# Progress report: Rammegors tidal Restoration.

## Phase 2


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# Contents

# Nederlandse samenvatting

In het Rammegors is het getij na ruim 40 jaar weer teruggebracht. Dit heeft de nodige veranderingen met zich mee gebracht. Het zoute water dat het gebied binnen stroomt, zorgt ervoor dat het terrein weer onder invloed staat van erosie en sedimentatie. Daarnaast past het vegetatiepatroon zich aan de zoute condities aan. Nieuwe soorten vogels en bodemdieren bevolken het gebied en ook de omwonende menselijke bevolking krijgt te maken met veranderingen. In de periode 2015-2018 (fase 1) zijn de ecologische ontwikkelingen en de effecten op het grond- en oppervlaktewater binnen het gebied en in het aangrenzende agrarische gebied gemonitord. Begin 2019 presenteerde het consortium van onderzoeksinstellingen de resultaten. Aan het eind van fase 1 bleek het gebied nog volop in ontwikkeling.

De voorliggende tussenrapportage voor fase 2 (2019 - 2024) bouwt voort op het eerste project en is uitgevoerd door hetzelfde consortium als in Fase 1. Het doel van de monitoring is om een breed beeld te vormen van de veranderingen die plaatsvinden in het gebied op middellange termijn van 10 jaar. De ingewonnen data zijn een bron voor kennisontwikkeling die gebruikt kan worden bij vergelijkbare projecten in de toekomst en voor het onderwijs. Bestaande monitoringsactiviteiten van Rijkswaterstaat zijn in dit monitoringsplan meegenomen.

Dit project richt zich op de belangrijkste biotische, abiotische en sociaal-economische veranderingen in het gebied. Dit zijn: verzilting via het grondwater, vegetatie- en bodem-ontwikkeling, kolonisatie van het gebied door bodemdieren, gebruik van het gebied door vogels en vissen, en de menselijke beleving/maatschappelijke acceptatie. Overige ontwikkelingen zoals het gebruik van het gebied door zoogdieren en insecten zijn in sterke mate afhankelijk van deze belangrijkste ontwikkelingen en zijn in dit rapport niet nader onderzocht.

**Vegetatie ontwikkeling**
Na 40 jaar is het getij in Rammegors hersteld. Hierdoor is de vegetatie aan het veranderen, van een vegetatie kenmerkend voor een zoet systeem naar vegetatie kenmerkend voor een zout getijde systeem. Eerder onderzoek heeft aangetoond dat de condities geschikt zijn voor de vestiging van schor-vegetatie. Het doel van het vervolg onderzoek is om patronen in het landschap te identificeren met behulp van drones. Deze patronen kunnen dan gerelateerd worden aan de ontwikkeling van vegetatie. Vegetatieopnames zijn in 2020 op 18 punten binnen het projectgebied uitgevoerd. De vegetatieontwikkeling wordt gebiedsdekkend in kaart gebracht met behulp van een multispectrale camera waarbij een drone wordt gebruikt als platform (lage-hoogte remote sensing). Daarnaast zijn de sedimenteigenschappen aan de oppervlakte bepaald en is de penetratieweerstand tot een diepte van 0.8 m op deze punten gemeten. Deze data, aangevuld met gegevens over de ondergrondse ontwikkelingen in waterstand en -kwaliteit, zullen in de tweede fase van het project worden gebruikt om te onderzoeken of er een relatie is tussen de ontwikkelingen in bodemeigenschappen en de vegetatieontwikkeling. Hiervoor is eerst een verdere vegetatie-ontwikkeling nodig

**Bodemleven**

Intergetijdengebieden vormen het leefgebied van veel soorten bodemdieren (macrozoöbenthos), zoals wormen, schaal- en schelpdieren. Het macrozoöbenthos vormt het belangrijkste voedsel voor een groot aantal soorten steltlopers, die bij laag water hun voedsel zoeken op de slikken en zandplaten. Het macrozoöbenthos is een goede indicator voor de ecologische kwaliteit van intergetijdengebieden. Het macrozoöbenthos is dan ook één van de kwaliteitselementen voor het bepalen van de ecologische toestand van overgangs- en kustwateren binnen de Kaderrichtlijn Water. Inzicht in de (ontwikkeling van) benthossamenstelling (soortenrijkdom, aantallen, biomassa's) in het Rammegors is dan ook een geschikte graadmeter om het ecologisch functioneren van het gebied te bepalen. Een belangrijke vraag in Fase 2 is hoe het macrozoöbenthos zich op middellange termijn (4-10 jaar) verder ontwikkelt. 24 monsterpunten zijn met een steekbuis op 5 transecten door het gebied in het voor- en na- jaar van 2017 en 2018 genomen (Fase 1) en nog eens 24 in het najaar van 2020 (Fase 2). Hierbij zijn sterke veranderingen in de soortensamenstelling van het gebied geobserveerd.

Een grote reductie in het aantal brakwater vlokreeftjes (*M.insidiosum)* en muggenlarven (*Chironomidae*) gecombineerd met een toename van wadkreeftjes (*C. volutator)* liet tijdens Fase 1 zien dat Rammegors vijf maanden na de derde opening nog steeds brakwaterkarakteristieken had maar dat een transitie naar een zoutwater-ecoysteem gaande was. In 2018 domineerden vooral wadslakjes (*Peringia ulvae),* Wadkreefjes en de veelkleurige zeeduizendpoot (*Hediste diversicolor*).

De bemonstering in Fase 2 liet zien dat wadkreeftjes helemaal uit het gebied zijn verdwenen en dat er nieuwe soorten dominant zijn, waaronder de borstelworm *Aphelochaeta* de meest opvallende dichtheden vertoond. Wadslakjes en de veelkleurig zeeduizendpoot laten vergelijkbare dichtheden en verspreidingen zien als tijdens eind Fase 1. Schelpdiersoorten, waaronder het nonnetje (*Limecola balthica),* die zich tijdens de eerste fase in het gebied gevestigd hebben in de tweede fase een hogere gemiddelde lengte. Ook de tere dunschaal, die in eerdere metingen nog ontbrak was in 2020 de meest voorkomende schelpdiersoort.

De soortenrijkdom was positief gecorreleerd met een aantal omgevingsfactoren, waaronder bulk dichtheid (compactheid van het sediment), hoogteligging en korrelgrootte. Hierbij vertoonde de soortenrijkdom de hoogste waarde rond de 0.4 m NAP en nam de biomassa toe met de hoogteligging. Hoewel de bulk dichtheid door de jaren heen is veranderd laat elk individueel jaar een afnemende trend zien waarbij lagere bulk dichtheden significant de lagere dichtheden in monsterpunten verklaren. Bij bulkdichtheid waarden boven de 1.5 g/cm$^3$ worden dan ook consistent zeer lage dichtheden geobserveerd. Onduidelijk is of de hogere bulk dichtheden lagere dichtheden veroorzaakten of dat een andere omgevingsfactor dit veroorzaakte en de lagere bulkdichtheden juist een resultaat zijn van de lage benthos dichtheden.

Gemeenschapsanalyse (NMDS) liet zien dat de soortengemeenschap in de eerste fase tussen het voorjaar en najaar van 2017 sterk veranderd is. Daaropvolgende bemonsteringen lieten geen significante veranderingen zien, wat impliceert dat veranderingen geleidelijker verlopen.

**Vis**

Kwelders vormen een belangrijk habitat voor een aantal vissoorten. Rammegors is in ontwikkeling naar een kwelder en is daarmee binnen de Oosterschelde een uniek gebied waarbij vissen vrij heen en weer kunnen zwemmen. In het najaar van 2020 en het voorjaar van 2021 hebben in totaal vier bemonsteringen plaatsgevonden waarbij er met fuiken en zegens is gevist. Hierbij zijn telkens zes fuiken 24 uur uitgezet, in zowel de eb- als vloed-richting om te onderzoeken welke vissen het gebied gebruiken. In totaal zijn negen vissoorten aangetroffen in het gebied, welk konden worden onderverdeeld in vier verschillende gildes: koornaarvis en haring (Marien juveniele - MJ), bot, grondel en zandspiering (Estuarien resident (ER)), paling en stekelbaars (Diadrome soort (CA)) en haring (Mariene seizoensgasten (MS)). Bij één soort, *Mugilidae spp.*, was het niet mogelijk om een gilde vast te stellen, doordat aangetroffen exemplaren niet tot exacte soort waren ge-identificeren en de soorten uit deze familie bij verschillende gildes behoren.

De aanwezigheid van juveniele bot (*Platichthys flesus*) in het voorjaar (<6cm) doet vermoeden dat het gebied als kinderkamer fungeert voor deze soort (Kroon 2009, Muus et al. 1999). Bot werd vooral tijdens de voorjaarsbemonstering aangetroffen, met de hoogste vangsten in april Dit kom overeen met de periode waarin jonge bot naar de kust trekt op zoek naar opgroeihabitat (februari tot juli).

Grondels (*Pomatoschistus spp.*) tot 4 cm zijn in zeer hoge getallen geobserveerd tijdens de najaarsbemonstering in okt 2020. Ook in de eerste bemonstering van voorjaar 2021 kwamen ze nog veel voor, maar bij de laatste bemonstering in juni ontbraken ze op alle monsterpunten.

Grote aantallen paling (*Anguilla anguilla)* werden tijdens elke bemonstering waargenomen. De hoogste aantallen waren in het najaar 2020 maar ook fuikvangsten in het voorjaar 2021, vooral mei en juni, lieten hogen aantallen zien. Een groot deel van de gevangen paling was tussen de 35-45 cm. Dit is de lengte waarop mannetjes geslachtsrijp worden, en ze zijn dan ongeveer tussen de 5 en 7 jaar oud (Tesch 1999). De meerderheid van de vangst bestond uit jonge vrouwtjes en/of bijna geslachtsrijpe mannetjes. Geslachtrijpe paling trekt in het najaar naar zee. Ook grotere palingen, veelal tot 65cm en een enkele van 75cm, werden aangetroffen in het gebied. Paling van deze lengteklassen zijn vrouwtjes, omdat vrouwtjes pas geslachtsrijp worden bij een lengte van rond de 55-60cm. Mannetjes migreren vóór het bereiken van deze lengte al naar zee. Op basis van de vangstgegevens is het aannemelijk dat het gebied fungeert als opgroei- en foerageer-gebied voor deze soort.

Tot slot zijn er ook relatief veel kornaarvissen (*Atherina presbyter*) gevangen, zowel in de fuik- als zegenbemonsteringen. Vangsten in het najaar van 2020 waren opvallend hoger en de lengtes opvallend kleiner. In het najaar werden koornaarvissen van 6-9 cm gevangen, waarschijnlijk dieren van ongeveer 1 jaar. Vrijwel alle individuen zijn voor hun tweede levensjaar geslachtrijp (Lorenzo & Pajuelo 1999). In het voorjaar werden vooral vissen met lengtes tussen de 9-11 cm gevangen, en namen de aantallen af in de loop van het voorjaar. Dit geeft aan dat het gebied vermoedelijk vooral gebruikt wordt door opgroeiende juvenielen van deze soort, en dat geslachtsrijpe individuen het gebied verlaten.

De resultaten laten zien dat (jonge) vissen Rammegors al snel hebben ontdekt. de rijke kwelderbegroeiing biedt bescherming aan jonge vis. Op basis van de uitgevoerde bemonsteringen kunnen we niet afleiden of de gevangen soorten over heel het getij heen actief gebruik maken van het gebied, of dat ze met het getij mee het gebied in en uit zwemmen/spoelen. Ook is het moeilijk conclusies te trekken over seizoensgebruik door vis, doordat er alleen in het voor- en najaar bemonsterd is.

**Grondwater**
De verandering van Rammegors van een zoet natuurgebied met een vast waterpeil naar een getijdegebied waarin twee keer per dag zout water naar binnen en naar buiten stroomt, heeft mogelijk effecten voor het grondwatersysteem in het omringende landbouwgebied. Het gemiddeld hogere peil kan uitstralen naar de omgeving waardoor mogelijk de grondwaterstand stijgt en ook meer kwel kan optreden. Daarnaast zal de ondergrond met zoet grondwater verzilten door infiltratie van zout water en ook dit heeft mogelijk consequenties voor de omgeving. De grondwater monitoring is er op gericht om deze

mogelijke effecten te kunnen volgen. Het meetprogramma bestaat uit het meten van grondwaterstanden (ondiep) en stijghoogte (grondwaterdruk op 10 tot 25 m diepte) en het meten van het zoutprofiel in de diepte met de zogenaamde EM-SlimFlex. Deze EM-SlimFlex metingen laten een zeer duidelijke en gestage verzilting zien van de ondergrond in Rammegors. Over het gehele meetdiepte-bereik (tot 15 m) wordt het aanwezige veelal zoete grondwater vervangen door zout grondwater door de infiltratie van Oosterscheldewater in Rammegors. De metingen van 2021 laten zien dat dit proces nog steeds gaande is. In het omringende landbouwgebied is er geen verzilting zichtbaar, op 3 van de 4 locaties blijft het grensvlak tussen zoet en zout grondwater stabiel op dezelfde diepte. Alleen voor het meetpunt in de Haaftenpolder, op circa 50 m van Rammegors is een duidelijk verandering zichtbaar, hier wordt de ondergrond zoeter. Het grensvlak is hier al ongeveer 4 tot 5 meter dieper komen te liggen. Vermoedelijk verdringt het infiltrerende zoute water, het aanwezige zoete grondwater richting het zuiden. Er wordt verwacht dat op den duur wanneer de ondergrond van Rammegors in zijn geheel is verzilt, ook de directe omgeving van Rammegors in een smalle zone rondom Rammegors zal verzilten. De grondwaterstands- en stijghoogtemetingen in het omringende landbouwgebied laten vooralsnog geen effect zien van het getijdegebied Rammegors. Maar een uitgebreidere analyse moet nog plaatsvinden. Zowel visuele analyse als de techniek tijdreeksanalyse geven nog geen aanwijzingen dat grondwaterstanden significant worden beïnvloed.

**Sociale aspecten**

Er gaat veel aandacht uit naar de wijze waarop kustlandschappelijke herinrichting, gericht op natuurherstel, zoals ontpolderen, de fysische en ecologische toestand van een gebied kan beïnvloeden. Fysieke ingrepen in het landschap, kunnen gevoelens van onbegrip veroorzaken en weerstand oproepen onder de lokale gemeenschap. Dit kan tot gevolg hebben dat natuurherstelprojecten vertraging oplopen of volledig moeten worden afgebroken. Ook kan weerstand tegen beleid en besluitvorming de verhoudingen tussen de gemeenschap en autoriteiten op scherp zetten. Het krijgen van inzicht in deze sociaalmaatschappelijke aspecten vormt een belangrijke aanvulling op de fysische en ecologische kennisontwikkeling rondom kustlandschappelijke herinrichting, en kan benut worden om toekomstige, vergelijkbare projecten te faciliteren.

Het hoofddoel van dit deelonderzoek is om te verkennen hoe de lokale gemeenschap nabij het Rammegors gebied de genomen natuurherstelmaatregelen beleven en waarderen. Om de uitkomsten van dit deelonderzoek in een breder perspectief te kunnen plaatsen, wordt een vergelijking gemaakt tussen opgedane inzichten met betrekking tot het Rammegors gebied en andere casuslocaties in Zeeland, waar natuurherstel plaatsvindt of heeft plaatsgevonden zoals Perkpolder en de Hedwige Prosperpolder.

Om te beginnen is een systematische verkenning van de bestaande wetenschappelijke literatuur uitgevoerd,  naar maatschappelijk relevante factoren die de veranderde beleving van (kust)landschappelijke herinrichtingen zouden kunnen verklaren. Daarnaast is gezocht naar methoden in eerdere onderzoeken om deze beleving nader te bepalen. Hieruit komt onder andere naar voren dat sociaal-demografische factoren en concepten als risicoperceptie, plaatsverbondenheid en institutioneel vertrouwen veelvuldig in onderzoek worden betrokken. Op basis van de uitkomsten van de systematische literatuurverkenning is een gestandaardiseerde enquête ontwikkeld, deze wordt momenteel, in de periode van November 2021 tot Mei 2022 uitgezet.

# 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 aquatic/marine bird species (Heip et al. 1995, Herman et al. 1999). Because of their value, these habitats are protected worldwide through international conventions and legislations, e.g. the Ramsar convention for the protection of migratory birds or the European Natura2000 legislation. Additionally, there is an increased sense of recognition to the essential ecosystem services these areas provide, such as nutrient cycling, carbon storage, coastal protection and food production.

Despite the 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 have been declining as a result of the construction of coastal defence infrastructures in the 1980’s. The construction of a storm surge barrier in the mouth of the Oosterschelde and two compartmentalization dams, at the landward side of the system, resulted in a decrease in tidal volume and tidal current velocities. Due to the decrease in tidal flow, the build-up of intertidal flats has since reduced. It is estimated that by 2100 less than half of the tidal flat area will remain in the Oosterschelde (de Ronde et al. 2013). In response, the Dutch government (Rijkswaterstaat), responsible for the management of the area, has been carrying out projects to conserve or increase the intertidal area in the Oosterschelde.

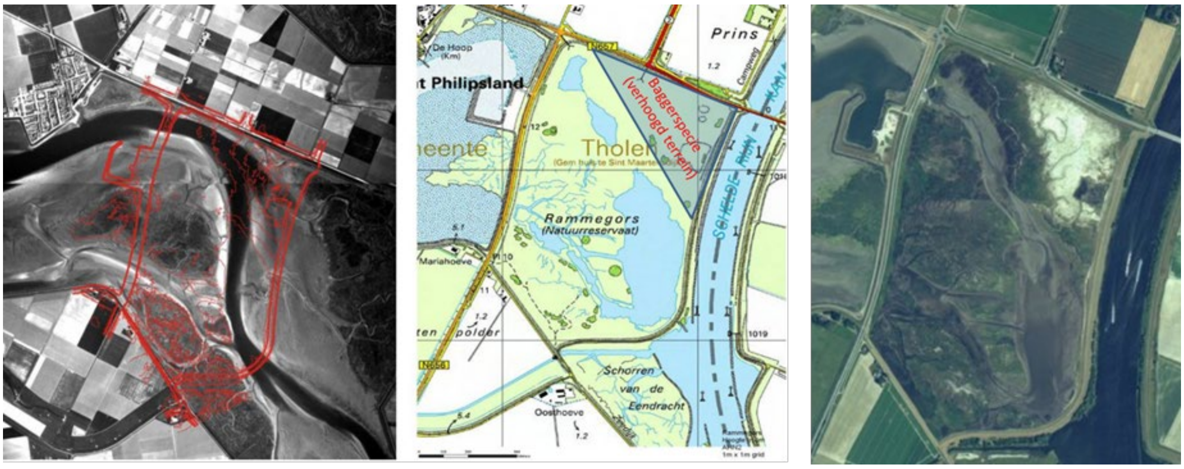



*Figure 1-1 Aerial view of the Rammegors area from 1966 with overlay of the current situation in red (left) and the situation before constructing the inlet (middle), and the current situation during low tide (right). Source: Rijkswaterstaat and satellietdataportaal*

## 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 1-2). Construction of the Schelde-Rijndijk and Krabbenkreekdam in 1972, cut off the area from the Oosterschelde and converted Rammegors into a freshwater wetland. To increase intertidal and marsh areas in the Oosterschelde, Rammegors was reconnected to the Oosterschelde in December 2014, by constructing an inlet. This reintroduced salt water and tidal influence into the area after 40 years (Figure 2). Since then three culverts (width: 3.5m; length: 60m) let the tidal flow enter the area, allowing for the development of typical salt marsh vegetation. The culverts close when the water level in the Oosterschelde is around +1.65 m NAP. On the Rammegors side of the culvert, a dam (Figure 1-3) was constructed near the inlet, to limit the water outflow of the area hereby ensuring a shallow water area remains (14 ha).

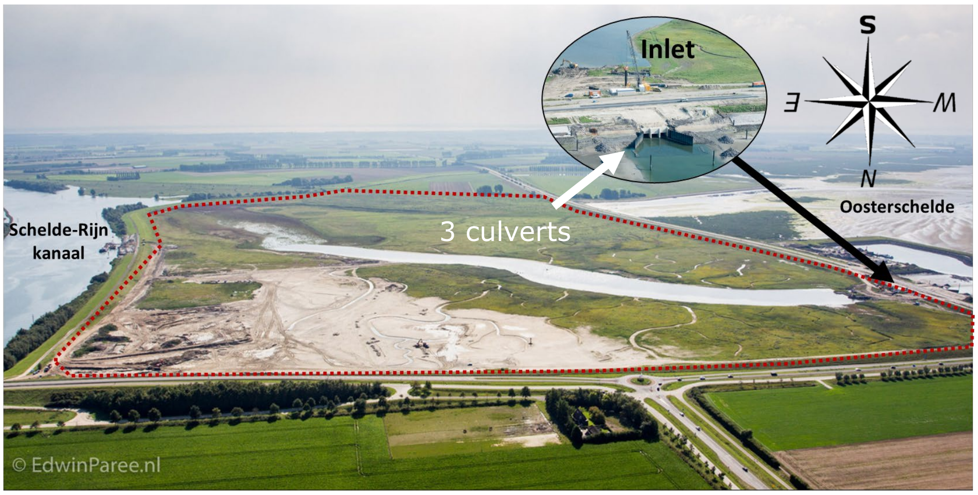



*Figure 1-2 Aerial picture of the Rammegors area (red dotted line) during the construction of the inlet (September 2014). Photograph was shot from the north side. Photo: Edwin Paree*

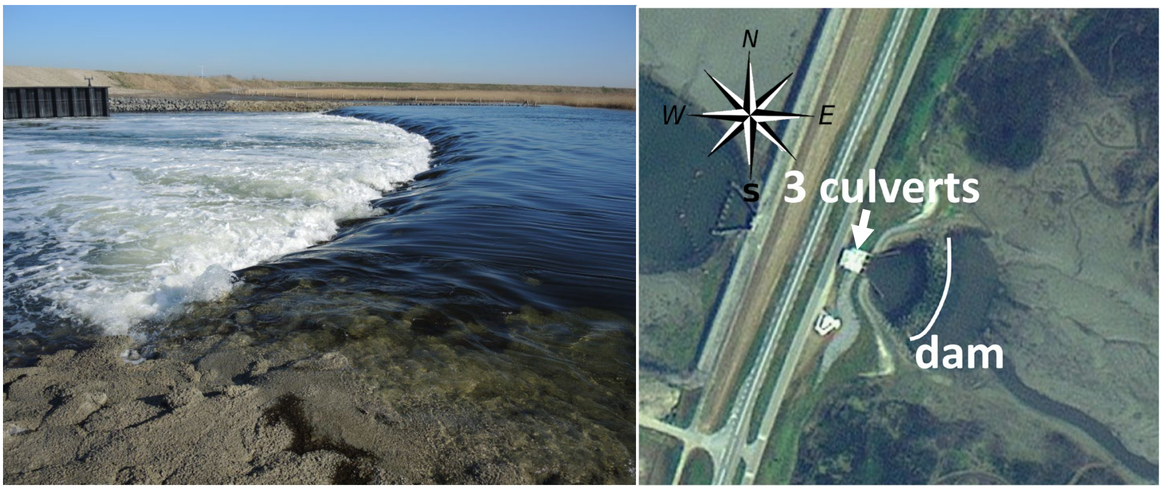



*Figure 1-3 Left: Outflow of saltwater during ebb from the Rammegors into the Oosterschelde through the three culverts. Photo: Tom Ysebaert. Right: Position of the dam in the Rammegors area and the three culverts in the inlet.*

## 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 were opened after construction works (**2nd opening**).
- April 22th 2015: culverts actively 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 complete dry situations (0% water cover) occurred.
- December 5th 2016: culverts opened after construction works (**3rd 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, is shaped by 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, Netherlands Institute for Sea Research (NIOZ) and Deltares and financed by Rijkswaterstaat. The monitoring focuses on the most likely biotic and abiotic developments in the area; salinization through the  of the surrounding polders, vegetation and soil development, and colonization by benthic organisms.

## 1.4 Research Goals

The overall question of this study is "how will the habitat develop in the Rammegors area?". This report is divided into multiple sections, each with their own research goals focussing on developments in vegetation, benthic, fish and bird fauna, groundwater and social aspects

### 1.4.1 Vegetation

After 40 years, tidal activity has been partially re-introduced. As a result of this, the vegetation associated with a freshwater wetland ecosystem is expected to and has already partly adapted to the vegetation associated with a saltwater wetland. The research conducted in phase 1 (van de Lageweg et al., 2019) concluded that the conditions are suitable enough for the establishment of salt-marsh vegetation. Sufficient seed was available and the hydrodynamic conditions were mild, indicating that establishment within Rammegors was expected to start relatively quickly after tidal introduction. First observations in the project area subsequently confirmed this (van de Lageweg et al., 2019; personal observations NIOZ).

In phase 2 we monitored at what rate, and which species of, freshwater vegetation is replaced by saltwater vegetation. The goal is to understand whether patterns in vegetation establishment can be recognised and how this relates to factors such as intertidal height and the presence/absence of certain freshwater species before the reintroduction of tide. A potential legacy effect is expected, where the presence of fresh water species will influence the establishment pattern and rate at which saltwater species occur. For example, wetland species like *Phragmitus australis* can cause significant soil changes due to their root morphology (Reijers et al., 2019). Hereby, oxygen levels and the presence of freshwater might be affected. These difference in soil characteristics might impact vegetational development and succession in these areas is expected to substantially differ in comparison to the vegetation dynamics from bare mud to salt marsh vegetation.

A second goal of this research is to develop a cost-effective way to monitor vegetation developments in similar salt marsh restoration projects. Hereby methods to monitor vegetational succession, based on low-altitude remote sensing techniques using a drone as a platform and a multispectral camera are investigated. Furthermore the possibility to use texture analysis (i.e., using neighborhood of pixels) to improve vegetation classifications will be investigated (Feng et al., 2015). These techniques might also improve vegetation classification based on the more straightforward Red Green Blue (RGB)-data that can be collected using off-the shelf cameras. Developing these techniques will benefit future marsh restoration projects. Moreover, these easy and cheap to employ low-altitude remote sensing techniques can be used to monitor effects of climate change due to sea level rise and changes in river run off, which is likely to result in salinity shifts along estuaries (Ross et al., 2015). Knowledge that is essential to develop, as changes in vegetation distribution can alter the functioning of these salt and fresh water wetlands, such as their role in coastal protection (Bouma et al., 2014).

### 1.4.2 Benthic Fauna

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. In this study we follow up on the benthic community and relate this to environmental changes.

### 1.4.3 Fish Fauna

Salt marshes can serve an important function as foraging/nursery grounds for young fish, due to the high food availability, presence of vegetation that can serve as protection and low currents. Tidal creeks in salt marshes have shown to be dominated by juvenile fish. In Mont-Saint-Michel (France) marsh creeks were found to be dominated by goby (*Pomatoschistus spp*.) and three-spined stickleback of all age groups, and mullet (*Mugilidae spp.*), sea bass (*Dicentrarchus labrax*) and flatfish in their very early life stages (Laffaille et al. 2000). Comparable results were also found in a study in the channels of Bull island, Dublin (Koutsogiannopoulou and Wilson 2007). Here catches were also dominated by goby, three-spined stickleback and juveniles of mullet and flounder (Koutsogiannopoulou and Wilson 2007). These species are defined as estuarine residents, indicating the marsh in these regions function as a habitat. A characteristic they have in common is their tolerance to a wide range of salinities and temperatures (euryhaline and eurythermal)(Laffaille et al. 2000).

Research in 'Het Verdronken Land van Saeftinghe', one of the largest intertidal areas of Europe, showed that species such as sea bass, flounder (*Platichthys flesus*), and goby actively use the tidal creeks of different salt marshes along the estuary as feeding ground (Hostens et al. 1996; Hampel et al. 2005). Analysis of the stomach contents of sea bass and flounder, caught in tidal creeks, revealed these fish mostly eat macrobenthic organisms and do not actively hunt for juvenile fish in marsh creeks. The presence of larger fish does not prevent the use of the salt marsh as a nursery by smaller peers or other species, and the predation rate does not outweigh the beneficial effects of the creeks for the nursery population within the creeks (Hampel et al. 2005).

The objective of the study was to understand the importance of salt marshes in the Oosterschelde serve for (juvenile) fish and how salt marshes are utilised. Monitoring in Rammegors was part of a bigger project where natural marshes were compared to manmade salt marshes (Mulder et al. n.d). The main research questions for Rammegors specifically are:

1. What is the ecological role of the developing salt marsh in Rammegors for fish?
   a. Which species utilise the area as nursery ground?
   b. Which species utilise the area as a feeding ground?
   c. Which species utilise the area as a spawning ground?
2. Does the vegetation development in the area affect the way fish utilise the area or the species composition?
3. Does the composition of the fish community in Rammegors change as the intertidal area develops towards a saltwater marsh?

### 1.4.4 Birds

It is important to understand the role Rammegors plays in functioning as a breeding, foraging and a tidal refuge area on a mid- to long- term period (4-10 years). Due the changes, the area has become less suitable as a breeding area for bird species (Arts *et al*. 2019). By using the RTK (Real-time kinematic positioning) monitoring data we would like to understand the following:

1. What species use the area as a tidal refuge area?
2. What species use the area as a breeding area?

3. How will the vegetational development affect the usage of the area for birds?

### 1.4.5 Groundwater

The objective of the groundwater monitoring is to determine the effects of the restoration of the tidal area on the groundwater system in and outside Rammegors.
The main research questions are:

1. What is the effect of the restoration of the tidal area on the fresh-salt distribution in the subsoil of Rammegors?
2. What is the effect of the restoration of the tidal area on the hydraulic heads, phreatic groundwater level, seepage in the agricultural area outside Rammegors?
3. What is the effect of the restoration of the tidal area on the fresh-salt distribution of the subsoil and surface water in the agricultural area outside Rammegors?

To answer the research questions, an extensive ground water monitoring network has been set up in and outside Rammegors. The network enabled to follow the developments of the fresh-salt distribution, hydraulic heads, ground water levels and surface water salinities. Furthermore, explorative model calculations were carried to predict effects on the ground water system in and outside Rammegors, of which the results are described in CoE (2019).

### 1.4.6 Social impact

Rstoration of coastal salt marsh ecosystems through dyke relocation and reestablishment of tidal flooding has become an increasingly important strategy to cope with sea-level rise and comply with biodiversity objectives. Most attention is usually directed to the biophysical and ecological changes associated with coastal realignment. While this line of research needs to be continued, it is equally important to gain insight into how changes of the physical environment are perceived by the local community.

Landscape interventions like coastal realignment are often controversial, politically sensitive and could give rise to strong (negative) emotional reactions from the nearby communities. A variety of factors could be driving these sentiments. In particular, an abrupt change of the landscape could be expected to disrupt place-related bonds and provoke feelings of disconnection with the social and physical surroundings (Brehm et al., 2013). Furthermore, concerns and objections could result from a lack of trust in authorities and planning procedures, perceived threats to local livelihoods and limited awareness of the coastal realignment process more broadly (Myatt et al., 2003; Roca and Villares, 2012; Schmidt et al., 2014).

A lack of societal support may result in the delay or complete abortion of planned coastal realignment projects and disturb relationships between authorities and the local community. In consequence, to facilitate coastal realignment interventions in the coming years, it is becoming  increasingly important to gain insight into how these interventions are perceived by local communities and what factors shape their perceptions.

Accordingly, in this study we investigate how the coastal realignment process that has taken place in the Rammegors area is perceived by the local community and other stakeholders in the area. We first examine how coastal realignment has changed the use and appreciation of the local landscape. Thereupon, we examine the level of societal support for coastal realignment and explore what factors determine support or opposition. To place our results in perspective, a comparison is drawn between the Rammegors area and other case study locations in Zeeland, including Perkpolder and the Hedwige Prosperpolder. The outcomes of this study will shed light on the social and societal feasibility of coastal realignment in Zeeland, and can be used to inform the planning and implementation of similar interventions, in Zeeland and elsewhere.

## 1.5 Progress delays

Due to the ongoing COVID situation, several results that were originally planned to be included in this progress monitoring report, are not. The pandemic has in particular cases caused substantial delays, either resulting in field work being postponed, practical work limited, equipment not arriving on time and/or laboratory work significantly backlogged due to a combination of both complete and partial closures of the facilities at various times. In other cases, the measurements were delayed but recently completely and are thus not yet ready. The status of each of the measurements within the project are indicated accordingly in this paragraph.

**Vegetation**
According to contract, multi spectral drone images were scheduled for 2020 and 2023. However, due to delays in delivering the multispectral camera related to the global COVID situation, no multispectral data could be obtained in 2020. Therefore, RGB-images were obtained instead. The multispectral images were collected one year later in August 2021. All obtained data still needs to be processed as the algorithms for image classification and segmentation are still in development. To facilitate the development of the methods and insights in the vegetation dynamics extra images will be taken every year. Thus, in 2019 and 2020 RGB-images are collected that will be used for developing the texture analysis approach for classifying vegetation. From 2021 onward (thus 2022, 2023 and 2024) multispectral imageries will be obtained of Rammegors. So next to the obligatory 2020 and 2023 datasets four additional vegetation maps will be constructed. From 2021 onward, no additional RGB-images will be taken as for the purpose of testing and developing the texture analysis the multispectral images can be transformed to emulate the RGB-images.

In short:

- RGB images – collected in 2020 and stitched (see results)
- Multispectral images – collected in 2021, classification in progress
- Drone image processing (script) – in progress

Together with the ground-truthing vegetational data, sediment characteristics data was collected in 2020. This was additional data to the monitoring plan that would enable to compare the results to other projects. Due to COVID-delays however these additional measurements have no yet been analysed.

