RESEARCH REPORT

Ecological management of water ditches

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1. Introduction

The Dutch agriculture is highly developed, making the Netherlands the second largest agricultural exporting country in the world. However, this extensive use of farming caused a steep decline of agricultural flora and fauna over the past 100 years (Centraal Bureau voor de Statistiek, 2020). Furthermore, due to increasing droughts and nitrate use, the water quality of agricultural ditches has degraded (*Klip, 2020)*. Ditches are vital for the removal of excess ground and surface water to support crop production (Needelman et al, 2007). The management of ditches affects some aspects of the landscape including vegetation, water quality and biodiversity. In recent years, dutch municipalities have provided subsidies for the construction of ecological managed ditches along farmers land (NU, 2021; Subsidieregeling natuurvriendelijke oevers 2016–2021.) Ecological managed ditches have an essential role in improving ecological water quality and conserving biodiversity (Vuister, 2010). Moreover, they provide ecosystem services such as groundwater recharge, flood attenuation and water purification (Dollinger, 2015).

One key aspect of ecological managed ditches is the buffer zone, which is the area along the ditch where the land and water meet. Vegetation in these buffer zones is useful for the removal of water pollutants from surface runoff, improving water quality of the ditch (Norris, 1993). However, the size and biodiversity of the bufferzone is heavily impacted by different agricultural management strategies, causing large differences in the level of impact on biodiversity and water quality. Non-ecologically managed ditches have little to no buffer zones and steep shoveled banks, offering no opportunities for the development of varied vegetation in and along ditches (Vuister, 2010). Ecologically-managed ditches, however, have a gradually decreasing slope, ensuring a buffer zone which provides a variation of growing conditions. This allows for a higher plant species richness (Manhoudt et al, 2007), and improves water quality of the ditch as a larger number of species could more effectively absorb the extra nutrients in the water (Cardinale, 2011). Furthermore, the effectiveness of the management is determined by its positive contributions to water quality (Evaluatie Effectiviteit

Natuurvriendelijke Oevers, 2019). Nevertheless, it remains debatable what the exact effects of vegetated buffer zones on water quality are.

This research aims to understand whether a vegetational biodiversity in the buffer zone influences the water quality of the ditch. Water transparency and algae coverage are viewed as measures of water quality. This study focuses on comparing buffer zones of ecologically managed ditches to semi-, and non-ecologically managed ditches. The following research question was addressed; “What are the effects of ecological managed ditches on plant diversity in the buffer zone, with relation to water quality?” In order to answer this question the following sub-questions were discussed: (1) Does the plant species richness of the buffer zone differ between different management types? (2) Does water transparency in the ditch differ among different management types? (3) Does the degree of algae coverage of the ditch differ among different management types? The methods section further explains the ways these three aspects will be measured. The results and discussion will show the correlation between biodiversity and water quality for the different management types. Lastly, the relevance section will emphasize the importance of ecological managed ditches for biodiversity and water quality, based on our findings.

2. Literature review

Since humans started intensive farming, society has made large-scale changes to the hydrology of ditches in between grasslands to improve crop productivity and yield (Lind *et al.*, 2019).

Figure 1: Example of an agricultural drainage ditch (geograph.org.uk, 2009)

These so-called ‘agricultural drainage ditches’ (Figure 1) are vital for the discharge of ground and surface water, enhancing crop production in poorly drained agricultural areas. Moreover, they transport agricultural contaminants to downstream water bodies (Brian A *et al.,* 2007). Due to intensified agriculture, most of these ditches consist of waterways with steep or shaved banks, offering no opportunities for the existence of varied buffer vegetation (Vuister, 2010). Therefore, the construction of these agricultural drainage caused modifications to the hydrology and natural vegetation, affecting biodiversity and many ecosystem functions provided by natural ditches (Lind *et al.*, 2019). In order to restore biodiversity, water quality and other ecological functions provided by these natural ditches, many Dutch municipalities give subsidies for the construction of ‘’ecological managed ditches’’ (NU, 2021; Hoogheemraadschap van Schieland en de Krimpenerwaard, 2016).

2.1 Ecological managed ditches

Ditches with steep or shaved banks offer almost no opportunities for the formation of varied buffer vegetation. Therefore, the key concepts behind an ecological managed ditch is the presence of a gradually rising or shallow bank along the side of the water, and the addition of a vegetated buffer zone (2.3) (Sollie *et al.,* 2011). This gradual transition from water to land creates various water depths, providing diverse growing conditions. The variety in growing conditions gives rise to the existence of a higher diversity of aquatic plants and animal species. Moreover, locally their presence improves physicochemical water quality, by trapping sludge, reducing suspended matter, balancing the oxygen levels as well as oxygen uptake, and conversion of nutrients in the water (Vuister, 2010).

