritima). 20% of the PQs does not change. Canoco analysis within the salt meadow zones shows significant succession/ageing (a change on the third axis).
- In two of the PQs, soil subsidence is the most likely cause of a change: 9.7 and 9.8 (periodic regression with annuals, 5% of all PQs). These PQs are located in the centre of De Hon, near a pool that has been there for decades. Near this pool, the same annuals are periodically observed. This area is subject to low levels of accretion (due to the large distance to the mudflat and inlets) and high levels of soil subsidence (near the centre of the subsidence). Ever since the soil started to subside, the PQs have been located on or below the lower limit of the central vegetation zone.
- Approximately 25% of the PQs was subject to regression/ageing of the salt meadow vegetation. The main cause of regression and/or regeneration of the salt meadow vegetation was not soil subsidence, but excessive hydration (= a reduction of aeration) as a result of a blocked inlet, or autonomous cliff erosion and crushing by cattle (10% and 15% of all PQs respectively).
- Based on a linear regression model, the salt meadow zoning process of 1986 is significantly explained by the height of the ground level. However, the zone hypothesis cannot hold as a prognosis for the effects of soil subsidence on salt meadow vegetation, since:
  1. (Zoning) can only be explained if the ground level had risen slightly (without accretion).
  2. (Succession) can largely be explained by the measured soil subsidence and accretion (the extent of the soil subsidence should actually be 5-10 times as big; the accretion figures are correct).
  3. (Ageing) can only be explained if the ground level had risen sharply (approx. 15 times the current subsidence).

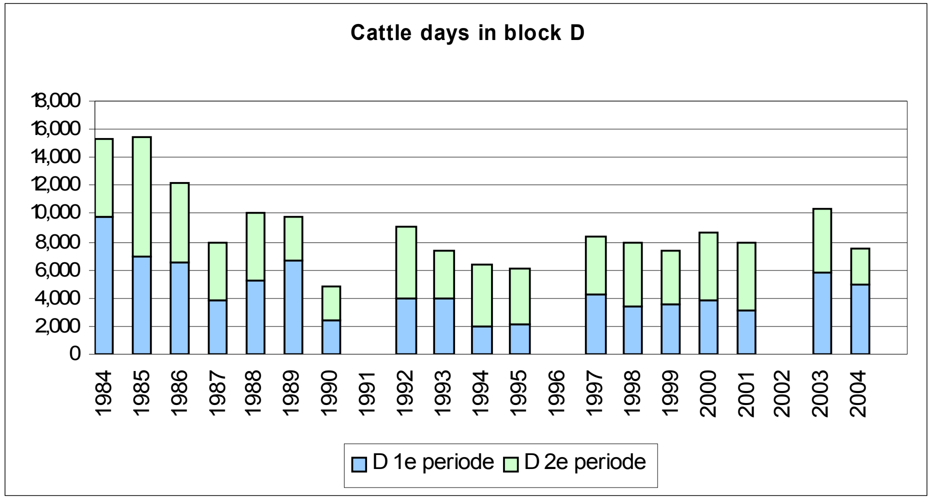
A striking example of gradual succession on Nieuwlandsrijd is the enormous increase of ***Artemisia maritima (on Ameland referred to as “flea plant”).*** *From 1986 onwards, the PQs show a gradual increase in plant height. The probably causes are less grazing by cattle and a shorter grazing period at the end of the eighties, early nineties (Molenaar, 2005). Limited succession in the PQ variety composition is a common occurrence. This can be explained as follows. Due to the “billiard cloth” grazing methods of 20 years ago, variety-led succession of the central salt meadow was obstructed. When grazing levels dropped, seedlings of Artemisia maritima appeared immediately as a result of autonomous succession. The next year, the roots of Artemisia maritima covered the entire PQ. This was also seen approximately 25 years ago, on extremely intensively grazed mainland salt meadows near Hilgenriedersiel in Germany.*

Some varieties have a varied existence. During the last few years, ***the annuals Suaeda maritima and Atriplex prostrate*** *in PQs 7 and 8 of line of direction 9 have been increasing intermittently. In 1997, Suaeda maritima was seen widely in that location, but by 1999 numbers had dropped again; the salt meadow is stable and diverse again. In 2002, Suaeda maritima is back as a result of extremely high levels of accretion during the winter on the entire Hon, followed in 2003 by Atriplex prostrate. The year 2004 sees annual rough growth of Atriplex prostrate and Suaeda maritima near these PQs, something that could be seen on all Wadden Sea salt meadows in 2004. It concerns annuals that show fast changes in response to disturbance, for instance in response to recent silt deposits or plants dying as a result of hard frost (documented on mainland salt meadows). On De Hon, the increase of the* ***clay layer thickness*** *could play a role (the intermittent appearance of the annual Suaeda maritima points to intermittent additional mineralisation).*

Comparison of vegetation maps 1988, 1993, 1997 and 2003:

- A field comparison of vegetation zones between 1988 and 2003 confirms the conclusions from the test areas (PQs) in transects:
  1. The vegetation on Nieuwlandsrijd has not changed dramatically.
  2. At the same time, De Hon shows regression as a result of soil subsidence (10 ha), ageing towards Elymus athericus (20 ha) and succession towards a new salt meadow (5 ha).
- Previous map comparisons with other salt meadows show a relative decrease of Elymus athericus on East Ameland. This could confirm our suspicions that soil subsidence slows down the ageing process towards climax plants.





1e periode	1st period
2e periode	2nd period

Zonering de Hon 1988

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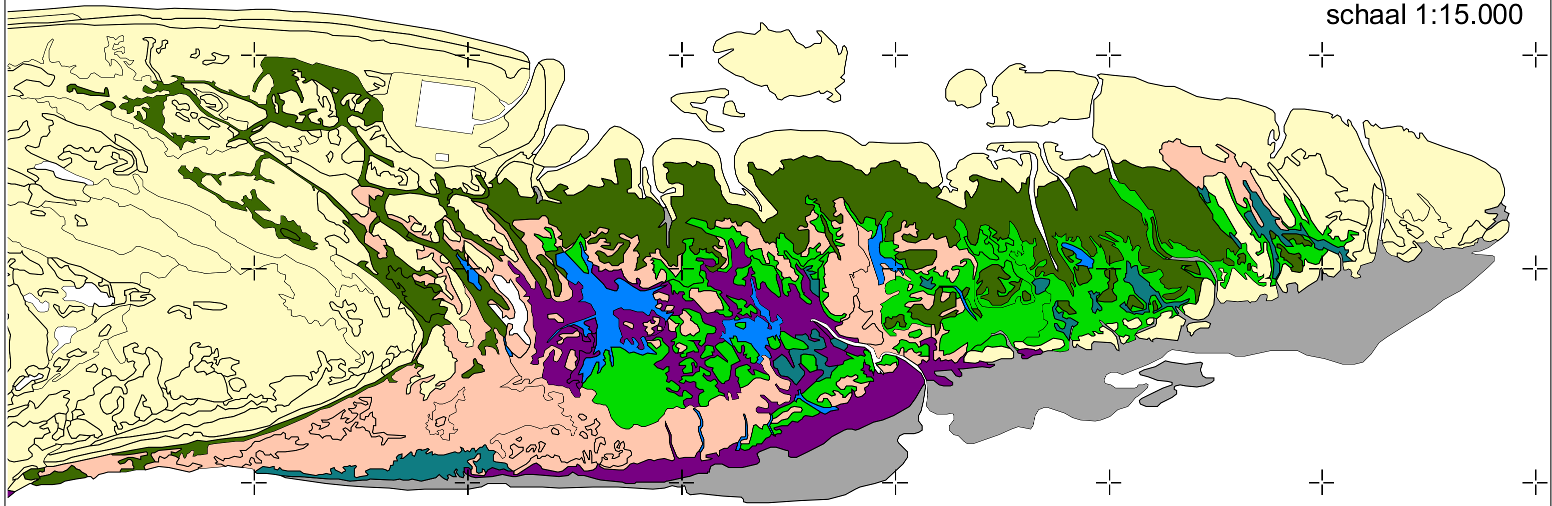

- kale zone
- pre-pionierzone
- pionierzone
- lage kwelderzone
- kwelderzone met pioniersoorten
- midden kwelderzone
- middenkwelderzone met kweek
- middenkwelderzone met R-soorten
- hoge kwelderzone
- hoge en brakke kwelderzone en zilte duinvalleien
- duinen
- water

ALTERRA

Rijkswaterstaat
Meetkundige Dienst

Zonering de Hon 2003

N

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- pre-pionierzone
- pionierzone
- lage kwelderzone
- kwelderzone met pioniersoorten
- midden kwelderzone
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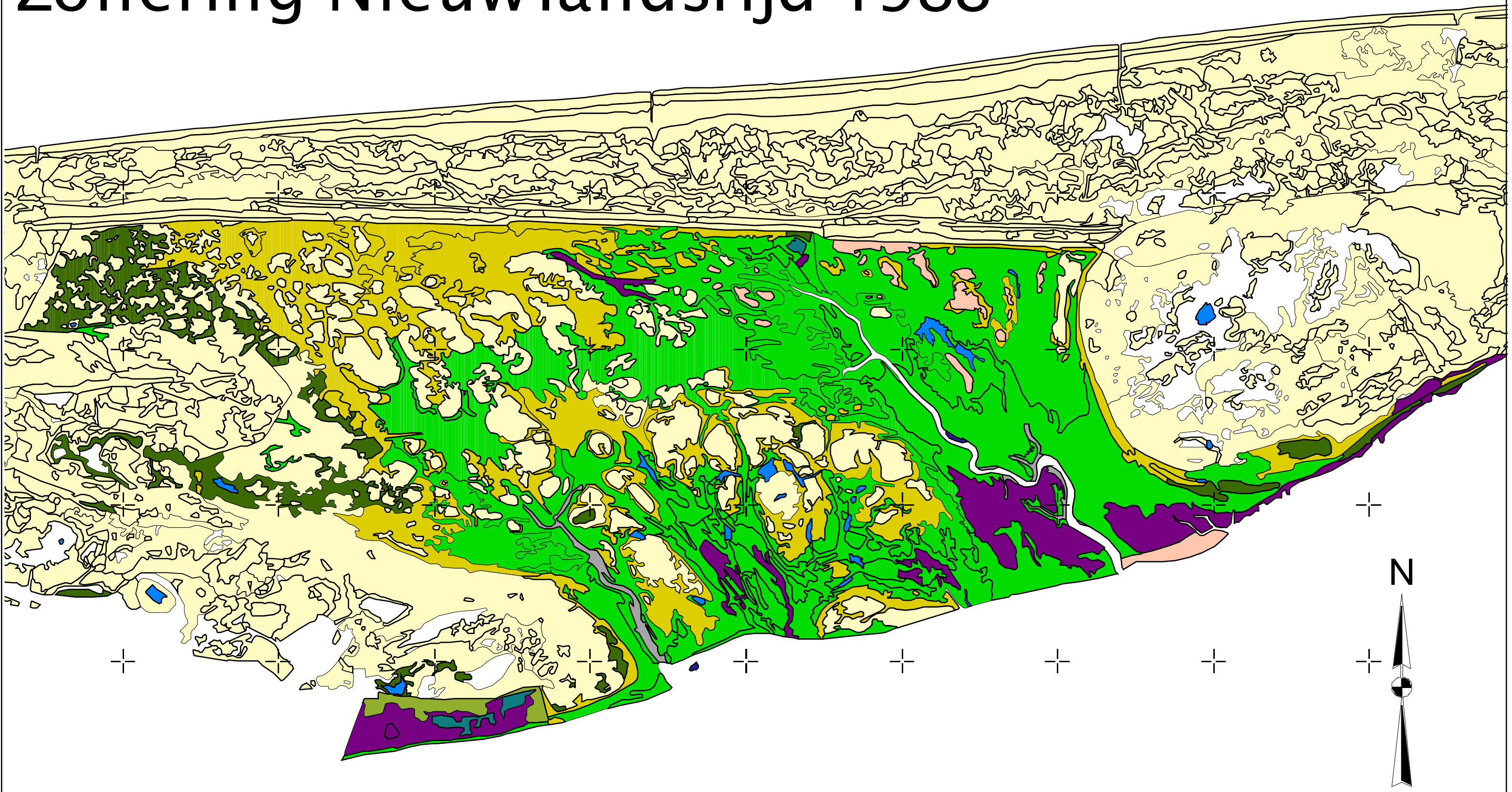
- water

ALTERRA
GREEN WORLD RESEARCH

Rijkswaterstaat
Meetkundige dienst

Zonering Nieuwlandsrijd 1988



kale zone
pre-pionierzone
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middenkwelderzone met R-soorten
hoge kwelderzone
hoge en brakke kwelderzone en zilte duinvalleien
duinen
water

