Ecosystem services of constructed wetlands under stable and fluctuating water levels

The case of Oostvaardersplassen & Marker Wadden

David Mornout | MSc Thesis | Water Resources Management Group

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Abstract

Natural wetlands undergo water level fluctuations because of hydrological and meteorological processes. Constructed wetlands, especially in densely populated deltas like the Netherlands, generally have a more stable, artificially managed water level. In this thesis, I investigate the differences in ecosystems services delivery by constructed wetlands under a stable and fluctuating water level management, as well as the extent to which they fulfil the demands of stakeholders. In two constructed wetlands in The Netherlands, the Oostvaardersplassen and Marker Wadden, I compared a sub-area with a stable water level versus a sub-area with a newly introduced, fluctuating water level. The ecosystem services water purification, biodiversity, and nutrient cycling were quantitatively analysed through field work. These and other relevant ecosystem services provided by the ecosystems and the demands of stakeholders from the ecosystems were qualitatively analysed through interviews.

It was found that the most widely demanded ecosystem services – habitat, biodiversity & recreation – are to a greater extent delivered under a fluctuating water level than under a stable water level. Stakeholders had different demands from the constructed wetlands; nature managers prioritised habitat and biodiversity while some government bodies prioritised recreation. Water purification, nutrient cycling and education are other ecosystem services frequently prioritised by stakeholders. Furthermore, it was found that the impact of management interventions should be considered on a broader spatial scale rather than only the local spatial scale of the management intervention. This was the case for the Marker Wadden, where further expanding the newly introduced fluctuating water level, for which basins at the Marker Wadden must be closed, will reduce interactions with Lake Markermeer. This leads to reduced ecosystem services delivery by Lake Markermeer. For the Oostvaardersplassen, such drawbacks were not found. This research contributes to taking explicit and deliberate management choices regarding water level management of constructed wetlands.

Keywords: constructed wetlands, water level management, ecosystem services, Marker Wadden, Oostvaardersplassen, the Netherlands

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Preface

In front of you lies my MSc thesis, titled 'Ecosystem services of constructed wetlands under stable and fluctuating water levels: The case of Oostvaardersplassen & Marker Wadden'. My name is David Mornout, and this research is one of my final steps to graduate from the MSc International Land and Water Management at WUR. I would like to shortly touch upon my research journey.

On September 25th, 2020, when I had just started my MSc program at WUR, I visited the Marker Wadden with a group of fellow water ambassadors. With today's knowledge, I can conclude that that day was a turning point in my studies. After this excursion, my friend Britt and I were imagined how cool it would be to do research in such a wetland. Some months later, that imagination became a reality. In our theses, we compared the Marker Wadden and Oostvaardersplassen in multiple ways, allowing us to do the field and lab work together. Besides learning a lot, we had a lot of fun on this exciting journey. It was great that we could execute all our field and lab work as planned, despite the unpredictable factor of the corona situation.

Over the past months, I learned about wetlands, aquatic ecology, and water level management. I also learned about the complexity of management and the different valid perspectives on sound management. In the interviews, I met a wide variety of experts in my field of studies. The conversations were not only useful in the light of this thesis, but also in my development from a student to a professional. Currently, I will continue to work on the topic of Nature-based solutions at WUR Student Challenges as well finish my last courses. Thereafter, in my final internship, I will surely be able to use the experience and knowledge gained to take next steps.

Ultimately, it was a truly fascinating experience, and I am glad for all the things that I have learned in the whole process. I hope you will enjoy reading my thesis and that it may contribute to not only my learning, but also serves as an inspiration and resources for others.

David Mornout

Wageningen, 25 March 2022

Acknowledgements

I am grateful to everyone who has contributed to this thesis project at any stage and in any way.

I would first like to thank my supervisors Gerardo van Halsema, Liesbeth Bakker and Kerstin Bouma. Gerardo has guided me in setting up this research and supported me in critically analysing my findings. I appreciate the inspiration and support Gerardo gave me to continuously improve my thesis. Liesbeth has introduced Britt and me to the Marker Wadden and provided a crash course on the archipelago. When I was slightly overconfident in entering the muddy wetland, Liesbeth was the one who guided me out – something I will remember for sure. Also at later stages, Liesbeth was there to help me progressing. Kerstin has been involved in all details of the research project; from providing valuable feedback on draft documents, sharing her experience and knowledge, to collaborating in the lab and field work. Of course, I would also like to thank my good friend Britt for being involved in this research project from start to finish. It was a great pleasure to work and learn with Britt over the past months.

I am furthermore thankful for my colleagues at NIOO-KNAW, who made me feel welcome at the institute as well as part of the Aquatic Ecology department. I am very grateful for the support from the research assistants at NIOO-KNAW, especially for Erik Reichman and Dennis Waasdorp for their help with the zooplankton samples. I would also like to thank Nico Helmsing and Femke van Beersum for their help, guidance, and support with amongst others the nutrient analyses. Furthermore, I am grateful for the support from other researchers working on the Marker Wadden. I experienced the meetings with them as pleasant opportunities to learn and share ideas. For this, I would like to thank Casper van Leeuwen in particular.

I would also like to thank all interviewees – whose names I am not mentioning here for privacy reasons – and the parties they represented. They spent time and energy in the conversations with me and later in going through the summary of the interviews.

This research would also not have been possible without full support by Staatsbosbeheer and Natuurmonumenten. I would like to thank Staatsbosbeheer for providing access to the Oostvaardersplassen and for facilitating the field work. I would like to thank Natuurmonumenten for the opportunity to stay at the Marker Wadden for multiple weeks and for assistance in the field when needed. We had so many valuable conversations with the volunteers at the Marker Wadden, who even facilitated us to do the fieldwork on stormy days, when we could not canoe ourselves.

While writing the proposal of this thesis, several people have thought along with me and provided feedback, support, and inspiration. For this, I would like to thank Joep de Leeuw, Ruurd Noordhuis and Raffaele Vignola. Furthermore, I would like to thank Dorine Dekkers, for sharing her expertise on water fauna. I would like also like to thank fellow students from my program and beyond for the moments of reflection and relaxation. In this regard, I would specifically want to thank Noa Tabak, for reviewing this thesis but also for the refreshing and energising coffee breaks and conversations we had.

Lastly, I very much appreciate the genuine interest and support from my friends and family. Thanks to them, I had a smile on my face from writing the first words of this thesis till submitting this final version.

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List of Abbreviations

C	Carbon
ES	Ecosystem Service(s)
NA	Not Applicable
NAP	Normaal Amsterdams Peil
MA	Millennium Ecosystem Assessment
MM	Lake Markermeer
MW	Marker Wadden
N	Nitrogen
NH_3	Ammonia
NAP	Amsterdam Ordnance Datum (Normaal Amsterdams Peil)
NIOO	Netherlands Institute of Ecology
NO_2^-	Nitrite
NO_3^-	Nitrate
NPNL	Nationaal Park Nieuw Land
NTU	Nephelometric Turbidity Unit
OM	Organic Matter
OVP	Oostvaardersplassen
P	Phosphorus
PO_4^{3-}	Orthophosphate
SD	Standard Deviation
Sed	Sediment
SOP	Standard Operating Protocol
SS	Suspended Sediment
SW	Shannon-Wiener index for biodiversity
Wat	Water
WUR	Wageningen University and Research
Zoo	Zooplankton

The hashtags (#) in the text refer to the number of an interview. Table 5 provides an overview of all interviews. Summaries of the interviews are included in the dataset of this thesis.

The Standard Operating Protocols to which this thesis refers are available at NIOO-KNAW.

1. Introduction

1.1 Background

Loss and degradation of wetlands is an indisputable reality, with a long-term loss of natural wetlands between 54 and 57% (Davidson, 2014). Pressures on wetlands, e.g., agriculture and urbanisation (Hu et al., 2017), are likely to increase in the future, resulting in further loss of wetlands and their ecosystem services (Molden, 2013). Natural wetlands undergo water level fluctuations under the influence of hydrological and meteorological processes, which maintain the pioneer stage of the wetlands (Vulink & Van Eerden, 1998). This pioneer stage provides favourable foraging conditions and habitats for birds (Van Eerden, 1998).

In densely populated deltas, such as the Netherlands, water levels of (constructed) wetlands are kept relatively stable to limit flood risk and ensure water availability during the dry seasons (Crawford, 1992). The lack of fluctuations strongly reduces wetland dynamics and habitat diversity (Bakker et al., 2016), preventing pioneer vegetation to re-establish and resulting in high grazing pressure on emergent vegetation (Beemster et al., 2010). To turn the tide, a more dynamic water level management strategy is introduced in two constructed wetlands in the Netherlands; the Oostvaardersplassen (OVP) and the Marker Wadden (MW) (Staatsbosbeheer, 2021) (Natuurmonumenten, #1). These constructed wetlands are part of the world's largest man-made nature park (National Park Nieuw Land) (29,000 ha), mainly consisting of wetlands (National Park Nieuw Land, 2021).

In a sub-area of the OVP, a more fluctuating water level management strategy is introduced as a response to decreasing bird populations and diversity over the past decades (Staatsbosbeheer, 2021). Following decennia of a relatively stable water level, lowering of the water level started in 2018, and the lowest water level was reached in the summer of 2021. The low water level will be maintained for a few consecutive years during which pioneer vegetation can re-establish. Thereafter, the water level will slowly rise towards the original level. A more dynamic water level management plan will be implemented following this reset. In a sub-area of the MW, the water level fluctuations are introduced to maintain the current pioneer stage of the ecosystem and to thereby prevent willow growth (Natuurmonumenten, #1). In contrast with the multi-annual fluctuations introduced in the OVP, the fluctuations in the sub-area of the MW follow an annual cycle (Natuurmonumenten, #1).

There is a need to assess whether the newly introduced fluctuating water level management strategy leads to the desired and anticipated effect regarding ecosystem services delivery. Furthermore, the effect of the newly introduced management on the delivery of other ecosystem services needs to be assessed. Finally, the effect of the newly introduced water management strategies on the fulfilment of the ecosystem services demanded by stakeholders should be considered. The assessment of the delivered ecosystem services and the fulfilment of demanded ecosystem services contributes to taking explicit and deliberate management choices regarding water level management of constructed wetlands, in which the implications of each choice are weighed.

1.2 Research questions

The above leads to the following main research question:

How does the delivery of ecosystem services and the fulfilment of the demanded ecosystem services differ under a relatively stable and a more fluctuating water level management strategy for both Oostvaardersplassen and Marker Wadden?

To answer this main research question, a two-tier approach is applied. The main research question is divided in three sub-research questions, the first of which belongs to Tier 1, and the second and third belong to Tier 2.

Tier 1: Quantitative assessment of the newly introduced water level management strategies on the ecosystem services water purification, biodiversity, and nutrient cycling.

1. What is the effect of the newly introduced water level management strategies on the ecosystem services water purification, biodiversity, and nutrient cycling delivered by MW and OVP?

Tier 2: Qualitative assessment of the effect from the newly introduced water level management strategies on ecosystem services and on the fulfilment of the ecosystem services demanded by stakeholders.

2. What is the effect of the newly introduced water management strategies on ecosystem services delivered by MW and OVP?

3. What is the effect of the newly introduced water management strategies on the fulfilment of the ecosystem services demanded by stakeholders?

1.3 Hypotheses

1.3.1 Tier 1

The fluctuating water level management strategies are introduced to either bring back or retain the pioneer vegetation stage of wetlands, thereby creating and preserving bird habitat. This has been proven to work in the OVP earlier (Vulink and Van Eerden, 1998), but also in other wetlands such as Dnestr Delta in Ukraine (Schogolev, 1996), Coto Doñana in Spain (Santoro et al., 2010) and Lake Mikri Prespa in Greece/Albania (Catsadorakis et al., 1996). It is hypothesised that the ecosystem services water purification, biodiversity, and nutrient cycling will be delivered to a larger extent under a more fluctuating water level than under a stable water level.

Regarding water purification, it is hypothesised that values for both turbidity and suspended sediment will be lower under a more fluctuating than a relatively stable water level, but only after vegetation has re-established. Emergent vegetation namely limits resuspension of sediment in wetlands (Dieter, 1990; Holliday et al., 2003). Literature also states that turbidity and suspended sediment are correlated and they are therefore hypothesised to show similar patterns (Gippel, 1989; Holliday et al., 2003). Before re-establishment of vegetation, turbidity and suspended sediment are hypothesised to be higher under a fluctuating water level than under stable water level, due to increased turbulence under decreasing water levels (G.-Tóth et al., 2011).

Regarding biodiversity, the hypothesis is to find an increase in abundance and diversity at low trophic levels (**Figure *1***) under a fluctuating water level. This hypothesis is based on an expected increase in overall productivity of the system under a fluctuating water level (Bayley, 1991; Growns et al., 2020), and on other studies concluding that temporary drawdown events have a positive effect in the subsequent years on the diversity and richness of water macrofauna (Van de Meutter et al., 2006), zooplankton (Arnott & Yan, 2002) and birds and macrophytes (Hanson & Butler, 1994).

More specifically, hypothesised is to find higher values for the Shannon-Wiener diversity index [H] for water macrofauna and zooplankton and under a fluctuating water level than under stable water level. Furthermore, it is hypothesised to find higher values for sediment macrofauna [g/m^2] and chlorophyll-a [mg/l] under a fluctuating water level than under a stable water level.

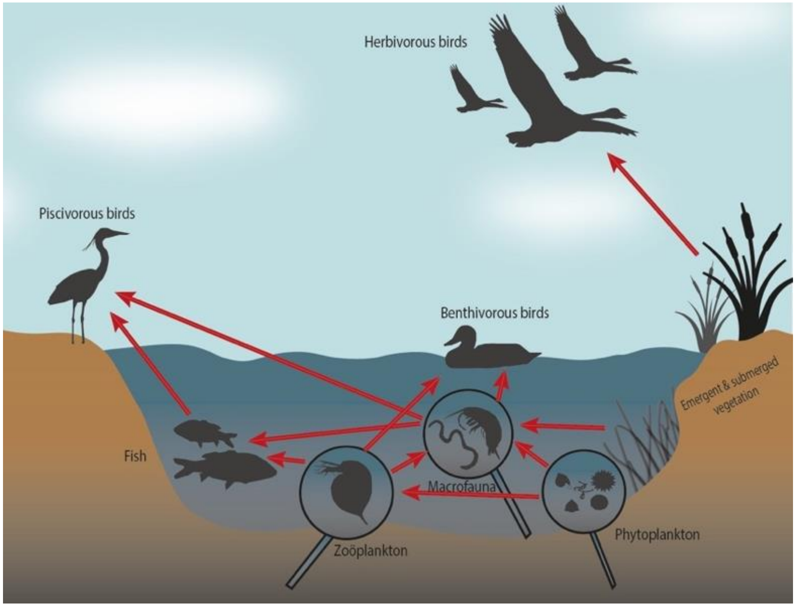

Figure 1: Simplified food web in constructed wetlands in the Netherlands (Bouma, 2021)

In natural systems, nutrient cycling is needed to balance nutrient uptake and decomposition. Constructed wetlands are often meant to purify water from intensively cultivated agricultural areas surrounding them, which is a form of water purification. The role of surrounding areas, possibly leaching nutrients to the wetlands, is not considered in this thesis. Regarding nutrient cycling, this research focuses on nutrient cycling interactions between water, suspended sediment, and sediment.

Hypothesised is that nutrient and organic matter levels are higher under a more fluctuating water level than under a stable water level. Nutrient dynamics in both the sediment and the water-sediment interface are affected by drawdown events, as they cause an increase in oxygen and light exposure on the sediment (Vonk et al., 2017). Drawdown and flooding cycles can lead to nutrients flushing out of the system due to coupling of aerobic and anaerobic processes (Furey et al., 2004), such as nitrification and denitrification resulting in a loss of nitrogen (N) (Vonk et al. 2017). On the other hand, the germination of plants, that is induced upon the exposed dry soils, can result in replacing organic matter and nutrients that are lost through oxidation (Gottgens & Crisman, 1991). Furthermore, already present organic material, such as dead leaves, from the riparian vegetation, can be broken down more quickly upon exposure of the sediment due to oxygen penetration. The fluctuating water level allows organic material to flush back into the aquatic system. The duration of the floods, droughts, and the interval, are critical variables in these processes (Baldwin & Mitchell, 2000).

In the OVP, the effects of the different water level management strategies are less likely to be observed as the last drawdown was already decades ago, from 1987 to 1991. At the MW, where drawdowns occur annually, effects are more likely to be measured.

1.3.2 Tier 2

Water level fluctuations alter ecosystem characteristics and thereby the ecosystems delivered by a constructed wetland (Janse et al., 2019). This reasoning also applies to the introduction of a fluctuating water level, which alters ecosystem characteristics and thereby ecosystem services delivery of the ecosystem. Effects of the newly introduced water management strategies on the delivery of ecosystem services, thereby also on the fulfilment of the ecosystem services demanded by stakeholders, are thus hypothesised to be found.

However, it needs to be studied whether the newly introduced water level management works out only positive in the light of the demanded services or whether there are also downsides to it. Depending on the extent to which the demanded ecosystem services are delivered under the newly introduced fluctuating water level management and how this differs from the situation under a stable water level, new management interventions in the future may be induced.

2. Concepts

Essential concepts within the framework used for this thesis are the water level management strategies, ecosystems, (provided) ecosystem services, demanded ecosystem services, and involved parties and stakeholders (**Figure *2***). These concepts and their application within this research are discussed in this chapter.

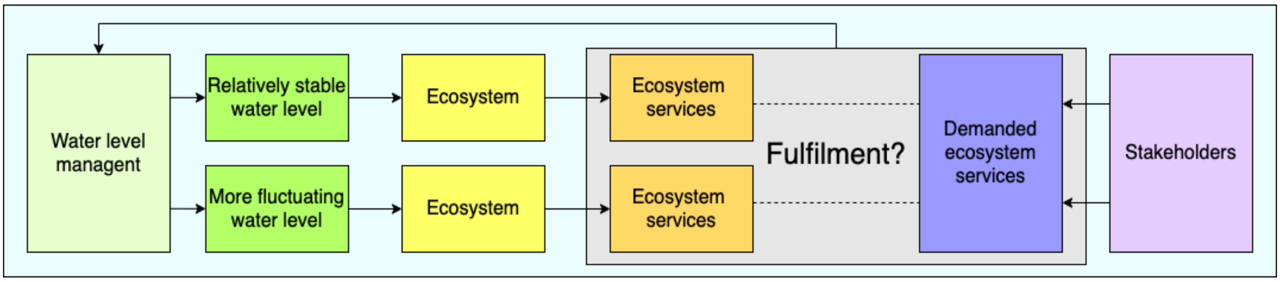

Figure 2: Conceptual framework on provided and demanded ecosystem services under different water level management strategies

The conceptual framework shows the effect of the different water level management strategies on the ecosystem and the ecosystem services it delivers. In the grey box, the fulfilment of the demanded ecosystem services is central. There is a feedback mechanism from this box to the water level management, as new management strategies arise from a gap in fulfilment. The recent introduction from more fluctuating water level management strategies is an example of a mismatch between provided and demanded ecosystem services leading to new water level management strategies.

2.1 Water level management strategies

Currently, both the OVP and the MW have sub-areas with a relatively stable and more fluctuating water level (**Table *1***). These water level management strategies are at the centre of this research setup. In Chapter 3, the water level management strategies are discussed in detail.

Table 1: Overview of study area and water level management of sub-areas

Area	Sub-area	Relatively stable or more fluctuating
MW	Other islands	Relatively stable
	Island C	More fluctuating
OVP	East	Relatively stable
	West	More fluctuating

2.2 Ecosystem

Ecosystems are seen as "*geographic places that represent areas of sufficiently similar topography, climate and biota*" (Blew, 1996, p. 171). Even though it can be argued that ecosystems have inherent geographic characteristics (Fitzsimmons, 1996), this approach will be used for this research project, as time limitations make simplifications unavoidable.

The OVP & MW consist of wetlands, which are defined as "*areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters"* by the Ramsar Convention in 1971 (Davis, 1994, p. 3).

2.3 Ecosystem services

Ecosystem services are defined as the benefits people obtain from ecosystems (Millennium Ecosystem Assessment (MA), 2005). The ecosystem services framework can be applied to various ecosystems, including wetlands (Wood & van Halsema, 2008). The widely accepted definition from MA is used in this research instead of other definitions of ecosystem services (De Groot et al., 2010). Ecosystem services are usually divided in 4 categories (**Table *2*** & **Table *3***)

Table 2: Ecosystem services categories, based on (Millennium Ecosystem Assessment (MA), 2005)

Category	Explanation
Provisioning	Goods produced or provided by ecosystems.
Regulating	Benefits from the processes of ecosystem regulation.
Cultural	Non-material benefits from ecosystems.
Supporting	Factors necessary for producing ecosystem services.

Table 3: Ecosystems services possibly provided by, or derived from, wetlands (Wood & van Halsema, 2008)

Services	Comments and examples
Provisioning	
Food	Production of fish, wild game, fruits and grains
Freshwater (a)	Storage and retention of water for domestic, industrial and agricultural use
Fibre and fuel	Production of logs, fuelwood, peat and fodder
Biochemical	Extraction of medicines and other materials from biota
Genetic materials	Genes for resistance to plant pathogens, ornamental species, etc.
Regulating	
Climate regulation	Source of and sink for greenhouse gases; influence local and regional temperature,
	Precipitation, and other climate processes
Water regulation (hydrological flows)	Groundwater recharge/discharge
Water purification and waste treatment	Retention, recovery and removal of excess nutrients and other pollutants
Erosion regulation	Retention of soils and sediments
Natural hazard regulation	Flood control and storm protection
Pollination	Habitat for pollinators
Cultural	
Spiritual and inspirational	Source of inspiration; many religions attach spiritual and religious values to aspects of wetland ecosystems
Recreational	Opportunities for recreational activities
Aesthetic	Many people find beauty or aesthetic value in aspects of wetland ecosystems
Educational	Opportunities for formal and informal education and training
Supporting	
Soil formation	Sediment retention and accumulation of organic matter
Nutrient cycling	Storage, recycling, processing and acquisition of nutrients

(a) While freshwater was treated as a provisioning services within the MA, it is also regarded as a regulating service by various sectors.

