Monitoring effecten van bodemdaling op Ameland-Oost

evaluatie na 23 jaar gaswinning — oktober 2011

Deel 3

Begeleidingscommissie
Monitoring Bodemdaling
Ameland

Inhoudsopgave

6. Maatschappelijk gebruik

Inhoudsopgave

6.1. Inleiding

Bodemdaling op Ameland en in het aangrenzende zee- en waddengebied is een interessant fenomeen vanwege de vergelijkbaarheid van processen die optreden bij zeespiegelstijging. Het onderscheid tussen beide is met name een kwestie van schaal (beperkt bij bodemdaling zowel in ruimte als tijd) en snelheid (groter in het geval van de bodemdaling door gaswinning op Ameland). Bodemdaling is ook interessant vanwege de maatschappelijke discussie die gevoerd is en wordt rond het thema gaswinning. In het maatschappelijk debat rond gaswinning gaat de discussie vooral over mogelijke schade aan ecologische kwaliteiten en in het maatschappelijk debat over zeespiegelstijging vooral over overstromingsrisico en dijkverhoging.

Toen de NAM in 1994 haar plannen openbaarde voor een aantal proefboringen in de Waddenzee ontstond een heftig maatschappelijk debat. Het debat voerde zover dat ook een aantal putten die reeds geboord waren vanaf de vaste wal niet in productie genomen mochten worden. Over de gasproductie en de bodemdaling op Ameland was geen discussie. De intensieve monitoring door wetenschappers, de begeleidingscommissie bestaande uit deskundigen van alle betrokken instanties en de openbare rapportages werden alom gerespecteerd en gewaardeerd.

Uit een analyse die door prof. J. Swart is uitgevoerd tijdens de eerste openbare audit in 2000 bleek echter ook dat de gedegen rapportages van de bodemdalingscommissie en de betrokken onderzoekers geen rol speelden in het maatschappelijk debat over gaswinning in het waddengebied. Het maatschappelijk debat leek zich autonoom te voltrekken met een frequentie in heftigheid van eens in de 10 jaar. Professor Swart concludeerde hieruit dat de rapportage van de monitoring wel grote waardering had bij de direct betrokken deskundigen en een kring van betrokkenen rond de vertegenwoordigers in de commissie, maar het grote publiek en een brede laag van beleidsvertegenwoordigers niet bereikte. Dat was een gemis, zowel vanwege de kennis met betrekking tot gevolgen van bodemdaling op natuurlijke processen als ook die van versnelde zeespiegelstijging. Hij adviseerde dan ook aanzienlijk meer te investeren in maatschappelijke verbreiding van de resultaten van het onderzoek.

6.2. Opvolging auditadvies

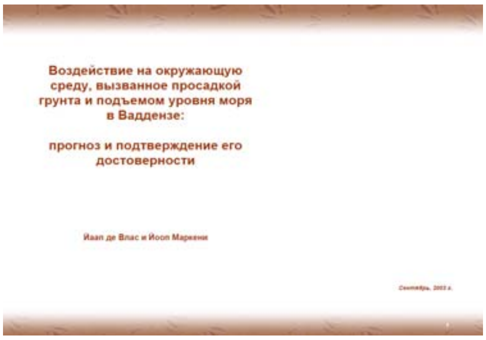
De commissie heeft op een aantal manieren gehoor gegeven aan dit advies:

1. Activeren betrokkenheid van het kennisinstituut Natuurcentrum Ameland, op Ameland

Vanaf 2000 is het Natuurcentrum Ameland actief betrokken bij de monitoring en vervult een belangrijke rol in de coördinatie van het onderzoek op het eiland. De nadruk ligt op eiland eigen aspecten waaronder de sedimentatiemetingen op het wad,, inundatieonderzoek in de duinvalleien, opnemen peilbuizen, inventarisatie van rode-lijst soorten planten, fotopanorama's, beweidingsonderzoek op het Nieuwlandsrijd en aanvullende vogeltellingen. Hiermee is niet alleen een directe verbinding ontstaan met de Amelanders, maar ook met de talrijke bezoekers van het Natuurcentrum Ameland.

2. Internationalisering door samenstellen van een algemene samenvatting in de Engelse en Russische taal, alsmede het leveren van samenvattingen van de hoofdrapporten in het Engels.

In 1999 werd door NAM een studie voltooid naar de cumulatieve effecten van bodemdaling door gaswinning in het gehele waddengebied. Deze studie werd geïntegreerd in de resultaten van de monitoring bodemdaling Ameland 1986-2000 in een handzaam boekje in de Engelse taal. Door de enthousiaste en vrijwillige inzet van 2 Russische studenten die Ameland bezochten tijdens de inmiddels opgestarte studieweekenden is een Russische vertaling tot stand gekomen. Doel was kennisoverdracht in relatie tot monitoring en bodemdaling in toendragebieden.



3. Publicatie van gegevens en deze samenvattingen via de website van Interwad www.waddenzee.nl

Een ieder die iets wil weten over de ontwikkelingen in het waddengebied begint bij de website van Interwad. Het is daarom een goed startpunt om de kennis met betrekking tot de gevolgen van bodemdaling breed toegankelijk te maken. In samenwerking met Interwad zijn 2 stappen ondernomen:

- Starten van een portal, met introductiefilmpje en alle rapporten en fotomaterialen. Dit portal is te vinden op de startpagina van Interwad en heeft een herkenbaar logo.
- Starten van een Viadeskcommunicatie om alle onderzoeksgegevens en commissieverslagen eenduidig voor de betrokken onderzoekers en commissieleden toegankelijk te maken.

4. Bijdrage leveren aan de aanstelling van 2 promovendi waarvan 1 uit Nederland en 1 uit Ethiopië.

Tijdens 2 voorgaande audits was het ontbreken van referentiegebieden in de monitoring van kwelders en duinen aan de orde gekomen. In samenwerking met de Rijksuniversiteit Groningen is gezocht naar een wijze om hiervoor een passende oplossing te vinden. Fundamenteel onderzoek leek hiervoor de aangewezen weg. Door het onderzoek niet uit te voeren als een nauw omschreven opdracht maar in wetenschappelijke vrijheid en tevens jonge mensen een kans te bieden zich te verbreden en te verdiepen werd een invulling gegeven aan een stukje maatschappelijke verantwoordelijkheid en de behoefte de gesignaleerde leemte in kennis te vullen. Over het onderzoek is in het voorliggende rapport gerapporteerd.

5. Verzorgen van lezingen en posterbijdragen op de wetenschappelijke symposia van het trilaterale Waddenzee overleg.

Op het wetenschappelijk waddensymposium te Esbjerg (april 2005) zijn door verschillende onderzoekers van de bodemdaling posters gepresenteerd en lezingen verzorgd over delen van het onderzoek. Ook is een lezing verzorgd over het geheel, waarbij de monitoring in relatie werd gebracht met versnelde zeespiegelstijging en de meest kwetsbare delen van de natuur. Het werd ondermeer geconcludeerd dat laaggelegen duinvalleien het meest gevoelig zijn en dat daarvoor geen internationaal programma bestaat. In het volgend symposium, Wilhelmshaven (maart 2009) werd een poster gepresenteerd m et het volledige overzicht van de monitoring en diverse wetenschappelijke lezingen die gezamenlijk een hele sessie vulden.

6. De introductie van studenten studieweekenden, zowel voor Nederlands hoger onderwijs als buitenlandse studenten

Sinds 2000 wordt studenten de mogelijkheid geboden tot een studie weekend op Ameland. Het programma is met name gericht op het verkennen van de ecologie door middel van lezingen en excursies. Op beperkte schaal wordt ook kennis gemaakt met de uitvoering van onderzoek. Studenten zijn afkomstig van diverse universiteiten en hogescholen en van verschillende opleidingen. Het programma wordt gesponsord door de NAM en uitgevoerd en getrokken door 2 vaste medewerkers, 1 van de NAM en 1 van het Natuurcentrum. Het programma omvat een mix van lezingen en excursies.

Figuur 6.1 *Studenten maken kennis met de natte duinvalleien van Ameland en het droogvallend wad van de Waddenzee en krijgen bruikbare informatie aangereikt over deze ecosystemen en hun relatie met bodemdaling n zeespiegelstijging.*
Students are introduced in wet dune valleys on Ameland and on tidal flats of the Wadden Sea and receive hands on experience of these ecosystems and their ecology in relation to subsidence and sea level rise

Gemiddeld werden 8-15 excursies per jaar georganiseerd bestaande uit 15-35 personen (ruim 3000 studenten). In deze jaren is specifiek een aantal keren samengewerkt met universitaire opleidingen die zich richten op buitenlandse studenten en stafmedewerkers. Met name kan genoemd worden de samenwerking met de Universiteit van Amsterdam (mastercursussen EPCEM, vooral gericht op Oost-Europese studenten) en met het Centre for Development and Innovation te Wageningen (cursus Stakeholder Participation en Analysis). Deze laatste richt zich vooral op studenten en leidinggevenden uit Azië en Afrika.

