THE EFFECTS OF RESTORATIVE MEASURES ON SPECIES COMPOSITION OF MACROINVERTEBRATES IN THE REEUWIJKSE PLASSEN

Rozemarijn Wielenga

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AERES HOGESCHOOL

Prologue

My name is Rozemarijn Wielenga and I am a bachelor student of the study applied biology at Aeres University of Applied Sciences. My last year I specialized in aquatic ecology by doing an international year on aquatic ecosystem analysis. In my last year I went to Portugal where me and my classmates wrote a report about invasive species in the Alqueva reservoir. After returning from Portugal I almost immediately went to Estonia for my company placement. It was the intention to write a thesis based on what I did in Estonia, but this went a little bit different. After my return to the Netherlands I had found a job at Aquon but did not have a subject for my thesis yet. This is when I came up with the idea to use the data of Aquon for my thesis.

This thesis is meant for people who work in the environmental sector and deal with water quality and macroinvertebrate research. Also, for people who are interested in macroinvertebrates.

I would like to thank Annet Pouw who guided me through this thesis and my minor years. I would like to thank all my colleagues at Aquon and Eric Verlaan and Frank van Schaik from Hoogheemraadschap Rijnland for helping me and providing me with data. And a special thanks to Tom Verhoeve who helped me with statistics and spelling checks.

Rozemarijn Wielenga 13-01-2020,
Leiden

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Summary

The Reeuwijkse Plassen have been dealing with a declining water quality for the past century. One of the problems is eutrophication due to in- and outflow of nutrient rich water from surrounding areas which caused algae blooms and turbid waters. The waterboard Hoogheemraadschap Rijnland implemented measures to improve the water quality according to Water Framework Directive (WFD). In 2011 two agricultural polders were disconnected from the Reeuwijkse Plassen to control in- and outflow of water and in 2012 construction of natural banks was started at all lakes. In 2014 and 2015 more polders were disconnected from the Reeuwijkse Plassen and a more naturally fluctuating water level was implemented. Because previous research showed that the Ecological Quality Ratio (EQR) score of the Reeuwijkse Plassen had not improved since the measures were taken, it was important to find out what has changed on a detailed level. This research thus looks into the changes in the species composition of macroinvertebrates at the Reeuwijkse Plassen after the WFD measures since 2010. This is firstly done by use of a repeated measures ANOVA, which examined the relationship between the species richness of (sub)classes of macroinvertebrates at the different KRW points over time, which established that the overall species richness of macroinvertebrates declined on all KRW points in the Reeuwijkse Plassen. Furthermore the species composition changed from an abundance of Chironomidae and in lesser amount Arachnida and Gastropoda, to mostly Chironomidae, Arachnida and Trichoptera. Following these results, changes in the species richness of the individual (sub)classes was examined by use of one-way ANOVA's and Welch's-ANOVA's, and Tukey post hoc tests and Games-Howell post hoc tests. These analyses established that the species richness of the Chironomidae, Gastropoda and Coleoptera has declined, which is likely due to a relative lower tolerance to physio-chemical changes that lower the water quality. The other (sub)classes did not show changes in the species richness. Oligochaeta are less likely to be affected due to the fact that sedimental biota are affected later than biota living above the sediment. Arachnida are also less likely to be affected as they are highly interactive with other macroinvertebrates. The altered physio-chemical parameters resulted in a lower water quality as soon as construction of natural banks was begun. Concluding that the species richness of the Chironomidae, Gastropoda and Coleoptera visibly declines after 2010 and shows to be correlated to the measures. The limitations and recommendations are also discussed.

Samenvatting

De Reeuwijkse Plassen heeft de laatste eeuw te maken met achteruitgang van de waterkwaliteit. Een oorzakelijk probleem is eutrofiering door in- en uitstroom van voedselrijk gebiedsvreemd water, wat algenbloei en troebel water veroorzaakte. Het waterschap Hoogheemraadschap Rijnland kwam met maatregelen voor de Reeuwijkse Plassen om de waterkwaliteit te verbeteren volgens de Kader Richtlijn Water (KRW). In 2011 zijn twee agrarische polders afgesloten van de Reeuwijkse Plassen om de in- en uitstroom te controleren en in 2012 is begonnen met de aanleg van natuurvriendelijke oevers in alle plassen. In 2014 and 2015 zijn meer polders afgesloten van de Reeuwijkse Plassen en is een natuurlijker waterpeil ingesteld. Omdat eerder onderzoek aantoonde dat de Ecologische Kwaliteitsratio (EKR) score van de Reeuwijkse Plassen niet verbeterd was sinds de maatregelen genomen waren, was het belangrijk te onderzoeken welke veranderingen er op een gedetailleerder niveau hebben plaatsgevonden. Zodoende kijkt dit onderzoek naar de veranderingen in de soortsamenstelling van de macro-invertebraten van de Reeuwijks Plassen na de KRW maatregelen sinds 2010. Dit is eerst gedaan door gebruik van een repeated measures ANOVA, die de relatie tussen de soortenrijkdom van de (sub)klassen van de macro-invertebraten op de verschillende KRW punten over tijd onderzocht. Hieruit volgde dat de soortenrijkdom van de macro-invertebraten op alle KRW punten van de Reeuwijkse Plassen afnam. De soortsamenstelling veranderde ook, van een abundantie van Chironomidae en in mindere mate Arachnida en Gastropoda, naar voornamelijk Chironomidae, Arachnida en Trichoptera. Vervolgens zijn de veranderingen in de soortenrijkdom van de individuele (sub)klassen onderzocht met one-way ANOVA's en Welch's-ANOVA's, en Tukey post hoc testen en Games-Howell post hoc testen. Deze analyses lieten zien dat de soortenrijkdom van de Chironomidae, Gastropoda en Coleoptera omlaag was gegaan, wat waarschijnlijk komt doordat ze een relatief lagere tolerantie hebben voor fysisch-chemische veranderingen die de waterkwaliteit verlaagden. De andere (sub)klassen vertoonden geen veranderingen in de soortenrijkdom. Oligochaeta hebben een kleinere kans om geaffecteerd te worden, omdat in het sediment levende organismen minder snel worden beïnvloed door de veranderende milieuomstandigheden van het water dan organismen die boven het sediment leven. Arachnida hebben ook een kleinere kans om geaffecteerd te worden doordat ze sterke interacties met andere macro-invertebraten hebben. De veranderende fysisch-chemische parameters zorgden voor een lagere waterkwaliteit die volgde op de constructie van de natuurvriendelijke oevers. Geconcludeerd wordt dat de soortenrijkdom van de Chironomidae, Gastropoda en Coleoptera zichtbaar afneemt na 2010 en gecorreleerd is aan de maatregelen. De restricties en aanbevelingen worden ook besproken.

Introduction

For the past thousand years a lot of landscapes in the Netherlands changed due to agriculture and urbanization. This caused more drainage of agricultural, industrial and human waste water into rivers and lakes which led to eutrophication. Eutrophication can influence lakes in a negative way and therefore it is preferred to have less polluted waters for healthier water systems (Gulati & van Donk, 2002).

Reeuwijkse Plassen

Somewhere between Gouda and Bodegraven thirteen smaller and bigger lakes are located which collectively are called the Reeuwijkse Plassen (Figure 1). The Reeuwijkse Plassen covers about 735 hectares (de Senerpont Domis & Bakker, 2015). This piece of nature has been formed by the removal of peat in the eighteenth century. The original plan for the Reeuwijkse Plassen was to drain the water, to make it suitable for agricultural land. However, this never happened and therefore a water landscape came to be, that is part of waterboard Hoogheemraadschap Rijnland (Hoogheemraadschap Rijnland, Reeuwijkseplassen, n.d.). All the lakes are interconnected except for the deepest lake, Broekvelden/Vettebroek. This lake originated by sand extraction and is thus different from the other lakes. According to the water framework directive (WFD) system, the water type of the Reeuwijkse Plassen is M27. This means the lakebed consist of more than 50% of peat. With the M27 water type, the pH is neutral or somewhat alkaline and the trophic state of the water can vary from oligotrophic to eutrophic (STOWA, 2012).

For decades, water boards have been struggling to maintain a good water quality because of phosphates and nitrogen flowing into the lakes (Braakhekke, Maker, & van Winden, 2009). This eutrophication caused algae blooms in certain periods of the year, which had the effect that big parts of the Reeuwijkse Plassen turned into a big green algae soup. Submerged macrophytes had no chance to grow which caused habitat loss for aquatic life. Around the year 2009, the lakes were covered with less than 1% submerged macrophytes and only 6% had vegetation along the littoral zone, while the biodiversity of macrophytes and macroinvertebrates was very low

Figure 1 - Reeuwijkse Plassen (Hoogheemraadschap Rijnland, n.d.)

(Hoogheemraadschap Rijnland, Schoon & Mooi). Since the eighties, the water board Hoogheemraadschap Rijnland, applied several methods to reduce the eutrophication. Several measures were taken like dredging of the lakes and restorations of natural banks. Until now (31-10-2019) none of the measures have had the intended effect on the water quality. Therefore, new plans needed to be made as to improve the water quality (Braakhekke, Maker, & van Winden, 2009).

To test whether the water quality has improved, after measures have been implemented, a scale called the Ecological Quality Ratio (EQR) is used that is based on biological indicators such as macroinvertebrates. This scale looks at the ratio between the value of the observed biological parameter and the expected value of reference condition for a given water body (European commission, 2007).

The EQR score ranges from zero to one, respectively having a bad to high ecological status (Figure 2). However, a high status (1) is only achievable for natural waterbodies. For modified waterbodies the highest EQR score is 0,6 which is seen as a potential good ecological status (European commission, 2007).

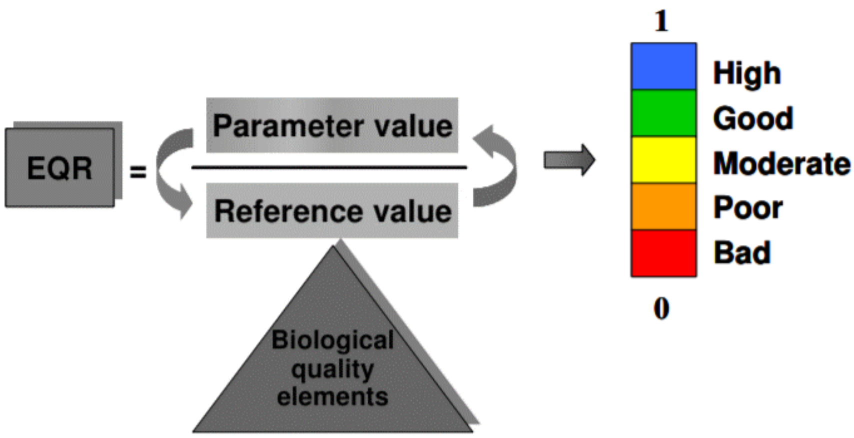


Figure 2 - Ecological Quality Ratio (European commission, 2007)

In previous research the EQR of the Reeuwijkse Plassen has been analysed and it was found that from the period from 2009 until 2011, the EQR score was 0,42. The EQR score of the period between 2012 and 2014 is 0,39. Conclusion is that there is no significant improvement in the EQR score of the Reeuwijkse Plassen (Torenbeek, 2016).

Measures

Since 2011, the waterboard Hoogheemraadschap Rijnland has implemented measures (Table 1) to improve the water quality. They started the project 'Schoon & Mooi Reeuwijkse Plassen' in 2009 and finished the last measures in 2015 (Hoogheemraadschap Rijnland, Reeuwijkseplassen, n.d.). Two different types of measures have been implemented, the restoration of lake beds (that helps creating more habitats for aquatic life and therefore more biodiversity), and the diversion of tributaries (thus making lakes self-sufficient and mostly reliant on rainwater) (Braakhekke, Maker, & van Winden, 2009).

In 2012, eighteen kilometres of natural banks were constructed in several places in the Reeuwijkse Plassen (Appendix Figure 1). The diversion of tributaries has been implemented between 2011 and 2015. In 2011 the agricultural polders Reeuwijk West and Abessinië were first disconnected from the lakes. This already caused a 30% reduction of the inlet of phosphate. In

2014 the Goudse Hout polder was disconnected, this water now flows directly into the Hollandse IJssel. The polder Stein-Noord was the last one to be disconnected in 2015. The inlet of water is now limited by the disconnection of the surrounding polders. In wet periods rainwater is stored, so during drier periods, nearly no nutrient rich water has to be let into the lakes. The lakes are now thus mainly fed by rainwater, though in drier periods there is an in- and outlet of water that lets in water from the Hollandse IJssel (Appendix Figure 1 and 2) (Hoogheemraadschap Rijnland, Schoon & Mooi; Laan, 2017).

Table 1 - Overview of the measures that have been taken at the Reeuwijkse Plassen (Hoogheemraadschap Rijnland, Reeuwijkseplassen, n.d.)

Year	Measures
2011	The agricultural polders Reeuwijk West and Abessinië have been disconnected from the lakes.
2012	Natural banks (18 km) have been constructed.
2014	The Kerfwetering has been renovated, because the banks of this historical sail route were damaged.
2014	The Goudse Hout polder has been disconnected and the surplus of water from this polder and from the adjacent Willens polder is directly pumped into the Hollandse IJssel by two new pumping stations and six (re)placed weirs.
2015	The Stein Noord polder has been disconnected so it will only get its water from the Enkele Wiericke. This water will flow through to Stein Noord via the Oukoop polder.
2015	The amount of external water inflow from neighbouring areas is limited by having a more naturally fluctuating water level. In wet periods retention of rainwater, which is clean and nutrient poor, heightens the water level to more natural level and in dry periods the water level is allowed to decline a bit more.

The effect of measures

Since the EQR score has not significantly improved since the measures in the Reeuwijkse Plassen have been implemented, it is important to find out what has changed on a detailed level. That is why this research will look into the changes in species composition of macroinvertebrates at the Reeuwijkse Plassen. The measures that have been taken are either construction work (restoring natural lake beds) or disconnections of eutrophic waterways, which lead to a water level that fluctuates more naturally and a lake which is mostly fed by rainwater.

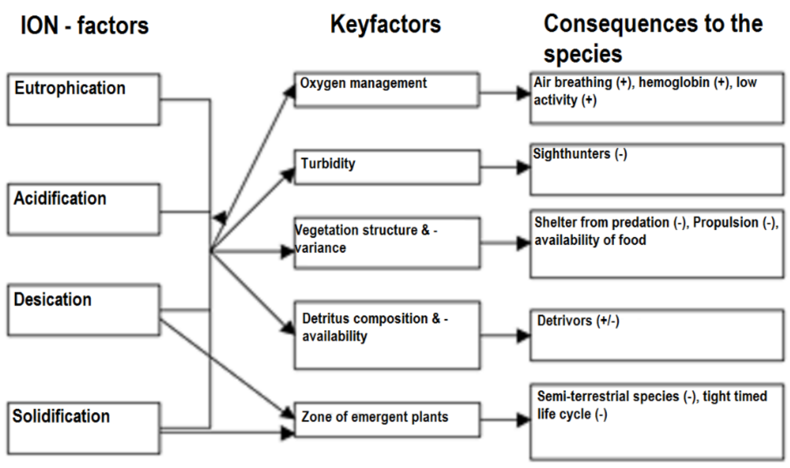


Figure 3 - Key factors and consequences for species after changes due to certain restorative measures (Lamers, et al., 2006)

When construction is done in and at waterways, key factors like the turbidity of the water and the variance of local vegetation are often diminished (Figure 3). Though construction measures do aim to improve the water quality and species composition of the macrophytes and macroinvertebrates, this is not always the case, certainly not at first (Lamers, et al., 2006). Whether the goal of these measures is attained depends on the recovery rate of the area, which is dependent on these key factors (Schep & Verbeek, 2018; STOWA, 2018). An extra point of care is that even if the area recovers rather quickly, unique and indicative species that were there initially, and which are possibly even common species in the surrounding areas, might not (be able to) return, which is a loss in biodiversity and might explain the fact that the EQR score has not improved. (Lamers, et al., 2006) However, the measures in the Reeuwijkse Plassen have not been implemented at all shores (Appendix Figure 1). As such the disturbances may have had a temporary downward effect on the species composition and EQR score, but these will likely recover due to the sheer size of the area of which parts will be nearly undisturbed. After five to ten years the macrophyte community of ditches peaks after restorative measures have been implemented, though an optimum for lakes is thus far unknown and is expected to take years. Since macroinvertebrates are oftentimes in need of certain macrophytes or other macrofauna, they too will follow the changes of these other organisms but with a slight delay (de la Haye, et al., 2011). Although these changes will probably take years, previous research has also found that implementing natural (lake/river) banks increases the ecological status of the water afterwards. Several recovered banks such as in the Maas, Noord-Hollands channel, Twente channel and some other waterbodies have been analysed. This analysis concluded that the diversity and abundance of macroinvertebrates increased while there is also more diversity in different feeding groups of macroinvertebrates (Soesbergen & Rozier, 2004). Ecological quality scores are higher on (reconstructed) natural riverbanks than at non-natural riverbanks (de la Haye, et al., 2011; Sollie, Brouwer, & de Kwaadsteniet, 2011).