ALTERRA

Rijkswaterstaat
Meetkundige Dienst

Zonering Nieuwlandsrijd 2003

N

schaal 1:20.000

pre-pionierzone	hoge kwelderzone
pionierzone	hoge en brakke kwelderzone en zilte duinvalleien
lage kwelderzone	duinen
kwelderzone met pioniersoorten	water
midden kwelderzone	
middenkwelderzone met kweek	
middenkwelderzone met R-soorten	

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GREEN WORLD RESEARCH

Rijkswaterstaat
Meetkundige dienst

Zonering De Hon 1988
Schaal

Zoning De Hon 1988
scale

Kale zone	bare zone
Pre-pionierzone	pre-pioneer zone
Pionierzone	pioneer zone
Lage kwelderzone	low salt meadow zone
Kwelderzone met pioniersoorten	salt meadow zone with pioneer species
Midden kwelderzone	central salt meadow zone
Midden kwelderzone met kweek	central salt meadow zone with growth
Midden kwelderzone met R-soorten	central salt meadow zone with R-varieties
Hoge kwelderzone	high salt meadow zone
Hoge en brakke kwelderzone en zilte duinvalleien	high and brackish salt meadow zone and brackish dune slack
Duinen	dunes
Water	water
Rijkswaterstaat Meetkundige Dienst	Directorate-General for Public Works and Water Management, Survey Dept.
Zonering De Hon 2003	***Zoning De Hon 20003***
Schaal	scale
Pre-pionierzone	pre-pioneer zone
Pionierzone	pioneer zone
Lage kwelderzone	low salt meadow zone
Kwelderzone met pioniersoorten	salt meadow zone with pioneer species
Midden kwelderzone	central salt meadow zone
Midden kwelderzone met kweek	central salt meadow zone with growth
Midden kwelderzone met R-soorten	central salt meadow zone with R-varieties
Hoge kwelderzone	high salt meadow zone
Hoge en brakke kwelderzone en zilte duinvalleien	high and brackish salt meadow zone and brackish dune slack
Duinen	dunes
Water	water
Rijkswaterstaat Meetkundige Dienst	Directorate-General for Public Works and Water Management, Survey Dept.
Zonering Nieuwlandsrijd 1988	***Zoning Nieuwlandsrijd 1988***
Schaal	scale
Kale zone	bare zone
Pre-pionierzone	pre-pioneer zone
Pionierzone	pioneer zone
Lage kwelderzone	low salt meadow zone
Kwelderzone met pioniersoorten	salt meadow zone with pioneer species
Midden kwelderzone	central salt meadow zone
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Midden kwelderzone met R-soorten	central salt meadow zone with R-varieties
Hoge kwelderzone	high salt meadow zone

Hoge en brakke kwelderzone en zilte duinvalleien	high and brackish salt meadow zone and brackish dune slack
Duinen	dunes
Water	water
Rijkswaterstaat Meetkundige Dienst	Directorate-General for Public Works and Water Management, Survey Dept.

Zonering Nieuwlandsrijd 2003	***Zoning Nieuwlandsrijd 2003***
Schaal	scale
Pre-pionierzone	pre-pioneer zone
Pionierzone	pioneer zone
Lage kwelderzone	low salt meadow zone
Kwelderzone met pioniersoorten	salt meadow zone with pioneer species
Midden kwelderzone	central salt meadow zone
Midden kwelderzone met kweek	central salt meadow zone with growth
Midden kwelderzone met R-soorten	central salt meadow zone with R-varieties
Hoge kwelderzone	high salt meadow zone
Hoge en brakke kwelderzone en zilte duinvalleien	high and brackish salt meadow zone and brackish dune slack
Duinen	dunes
Water	water
Rijkswaterstaat Meetkundige Dienst	Directorate-General for Public Works and Water Management, Survey Dept.

Maps of East Ameland salt meadows from 1986 to the present

Changes in salt meadow areas

Vegetation maps are a valuable tool to measure all changes in the salt meadow PQs. The zoning maps show the surface measurements of the vegetation zones, covering several years.

*On **Nieuwlandsrijd**, a fixed polygon of the entire salt meadow is used. The salt meadow's southern boundary with the mudflat is largely determined by the stone facing, while the northern boundary is determined by the bicycle track. The observed changes can be explained as follows:*

- *Due to the polygon used, the change of the **entire salt meadow area** can only refer to the mapped boundary with the dunes.*
- *The following have been relatively **stable** throughout the years: the pioneer zones, the low salt meadow zones, the central salt meadow zone, Elymus athericus and water.*
- *A striking element on the 2003 map is the succession in the centre of Nieuwlandsrijd, from central salt meadow towards 47 ha of **central salt meadow with (high) R-varieties**. In the evaluations of 1995 and 2002, similar changes between the dunes and the two high salt meadow zones were attributed to small changes within the compounds of vegetation varieties that make up our vegetation zones.*
- *The **areas on either side of the Oerdsloot** are another striking aspect: the four sets of maps show, alternately, low + central salt meadow (1988), low salt meadow (1993), nearly all zones (1997) and low salt meadow (2003). The changes in this bare-grazed salt meadow are subject to how pictures are interpreted.*
- *A field comparison of vegetation zones between 1988 and 2003 confirms the picture of the PQs: the vegetation on Nieuwlandsrijd has not changed dramatically.*

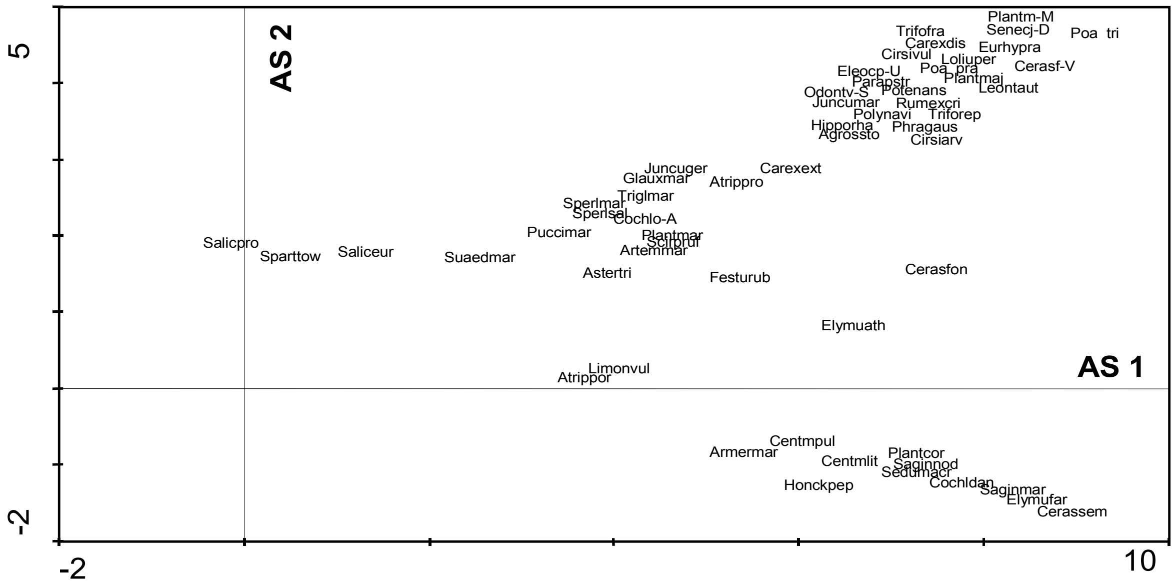
*On **De Hon**, a fixed polygon of the six southern 500x500 metre cabinets was used, thus underestimating the total salt meadow area by about a third. This was done in order to be able to properly map out any changes to the surface of the southern salt meadow with the mudflat. After all, the northern border region of the salt meadow with the dynamic dune area (which, like Nieuwlandsrijd, is difficult to map) falls outside this polygon.*
The observed changes can be explained as follows:

- *The **total area** of all zones within the polygon has **grown** by more than **15 ha**.*
- *Part of the pioneer zone along the south-east of De Hon has changed into a pre-pioneer zone.*
- *A striking aspect is the **ageing of approx. 20 ha** of central salt meadow zone towards Elymus athericus.*
- *Then there is the **regression of approx. 10 ha** central salt meadow zone towards low salt meadow zone in the centre of De Hon (and shifts within compounds of vegetation varieties). This is reasonably similar to PQs 9.7 and 9.8, and can be explained by soil subsidence and low accretion.*
- *Finally, we can see **succession towards 5 ha of new salt meadow** in the centre of De Hon, on the mudflat side.*
- *In the simplified zone maps, the **salt meadow pools** do not show up well. The map areas in question are recognisable in the original RWS-AGI set op maps of 1988-2003. In 2003, the small salt meadow pool near transect IX measures 0.6 ha and is bare. The large salt meadow pool south to south-west of the beacon on De Hon measures 2.4 ha, and the bare area decreases in 1988, 1997 and 2003 to 100%, 65% and 10% respectively.*
- *A field comparison of vegetation zones between 1988 and 2003 confirms the picture of the PQs: at the same time, De Hon shows regression as a result of soil subsidence, ageing towards Elymus athericus and succession of a new salt meadow.*

Statistical analysis of the salt meadow PQs on Ameland

The results of the monitoring process demonstrate that the vegetation of the salt meadows on East Ameland did change between 1986 and 2003, but this change can only be partially attributed to soil subsidence. There are indeed significant correlations between changes in vegetation and soil subsidence, but the extent of the regression coefficients shows that there is no or only a partial causal connection.

During the analysis, the PQs were subdivided into four groups (pioneer zone, low salt meadow, central salt meadow and high salt meadow) and the vegetation was positioned along three gradients (‘axes’). The axes can be defined as zoning (axis 1), succession (axis 2) and ageing (axis 3). The only variables that do not show a linear trend in time are the score on the first axis and the flooding frequency. Both show a minimum in 1993 and a maximum around the year 2000. That could be the cause of the effects of the sea level regime having an effect on the first axis of nearly significant. However, the regression coefficient carries the wrong symbol: the score on the first axis is low when the flooding frequency is low, i.e. it seems as if the vegetation looks more like that of the lower zones during periods of low flooding frequencies! Also, the shifts through time along the first axis are not significant, and that is why we assume this inconsistency is based on chance.



Apart from a local maximum in 2001, the scores on the second axis in the high salt meadow zone show a monotonous falling trend, which is difficult to explain. Since the second axis is positively related to grazing, a fall in grazing intensity could be an explanation. However, the grazing intensity on the Nieuwlandsrijd was virtually constant throughout the monitoring process. Also, the downward trend on the second axis seems to appear on both the Nieuwlandsrijd and De Hon (where no grazing occurs). It seems that in 2003, the vegetation of the higher sections of the Nieuwlandsrijd is very similar to that of the higher sections of De Hon in 1986. According to the analysis this change can partially, but certainly not fully, be explained by soil subsidence.

The biggest changes can be seen along the third axis. Here we see a sharply rising trend in all zones, which contradicts what we would expect when assuming soil subsidence. Since the third axis is hardly related to the measured abiotic variables and it strongly corresponds with the Ellenberg indicator for the availability of nutrients, it is obvious to explain this change as ‘succession’ or ‘ageing’. The varieties that take up extreme positions on the third axis are an indication of the changes that have taken place: varieties with low scores have decreased and those with high scores have increased. It seems that: Poa trivialis, Senecio jacobaea, Cirsium arvense, Polygonum aviculare, Elymus athericus, Lolium perenne have increased;

Cerastium semidecandrum, Sagina maritima, Elymus farctus, Cochlearia danica, Centaurium litorale and Sedum acre among others, have decreased. It seems that the open vegetation of sandy tops has decreased, while dense grassy vegetation has increased.

Both the Nature Conservation Value (NBW) and the number of varieties show a monotonous falling trend (except local maximums in NBW in 1991 and 2000). Like the study of the dunes (Van Dobben & Slim, this report) we can see a considerable loss of varieties: approx. 3.5 varieties per PQ on average. However, as noted before, the two indicators for biodiversity are related to altitude in different ways: the number of varieties is positively related to altitude, while NBW is negatively related. This means that the drop in the number of varieties can at least partly be explained by soil subsidence, but the drop in NBW cannot. When comparing the ‘courses’ of the PQs along the three DCA axes and the relation of the indicators for biodiversity to these axes, it was concluded that the change in vegetation that has led to a drop in the number of varieties and NBW mostly corresponds with the change represented by the shift along the third axis. We have already concluded that this shift cannot be related to soil subsidence. As such, it is improbable that a drop in NBW and the number of varieties is a direct result of soil subsidence. An exception is the drop in the number of varieties in zone 4, which coincides with a shift to lower values along the second axis. This change can be attributed to soil subsidence, but not entirely, as the extent of soil subsidence is too small for that.

We can conclude that, in general, the biodiversity of the salt meadows has decreased, but that this can be attributed to soil subsidence only to a small extent. The main cause of the decreasing biodiversity (i.e. coinciding with a shift to higher values on the third DCA axis) cannot be determined on the basis of the information collected for this project. The shift along the third axis can be characterised as succession /ageing. The probable causes are natural processes which may have been expedited as a result of atmospheric deposition of nitrogen. A link to soil subsidence seems unlikely, also because similar changes are seen in salt meadows elsewhere in the Netherlands, but also in the dunes. Furthermore, a link with grazing is improbable too, as the grazing burden has been virtually constant throughout the monitoring period.