7. Organisatie van cursussen in relatie tot monitoring.

Sinds 2007 is een samenwerking aangegaan met het Van Hall instituut te Leeuwarden, waarbij het veldwerk voor de cursus Milieukunde voor deeltijdstudenten op Ameland wordt gegeven. Hierbij wordt uitvoerig onderzoek verricht in het bodemdalingsgebied onder deskundige leiding. De rapporten zijn eveneens openbaar en tot nut van de onderzoekers die de monitoring verrichten en te verkrijgen via de cursus coördinator Gerrie Koopman.
In 2010 werd als test een cursus monitoring opgezet voor studenten milieukunde van het Van Hall instituut (studievereniging Hallieu). Hierbij werden verschillende colleges gegeven gevolgd door zelfstandig uit te voeren 24-uurs metingen in de Oerdsloot. De aanpak was een succes en is in 2011 herhaald.

8. Plaatsen van de uitkomsten van het onderzoek in de context van zeespiegelstijging.

Bodemdaling in niet omdijkte gebieden kan beschouwd worden als een relatieve zeespiegelstijging. In de eerste 20 jaar van de monitoring was de bodemdalingsnelheid relatief hoog. Gedurende enkele jaren is de bodemdalingsnelheid hoger geweest dan de gemiddelde zeespiegelsnelheid in het meest ongunstige scenario (resp. 15 mm/j en 12 mm/j).. De bodemdaling op Ameland kan dan ook gezien worden als een heel groot experiment met als onderzoeksvraag: hoe reageren de wadden, kwelders en duinen als de zeespiegel plotseling snel gaat stijgen? Het antwoord is te lezen in dit rapport en houdt verband met veranderingen die optreden in kwelders en lage duinvalleien (met een open verbinding met de zee). Dat is interessant, want dit aspect is nog niet opgenomen in internationale onderzoeksprogramma's. Een en ander heeft mogelijk consequenties voor vogels die broeden in de middenkwelder omdat de opslibbing daar achterblijft. Alle andere gebieden lijken de daling goed op te kunnen vangen, mede dankzij het suppletiebeleid van de overheid. Sedimentatiemetingen op het wad met behulp van grondankers hebben in deze een redelijk nauwkeurig (mm tot cm) inzicht gegeven in de sedimentatie/erosie op de wadplaten.

6.3. Conclusies

De auditaanbeveling van professor Swart in 2000 heeft een groot gevolg gehad voor de Ameland monitoring. Het advies heeft niet alleen geleid tot een groot aantal nieuw activiteiten, maar ook de aanpak van en het denken over communicatie en omgang met de samenleving verlevendigd. Of dit ook op beleidsniveau heeft geleid tot een nieuw maatschappelijk debat over gaswinning, gestoeld op relevante kennis, kan niet zondermeer worden gesteld. Zeker is wel dat duizenden studenten uit binnen en buitenland enthousiast en inhoudelijk betrokken zijn geraakt bij de menselijke activiteiten en de monitoring in het waddengebied en het gebied zelf.

Bijlage A NIOZ-Rapport: An exploration regarding the perceiveddifference in the number of species persample between Ameland and the otherisland regions.

An exploration regarding the perceived difference in the number of species per sample between Ameland and the other island regions.

Synoptic ***I***ntertidal ***BE***nthic ***S***ampling (SIBES) Group

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NIOZ Royal Netherlands Institute for Sea Research

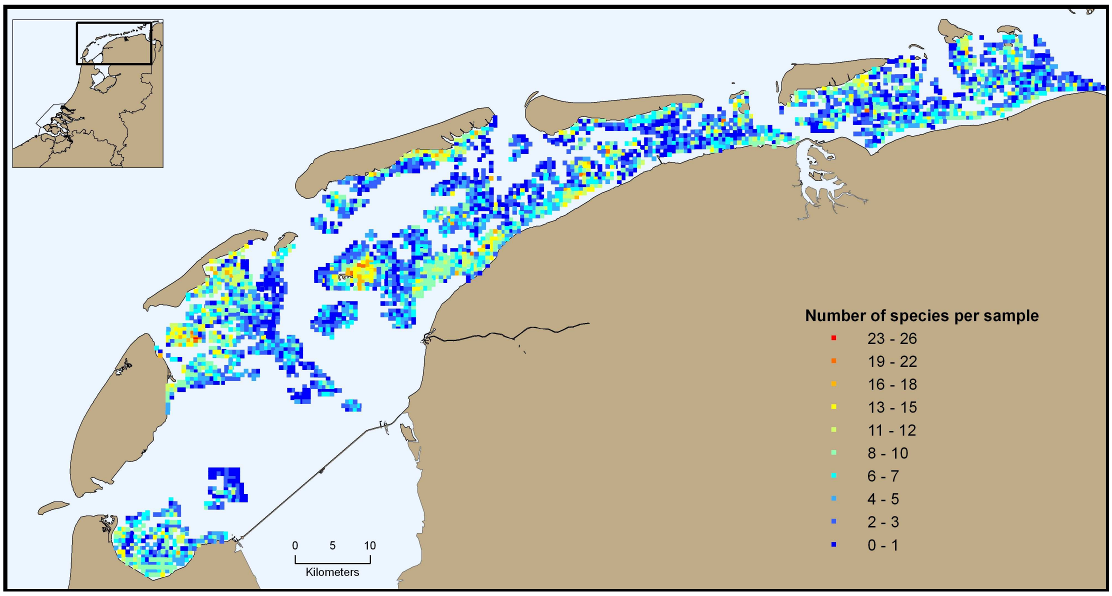
0. Summary

The objective of this study is to explore the perceived difference in species richness between Ameland and the other Island regions; Vlieland, Terschelling, Schiermonnikoog and Rottumeroog. In 2008 and 2009, the number of species per sample in the Ameland region (i.e. within 2.5km from the island and east of the tidal divide) was significantly lower compared to the Vlieland, Schiermonnikoog and Rotturmeroog region. It was not significantly lower compared to the Terschelling region and in 2009, the number of species per sample in the Terschelling region was even lower than the Ameland region. However, it should be noted that the variation in species richness within each island region, tend to be as large or larger than the species richness between the islands.

The mean and median grain size was also highest in the Terschelling and Ameland region. Relating the number of species to several covariates describing the local sediment conditions, shows that the variability in grain size (quantified by the standard deviation of particle sizes), best describes the variability in local species richness. Thus, this analysis shows that local species richness in the area of interest was positively correlated with the diversity of the sediment. Therefore to fully understand the effect of natural gas exploration on macrozoobenthos, it is first essential to understand the effect of land subsidence and other (a)biotic processes on the sediment characteristics.

1. Preface and introduction

Based on the map of the macro fauna biodiversity (Fig. 1) presented in Aarts et al. (2010), the perception of some members of the Ameland commission and the NAM was that the area south of Ameland was characterized by a lower species richness, where species richness was defined as the number of species per sample. In SIBES (2010), a slightly more detailed exploration of the Ameland region was carried out. In that study, a comparison was carried out between regions near Ameland with and without land subsidence resulting from natural gas exploration. Upon request, a different approach is taken here. In this study a comparison in species richness *between* the islands was made. More specifically, this study tries to assess if species richness differs between the island regions, if Ameland significantly differs from the other regions and if the Ameland region is characterized by a relatively larger decrease or smaller increase from 2008 to 2009.



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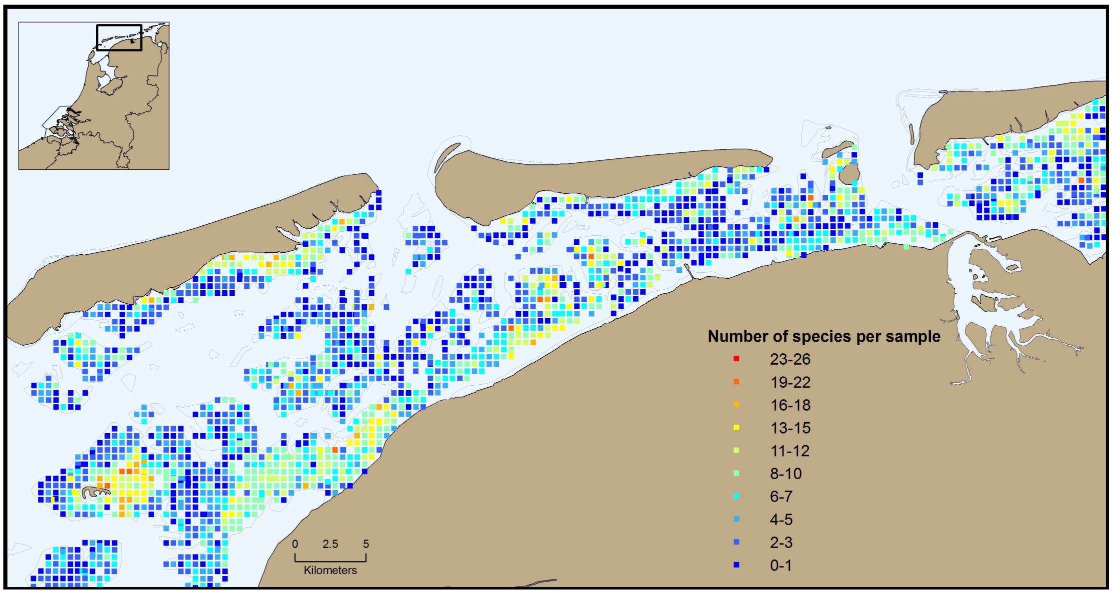


b.

Figure 1. Distribution of the number of species per sample in the entire Wadden Sea (a) and near Ameland (b) in 2008.

