Perkpolder - Phase 2 (2019 - 2024)

The transition from a freshwater agricultural area to a saltwater nature reserve

Author(s): Chiu Cheng, Susanne van Donk, Brenda Walles, Tom Ysebaert, Jim van Belzen, Lauren Wiesebron, Marte Stoorvogel, Greg Fivash, Tjeerd Bouma, Vincent Bax, Wietse van de Lageweg and Lodewijd de Vet

Wageningen University & Research report C097/21

Perkpolder – Phase 2 (2019 – 2024)

The transition from a freshwater agricultural area to a saltwater nature reserve

Author(s): Chiu Cheng, Susanne van Donk, Brenda Walles, Tom Ysebaert, Jim van Belzen, Lauren Wiesebron, Marte Stoorvogel, Greg Fivash, Tjeerd Bouma, Vincent Bax, Wietse van de Lageweg and Lodewijk de Vet

Wageningen Marine Research
Yerseke, December 2021

Wageningen Marine Research report C097/21

WAGENINGEN
UNIVERSITY & RESEARCH

Chiu Cheng, Susanne van Donk, Brenda Walles, Tom Ysebaert, Jim van Belzen, Lauren Wiesebron, Marte Stoorvogel, Greg Fivash, Tjeerd Bouma, Vincent Bax, Wietse van de Lageweg and Lodewijk de Vet*, 2021. Perkpolder – Phase 2 (2019 – 2024); The transition from a freshwater agricultural area to a saltwater nature reserve*. Wageningen, Wageningen Marine Research, Wageningen Marine Research report C097/21.

Keywords: Managed realignment, benthic macrofauna, birds, sediment grain size, tidal marsh, vegetation, colonization, morphology, place attachment.

Client: Rijkswaterstaat Water, Verkeer en Leefomgeving
Attn.: Yuri de Nooijer
Griffioenlaan 2
3526 LA Utrecht

This report can be downloaded for free from https://doi.org/10.18174/558193
Wageningen Marine Research provides no printed copies of reports

Wageningen Marine Research is ISO 9001:2015 certified.

KvK nr. 09098104,
WMR BTW nr. NL 8113.83.696.B16.
Code BIC/SWIFT address: RABONL2U
IBAN code: NL 73 RABO 0373599285

A_4_3_2 V31 (2021)

Contents

Table of Contents

Samenvatting

Het zoute water dat sinds 25 juni 2015 het Perkpolder projectgebied binnen stroomt zorgt ervoor dat het terrein onder de invloed van het getij staat en onderhevig is aan sedimentatie en erosie. Het vegetatiepatroon zal zich aanpassen aan de nieuwe zoute condities. Nieuwe vogelsoorten en bodemdieren maken van het gebied gebruik. Ook omwonenden en recreanten ervaren de veranderingen. In de periode 2015-2018 zijn de morfologische en ecologische ontwikkelingen gemonitord in het buitendijkse natuurgebied, inclusief de monding, en de effecten op het grond- en oppervlaktewater in het aangrenzende agrarische gebied. Begin 2019 presenteerde het consortium van onderzoeksinstellingen de resultaten. Het morfologische en ecologische onderzoek betrof de morfologische veranderingen en de sturende hydrodynamische processen, grondwaterstanden die onder invloed kwamen van het getij, vegetatie ontwikkeling, kolonisatie door het macrozoöbenthos en het gebruik van het gebied door vogels. In deze periode van drie jaar werden de grootste veranderingen verwacht. Op het eind van fase 1 bleek het gebied nog volop in ontwikkeling.

Het voorliggende projectplan voor Fase 2 bouwt voort op het eerste projectplan en zal worden uitgevoerd door hetzelfde consortium dat Fase 1 heeft uitgevoerd. Het plan beoogt een beeld te vormen van de morfologische en ecologische veranderingen die gaan plaatsvinden in het gebied op de middellange termijn van 10 jaar. Hoe deze veranderingen de maatschappelijke beleving en waardering van dit soort buitendijkse gebieden beïnvloed maakt ook onderdeel uit van Fase 2. Het gebied is nog volop in ontwikkeling en deze monitoring laat toe om ook op langere termijn inzicht te verschaffen in hoe estuariene natuur ontwikkelt in Perkpolder en of de doelstellingen gehaald worden. Het Perkpolder Fase 2 project biedt unieke kansen om de veranderingen te monitoren en te onderzoeken. Er is weinig kennis beschikbaar over de natuurontwikkeling bij een ontpoldering, waarbij een plotseling omslag is van zoet naar zout, van land naar water (getij) en de sedimentatie- en erosieprocessen een rol gaan spelen.

Het project bestaat uit een consortium van brede expertise. In dit Perkpolder Consortium fungeert Wageningen Marine Research (WMR) als penvoerder. Naast WMR vormen het Koninklijk Nederlands Instituut voor Onderzoek der Zee (NIOZ), Deltares en Hogeschool Zeeland UAS als de partners in het consortium. Deze partners erkennen de noodzaak tot samenwerking om de projectdoelstellingen te kunnen verwezenlijken. De samenstelling van en de samenwerking binnen het Perkpolder Consortium faciliteert een bundeling van noodzakelijke expertises en garandeert een efficiënte uitwisseling van kennis en innovatie.

Hydro- en morfodyaniek
De hydrodynamica en de morfologische veranderingen in Perkpolder spelen een belangrijke rol in de ecologische ontwikkeling van het systeem. Het sedimenttransport naar Perkpolder wordt in detail onderzocht door inzichten uit morfologische metingen en een modelstudie te combineren. Specifiek is er aandacht voor de tijdsvariaties van het sedimenttransport en de oorsprong van het geïmporteerde sediment (bijvoorbeeld het intergetijdengebied voor de monding van Perkpolder). Een goed inzicht van waar het sediment van afkomstig is en welke processen het sedimenttransport sturen, zal ons helpen de toekomstige ontwikkelingen in Perkpolder beter te kunnen begrijpen.

Vegetatie
Sinds 2019 is zijn ontwikkelingen in de bodemeigenschappen en vegetatie ontwikkeling gebied dekkend gemonitord. Door COVID beperkingen is nog niet alle data van de bodemmonsters verwerkt en geanalyseerd. Er is daarom gefocust op de ontwikkeling van de vegetatie in het projectgebied. Vegetatieontwikkelingen lijken juist afgelopen jaar op gang te komen. Het aantal slijkgras (*Spartina anglica*) pollen, welke door transplantatie in het gebied zijn gekomen, is sinds 2018 stabiel en ze nemen door de band genomen toe in diameter en biomassa per oppervlakte-eenheid. Dit jaar, in 2021, is voor het eerst grootschalige zaailing vestiging waargenomen van slijkgras (*S. anglica*). De waargenomen vestiging van nieuw slijkgras komt overeen met de toename in bodemhoogte. Daar waar de getijdenplaat hoog genoeg is en niet meer elk getij worden overstroomd vinden we ook de

vestigingsplaatsen. We vinden dat vestiging al kan plaatsvinden vanaf 0,1% van de overgeslagen getijden. Hoe de bodemeigenschappen deze drempelwaarde beïnvloed zal moeten blijken uit de verdere analyse van de ontwikkelingen in de andere gemeten bodemeigenschappen. Deze resultaten suggereren dat de vegetatievestiging en -ontwikkeling snel op gang kan komen zodra de bodemhoogte in het projectgebied boven de 1 m NAP heeft bereikt.

Bodemdieren

De eerste fase van dit project liet zien dat de ontwikkeling van de bodemgemeenschap na het getijherstel in Perkpolder bemoedigend was. Binnen een relatieve korte periode werd een biologisch actief slikkengebeid gevormd. Er was al een zichtbare ontwikkeling van de benthische macrofaunagemeenschap in de eerste paar jaren. Nu na ruim vijf jaar sinds de opening van de polder blijft deze trend verder veranderen en ontwikkelen. Bodemdieren nemen in soortenrijkdom en biomassa toe bij Perkpolder tussen 2015 en 2020, terwijl dichtheid toeneemt in het eerste jaar na de opening van de polder en is van najaar 2016 tot voorjaar 2018 al weer afgenomen. De laatste twee jaar is het min of meer gestabiliseerd. In de recentste jaren is dichtheid verminderd vanwege een grote daling in het aantal polychaetes (wormen) en Malacostraca (klein schaaldier). Anderzijds wordt biomassa steeds groter voornamelijk als gevolg van een toename in het aantal bivalves (tweekleppigen), vooral door de slijkgapers (*Scrobicularia plana*). De multivariaat analyse suggereert dat de bodemgemeenschap nog steeds aan het veranderen is maar het verschuif toch dichterbij naar vergelijkbare gebieden in de buurt van Perkpolder.

Vogels

Het aantal (benthos-etende) vogels dat tijdens laagwater Perkpolder bezoekt lijkt iets te zijn toegenomen tussen 2017-2018 en 2020-2021. De toename is het meest duidelijk te zien in de periode 2019-2020, in de laatst getelde periode van 2020-2021 zijn de aantallen weer iets lager, met uitzondering van relatief hoge aantallen in december. Perkpolder lijkt hiermee aantrekkelijker te zijn geworden voor benthos-etende vogels. Onder de meest voorkomende soorten zijn de scholekster en bonte strandloper iets toegenomen over de tijd. Deze vogels foerageren gewoonlijk met laagwater op (onder andere) droogvallende platen. Aantallen vogels nemen niet in elk telgebied toe; dit heeft mogelijk te maken met de verspreiding en fluctuaties in bodemdieren.

Onderwijsversterking en kennisverspreiding

Er gaat ook veel aandacht uit naar de wijze waarop kustlandschappelijke herinrichting gericht op natuurherstel, zoals ontpolderen, de fysische en ecologische toestand van een gebied kan beïnvloeden. Tegelijkertijd is het ook van groot belang om inzicht te krijgen in de mate waarin een fysieke verandering van het landschap een sociale of maatschappelijke verandering in datzelfde gebied teweeg kan brengen. Fysieke ingrepen in het landschap, waarbij ook een verandering van de gebruiks- en/of belevingswaarde van het landschap optreedt, 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. Om in de komende jaren natuurherstel op een goede manier te kunnen blijven uitvoeren, wordt het steeds belangrijker om te begrijpen hoe natuurherstelprojecten en de hiermee gepaard gaande veranderingen van het landschap door lokale gemeenschappen worden ervaren, en welke factoren hieraan ten grondslag liggen. 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 Perkpolder de genomen natuurherstelmaatregelen in Perkpolder beleeft en waardeert. Om de uitkomsten van dit deelonderzoek in een breder perspectief te kunnen plaatsen, zal een vergelijking worden gemaakt tussen opgedane inzichten in Perkpolder en andere casuslocaties in Zeeland waar natuurherstel plaatsvindt of heeft plaatsgevonden, zoals het Rammegors gebied en de Hedwige Prosperpolder. Om te beginnen is een systematische verkenning van de bestaande wetenschappelijke literatuur uitgevoerd om in kaart te brengen welke factoren de maatschappelijke beleving van (kust)landschappelijke herinrichting zouden kunnen verklaren, en welke methoden in eerdere onderzoeken zijn gebruikt 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 naar maatschappelijke aspecten rondom kustlandschappelijke herinrichting worden betrokken. Op basis van de uitkomsten van de systematische literatuurverkenning is een gestandaardiseerde enquête ontwikkeld. Deze enquête, waarin een elftal concepten en aandachtsgebieden aan de orde worden gesteld, zal in de periode tussen november 2021 en mei 2022 worden uitgezet in de omgeving van Perkpolder en de andere casuslocaties in Zeeland om de maatschappelijke beleving van kustlandschappelijke herinrichtingsprojecten in kaart te brengen.

Summary

Salt water has been able to flow into the Perkpolder project area since its opening in June 2015, ensuring that the site is under the influence of the tide and subject to sedimentation and erosion. The vegetation pattern is expected to adapt to the new saline conditions, while new bird species and benthic animals also make use of the area. Local residents and vacationers are also experiencing the changes. During the period of 2015-2018, the morphological and ecological developments in the nature reserve outside of the dikes, including in the estuary, and the effects on the groundwater and surface water in the adjacent agricultural area were monitored. At the beginning of 2019, the consortium of research institutions presented the results from the first phase of this project. The morphological and ecological research were focused on the morphological changes and the predominant hydrodynamic processes, groundwater levels that were influenced by the tide, vegetation development, colonization by the benthic macrofauna and the use of the area by birds. The biggest changes were expected during this three-year period. However, the area was still in full development at the end of this phase.

The current project plan for Phase 2 builds on the previous plan and will be implemented by the same consortium as before. The plan aims to reveal the morphological and ecological changes that will take place in the area over the medium term of 10 years. How these changes will affect the social perception and appreciation of these types of areas outside the dikes is also a part of Phase 2. As this area is still actively developing, the monitoring will provide long-term insight into how the Perkpolder estuary develops and whether the objectives will be achieved. The Perkpolder Phase 2 project offers unique opportunities to monitor and investigate such changes. Presently, little knowledge is available regarding the development of nature following depoldering, where there is a sudden switch from fresh to saltwater, from land to water (tide) and the sedimentation and erosion processes also start to play a role in this development.

The project consortium covers a broad expertise, where Wageningen Marine Research (WMR) acts as the secretary. In addition to WMR, the Royal Netherlands Institute for Sea Research (NIOZ), Deltares and Hogeschool Zeeland (HZ) are also partners. These partners all recognize the need for cooperation in order to achieve the project objectives. The composition of, and cooperation within, the Perkpolder Consortium facilitates the assemblage of the necessary expertise and guarantees an efficient exchange of knowledge and innovation.

Hydro- and morphodynamics

The hydrodynamics and morphological changes in Perkpolder play an important role in the ecological development of the system. The sediment transport to Perkpolder will be investigated in detail by combining insights from morphological measurements with a model study. Specific attention will be devoted to the time variations in the sediment transport and the origin of the imported sediment (e.g., the intertidal area in front of the Perkpolder estuary). A good understanding of where the sediment comes from and which processes drive the sediment transport will help us to better understand future developments in Perkpolder.

Vegetation

Since 2019, the developments in the soil properties and vegetation in the area have been monitored comprehensively. Due to COVID restrictions, not all of the data from the soil samples have been processed and analyzed yet. The focus is therefore on the development of the vegetation in the project area. Vegetation developments seem to have started just last year. The number of mud grass (*Spartina anglica*) pollen, which have come into the area through transplantation, has been stable since 2018 and they are increasing in diameter and biomass per unit area. In 2021, the large-scale seedling establishment of the mud grass (*S. anglica*) has been observed for the first time. This observation of new mud grass corresponds to the increase in soil height. We also find settlement sites where the tidal flat is high enough such that they are no longer flooded during each tide, and the settlement can already take place with 0.1% of the tides skipped. How the soil properties will influence this threshold value will

become apparent through further analyses of the developments in the other measured soil properties. These results suggest that vegetation establishment and development can start quickly, once the soil height in the project area has exceeded 1 m NAP.

Benthic macrofauna

The first phase of this project showed that the development of the benthic community following the tidal recovery in Perkpolder was encouraging. Within a relatively short period of time, a biologically active area was formed. There was already a visible development of the benthic macrofauna community in the first few years. Now, after more than five years since the opening of the polder, this trend continues. Benthic animals increased in species richness and biomass at Perkpolder between 2015 and 2020, while the density increased in the first year after the opening of the polder, followed by a decrease from autumn 2016 to spring 2018. It has more-or-less stabilized in the last two years. More recently, the density has decreased due to a large drop in the number of polychaetes (worms) and Malacostraca (small crustaceans). On the other hand, the biomass is growing mainly due to an increase in the number of bivalves, especially by the mud gaps (*Scrobicularia plana*). The multivariate analysis suggests that the benthic community is still changing, and appears to be shifting closer to similar intertidal habitats near Perkpolder.

Birds

The number of (benthos-eating) birds that visit Perkpolder during low tide seems to have increased slightly between 2017-2018 and 2020-2021. The increase is most clearly visible in the period 2019-2020, while in the last counting period of 2020-2021, the numbers were slightly lower again, with the exception of relatively high numbers in December. Overall, Perkpolder seems to have become more attractive for benthos-eating birds. Among the most common species, the oystercatcher and sandpiper have increased slightly over time. These birds usually forage at low tide on tidal flats, among other similar environments. However, the bird numbers do not increase in every counting area, which may have something to do with the distribution and fluctuations in the benthic animals.

Educational reinforcement and knowledge dissemination

Much attention is also devoted to the way in which coastal landscape redevelopment projects aimed at restoring nature, such as through depoldering, can influence the physical and ecological conditions of an area. At the same time, it is also very important to gain more insight into the extent to which a physical change in the landscape can bring about social or societal change in the same area. Physical interventions in the landscape, which can also modify the use and/or amenity value of the landscape, can cause feelings of incomprehension and arouse resistance among the local community. This can mean that nature restoration projects are delayed or have to be completely aborted. Resistance to policy and decision-making can also worsen the relationship between the community and authorities. In order to be able to continue carrying out nature restoration in the coming years, it is increasingly important to understand how these nature restoration projects, and the associated changes to the landscape, are perceived by the local communities, and which factors underlie them. Gaining insight into these social aspects is an important addition to the physical and ecological knowledge development regarding coastal landscape redevelopment, and can be insightful in facilitating comparable projects in the future.

The main aim of this component of the project is to explore how the local community near Perkpolder experiences and appreciates the nature restoration measures taken there. In order to place the results of this study in a broader perspective, a comparison will be made between the insights gained at Perkpolder with other case locations in Zeeland, where nature restoration is currently taking place or has already occurred, such as at the Rammegors area and the Hedwige Prosperpolder. Firstly, a systematic exploration of the existing scientific literature was carried out to map out the relevant factors that could explain the social perception of (coastal) landscape redevelopment, and identify the methods which have been used in previous studies to further determine this perception. It is clear that socio-demographic factors and concepts such as risk perception, locality and institutional trust are frequently involved in research related to the social aspects of coastal landscape redevelopment. Based on the results of the systematic literature search, a standardized survey has been developed. In the period between November 2021 and May 2022, this survey will be deployed in the vicinity of Perkpolder and the other case locations in Zeeland in order to map the social experience of coastal landscape redevelopment projects. In particular, eleven concepts and areas of interest will be discussed.

1 Introduction

The intertidal habitats are important for absorbing and attenuating wave energy, and are also an important buffer against flooding. With the impending projected sea level rise, these habitats are expected to grow to higher elevations and move further inland in the process. However, this progression is hindered by a variety of factors, including hard structures and other man-made barriers for coastal/flood defense, which is known as coastal squeeze. The combination of a loss of such intertidal habitats and rising sea level results in higher maintenance costs for coastal protection and calls for the need to develop more cost-effective, sustainable solutions regarding coastal protection. One common method that is used for both compensating habitat loss and increasing the sustainability of coastal protection measures is through the employment of managed realignment, where the defenses are set further back towards the inland to allow the ground elevation to naturally increase (Esteves, 2014). By moving the structures landward, the newly-exposed areas will be allowed to flood during tidal inundation. Examples can be seen in riverine systems, where following the set-back of defenses along the bank, the river was again able to connect to its flood plain. As a result, flood mitigation was improved as more room was made available for the river to buffer against high precipitation levels.

Perkpolder is one of the first cases in the Dutch part of the Scheldt estuary where such a managed realignment has been employed under a climate adaptation measure, and serves as an example for other areas that are likely to be flooded in the near future, such as at Hedwige-Prosper. Given that these newly-developing intertidal habitats will rise with sedimentation, they have the ability to buffer the surrounding dikes and coastal structures from rising sea levels. Such a creation of intertidal habitats through managed realignment is a “soft” engineering alternative to traditional methods for coastal protection and could even reduce the maintenance costs of dikes, not to mention the other potential environmental and societal benefits. However, it is important to understand how exactly the newly-flooded coastal areas will develop over time in order to continue improving the ways in which the coasts are managed. Will these flooded areas gradually develop into productive ecosystems with high ecological and recreational value, or remain in an undesirable state over an extended period of time? Such insights into the development of flooded areas would provide valuable information to decision makers, who will then be equipped with sufficient knowledge for future implementation of these mitigation measures.

In intertidal flat systems, the primary producers such as benthic diatoms are the foundation of the benthic food web. They serve as an important food source for many primary consumers such as benthic macrofauna (benthos), including groups such as the polychaetes, mollusks and crustaceans. These benthic organisms are, in turn, a key food source for the higher, secondary consumers such as fish, large crustaceans and birds. The rate in which the benthic macrofaunal community develops within a newly flooded coastal area is expected to influence total biodiversity and ecosystem functioning over time. Previous studies have shown how the initial colonization by the benthos could occur within just a few days, and even reach a stable community composition after a few months or a few years (Moseman et al. 2004; Mazik et al. 2007), although in some cases it has been shown to take years to decades (Levin et al. 1996; Craft and Sacco 2003). Both the initial colonization and succession depend on the local environmental conditions. Sediment characteristics are one such key factor that can affect the colonization and succession. For example, whereas no colonization of benthos was found on agricultural remains, they rapidly colonized other areas that contained newly accreted sediments (Garbutt et al. 2006). In the phase one of this project, for example, there were already 19 macrobenthic species found at Perkpolder, just 4 months after the intentional dike breach (van de Lageweg et al. 2019). Therefore, in order to understand the development of a newly flooded area, continued monitoring is necessary given that there is not yet a consensus on how newly flooded area are colonized and develop over time.

In addition, the presence or absence of vegetation is an important factor in steering the development of tidal marshes, and can determine the success and quality of natural functioning in restored tidal ecosystems (Gourgue et al., 2021; Kirwan et al., 2010; Temmerman et al., 2007). Vegetation invokes biogeomorphic feedbacks - that is, the interactions between waterflow, sediment erosion or accretion and vegetation growth or die-off. This results in typical tidal marsh structures such as the tidal creek network, which can affect the accretion of the average bed level (Fagherazzi et al., 2012; Gourgue et al., 2021; Kirwan et al., 2010; Temmerman et al., 2007). Once the vegetation is present at sufficient coverage and density (Bouma et al., 2009), it speeds up the accretion of sediment in the area over the landscape scale, and thus also in areas with an embankment (Gourgue et al., 2021). Both the speed and the extent of dispersion of the vegetation colonization on the tidal flat are important controls on the final functioning of the tidal ecosystem (Schwarz et al., 2018). Fast, dispersed recruitment over large areas of the tidal flat will result in the fixation and further consolidation of creeks that are already imprinted in the soft sediment due to evenly spread biogeomorphic feedbacks (Schwarz et al., 2018). On the other hand, a more gradual and heterogenous establishment and development can result in asymmetric enforcement of the biogeomorphic feedbacks, affecting the creek network by reorganizing and overriding the drainage structures initially present on the tidal flat before the vegetation was established (Schwarz et al., 2018). Recent work has revealed that such self-organized creek networks are more efficient in distributing sediments and draining water (Schwarz et al., 2018). Therefore, such self-organized creek networks that result from symmetry-breaking feedbacks are suggested to boost the stability and adaptability of tidal marshes in the face of climate change and sea level rise (Fagherazzi et al., 2012; Kirwan et al., 2010). Hence, having a good understanding of which factors drive the homogenous or heterogenous recruitment and development of vegetation in tidal systems is key to understanding their long-term functioning.

The rate of the establishment of vegetation on tidal flats can be a key bottleneck limiting the development and resilience of tidal marshes (Zhu et al., 2020). For instance, in some parts of the Western Schelde estuary, the vegetation develops much slower than can be expected based on the intertidal elevation (i.e., inundation duration) alone (Hu et al. 2015). Recent developments to better understand the recruitment dynamics of tidal vegetation suggests the time windows of favorable conditions to be a key factor (Balke et al. 2011, 2014). These benign windows have been coined ‘Windows of Opportunity’ (WoO) and can be related to tidal inundation and hydrodynamic forcing due to tides and waves (Hu et al., 2015). In another study, it has been shown that short-term sediment dynamics determine seedling establishment success, which suggests that the windows of stable sediments might be equally important, or perhaps even more so, for establishment (Bouma et al., 2016). Further development of the WoO framework reveals that bare and vegetated tidal flats are alternate states of one another. Short-term variability in hydrodynamic forcing is key to “unlocking” these states as they result in predictable statistical patterns (van Belzen et al. in prep.). The i) growth rate, ii) magnitude of the stressful condition and iii) length of the benign period turn out to be key determinants for predicting whether a window becomes an opportunity. Hence, it is important to link the relevant environmental parameters to these three key determinants to better understand initial vegetation development on restored tidal flats.