In short:
- Penetrologger – collected but not yet processed
- Shear vane – collected but not yet processed
- 20-cm sediment cores – collected but not yet analysed in the lab
- Mud layer depth – collected but not yet processed

**Benthos**
Due to the COVID lockdown there has been a huge backlog on the processing of samples in the analytical lab and as a result, the statistical analysis of Chl-a concentrations and benthic ash free fry weight. The development in the soil properties will be updated in the final report.

In short:
- Chl-a – collected but not yet analysed in the lab.
- Benthic ash free dry weight – benthos collected but ash free dry weight not yet analysed in the lab

**Groundwater**
Most activities that encompassed the monitoring of the groundwater were performed according to schedule. One exception is the hourly surface salinity, which have been measured but not yet analysed and thus are missing from this report.

**Social**
In the spring/summer of 2021, the HZ Resilient Deltas research group administered the questionnaire in the field in the context of a research project (ReAshore, within the NWO program "Living Labs in the Dutch Delta") that is taking place in parallel to the research in Rammegors, Perkpolder and the Hedwige Prosperpolder. Processing and analysis of the collected data is currently taking place and will provide insight into the adequacy and statistical validity of the questionnaire. Upon completion of these adequacy and validity checks, the questionnaire will be finalized and administered nearby the Rammegors area as well as nearby Perkpolder and the Hedwige Prosperpolder. Data collection nearby the Rammegors area is scheduled for the period between November 2021 and May 2022.

# 2 Materials and Methods

## 2.1 Vegetation

### 2.1.1 Soil and vegetation at 18-point sampling scheme

Since the opening of Rammegors in 2014, soil properties and vegetational development have been monitored at 18 stations (Figure 2-1). At each station trough RTK-dGPS, surface elevation is being measured in m NAP with an accuracy of ±1 cm. Furthermore the grain size, bulk density and water content are being determined, in the top layer (3cm). A proxy for erodibility is obtained through a shear vane and the penetration resistance is measured, using a penetrologger, up to a depth of 80 cm using a 5 cm$^2$ cone of 60°. To align data on sediment properties with benthos developments the fieldwork has been carried out at the end of August. An overview of the data collected thus far can be observed in Table 2-1.

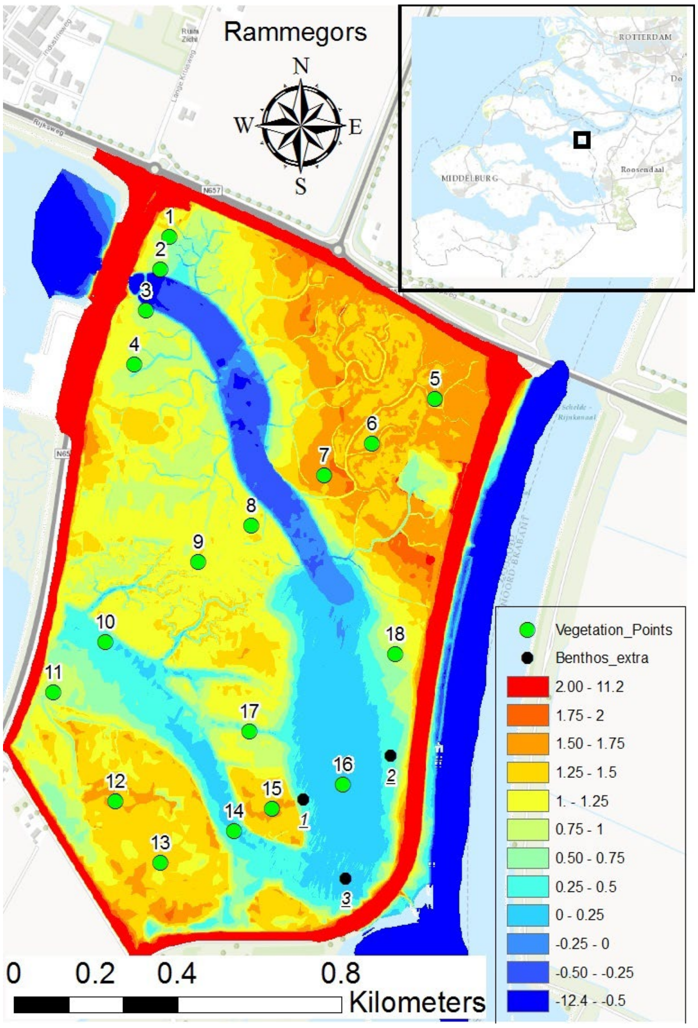



*Figure 2-1 18-point sampling grid for soil and vegetation properties*

### 2.1.2 Vegetation mapping using low-altitude remote sensing with a drone.

Vegetational development will be monitored through a remote sensing technique called low-altitude imaging, using a drone as the platform for a multispectral camera. The equipment used in low-altitude airborne approaches is relatively cheap (between €2,000.- and €20,000.-). Due to the low altitude of the drone, atmospheric interference or cloud cover is hardly an issue. Moreover, it is easy to employ, making it a flexible method for timing and executing 'flights' and obtaining images quickly and repeatedly. Nevertheless, despite these advantages, low-altitude remote sensing approaches are still not a common practice in ecology. In this project a method for texture analysis will be developed, as an approach for mapping tidal vegetation in salt-marsh environments. More information on the exact method of this can be found in Annex 1.

We will compare the method of texture analysis with the more conventional multispectral approach. It will be tested if texture analysis applied to the simpler RGB-data can rival vegetation classification based solely on multispectral data. If successful, texture analysis can be a valuable addition to the toolbox for remotely sensed monitoring of coastal vegetation and sediments.

*Table 2-1 Overview of the data that has been collected and processed since 2019.*

| Visiting date | dGPS | Sediment sample | Penetro-logger | Shear vane | Mapping vegetation | Drone |
|---|---|---|---|---|---|---|
| 2019/08/30 | | | | | | RGB |
| 2020/08/30 | X | X | X | X | X | RGB |
| 2021/08/30 | | | | | | Multispecral |

Needs to be processed

After the methods based on multispectral and texture analysis are developed, they will be used to map the vegetation development, i.e., looking specifically where the typical marsh-vegetation species gain or lose area and try to explain this development based on the measured surface and subsurface soil developments and properties. Currently classification of the images is taking place. The second multispectral drone imaging is scheduled to take place in 2023, after which developments can be described.

### 2.1.3 Collecting training data

Training data is required for the classification of the of vegetational species from the drone imaging. For this, a one-time field collection was conducted, where presence/absence vegetational data of species was collected at the 18-point locations in 2020 (Figure 2-1). At each point, 5 quadrats (1m$^2$) were laid out randomly within a 5m radius from the station. The observed vegetation was then identified to species level (Table 2-2). The purpose of this data is ground truthing, a method that uses known information to infer future patterns, and will be used as training data for the classification on the multispectral images.

*Table 2-2 Overview of vegetational species observed in Rammegors at the 18 sampling stations in 2020.*

| **Name** | **Dutch common name** |
|---|---|
| *Agrostis stolonifera* | Fioringras |
| *Aster tripolium* | Zeeaster (lamsoor) |
| *Atriplex littoralis* | Strandmelde |
| *Atriplex prostrata* | Spiesbladmelde |
| *Calamagrotis epigejos* | Duinriet |
| *Carduus spp.* | Distel |
| *Elymus athericus* | Zeekweek |
| *Eupatorium cannabinum* | Koninginnekruid |
| *Juncus gerardii* | Zilte Rus |
| *Mentha aquatica* | Watermunt |
| *Phragmites australis* | Riet |
| *Puccinellia maritima* | Gewoon kweldergras |
| *Salicornia procumbens* | Zeekraal |
| *Suaeda maritima* | Klein schorrenkruid |
| *Urtica spp.* | Brandnetel |

## 2.2 Ground water

The development of the intertidal area of Rammegors will possibly influence the groundwater characteristics in Rammegors and the surrounding area. In 2011 a monitoring program on phreatic groundwater levels for the two polders bordering Rammegors (Prins Hendrikpolder and Haaftenpolder) was set up. However, **phreatic groundwater** measurements are relatively shallow, and as infiltration takes place through the aquifer, an underground layer of permable soil, deeper measurements were necessary.In March 2016 the monitoring program was therefore extended by installing four deep piezometers in the polders, which measure the **hydraulic head**. In addition to this, piezometers were set up to also measure the fresh-salt distribution in the aquifer (indicated by red circles, Figure 2-3).

In May 2017, 5 deep piezometers were installed in Rammegors (Pb1-Pb5, Figure 2-3). The current monitoring program involves: hourly monitoring of 1. phreatic groundwater levels, 2. hydraulic heads, 3. surface water salinity and taking yearly measurements of the fresh-salt distribution using EM-SlimFlex.

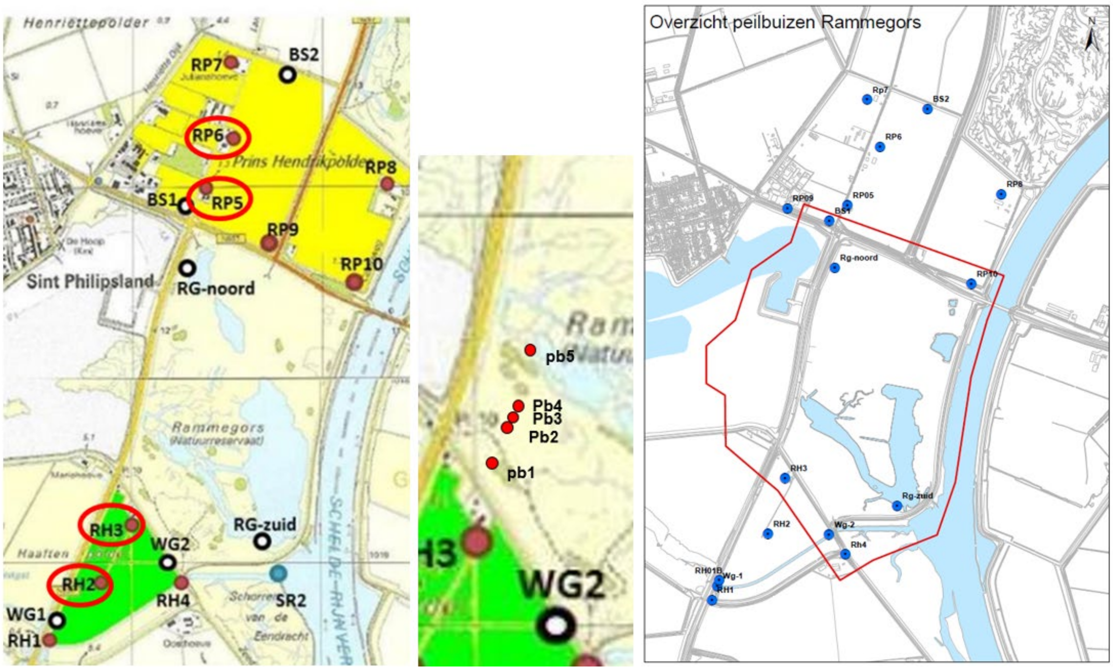



*Figure 2-2 The locations of piezometers in the Haaftenpolder (code RH) and the Prins Hendrikpolder (code RP) and in the tidal area (pb1-pb5). Red encirceled locations also measure the salt distribution in the aquifer.*

### 2.2.1 Phreatic groundwater level

The **phreatic groundwater level** is important as it controls the hydrological conditions for agriculture, nature and urban area. It determines crop damage during wet or dry conditions. Although the phreatic groundwater level is easy to measure, effects of changes, like the restoration of the tidal area, are difficult to extract from measured time series. This is due to the fact that measured values are strongly affected by precipitation, evaporation and drainage from ditches and tile drains. In general, this response is much larger than effects of interventions. At several locations in the agricultural area (Figure 2-3), phreatic groundwater levels have been measured since 2011 (Table 2-3).

### 2.2.2 Hydraulic head

The **hydraulic head** is the water pressure at a certain depth, and is situated at greater depths than the groundwater level and are measured in the so-called **aquifer**. Water level changes in Rammegors are expected to propagate through this aquifer. If no effects are visible in the measured hydraulic heads, then no effects on phreatic groundwater levels and seepage fluxes can be expected. The phreatic groundwater levels and hydraulic heads are measured with a frequency of one hour using a Diver.

### 2.2.3 Surface water salinity

At 4 locations, <u>the salinity (EC) of the surface water</u> was measured with a frequency of one hour using CTD-divers. The goal of these measurements is to monitor the salinity of the surface water coming from the Scheldt-Rijn canal, which is used for agriculture in the polder area.

### 2.2.4 Fresh – Salt Distribution

At four locations in the agricultural area (RH2, RH3, RP5, RP6) and five locations in the tidal area (PB1-PB5), the <u>fresh-salt distribution</u> in the subsoil was measured with the EM-SlimFlex tool Figure 2-2. The EM-SlimFlex is a borehole logging tool developed by Deltares and the German company Anatres which can be used in piezometers from 1.5 inch (3.8 cm) in diameter and therefore very suitable to monitor changes in the fresh-salt distribution. In the tool a primary electromagnetic (EM) field is generated by an alternating current in a 'transmitting' coil, which induces a secondary EM field in the subsurface. Both the primary and secondary fields are measured in a receiver coil. From the difference in phase and amplitude of the two EM fields the electrical conductivity of the subsurface can be determined. The EM-SlimFlex measurements are repeated every year and started in 2016. The measurements were corrected for temperature to a reference temperature of 25 Co, assuming a field temperature of 10.5$^{o}$C for the entire depth.

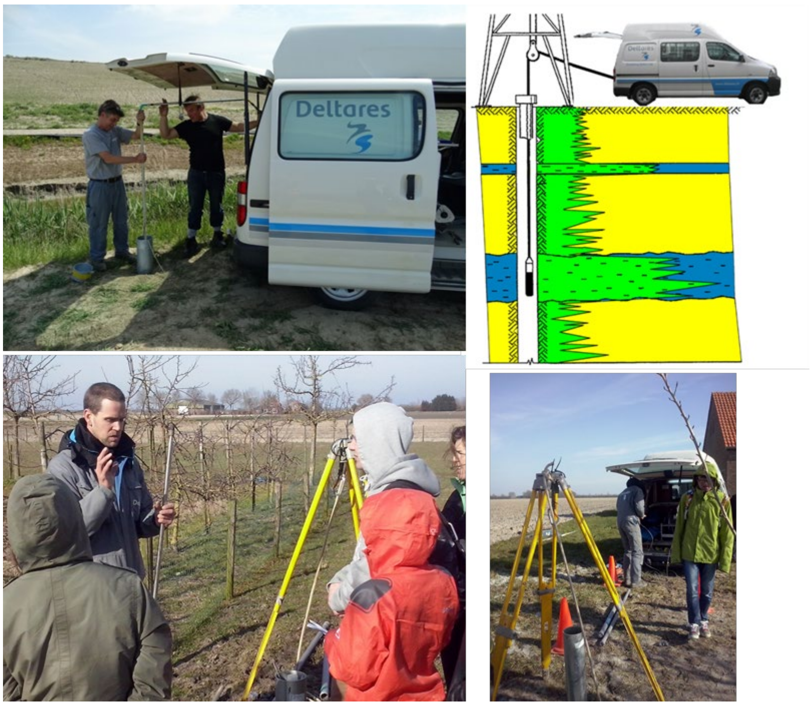



*Figure 2.2 SlimFlex-EM measurements in a piezometer to measure the salinity distribution in the subsoil (above).Explanation of the EM-SlimFlex-method to HZ-students in Rammegors*

### 2.2.5 Data analysis – time series model

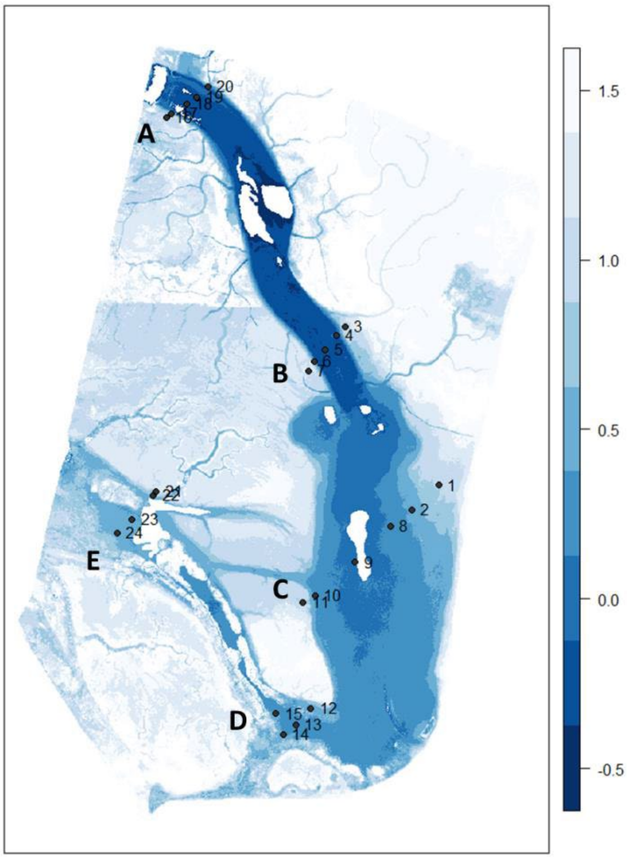
In order to determine effects of the development of the tidal area, **time series analyses** were applied to the measured groundwater level- and hydraulic head- data. Since precipitation and evaporation predominantly affect the dynamics of groundwater head time series, effects of other interventions can be difficult to see. These meteorological variations were therefore filtered out through time series analysis methods, pointing out other underlying effects. An elaborate description on the used time series model can be found in Annex II.

*Table 2-3 Available groundwater timeseries*

| | Name | Land surface [m NAP] | Screen relative to land surface [m] | Start timeseries | End timeseries |
|---|---|---|---|---|---|
| Haaftenpolder | RH01A | 0.24 | 2.5 | 18-7-2013 | 14-12-2018 |
| | RH02A | 1.12 | 2.5 | 15-11-2011 | 14-12-2018 |
| | RH02B | 1.12 | 2.5 | 16-12-2011 | 25-6-2021 |
| | RH02_deep | 1.13 | 8.0 | 4-4-2016 | 25-6-2021 |
| | RH02_deep | 1.13 | 23.0 | 14-12-2018 | 25-6-2021 |
| | RH03_shallow | 1.44 | 2.5 | 31-1-2013 | 20-7-2017 |
| | RH03_deep | 1.49 | 8.0 | 4-4-2016 | 25-6-2021 |
| | RH03_deep | 1.49 | 23.0 | 20-3-2019 | 25-6-2021 |
| | RH04A | 0.10 | 2.5 | 16-12-2011 | 14-12-2018 |
| Prins Hendrikpolder | RP05_shallow | 1.14 | 2.1 | 15-11-2011 | 30-11-2015 |
| | RP05_deep | 1.14 | 8.0 | 4-4-2016 | 14-12-2018 |
| | RP05_deep | 1.14 | 23.0 | | |
| | RP06_shallow | 1.50 | 2.1 | 15-11-2011 | 25-6-2021 |
| | RP06_deep | 1.50 | 8.0 | 4-4-2016 | 12-6-2020 |
| | RP06_deep | 1.50 | 23.0 | 23-5-2019 | 25-6-2021 |
| | RP07 | 1.44 | 2.1 | 15-11-2011 | 25-6-2021 |
| | RP082.1 | 1.10 | 2.1 | 15-11-2011 | 25-6-2021 |
| | RP09 | | 3.25 | 18-7-2013 | 20-12-2016 |
| | RP10 | | 3.25 | 18-7-2013 | 27-11-2017 |
| Tidal area | PB1_shallow | .. | 2 | 4-5-2017 | 25-6-2021 |
| | PB1_deep | 1.54 | 14 | 4-5-2017 | 25-6-2021 |
| | PB2_shallow | 1.3 | 2 | 4-5-2017 | 12-8-2018 |
| | PB2_deep | 1.31 | 14 | 4-5-2017 | 25-6-2021 |
| | PB4 | 0.82 | 14 | 4-5-2017 | 25-6-2021 |
| | PB5 | 0.6 | 14 | 4-5-2017 | 25-6-2021 |
| | RG11 | 2.84 | ? | 2-2-2017 | 14-12-2018 |
| | RG12 | | ? | 2-2-2017 | 14-12-2018 |

## 2.3 Benthic sampling

To quantify the colonisation of macrobenthic infauna and their community structure twenty stations, along four transects with varying distances from the inlet, were sampled within Rammegors in 2017 (Figure 2-4, A, B, C, D). In 2018 an additional transect (E, Figure 2-4) was added at the end of the creek. The transects cross the main tidal creek and include the creek and creek banks without vegetation. Large parts of Rammegors were 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, 13 and 23) or on the unvegetated tidal flat (stations 1, 2, 4, 6, 8, 12, 14, 15, 16, 17, 18, 19, 20, 21, 22 and 24). None of the sampling stations were located in areas covered in reed due to sampling difficulties. These twenty-four stations were sampled on May 17th (spring) 2017, September 5th (autumn) 2017, June 14th (spring) 2018 and September 3th (autumn) 2018.




| transect | station | x | y | z |
|---|---|---|---|---|
| A | 16 | 71316.0 | 403461.7 | 0.70 |
| A | 17 | 71327.6 | 403470.4 | 0.38 |
| A | 18 | 71358.6 | 403490.2 | -0.53 |
| A | 19 | 71380.2 | 403505.0 | -0.56 |
| A | 20 | 71403.7 | 403528.0 | -0.04 |
| B | 3 | 71694.9 | 403018.4 | 0.87 |
| B | 4 | 71676.3 | 402999.0 | -0.18 |
| B | 5 | 71652.5 | 402968.5 | -0.30 |
| B | 6 | 71629.1 | 402944.7 | -0.13 |
| B | 7 | 71617.2 | 402924.4 | 1.04 |
| C | 1 | 71893.2 | 402681.7 | 0.80 |
| C | 2 | 71836.1 | 402630.0 | 0.37 |
| C | 8 | 71790.7 | 402594.4 | 0.16 |
| C | 9 | 71715.8 | 402517.6 | 0.09 |
| C | 10 | 71631.5 | 402447.1 | 0.28 |
| C | 11 | 71605.1 | 402433.3 | 0.93 |
| D | 12 | 71622.3 | 402207.4 | 0.46 |
| D | 13 | 71589.9 | 402172.9 | 0.27 |
| D | 14 | 71564.0 | 402152.8 | 0.43 |
| D | 15 | 71548.2 | 402196.5 | 0.49 |
| E | 21 | 71295.0 | 402667.5 | 0.91 |
| E | 22 | 71288.9 | 402659.4 | 0.57 |
| E | 23 | 71242.8 | 402608.4 | 0.43 |
| E | 24 | 71211.6 | 402579.5 | 0.49 |

*Figure 2-3* The twenty four benthic sampling points, along 5 transects (A till E), in Rammegors (2 by 1 km) (left). X, Y, Z coordinates of the benthic sampling stations (Z in m NAP, situation September 2018) are presented in the right table. *Stations 21 to 24 were only sampled in 2018.*

Macrobenthic infauna was sampled using a cylindrical corer, with a a diameter of 10 cm and a surface area of 78 $cm^2$, to a maximum depth of 35 cm. Due to plant remains and roots, at most locations it was not possible to reach a depth of 35 cm. Three replicates were taken randomly at each station, pooled and sieved in the field through a 1 mm mesh. The residue was preserved in a 4% buffered formaldehyde solution and stained with Rose Bengal. In the lab specimens were sorted and identified to the lowest possible taxonomic level, counted, wet weighted and preserved in the same formaldehyde solution. The quanity of individuals for each species observed at each station was converted to density (number of species $m^{-2}$). Worm counts were bases on the number of heads found in a sample. If only tails were found in the sample, an exception was made and echt tail was recorded as one individual. Biomass was calculated by converting total wet weight per station per species to total ash free dry weight (AFDW) in $g \cdot m^{-2}$ using species specific conversion factors as described in Craeymeersch and Escaravage (2014). In addition, *Arenicola marina* densities were counted by counting heaps in the field within 0.25 m2 (n=10) at each sampling station. At each station a single sediment sample (18.5 cm3) was collected from the upper 3 cm (using a 1.4 in diameter syringe from which the tip was cut off) and stored in a pre-weighed sample bottle. In addition salinity of the surface water was measured at each transect in the main gully in spring 2017.

Samples were wet weighted and placed in a freezer for a minimum of 3 days before opening the bottles and freeze drying (Christ® Alpha 1-4) the sediment samples for 4 days (-50ºC). Samples were reweighed after freeze drying. Bulk density of the sediment ($g \cdot cm^{-3}$) was calculated as ratio dry weight to the sampled volume. Sediment particle size distribution was determined by laser diffraction (Malvern Mastersizer 2000), from which the median grain size of the sediment $D_{50}$ (µm) as well as the size distribution (percentage coarse, medium, fine and very fine sand, and silt) was derived. Elevations (m NAP) were measured using a differential GPS device with a horizontal and vertical measure accuracy of 8 and 13 mm, respectively (Leica GS12, Leica Geosystems AG, Switzerland, correction signal: SmartNet, Leica Geosystems, the Netherlands). Additionally, Chlorophyll *a* (µg $cm_3$), as a measure for food availability for benthic animals, was measured by three pooled sediment samples collected from the upper 1 cm of the sediment, using a 1 cm in diameter syringe from which the tip was cut off. The samples were stored in the dark at -80$^0$C after which they were freeze dried and analysed spectrophotometrically according to Aminot and Rey (2002).

Based on the benthic macroinfauna samples several biological indicators were defined and linked to abiotic parameters. We defined:
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 $m^2$ but per station.

(1) Density, which is the amount of individuals per species found in the cores, converted to number of individual species $m^{-2}$.
(2) Biomass, which is the total wet weight per station per species converted to the total ash free dry weight in g $m^{-2}$ using species specific conversion factors as described in Craeymeersch and Escaravage (2014).

*Figure 2-4* 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 cockles (C. edule and C. glaucum) observed in autumn 2017 (bottom right photo). Photos: Tom Ysebaert en Brenda Walles.

### 2.3.1 Statistical analysis

Sampling stations that saw no macrofaunal organisms were removed from the analysis.

*Univariate*
A linear regression model was applied to species richness, density and biomass in relation to the abiotic data. For relationships in which non-linear assumptions were made a Generalised additive model was used (using the R-package "mgcv" and k=2).

*Multivariate*
Changes in macroinvertebrate community composition were analysed with an NMDS ordination on densities (using the R-package: "vegan"), which was run for 20 iterations at k=2 (decreased number of dimensions) before obtaining a solution. A double square root transformation was applied followed by a Wisconsin double standardisation to down-weight the importance of highly abundant species, allowing for mid-range and rare species to exert influence on the calculation of similarity. Rare species, of which the density in at least 3 samples did not surpass 1% of the total density, were removed from the analysis.

## 2.4 Fish sampling

In the autumn of 2019 and spring of 2020 a pilot study was conducted to understand the best sampling method to measure fish fauna in salt marshes. Based on this pilot study, further methods were selected and applied to the monitoring program that consisted of four sampling moments in: October 2020, April 2021, May 2021 and June 2021. Sampling was conducted with a mixture of passive- (fyke nets) and active- fishing gear (seine nets).

Each catch was put in a separate bucket, photographed and recorded.  If the volume of the catch was too large (e.g. juvenile fish/shrimp), a sub-sample was taken and recorded. The following variables were registered: species, length and quantity. Fish species and shrimp were counted and measured. All other species captured were just counted. The European shore crab *Carcinus maenas* was, due to vast observed quantities, counted and divided in two groups: small (up to 2 cm) and large (>2 cm).

### 2.4.1 Fyke nets

For each sampling moment, 3 large fyke nets and 3 smaller fyke nets were set out, due to availability. The  mesh size of the first two throats was 10 mm, whereas the mesh size of the cod-end was 5.5 mm. The height of the first hoop was 60 cm or 85 cm, for the smaller (N=3) and larger (N=3) fyke nets consecutively. Each fyke contained two four metre long wings with a mesh size of 10 mm. The fyke net was held in place by three steel rods that were wedged into the soil (Figure 2-6).


*Figure 2-5 S*etting out (one in each direction) and emptying the fish fykes in Rammegors in April 2021.

The locations of the fyke nets were based on the following objectives:

- Fyke nets were deployed near the mouth of the salt marsh and further up in the salt marsh; to determine which species might have been transported into the salt marsh with the tide and which species utilize the area more permanently.
- Per location one of the two fyke nets was positioned with the opening towards the Oosterschelde and the other with the opening towards the salt marsh; this way the nets would capture fish entering and leaving the salt marsh.
- Fyke nets were positioned in such a way that they did not completely block off the creek.
- Fyke nets were always positioned in a location where water remains (e.g. pool) during low tide.
- Fyke nets were deployed around low tide and were left to fish for 24 hours: two tidal cycles.

### 2.4.2 Seine nets

Two different types of seine nets were used. The seine net that was used most often was 10 m wide and 2 m high.  The mesh size in the wings was 5 mm whereas the mesh size in the cod end was 2.5 mm. The smaller seine net was 3 m wide and 1.5 m high with a mesh size of 2.5 mm. The mesh sizes in the seine nets were deliberately chosen to be smaller in comparison to the fyke nets as it the aim was to also catch juvenile and small fish species that the fyke nets would miss.

Seine-net sampling occurred during low tide. Tidal pools were hereby predominantly sampled, which potentially functions as a fish retreatment area from the salt marsh when the tide is out. The distance over which the seine net was hauled was recorded.

## 2.5 Bird sampling

Bird counts in the entire Eastern Scheldt have been monitored as a part of the MWTL-monitoring program since 1990, and are conducted by DMP (Delta Milieuprojecten). Counts took place during high tide, when birds gather at high tide roosts. A more elaborate description of the method used for the bird counts can be found in Hoekstein et al 2021. The data on bird utilisation in Rammegors from 1993-2018 was analysed in this report, which all had the same months in which counts took place (Jan, Feb, May, Aug, Nov, Dec).

## 2.6 Social impact analysis

A systematic review of the scientific literature was conducted to gain insight into the existing body of research, on public attitudes to coastal realignment and comparable policy-induced landscape interventions. Specifically, the review aimed to collect published evidence about 1) how landscape interventions are perceived by local communities, and 2) what research methods and evaluation frameworks have been used to measure these perceptions. The outcomes of the review were used as input for the conceptualization of a rigorous survey questionnaire to measure the attitude toward the coastal realignment process in the Rammegors area and other locations in Zeeland, including Perkpolder and the Hedwige Prosperpolder. Both the systematic literature review and the design of the survey instrument were carried out in close collaboration with the HZ Resilient Deltas research group.

### 2.6.1 2.1 Systematic literature review

The systematic review centered around the concept of place attachment; a well-established psychological theory that describes the "positively experienced bonds, sometimes occurring without awareness, that are developed over time from the behavioral, affective and cognitive ties between individuals and/or groups and their socio-physical environment" (Brown and Perkins, 1992, p. 284). This emphasis on place attachment was considered to be useful, given that public perception of policy-induced landscape transformations is largely shaped by the extent to which these transformations disturb the bonds people have with their socio-physical surroundings. On the other hand, despite this study's focus on coastal management interventions, it was decided to consider research articles on interventions focusing on other landscape typologies such as rivers or estuaries as well. Foremost, because river and coastal management interventions could be expected to provoke similar social responses, and the research methods used to evaluate these responses could be relevant for the purposes of our analysis and subsequent development of the survey instrument.

Correspondingly, a search for peer-reviewed research articles was performed using the online Ebscohost (Abstract, Title, Keywords) search engine. The search was performed in June 2020 using the following search key: *sense of place OR place attachment OR place meaning OR place identity OR attitude OR perception OR opinion AND river management OR coastal management OR flood management OR flood plain OR floodplain OR managed realignment OR depoldering OR de-poldering OR depolderisation NOT disaster OR risk*.

The search returned a total of 224 research articles. As a first filter, the titles and abstracts of the output articles were reviewed to verify if the topic and contents of the articles were conducive to the analysis. This first screening process resulted in a reduced sample of 82 articles. The articles within this sample were subjected to full text revisions to identify case studies that describe societal impacts and public attitudes related to the implementation of coastal and river management interventions. Information in the articles associated with the applied research methodologies and measurement variables was identified and extracted to an Excel data table for later analysis purposes. Through this process, 45 (55%) articles were discarded as they did not present the required information, resulting in a total of 37 articles. To expand the number of case studies, a snowball sampling procedure was applied, in which the reference list of the 37 articles were consulted to identify additional relevant articles. This procedure yielded 5 additional articles, resulting in a final sample of 42 articles.

### 2.6.2 Survey design

The information collected through the literature review was used as input for conceptualizing a survey questionnaire to measure the public perception of the coastal realignment intervention in the Rammegors area and other locations in Zeeland, including the Perkpolder area and the Hedwige Prosperpolder. In particular, we critically evaluated the theoretical concepts and measurement variables that have been used in previous studies, and assessed to what extent these could be applicable in the context of the research we foresee in Rammegors and the other case study locations. The most promising concepts and research methods were identified and where needed adapted, and subsequently integrated into the survey. A separate survey was developed for Rammegors, Perkpolder and the Hedwige Prosperpolder individually, with equivalent questions to allow for comparison between the different case study locations, while taking into account case study-specific information to provide context.