2. Methods

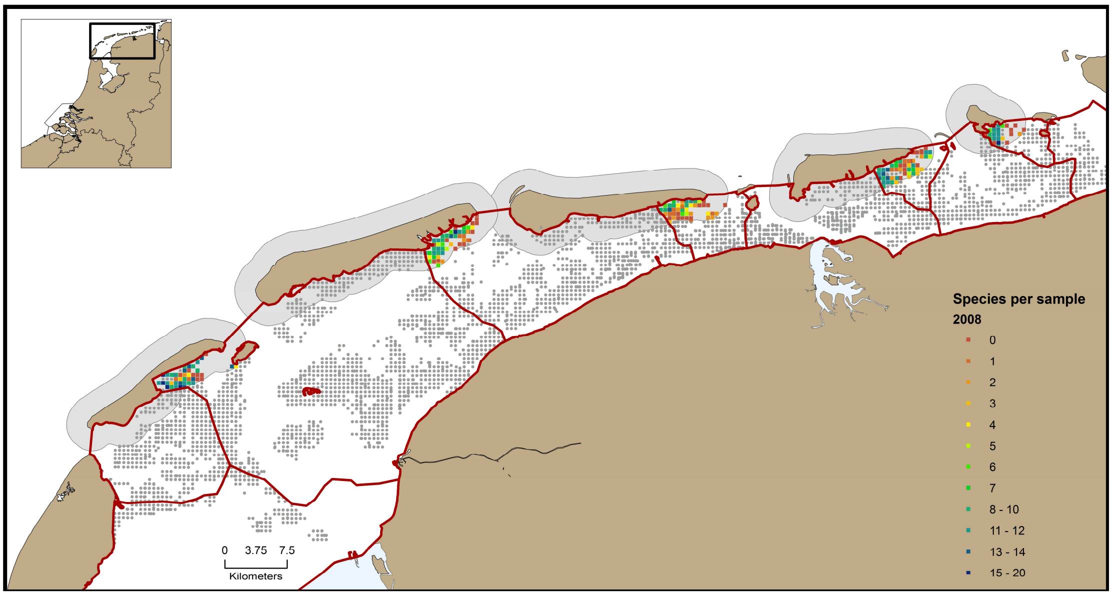
Information on the sampling design, data collection in the field and laboratory analyses can be found in Aarts et al. (2010) and Aarts et al. (2011). The sampling points considered in this study, are all points within 2.5 kilometer of Vlieland, Terschelling, Ameland, Schiermonnikoog en Rottumeroog and east of the corresponding tidal divides (Fig 2). For each region the mean (and standard error) was estimated. Based on these data points, statistical tests were carried out to assess whether the mean number of species between regions differed. This was done by fitting a Generalized Linear Models (GLMs) to the data, defining the number of species per sample as a quasi-Poisson distributed response variable. To determine the mean and standard error estimates, an intercept-only GLM was fitted to data points from the year and region of interest. To assess whether Ameland was significantly different from the other regions, an indicator variable (1 if a data points belongs to the Ameland region, and 0 otherwise) was included as a covariate. An F-test was used to determine whether the GLM with and without this covariate was significantly different.

The number of species per sample is defined as the sum of species-specific occupancies (1 or 0). So if Ameland significantly deviates from other Wadden island regions, we may want to know for which species the occupancy probability differs between the regions. To test this, GLMs are fitted to species-specific presence-absences observed at each sampling location. The presence-absence data is assumed to follow a binomial distribution. A variable indicating whether the data point is within the Ameland region or elsewhere is included as a covariate and an ANOVA test is used to test whether the covariate (i.e. in- or outside Ameland) significantly improves the model.

Finally this study inspects the correlation between the number of species per sample and sediment characteristics. The list of sediment specific covariates can be found in Table 1. Each covariate is included as a separate term and the covariate leading to a model with the lowest AIC is selected.

3. Results

Fig. 3 shows the number of species per sample within the area of interest. The species richness differs significantly between regions for both 2008 (ANOVA GLM F-test, $F = 6.0806$, $p = 0.00012$) and 2009 ($F = 8.5511$, $p = 1.730 \cdot 10^{-06}$). In 2008, all other island regions (Terschelling, Vlieland, Schiermonnikoog and Rottumeroog) are characterized by a larger mean number of species per sample. Rottumeroog (t-value = 2.808, p= 0.00543), Schiermonnikoog (t-value = 2.250, p= 0.02538) and Vlieland (t-value = 4.546 , p= <0.001) significantly deviate from Ameland. Terschelling has a higher number of species per sample, but this is not significantly different from Ameland (t-value = 1.816, p= 0.07069). Also in 2009, the species richness is higher in all regions, except for Terschelling. Similar to 2008, Rottumeroog (t-value = 2.674, p= 0.00799), Schiermonnikoog (t-value = 2.326, p= 0.02082) and Vlieland (t-value = 4.806, p= <0.001) significantly deviate from Ameland. When we compare Ameland with the data points from the other regions grouped together, we find a significant difference for both 2008 ($F = 12.643$, $p = 0.0005$) and 2009 ($F = 9.4339$, $p = 0.002359$). Next we test whether the number of species per sample has increased in 2009 relative to 2008 and whether this increase (or decrease) is different for the Ameland region. The number of species per sample for all points considered in this study was higher in 2009 (mean $\lambda = 7.494$, 95% CI = [6.862, 8.185]) compared to 2008 (mean $\lambda = 5.615$, 95% CI = [5.005, 6.299], $F = 15.742$, $p = 8.351 \cdot 10^{-5}$). Also in the Ameland region, the number of species per sample increased significantly from 2008 to 2009 ($F = 10.249$, $p = 0.001717$) and the relative increase is higher for the Ameland region, but this difference is not significant (t-value = 1.322, p= 0.186765).



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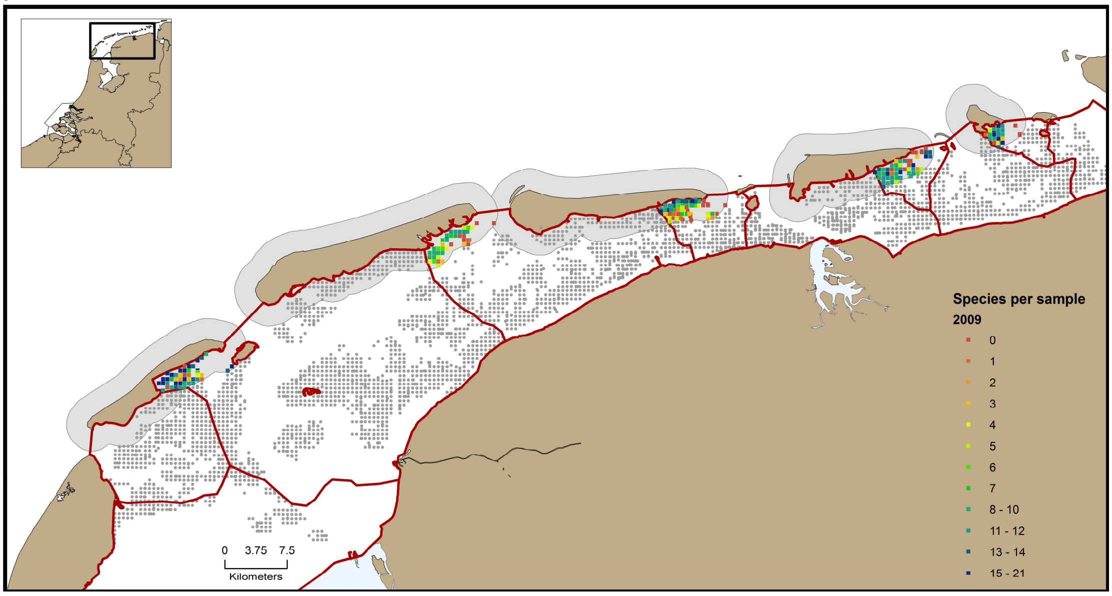

b.

Figure 2. Number of species per sample for 2008 (a) and 2009 (b) based on data points within the study region of interest. The dark red lines indicate the borders of the tidal basins and the light grey polygons represent the 2.5 km buffer around the islands of interest.

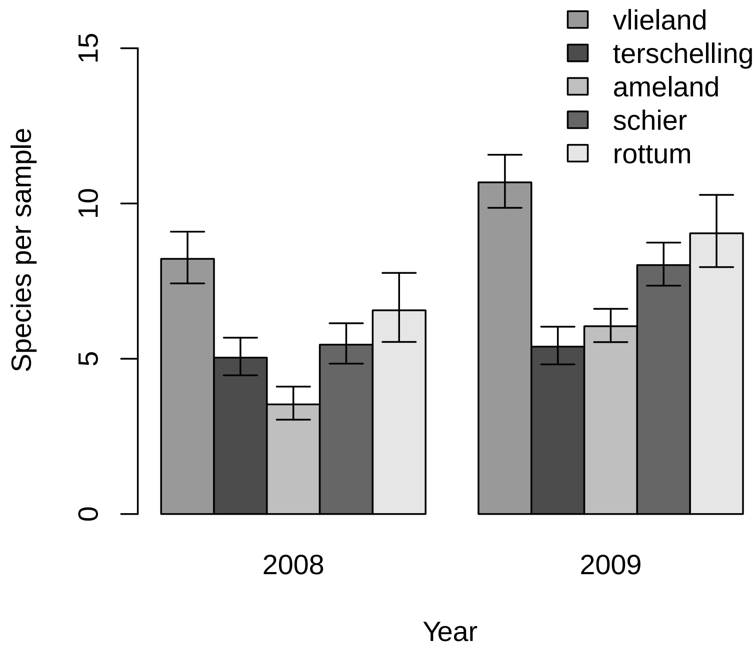

Figure 3. Mean number of species per sample (plus and minus the standard error) for the five Wadden Sea island regions (i.e. within 2.5 km from Vlieland, Terschelling, Ameland, Schiermonnikoog and Rottumeroog, and east of the tidal divide) for 2008 and 2009. In 2008, Ameland was characterized by the lowest number of species per sample.