The place of biodiversity in the ecosystem services framework is debatable. Biodiversity is sometimes regarded as an ecosystem service, while in some cases, the term biodiversity is used as a synonym for ecosystem services, implying that if ecosystem services are managed well, the same can be said for biodiversity (Mace et al., 2012). Wood and van Halsema (2008, p. 13) mention that *"biodiversity contributes to all of the ecosystem services depending on the perspective from which it is viewed and the service which is focused on."* In this thesis, biodiversity is considered a separate category in the ecosystem services framework.

2.4 Provided and demanded ecosystem services

As the MW & OVP are artificial and managed wetlands, the management is based on the demands from stakeholders, as is also expressed by the feedback mechanism in the conceptual framework (**Figure *2***). These demands from stakeholders have ramifications for the future (water level) management of the wetlands, thereby the state of the ecosystem and the delivered ecosystem services.

3. Study area and problem description

3.1 Context and broad picture

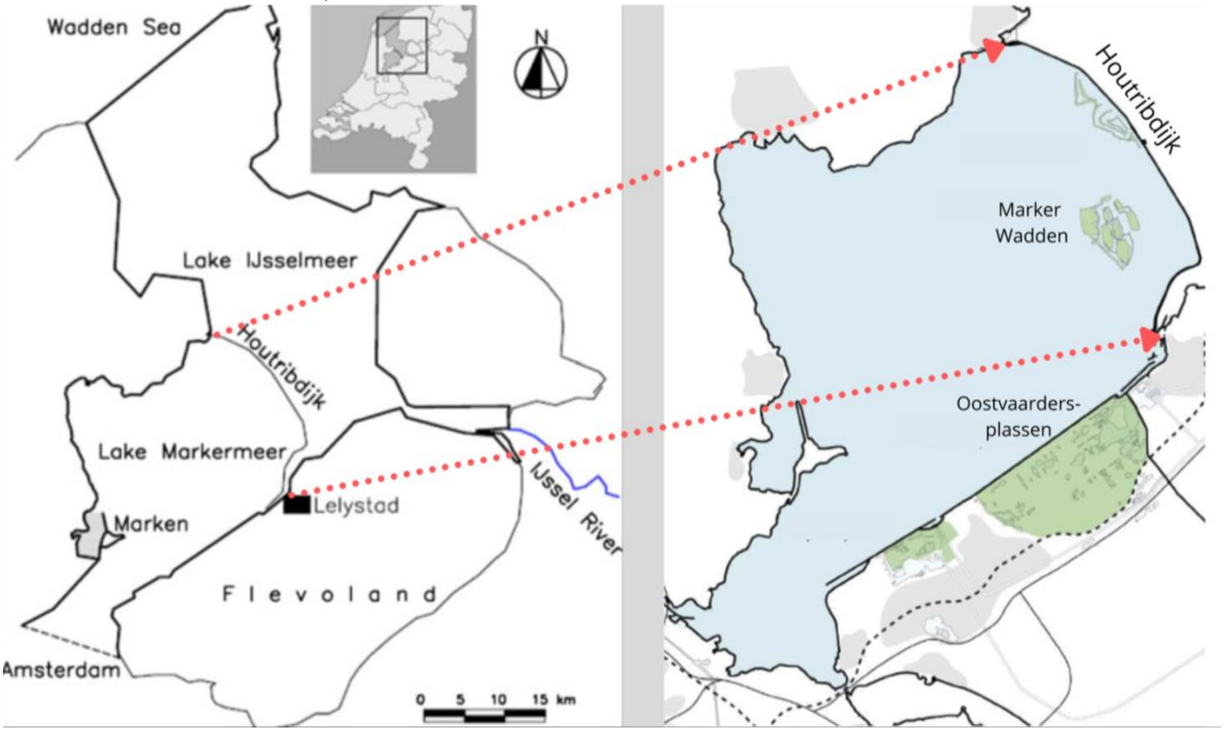

Figure 3: *Left:* Lake Markermeer and Lake IJsselmeer (the former Zuiderzee sea estuary) in central Netherlands (Kelderman et al., 2012) and *Right:* Location of the Oostvaardersplassen & Marker Wadden around and in the Lake Markermeer (Provincie Flevoland et al., 2019)

In 1932, the former Zuiderzee sea was separated from the North Sea by the construction of the Afsluitdijk, and Lake IJsselmeer was created (**Figure *3***). The original marine environment changed into a freshwater environment and became attractive for water birds as a wintering and migration area (van der Zwaag, 1984). The Markerwaard polder was one of the five areas within the former Lake IJsselmeer that were planned to be reclaimed (Venstra, 1955). However, after completion of the Houtribdijk (**Figure *3*** and **Figure *4***) between Enkhuizen and Lelystad in 1976, the Markerwaard was not reclaimed as the demand for agricultural area was fulfilled, and Lake Markermeer (MM) was formed (Van Riel et al., 2017) with a surface area of 680 km^2 (Kelderman et al., 2012). The decision to not construct the Markerwaard was also influenced by functions of the waterbody that were deemed more important than the creation of more land. These functions include a foraging area for birds, a freshwater reservoir to buffer the Dutch water system, and recreation. The OVP is located on the border of this lake, while the MW is located in the lake (**Figure *3***, right).

Figure 4: The Houtribdijk separates the turbid Lake Markermeer (left) from the more clear Lake IJsselmeer (right) (Kaffener et al., 2019)

The Houtribdijk limits the exchange of water, nutrients, and fauna between MM and Lake IJsselmeer. Nutrient levels in the water column of the MM are currently low due to closing off most marine and riverine inputs and retention of available nutrients in the iron-rich sediment (Leeuwen et al., 2021). The successful fight against eutrophication in recent decades led to a decreased supply of nutrients. The lower nutrient load also led to lower quality of algae as feed and as a basis for the food web (Noordhuis et al., 2014).

The Houtribdijk is furthermore one of the reasons for the high turbidity of the MM, as are the minimal possibilities for sediments to settle due to the lack of water plants and soft banks (van Duin, 1992). The high turbidity is further enforced by its limited depth (3.6 m on average), due to which wind and waves in the lake cause high rates of resuspension of sediments (Kelderman et al., 2012; Vijverberg et al., 2011). The high turbidity disables light to enter the water column and thereby hinders photosynthesis of water plants, leading to a reduced water plant population. As a result, the fish populations declined, as they need spawn areas with water plants (Noordhuis, 2010). This led to lower bird numbers, who depend on the fish as feed.

Specifically, in the eighties of the last century, bird populations from many species started to decline (Van Riel et al., 2017). In 2009, Natura 2000 bird population objectives were set for the Markermeer area. Conservation objectives have been set for 19 bird species and for 10 of them also improvement objectives (Van Riel et al., 2017). The limited area of soft land water transitions and the limited food availability make it challenging to reach the Natura 2000 goals in the Markermeer area (Van Riel et al., 2017).

Another explanation for the decreasing ecological value of the MM is the lack of natural water level fluctuations. The water level is artificially managed and has very limited fluctuations over the year (**Table *4***), limiting the nutrient flux from land to water (van der Geest and Noordhuis, 2021). Wind, ghowever, results in temporary skews of water up to several meters, with higher water levels in the East / North East, towards the Houtribdijk, and lower water levels in the West / South West (ten Brinke et al., 2008).

Table 4: Band width water levels of Lake Markermeer and Lake Ijsselmeer (Ministerie van Infrastructuur en Waterstaat, 2018)

Band width water level	Lake Markermeer (m NAP)	Lake IJsselmeer (m NAP)
Winter (November – February)	-0.40 to -0.20	-0.40 to -0.05
Transition (October & March)	-0.40 to -0.10	-0.40 to -0.10
Summer (April – September)	-0.30 to -0.10	-0.30 to -0.10

The water level in the MM is slightly higher in summer than in winter, meaning that the fluctuations are opposite from natural cycles and negatively affect ecological values of the area. This water level management strategy is in place as a water retention ecosystem service to the Dutch water management system; it allows the MM to bring water into its surroundings in case of droughts and to receive drainage water in wetter times (ten Brinke et al., 2008).

To maintain the relatively stable water level, water is let in and out of the MM (**Figure *5***). Water from Lake IJsselmeer is let into the MM in summer, while water from the MM is let into Lake IJsselmeer in winter. In summer, water from the MM is also let into the Noordzeekanaal and the polder system of Noord-Holland, to provide fresh water and prevent salinity intrusion (ten Brinke et al., 2008). The IJsselmeer is both a significant supplier and receiver of water from the MM (**Figure *5***).

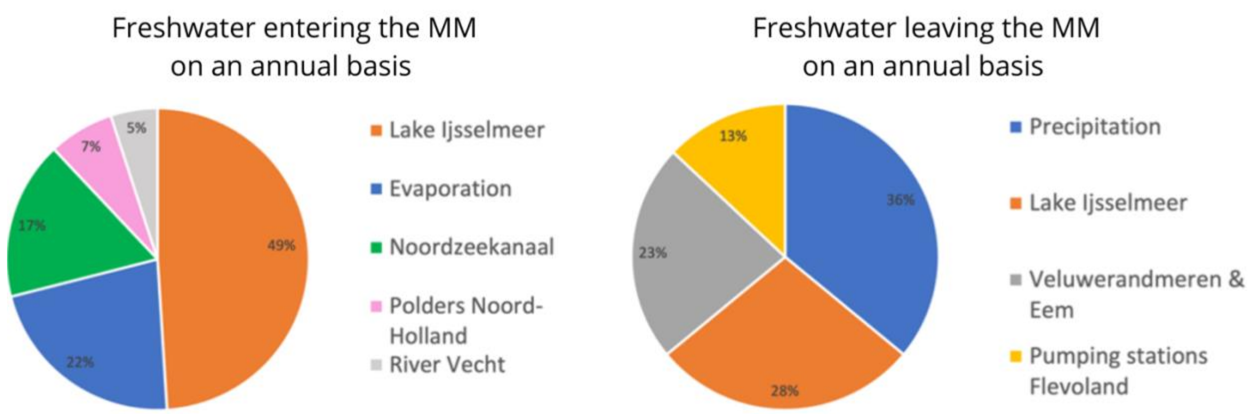

Figure 5: Freshwater entering (left) and leaving (right) Lake Markermeer on an annual basis, based on (ten Brinke et al., 2008)

3.2 Oostvaardersplassen

The OVP (**Figure *6***) is located on the border of the MM and was constructed in 1968 as part of the South Flevoland polder (Wigbels, 1990). The OVP has a surface area of 5,600 ha, of which 3,600 ha consists of wetlands. This research focuses on the wetlands part and not on the fenced grassland part where large grazers live.

Figure 6: Map showing the OVP and its wetlands, which are in the "West" and "East". In the "West", currently, a fluctuating water level management strategy is introduced (Bouma, 2020)

In 1987, a multiannual drawdown event (4 years) was introduced in the west part of the OVP. This allowed pioneer vegetation to re-establish under similar conditions as when the OVP was constructed in 1968 (**Figure *7***). This successfully led to the return of breeding and migrating birds, which were in danger of disappearing before (Vulink & Van Eerden, 1998).

In 2014, it was concluded that management of the OVP had to change to reach the Natura 2000 bird goals. This led to a new artificial drawdown event in the West (**Figure *6***), which is referred to as the Moerasreset (swamp-reset). The current Moerasreset, which resembles multiple consecutive dry years, differs from the previous one as also after the reset, the water level will be managed more dynamically (Provincie Flevoland, 2018b). During the project Moerasreset, the new dynamic water management plans are planned and prepared (Provincie Flevoland, 2018b), potentially including annual cycles. The multi-annual reset and the more dynamic water level management following are referred to as fluctuating (**Table *1***).

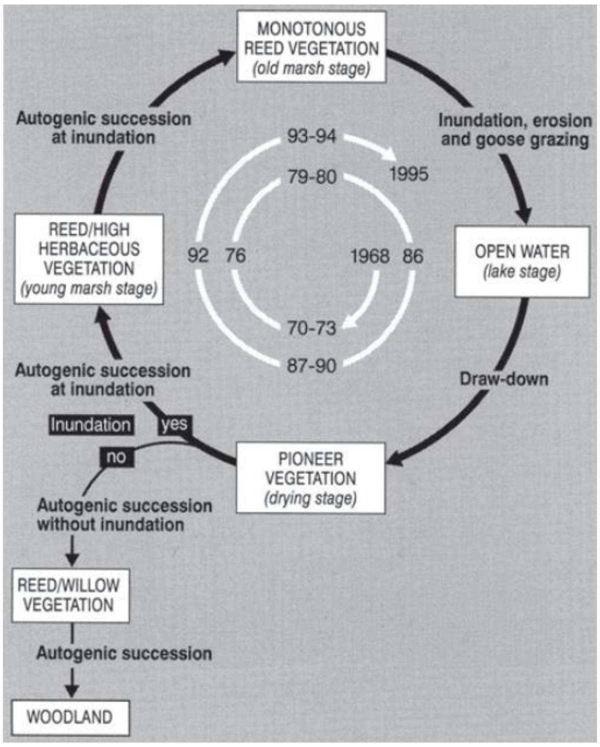

Figure 7: Cyclic vegetation development in the Oostvaardersplassen (Vulink & Van Eerden, 1998)

Before the Moerasreset, the water level in the OVP had minor fluctuations; in summer, it was 25 to 30 cm lower than in winter under the influence of evaporation and precipitation (Staatsbosbeheer, #11). The weir for the whole wetland area had a constant height, which limited the water level rise in winter. In the eastern part of the wetland, this is still the case. This water level management strategy is referred to as stable (**Table *1***).

The lowering in the West of the OVP started in October 2018 and in the summer of 2021 the lowest level was reached. Depending on vegetation development, the water level will be allowed to rise again from 2024 onwards. The amount of time this takes, depends on rain and evapotranspiration.

The initial water level at the start of the Moerasreset was -3.70 NAP, while the lowest water level under the project will be -4.60 NAP (± 10 cm) (Provincie Flevoland, 2018b). During the project, the large lake partially dries out while pools and mudflats are created (**Figure *8***) (Staatsbosbeheer, 2021). The eastern part of the OVP is not included in the project, as that could lead to the disappearance of species with different habitat preferences (Provincie Flevoland, 2018b).

Figure 8: Visualisation project Moerasreset, with on the left high water level and on the right low water level, adapted from (Provincie Flevoland, 2018a)

3.3 Marker Wadden

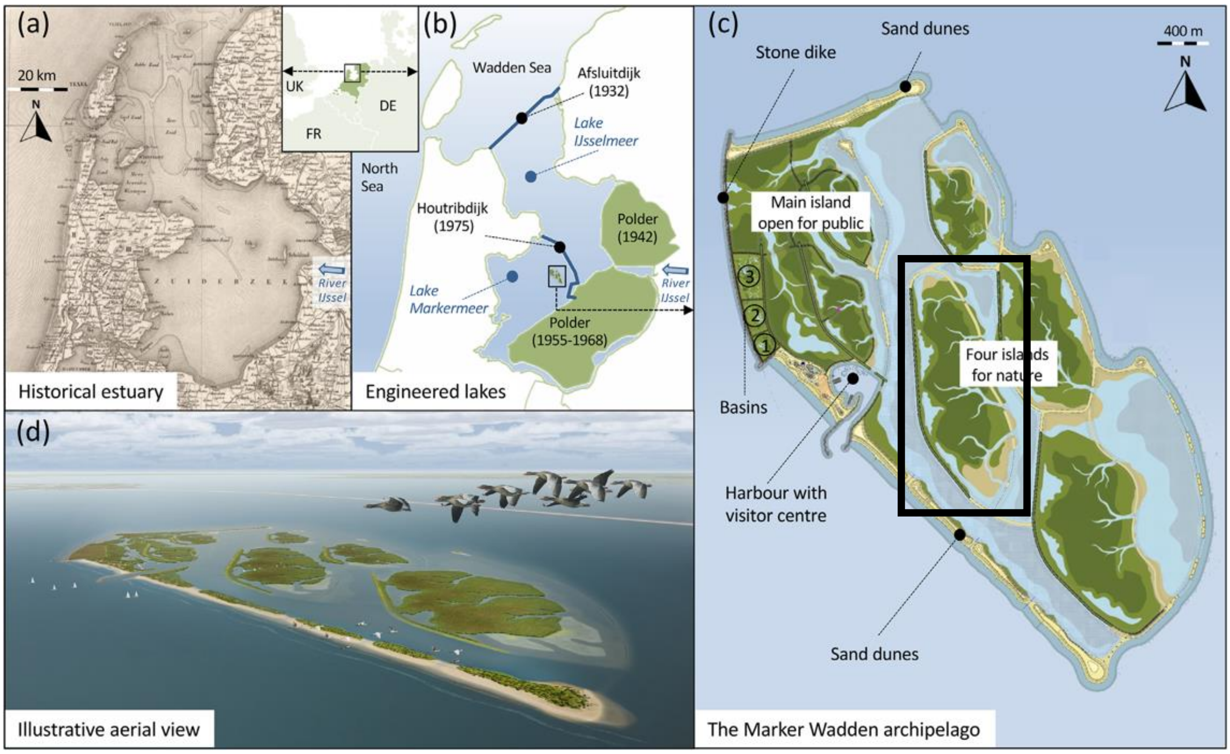

Figure 9: Overview of the location and structure of the Marker Wadden. In (C), the black box shows Island C. (Temmink et al., 2022)

Development of the MW (**Figure *9***) started in 2016. In 2021, five islands were completed, and two more islands are expected to be finished by 2023 (Natuurmonumenten, 2021).

The MW has been built to trap sediment from the MM and thereby lower the turbidity and increase the water quality of the MM. The MW creates some of the much-needed gradual land-water transitions, which are important for increasing the ecological value of the MM. Furthermore, with the construction of the MW, suitable spawn areas for fish and a mosaic of habitats for birds are created, as well as for species at lower trophic levels, enabling the MW to be(come) a bird and fish paradise (Provincie Flevoland et al., 2019). The archipelago is also intended to stimulate primary production in the MM by creating gradual land-water transitions (Leeuwen et al., 2021).

As the MW has just been constructed and expansion is currently taking place, the ecosystem is, unlike the OVP, in a pioneer phase. The water level of most parts of the MW is directly regulated via the MM, as the wetlands of the MW are directly connected to the MM. This is not the case for island C (**Figure *9***, **Figure *10***, and **Figure *11***). Island C is hydrologically separated from the MM and has a seasonally fluctuating water level (**Figure *12***). Its water level is regulated via one pump and one outlet (**Figure *10***). Until June / July, the water level is kept high, after which the outlet opens, and water leaves the island. In the months following, the island almost completely dries; only some pools are in place. The water level rises again in winter and spring, both via rain and pumping. During this period the outlet is closed to prevent the water from leaving. The fluctuating water level is in place to prevent willow growth, stimulate pioneer vegetation and limit sediment subsidence (Natuurmonumenten, #1). The water level management on Island C is referred to as fluctuating, while the water level of the MM and thus other places of the MW is referred to as stable (**Table *1***).

Figure 10: Outlet of inland water at island C, photo from July 2021 when the island was getting drier (Photo made by author)

Figure 11: Aerial photo of part of Island C, which has almost dried completely in two months, and where a lot of pioneer vegetation has established, photo from September 2021 (Boskalis, 2021)

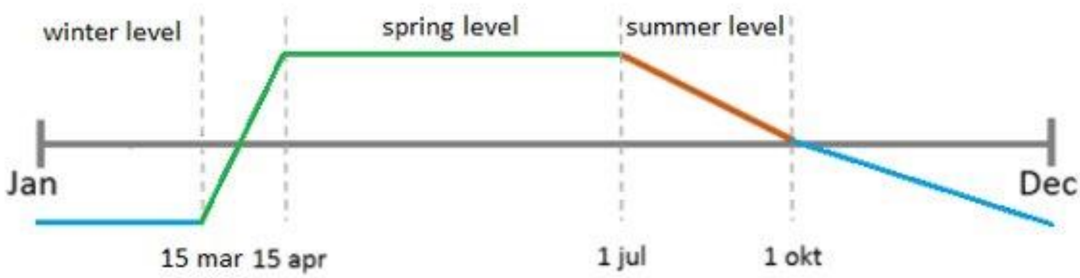

Figure 12: The annual water fluctuations at Island C (Julian Voet, 2021)

4. Methodology

The quantitative analyses in Tier 1 and the qualitative analysis in Tier 2 are applied to answer the main research question and sub-research questions. The methodology of Tier 1 consists of fieldwork, lab work, and statistical analysis, while for Tier 2, interviews with stakeholders form the core of the methodology.

4.1 Tier 1: Quantitative assessment

To quantitively assess ecosystem services, fieldwork has been executed and samples have been taken in the MW (**Figure *13***) and OVP (**Figure *14***) in July, August, and September 2021 (Annex 9.3). Furthermore, some extra samples taken in the West of the OVP in May 2021 have been analysed to account for missing data (Annex 9.3). For most parameters, 5 to 10 samples have been taken at each sub-area every considered month (Annex 9.3).