On restored tidal flats, a number of processes are potential factors in driving growth and successful vegetation recruitment. In addition to the usual parameters, such as hydrodynamic forcing due to tide and waves (Hu et al., 2015), other environmental conditions might be even more dominant in more-sheltered sites, such as Perkpolder. Previous experimental work in Mega Marsh Organs (Cao et al. 2021) executed at Perkpolder has revealed that muddy and poorly-drained conditions can stunt vegetation development (Cao et al., 2021) which can prevent the vegetation from crossing the hydrodynamic tolerance threshold. Moreover, the development of soil properties and microtopography can have an important impact on the growth rate of the vegetation, thereby affecting the ability of it to develop into a stable patch (Fivash et al., 2020). Such microtopography can be facilitated by the development of filamentous algae (van de Vijsel et al., 2021). Therefore, insights into the potential changes in the sediment properties (like soil, water content, mud content, etc.) and linking it to vegetation growth rates and establishment is paramount so that we can understand at which tidal elevations and under which context the establishment will start to deviate from the norm, and also how the initial establishment will be distributed.

The time required before the vegetation can establish and develop is thus a key question to managed realignment projects such as Perkpolder. Understanding how short-term dynamics affect long term stability is a key knowledge gap in understanding coastal vegetated ecosystems and functioning, such as their role in estuarine functioning and coastal protection (Bouma et al., 2014). In order to gain more insight into the vegetation establishment and development in managed realignment projects during this second phase of the Perkpolder project (2019 – 2024), we aim to generate insights into:

- The spatial and temporal development of sediment properties at Perkpolder

- The relation between sediment properties and spatial context, e.g., related to the design of the restoration, such as distance to inlets or creeks
- The spatial and temporal dynamics of establishment and development of tidal vegetation at Perkpolder
- The interdependence between sediment development, benthos and vegetation establishment

The benthic macrofaunal community comprises a diverse range of invertebrate animals greater than 1 mm in size, and that are also often a ubiquitous component of the sedimentary environment in marine, coastal and estuarine habitats (Snelgrove 1998). Particularly in species-rich environments, this community composition can cover quite a wide range of both taxonomic and functional groups and also feeding and mobility behaviors. Some of these benthic organisms activity burrow through the sediment, while others can create burrows and other structures, all of which can alter the erosional processes in the upper sediment layers (Jones et al. 1997; Meysman et al. 2006; Kristensen et al. 2012). Moreover, many of these benthic species are also sensitive to environmental disturbances, and changes to the sedimentary and/or hydrodynamic conditions could pose consequences for the number of species (species richness), the density of a species (abundance) and/or the biomass of particular species (Rees et al. 2007; Reiss et al. 2010).

The first phase of the Perkpolder study was in part focused on studying the initial colonization and development of the benthic macrofaunal community in the newly-flooded managed realignment area. Samples were collected in the autumn and spring, from autumn 2015 until autumn 2018. The development of this community was assessed by comparing it with the ones from adjacent intertidal areas in the Schelde estuary (MWTL 2010 – 2014 dataset), as well as trying to link these community patterns to some of the environmental responses, such as sediment characteristics. In this second phase, we continue to assess the development of the benthic community and compare it to both the results from phase one of this project and more-recent data from nearby environments (MWTL 2014 – 2017) to determine whether the conditions at Perkpolder are gradually transitioning towards these adjacent environments, and whether this would also be reflected in the community assemblage.

Following the opening of Perkpolder and the expected recolonization of the sediment by the macrobenthic infauna, it was also expected that the newly-formed tidal basin would be utilized by birds, The Scheldt estuary is known to be an important habitat for a large number of birds, and the intertidal flats provide essential feeding grounds for waders, which feed on the benthic organisms. During the first phase of this project, the number of birds found in the realignment site were counted during the autumn and winter months. This current study continues to track the development in the number and types of birds that forage at this managed realignment location

In addition, the physical conditions of Perkpolder, such as morphology, sediment transport and flow velocities are also important for the development of the vegetation, benthos and overall environmental conditions of the area. Such studies on the hydrodynamics and morphodynamics are currently in progress to explain the temporal variability in the sediment import into Perkpolder and the origin of this sediment. Specifically, this will be studied through a model in Delft3D to determine the mechanisms and processes that drive the morphological development in the area.

Lastly, the deliberate restoration of coastal salt marsh ecosystems through dike relocation and the reestablishment of tidal flooding has in general become an increasingly important strategy to cope with sea-level rise and comply with biodiversity objectives. Much attention is being 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 near these environments (e.g., societal aspects).

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

A lack of societal support may result in the delay or complete abandonment of planned coastal realignment projects and disturb relationships between authorities and the local community. As a consequence, to facilitate coastal realignment interventions in the coming years as best as possible, 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 near Perkpolder 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. In addition, we examine the level of societal support for coastal realignment and explore what factors determine such support or opposition. To then place our results in broader perspective, a comparison will be drawn between the Perkpolder area and other case study locations in Zeeland, including Rammegors 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, whether it be in Zeeland or elsewhere.

2 Materials and Methods

2.1 The study area

The Scheldt estuary is one of the longest estuaries in NW Europe with a complete salinity gradient. It is a macrotidal system measuring 160 km from the mouth, near Vlissingen (The Netherlands), to Ghent (Belgium). The study area is specifically located in the Western Scheldt, the Dutch part of the River Scheldt which connects to the North Sea (Figure 2.1). The mean tidal range in the Western Scheldt increases from 3.5 m at the mouth of the estuary to 5 m at the Dutch/Belgian border. In addition, the mean annual river discharge is approximately 105 $m^3 s^{-1}$, with low summer discharges (20 $m^3 s^{-1}$) and high winter discharges (400 $m^3 s^{-1}$). Depending on this river discharge, the residence time of the water in the estuary ranges from 1 to 3 months (Soetaert & Herman, 1995). Moreover, the Western Scheldt has a complex morphology with both flood and ebb channels and also intertidal mud and sand flats, while the average depth of the channel is 15-20 m. Furthermore, this estuary is an important Nature 2000-area for a large number of bird species. This is particularly the case in the intertidal flats, which serve as essential feeding grounds for waders and where the benthic macrofauna serves as important food sources for waders.

At Perkpolder, a 75 ha intertidal habitat was created under a managed coastal realignment project, where new dikes were constructed along the inland perimeter and flooding was allowed to occur through a single breach in the original dike (Figure 2.1). Prior to the inundation, the area was primarily used for agriculture. Channels had to be dug in the realignment site prior to the flooding to ensure that the water would remain in the area to enhance ecological development of the area. On 25th of June 2015 a single breach in the sea defenses at Perkpolder allowed 75 ha of farmland to be inundated by the sea for the first time in at least 380 years. This new inflow of water had a direct impact on erosion and sedimentation processes, both of which gave rise to morphological changes in the area. The resulting intertidal habitat can be classified as low dynamic, mid littoral (25-75% emersion time) located at the poly/mesohaline (average salinity between 10-18) transition zone of the Western Scheldt.

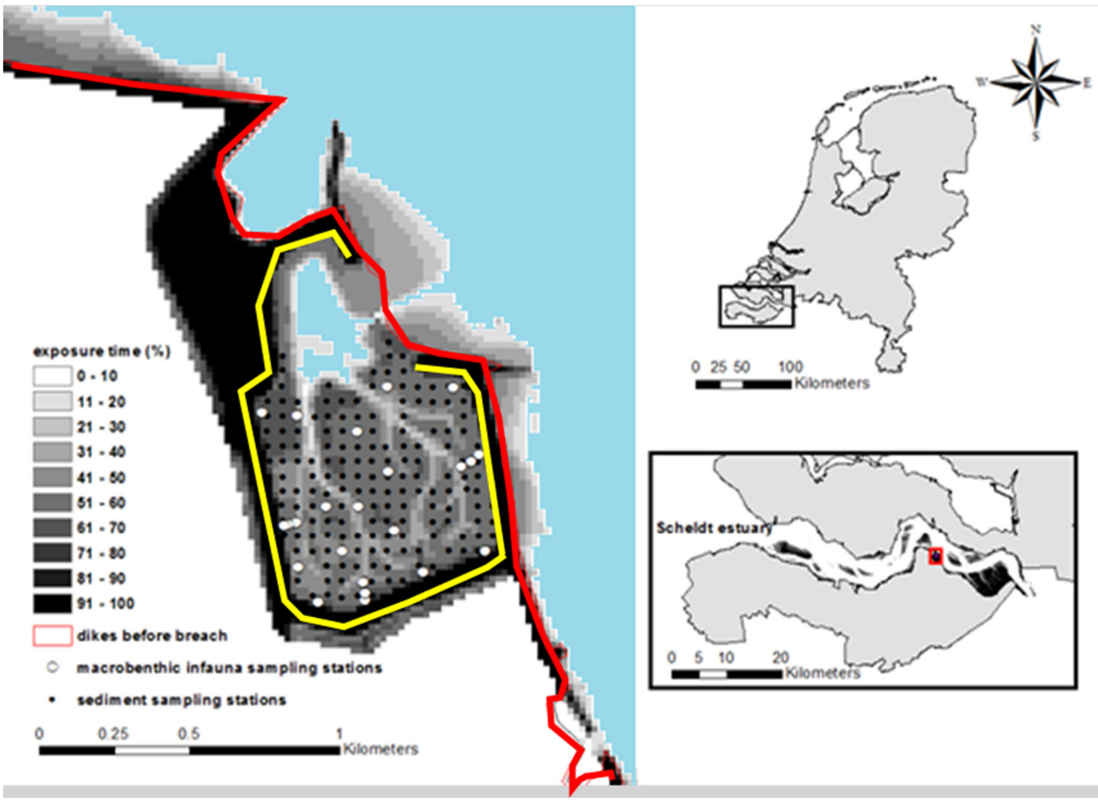


Figure 2.1. Map of the Perkpolder managed realignment site in the Western Scheldt estuary (southwest of The Netherlands) with the twenty-three macrobenthic infauna sampling stations and the two-hundred

sediment characteristic sampling stations (in the period 2015 – 2018). The red line indicates the original dike, while the yellow line represents the new dike.

2.2 Monitoring plan

2.2.1 Morphological changes (Deltares)

It is clear that the ecological development of Perkpolder is strongly affected by the hydrodynamics and morphodynamics in the basin. Due to the opening of the levee, sediment has been gradually imported into the Perkpolder basin, resulting in accretion of the intertidal area. In the previous phase of the project, we observed substantial temporal variations in the sediment import measurements, which we do not yet understand; there was even an export of sediment at certain moments (van de Lageweg et al. 2019). Furthermore, it is still unclear where the imported sediment originates from. Potential sources are the original tidal flat in front of Perkpolder (around the mouth of the basin) and sediment that is in suspension in the channel of the Western Scheldt. Understanding the sources is essential in order to accurately assess the future evolution of Perkpolder.

To that end, an MSc student will focus his or her graduation thesis on this topic. The main objective of this MSc thesis is to unravel the specific processes which steer the import of sediment into the Perkpolder area and to also determine where the imported sediment originates from. The first step of the research is to describe the morphological evolution of the area using insights from the project obtained thus far, and analysing recent morphological data. This first step will help develop the hypotheses on the sediment import mechanisms. In the second step, the hypotheses will be tested with a numerical model. The model allows for scenarios in which transport pathways from the source locations could be studied in detail and also for the testing of the importance of individual processes (e.g., by turning processes on and off). Currently, we are in the phase of hiring a student.

2.2.2 Vegetation (NIOZ)

2.2.2.1 Soil properties

In order to monitor the spatio-temporal variations in the sediment accumulation, as well as the potential changes in the physical properties, several sampling campaigns have been undertaken following the opening of Perkpolder and exposure to inundation in 2015 (phase one). The spatial variability in the parameters were investigated by sampling at up to 200 stations over a sampling grid that covered the entire project area. The stations were more-or-less equally-spaced throughout this managed realignment in 2016, 2017 and 2018 (Figure 2.1). The same sampling resolution was continued in 2019 and 2020. However, to reduce the workload, the sampling grid has been reduced to 76 grid points in 2021 (Fig. 2.2; Table 2.1), which still sufficiently covers the entire area. In addition to this full coverage sampling campaign, there was also a 15-point sampling scheme matching the 15 stations at which vegetation tussocks were transplanted in 2015 (see upper left panel in Figure 3.1).

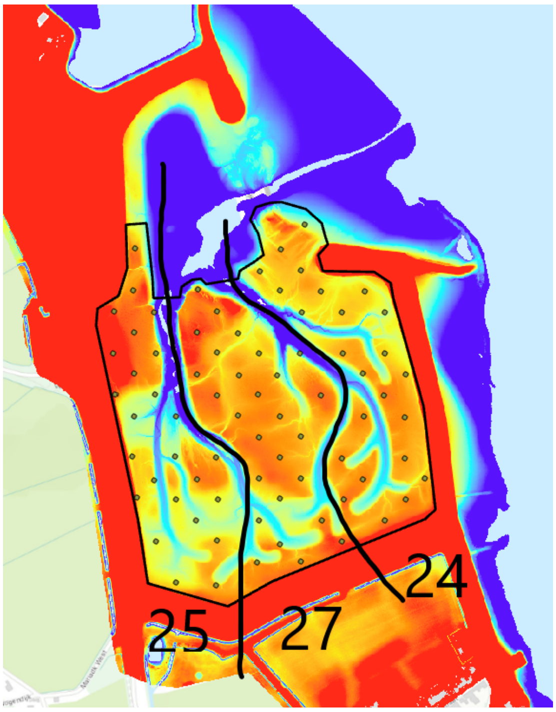


Figure 2.2. Adapted sampling grid for the sediment properties since 2021, with 76 points spread evenly throughout the project area. The numbers indicate the number of samples that were collected per day of fieldwork.

At each of the stations from the full coverage and also the 15-point sampling scheme, the same set of sediment properties were obtained. From the tidal flat surface samples, the grain size was determined with a sample covering the top 3 cm of sediment using a 3.5-cm diameter cut-off syringe, after which the samples were stored in pre-weighed sample vials. The sediment was first wet-weighed and placed in a freezer for a minimum of 3 days before opening the bottles and freeze drying them in a freeze dryer (Christ® Alpha 1-4) for at least 4 days. These dried samples were then re-weighed. In addition, the grain size, bulk density and water content was measured at 2-cm intervals (sediment slices) down to 20 cm from the 20-cm sediment cores that were also taken. The bulk density of the sediment (g cm^{-3}) was calculated as a ratio of dry weight to the sampled volume. Sediment grain size distribution was determined by laser diffraction (Malvern Mastersizer 2000; McCave et al. 1986), from which the median grain size of the sediment D_{50} (µm) as well as the size distribution of five different size classes (percentage of coarse, medium, fine, very fine sand, and silt) was determined.

The average depth of the mud layer (cm) on top of the old farmland was randomly measured (n=10) at each station using a ruler. Using a penetrologger, the penetration resistance was measured to a depth of up to 80 cm. Furthermore, the sediment erosion resistance (kPa) was measured using a shear vane. Using RTK-dGPS, the elevation of the tidal flat surface was measured in m NAP with ±1 cm accuracy. Moreover, the depth of the mud layer was measured to track accretion at every station station. To better-align data comparability between the sediment properties with benthos developments, the fieldwork is always carried out in the end of September or early October. See Table 2.1 for an overview of the data collected thus far in phase two of this project. The data is collected over 3 consecutive days (the indicated areas and number of samples taken in 2021 are shown in Figure 2.2). Next to the dGPS measurements, an echosounder (single beam) was also used to determine the development of the tidal flat elevation. The echosounding is performed from a small boat by sailing in a grid at about 1 m water depth. The echosounding data was collected in both July and September (Table 2.1). The data from this are currently being processed.

Table 2.1. Overview of data collected and processed since 2019 by NIOZ.

Date	dGPS	Grain size Top 3 cm	Grain size 20 cm Core	Bulk-density	Depth Mud	Penetro-logger	Shear vane	Drone	Echo-sounder
2019/09/13	X	X		X	X	X	X		X
2020/06/13									X
2020/09/19	X	X		X	X	X	X	RGB	
2021/06/03									X
2021/09/15	X		X	X	X	X	X	Multispectral	

Sampling periods	Needs to be processed

2.2.2.2 Vegetation dynamics

Monitoring the spatial patterns in vegetation establishment and development has been done via 1) field observations and 2) remote sensing using low-altitude imaging by a drone. During field observations, dGPS locations of the tussocks and seedlings are obtained, which also revealed the surface elevation. The diameter of six *Spartina anglica* tussocks were measured over two perpendicular directions. These six tussocks are the only surviving patches of a more-extensive transplantation of 15 tussocks executed in 2015 as part of the experimental work done in phase one of the project. Moreover, the stem height and above-ground biomass was sampled by cutting all of the above-ground vegetation in a 25 by 25 cm square frame.

To map seedling establishment in a more-manageable, but still fully-sufficient, way, an alternative method utilizing low-latitude remote sensing data collected by a drone will be developed within the project in the future. Images using a multi-spectral camera will be taken throughout the entire area. We will use the method developed by Fivash et al. (2021) based on a 3D terrestrial laser scanner to identify the presence or absence of seedlings. We will then validate this further through manual observations in the field combined with the measured dGPS locations of the seedlings (see above). To calibrate and validate this approach, data will be collected at a number of additional field sites, given that the seedling establishment at Perkpolder is still quite limited.

2.2.2.3 Linking soil and vegetation dynamics

As a first step towards understanding the link between soil development and vegetation dynamics, we analyzed how the change in soil surface elevation affected the inundation time and frequency. We specifically focused on the skipping of tides as the development of the theoretical framework (van Belzen et al., in prep) has revealed that the lengthening of periods of benign hydrodynamic conditions can be a key driver for creating WoO's. In case of water-level variations driven by tides, this is related to the absence of one or more tidal inundations, e.g., as the result of spring-neap and meteorologically-driven variations. The tide skipping analysis is based on the observed water-level variations at the Hansweert station (RWS) and the tidal flat elevation in the same year. The number of tides skipped is determined for each elevation of the tidal flat and expressed as a fraction of the total number of tides in the timeframe used (one year).

2.2.3 Colonization by benthic macrofauna (WMR)

In order to quantify the colonization of the benthic macrofauna (also known as macrobenthic infauna) and their community structure in this phase two of the Perkpolder project, several years of sampling had already been undertaken since the autumn of 2015 from the phase one of the project, just four months after the breach. Subsequent sampling took place annually in both the spring and autumn for three more years (2016, 2017 and 2018). During 2015, 2016 and 2017, samples were collected at sixteen, relatively easily-accessible stations situated close to the dike. Since spring 2018, extra samples (for a total of 23) were added to cover the central part of the managed realignment site. The same sampling scheme continues to be employed in this phase two of the project inside the managed realignment site, and 23 stations were again sampled in the most-recent campaign in autumn 2020 (Figure 2.3).

The macrobenthic infauna was sampled using a 10-cm diameter corer (e.g., 78 cm^2 surface area) to a maximum depth of 35 cm. At each station, three replicates were taken randomly, pooled and sieved in the field through a 1 mm mesh sieve. The residue was preserved in 4% buffered formaldehyde solution and stained with Rose Bengal. The preserved specimens were then sorted in the benthos lab and identified to the lowest possible taxonomic level, counted and wet-weighed. The total number of species (species richness) can then be determined, followed by the number of individuals per species found at each station, converted to density (number of ind. m^{-2}). Worm counts were based on the number of heads found in a sample. When only a tail was found it was recorded as 1 individual of this species. In addition, the biomass was calculated by converting total wet weight to total ash free dry weight (AFDW) in g m^{-2} using a species-specific conversion factor as described in Craeymeersch and Escaravage (2014). Furthermore, the lugworm *Arenicola marina* densities were counted in the field using 0.25 m^2 quadrants (n=10), which were also randomly taken at each sampling station.

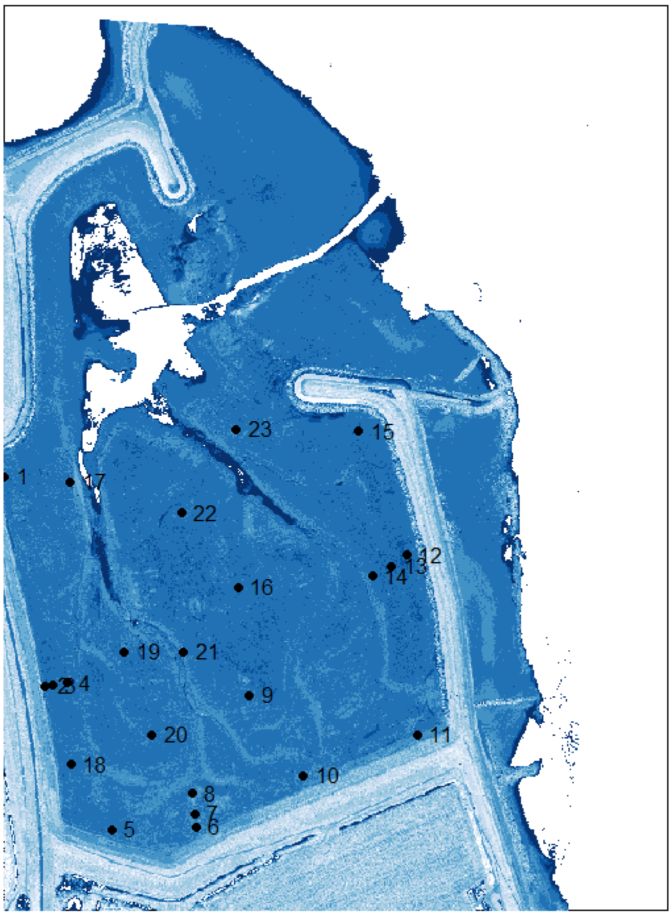


Figure 2.3. The 23 macrobenthic sampling locations undertaken in September 2020, following the sampling protocol used since 2018 from phase one of the project.

2.2.3.1 Comparison of the community structure in the managed realignment area versus natural tidal flats

The Ministry of Transport, Public Works and Water Management has been monitoring the benthic macrofauna of the Western Scheldt as part of a biological monitoring programme (MWTL) since 1992. To compare the community structure in the managed realignment area at Perkpolder to that of natural nearby tidal flats, a subset of the MWTL dataset (based on location and ecotope) is extracted. The managed realignment area, located on the poly/mesohaline transition zone, can be classified as a low dynamic, mid littoral ecotope according to the Dutch ecotope system used in Scheldt estuary, the so-called ZES (Zoute Ecotopen Stelsel, Bouma et al. 2005). A total of 28 macrobenthic samples taken between 2014 and 2017, within these low dynamic, mid littoral ecotopes, between 3º59.659'E and 4º6.550'E (58000 and 66000 Rijksdriehoek) were used in the analysis (Figure 2.4).