In summary, the perception that in 2008 the Ameland region was characterized by a lower number of species per sample is correct. Similar to SIBES (2010), we now look at species-specific differences in occupancy in an attempt to understand for which species it is different.
Table A.1 shows for each species the occupancy probability near Ameland and elsewhere for both 2008 and 2009. The probability of finding a species in each sample in 2008 within the Ameland region was significantly less for the following species: *Capitella capitata, Aphelochaeta marioni, Aphelochaeta marioni, Nereis diversicolor, Arenicola marina, Oligochaeta sp., Hydrobia ulvae* and *Mya arenaria*. For 2009, the following species were less common in the Ameland region: *Aphelochaeta marioni, Nereis diversicolor, Arenicola marina, Oligochaeta sp., Nereis longissima, Eteone longa and Gammarus spec.. Nephtys cirrosa, Magelona johnstoni, Nephtys caeca* and *Tellina tenuis* were more common in the Ameland region in 2009.

Next, the sediment samples were used to characterize the different regions. In 2008, sediment samples were collected every 1000 meter, resulting in a total of 47 sample points within the regions of interest. Fig. 4 shows the mean, median, mode, and standard deviation of the particle size for each of the five regions. Fig. 5 shows the spatial distribution of mean grain size. Schiermonnikoog ("schier") has the lowest mean, median and mode (of) grain size. Terschelling has the highest mean, median and mode. Rottumeroog only has 3 data points, so these estimates are highly uncertain. The Vlieland and Schiermonnikoog region, both characterized by low mean and median grain size, also have the largest number of species per sample. In contrast, Terschelling and Ameland have the highest mean grain size and are characterized by the lowest number of species per sample.

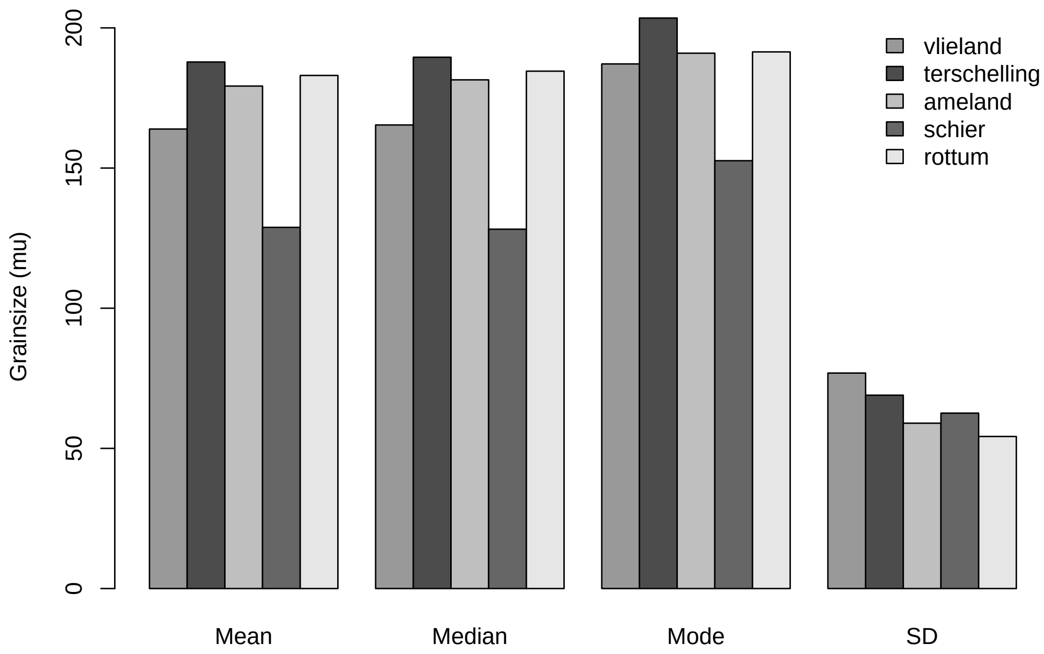

Figure 4. Mean, median, mode and standard deviation (SD) of the grain particles for the five regions, based on the 2008 sampling program.

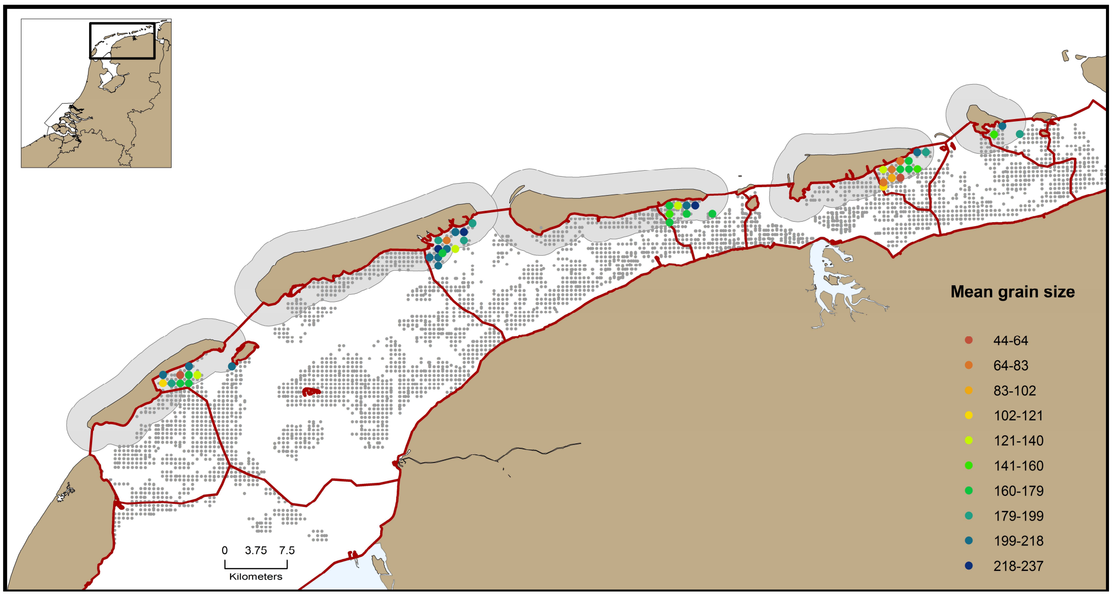

Figure 5. Mean grain size at sample points within the five regions, based on the 2008 sampling program.

Finally, the relation between the number of species per sample and sediment characteristics was investigated. Table 1 shows how well each covariate describes the observed number of species in the samples. The standard deviation of grain size explains the number of species per sample best (Coefficient = 0.022612, SE = 0.002908, z-value = 7.776, p-value = $7.47 \cdot 10^{15}$).
Fig. 6 shows the relation between the number of species per sample and the standard deviation of particle size.

Table 1. The ability of each covariate to explain the variability in the number of species per sample. The log-likelihood describes the fit between data and the model (including the covariate). A high Log-likelihood represents a good fit. The AIC is a measure of model quality. It is based on the Log-likelihood but it also includes a penalty for the number of covariates in the model. The model with the lowest AIC is considered as the best model.

Covariate	*Log-likelihood*	*AIC*
Mean	-177.775	359.549
Median	-175.822	355.6444
Mean/Median ratio	-180.231	364.4629
Mode	-164.772	333.5439
SD[1]	-155.255	**314.5100**
CV[2]	-183.466	370.9311
Variance	-157.69	319.3807
Kurtosis	-183.78	371.5606
Skewness	-179.135	362.2701
d10[3]	-180.446	364.8918
d50	-175.822	355.6444
d90	-166.519	337.0374
Volume% <2um	-183.778	371.5569
Volume% <4um	-183.762	371.5243
Volume% <10um	-183.75	371.4996
Volume% <8um	-183.754	371.5078
Volume% <16um	-183.765	371.5305
Volume% <25um	-183.78	371.5608
Volume% <125um	-181.571	367.1424
Volume% <63um	-183.676	371.3526
Volume% <250um	-171.242	346.4830
Volume% <1000um	-183.199	370.3988
Volume% <500um	-180.369	364.7381
Volume% <2000um	-183.781	369.5623

[1]SD = standard deviation of particle size
[2]CV = Coefficient of Variation
[3]d10 = Grain size at the 10% quantile, i.e. all particles are sorted from small to large. If there are e.g. 100 particles, d10 is the grain size of the 10th particle.