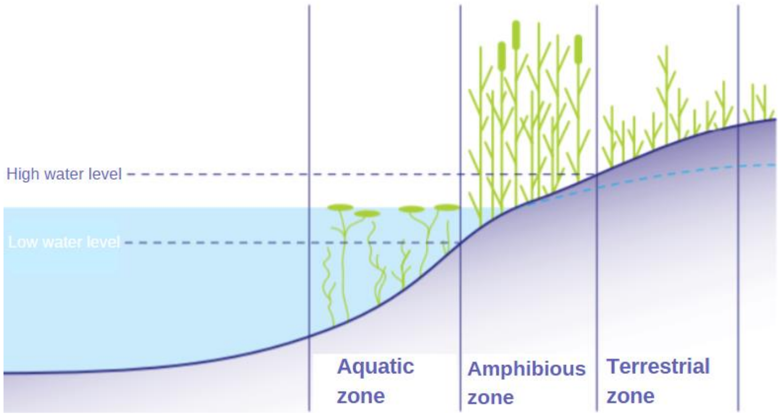

Figure 2: Three distinguished zones: the aquatic zone, amphibious zone, and terrestrial zone (Spier et al, 2019).

In Spier et al. (2019) the following three different zones are distinguished; the aquatic zone, amphibious zone and terrestrial zone (Figure 2, Spier *et al*, 2019). These are respectively the zone below the low-water mark, the reclaimed or permanently very shallow zone and the zone above the high water mark which is still influenced by groundwater conditions. The variation from land to water in these zones is called vertical variation (Sollie, 2011). Dividing ditches into these three different zones is characteristic for ecologically managed ditches and is necessary to achieve a combination of factors. The different zones can each provide a home for a different animal and plant species as well as help with water level managemen and buffer systems (Spier *et al*, 2019).

2.2 Vegetated buffer zones

Buffer zones encompass the vegetated area along water ditches in such a manner that they form a natural buffer between the waterways and the surrounding land. Known is that vegetated buffer zones, both directly and indirectly, influence biological processes such as nutrient uptake, organic matter supply, soil stabilization and groundwater drainage (Parkyn, 2004). In addition, vegetated buffer zones provide habitat to species in fragmented landscapes (Mankin et al., 2007), directly increasing the floral and faunal diversity (Parkyn, 2004). However, the influence and effect of these buffer zones are dependent on multiple factors including vegetation, soil types, climate, topography, nutrient load, and their width (Hefting *et al*., 2005).

Figure 3: Example of a vegetated buffer zone alongside a ditch (Waterschap Hollandse Delta, date)

Furthermore, ecologically managed ditches contribute to the three main natural processes namely; nutrient uptake by plants, storage in organic matter and denitrification (Sollie *et al.*, 2009). First, nutrients such as nitrogen and phosphate are absorbed by plants in the buffer zone, preventing runoff. Secondly, in vegetated buffer areas, the supply of organic material is higher than in non-vegetated areas resulting in less accumulation, which is a process that removes useful nutrients from surface water. Lastly, decreased denitrification processes are associated with ecological managed buffer zones which means nitrate, an essential nutrient for plant growth, can no longer be used by plants which results in a decrease of plant diversity and density (Spier *et al*, 2019) (Sollie *et al*, 2011).

2.3 Water quality

Finally, zooming in on a specific function, the construction of ecological managed ditches contributes to the improvement of water quality. Ecologically managed ditches create better living conditions for aquatic species, take up excess nutrients, and the presence of a buffer zone minimizes runoff. More specifically, the biodiversity of plants on buffer zones provide habitats for a larger number of aquatic species that are essential in maintaining a balanced aquatic ecosystem. Additionally, the buffer zone vegetation forms the basis for the provisioning of oxygen in the water (Hoogheemraaschap van Delfland, 2010) For these reasons, a diverse and species rich ecological ditch management is beneficial to the water quality in the ditch.

Moreover, a common issue in agriculture is the process of eutrophication in drainage ditches, degrading the water quality. Eutrophication is caused by over-fertilisation with nitrogen and phosphorus, providing an excess of nutrients leaching into the ditch water. Excessive concentrations of nitrate in the water can lead to algae blooms or a duckweed cover, resulting in underdevelopment of aquatic plants, because sunlight is unable to reach the bottom (Spier *et al*, 2019). Moreover, some algae species produce chemical toxins which harm aquatic species (Kramer, 2017). In this way, the process of eutrophication creates a loss of biodiversity, causes anoxic water conditions, and blocks agricultural functions of the ditches (Janse, 1998). As mentioned before, vegetated buffer zones play an essential role in improving water quality, as they could take up a larger excess of nutrients in the water due to a high plant species richness (Sollie, 2009).

In conclusion, the construction of ecological managed ditches and implementation of vegetated buffer zones, improves water quality, provides opportunities for natural development, and increases biodiversity (Sollie *et al.*, 2011). This research aims to understand the effects of plant diversity in the buffer zones on water quality in ecological managed ditches, and vice versa.

3. Methodology

Fifteen ditches of six different farmers were selected to be researched, all located around Driebruggen, Utrecht. The measurements that were taken can be divided into three categories:

(1) Water quality; measured by examining the two following characteristics of:
   (a) water transparency
   (b) algae coverage
(2) Plant diversity in the buffer zones
(3) General measurements

3.1 Measuring the water quality

The water quality was measured qualitatively by means of observations of transparency and algae coverage. The clarity of water can vary from turbid to clear, turbidity is the absence of transparency, and according to Ritter (2010) an "optical property caused by particles suspended in water". As mentioned in the literature review, it is important that the water quality is measured, as it can affect as well as be affected by the biodiversity in the ditch. These visible observations of water quality were made by filling a transparent bottle with the ditch water. This way, comparisons of samples from different ditches could easily be made. This method is based on the principle of sampling: it is impossible to measure these variables for the whole ditch, as transparency in the ditch itself cannot be clearly seen because of vegetation and depth, and it is simply impossible to measure the water clarity of all water in the ditch. Therefore, one sample per ditch was taken in order to review the water quality. The water transparency was defined with an ordinal scale and was allocated a level from 1 to 3, where level 1 corresponds with clear and nearly colorless water, level 2 with clear yet yellow water and 3 with completely turbid water.