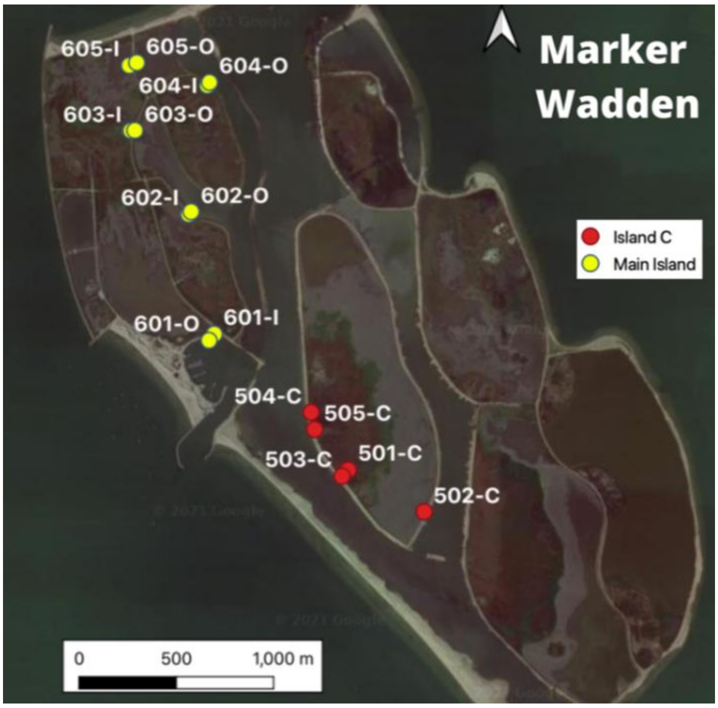

Figure 13: Sample locations Marker Wadden

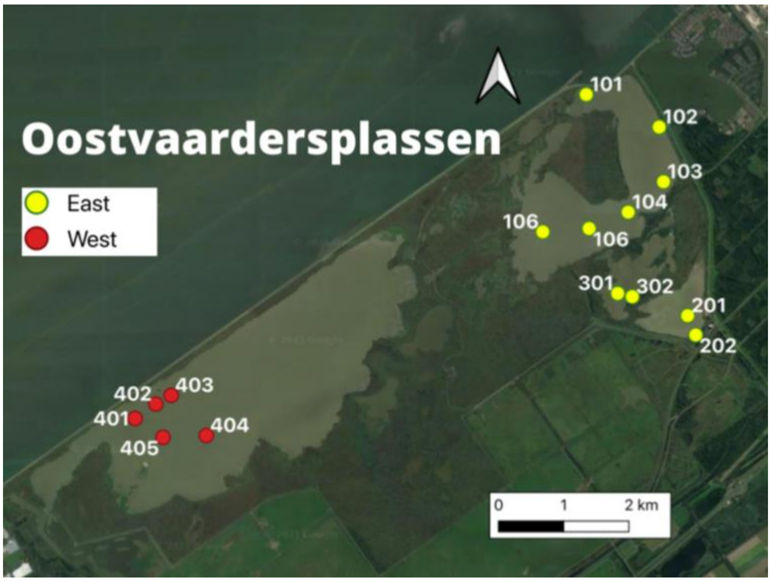

Figure 14: Sample locations Oostvaardersplassen.

For all parameters considered in Tier 1, it was tested whether there were significant differences in mean values obtained in sub-areas with a stable and fluctuating water level management strategy. This was done for the OVP and MW separately. Analyses have been executed over mean values of all considered months.

If the data followed a normal distribution, a Welch T-Test was executed. The Welch T-Test is used instead of the more commonly used Student-T Test, as it is more reliable when two samples have unequal variances and/or unequal sample sizes (Ruxton, 2006). When data was not normally distributed, it was tested whether the data was normally distributed after a log transformation. When that was the case, a Welch T-Test was done on the log transformed data. When that was not the case, the Mann–Whitney U Test was done on the non-transformed data. This is a nonparametric test and is suitable for unpaired samples. For this thesis, a confidence interval of 95% is considered. All statistical analyses were carried out in RStudio (version 1.4.1717) and Excel.

4.1.1 Water purification

To assess the water purification function of the artificial wetlands, the turbidity [NTU] and the suspended sediment (SS) [mg/l] have been assessed. This narrow focus stems from the relatively high turbidity levels in the MM and OVP, which impede water flora to establish. Left out in this assessment are other water purification functions such as the retention, recovery and removal of excess nutrients and pollutants by helophytes (MA, 2005).

To assess turbidity, water samples were taken by filling jars with 1 litre of undisturbed water at each sampling location. Subsamples were taken from these jars after mixing the water with the settled sediment in the jar. These subsamples were used to measure turbidity [NTU] with a turbidity meter. To prevent disturbance, the water column was sampled prior to other measurements. Disturbances would cause finding higher values than the actual values.

The same filled jar was taken to the lab to assess the amount of SS [mg/l]. There, SS concentrations were determined by filtering 5-100 ml (filtration volumes were dependent on the particle content of the water) water over pre-washed and pre-weighed GF/F filters (Whatman, Maidstone, UK). Before taking the subsample from the jar, it was mixed well. After drying the filters at 60 °C for at least 1 hour, they were reweighed to determine the weight increase and thereby the amount of suspended sediment in the filtered water.

4.1.2 Biodiversity

To assess the biodiversity of the MW and OVP, zooplankton [H], water macrofauna [H], sediment macrofauna [g/m^2] and chlorophyll-a [mg/l] were assessed. Chlorophyll-a is a reliable and commonly used proxy for the total phytoplankton biomass (Gregor & Maršálek, 2004). These indicators are all related to the bird-focussed biodiversity goals of the area considered in this thesis, as there should be enough food availability at lower trophic levels to reach bird populations goals. For zooplankton and water macrofauna, the Shannon-Wiener diversity index [H] is used. This index considers the number of species living in a habitat (richness) and their relative abundance (evenness). The index value rises with the number of species and the evenness of their abundance. For sediment macrofauna [g/m^2] and phytoplankton [mg/l], abundance was assessed. Within sediment macrofauna and phytoplankton, diversity was not assessed. Still, these indicators fall under biodiversity, as their abundance is linked to bird-focussed biodiversity goals.

The concentration of chlorophyll-a in the water column was assessed by filtering 5-100 ml (filtration volumes were dependent on the particle content of the water) of water over pre-washed GF/F filters (Whatman, Maidstone, UK). The subsample was taken from a jar filled with undisturbed water from the field. Before taking the subsample, the jar was mixed well. The filters were stored at -20 °C. After thawing, the filters were extracted with 80% ethanol in an 80 °C water bath and passed through Millipores Millex FG 0.2 µm membrane filters. Chlorophyll-a concentrations were measured on the filtrate part through High Performance Liquid Chromatography (HPLC, UltiMate 3000 (Thermo Scientific), Waltham Massachusetts, United States).

To assess zooplankton abundance, zooplankton samples were collected by filtering 30 litres of water through an 80-µm mesh size net in the field at each sampling location. As it was not always possible to collect 30 litres due to very limited water depth and/or high turbidity, sometimes less water has been collected. This has been corrected for in calculations afterwards. The samples were fixated with lugol solution for preservation for later analysis in the lab. In the lab, a subsample of 1-3 ml was taken and put on a petri dish, to count and determine the zooplankton species present. Zooplankton specimens were counted using a stereomicroscope. Cladocera were identified to the genus level, whereas Copepoda were divided in the two dominant orders in the samples: Calanoida and Cyclopoida. Copepoda in the naupliar stage were counted but not distinguished taxonomically. Rotifers were counted but not considered in the analysis as part of that population passes the 80-µm mesh size net.

To assess sediment macrofauna, sediment cores (depth: 10 cm, width: 5.5 cm) were collected; 4 cores at MW and 8 cores at OVP, around each sampling location. The sediment core was sieved over a 0.71 mm metal mesh. The materials retained on the mesh were transferred into a white photo tray, from which the macrofauna was collected, using tweezers and a pipette. The macrofauna was then stored in 50 ml tubes with 70% ethanol. In the laboratory, the biomass of the sediment fauna was weighted by first weighing the ethanol solution and the fauna together, and then only weighing the ethanol. This method allows one to preserve the sample in good state for analysis later. The weight is corrected for loss of ethanol in the process, which was found by following the same procedure for a sample with only ethanol.

To assess water macrofauna, different methods have been used at MW and OVP. The relatively high water levels at OVP and lower water levels at MW namely required a different methodology. At the OVP, a cylindrical tube (height: 1 m, diameter: 0.5 m) was placed in the water, with one opening pressed in the sediment. Nets (mesh size: 1 mm) were used to catch the macrofauna present in the tube. The caught fauna was then stored in 50 ml tubes with 70% ethanol. All the fauna was assumed to be caught once no more fauna was caught in three consecutive attempts. At the MW, a macrofauna net was used to walk a 10 m transect along the shoreline. Considering the dimensions of the net and the water depth, the sampled volume was calculated. The transect was walked against wind and/or water direction to prevent loss of macrofauna. While walking, the net bounced softly on the sediment to activate the fauna. The catch was put in a white photo tray, from which it was put in 50 ml tube with 70% ethanol using tweezers and a pipette. Later, the caught species were determined in the lab, to at least taxonomic class and further when possible. Benthic macrofauna caught while catching water macrofauna were not counted.

4.1.3 Nutrient cycling

To assess nutrient cycling at the OVP & MW, the nutrient and organic matter content of the sediment, suspended sediment, and water were assessed.

To assess the sediment's organic matter (OM) and nutrient content, an additional sediment stitch was taken at each sampling location. Standard Operating Protocol (SOP) Chem-0100 from the NIOO was used to determine the OM content of the sediment. This SOP was also used to prepare subsamples for P analysis, which was performed using the P-Olsen extraction, following SOP Chem-0113 from the NIOO. SOP Chem-0110 from the NIOO was followed to determine the C and N content of the sediment.

To assess the OM of the suspended sediment, the same filter that was first used to assess the amount of suspended sediment was used, following SOP Chem-0100) from the NIOO. To assess the C and N content of the suspended sediment, another subsample was taken from a well-shaken jar of water taken in the field and filtered over pre-washed and GF/F filters (Whatman, Maidstone, UK). Then, SOP Chem-0110 from NIOO was followed. The remainder of the same filter was used for P analysis, for which it was combusted in a Pyrex glass tube at 550°C for 30 min. Subsequently, 5 ml of persulfate (2.5%) was added to the glass tube, after which the samples were autoclaved for 30 min at 121°C. Digested P (as PO_4^{3-}) was then measured on an Auto-Analyzer.

To assess the dissolved nutrients, 12-15 ml of filtrate from a previous filtration was collected in 15 ml tubes and stored at -20 degrees Celsius, to be thawed for analysis later. Phosphate, ammonium, nitrate, and nitrite were analysed using a SAN+ CFA system (SKALAR, Breda, the Netherlands).

4.2 Tier 2: Qualitative assessment

To qualitatively assess the effect of the newly introduced water level management strategies on the delivered ecosystem services and the fulfilment of the by stakeholders demanded ecosystem services, interviews were conducted with stakeholders. Triangulation with literature took place to validate data provided in the interviews and to develop a more comprehensive understanding. This triangulation does not include a systematic literature review. Instead, based on data from the interviews, specific literature sources, often specifically on either the MW or OVP, have been tapped into.

To assess the fulfilment of demanded ecosystem services, an overview of all relevant stakeholders has been made (**Figure *15***). Three main groups identified within the stakeholder landscape are: nature managers, governments, and interest groups. The stakeholder landscape is characterised by collaboration and interaction via Nationaal Park Nieuw Land (8 parties) (Provincie Flevoland et al., 2019) and Coalitie Blauwe Hart Natuurlijk (8 parties, some overlap with National Park Nieuw Land) (Coalitie Blauwe Hart Natuurlijk, 2022).

Natuurmonumenten and Staatsbosbeheer together form the group nature managers. Natuurmonumenten executes the management of the MW while Staatsbosbeheer is managing the OVP. In the government group, there is the Province of Flevoland, two municipalities with areal in the OVP, the water board Zuiderzeeland and Rijkswaterstaat. The province of Flevoland is responsible for the management of the OVP. Water board Zuiderzeeland is responsible for safeguarding water safety in the polder and for both the quantitative and qualitative side of water management in the province of Flevoland, and therefore also involved. Rijkswaterstaat is managing lake Markermeer on behalf of the Dutch government. Lastly, interest groups considered are Sportvisserij Nederland, Nederlandse Vissersbond, Vogelbescherming and IJsselmeervereniging. Sportvisserij Nederlands represents the interests of recreational fishermen while the Nederlandse Vissersbond represents the interests of professional fishermen. The Vogelbescherming is an organisation committed to wild birds and their habitat. The IJsselmeervereniging is committed to responsible management of the IJsselmeer area in many respects.

Figure 15: Stakeholder mapping in three categories; nature managers, government bodies, and interest groups

After identification, the stakeholders (**Table 5Error! Reference source not found.**) were contacted (mainly via email) and invited for a semi-structured online one-hour interview. Before the interview, a list with questions and topics (Annex 9.2) was sent to the interviewees, mentioning that these would be useful to guide the interview but are not leading. After the interview, a summary of the conversation was sent to the interviewee, asking for verification and additions. Interviewees often advised whom to contact for more interviews, within and outside their organisation.

Next to providing information on the delivery of ecosystem services, the interviews were meant to answer the research question on demanded ecosystem services. Therefore, questions were posed on the functions and services deemed important by the interviewed party. These answers were analysed per party and for the three earlier identified groups.

Table 5: List of interviewed parties, their involvement in OVP and/or MW (green is involved), function of the interviewee and date of the interview. The # refers to the number of the interview.

#	Party	OVP	MW	Function	Date interview
1	Natuurmonumenten			Executive nature manager MW	17/09/2021
2	Natuurmonumenten			Recreation and communication manager MW	17/11/2021
3	Province of Flevoland			Policy advisor nature	05/11/2021
4	Municipality of Lelystad			Policy advisor and ecologist	22/11/2021
4	Municipality of Lelystad			Policy advisor and program manager sustainability	22/11/2021
5	Municipality of Almere			Senior advisor ecology	16/11/2021
5	Municipality of Almere			Policy advisor climate adaptation and water	16/11/2021
6	IJsselmeervereniging			Chair	26/08/2021
7	Sportvisserij Nederland			Program manager Ijsselmeer area	20/09/2021
8	Water board Zuiderzeeland			Policy advisor	17/11/2021
8	Water board Zuiderzeeland			Hydrologist	17/11/2021
9	Nederlandse Vissersbond			Secretary and Markermeer expert	19/11/2021
10	Staatsbosbeheer			Communication manager OVP	03/11/2021
11	Staatsbosbeheer			Provinical ecologist OVP	01/12/2021
11	Staatsbosbeheer			Senior Consultant Ecology	01/12/2021
12	Vogelbescherming			Policy officer Ijsselmeer area	05/11/2021
13	Rijkswaterstaat			Advisor water level management and swimming water	21/12/2021
14	Rijkswaterstaat			Technical manger	12/01/2022
15	Rijkswaterstaat			Senior advisor water systems	13/01/2022
16	Rijkswaterstaat			Ecologist central Netherlands	17/01/2022

5. Results

Results from the quantitative approach (Tier 1) are provided in chapter 5.1, followed by results from the qualitative approach (Tier 2) in chapter 5.2.

5.1 Tier 1: Quantitative

In the quantitative analysis, the ecosystem services water purification, biodiversity, and nutrient cycling were assessed. For some of the parameters considered, significant differences were found between the average values obtained under sub-areas with a stable and fluctuating water level.

Water purification

Turbidity [NTU] and suspended sediment (SS) [mg/l] concentration in the water column were significantly higher under a fluctuating water level than under a stable water level at the OVP. For these parameters, there were no significant differences at the MW (Table 6, Figure 16 & Figure 17). The findings at the OVP are in line with the hypothesis that values for turbidity and suspended sediment are higher when the water level is lowering.

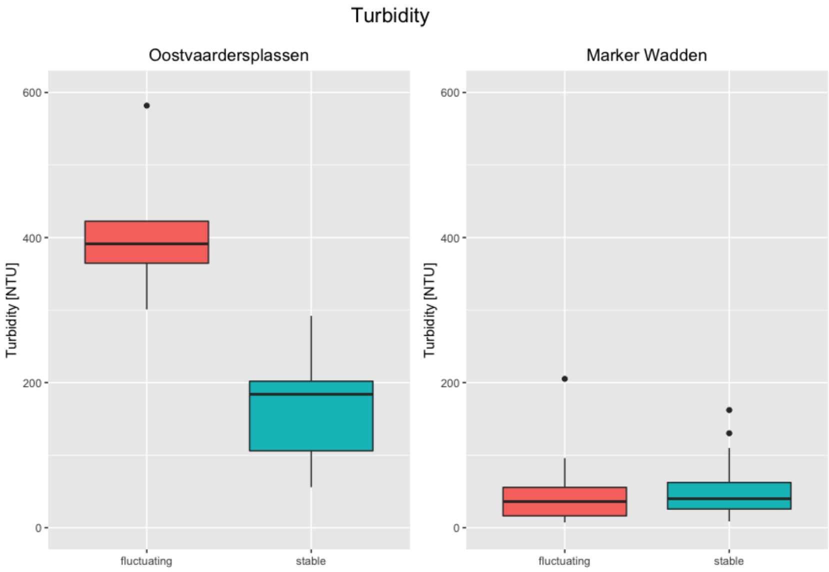

Figure 16: Turbidity of the water under fluctuating and stable water levels at the OVP and MW

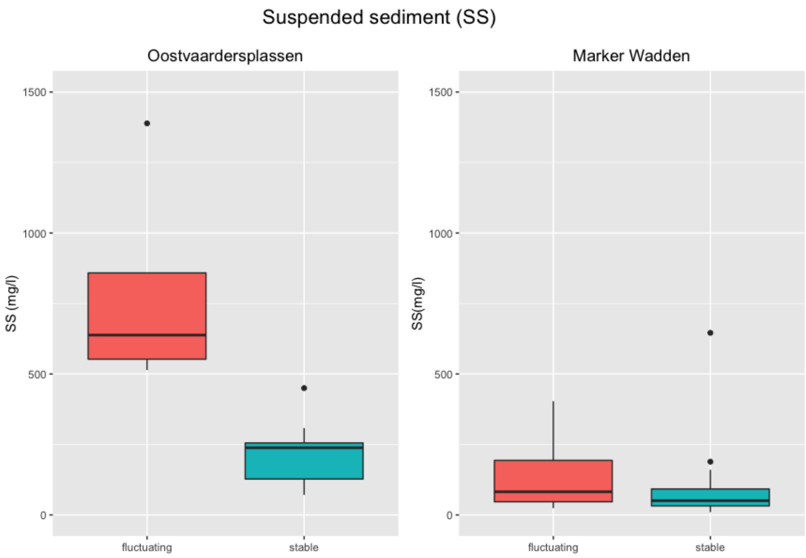

Figure 17: Suspended concentration of the water under fluctuating and stable water levels at the OVP & MW

Table 6: Overview results Tier 1. Blue and yellow shading indicate significant differences with blue having higher values than yellow. Grey shading indicates nonsignificant differences. Graphs, standard deviations, sample size and statistical tests used, can be found in Annex 9.1

				Oostvaardersplassen			Marker Wadden		
Ecosystem service		Parameter	Unit	Fluctuating water level (mean)	Stable water level (mean)	Significance (P value)	Fluctuating water level (mean)	Stable water level (mean)	Significance (P Value)
Water purification		Turbidity	NTU	412.24	159.66	***<.001***	49.48	50.34	0.57
		Suspended sediment	mg/l	790.34	205.43	***<.001***	125.58	84.37	0.071
Biodiversity		Zooplankton	H	0.76	0.97	0.105	0.91	1.28	***<.001***
		Water macrofauna	H	No data	0.04	NA	0.86	0.87	0.908
		Sediment macrofauna	g/m^2	No data	20.76	NA	6.18	16.11	0.334
		Chlorophyll-a	mg/l	0.289	0.157	***<.001***	0.016	0.058	0.052
Nutrient cycling	Sediment	OM_Sed	%	10.78	6.78	0.197	12.05	10.24	0.340
		C_Sed	mg/kg	1865.36	1528.36	0.441	54660.95	29275.86	0.514
		N_Sed	mg/kg	30360.50	27572.90	0.551	3209.26	1838.13	0.240
		P_Sed	mg/kg	13.38	29.67	0.075	15.55	14.80	0.092
	Suspended sediment	OM_SS	%	4.31	2.89	***<.001***	3.50	3.02	***0.025***
		C_SS	mg/kg	5.91	18.23	***0.013***	6.66	7.16	0.693
		N_SS	mg/kg	5.11	1.92	***0.001***	0.61	0.79	0.543
		P_SS	mg/kg	1.32	0.55	***0.047***	0.21	0.24	0.917
	Water	N_Wat	mg/l	0.0416	0.0725	0.759	0.0627	0.0386	***0.011***
		P_Wat	mg/l	0.0390	0.1091	***0.004***	0.0322	0.0663	0.604
		NH3_Wat	mg/l	0.0358	0.0732	0.734	0.2221	0.0516	***0.016***
		NO2_Wat	mg/l	0.0038	0.0119	0.750	0.0112	0.0029	***0.001***
		NO3_Wat	mg/l	0.03780	0.06055	1	0.05153	0.03570	***0.034***

Biodiversity
For zooplankton, Shannon-Wiener Diversity index values were significantly higher under a stable water level than under a fluctuating water level at the MW (**Figure *18***). For water macrofauna [H], sediment macrofauna [g/m^2] and chlorophyll-a [mg/l], there were no significant differences between a stable and fluctuating water level at the MW. In contrast, at the OVP, chlorophyll-a levels were significantly higher under a stable water level than under a stable water level. At the OVP, no significant differences were found for zooplankton. For water and sediment macrofauna at the OVP, no samples from areas with a fluctuating water level were analysed, making comparison impossible.

These findings are, except for chlorophyll-a [mg/l] at the OVP, not in line with the hypotheses, as it was hypothesised that for zooplankton [H], water macrofauna [H], sediment macrofauna [g/m^2] and chlorophyll-a [mg/l] higher values would be found under a fluctuating water level than under a stable water level.

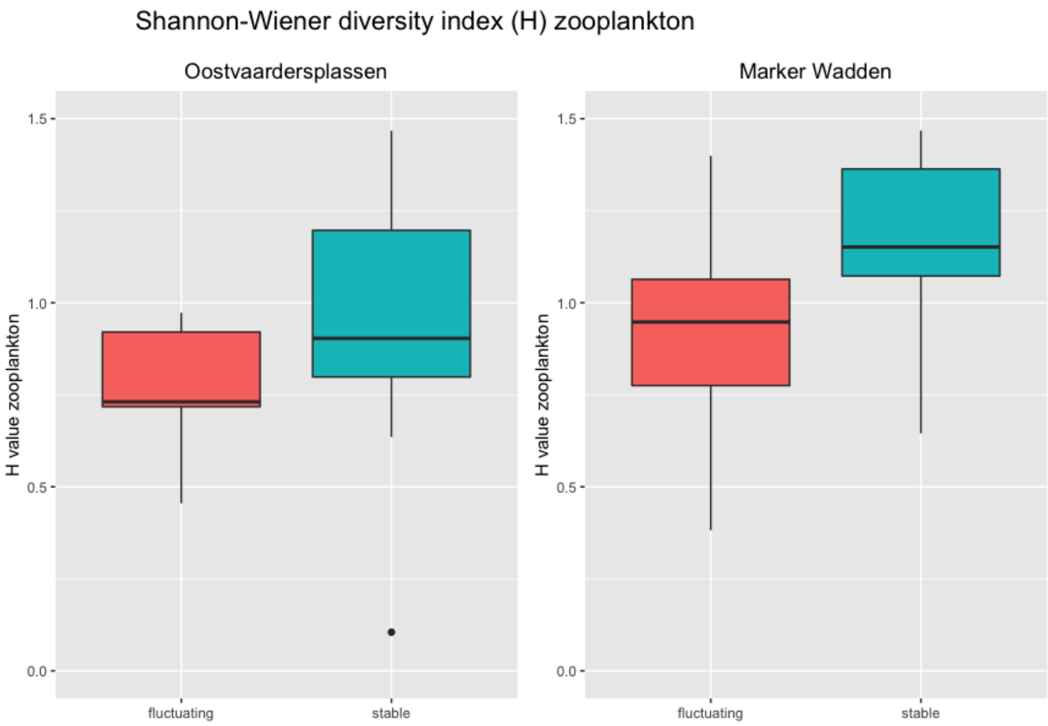

Figure 18: Shannon-Wiener diversity index for zooplankton at OVP & MW

Nutrient cycling
Results from comparisons between areas with a stable and a fluctuating water level either showed higher nutrient levels under a fluctuating water level or no significant differences. The only exception is carbon in suspended sediment, for which, at the OVP, significantly higher values were found under a stable water level than under a fluctuating water level.