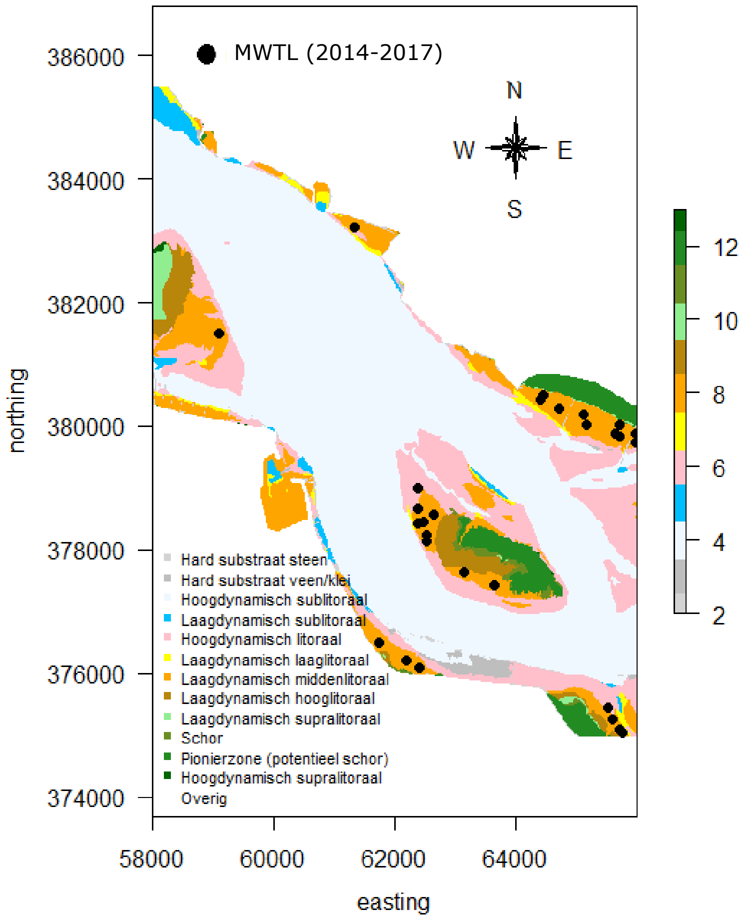


Figure 2.4. Map of the Scheldt estuary around the Perkpolder project area. Using the latest available data from the MWTL programme between 2014-2017, 28 stations from nearby locations that fall within the same habitat zonation (low dynamic, mid littoral) were selected to compare with the Perkpolder community composition.

2.2.3.2 Explanatory environmental variables

To both determine the sedimentary characteristics and compare that with the macrobenthic results, environmental parameters were also sampled from the 23 stations (Figure 2.3). These included the median grain size (D_{50}, μm) and sediment grain size distribution (volumetric percentage of coarse, medium, fine and very fine sand, and silt), bulk density (g cm^{-3}) and sediment elevation. The top 3 cm of sediment was sampled with a cut-off syringe for the grain size, bulk density and size distribution (see subsection 2.2.2.1 for details on how these samples were processed and measured). In addition, we also took the top 1-cm for chlorophyll *a* (chl *a*, μg g^{-1}), as a measure of the food availability for the benthic animals. This was done by randomly sampling three areas at each station from the top 1 cm of sediment using a cut-off syringe, and pooling the samples together. Given the sensitivity of chl *a*, these samples were stored in the dark at -80ºC after which they were freeze dried and kept at -80 ºC until they were spectrophotometrically analyzed according to Aminot and Rey (2000). We first compare the results from each sampling season to show how the different sediment parameters may have changed over time.

To explore how species and community traits varied with environmental characteristics as well as through time, additional multivariate analyses were conducted using the R package "mgcv" (Wood 2021) in the program R (R Core Team, 2020). Multivariate generalized linear models were used to examine environmental drivers of species richness, total abundance (density) and total biomass, as they allowed us to run linear models on all taxa responses simultaneously. To obtain statistical significance of environmental explanatory variables, ANOVAs were run to test for the significance between the biotic and abiotic parameters. Model fits were checked using residual plots.

2.2.3.3 Statistical analysis

A multivariate analysis (Principal component analysis, PCA) was performed to assess the development of the community structure of the benthic macrofauna, both between phase one and the first sampling (Sep. 2020) of phase two, as well as the latest MWTL composition (2014 – 2017) from similar ecotopes in the adjacent areas. To avoid ambiguity, specimens that had only been determined at class or phylum level were left out of the PCA analysis of the community composition. Nemertea and Oligochaeta were included. In cases where there were individual species of a genus that could not be identified to species level, all of the species were merged into genus + species. The community structure was analysed using multivariate statistics using the R package 'vegan' (Oksanen et al. 2018). A Bray-Curtis similarity matrix was constructed from fourth root-transformed densities of the macrobenthic taxa with a dummy variable (with a value of 1) to overcome the problems associated with the complete absence of organisms at one station inside the realignment site that occurred only in the autumn 2018 campaign. A Non-metric multidimensional scaling (nMDS) was applied to the similarity matrix to represent, as closely as possible, the pairwise (dis)similarity between objects in a two-dimensional space. The nMDS is a rank-based approach. This means that the original distance data is substituted with ranks. A total of 999 permutations were performed.

2.2.4 Bird counts (WMR)

During the first two years of the phase one project, the counting of the birds in the realignment site was carried out during low tide on seven occasions during the autumn and winter months (2016: Feb, Mar, 2*Oct, Nov, Dec; 2017: Jan). No attempt was made to establish a reference area on which bird counts would be made. From September 2017 onwards, the methodology changed in low and high tide bird counts during each calendar month. Since August 2017, the birds have been counted every month within one low tide. The birds were then identified to species level and their behavior was scored (foraging or resting). The counting is carried out by a fixed group of volunteers from the nature protection society "De steltkluut". In order to limit disturbance, counts were carried out from a slowly moving car on the road along the dike. A total of 50 counts between August 2017 and September 2021 were used for the analysis. The area has been divided into six counting blocks (Figure 2.5).The number of counted birds are corrected for surface area and are expressed as individuals per hectare per counting block.

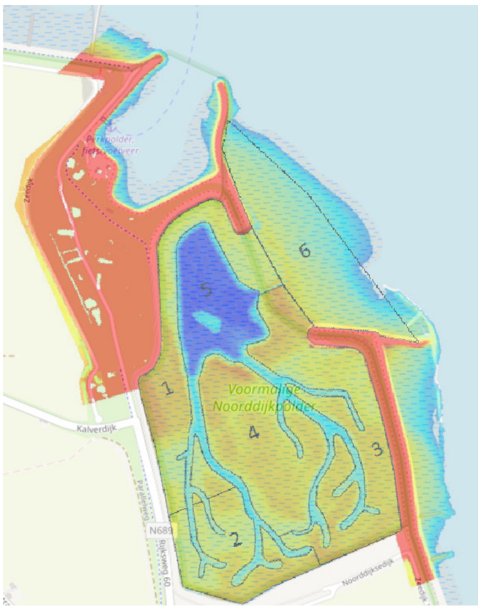


Figure 2.5. The six designated bird counting blocks within Perkpolder.

Counts were grouped in "bird periods"; a period starts in July of one year and ends in the June from the following year. In this way, consecutive winter months (December, January and February) are captured within one period for the comparisons and we can correct for any seasonal fluctuations over time. Here, the first count of the series was started in August 2017. When comparing the years in "bird periods", we can include all of the counts for the change in bird numbers over years. Following the grouping of the data into periods, the number of birds per hectare per counting block was then calculated, followed by a calculation on the average per month. Species that are usually not related to mudflats were removed, such as songbirds, crows, owls and most birds of prey. The remaining bird species were assigned to a group based on their main/usual diet or family: benthos-eating waders like Eurasian curlew, oystercatchers, red knots, dunlins; other waders that are usually more commonly observed in agricultural fields like black-tailed godwits, Northern lapwing and golden plover; benthos-eating duck species such as common eider and tufted ducks; (mainly) plant eating goose and ducks including the Eurasian wigeon, mallard and Canada goose; gulls such as black-headed gull and herring gull and fish eating bird species such as egrets, grebes, terns, spoonbills and cormorants (Table 2.2). For the analysis on the change in the number of birds over time, both the total bird numbers associated with this area as well as the sum of the benthos-eating waders and gulls were analyzed.

Table 2.2. Overview of bird species per group

Diet/family group	**Bird species**
Benthos-eating waders	Bar-tailed godwit, black-tailed godwit, common greenshank, common redshank, common ringed plover, common sandpiper, dunlin, Eurasian curlew, Eurasian whimbrel, grey plover, oystercatcher, pied avocet, red knot, ruff, sanderling, sand plover, shelduck, spotted redshank, turnstone
Other waders	Black-tailed godwit, golden plover, Northern lapwing
Benthos-eating duck species	Common eider, tufted duck
Plant-eating geese and ducks	Barnacle goose, brant geese, Canada goose, Eurasian coot, Eurasian teal, Eurasian wigeon, Egyptian goose, gadwall, greylag goose, mallard, Northern pintail
Gulls	Black-headed gull, common gull, greater black-backed gull, herring gull, lesser black-backed gull, Mediterranean gull
Fish-eating species	Black tern, common tern, Eurasian spoonbill, great cormorant, great crested grebe, great egret, great blue heron, little egret, osprey, red-breasted merganser

2.2.5 Socio-economic aspects (HZ)

2.2.5.1 Systematic literature review

A systematic review of the scientific literature was conducted to gain insight into the existing body of research on public attitudes to coastal realignment projects 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 near Perkpolder and other locations in Zeeland, including Rammegors and the Hedwige Prosperpolder. Both the systematic literature review and the design of the survey instrument were carried out in close collaboration with the Hogeschool Zeeland University of Applied Sciences (HZ) Resilient Deltas research group.

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, we decided to consider research articles about interventions focusing on other landscape typologies such as rivers or estuaries as well. Firstly, because river and coastal management interventions could be expected to provoke similar social responses, and also since 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 keys: *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 second sample of 82 articles. The articles within this second sample were subjected to full text reviews 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 into 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.

2.2.5.2 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 Perkpolder area and other locations in Zeeland, including the Rammegors 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 at Perkpolder 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 each of the three case study locations with equivalent questions to allow for comparison between the different case study locations, while taking into account case study-specific information to provide context.

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 programme Living Labs in the Dutch Delta) that is taking place in parallel to the research at Perkpolder, Rammegors 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 in Perkpolder as well as in the Rammegors area and the Hedwige Prosperpolder. Data collection at Perkpolder is scheduled for the period between November 2021 and May 2022.

The literature study and survey and data analysis from the HZ is currently ongoing. The work involves different groups and student projects:

- The findings from the Perkpolder phase one monitoring were shared with 2nd year HZ Water Management students as part of the module Ecological Engineering
- The findings of the Perkpolder phase one 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. A field visit to the Perkpolder area was scheduled on 18 October, while Rammegors has already been visited (Figure 4.1). These students assisted the lecturers in performing the surveys.

- The findings from the Perkpolder phase one monitoring and plans for the current phase two 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.

Coordinates of approximate survey location nearby Perkpolder (town of Kloosterzande):
51°22'15.6"N 4°00'52.8"E (degrees); 51.370996, 4.014663 (UTM)

2.3 Current situation

2.3.1 Delays

Due to the ongoing COVID situation, several results that were planned to be provided in this progress monitoring report are unfortunately not included. 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 that this project involves are indicated accordingly in this paragraph.

In particular, there has been a huge backlog on the processing of samples in the analytical lab (Table 2.1) and as a result, the statistical analysis of the soil data. Consequently, this report will only inform about the results of the vegetation dynamics. The development in the soil properties will be updated in the final report. The soil properties in which the results have been delayed include:

1. Penetrollogger – collected but not yet processed
2. Shear vane – collected but not yet processed
3. 20-cm sediment cores – collected but not yet analyzed by the lab
4. Mud layer depth – collected but not yet processed

Multi-spectral drone images were scheduled for 2020 and 2023 according to the phase two contract. However, due to delays in delivering the multi-spectral camera related to the COVID situation, this data was not obtained in 2020. RGB-images were collected instead, and will be processed through spectral analysis. The multi-spectral data was recently collected in 2021, and this data still needs to be processed. When all of the soil data has been processed, and the spatial and temporal development are analyzed, regression analysis will be employed to identify and study further links between soil and recruitment and development of vegetation. This analysis is still in progress. This is in regards to:

1. Vegetation – drone image analysis
    - RGB images - collected but not yet processed
    - Multispectral images – recently collected but not yet processed
    - Drone image processing (script) – in progress

HZ survey and analysis of the results – delayed due to COVID; currently in progress

3 Results

3.1 Vegetation

3.1.1 Vegetation development

Vegetation development from 2015 to 2021 has mostly been characterized by the disappearance of transplanted vegetation patches (Figure 3.1). Out of the original 15 *Scirpus maritimus* and the 15 *S. anglica* tussocks transplanted in July 2015 (as part of experiments in phase one of the Perkpolder project) only 6 tussocks were present in 2018, which are still present as of September 2021. No other vegetation dynamics have been observed up to 2018. During field visits in 2019 and 2020, it was apparent that no substantial and lasting seedling establishment had taken place. However, in 2021, the seedling establishment of *S. anglica* did occur in the western part of the area. See the dGPS coordinates collected in June and September 2021 and the detailed inset of this observation (Figure 3.1).

In general, the remaining tussocks developed well except for tussock 11 (Figure 3.2). These surviving tussocks developed from an average diameter of 62 ± 6 cm in 2017, to 152 ± 11 cm in 2018 and 291 ± 77 cm in 2021. On average, the diameter of the tussocks expanded about 55 cm yr^{-1}, i.e., the lateral expansion rate of *S. anglica* is therefore 28 $cm.yr^{-1}$. Also, the average shoot height developed from 38 ± 5 cm in 2017, to 63 ± 3 cm in 2018 and 75 ± 6 cm in 2021. The above ground biomass developed from 1294 ± 154 g m^{-2} in 2018 to 1860 ± 151 g m^{-2} in 2021, on average.

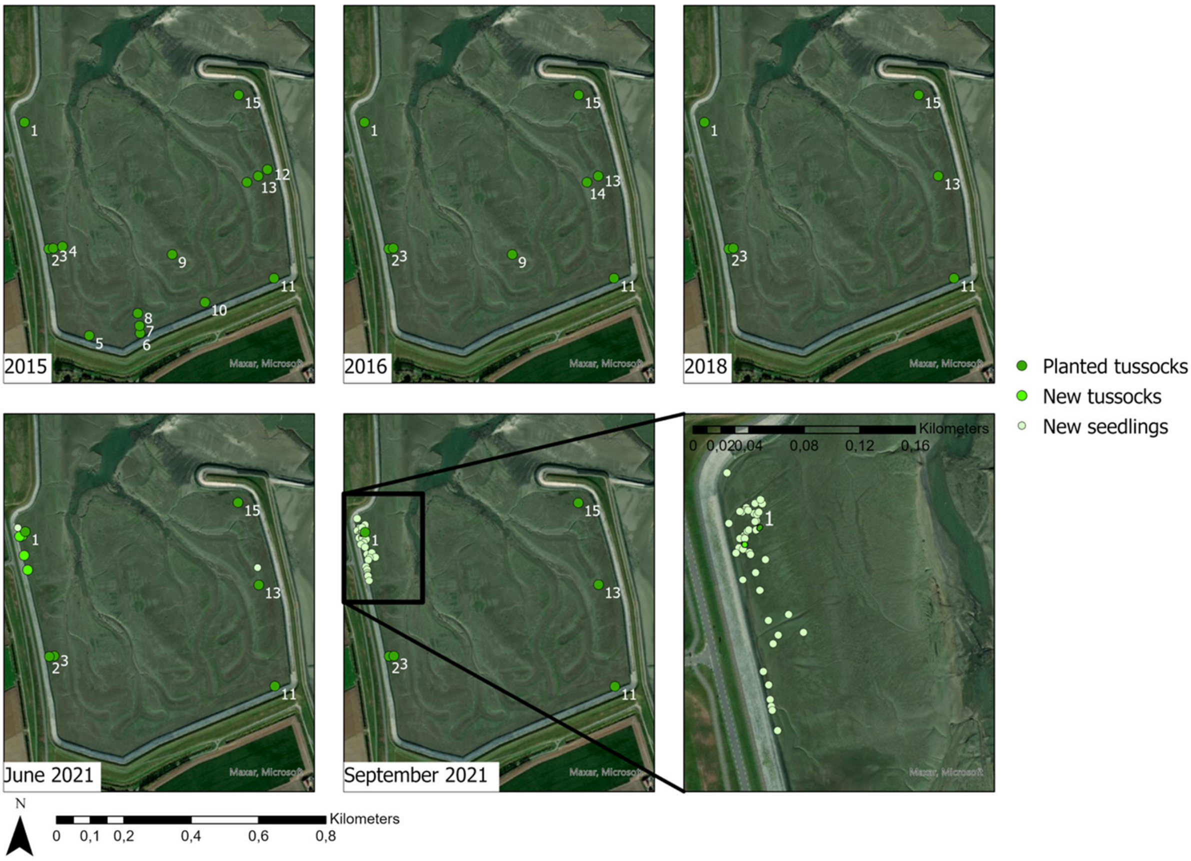


Figure 3.1. The development of tussocks and seedlings by manual observations.

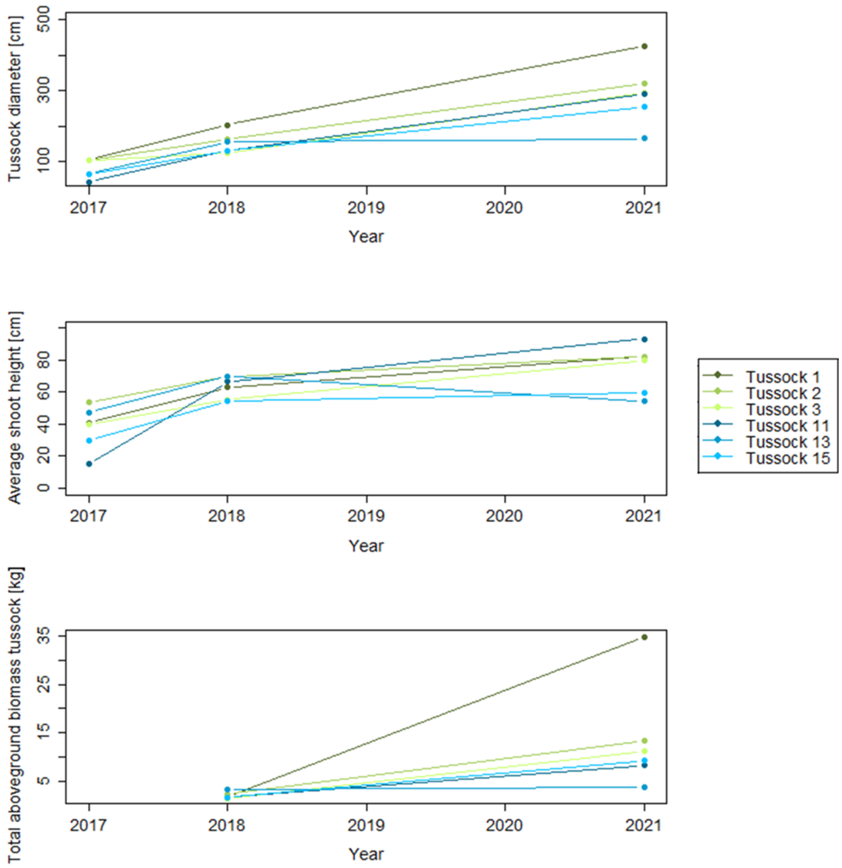


Figure 3.2. Tussock development from the six surviving transplanted tussocks.

3.1.2 Linking soil and vegetation development

The analysis of the tidal flat elevation reveals that some parts of the tidal flat in the project area have risen to an elevation approaching 1 m NAP. Specifically, this includes the western part of the project area and also some patches on the tidal flat in the middle of the project area. In these areas, the tide skipping analysis shows that >0.1% of the tides are skipped, which means that longer periods with hydrodynamically benign conditions are occurring, which are potentially better-suited for vegetation establishment (Figure 3.3).

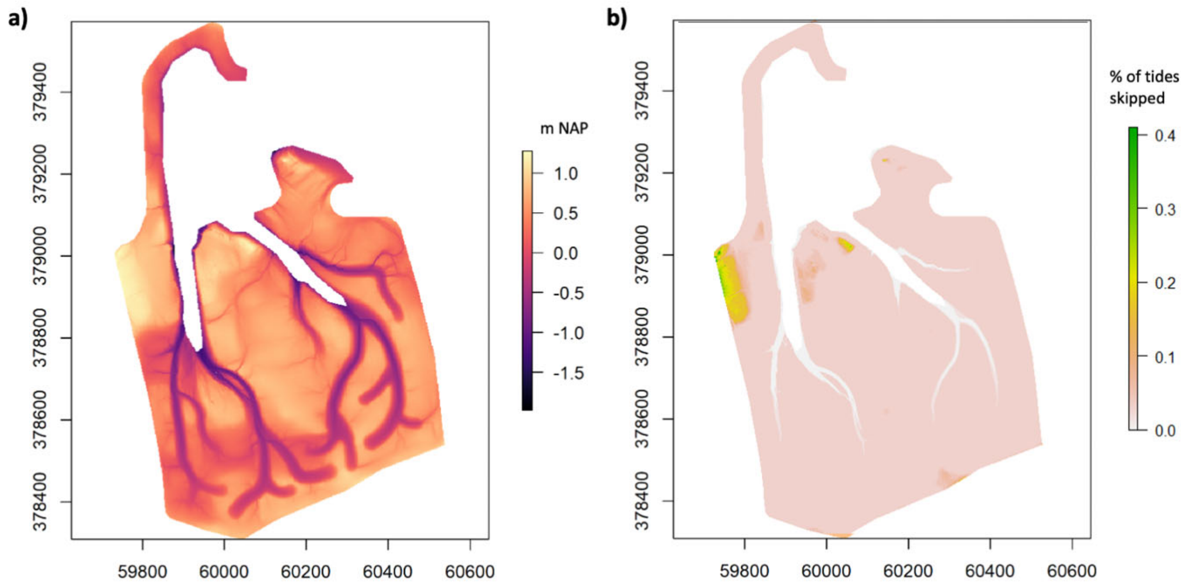


Figure 3.3. (a) Tidal flat elevation of Perkpolder in 2020 (b) and predictions of tide skipping events for the same year which can favor vegetation establishment.

3.2 Benthic macrofauna

3.2.1 Macrobenthic development

From 2015 to 2020 (except 2019, in which no macrobenthic sampling was undertaken), there has been a gradual shift in the species richness, total abundance (density) and also the total biomass, with some parameters increasing or decreasing between certain years. Overall, the species richness has increased significantly over time, from 19 in 2015, to 25 species in 2020, with a peak of 26 species in October 2016 (Figure 3.4 and Table 3.1). The species richness from the MWTL is considerably higher, at around 40. However, in terms of the average total abundance, the autumn of 2016 exhibited the highest number overall, due primarily to the very high counts from the many small opportunistic, highly mobile species from the class Malacostraca observed early on (Figure 3.4 and Table 3.2), as well as from the polychaetes, all of which have subsequently seen a drastic decrease, although the latter was still the dominant group even in the most-recent campaign. In contrast, the average total biomass has seen a steady increase, with the highest amount observed in autumn 2020. The biomass from both October 2018 and September 2020 exceeded that from the latest MWTL data (2014 – 2017, Figure 3.4).

In terms of occurrence, the top five species in autumn 2020 included: *Cyathura carinata* (100%), *Pygospio elegans, Heteromastus filiformis, Abra tenuis and Hediste diversicolor* (all 96%; Table 3.1). The most abundant species included: *H. filiformis* (5165 ± 3105 ind. m^{-2}), *C. carinata* (1207 ± 693 ind. m^{-2}), *Peringia ulvae* (1137 ± 1006 ind. m^{-2}), *P. elegans* (915 ± 1345 ind. m^{-2}) and *Abra tenuis* (722 ± 843 ind. m^{-2}; Table 3.2). The five heaviest taxa (dominance in terms of total biomass) were: *Scrobicularia plana* (16.2 ± 19.9 g m^{-2}), *H. diversicolor* (3.01 ± 2.2 g m^{-2}), *H. filiformis* (2.9 ± 1.7 g m^{-2}), *Limecola balthica* (1.6 ± 1.9 g m^{-2}) and *Ruditapes sp.* (1.3 ± 4.2 g m^{-2}; Table 3.3).