The algae coverage was also measured because this affects the water quality and in turn the biodiversity, as mentioned in the literature review. The variable of algae coverage was defined as ordinal and determined by three levels of algae coverage which was estimated based on the visible layer of algae on the water surface of the ditches. An ordinal scale of 1 to 3 was used where 1 implied the lowest coverage over the whole ditch and 3 implied the highest. Ditches in Category 1 have an algae coverage of 0 to 20 percent. Ditches in Category 2 have an algae coverage of 20 to 60 percent, and ditches in Category 3 an algae coverage of more than 60 percent.

3.2 Measuring plant diversity in the buffer zones

The plant diversity was examined by taking samples of vegetation within the buffer zone; these samples had a length of 10m directly adjacent to the water in the ditch. Within this area, one plant of each species was picked from the buffer zone and stored in a paper bag. The plants from these samples were identified and counted later.

3.3 Size

The width and depth of the ditch was measured using measuring tape and a wooden stick

3.4 Level of ecological management

The ditches that were examined did not all have the same level of ecological management. Due to this difference in management, a comparison could be made to reveal a potential correlation between characteristics of the ditch and the level of ecological management. Each ditch was classified into a category. Category 1 includes ditches that are fully ecologically managed, i.e. that have both gently sloping banks and a buffer zone in which no mowing or fertilization takes place. Category 2 includes ditches that have some but not all of these characteristics. The last category consists of ditches which are not managed ecologically at all, and thus possessed none of the previously mentioned characteristics.

Seven ditches from the first category were examined, and four each for the other two categories; so in brief:

- Category 1 = ecological managed ditch (*n* = 7);
- Category 2 = semi ecological managed (displayed 1 or 2 characteristics, such as less steep bank, or not mowed/fertilized of an ecological managed ditch) (*n* = 4);
- Category 3 = non-ecological managed ditch (*n* = 4).

The data collected was later displayed in bar graphs and histograms, and were analyzed with the help of SPSS. Furthermore, the Spearman's rank test was performed in order to find the significance value; this p-value would show whether the correlation is significant or not.

4. Results

4.1 Plant diversity

The results of the plant species survey are visible in Figure 4.

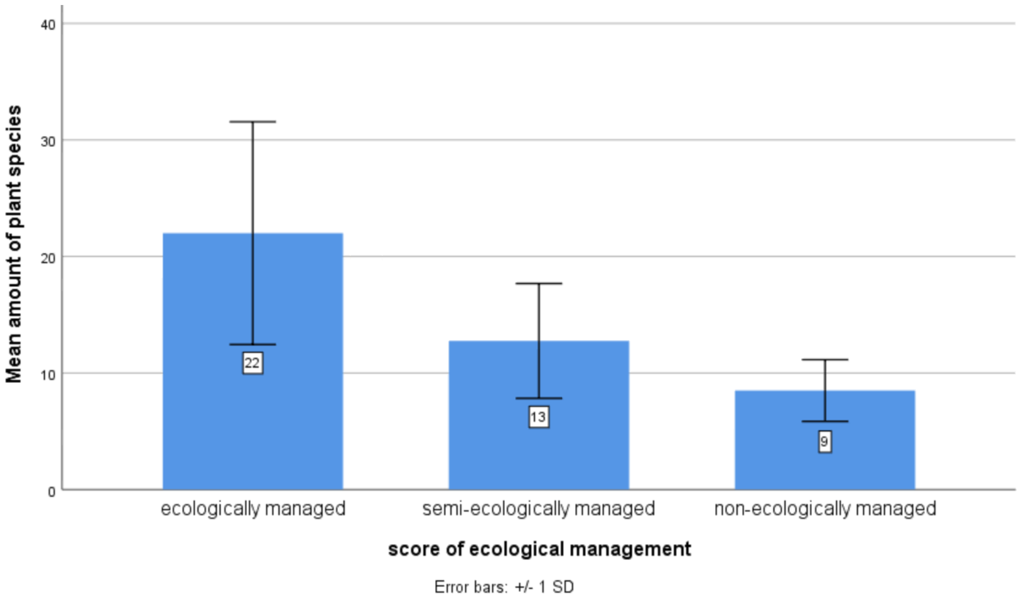

Figure 4: Graph comparing plant diversity and level of ecological management.

The y-axis shows the amount of plant species found on average. The x-axis is categorized into the categories of ecological management as described in the methodology. The Spearman's rank correlation test gave a p-value of 0.004. This means that the correlation between plant diversity and the level of ecological management is significant. This graph shows a relationship between the level of ecological management and the amount of plant species: when ecological management decreases, plant diversity decreases. The average number of plant species is 22 for ecologically managed ditches and this decreases down to 9 for non-ecologically managed ditches.

4.2 Algae coverage

As explained in the methodology, the algae coverage is also divided into three categories with 1 being a low degree of coverage and 3 a high one. The graph in Figure 5 shows the relationship between algae coverage and the degree of ecological management of the ditch. The numbers on the y-axis show the score of algae coverage.