Regarding the sediment, at both the MW and OVP, organic matter, nitrogen, carbon, and phosphorus concentrations did not differ significantly under the different water level management strategies. For the suspended sediment, however, organic matter concentrations were significantly higher under a fluctuating water level than under a stable water level at both the MW and OVP (**Figure *19***). At the OVP, the same is true for nitrogen and phosphorus, while the opposite was found for carbon. At the MW, no significant differences were found for carbon, phosphorus, and nitrogen.

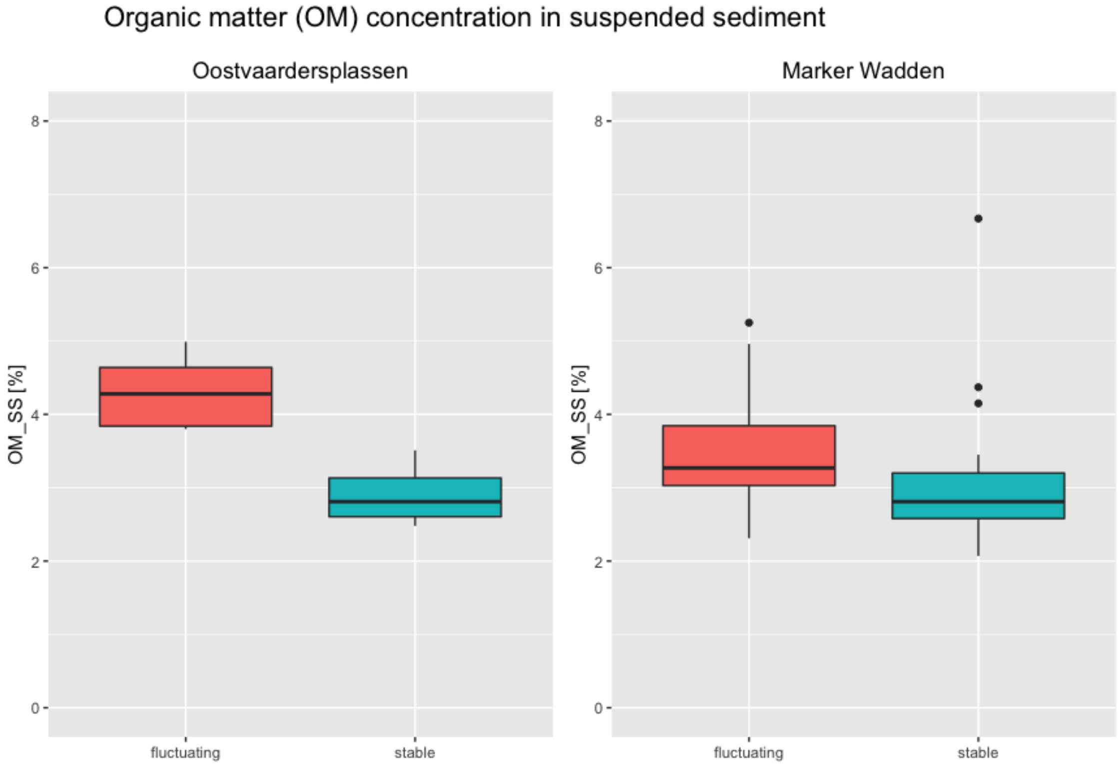

Figure 19: Organic matter (OM) in suspended sediment (SS) at OVP & MW

For the sediments in the water, most significant differences were found at the MW. There, the values for nitrogen, ammonia, nitrite, and nitrate were significantly higher under a fluctuating water level than under a stable water level. For these, no significant differences are observed at the OVP. On the contrary, at the OVP, phosphorus values were significantly higher under a fluctuating water level than under a stable water level, while at the MW there was no significant difference found for phosphorus.

The findings for the ecosystem services nutrient cycling are partly in line with the hypotheses that nutrient and organic matter levels would be higher under a fluctuating water level than under a stable water level. This was namely found for a variety of parameters in the suspended sediment and water, but not in the sediment.

5.2 Tier 2: Qualitative

5.2.1 Delivery of ecosystem services

Several ecosystem services are delivered to a larger extent under a fluctuating water level than under a stable water level at both the MW and OVP (**Table *7*Table *7***). Especially the cultural, supporting and biodiversity services, show a positive response towards the introduction of a fluctuating water level. At the OVP, all services either respond positive or neutral to the introduction of a fluctuating water level. At the MW, food and water purification respond negatively to the introduction of a fluctuating water level. This is due to the closing of basins at the MW, which is a prerequisite for a fluctuating water level, and the limited interaction between the MW and MM this results in. There are tensions between optimising the local ecosystem services delivery at the MW and the impact the MW is intended to have on the MM. This is acknowledged by the interviewees and elaborated upon later in this chapter.

Table 7: Overview of delivered ecosystem services. - = low, 0 = not applicable, + = medium, ++ = high. * = Also quantitatively discussed in Tier 1.

		Oostvaardersplassen		Marker Wadden	
Group	Ecosystem service	Stable	Fluctuating	Stable	Fluctuating
Provisioning	*Food*	0	0	++	+
	Fresh water	0	+	0	0
Regulating	*Water purification**	--	+	++	+
	Climate regulation	0	0	0	0
	Flood protection	0	+	+	+
Cultural	*Recreation*	+	++	+	++
	Aesthetics	+	++	+	++
	Education	++	++	++	++
Supporting	*Habitat*	+	++	+	+
	*Nutrient cycling**	+	++	+	+
Biodiversity*		-	++	+	++

Cultural services

At the MW, there is opportunity for recreation at one of the five islands. At the OVP, recreation opportunities are mainly found at the borders of the wetland (Staatsbosbeheer, #10). Recreation and aesthetics are to a larger extent delivered under a fluctuating water level than under a stable water level at both the OVP and MW. This is in line with the increased areal of pioneer habitat under this water level management strategy. The pioneer habitat and associated flora and fauna, including birds, increase the potential for recreation following their aesthetic values. This is demonstrated by bird watchers, who visit the OVP and MW for their wetland bird populations.

Both wetlands provide opportunity to learn about (constructed) wetlands and the (history of) water and nature management in the Netherlands. The water level management strategy in place does not affect the possibility to learn about these. Recently, learning about nature was found to be the most important reason for visiting the MW (Natuurmonumenten, #2).

Supporting services

At the OVP, the fluctuating water level is introduced to facilitate the comeback of pioneer habitat at the expense of open water habitat. Among the interviewees, there was agreement on the pioneer habitat being more desirable than open water habitat, considering the Natura 2000 bird goals at the OVP. Both habitat and nutrient cycling are to a larger extent delivered under a fluctuating water level than under a stable water level at the OVP.

At the MW, the fluctuating water level ensures retaining the current pioneer wetland habitat, but it also reduces spawning habitat for fish in the MM due to the closing of basins at the MW, which is prerequisite for a fluctuating water level. Furthermore, the closing of dikes reduces the positive impact the MW is intended to have on the MM regarding nutrient cycling. For both habitat and nutrient cycling, there was no consensus on whether the situation under a stable or fluctuating water level would be more beneficial overall.

Biodiversity
The bird-related biodiversity goals at the OVP have more potential to be reached under a fluctuating water level than under a stable water level. The water level fluctuations at the MW are also beneficial in creating valuable (bird) habitat at a local spatial scale. When also considering the MM, this service would be valued lower under a fluctuating water level at the MW.

Provisioning services
The MW provides spawning habitat for fish and there are signs that the MW positively contributes to fish populations in the MM (van der Winden, 2019) and at least not negatively affect fisheries (Leeuwen et al., 2021). In an interview, a representative of Nederlandse Vissersbond said, "*There could in theory be an advantage of the MW for fisheries, but this is currently not noticed by fishermen.*" (Nederlandse Vissersbond, #9). To implement a fluctuating water level at the MW, basins must be closed. This reduces the available spawning habitat and thereby limits the potentially positive effect of the MW on fish populations and potentially fisheries. In contrast with the MW, food is not a relevant ecosystem service for the OVP, as there is no agriculture in the area nor fisheries.

Fresh water is, in contrast with the MW, a relevant service from the OVP which could theoretically be used to store water. However, the topography of the area is less suitable for this purpose, as it is one of the highest places in the polder. Waterschap Zuiderzeeland does therefore not see fresh water (retention) as a service the OVP provides, but the area can easily be used to store precipitation that falls in the OVP (Waterschap Zuiderzeeland, #8). Under a fluctuating water level, there is more potential to store water, provided that the water level prior to storing water is lower than the water level under a stable water level management.

Regulating services
In the OVP, there will be more water purification under a fluctuating water level than under s stable water level, due to more sediment-water interactions and vegetation purifying the water. Furthermore, there will be more exchange of water between the OVP and MM under a fluctuating water level, further increasing the quantity of water purified by the wetlands. This assumes that water is pumped into or taken from the MM to facilitate water level fluctuations in the OVP.

For the MW, satellite images show that at the wind-sheltered side of the archipelago, the concentrations of suspended sediment are lower than elsewhere (Figure 20). The effects of wind on the concentrations and the disturbances occurring due to construction works at the MW, make it hard to quantify the effect of the MW on the MM. However, when more basins are closed within the island, to allow a fluctuating water level management, there will be less possibility for sediment to settle. Furthermore, there will be less interaction between the MM and the water purifying reed marshes (Rijkswaterstaat, #16).

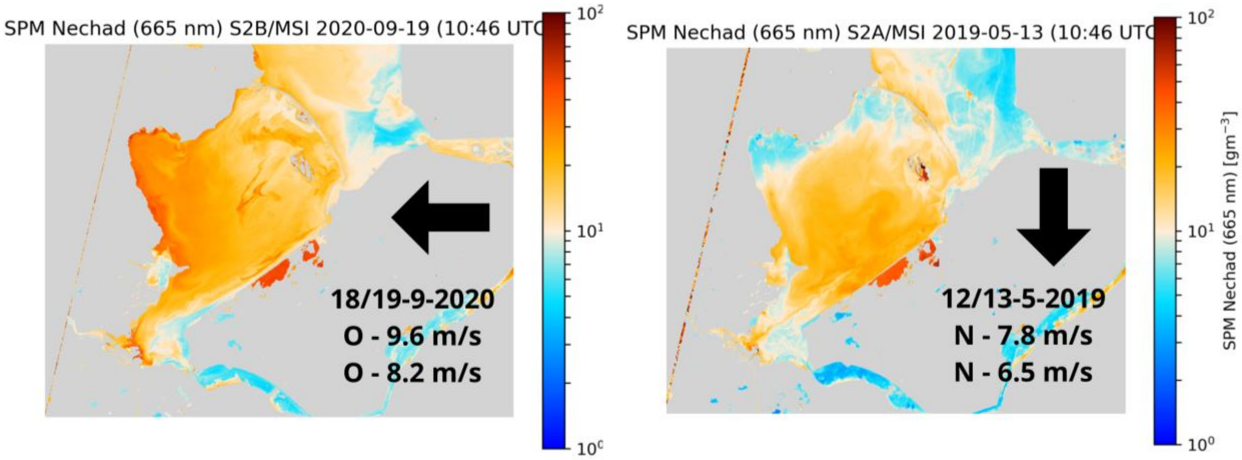

Figure 20: Suspended matter concentration of the MM under different wind directions; east wind at left picture and north wind at right picture. Maps are based on Sentinel images and have been made at Deltares by M. Eleveld.

The role of wetlands in regulating the climate via sequestering and storing carbon is increasingly recognised (Frolking & Roulet, 2007). However, the marine sediment in the OVP and MW has high sulphur concentrations, leading to high sulphate concentrations under anaerobic conditions, allowing bacteria to quickly turn over the stored carbon (Staatsbosbeheer, #11). The potential for climate regulation is thus very limited for both wetlands, independent of the water level management strategy (Staatsbosbeheer, #11).

Regarding flood protection, the OVP can be used to store water and thereby prevent floods. However, its topography makes this rather challenging. The MW only indirectly has a flood protection function, by limiting the waves and wind exposure on the Houtribdijk. Whether or not closing basins, which is required for the fluctuating water level, is altering this ecosystem service, is hard to predict.

Tensions MW - MM

The newly introduced fluctuating water level at the MW, does alter both the ecosystem services delivered by the MW and the MM. From the MW-perspective, the fluctuating water level is beneficial for the delivery of the ecosystem services habitat, biodiversity, nutrient cycling, and water purification at a local level. At this spatial scale, beneficial means a positive contribution to the bird paradise the MW is meant to be.

From the MM-perspective, interaction between the water in MM and MW should be optimised to have increased delivery of ecosystem services from the lake. Closing basins as the MW, which is needed to have a fluctuating water level, leads to limited interaction with the MW and therefore a limited positive impact on the MM (Rijkswaterstaat, #16).

5.2.2 Fulfilment of demanded ecosystem services

The demanded ecosystem service differed amongst the stakeholders, even though recreation, habitat, and biodiversity are the most widely demanded services (Table 8). These services are delivered to a larger extent under a fluctuating water level than under a stable water level, when only considering the local spatial scale of the OVP and MW.

Table 8: Ecosystem services demanded by involved stakeholders. The # refers to the number of the interview in which the ecosystem service was mentioned.

Legend
Not mentioned or not applicable
Potentially important in future
Important or needed for most important
Most important

Oostvaardersplassen		Provisioning		Regulating			Cultural			Supporting		-
		Food	Fresh water	Water purification	Climate regulation	Flood protection	Recreation	Aesthetics	Education	Habitat	Nutrient cycling	Biodiversity
Nature managers	Staatsbosbeheer				#10		#10, #11	#10, #11	#10, #11	#10, #11	#10	#10, #11
Government bodies	Municipality of Lelystad						#4		#4	#4		#4
	Municipality of Almere						#5			#5		#5
	Province of Flevaond		#3	#3	#3	#3	#3			#3		#3
	Water board Zuiderzeeland		#8	#8			#8	#8	#8	#8	#8	#8
	Rijkswaterstaat			#14,15,16						#14,15,16	#14,15,16	#14,15,16
Interest groups	Vogelbescherming						#12	#12		#12		#12
	Nederlandse Visserijbond									#9		

Marker Wadden		Provisioning		Regulating			Cultural			Supporting		-
		Food	Fresh water	Water purification	Climate regulation	Flood protection	Recreation	Aesthetics	Education	Habitat	Nutrient cycling	Biodiversity
Nature managers	Natuurmonumenten			#1, #2			#1, #2		#1, #2	#1, #2	#1	#1, #2
Government bodies	Municipality of Lelystad			#4			#4		#4	#4	#4	#4
	Municipality of Almere			#5			#5			#5	#5	#5
	Province of Flevaond						#3			#3		#3
	Water board Zuiderzeeland		#8	#8			#8	#8	#8	#8	#8	#8
	Rijkswaterstaat			#14,15,16						#14,15,16	#14,15,16	#14,15,16
Interest groups	Vogelbescherming						#12	#12		#12		#12
	Ijsselmeervereniging						#6		#6			
	Sportvisserij Nederland			#7			#7			#7	#7	#7
	Nederlandse Visserijbond	#9							#9	#9		

For both wetlands, the nature managers value the ecosystem services habitat and biodiversity as most important. These services are also listed as important – and sometimes even most important – by the government bodies. Interest groups also frequently mention these services as important, even though they sometimes have other priorities such as food (fisheries), water purification, and education.

Parties often have different demands per wetland. Such as the province of Flevoland, who lists biodiversity and habitat as most important for the OVP – as this party is responsible for reaching the Natura 2000 goals there – while it lists recreation as most important for the MW (Province of Flevoland, #3). This can be explained by the fact that reinforcing the nature values of the MM is the national government's responsibility, not of the province (Province of Flevoland, #3). On the other hand, nature managers list biodiversity and habitat as the most important services while not being responsible for reaching the goals. The Vogelbescherming is, as an interest group, on the same page as the nature managers.

Nutrient cycling and water purification are often not explicitly mentioned by stakeholders. However, improving habitat and biodiversity in the MM (via the MW), creating gradual land water transitions, gradients in turbidity in the MM, and the importance of reed marshes were mentioned frequently. Nutrient cycling and water purification are also considered demanded services in these cases.

Recreation and education are often seen as important, by the different parties. For Natuurmonumenten, they are amongst others essential as they are important drivers for people to visit the MW (Natuurmonumenten, #2). Sportvisserij Nederland emphasises that prior to creating opportunity for recreational fisheries, an improvement of aquatic ecosystems functioning is needed. Therefore, this party attaches value to the ecological value of the ecosystems as well as recreation (Sportvisserij Nederland, #7). The municipality of Lelystad finds it important that the wetlands are "*experienceable for visitors*" (Municipality of Lelystad, #4). This municipality also finds it crucial to involve citizens in nature development and create more awareness of the importance of biodiversity. Recreation is also deemed important by the municipality of Almere (Municipality of Almere, #5) and the IJsselmeervereniging (IJsselmeervereniging, #6). The latter was initially against construction of the MW, as it attaches a lot of value to the open character of the area (IJsselmeervereniging, #6).

There is friction in the delivery of the most demanded ecosystem services. In the OVP, recreation is only possible at the borders of the wetland, as recreation within the wetland would cause disturbance and thereby limited delivery of the ecosystem services biodiversity and habitat (Staatsbosbeheer, #10 and #11). Regarding the MW, recreation is only possible at one of the five islands, for the same reason as mentioned for the OVP. An increased focus on delivering habitat and biodiversity, would on the other hand go at the costs of recreation (Natuurmonumenten, #1).

For the MW, the ecosystem services habitat and biodiversity can both be associated with the MW as well as the MM. On the one hand, a "fish and bird paradise" is created at the MW, improving habitat and biodiversity at a local spatial scale (Rijkswaterstaat, #14). On the other hand, the MW is built to ecologically improve the MM, thereby improving the delivery of the ecosystem services habitat and biodiversity of the MM (Rijkswaterstaat, #14). In this assessment, both interpretations are seen as a demanded ecosystem service from the MW when mentioned by a stakeholder.

6. Discussion

This thesis aimed to assess how the delivery of ecosystem services and the fulfilment of the demanded ecosystem services differ under a stable and a fluctuating water level management strategy at the OVP and MW. Regarding the delivery of ecosystems services, results show that the newly introduced fluctuating water level management strategy alters the ecosystem services delivery of the constructed wetlands, in line with the used framework. The most widely demanded ecosystem services (habitat, biodiversity, and recreation) are delivered to a greater extent under a fluctuating water level than under a stable water level, when considering the local spatial scale of the MW and OVP. However, to take explicit and deliberate management choices, one should also consider the impact that local management interventions have on a larger spatial scale. This is shown by the negative effects of closing basins at the MW, which is a prerequisite for a fluctuating water level there, has on the MM.

The results from this thesis are discussed in Section 6.1 with the help of literature. Later, in Section 6.2, methodological aspects and the framework used are discussed. In both sections, results from the quantitative and qualitative analyses are consecutively addressed.

6.1 Results discussion

6.1.1 Tier 1: Quantitative

Multiple processes affecting water purification parameters

Turbidity and suspended sediment concentration showed similar patterns, as hypothesised, with no significant differences at the MW and significantly higher values under a fluctuating water level than under a stable water level at the OVP. The findings at the OVP are in line with the hypothesis that values for turbidity and suspended sediment are higher when the water level is lowering, while at the MW, the findings were not in line with that hypothesis.

The higher values for turbidity and suspended sediment under a fluctuating water level, as found at the OVP, can be explained in multiple ways. It can be explained by the increased turbulence following the water level drop, as was found for Lake Balaton (Hungary), which is a large shallow lake (Lake Balaton, Hungary) (G.-Tóth et al., 2011). Besides increased turbulence, the higher chlorophyll-a concentrations in the West of OVP, as found in this thesis, could have led to higher values for turbidity and suspended sediment concentration under a fluctuating water level than under a stable water level at the OVP.

Overall, turbidity and suspended sediment levels were higher in the OVP than in the MW. This might be attributed to carp and bream, which are present in much higher density in the OVP than in the MM. The feeding strategy of these benthic fish causes high turbidity and suspended sediment levels (Breukelaar et al., 1994). Another potential reason for the lower turbidity and suspended sediment concentrations at the MW, are the dried land parts between the pools at the MW, which offer plants habitat to establish, creating partly sheltered areas. These sheltered circumstances increase the settlement of sediment and thereby decrease turbidity and suspended sediment concentrations (Noordhuis, 2010).

For the MW, it could furthermore be argued that the lack of differences between sub-areas with different water level management strategies for turbidity and suspended sediment results from the current homogeneity of the archipelago, following its recent construction. Over time, heterogeneity between sub-areas will potentially increase under the influence of the different water level management strategies. Increased heterogeneity will potentially translate into significant differences in the values of the parameters assessed for water purification.

Biodiversity and abundance at low trophic levels
The measured effect of the newly introduced water level management strategies on the ecosystem service biodiversity is overall not in line with the hypothesis that chlorophyll-a [mg/l], zooplankton [H], water macrofauna [H] and sediment macrofauna [g/m^2] would be higher under a fluctuating water level.