Disconnecting eutrophic waterways and retaining more rainwater, is likely to make the lakes themselves less eutrophic. However, even if these changes take effect, they might influence the species composition of the macroinvertebrates in a negative way at first. In the ditches of the nature reserve Nooitgedacht this effect was observed, and recovery and improvement of the species composition was only slightly visible eight years after the initial measure was taken. The Reeuwijkse Plassen are expected to show a comparable change in species composition and might be lower or just recovering due to these measures. (Nijboer & Bosman, 2006)

In total it is expected that due to the measures, the species composition of the macroinvertebrates will be negatively influenced at first. Due to the fact that there are multiple measures in multiple years, it is expected that this effect might be spread out over multiple areas or over a longer timeframe. Recovery is hoped for, though it is not expected as some macroinvertebrates only follow after their host plants have settled and invertebrates also use certain macrophytes as a food source and as shelter (Papas, 2007).

Research questions

Main question: How has the species composition of macroinvertebrates changed in the Reeuwijkse Plassen after the Water Framework Directive measures since 2010?

- What changes are visible in the species composition of macroinvertebrates?
- Are there changes within the (sub) classes of the macroinvertebrates?
- Are these changes correlated to the measures?

Reader

In the first chapter of this research an introduction of the problem and area are explained. Also, the predicted effect and research questions are discussed. In the second chapter the method of how this research is been done is explained, which data is used and how it is processed. The third chapter shows the results that followed out of the analysis of the data. In chapter four the results are discussed based on the sub questions and available literature, the last part of this chapter will list the limitations of the study and possible effects of these limitations on the results. The fifth chapter gives a short summary about the reason for the research after which the conclusion of this research is given per sub question as to answer the main question. The last chapter gives recommendations for future research focused on improvements of the method or new lines of research.

Method

To find out whether the measures that were taken at the Reeuwijkse Plassen influenced macroinvertebrates, data needed to be analyzed. This has been done by using the Water Framework Directive (WFD) points that have been set by the water board Hoogheemraadschap Rijnland (Figure 4).

Sample information

The macroinvertebrates were caught according to the WFD protocol (STOWA, 2014). In the laboratory the macroinvertebrates were determined by employees of Aquon, a company specialized in fresh water research, on species level under the microscope, which is also been done in accordance with the WFD protocols.

This data from the macroinvertebrates has then been put into Aquadesk, a programme used for logging and sharing data.

Data processing

To be able to work with the data, all data was then exported as a CSV file for analysis.

The data for macroinvertebrates has been organised as follows: Locations, date and time of measurement, species, (characteristics,) number of organisms of the species, and the calculated number of organisms.

Since there are many locations (Figure 3), locations have been bundled as follows: There are multiple locations (KRW11_xxx) with the same number labelled with 'a, b, c and d', which have been sampled at the same date and time and are located within the same lake. These locations have been bundled into one "point" with that same number. Only those "points" that consist of at least 2 locations per year have been taken into account, as a point will otherwise not give a solid representation of the specific lake. Per point the species composition (number of different species) has then been made by ordering the results per (sub)class. These new "points" (n=5 per year for the macroinvertebrates) are the data (Table 2) which is used for all analyses. These "points" will thus show the species composition and species richness of each individual lake for that specific year.

Table 2 - Example of the dataset that will be used for analysis

Point	(Sub)class 1	(Sub)class 2	(Sub)class 3		(Sub)class x
KRW11_01-2010					
KRW11_02-2010					
KRW11_XX-2010					
KRW11_01-2012					
KRW11_01-2012					
KRW11_XX-2012					
KRW11_01-2016					
KRW11_02-2016					
KRW11_XX-2016					

First this data has been analysed by use of a repeated measures ANOVA to compare the data from 2012 with 2010, 2016 with 2010 and 2016 with 2012. This way differences in time can be seen as well as differences between the lakes. It was assumed that the data would be normally distributed and would have homogeneity of variance, as this is warranted for this specific test. Should this not have been the case, either transformations or a non-parametric test would have been needed.

Then the data was plotted per (sub)class per point to show the changes in species composition over the years. Only those (sub)classes that reach at least 5 different species at some point in time have been taken into account for further analysis, as a lesser amount of different species is unlikely to reach any statistical significance even in the event that there might be a change.

To give a more in-depth view of the changes, the (sub)classes that have been selected for further analysis, have been analysed by use of a one-way ANOVA. Following significance or a trend, post hoc testing by a Tukey post hoc test has been done to show the directionality of the differences. In the event that the prerequisited homogeneity of variance was not found, an alternative ANOVA, called a Welch's-ANOVA was done. In this case, following significance or a trend, post hoc testing by a Games-Howell post hoc test has been done to show the directionality of the differences.

The results from this analysis have been compared to the measures that were taken at certain points in time and at certain geographical points, as well as to the physio-chemical data in Appendix 3. In case differences between lakes arose a comparison would have also been done visually by comparing the map of the measures with the collected results. This way differences or lack thereof could possibly be explained.

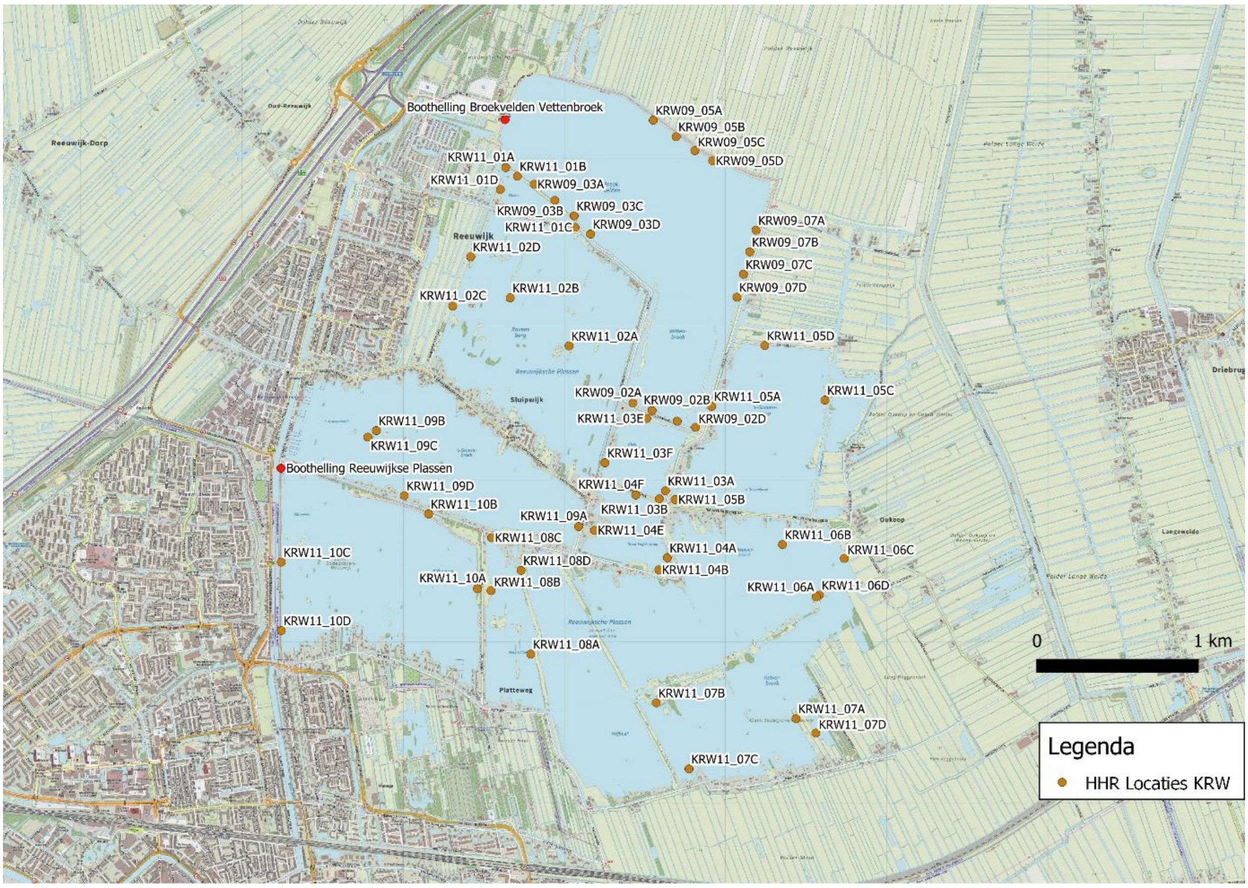


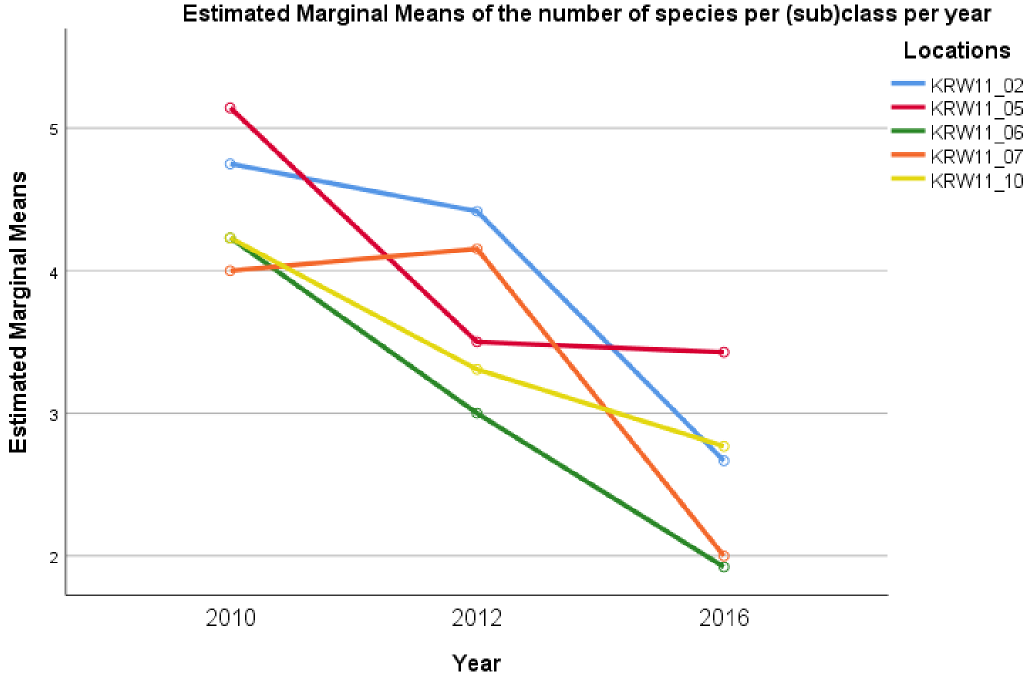
Figure 4 - Sample locations at the Reeuwijkse Plassen

Results

The data that is used for this research was collected by the company Aquon and has been analyzed in the program SPSS.

Overall changes in the species composition of macroinvertebrates

To see if there are changes in the species composition of macroinvertebrates, the data has been put into the program SPSS. This resulted in multiple graphic representations like the one below and the following results.



Graph 1 - The estimated marginal mean of the number of species per (sub)class per location set out against 2010, 2012 and 2016

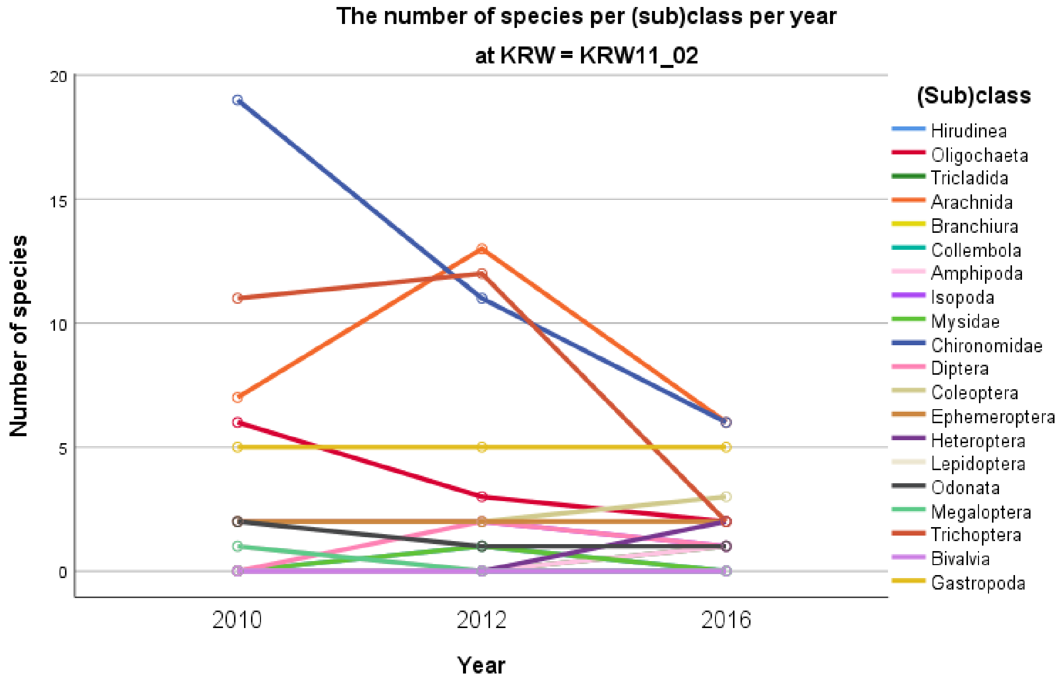
Graph 1 shows the values of the estimated marginal mean of the number of species per (sub)class per location per year. It is visible that the estimated marginal mean is lower every year ($F(1.804,108.266) = 11.611$, $P < .001$), so a decline is visible in all KRW locations as well as on average. This means the number of species per (sub)class is declining on average as well.

Furthermore, no statistical effect has been seen between the different locations nor has a combinatory effect been seen. This means that the locations are not statistically different from each other, nor different from each other over time regarding the average amount of species per (sub)class, though the average number of species per (sub)class is declining over time for all locations.

Species composition per KRW location

To make changes in the species composition visible, graphs were also made per location. These graphs show declines and increases in the number of species per (sub)class. Under the graphs, tables show an overview of the number of species in each year of the main (sub)classes. Only those (sub)classes that had at least five different species at some point in time have been taken into account and have been subsequently analysed.