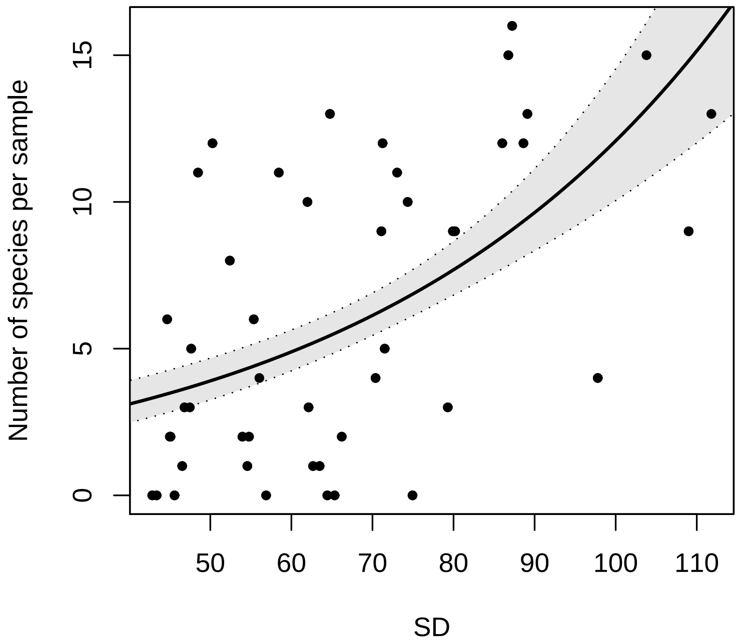

Figure 6. Relation between variability in grain size (SD = standard deviation) and number of species per sample. Only macrozoobenthos samples within the island regions (i.e. Vlieland, Terschelling, Ameland, Schiermonnikoog and Rottumeroog) and at sediment sample locations are used in the analysis.

4. Discussion & conclusion

In 2008 and 2009, the number of species per sample in the Ameland region was significantly lower compared to the Vlieland, Schiermonnikoog and Rotturmeroog region. It was not significantly lower compared to the Terschelling region and in 2009, the number of species per sample in the Terschelling region was even lower than the Ameland region. It should be noted that the variation in species richness within each island regions, tend to be as large or larger than the species richness between the island. Due to this relative high small scale spatial differences in species richness, this detailed study is complicated by the fact that it is difficult to select an appropriate reference area. Furthermore, within the Ameland region, the number of species per sample near the Ameland coast (and with the largest land-subsidence), tend to be higher (SIBES 2010).

So what is the most important determinant for species richness? A first inspection of the spatial pattern in species richness, suggest that it is closely correlated with sediment characteristics. Using a Generalized Linear Model fitted to data from macrozoobenthos collected at sediment sampling locations within the island regions defined above, reveals that the diversity in sediment type is the best descriptor of species richness.

The question whether land-subsidence is responsible for the relative low species richness near Ameland, cannot be answered conclusively. Indeed, Ameland has the lowest mean number of species per sample in 2008, but in 2009 Terschelling has the lowest number of species per sample, even though it is not affected by land-subsidence. Therefore to understand the impact of land-subsidence, it is first necessary to quantify how other biotic and abiotic processes shape the macrozoobenthos distribution in space and time.

5. References

Aarts, G., Dekinga, A., Holthuijsen, S., ten Horn, J., Smith, J., Kraan, C., Brugge, M., Bijleveld, A., Piersma, T. and v.d. Veer, H. 2010. Benthic macrofauna in relation to natural gas extraction in the Dutch Wadden Sea. NIOZ rapport 2010.

Aarts, G. Koolhaas, A., Dekinga, A., Holthuijsen, S., ten Horn, J., Smith, J., Brugge, M., Piersma, T. and H. van der Veer. 2011. Benthic macrofauna in relation to natural gas extraction in the Dutch Wadden Sea: Report on the 2008 and 2009 sampling program. NIOZ rapport 2011-3

SIBES. 2010. A short exploration of the intertidal benthic species richness around Ameland. NIOZ supplement 2010

Appendix A

Table A.1. Mean probability a species is found in the sample for the Ameland region and all other regions (i.e. Vlieland, Terschelling, Schiermonnikoog and Rottumeroog), the Chi^2 statistics and corresponding p-value. Species are sorted based on the occupancy probability observed near Ameland in 2008.

	2008				**2009**			
	Mean occupancy				Mean occupancy			
Species name	**Ameland**	**Elsewhere***	**Chi²**	**p-value**	**Ameland**	**Elsewhere***	**Chi²**	**p-value**
Scoloplos armiger	0.429	0.456	-0.118	0.731	0.536	0.514	-0.104	0.747
Macoma balthica	0.265	0.33	-0.758	0.384	0.333	0.44	-2.714	0.099
Lanice conchilega	0.245	0.308	-0.753	0.386	0.202	0.291	-2.397	0.122
Cerastoderma edule	0.245	0.313	-0.884	0.347	0.31	0.349	-0.391	0.532
Pygospio elegans	0.204	0.368	-4.985	0.026	0.44	0.594	-5.408	0.02
Capitella capitata	**0.204**	**0.423**	**-8.453**	**0.004**	0.357	0.48	-3.514	0.061
Aphelochaeta marioni	**0.204**	**0.418**	**-8.07**	**0.005**	**0.369**	**0.543**	**-6.928**	**0.008**
Nephtys hombergii	0.184	0.104	-2.087	0.149	0.036	0.08	-2.008	0.156
Nereis diversicolor	**0.184**	**0.429**	**-10.706**	**0.001**	**0.262**	**0.463**	**-9.886**	**0.002**
Urothoe poseidonis	0.143	0.231	-1.914	0.166	0.25	0.32	-1.356	0.244
Arenicola marina	**0.102**	**0.335**	**-11.955**	**0.001**	**0.31**	**0.497**	**-8.294**	**0.004**
Oligochaeta sp.	**0.102**	**0.39**	**-16.926**	**0**	**0.262**	**0.503**	**-13.953**	**0**
Nereis longissima	0.082	0.082	0	0.986	**0**	**0.057**	**-8.032**	**0.005**
Spio martinensis	0.061	0.077	-0.145	0.703	0.06	0.057	-0.006	0.939
Polydora cornuta	0.061	0.165	-3.975	0.046	0.107	0.2	-3.709	0.054
Phyllodoce maculata	0.061	0.055	-0.028	0.867	0.083	0.023	-4.698	0.03
Carcinus maenas	0.061	0.077	-0.145	0.703	0.131	0.131	0	0.992
Eteone longa	0.061	0.154	-3.318	0.069	**0.262**	**0.434**	**-7.395**	**0.007**
Nephtys cirrosa	0.061	0.088	-0.388	0.533	**0.083**	**0.011**	**-8.104**	**0.004**
Nereis succinea	0.061	0.049	-0.105	0.746	0.048	0.103	-2.447	0.118
Bathyporeia sarsi	0.041	0.033	-0.068	0.794	0.071	0.034	-1.664	0.197
Malmgreniella lunulata	0.041	0.049	-0.066	0.798	0.06	0.051	-0.072	0.789
Marenzelleria viridis	0.041	0.088	-1.366	0.243	0.095	0.131	-0.731	0.393
Nereis virens	0.041	0.038	-0.006	0.94	0.012	0.034	-1.244	0.265
Magelona johnstoni	0.041	0.011	-1.646	0.2	**0.071**	**0**	**-13.811**	**0**
Nephtys caeca	0.041	0.011	-1.646	0.2	**0.048**	**0**	**-9.14**	**0.003**
Tellina tenuis	0.041	0.027	-0.218	0.641	**0.036**	**0**	**-6.83**	**0.009**
Spiophanes bombyx	0.02	0.038	-0.424	0.515	0.036	0.029	-0.094	0.759
Heteromastus filiformis	0.02	0.104	-4.513	0.034	0.143	0.211	-1.809	0.179
Eumida sanguinea	0.02	0.033	-0.227	0.634	0.024	0.086	-4.181	0.041
Crangon crangon	0.02	0.049	-0.925	0.336	0.024	0.023	-0.002	0.962
Corophium sp.	0.02	0.066	-1.856	0.173	0.071	0.12	-1.522	0.217
Littorina littorea	0.02	0.027	-0.081	0.777	0	0.023	-3.166	0.075
Mytilus edulis	0.02	0.027	-0.081	0.777	0.06	0.069	-0.077	0.781
Abra tenuis	0.02	0.071	-2.201	0.138	0.036	0.069	-1.218	0.27
Scrobicularia plana	0.02	0.071	-2.201	0.138	0.071	0.12	-1.522	0.217
Tellina fabula	0.02	0.011	-0.239	0.625	0	0.011	-1.576	0.209