# 3 Environmental conditions

## 3.1 Elevation

Throughout the sampling period, elevations did not change when taking all sampling

*Table 3-1* Summary of mean values (se) of all measured conditions in the Rammegors area between 2017-2020

| Parameter | Rammegors area 2017 (n=20) spring | 2017 (n=20) autumn | 2018 (n=24) spring | 2018 (n=24) autumn | 2020 autumn |
|---|---|---|---|---|---|
| **Abiotic characteristics** | | | | | |
| $d_{50}$ (mm) | 101.6 (11.2) | 102.4 (10.8) | 91.4 (9.3) | 93.1 (9.1) | 96.5 (9.6) |
| Coarse sand (%) | 0.3 (0.2) | 0.1 (0.1) | 0.4 (0.1) | 0.4 (0.1) | 0.9 (0.3) |
| Medium sand (%) | 6.8 (1.4) | 5.6 (0.8) | 5.9 (0.9) | 5.6 (0.1) | 5.6 (1,2) |
| Fine sand (%) | 34.1 (4.5) | 35.8 (4.9) | 29.7 (3.7) | 29.6 (3.8) | 30.1 (3.9) |
| Very fine sand (%) | 27.7 (1.5) | 27.6 (1.5) | 27.0 (1.9) | 28.5 (1.4) | 27.8 (1.8) |
| Clay/silt (%) | 31.3 (5.5) | 31.0 (6.0) | 37.2 (4.6) | 36.1 (4.5) | 35.0 (4.7) |
| elevation (m NAP) | 0.37 (0.09) | 0.37 (0.09) | 0.38 (0.08) | 0.33 (0.09) | 0.32 (0.10) |
| Chlorophyll-a (µg $g^{-1}$) | 36.4 (8.3) | 30.2 (7.6) | 25.2 (4.0) | 24.4 (3.4) | |
| Organic matter (%) | 9.0 (2.0) | 7.2 (1.7) | 5.8 (1.3) | 8.7 (1.6) | |
| Bulk density | 1.08 (0.10) | 1.93 (0.11) | 1.54 (0.07) | 1.66 (0.08) | 1.65 (0.08) |
| **Macrofauna** | | | | | |
| No. of taxa | 10.0 (0.9) | 5.9 (0.7) | 7.8 (0.7) | 7.4 (0.7) | |
| No. of ind. ($m^{-2}$) | 8049 (1779) | 3028 (653) | 3149 (819) | 4122 (735) | 5291 (1080) |
| Biomass (g $m^{-2}$) | 6.14 (1.21) | 5.66 (1.01) | 5.61 (0.94) | 11.23 (1.46) | |

stations in Rammegors into account (Table 3-1). However, when looking at the average elevation taken across individual transects,  a decrease can be observed between spring 2017 and autumn 2018 (Figure 3-3). Sampling stations taken within transects near the inlet, are positioned lower than those at the end of the creek. Transects A and B saw the strongest declines in mean elevation within the sampling period and still show a declining trend.

## 3.2 Sediment Composition

Mean sediment characteristics show that the Rammegors area contains silt rich sediments with a relatively low average median grain size (Figure 3-1 & Table 3-1). Transect A contains the highest median grain sizes, the highest percentages of medium sized sediments and the lowest percentage of silt. Transect E contains the lowest median grain sized and also sees the highest percentages of silt. Coarse sediment particles are almost absent in the Rammegors area.

## 3.3 Bulk density compaction

Opposite to mean elevation, mean bulk density decreases with distance from the inlet, where the lowest bulk densities are observed in transect E and the highest in transect A (Figure 3-2). When disregarding magnitude, all transects seem to follow the same pattern in regards to bulk density. Here, soon after the realignment of the Rammegors area, soil compaction took place, as can be seen by the large increase in mean bulk density between spring and autumn 2017 (Table 3-1). In spring 2018 the bulk density decreased significantly again. Between spring 2018 and autumn 2020 values appear to have stabilised, with the exception of transect B.

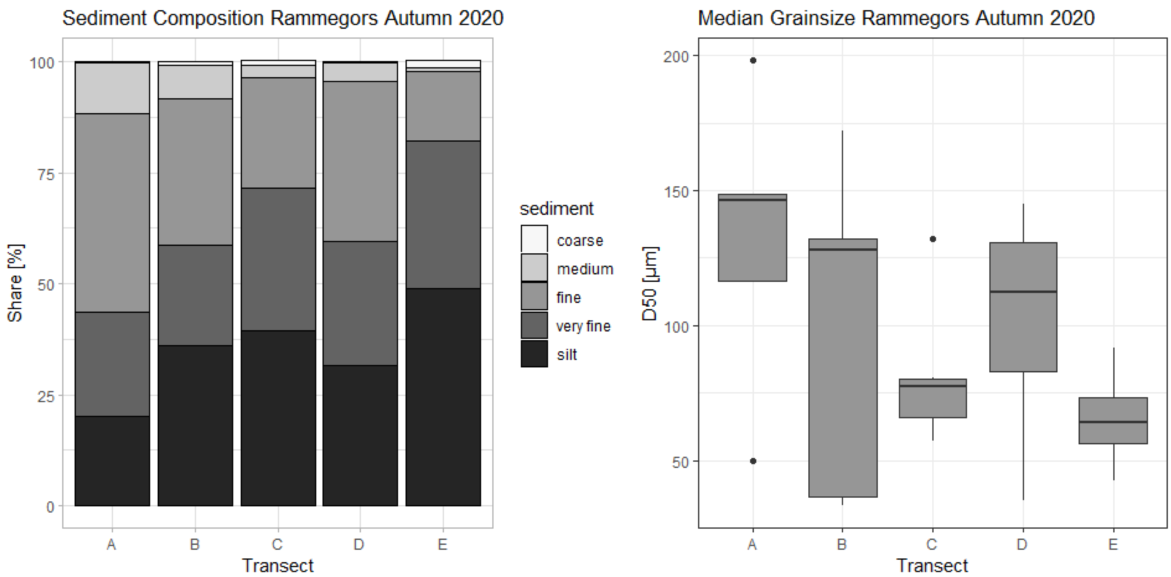



*Figure 3-1 Average sediment composition and distribution of median grainsize observed per transect in Rammegors during Autumn 2020. Appendix XX shows identical graphs for all sampling moments.*

## 3.4 Chl-a

Mean chl-a concentrations decreased between spring 2017 and autumn 2018, especially in transect D (Table 3-1).

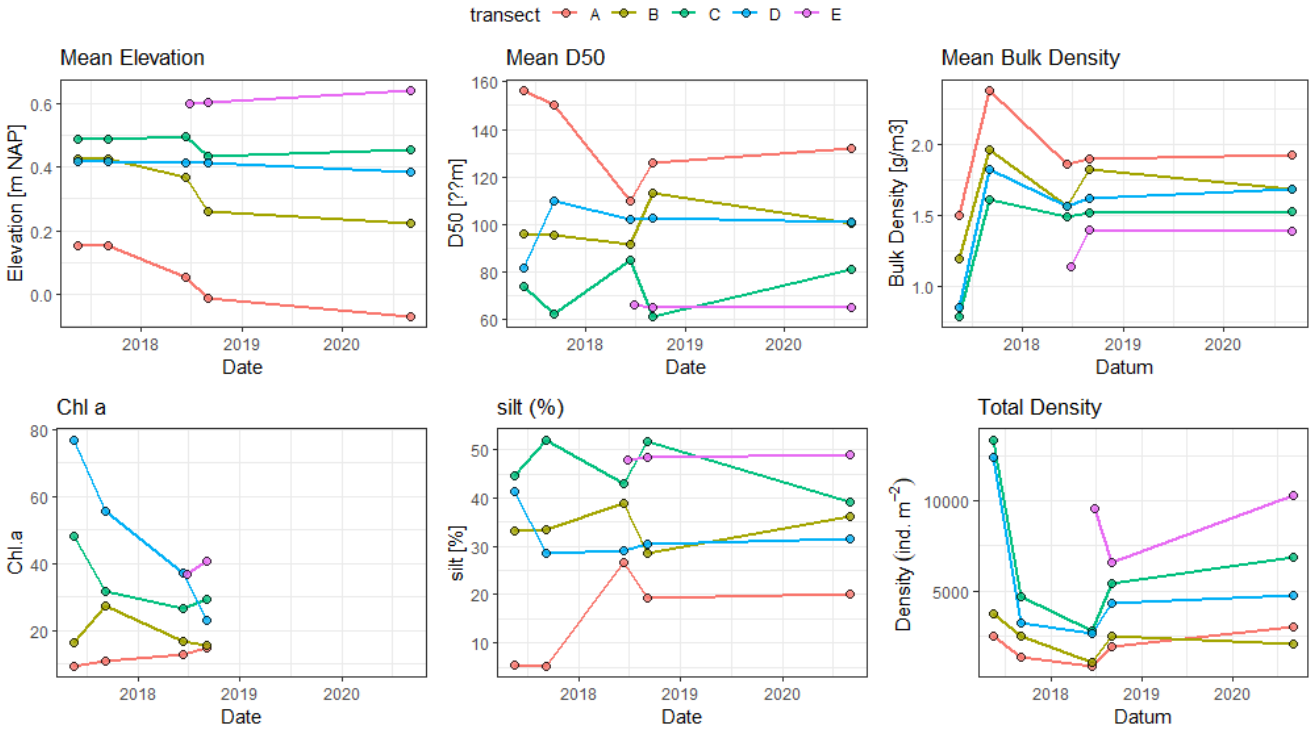



*Figure 3-2 Development of environmental variables in the Rammegors area between spring 2017 and autumn 2020, showing each transect separately.*

## 3.5 Groundwater

Before 1972, Rammegors was part of a well-developed tidal system with a constant supply of salt water originating from the Eastern Scheldt. The area has since been embanked by the Krabbenkreekdam and the Oostdam, respectively situated on the western and eastern sides of the Rammegors. During the construction of the Scheldt-Rhine channel, the north-eastern part of the Rammegors was used as a silt depot. After the embankment in 1972, Rammegors became hydrologically isolated, with no connection with the surrounding surface waters until the first re-opening in 2014. During this ~40 year embanked period, the infiltration of rainwater caused the subsoil to freshen.

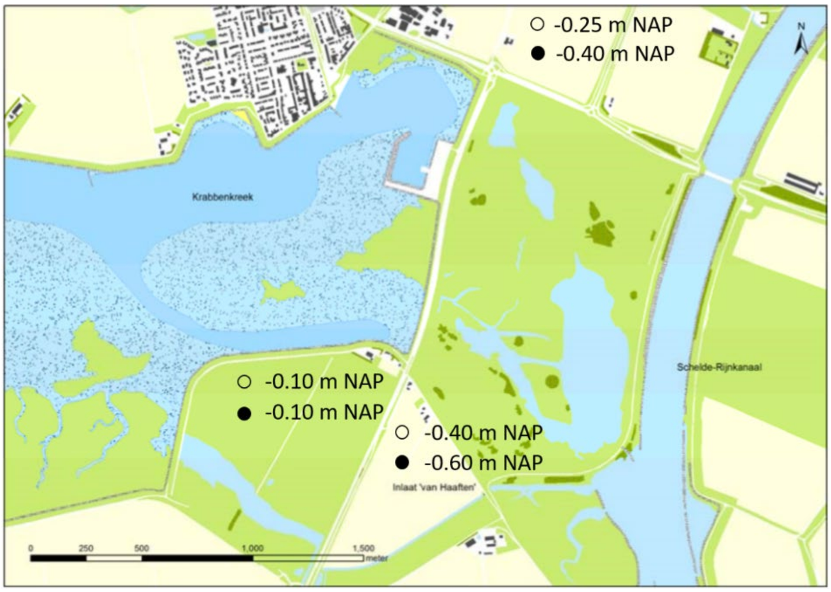



*Figure 3-3 Overview map of Rammegors. Open circle is average water level in summer, closed circle is average water level in winter (Arcadis and Rijkwaterstaat, 2013).*


*Figure 3-4 Overview of surrounding waters near Rammegors (source: Google maps). Left figure: 1: Eastern Scheldt. 2: Zijpe. 3: Volkerak. 4: Krabbenkreek. 5: Scheldt-Rhine canal. Red dot: Stavenisse. Red square: Rammegors. Right figure: Rammegors in more detail. a: Krabbenkreekdam. b: Oostdam. Yellow dot: Inlet 'Van Haaften'.*

The development of an intertidal area within Rammegors could possibly influence the groundwater characteristics in Rammegors and the surrounding area.Three major surrounding surface waters are:

- Krabbenkreek (tributary of Easternscheldt)
- Scheldt-Rhine channel (inlet 'Van Haaften')
- Surrounding polders (Tholen and St. Philipsland)

As a branch of the Eastern Scheldt, the Krabbenkreek is influenced by tides from the North Sea. The Scheldt-Rhine canal is situated east of Rammegors and contains fresh water from Krammer-Volkerak at a level close to NAP (-0.12 m NAP). A small inlet ('Van Haaften') is situated south of Rammegors (Figure 3-4). In summer, fresh water from the Scheldt-Rhine channel is used to maintain the water levels of island Tholen.

Rammegors borders two polders. North of Rammegors, the 'Prins Hendrikpolder' maintains an average water level of -0.25 m NAP in summer and -0.40 m NAP in winter. South of Rammegors, the 'Van Haaften polder' maintains an average water level of -0.40 m NAP in summer and -0.60 m NAP in winter (Arcadis and Rijkwaterstaat, 2013). The water levels in the polders, during the summer are maintained, through the inlet with the water from Scheldt-Rhine channel.

Since the final opening, on December 7th 2016, Rammegors has been semi-diurnally influenced by tides. Currently, the average low and high tide in the area are +0.33 and +1.36 m NAP respectively. The maximum water height is set at +1.65 m NAP, due to safety measures when water levels in the Krabbenkreek are too high (Arcadis and Rijkwaterstaat, 2013). These maximum water levels of 1.65 m NAP are reached only during springtide.

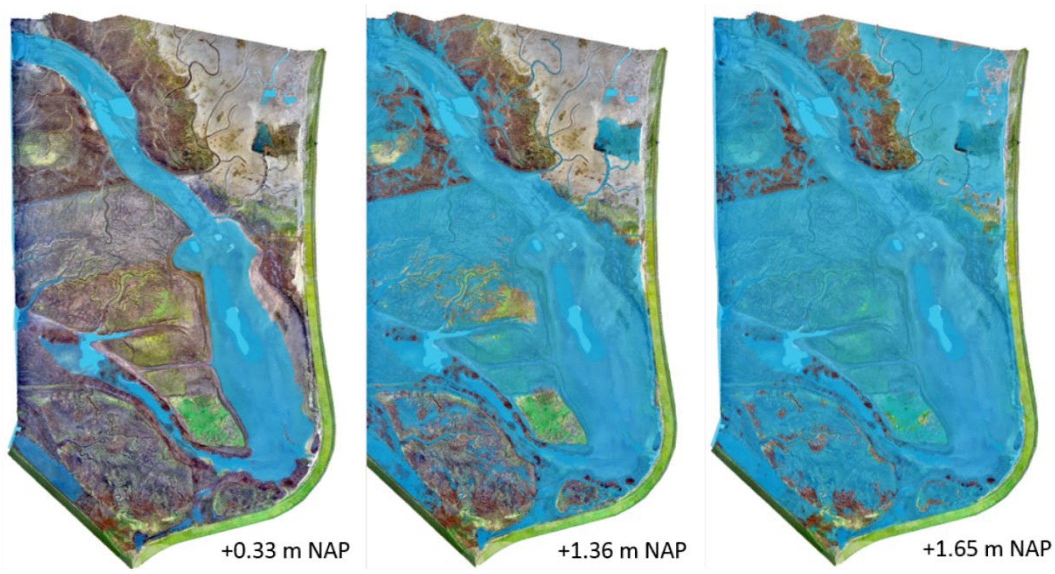



*Figure 3-5 Inundated area (blue) in Rammegors during different tidal situations. Left: low tide at ~+0.33 m NAP; center; high tide at ~+1.36 m NAP; right: spring tide at +1.65 m NAP (source: Rijkswaterstaat).*

3.5.1 Groundwater flow in and around Rammegors

The restoration of the tidal area Rammegors resulted in (1) a constant flow of saline surface water into Rammegors, (2) an average higher water level in Rammegors and (3) a change from a constant water level to a tidal fluctuating water level. These changes have consequences for the groundwater system in Rammegors and may also influence the area outside Rammegors.

The average phreatic **groundwater level** in the intertidal area was found to be slightly higher (0.97m NAP at Pb2) than the mean water level in the area (0.85 m NAP), this due to the fact that groundwater does not drain fast enough during low tide and the levels are situated close to the surface.

The phreatic water levels at the surface seem to largely determine the **hydraulic heads** situated deeper in the aquifer (see Figure 3-6). The presence of a tidal pattern at this depth (~15m) indicates that almost no hydraulic resistance is present between the surface and the aquifer. Furthermore, at high tide, the peak is much sharper than during low tide, which indicates that the transition from high to low tide is much faster than from low to high tide. Figure 3.5 shows that in September 2019 the shallow phreatic groundwater level drops faster than the deep hydraulic head.

The hydraulic heads in the aquifer fluctuates between 0.8 and 1.2 m NAP, with a mean head of 0.96 m NAP. The piezometer Pb5 at the shore of a creek shows a lower aquifer head of about 0.74 m NAP caused by the drainage of the nearby creek (see Figure 3-6). In this figure also a gradient from Pb1 to Pb 5 is clearly visible caused by the drainage of the creek.

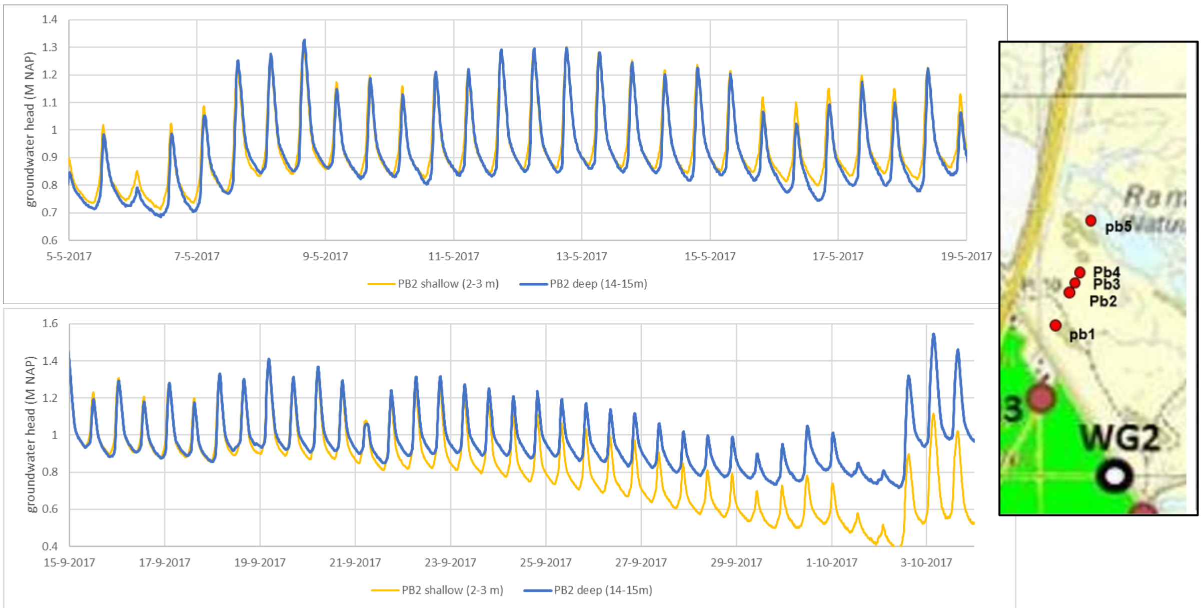



*Figure 3-6 The phreatic groundwater level (PB2 shallow) and the hydraulic head (PB2 deep) in the tidal area of Rammegors.*

The mean hydraulic head in the tidal area of 0.74-0.96 m NAP is significantly higher than the aquifer head in the surrounding polders (around 0.2-0.3 m NAP), the Krabbenkreek (around -0.02 m NAP) and the Scheldt-Rhine Canal (-0.1 m NAP). This means that groundwater is flowing from Rammegors to all directions indicating that Rammegors is an infiltration or groundwater recharge area.

### 3.5.2 Groundwater level and hydraulic head time series adjacent polders

Phreatic groundwater levels (screen at 2-3m) are available from 2011 for the polders north and south of Rammegors, and hydraulic head data (screen at 9-10m and 24-25m) from 2016 (Appendix VI).

In the Prins Hendrikpolder, the phreatic groundwater level is situated approximately 0.5 to 1.0 meter below the land surface on the side bordering Rammegors (South), whereas levels in the centre of the polder reach down to approximately 1.0 to 1.75 meter below the surface. In summer, the groundwater level is about half a meter lower than in winter. Measurements in both a shallow and deep screen at measuring point RP06 show that the head in the deep screen is higher than in the shallow screen, and thus that seepage is taking place.

In the Haaftenpolder, situated south of Rammegors, the groundwater level is located about 1.5 meter below the surface in summer and rises to close to the surface in winter. Fluctuation in the groundwater table resulting from precipitation events seem to be larger in comparison to the Prins Hendrikpolder. Measurements in a deep and a shallow screen at RH02 show that no or only slight seepage takes place; the groundwater heads in both screens are more or less equal, indicating that a significant resistant layer between the shallow phreatic and deep groundwater system is absent.

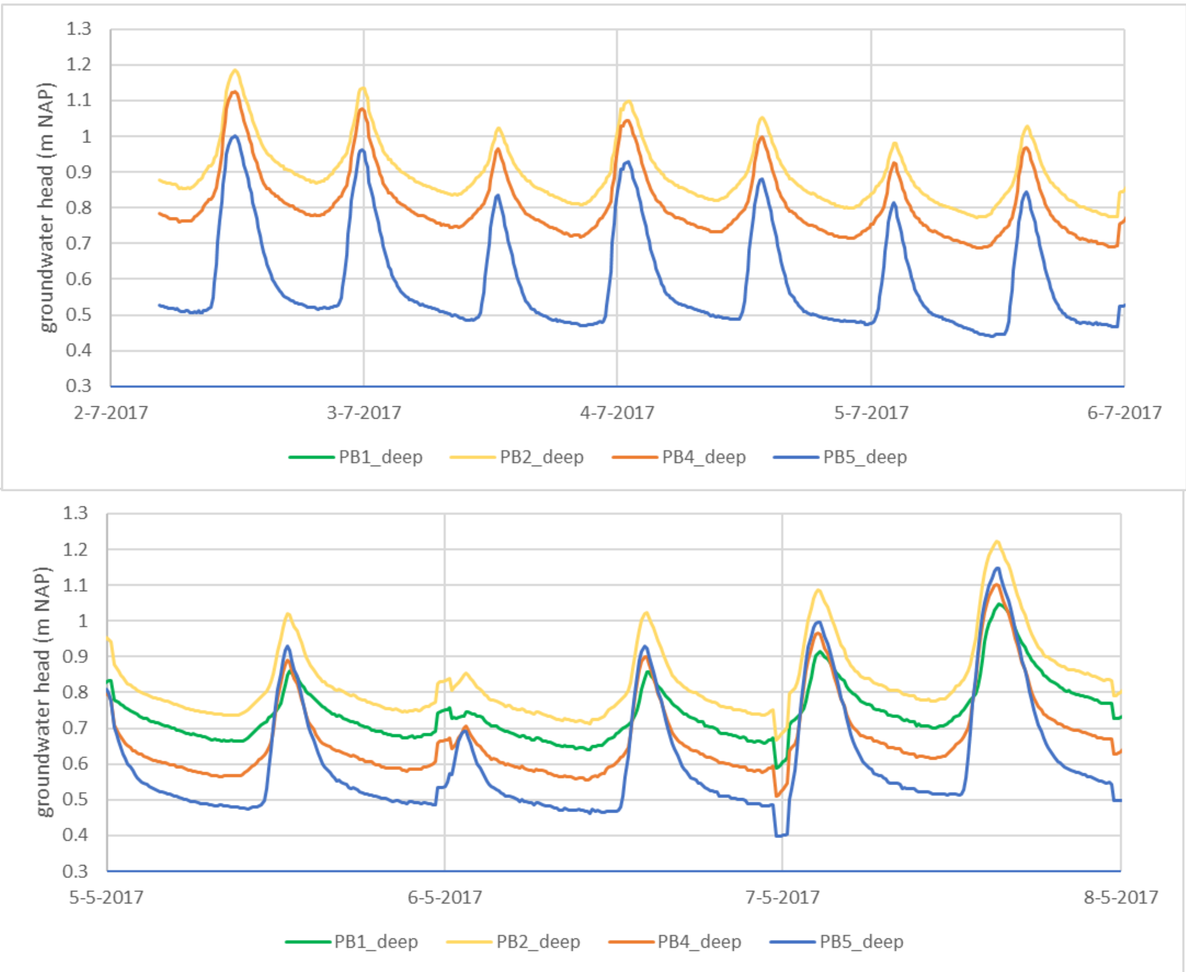



Figure 3-7 *The aquifer heads in the Rammegors for two different periods.*

### 3.5.3 Possible effects on groundwater due to opening of Rammegors

The groundwater heads in the aquifer are important to monitor since effects of changes like the opening of Rammegors propagate via the aquifer.

In late May 2017, the inlet was closed for about 2 weeks due to construction works. In this period no tidal activity took place causing (stagnant) water to cover the entire area, resulting in relatively constant high water levels being observed. This high-water level slowly decreased as water slowly infiltrated in the subsoil (Figure 3-8b).

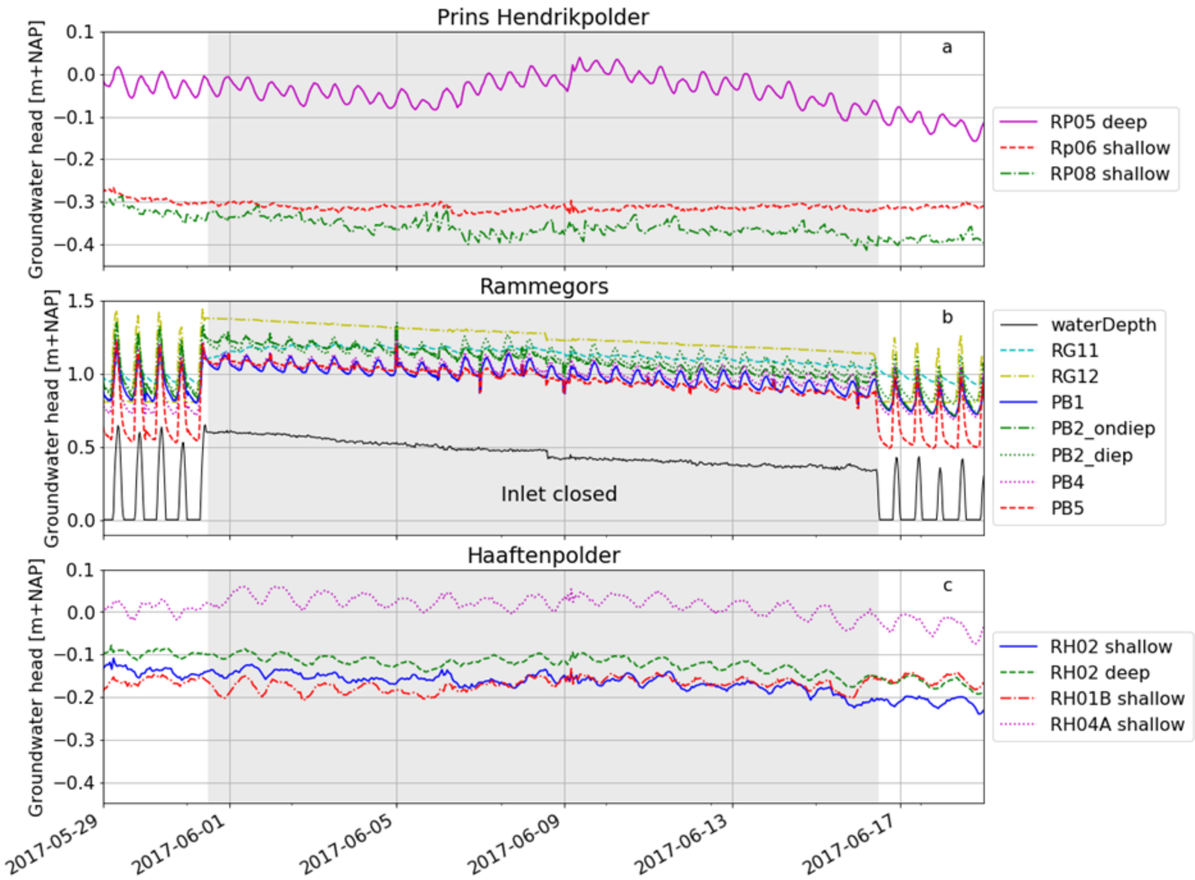



Figure 3-8 *Groundwater heads in meter above NAP in the Prins Hendrikpolder (a), Rammegors area (b) and Haaftenpolder (c) during the closure of the inlet in June 2017.*

Because of the high-water level in the area, the hydraulic heads in Rammegors also maintained at a high level (Figure 3.6b). These levels still showed slight tidal fluctuations, but to a much lesser extent than before and after the closure. This shows that the groundwater system is still connected with the tides of the Oosterschelde (Krabbenkreek), at no more than 200 m distance from the piezometers.

There is no clear response of the groundwater system, outside Rammegors, due to the temporary higher and stagnant water level in Rammegors (Figure 3.6). Both the phreatic groundwater levels and the heads in the deeper piezometers in the Haaftenpolder show a daily fluctuation of several centimetres as a result of evapotranspiration (Figure 3-8c) and no tidal effects are visible. This shows that there is a tight connection between the phreatic groundwater system where evaporation takes place and the aquifer at a depth of 15 meter in the Haaftenpolder: there is hardly any resistance between the layers. In the Prins Hendrik polder the aquifer head at RP05 is clearly affected by the tides with no daily variation (Figure 3-8a), which indicates the presence of more resistant clay or peat layer between the shallow phreatic system and the aquifer. The fact that the aquifer head at RP05 is affected by the tides during the closure of the Rammegors inlet and that the tidal fluctuations are the same as during opening of the inlet shows that the aquifer at this location is dominantly influenced by the Oosterschelde rather than by the Rammegors area. This piezometer also shows a trend over several days: the groundwater head rises between June 6th and June 9th followed by a decrease. This trend is caused by the springtide-neap tide cycle of the Oosterschelde (Krabbenkreek).

The large influence of the Oosterschelde on the groundwater aquifer heads in the polders in contrast to Rammegors is explained by its nearby position, the large surface area of the Krabbenkreek and the large depth of the Krabbenkreek creating a direct and open connection with the aquifer.

*Time series analysis – removing noise*
As in the previous section is shown, there is no visible indication that the aquifer heads and phreatic groundwater levels in these areas have been affected by changes of water levels in Rammegors. We applied time series in order to filter out the effect of precipitation and evaporation making possible effects of other interventions more visible. The model is trained for the period before the first opening of Rammegors (before December 2014) for the shallow piezometers. And for the deep piezometers, which were installed in April 2016, the period after 2017 was used as training period (after the last opening at 7$^{th}$ Of December 2016).

Figure 3-9 shows two examples of the results of the time series analysis, showing the modelled and observed groundwater heads. For RP-08 the modelled time series follows nicely the observed groundwater levels indicating that the dynamics and absolute levels are only influenced by variations of precipitation and evaporation (and natural drainage). The lower observed groundwater level in 2019 is the result of a sensor error. For RH-02 the model was trained for the period the 2017-2021 following nicely the observed levels for this period but shows a deviation in the period before 2017. Here, the modelled time series (based on meteorological data only) were lower than observed. Due to the opening at the end of 2016, we should expect the opposite; higher groundwater heads after opening. The cause of this is not clear yet and will be examined in a later stage, although also sensor displacement could be the cause here.

In Annex VII all applied time series analysis results are presented. From this analysis no clear effect on groundwater levels and head outside Rammegors could be detected, which is in line with the previous visible interpretations.

