Development of the benthic macrofauna community after tidal restoration at Rammegors

Progress report 1

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This report is part of the Rammegors monitoring project that was executed by the Centre of Expertise Delta Technology. This is a consortium formed by the University of Applied Sciences (Zeeland), Wageningen Marine Research, NIOZ and Deltares and financed by Rijkswaterstaat. This research was also partly financed by the Ministry of Public Affairs, within the framework of the Kennisbasis Programme System Earth Management (project KB-24-001-13).

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Contents

Summary

The managed realignment project Rammegors aims at re-establishing estuarine nature in a formerly freshwater wetland. For this purpose, a tidal inlet was constructed in the Krabbekreekdam to generate a reduced tidal influence that should allow the development of salt marsh area, tidal flat area and low energetic shallow sub-tidal. A central question of the Rammegors tidal restoration project is how the flora and fauna will develop in the area.

To understand the biotic and abiotic processes related to the tidal restoration in Rammegors, a monitoring programme is being executed by the Centre of Expertise Delta Technology. The monitoring focuses on the main biotic and abiotic developments in the area. This progress report only focuses on the early colonization of macrobenthic invertebrates in Rammegors.

Benthic macrofauna and sediment sampling took place in spring and autumn 2017 at twenty stations along 4 transects with varying distances to the outlet. A fast colonization of the benthic macrofauna was observed in Rammegors. Twenty and twenty-eight taxa were observed in the area in spring and autumn 2017 respectively. The communities significantly differed between spring and autumn. In spring densities reached high values, especially for the brackish mud shrimp *Manocorophium insidiosum* and mosquito larvae *Chironomidae*. In autumn these brackish species almost disappeared from the area. Their presence in autumn, even in low numbers, as well as the observation of the brackish cockle *Cerastoderma glaucum* indicate that, after the tidal restoration, parts of Rammegors are still under influence of brackish water. A relation was found between elevation and the benthic macrofauna development. Species richness showed an optimum around +0.4m NAP with lower values at both lower and higher elevations. Total density significantly increased with elevation, with highest total density at the higher elevations and a gradient in ecological richness was observed with higher richness further from the inlet.

As the spring community significantly differs from the autumn community, we will continue sampling in both seasons in 2018.

1 Introduction

Intertidal areas, like mudflats, sand flats, seagrass beds and saltmarshes, are productive components of coastal ecosystems, characterized by a high primary production, sustaining benthic organisms that serve as food to many fish and waterbird species (Heip et al. 1995, Herman et al. 1999). Because of their value, these habiats are worldwide protected by international conventions and legislations, e.g. the Ramsar convention for the protection of migratory birds or the European Natura2000 legislation. Also it is increasingly recognized that intertidal areas provide essential ecosystem services such as nutrient cycling, carbon storage, coastal protection and food production.
Despite these ecosystem services and protected status, intertidal areas are under pressure from human-induced changes that affect their quantity and quality (Lotze et al. 2006, Airoldi and Beck 2007). In the Oosterschelde estuary, intertidal areas are declining as a consequence of coastal defence infrastructures constructed in the 1980's. The construction of a storm surge barrier in the mouth of the Oosterschelde and two compartmentalization dams in the back of the system resulted in a decrease in tidal volume and tidal current velocities. Due to the decrease in tidal flow, the building-up of intertidal flats has reduced. Consequently, the tidal flats in the Eastern Scheldt are eroding since the construction of the storm surge barrier. By 2100 less than half of the tidal flat area will remain in the Oosterschelde (de Ronde et al. 2013). The Dutch government (Rijkswaterstaat), responsible for the management of this Natura2000 area, implements projects to conserve or increase the intertidal area in the Oosterschelde.

1.1 Tidal recovery at Rammegors

In the 1970s, the Rammegors area was still part of the Oosterschelde, characterized by deep gullies, tidal flats and marshes (Figure 1). Construction of the Schelde-Rijndijk and Krabbenkreekdam in 1972 cut off the area from the Oosterschelde and changed Rammegors into a freshwater wetland. To increase intertidal areas and marshes in the Oosterschelde, Rammegors was reconnected to the Oosterschelde in December 2014, by constructing an inlet to reintroduce tidal influences into the Rammegors area after 40 years (Figure 2). Three culverts (width: 3.5m; length: 60m) generate a reduced tide that allow the development of typical salt marsh vegetation. The culverts will be closed when the water level at the Oosterschelde side is around +1.65 m NAP. At the Rammegors side, a dam (Figure 3) was constructed near the inlet to limit the water outflow of the area, to ensure a shallow water area in the Rammegors (14 ha).