Pectinaria koreni	0.02	0	-3.117	0.077	0	0.006	-0.786	0.375
Aricidea minuta	0	0	0	1	0	0	0	1
Streblospio shrubsolii	0	0.016	-1.441	0.23	0.024	0.034	-0.218	0.641
Gammarus spec	0	0.038	-3.396	0.065	**0.012**	**0.114**	**-10.532**	**0.001**
Mysta picta	0	0.011	-0.958	0.328	0	0	0	1
Nemertini sp.	0	0.038	-3.396	0.065	0.036	0.034	-0.003	0.953
Glycera alba	0	0.005	-0.478	0.489	0	0	0	1
Bodotria scorpioides	0	0	0	1	0	0	0	1
Nereis sp.	0	0.011	-0.958	0.328	0.012	0.017	-0.107	0.743
Phyllodoce mucosa	0	0.022	-1.926	0.165	0.083	0.143	-1.973	0.16
Autolytus prolifer	0	0.005	-0.478	0.489	0.012	0	-2.26	0.133
Mysella bidentata	0	0	0	1	0	0.046	-6.394	0.011
Ensis americanus	0	0.022	-1.926	0.165	0.083	0.074	-0.064	0.8
Harmothoe sarsi	0	0.005	-0.478	0.489	0.012	0.046	-2.313	0.128
Hydrobia ulvae	**0**	**0.198**	**-18.882**	**0**	0.167	0.194	-0.291	0.59
Mya arenaria	**0**	**0.093**	**-8.463**	**0.004**	0.012	0.074	-5.472	0.019
Echinocardium cordatum	0	0	0	1	0	0	0	1
Polydora caeca	0	0	0	1	0	0	0	1
Travisia forbesii	0	0	0	1	0	0.006	-0.786	0.375
Bathyporeia pilosa	0	0	0	1	0	0.006	-0.786	0.375
Nephtys spec.	0	0.005	-0.478	0.489	0.024	0.006	-1.488	0.223
Retusa obtusa	0	0.005	-0.478	0.489	0.012	0.034	-1.244	0.265
Sagartia troglodytes	0	0	0	1	0	0	0	1
Asterias rubens	0	0	0	1	0	0.011	-1.576	0.209
Petricola pholadiformis	0	0.005	-0.478	0.489	0	0.006	-0.786	0.375
Jaera albifrons	0	0	0	1	0	0	0	1
Scolelepis bonnieri	0	0	0	1	0	0	0	1
Abra alba	0	0.005	-0.478	0.489	0.012	0.04	-1.758	0.185
Scolelepis foliosa	0	0	0	1	0	0.006	-0.786	0.375
Streptosyllis websteri	0	0	0	1	0	0	0	1
Nephtys longosetosa	0	0	0	1	0.024	0	-4.537	0.033
Crepidula fornicata	0	0	0	1	0	0	0	1
Microphthalmus similis	0	0	0	1	0	0.006	-0.786	0.375
Polydora ciliata	0	0	0	1	0	0	0	1
Phoxichelidium femoratum	0	0	0	1	0	0	0	1
Melita palmata	0	0	0	1	0.012	0.011	-0.001	0.973
Harmothoe ljungmani	0	0	0	1	0	0	0	1
Lepidochitona cinerea	0	0.005	-0.478	0.489	0	0	0	1
Pagurus bernhardus	0	0	0	1	0	0	0	1
Harmothoe imbricata	0	0	0	1	0	0	0	1
Metridium senile	0	0.005	-0.478	0.489	0	0.006	-0.786	0.375
Eulalia viridis	0	0	0	1	0	0	0	1
Neomysis integer	0	0	0	1	0	0	0	1
Fish Sp.	0	0	0	1	0	0	0	1
Crassostrea gigas	0	0.005	-0.478	0.489	0.012	0.011	-0.001	0.973
Hemigrapsus takanoi	0	0	0	1	0	0	0	1

Tellimya ferruginosa	0	0	0	1	0	0	0	1
Magelona mirabilis	0	0	0	1	0	0	0	1
Hemigrapsus sanguineus	0	0	0	1	0	0	0	1
Littorina saxatilis	0	0	0	1	0	0	0	1
Harmothoe impar	0	0	0	1	0	0.006	-0.786	0.375
Malacoceros fuliginosus	0	0	0	1	0.024	0.011	-0.536	0.464
Elminius modestus	0	0	0	1	0	0.011	-1.576	0.209
Hydrobia ventrosa	0	0	0	1	0.012	0	-2.26	0.133
Balanus crenatus	0	0	0	1	0.012	0.011	-0.001	0.973
Microprotopus maculatus	0	0	0	1	0	0	0	1
Gammarus salinus	0	0	0	1	0	0	0	1
Manayunkia aestuaria	0	0	0	1	0	0	0	1
Glycera rouxi	0	0	0	1	0	0	0	1
Pseudopolydora pulchra	0	0	0	1	0	0	0	1
Aonides oxycephala	0	0	0	1	0	0	0	1
Ophiura texturata	0	0	0	1	0	0	0	1
Gammarus obtusatus	0	0	0	1	0	0	0	1
Spisula subtruncata	0	0	0	1	0	0	0	1
Praunus inermis	0	0	0	1	0	0	0	1
Idotea balthica	0	0	0	1	0	0	0	1
Bathyporeia tenuipes	0	0	0	1	0	0	0	1

Bijlage B RUG Proefschrift: Effecten van bodemdaling ten gevolge van gaswinning op Ameland in relatie tot autonome processen in de Waddenzee

Effecten van bodemdaling ten gevolge van gaswinning op Ameland in relatie tot autonome processen in de Waddenzee

1. Korte beschrijving van het onderzoekproject

Sinds het begin van de gaswinning in 1987 is er bijgehouden wat de effecten zijn van de bodemdaling. Er is echter geen vergelijking gemaakt met een controle eiland om te kijken of de gevolgen inderdaad het resultaat zijn van deze bodemdaling of dat er andere autonome processen plaatsvinden. Hierdoor is er gevraagd om een onderzoek in te stellen waarin een vergelijking wordt gemaakt tussen Ameland en de 0-referentie Schiermonnikoog. Waar mogelijk word ook gekeken naar data van andere locaties, zoals Terschelling en Skållingen (DK). Dit onderzoek is in 2008 gestart en moet eind 2012 afgerond zijn.
In deze studie ligt de concentratie op het voorkomen van plantensoorten en plantengemeenschappen in relatie tot hoogte van het maaiveld, afstand tot slenken en de rand van de kwelder, leeftijd van de kwelder, sedimentatie, autocompactie van het sediment, vernatting en begrazing. Eerdere studies hebben het belang van bovenstaande factoren aangeduid. Deze studie zal ingaan op de genoemde relaties op uiteenlopende ruimtelijke schalen zoals die al worden toegepast op verschillende zandige kwelders in de Waddenzee. Lange termijn studies zijn een voorwaarde voor het vinden van deze relaties.

Al beschikbare ruimtelijke schalen, studiegebieden en perioden van monitoring zijn hieronder aangegeven.

1) **gehele kwelder** (500 ha) grid van 800 punten
    Inclusief maaiveldhoogte, dikte van het sediment, vegetatie
        Schiermonnikoog 1996/2004/2010
        Ameland 2009

2) **supertransect** van het wad tot het strand (1000 m x 100 m) cellen of 10 m x 10 m
    Inclusief maaiveldhoogte, dikte van het sediment, vegetatie
        Schiermonnikoog 1993/2002/2008 /2010
        Rottumerplaat 2003
        Mellum DE 2003
        Ameland 2010

3) **klein transect** van de voet van duin tot middenkwelder (60 m x 10 m) cellen van 1 m x 1 m
    Inclusief maaiveldhoogte, dikte van het sediment, soorten, sedimentatie
        Schiermonnikoog 1992/1997/2001/2005/2009
        Terschelling 1993/1997/2001/2005/2009
        Skållingen DK 1992/1997/2001/2005/2009
        Ameland 2009

4) **permanente quadraten pq's** op beweide en onbeweide kwelder (2 m x 2 m)
    Inclusief soorten, soms maaiveldhoogte en sedimentatie
        Schiermonnikoog 1972-2010
        Terschelling 1973-2003
        Ameland 1987-2010
        Skållingen DK 1975-2009
        Langli DK 2000-2009

5) **Drainage systeem** systeem rondom een slenk (100 ha) grid 900 punten
inclusief maaiveldhoogte, dikte van het sediment, sediment concentratie in getijwater.
        Schiermonnikoog 2010

De bovenstaande monitoring wordt voortgezet op Ameland: 1) gehele kwelder grid, 4) pq's. Voor zowel Ameland als Schiermonnikoog: 5) de schaal van drainage-eenheid (slenk, oeverwal, depressie (tot 100 ha) ten aanzien van maaiveldhoogte, dikte van het sediment, sedimentatie en vegetatie.
Deze procedure zal inzicht verschaffen en uitmonden in een model voor de dynamiek van abiotische factoren en soorten op uiteenlopende ruimtelijke schaal van zandige kwelders. De studie zal bijdragen aan het begrijpen van de dynamiek van kwelders en onderscheid mogelijk maken tussen autonome dynamiek (inclusief zeespiegelstijging) en die veroorzaakt door bodemdaling ten gevolge van gaswinning.

3. Ondersteuning

De wetenschappelijke begeleiding van het project berust bij Prof. Jan P. Bakker, die ook zal optreden als promotor voor de dissertatie die uit het project voortkomt. Daarnaast fungeren Dr. Han van Dobben, Drs. Kees Dijkema (IMARES Wageningen University Research) en Prof. Stijn Temmerman (Universiteit van Antwerpen) als medeadviseurs voor het project.

Bijlage C RUG Proefschrift: Vegetation dynamics of temporal wetlands under a changingglobal climate

FORMBursarytrainingandsupportplan

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Date of birth:16-04-1982

Faculty: W & N

Field: Environmental Science and ecology

Research Institute: IVEM Start date: September 2008

End date: August 2012

Title research project:

Vegetation dynamics of temporal wetlands under a changing global climate

Short description of the research project

In the Netherlands, global warming will lead to higher sea water levels along the coastal area, which will lead to increased flooding frequencies in interdunal wetlands. Lowering of the surface due to abstraction of gas on the island of Ameland has the same effect. A good evaluation of the effects of gas abstraction on the flooding frequency of coastal wetlands is complicated by another effect of global warming; increased precipitation during the winter and less precipitation, but more intense rainfall during short periods. Therefore, the dry dunes will become dryer, but the wetlands could become wetter. It is very likely that summer flooding will become more frequent and this has a very negative effect on the vegetation of dune slacks, which is adapted to prolonged flooding in winter and spring, but to low water levels in the summer. The typical vegetation of wet dune slack is characterized by a large biodiversity with various life and growth forms: annuals, biennials, perennials, young shrubs.