The significantly lower zooplankton values [H] under a fluctuating water level at the MW, are in line with a study on Lake Balaton (Hungary), in which it was found that the populations of several zooplankton species decreased by 60–90% simultaneously with the water-level decrease and regenerated once the water level increased (G.-Tóth et al., 2011). The increased turbulence coupled with the water-level decrease caused this response by the zooplankton communities (G.-Tóth et al., 2011). This could have been the case at the MW too, as values for suspended sediment were higher under a fluctuating water level than under a stable water level. These differences are however only close to significant (P = 0.071). At the OVP, the differences in suspended sediment concentration between the different water level management strategies were significant. However, at the OVP, for the same comparison, the differences for zooplankton [H] were not significant (P = 0.105). Tersely, the patterns for zooplankton and suspended sediment are at both the OVP and MW in line with findings from G.Tóth et al. (2011), making increased turbulence a plausible cause for the decrease in zooplankton [H], even though this has not been statistically proven in this thesis.

For both water macrofauna [H] and sediment macrofauna [g/m^2], it was hypothesised that values would be higher under a fluctuating water level, based on literature in which it was found that temporary drawdown events have a positive effect on the diversity and richness of macrofauna (Van de Meutter et al., 2006). However, at the MW, no significant differences between areas with a stable and fluctuating water level were found. At the OVP, comparisons could not be made due to missing data. It could be that increases in values for sediment macrofauna [g/m^2] and water macrofauna [H] have not been observed due to increased potential for birds to feed on them when the water level is decreasing.

The significantly higher chlorophyll-a values [mg/l] under a fluctuating water level than under a stable water level at the OVP, are conflicting with the high values for turbidity and suspended sediment, following the negative correlation between chlorophyll-a and light penetration (Gorde & Jadhav, 2013). Vonk et al. (2017) mention that water drawdown events will improve light penetration and thereby potentially cause an increase in chlorophyll-a levels. One could thus also argue that the high chlorophyll-a levels, found under a fluctuating water level at the OVP, contribute to the high turbidity. However, this is likely not the case for the OVP, since Vonk et al. (2017) address the situation after pioneer vegetation has established and the water level rises again, as the water will then be less turbid. Furthermore, the high turbidity at the OVP is likely to have been caused by increased turbulence (G.-Tóth et al., 2011), and therefore not (only) by chlorophyll-a.

The values found for chlorophyll-a at the OVP, both in areas with a stable and fluctuating water level, are much lower than values found in another study on the OVP (Oosterberg, 1995). This could be explained by the temporal variation chlorophyll-a concentrations generally show over the seasons (Marshall & Peters, 1989) in combination with the limited timespan of the fieldwork for this thesis. The values found by Oosterberg (1995), for the OVP, are already lower than one would expect based on the eutrophic conditions. Oosterberg (1995), unlike Gorde & Jadhav (2013), attributes the low chlorophyll-a concentrations to the high zooplankton population and the lack of young planktivorous fish and chameleon shrimp. The values found for chlorophyll-a at the MW are in the same order of magnitude as values mentioned in another study on Lake Markermeer banks (van Duin, 1992) and, more recently, in and around the MW (Jin, 2021).

Increased nutrient & organic matter values under a fluctuating water level

The introduced fluctuating water level seems to positively contribute to nutrient cycling, via increased nutrient / organic matter levels in suspended sediment and water. The absence of significant differences for nutrients and organic matter in the sediment could be attributed to the combination of multiple simultaneous processes. On the one hand, nutrient concentrations in the sediment can increase under a drawdown event due to the penetration of oxygen in the sediment that can accelerate the decomposition of organic matter (van Dijk et al., 2013). On the other hand, phosphorus concentrations have the potential to decrease soon after falling dry (Loeb et al., 2008) and denitrification, following oxidation of ammonium, leads to loss of nitrogen (van Dijk et al., 2013). The processes in the sediment might have led to the observed increased concentrations of organic matter and nutrients in the suspended sediment and in the water column. However, also the increased interaction with shore zones under a fluctuating water level might have attributed to this. This can be explained by the increased opportunity for nutrients and organic matter in the shore zone sediment to bind to suspended sediments or dissolve in the water, boosting the aquatic system (Gottgens, 1994).

6.1.2 Tier 2: Qualitative

The most widely demanded ecosystem services (recreation, habitat, and biodiversity) are delivered to a greater extent under a fluctuating water level than under a stable water level, as was found in the interviews. Considering this, one would argue that the fluctuating water level should be implemented more widely. However, when also considering a broader spatial scale than the local spatial scale of the management intervention, one finds negative results from the introduction of a fluctuating water level at the MW on the MM. For the OVP, on the other hand, no adverse side effects, on a local and broader spatial scale, of the newly introduced fluctuating water level are identified.

At the MW, the closure of basins is a prerequisite to have water level fluctuations in the current situation, in which the MM has a relatively stable water level. The closure of basins at the MW limits interaction between the MM & MW. These limited interactions cause a decrease in ecosystem services delivery by the lake, compared to the situation with open basins at the MW. The limited interactions under a fluctuating water level at the MW, reduce the ecosystem services food, water purification, habitat, nutrient cycling, and biodiversity at the MM level (**Table *9***). When basins at the MW close, at MM level the ecosystem service food is reduced to the decrease in spawning habitat for fish, while nutrient cycling and water purification are reduced due to the decrease in water-shore interaction. As a resultant of the other ecosystem services, biodiversity is also expected to decrease. This research advocates thus for a proper analysis of the effects of a management intervention on a broader spatial scale than only the local spatial scale of the management intervention.

Table 9: Delivered ecosystem services analysis including preliminary analysis lake Markermeer

		Marker Wadden	Markermeer
Group	Ecosystem service	Effect of introducing fluctuating water level at MW	Effect of introducing fluctuating water level at MW
Provisioning	*Food*	-	-
	Fresh water	0	Not considered
Regulating	*Water purification*	-	-
	Climate regulation	0	Not considered
	Flood protection	0	Not considered
Cultural	*Recreation*	+	Not considered
	Aesthetics	+	Not considered
	Education	0	Not considered
Supporting	*Habitat*	0	-
	Nutrient cycling	0	-
Biodiversity		+	-

When assessing the ecosystem services delivery by the MW, assessed in the interviews, there was no clear distinction made between the effects of the fluctuating water level at MW and MM level. Therefore, part of the effect of the fluctuating water level on the MM is already considered in the initial assessment of the delivered ecosystem services of the MW. This is the case for the ecosystem services food and water purification, which showed a decrease in delivery under the introduction of a fluctuating water level. A similar note can be made for habitat and nutrient cycling, which would be delivered to a larger extent when strictly considering the local spatial scale of the MW. In the overview provided in the results section, which is based on the interviews, the effect on the MM is thus already (partly) incorporated in the analysis for the MW.

The effect the MW has on the MM, should be the main concern for managing the wetlands, following the reason of constructing related to improving the ecological status of the MM. However, construction of the archipelago has been initiated by Natuurmonumenten – who is also managing the wetlands - while framing the MW as a bird paradise. The focus on small scale improvements at the MW by introducing a fluctuating water level, with the bird goals in mind, hinders the initially aimed for restoration of the MM. The extent to which this happens has not been quantified.

6.2 Methodological discussion

Overall, this research showed that improved delivery of ecosystem services at a local spatial scale can negatively affect the delivery of ecosystem services on a larger spatial scale. Therefore, it is recommended to not only assess the management implications on the spatial scale of intervention, but also at the larger spatial scale of impact. This requires updating the conceptual framework, which now only considers the local spatial scale of management.

In the next section methodological aspects of the quantitative tier are discussed, after which, one section later, methodological aspects of the qualitative tier are discussed.

6.2.1 Tier 1: Quantitative

(Mis)matches in biodiversity goals, parameters, and sampling methods

Looking into methodological aspects, the Shannon-Wiener diversity index, which is used for zooplankton and water macrofauna, is a biodiversity indicator and not directly a food availability indicator for higher trophic levels. The latter is what matters most in the light of the bird-related biodiversity goals in the research area. Sediment macrofauna [g/m^2] can be considered a food availability indicator under the assumption that the fauna contributing to food availability for birds lives in the sampled upper 10 cm of the sediment (Matisoff et al., 1985). Furthermore, the methods used in this thesis focus on the diversity and abundance of low trophic levels at a specific point in time, rather than on the productivity of these trophic levels. In future research, putting more emphasis on productivity would therefore be useful, as in the MM a declining primary productivity has likely impaired biodiversity at higher trophic levels (van Leeuwen et al., 2021).

Regarding sampling methods, for zooplankton the whole water column has been sampled at the MW, due to the very limited water depths, while at the OVP only the upper layer has been sampled. However, several studies show that zooplankton is generally not vertically equally distributed (Lampert, 2005; Vad et al., 2013). It is recommended to consider this in the design of future research by using a uniform methodology per parameter.

For water macrofauna, the method applied at the MW might have been more successful in catching water macrofauna close to the sediment, as there the net was bounced softly on the sediment to activate the fauna. This makes it challenging to compare the OVP and the MW on water macrofauna, based on findings from this thesis.

Assessment of complete water level cycle

For the quantitative tier of this thesis, only a small part of the water level cycle has been assessed, following the timing of the fieldwork. Samples have only been taken during the drawdown when the water level was lowering. This has implications for the results, which cannot be seen as results for the complete water level cycle.

Once pioneer vegetation has re-established and the water level rises again, the ecosystem characteristics and thereby the ecosystem services delivery will namely be different. Then, decreases in turbidity and suspended sediment are expected (Hanson & Butler, 1994). Furthermore, at the OVP, the concentration of carp and bream will initially be low when the water level rises again, limiting bioturbation, increasing confidence in the expected low turbidity and suspended sediment levels. Also, the indicators for biodiversity and nutrient cycling are expected to have different values in different phases of the water level cycle. For biodiversity, the hypotheses for increased abundance and diversity at low trophic levels under a fluctuating water level therefore still stand.

To better understand to what extent the ecosystem service water purification, biodiversity and nutrient cycling are delivered under the different water level management strategies, it is therefore recommended to assess all stages of the water level in future research, instead of only during the water level drawdown as was done for this thesis. Doing so, would provide a more complete understanding of how the parameters respond to the newly introduced fluctuating water level, rather than only showing a snapshot of a particular moment in the water level cycle. Sampling over the whole water level cycle, would thereby also better fit the research questions posed in this thesis on how the delivery of the ecosystem services water purification, biodiversity, and nutrient cycling change by the introduction of a fluctuating water level management strategy.

6.2.2 Tier 2: Qualitative

The assessment of demanded and provided ecosystem services is based on information provided by interviewees who might have specific interests and who might not be a perfect representative of their party. This is partly countered by (sometimes) interviewing multiple people per party and triangulation with literature. The interviewees all responded to my request to interview them or responded to the request within their organisation to be interviewed. This might have led to a selection of interviewees who e.g., like to share their vision, have time for the interview and are interested in the assessment of ecosystem services. This might have led to bias in the results of provided and demanded ecosystem services. Lastly, the semi-structured set-up allowed the interviews to be flexible and tailored but also hard to compare.

To better structure the interviews, it is recommended to ask interviewees to rank their demanded ecosystem services at the end of the interview. Furthermore, it is recommended to distinguish the different spatial scales of ecosystem services delivery and demand more clearly. Thereby, the interviewer would ask the interviewee explicitly on what ecosystem services it demands from the area of interest as well as the area on which it might have an impact.

Taking up the recommendations as provided in the discussion of thesis in future research, will contribute to a completer and more useful overview of the provided and demanded ecosystem services of constructed wetlands and their surroundings.

Lastly, it should be noted that thesis only focussed on the water level management of the constructed wetlands, being the OVP & MW. It did not focus on the water level management of the MM. Therefore, the effect of the locally introduced fluctuating water level on the MM has been discussed, and not vice versa.

7. Conclusion

This research aimed to assess the differences in ecosystems services delivery by two constructed wetlands, the Marker Wadden and Oostvaardersplassen, under a stable and fluctuating water level management strategy, as well as the extent to which they fulfil the demands of stakeholders. Based on quantitative and qualitative analyses, it can be concluded that the introduction of a fluctuating water level in the constructed wetlands leads to larger delivery of the most widely demanded ecosystem services, being habitat, biodiversity, and recreation at the local scale of the Marker Wadden and Oostvaardersplassen. By finding negative side-effects of the newly introduced fluctuating water level at the Marker Wadden on Lake Markermeer, this research also showed that improved delivery of ecosystem services at a local spatial scale can negatively affect the delivery of ecosystem services on a larger spatial scale.

This research contributes to understanding the complexity of ecosystem services delivery and demand related to constructed wetlands. Finally, it contributes to taking explicit and deliberate management choices regarding the water level management of constructed wetlands.

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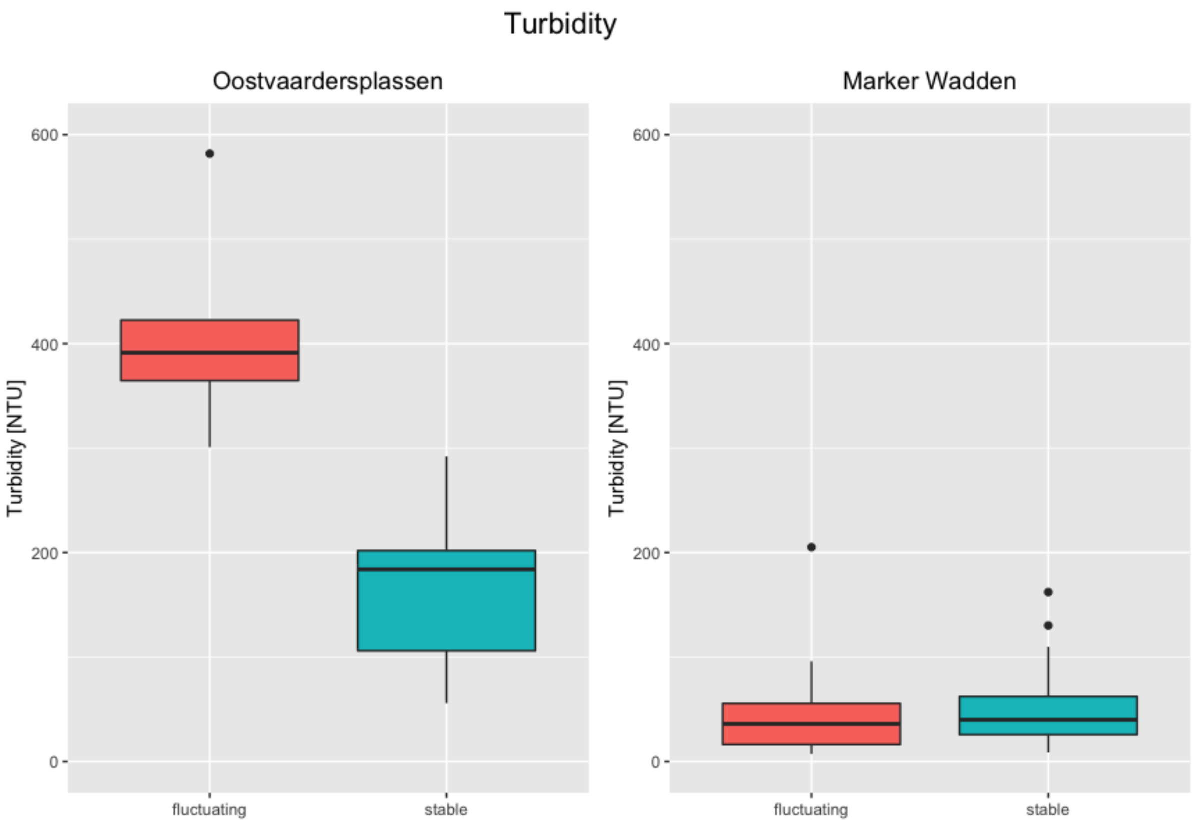
9. Annexes

9.1 Statistics of quantitative analysis

In the following subchapters, per variable, an overview of the statistical analysis is provided. In the tables, F stands for sub-area with a fluctuating water level, while S stands for sub-area with a stable water level. N stands for the number of samples analysed. Mean stands for the mean value of all samples in that row. SD stands for the standard deviation of the values obtained for the variable assessed and is included per sub-area considered. In the tables, green shading indicates a significant difference in the mean value obtained for the two sub-areas considered of either the OVP or MW. Below the tables, the results are visualised in boxplots.

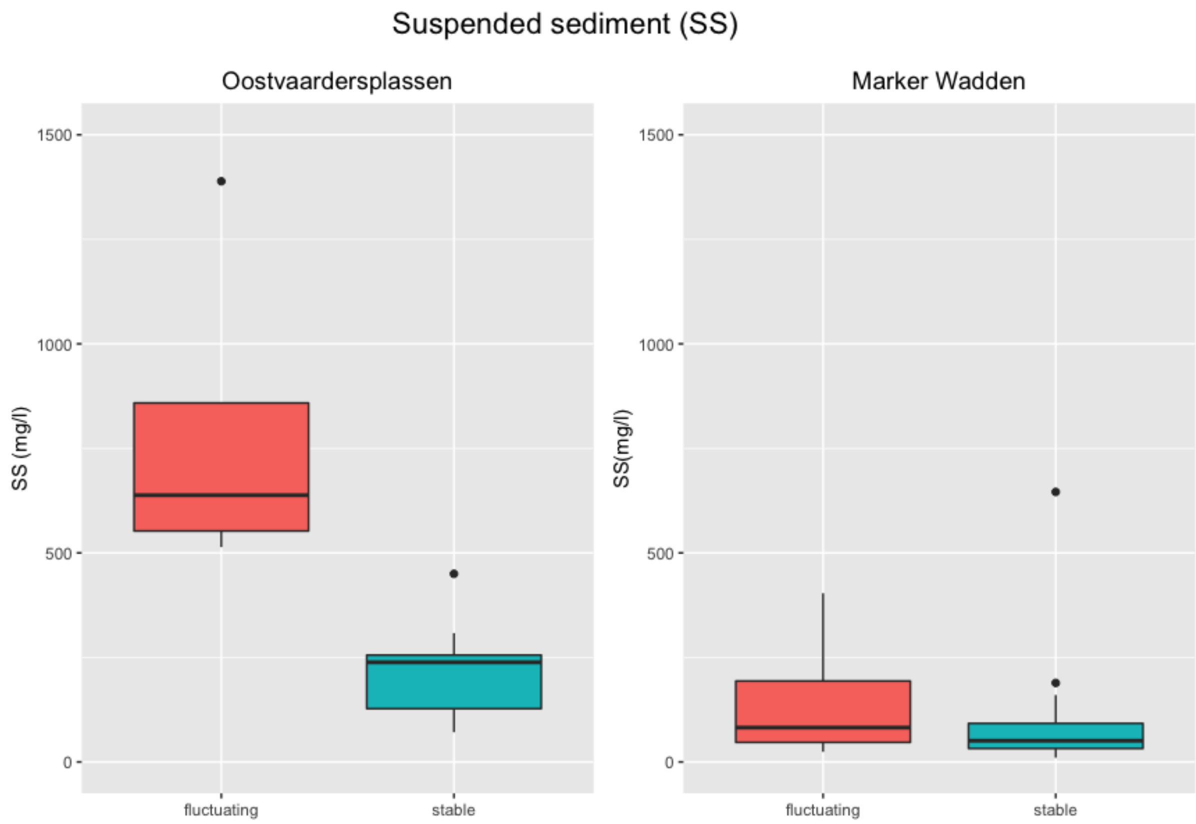
9.1.1 Turbidity

Turbidity [NTU]							
Area	F or S	N	Mean	SD	P-Value		
					Welch T-Test	Welch T-Test on log data	Mann–Whitney U Test
OVP	F	5	412.24	104.87		< .001	
OVP	S	20	159.66	63.51			
MW	F	30	49.48	50.59		0.570	
MW	S	15	50.34	36.85			



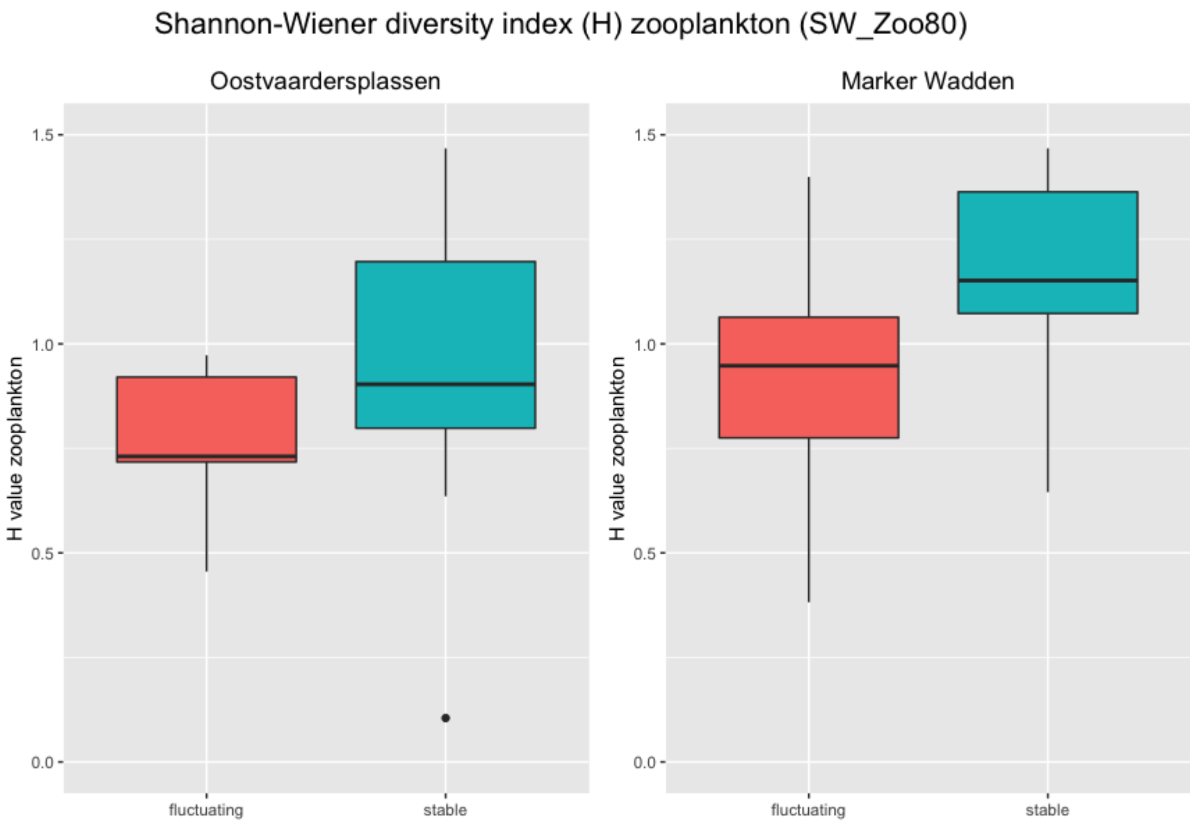
9.1.2 Suspended sediment

Suspended sediment [mg/l]							
Area	F or S	N	Mean	SD	P-Value		
					Welch T-Test	Welch T-Test on log data	Mann–Whitney U Test
OVP	F	5	790.34	360.23		< .001	
OVP	S	20	205.43	92.75			
MW	F	30	125.58	108.54		0.071	
MW	S	15	84.37	115.60			