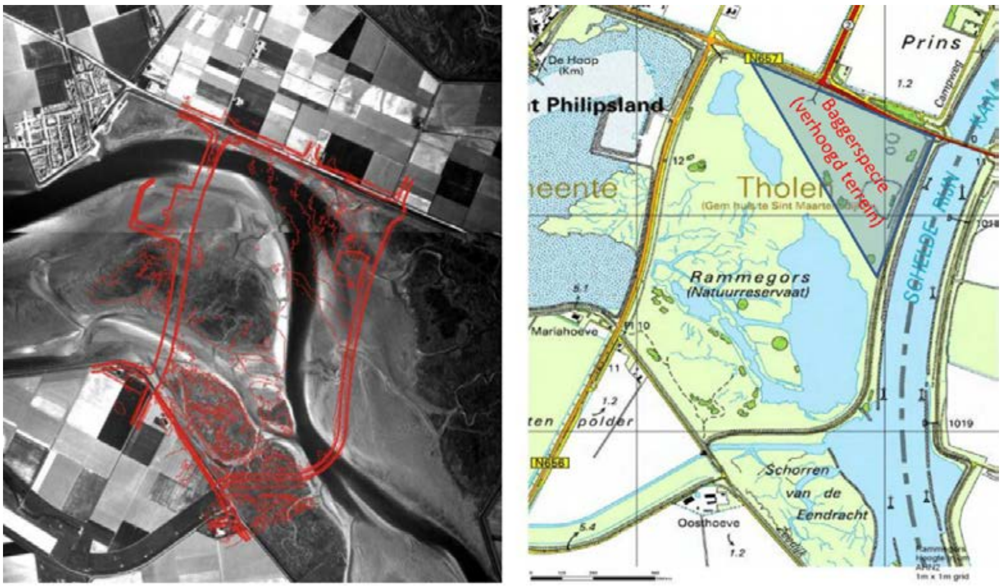


Figure 1 *Aerial view of the Rammegors area from 1966 (left) and the current situation (right). Source: Rijkswaterstaat*

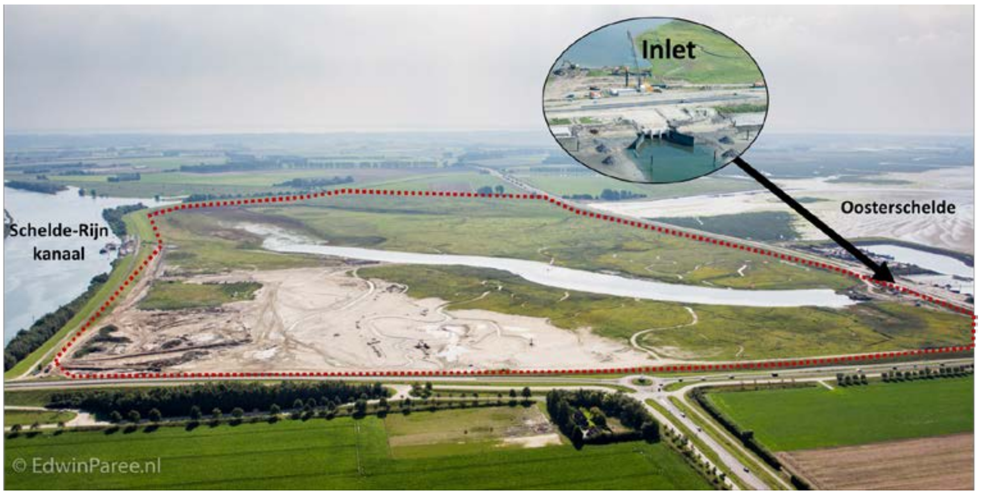


Figure 2 *Aerial picture of the Rammegors area (red dotted line) during the construction of the inlet (September 2014). Photo: Edwin Paree*

Figure 3 *Outflow of saltwater during ebb from the Rammegors (right side of photo) into the Oosterschelde through the culverts in the Krabbenkreekdam (left side of photo). Photo: Tom Ysebaert*

1.2 Technical problems

After the first opening on December 5th 2014, several unforeseen technical problems occurred.

- December 19th 2014: culverts closed due to scour of the sandy channel bottom at the Eastern Scheldt side. A stagnant water body remained in the Rammegors area, covering 50% of the area.
- February 18th 2015: culverts opened after construction (2th opening).
- April 22th 2015: culverts closed due to a breach in the dam at the Rammegors side. Culverts remained closed during most part of the year for safety reasons. In this period both stagnant water covering 100% of the Rammegors area, as well as no water (0%) was observed (pers. obs. NIOZ).
- December 5th 2016: culverts opened after construction works (3th opening).
- May 1st 2017: culverts closed for one week to replace a cylinder. Stagnant water covering 75% of the Rammegors area.
- September 1st 2017: culverts closed for one week to replace a sensor. Stagnant water covering 75% of the Rammegors area.

1.3 Monitoring

The development of the Rammegors area from a stagnant freshwater area into a tidal system with intertidal mudflats and salt marshes depends on many factors related to the characteristics of the former freshwater area and the conditions of the adjacent estuarine environment.

Important environmental factors include:
- Salinity
- Emersion or inundation time
- Sedimentation rate
- Sediment composition
- Drainage
- Hydrodynamic conditions (waves, currents)
- Initial soil conditions and presence of former vegetation
- etc.

To understand the biotic and abiotic processes related to the tidal recovery in Rammegors, a monitoring programme was executed by the Centre of Expertise Delta Technology. This is a consortium formed by the University of Applied Sciences (Zeeland), Wageningen Marine Research, NIOZ and Deltares and financed by Rijkswaterstaat. The monitoring focuses on the main biotic and abiotic developments in the area, which are possible salinization through the groundwater of the surrounding polders, vegetation and soil development, and colonization by the benthic organisms.
This progress report only focus on the early colonization of benthic macroinvertebrates in Rammegors. Due to the technical problems the first benthic sampling took place in spring 2017. This first progress report presents data from the benthic sampling done in spring and autumn 2017 after the 3th opening in December 2016.