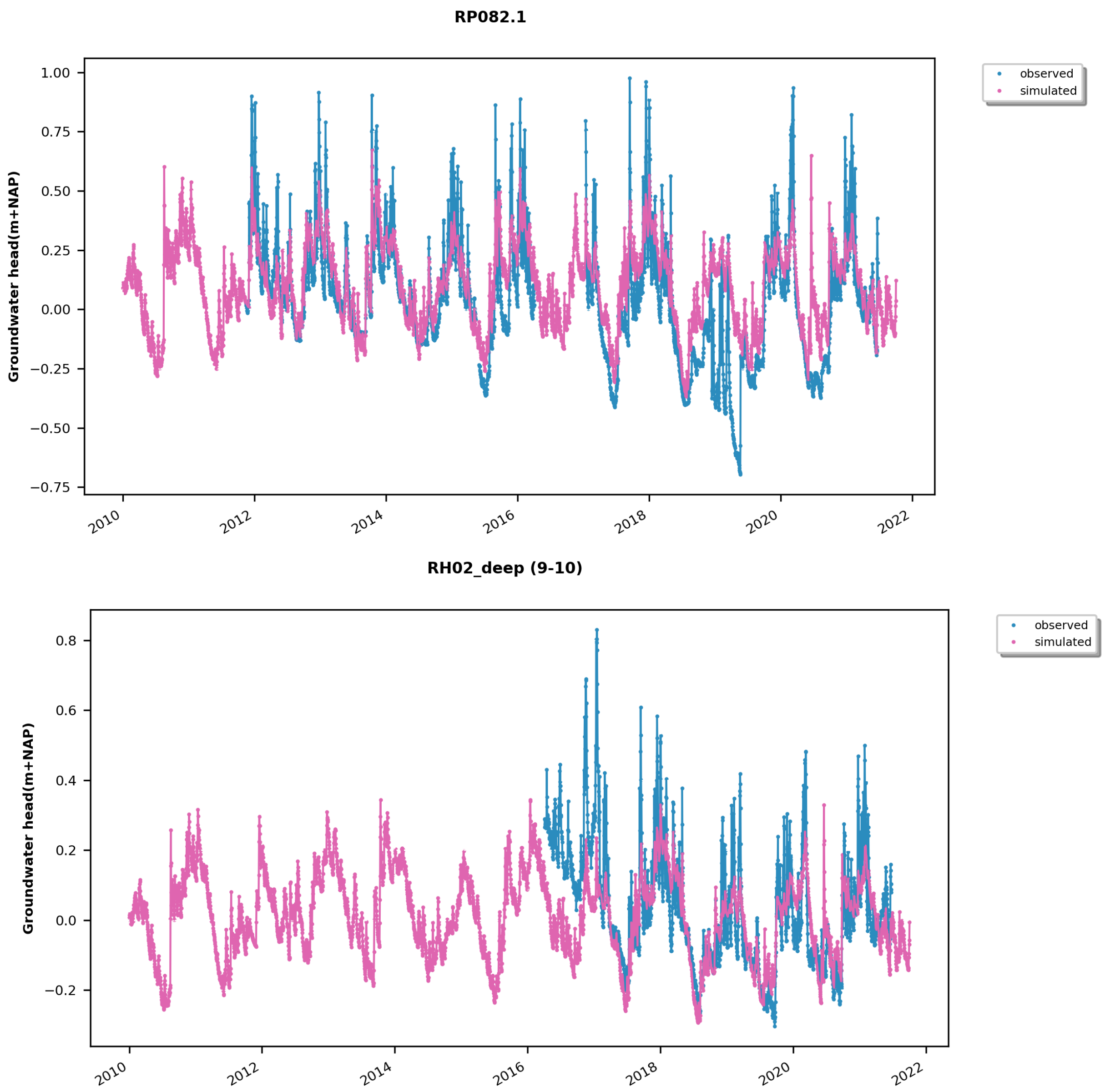



*Figure 3-9* Two results of the time series analysis for the shallow phreatic piezometer RP-08 and the deep piezometer of RH-02 in the aquifer. The blue lines indicate the observed heads and the red lines indicate the modelled heads.

### 3.5.4 Salinisation within Rammegors

Depth-salinity profiles have been measured annually since 2016, at five locations in the tidal area of Rammegors and four location in the surrounding polder. The monitoring locations in the tidal area are situated at different elevations, which consequently result in differences in tidal flooding. The results for the tidal area are presented in Annex VIII. The figures clearly shows salinization taking place atall locations.

Pb1 is located at a relatively high elevation (1.42 m NAP) and thus only floods a few times per month, during spring tide. As a result, salinisation appears to progress slower in the first years in comparison to the rest of the locations. In 2017, the entire profile was relatively fresh and only in the top 1-2 meter the salinity is increased indicating a salinization from above. However, in the following years the salinization rate seems to be more or less equal for the top 11 meters. This indicates that salinization is not only taking place from the surface both importantly also lateral. After 2019, also below 11 m depth salinization is visible.

Pb2, pb3 and pb4 seemed to start off with relatively saline conditions, in the upper 10-11 meter, when monitoring started. This is likely the result of the incidental openings that happened after December 2014 (monitoring started in 2017). Since 2014 salt water has entered Rammegors and a stagnant salt water body was present for parts of the period between December 2014 and December 2016. It is clearly visible when comparing the 2017, 2018, 2019, 2020 and 2021 measurements that the salinization is actively taking place in the tidal area. The salinization is highest for the upper 10-11 meters. During this period, for the entire depth the groundwater salinity in the subsoil has increased by a factor 2.0 to 4.0. The relative increase for Pb1 is even more (5 tot 11) due to the much fresher start in 2017.

Pb5 is situated at an elevation of 0.60 m NAP, at the border of a permanent surface water body which contains salt water since the first opening in December 2014. Salinization of location Pb5 is clearly different form the other locations in the tidal area. The measurements show a relatively fresh top 5 meters and increasing salinity with depth, which is not what we expected. Salinization for this location is only visible for the years 2020 and 2021 but a reason for this delayed salinization is not clear yet.
In Annex VIII, the absolute increase (or decrease) in salinity between 2016/2017 and 2021 is presented. The figures show that for Pb1, the salinization rate is more or less the same as for Pb2, 3 and 4. They all show that salinization is predominantly a lateral process for these locations.

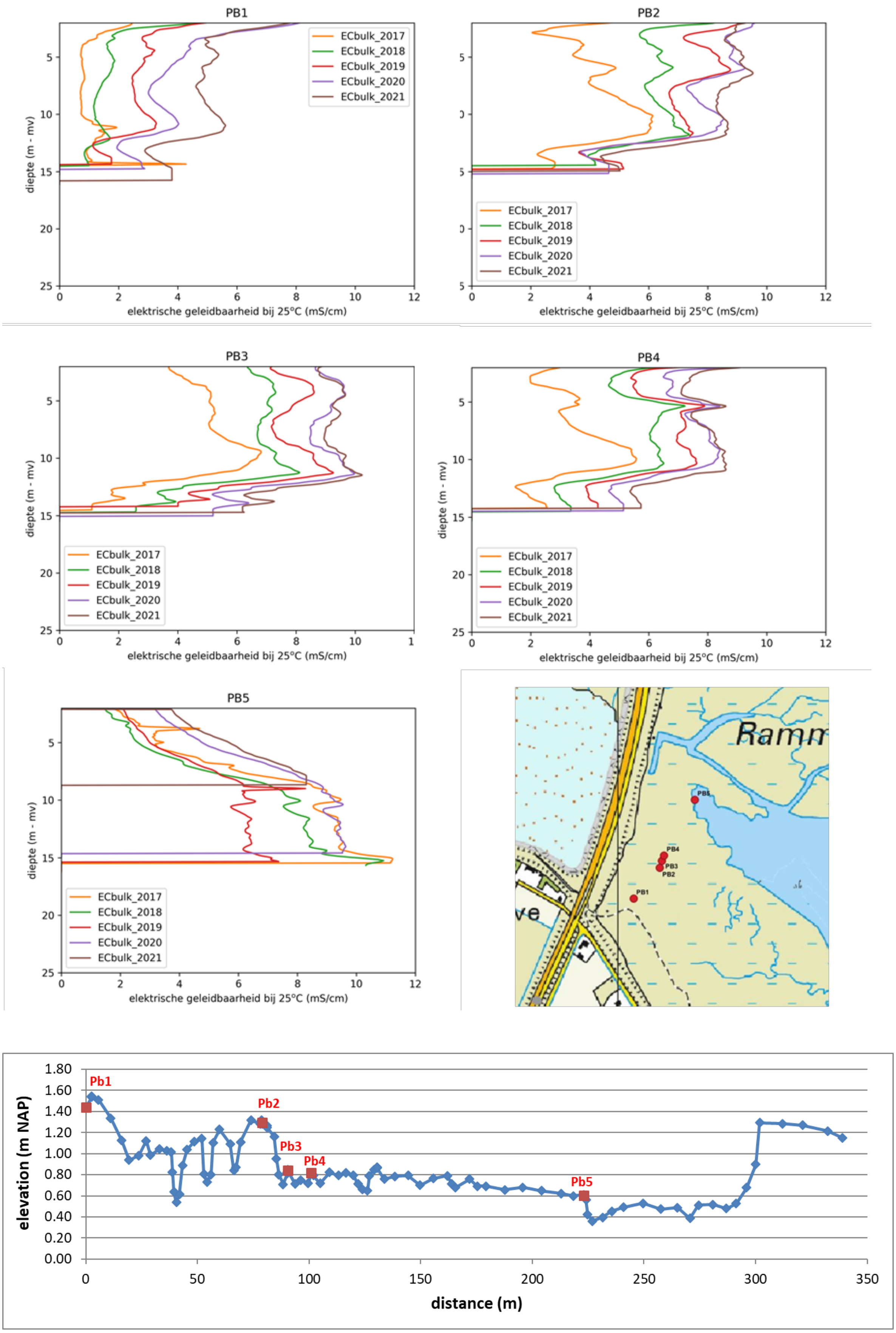



*Figure 3-10* The aquifer *EM-SlimFlex-measurements for five locations in the tidal area, for the period 2017-2021 and a profile of the ground level with the location of the monitoring locations*

### 3.5.5 Salinisation outside of Rammegors

All locations in the agricultural area show a relatively shallow fresh-salt interface depth which is defined as the centre of the transition between fresh and saline groundwater (Figure 3.9).

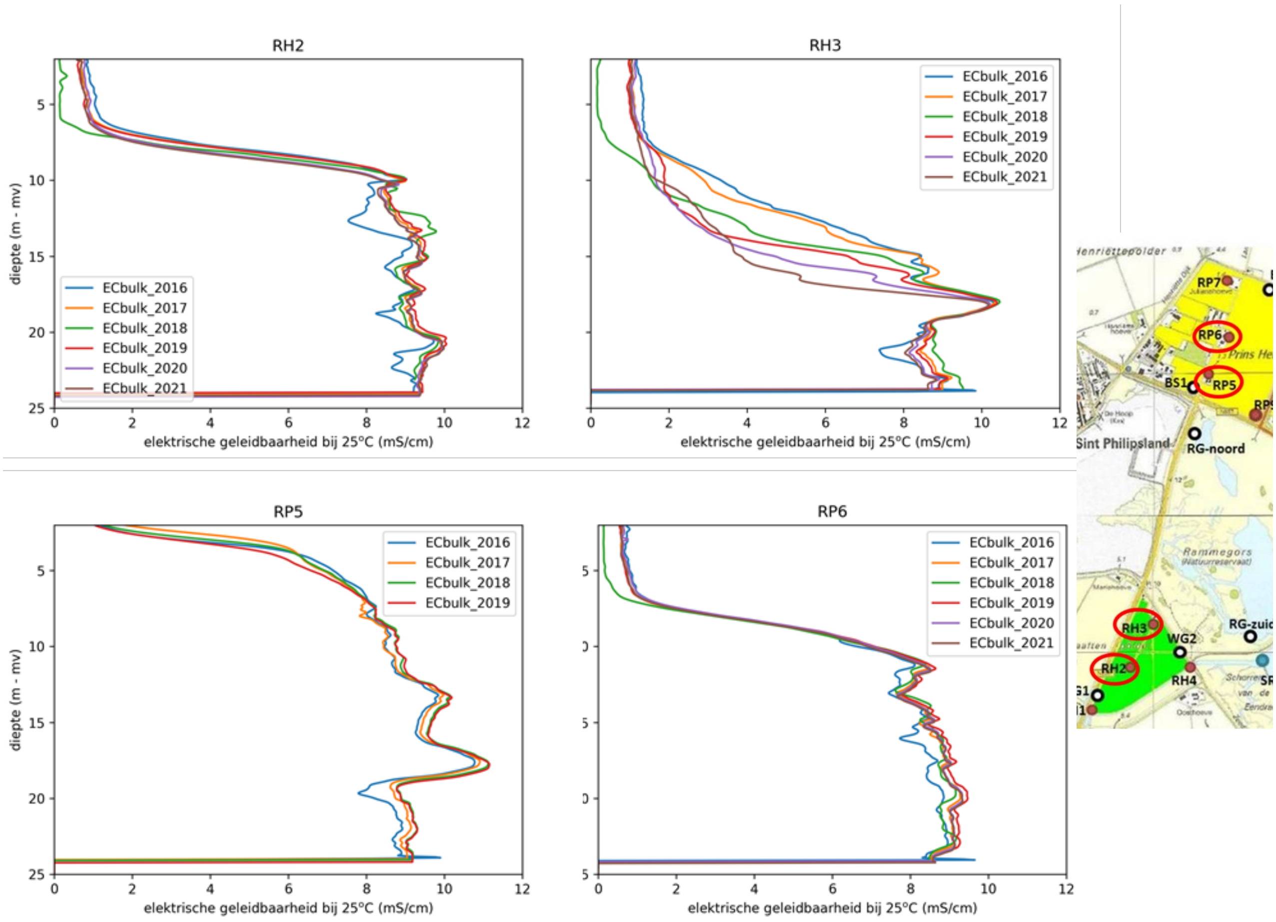



*Figure 3.9 The aquifer* EM-SlimFlex-measurements for four locations in the agricultural area around Rammegors, for the period 2016-2021.

Of the two locations sampled in the Haaftenpolders, the lowest interface depth was found at 8m below surface with a small transition zone. The interface at RH-03 was found to be situated at 12m below surface, but the transition zone here was much wider, indicating that mixing processes have been more active.

At RP-5 in the Prins Hendrikpolder, the interface is much shallower, i.e. 2.5 m below surface and for RP-06 at 8 m below surface level. The differences of the interface and absolute salinities (see Annex VIII) for RP-05, RP-06 and RH02 between the different years 2016-2021 are minimal and within the accuracy of the measurements. No changes in salinity has occurred during these 6 years for these locations. However, RH3 show an ever-growing freshwater lens since 2016. In 2016 the interface can be determined at a depth of around 12 m below surface while in 2021 it is increased with 4 to 5 m to a depth of around 17 m below surface. A possible explanation could be the fact that fresh water which is/was present below Rammegors is pushed away laterally in the direction of the Haaftenpolder. Note that this freshening was not observed for the Prins Hendrikpolder. The difference between the two polders is probably due to the presence of a resistant (peat-clay) in the northern part of the area which is absent in the southern part (see Figure 3.10). Also, the time series gave evidence for the absence of such a layer in the southern Haaftenpolder.

When such a resistant layer is absent, the aquifer is thicker and more permeable, and freshening and salinization processes occur at a higher flux.

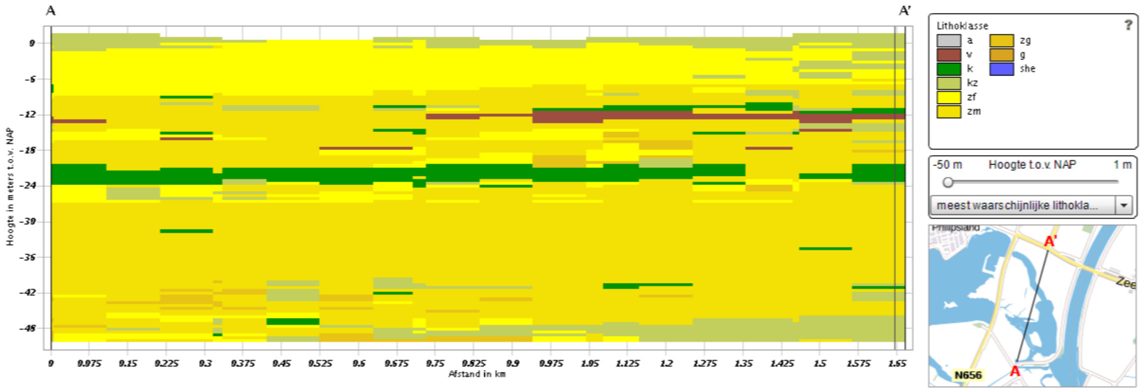



*Figure 3.10 North-south cross section of Rammegors made by GeoTOP v1.3. Legend: a: antropogenic, v: peat, k: clay, kz: clayey/loamy sand, zf: fine sand, zm: moderate coarse sand, zg: coarse sand, g: gravel, she: shelves (source:TNO (2013)).*

# 4 Vegetation

In 2020 a project area covering stitched image was created based on the RGB-images collected in August (Figure 4-1). This stitched image can be used for vegetation mapping. Moreover, it is possible to use the stitched information for  to create an elevation map based on structure-from-motion photogrammetry techniques.

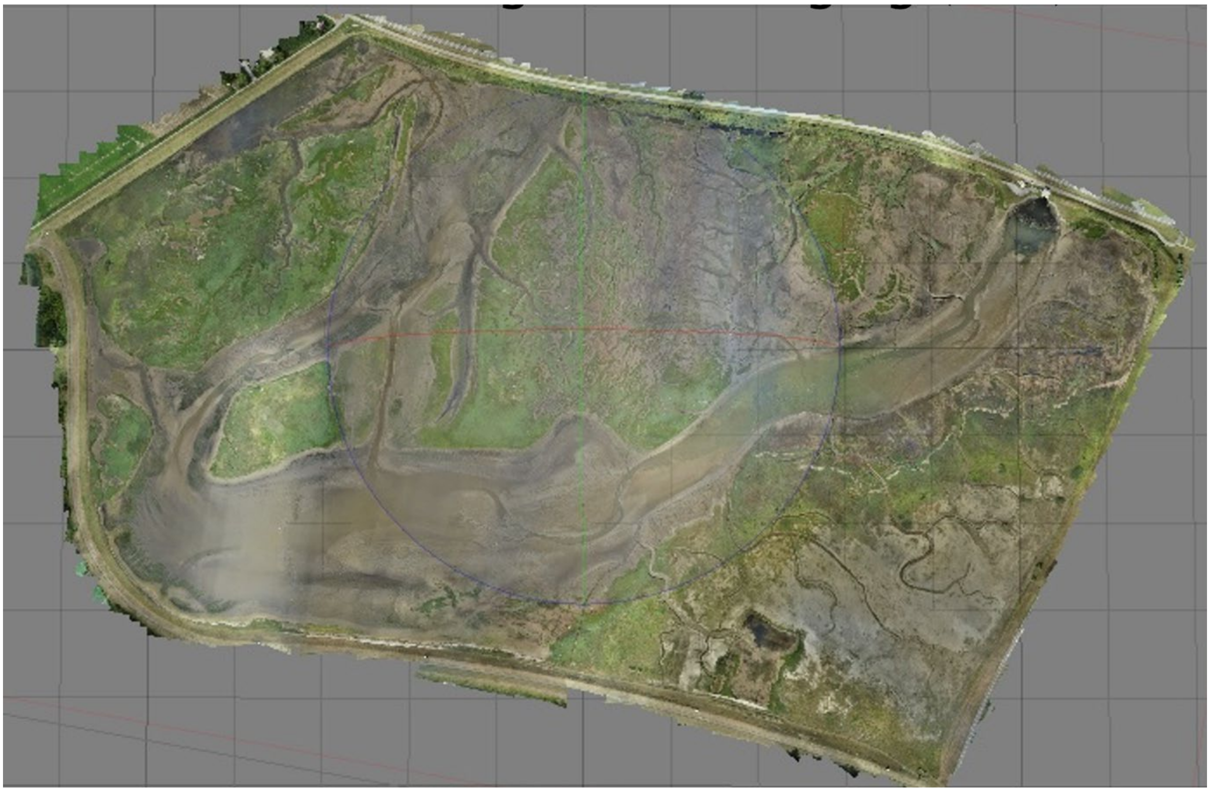


*Figure 4-1 Overview of stitched RGB-images of the Rammegors project area in 2020.*

# 5 Benthic Fauna

## 5.1 Macrobenthic development

Within five months after the third opening in December 2016, a rapid colonisation of 22 species was observed during the first sampling in spring 2017. The total number of species observed increased at each subsequent sampling moment, to 38 in Autumn 2020 (Table 3-1).

The highest total densities were observed during the first sample moment in Spring 2017 (8049 ± 7956 ind. $m^{-2}$). Hereby the maximum density at a single location was 33.910 ind. $m^{-2}$, of which 18164 ind. $m^{-2}$ consisted of *Monocorophium insidiosum* and 8191 ind. $m^{-2}$ of *Chironomidae.* A strong decrease in total benthic density was observed in autumn 2017 (2921 ± 3028 ind. $m^{-2}$); spring 2018 (4014 ±3149 ind. $m^{-2}$) ; autumn 2018 (3602 ±4122 ind. $m^{-2}$). The most recent sampling moment in autumn 2020 saw an increase (5290 ± 5291 ind. $m^{-2}$).

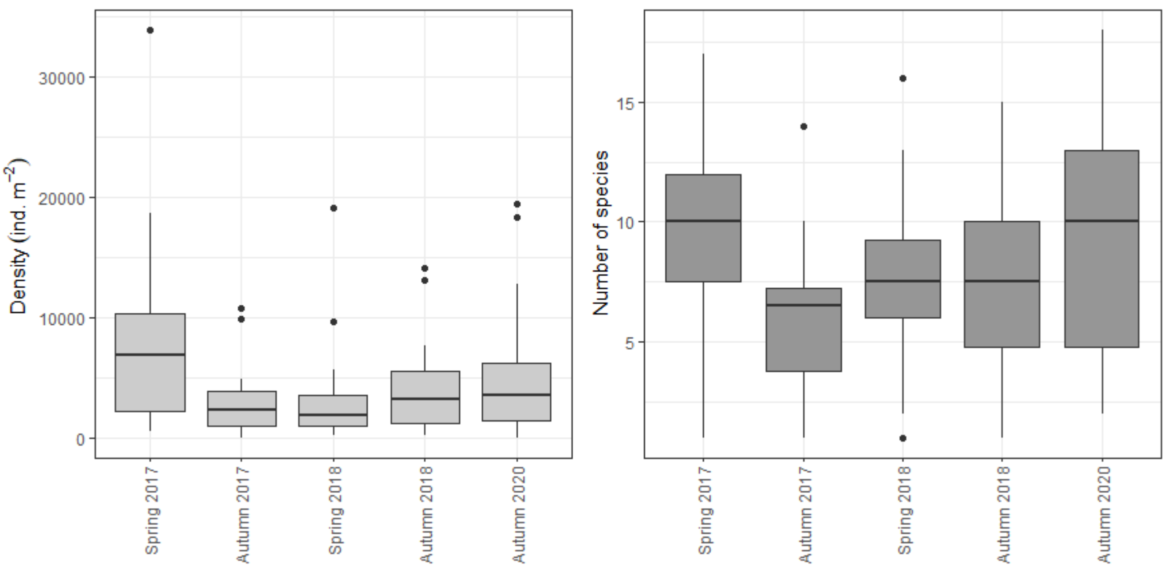



*Figure 5-1 Distribution of observed density and species richness over all sampling stations during each sampling moment in Rammegors. n = 20 in 2017 and n= 24 in 2018 and 2020.*

Although the total number of species in the area is increasing, average numbers per location follow the same pattern as total density, where the highest quantities were observed during the first observation in spring 2017, followed by a strong decrease in Autumn 2017 and then a gradual increase.

Spatially, transects E and C show the highest densities (Figure 5-1 & Figure 5-2). Not only did the quantity of species observed change, large differences are also apparent between which species were observed for each sampling moment (Figure 5-3). Hereby different species dominate the community at different instances.

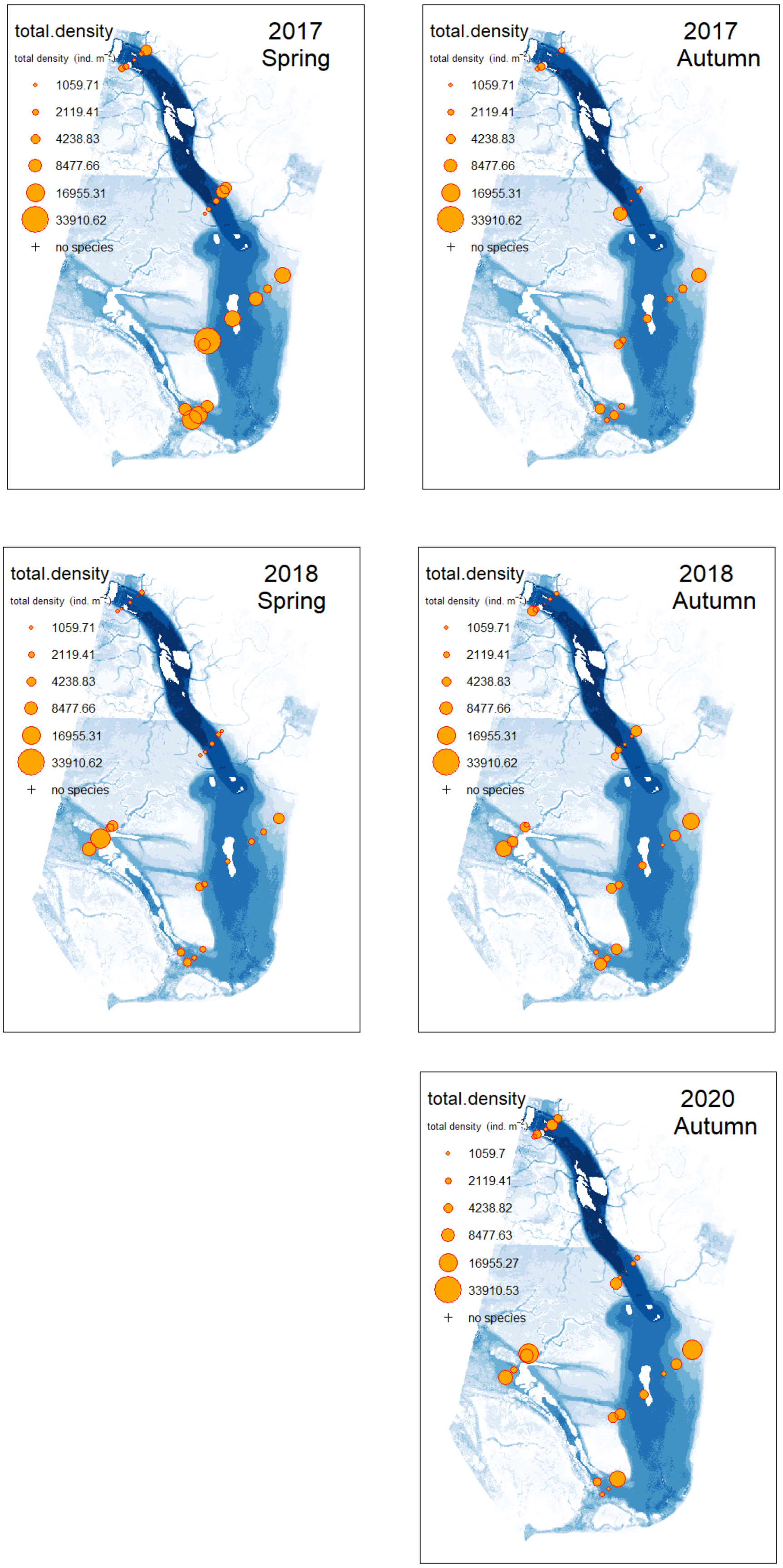



*Figure 5-2 Benthic fauna densities observed spatially in Rammegors between spring 2017 and autumn 2018.*

**Stable species**

Certain species do not show significant changes in density and/or occurrence as the Rammegors area developed. Densities of *Hediste diversicolor* seem to fluctuate, but occurrence is relatively stable. This species occurred in all transects (Figure 5-3). Mudsnails (*Peringia ulva*) show a relatively stable occurrence across sampling moments, however much higher densities seem to occur in Autumn. Observed mean densities and occurrence of *Heteromastus filiformus* was especially high during autumn sampling moments (2017: 155±409; 2018: 92±158; 2020: 110±144 ind. $m^{-2}$) as opposed to spring (2017:15±18; 2018: 28±48ind. $m^{-2}$). No strong annual trend can be observed in any of these species.

**Decreasing species**

Some species were dominant initially after connecting the area with the Oosterschelde, yet have since drastically decreased or completely disappeared from the area. In spring 2017, the brackish mud shrimp *Monocorophium insidiosum* (Crawford 1937) occurred in 80% of the sampling stations and was by far the most dominant species (2988± ind. $m^{-2}$) (Table 5-1). The following autumn (2017) observed occurrence and density decreased drastically, and the species has been completely absent during the two most recent sampling moments. Similarly the mosquito larvae *Chironomidae* was vastly abundant during the first measurement in Spring 2017 (1462 ± 2214 ind. $m^{-2}$ ), and has almost disappeared from the area, with mean densities reaching just 11 ± ind. $m^{-2}$ and occurrence just 8% in autumn 2020. *Capitella spp.* was one of the most dominant species during the first sampling in spring 2017 (70%; 170±194 ind. $m^{-2}$). However the following sampling moment in autumn 2017 the species showed a strong decline (30%; 47±101 ind. $m^{-2}$). In autumn 2020 the species was only observed in transect A near the inlet and transect E furthest away from the outlet (Figure 5-3), with overall average densities decreasing to 60 ±139 and occurrence to 21%. Lastly the polychaete O*ligochaeta* occurred in the highest mean densities during the first sampling in spring 2017 (1367 ± 2835 ind. $m^{-2}$), especially in the central sampling points of the area (transects B,C and D, see Figure 5-3). In the following sampling moments the species was observed much less (autumn 2020: 221 ±925 ind. $m^{-2}$), however it still occurred in central sampling locations.

**New species**

Other species were not or rarely found during early sampling moments and have since appeared to become more dominant. *Aphelochaeta* was first found in the area in Autumn 2017 (6.4 ±21 ind. $m^{-2}$), since then it increased very fast and in autumn 2020 it was the most abundant species by average density (2097 ±3799 ind. $m^{-2}$). The marine amphipod *Corophium volutator* was not observed during early samplings in 2017, yet average densities had drastically increased by spring 2018 (683 ± 1752 ind. $m^{-2}$). In autumn 2018 occurrence declined although densities remained high (460 ±1752 ind. $m^{-2}$). In this year the species was only observed in the transect furthest away from the inlet, where it contributed to a large part of the total density (transect E and D, see Figure 5-3).