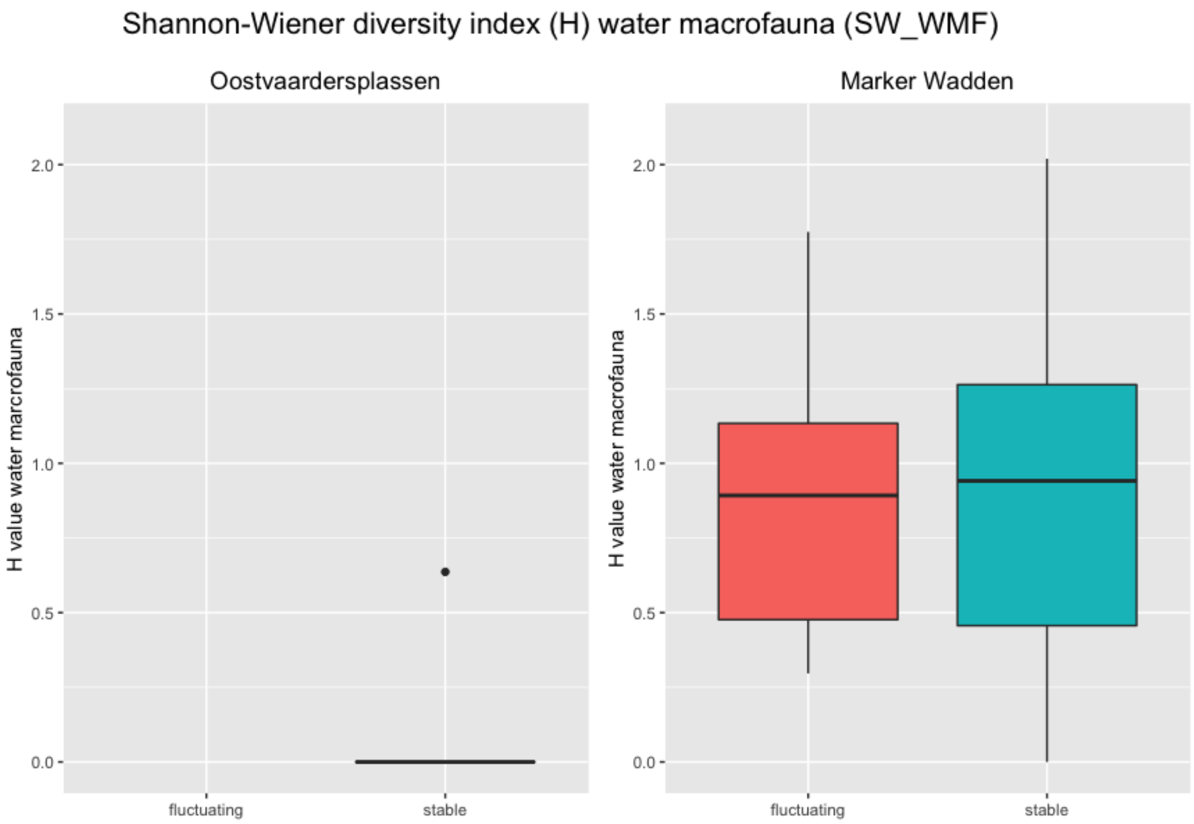
9.1.3 Shannon-Wiener diversity index zooplankton

Shannon-Wiener diversity index [H] zooplankton							
Area	F or S	N	Mean	SD	P-Value		
					Welch T-Test	Welch T-Test on log data	Mann–Whitney U Test
OVP	F	5	0.76	0.20	0.105		
OVP	S	20	0.97	0.33			
MW	F	30	0.91	0.31	< .001		
MW	S	15	1.28	0.32			



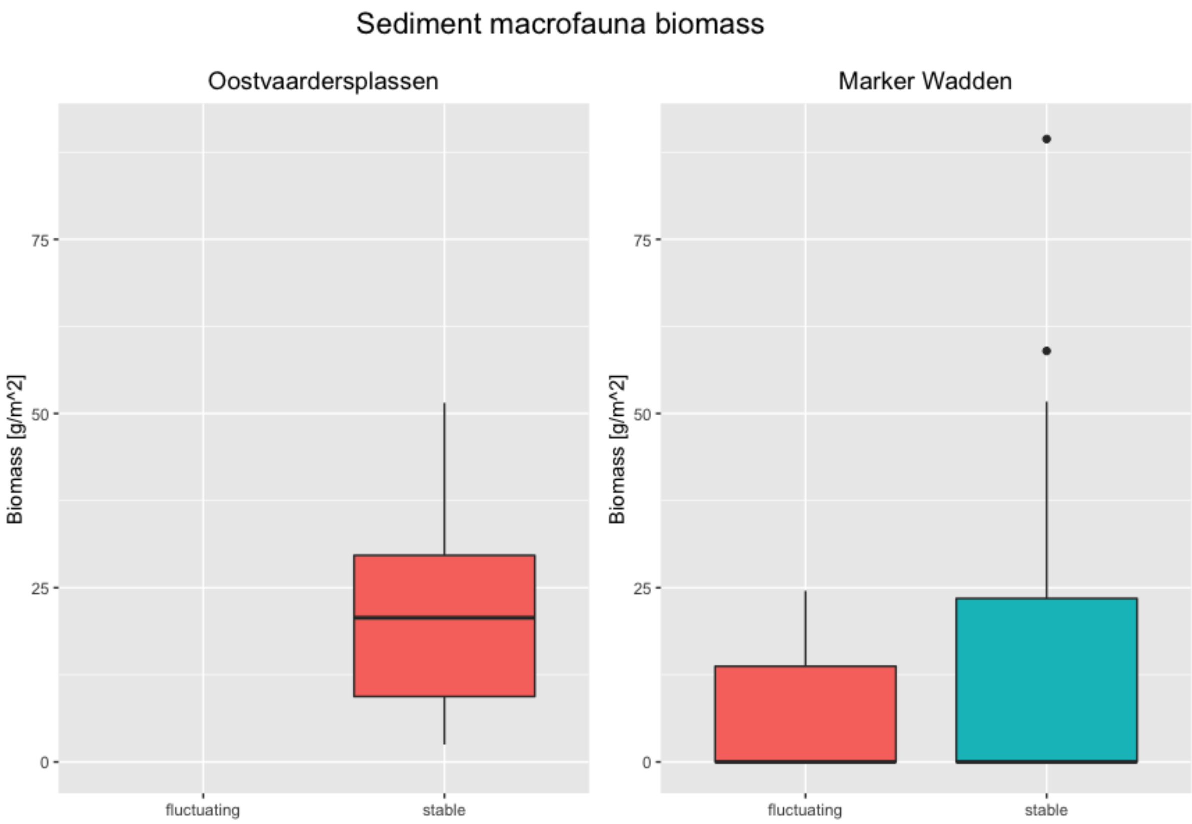
9.1.4 Shannon-Wiener diversity index water macrofauna

Shannon-Wiener diversity index [H] water macrofauna							
Area	F or S	N	Mean	SD	P-Value		
					Welch T-Test	Welch T-Test on log data	Mann–Whitney U Test
OVP	F	0					
OVP	S	15	0.04	0.16			
MW	F	30	0.86	0.46	0.908		
MW	S	15	0.87	0.57			



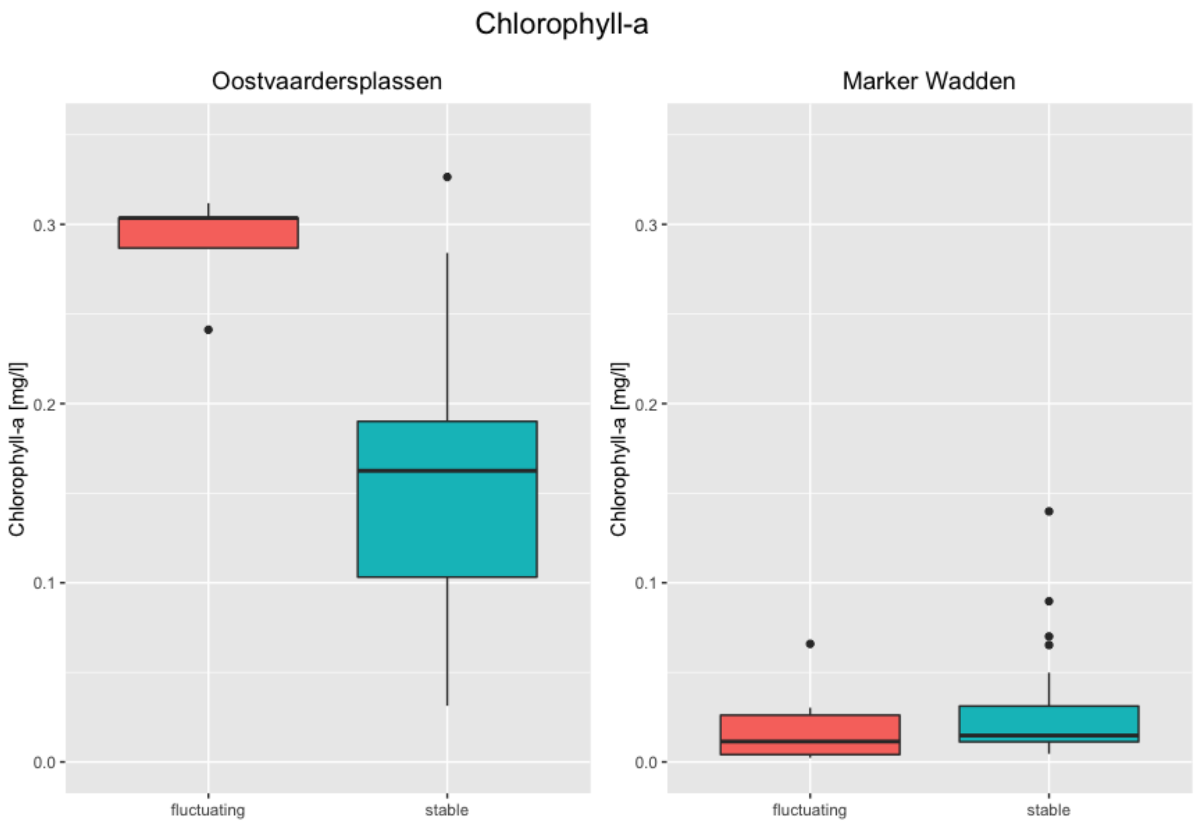
9.1.5 Sediment macrofauna biomass

Sediment macrofauna biomass [g/m^2]							
Area	F or S	N	Mean	SD	P-Value		
					Welch T-Test	Welch T-Test on log data	Mann–Whitney U Test
OVP	F	0					
OVP	S	15	20.76	14.69			
MW	F	30	6.18	8.79			0.334
MW	S	15	16.11	23.41			



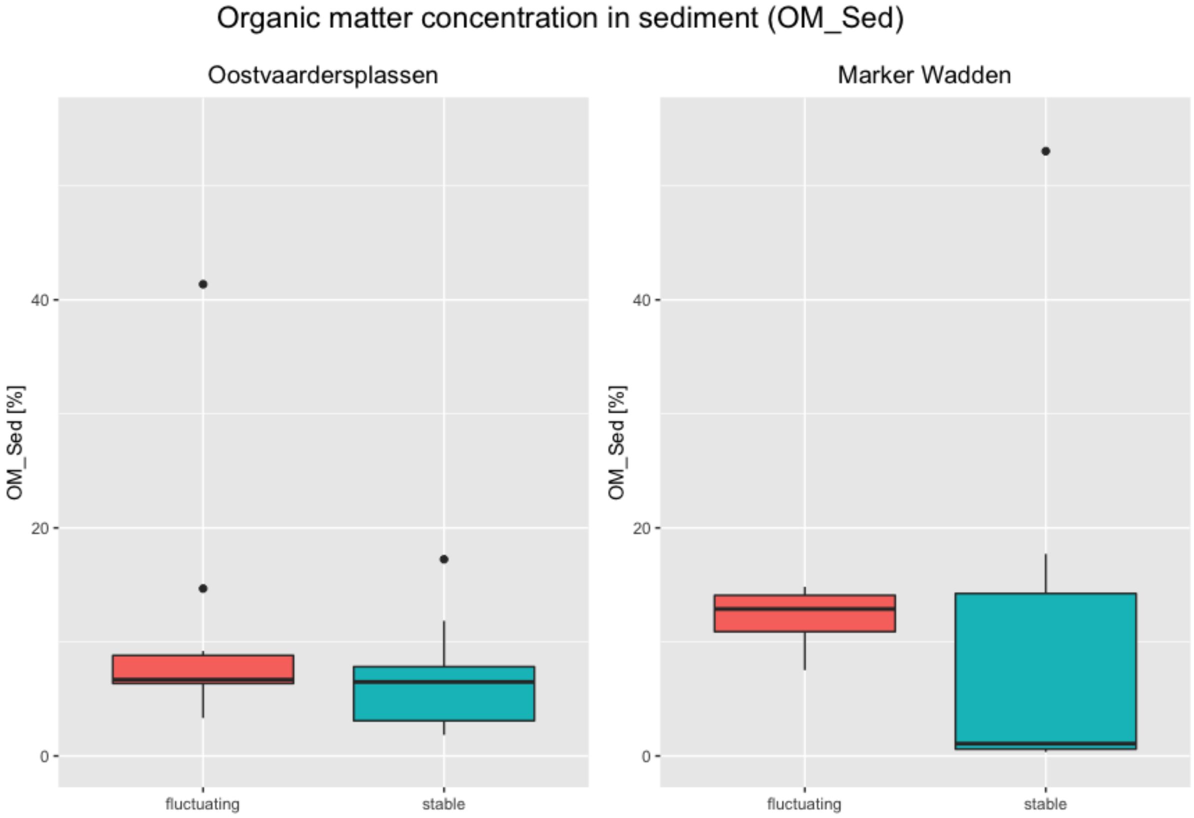
9.1.6 Chlorophyll-a

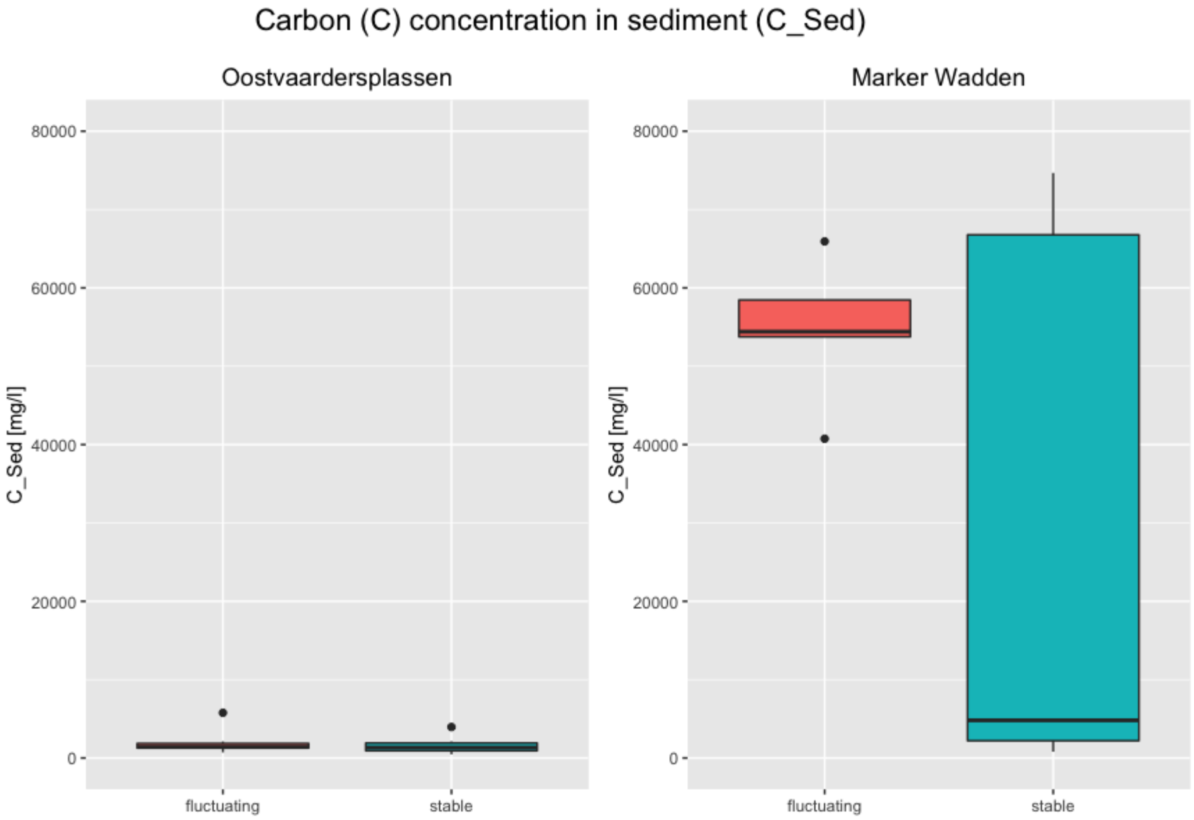
Chlorophyll-a [mg/l]							
Area	F or S	N	Mean	SD	P-Value		
					Welch T-Test	Welch T-Test on log data	Mann–Whitney U Test
OVP	F	5	0.289	0.028	< .001		
OVP	S	20	0.157	0.077			
MW	F	30	0.016	0.017			0.052
MW	S	15	0.058	0.169			



9.1.7 Nutrients and organic matter in the sediment

Organic matter concentration in sediment (OM_Sed) [%]							
Area	F or S	N	Mean	SD	P-Value		
					Welch T-Test	Welch T-Test on log data	Mann–Whitney U Test
OVP	F	10	10.78	11.15		0.197	
OVP	S	10	6.78	4.83			
MW	F	5	12.05	2.93			0.340
MW	S	10	10.24	16.53			
Carbon (C) concentration in sediment (C_Sed) [mg/kg]							
Area	F or S	N	Mean	SD	P-Value		
					Welch T-Test	Welch T-Test on log data	Mann–Whitney U Test
OVP	F	10	1865.36	1435.44		0.441	
OVP	S	10	1528.36	1016.85			
MW	F	5	54660.95	9162.86			0.514
MW	S	10	29275.86	34332.71			
Nitrogen (N) concentration in sediment (N_Sed) [mg/kg]							
Area	F or S	N	Mean	SD	P-Value		
					Welch T-Test	Welch T-Test on log data	Mann–Whitney U Test
OVP	F	10	30360.50	12906.89		0.551	
OVP	S	10	27572.90	11164.68			
MW	F	5	3209.26	962.19			0.240
MW	S	10	1838.13	2421.78			
Phosphorus (P) concentration in sediment (P_Sed) [mg/kg]							
Area	F or S	N	Mean	SD	P-Value		
					Welch T-Test	Welch T-Test on log data	Mann–Whitney U Test
OVP	F	10	13.38	4.12			0.075
OVP	S	10	29.67	26.86			
MW	F	5	15.55	3.51		0.092	
MW	S	10	14.80	20.71			


Organic matter concentration in sediment (OM_Sed)
Oostvaardersplassen
Marker Wadden
OM_Sed [%]
40
20
0
fluctuating
stable