1.4 Research questions

A central question of the Rammegors tidal restoration project is how the biology will develop in the area. Estuarine habitats will develop over time, but little is known about the spatial and temporal characteristics of this development. This report focus on the development of the benthic macrofauna. Intertidal and shallow subtidal habitats are important habitats for many species of macrobenthos, including polychaetes, molluscs and crustaceans. These organisms are central elements of the estuarine foodweb, as they are important consumers of phytoplankton and microphytobenthos, and on the other hand are a crucial food source for higher trophic levels such as birds and fish.
The intertidal benthic biota have to survive in a harsh and variable environment. Temperature, light, emersion time and water saturation vary not only according to tidal and diurnal rhythms, but also with seasonal and short-term weather variations. Physical stress is exerted by tidal currents and waves, the impact of which varies in space and time.

The main question related to the Rammegors project are:
1. Understanding the development of the benthic macrofauna in relation to:
   - The elevation gradient
   - The presence of the existing (remaining) freshwater vegetation
   - The presence of the developing salt marsh vegetation
   - The sedimentation rate in the area
2. Are benthic communities in Rammegors similar to benthic communities in similar ecotopes in the Oosterschelde?
3. How does the development of Rammegors compare to the development of Perkpolder in the Westerschelde? What can be learned about the design of de-polder areas?

This report focuses only on the early development of the benthic macrofauna following the first year after the 3rd opening in December 2016.

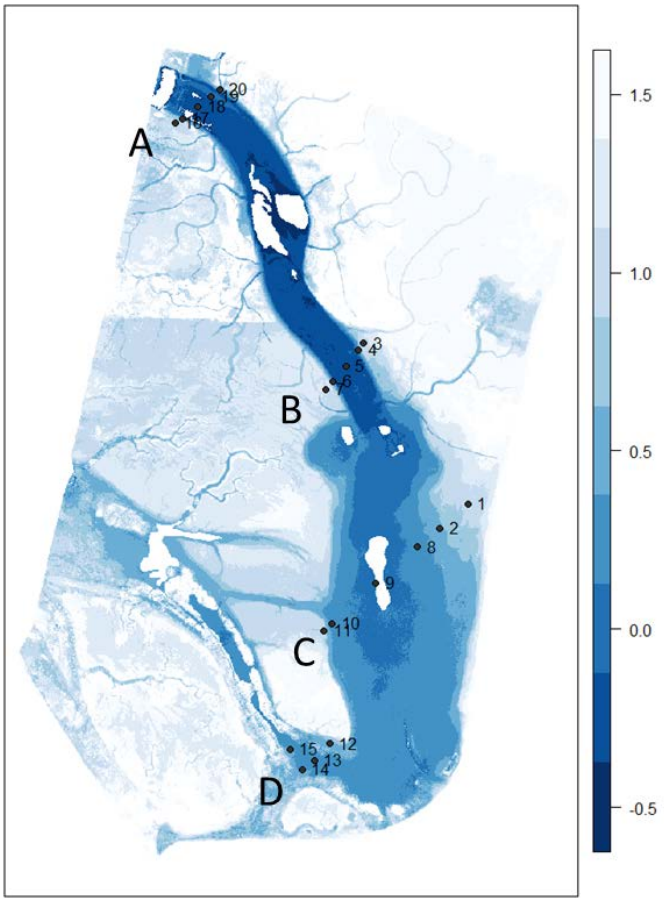
2 Material and Methods

2.1 Benthic sampling

A total of twenty sampling stations, along four transects with varying distances from the inlet, were chosen within Rammegors (Figure 2). The transects cross the main tidal creek and include the creek and creek banks without vegetation. Large parts of Rammegors are still covered with reed (Elschot et al. 2016) or remnant plant parts. Sampling stations were located between remnant plant parts (station 7 and 10), areas with newly established plants (*Salicornia europaea*) (station 3 and 11), permanently submerged areas (station 5, 9 and 13) or on the unvegetated tidal flat (stations 1, 2, 4, 6, 8, 12, 14, 15, 16, 17, 18, 19, 20). None of the sampling stations were located in areas covered in reed due to sampling difficulties. These twenty stations were sampled on May 17th (spring) and September 5th (autumn) 2017.
At each station the following parameters were collected/measured (Figure 3).

- Benthic macrofauna: 3 cores (pooled), 10 cm ø, 10-20 cm deep, sieved over 1 mm mesh;
- *Arenicola* density: average count of castings within 0.25m^2 (n=5).
- Sediment composition: 1 sediment syringe, 3 cm diameter, 3 cm deep;
- Chlorophyll *a* content: 3 sediment syringes (pooled), 1 cm diameter, 1 cm deep;
- Coordinates (X,Y) and elevation (Z) with dGPS.

Additionally salinity of the surface water was measured at each transect in the main gully.