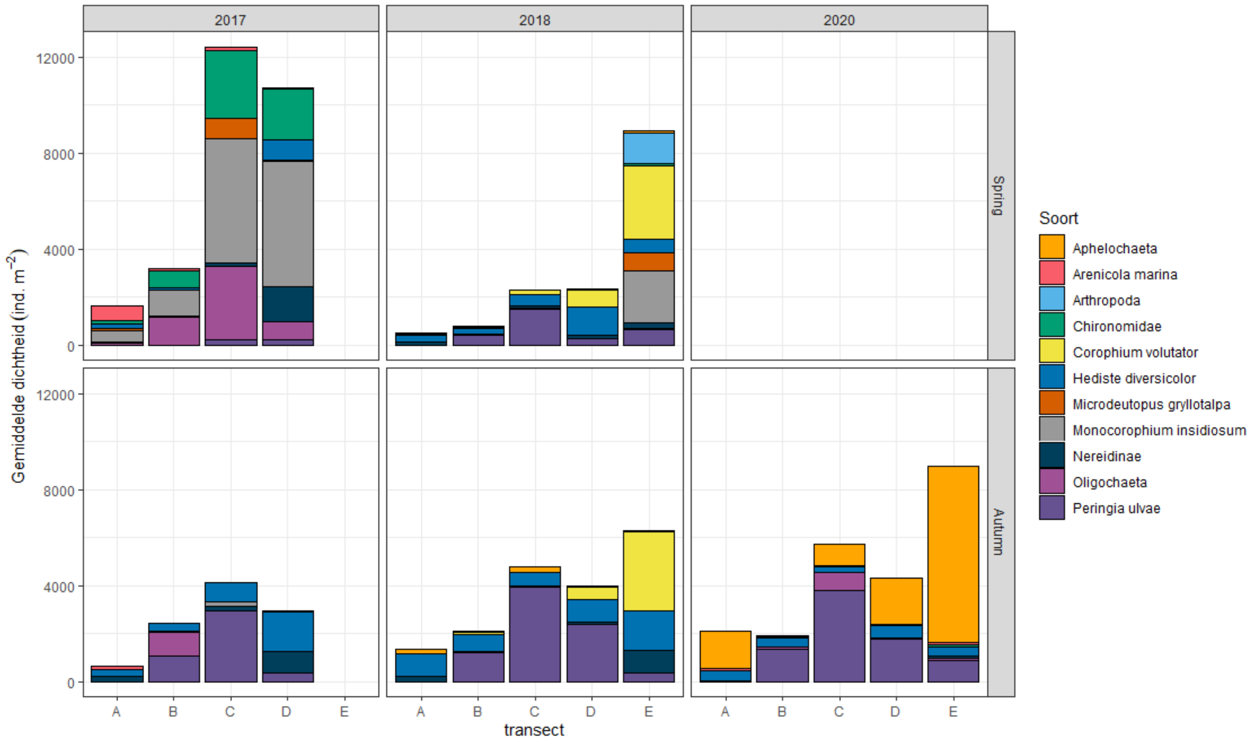



*Figure 5-3 Species composition showing the average densities found, of the most dominant species based on abundance and occurence, per transect per sampling instant in Rammegors. Height of bars do not indicate total biomass observerd due to only a select amount of species being included.*

| | Occurence % | | | | | Density (ind. m2) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **species/Taxon** | **Spring 2017** | **Autumn 2017** | **Spring 2018** | **Autumn 2018** | **Autumn 2020** | **Spring 2017** | **Autumn 2017** | **Spring 2018** | **Autumn 2018** | **Autumn 2020** |
| *Monocorophium insidiosum* | 80 | 10 | 17 | | | 2988 | 45 | 357 | | |
| *Chironomidae* | 75 | 10 | 8 | 8 | 8 | 1462 | 11 | 16 | 5 | 11 |
| *Hypereteone foliosa* | 75 | 50 | 42 | 21 | 29 | 146 | 57 | 25 | 20 | 23 |
| *Arenicola marina* | 70 | 25 | 25 | 4 | 46 | 238 | 30 | 12 | 2 | 64 |
| *Capitella spp.* | 70 | 30 | 12 | 38 | 21 | 170 | 47 | 9 | 39 | 60 |
| *Hediste diversicolor* | 65 | 80 | 88 | 88 | 88 | 263 | 719 | 520 | 778 | 375 |
| *Nereidinae* | 65 | 60 | 67 | 46 | 21 | 359 | 306 | 120 | 161 | 30 |
| *Polydora cornuta* | 65 | 10 | 58 | 25 | 46 | 178 | 13 | 131 | 62 | 97 |
| *Oligochaeta* | 60 | 5 | 25 | 12 | 29 | 1367 | 246 | 21 | 5 | 221 |
| *Pygospio elegans* | 55 | 20 | 38 | 17 | 50 | 161 | 13 | 110 | 35 | 83 |
| *Peringia ulvae* | 45 | 45 | 62 | 58 | 58 | 132 | 1231 | 621 | 1648 | 1680 |
| *Gammarus* | 35 | | | | | 68 | | | | |
| *Microdeutopus gryllotalpa* | 35 | 5 | 8 | | | 270 | 11 | 127 | | |
| *Streblospio benedicti* | 35 | 30 | 38 | 38 | 29 | 157 | 64 | 53 | 50 | 90 |
| *Eteone* | 30 | 5 | 4 | 12 | | 21 | | 2 | 4 | |
| *Gammarus locusta* | 30 | | 4 | | | 23 | | 2 | | |
| *Arenicola* | 20 | 15 | 8 | 4 | 8 | 13 | 6 | 2 | 2 | |
| *Heteromastus filiformis* | 20 | 60 | 42 | 62 | 75 | 15 | 155 | 28 | 92 | 110 |
| *Idotea* | 15 | | | | | 11 | | | | |
| *Insecta* | 5 | 10 | 8 | 4 | 4 | 2 | 4 | 5 | 5 | 7 |
| *Phyllodoce mucosa* | 5 | 5 | | | 8 | 4 | 4 | | | 4 |
| *Praunus* | 5 | | | | | 2 | | | | |
| *Alitta virens* | | 40 | 25 | 50 | 12 | | 32 | 18 | 50 | 20 |
| *Limecola balthica* | | 20 | 25 | 29 | 17 | | 11 | 11 | 16 | 16 |
| *Aphelochaeta* | | 10 | 33 | 38 | 75 | | 6 | 34 | 117 | 2097 |
| *Carcinus maenas* | | 10 | 4 | 4 | 12 | | 4 | 2 | 2 | 7 |
| *Cerastoderma edule* | | 10 | 8 | 4 | | | 4 | 4 | 4 | |
| *Actiniaria* | | 5 | | | 4 | | 2 | | | 2 |
| *Alitta succinea* | | 5 | | 12 | 29 | | 2 | | 2 | 12 |
| *Cerastoderma glaucum* | | 5 | | | | | 2 | | | |
| *Corophium volutator* | | 5 | 62 | 25 | | | 2 | 683 | 460 | |
| *Crangon crangon* | | 5 | 12 | 8 | | | 2 | 7 | 5 | |
| *Bivalvia* | | | 8 | 12 | 12 | | | 2 | 53 | 9 |
| *Nemertea* | | | 8 | 12 | 17 | | | 4 | 12 | 9 |
| *Ruditapes* | | | 8 | 4 | | | | 4 | 4 | |
| *Arthropoda* | | | 4 | | | | | 212 | | |
| *Cerastoderma* | | | 4 | | | | | 2 | | |
| *Gastropoda* | | | 4 | | | | | 2 | | |
| *Melita palmata* | | | 4 | | | | | 2 | | |
| *Scrobicularia plana* | | | 4 | 4 | 25 | | | 2 | 2 | 14 |
| *Spio martinensis* | | | 4 | | 4 | | | 4 | | 5 |
| *Glycera tridactyla* | | | | 4 | | | | | 2 | |
| *Magelona* | | | | 4 | | | | | | |
| *Mya arenaria* | | | | 4 | 17 | | | | 2 | 9 |
| *Nephtys hombergii* | | | | 4 | | | | | | |
| *Ruditapes philippinarum* | | | | 4 | 4 | | | | 2 | 7 |
| *Spionidae* | | | | 4 | | | | | | |
| *Abra tenuis* | | | | | 58 | | | | | 175 |
| *Eteone longa* | | | | | 25 | | | | | 16 |
| *Corophium arenarium* | | | | | 12 | | | | | 4 |
| *Microdeutopus* | | | | | 8 | | | | | 9 |
| *Pseudopolydora paucibranchiata* | | | | | 8 | | | | | 7 |
| *Cyathura carinata* | | | | | 4 | | | | | 2 |
| *Eunereis longissima* | | | | | 4 | | | | | 2 |
| *Hydrozoa* | | | | | 4 | | | | | 2 |
| *Melinna palmata* | | | | | 4 | | | | | 2 |
| *Mysta picta* | | | | | 4 | | | | | 2 |
| *Philoscia muscorum* | | | | | 4 | | | | | 2 |
| *Polydora* | | | | | 4 | | | | | |
| *Porcellio scaber* | | | | | 4 | | | | | 5 |
| *Praunus flexuosus* | | | | | 4 | | | | | 2 |
| *Scoloplos armiger* | | | | | 4 | | | | | 2 |
| **Total** | **22** | **28** | **33** | **34** | | | | | | |

## 5.2 Shell lengths

Across all years a total of 7 bivalve species were observed in Rammegors. The total observed bivalve density increased in 2020, which was mainly due the introduction of a new species in the area. In 2020, *Abra tenuis* was observed for the first time, hereby reaching an average density of 175 ±267 ind. m$^{-2}$ and an occurrence of 58%. The average length observed was 4.8 ± 1.6mm.

Baltic tellin (*Limecola balthica*) shows an increase in size over sampling years. Here, an average of 4.2 ±1.3 and 4.8 ±3.8 mm was found in the autumn of 2017 and 2018 respectively. In 2020 the average length observed increased slightly to 12.6 ± 4.0mm. This could indicate that the recruited individuals that settled in the area in 2017, are now growing.

The soft-shell clam (*Mya arenaria)* was observed from 2018 onwards, however quantities caught (n=7) do not allow for the interpretation length differences between years.

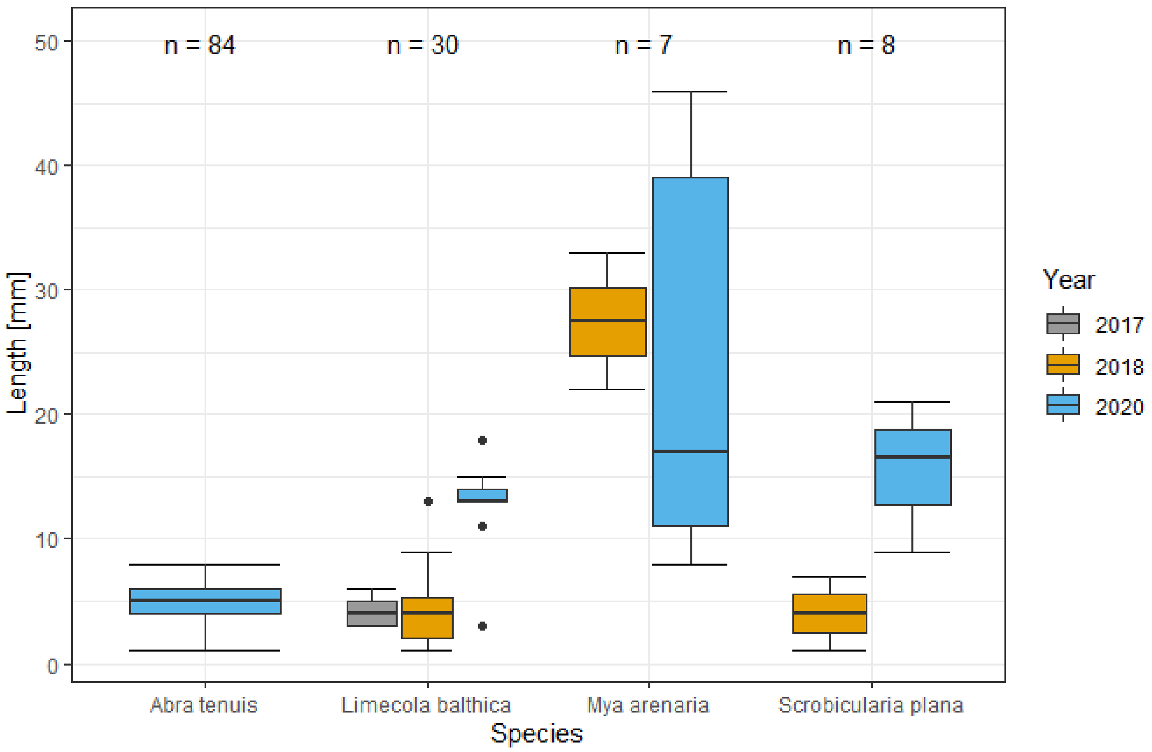



*Figure 5-4 Shell lengths [mm] for the four most abundant species found in Rammegors between 2017 - 2020*

## 5.3 Relation to environmental conditions

This section discusses the results of all sampling moments, results of individual sampling moments can be observed in annex V. Elevation has a significant effect on observed total densities of benthos (GAM: P= 0.0031, k= 3) and species richness (GAM: P < 0.001, k= 3)(Figure 5-5). Observed densities increase with increasing elevation and species richness increases up until an optimum elevation of approx. 0.4 m, after which it declines again.

A significant decreasing trend with increased bulk density can be observed (GAM: P<0.001, k=3) (Figure 5-6). This trend is apparent during each sampling moment (Annex V). Species richness does not seem to decrease significantly.

Median grain size has a significant effect on observed densities (GAM: P < 0.001, k = 4) but not on species richness. An optimum median grain size of approximately 60 mμ can be observed (Figure 5-7).

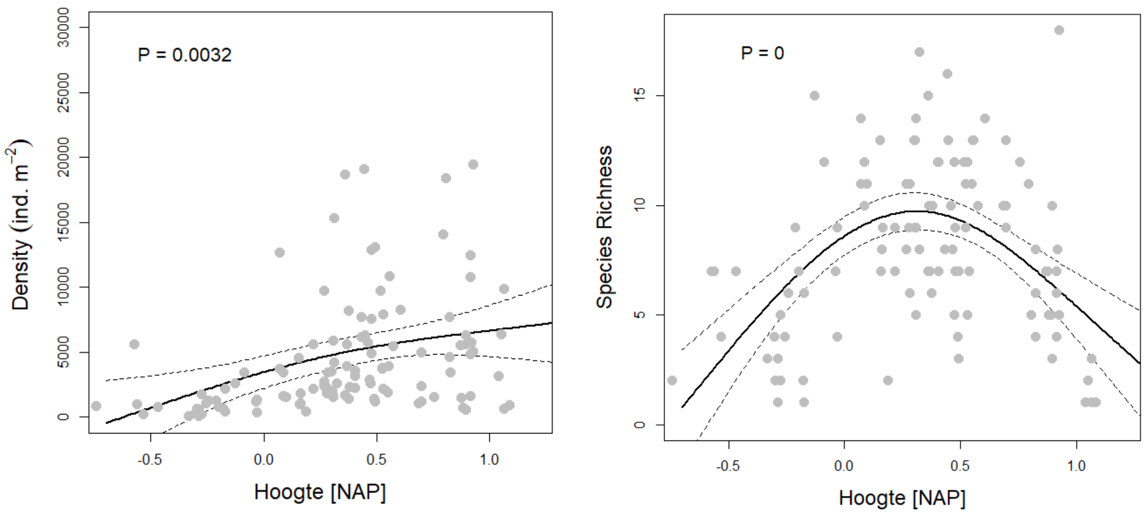



*Figure 5-5 Species density and richness in relation to elevation in m NAP across all sampling moments, dashed lines indicate the 95% confidence interval of the mean.*

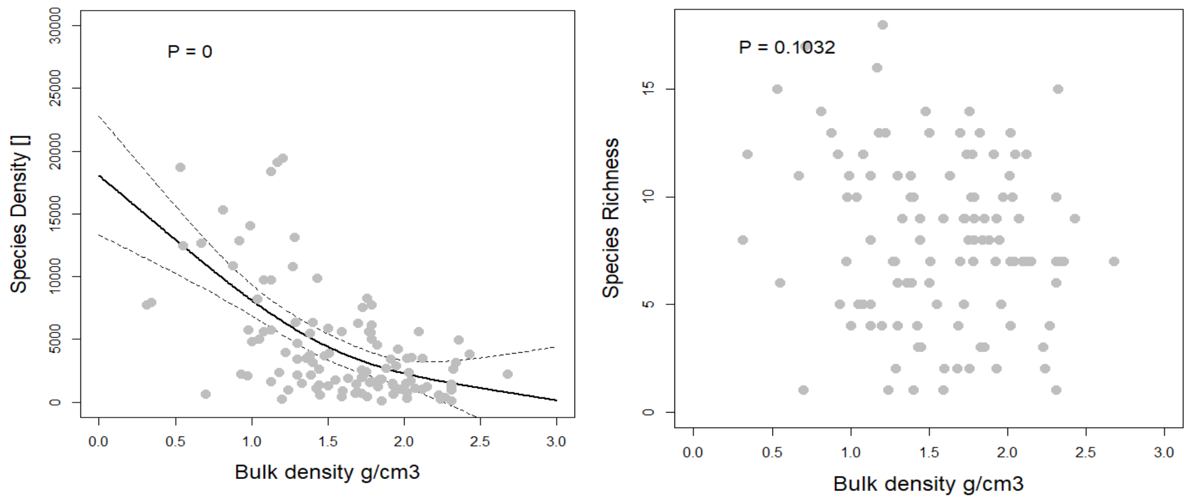



*Figure 5-6 Species density and richness in relation to bulk density across all sampling moments, dashed lines indicate the 95% confidence interval of the mean.*

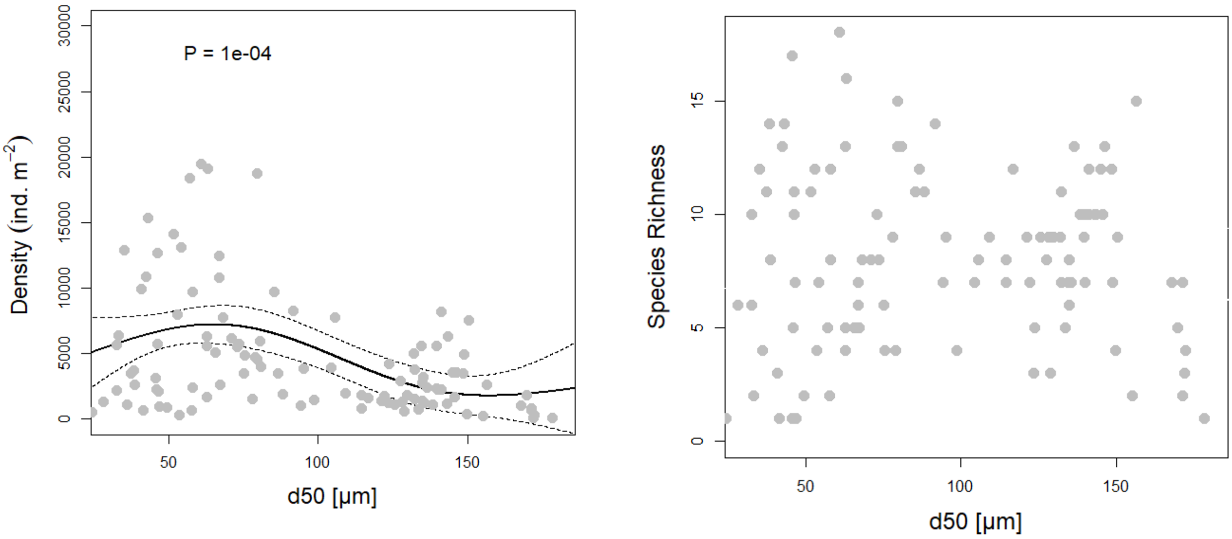



*Figure 5-7 Species density and richness in relation to meidan grain size across all sampling moments, dashed lines indicate the 95% confidence interval of the mean.*

## 5.4 Community structure

The benthic community composition showed high dissimilarity between the first sampling moment in spring 2017 and the other sampling moments, indicating an initial transition. From autumn 2017 onwards the community does not show a clear trend and the points overlap (Figure 5-8).

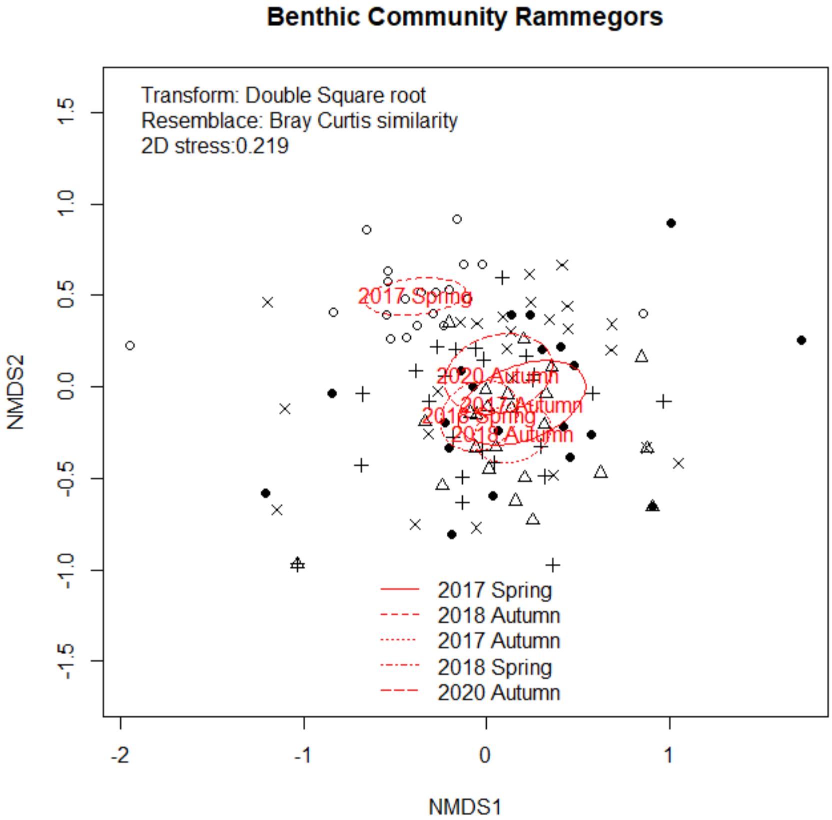



*Figure 5-7 nMDS-plot showing changes in benthic community composition from spring 2017 till autumn 2018 at the Rammegors area based on abundance data. Each point represents a sampling station. The different symbols indicate the different sampling moments (closed circles: spring 2017; open circles: autumn 2017; closed triangles: spring 2018; open triangles: autumn 2018). Distance between points is a measure of dissimilarity in benthic community composition. The eclipse (red) denote the 95% confidence interval for each sampling moment.*

# 6 Fish

## 6.1 Fish Catches

### 6.1.1 Sampling I: October 2020

A total of five fish species were caught in October 2020: Eel (*Anguilla anguilla*), Goby (*Pomatoschistus spec*.), Mullet (*Mugilidae spp.*), Herring (*Clupea harengus)* and sand smelt (*Atherina presbyter) (*Figure 6-1*)*. Large quantities of fish were observed in both the fyke nets (130) as well as the seine nets (3585) (Table 6-1 & Table 6-2). Eel was most abundant in the fyke net catches, especially those located near the inlet. Goby was caught using both the fyke net as well as the seine net, and represented 99.1% of all seine net catches (Table 2). Mullet was also caught using both methods, numbers however were limited. Herring and sand smelt (*Atherina presbyter*) were both only caught using the seine net.

### 6.1.2 Sampling II: April 2021

A total of seven species were caught in April 2021, of which four species that had not been observed before including flounder (*Platichthys flesus*), three-spined stickleback (*Gasterosteus aculeatus*), sprat (*Sprattus sprattus*) and sandeel (*Ammodytes tobianus*)(Figure 6-2). Herring and mullet were not observed. The total number of fish observed was slightly lower in the fyke nets (110) and significantly lower in the seine nets (328), in comparison to the sampling in October 2020 (Table 6-1 & Table 6-2). The latter was the result of the decreased number of caught goby, which dominated the seine net catches in October. It must be noted that the total distance fished with the seine net was lower during this sampling (90m), however when accounting for this the number of gobies caught was still vastly lower. (Juvenile) flounder was the second most abundant species caught during this sampling especially in the seine net, presumably due to the smaller mesh sizes. The number of eel caught was noticeably less, yet most were still caught close to the entrance.

### 6.1.3 Sampling III: May 2021

A total of six fish species were caught in May 2021 (Figure 6-3). The total number of fish observed was lower in both the fyke nets (60) and in the seine nets (217) than during the previous sampling in April (Table 6-1 & Table 6-2). The number of eel caught, on the other hand, was a lot higher (53). Goby catches decreased once more and flounder catches stayed approximately the same.

### 6.1.4 Sampling IV: June 2021

A total of five fish species were caught in June 2021 (Figure 6-4). The total number of fish caught in the seine was at its lowest (44) but the total number of fish caught in the fykes was slightly higher (70) in comparison to the previous sampling in May (Table 6-1 & Table 6-2). Only two gobies were caught.

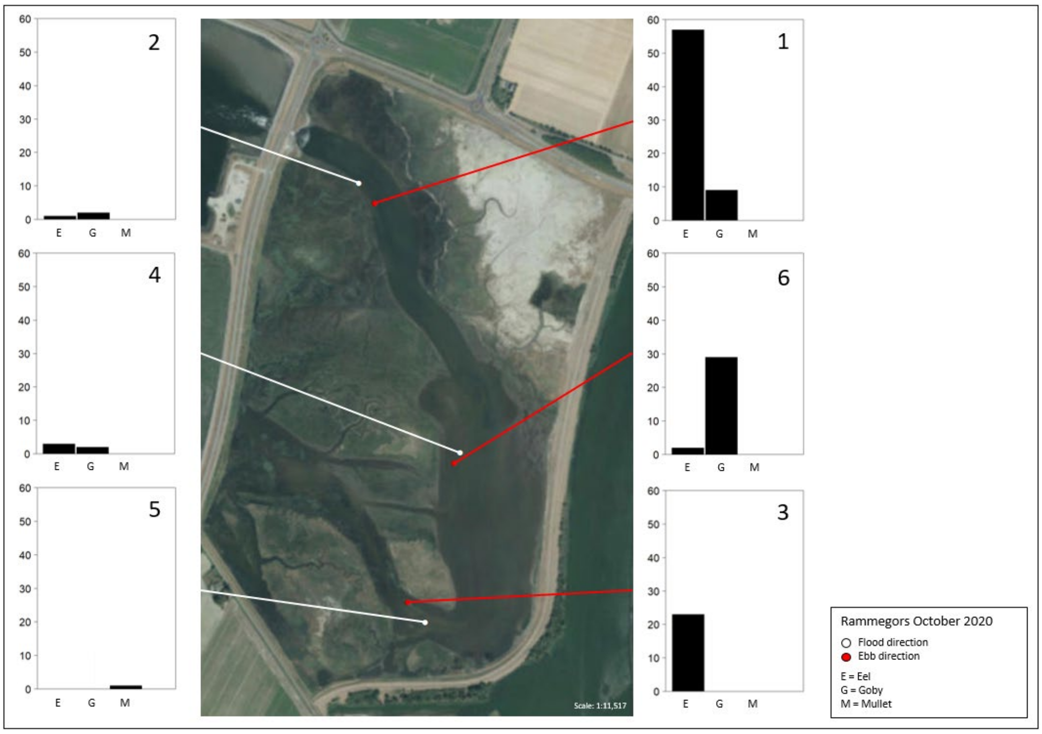



*Figure 6-1 The number of fish caught in the fyke nets in Rammegors during sampling in October 2021. For each net, the number per species is shown. The different coloured points show the direction the opening of the fyke net was positioned in; flood direction (white) or ebb direction (red).*

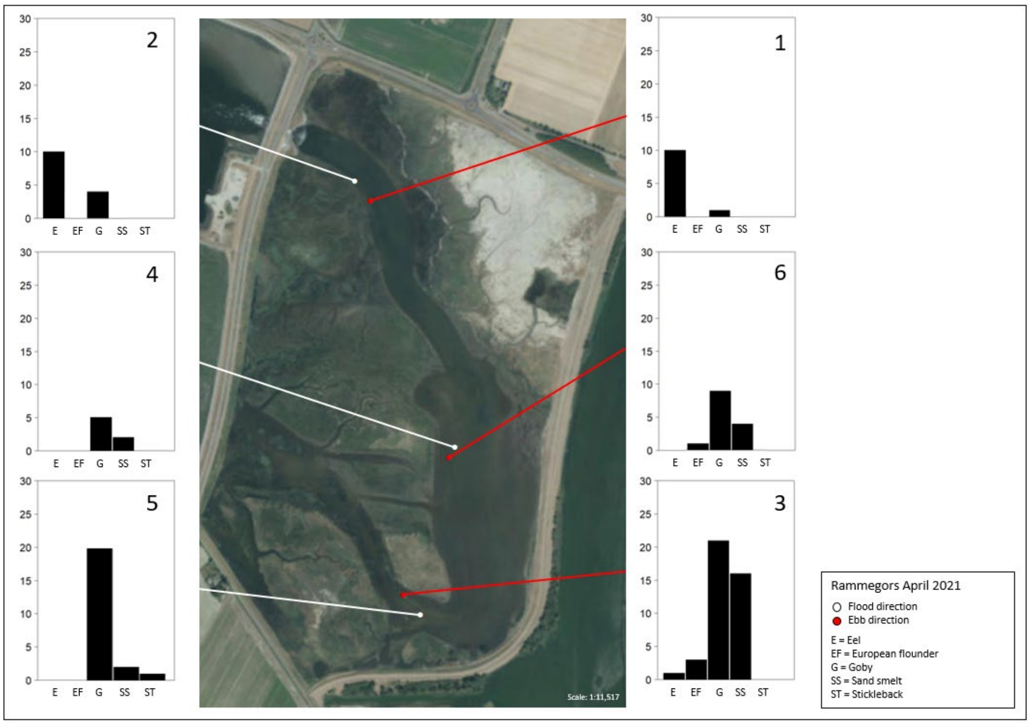



*Figure 6-2 The number of fish caught in the fyke nets in Rammegors during sampling in April 2021. For each net, the number per species is shown. The different coloured points show the direction the opening of the fyke net was positioned in; flood direction (white) or ebb direction (red).*

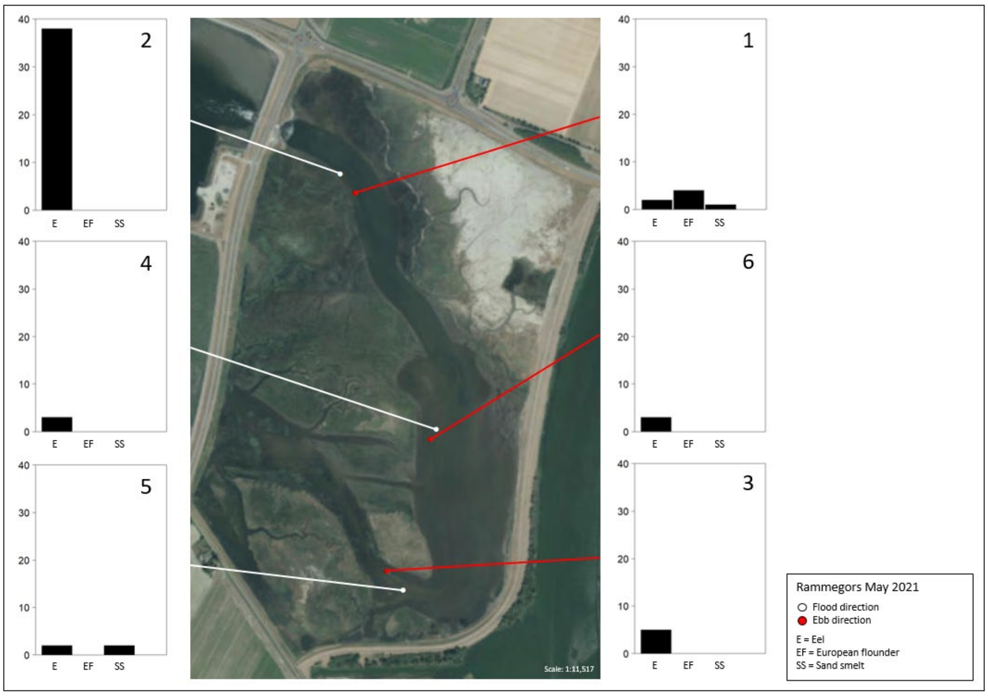



*Figure 6-3 The number of fish caught in the fyke nets in Rammegors during sampling in May 2021. For each net, the number per species is shown. The different coloured points show the direction the opening of the fyke net was positioned in; flood direction (white) or ebb direction (red).*

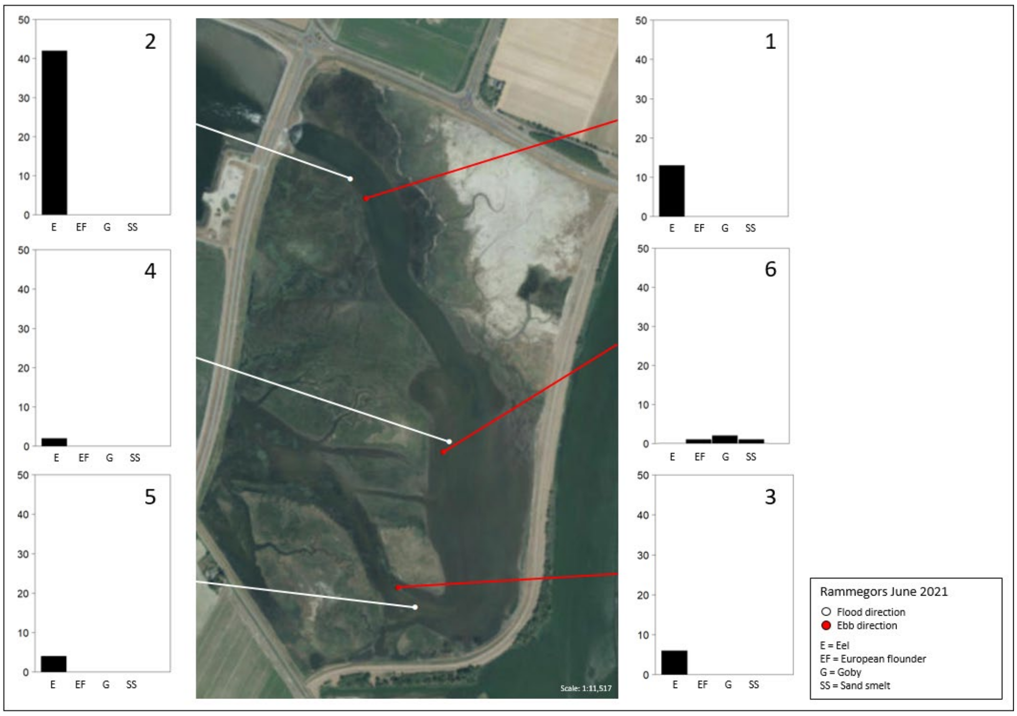



*Figure 6-4 The number of fish caught in the fyke nets in Rammegors during sampling in June 2021. For each net, the number per species is shown. The different coloured points show the direction the opening of the fyke net was positioned in; flood direction (white) or ebb direction (red).*

### Size distributions

Eels were caught across a variety of size ranges during the first sampling in October 2020. In April no eel larger than 45cm was caught, yet in the subsequent spring sampling moments (May and June) eels across similar size ranger to October 2020 were caught. Overall the eel caught had lengths ranging from 16 to 63 cm, with the majority being 30 to 40 cm, and a second, smaller peak around 50 cm (Figure 6-5).

Mullet were caught in lengths ranging from 1 to 5 cm, with the majority being 3 cm.

All herring and sand smelt in the catches had lengths between 6 and 8 cm.

Goby lengths ranged between 2 and 5 cm, with the majority being 3 or 4 cm in both types of fishing gear during all sampling moments.

European flounder (30.2% of the seine catches), was mostly caught in lengths ranging from 2 to 4 cm, with the majority being 3 cm (Figure 6-5). Next to that, a single 1 cm flounder and a single 8 cm flounder were caught.

## 6.3 Rammegors as a habitat for fish

The species caught during the monitoring activities in Rammegors can be classified into four different estuarine guilds: marine juveniles, marine seasonal migrants, diadromous migrants, and estuarine residents. On average eel catches were highest in the fyke nets placed closest to the inlet of the area. Due to the high variability in catches between fykes positioned towards/away from the entrance between sampling moments, we cannot distinguish if there was a tidal effect on the catches. Highest quantities of goby were clearly observed in October, as the spring progressed into summer lower quantities of goby were observed with each sampling moment, with the lowest catches in June.