Pools formed by dammed up inlet at PQs 9.10-9.12 on De Hon (March 2004)

Former salt meadow pool on De Hon, west of line of direction IX (September 2004)

Monitoring process of inundation of dune slacks

Based on contributions by

Johan Krol

Pieter Slim

Gerard Heuvelink

Harold Kuipers

Gerard Dirkse

Han van Dobbe

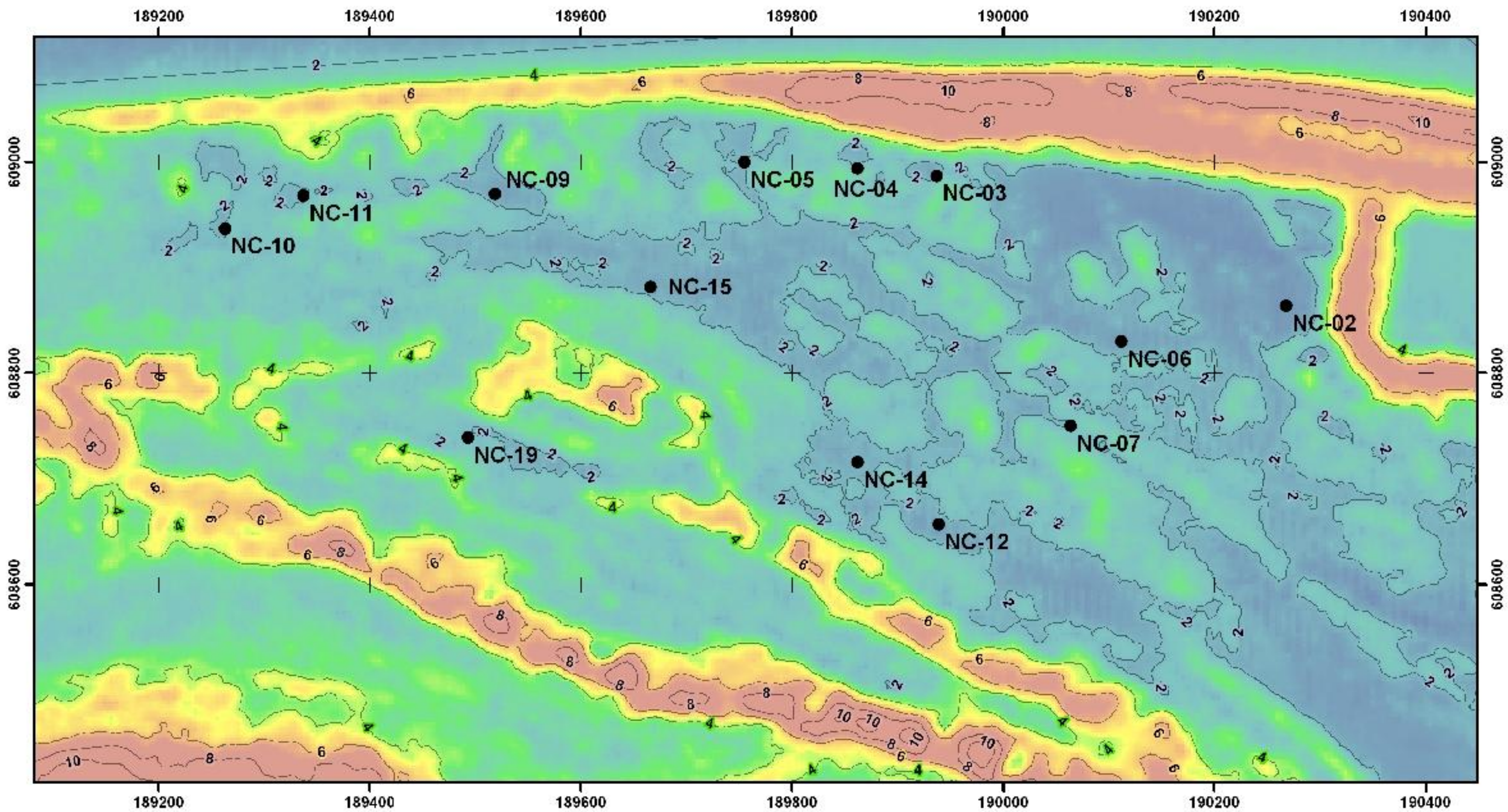
The water regime of the dune slacks in the soil subsidence area

The reason for initiating this element of the monitoring process was the death of sea buckthorn (observed in 1994) in several slacks west of the NAM extraction location, and the excessive hydration of the vegetation in these slacks, which was observed later. Trying to explain why sea buckthorns were dying as a result of changes to the flooding frequency with seawater or other changes in the water regime in the area was one of the tasks in this study. This study also serves as the start of the monitoring process of the water regime in the lowest slacks in the soil subsidence basin on Het Oerd. Flooding with seawater, precipitation, water levels and a number of water quality parameters in the slacks have been included in this programme, and this report contains details for the 2001-2002, 2002-2003 and 2003-2004 winter seasons.

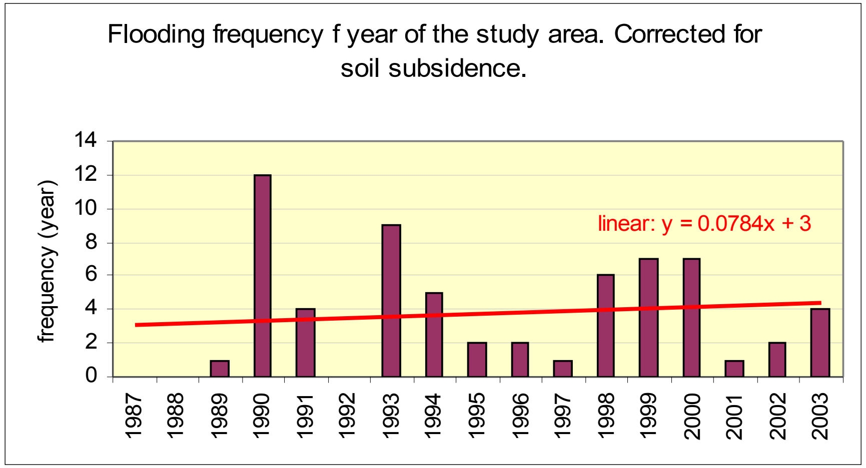
Poles were placed in 13 smaller slacks between beach post 21.6 and the NAM location (near beach post 22.6) on Het Oerd, making it possible to measure the water level above ground level. During the October-April period, the water level and a number of water quality parameters in these locations were defined.

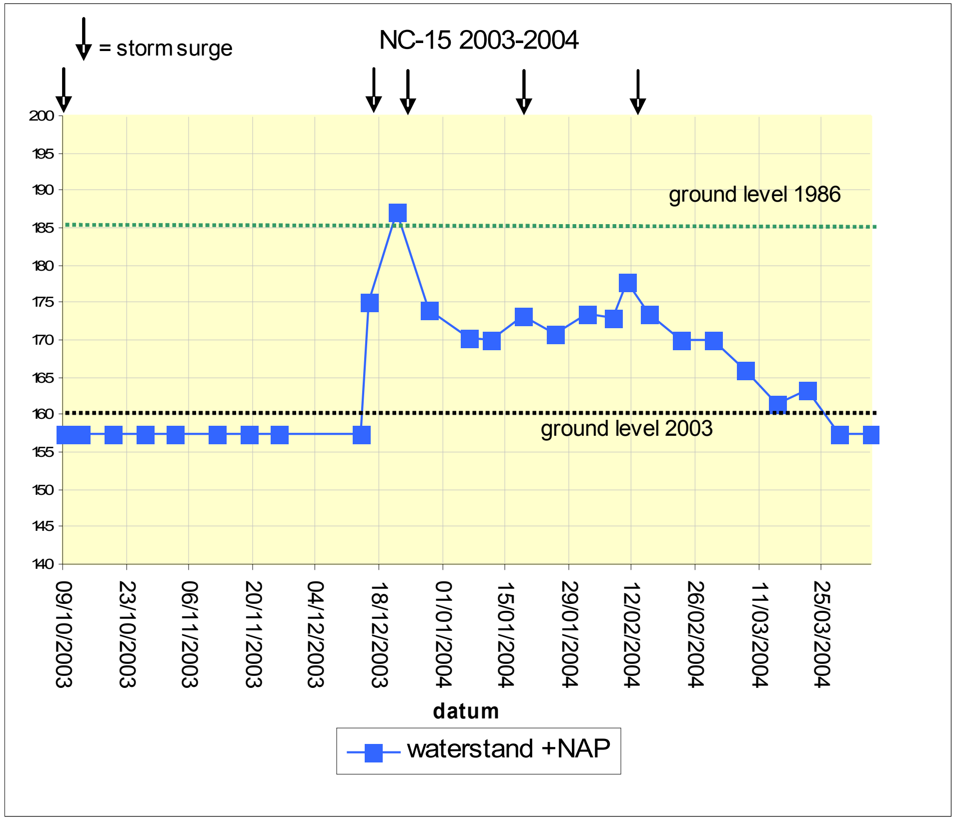
Soil subsidence measurements show that, between 1987 and 2003, all slacks have fallen by more than 25 cm on average. The slacks are located in a relatively flat area, and the ground levels of the lowest parts only vary by between 1.35 and 1.57 m above Amsterdam Ordnance Datum (measurement of 2001). During this study period, the soil appears to be raised as a result of drifting beach sand and soil formation by vegetation. During the 2002-2004 period, this raising amounted to an average of 2.6 cm.

The strong rise in flooding frequency, predicted in earlier reports, as a result of soil subsidence has not materialised. Even if we fully take into account the annual changes to sill heights caused by soil subsidence, the flooding frequency trend only increases from 3 to 4 annually. The prognosis was a rise from 4 to 20 annual floods, and a soil subsidence of 27 cm. Furthermore, salt levels in the groundwater had not structurally changed between 1991 and 2004. Some observation wells show a slight rise over the years, and others even show a slight drop. The groundwater was brackish as early as 1992, and it still is.



Relief map of the slacks in the research area, showing the locations and codes of the measuring points.



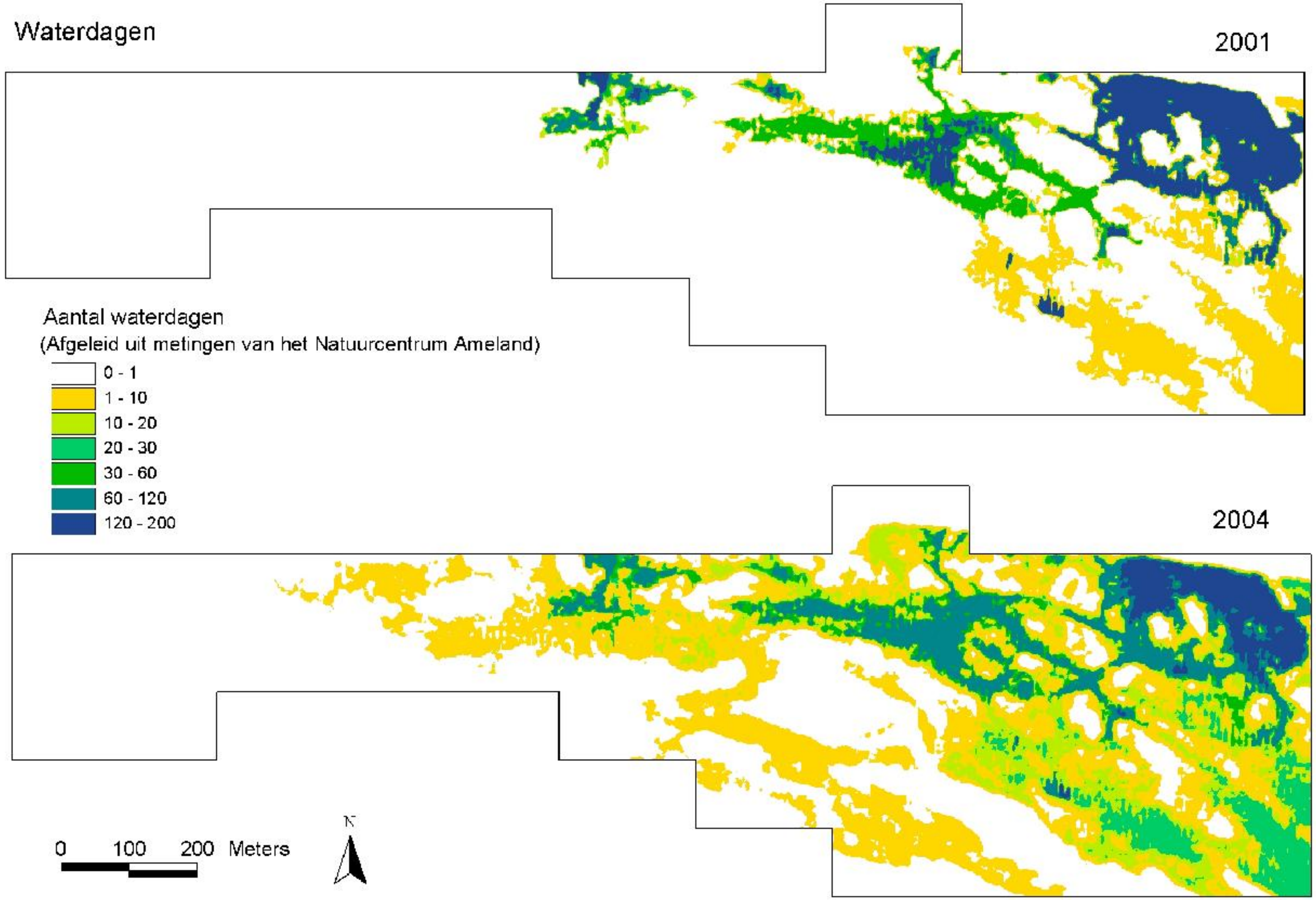


The annual flooding frequency of the lowest slacks as derived from the water levels at the Wierumer site for the 1987-2003 period. All flooding events have been corrected for soil subsidence up to 27 cm in 2003.