KRW11_02



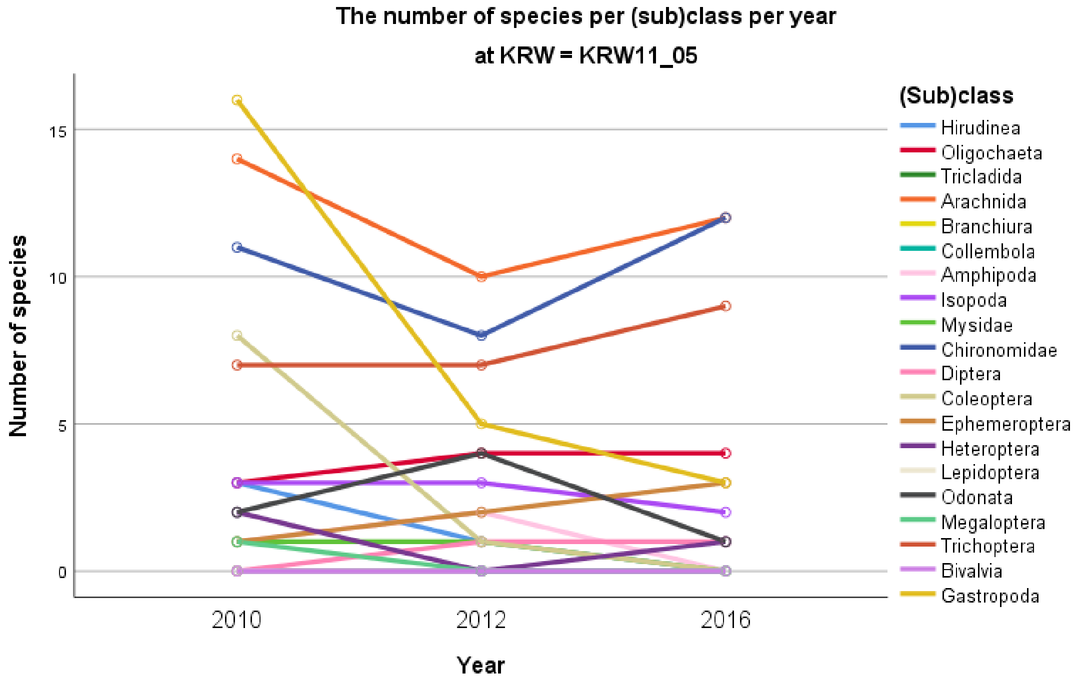
Graph 2 - The number of species per (sub)class at KRW11_02 set out against 2010, 2012 and 2016

Table 3 - The number of species per (sub)class at KRW11_02 in 2010-2012-2016

KRW11_02	2010	2012	2016
Chironomidae	19	11	6
Arachnida	7	13	6
Trichoptera	11	12	2
Oligochaeta	6	4	2
Gastropoda	5	5	5
Coleoptera	2	2	3
Amphipoda	1	0	1

At KRW11_02 (Graph 2, Table 3) the (sub)class that declines the most in species richness is the Chironomidae. The Arachnida increase in species richness at first and after 2012 the number of species drops by half. The number of Trichoptera initially increases by one to twelve, after which in 2016 only two species in this (sub)class remain. A steady decline of the species richness is seen with the (sub)class Oligochaeta. With the Gastropoda, the species richness stays the same throughout 2010, 2012 and 2016. The Coleoptera increase by one species after 2012, though are near the same (2±1) throughout. In 2010 one species of Amphipoda was found, in 2012 no Amphipoda were found however, and in 2016 one species of Amphipoda was found again.

KRW11_05



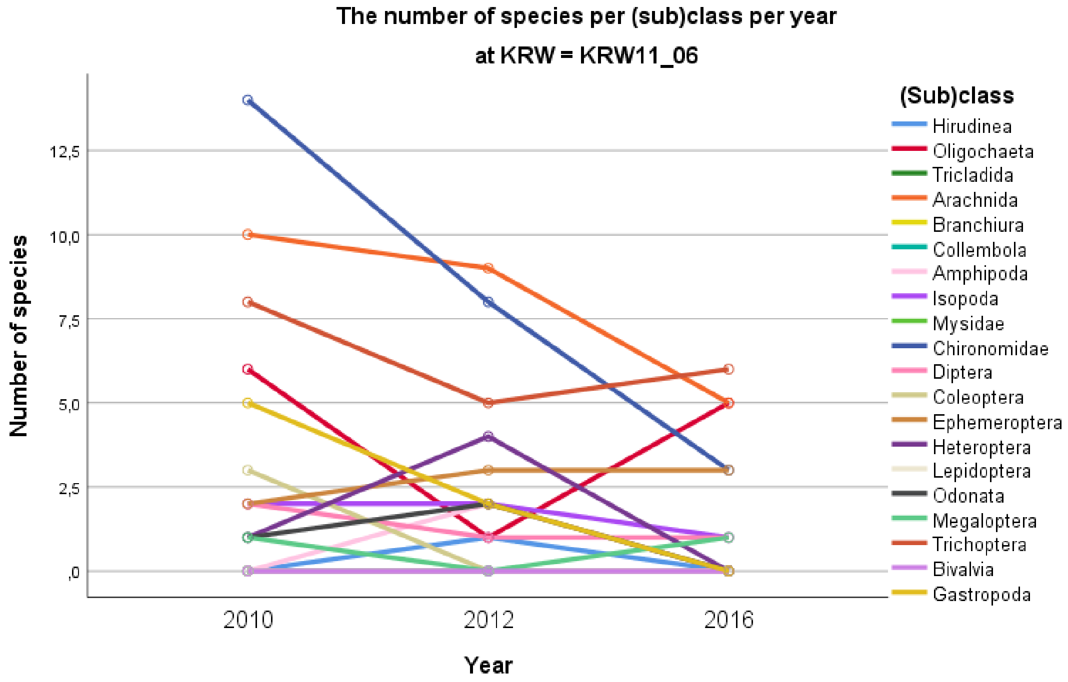
Graph 3 - The number of species per (sub)class at KRW11_05 set out against 2010, 2012 and 2016

Table 4 - The number of species per (sub)class at KRW11_05 in 2010-2012-2016

KRW11_05	2010	2012	2016
Chironomidae	11	8	12
Arachnida	14	10	12
Trichoptera	7	7	9
Oligochaeta	3	4	4
Gastropoda	16	5	3
Coleoptera	8	1	0
Amphipoda	1	2	0

At KRW11_05 (Graph 3, Table 4) the (sub)class that declines the most in species richness is the Gastropoda. The Chironomidae decrease in species richness at first and after 2012 the number of species is the same (11±1) as in 2010. The (sub)class of Arachnida fluctuates around 12 different species (±2). The number of Trichoptera initially does not change, after which in 2016 an increase of two species in this (sub)class is visible. A steady number of species (4±1) is seen with the (sub)class Oligochaeta. The Coleoptera decrease to just one species in 2012 and in 2016 no Coleoptera species were found. In 2010 one species of Amphipoda was found, in 2012 two Amphipoda species were found, and in 2016 no species of Amphipoda were found.

KRW11_06



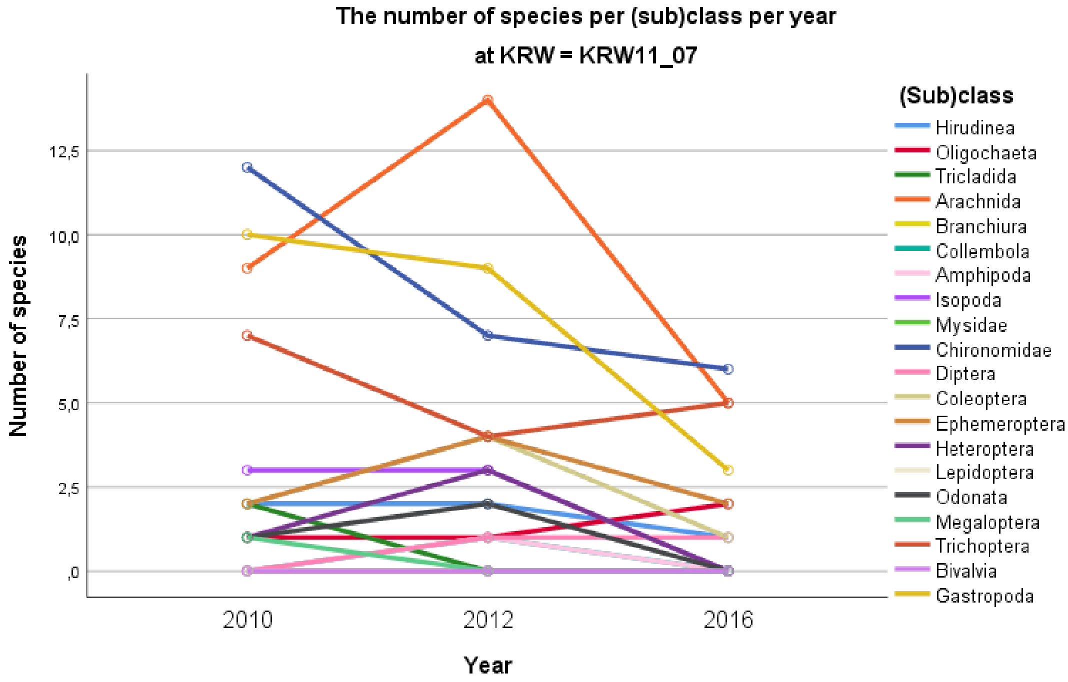
Graph 4 - The number of species per (sub)class at KRW11_06 set out against 2010, 2012 and 2016

Table 5 - The number of species per (sub)class at KRW11_06 in 2010-2012-2016

KRW11_06	2010	2012	2016
Chironomidae	14	8	3
Arachnida	10	9	5
Trichoptera	8	5	6
Oligochaeta	6	1	5
Gastropoda	5	2	0
Coleoptera	3	0	0
Amphipoda	0	2	0

At KRW11_06 (Graph 4, Table 5) the (sub)class that declines the most in species richness is the Chironomidae. The Arachnida stay the same (10±1) in species richness at first and after 2012 the number of species drops by half. The number of Trichoptera initially decreases by ¼, after which the number of species in this (sub)class remains the same (6±1). A decline is seen in the species richness of the (sub)class Oligochaeta, just one remains in 2012, however in 2016 the number of species is the same (5±1) as in 2010. With the Gastropoda, the species richness steadily declines throughout 2010, 2012 and 2016, with no remaining species in 2016. The Coleoptera decrease to zero species after 2010 and in 2016 there were still no Coleoptera species. In 2010 and 2016 no Amphipoda species were found, in 2012 two Amphipoda species were found however.

KRW11_07



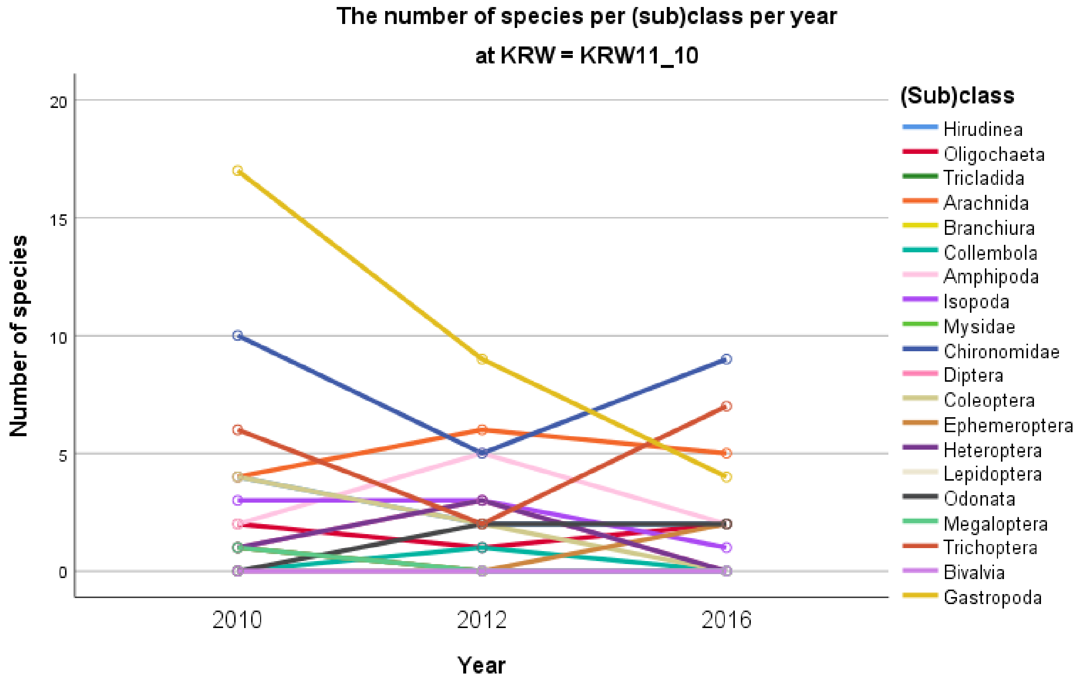
Graph 5 - The number of species per (sub)class at KRW11_07 set out against 2010, 2012 and 2016

Table 6 - The number of species per (sub)class at KRW11_07 in 2010-2012-2016

KRW11_07	2010	2012	2016
Chironomidae	12	7	6
Arachnida	9	14	5
Trichoptera	7	4	5
Oligochaeta	1	1	2
Gastropoda	10	9	3
Coleoptera	2	4	1
Amphipoda	0	1	0

At KRW11_07 (Graph 5, Table 6) the (sub)class that initially declines the most in species richness is the Chironomidae. The Arachnida, though in 2012 the number of species increases from 9 to 14, after 2012 the species richness drops by half(2010-2016)/two-thirds(2012-2016). The number of Trichoptera initially decreases by ¼, after which the number of species in this (sub)class remains the same (4±1). The number of species with the (sub)class Oligochaeta increases to 2 in 2016 but stays the same(1±1) overall. With the Gastropoda, the number of species stays the same (9±1) in 2010 and 2012 after which it drops by two-thirds. The Coleoptera first double in species richness to 4 different species and decline in number after that to just 1 species that was found in 2016. In 2010 and 2016 no Amphipoda species were found, in 2012 one Amphipoda species was found however.

KRW11_10



Graph 6 - The number of species per (sub)class at KRW11_10 set out against 2010, 2012 and 2016

Table 7 - The number of species per (sub)class at KRW11_10 in 2010-2012-2016

KRW11_10	2010	2012	2016
Chironomidae	10	5	9
Arachnida	4	6	5
Trichoptera	6	2	7
Oligochaeta	2	1	2
Gastropoda	17	9	4
Coleoptera	4	2	0
Amphipoda	2	5	2

At KRW11_10 (Graph 6, Table 7) the (sub)class that declines the most in species richness is the Gastropoda. The Chironomidae decrease in species richness at first and after 2012 the number of species is the same (10±1) as in 2010. The (sub)class of Arachnida fluctuates around 5 different species (±1). The number of Trichoptera initially declines by two-thirds, after which in 2016 the same (6±1) number of species as in 2010 is visible. A steady number of species (2±1) is seen with the (sub)class Oligochaeta. The Coleoptera decrease by half in 2012 and in 2016 no Coleoptera species were found. In 2010 and 2016 two species of Amphipoda were found, though in 2012 five species of Amphipoda were found.