Station	X	Y	Z
1	71906.357	402692.703	0.92
2	71848.636	402643.353	0.52
3	71694.952	403018.333	0.89
4	71685.138	403005.824	0.38
5	71659.972	402971.518	-0.17
6	71634.400	402939.939	-0.03
7	71618.638	402923.591	1.06
8	71802.162	402604.209	0.27
9	71719.838	402533.434	0.07
10	71631.750	402450.801	0.32
11	71615.019	402436.824	0.82
12	71626.082	402208.466	0.53
13	71596.203	402174.287	0.31
14	71570.863	402156.742	0.36
15	71546.930	402197.400	0.48
16	71315.877	403461.885	0.70
17	71329.853	403470.089	0.40
18	71361.714	403495.360	-0.29
19	71389.217	403515.274	-0.28
20	71405.804	403529.226	0.22

Figure 2 *The twenty benthic sampling points, along 4 transects (A till D), in Rammegors. X, Y, Z coordinates of the benthic sampling stations (Z in m NAP, situation September 2017) are presented in the right table.*

Sediment samples were wet weighted, freeze dried, and dry weighted, but still awaiting to be analysed for grain size with a Malvern (NIOZ). Chlorophyll *a* samples were stored at -80□C, freeze dried but still awaiting to be analysed. The benthic macrofauna samples were fixed with a buffered formaldehyde solution. In the lab the benthic macrofauna samples were sorted out and all specimens were identified, counted and (optionally) weighted. Based on the benthic macrofauna samples several biological indicators were defined and linked to abiotic parameters. We defined:

(1) Species richness, which is a measure of the diversity (number of different taxa) of the macrofauna community at each sampling station. Species richness is the number of taxa found in the sample. As this is dependent on the sampled surface it is not expressed per m^2.
(2) Density, which is the amount of individuals per species found in the cores, converted to number of species m^{-2}. Worm counts are based on the number of heads found in a sample. When only tails were found, we recorded this as 1 individual of this species.
(3) Biomass, which is the total wet weight converted to the total ash free dry weight in g m^{-2} using species specific conversion factors as described in Craeymeersch and Escaravage (2014).
(4) A comprehensive indicator ‘Ecological richness’, which combines the three biological indicators mentioned above (Ysebaert et al. 2016). The variables species richness, density and biomass were first standardized by subtracting the average of the variable from the observation and sequentially divided by the standard deviation of the variable.

Figure 3 *Benthic macrofauna sampling in the Rammegors area, May 2017 (top photos) and September (bottom photos) 2017. Notice the thick peat layer (top right photo). First cockels (C. edule and C. glaucum) observed in autumn 2017 (bottom right photo). Photos: Tom Ysebaert & Brenda Walles*

2.2 Statistical analysis

Multivariate

Changes in macroinvertebrate community composition was analysed with NMDS ordination (with the package "vegan" in R) which was run for 20 iterations at k=2 (decreased number of dimensions) before obtaining a solution. Abundance was square root transformed, and then submitted to Wisconsin double standardization to down-weight the importance of the highly abundant species allowing for the mid-range and rare species to exert influence on the calculation of similarity. Rare species, of which only one individual was found, were removed. Twenty-one taxa were included in the multivariate analysis.

Regression analyses are performed for species richness, density, biomass and ecological richness in relation to the elevation. This will also be done for the sediment characteristics, once the sediment data is obtained.

3 Results

3.1 Environmental conditions

The elevation of the twenty sampling stations ranged between -0.29 and +1.06 m NAP in autumn 2017. The bulk density (in g cm^{-3}) significantly increased ($p<0.001$) and the percentage water content significantly decreased ($p=0.008$) over time, which might be due to compaction of the sediment. Percentage water in the sediment increases with increasing distance from the inlet (Figure 4). Salinity of the surface water was high with 31 psu at each transect.

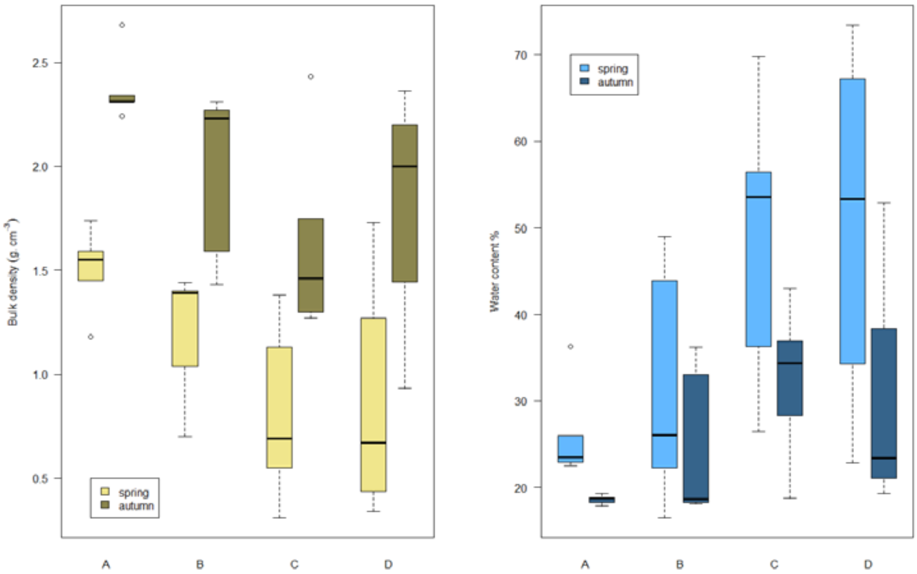


Figure 4 *Changes in bulk density (g cm^{-3}) and water content (%) in time and with increasing distance to the inlet. A, B, C and D refer to the different transects indicated in Figure 2.*