Ground level simulation for 1986 in a chart of water levels near measuring point NC15 during the 2003-2004 winter season.

Waterstand +NAP water level above Amsterdam Ordnance Datum

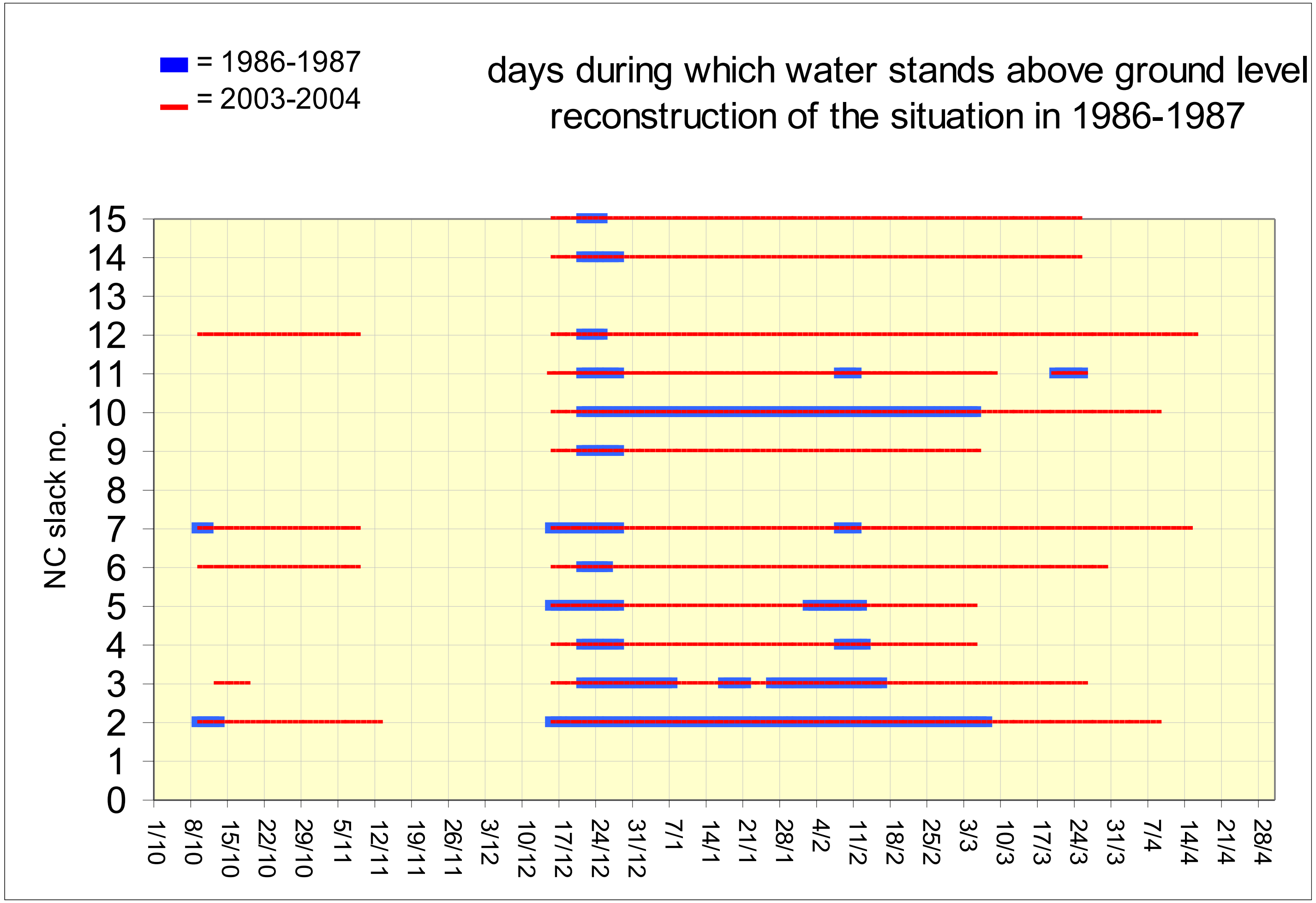
Still, after soil subsidence these slacks seem to be flooded during the winter for longer periods of time than they used to, i.e. 3 - 4 months per year. This is a combined result of incoming seawater and precipitation. The groundwater levels in this area have risen due to soil subsidence, as a result of which it takes longer for the ground level to dry out again, particularly after having been flooded with seawater. This is the most important change in the area observed during this study, which also had and still has consequences for local nature. The death of sea buckthorns on the slack floors, observed in 1994, is an example thereof, but it also explains why the sea buckthorn re-established itself on the top edges of the slacks.



The number of "water days" is a determining factor for the development of vegetation varieties. The maps alongside were developed by Alterra in cooperation with the Nature Centre Ameland, and serve as a basis for the vegetation study.

In order to see the development in perspective, please recalculate according to the 1987 situation.

Waterdagen	Water days
Aantal waterdagen	Number of water days
(Afgeleid uit metingen van het Natuurcentrum Ameland)	(Derived from measurements carried out by the Nature Centre Ameland)
Meters	Metres



Reconstruction of inundation duration in 1986-1987 as a result of a correction of the soil subsidence of 2003 by 27 cm. It now becomes apparent to what extent the inundation time has changed in different slacks. The change in water regime is of vital importance for continued vegetation development.

Monitoring and mapping of dune slack vegetation

In 1995 it was established that many sea buckthorn bushes were dying across a large area in a number of young dune slacks. Furthermore, 1994 also saw the death of elderberry and hawthorn bushes in two small isolated slacks in the Oerderduinen. It has been demonstrated that the death of sea buckthorn was caused by extremely high floods from the Wadden Sea during the 1989-1992 period. The elderberry and hawthorn bushes died because groundwater levels far exceeded the ground level during an extremely wet 1993-1994 period, caused by precipitation. That is why it has been concluded that in the dynamic East Ameland area, the effect of soil subsidence on vegetation was highly subsidiary to the disturbance that is intrinsic to the ‘natural dynamics’ (storms, precipitation).

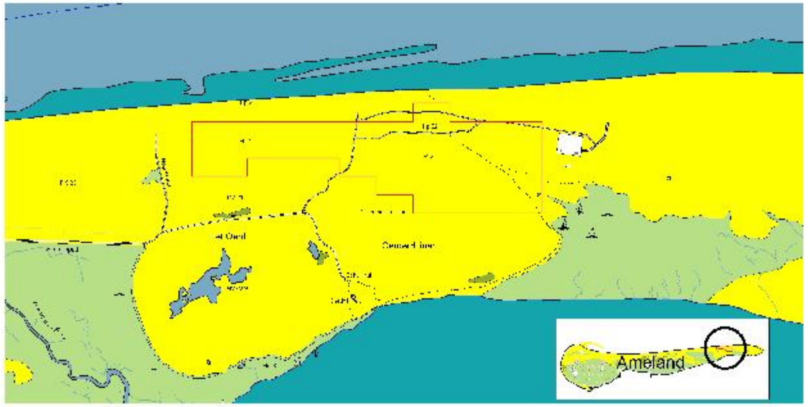
During the interim evaluation of the monitoring study in 2000, the Supervisory Committee Monitoring Soil Subsidence Ameland decided to monitor the dune slacks more intensively, partly on the basis of the audit carried out by the University of Groningen. The area of dying sea buckthorns measured approx. 25 ha, but the area subject to comprehensive monitoring measures 70 ha. During this study, the changes in vegetation are studied on the basis of local information and field mapping.

Monitoring of vegetation

The vegetation was monitored by using a new, improved method. Both in 2001 and 2004, vegetation surveys were carried out in 70 locations in order to describe the (changes in) vegetation. This local information (test areas or PQs of 4 m^2) in a density of 1 survey/ha not only comprises the vegetation survey itself, but also location, altitude, exposure, soil, moisture, presence of rabbits, etc. Another 70 measurement locations were added in 2004 (see Geo-statistical mapping). All survey points were plotted out extremely carefully in a statistically responsible manner, using modern geodetic equipment.

Cluster analysis-led automated classification of all vegetation surveys led to a local vegetation typology which ties in well with the national reference system. For the sake of field mapping, the typology has been reduced to four types that are relevant to mapping, while any mutual changes can be ecologically interpreted well in relation to soil subsidence. In the cluster analysis, 10 out of the same 70 PQs studied in 2001 and 2004 end up in a different vegetation variety and as such have changed. A number of PQs of one variety changed into the other and vice versa. Some PQs of the ‘Rough and bushy dunes’ developed into ‘Grassy dunes’, and one PQ became more brackish.
In a more integrated, multi-variation analysis of the surveys of the 70 same PQs from 2001 and 2004, the variety plot of the surveys shows that the varieties defined for mapping are clearly recognisable, and have ecological relevance. The plot with environmental variables clarifies this significance; the most important are moisture, Y-coordinate, salt content, X-coordinate and calcium content. The plot with the average sample scores per vegetation variety in 2001 and 2004 shows that the shift in time is relatively small compared to the distance between the varieties. No obvious trend can be observed in the shift between 2001 and 2004. Only the ‘Rough and bushy dunes’ shift somewhat between 2001 and 2004 towards ‘Wet, brackish slacks’.

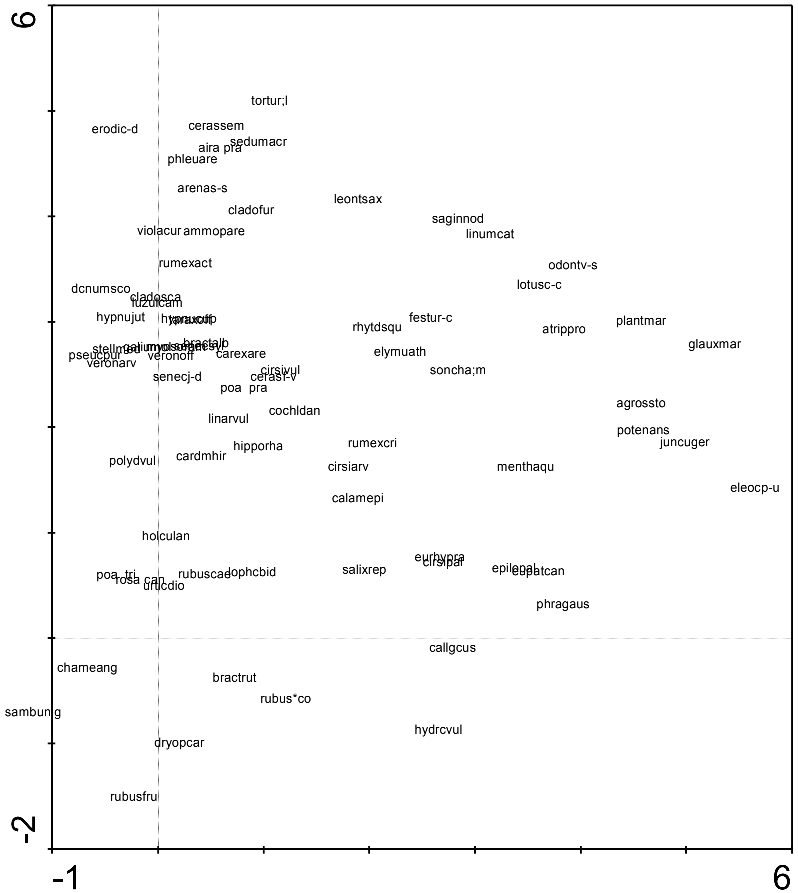
Both isolated slacks with dying elderberry and hawthorn bushes have not been re-inundated since 1993-94. The elderberry is starting to sprout again in places and turns out not to be dead everywhere. Also, elderberry and hawthorn are re-establishing themselves. The vegetation has not changed dramatically, but it is getting rougher. The conclusion is that on this scale, no major changes have occurred since then.