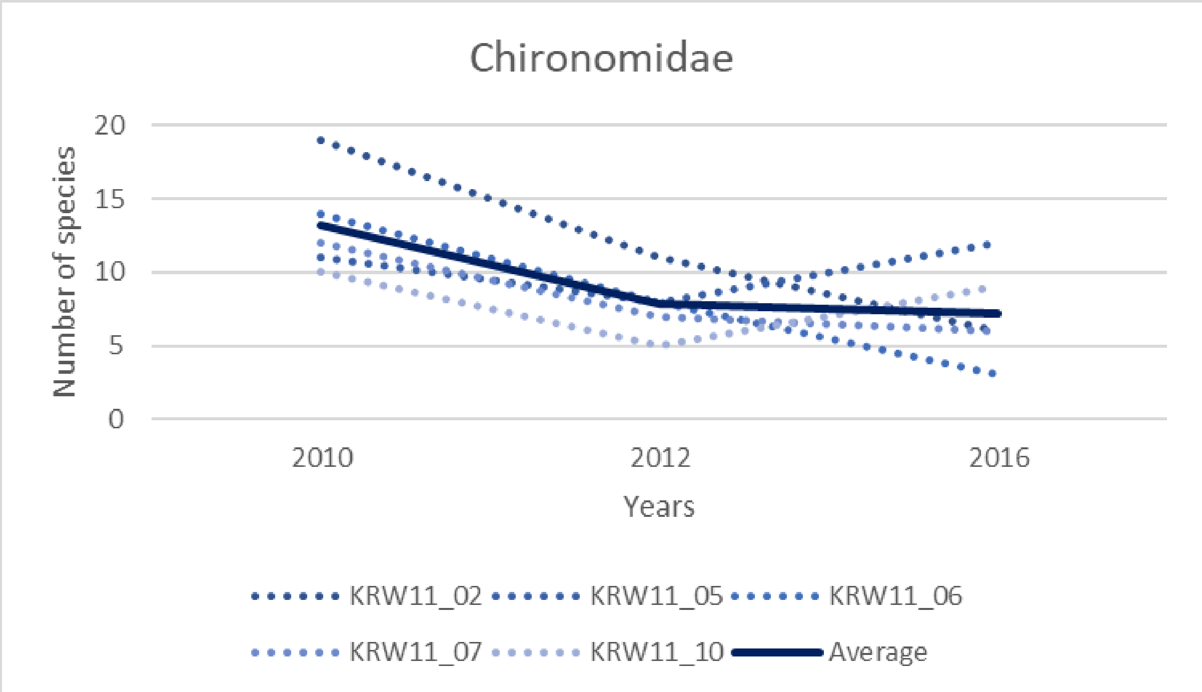
Overview of the species composition per KRW location

When looking at the species composition, it becomes clear that changes are taking place. Initially Chironomidae have the highest species richness, closely followed by the Arachnida and Gastropoda. In 2012 this changes to the Arachnida becoming the group with the highest species richness, closely followed by the Chironomidae and partially the Trichoptera and Gastropoda. In 2016 the highest species richness can be found for the Chironomidae and Arachnida which are then closely followed by the Trichoptera. The (sub)class with the least species richness is initially the Amphipoda, closely followed by the Coleoptera and Oligochaeta. In 2012 all these (sub)classes can be considered as having the lowest species richness. In 2016 the Amphipoda are once again the (sub)class with the least species richness, with the Coleoptera following closely and the Gastropoda and Oligochaeta being in the middle segment.

Differences per (sub)class

This paragraph shows graphs of the mean and the overall number of species on every location.

Chironomidae



Graph 7 - The number of species of Chironomidae per location set out against 2010, 2012 and 2016 - Included is the mean value of the number of Chrionomidae species per year

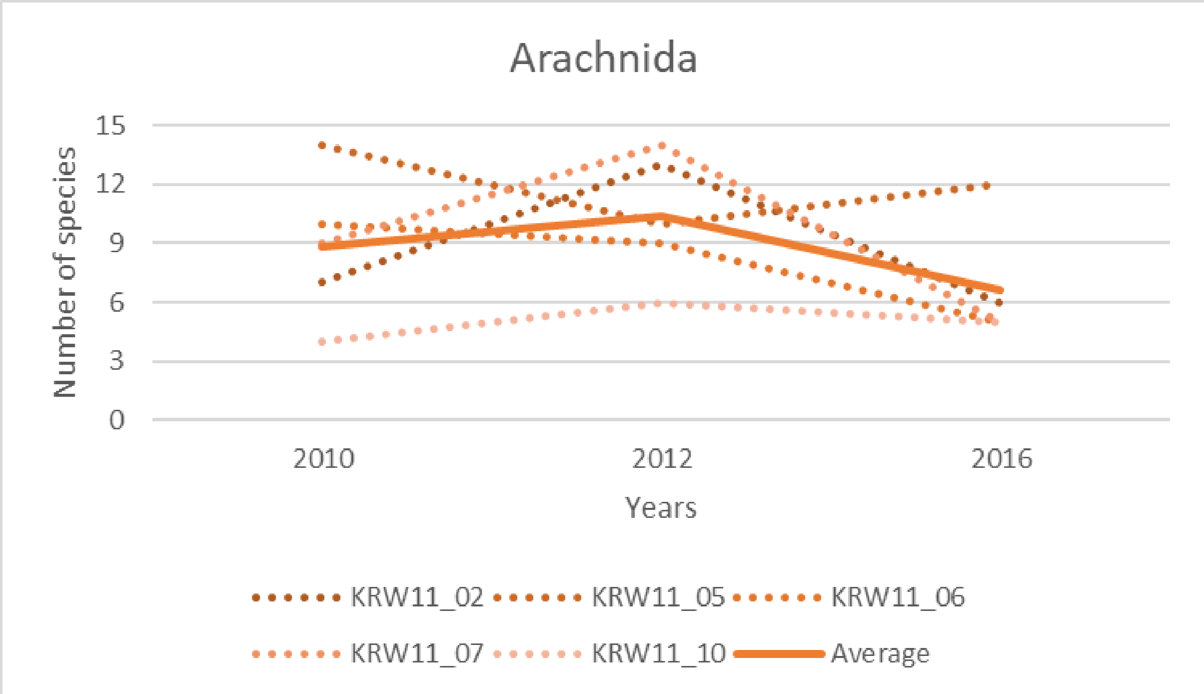
Table 8 - The number of species of Chironomidae per location in 2010-2012-2016

Chironomidae	2010	2012	2016
KRW11_02	19	11	6
KRW11_05	11	8	12
KRW11_06	14	8	3
KRW11_07	12	7	6
KRW11_10	10	5	9

Graph 7 (Table 8) shows that from 2010-2016 the average number of species of Chironomidae is halved and is declining in consecutive measures to get there. At most 19 different species can be found in 2010 at KRW11_02, the least number of species (3) can be found in 2016 at KRW11_06, though at the same time at KRW11_05 twelve different species of Chironomidae can be found. Furthermore, KRW11_05 and KRW11_10 seem to have as many species (±1) in 2016 as before in 2010, though the other locations see drops of 50% or more in that timeframe.

By use of a one-way ANOVA ($F(2,12) = 5.629$, $p = .019$) a statistically significant difference of the number of different Chironomidae species between years was determined. Following that, a Tukey post hoc test was used that showed that the number of different species of Chironomidae was lower in 2012 (7.8 ± 2.2, $p = .044$) and 2016 (7.20 ± 3.4, $p = .026$) compared to 2010 (13.2 ± 3.6). There was no statistically significant difference between 2012 and 2016 ($p = .950$).

Arachnida



Graph 8 - The number of species of Arachnida per location set out against 2010, 2012 and 2016 - Included is the mean value of the number of Arachnida species per year

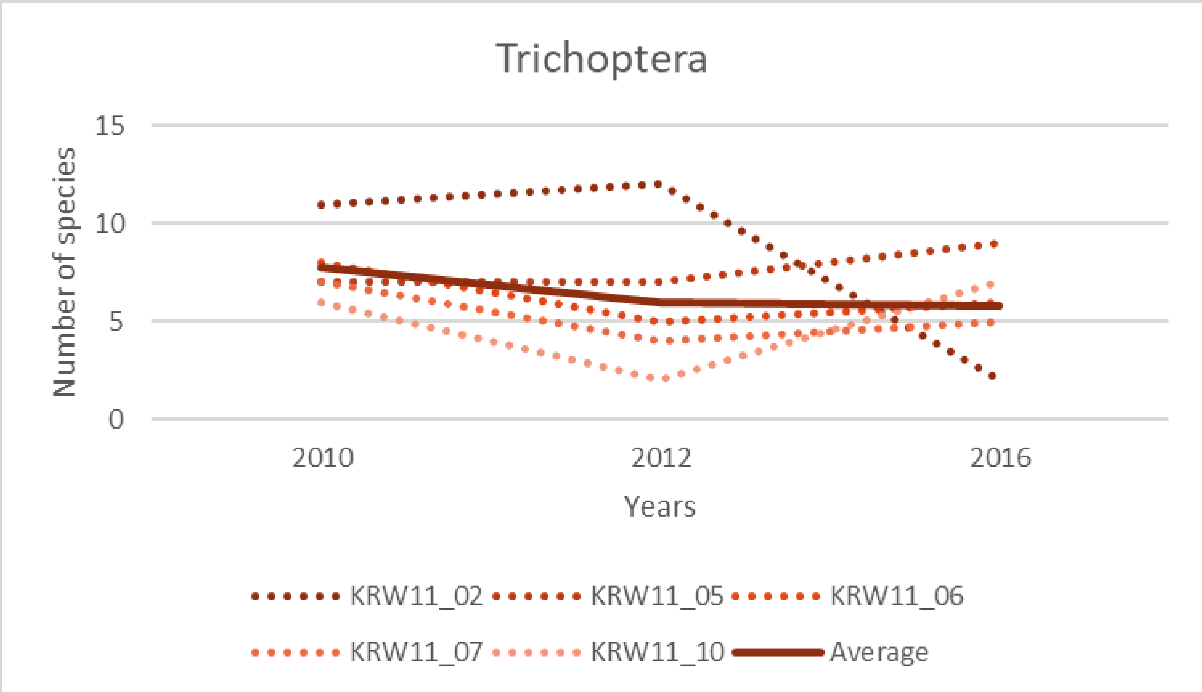
Table 9 - The number of species of Arachnida per location in 2010-2012-2016

Arachnida	2010	2012	2016
KRW11_02	7	13	6
KRW11_05	14	10	12
KRW11_06	10	9	5
KRW11_07	9	14	5
KRW11_10	4	6	5

Graph 8 (Table 9) shows that from 2010-2016 the average number of species of Arachnida fluctuates. Though initially it heightens in 2012, absolute numbers show that the maximum number of species per location does not heighten. KRW11_05 has 14 different species of Arachnida in 2010, in 2012 the maximum is also 14 though for KRW11_07, with KRW11_02 being a close second with 13 different species. In 2016 the maximum number of Arachnida drops to 12 (KRW11_05) though at all other locations the number is half that or less.

By use of a one-way ANOVA ($F(2,12) = 1.640$, $p = .235$) no statistically significant difference of the number of different Arachnida species between years was determined.

Trichoptera



Graph 9 - The number of species of Trichoptera per location set out against 2010, 2012 and 2016 - Included is the mean value of the number of Trichoptera species per year

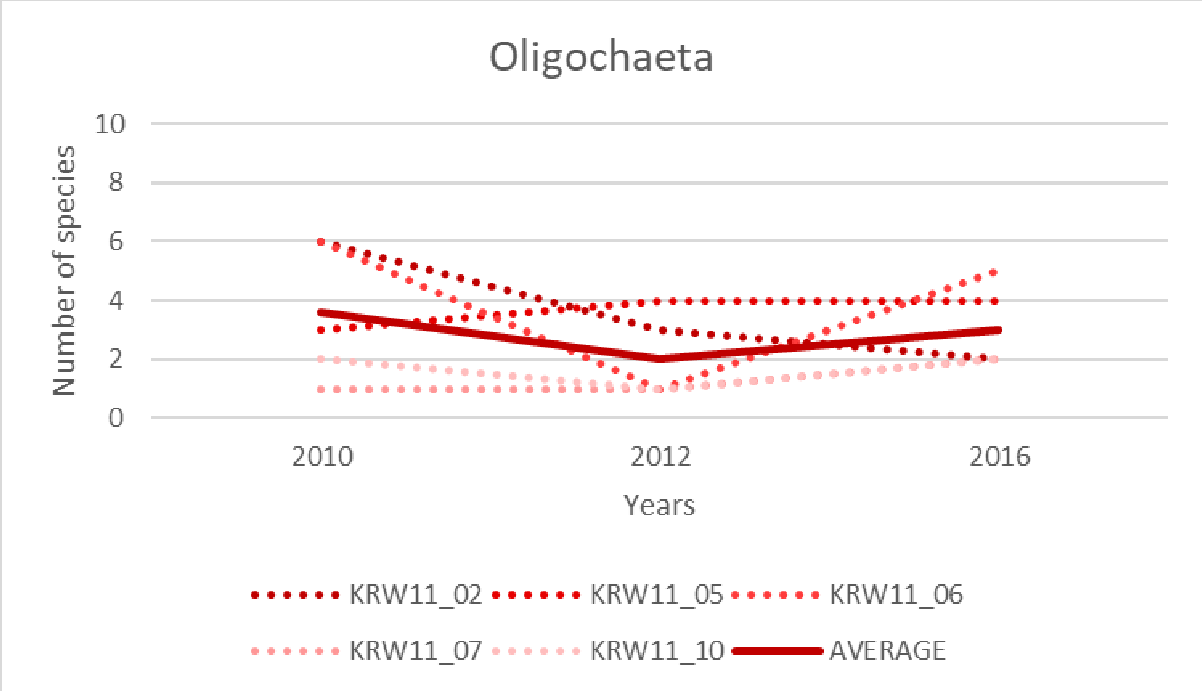
Table 10 - The number of species of Trichoptera per location in 2010-2012-2016

Trichoptera	2010	2012	2016
KRW11_02	11	12	2
KRW11_05	7	7	9
KRW11_06	8	5	6
KRW11_07	7	4	5
KRW11_10	6	2	7

Graph 9 (Table 10) shows that from 2010-2016 the average number of species of Trichoptera is declining in consecutive measures. Most species can be found at KRW11_02 (2010: 11; 2012: 12) though in 2016 the number of species drops to an overall minimum of two. In 2012 the same minimum is reached once at KRW11_10, however, just as all other locations, with the exception of KRW11_02, the number of species of Trichoptera is nearly as high or higher in 2016 as/than in 2010 (max±2)

By use of a one-way ANOVA ($F(2,12) = .731$, $p = .502$) no statistically significant difference of the number of different Trichoptera species between years was determined.