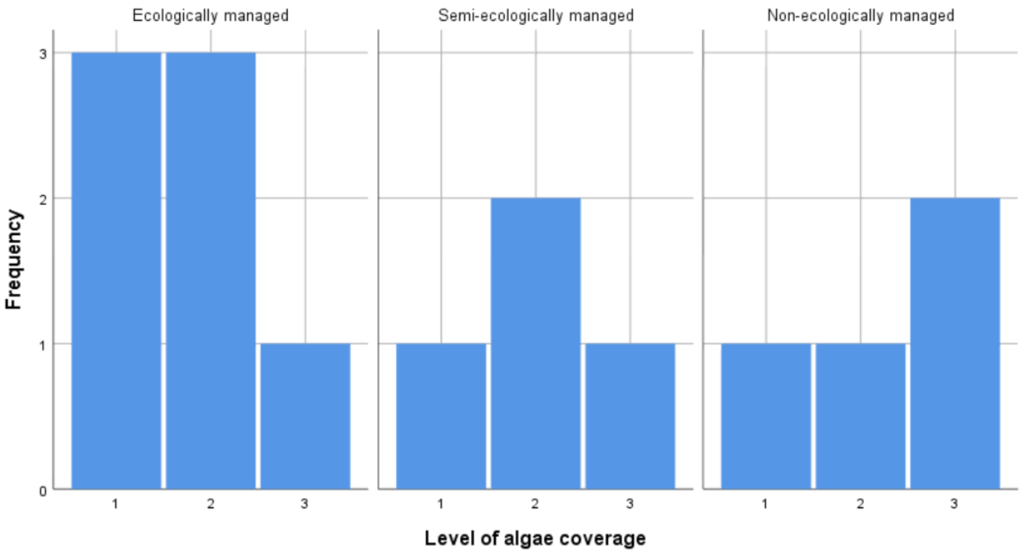

Figure 5: Graph comparing algae coverage and level of ecological management.

The graph shows that an ecologically managed ditch most often had a low or medium algae cover (6 out of 7 ditches) and a non-ecologically managed ditch most often had a medium or high algae cover (3 out of 4 ditches).

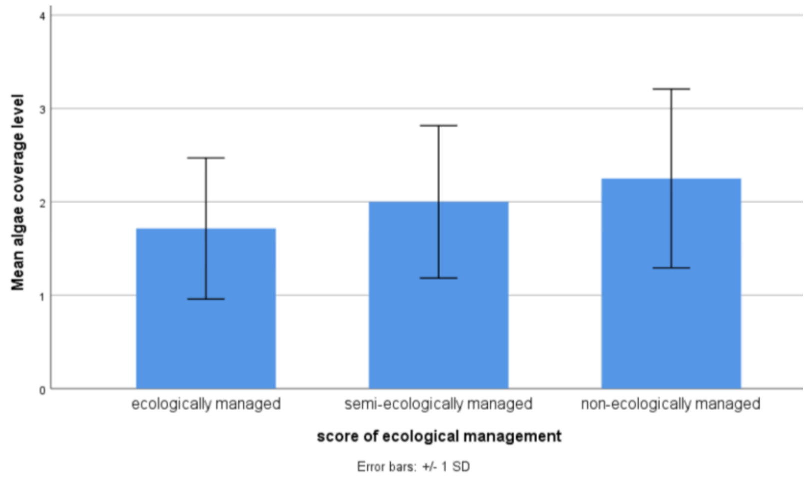

Figure 6: Graph comparing average algae coverage and level of ecological management.

The main trend in algae coverage is best visible in Figure 6: as the level of ecological management increases the average algae coverage decreases. After conducting the Spearman's rank test, it was found that the significance is 0.301 (the p-value). This means that this correlation is not significant.

4.3 Transparency

Figure 7 shows the results of the research on transparency. Transparency is also divided into three categories with level 1 being the highest transparency and level 3 the lowest.

Figure 7: Graph comparing level of transparency and level of ecological management

The graph shows that the vast majority of ditches that are managed ecologically have a transparency level 1 (5 out of 7). The non-ecologically managed ditches have the highest frequency (2 out of 4) of turbid water. as the level of ecological management increases the average algae coverage decreases. This trend, of a higher transparency with a higher level of ecological management, is even more visible in Figure 8.

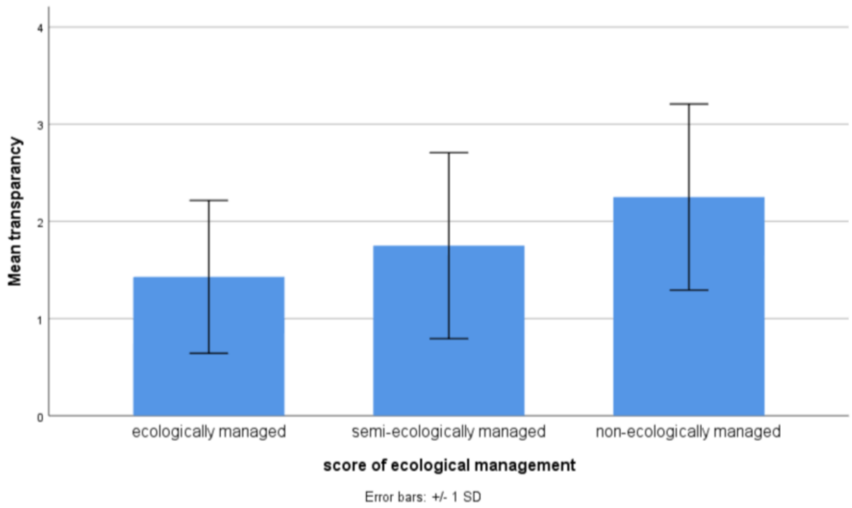

Figure 8: Graph comparing average level of transparency and level of ecological management

The Spearman's rank correlation coefficient (p-value) is 0.147. This means that this correlation between the level of ecological management and transparency is not significant enough to assume that this is always the case.