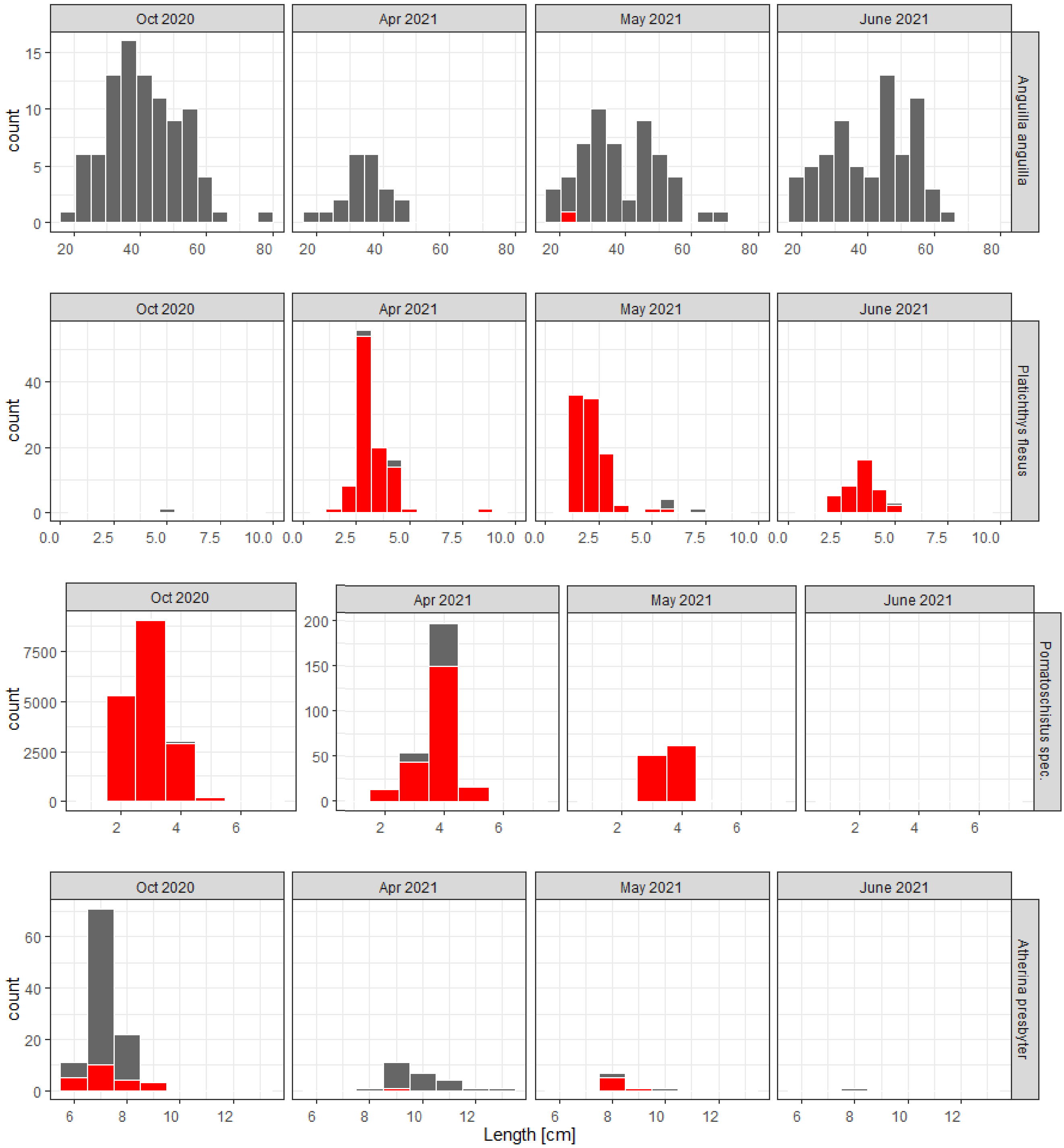



*Figure 6-5 Length frequency distribution of European eel (Anguilla anguilla), European flounder (Platichthys flesus), Goby (Pomatoschistus spp.) and Sand smelt (Atherina presbyter) caught in Rammegors during each sampling event from Oct 2020 – June 2021. Grey bars indicate fyke catches whereas red bars indicate seine catches. A different y-axis is shown for each species and for goby in October 2020. Effort per sampling moment is identical for all fyke catches (6 nets set out for ~24hrs), yet differs for seine catches (Oct: 225m, Apr: 90m, May: 113m, Jun: 90m).*

*Table 6-1 Total numbers observed per species per sampling in the fyke nets in Rammegors.*

| Species/Taxon | Rammegors | | | |
|---|---|---|---|---|
| | **Oct 2020** | **Apr 2021** | **May 2021** | **Jun 2021** |
| *Number of fyke nets* | *(n = 6)* | *(n = 6)* | *(n = 6)* | *(n=6)* |
| *Anguilla anguilla* | 86 | 21 | 53 | 67 |
| *Atherina presbyter* | | 24 | 3 | 1 |
| *Gasterosteus aculeatus* | | 1 | | |
| *Mugilidae spec.* | 1 | | | |
| *Platichthys flesus* | | 4 | 4 | 1 |
| *Pomatoschistus spec.* | 43 | 60 | | 1 |
| **Total** | 130 | 110 | 60 | 70 |
| **Number of species** | 3 | 5 | 3 | 4 |

*Table 6-2 Total numbers observed per species per sampling in the seine nets in Rammegors. Please note that effort between sampling moments differed.*

| Species/Taxon | Rammegors | | | |
|---|---|---|---|---|
| | **Oct 2020** | **Apr 2021** | **May 2021** | **Jun 2021** |
| *Number of transects* | *n = 4* | *n = 3* | *n = 3* | *n=3* |
| *Total fished distance* | *225 m* | *90 m* | *113 m* | *90m* |
| *Ammodytes tobianus* | | 2 | | |
| *Anguilla anguilla* | | | 1 | |
| *Atherina presbyter* | 14 | 1 | 6 | |
| *Clupea harengus* | 8 | | | |
| *Gasterosteus aculeatus* | | | | 3 |
| *Mugilidae spec.* | 10 | | 1 | |
| *Platichthys flesus* | | 99 | 93 | 38 |
| *Pomatoschistus spec.* | 3553 | 225 | 116 | 2 |
| *Sprattus sprattus* | | 1 | 3 | |
| **Total** | 3585 | 328 | 217 | 44 |
| **Number of species** | 4 | 5 | 6 | 3 |

# 7 Birds

In the period right before the introduction of tidal activity into Rammegors (2011-2015), on average the most commonly observed bird species included the Barnacle goose, European golden plover, Greylag goose, Eurasian wigeon and the Eurasian teal (Figure 7-1A). Most of these species show a large reduction in numbers after the opening, however some of these already declined prior to this. Other species increased such as the Northern lapwing. Observations of fish eating birds, such as the Cormorant, Black-headed gull, Great egret and Eurasian spoonbill, also vastly increased after the introduction of tides to the area (Figure 7-1B).

Currently no link between bird utilisation of the area and the vegetational development can be made as the classification algorithm for vegetation from satellite imagery is still under development.

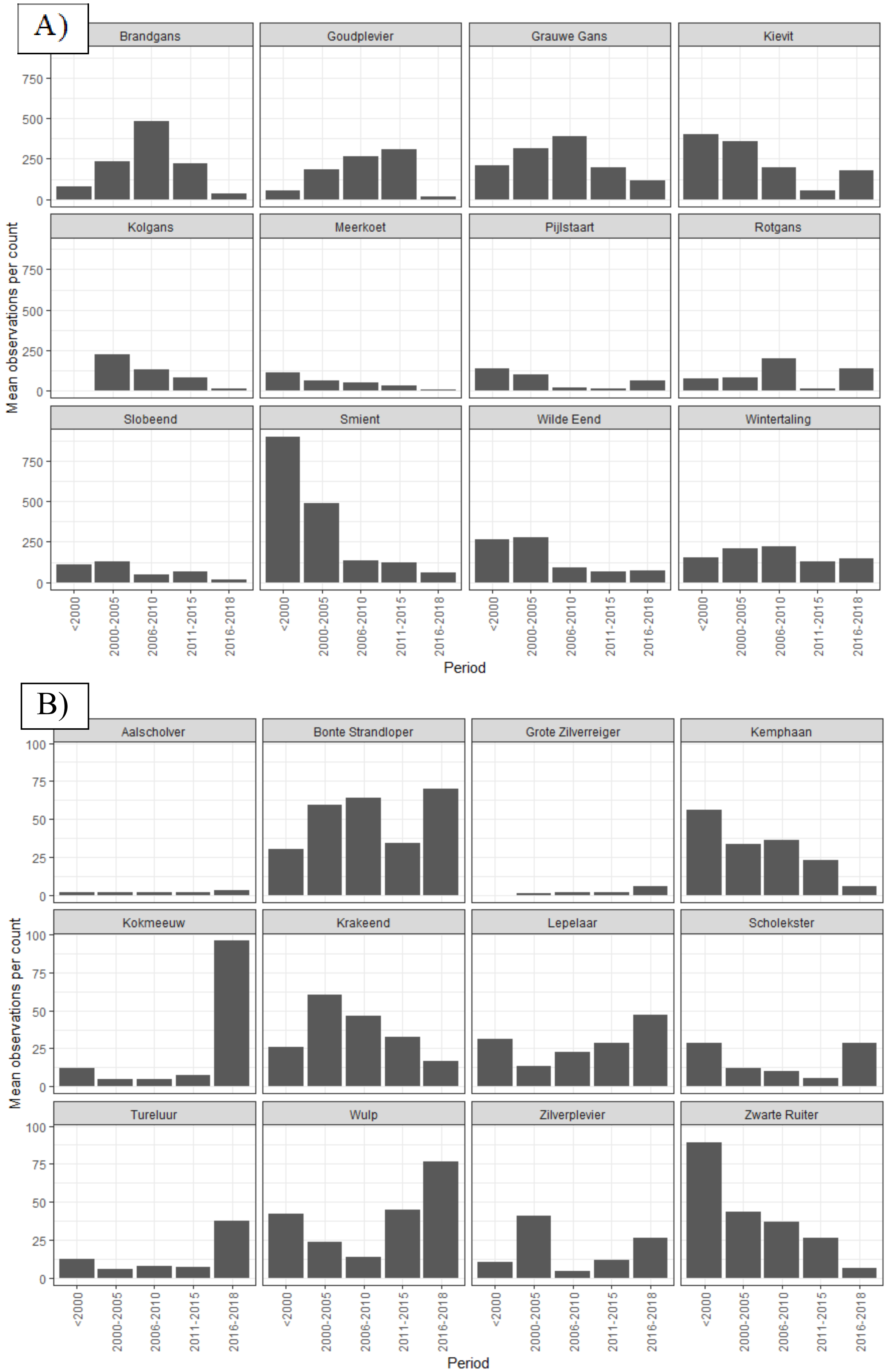



*Figure 7-1 Mean number of observations per count for several periods since monitoring started in 1993. Hereby the most common species (A) and relatively common species (B) are plotted with a different y-axis. The last period (2016-2018) indicates the timeframe in which Rammegors has been exposed to tidal inflow.*

# 8 Natura 2000/KRW objectives

## 8.1 Kaderrichtlijn Water

Within the KRW, the Rammegors area is categorised under K2: coastal waters.

### 8.1.1 Salinization of surrounding area through ground water

The monitoring results does not show any salinization of the groundwater in the area surrounding Rammegors. At one monitoring location in the Haaftenpolder (RH-03) the freshwater lens is even growing since the opening of the Rammegors. This is probably the result of the fact that saline water is now infiltrating in the Rammegors pushing the present freshwater laterally to the south. In the southern part of Rammegors, a low-permeable peat layer is missing which could be the cause of this faster freshening process. At the long-term timescale (this will be quantified at a later stage), the entire freshwater volume in Rammegors will be replaced by saline water and it is expected that also at location RH-03, the groundwater will eventually become more saline.

# 9 Social perception of the area

As a result of opening the culvets and allowing tides to reach the Rammergors area, it is no longer accessible to the general public.

## 9.1 Literature review

The systematic review of the scientific articles resulted in a comprehensive Excel database with information on  theoretical concepts, applied research methods and relevant insights as presented in the studies. More specifically, the database contains bibliographic details and subject areas of the articles,

Forty-two publications (or 18% of the publications screened) reported on **social responses to policy-induced landscape transitions**. These publications included in total 47 case study locations (Figure 9-1a). Most (83%) of the case studies were conducted in Europe, particularly in the United Kingdom (25%) and the Netherlands (19%). The majority of case studies focused on coastal interventions (49%) and riverine interventions (35%). In the Netherlands, 8 out of 9 case studies focused on riverine landscape interventions, primarily related to the "Programma Ruimte voor de Rivier" information on research design (e.g. country, theoretical framework, data collection methods, landscape typologies), measurement variables and frameworks, the type of landscape interventions studied and key findings (e.g. insights and recommendations). The following provides a brief overview of some of the outcomes of the review.

We classified the theoretical concepts and  measurement variables, which were used in the articles to evaluate the social response to landscape transitions, into ten main variable classes, see Figure 9-1b. The measurement variables most commonly employed in the articles included sociodemographic variables, followed by variables related to landscape perception, level of support or acceptation, and risk perception. In nearly all articles a reference was made to place attachment and related concepts like sense of place and belongingness (in Figure 9-1b classified as "Landscape Perception" variables). However, only 8 studies used place attachment as the main theoretical framework, and empirically measured and validated the level of place attachment among the study population and examined how place attachment relates to support or opposition to policy-induced landscape transformation. Importantly, in all of these 8 studies place attachment was found to be correlated with the level of support or opposition to landscape transformations, suggesting that attention for place attachment is helpful when studying perceptions of landscape interventions. Risk perception was most commonly evaluated in terms of perceived flood risks, while less studies evaluated the perceived risk of losing physical property, livelihoods and related aspects. On the other hand, only 2 out of 42 publications evaluated how social norms could influence public perception of landscape transitions. This, in spite of a large body of evidence showing that social norms could have an important influence on behavior and perceptual processes (e.g. Lo, 2013).

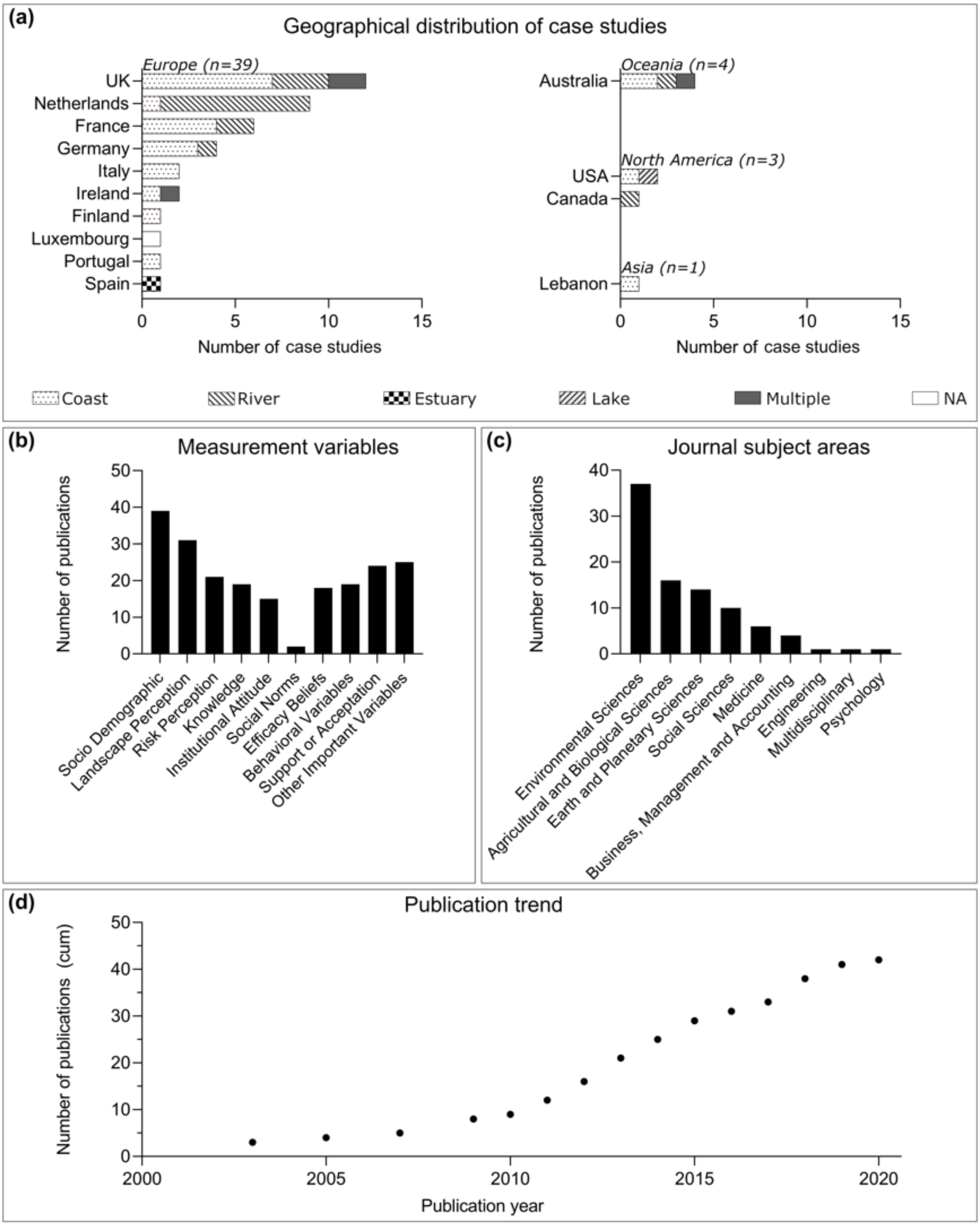



*Figure 9-1 Quantitative results from the literature review on social responses to policy induced landscape transitions, showing the geographical distribution of case studies (a) measurement variables used in the studies (b), subject areas of the journals in which the articles were published (c) and the publication trend (d).*

The SCImago Journal & Country Rank database was consulted to define the subject areas of the journals in which the articles were published (Figure 9-1c). Most of the articles were published in Environmental Sciences journals, followed by journals classified as Agricultural and Biological Sciences, and Earth and Planetary Sciences. As shown in Figure 1c, only one article was published in a journal classified as Psychology. This lack of publication in psychology-related journals was contrary to expectations, given that the formation of perceptions and attitudes toward landscape changes is primarily a psychological process.

The accumulative number of publications over time is outlined in Figure 9-1d. As shown in the figure, the publication rate of articles appears to have increased from 2010 onward, suggesting that attention for research on the perception of policy-induced landscape interventions has been increasing over the past decade. However, note that the trend is based on a relatively small sample of 42 articles. Hence, to gain a more robust insight into how the attention for the topic has evolved over time, it would be necessary to increase the sample size by adding more articles to the literature review. This could be achieved, for instance, by expanding the literature search through consultation of scientific databases like SCOPUS or Web of Science (which have not been used for the current review) to identify additional articles.

## 9.2 Survey questionnaire

The insights from the literature review were used to conceptualize a survey questionnaire to investigate how the coastal realignment process in the Rammegors area is perceived by the nearby community. The main body of the questionnaire is subdivided into two parts. Part 1 contains questions related to the general perception of the landscape around the sea dikes in Zeeland, whereas part 2 focuses on the Rammegors area more specifically, and contains questions about the perception of the coastal realignment intervention and the associated changes of the local landscape. Some of the questions in part 1 and part 2 of the questionnaire are equivalent, which will allow for comparison and differentiation between landscape appreciation on a regional (i.e. Zeeland) and local level (i.e. Rammegors). Table 9-1. provides a more detailed overview of the themes and concepts included in the survey questionnaire and which specific studies were consulted to develop the questionnaire items.

*Table 9-1 Overview of the themes and concepts of the survey and references that were consulted to develop the questionnaire items.*

| Themes and concepts | Consulted literature to develop questionnaire |
|---|---|
| Type and frequency of activities on and around the dikes in Zeeland | -- |
| Identification and mapping of places with a special meaning | Brown et al. (2015), Brown and Raymond (2007) |
| Overall landscape attractiveness | Ratter and Gee (2012), De Vries et al. (2013) |
| Familiarity with the area and place attachment | Jacobs and Buijs (2011), Verbrugge and van den Born (2018), and others. |
| Emotions and feelings related to the physical and social surroundings | -- |
| Risk perception and concerns | Goeldner-Gianella et al. (2015) and others. |
| Attitudes and level of support for coastal realignment | Myatt et al. (2003), Esteves and Thomas (2014) |
| Social norms | Bicchieri (2016) |
| Efficacy beliefs | McKinley et al. (2020), Rojas et al. (2017) |
| Institutional attitudes and trust | Jones and Clark (2014), Schmidt et al. (2014), and others. |
| Sociodemographic variables | -- |

## 9.3 Education & dissemination

- Findings of Perkpolder and Rammegors Phase 1 monitoring were shared with 2nd year HZ Water Management students as part of the module Ecological Engineering
- Findings of Perkpolder and Rammegors Phase 1 monitoring were shared with HZ Master River Delta Development students to teach about coastal landscape transitions
- A sub-group of 6 Master RDD students is currently working with the Building with Nature research group as part of their Living Lab assignment. They have recently visited the Rammegors area and a field visit to the Perkpolder area is scheduled on 18 October. These students will assist the lecturers in performing the surveys.
- Findings of Perkpolder and Rammegors Phase 1 monitoring and plans for the current Phase 2 monitoring were shared with the international Polder2Cs (https://polder2cs.eu/) consortium as part of a session about managed realignment in the South West Delta. See full recording of the session here: https://polder2cs.eu/news/managed-realignment-coastal-management-tool.

*Figure 9-2 HZ Master River Delta Development students visiting the Rammegors area in October 2021 as part of their Living Lab assignment on the transition in the coastal landscape of Perkpolder and Rammegors.*

# 10 Discussion

## 10.1 Environmental conditions

### 10.1.1 Groundwater

The restoration of the tidal area Rammegors resulted in (1) a constant flow of saline surface water into Rammegors, (2) an average higher water level in Rammegors and (3) a change from a constant water level to a tidal fluctuating water level.
This caused infiltration of saline water into the subsoil of Rammegors. The monitoring results show that this process is still going on and it may take several years (> 5 years) until the entire upper-aquifer is salinized. In the polder areas around Rammegors no salinisation was observed and in 3 out of 4 locations, a very steady fresh-salt interface is observed during the monitoring period 2016-2021. However, one location in the Haaftenpolder close to Rammegors shows signs of freshening subsoil. Here the freshwater lens has grown with about 5 meters during the period 2016-2021. This is probably due to the fact that the original freshwater below Rammegors is replaced by saline water and pushed laterally outside the Rammegors area. It is expected that when the upper-aquifer below Rammegors has finally totally salinized, the freshening at Haaftenpolder stops and that salinities will increase again.
The monitoring results don’t show any evidence that aquifer heads and groundwater levels in the surrounding agricultural area are significantly affected by the restoration of the tidal area Rammegors. No crop damage due to increased groundwater levels are expected.

### 10.1.2 Vegetation

Vegetation recordings took place in 2020 at 18 points in the project area. In addition, the sediment properties on the surface were determined and the penetration resistance measured at these points to a depth of 0.8 m. This data, supplemented with data on underground developments in water level and quality, will be used in the second half of the project to investigate whether there is a relationship between developments in soil properties and vegetation development. To be able to proceed, a sufficiently progressive development of the vegetation must first be observed. As we are too early in the project - i.e., not enough data are available, and the image analysis techniques are still under development- the relationship between developments in soil properties and vegetation development cannot be investigated yet.

## 10.2 Macrobenthic community

### 10.2.1 Benthic development

The observed decrease of *M. insidiosum* combined with an increase of *C. volutator* indicate that the Rammegors area was still brackish five months after the third opening but transferred to a marine system. Also the occurrence of the brackish cockle *Cerastoderma glaucum*, as well as high occurrence of Chironomidae in 2017 followed by a decline in 2018 indicates this transition. In autumn 2018 the Rammegors area was dominated by gastropoda and polychaeta of which mudsnails (*Peringia ulvae)* and *Corophium volutator*, respectively contributed most to the total abundance. Biomass increased over time, with polychaetes contributing most to the total biomass. In 2020 *Corophium* had completely disappeared and *Aphelochaeta* appeared as a new dominant species. Mud snails (*Peringia ulvae)* densities remained high.

### 10.2.2 Bulk density

Bulk density showed to have a significant impact on observed species densities, with higher densities being observed at lower bulk densities. Perhaps the higher bulk density (during compaction) observed in 2017 autumn can explain the lower mean observed densities during this sampling moment. However it is uncertain whether the high bulk densities are the cause or the result of the observed low densities of benthic fauna, as the absence of benthic organisms can also cause high bulk densities.

## 10.3 Utilisation of Rammegors by fish

### 10.3.1 Juvenile flatfish

During the sampling moments in Rammegors in April and May 2021, European flounder was very abundant in fyke catches, where lengths ranged between 1 and 8 cm. At these lengths this species is still considered juvenile (Kroon 2009, Muus et al. 1999), indicating flounder utilise the salt marsh as a nursery site during spring. European flounder are known to spend their juvenile life stage in nursery areas along the coast, and reside in shallow coastal water between February and July (Muus et al. 1999, Reeze et al. n.d.).

### 10.3.2 European Eel

Eel was caught in a variety of lengths, the majority of which was around 35-45 cm, indicating and age of approximately 5 to 7 years (Tesch 1999). More importantly, this length indicates male eels reaching sexual maturity (30–45 cm), which is non-dependent on the eels age (Müller 1975, Vøllestad and Jonsson 1986). This shows the majority of eel caught were probably almost sexually mature males (silver eel) and younger females (Figure 10-1). The group around 50 cm are likely older females (Figure 10-1), that have not become silver eel yet, as females take longer to become sexually mature (54–61 cm) (Hoestlandt 1991). This group is expected to exist of female eel only, as male eel migrate away before they reach this length, resulting in eel above 50 cm being practically always female (Reeze et al. n.d.). However, growth, maturation and sexuality in eel are highly dependent on environmental factors (Personal communication, Tesch 1999). Fewer and smaller eels were caught in Rammegors in April 2021. In May and June, more eels were caught again, following the same length distribution as in October 2020 (Figure 10-1). Eels migrate mostly between September and November (Personal communication, Reeze et al. n.d.), which could indicate the eel caught in autumn 2020 were migrating and used the salt marshes as foraging ground. This presumption is strengthened as silver eel were caught in Rammegors during this sampling moment. It is also possible eels use salt marshes as their permanent foraging area or habitat, as lengths show non-sexually mature fish extensively using the marshes. Especially Rammegors forms a suitable habitat for eel, because of the soft sediment, permanent waterbody, vegetation coverage, and sufficient food sources, (Elschot et al. 2016, ICES/EIFAC 2004). Finally, factors that may attract eel are present in the area: freshwater seepage and the abundance of degrading organic material (Walles et al. 2019). Further research on the eel in Rammegors is needed to draw a solid conclusion on the function this salt marsh has for eel.

### 10.3.3 Goby

Most of the Goby (*Pomatoschistus spec.*) caught was within the lengths of 3 or 4 cm. This length indicates the fish could be approximately 1 year old and reaching sexual maturity (Doornbos and Twisk 1987). Larger and smaller lengths also occurred, yet were less common. The presence of this wide length range indicates gobies use the area in all life stages, corresponding to their status as estuarine residents. Highest quantities of goby were clearly observed in October, as the spring progressed into summer lower quantities of goby were observed with each sampling moment, with the lowest catches in June.

### 10.3.4 Sand smelt

Sand smelt (*Atherina presbyter*) was caught during all samplings. Lengths ranged from 6 to 9 cm in autumn 2020, and from 7 to 12 cm in Rammegors in spring 2021. These lengths indicate that individuals caught in autumn 2020 are approximately 1 year old, which is the end of their juvenile stage and when they sexually mature (Lorenzo & Pajuelo 1999).. Lengths caught in spring 2021, indicate an age of approximately 1 to 3 years old (Lorenzo & Pajuelo 199). Sand smelt are known to use estuaries and tidal areas to spawn (Calle et al. 2020). The fact that mostly juvenile fish or young adults were caught, could indicate that these fish use the salt marshes as a nursery ground in their juvenile life stage. However, the presence of larger sand smelt (age 2+ or 3+) in Rammegors in spring 2021, indicates that adult fish use the salt marsh as well.

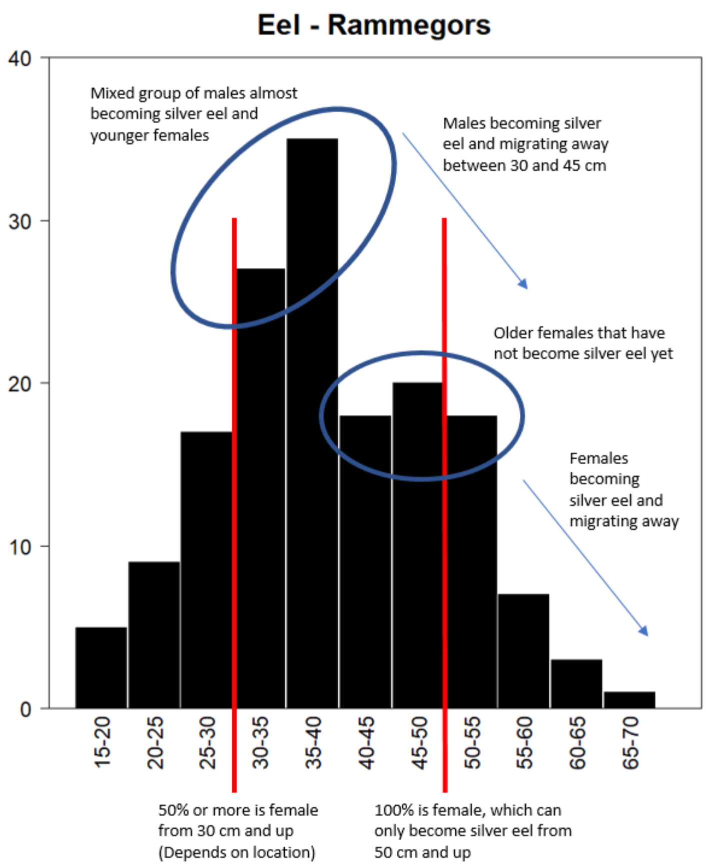



*Figure 10-1 Length frequency distribution of eels caught in Rammegors between October 2020-May 2021, including speculations on what the size groups indicate.*

# 11 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 Dutch Ministry of Agriculture, Nature and Food Quality, within the framework of the Wageningen University Knowledge Base programme: KB36 Biodiversity in a Nature Inclusive Society (project number KB-36-003-033). We would also like to acknowledge Daan van Houte, a HZ student, for his great contribution to the analysis of the fish communities in Rammegors, during his thesis-internship, in Spring 2021.

# 12 Quality Assurance

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

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# Justification

Report C002/22
Project Number: 4313100126

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

Approved: Dr. Ingrid Tulp
Researcher

Signature: 

Date: 19th of January 2022

Approved: Drs. J. Asjes
MT member Integration

Date: 21 January 2022

# Annex I Method for vegetational development

The high level of detail in low-altitude imagery, caused by shadows and highlights imposed by e.g. the micro-topography of the surface or the complexity of the vegetation canopy, paradoxally poses challenges for image classification and analysis. Traditional image segmentation- and subsequent classification algorithms based on (multi) spectral data usually fail, unless the imagery is resampled to a lower resolution or a smoothing algorithm is applied. This means, however, that potential useful information enclosed in the images, which is needed to study small-scale ecological details, is lost. In this project we will develop a method for texture analysis, as an approach for mapping tidal vegetation in salt-marsh environments. Using aerial images derived by low-altitude aerial photography from a drone, fine scale textural differences at an ecological relevant scale on the marsh, are analysed and used to map vegetation species/types (Fig.I-1). We will compare the method of texture analysis with the more conventional multispectral approach.

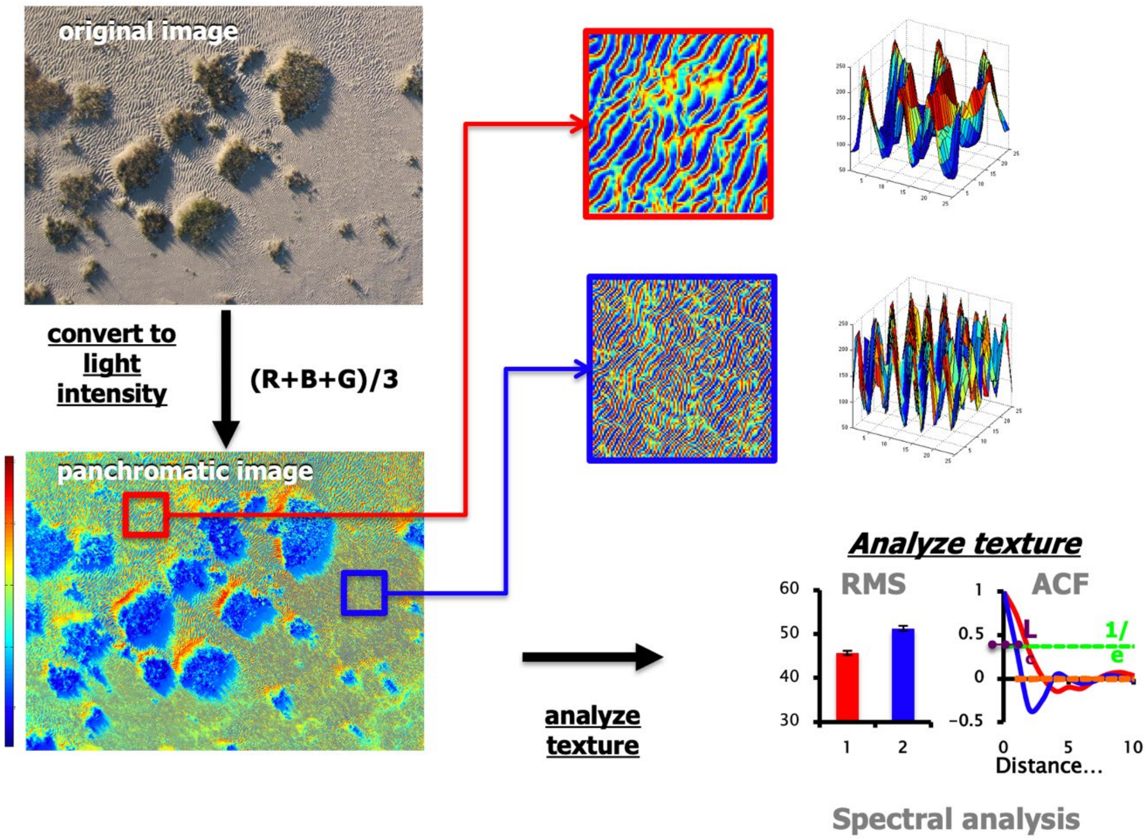



*Figure I -1: Example of the procedure used in the texture analysis methodology to classify groups of pixels (neighborhood operation). Here an example is shown that can also classify sediment textures (sand ripples). Example textures which can be used for classification: RMS = Root Mean Square Deviation; ACF = autocorrelation function.*

# Annex II Method for groundwater time series models.

Time series models are based on the response of an impulse function, i.e. hydraulic head, to a stress, i.e. precipitation and evaporation. The method was first proposed by Box & Jenkins (1970) and later developed further by others to analyze and simulate the influence of external stresses on a measured time series.