Oligochaeta



Graph 10 - The number of species of Oligochaeta per location set out against 2010, 2012 and 2016 - Included is the mean value of the number of Oligochaeta species per year

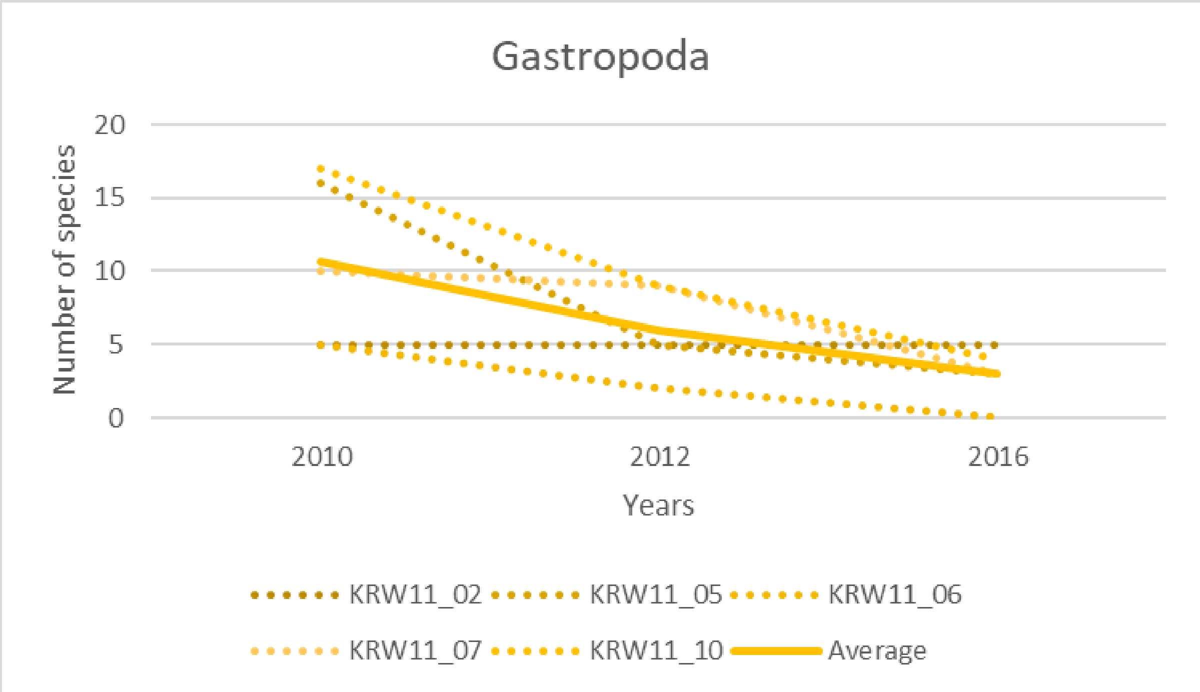
Table 11 - The number of species of Oligochaeta per location in 2010-2012-2016

Oligochaeta	2010	2012	2016
KRW11_02	6	4	3
KRW11_05	3	4	4
KRW11_06	6	1	5
KRW11_07	1	1	2
KRW11_10	2	1	2

Graph 10 (Table 11) shows that from 2010-2016 the average number of species of Oligochaeta is fluctuates. Though initially it lowers in 2012, it seems to recover to near initial numbers for 2016. Absolute numbers also show that the initial number of species per location does not change (±1), except for KRW11_02, which halves when comparing 2016 with 2010. The biggest change is found at KRW11_06 which declines from 6 species (maximum of 6 overall) in 2010 to just 1 in 2012, though in the end it houses 5 different species.

By use of a one-way ANOVA ($F(2,12) = .804$, $p = .470$) no statistically significant difference of the number of different Oligochaeta species between years was determined.

Gastropoda



Graph 11 - The number of species of Gastropoda per location set out against 2010, 2012 and 2016 - Included is the mean value of the number of Gastropoda species per year

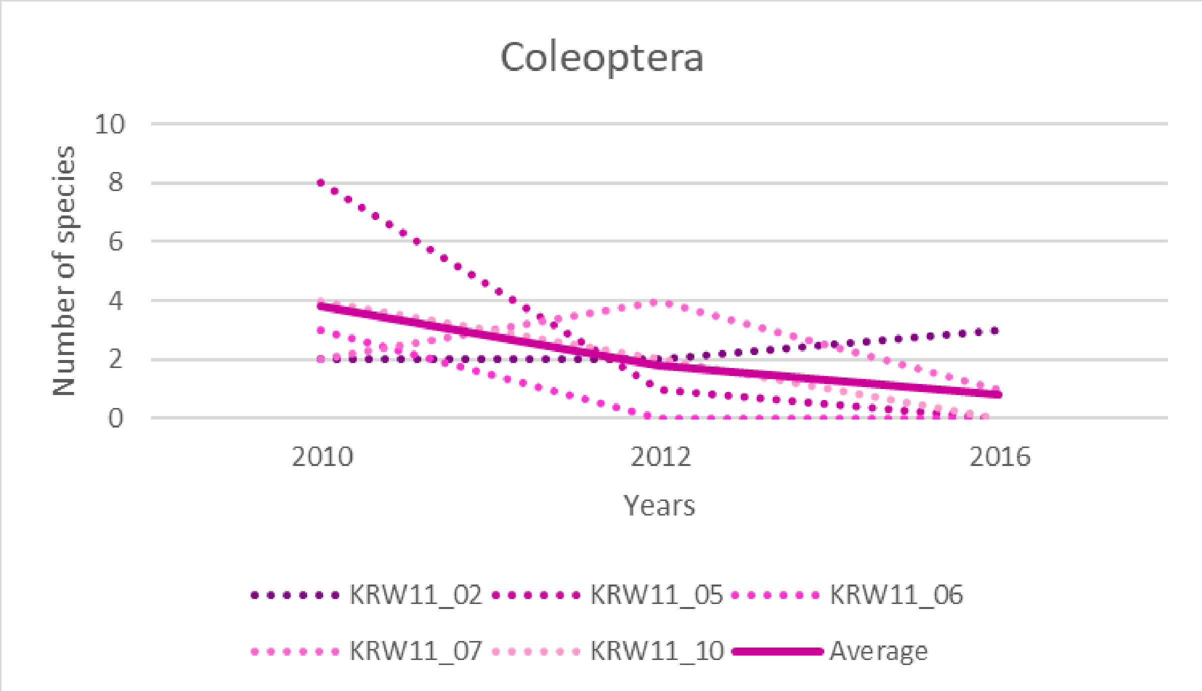
Table 12 - The number of species of Gastropoda per location in 2010-2012-2016

Gastropoda	2010	2012	2016
KRW11_02	5	5	5
KRW11_05	16	5	3
KRW11_06	5	2	0
KRW11_07	10	9	3
KRW11_10	17	9	4

Graph 11 (Table 12) shows that from 2010-2016 the average number of species of Gastropoda is more than halved and is declining in consecutive measures to get there. At most 17 different species can be found in 2010 at KRW11_10, the least number of species (0) can be found in 2016 at KRW11_06, though at the same time at KRW11_02 five different species of Gastropoda can be found. KRW11_02 is also the only location that does not decline in the number of species, but continually has 5 different species of Gastropoda. However, in 2010 the minimum number of species was 5, which was the maximum for 2016.

Since for this (sub)class the assumption of homogeneity of variance was not met, Welch's-ANOVA was used (Welch's $F(2,12) = 7.014$, $p = .054$). No statistically significant difference of the number of different Gastropoda species between years was determined, though a trend was observed. Following that, a Games-Howell post hoc test was used that showed that the number of different species of Gastropoda did not differ in 2012 (6.00 ± 3.0, $p = .323$) and 2016 (3.00 ± 1.9, $p = .085$) compared to 2010 (10.60 ± 5.8). However, 2010-2016 showed a downward trend. There was also no statistically significant difference between 2012 and 2016 ($p = .212$).

Coleoptera



Graph 12 - The number of species of Coleoptera per location set out against 2010, 2012 and 2016 - Included is the mean value of the number of Coleoptera species per year

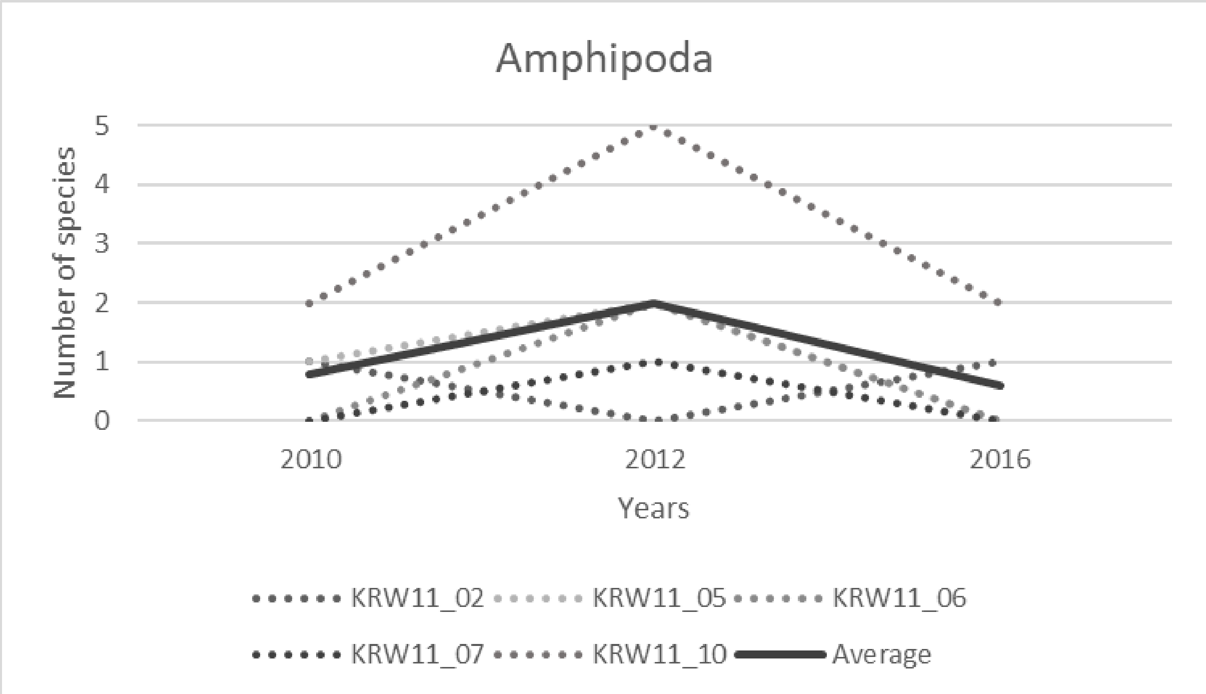
Table 13 - The number of species of Coleoptera per location in 2010-2012-2016

Coleoptera	2010	2012	2016
KRW11_02	2	2	3
KRW11_05	8	1	0
KRW11_06	3	0	0
KRW11_07	2	4	1
KRW11_10	4	2	0

Graph 12 (Table 13) shows that from 2010-2016 the average number of species of Coleoptera is more than halved and is declining in consecutive measures to get there. At most 8 different species can be found in 2010 at KRW11_05, the minimum however is 0 species, something that is seen at KRW11_06 since 2012 and furthermore is seen at KRW11_05 and KRW11_10 in 2016, while only 1 species remains at KRW11_07 in 2016. At the same time however at KRW11_02 two different species of Coleoptera can be found in 2010 and 2012 and in 2016 this even increases by one.

By use of a one-way ANOVA ($F(2,12) = 3.465$, $p = .065$) no statistically significant difference of the number of different Coleoptera species between years was determined, though a trend was observed. Following that, a Tukey post hoc test was used that showed that the number of different species of Coleoptera did not differ in 2012 (1.80 ± 1.5, $p = .237$) and 2016 ($.80 \pm 1.3$, $p = .058$) compared to 2010 (3.80 ± 2.5). However, 2010-2016 showed a downward trend. There was also no statistically significant difference between 2012 and 2016 ($p = .673$).

Amphipoda



Graph 13 - The number of species of Amphipoda per location set out against 2010, 2012 and 2016 - Included is the mean value of the number of Amphipoda species per year

Table 14 - The number of species of Amphipoda per location in 2010-2012-2016

Amphipoda	2010	2012	2016
KRW11_02	1	0	1
KRW11_05	1	2	0
KRW11_06	0	2	0
KRW11_07	0	1	0
KRW11_10	2	5	2

Graph 13 (Table 14) shows that from 2010-2016 the average number of species of Amphipoda fluctuates. A rise in the number of species is seen though in 2012 that is also seen in absolute numbers, except for KRW11_02, which has no Amphipoda species in 2012. All other locations do have one or more Amphipoda species in 2012, and KRW11_05 has in that moment an overall maximum of 5 different species of Amphipoda. 2016 however is nearly identical to 2010, with the only difference being the absence of Amphipoda at KRW11_05 in 2016 compared to 1 in 2010. Moreover, both in 2010 and 2016 no Amphipoda were found for 2-3 locations and 1-2 locations had just one species.

By use of a one-way ANOVA ($F(2,12) = 1.720$, $p = .220$) no statistically significant difference of the number of different Amphipoda species between years was determined.

Relation to the measures

As seen in Appendix 1, natural banks were implemented in every lake of the Reeuwijkse Plassen. All these measures were started in 2012 (Table 1). When looking through physio-chemical data (Appendix 3) for KRW11_05, KRW1_06 and KRW11_10, it became clear that these measures had an adverse effect on the water quality. Overall the nutrient load was elevated just as measures were taken and the turbidity increased as well. At the same time, the biochemical oxygen demand (BOD) increased, and the acidity fluctuated more, while the hydrogen carbonate levels (acidity buffer) went down. All variables returned to previous levels after 1,5-2 years.

Another find was that potassium and sodium fluctuate less strongly after 2011, at which time the agricultural polders were disconnected from the lakes (Table 1), thus showing a stabilizing effect for the water quality.

Since a few (sub)classes of macroinvertebrates show a downward trend or negative effect after 2010, it seems there is a correlation between construction of the natural banks and the change in species composition.

Discussion

Implementing natural banks has been shown to improve the ecological status of water bodies (de la Haye, et al., 2011; Sollie, Brouwer, & de Kwaadsteniet, 2011; Soesbergen & Rozier, 2004). However, the EQR score of the Reeuwijkse Plassen has not significantly improved (Torenbeek, 2016). The aim of this study is thus to see what kind of changes have taken place in, and if there is a visible trend in the macrofauna composition in the Reeuwijkse Plassen after measures were taken. To give an overview of what is going on, results will first be analyzed by looking at the overall changes in biodiversity by use of the estimated marginal mean of the number of species per (sub)class per year. This will be followed by an overview of the species composition per location. Then, a more in-depth analysis of the number of species per (sub)class is made by comparing the mean number of species over the years. Lastly the changes in species composition are related to the measures.

Overall changes in the species composition of macroinvertebrates

Though implementation of natural banks has been shown to improve the ecological status of water bodies, this change is often not instant (Lamers, et al., 2006). Macroinvertebrates especially show a tendency to be in need of recovery for years after changes have been made (de la Haye, et al., 2011). As thus the macroinvertebrate community was considered to be different from, and biodiversity-wise lower than before the measures were implemented. This research follows this hypothesis in the way that the biodiversity indeed declines over the years. Furthermore it was found that the locations are not statistically different from each other. It is expected that this is due to the fact that all lakes are connected in some way, and because measures were taken in all lakes at the same time.

Overview of the species composition per KRW location

Though changes take place in the species composition, the sheer number of Chironomidae species continues to be mostly predominant throughout the years even though they are negatively affected over time. This is probably the case because in general the (sub)class of Chironomidae is one of the most abundant and diverse groups of the macroinvertebrates (Bazzanti, Mastrantuono, & Solimini, 2012). Another reason for the predominant position of Chironomidae after being negatively influenced by the measures might be that Chironomidae are considered a pollution-tolerant family and thus combined with the size of the family have a higher chance of occurrence (Chowdhury, Gallardo, & Aldridge, 2016).

The Arachnida also take up a sizeable part of the species composition, this is in part because this group is also more abundant and diverse than most other macroinvertebrates. At the same time, the fact that Arachnids have are highly interactive with other members of the macroinvertebrates, either as parasites or predators, makes them less likely to be influenced by changes when these other macroinvertebrates also remain (Goldschmidt, 2016).

The (sub)class that makes for the greatest overall change in species composition is the Gastropoda, initially at most waters there is a great number of different species, however in the following years the size of this group declines to being in the middle segment of the overall number of species. The reason why the number of Gastropoda species declines this much is unclear and richness patterns are poorly understood (Miller, Ramos, Hauffe, & Delicado, 2018). The likeliest explanation however is that most Gastropoda species are probably less tolerant for changes than other macroinvertebrates.