5. Discussion

The main findings of this study suggests that a greater variety of plant species is found along ecologically managed buffer zones, which is in line with previous research and will be discussed in the following paragraph. This research in particular aims to answer the following research question: “What are the effects of ecological managed ditches on plant diversity in the buffer zone, with relation to water quality?” In order to find the answer to this question, three components of water ditches and their vegetated buffer zones have been investigated; plant diversity, algae coverage and transparency of the water. Each of these components will therefore also be analyzed on the basis of these levels in this discussion section.

Plant diversity

Figure 4 shows the average number of plant species for each level of ecological management. The results show there are more plant species present in the vegetated buffer zone along an ecologically managed water ditch. The corresponding p-value of .004 suggests a significant relationship between the level of ecological management and the amount of plant species is observed: when ecological management increases, plant diversity increases as well.

Our findings can be supported by previous research (Solli, 2009) as it already stressed non-ecological managed ditches not only occur or limit the unnatural level and morphology of water ditches but also limit the plant growth of the vegetated buffer zone. The presence of vegetation forms the basis of the ecosystem in and around the water and it is important for the environmental conditions of both aquatic animals and other animals, such as insects and amphibians, that live in the buffer zone (Vuister, 2019).

In addition to collecting data on the number of different plant species, the different species were identified for every ditch to see what species were more rare, and whether these uncommon species occurred more on ecologically managed ditches than on non-ecologically managed ditches. Note that an unknown number of species might be either left out or may have been counted twice, because they could have been mistaken for different species.

Additionally, defining plant species could have been less precisely executed at some sites than others. However, with a consistent method of collecting plant diversity samples, this should not have a significant impact on the reliability of the research, as these mistakes will likely be made in the same quantity in every site.

The most common species that occurred for both management types were several varieties of taraxacum officinale as well as glechoma hederacea, holcus lanatus, rumex acetosa, urtica and other unknown grass species. Species that were sometimes observed in non-ecologically managed ditches are myosotis scorpioides, mentha aquatica and glyceria maxima. Although these species were quite uncommon here, they were present in almost every ecologically managed ditch. More diverse plant species have been found in ecologically friendly ditches as well as more uncommon species such as tussilago farfara, oenanthe fistulosa, glyceria fluitans, poa and lysimachia thyrsiflora.

The finding of more different plant species is in line with previous research, which showed ecologically managed vegetated buffer zones provide habitat to species in fragmented landscapes (Mankin et al., 2007) as well as directly increasing the floral and faunal diversity (Parkyn, 2004). Moreover, it is worth noting that in ecologically managed ditches, occasionally rare species were found such as lonicera periclymenum, matricaria discoidea and even pisum sativum var. saccharatum. Observation of rare species implies the presence of better conditions for plant growth (Vuister, 2010).

Algae coverage

In order to examine the effect of the ecological management of water ditches on algae coverage. Figure 5 shows the frequency of the level of algae coverage for each level of ecological management. Note that the algae coverage was based on a visual estimation, therefore the interpretation can be less reliable. The results imply that as the level of ecological management increases the average algae coverage decreases. The findings show that semi and non-ecologically managed ditches have a lower frequency at level 1 of algae coverage and a higher frequency at level three. This relationship could occur due to the higher plant diversity, as excessive nutrients (such as nitrogen, phosphorus, carbon, and potassium), which are the main cause of algae growth, are absorbed by the vegetated buffer zone and therefore cannot cause runoff. However the p value of .301 suggests this relationship between algae coverage and the score of ecological management is statistically insignificant. The insignificance could have been caused by other non examined factors in this research such as temperature, nitrogen and phosphate concentrations. Furthermore, eutrophication of drainage ditches by over-fertilization with nitrogen and phosphorus was not precisely measured, however it was apparent that there were effects of eutrophication. Due to the fact that it caused a shift from mainly submerged aquatic vegetation to a dominance of duckweed. This causes anoxic conditions, meaning a loss of biodiversity and hampers the agricultural functions of the ditches, lowering the water quality (Janse & van Puijenbroek, 1998). In order to measure eutrophication as well as the other components, exclusive equipment and more time is needed which was not available for this research and therefore this missing data could possibly have influenced the outcomes.

Transparency

Figure 7 shows the frequency of the level of transparency for each level of ecological management. At ecologically managed ditches, the highest frequency is observed at level 1 of transparency. For level 3 of transparency, the highest frequency was found at non ecological managed ditches, although it is not a large difference. The results imply the vast majority of ecologically managed ditches contain clear water in comparison to the semi- and non ecologically managed ditches. However, the Spearman's rank correlation coefficient of 0.147 suggests there is not a significant relationship between transparency and the level of ecological management. This insignificance could have been caused by the inconclusive quantitative research methods.