In this method, a modelled time series is obtained through convolution of impulse response functions with stress time series. An impulse-response function describes the evolution of the variable of interest along a specified time horizon after a stress in a given moment. The shape of the impulse response function is based on a parametric function. The parameters of this function are optimized by fitting the modelled time series to a measured time series. A gamma probability density function which is considered a reasonable approximation for the response of groundwater level to precipitation, is used to represent the impulse response function and is defined as (Besbes and de Marsily, 1984):

$$\theta(t) = A\frac{a^n}{\Gamma(n)}t^{n-1}e^{-at} \qquad (1)$$

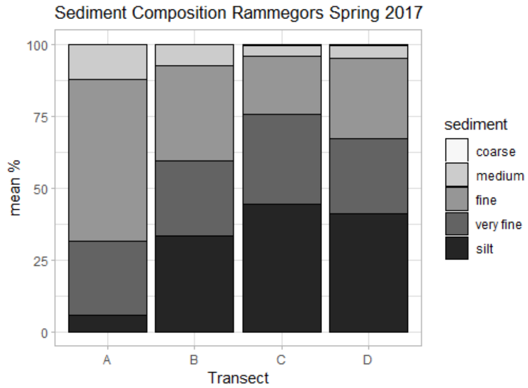
where $A$ equals the area under the impulse response function, $n$ is the shape parameter, $a$ is the scale of the function, $\Gamma$ is the gamma function and $t$ is the time after the impulse. The response of groundwater heads to precipitation and evaporation can then be obtained through convolution of the impulse response function with a precipitation and evaporation time series:

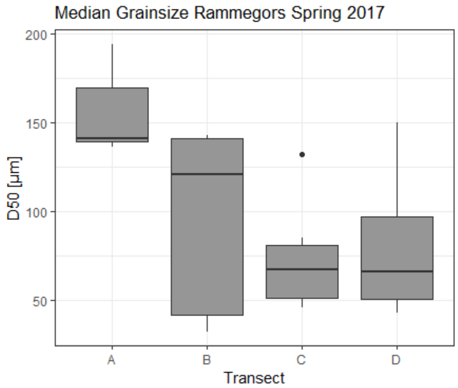
$$h_t = \sum_{\tau=-\infty}^{t}(N_\tau - f_c E_\tau)A\frac{a^n}{\Gamma(n)}\tau^{n-1}e^{-a\tau} + h_d + n_t \qquad (2)$$

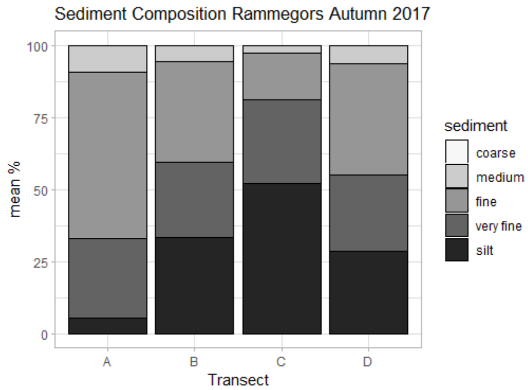
where $h_t$ is the groundwater head, $N_\tau$ and $E_\tau$ are precipitation and evaporation, respectively, $f_c$ is the evaporation factor, $h_d$ is the base elevation of the time series model and $n_t$ is noise part.

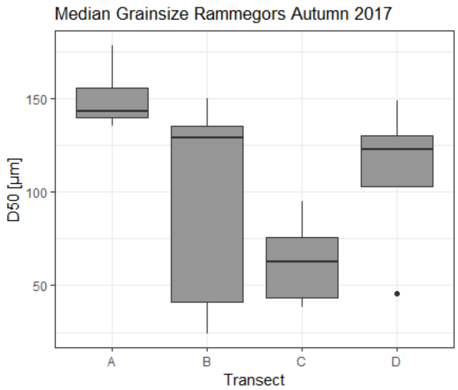
The parameters of the impulse response function are obtained with an optimization technique. In this method, parameters of the impulse response function are changed through several iterations until the residuals are minimized. It should be noted that this method assumes a linear relation between impulse and response which means that non-linear behavior is not covered. The software Pastas (Collenteur et al., 2019) has been used to derive the impulse-response functions of the Rammegors time series.

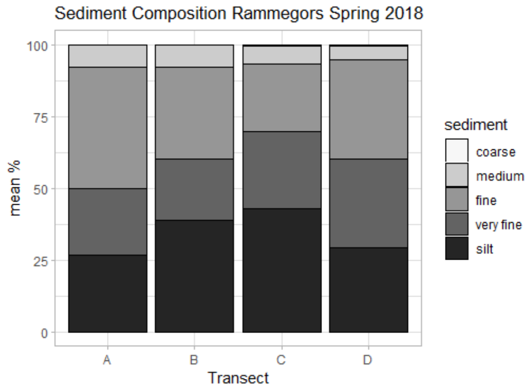
# Annex III – Annual Sediment Results

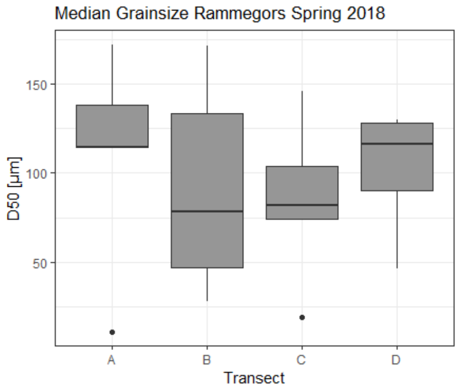


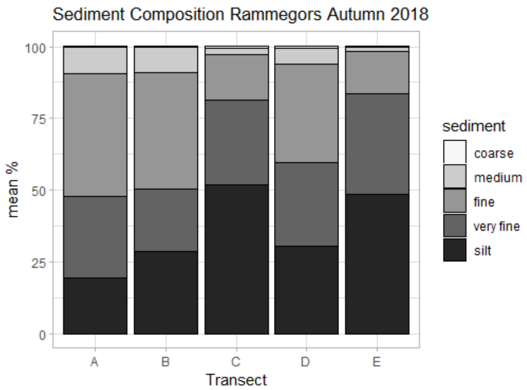



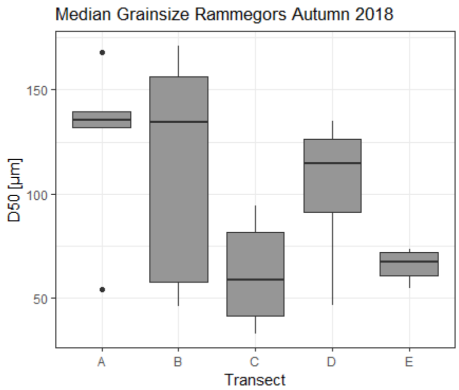



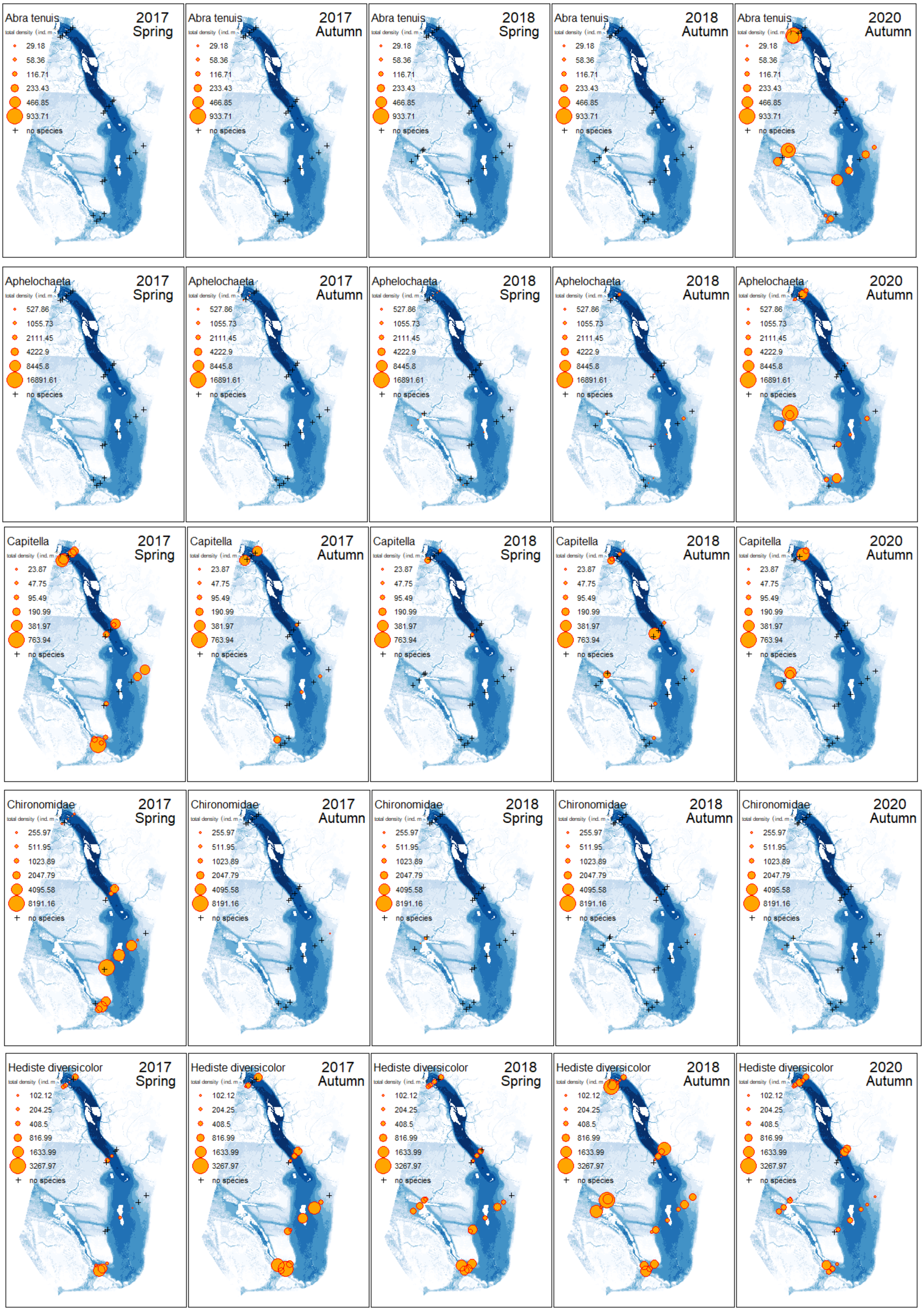



# Annex IV – Spatial observed densities ind. species



Abra tenuis
2017 Spring
2017 Autumn
2018 Spring
2018 Autumn
2020 Autumn
29.18
58.36
116.71
233.43
466.85
933.71
no species
Aphelochaeta
527.86
1055.73
2111.45
4222.9
8445.8
16891.61
Capitella
23.87
47.75
95.49
190.99
381.97
763.94
Chironomidae
255.97
511.95
1023.89
2047.79
4095.58
8191.16
Hediste diversicolor
102.12
204.25
408.5
816.99
1633.99
3267.97

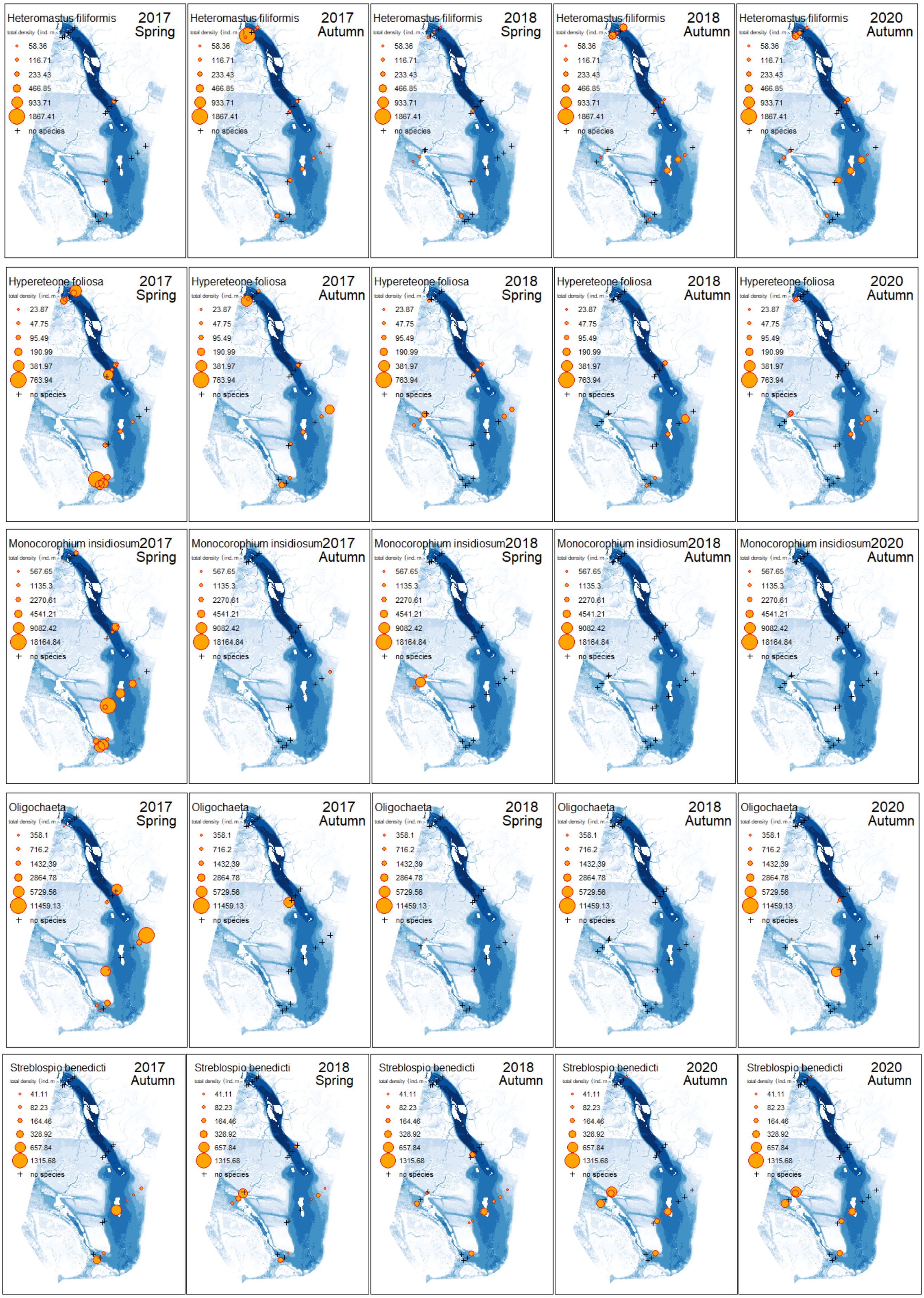
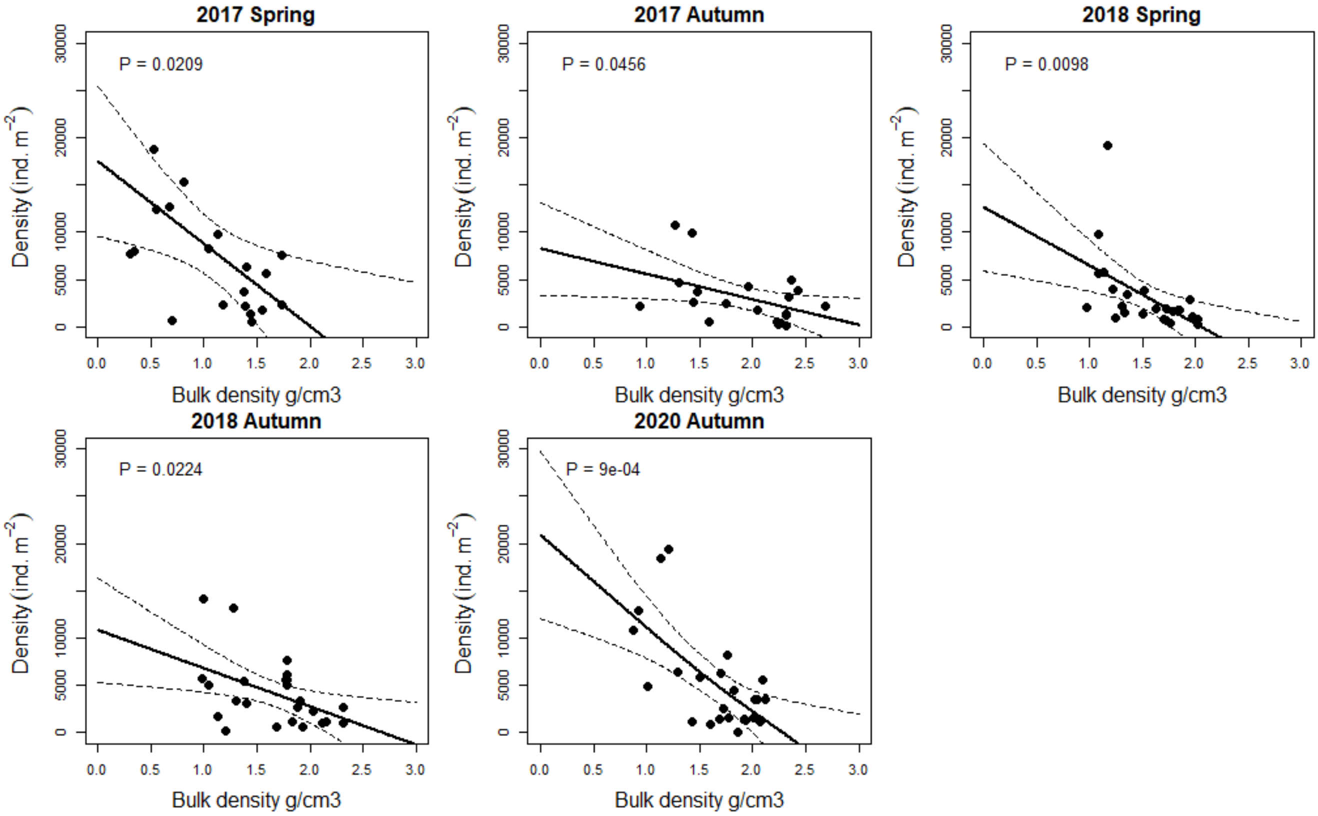
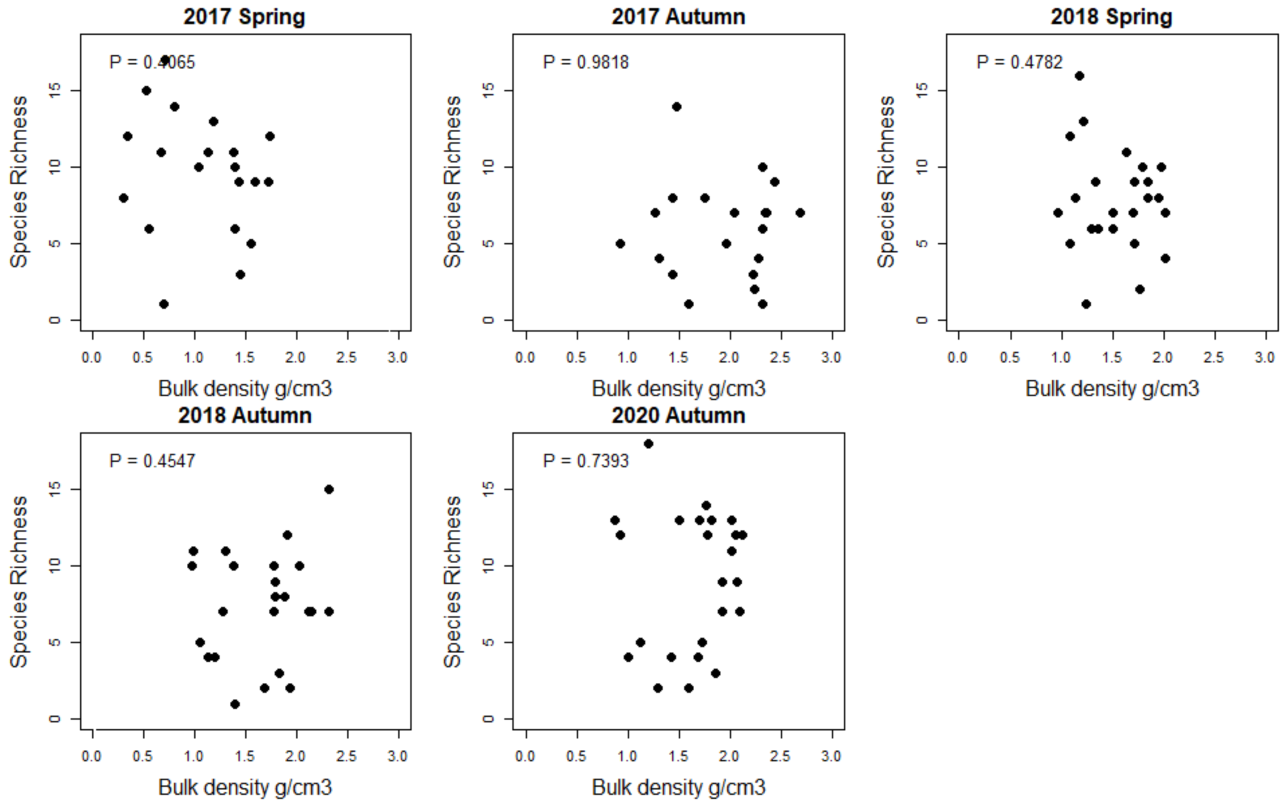
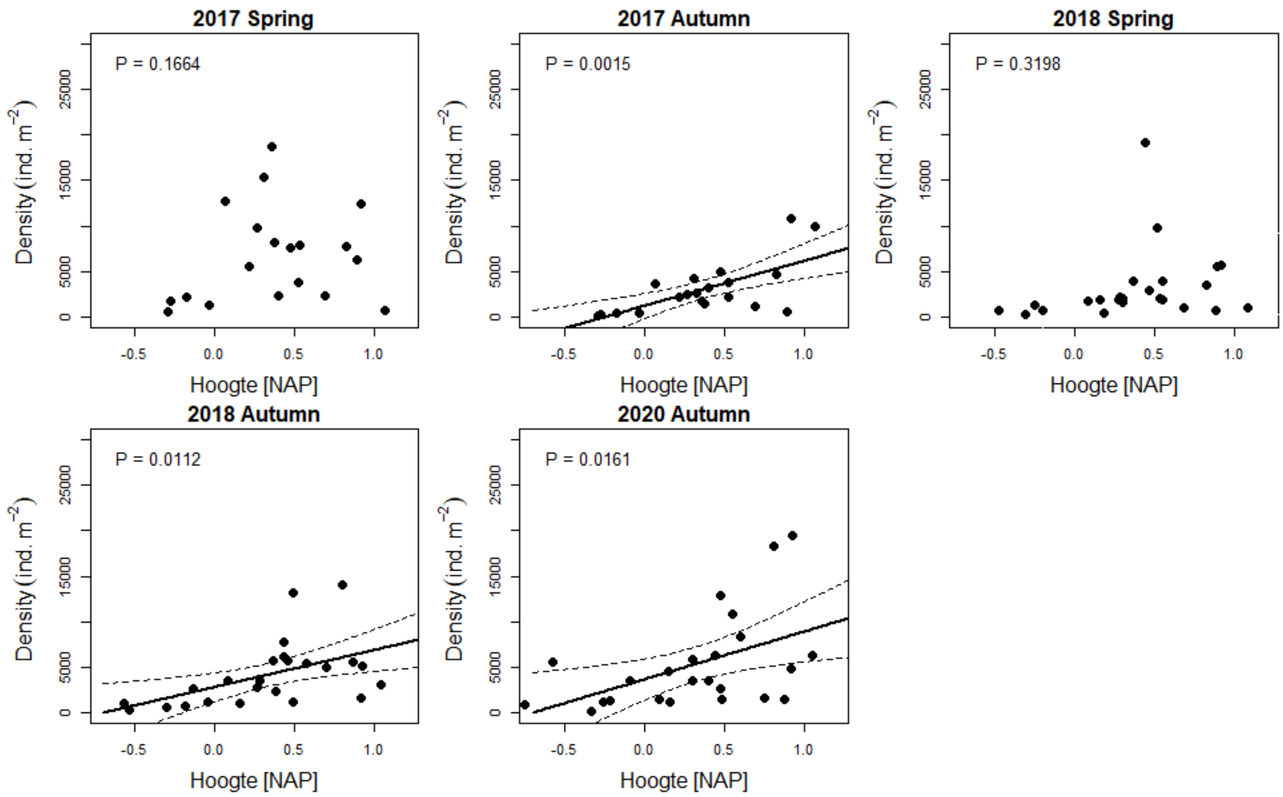


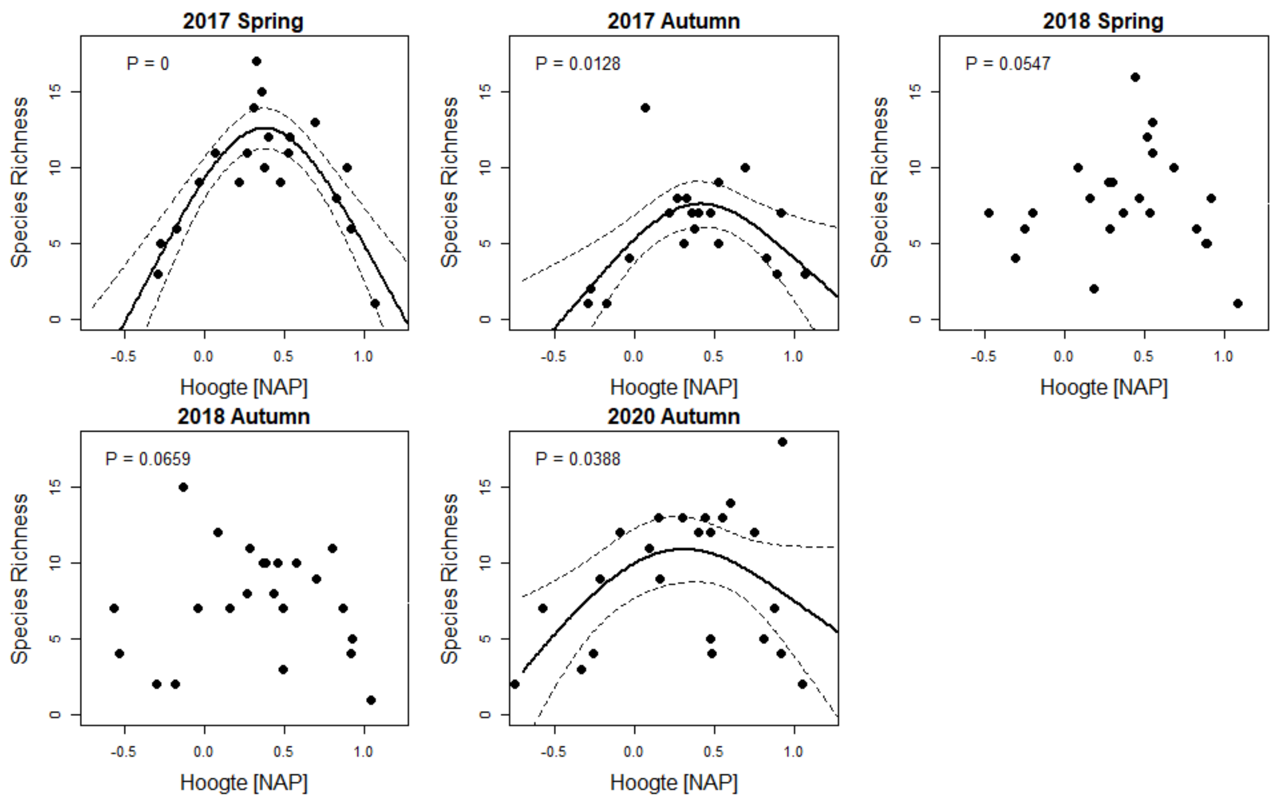

*Figure 12-1 Observed spatial and temporal distribution of declining species across the transects samples in the Rammegors area. Background: LIDAR 20XX*

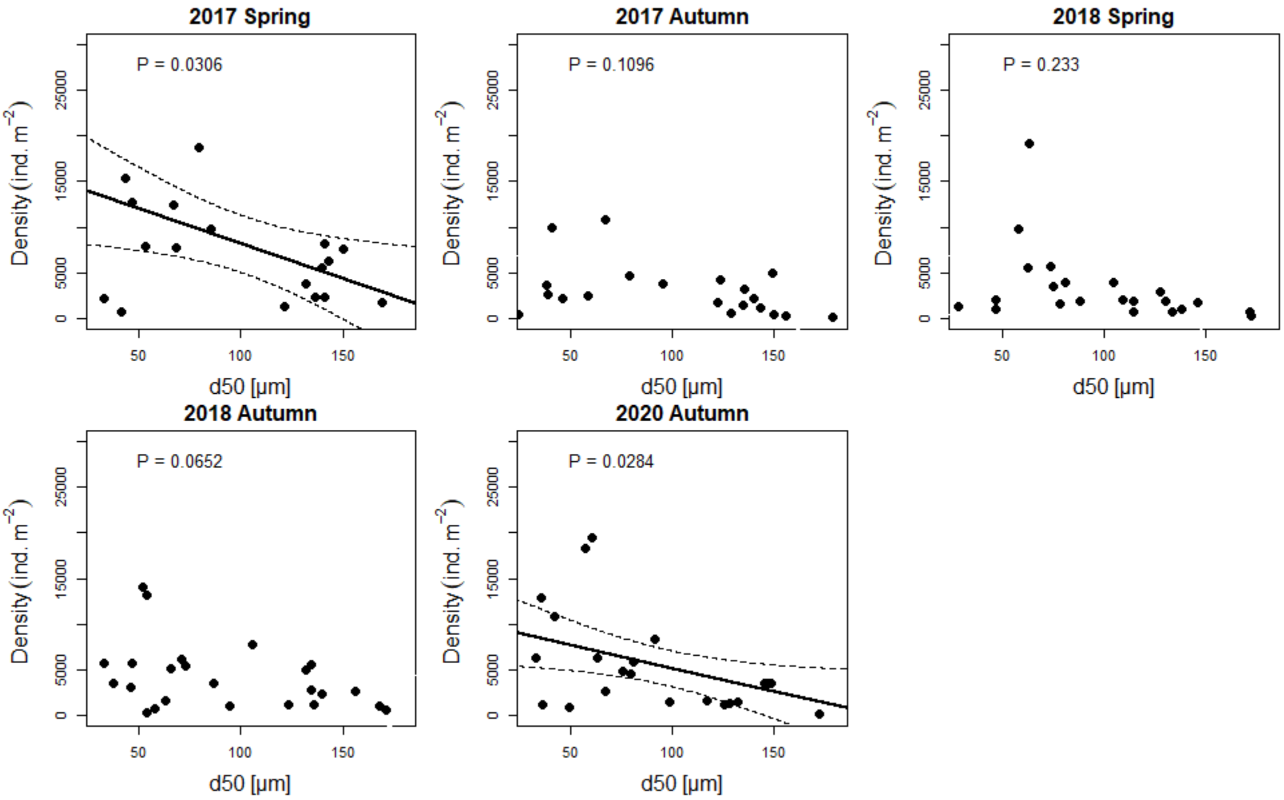
# Annex V– annual relation with environment