Several species also displayed notable changes. *Corophium volutator*, which initially occurred at all stations and was among the most abundant species, first showed a decrease in May 2018, followed by a drastic drop in the autumn of the same year. It has since completely disappeared in 2020 (Table 3.1; Figure 3.5). Other taxa which have seen a drastic or complete decrease include Nemertea, Oligochaeta (though not only in 2020), Eteone and *Alitta succinea*. On the other hand, several species appear to have proliferated since 2015, such as *P. ulvae*, *Cyathura carita*, *S. plana* (though somewhat lower in 2020 compared to autumn 2018), *H. diversicolor and Cerastoderma edule* (Figure 3.7). Notably, *A. tenuis* was sampled for the first time in 2020 at all 23 stations (Figure 3.6). Moreover, the invasive amphipod, *Grandidierella japonica*, which was first observed in the Noordzeekanaal in 2017 (Nature Today 2017), was also collected for the first time at this location. It was found at almost half of the stations.

One of the largest contributors from recent years to biomass is *S. plana*, comprising well over 50% of the total biomass in 2020, even though the counts were lower compared to 2018 (Tables 3.2 and 3.3; Figure 3.8). The newly-sampled *A. tenuis* is another notable contributor to the total biomass. Overall, the increase in the biomass of bivalves is the main reason the total biomass continues to increase over time (Figure 3.6 and Table 3.3) and exceeds that of the MWTL.

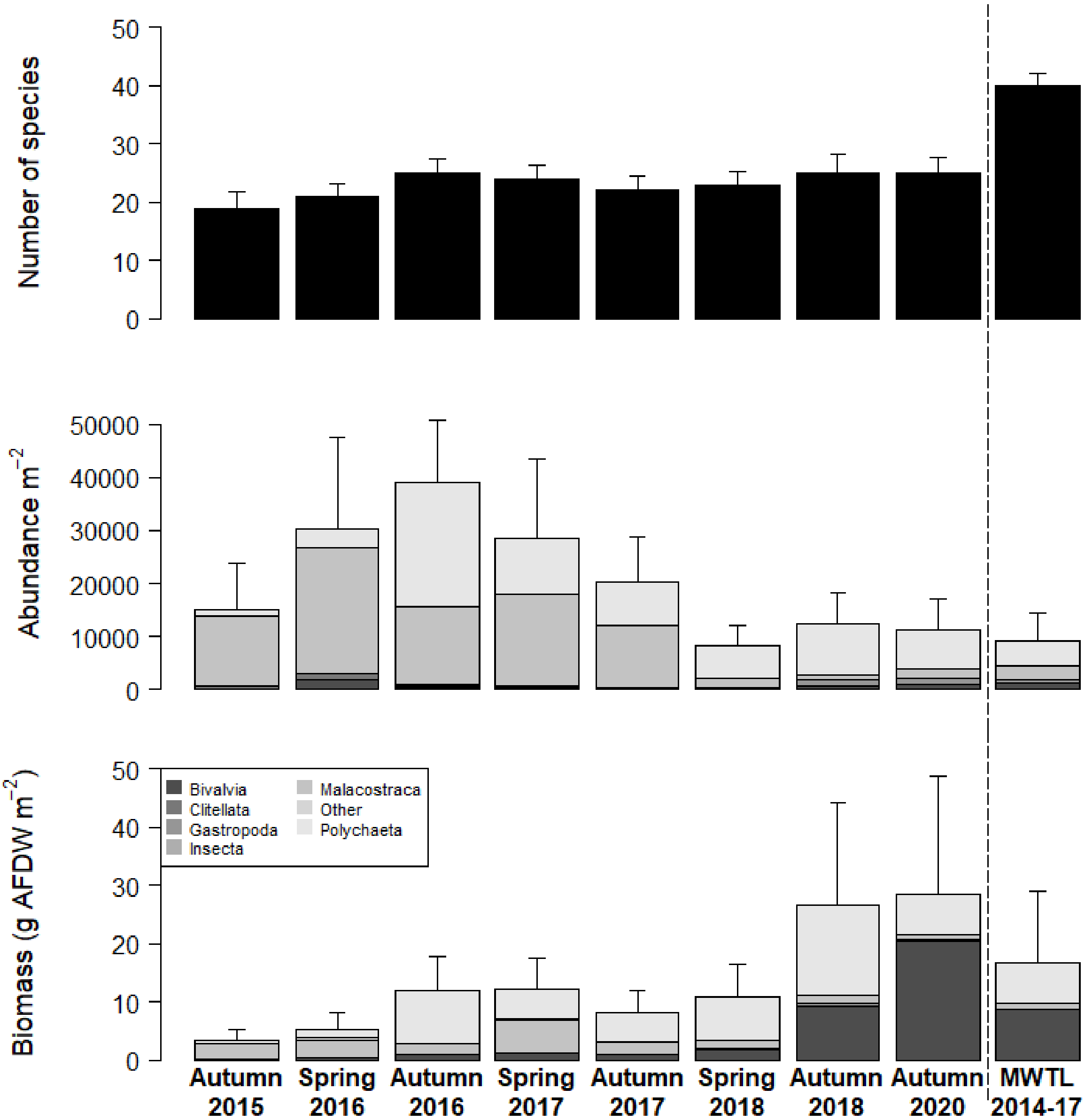


Figure 3.4. The total number of species, average abundance and average biomass between each sampling campaign from both phases of the Perkpolder project, as well as the MWTL 2014 – 2017 (separated by dashed vertical line). The error bars for the number of species represents the standard deviation between the stations within each campaign. The error bars for the abundance and biomass represent the standard deviation of the major class taxonomic groups.

Table 3.1. The species occurrence (% of total number of stations in which each taxon was found) over the different campaigns, and the total number of species. The list is sorted based on the highest occurrence values from the autumn 2015 campaign.

Species/Taxon	Occurrence % Autumn 2015	Spring 2016	Autumn 2016	Spring 2017	Autumn 2017	Spring 2018	Autumn 2018	Autumn 2020
Corophium volutator	100	100	100	100	100	83	23	
Polydora cornuta	94	31	88	88	50	17	73	78
Nemertea	88	88	50	75	56	13	36	
Oligochaeta	88	81	38	25			5	
Limecola balthica	81	69	100	100	75	65	82	57
Pygospio elegans	81	100	100	100	94	91	100	96
Eteone sp.	56	31	69	56	38	4	9	9
Alitta succinea	50	50	81	94	94	78	36	17
Aphelochaeta	50	38	75	44	63	39	41	39
Crangon crangon	44	56	13	69	31	57	18	35
Hypereteone foliosa	44	31	44	63	81	87	32	17
Streblospio benedicti	44	6	63	38	13	9	5	17
Heteromastus filiformis	38	6	100	100	100	100	95	96
Peringia ulvae	38		63	13	44	48	86	91
Chironomidae	31		13	6				
Cyathura carinata	31	31	69	63	94	91	95	100
Nudibranchia	19		6					
Insecta	13	13	19			13	9	
Scrobicularia plana	6	6		13	44	57	86	61
Abra tenuis								96
Alitta virens			6					
Arenicola sp.			13	13				
Arenicola marina								9
Bathyporeia sp.				6		4		
Bathyporeia sarsi						4		
Bivalvia		13			6		14	
Carcinus maenas					13		27	39
Caridea								4
Cerastoderma edule					13	4	9	22
Dox vittatus			6					
Ensis sp.					6			
Gammarus sp.		6		6	6			
Gastropoda						4		
Grandidierella japonica								48
Hediste diversicolor		6	75	81	56	83	95	96
Hemigrapsus sp.							23	
Isopoda			6					
Mya arenaria			6			4	9	
Nephtys caeca								4
Nereidinae								22
Nereis sp.		6	69	69	50	4	82	
Pisces								4
Platyhelminthes				6				
Polychaeta			6					
Polydora sp.								4
Praunus sp.				6				
Pseudopolydora pulchra		6						
Ruditapes sp.		100					5	9
Number of species	19	21	26	24	22	23	25	25

Table 3.2. The total abundance (density) of each individual species (ind. m^{-2}) over the different campaigns, as well as the total abundance per campaign. The list is sorted based on the highest values from the autumn 2015 campaign. The standard deviation (±) of the individual species is calculated over the number of stations, while the standard deviation of the total from each campaign is based on all species from all stations in that campaign.

	Density (ind. m^{-2})							
Species/Taxon	**Autumn 2015**	**Spring 2016**	**Autumn 2016**	**Spring 2017**	**Autumn 2017**	**Spring 2018**	**Autumn 2018**	**Autumn 2020**
Corophium volutator	13083 ± 8451	23418 ± 19080	14358 ± 6721	17157 ± 14501	10862 ± 8394	1284 ± 2293	156 ± 640	
Oligochaeta	586 ± 1037	1090 ± 2787	265 ± 649	16 ± 31			8 ± 36	
Polydora cornuta	584 ± 536	48 ± 109	570 ± 822	204 ± 197	64 ± 111	11 ± 26	100 ± 92	369 ± 569
Limecola balthica	130 ± 124	1931 ± 2734	347 ± 200	509 ± 626	103 ± 102	92 ± 111	131 ± 130	48 ± 56
Pygospio elegans	127 ± 163	3271 ± 2498	1761 ± 1577	4886 ± 4065	1578 ± 1808	1268 ± 1621	1734 ± 2567	915 ± 1345
Nemertea	85 ± 60	183 ± 218	29 ± 37	93 ± 102	64 ± 97	7 ± 21	19 ± 28	
Alitta succinea	80 ± 132	64 ± 86	114 ± 106	294 ± 209	178 ± 141	159 ± 165	29 ± 53	90 ± 254
Eteone sp.	45 ± 48	29 ± 59	74 ± 74	69 ± 87	24 ± 38	2 ± 9	6 ± 20	4 ± 12
Cyathura carinata	40 ± 73	32 ± 75	162 ± 192	111 ± 134	621 ± 604	559 ± 450	693 ± 473	1207 ± 693
Hypereteone foliosa	37 ± 49	19 ± 35	37 ± 60	56 ± 57	122 ± 117	140 ± 115	21 ± 36	46 ± 144
Aphelochaeta	34 ± 47	29 ± 43	77 ± 76	45 ± 65	64 ± 71	33 ± 57	58 ± 115	306 ± 1098
Streblospio benedicti	34 ± 52	3 ± 11	80 ± 83	37 ± 60	5 ± 14	4 ± 12	2 ± 9	17 ± 47
Crangon crangon	29 ± 43	141 ± 302	5 ± 14	194 ± 418	37 ± 95	114 ± 187	10 ± 22	31 ± 55
Heteromastus filiformis	29 ± 51	5 ± 21	20438 ± 10163	4581 ± 1984	6093 ± 2008	4342 ± 2464	6337 ± 3551	5165 ± 3105
Chironomidae	19 ± 31		19 ± 64	8 ± 32				
Peringia ulvae	16 ± 21		233 ± 367	11 ± 33	313 ± 752	129 ± 246	1154 ± 1240	1137 ± 1006
Insecta	13 ± 43	5 ± 14	93 ± 275			9 ± 25	10 ± 32	
Nudibranchia	8 ± 17		3 ± 11					
Scrobicularia plana	5 ± 21	3 ± 11		8 ± 23	56 ± 98	78 ± 109	449 ± 397	127 ± 186
Abra tenuis								722 ± 843
Alitta virens			3 ± 11					
Arenicola sp.			13 ± 43	11 ± 33				
Arenicola marina								4 ± 12
Bathyporeia sp.				3 ± 11		2 ± 9		
Bathyporeia sarsi						2 ± 9		
Bivalvia		8 ± 23			3 ± 11		17 ± 52	
Carcinus maenas					5 ± 14		19 ± 34	18 ± 25
Caridea								2 ± 9
Cerastoderma edule					8 ± 23	2 ± 9	6 ± 20	11 ± 23
Donax vittatus			5 ± 21					
Ensis sp.					5 ± 21			
Gammarus sp.		3 ± 11		3 ± 11	3 ± 11			
Gastropoda						2 ± 9		
Grandidierella japonica								522 ± 1436
Hediste diversicolor		3 ± 11	178 ± 201	215 ± 199	119 ± 145	196 ± 202	1148 ± 1076	563 ± 385
Hemigrapsus sp.							14 ± 30	
Isopoda			3 ± 11					
Mya arenaria			13 ± 53			2 ± 9	4 ± 12	
Nephtys caeca								2 ± 9
Nereidinae								63 ± 146
Nereis sp.		3 ± 11	154 ± 223	141 ± 239	72 ± 118	2 ± 9	272 ± 254	
Pisces								2 ± 9
Platyhelminthes				3 ± 11				
Polychaeta			53 ± 212					
Polydora sp.								2 ± 9
Praunus sp.				8 ± 32				
Pseudopolydora pulchra		5 ± 21						
Ruditapes sp.							2 ± 9	7 ± 28
Total density	**14984 ± 2982**	**30291 ± 5101**	**39088 ± 4770**	**28661 ± 3645**	**20398 ± 2575**	**8438 ± 940**	**12399 ± 1299**	**11380 ± 1050**

Table 3.3. The total biomass of each individual species (g AFDW m^{-2}) over the different campaigns, as well as the total density. The list is sorted based on the highest values from the autumn 2015 campaign. The standard deviation (±) of the individual species is calculated over the number of stations, while the standard deviation of the total from each campaign is based on all species from all stations in that campaign.

	Biomass (g AFDW m^{-2})							
Species/Taxon	**Autumn 2015**	**Spring 2016**	**Autumn 2016**	**Spring 2017**	**Autumn 2017**	**Spring 2018**	**Autumn 2018**	**Autumn 2020**
Corophium volutator	2.74 ± 2	2.86 ± 3.05	1.75 ± 1.008	5.507 ± 3.85	1.54 ± 1.18	1.054 ± 2.015	0.049 ± 0.208	
Polydora cornuta	0.11 ± 0	0.02 ± 0.04	0.045 ± 0.065	0.024 ± 0.037	0.01 ± 0.01	0.008 ± 0.018	0.014 ± 0.016	0.083 ± 0.271
Limecola balthica	0.10 ± 0	0.342 ± 0.54	0.86 ± 0.67	0.71 ± 0.481	0.84 ± 0.90	1.306 ± 1.465	1.27 ± 1.198	1.578 ± 1.908
Nemertea	0.06 ± 0	0.45 ± 0.56	0.023 ± 0.047	0.173 ± 0.242	0.022 ± 0.03	0.006 ± 0.02	0.007 ± 0.014	
Heteromastus filiformis	0.05 ± 0	0.041 ± 0.08	7.632 ± 4.682	2.19 ± 1.223	3.72 ± 1.64	3.13 ± 2.015	8.26 ± 5.576	2.931 ± 1.739
Hypereteone foliosa	0.05 ± 0	0.025 ± 0.05	0.010 ± 0.017	0.022 ± 0.028	0.01 ± 0.014	0.06 ± 0.065	0.001 ± 0.002	0.007 ± 0.026
Alitta succinea	0.05 ± 0	0.78 ± 1.051	0.06 ± 0.097	0.464 ± 0.56	0.88 ± 0.95	1.58 ± 1.73	0.76 ± 1.736	0.357 ± 0.85
Hediste diversicolor	0.03 ± 0	0.19 ± 0.77	1.045 ± 1.158	2.23 ± 1.61	0.46 ± 0.94	2.53 ± 2.59	5.631 ± 4.059	3.011 ± 2.2
Eteone sp.	0.024 ± 0	0.039 ± 0.094	0.037 ± 0.059	0.02 ± 0.03	0.01 ± 0.014	0.0002 ± 0.001	0.513 ± 2.399	0.0002 ± 0.001
Pygospio elegans	0.023 ± 0	0.284 ± 0.204	0.111 ± 0.086	0.22 ± 0.224	0.096 ± 0.14	0.091 ± 0.117	0.131 ± 0.18	0.063 ± 0.1
Crangon crangon	0.020 ± 0	0.103 ± 0.281	0.003 ± 0.007	0.062 ± 0.156	0.08 ± 0.19	0.096 ± 0.163	0.020 ± 0.061	0.03 ± 0.059
Cyathura carinata	0.01 ± 0	0.022 ± 0.058	0.08 ± 0.101	0.104 ± 0.14	0.31 ± 0.33	0.298 ± 0.182	0.337 ± 0.259	0.468 ± 0.366
Insecta	0.01 ± 0	0.002 ± 0.006	0.05 ± 0.17			0.006 ± 0.018	0.003 ± 0.011	
Oligochaeta	0.005 ± 0	0.021 ± 0.05	0.002 ± 0.005	0.0001 ± 0.0004			0.0001 ± 0.001	
Streblospio benedicti	0.005 ± 0	0.001 ± 0.002	0.006 ± 0.007	0.005 ± 0.008	0.001 ± 0.002	0.0003 ± 0.001	0.0001 ± 0.001	0.002 ± 0.01
Nudibranchia	0.003 ± 0		0.0002 ± 0.001					
Aphelochaeta	0.003 ± 0	0.004 ± 0.007	0.014 ± 0.02	0.006 ± 0.009	0.01 ± 0.01	0.012 ± 0.025	0.014 ± 0.027	0.037 ± 0.133
Chironomidae	0.003 ± 0		0.001 ± 0.003	0.008 ± 0.034				
Peringia ulvae	0.001 ± 0		0.080 ± 0.1	0.005 ± 0.022	0.14 ± 0.3	0.065 ± 0.112	0.56 ± 0.67	0.4 ± 0.396
Scrobicularia plana	0.0001 ± 0	0.013 ± 0.051	0.063 ± 0.25	0.468 ± 1.481	0.06 ± 0.14	0.50 ± 0.84	6.357 ± 11.607	16.197 ± 19.86
Abra tenuis								1.17 ± 1.474
Alitta virens			0.14 ± 0.55					
Arenicola sp.				0.0001 ± 0.0002			0.132 ± 0.62	
Arenicola marina								0.438 ± 1.532
Bathyporeia sp.				0.0002 ± 0.001		0.0002 ± 0.001		
Bathyporeia sarsi								
Bivalvia		0.015 ± 0.061					0.11 ± 0.44	0.093 ± 0.448
Carcinus maenas					0.04 ± 0.12		0.724 ± 2.22	0.089 ± 0.19
Caridea								0.001 ± 0.003
Cerastoderma edule					0.0 ± 0.12	0.06 ± 0.28	0.011 ± 0.05	0.13 ± 0.411
Donax vittatus			0.003 ± 0.011					
Ensis sp.								
Gammarus sp.		0.0001 ± 0.001		0.0001 ± 0.0002				
Gastropoda						0.001 ± 0.003		
Grandidierella japonica								0.037 ± 0.09
Hemigrapsus sp.							0.054 ± 0.109	
Isopoda			0.0004 ± 0.0001					
Mya arenaria			0.009 ± 0.037			0.028 ± 0.13	1.51 ± 5.63	
Nephtys caeca								0.015 ± 0.069
Nereidinae								0.008 ± 0.02
Nereis sp.		0.0004 ± 0.002	0.022 ± 0.041	0.007 ± 0.013	0.012 ± 0.02	0.0001 ± 0.001	0.092 ± 0.25	
Pisces								0.002 ± 0.011
Platyhelminthes				0.07 ± 0.2				
Polychaeta		0.001 ± 0.004	0.0004 ± 0.002					
Polydora sp.								0.0001 ± 0.0003
Praunus sp.				0.001 ± 0.002				
Pseudopolydora pulchra		0.001 ± 0.004						
Ruditapes sp.							0.002 ± 0.008	1.27 ± 4.216
Total biomass	**3.31 ± 1**	**5.22 ± 0.62**	**12.05 ± 1.52**	**12.23 ± 1.232**	**8.25 ± 0.897**	**10.84 ± 0.89**	**26.56 ± 2.18**	**28.42 ± 3.195**

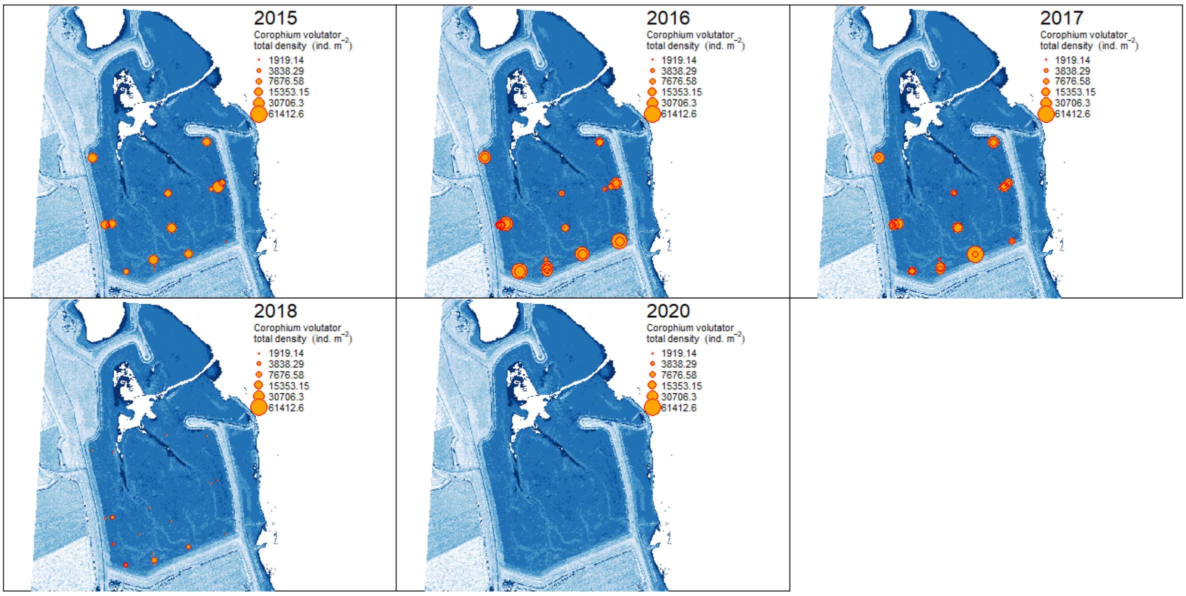


Figure 3.5. Density of *C. volutator* from 2015 to 2020, the latter of which did not contain any of this once-abundant pioneering species at Perkpolder.

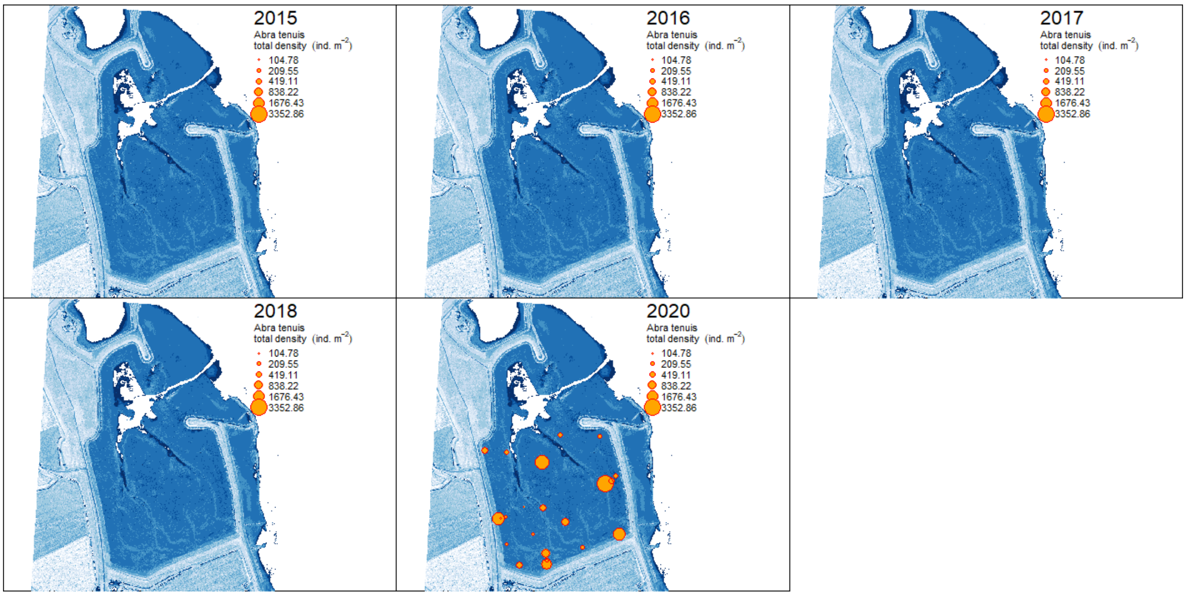


Figure 3.6. Density of the newly-sampled *A. tenuis* from autumn 2020, which was found at all 23 stations.