Research has proven that the ecological management of agricultural ditches have positive results in mitigating the harmful effects of agriculture by improving water quality (Cardinale, 2011). Moreover, research shows the vegetated buffer zones along water ditches in combination with a gradual transition from water to land contribute to the ecological quality of water. Therefore, this research includes investigation on whether there is a relationship between water quality and the level of ecological management of water ditches and their vegetated buffer zones by looking at the transparency of water.

Turbidity of water is a measure of the degree to which the water loses its transparency due to the presence of suspended particulates (mentioned in methodology). However, note that water containing a multitude of dissolved and undissolved substances is a very complicated medium to examine. In this case we saw for ourselves whether water is cloudy or clear, but for further research it can also be interesting to measure the transparency quantitatively with, for example, a spectrophotometer and to be able to estimate the chemical composition of your water in order to obtain more relevance. Previous research done on water quality monitoring schemes rely on estimation methods as it is often far too expensive to monitor water quality properties continuously (Lessels & Bishop, 2013). However, note that how transparent or opaque water is can be a subjective measurement because the estimation was solely based on visuals and the interpretation depends on the person and can therefore be biased and less reliable.

Defining the level of transparency/turbidity for water ditches can be used as a good method of measuring water quality (Lessels & Bishop, 2013) (see Methodology - Measuring water quality). However, clear water is not always healthy, and likewise turbid water does not necessarily indicate an issue and it is more often a change in turbidity that indicates an issue, such as the development of an algal bloom on a lake, or a steady increase in suspended sediment in a river due to a polluted tributary (Lessels & Bishop, 2019).

Further research

The results of this research show the effects of ecological managed buffer zones on plant abundance and diversity to a certain extent, however, not all correlations could be defined as significant. As mentioned in the beginning of the discussion; aside from the positive correlation between level of ecological management and plant diversity, no other relationship or difference was found to be statistically significant. The cause for insignificance could be found in inconsistencies or mistakes in the used measuring methods as well as a number of encountered practical difficulties which were mentioned before. Due to the fact that the fieldwork could only be done in one week and several tools to conduct a better methodology were not present, it raises questions about the design and validity of the study. Moreover, research was done by different groups spread out over three days and therefore the measurements were not always done in the same manner.

Although identifying plant abundance and diversity in ecologically en non-ecogically managed ditches represents a critical first step in analyses of how different management types affect water quality and biodiversity, once this is identified, additional work needs to be done.

6. Conclusion

The purpose of this research was to identify the effects of ecological managed buffer zones on plant diversity with relation to water quality. Based on the analysis conveyed, the following conclusions can be drawn:

- The vegetated buffer zones along ecological friendly water ditches contain a larger number of different plant species and density.
- The water quality, based on classifying water samples on a water transparency scale, is better for ecological friendly ditches than for non-ecological friendly ditches.
- Algae coverage is higher for non-ecologically managed than for ecologically managed water ditches
- Ecological friendly management suggests an increase in plant diversity and water quality as well as a decrease in algae growth which is beneficial for biodiversity. Therefore it is recommended that where possible, ecological management strategies should be adopted by farmers.

With a now accurate documentation of ecologically manages water ditches and their effect on plant diversity and abundance, as well as an overview of the effects of algae and water quality, a more complete knowledge of the biological processes regarding water ditches in farmland and conceive understanding for long-term significance of ecologically management types are facilitated. By understanding the relationship between ecologically management and plant diversity, and of the effect of these factors on water quality and biodiversity, management stakeholder and farmers can take steps to improve the nature-friendly agriculture in the Netherlands.

7. Relevance

This research proves that ecologically managed ditches result in an increased biodiversity of vegetation, and hypothesizes that this increase in vegetation results in better water quality. Previous literature review suggests that the ecologically friendly zone management reduces pollution risks to waterways from agricultural runoff (Syversen, 2003). Moreover, vegetated buffers can trap contaminants in runoff, increase soil infiltration of soluble pollutants and enable deposition of suspended particles within the buffer soil profile (Renouf & Harding, 2015). Vegetation in the buffer zone can influence water flow, both surface and subsurface, through root systems and has direct effects on stream functioning (Parkyn, 2004). Vegetation management in buffer zones is therefore widely recommended and promoted in agricultural areas to improve chemical water quality in streams as well as biodiversity.

Furthermore, the research focuses particularly on the biodiversity of this vegetation in the buffer zones, as biodiversity loss is one of the most impactful and severe consequences of intensive agriculture (Tsiafouli *et al*, 2015). Additionally, the research suggests a correlation between high biodiversity and high water clarity, which can be linked to water quality. Biodiversity was researched as it is a significant driving factor for ecosystem functioning (Cardinale, 2012). A crucial property of biodiversity is the increase in stabilisation that it can grant the ecosystem, the increase in plant properties can protect the ecosystem in case of threatening conditions such as diseases or harsh weather. The genetic variety has particular benefits for the physical stability of the ditch as well, the increase in plant growth results in variety and quantity of roots, plant roots can increase the strength of sloped surfaces due to hydrological as well as mechanical processes (Easson, 2002).