Differences per (sub)class

After having looked at the different locations, and having seen that there are changes over time, it is important to gain a deeper understanding of these changes. To reach this goal, the number of species per (sub)class will now be compared over the years.

For the macroinvertebrate groups Chironomidae, Coleoptera, Gastropoda, Oligochaeta, Trichoptera, Arachnida and Amphipoda, species richness has been positively correlated to the water quality (Dong, Geng, Cai, & Ji, 2014; Pham, 2017; Savić, Ranđelović, Đorđević, & Pešić, 2016; Odume & Muller, 2011; Goldschmidt, 2016; Gombeer, Knapen, & Bervoets, 2011). Due to the construction of the natural banks, certain key factors have declined. The turbidity increased and it is likely that the vegetation structure was in need of recovery, while eutrophication and the biochemical oxygen demand (BOD) was also heightened. These negative changes in water quality have sequentially led to a downward trend of the species richness of Coleoptera and Gastropoda and a negative correlation with the species richness of Chironomidae.

Though expected due to previous research, the (sub)classes of the Oligochaeta, Amphipoda, Trichoptera and Arachnida have not shown to be statistically different over the years. A reason for the Oligochaeta might be found in the fact that disturbances that depend on an influx of nutrients through the water, are likely to affect biota living above the sediment, before affecting biota living in/below the sediment (Lake, et al., 2000). Since the water quality was only temporarily affected due to the measures, it is likely that no permanent changes will be had in the ecological conditions of the Oligochaeta. Changes were also expected for the Arachnida, though since they interact highly with other macroinvertebrates as either parasites or predators, they are less likely to be influenced by environmental changes as long as their hosts and/or preys also remain (Goldschmidt, 2016). Though changes were also expected for Amphipoda and Trichoptera, it might be that construction of the natural banks and the following change of key factors, was not profound enough to have an effect on the species composition of these macroinvertebrates. Alternately it might also be that mostly tolerant species were occurring in 2010 and thus no significant changes were found as those species would not be affected.

Relation to the measures

Physio-chemical data shows changes after measures were taken, after 2010 a few (sub)classes of macroinvertebrates show a downward trend or negative effect after 2010, it seems that there is a correlation. Though not all expected (sub)classes reacted negatively to the observed changes in water quality due to the measures, it might be that those groups originally consisted of more tolerant species.

Limitations

Although every sample was taken by the WFD protocols there can still be differences in observed species because of the way people sample. Changes can arise as such that species are missed in one year and found in the other, not because they were absent in one but because the personal way of sampling, e.g. missing certain habitats or scooping in a different way. However this is not likely to have too much of an effect as changes were observed in some benthic species and not in others, else way it would be expected that a drop in species richness would be visible for al (sub)classes of a specific habitat. The determination of the macroinvertebrates is done by specialists but even they can make mistakes in species as it is sometimes difficult to see certain distinction between species. Although samples are taken around the same period (April, May and June) every year, this can have differences as well as temperatures can vary in each month every year. Some species are likely to develop their larval stages more rapidly in warmer temperatures and will thus no longer be found anymore, resulting in a lower species richness, while that is not a realistic observation. Since KRW points were made from multiple subsamples per lake (normally 4) and this number was not always the same over all point and years, errors might have arisen in the data, resulting in a lower species richness. Though this was only a problem for 2010, resulting in the fact that changes that were found are likely to be true, albeit less pronounced, and expected changes that were not found, might be overlooked because of this. Lastly the correlation of the natural banks with the change in species composition has been made under the assumption that the other two lakes are showing the same physio-chemical changes as the three lakes of which data was available. Though since all lakes are connected in some way and none of the lakes are statistically different from another in the estimated marginal mean of the number of species per (sub)class, thus all lakes show the same changes over the years, it is expected that the physio-chemical data for the other two lakes is the same as well and the following correlation with the change in species composition holds true as well.

Conclusions

To improve the water quality of the Reeuwijkse Plassen, waterboard Hoogheemraadschap Rijnland came up with measures such as natural banks and limited inflow of nutrient rich water from the surrounding area. Till now the Ecological Quality Ratio (EQR) score has not improved. After constructions have been done, macroinvertebrates need some time to recover. Therefore, it will likely also take some time before the EQR score is improved as well. This research was thus started to see whether changes in macroinvertebrate composition can be found.

Overall the species richness of macroinvertebrates declined on all KRW points in the Reeuwijkse Plassen over the years 2010, 2012 and 2016. Furthermore the species composition changed from an abundance of Chironomidae and in lesser amount Arachnida and Gastropoda, to a species composition of mostly consisting of Chironomidae, Arachnida and Trichoptera.

Changes were also found within the (sub)classes of the Chironomidae, Gastropoda and Coleoptera. The decline of the species richness for these (sub)classes and not the others is likely due to a relative lower tolerance to changes of certain key factors as turbidity and vegetation structure and due to eutrophication and a heightened BOD. Oligochaeta are less likely to be affected in this timeframe due to the fact that biota living in/below the sediment are affected later than biota living above the sediment. Arachnida are also less likely to be affected by the environmental changes as they are highly interactive with other macroinvertebrates which might have remained.

The physio-chemical parameters show to be changed resulting in a lower water quality as soon as construction of natural banks was begun. Consequently some (sub)classes of macroinvertebrates show a visible decline at the same time that can be correlated to these changes. Some species of these (sub)classes are influenced by eutrophication, a heightened demand of BOD, increased turbidity and changes in the vegetation structure and thus disappear.

Recommendations

The data for this research that was available via Aquon, was acquired by use of partially different sample points in 2010. Because of this, the exact KRW locations as used in consecutive years were not always sampled, nor all lakes. Because of this difference, not all KRW locations and points could be taken in for analysis. Only those points consisting of at least two locations were analyzed. Because of this, the dataset was not exactly the same between the years, which caused difficulties and resulted in the fact that only five out of ten lakes could be analyzed. Therefore it is recommended to safeguard use of the uniform KRW way to collect and save data in the future as to exclude difficulties with comparing data.

It would make the research even more interesting if it were possible to analyze data ranging from a couple of years before 2010 and after 2016. In that way it might possible to see whether the declining of species is a trend that was already occurring or that, as is hypothesized by this research, it is something that happened because of the measures. The years after 2016 might show an increase in species richness, as macroinvertebrate communities recover and perhaps flourish because of the intended effect of the measures.

To give a more wholesome view of what has happened with the ecology of the Reeuwijkse Plassen it would also be advisable to take changes to the macrophytes and terrestrial plants into account. Occurrence of certain species and/or changes in their abundance might be indicative for certain changes in the macroinvertebrate community.

Lastly, this research report has looked at species richness but not at the specific genus or species. It is recommended that in a future research this data will be analyzed for changes at these levels. If done, it is possible to find out whether the species composition did not only change due to a decline in the species richness of some (sub)classes, but perhaps also changed more profoundly due to the loss and gain of certain species in different years. As could also be the case with (sub)classes that did not show any changes at this higher taxonomic level that this research looked at.

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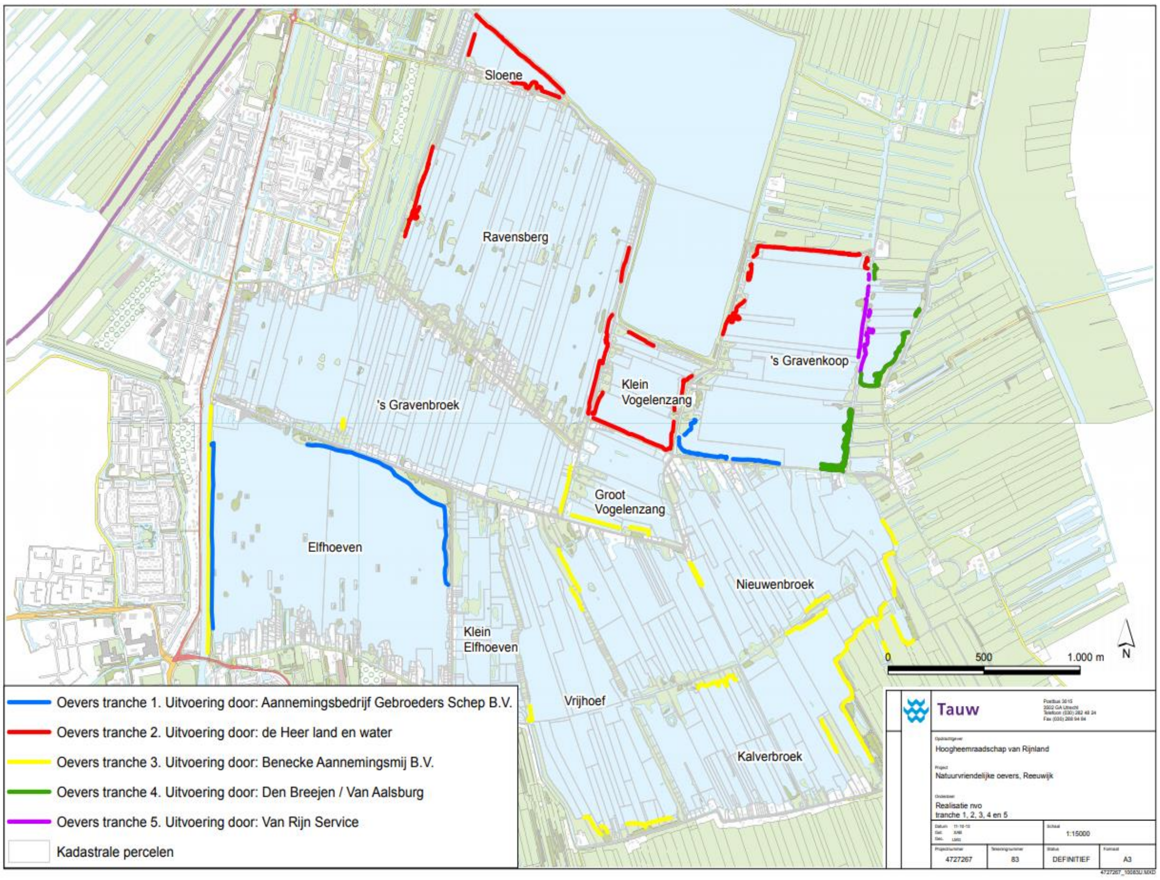
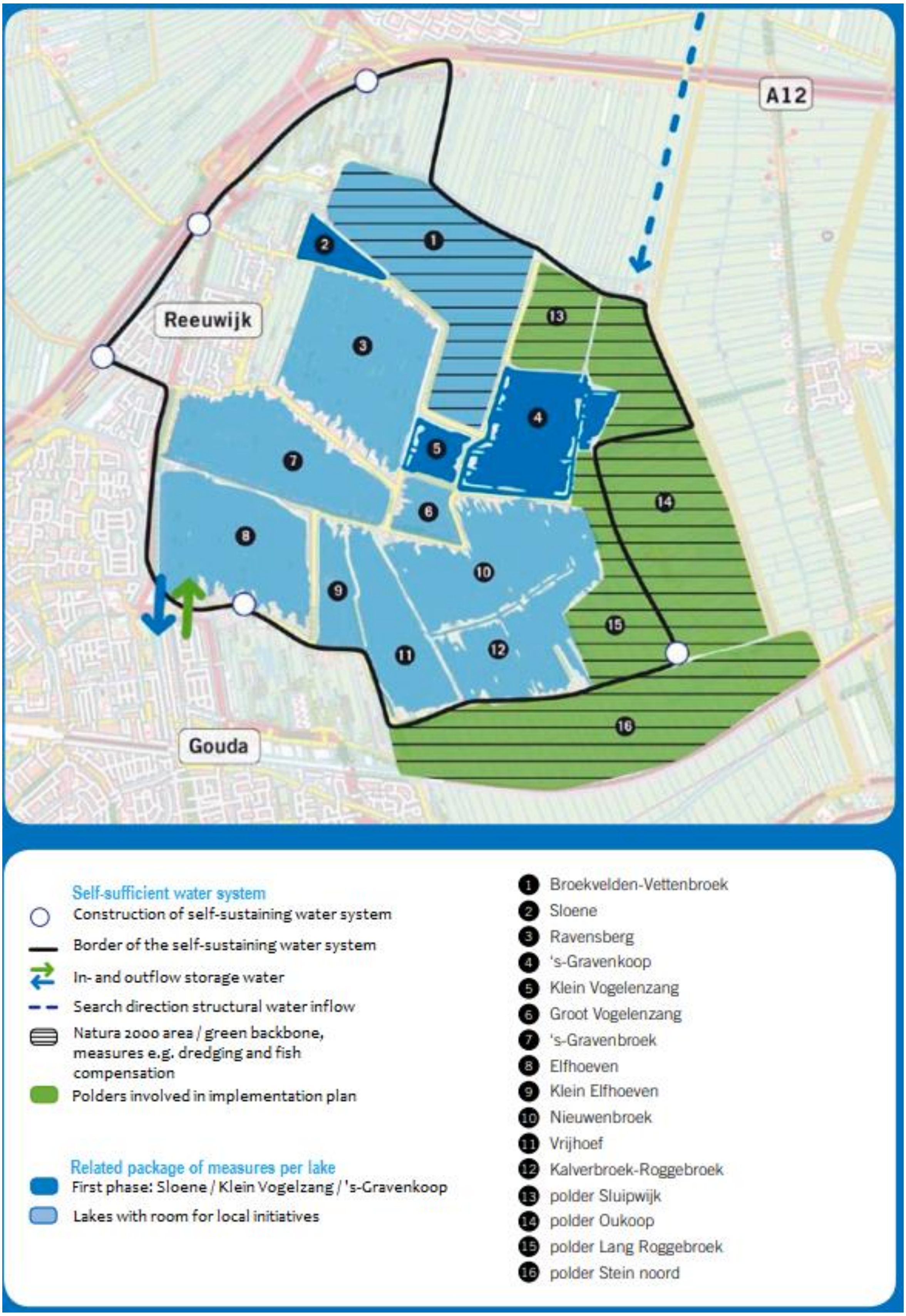
Appendix

Appendix 1 – overview of implemented natural banks



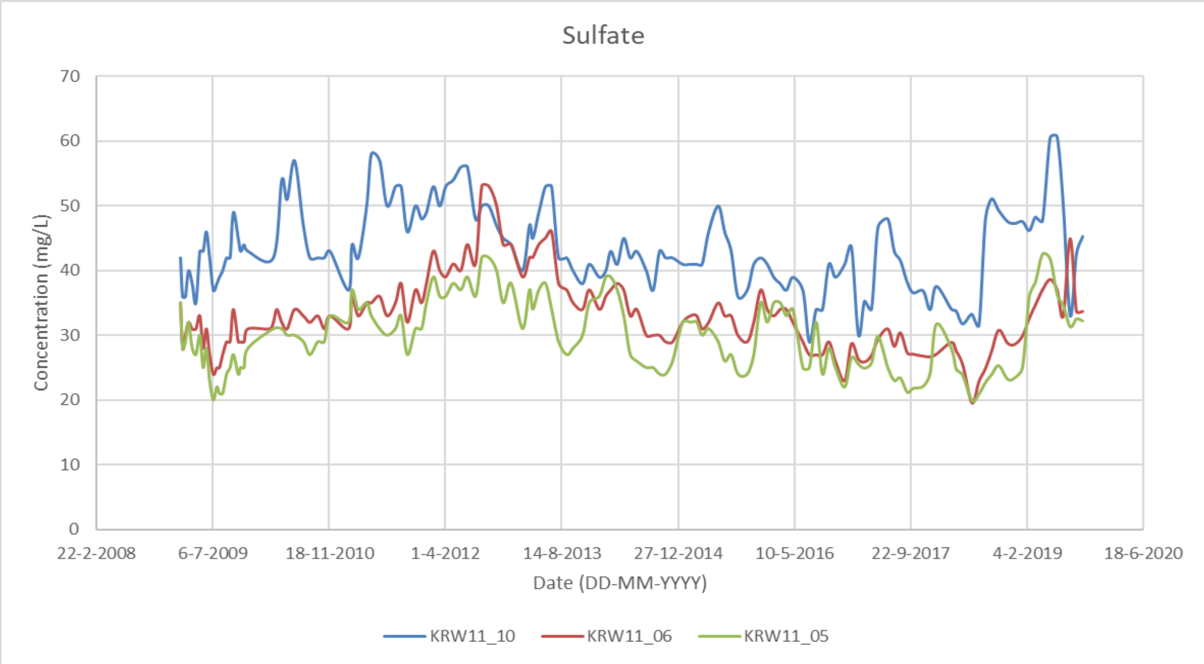
Appendix Figure 1 - Locations of the implemented natural banks in the Reeuwijkse Plassen (Hoogheemraadschap Rijnland, Schoon & Mooi).