3.2 Benthic macrofauna

Species richness
In spring 2017, a total of 22 taxa were found in the 20 samples, 13 belonging to Annelida, 8 to Arthropoda and 1 to Mollusca. In autumn 2017, a total of 28 taxa were determined, 16 belonging to Annelida, 11 to Arthropoda, 1 to Cnidaria and 4 to Mollusca (Table 1). On average, number of taxa per station decreased from 9,6 ± 0,9 (mean ± SE) taxa per station in spring to 5.9 ± 0.7 taxa in autumn. Species richness showed a significant relation with elevation, with an optimum around +0.4m NAP and lower values at both lower and higher elevations (Figure 5). Total density in autumn also showed a significant relation with elevation, with higher densities at higher elevations.

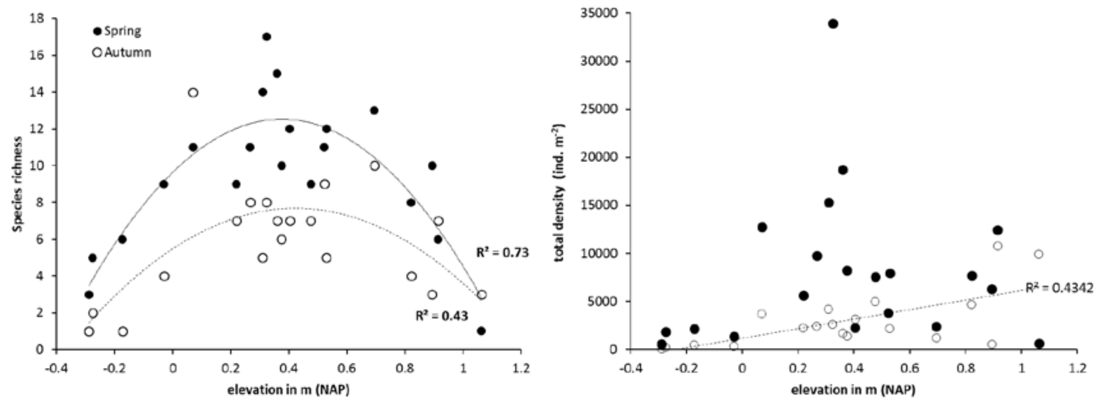


Figure 5 *Left: Species richness along an elevation gradient (in m NAP). Lines represent polynomial regression lines for the macrofauna community in spring ($F_{3,16}$=15.38, p<0.001, solid line) and autumn ($F_{3,16}$=4.43, p=0.019, dotted line) in the Rammegors area. Right: Total density along an elevation gradient. In Autumn, total density significantly increases with elevation ($F_{1,18}$=13.81, p=0.002).*

Density

The total average density decreased from 8063 ± 1779 ind.m^{-2} (mean ± SE) in spring to 3041 ± 654 ind.m^{-2} in autumn 2017 (Table 1, Figure 6). In autumn the first bivalves (*Cerastoderma edule, Cerastoderma glaucum and Limecola balthica*) with shell lengths <10mm were observed in the area. The most common and abundant species in spring 2017, *Monocorophium insidiosum*, declined in autumn to only 1.5% of the density found in spring. The observed reduction of *M. insidiosum*, usually found in brackish waters (Crawford 1937), could indicate that the Rammegors area is transferring to a more saline environment. The same is true for the Chironomidae. However, the occurrence of the cockle *Cerastoderma glaucum*, commonly found in brackish water, indicates that part of the Rammegors area is still brackish.