Additionally, the increase in biodiversity can have benefits outside of the ditch. Biodiversity increase can lead to a decrease in nutrient accumulation that is often associated with intensive farming, i.e. accumulation of phosphorus and nitrogen (Sollie *et al*, 2009). The increased uptake of nitrogen has many benefits, as the excess of nitrogen that has built up due to fertilization has damaging effects on water and soil quality. The excess of nitrogen in the environment leads to an increase in nitrous-oxide, which is a potent greenhouse gas, in the atmosphere, as well as acidification and eutrophication of groundwater. (Pardo, *et al.,* 2011).

The results of this research are an essential part of the larger body of research that focuses on proving the effectiveness of agricultural adaptations in order to farm more sustainably in the future. Small and relatively uncomplicated adaptations in ditch management such as limited mowing and fertilizing have proven to be effective in increasing biodiversity and water quality in the results of this research, and can therefore likely impact the environment in a positive manner. Agriculture and sustainability have been two contradictory fields, but in order to be able to mitigate the harming effects that agriculture has on ecosystem services, it will be necessary to work together increasingly. Small and relatively simple adaptations such as the one discussed in this research are necessary as they can bring the two previously opposing fields together in cooperation by increasing the sustainability of farming without being too expensive or invasive to farmers.

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8. References

AWWA. Staff. (2011). *Water Quality* (4de ed.) [E-book]. American Water Works Association. https://ebookcentral.proquest.com/lib/uunl/reader.action?docID=3116743

Cardinale, B. (2012). Impacts of Biodiversity Loss. *Science*, *336*(6081), 552–553. https://doi.org/10.1126/science.1222102

Cardinale, B. J. (2011). Biodiversity improves water quality through niche partitioning. Nature, 472(7341), 86–89. https://doi.org/10.1038/nature09904

Centraal Bureau voor de Statistiek. (2020, February 6). Afname flora en fauna in agrarisch gebied sinds 1900. https://www.cbs.nl/nl-nl/achtergrond/2020/06/afname-flora-en-fauna-in-agrarisch-gebied-sinds-1900

Dollinger, J., Dagès, C., Bailly, J. S., Lagacherie, P., & Voltz, M. (2015). Managing ditches for agroecological engineering of landscape. A review. *Agronomy for Sustainable Development*, *35*(3), 999–1020. https://doi.org/10.1007/s13593-015-0301-6

Dosskey, M. G., Vidon, P., Gurwick, N. P., Allan, C. J., Duval, T. P., & Lowrance, R. (2010). The Role of Riparian Vegetation in Protecting and Improving Chemical Water Quality in Streams1. *JAWRA Journal of the American Water Resources Association*, *46*(2), 261–277. https://doi.org/10.1111/j.1752-1688.2010.00419.x

Easson, G. (2002). The Effects of Riparian Vegetation on Bank Stability. *Environmental and Engineering Geoscience*, *8*(4), 247–260. https://doi.org/10.2113/8.4.247

Fondriest Environmental, Inc. “Measuring Turbidity, TSS, and Water Clarity.” Fundamentals of Environmental Measurements. 5 Sep. 2014. Web

Gregory, S. V., Swanson, F. J., McKee, W. A., & Cummins, K. W. (1991). An Ecosystem Perspective of Riparian Zones. *BioScience*, *41*(8), 540–551. https://doi.org/10.2307/1311607

HDSR, 2017. *Farm ditch.* [image] Available at: <https://www.hdsr.nl/@55172/waterschap-zoekt/> [Accessed 18 June 2021].

Hoogheemraadschap van Delfland. (2010, July 6). *Algemene Regels Natuurvriendelijke Oevers*. https://www.hhdelfland.nl/overheid/beleid-en-regelgeving/bijbehorende-documenten/documenten-beleidsregels/algemene-regels-natuurvriendelijke-oevers#:~:text=Als%20een%20natuurvriendelijke%20oever%20binnen,be%C3%AFnvloeden%2C%20waardoor%20wateroverlast%20kan%20ontstaan.

Hoogheemraadschap van Schieland en de Krimpenerwaard. (2016, January 21). *Subsidieregeling natuurvriendelijke oevers 2016–2021*. Decentrale regelgeving overheid. http://decentrale.regelgeving.overheid.nl/cvdr/XHTMLoutput/Actueel/Hoogheemraadschap%20van%20Schieland%20en%20de%20Krimpenerwaard/CVDR394066.html

Hydraulic Engineering Rapports. (2011, september). *Handreiking natuurvriendelijke oevers: Een standplaatsbenadering* (Nr. TPE600500). Stowa. http://resolver.tudelft.nl/uuid:48182d04-a9a8-4140-a49e-f899bc2781f6

Janse, J. H., & Van Puijenbroek, P. J. (1998). Effects of eutrophication in drainage ditches. Environmental Pollution, 102(1), 547–552. https://doi.org/10.1016/s0269-7491(98)80082-1

Klip, H. (2020, November 25). Natuurorganisaties: beheerplannen Europese rivieren beneden de maat. H2O/Waternetwerk. https://www.h2owaternetwerk.nl/h2o-actueel/rivm-meer-nitraat-in-water-op-landbouwbedrijven

Kramer, N. (2017, October 6). How to predict algae growth and detect pollution. Water Alliance. https://wateralliance.nl/en/how-to-predict-algae-growth-and-detect-pollution/

Lenntech.com. 2021. Turbidity. [online] Available at: <https://www.lenntech.com/turbidity.htm> [Accessed 14 June 2021].