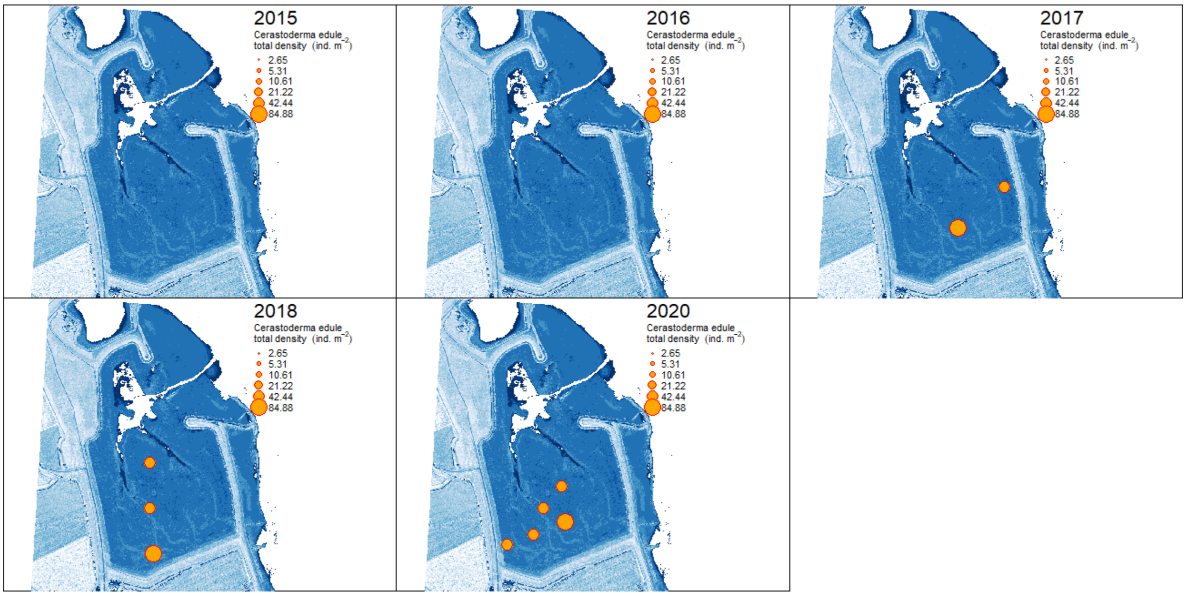


Figure 3.7. Density *C. edule*, which was first sampled at Perkpolder in 2017, and has since been increasing steadily.

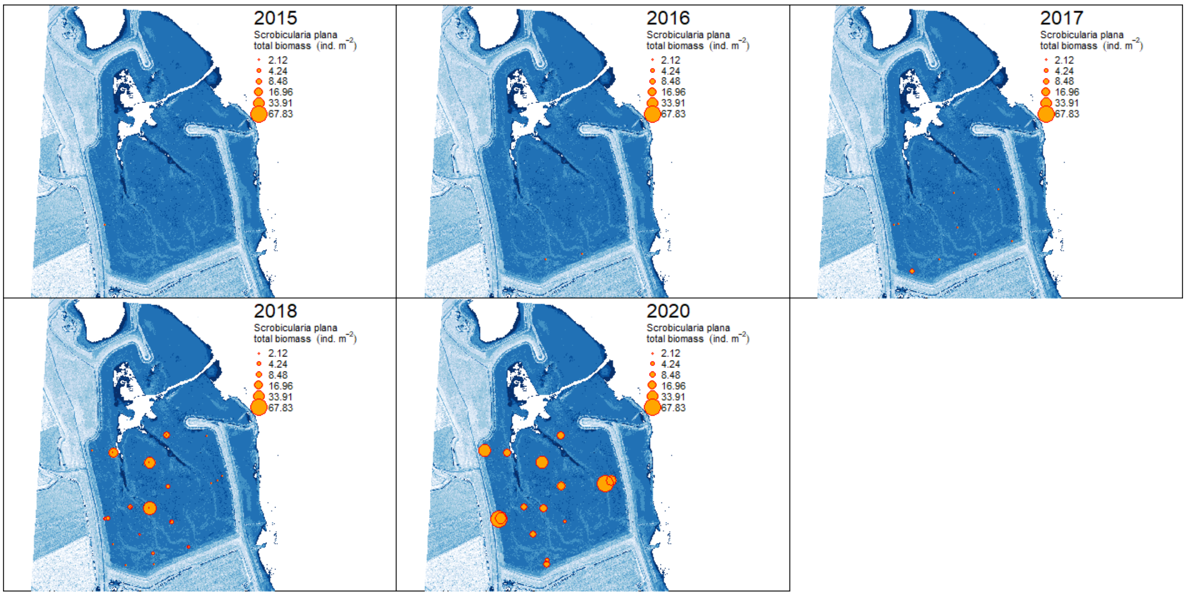


Figure 3.8. Biomass of the bivalve *S. plana*, which constituted more than 50% of the total biomass in autumn 2020.

3.2.2 Sediment characteristics

3.2.2.1 Time series

Sediment samples have been collected from each campaign from phase one of the project, and most recently from September 2020 (first sampling within phase two by WMR). The sediment is characterized through the D_{50} and five grain size fractions. The overall sediment composition at Perkpolder has been and remains very fine sand, with an average D_{50} well under 100 µm. Sandy environments comprising of fine or medium sand is usually on the order of 250 µm D_{50} or more, and often with little to no silt. At Perkpolder, the silt content remains well above 60% (volumetric), showing a considerable increase within the first 1 – 1.5 year after the opening of the dike, followed by either increases or decreases thereafter (Figure 3.9). The changes in the silt fraction at Perkpolder are very much related to the very fine sand fraction, where the two fractions are more-or-less inversely proportional. The other three sediment fractions comprise a very small percentage of the sediment composition, and do not differ signifcantly over time (Figure 3.9).

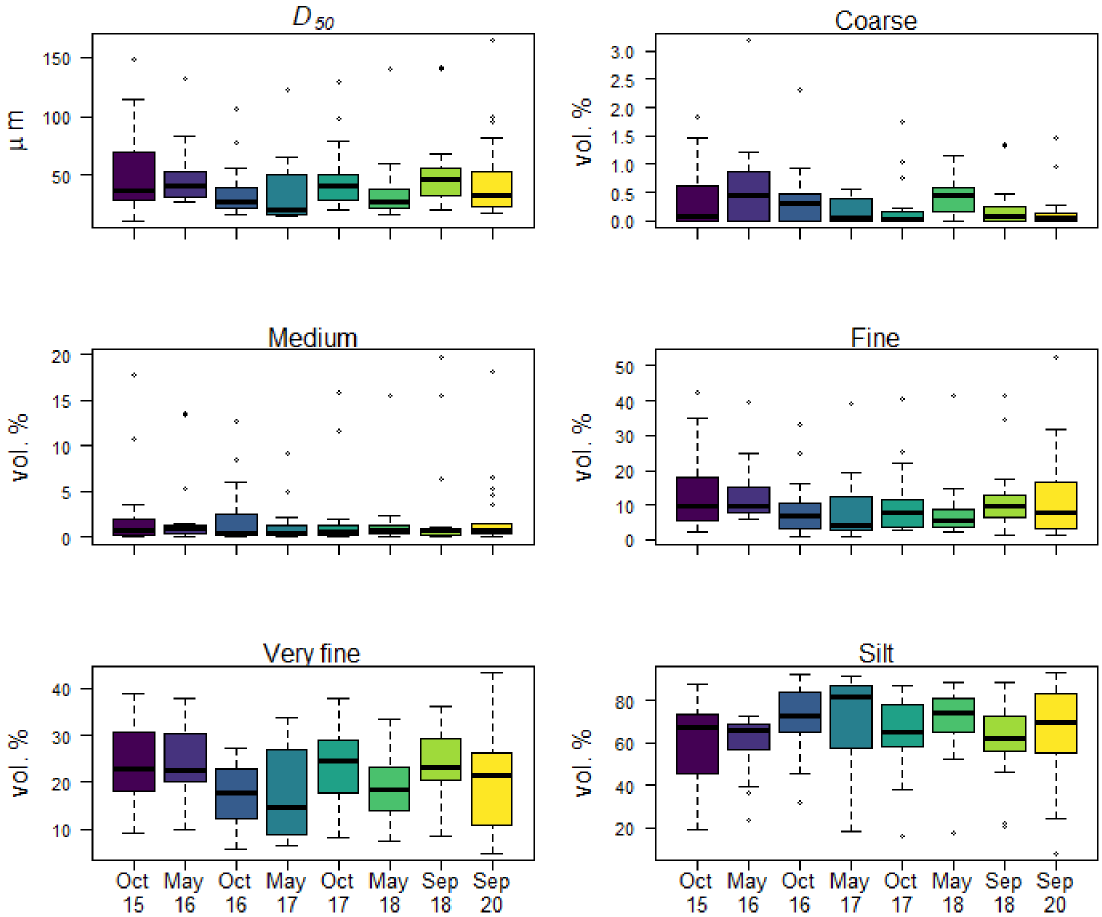


Figure 3.9. Comparison of the D_{50} and five sediment fractions from each of the sampling campaigns.

The bulk density has been measured during each campaign, except in October 2017. There was initially an increase within the first year following the opening of the dike, representing an elevation in sediment compaction during this time. In the second year, the bulk density exhibited a decreasing trend, and was particularly low in May 2017. Another increase was observed in the autumn of the same year. The following year, there was another decrease (both spring and autumn), followed by a slight increase in autumn 2020 (Figure 3.10).

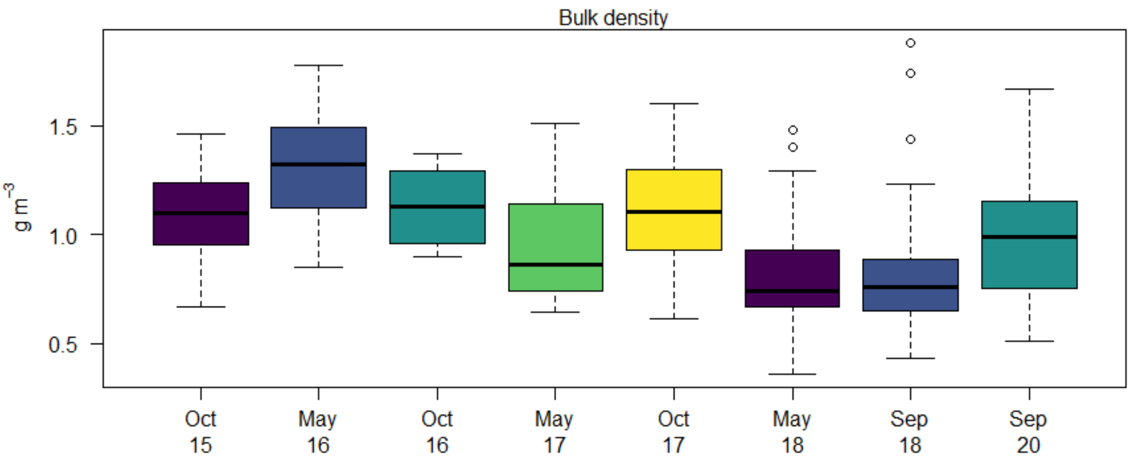


Figure 3.10. Bulk density between each of the sampling campaigns.

The chl *a* data shows fluctuations from spring 2016 to spring 2018, followed by a significant increase since spring 2018, with the highest concentration observed in the latest campaign (autumn 2020) compared to previous measurements (Figure 3.11).

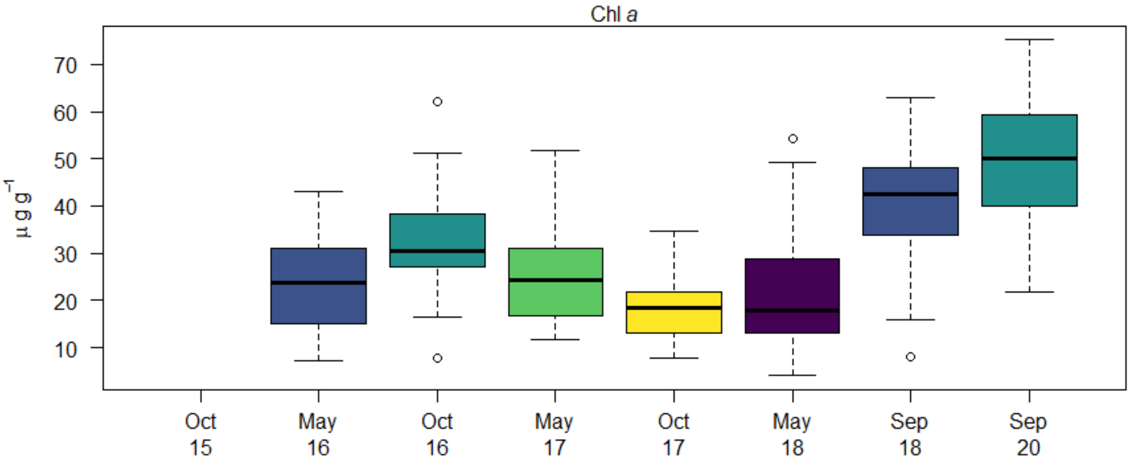


Figure 3.11. The chl *a* concentration over time. Data is not available from the first sampling campaign.

3.2.2.2 Relation to environmental conditions

One of the objectives in this project is to try and link the environmental parameters (sediment characteristics, chl *a* and hydrodynamic conditions) and ongoing changes with the macrobenthic community composition. Here, we focus only the comparison between the benthos and the sediment elevation. The other comparisons will be updated into the final report from this project.

A linear regression has been conducted between the three macrobenthic parameters (species richness, total abundance and total biomass) and the abiotic parameters: bulk density, D_{50}, the five sediment fractions, sediment elevation and chl *a*. Most of the abiotic parameters did not show a significant relation with the three macrobenthic parameters. Compared on the whole (no differentiation between the campaigns), the species richness showed a correlation with the elevation (Figure 3.12; $p < 0.05$). With the total abundance, there was a statistically significant correlation with bulk density in (Figure 3.13; $p < 0.05$). Furthermore, the total biomass showed a correlation with the coarse and silt fractions, as well as the elevation (Figure 3.14; $p < 0.05$), while.

A significant correlation was found between species richness and elevation in autumn 2015 (Figure A1), the bulk density in autumn 2020 (Figure A2). In addition, the total abundance showed a positive correlation with the bulk density in spring 2018 (Figure A3). However, the total biomass showed a significant correlation with the bulk density in spring 2017 and 2018 and autumn 2018, the coarse sand fraction in spring 2017, with the medium sand fraction in autumn 2018, the very fine sand fraction in autumn 2020 and chl *a* in autumn 2018 (Figures A4 to A8).

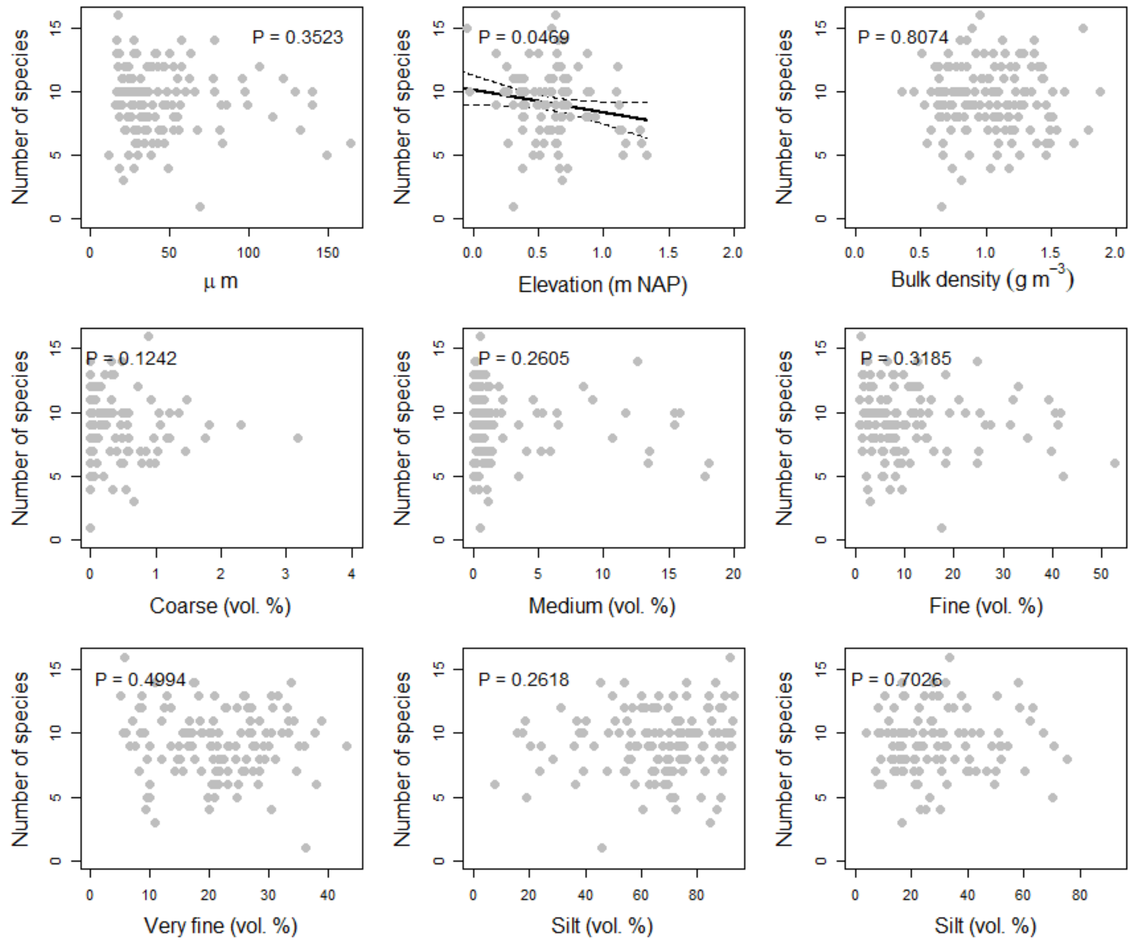


Figure 3.12. The species richness plotted against the abiotic parameters over the entire dataset; the campaigns were not differentiated. Linear regressions are shown where there is a statistically significant correlation between the biotic and abiotic parameter. The dashed lines represent 95% confidence intervals.

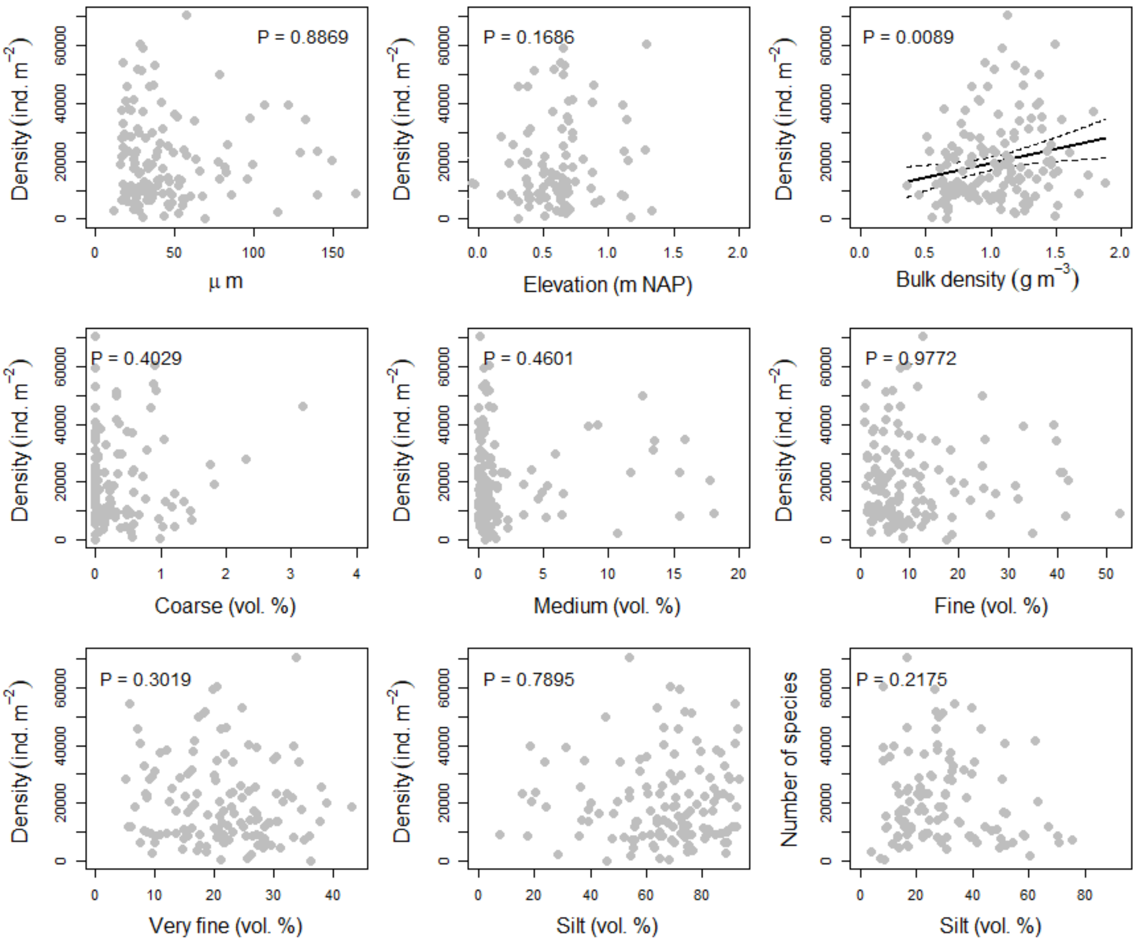


Figure 3.13. The total abundance (density) plotted against the abiotic parameters over the entire dataset; the campaigns were not differentiated. Linear regressions are shown where there is a statistically significant correlation between the biotic and abiotic parameter. The dashed lines represent 95% confidence intervals.

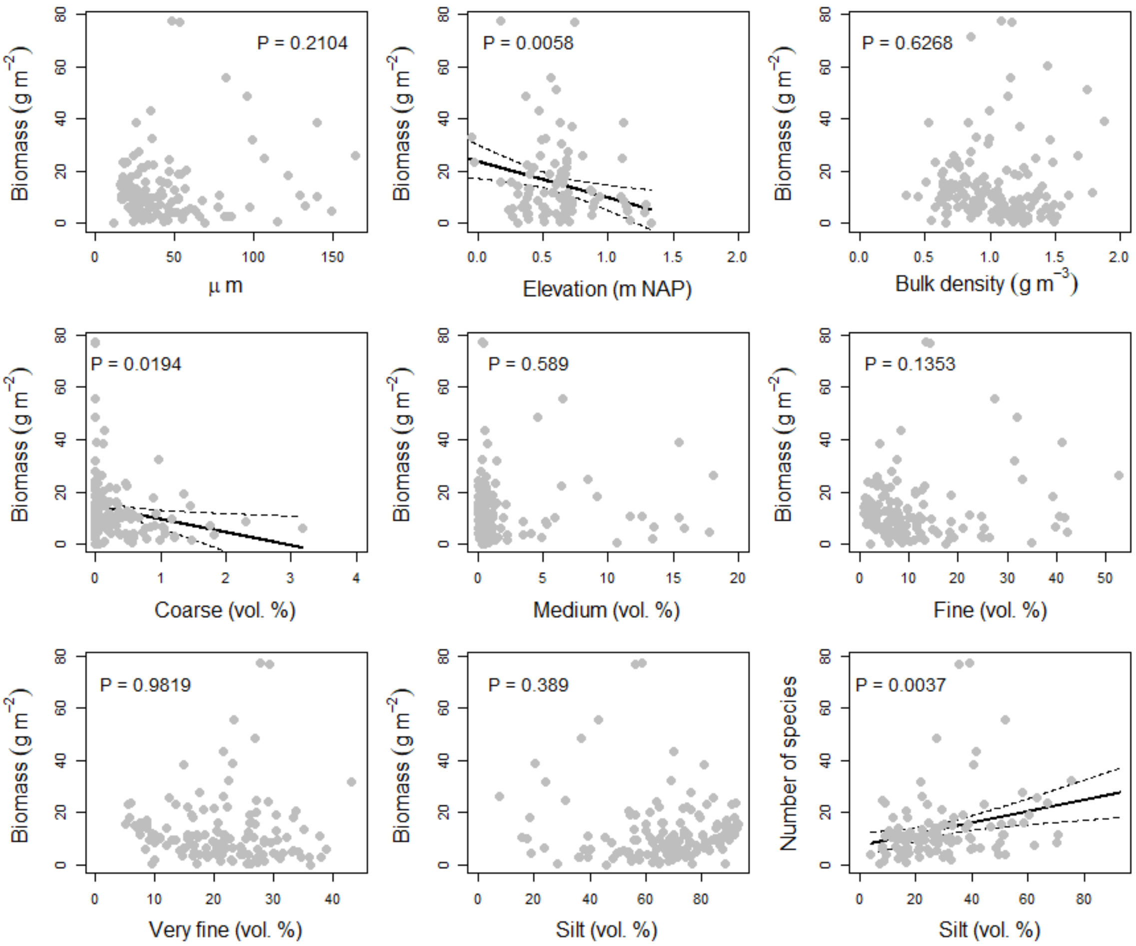


Figure 3.14. The total biomass plotted against the abiotic parameters over the entire dataset; the campaigns were not differentiated. Linear regressions are shown where there is a statistically significant correlation between the biotic and abiotic parameter. The dashed lines represent 95% confidence intervals.