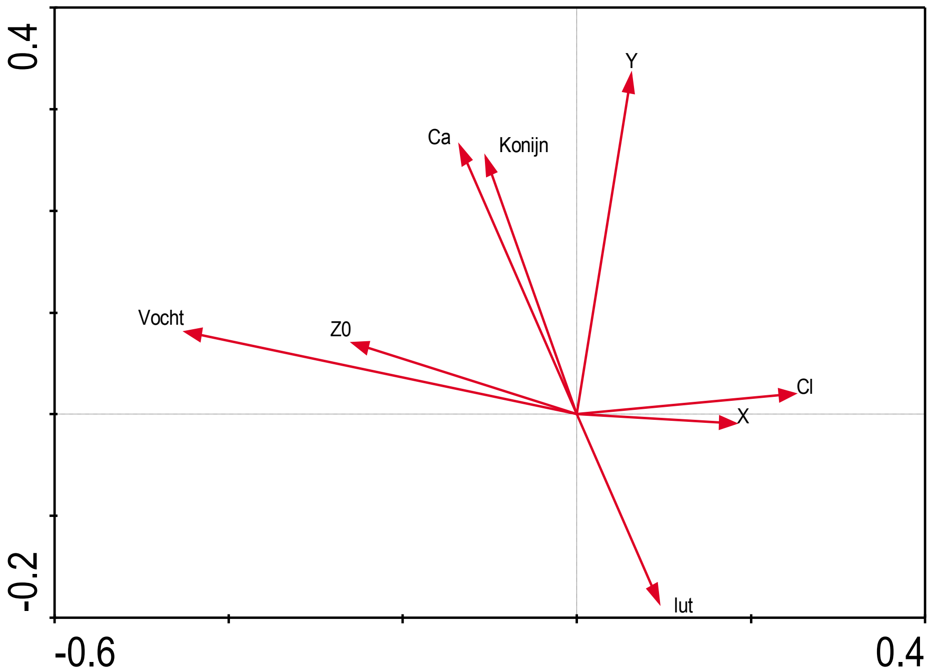
Location of the study area on East Ameland. The North Sea lies to the north, the NAM location to the north-east: the funnel-shaped dune slack is open on the south-east side, allowing high tides from the Wadden Sea to enter.

Type	***Local typology***	***Vegetation of the Netherlands***
A	Bare dune toe	Agropyro-Honckenyion peploidis
B11, **B12** **B21,** **B22**	Wet, brackish slacks Wet, brackish slacks (drier)	Lolio-Potentillion anserinae Armerion maritimae Saginion maritimae
C1 **C2**	Rough and bushy dunes Rough and bushy dunes (wetter)	Salicion cinereae Berberidion vulgaris and other bushes and rough growth
D	Marram dunes on the sea side	Ammophilion arenariae *RG Ammophila arenaria-Carex arenaria-[Ammophiletea/Koelerio-Corynephoretea]* Tortulo-Koelerion Polygalo-Koelerion
E	Grassy dunes	Tortulo-Koelerion Polygalo-Koelerion *RG Calamagrostis epigejos-[Cladonio-Koelerietalia]* Berberidion vulgaris

Local vegetation typology determined on the basis of cluster analysis of all surveys carried out in 2001 and 2004.



Multi-variation analysis with variety plot of the surveys. The 1^{st} (horizontal) axis indicates the gradient of (left) dry to (right) wet; the 2^{nd} (vertical) axis indicates the gradient of open dune (top) to rough and bushy dunes (bottom).



Multi-variation analysis with plot environmental variables. The 1^{st} (horizontal) axis shows the gradient from (left) dry, high and freshwater (‘moisture, ZO=altitude in 2001) to (right) low, wet and brackish (X=X-coordinate that indicates near distance to inflow from the Wadden Sea, Cl); the 2^{nd} (vertical) axis shows the gradient from (top) calcareous, short distance to the North Sea and rabbit grazing (Ca^+, Y-coordinate), to (bottom) clay content.

Vocht	Moisture
Konijn	Rabbit
Lut	Clay

Geo-statistical vegetation mapping

Field vegetation maps for 2001 and 2004 were subsequently prepared for the 70 ha research area in the dune slacks on East Ameland. These maps were made using the geo-statistical interpolation method known as universal indicator kriging. Universal indicator kriging is a combination of linear regression - with the presence of a vegetation variety being predicted on the basis of auxiliary information in the form of a digital altitude model and information derived from that, such as slope, exposure and flooding frequency - and a spatial interpolation from vegetation varieties determined in measuring locations (70 locations in 2001, and 140 locations in 2004). The spatial interpolation is based on the extent of spatial correlation in the vegetation varieties, which are quantified by means of a variogram and estimated on the basis of the observations.

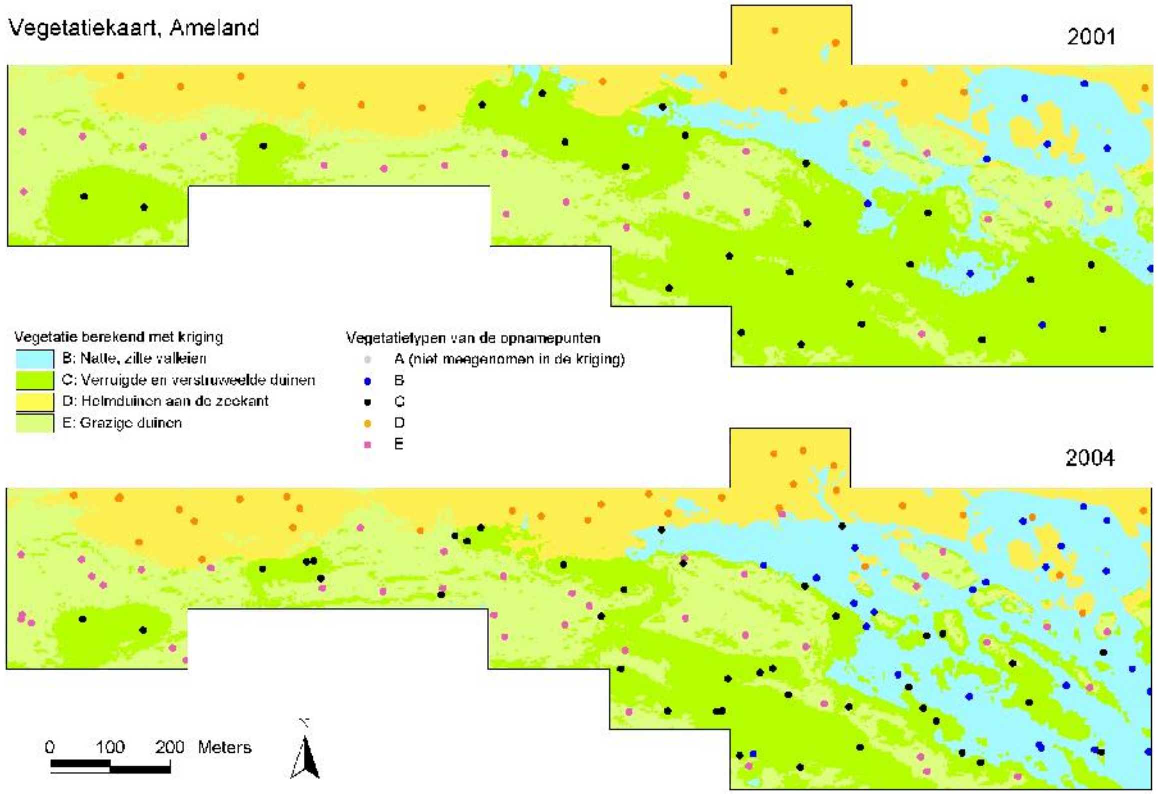
For the purposes of mapping, four vegetation varieties can be distinguished:

- Wet, brackish slacks;
- Rough and bushy dunes;
- Marram dunes on the sea side, and
- Grassy dunes.

In both resultant vegetation maps, the ‘Marram dunes on the sea side’ variety mainly occurs in the northern dunes that border onto the sea strip, and ‘Grassy dunes’ and ‘Rough and bushy dunes’ alternate in the remainder of the area. The ‘Wet, brackish slacks’ variety mainly occurs in the east corner of the area, where altitude is relatively low and the groundwater regularly sits above ground level. Also, the seawater can penetrate this part of the area in extreme weather conditions. This is demonstrated by the application of a digital altitude model of the area. The low sections that are connected to the Wadden Sea clearly are located in the south-eastern part of the site.

When comparing the two vegetation maps, ‘Rough and bushy dunes’ gradually make way for ‘Wet, brackish slacks’ between 2001 and 2004. This is also apparent from the table of vegetation variety areas for those two years. The increase of the ‘Wet, brackish slacks’ area can be explained by the observed excessive hydration in the area, which may be caused by coincidental weather influences and relative soil subsidence. The excessive hydration can be clearly seen on the ‘water days’ maps (the number of days per year that locations in that area are submerged). The maps clearly show that the regularly inundated area covers a much larger area in 2004 than it did in 2001.

Between 2001 and 2004, soil subsidence in the area was less than 3 cm. The conclusion is that this seems too little to explain the excessive hydration and change in vegetation, but due to the complex and possibly delayed influence of soil subsidence on vegetation development, we cannot be certain about this. Future monitoring may give a decisive answer on this and it may reveal whether the excessive hydration and corresponding vegetation changes in this area are coincidental or structural.



Vegetation map of the area covering the years 2001 and 2004, showing the vegetation variety in the 70 measurement locations in 2001 and the 140 measurement locations in 2004 that were the subject of vegetation surveys.

Vegetation variety	***2001***	***2004***
Brackish, wet slacks	13	24
Rough and bushy dunes	39	26
Marram dunes on the sea side	21	22
Grassy dunes	27	28

The areas of the four vegetation varieties for the years 2001 and 2004, expressed as a percentage of the total area surface.

Vegetatiekaart Ameland	Vegetation map Ameland
Vegetatie berekend met kriging	Vegetation calculated on the basis of kriging
Natte, zilte valleien	Wet, brackish slacks
Verruigde en verstruweelde duinen	Rough and bushy dunes
Helmduinen aan de zeekant	Marram dunes on the sea side
Grazige duinen	Grassy dunes
Vegetatietypen van de opname punten	Vegetation varieties at the survey points
Niet meegenomen in de kriging	Not included in the kriging

Dunes

Based on a contribution by

Han van Dobben

Pieter Slim

Dunes

In order to determine the effects of gas extraction on the vegetation of the high salt meadows and dunes on East Ameland, 56 permanent quadrates (PQs) of 2x2 m were established - before the gas extraction activities started - across the gradients from low to high and from little to extensive soil subsidence. Another 10 PQs were added in 1989. As such, all vegetation varieties present in this area in 1986 have been sampled, with the exception of the actual salt meadows that are the subject of a separate study (Dijkema, Molenaar & van Dobben, this report). The vegetation of the PQs was surveyed with three-year intervals, from 1986 until 2001. Groundwater level wells, to be surveyed each spring, have been placed near the PQs. The soil in the PQs has been sampled and analysed once, while the soil subsidence has been measured at regular intervals. Details relating to precipitation, evaporation and the sea level regime were obtained from observations at standard survey stations. It has been assumed that the main effect of gas extraction is soil subsidence, and that this soil subsidence in its turn has ecological effects as a result of a rise in the groundwater level and the flooding frequency.

Due to the large number of surveys (386) and the many varieties (276), an analysis per PQ or variety is impracticable. That is why an attempt has been made to establish a number of main areas of variation (‘gradients’) in vegetation, and to find out how the vegetation has changed in relation to these gradients. Since one important question of the study is whether soil subsidence causes a loss of biodiversity, two measurements for the changes in biodiversity through time have been determined as well.

They are (1) the ‘nature conservation value’ (an estimate of the chances of varieties being on the red list) and (2) the total number of varieties per PQ.

There seem to be three important gradients in vegetation: from wet to dry, from freshwater to brackish and from oligotrophic to eutrophic conditions. The first two gradients are shown in the ordinance diagram. Based on these gradients, the vegetation has been subdivided into six varieties: (1) shifts from salt meadow to dunes, (2) high salt meadow, (3) dune pools and their banks, (4) rough and bushy dunes, (5) dune heather, and (6) short-grass dunes. Varieties (1) and (3) in particular are valued highly by ecologists, as they are reasonably rare.