Natural succession in dune slacks starts with a pioneer phase in which small pioneer species establish on an almost bare soil, which usually is covered with a thin layer of green algae and laminated microbial mats. Depending on the local hydrological and climatological situation, these wetlands can become quite productive within a decade by natural succession, or they can remain in a low productivity state for many decades (up to 80 years). These wetlands are not restricted to coastal areas, but they also occur in mountain areas above the tree lines. In the present project, we will test if observed vegetation changes on the Dutch Wadden Sea islands during 14-19 years correspond to predicted changes in summer precipitation as a result of global warming. For this, we need to 'translate' changes in precipitation into changes in flooding frequency and then translate them to vegetation changes. We will also compare the vegetation composition of the Dutch Wadden Sea islands with coastal wetlands in South Africa and with temporal wetland in mountain areas off South Africa and Ethiopia and compare functional traits of wetland species withhydrologicaland climatologicalconditionsinthoseareas.

Background and theory

Dune slacks are low laying areas within the coastal dunes where high water table prevail during the winter and the spring (Laan 1979, Grootjans et al. 1998). During the summer the water table may drop

50-100 cm below the surface layer (1993, 2002), which results in alternating wet-dry cycle. Dune slacks can be formed in natural ways or by human activities in the dune complexes. Natural means of dune slack formation can be by an extensive sand blowing (secondary dune slack formation) or by formation of dune ridges (primary dune slack formation) on the former sand beach plain that might halt the influence of the sea water either partially or wholly (Lammerts 1998). Dune slack can also be formed when people dig out sand to build dykes in order to protect flooding by the sea water or to reclaim lands for agricultural purposes (Grootjans et al. 2002, Ilona 2004). Dune slack soils are usually calcareous because they often originated from recently deposited sand that is rich in shell materials. But when dune slack is formed on a beach plain with low initial lime content, it can be acidic (Grootjans et al. 2008). Soil in primary dune slacks is buffered against acidification by a combination of brackish surface water, $CaCO_3$ rich sand and calcareous groundwater. However,secondary slacks may or may not feed by calcareous ground water.

Succession in dune slacks started when secondary slack is initiated in a dune complex by extensive sand blowing or when dune ridge is formed along the former sand beach plain. It often starts when small pioneer species such as Littorella uniflora establishes on bare soil. During this stage, a thin layer of green algae and laminated microbial mat cover the surface creating a more harsh condition for the establishment of late successional species (van Gemerden 1993). Following the establishment of pioneer species, comes phanerograms adapted to a very low nutrient availability. During the later stage, pleurocarpic bryophytes and typical dune slack species come in and create the stage which encompasses many read list species such as Dactyloriza incarnata, Epipactis palustris and Liparis loeselii (Grootjans et al. 2008). This leads to a rapid accumulation of organic matter and increase nutrient availability for the growth of tall grasses and shrubs. The succession rate and soil development in dune system is largely controlled by the productivity of the ecosystem, decomposition of organic matter and recycling of nutrients within the ecosystem (Verhoeven et al. 1996). Low nutrient status and high pH is required to slow down the rate of succession in dune slack habitats. Therefore, low productivity during the first few years of vegetation development and high hydrological dynamics may stabilize succession rate for some time; i.e. groundwater discharge stimulate decomposition of organic matter. Furthermore, the differential effect of growth limiting nutrients, late successional species being limited by both nitrogen and phosphorous while early stage species are only nitrogen limited (Willis 1963, Ernst et al. 1996), can also stabilize succession to some extent. Some species such as Schoenus nigricans can retain nutrients in their tissue, lead to a spatial aggregation of nutrients in the habitat, and lock access by late successional species.

Under natural conditions, early stage dune slack habitats are nutrient poor habitat. Major nutrients like nitrogen and phosphorus are available only in a very small amount (Lammerts 1997). However, nutrients accumulate during natural succession and consequently the species composition of dune slacks change over time(Olff et al. 1993). Compared to old slacks, young slacks are very nutrient poor and the vegetation cover is low; yet they are rich in species diversity. They show a large variability in vegetation composition depending on their substrate characteristics and hydrological regimes (Grootjans et al. 2002). They comprises different life and growth forms: annuals, biennials, perennials, shrubs and small trees (Crawford and Wishart 1966, Grootjans et al. 2002). A considerable number of endangered and red list species are found in young dune slacks, for instance, Schoenus nignicans, Epipactis palustris, Dactylorhiza incarnata, Liparis loeselii, Gentianella amarelle, Parnassia palustris, Eleocharis quinquefolia and Equisetum variegatum (Grootjans 1991). Most of these species are calciole and they show optimal growth during the early stage of dune slack development. In contrast, when natural succession occurs, older dune slacks have large nutrient stocks both in the soil organic layer and in the vegetation. This leads to the establishment of high nutrient demanding tree and shrub species, which eventually out compete small and pioneer species (Olff et al. 1993). As a result, old dune slacks are most often poor in species diversity and are covered with tall shrubs and trees.

Typical dune slack species have developed adaptations to nutrient poor and hydrologically very dynamic dune habitats. Tolerance to anoxic condition is one of the most important adaptations for early stage dune slack species. Plant species with aeranchyma, such as Schoenus nignicans, Littorella uniflora and several Carex spp., can thrive under anoxic waterlogged condition as long as their top shoots kept in contact with the atmosphere (Jones 1972). They can counteract the deprivation of oxygen by high levels of radial oxygen loss (ROL). However, late successional species without ROL capabilities cannot establish under water logged and anoxic conditions. Under such anoxic conditions, high concentrations of reduced sulfide, iron and manganese prevail in the rooting zone to which late successional species such as Calamagrostis epigejos are not adapted (Lammerts 1998). Therefore, under extended waterlogged conditions during winter and spring periods, early successional species can survive the stress and win the competition over late successional species. In addition, early stage dune slack species such as Littorella uniflora, Centaurium puchellum, and Radiola linoides have a very low nutrient demand due to their small size (Grootjans et al. 2008). When compared to the late successional species and small herbaceous species, early stage sedge species such as S. nignicans have very low demand for phosphorous and nitrogen. Unlike late successional species, their growth is not phosphorous limited. S. nignicans which has tussocks diameters up to 35cm, being a dominant producer in an early stage of dune slack development, can retain 1gN per tussock for years, which is equivalent to 10-25kg N/ha. In this way it keeps nutrients locked in its biomass and make it unavailable for the growth of high nutrient demanding late successional species (Grootjans et al. 2008).

However, during the past few decades there has been a steep decline in typical basiphilous pioneer stage dune slack species along the cost of Holland. Several authors have related this decline of pioneer species to several key environmental variables like: organic matter accumulation (Olff et al. 1993, Sival and Grootjans 1996, Berendse et al. 1998). In addition, hydrological changes due to groundwater abstraction for drinking purposes or drainage for agricultural purposes, plantation of trees to stop sand blowing, mass recreation and atmospheric nitrogen deposition (Laan 1979, Grootjans et al. 1988, Grootjans 1991, van Dijk and Grootjans 1993, Grootjans et al. 1996, Grootjans et al. 1998, Lammerts 1998, Lammerts et al. 2001, Munoz-Reinoso 2001, Ilona 2004, Grootjans et al. 2006, Jones et al. 2006), and herbivory (Ranwell 1960, Bakker

1985) are considered important. Furthermore, new dune formation has been stabilized which might be translated into permanent losses of early and mid-successional dune slack species (Smith et al. 2007) due to loss of habitat. Indeed all these key environmental variables exhibit complex interactions influencing one another and the abundances and compositions of plant communities. For instance exfiltration of calcareous groundwater is found to be very important in buffering and keeping the soil pH at higher level and facilitate mineralization of organic matter (van Dijk and Grootjans 1993, Sival and Grootjans 1996, Lammerts 1997, 1998, Adema et al. 2005, Grootjans et al. 2008).

The hydrology of a dune slack is very dynamic because most slacks are fed by water from various sources. These can be water from precipitation, surface water and groundwater (Grootjans et al. 2008). While the precipitation water is mostly acidic, water from the latter two is usually calcareous. The hydrological regime of dune slacks is even more complex when groundwater enters into the system from different hydrological systems (Munoz-Reinoso 2001, Grootjans et al. 2002). Those dune slacks situated at the low-lying periphery of the main dune system are often fed by calcareous groundwater from the main hydrological system. In addition, seepage slacks can also be found in areas where a thick layer of clay or peat prevents infiltration to the deeper layers and resulted in a regional groundwater discharge zone. This kind of slack function is termed as 'flow-through lakes' with ground water discharge in one part of the slack and infiltration of surface water in another part of the slack (Stuyfzand 1993). In addition, when many slacks occur side by side, slight differences in water levels between slacks may initiate groundwater flow from one slack to another (Grootjans et al. 1996). Therefore, in order to understand the dynamics of dune slack vegetation, knowledge about the hydrological dynamics in dune habitat is fundamental.