Carbon (C) concentration in sediment (C_Sed)
Oostvaardersplassen
Marker Wadden
C_Sed [mg/l]
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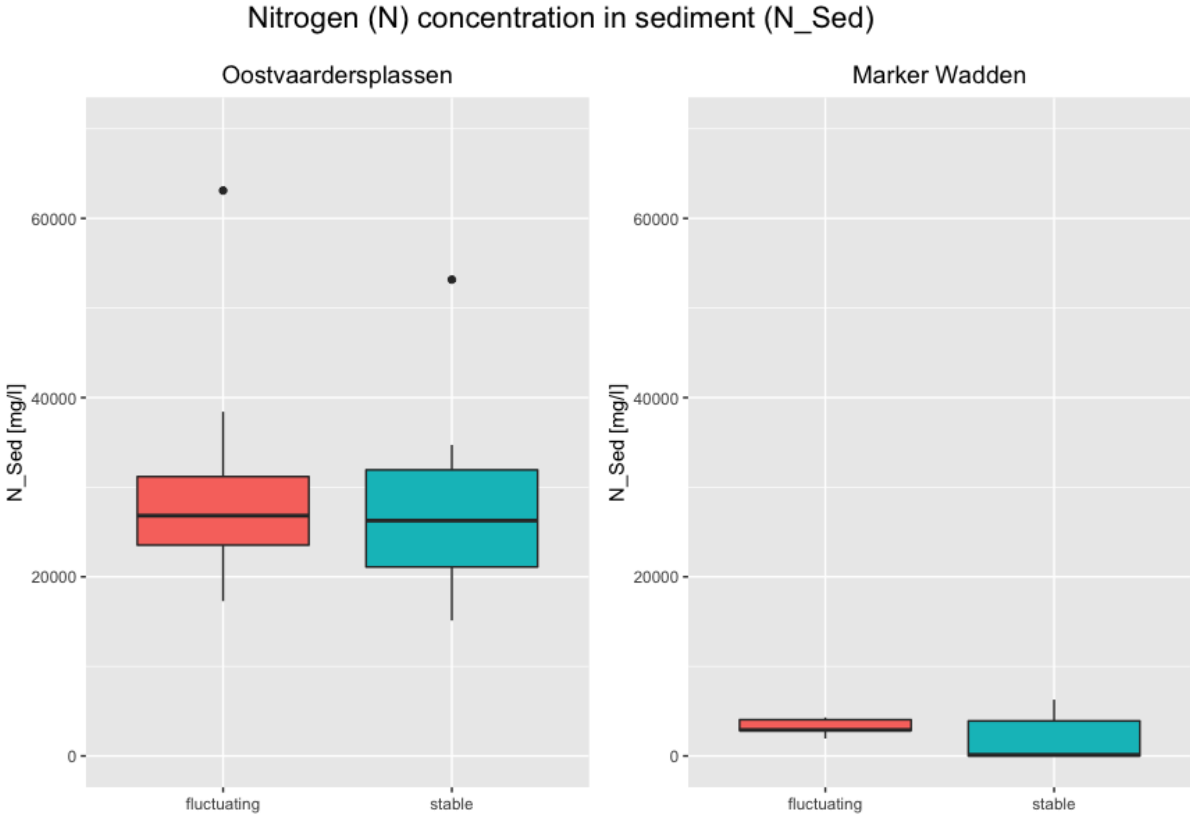
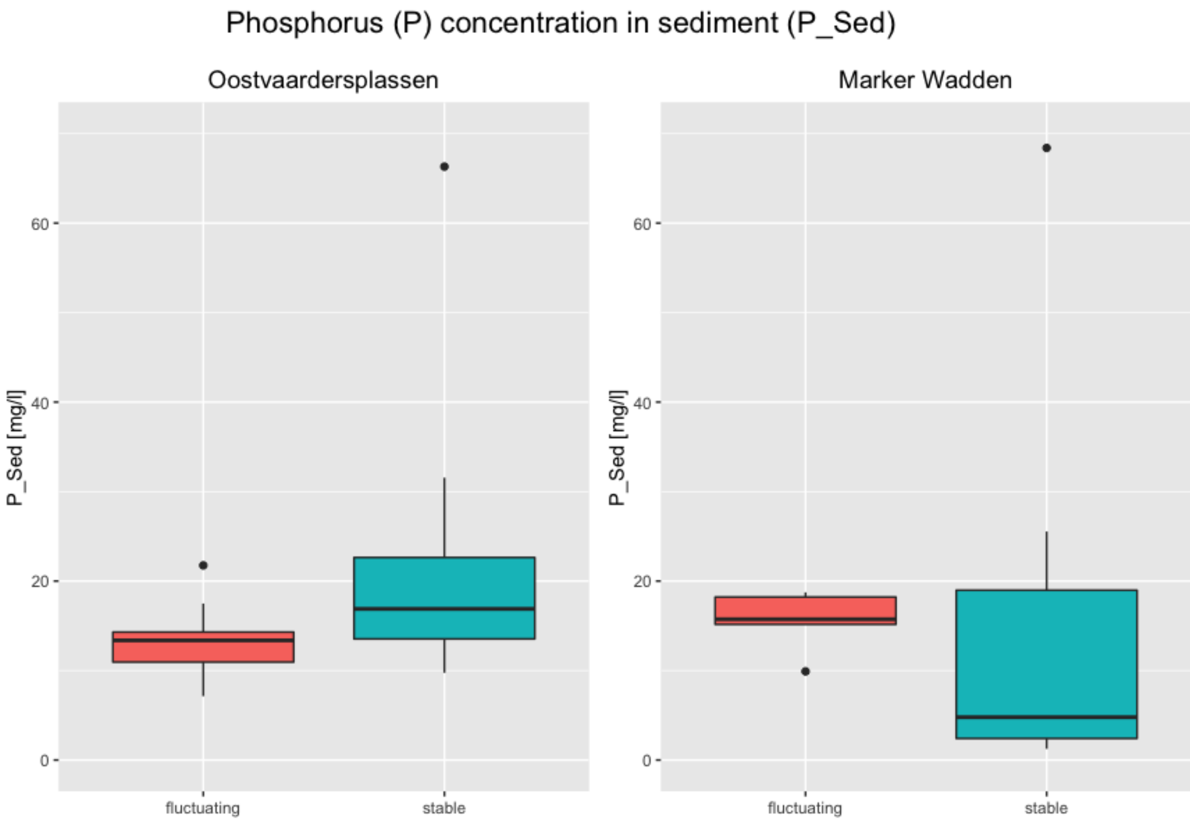
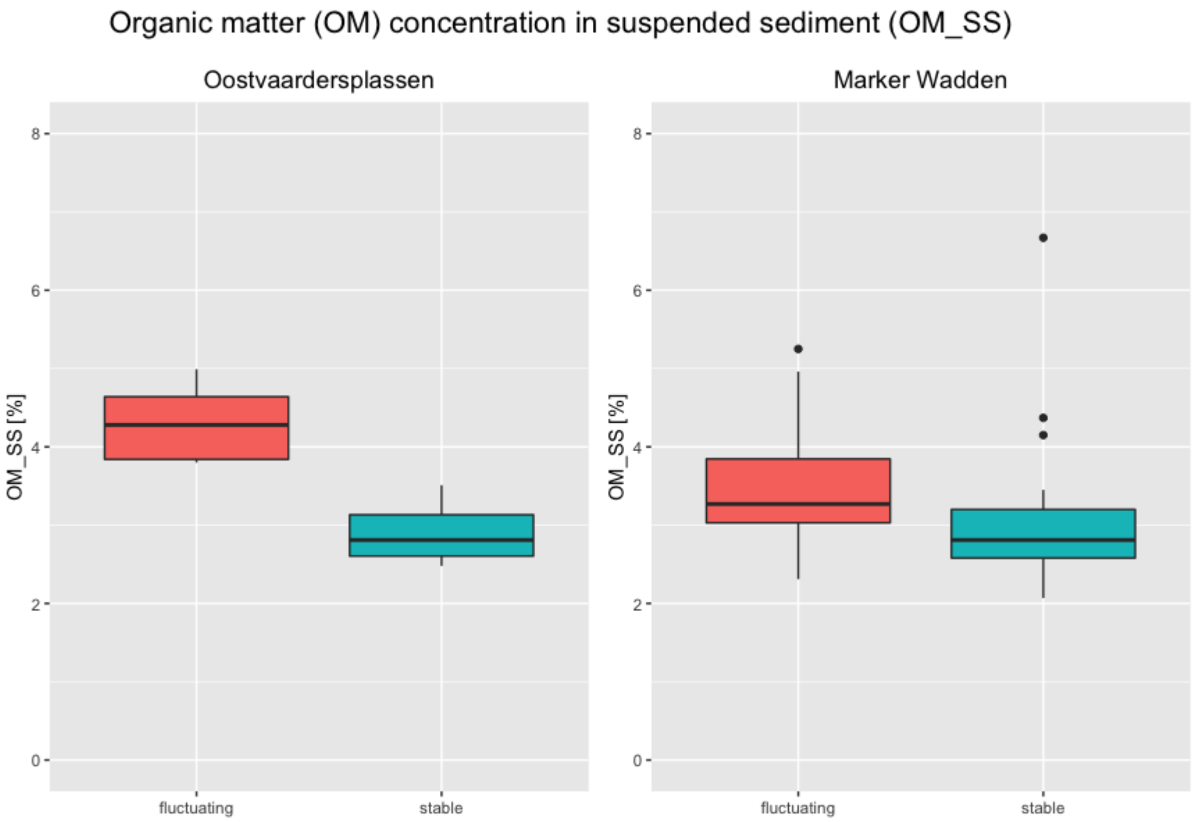
60000
40000
20000
0
fluctuating
stable

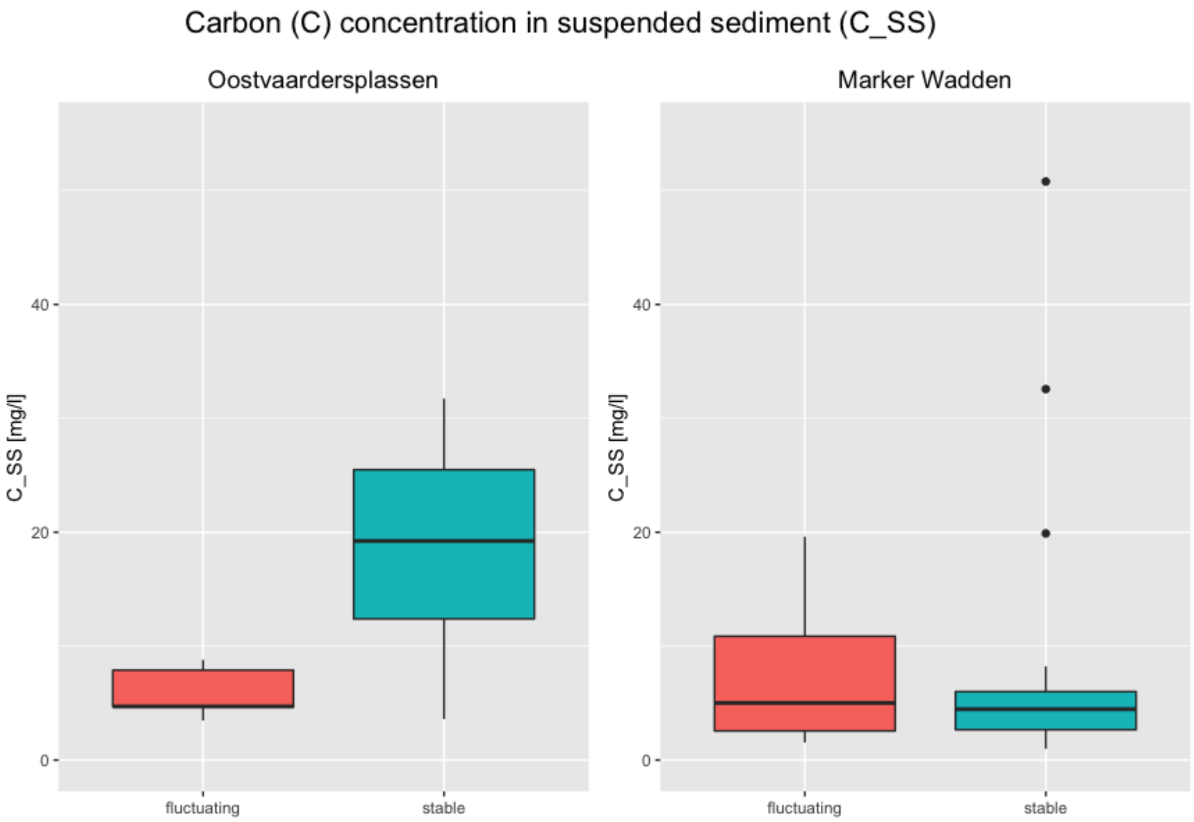

Nitrogen (N) concentration in sediment (N_Sed)
Oostvaardersplassen
Marker Wadden
N_Sed [mg/l]
60000
40000
20000
0
fluctuating
stable

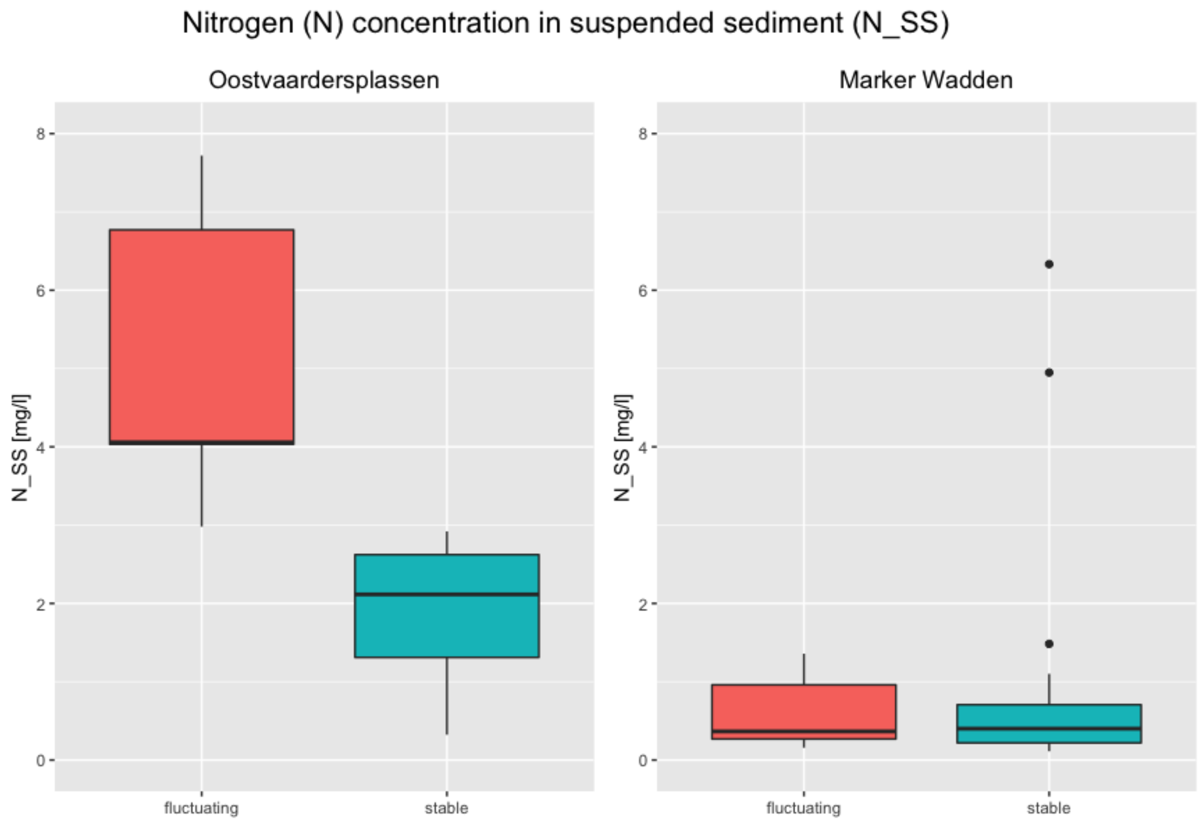

Phosphorus (P) concentration in sediment (P_Sed)
Oostvaardersplassen
Marker Wadden
P_Sed [mg/l]
60
40
20
0
fluctuating
stable

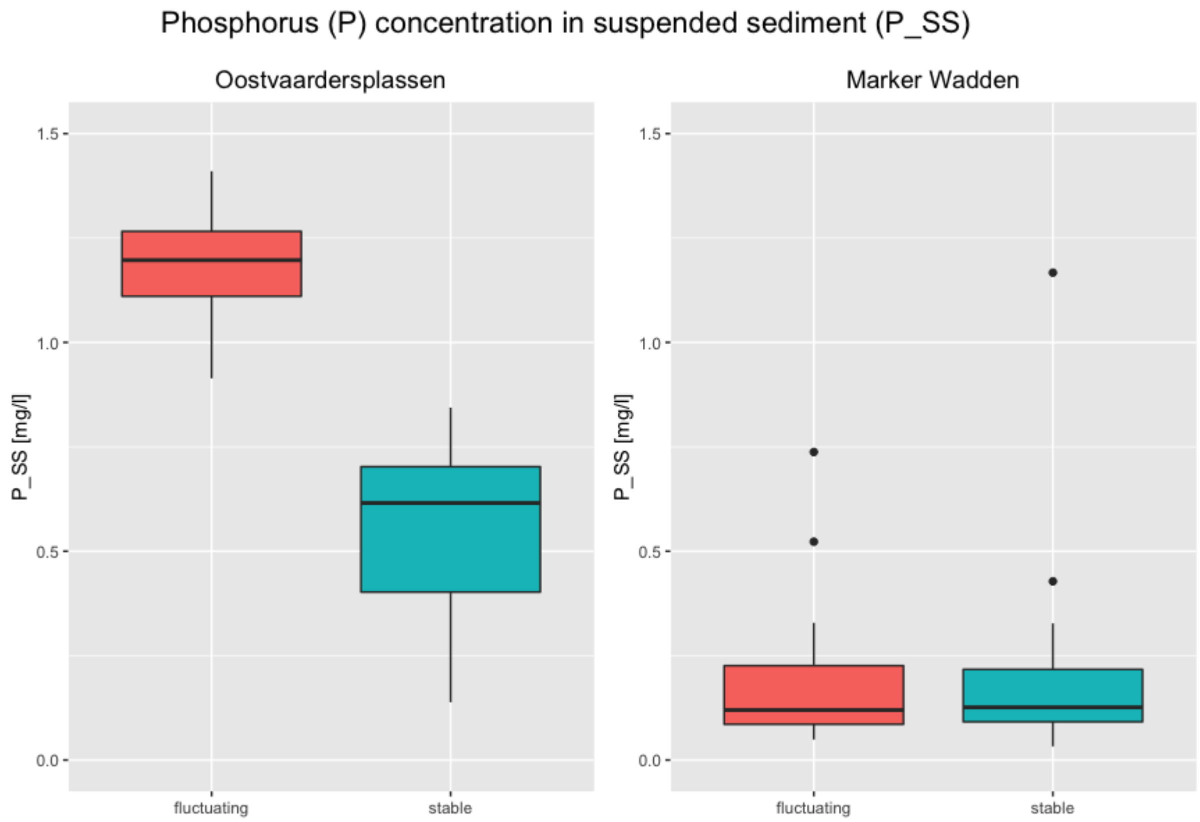
9.1.8 Nutrients and organic matter in the suspended sediment

Organic matter concentration in suspended sediment (OM_SS) [%]							
Area	F or S	N	Mean	SD	P-Value		
					Welch T-Test	Welch T-Test on log data	Mann–Whitney U Test
OVP	F	5	4.31	0.51			< .001
OVP	S	20	2.89	0.35			
MW	F	30	3.50	0.84			0.025
MW	S	15	3.02	0.85			
Carbon (C) concentration in suspended sediment (C_SS) [mg/kg]							
Area	F or S	N	Mean	SD	P-Value		
					Welch T-Test	Welch T-Test on log data	Mann–Whitney U Test
OVP	F	5	5.91	2.30	0.013		
OVP	S	20	18.23	8.05			
MW	F	30	6.66	5.34		0.693	
MW	S	15	7.16	10.30			
Nitrogen (N) concentration in suspended sediment (N_SS) [mg/kg]							
Area	F or S	N	Mean	SD	P-Value		
					Welch T-Test	Welch T-Test on log data	Mann–Whitney U Test
OVP	F	5	5.11	2.02		0.001	
OVP	S	20	1.92	0.81			
MW	F	30	0.61	0.43			0.543
MW	S	15	0.79	1.37			
Phosphorus (P) concentration in suspended sediment (P_SS) [mg/kg]							
Area	F or S	N	Mean	SD	P-Value		
					Welch T-Test	Welch T-Test on log data	Mann–Whitney U Test
OVP	F	5	1.32	0.36		0.047	
OVP	S	20	0.55	0.22			
MW	F	30	0.21	0.19		0.917	
MW	S	15	0.24	0.36			


Organic matter (OM) concentration in suspended sediment (OM_SS)
Oostvaardersplassen
Marker Wadden
OM_SS [%]
0
2
4
6
8
fluctuating
stable

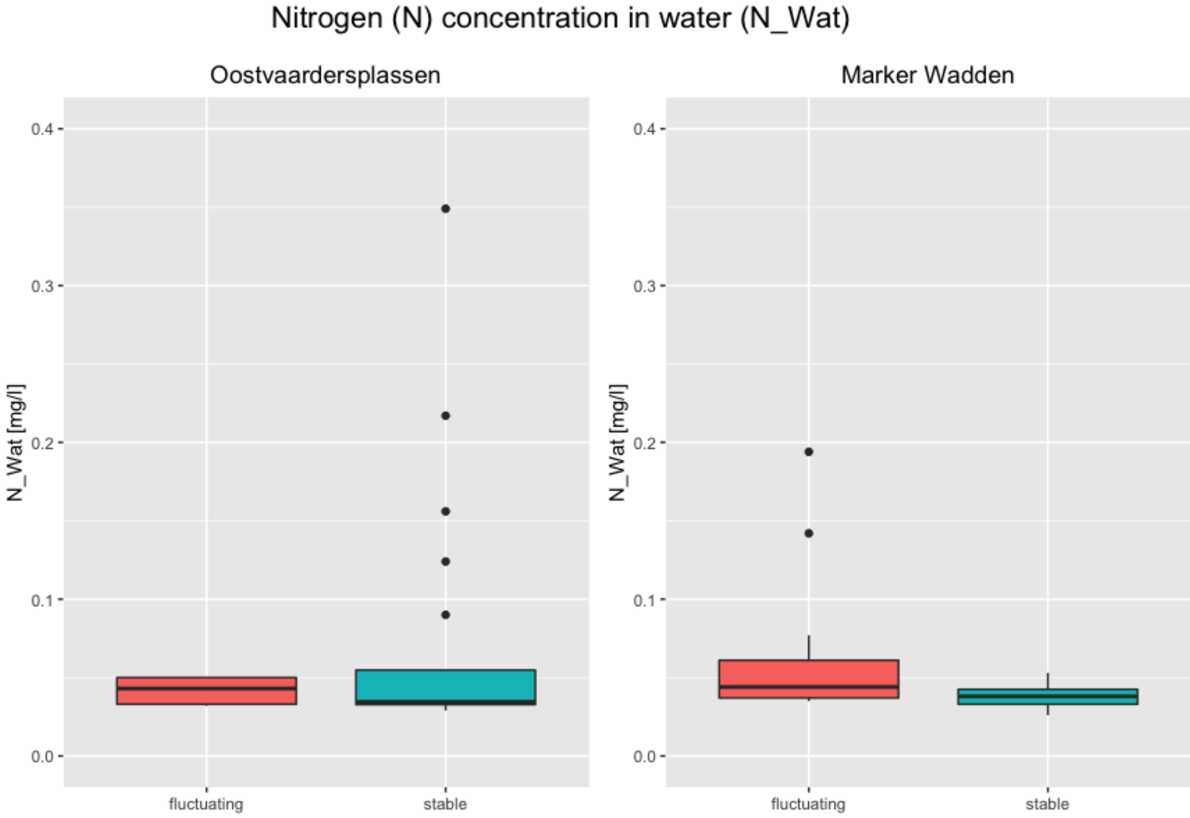

Carbon (C) concentration in suspended sediment (C_SS)
Oostvaardersplassen
Marker Wadden
C_SS [mg/l]
0
20
40
fluctuating
stable