The changes through time have been determined for each variety. These changes seem to be very small compared to the interrelated differences. Furthermore, the changes are more cyclic than relative in nature. This leads us to think that the changes are, at least partially, influenced by the weather. There are two abiotic variables in the coastal environment which determine the vegetation to a great extent, and which are affected by the weather themselves: the groundwater level and flooding frequency. However, these two are also affected by soil subsidence: when the soil subsides, both the groundwater level and flooding frequency are expected to rise. These considerations have led to the following concept model:

- the changes in vegetation are a result of weather influences and soil subsidence. Both can manifest themselves through the groundwater level and flooding frequency;
- the influence of the weather on the groundwater level can be characterised by means of the net precipitation, and the influence of the weather on the flooding frequency per PQ can be characterised by means of the flooding frequency on a set altitude of 2 m above Amsterdam Ordnance Datum;

- the aforementioned influence of the weather and soil subsidence on the groundwater level and flooding frequency (and as such on the vegetation) comprises two signals: an oscillating signal (weather influence) and a monotonous (in this case linearly presupposed) signal (soil subsidence).

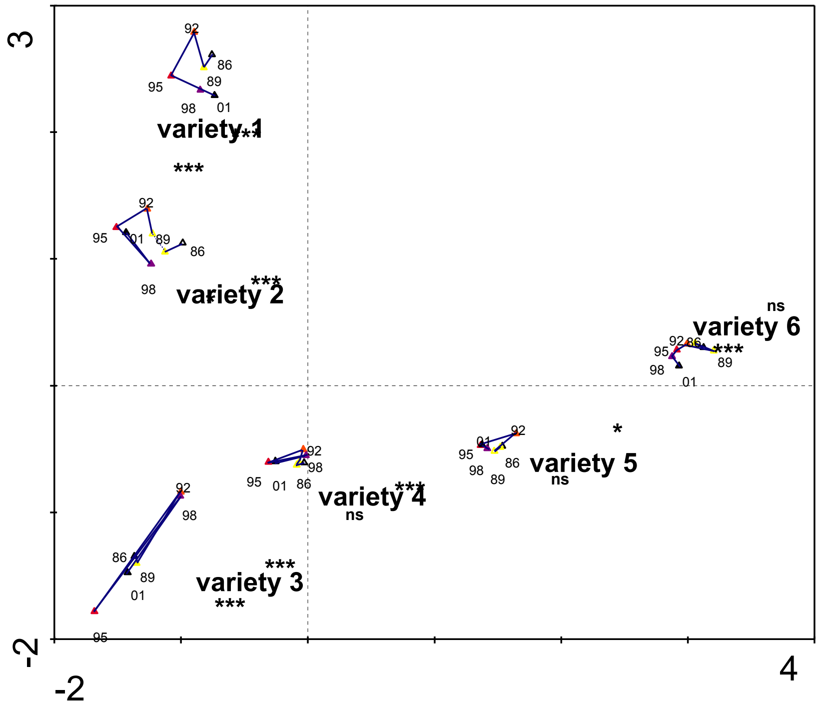
Linear regression has been used to try and separate these two signals. One must realise that in this model, each linear signal will be interpreted as an effect of soil subsidence, while other abiotic factors may also show a temporal trend. That is why it has been determined for the linear trend - with a view to its size and direction - whether it can indeed be interpreted as an effect of soil subsidence. The following concept model has been used:
- when the soil subsides by X cm in a certain location, the vegetation in that location will start to look like that of a different location which, in the original situation, already was X cm lower than that first location;
- by reversing this argument, soil subsidence can be predicted on the basis of changes to vegetation;
- by comparing this 'predicted' soil subsidence to the actual soil subsidence, it can be established whether the linear signal in the changes to vegetation can be attributed to soil subsidence.

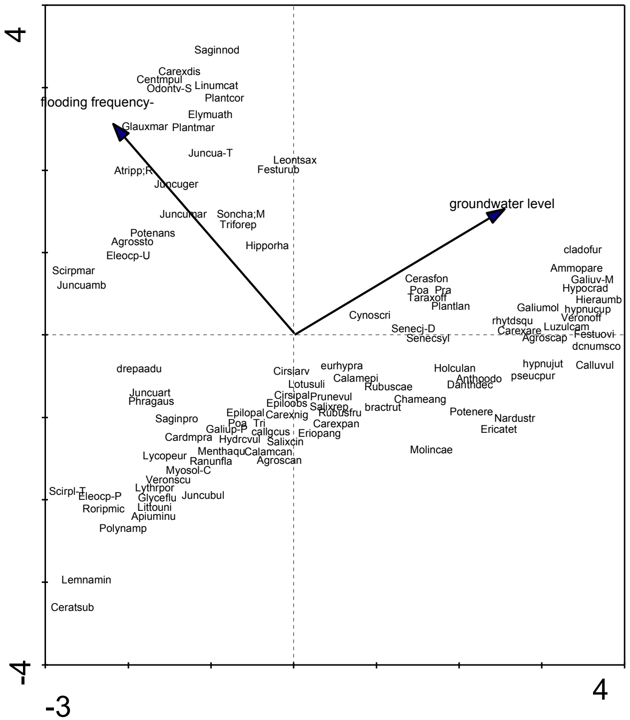
The results of the above analysis can be summarised as follows:
- the changes in vegetation along the wet-dry and the freshwater-brackish gradients can be attributed to a combination of weather influences and soil subsidence. Both have a small yet statistically significant influence on the vegetation;
- the changes in vegetation along the oligotrophic-eutrophic gradient, and the changes in biodiversity can be attributed neither to weather influences nor soil subsidence.

The biodiversity shows a slightly falling trend; this applies to both the nature conservation value and the number of varieties. This trend is most significant in the high salt meadows, which saw an average loss of 6 to7 varieties per PQ between 1986 and 2001. The fall in the number of varieties is however not significantly related to soil subsidence. The drop in the nature conservation value does have a significant relation with soil subsidence, but it cannot be the cause, as soil subsidence should lead to an increase of the nature conservation value. This is understandable when you think that soil subsidence leads to a higher flooding frequency, and as such to a more salt meadow-like vegetation that is highly valued.

The changes in biodiversity and those along the oligotrophic-eutrophic gradient seem to run remarkably parallel to each other. It is therefore believed that the loss in biodiversity is caused by the same thing as the change along the oligotrophic-eutrophic gradient, i.e. a shift towards the eutrophic side. This trend for rougher shrubs can also be seen in dunes and salt meadows elsewhere in the Netherlands. As neither groundwater nor flooding frequency play a role in the dry dunes, this is another indication that soil subsidence cannot be the cause of rougher shrubs. In order to make a solid analysis of the effects of soil subsidence it is therefore necessary for the monitoring process to also include the varieties that are not directly affected by subsidence. It is therefore not possible to establish the actual cause of rougher shrubs on the basis of the details of this study. Perhaps it mainly is the natural succession, which is accelerated by atmospheric deposition, or changes in environmental management and a fall in the number of rabbits.

The analysis shows that the weather effects do manifest themselves in the vegetation, albeit slightly delayed. This has a 'cushioning' effect on the changes: before the effect of a dry period fully manifests itself in the vegetation, that period has ended. This may also apply to soil subsidence, but since that concerns a linear change, that delay in time cannot be determined. If there is such a delay, it is possible that the vegetation will continue to respond to the subsidence for a number of years after the gas extraction activities have ended. It is therefore necessary to continue the monitoring process, possibly less frequently, until after the gas extraction and soil subsidence processes have ended.





Explanation of the abbreviated generic names: Agroscan, *Agrostis canina;* Agroscap, *Agrostis capillaris;* Agrossto, *Agrostis stolonifera;* Ammopare, *Ammophila arenaria;* Anthoodo, *Anthoxanthum odoratum;* Apiuminu, *Apium inundatum;* Atripp;R, *Atriplex prostrata var. prostrata;* bractrut, *Brachythecium rutabulum;* Calamcan, *Calamagrostis canescens;* Calamepi, *Calamagrostis epigejos;* callgcus, *Calliergonella cuspidata;* Calluvul, *Calluna vulgaris;* Cardmpra, *Cardamine pratensis;* Carexare, *Carex arenaria;* Carexdis, *Carex distans;* Carexnig, *Carex nigra;* Carexpan, *Carex panicea;* Centmpul, *Centaurium pulchellum;* Cerasfon, *Cerastium fontanum;* Ceratsub, *Ceratophyllum submersum;* Chameang, *Chamerion angustifolium;* Cirsiarv, *Cirsium arvense;* Cirsipal, *Cirsium palustre;* cladofur, *Cladonia furcata;* Cynoscri, *Cynosurus cristatus;* Danthdec, *Danthonia decumbens;* dcnumsco, *Dicranum scoparium;* drepaadu, *Drepanocladus aduncus;* Eleocp-P, *Eleocharis palustris subsp. palustris;* Eleocp-U, *Eleocharis palustris subsp. uniglumis;* Elymuath, *Elymus athericus;* Epiloobs, *Epilobium obscurum;* Epilopal, *Epilobium palustre;* Ericatet, *Erica tetralix;* Eriopang, *Eriophorum angustifolium;* eurhypra, *Eurhynchium praelongum;* Festuovi, *Festuca ovina;* Festurub, *Festuca rubra;* Galiumol, *Galium mollugo;* Galiup-E, *Galium palustre subsp. elongatum;* Galiup-P, *Galium palustre subsp. palustre;* Galiuv-M, *Galium verum subsp. maritimum;* Glauxmar, *Glaux maritima;* Glyceflu, *Glyceria fluitans;* Hieraumb, *Hieracium umbellatum;* Hipporha, *Hippophae rhamnoides;* Holculan, *Holcus lanatus;* Hydrcvul, *Hydrocotyle vulgaris;* hypnucup, *Hypnum cupressiforme;* hypnujut, *Hypnum jutlandicum;* Hypocrad, *Hypochaeris radicata;* Juncuamb, *Juncus ambiguus;* Juncuart, *Juncus articulatus;* Juncua-T, *Juncus alpinoarticulatus subsp. atricapillus;* Juncubul, *Juncus bulbosus;* Juncuger, *Juncus gerardi;* Juncumar, *Juncus maritimus;* Lemnamin, *Lemna minor;* Leontsax, *Leontodon saxatilis;* Linumcat, *Linum catharticum;* Littouni, *Littorella uniflora;* Lotusuli, *Lotus uliginosus;* Luzulcam, *Luzula campestris;* Lycopeur, *Lycopus europaeus;* Lythrpor, *Lythrum portula;* Menthaqu, *Mentha aquatica;* Molincae, *Molinia caerulea;* Myosol-C, *Myosotis laxa (subsp. cespitosa);* Nardustr, *Nardus stricta;* Odontv-S, *Odontites vernus subsp. serotinus;* Phragaus, *Phragmites australis;* Plantcor, *Plantago coronopus;* Plantlan, *Plantago lanceolata;* Plantmar, *Plantago maritima;* Poa pra, *Poa pratensis;* Poa tri, *Poa trivialis;* Polynamp, *Polygonum amphibium;* Potenans, *Potentilla anserina;* Potenere, *Potentilla erecta;* Prunevul, *Prunella vulgaris;* pseucpur, *Pseudoscleropodium purum;* Ranunfla, *Ranunculus flammula;* rhytdsqu, *Rhytidiadelphus squarrosus;* Roripmic, *Rorippa microphylla;* Rubuscae, *Rubus caesius;* Rubusfru, *Rubus fruticosus;* Saginnod, *Sagina nodosa;* Saginpro, *Sagina procumbens;* Salixcin, *Salix cinerea;* Salixrep, *Salix repens;* Scirpl-T, *Scirpus lacustris subsp. tabernaemontani;* Scirpmar, *Scirpus maritimus;* Senecj-D, *Senecio jacobaea subsp. dunensis;* Senecsyl, *Senecio sylvaticus;* Soncha;M, *Sonchus arvensis var. maritimus;* Taraxoff, *Taraxacum officinale s.l.;* Triforep, *Trifolium repens;* Veronoff, *Veronica officinalis;* Veronscu, *Veronica scutellata.*

*Gradients in the dunes and high salt meadows. The pictures must be 'superimposed' (at a similar scale, use the measurements along the edge). A rough generic composition of the varieties (and the changes thereto over the years) is given by the abbreviated generic names that lie close to each variety. The most important abiotic gradients are shown in the left picture (the groundwater level falls in line with the direction of the arrow, and the flooding frequency increases in line with the direction of the arrow). The picture on the right shows for each variety whether the shift in time is statistically significant (alongside in a horizontal direction, below in a vertical direction; ***, P<0.001; **, P<0.01; *, P<0.05; ns, P>0.05).*

Birds

Based on a contribution by

Marcel Kersten

Birds

The Ameland mudflat bird survey group has been counting high tides on a regular basis since 1972. The objective is to compare the initial numbers of mudflat birds before gas extractions started in 1986 to the current numbers of mudflat birds in the 2000-2004 period.