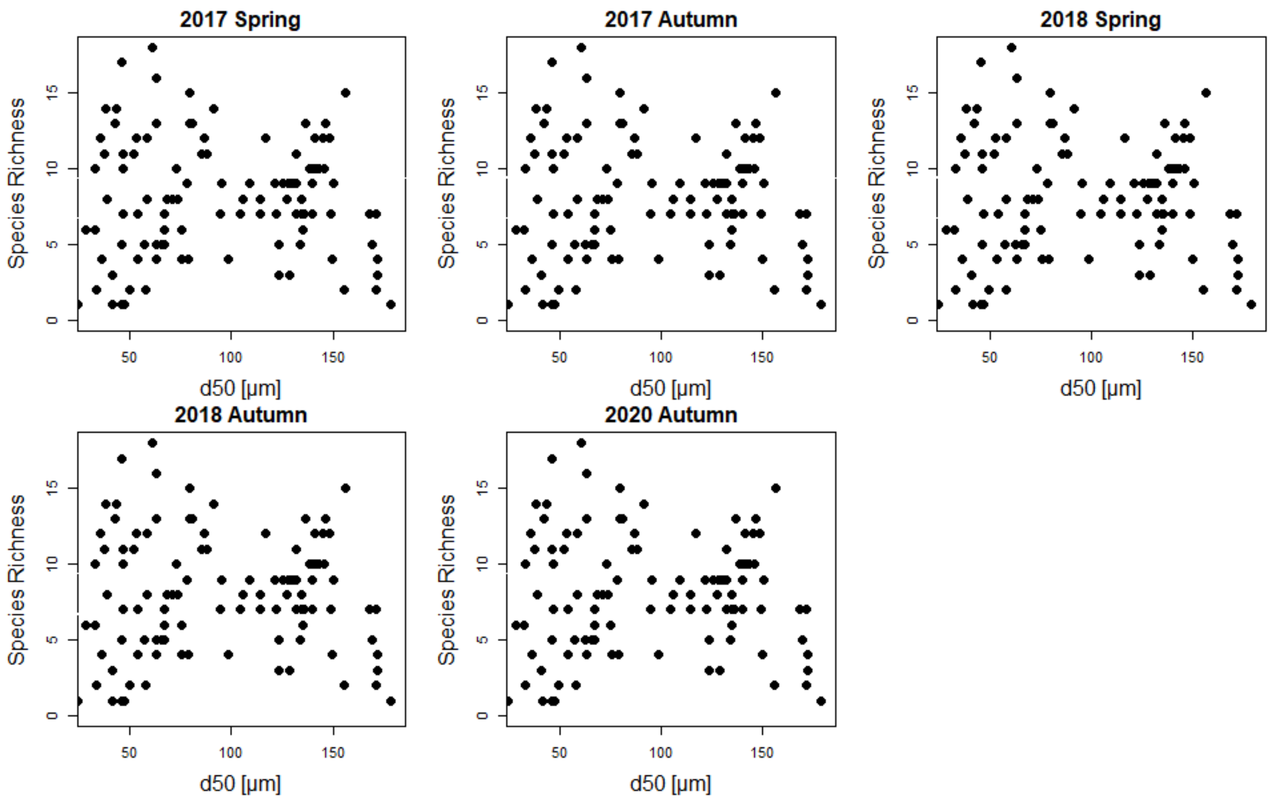



2017 Spring
P = 0.1664
2017 Autumn
P = 0.0015
2018 Spring
P = 0.3198
2018 Autumn
P = 0.0112
2020 Autumn
P = 0.0161
Density (ind. m^-2)
Hoogte [NAP]


2017 Spring
P = 0
2017 Autumn
P = 0.0128
2018 Spring
P = 0.0547
2018 Autumn
P = 0.0659
2020 Autumn
P = 0.0388
Species Richness
Hoogte [NAP]


2017 Spring
P = 0.0306
2017 Autumn
P = 0.1096
2018 Spring
P = 0.233
2018 Autumn
P = 0.0652
2020 Autumn
P = 0.0284
Density (ind. m$^{-2}$)
d50 [µm]


2017 Spring
2017 Autumn
2018 Spring
2018 Autumn
2020 Autumn
Species Richness
d50 [µm]

# Annex VI – Groundwater head time series

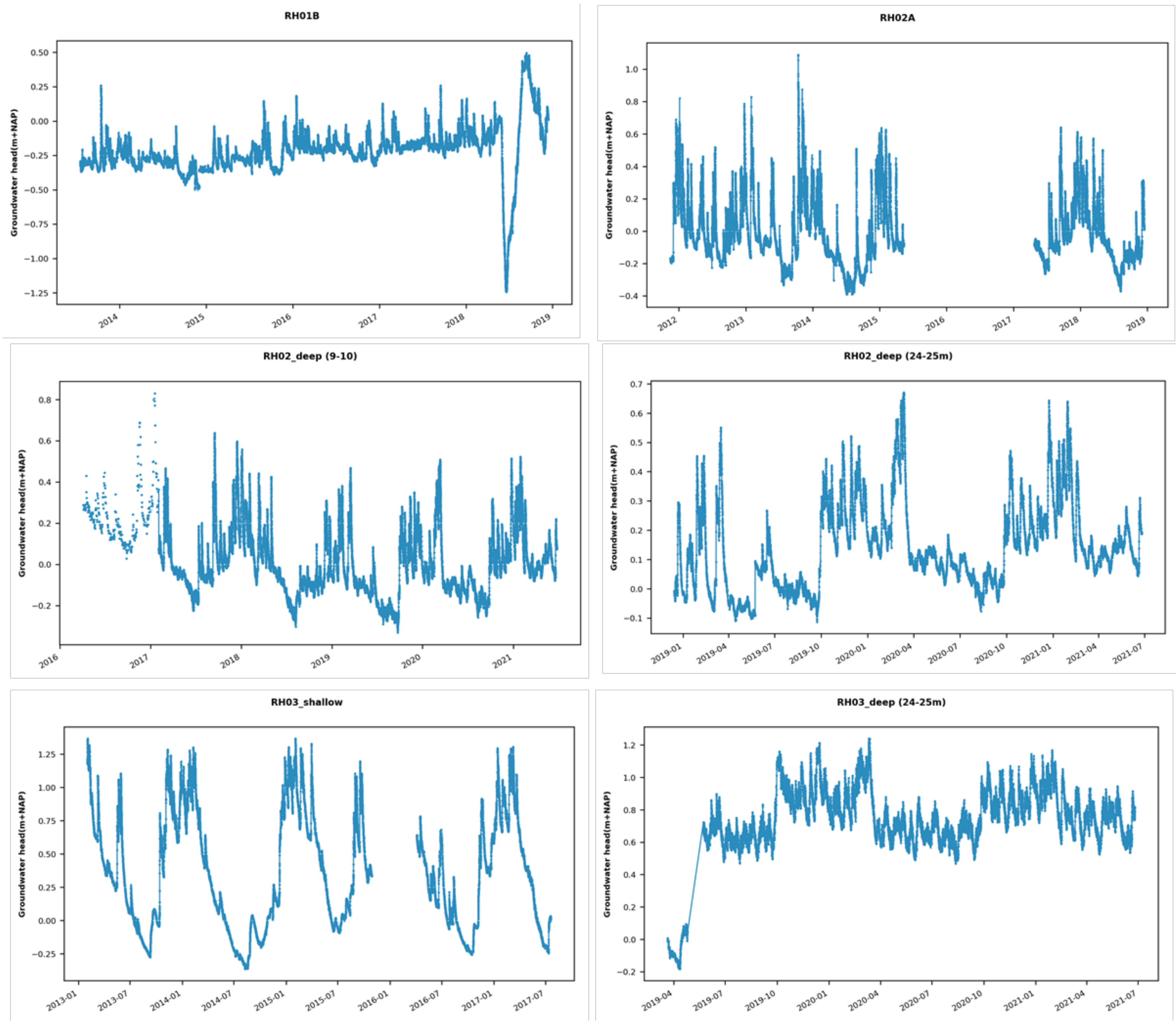
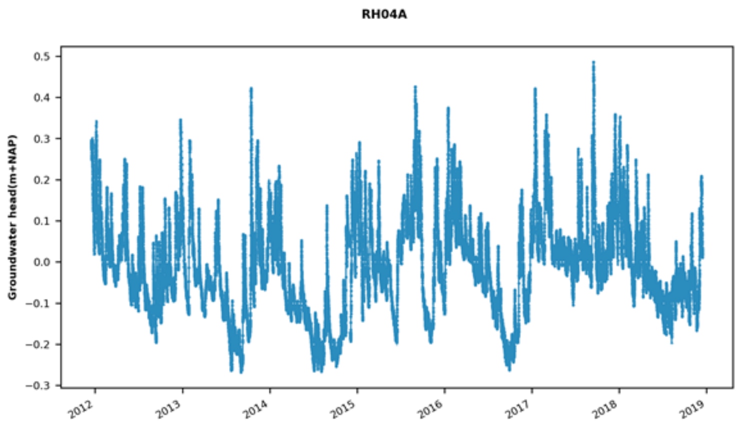
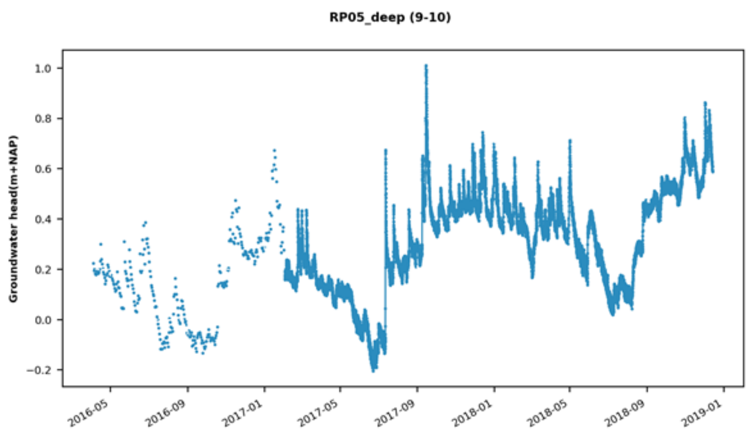
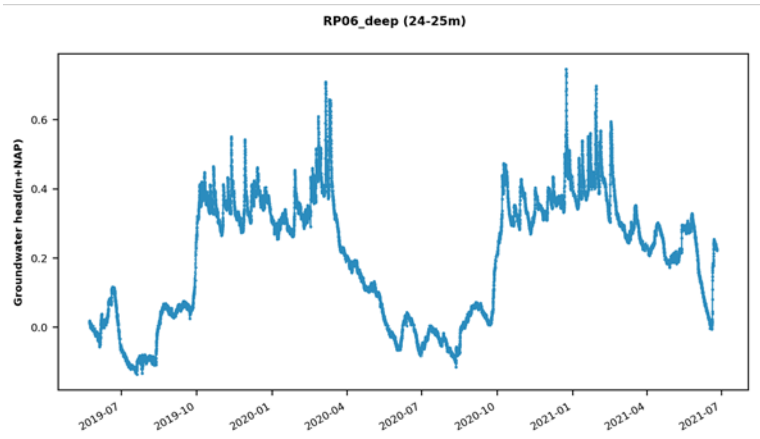
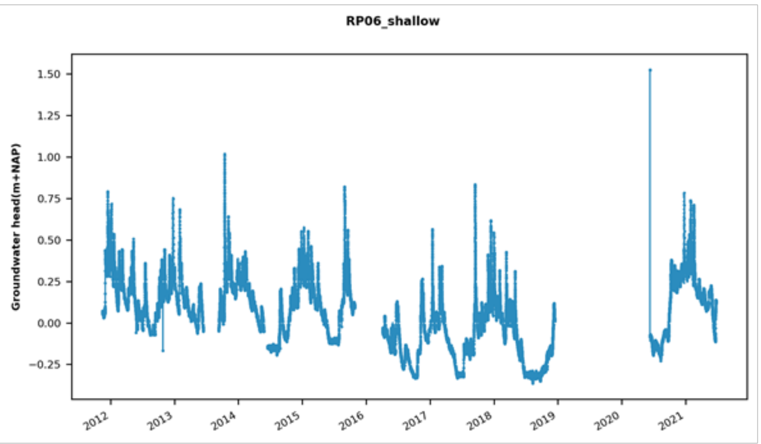


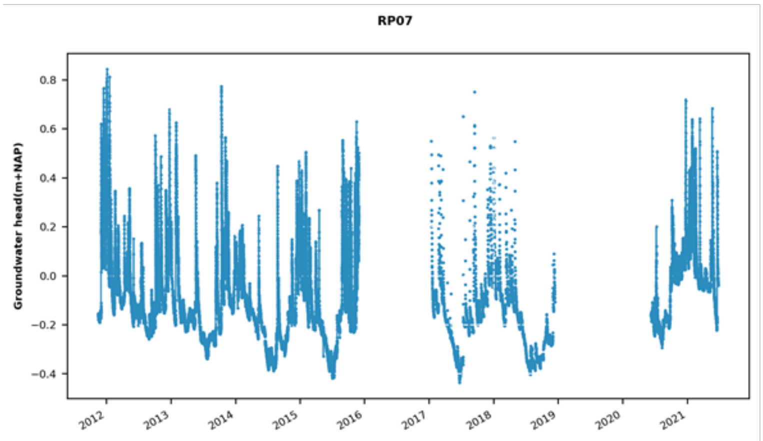

*Figure Groundwater head for all locations, shallow locations show groundwater levels and deep locations show the hydraulic heads.*

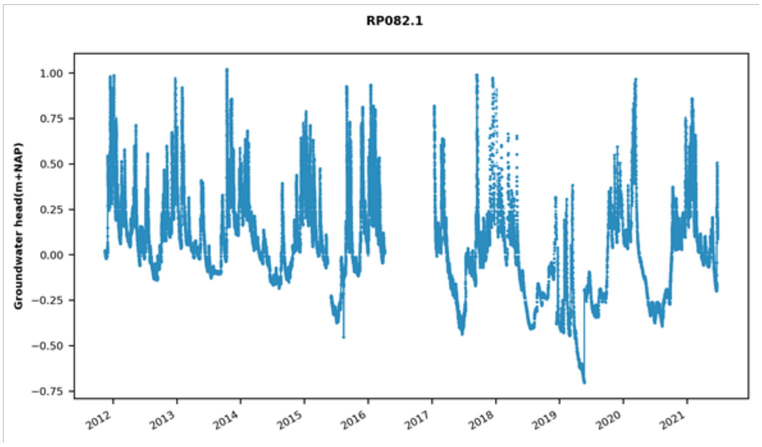

RH04A
Groundwater head(m+NAP)
0.5
0.4
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
2012
2013
2014
2015
2016
2017
2018
2019

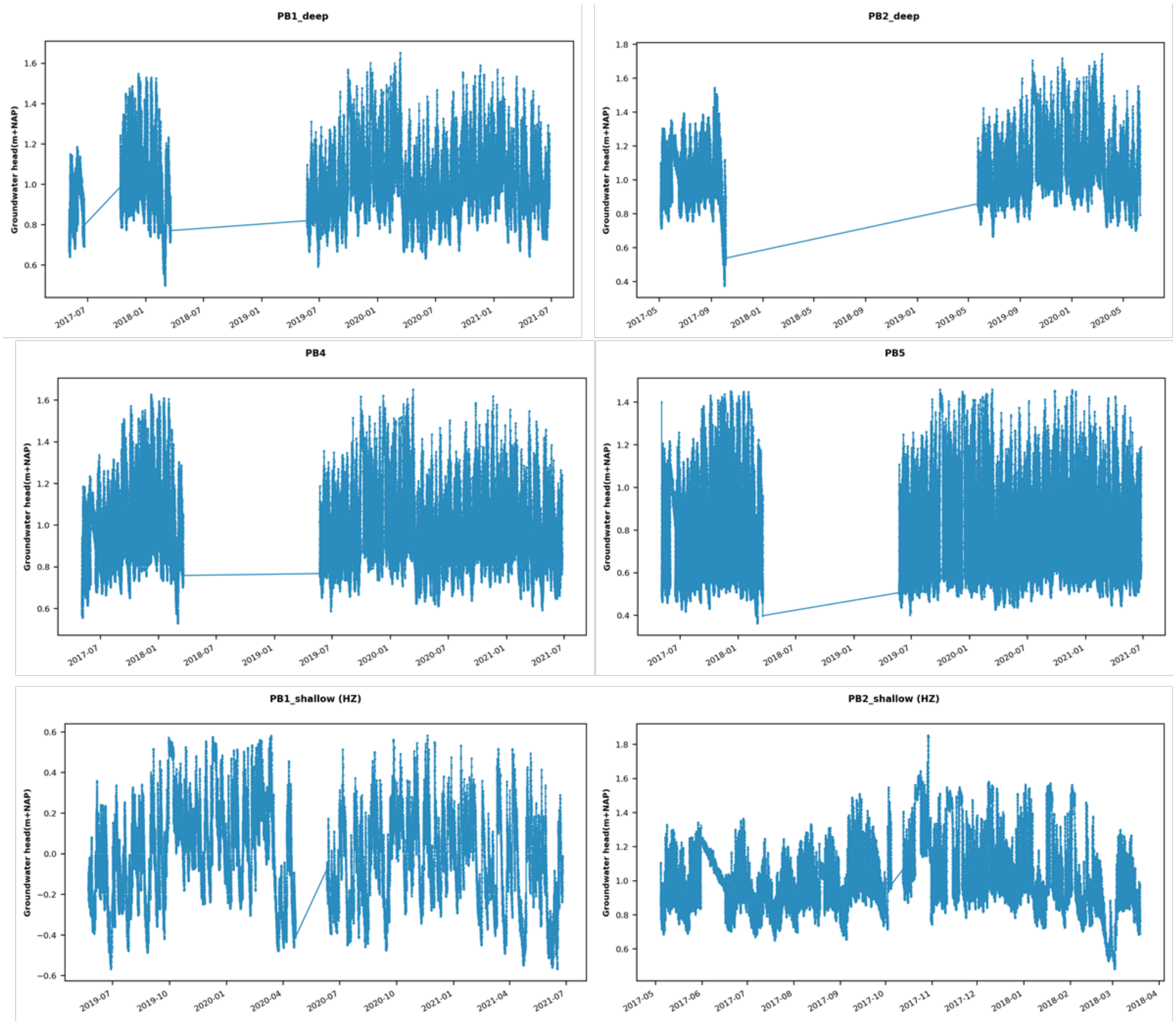

RP05_deep (9-10)
Groundwater head(m+NAP)
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
2016-05
2016-09
2017-01
2017-05
2017-09
2018-01
2018-05
2018-09
2019-01


RP06_deep (24-25m)
Groundwater head(m+NAP)
0.6
0.4
0.2
0.0
2019-07
2019-10
2020-01
2020-04
2020-07
2020-10
2021-01
2021-04
2021-07

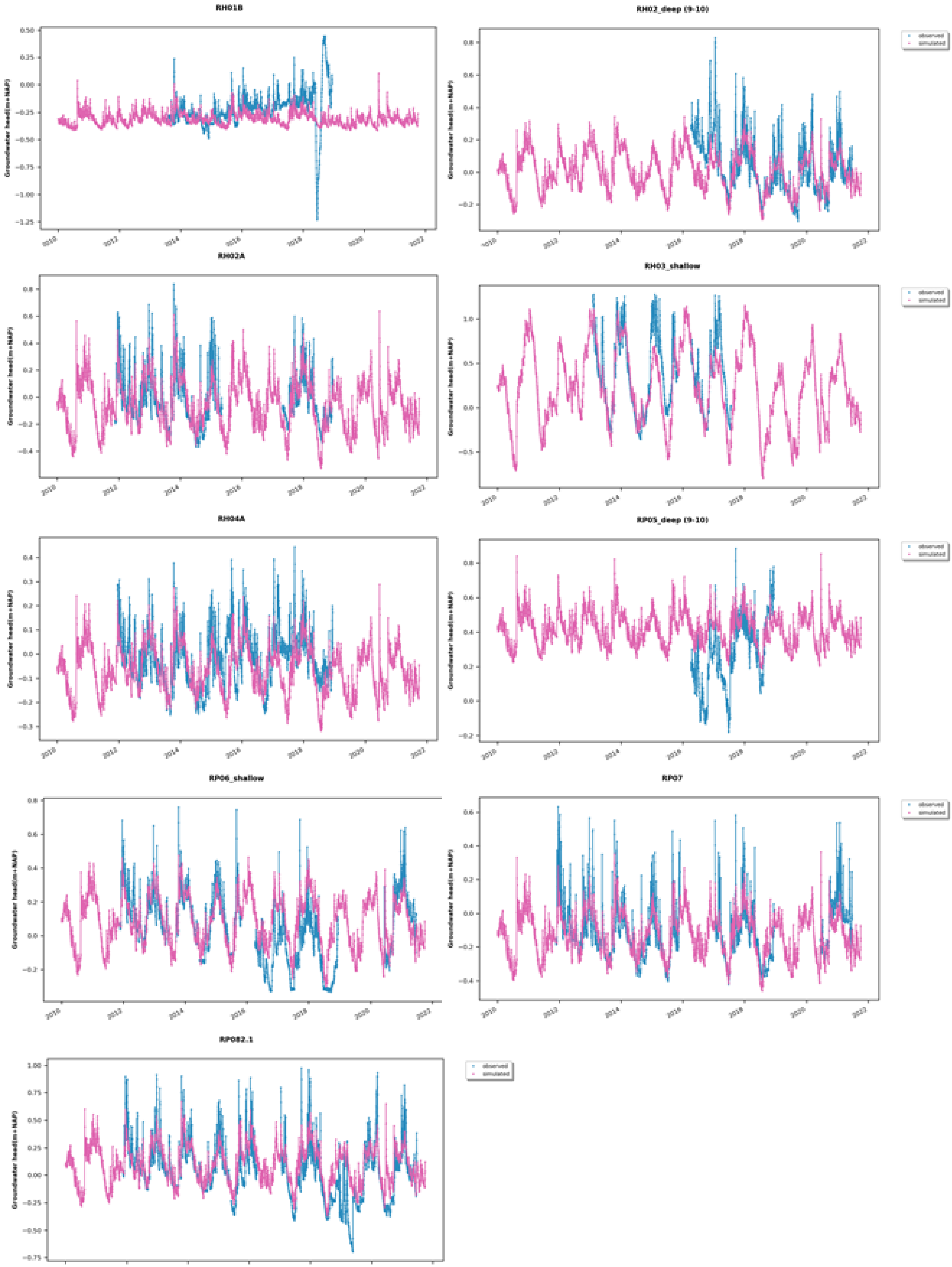

RP06_shallow
Groundwater head(m+NAP)
1.50
1.25
1.00
0.75
0.50
0.25
0.00
−0.25
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021

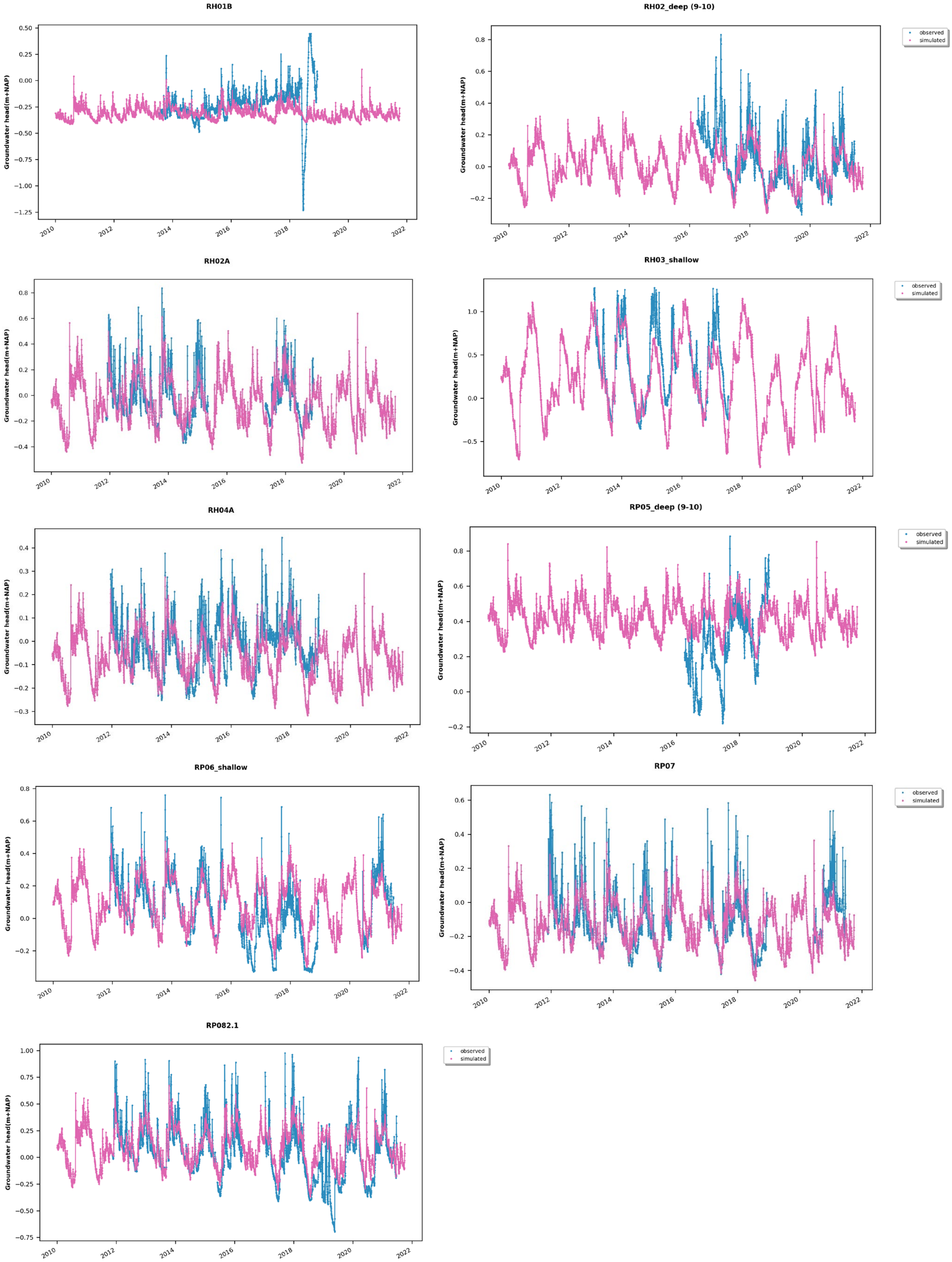

RP07
Groundwater head(m+NAP)
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021


RP082.1
Groundwater head(m+NAP)
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021


PB1_deep
PB2_deep
PB4
PB5
PB1_shallow (HZ)
PB2_shallow (HZ)
Groundwater head(m+NAP)

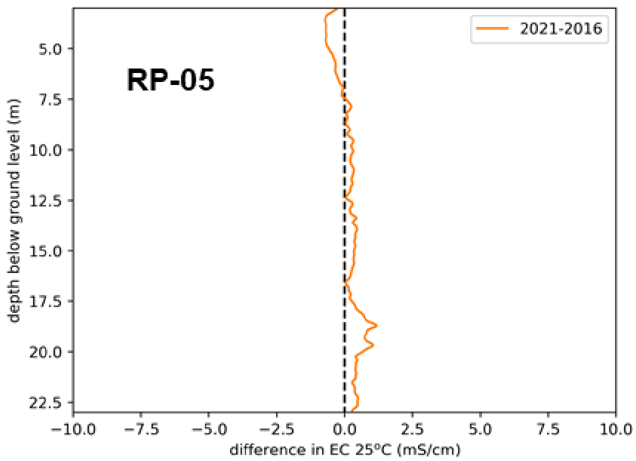
# Annex VII – Results of Time series analysis

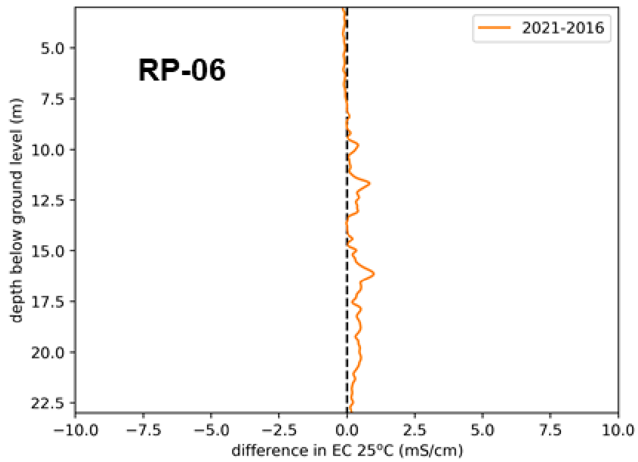


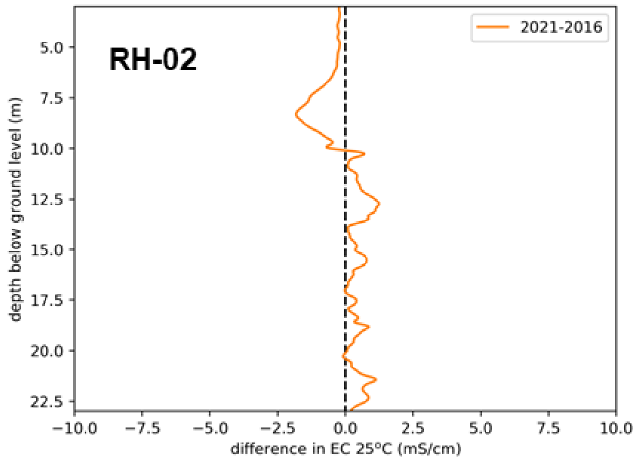

RH01B
RH02_deep (9-10)
RH02A
RH03_shallow
RH04A
RP05_deep (9-10)
RP06_shallow
RP07
RP082.1
Groundwater head(m+NAP)
observed
simulated

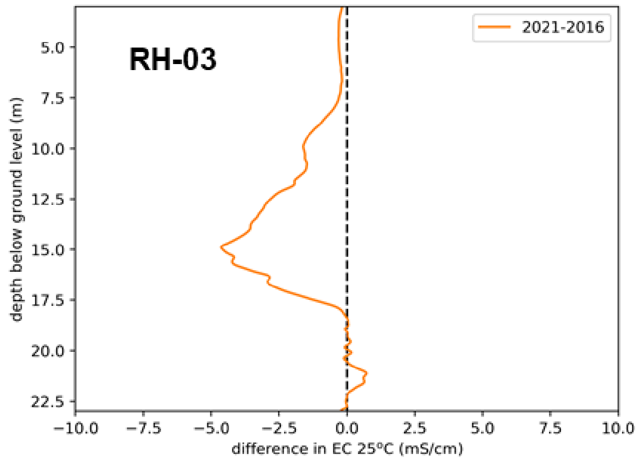
# Annex VIII – Salinity profiles EM-SlimFlex

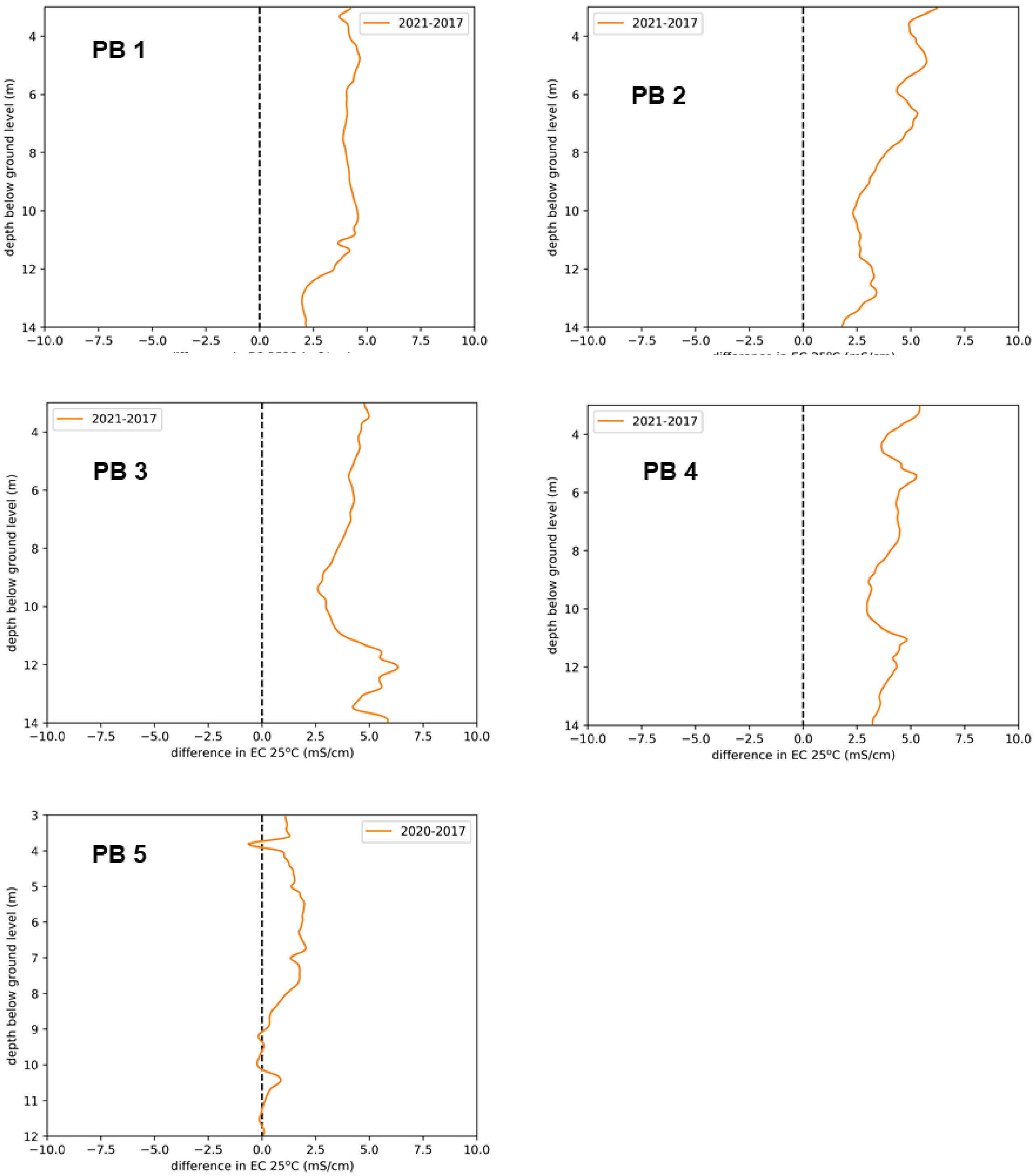
The salinity profiles below show the absolute differences in salinity between year 2021 and the beginning of the monitoring (2016 and 2017).




PB 1
2021-2017
depth below ground level (m)
PB 2
2021-2017
depth below ground level (m)
PB 3
2021-2017
depth below ground level (m)
difference in EC 25ºC (mS/cm)
PB 4
2021-2017
depth below ground level (m)
difference in EC 25ºC (mS/cm)
PB 5
2020-2017
depth below ground level (m)
difference in EC 25ºC (mS/cm)

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