Appendix 2 – Overview of water in- and outflow

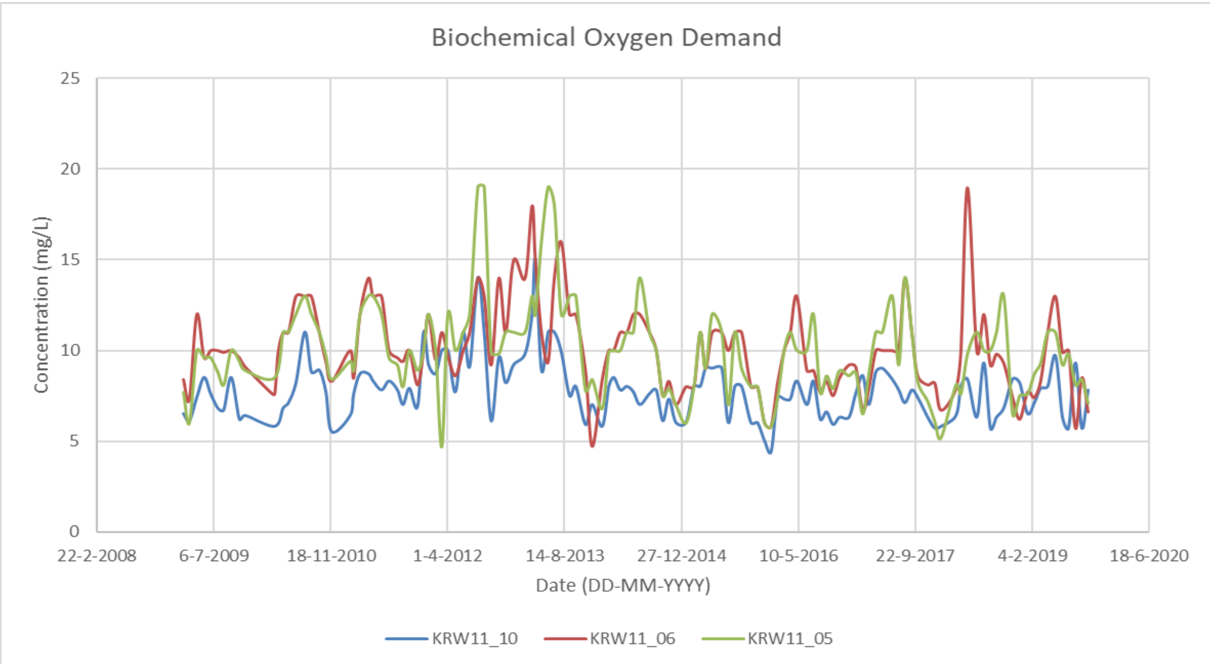


Appendix Figure 2 - Overview of the water in- and outlets of the Reeuwijkse Plassen (Hoogheemraadschap Rijnland, Schoon & Mooi).

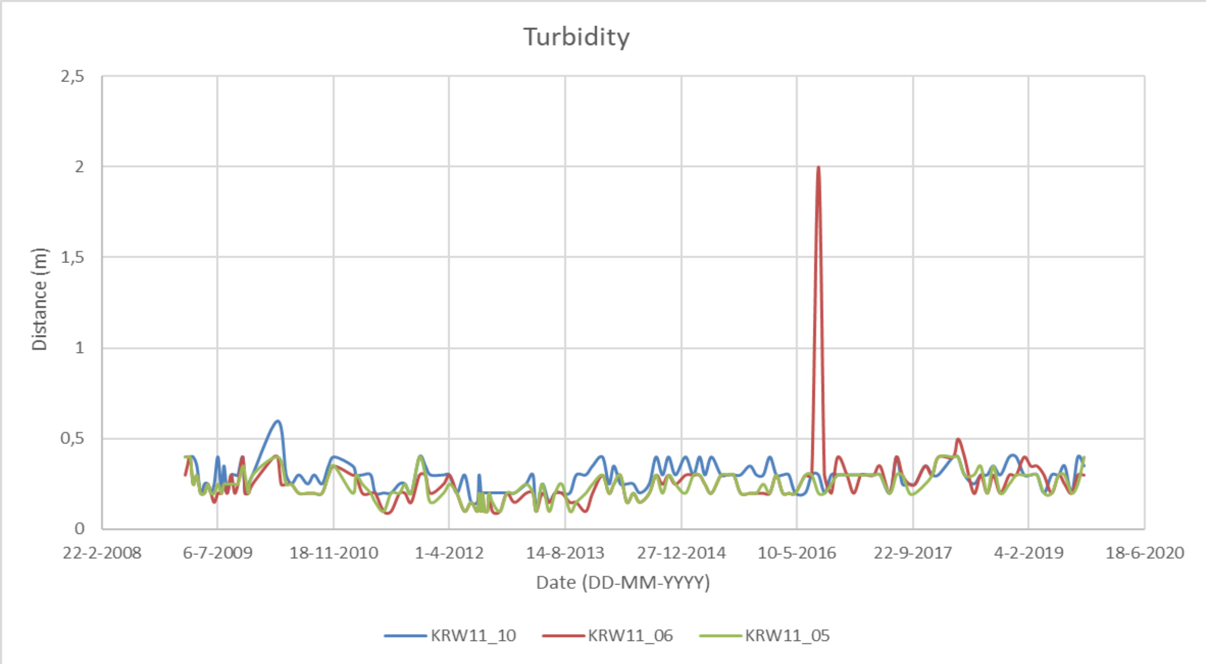
Appendix 3 – Graphs of physio-chemical parameters



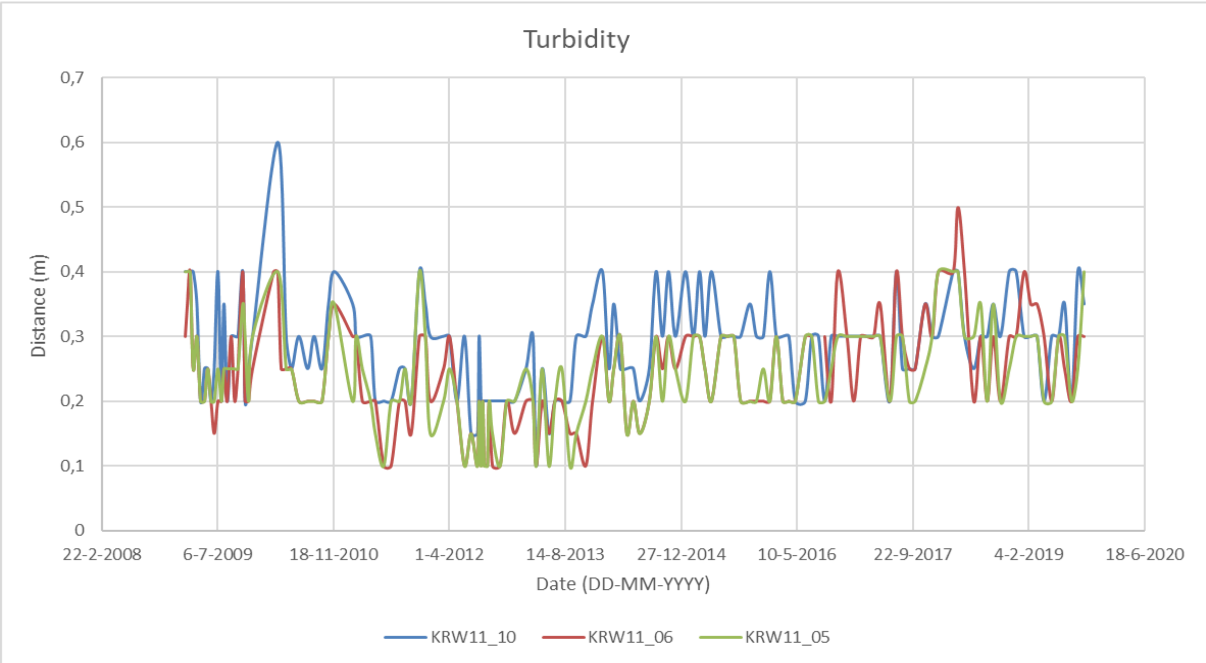
Appendix Graph 1 – The sulfate concentration (mg/L) between 2009 and 2019 for KRW11_05, KRW11_06 and KRW11_10



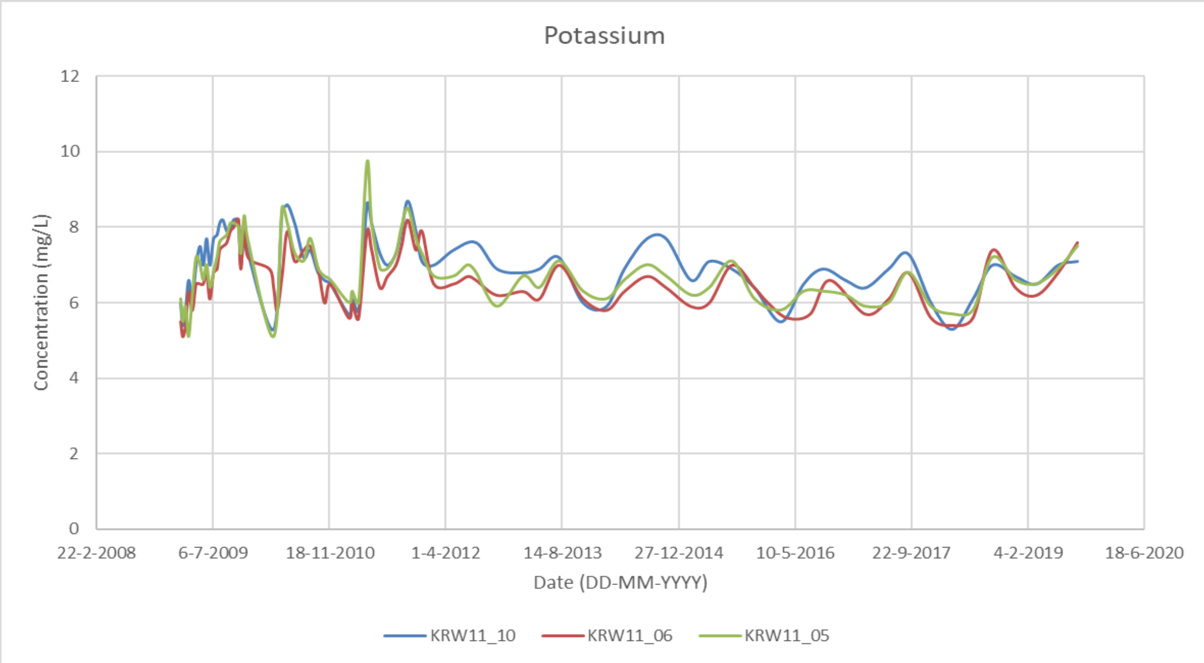
Appendix Graph 2 – The biochemical oxygen demand (BOD) (mg/L) between 2009 and 2019 for KRW11_05, KRW11_06 and KRW11_10



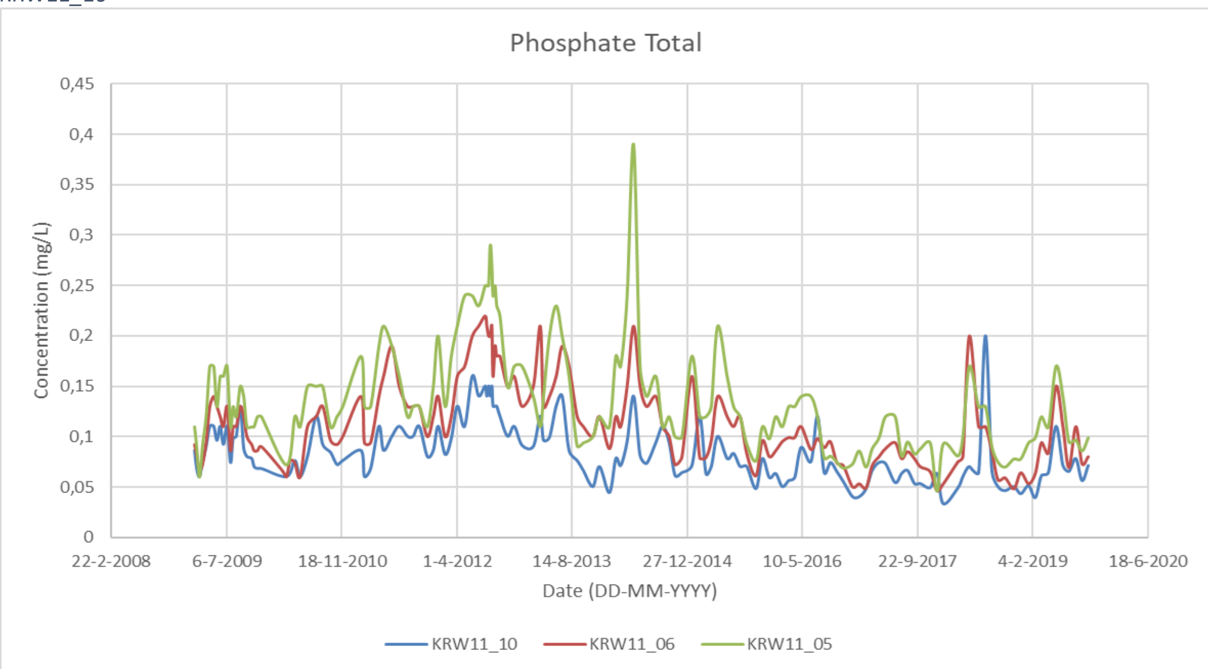
Appendix Graph 3 – The original turbidity (distance in m) data between 2009 and 2019 for KRW11_05, KRW11_06 and KRW11_10, with an anomalous spike in 2016