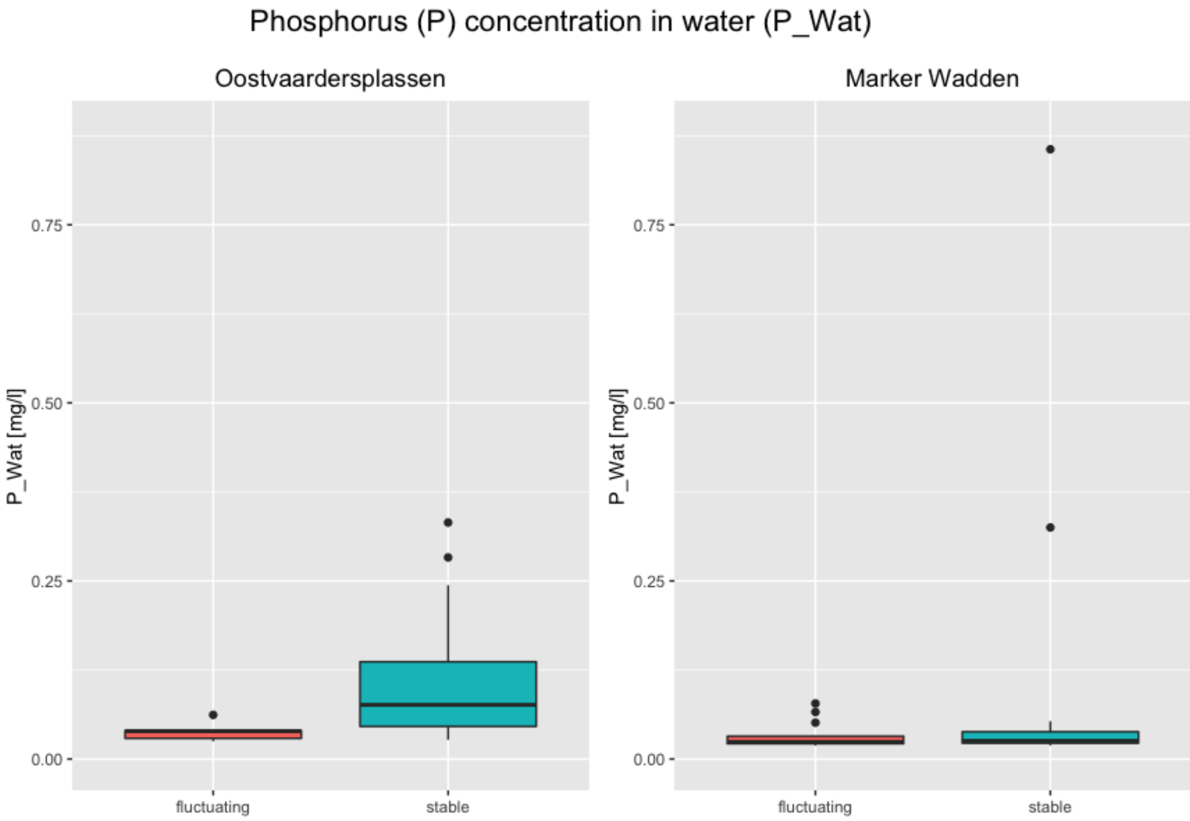

Nitrogen (N) concentration in suspended sediment (N_SS)
Oostvaardersplassen
Marker Wadden
N_SS [mg/l]
0
2
4
6
8
fluctuating
stable

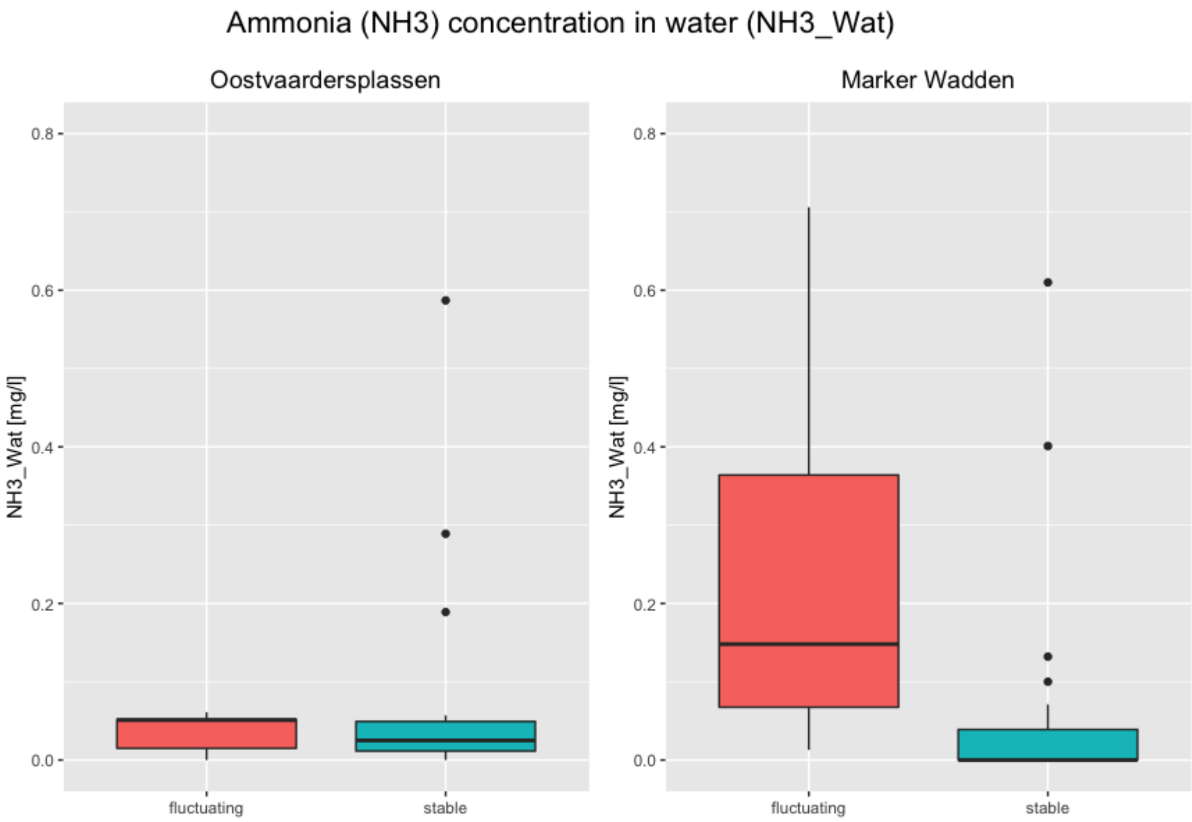

Phosphorus (P) concentration in suspended sediment (P_SS)
Oostvaardersplassen
Marker Wadden
P_SS [mg/l]
0.0
0.5
1.0
1.5
fluctuating
stable

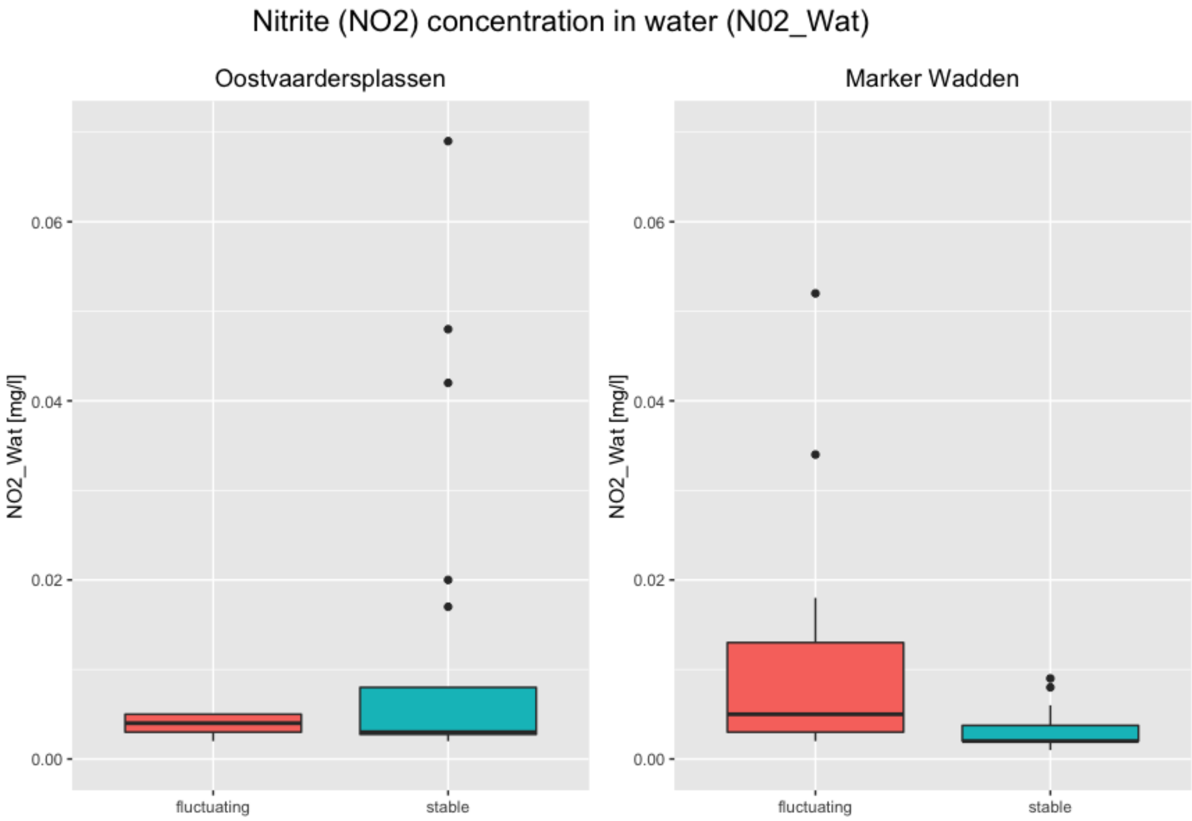
9.1.9 Nutrients in water

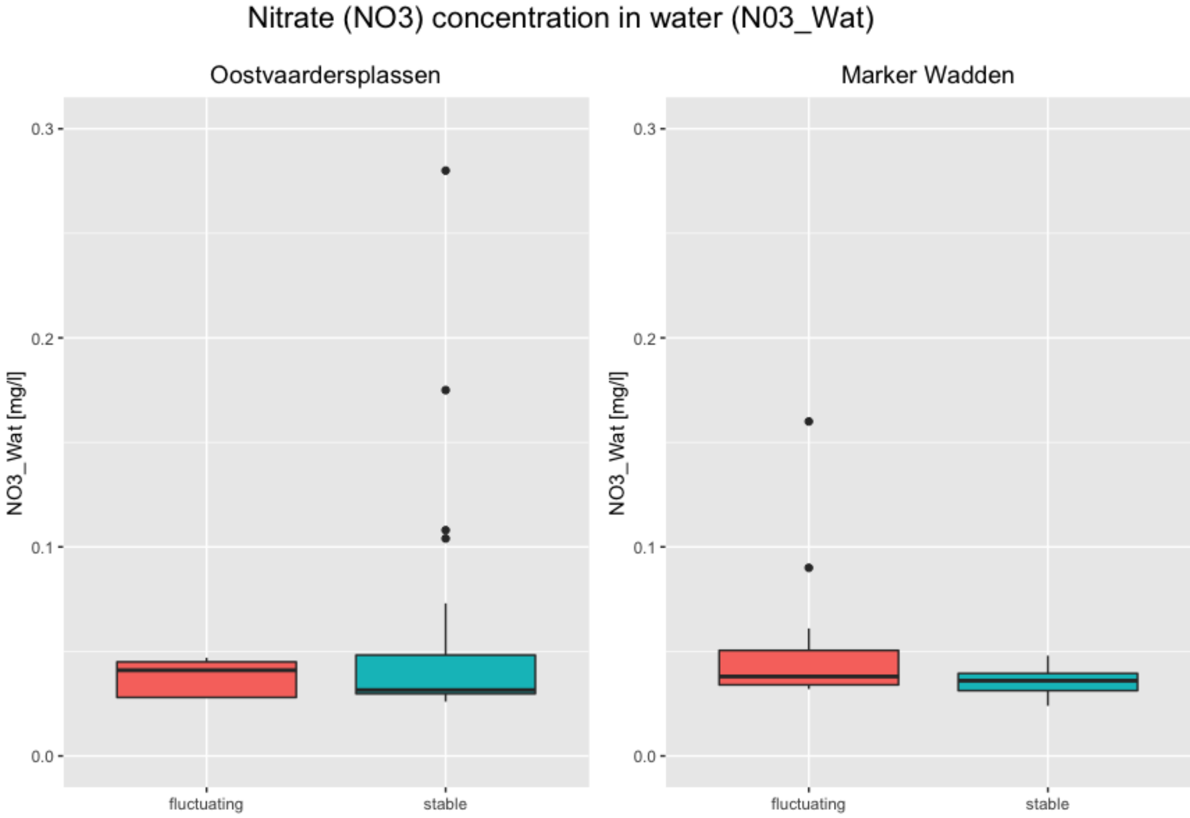
Nitrogen (N) concentration in water (N_wat) [mg/l]							
Area	F or S	N	Mean	SD	P-Value		
					Welch T-Test	Welch T-Test on log data	Mann–Whitney U Test
OVP	F	5	0.0416	0.0088			0.759
OVP	S	20	0.0725	0.0826			
MW	F	30	0.0627	0.0455			0.011
MW	S	15	0.0386	0.0074			
Phosphorus (P) concentration in water (P_wat) [mg/l]							
Area	F or S	N	Mean	SD	P-Value		
					Welch T-Test	Welch T-Test on log data	Mann–Whitney U Test
OVP	F	5	0.0390	0.0144		0.004	
OVP	S	20	0.1091	0.0894			
MW	F	30	0.0322	0.0181			0.604
MW	S	15	0.0663	0.1589			
Ammonia (NH_3) concentration in water (NH3_wat) [mg/l]							
Area	F or S	N	Mean	SD	P-Value		
					Welch T-Test	Welch T-Test on log data	Mann–Whitney U Test
OVP	F	5	0.0358	0.0267			0.734
OVP	S	20	0.0732	0.1398			
MW	F	30	0.2221	0.2110			0.016
MW	S	15	0.0516	0.1310			
Nitrite (NO_2^-) concentration in water (NO2_wat) [mg/l]							
Area	F or S	N	Mean	SD	P-Value		
					Welch T-Test	Welch T-Test on log data	Mann–Whitney U Test
OVP	F	5	0.0038	0.0013			0.750
OVP	S	20	0.0119	0.0189			
MW	F	30	0.0112	0.0142			0.001
MW	S	15	0.0029	0.0020			
Nitrate (NO_3^-) concentration in water (NO3_wat) [mg/l]							
Area	F or S	N	Mean	SD	P-Value		
					Welch T-Test	Welch T-Test on log data	Mann–Whitney U Test
OVP	F	5	0.03780	0.0092			1
OVP	S	20	0.06055	0.0643			
MW	F	30	0.05153	0.0338			0.034
MW	S	15	0.03570	0.0060			


Nitrogen (N) concentration in water (N_Wat)
Oostvaardersplassen
Marker Wadden
N_Wat [mg/l]
0.4
0.3
0.2
0.1
0.0
fluctuating
stable


Phosphorus (P) concentration in water (P_Wat)
Oostvaardersplassen
Marker Wadden
P_Wat [mg/l]
0.75
0.50
0.25
0.00
fluctuating
stable


Ammonia (NH3) concentration in water (NH3_Wat)
Oostvaardersplassen
Marker Wadden
NH3_Wat [mg/l]
0.0
0.2
0.4
0.6
0.8
fluctuating
stable


Nitrite (NO2) concentration in water (N02_Wat)
Oostvaardersplassen
Marker Wadden
NO2_Wat [mg/l]
0.00
0.02
0.04
0.06
fluctuating
stable


Nitrate (NO3) concentration in water (N03_Wat)
Oostvaardersplassen
Marker Wadden
NO3_Wat [mg/l]
0.3
0.2
0.1
0.0
fluctuating
stable

9.2 Example of list of questions and topics sent to interviewees

Before the interview, a list with questions and topics was sent to the interviewees, mentioning that these would be useful to guide the interview but are not leading. These emails were tailored towards the specifics of the stakeholder. The list with questions and topics sent to the municipality of Almere is included below, as an example of such a document.

Context: Ik bestudeer de gevraagde en geleverde ecosysteemdiensten van twee constructed wetlands, namelijk de Marker Wadden en de Oostvaardersplassen. In de OVP is mijn onderzoeksgebied het moerasgedeelte (het deel het dichts bij het Markemeer), omdat dat het beste vergelijkbaar is met de Marker Wadden en voldoet aan mijn definitie voor wetland. Ik breng zowel in kaart wat de gebieden te bieden hebben onder stabiel en fluctuerend peil als de wensen van gebruiker. Ik combineer veldwerk (bodem- en waterfauna, zoöplankton, nutriënten, organische stof, biomassa) met literatuur en interviews met stakeholders. Ik ben dus blij dat u met mij het gesprek aan wilt gaan!

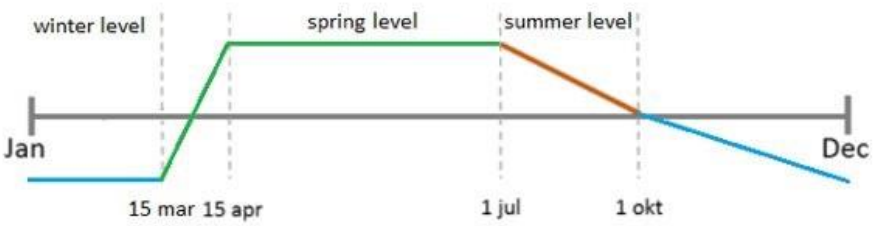
Wellicht zijn sommige vragen minder passend of juist heel goed passend bij uw expertise binnen of buiten Gemeente Almere (GA). Afhankelijk hiervan kunnen we het gesprek vormgeven. Extra input waar ik nog niet aan heb gedacht, is natuurlijk ook meer dan welkom.

In de vragen komt vaak "functies" naar voren, dit is gelinkt aan ecosysteem-diensten. Ecosyteem-diensten die ik meeneem in onderzoek zijn voedsel, water storage/ retention, flood protection, climate regulation, education, recreation, aesthetic, habitat, nutrient cycling en biodiversiteit. Maar laat je hierdoor vooral niet beperken bij het denken aan functies van de gebieden!

- Markermeer (MM)
  - Hoe kijkt GA aan tegen het Markermeer zoals het nu is?
  - Wat zijn voor GA de belangrijkste functies van het Markermeer?
  - Wat is de invloed van het waterpeilbeheer op deze functies? Welk waterpeilbeheer heeft de voorkeur voor GA en waarom?
  - Wat zijn andere belangrijke functies van het MM, functies die voor andere stakeholders van belangrijk? En wat is de invloed van het waterpeilbeheer op die functies?
  - Zijn er tegenstrijdige belangen / functies binnen GA m.b.t tot de waterpeildynamiek op het MM?
- Oostvaardersplassen (OVP) (het moerasgedeelte)
  - Waarin verschilt de huidige Moerasreset met de vorige reset?
  - Wat zijn voor GA de belangrijkste functies van de OVP?
  - Wat doet het waterpeilbeheer met de ecosysteemdiensten van de OVP?
    - Voedsel
    - Water storage / retention
    - Flood protection
    - Climate regulation
    - Education
    - Recreation
    - Aesthetic
    - Habitat
    - Nutrient cycling
    - Biodiversity

- Ziet GA iets in het uitbreiden van Moerasreset projecten in andere wetlands of delen van de OVP? Waarom wel / niet?

- Marker Wadden (MW)
  - Hoe kijkt GA aan tegen (de aanleg van) de MW?
  - In hoeverre is GA betrokken bij het project MW?
  - Wat zijn voor GA de belangrijkste functies van de MW? Wat zijn minder belangrijke functies?
  - Wat ziet GA als gewenste ontwikkeling voor en op de MW?
  - Op de MW is een eiland afgesloten van het MW, het water in dit eiland volgt een seizoensdynamiek (zie figuur onderaan deze blz.), d.m.v. pompen en outlets. Hoe kijkt het GA hier tegenaan? Wat zijn hier voor- / nadelen van? Is dit ook wenselijk in OVP?
  - Wat doet het waterpeilbeheer met de ecosysteemdiensten van de MW?
    - Voedsel
    - Water storage / retention
    - Flood protection
    - Climate regulation
    - Education
    - Recreation
    - Aesthetic
    - Habitat
    - Nutrient cycling
    - Biodiversity



9.3 Overview of analysed samples

Overview of analysed samples with S = Stable water level and F = Fluctuating water level. All samples have been taken in 2021, in the months mentioned in the table below. The exact dates at which the samples have been taken can be found in the dataset of this research.

				Amount of analysed samples													
				Oostvaardersplassen								Marker Wadden					
				May		July		August		September		July		August		September	
Ecosystem service		Parameter	Unit	S	F	S	F	S	F	S	F	S	F	S	F	S	F
Water purification		Turbidity	NTU			5	5	10		5		10	5	10	5	10	5
Water purification		Suspended sediment	mg/l			5	5	10		5		10	5	10	5	10	5
Nutrient cycling	Sediment	OM	%		10			10						10	5		
Nutrient cycling	Sediment	C	mg/kg		10			10						10	5		
Nutrient cycling	Sediment	N	mg/kg		10			10						10	5		
Nutrient cycling	Sediment	P	mg/kg		10			10						10	5		
Nutrient cycling	Suspended sediment	OM	%			5	5	10		5		10	5	10	5	10	5
Nutrient cycling	Suspended sediment	C	mg/kg			5	5	10		5		10	5	10	5	10	5
Nutrient cycling	Suspended sediment	N	mg/kg			5	5	10		5		10	5	10	5	10	5
Nutrient cycling	Suspended sediment	P	mg/kg			5	5	10		5		10	5	10	5	10	5
Nutrient cycling	Water	N	mg/l			5	5	10		5		10	5	10	5	10	5
Nutrient cycling	Water	P	mg/l			5	5	10		5		10	5	10	5	10	5
Nutrient cycling	Water	NH_3	mg/l			5	5	10		5		10	5	10	5	10	5
Nutrient cycling	Water	NO_2^-	mg/l			5	5	10		5		10	5	10	5	10	5
Nutrient cycling	Water	NO_3^-	mg/l			5	5	10		5		10	5	10	5	10	5
Biodiversity		Zooplankton	H			5	5	10		5		10	5	10	5	10	5
Biodiversity		Water macrofauna	H					10		5		10	5	10	5	10	5
Biodiversity		Sediment macrofauna	g/m^2					10		5		10	5	10	5	10	5
Biodiversity		Chlorophyll-a	mg/l			5	5	10		5		10	5	10	5	10	5