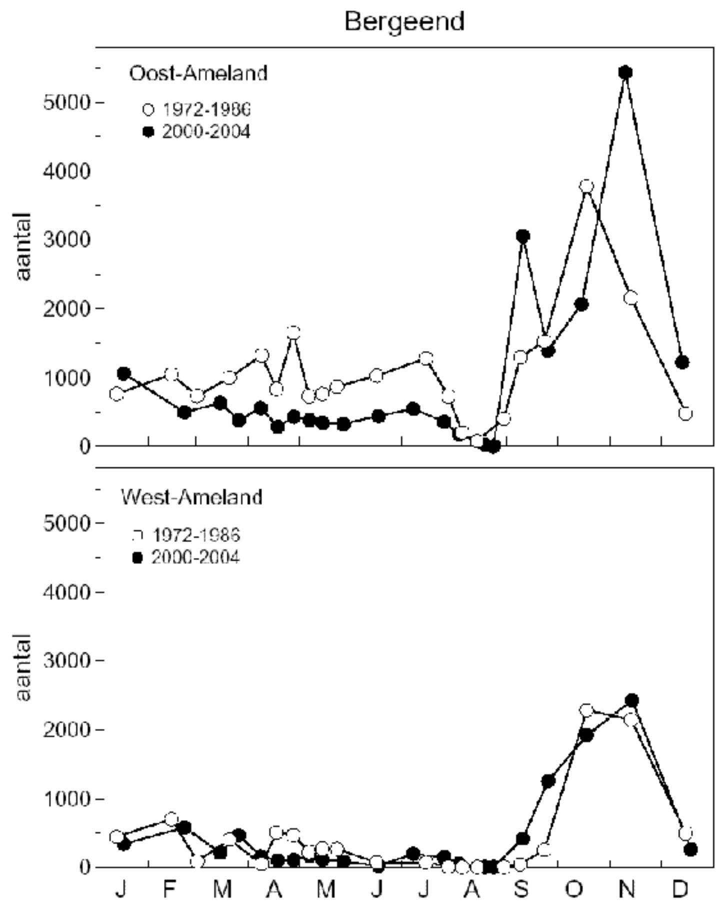
In order to be able to assess whether a possible change in the number of mudflat birds on East Ameland is linked to the soil subsidence that has occurred as a result of gas extraction, the changes to the number of mudflat birds on West Ameland are also included in the study. The soil subsidence basin is entirely located in the food area of the mudflat bird population on East Ameland and comprises about two-thirds of this food area. The food area of the mudflat birds on West Ameland lies west of the Nes ferry causeway and out of reach of the soil subsidence basin. The mudflat birds of East and West Ameland are separate populations; they do not or hardly ever come into contact with each other.

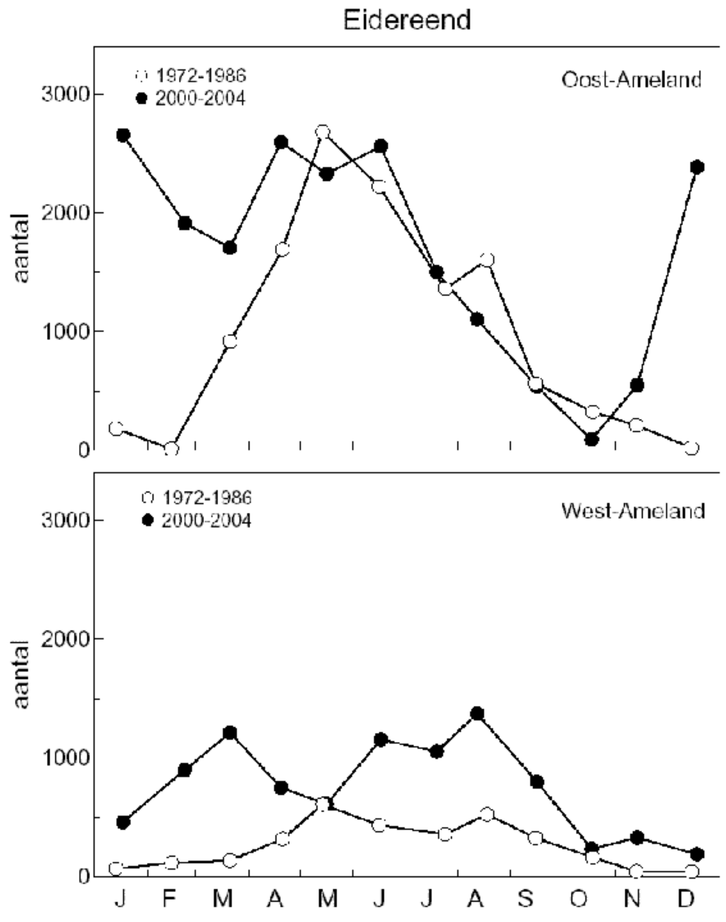
The study is confined to those bird species that are entirely or mostly dependent on shallows in the Wadden Sea that fall dry at low tide. These bird species are potentially most affected by soil subsidence, as their original food areas are accessible for shorter periods of time during low tide. Other varieties of water birds, herbivorous geese and ducks in particular, that forage in large numbers in the polders and salt meadows on the island fall outside the scope of this study. It mainly concerns 14 species, i.e.: two species of duck (eider duck and shelduck) and 12 species of waders (oystercatcher, ringed plover, grey plover, golden plover, turnstone, curlew, bar-tailed godwit, avocet, redshank, greenshank, dunlin and knot).

There are high tide safe locations in three sub-areas on East Ameland: De Hon, the Nieuwlandsrijd and the polder east of Nes. Due to disruptions and water level differences, the mudflat birds do not always use the same high tide safe locations, but regularly alternate between these sub-areas. In order to prevent exchange leading to an over or underestimation of the number of birds present, the high tide counts in the sub-areas were carried out simultaneously.

There are four sub-areas on West Ameland: the polder west of the ferry causeway near Nes up to the Balummerbocht, the polder west of the Ballumerbocht, the salt meadow outside the dike near Hollum and the Green beach north of Ballum. The latter sub-area was formed recently and has been serving as a high tide safe location for mudflat birds looking for food on the mudflat under West Ameland only since 1990. The high tide counts of the different sub-areas on West Ameland were also carried out simultaneously, usually 1 day before or 1 day after the corresponding count on East Ameland.

The changes in numbers during the winter period are analysed on the basis of the average of all counts in the November-January period.
During the traverse periods, the number of birds present varies so often, that the average yields no practicable data to determine changes between 1972-1986 and 2000-2004. The maximum number of observed birds is potentially a better figure, but it tends to be susceptible to incidents (peaks). A practical compromise is to determine the average of the three highest counts for each traverse period (max. (3)). This will reduce the effects of peaks. Apart from max. (3), the number of bird days spent is also calculated during the traverse periods. A bird day is the sum of the number of birds between the first and the last day of the traverse period.





Bergeend	shelduck
Eidereend	eider duck
Oost-Ameland	East Ameland
West-Ameland	West Ameland
Aantal	number

Changes in the number of hibernating mudflat birds on East Ameland since the start of gas extractions and soil subsidence in 1986. The average number of hibernating birds (average) and the standard error (s e) have been calculated on the basis of high tide counts during the months of November, December and January. There are 22 counts that date back to before the start of the gas extraction activities (1972-1986). There are 12 counts for the 2000-2004 period.

	1972-1986		2000-2004		change
	average	s e	average	s e	
Eider duck	159	± 42	1734	± 1008	+ 991%
Shelduck	695	± 161	1107	± 358	+ 59%
Oystercatcher	13501	± 1008	11377	± 771	– 16%
Ringed plover	-	-	-	-	-
Grey plover	203	± 31	633	± 275	+ 212%
Golden plover	195	± 57	1427	± 322	+ 632%
Turnstone	91	± 19	193	± 28	+ 112%
Curlew	3420	± 519	3670	± 474	+ 7%
Bar-tailed godwit	102	± 26	122	± 48	+ 20%
Avocet	-	-	-	-	-
Redshank	687	± 79	290	± 88	– 58%
Greenshank	-	-	-	-	-
Dunlin	2474	± 415	5773	± 956	+ 133%
Knot	67	± 34	2395	± 528	+ 3475%

Changes in numbers since 1972-1986

The increase and decline of the different species of mudflat birds since the start of the gas extraction activities (1972-1986) have been studied. The most striking result is that for most species, the number of birds stopping for food has changed much during the past two decades. Over a period of approximately 20 years, nearly half of the possible comparisons are subject to a change by more than a factor of two (halved or doubled). These changes took place both on East Ameland and West Ameland, and in both areas there have been more increases than declines.

Extent of the changes in the number of mudflat birds (and the number of bird days) during the transverse periods and during the winters on East and West Ameland since the start of the gas extraction activities on East Ameland.

change	numbers 2000-2004 compared to numbers 1972-1986	East Ameland	West Ameland
sharp decline	< – 50%	8	4
decline	–20% - –50%	4	7
remained equal	–20% - +20%	9	13
increase	+20% - +100%	17	8
sharp increase	> +100%	13	19

Soil subsidence and changes in numbers East Ameland

There has been soil subsidence on East Ameland since 1986, but nothing on West Ameland. Apart from soil subsidence, other changes have occurred in the interim period that had different consequences for East and West Ameland. The mussel beds that disappeared from the entire Wadden Sea around 1990 as a result of shellfish fishing, recovered quicker on West Ameland than on East Ameland. Hardly any new mussel beds have established to date, particularly on and east of the area where tidal currents meet. That is why those areas are still without the muddy zones around the mussel beds that are vital to various bird species.

Changes in the mudflat bird populations on East and West Ameland since the start of gas extractions in 1986

species	season	changes in percentages		changes in numbers	
		East Ameland	West Ameland	East Ameland	East Ameland corrected for changes on West Ameland
Eider duck	winter	+ 991%	+ 489%	+ 1575	+ 797
Shelduck	autumn	+ 55%	+ 3%	+ 3143	+ 2971
	winter	+ 59%	– 30%	+ 412	+ 621
Oystercatcher	winter	– 16%	– 25%	– 2124	+ 1251
Ringed plover	spring	– 58%	+ 78%	– 57	– 133
	autumn	+ 29%	+ 83%	+ 59	– 113
Grey plover	spring	+ 63%	+ 13%	+ 784	+ 623
	autumn	+ 31%	+ 101%	+ 722	– 1649
	winter	+ 212%	0%	+ 430	+ 430
Golden plover	spring	+ 741%	+ 602%	+ 8401	+ 1580
	winter	+ 632%	+ 388%	+ 1232	+ 475
Turnstone	spring	– 40%	+ 129%	– 145	– 615
	autumn	–81%	–20%	– 916	– 691
	winter	+ 112%	+ 144%	+ 102	– 29
Curlew	spring	– 26%	+ 8%	– 1528	– 1998
	winter	+ 7%	+ 158%	+ 250	– 5153
Bar-tailed godwit	spring	+ 76%	+ 131%	+ 3618	–2648
	autumn	+ 7%	+ 88%	+ 273	– 3272
	winter	+ 20%	– 69%	+ 20	+ 90
Avocet	autumn	– 74%	+ 12%	– 436	– 507
Redshank	spring	– 55%	– 71%	– 459	+ 134
	autumn	+ 15%	– 12%	+ 292	+ 530
	winter	– 58%	– 82%	– 397	+ 166
Greenshank	spring	– 23%	+ 36%	– 38	– 98
	autumn	+ 54%	– 33%	+ 335	+ 541
Dunlin	spring	+ 86%	+ 2%	+ 6485	+ 6334
	autumn	+ 9%	– 31%	+ 1765	+ 7655
	winter	+ 133%	– 49%	+ 3299	+ 4511
Knot	spring	+ 1969%	+ 480%	+ 571	+ 432
	autumn	+ 1718%	+ 546%	+ 16737	+ 11419
	winter	+ 3475%	+ 61%	+ 2328	+ 2297

The corrected changes in number on East Ameland form the best estimates of the changes in mudflat bird populations on East Ameland, which occurred at the same time as the soil subsidence. The observed effects are not univocal, but differ per species. They could be caused by the mudflat becoming less muddy or by the disappearance of the mussel beds, whether or not in combination with soil subsidence, and are discussed below.

- Species on East Ameland that have declined in numbers both in absolute terms and in comparison to West Ameland (ringed plover, turnstone, curlew and avocet). The decline of these species must be attributed to changes which only occurred on East Ameland. The ringed plover and avocet prefer a very muddy mudflat, while the turnstone and curlew often forage on and near mussel beds.
- Species whose numbers have actually increased, but the corrected number of which has declined (grey plover and bar-tailed godwit). However, the negative effect is amply compensated by positive changes that occurred at the same time.
- Species with regard to which it is unclear whether the population has increased or declined (greenshank). The number of greenshanks declined during the spring migration and increased during the autumn migration.
- Species whose numbers have actually declined, but the corrected number of which has increased (oystercatcher and redshank). The undeniable decline of these species must be attributed to changes which occurred elsewhere too.
- Species on East Ameland that have increased in numbers both in absolute terms and in comparison to West Ameland (eider duck, shelduck, golden plover, dunlin and knot). The increase of these species must be attributed to changes which only occurred on East Ameland. With the exception of the eider duck, these species avoid mussel beds and extremely muddy mudflats.