3.2.3 Macrobenthic community structure

It is clear from the multivariate analysis that each campaign exhibits a significantly different macrobenthic community composition; e.g., it continues to shift over time, following the opening of Perkpolder in 2015. Compared to the MWTL dataset (2014 – 2017) from similar habitats in the area, the Perkpolder community appears to have moved closer towards the MWTL, although there are still differences observed. Moreover, the available MWTL dataset does not include the most-recent years, which could mean that newly-samples species from Perkpolder, such as *A. tenuis* and *G. japonica*, might be missed . Nevertheless, the shift from autumn 2018 to autumn 2020 is relatively smaller than before, considering the two-year gap between these campaigns (Figure 3.15).

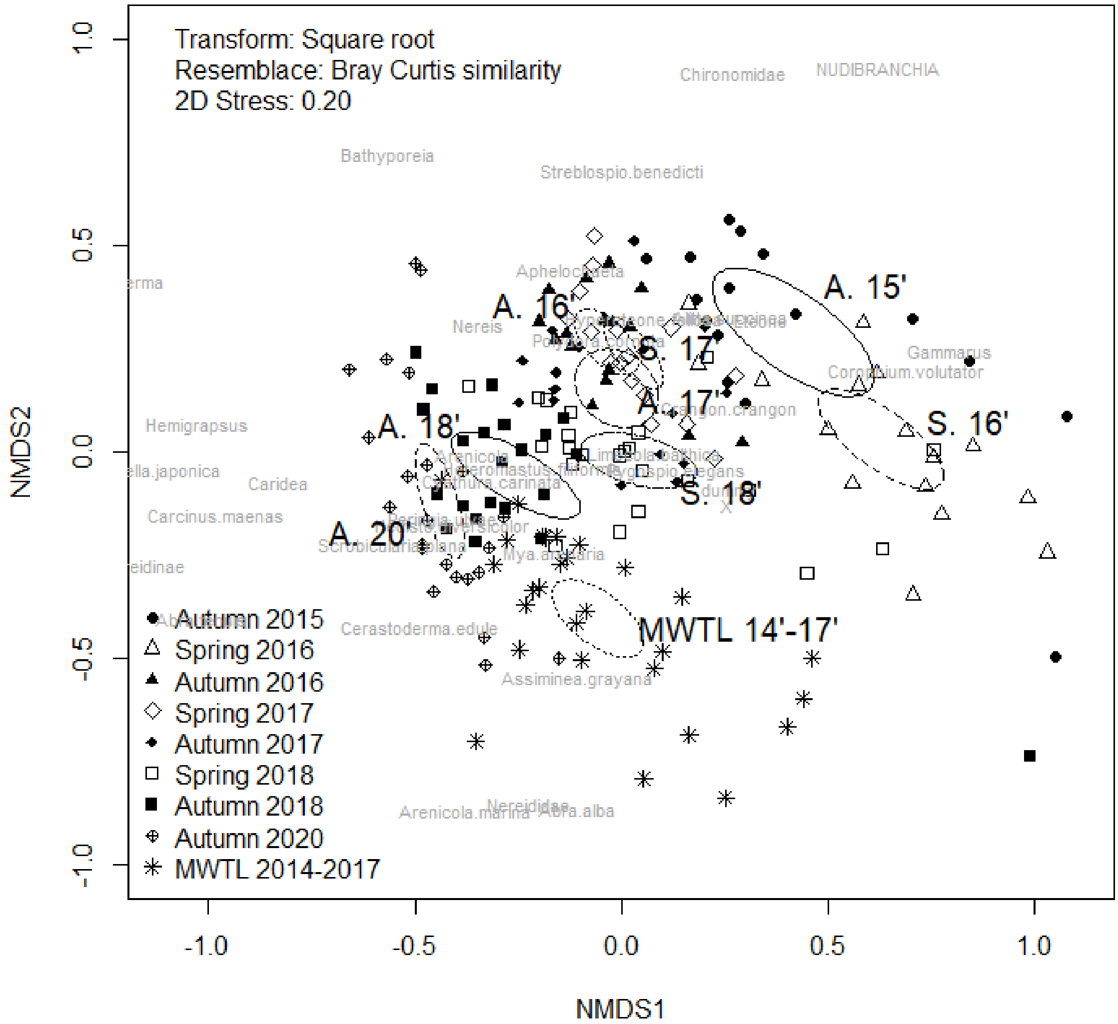


Figure 3.15. An nMDS plot of the benthic community composition over time, from 2015 to 2020, as well as the latest available MWTL (2014 – 2017) data. Each point represents a sampling station. The circular outlines show the 95% confidence intervals for each campaign. The greater the distance between the circles, the larger the differences in community composition. A. = autumn; S. = spring.

3.3 Birds

Over time, the number of benthos-eating bird species observed during low tide are, on average, slightly higher in the period 2019-2020 and 2020-2021 compared to the earlier periods (Figure 3.16). This is particularly the case in the period 2019-2020, where the bird numbers are higher in autumn and winter. However, the number of benthos-eating birds are on average lower again in the period 2020-2021, with the exception of very high numbers in December (Figure 3.16). The most common bird species in Perkpolder are the bar-tailed godwit, black-headed gull, common tern, dunlin, Eurasian curlew, Eurasian wigeon, herring gull, mallard, oystercatcher and shelduck (Figure 3.17). Over the years, the average number of dunlins and oystercatchers per hectare have increased somewhat in numbers (Figures 3.18 and 3.19). Moreover, the number of benthos-eating bird species have only increased in counting blocks 4 and 5 (Figure 3.19).

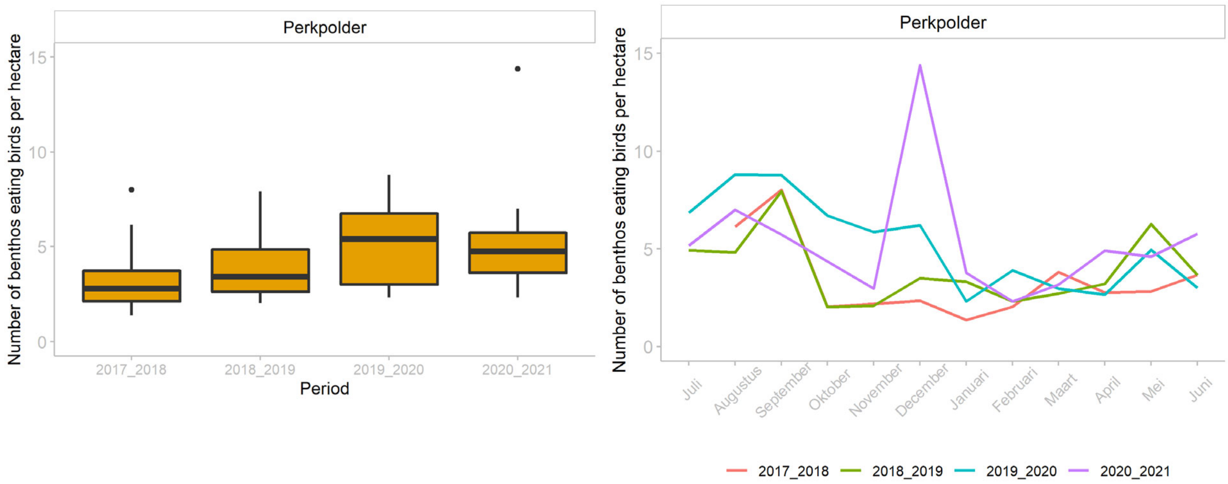


Figure 3.16. The number of benthos-eating bird species per hectare per "bird period" (left) and over months (right).

Figure 3.17. The most common bird species in Perkpolder per "bird period".

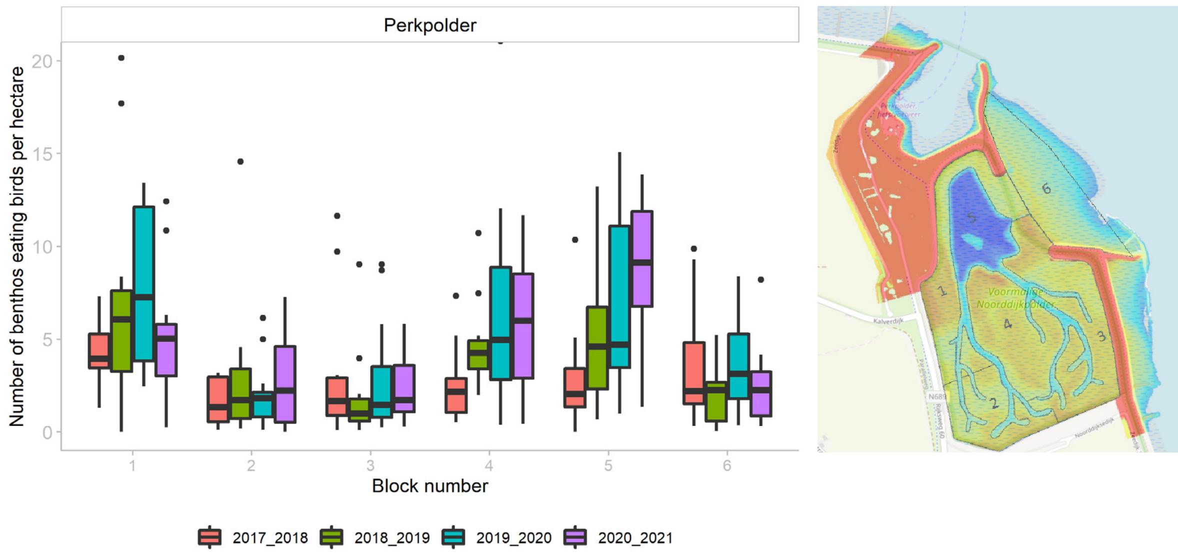


Figure 3.18. The number of benthos-eating bird species per hectare and count block per "bird period".

Figure 3.19. The number of birds per hectare and count block per "bird period". Bird species are divided into different bird categories based on their foraging behavior or morphology.

3.4 Socio-economic aspects

3.4.1 Literature review

The systematic review of the scientific articles resulted in a comprehensive 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, 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.

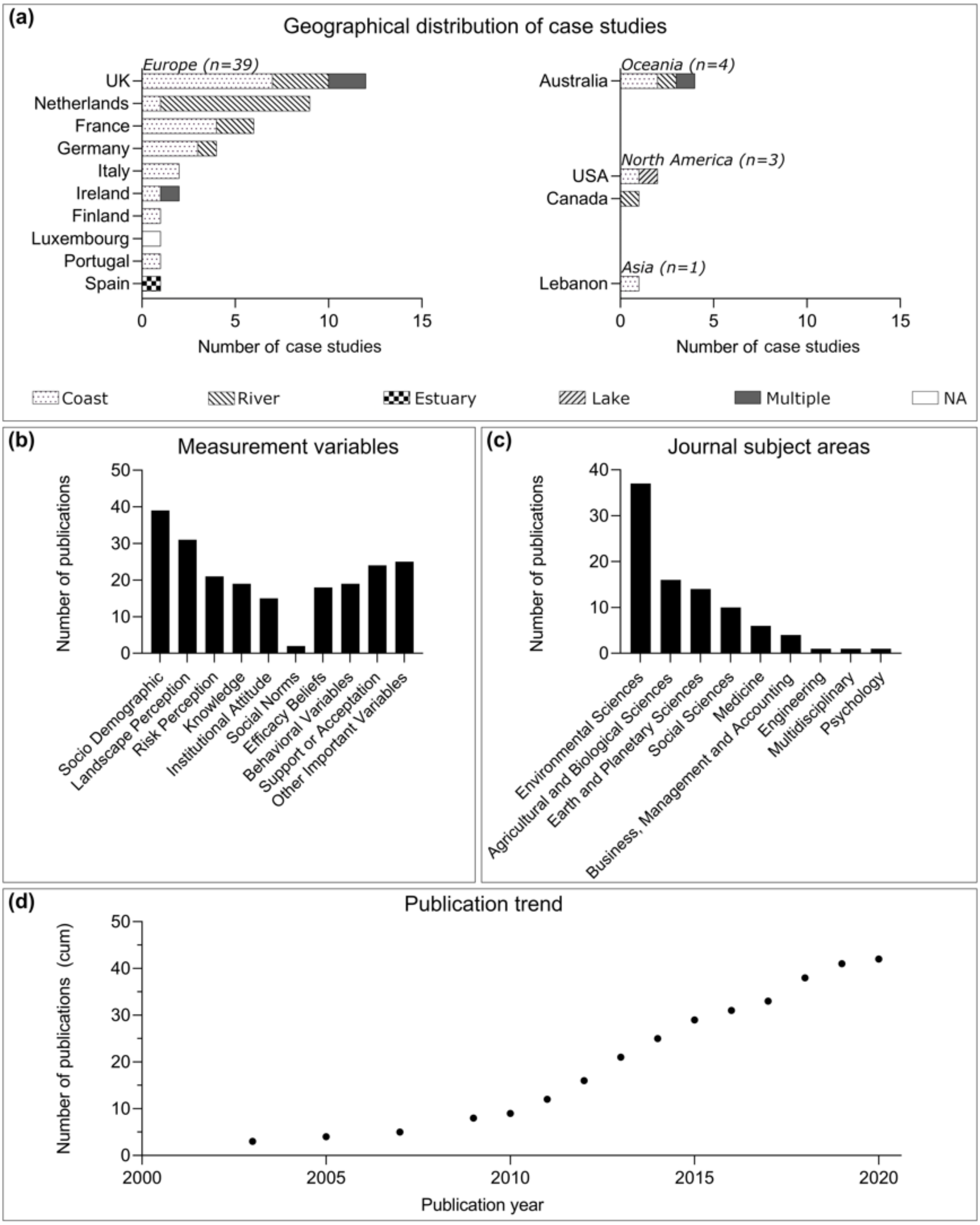


Figure 3.20. Quantitative results from the literature review on social responses to policy-induced landscape transitions, showing the geographical distribution of case studies (a) measurement variables used in the studies (b), subject areas of the journals in which the articles were published (c) and the publication trend (d).

Forty-two publications (or 18% of the publications screened) reported on social responses to policy-induced landscape transitions. These publications included 47 case study locations in total (Figure 3.20a). 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 Room for the River programme (Havinga and Nederlanden 2018).

In each publication, we identified all theoretical concepts and measurement variables which were used to evaluate the social response to landscape transitions. Similar concepts and variables used across the different studies were identified and classified into 10 classes (Figure 3.20b). The measurement variables most commonly employed in the articles included sociodemographic variables, followed by variables related to landscape perception, level of support or acceptance 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 3.20b 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. Notably, in all 8 studies, the 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 fewer 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 about landscape transitions. This is in spite of the large body of evidence showing that social norms could have an important influence on behavior and perceptual processes (e.g. Lo, 2013).

The SCImago Journal & Country Rank database was consulted to define the subject areas of the journals in which the articles were published (Figure 3.20c). 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 3.20c, only one article was published in a journal classified as Psychology. The 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 cumulative number of publications over time is outlined in Figure 3.20d. As shown in the figure, the publication of articles appears to take place at a higher rate from 2010 onward, suggesting that the attention for research on the perception of policy-induced landscape interventions has been increasing over the past decade. However, it should be pointed out that the trend is based on a relatively small sample (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 the consultation with scientific databases such as SCOPUS or Web of Science (which have not been used for the current review) to identify additional articles.

3.4.2 Survey questionnaire

The insights from the literature review were used to conceptualize a survey questionnaire to investigate how the coastal realignment process in the Perkpolder area would be perceived by the nearby community. Table 3.4 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. The main body of the questionnaire was subdivided into two parts. Part 1 contained questions related to the general perception of the landscape around the sea dikes in Zeeland, whereas part 2 focused on the Perkpolder area more specifically, and contained questions about the perception of the coastal realignment intervention and the associated changes of the local landscape. Some of the questions from part 1 and part 2 of the questionnaire are equivalent, which would allow for comparison and differentiation between landscape appreciation at the regional (i.e. Zeeland) and local levels (i.e. Perkpolder).

Table 3.4. 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
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	--

4 Discussion

4.1 Vegetation

Up until 2020, the vegetation development has been rather slow. The number of transplanted patches have remained stable since 2018, and has been slowly but steadily expanding at about 0.2 to 0.3 m per year. But as of 2021 no new recruitment has occurred, only a trivial part of the project area was colonized via this process. However, most recently, in 2021, we have observed Spartina seedlings suddenly establishing on some parts of the tidal flat. The pattern of seedling establishment (Figure 2.2) and the percentage of tides skipped (Figure 3.1) are in agreement, suggesting that even a small fraction of prolonged periods of benign hydrodynamic conditions can already serve as an important WoO for *S. anglica* settlement.

In the areas with vegetation recruitment, just above 0.1% of the time tides are skipped. This suggests that only a small improvement in the amount time that seedlings are not exposed to hydrodynamic conditions is enough to allow for the successful establishment under the sheltered conditions of this site. Thus, it would appear that the area can undergo a quick transformation to a vegetated area once the tidal flat reaches about 1 m NAP due to accretion. This low threshold is in stark contrast to seedling establishment patterns observed on an exposed tidal flat in an estuary (Zuidgors), where seedlings also required a long-enough window of mild wave conditions (Hu et al., 2015). Nevertheless, there are sites along the Western Schelde estuary where Spartina vegetation occurs below 1 m NAP (van Belzen et al., 2017), which suggest that improving the growth conditions can result in establishment at lower intertidal elevations than what is occurring in the Perkpolder project area. Soil conditions, such as the water content and microtopography, might affect the rate at which the establishing seedlings can develop tolerance to the hydrodynamic conditions (Cao et al., 2021; Fivash et al., 2020). Further analysis is needed to see if some of the soil properties might be affecting the growth rates and thereby the critical window size (number of consecutive tides skipped) that is required for the seedlings to establish. This will be the focus in follow up reports.

4.2 Macrobenthic community composition

Since the opening of the dike at Perkpolder in 2015, the area has seen changes in the morphological conditions, partly through the importation of sediment into it. In the previous phase (one) of the project, accretion was observed to have occurred over time, which enhances the protection against floods since the elevated tidal flat can both absorb and attenuate more wave energy. The changes in the sedimentary conditions has presumably been a cause for the changes in the macrobenthic community composition over time. Just months after the opening of the dike, there were already 19 species found. Previous studies, such as in the Tollesbury estuary in the UK (Garbutt et al. 2006), have shown that invertebrate animals tend to only colonize newly accreted sediments within a realignment and that such establishment occurred more slowly where the sediment was more compact. Nevertheless, the species richness continued to increase at Perkpolder, though it has somewhat stabilized at 25 species in autumn 2020.

Now, after 5 years since the dike breach, the overall macrobenthic community composition continues to gradually shift. Especially in autumn 2020, it appears to have moved closer to that from comparable habitats near Perkpolder (MWTL data), with some clear overlaps. Early colonizers such as the mud shrimp *C. volutator* have since disappeared completely in the latest campaign, while several new species have been found (Walles et al. 2019; van de Lageweg et al. 2019; Norkko et al. 2006). The biomass also continues to increase overall, coinciding with the increase in the chl *a* concentrations. It is still possible that the community composition at Perkpolder will sufficiently stabilize within the next few years, which would then be occurring on a relatively quick timescale (years as opposed to decades). We clearly see that the managed realignment area at Perkpolder was relatively quickly transformed into a biologically active intertidal area, but also that it is not yet in equilibrium. Since the first sampling in autumn 2015, the benthic community has been continuing to develop towards the communities found on nearby tidal flats from the MWTL surveys.

Moreover, the macrobenthic organisms that live in the intertidal zone need to be able to withstand a wide range of abiotic conditions and environmental disturbances, such as changes in the sediment conditions, as well as constant sediment erosion and accretion. For example, while the bulk density initially increased within the first year after the dike breach, it has since decreased to the levels from the first sampling campaign and has remained stable over the last few years. Global climate change is expected to increase environmental disturbances, such as storms, which would create greater extremes in sediment dynamics. The initial comparisons between the macrobenthic parameters (species richness, total abundance and biomass) and the abiotic parameters show some promising results, even though many of the parameters do not appear to show a strong correlation. Further analyses will be undertaken to try and identify the most-relevant relationships in order to explain the community compositional patterns, including through multiple linear regression and multivariate comparisons to try and determine how strong the relationships are and what the main explanations might be. Additional measurements such as soil erosion resistance, the mud layer depth and the penetration resistance of the sediment will also be used in the comparisons when the results become available.

4.3 Birds

Benthos-eating and other bird species have increased somewhat over time during low tide, after the introduction of tides into Perkpolder. The increase in bird numbers are most clearly seen in the period 2019-2020; in this period bird numbers are higher in autumn and winter. The number of benthos-eating birds are on average lower again in the period 2020-2021 compared to the previous period, with the exception of very high numbers in December. Among the most common bird species, dunlins and oystercatchers have increased in numbers over time. These birds are benthos-eating species which are commonly foraging on intertidal flats. However, an increase in benthos-eating bird species is only seen in counting block 4 and 5. Counting block 4 consists of a relatively large intertidal area and block 5 consists partly out of a small pond. An increase in these bird species might be correlated to the abiotic and biotic conditions there. In future studies, a comparison between fluctuations in bird numbers and their benthic prey species will be done.

The second phase of the Perkpolder project builds upon the previous project by allowing us to continue monitoring both the biotic (e.g., benthic macrofauna and birds), the abiotic characteristics (grain size distribution, bulk density, sediment elevation and chl *a*), the hydrodynamic conditions and associated sediment transport and also the socio-economic aspects from the local community and how the project is generally viewed. It is important to understand how newly-flooded coastal areas will develop over time, as well as the local attitudes about these managed realignment projects so that we can continue to implement coastal management as effectively as possible in the future.

5 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. This certificate is valid until 15 December 2021. The organisation has been certified since 27 February 2001. The certification was issued by DNV GL.

References

Aminot, A. & F. Rey (2000). Standard procedure for the determination of chlorophyll a by spectroscopic methods. International Council for the Exploration of the Sea. ISSN 0903-2606.

Balke, T., Bouma, T. J., Horstman, E. M., Webb, E. L., Erftemeijer, P. L., & P. M. Herman (2011). Windows of opportunity: thresholds to mangrove seedling establishment on tidal flats. *Marine Ecology Progress Series*, *440*, 1-9.