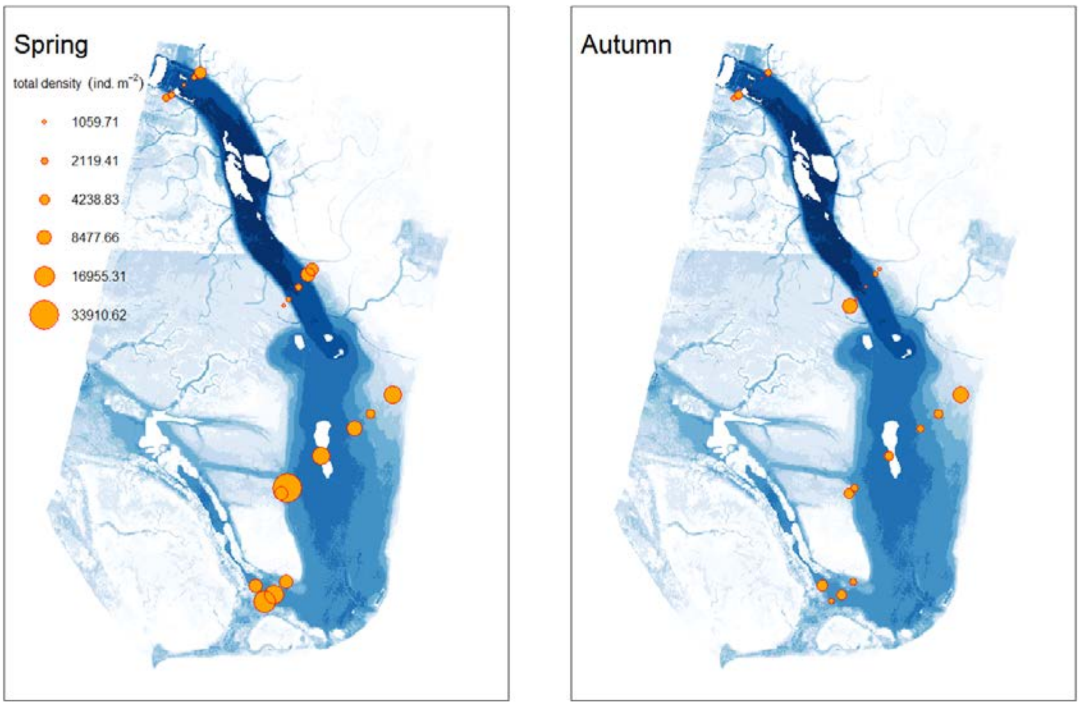


Figure 6 *Spatial map of total density (ind. m^{-2}) found at each sampling station at the Rammegors area in spring and autumn 2017.*

Table 1 Observed species/taxon in the Rammegors area with their occurrence (% of the 20 samples) and the average density of each species/taxon observed in spring and autumn 2017.

Species/taxon	occurence %		Density ± SE (ind. m^{-2})	
	spring	**autumn**	**spring**	**autumn**
Arenicola marina	80	30	254 ± 74	45 ± 17
Monocorophium insidiosum	80	10	2988 ± 1007	45 ± 35
Chironomidae	75	10	1462 ± 495	11 ± 9
Hypereteone foliosa	75	50	149 ± 42	57 ± 22
Capitella capitata	70	30	172 ± 43	47 ± 23
Hediste diversicolor	65	80	265 ± 107	719 ± 191
Nereis	65	60	359 ± 182	306 ± 117
Polydora cornuta	65	10	178 ± 59	13 ± 11
Oligochaeta	60	5	1367 ± 634	246 ± 246
Pygospio elegans	55	20	161 ± 53	15 ± 8
Peringia ulvae	45	45	132 ± 50	1231 ± 535
Gammarus	35	0	68 ± 40	
Microdeutopus gryllotalpa	35	5	270 ± 170	11 ± 11
Streblospio benedicti	35	30	157 ± 74	64 ± 36
Eteone	30	5	23 ± 9	2 ± 2
Gammarus locusta	30	0	23 ± 9	
Heteromastus filiformis	20	60	17 ± 11	157 ± 91
Idotea	15	0	11 ± 7	
Insecta	5	10	2 ± 2	4 ± 3
Phyllodoce mucosa	5	5	4 ± 4	4 ± 4
Praunus	5	0	2 ± 2	
Actiniaria	0	5		2 ± 2
Alitta succinea	0	5		2 ± 2
Alitta virens	0	40		34 ± 13
Aphelochaeta marioni	0	10		6 ± 5
Carcinus maenas	0	10		4 ± 3
Cerastoderma edule	0	10		4 ± 3
Cerastoderma glaucum	0	5		2 ± 2
Corophium volutator	0	5		2 ± 2
Crangon crangon	0	5		2 ± 2
Limecola balthica	0	20		11 ± 5

Biomass

The total average biomass in spring (6.3 ± 1.2 g Afdw.m^{-2}) and autumn (5.7 ± 1.0 g Afdw.m^{-2}) were comparable (Figure 7). A decrease in biomass was observed for 10 of the 11 stations located below +0.39 m NAP, whereas an increase in biomass was observed for 7 of the 9 stations located above +0.39 m NAP.

Community changes

The n-MDS based on sampling moment showed a clear separation among sampling moments (Figure 8). The community in spring significantly differed from the community in autumn. The same separation exist among the transects in spring and autumn. Eclipse of transect A were closed to each other, indicating smallest dissimilarity in benthic community composition near the inlet.