The balance between precipitation and groundwater discharge affects the vegetation composition of dune slack habitats. Extreme weather condition may alter this balance in way that it influences the course of vegetation development. This influence can be directional change away from the initial stage (succession) or it can be a reversible change (fluctuation). Many studies dealt with the effects of extreme weather conditions mainly focused on fluctuations (Rabotnov 1966, Pitt and Heady 1978, Laan 1979, Olff et al. 1988, Houle and Phillips 1989, de Leeuw et al. 1990). The above-mentioned studies were mainly based on a relatively short period (3-15yrs) and it is not a surprise that most of their findings point to fluctuations than directional changes in community composition they studied. Indeed vegetation records over long period mostly show fluctuations in the beginning but a directional changes during the latter stage in the course of development (Myster and Pickett 1988, Myster and Pickett 1994, Collins et al. 2000). Fluctuations during the early stage of succession may point to the role of stochastic event during the early stage of succession (Collins et al. 2000). But these kind of directional changes are very often related to the impacts of human interferences in the environment (Beeftink 1979, Noordwijk-Puijk et al. 1979, Dorp et al. 1985, Grootjans 1991). In line with this, when the ground water is affected due to water abstraction or any other deleterious human activities in the dune complexes, then precipitation water may dominate over ground water and shift the balance in the direction of rain water which is basically acid water. Under such circumstances, extreme weather condition may affect the buffering capacity of dune system and lead to an intensive acidification of dune soil. Consequently, species poor acidophilic vegetation might establish lead to the decline of endangered calcareous dune slack species.

Global climate is changing with an unprecedented speed. Studies show a decadal increase of precipitation by 0.5-1.0% in mid- and high latitude areas of the Northern Hemisphere while the reverse is true in sub-tropics and tropics. In Northern hemisphere climate warming has resulted in a decreased diurnal temperature due to an increase in minimum temperature at about twice the rate of an increase of the maximum temperature (Walther et al. 2002). The coast of NW Europe is characterized by frequent flooding during winter and spring but dry summer. The Dutch coast has an Atlantic climate where precipitation dominates over evaporation (Grootjans et al. 2002). Consequently, coupled with the current increase of precipitation water due to global climate change, even more precipitation water is getting into dune system. This surplus precipitation should be countered in order to maintain calcareous vegetation in these habitats. Moreover, the amount of precipitation surplus getting into the system varies from year to year. This annual variability in rainfall might affects both water table and the balance between groundwater and precipitation (Grootjans 1991). Therefore, understanding the effect of climate change requires making a distinction between annual fluctuation and long term vegetation change.

Climate change influences coastal habitats as it does other ecosystems. Bakker et al. (1979) in (van der Hagen et al., 2008) had developed a conceptual model of dune slack development (Fig. 1).

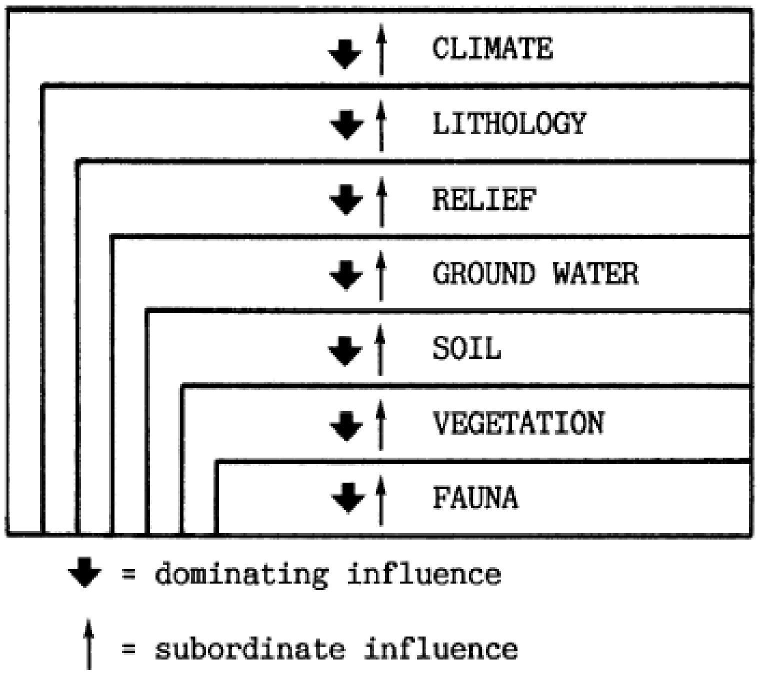

Fig. 1. Conceptual model of dunes. Factors influencing dune development are shown based on their either dominant or subordinate effects. Adopted from van der Hagen et al., 2008 paper published on Journal of Nature Conservation.

From this model, climate is the most dominant factor that influence dune slack vegetation development. Nevertheless, understanding the effect of climate on vegetation development is not as such easy bossiness. In dune slack environment, typical dune species are limited relatively by few known key environmental variables (Lammerts and Grootjans 1998). Yet how change in global climate affect these factors is not clear. In temperate climate, precipitation is on increase due to global climate change. This increase in precipitation might lead to a prominent decalcification and a rapid acidification of top layer soil in dune slacks. Specifically in areas where the initial lime content is low, which is the case in the Wadden sea area with less than 2% initial lime content (Grootjans et al. 2002), the effect of surplus precipitation could be deleterious for calcareous rare species.

Generally, high water table is important to maintain the stability of pioneer vegetation as long as the groundwater is rich in Ca+ and HCO3- and pH is buffered at a high level. Nonetheless, when the buffering capacity of dune slack is compromised because of human interferences in the hydrological functioning of dune slacks, then the effect of precipitation surplus can be even pronounced. It means acidic rainwater contributes a large portion to the water table and it leads to acidification of dune soil. When soil pH drops below some limit (pH=6), then the habitat become less suitable for the growth of calcareous species. Therefore, maintenance of hydrological condition may keep the soil pH high with the discharge of calcareous ground water to the surface. In this project, we aim to elucidate the effect of rainfall fluctuation on the dynamics of dune slack vegetation on the barrier island of the Dutch Wadden seacoast.

Hypothesis

- When the hydrological functioning of dune system is altered, then

– Precipitation surplus accelerate succession in dune slacks and lead to the decline or local extinction of endangered dune slack species

Research questions:

1. What is the effect of weather fluctuation (precipitation increase or decrease) on the development of dune slack vegetation?

2. How does the vegetation respond to the rise of water level due to rewetting or to the rise of water level as a result of soil subsidence?

3. What are the environmental variables that influence vegetation development on Dutch coastal dune slacks?

4. What are the similarities and difference in functional types of human influenced Dutch coastal dune slacks and natural dune areas of South Africa?

Plans and Activities B.W.Dullo

In accordance with the study plan set out, the writer of chapter 4.5 (Bikila W. Dullo) has followed courses such as: Multivariate Statistical Analysis course, publishing in English Course, Database management course, Several ArcGIS courses (such as Spatial Analyst, 3D Anslyst, Geoprocessing, Map projections and others) and Dutch language courses. In addition, I have given a poster presentation on Netherlands Annual Ecology Meeting in February 2010, Oral presentation in South Hampton UK in April 2010, Oral Presentation in Avignon, France on Ecological Restoration European chapter conference and Oral presentation on a peat land symposium held in Khanty-mansiysk, Siberia, Russia in June/July 2011. Another oral presentation is under preparation for a World Conference on Ecological Restoration to be held in Merida, Mexico in August 2011. Two field excursions and field works were conducted outside of the Netherlands in Ethiopian Mountains and South Africa on the shore of Lake St. Lucia from September to December 2010. The data collected from these places will be analyzed and published within the scope of my PhD research. In addition, I have participated on collecting data from almost all Wadden Sea Islands and also with master students who worked with my supervisor Prof. dr. Ab Grootjans.

1. Thus far, a study on Texel Moksloot area about vegetation dynamics after sod-cutting (18 years) is finalized and ready for submission. The main focus of this study was whether or not it is possible to restore pioneer dune slack habitats and maintain the these species for many years.

2. The second study in the dune slack Koegelwieck on Terschelling focuses on the role of plant species in engineering their habitat and creating alternative stable states. This study challenges the concept of chronosequence in ecological research and will try to understand the role played by species such as Littorella uniflora in postponing a shift from one chronosequence stage to another. A manuscript will be ready for submission to a journal in early December 2011. The main content of this article is summarized in this report.

3. A further study on soil organic matter accumulation in dune slacks on all Wadden Sea Islands in reference to hydrological settings (seepage and infiltration sites), and vegetation types, is being conducted with collaboration with colleagues and will be finalized in October 2011.

4. An international third study is being conducted on species functional types in natural wetlands along the coast of Lake St. Lucia, in Mountain wetlands in Ethiopia (Bale Mountains) and in the Drakensburg Mountains in South Africa. We will compare the results with species functional types in dune slacks of the Wadden Sea Islands. This study will help us in understanding the role played by functional types in adaptation to climate change and also vital in unraveling functional response traits that are common in these habitats. This study will be finalized in February 2011.

5. In the General Discuussion of the thesis I will discuss the results of the long-term monitoring study on Ameland with long-term monitoring results on other wadden Sea islands which are not affected by soil subsidence. This will be completed before the end of August 2012.