Balke, T., Herman, P. M. J., & T. J. Bouma (2014). Critical transitions in disturbance-driven ecosystems: identifying W indows of O pportunity for recovery. *Journal of Ecology*, *102*(3), 700-708.

Bicchieri, C. (2016). Norms in the wild: How to diagnose, measure, and change social norms. Oxford University Press.

Bouma, H., D.J. de Jong, F. Twisk & K. Wolfstein (2005). "Zoute wateren EcotopenStelsel (ZES.1): Voor het in kaart brengen van het potentiële voorkomen van levensgemeenschappen in zoute en brakken rijkswateren", RIKZ rapport 2005.024, Middelburg.

Bouma, T. J., Friedrichs, M., Van Wesenbeeck, B. K., Temmerman, S., Graf, G., & P. M. J. Herman (2009). Density-dependent linkage of scale-dependent feedbacks: A flume study on the intertidal macrophyte Spartina anglica. *Oikos*, *118*(2), 260-268.

Bouma, T. J., van Belzen, J., Balke, T., Zhu, Z., Airoldi, L., Blight, A. J., ... & P. M. J. Herman (2014). Identifying knowledge gaps hampering application of intertidal habitats in coastal protection: Opportunities & steps to take. *Coastal Engineering*, *87*, 147-157.

Bouma, T. J., van Belzen, J., Balke, T., van Dalen, J., Klaassen, P., Hartog, A. M., ... & P. M. J. Herman (2016). Short-term mudflat dynamics drive long-term cyclic salt marsh dynamics. *Limnology and Oceanography*, *61*(6), 2261-2275.

Brehm, J.M., Eisenhauer, B.W., & R. C. Stedman (2013). Environmental concern: examining the role of place meaning and place attachment. Society & Natural Resources 26, 522-538.

Brown, B. B. & D. D. Perkins (1992). Disruptions in place attachment, Place attachment. Springer, pp. 279-304.

Brown, G., & C. M. Raymond (2007). The relationship between place attachment and landscape values: Toward mapping place attachment. Applied geography 27, 89-111.

Brown, G., Raymond, C.M. & J. Corcoran (2015). Mapping and measuring place attachment. Applied geography 57, 42-53.

Cao, H., Zhu, Z., van Belzen, J., Gourgue, O., van de Koppel, J., Temmerman, O. S., ... & T. J. Bouma (2021). Salt marsh establishment in poorly consolidated muddy systems: effects of surface drainage, elevation, and plant age. *Ecosphere*, *12*(9), e03755.

Craeymeersch, J., & V. Escaravage (2014). Perceel Benthos. PMR Monitoring natuurcompensatie Voordelta. Eindrapport 1e fase 2009-2013 deel B. . In: T. Prins and G. van der Kolff. Delft D (ed) Deltares rapport 1200672-ZKS-0043.

Craft, C., J. Sacco (2003). Long-term succession of benthic infauna communities on constructed *Spartina alterniflora* marshes. *Marine Ecology Progress Series* **257**: 45-58.

De Vries, S., Buijs, A.E., Langers, F., Farjon, H., van Hinsberg, A. & F. J. Sijtsma (2013). Measuring the attractiveness of Dutch landscapes: Identifying national hotspots of highly valued places using Google Maps. Applied geography 45, 220-229.

Esteves, L.S. & K. Thomas (2014). Managed realignment in practice in the UK: results from two independent surveys. Journal of Coastal Research, 407-413.

Esteves, L.S. (2014). Managed realignment: a viable long-term coastal management strategy? Springer Briefs in Environmental Science. Springer, New York, pp. 1–139. http://dx.doi.org/10.1007/978-94-017-9029-1.

Fagherazzi, S., Kirwan, M. L., Mudd, S. M., Guntenspergen, G. R., Temmerman, S., D'Alpaos, A., ... & J. Clough (2012). Numerical models of salt marsh evolution: Ecological, geomorphic, and climatic factors. *Reviews of Geophysics*, *50*(1).

Fivash, G. S., van Belzen, J., Temmink, R. J., Didderen, K., Lengkeek, W., Heide, T. V. D. & T. J. Bouma (2020). Elevated micro-topography boosts growth rates in Salicornia procumbens by amplifying a tidally driven oxygen pump: implications for natural recruitment and restoration. *Annals of botany*, *125*(2), 353-364.

Fivash, G. S., Temmink, R. J., D’Angelo, M., van Dalen, J., Lengkeek, W., Didderen, K., ... & T. J. Bouma (2021). Restoration of biogeomorphic systems by creating windows of opportunity to support natural establishment processes. *Ecological Applications*, *31*(5).

Garbutt R.A., C.J. Reading, M. Wolters, A.J. Gray & P. Rothery (2006). Monitoring the development of intertidal habitats on former agricultural land after the managed realignment of coastal defences at Tollesbury, Essex, UK. *Marine Pollution Bulletin* **53**: 155-164.

Goeldner-Gianella, L., Bertrand, F., Oiry, A. & D. Grancher (2015). Depolderisation policy against coastal flooding and social acceptability on the French Atlantic coast: The case of the Arcachon Bay. Ocean & Coastal Management 116, 98-107.

Gourgue, O., van Belzen, J., Schwarz, C., Vandenbruwaene, W., Vanlede, J., Belliard, J. P., ... & S. Temmerman (2021). Biogeomorphic modeling to assess resilience of tidal marsh restoration to sea level rise and sediment supply. *Earth Surface Dynamics Discussions*, 1-38.

Havinga, R. & H. d. Nederlanden (2018). Ruimte voor de Rivier, Oogst ruimtelijke kwaliteit. Planologische kernbeslissing Ruimte voor de Rivier (deel 4). Nota van Toelichting, M.v.V. Ministerie van VenW, Ministerie van LNV, 2007.”

Hu, Z., van Belzen, J., van Der Wal, D., Balke, T., Wang, Z. B., Stive, M. & T. J. Bouma (2015). Windows of opportunity for salt marsh vegetation establishment on bare tidal flats: The importance of temporal and spatial variability in hydrodynamic forcing. *Journal of Geophysical Research: Biogeosciences*, *120*(7), 1450-1469.

Jacobs, M.H. & A. E. Buijs (2011). Understanding stakeholders' attitudes toward water management interventions: Role of place meanings. Water Resources Research 47.

Jones, C. G., J. H. Lawton & M. Shachak (1997). Positive and Negative Effects of Organisms as Physical Ecosystem Engineers. America (NY). **78**: 1946–1957. doi:10.1890/0012-9658(1997)078[1946:PANEOO]2.0.CO;2

Jones, N. & J. R. Clark (2014). Social capital and the public acceptability of climate change adaptation policies: a case study in Romney Marsh, UK. Climatic Change 123, 133-145.

Kirwan, M. L., Guntenspergen, G. R., D'Alpaos, A., Morris, J. T., Mudd, S. M. & S. Temmerman (2010). Limits on the adaptability of coastal marshes to rising sea level. *Geophysical research letters*, *37*(23).

Kristensen, E., G. Penha-Lopes, M. Delefosse, T. Valdemarsen, C. O. Quintana & G. T. Banta (2012). What is bioturbation? the need for a precise definition for fauna in aquatic sciences. Mar. Ecol. Prog. Ser. **446**: 285–302. doi:10.3354/meps09506

Levin L.A., D. Talley & G. Thayer (1996). Succession of macrobenthos in a created salt marsh. *Marine Ecology Progress Series* **141**: 67-82.

Lo, A.Y. (2013). The role of social norms in climate adaptation: Mediating risk perception and flood insurance purchase. Global Environmental Change 23, 1249-1257.

McCave, I. N., R. J. Bryant, H. F. Cook & C. A. Coughanowr (1986). Evaluation of a laser-**147 |** Page diffraction-size analyzer for use with natural sediments. J. Sediment. Res. **56**: 561–564. doi:10.1306/212F89CC-2B24-11D7-8648000102C1865D

M. Elliott (2007). Physical and biological development of a newly
breached managed realignment site, Humber estuary, UK. *Marine Pollution Bulletin* **55**: 564-578.

McKinley, E., Pages, J.F., Ballinger, R.C. & N. Beaumont (2020). Forgotten landscapes: Public attitudes and perceptions of coastal saltmarshes. Ocean & Coastal Management 187, 105117.

Meysman, F. J. R., J. J. Middelburg & C. H. R. Heip (2006). Bioturbation: a fresh look at Darwin's last idea. Trends Ecol. Evol. **21**: 688–695. doi:10.1016/j.tree.2006.08.002Mazik, K., J.E. Smith, A. Leighton,

Moseman S.M., L.A. Levin, C. Currin & C. Forder (2004). Colonization, succession, and nutrition of macrobenthic assemblages in a restored wetland at Tijuana Estuary, California. *Estuarine Coastal Shelf Science* **60**: 755-770.

Myatt, L., Scrimshaw, M. & Lester (2003). Public perceptions and attitudes towards a current managed realignment scheme: Brancaster West Marsh, North Norfolk, UK. Journal of Coastal Research, 278-286.

Nieuwe exoot: Japanse vlokreeftjes in het Noordzeekanaal (2018). Nature Today. https://www.naturetoday.com/intl/nl/nature-reports/message/?msg=24294

Norkko, A., R. Rosenberg, S. F. Thrush and R. B. Whitlatch (2006). Scale- and intensity-dependent disturbance determines the magnitude of opportunisitc response. Journal of Experimental Marine Biology and Ecology 330, 195-207.

Oksanen J, F.G. Blanchet, M. Friendly, R. Kindt, P. Legendre, D. McGlinn, P.R. Minchin, R.B. O'Hara, G.L. Simpson, P. Solymos, M.H.H. Stevens, E. Szoecs & H. Wagner (2018). Vegan: community ecology package. R package version 2.5-3

R core Team (2020). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria Ratter, B.M., Gee, K. (2012) Heimat–a German concept of regional perception and identity as a basis for coastal management in the Wadden Sea. Ocean & Coastal Management 68, 127-137.

Rees, H. L., J. D. Eggleton, E. Rachor & others (2007). The ICES North Sea Benthos Project 2000: aims, outcomes and recommendations. Ices Cm 2007/a:21. 1–22

Reiss, H., S. Degraer, G. C. A. Duineveld & others. (2010). Spatial patterns of infauna, epifauna, and demersal fish communities in the North Sea. ICES J. Mar. Sci. J. du Cons. 67: 278–293. doi:10.1093/icesjms/fsp253

Roca, E. & M. Villares (2012). Public perceptions of managed realignment strategies: the case study of the Ebro Delta in the Mediterranean basin. Ocean & Coastal Management 60, 38-47.

Rojas, O., Zamorano, M., Saez, K., Rojas, C., Vega, C., Arriagada, L. & C. Basnou (2017). Social perception of ecosystem services in a coastal wetland post-earthquake: A case study in Chile. Sustainability 9, 1983.

Schmidt, L., Gomes, C., Guerreiro, S. & T. O'Riordan (2014). Are we all on the same boat? The challenge of adaptation facing Portuguese coastal communities: Risk perception, trust-building and genuine participation. Land Use Policy 38, 355-365.

Schwarz, C., Gourgue, O., van Belzen, J., Zhu, Z., Bouma, T. J., van De Koppel, J., ... & S. Temmerman (2018). Self-organization of a biogeomorphic landscape controlled by plant life-history traits. *Nature Geoscience*, *11*(9), 672-677.

Snelgrove, P. V. R. (1998). The biodiversity of macrofaunal organisms in marine sediments. Biodivers. Conserv. 7: 1123–1132. doi:10.1023/A:1008867313340

Soetaert, K. & P. M. J. Herman (1995). Estimating estuarine residence times in the Westerschelde (The Netherlands) using a box model with fixed dispersion coefficients. *Hydrobiologia* **311**, 215–224.

Temmerman, S., Bouma, T. J., van de Koppel, J., van der Wal, D., de Vries, M. B. & P. M. J. Herman (2007). Vegetation causes channel erosion in a tidal landscape. *Geology*, *35*(7), 631-634.

van Belzen, J., van De Koppel, J., Kirwan, M. L., van Der Wal, D., Herman, P. M., Dakos, V., ... & T. J. Bouma (2017). Vegetation recovery in tidal marshes reveals critical slowing down under increased inundation. *Nature Communications*, *8*(1), 1-7.

van de Lageweg, W. I., J. N. Salvador de Paiva, L. de Vet, J. J. van der Werf, P. de Louw, M. Visser, S. Galvis Rodriguez, B. Walles, T. J. Bouma & T. J. W. Ysebaert (2019). Perkpolder Tidal Restoration: Final Report, Centre of Expertise Delta Technology

van de Vijsel, R. C., van Belzen, J., Bouma, T. J., van der Wal, D. & J. van de Koppel (2021). Algal-Induced Biogeomorphic Feedbacks Lay the Groundwork for Coastal Wetland Development. *Journal of Geophysical Research: Biogeosciences*, e2021JG006515.

Verbrugge, L. & R. van den Born (2018). The role of place attachment in public perceptions of a re-landscaping intervention in the river Waal (The Netherlands). Landscape and Urban Planning 177, 241-250.

Walles, B., E. Brummelhuis, J. van der Pool, L. Wiesebron and T. Ysebaert (2019). Development of benthos and birds in an intertidal area created for coastal defence (Scheldt estuary, the Netherlands). Wageningen University & Research report.

Wood, S. (2021). mgcv: Mixed GAM Computation Vehicle with Automatic Smoothness Estimation, available at: https://cran.r-project.org/web/packages/mgcv/index.html

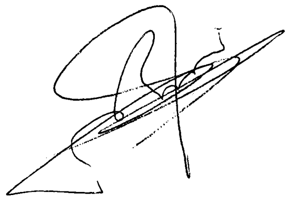
Zhu, Z., van Belzen, J., Zhu, Q., van de Koppel, J. & T. J. Bouma (2020). Vegetation recovery on neighboring tidal flats forms an Achilles' heel of saltmarsh resilience to sea level rise. *Limnology and Oceanography*, *65*(1), 51-62.

Report C097/21
Project Number: 4313100125

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

Approved: Dr. J.A.M. Craeymeersch
Colleague scientist

Signature:



Date: December 1, 2021

Approved: Drs. J. Asjes
Manager Integration

Signature:

Date: December 2, 2021

Annex 1 Title annex

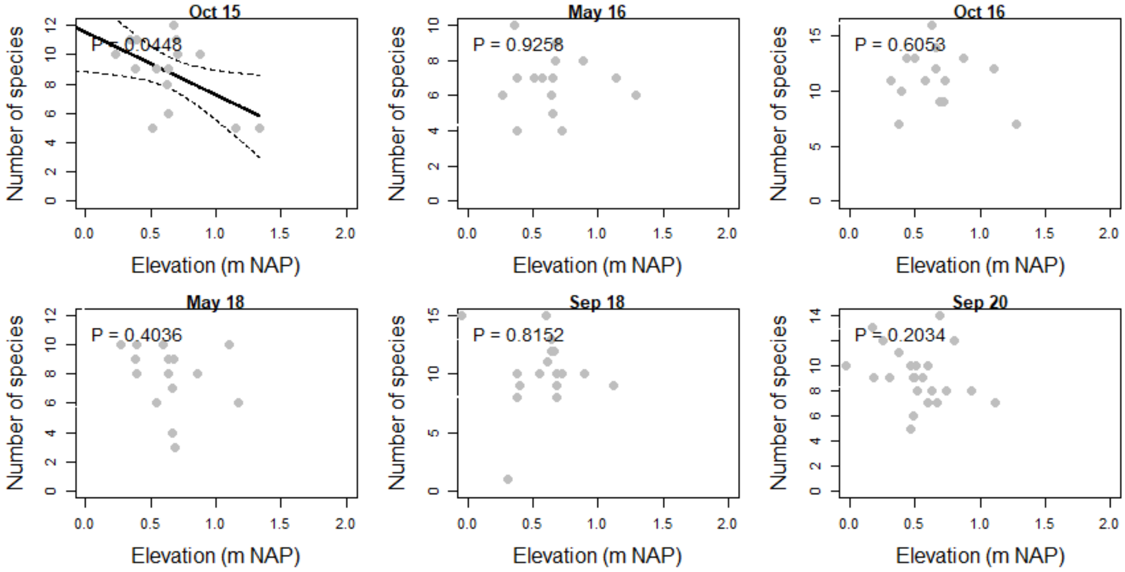


Figure A1. The total number of species plotted against elevation. Linear regression only shown when significantly correlated. The dashed lines represent 95% confidence intervals.

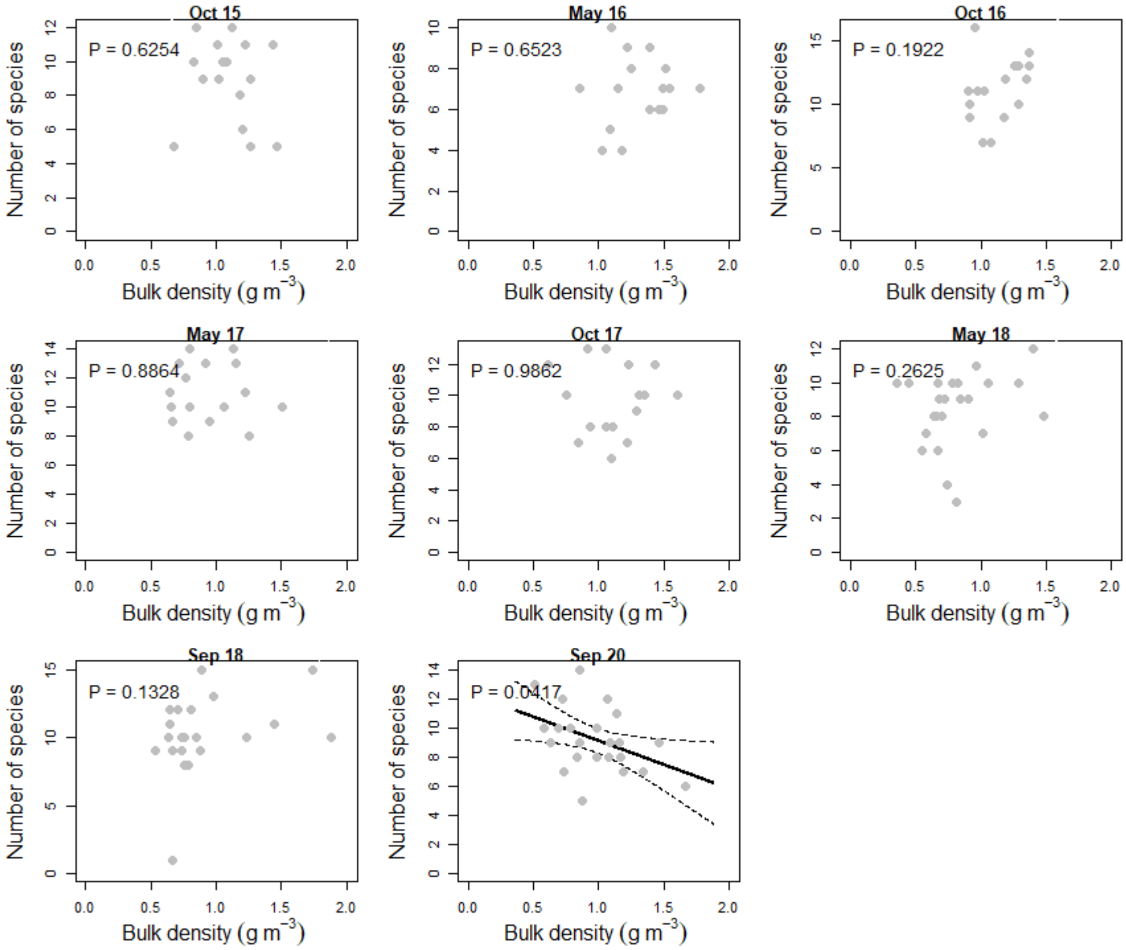


Figure A2. The total number of species plotted against bulk density. Linear regression only shown when significantly correlated. The dashed lines represent 95% confidence intervals.

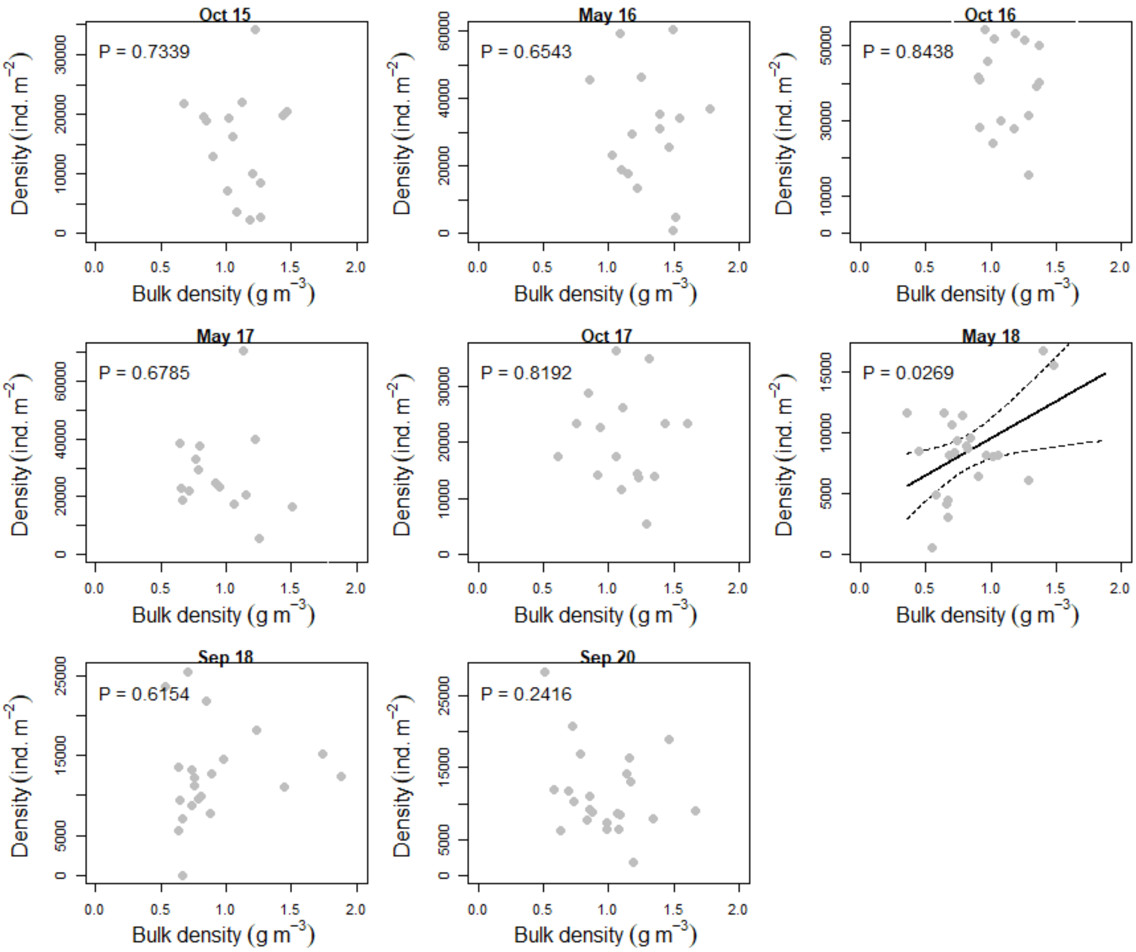


Figure A3. The total abundance plotted against the bulk density. Linear regression only shown when significantly correlated. The dashed lines represent 95% confidence intervals.