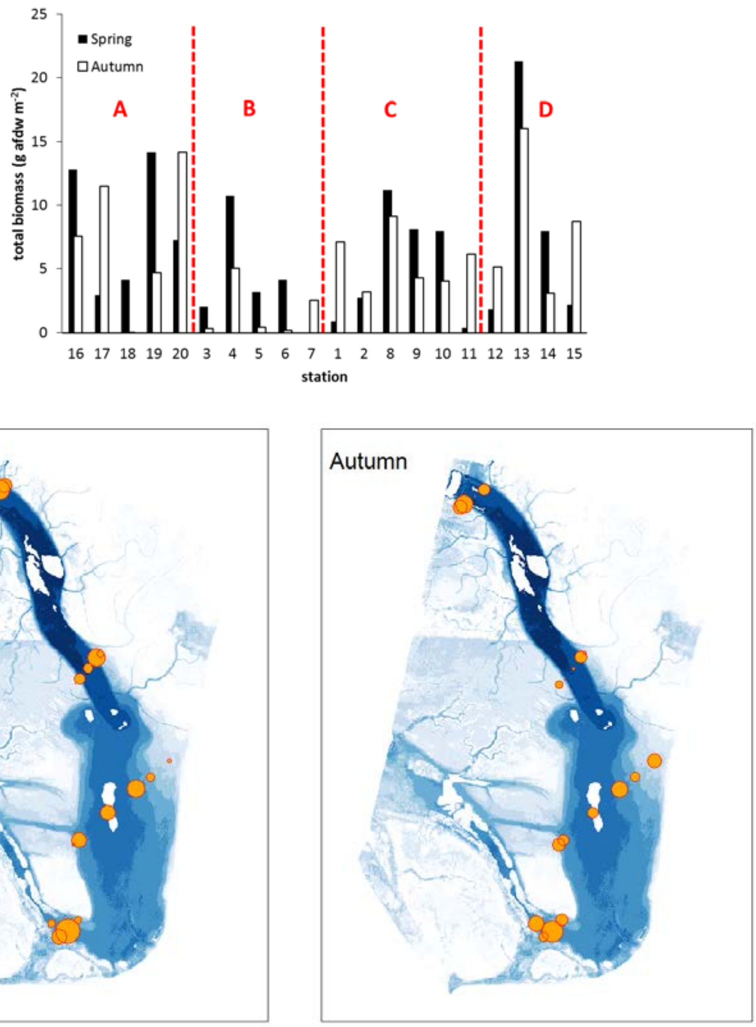


Figure 7 *Total biomass (g Afdw.m^{-2}) at each sampling station at the Rammegors area in spring and autumn 2017.*

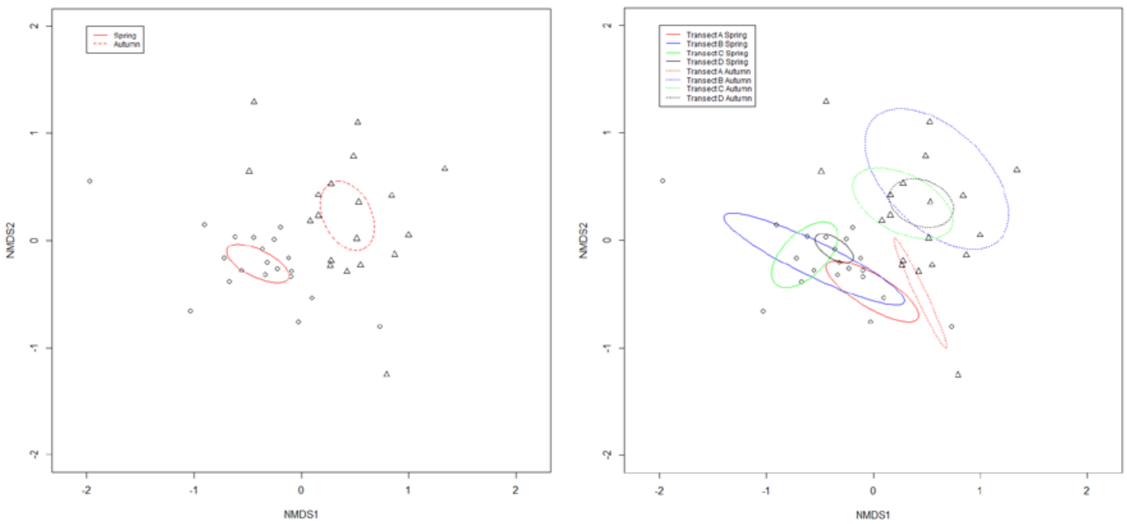


Figure 8 *nMDS-plot of the changes in benthic community composition from spring (circles) till autumn (triangles) 2017 (left) for the four transects (right) based on density data (Stress=0.16, k=2). Each point represents a sampling station and the distance between the points is a measure of the dissimilarity in benthic community composition. The eclipses denote the 95% confidence interval for each particular transect in each season.*

Ecological richness

There is a gradient in ecological richness, with higher richness further from the inlet, figure 9.