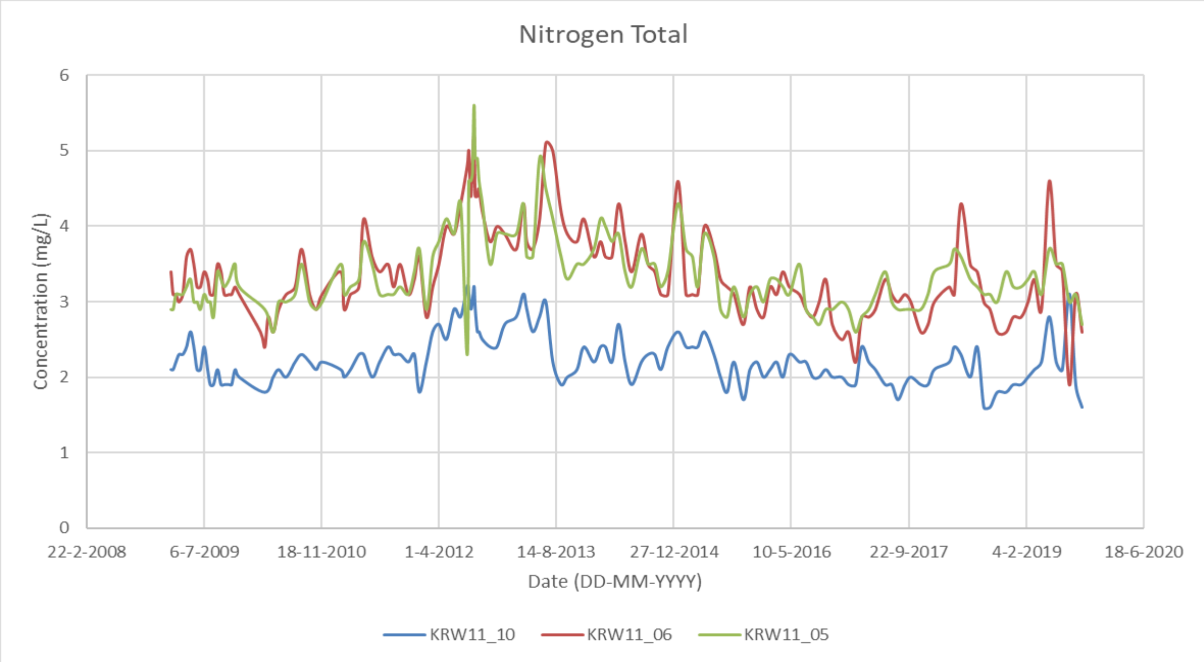
Appendix Graph 4 – The turbidity (distance in m) between 2009 and 2019for KRW11_05, KRW11_06 and KRW11_10, without the anomalous spike in 2016



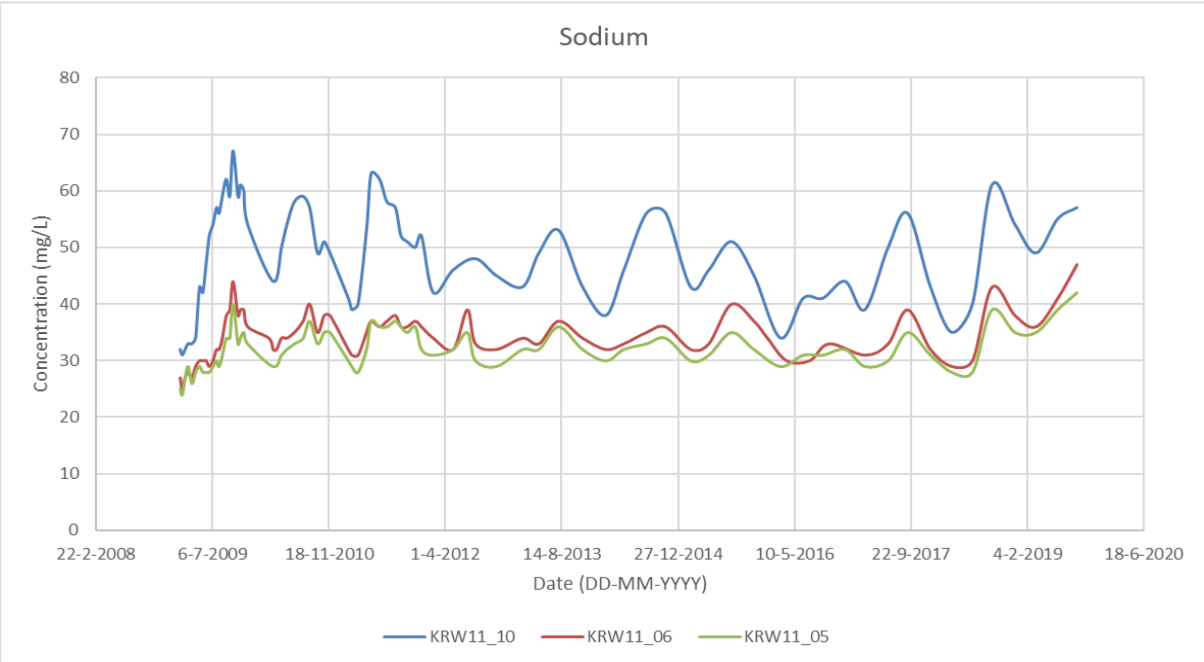
Appendix Graph 5 – The potassium concentration (mg/L) between 2009 and 2019 for KRW11_05, KRW11_06 and KRW11_10



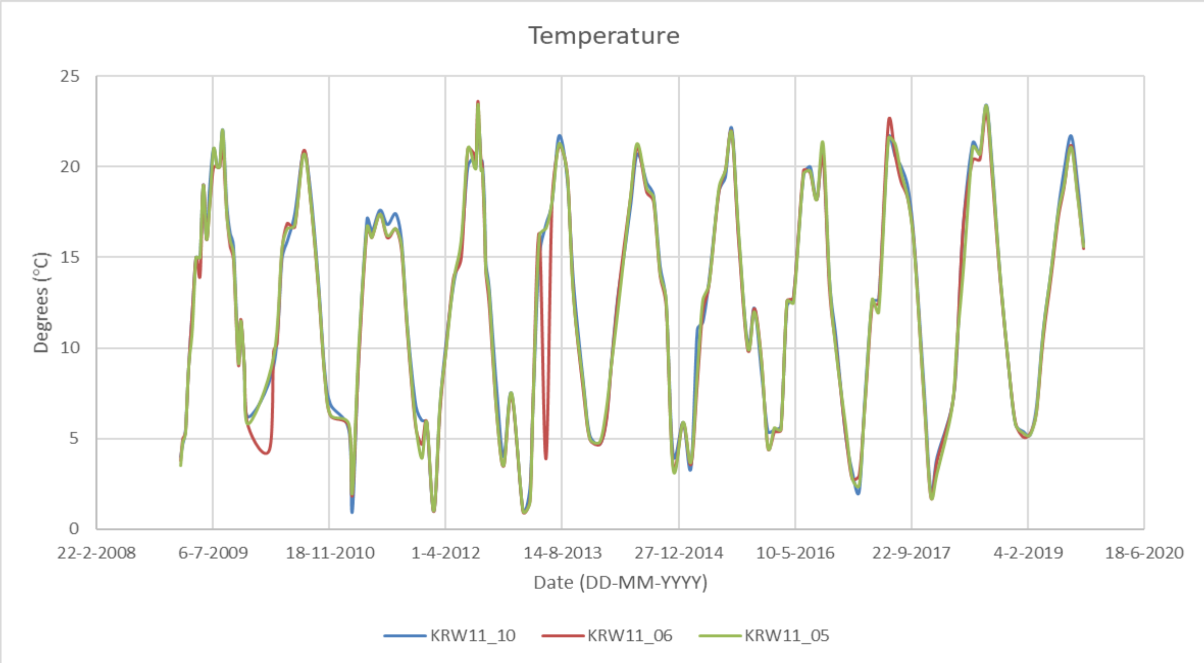
Appendix Graph 6 – The total phosphate concentration (mg/L) between 2009 and 2019 for KRW11_05, KRW11_06 and KRW11_10



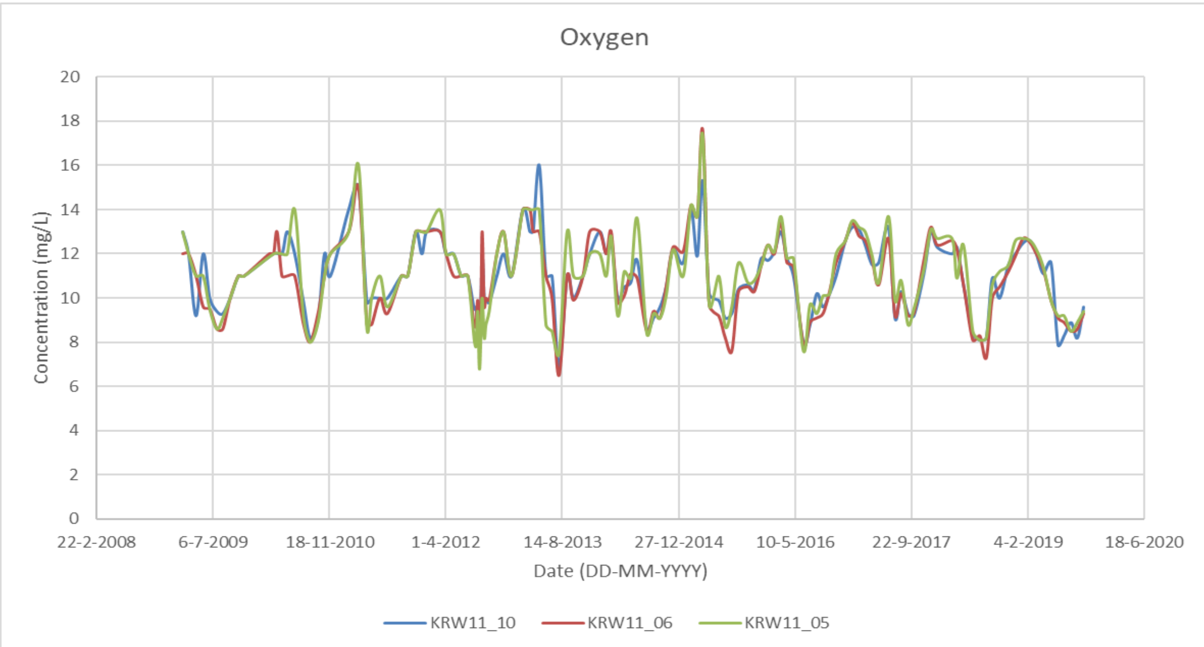
Appendix Graph 7 – The total nitrogen concentration (mg/L) between 2009 and 2019 for KRW11_05, KRW11_06 and KRW11_10



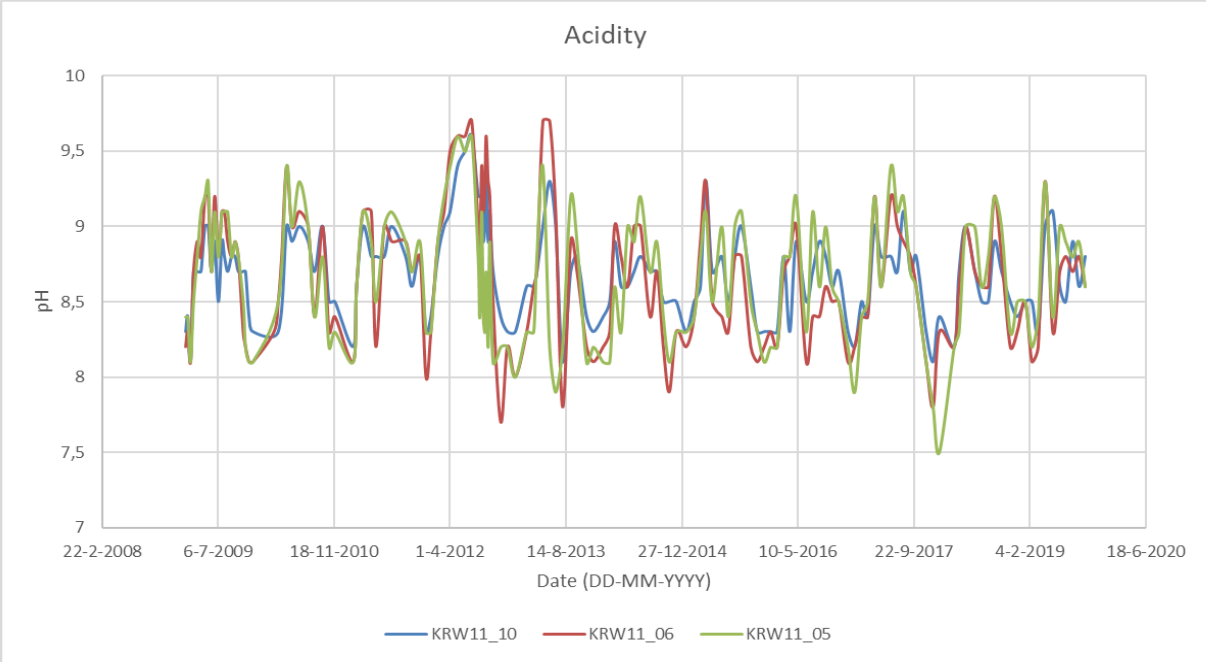
Appendix Graph 8 – The sodium concentration (mg/L) between 2009 and 2019 for KRW11_05, KRW11_06 and KRW11_10



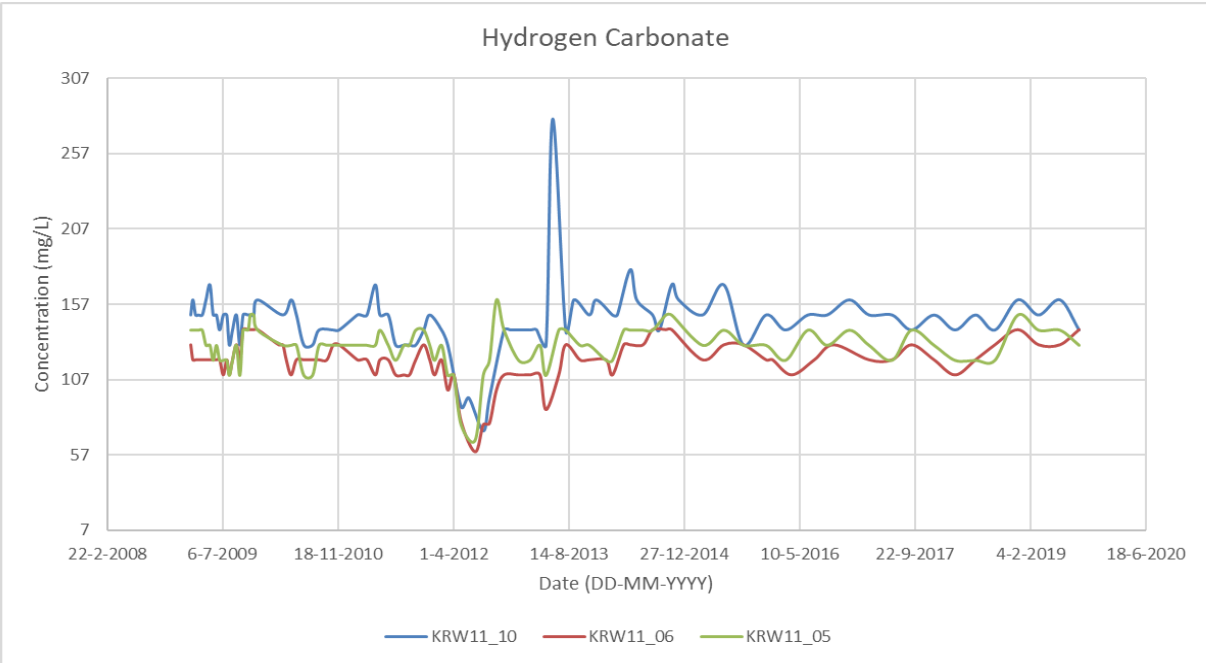
Appendix Graph 9 – The temperature (°C) between 2009 and 2019 for KRW11_05, KRW11_06 and KRW11_10



Appendix Graph 10 – The oxygen concentration (mg/L) between 2009 and 2019 for KRW11_05, KRW11_06 and KRW11_10



Appendix Graph 11 – The pH between 2009 and 2019 for KRW11_05, KRW11_06 and KRW11_10



Appendix Graph 12 – The hydrogen carbonate concentration (mg/L) between 2009 and 2019 for KRW11_05, KRW11_06 and KRW11_10