During the soil subsidence period (1986-present), changes have taken place, which have had a negative effect on four species (ringed plover, turnstone, curlew and avocet) and a positive effect on five other species (eider duck, shelduck, golden plover, dunlin and knot). The changes to the population size of the aforementioned species are probably related to changes in the soil composition. The species that have declined in numbers prefer extremely muddy mudflats or mussel beds, while four out of the five species whose numbers increased avoid this type of habitat.

Conclusions

Two-thirds of the food area of the mudflat birds on East Ameland have been subjected to soil subsidence since gas extractions started in 1986. The food area of the mudflat birds on West Ameland lies outside the soil subsidence basin. The sizes of the mudflat bird populations on both East and West Ameland have changed significantly since 1972-1986. Furthermore, both areas have seen more increases than decline.

On East Ameland, the oystercatcher, ringed plover, turnstone, curlew, avocet and redshank have declined in numbers, while the eider duck, shelduck, grey plover, golden plover, bar-tailed godwit, dunlin and knot have increased in numbers.

Some species experienced a similar change on Ameland West, where no soil subsidence has taken place. After correction for the changes on West Ameland, it also emerged that during the soil subsidence period, any changes that occurred had a negative effect on four species (ringed plover, turnstone, curlew and avocet) and a positive effect on five other species (eider duck, shelduck, golden plover, dunlin and knot). The changes to the population size of the aforementioned species on East Ameland is not caused by changes in altitude, but is rather linked to changes in the composition of the mudflat floor. The species that have declined in numbers prefer mussel beds or extremely muddy mudflats, while four out of the five species whose numbers increased avoid this type of habitat.

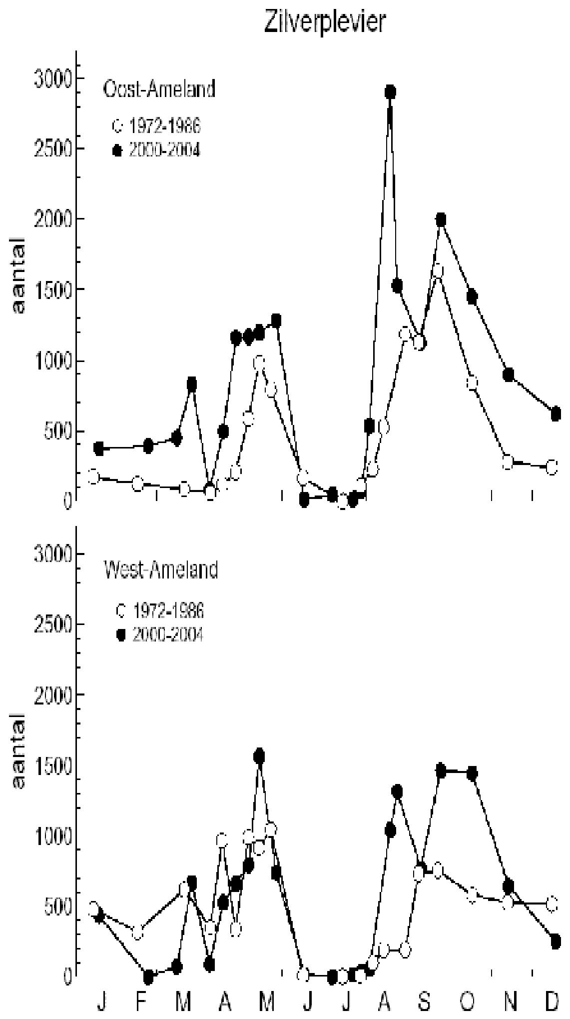
The disappearance of the mussel beds is not the result of soil subsidence, but occurred in the entire Dutch Wadden Sea. The extensive mussel bed complexes in the area near Ameland where tidal currents meet were destroyed by shellfish fishing at the end of the eighties. Along with the mussel beds, the muddy zones associated with them also disappeared.

Changes in the population size of a number of mudflat bird species on East Ameland in relation to the size of the migratory population.

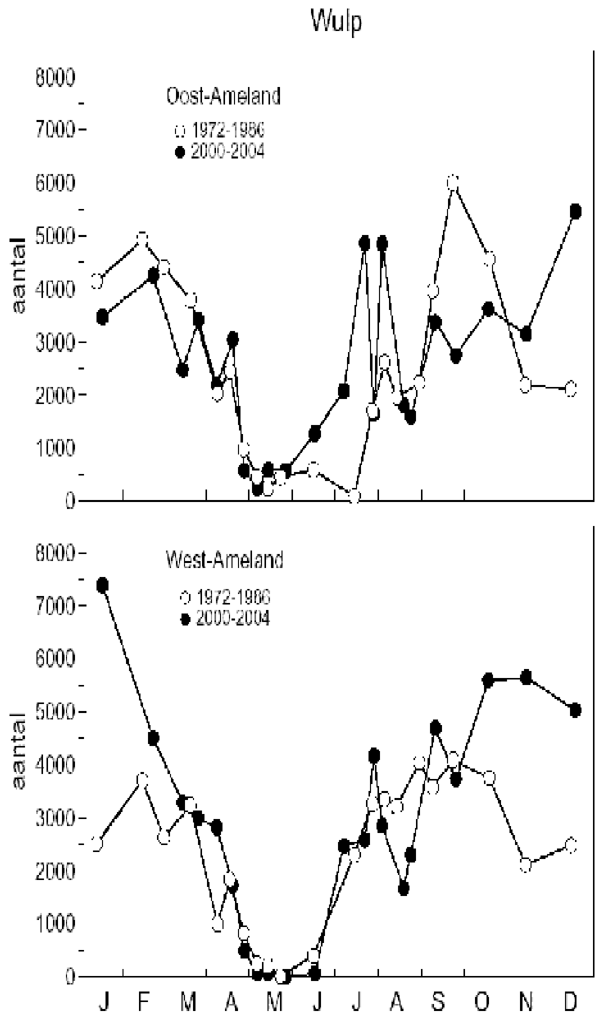
species	Population size East Atlantic migration route[1]	Corrected changes in numbers East Ameland	Fraction of the migratory population	
			decline	increase
Eider duck	1 030 000	+ 797		+ 0.00077
Shelduck	300 000	+ 2971		+ 0.00990
Ringed plover	210 000	– 133	– 0.00063	
Golden plover	800 000	+ 1580		+ 0.00198
Turnstone	100 000	– 691	– 0.00691	
Curlew	420 000	– 5153	– 0.01227	
Avocet	73 000	– 507	– 0.00695	
Dunlin	1 330 000	+ 7655		+ 0.00576
Knot	450 000	+ 11419		+ 0.02538
		som	– 0.02676	+ 0.04379

[1] Wetlands International (2002).

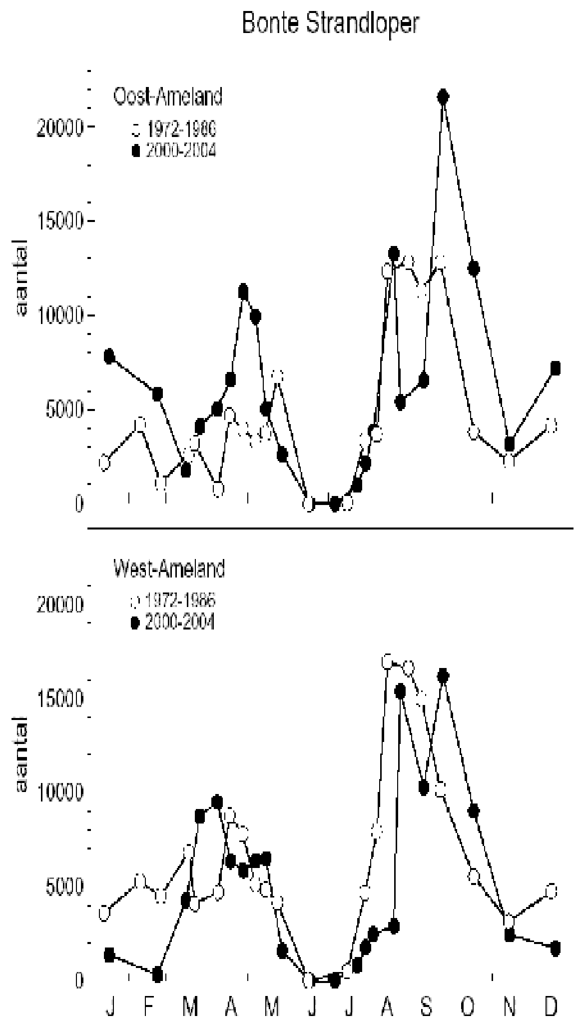
Example of a species that increases, and whose numbers are falling locally



Example of a species in decline



Example of a species that increases



Zilverplevier	grey plover	Oost-Ameland	East Ameland
Wulp	curlew	West-Ameland	West Ameland
Bonte Strandloper	dunlin		
Aantal	number		

Committee and Researchers

About the Supervisory Committee Monitoring Soil Subsidence Ameland

The first formal and reliable prognosis of soil subsidence caused by gas extraction on Ameland was made in 1985. All predictions made before that time are based on rough estimates. On the basis of that first formal prognosis, Delft Hydraulics and the National Institute for Nature Management (now known as **WL | delft hydraulics** and **Alterra**) drew up an environmental impact report. It predicted consequences for the morphology, the mudflats, the food supply for birds, erosion and regression of the salt meadow, etc. However, the structure was already in place and the licence for production had been granted.

As the manager of the area, the provincial nature organisation **It Fryske Gea** was confronted with potentially serious consequences, and it was extremely unhappy with the situation. It sent the **NAM** (Dutch oil company) a letter, asking them to accept its responsibilities and to actually determine the consequences of gas extraction by monitoring the activities.

With a view to the credibility of the setup and outcome, the NAM turned to the **Ministry of Agriculture, Nature and Food Quality** and the **Ministry of Transport, Public Works and Water Management**, with the request to form a supervisory committee. The Committee was to safeguard independence and was given the task of monitoring progress and supervising completeness and quality. The Committee was formed in 1986 and now comprises the following representatives:

Institution	***Members***
Municipality of Ameland	P. IJnsen K. Naaijer
It Fryske Gea	H. de Vries
Ministry of Agriculture, Nature and Food Quality, department for Regional Affairs - North	G. Mast
Nederlandse Aardolie Maatschappij (NAM)	J. Marquenie (secretary) S. Schoustra (2nd secretary)
Independent (National Institute for Coastal and Maritime Management)	J. de Vlas (chairman)
Province of Friesland	P. Bot W. Elberhorst
Directorate-General for Public Works and Water Management for the Northern Netherlands	A. Prakken A. Nicolai

The chairman, formerly employed at the Ministry of Agriculture, Nature and Food Quality, is currently employed at the **National Institute for Coastal and Maritime Management**, and takes part as an independent chairman. The NAM runs the secretariat. Resolutions are passed by a majority of votes and have so far been unanimous.

All members contribute their own expertise and as such add substantive value. The Committee is independent. This independence is safeguarded as follows:

- Committee members take part at their own expense and contribute their expertise. The research is paid for by the NAM, but the Committee manages and approves the research. The researchers report to the Committee.

- Progress is monitored by means of annual Committee meetings and meetings between the Committee and the Researchers. This allows for flexible anticipation in respect of new developments. The Chairman, Secretary and Committee pay regular field visits.

- A public report is released every 5 years. In 2000, the report was publicly defended in front of a forum of well-known scientists. The meeting was organised by Groningen University. Groningen University has promised to organise another technical-scientific meeting in 2005.

The procedure outlined above guarantees a high level of independence, openness and flexibility. It allows for the measuring programme to be adjusted in a transparent manner, depending on new insights.

The Committee possesses the required authority and trust and can take decisive action. So far, this has led to a responsible and efficient use of tools with a positive public response.

About the scientists who carried out the research

The initial research was led and shaped by W.D. Eysink (WL), N.M.J.A. Dankers, P.A. Slim and K. Dijkema (Alterra). Of course, many other researchers were involved over the years.

At this moment, the following institutions and key persons are involved:

Institution	Researcher	Type of data
WL | delft hydraulics	W.D. Eysink (until 2005) Z. Wang (from 2005)	Morphology Precipitation Tidal information Groundwater levels Economic aspects
Alterra	K.S. Dijkema P.A. Slim M.E. Sanders H.F. van Dobben	Salt meadows Dune slacks, dunes Remote Sensing Dunes, salt meadows
Nature Centre Ameland	J. Krol M. Kersten W. Molenaar	Dune slacks, mudflat measuring Birds, mudflat measuring Groundwater Grazing study
NAM	D. Doornhof S. Schoustra W. Veldwisch	Prognoses Data management Levelling Precipitation and groundwater levels
Directorate-General for Public Works and Water Management		Levelling supervision Soundings
It Fryske Gea		Bird counts Observation wells
The Ministry of Agriculture, Nature and Food Quality		Bird counts

Apart from these researchers, various employees made an enthusiastic and professional contribution to the results in this report. We would like to mention the NAM employees on the Ameland gas extraction location, It Fryske Gea, the Directorate-General for Public Works and Water Management and “De Vennoot”.

Notes