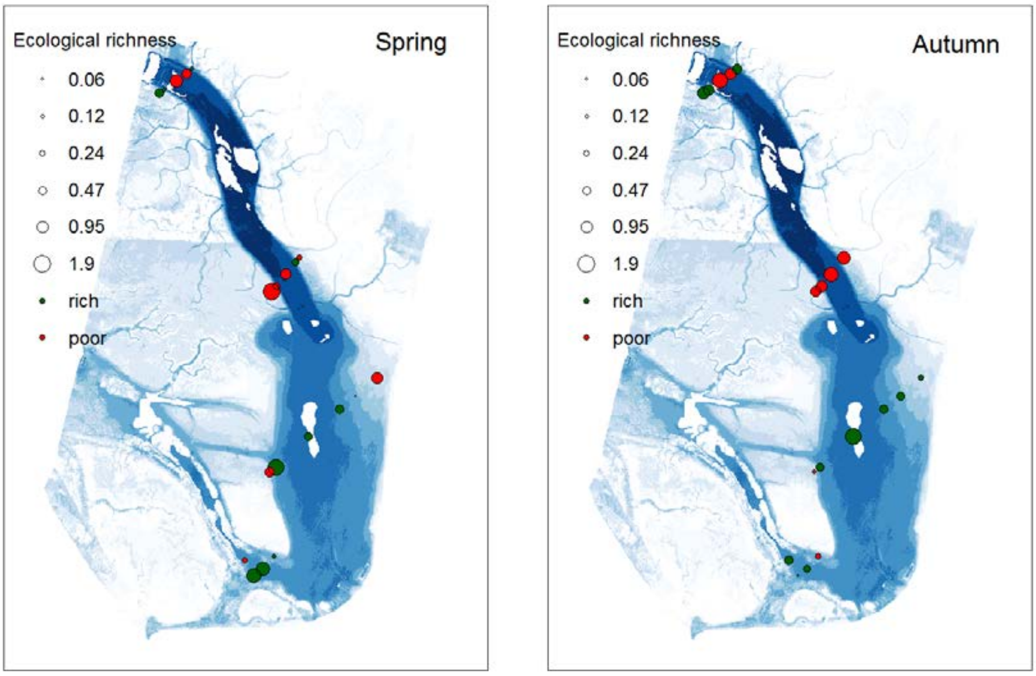


Figure 9 *Distribution map of ecological richness in the Rammegors area in spring and autumn 2017. The radius of the circles is proportional to the ecological richness, green circles are positive values, red circles are negative values.*

4 Conclusions and recommendations

A fast colonization of the benthic macrofauna was observed in Rammegors. Twenty and twenty eight taxa were observed in the area in spring and autumn 2017 respectively, based on a sampling of 20 stations. The communities significantly differed between spring and autumn. In spring densities reached high values, especially for the brackish mud shrimp *Manocorophium insidiosum* and mosquito larvae *Chironomidae*. In autumn these brackish species almost disappeared from the area. Their presence in autumn, even in low numbers, as well as the observation of the brackish cockle *Cerastoderma glaucum* indicate that, almost a year after the tidal restoration, parts of Rammegors are still under influence of brackish water.

Benthic macrofauna development shows a relation with elevation. An optimum of species richness was found around 0.4m NAP with lower values at both lower and higher elevations. Total density significantly increases with elevation, with highest total density at the higher elevations. For the ecological richness a gradient was observed with higher richness further from the inlet.

As the spring community significantly differs from the autumn community, we will continue sampling in both seasons in 2018. A 5th transect at the fare end of the channel could give more insight in the observed gradient in ecological richness. Salinity is high (31 psu) in the main channel of Rammegors. In future monitoring, it will be interesting to link the benthic community with salinity in the sediment (measured by the HZ), to understand the occurrence of brackish species.

Acknowledgement

This report is part of the Rammegors monitoring project that was executed by the Centre of Expertise Delta Technology. This is a consortium formed by the University of Applied Sciences (Zeeland), Wageningen Marine Research, NIOZ and Deltares and financed by Rijkswaterstaat. This research was also partly financed by the Ministry of Public Affairs, within the framework of the Kennisbasis Programme System Earth Management (project KB-24-001-13).

5 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2008 certified quality management system (certificate number: 187378-2015-AQ-NLD-RvA). This certificate is valid until 15 September 2018. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V.

Furthermore, the chemical laboratory at IJmuiden has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2021 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation. The chemical laboratory at IJmuiden has thus demonstrated its ability to provide valid results according a technically competent manner and to work according to the ISO 17025 standard. The scope (L097) of de accredited analytical methods can be found at the website of the Council for Accreditation (www.rva.nl).

On the basis of this accreditation, the quality characteristic Q is awarded to the results of those components which are incorporated in the scope, provided they comply with all quality requirements. The quality characteristic Q is stated in the tables with the results. If, the quality characteristic Q is not mentioned, the reason why is explained.

The quality of the test methods is ensured in various ways. The accuracy of the analysis is regularly assessed by participation in inter-laboratory performance studies including those organized by QUASIMEME. If no inter-laboratory study is available, a second-level control is performed. In addition, a first-level control is performed for each series of measurements.
In addition to the line controls the following general quality controls are carried out:

- Blank research.
- Recovery.
- Internal standard
- Injection standard.
- Sensitivity.

The above controls are described in Wageningen Marine Research working instruction ISW 2.10.2.105. If desired, information regarding the performance characteristics of the analytical methods is available at the chemical laboratory at IJmuiden.

If the quality cannot be guaranteed, appropriate measures are taken.

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Justification

Report C110/17
Project Number: 4313100022

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

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Scientific researcher

Signature:

Date: 20/12/2017

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Wageningen Marine Research is the Netherlands research institute established to provide the scientific support that is essential for developing policies and innovation in respect of the marine environment, fishery activities, aquaculture and the maritime sector.

Wageningen University & Research:
is specialised in the domain of healthy food and living environment.

The Wageningen Marine Research vision
'To explore the potential of marine nature to improve the quality of life'

The Wageningen Marine Research mission

- To conduct research with the aim of acquiring knowledge and offering advice on the sustainable management and use of marine and coastal areas.
- Wageningen Marine Research is an independent, leading scientific research institute

Wageningen Marine Research is part of the international knowledge organisation Wageningen UR (University & Research centre). Within Wageningen UR, nine specialised research institutes of the Stichting Wageningen Research Foundation have joined forces with Wageningen University to help answer the most important questions in the domain of healthy food and living environment.