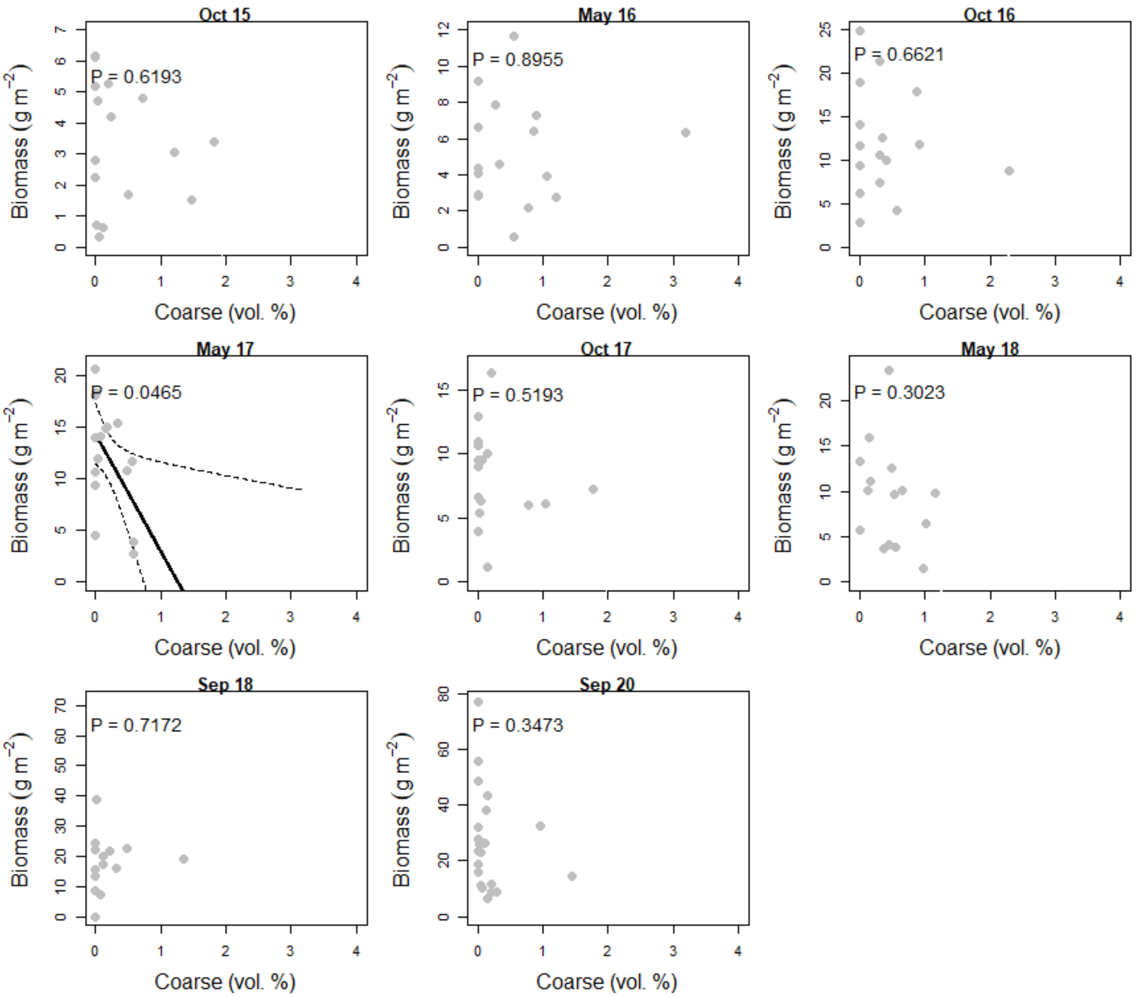


Figure A4. The total biomass plotted against the coarse sand fraction. Linear regression only shown when significantly correlated. The dashed lines represent 95% confidence intervals.

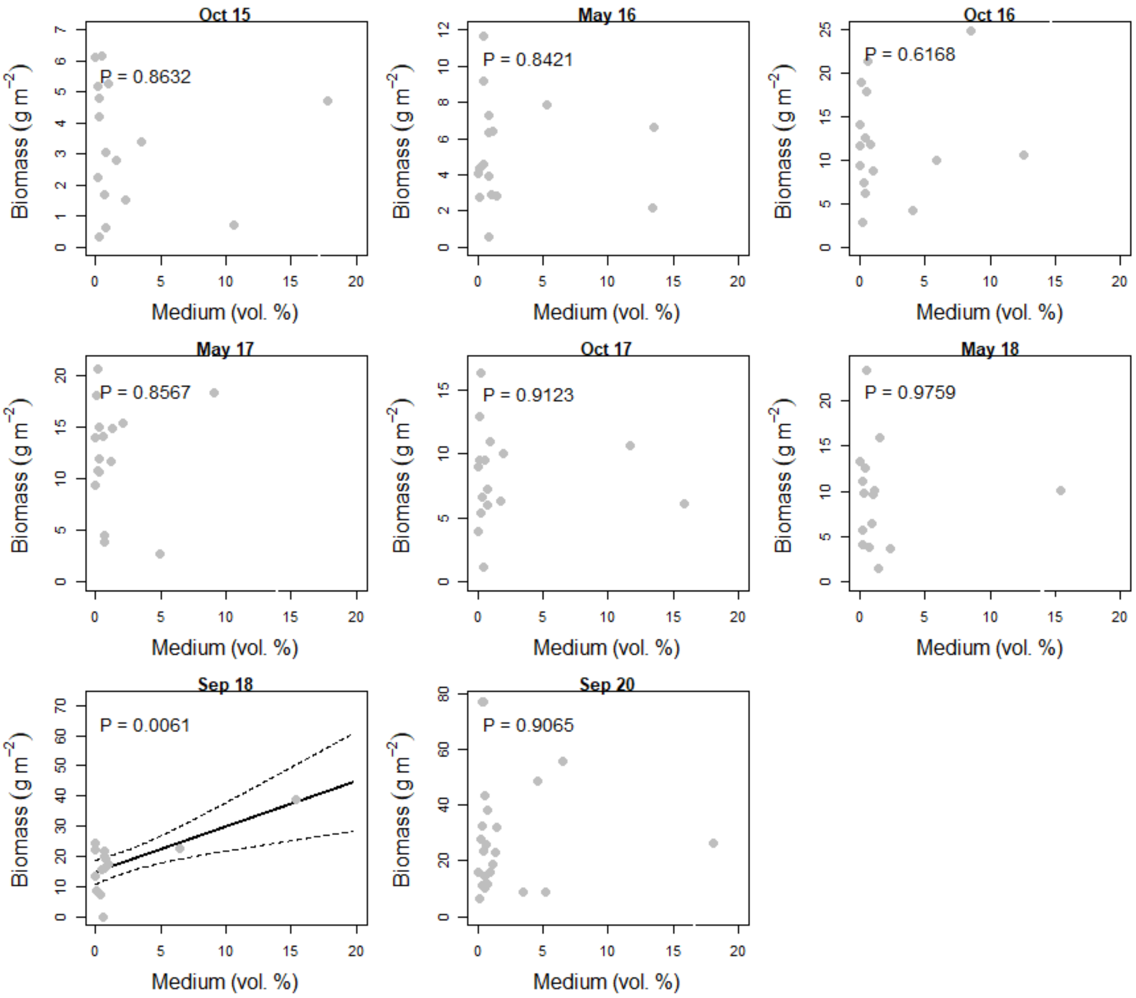


Figure A5. The total biomass plotted against the medium sand fraction. Linear regression only shown when significantly correlated. The dashed lines represent 95% confidence intervals.

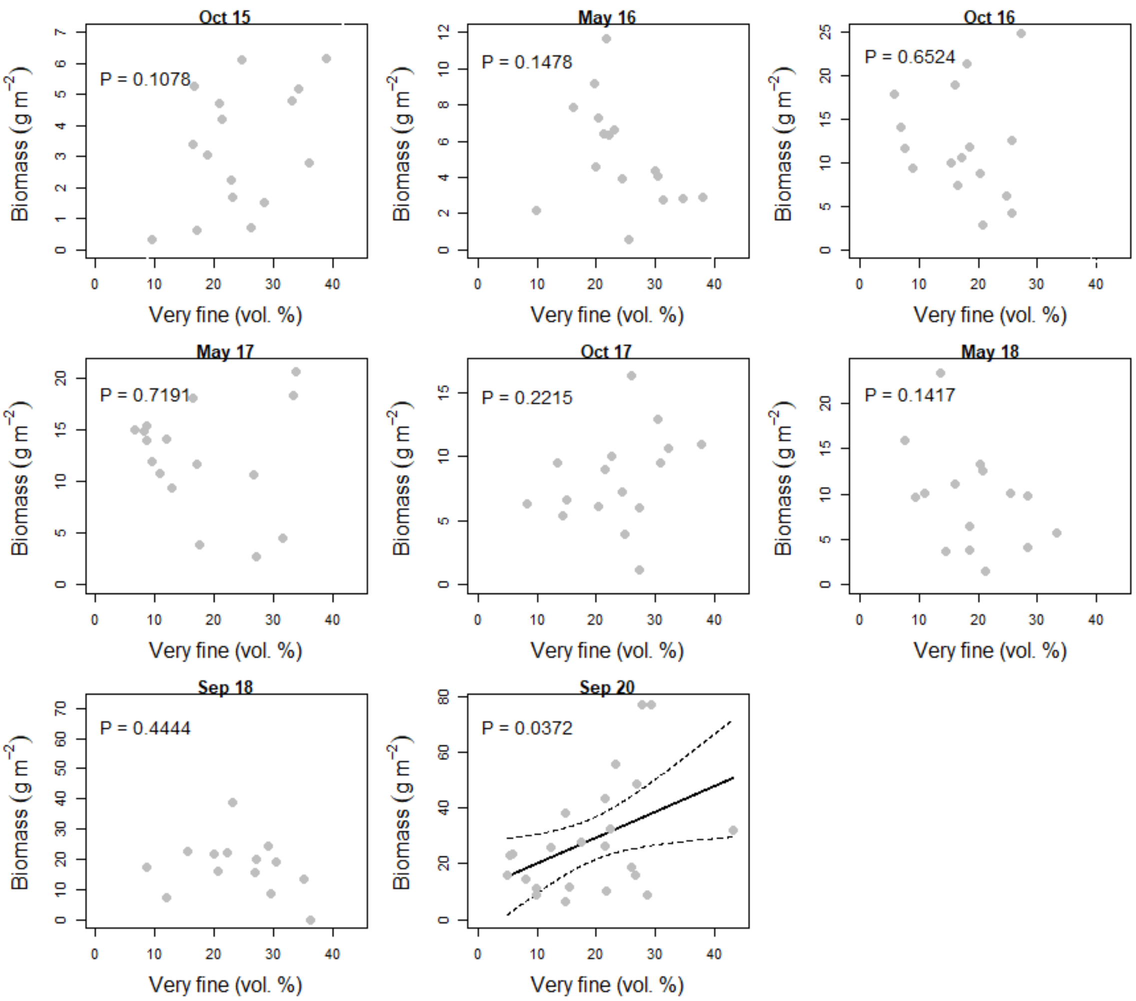


Figure A6. The total biomass plotted against the very fine sand fraction. Linear regression only shown when significantly correlated. The dashed lines represent 95% confidence intervals.

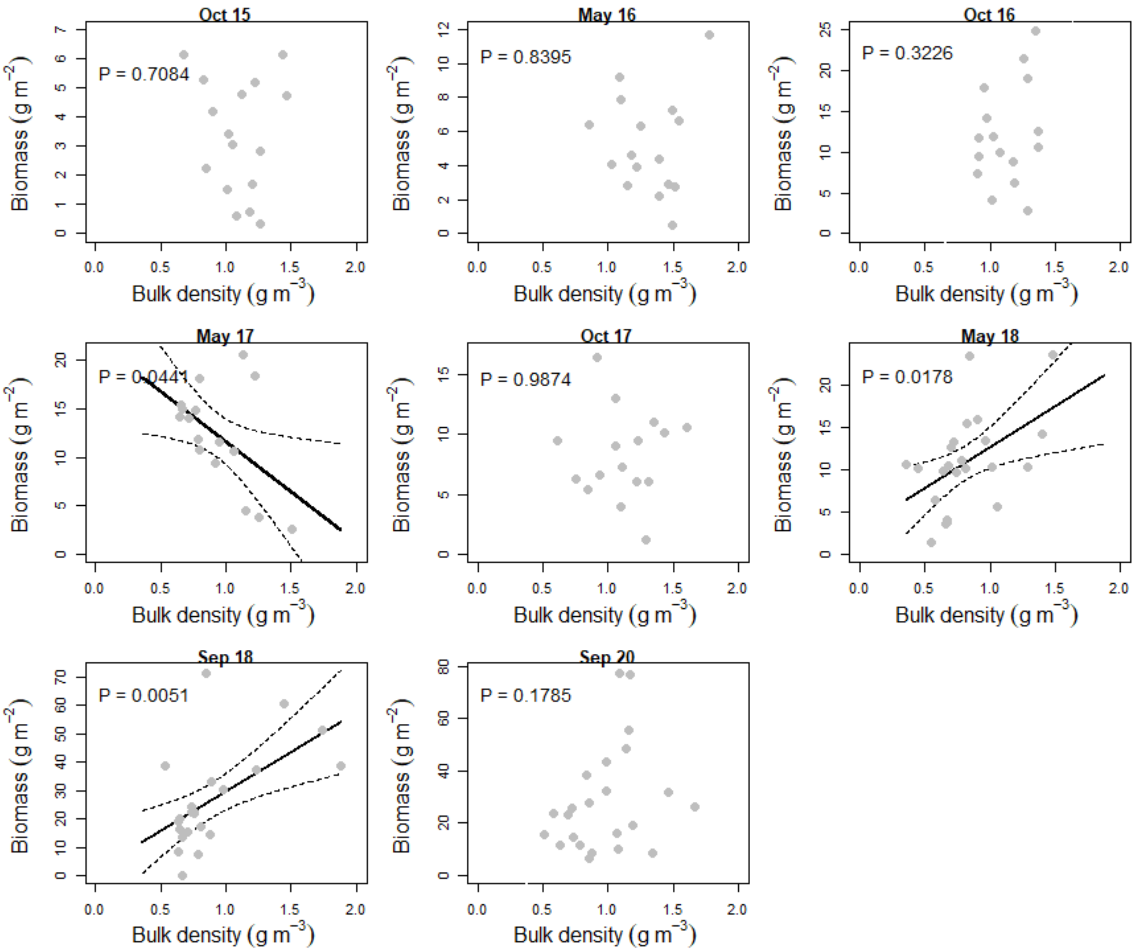


Figure A7. The total biomass plotted against the bulk density. Linear regression only shown when significantly correlated. The dashed lines represent 95% confidence intervals.

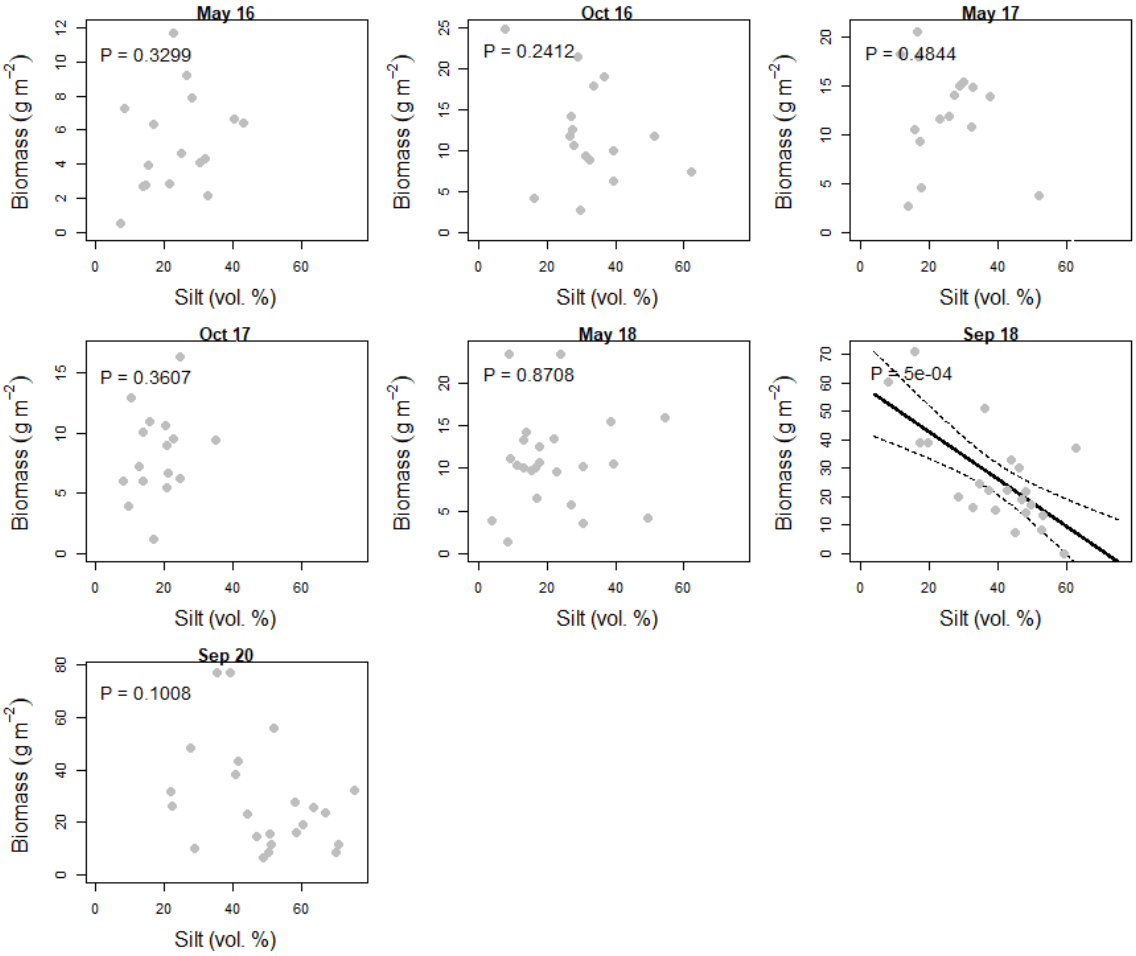


Figure A8. The total biomass plotted against the chl *a*. Linear regression only shown when significantly correlated. The dashed lines represent 95% confidence intervals.

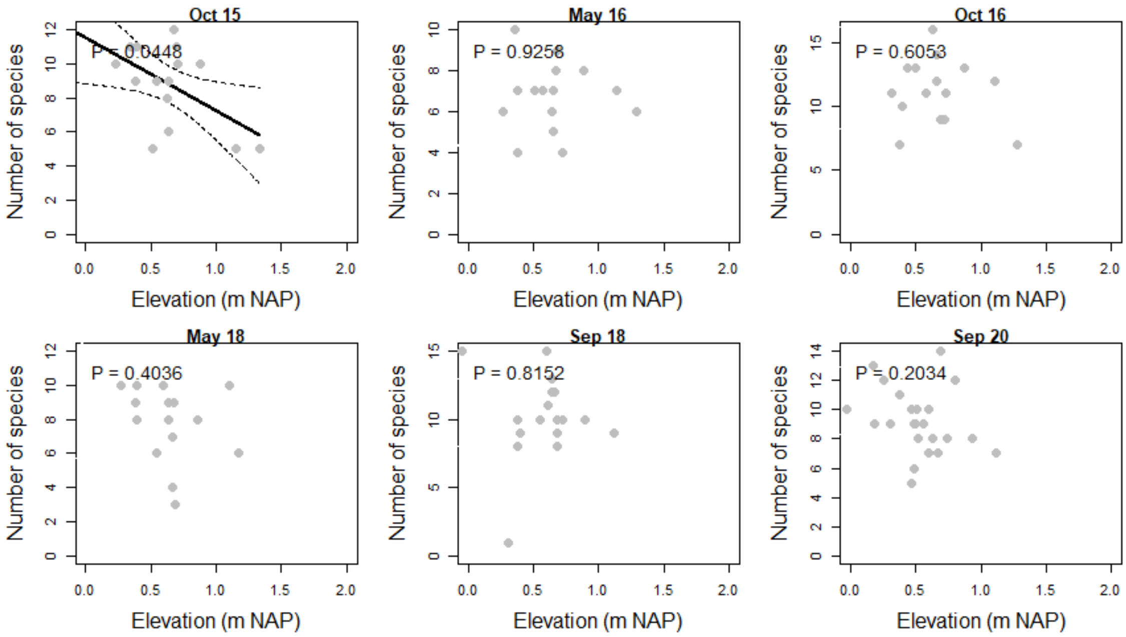


Figure A9. The species richness plotted against the elevation. Linear regression only shown when significantly correlated. The dashed lines represent 95% confidence intervals.

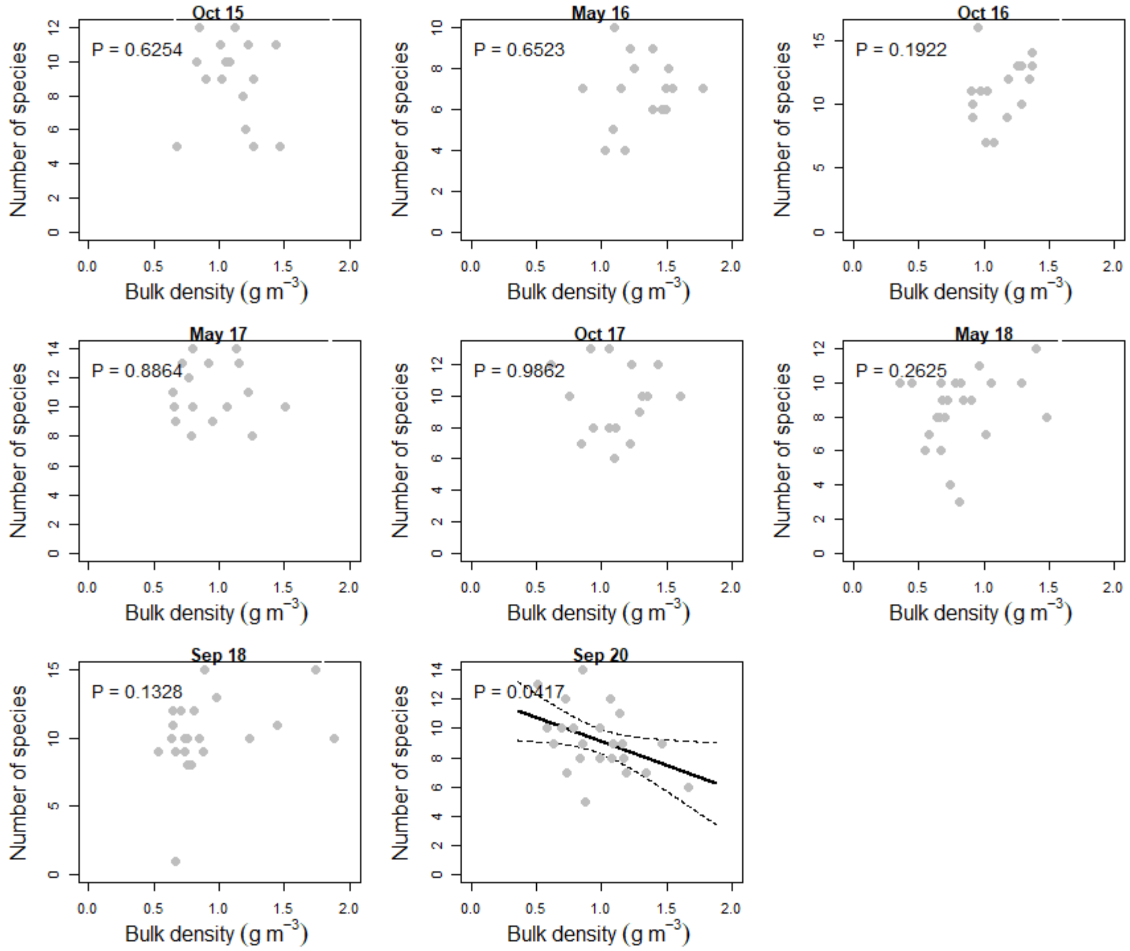


Figure A10. The species richness plotted against the bulk density. Linear regression only shown when significantly correlated. The dashed lines represent 95% confidence intervals.

Wageningen Marine Research
T +31 (0)317 48 7000
E: marine-research@wur.nl
www.wur.eu/marine-research

Visitors' address
- Ankerpark 27 1781 AG Den Helder
- Korringaweg 7, 4401 NT Yerseke
- Haringkade 1, 1976 CP IJmuiden