Lessels, J., & Bishop, T. (2013). Estimating water quality using linear mixed models with stream discharge and turbidity. Journal of Hydrology, 498, 13–22. https://doi.org/10.1016/j.jhydrol.2013.06.006

Lind, L., Hasselquist, E. M., & Laudon, H. (2019). Towards ecologically functional riparian zones: A meta-analysis to develop guidelines for protecting ecosystem functions and biodiversity in agricultural landscapes. *Journal of Environmental Management*, *249*, 109391. https://doi.org/10.1016/j.jenvman.2019.109391

Mankin, K. R., Ngandu, D. M., Barden, C. J., Hutchinson, S. L., & Geyer, W. A. (2007). Grass-Shrub Riparian Buffer Removal of Sediment, Phosphorus, and Nitrogen From Simulated Runoff. *Journal of the American Water Resources Association*, *0*(0), 070702133859004-??? https://doi.org/10.1111/j.1752-1688.2007.0090.x

Manhoudt, A., Visser, A., & de Snoo, G. (2007). Management regimes and farming practices enhancing plant species richness on ditch banks. Agriculture, Ecosystems & Environment, 119(3–4), 353–358. https://doi.org/10.1016/j.agee.2006.08.004

Natuurvriendelijke oever - Biodivercity. (z.d.). Biodivercity. Available at: <http://www.biodivercity.nl/index.php/biotoop/5/detail#:%7E:text=Helofyten%20zijn%20bijvoorbeeld%20riet%2C%20kleine,%2Dmij%2Dnietje%20en%20rietorchis> [Accessed 21 May 2021].

Needelman, B. A., Kleinman, P. J. A., Strock, J. S., & Allen, A. L. (2007). Improved management of agricultural drainage ditches for water quality protection: An overview. *Soil and Water Conservation Society*, *2007*(62), 171–178. https://www.jswconline.org/content/62/4/171/tab-article-info

Norris, V. (1993). The use of buffer zones to protect water quality: A review. Water Resources Management, 7(4), 257–272. https://doi.org/10.1007/bf00872284

NU.nl. (2021, 23 april). Provincie Utrecht maakt 12 miljoen vrij voor de aanleg van meer natuur. *NU - Het laatste nieuws het eerst op NU.nl*. https://www.nu.nl/utrecht/6129425/provincie-utrecht-maakt-12-miljoen-vrij-voor-de-aanleg-van-meer-natuur.html

Oceanservice.noaa.gov. Low or depleted oxygen in a water body often leads to 'dead zones '— regions where life cannot be sustained. Available at: <https://oceanservice.noaa.gov/hazards/hypoxia/> [Accessed 21 May 2021].

Pardo, L. H., Fenn, M. E., Goodale, C. L., Geiser, L. H., Driscoll, C. T., Allen, E. B., Baron, J. S., Bobbink, R., Bowman, W. D., Clark, C. M., Emmett, B., Gilliam, F. S., Greaver, T. L., Hall, S. J., Lilleskov, E. A., Liu, L., Lynch, J. A., Nadelhoffer, K. J., Perakis, S. S., . . . Dennis, R. L. (2011). Effects of nitrogen deposition and empirical nitrogen critical loads for ecoregions of the United States. *Ecological Applications*, *21*(8), 3049–3082. https://doi.org/10.1890/10-2341.1

Parkyn, S. (2004). Review of Riparian Buffer Zone Effectiveness. *MAF Technical Paper*, *2004*(05). https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.74.742&rep=rep1&type=pdf

Patel, H., & Vashi, R. T. (2015). *Characterization and Treatment of Textile Wastewater*. Elsevier.

Renouf, K., & Harding, J. (2015). Characterising riparian buffer zones of an agriculturally modified landscape. *New Zealand Journal of Marine and Freshwater Research*, *49*(3), 323–332. https://doi.org/10.1080/00288330.2015.1013475

Ritter, J., 2010. *Water quality*. Denver, Colo: American Water Works Association.

Sollie, S., de Kwaadsteniet, P., & Tauw. (2009). Gebruik begroeide oeverzones voor verbetering waterkwaliteit. *Platform*, *H2O*(6), 27–29. https://edepot.wur.nl/341780

Sollie, S., Janse, J. H., Mooij, W. M., Coops, H., & Verhoeven, J. T. A. (2008). The Contribution of Marsh Zones to Water Quality in Dutch Shallow Lakes: A Modeling Study. *Environmental Management*, *42*(6), 1002–1016. https://doi.org/10.1007/s00267-008-9121-7

Spier, J. L., van de Haterd, R. J. W., Achterkamp, B., Smit, T., & de la Haye, M. A. A. (2019, oktober). *Evaluatie Effectiviteit Natuurvriendelijke Oevers*. Hoogheemraadschap van Delfland. https://www.hhdelfland.nl/overheid/RapportEvaluatieeffectiviteitnvosDelflanddefv3.pdf

Subsidieregeling natuurvriendelijke oevers 2016–2021. (2016, January 21). Subsidieregeling natuurvriendelijke oevers 2016–2021. https://lokaleregelgeving.overheid.nl/CVDR394066

Syversen, N. (2005). Cold-climate vegetative buffer zones as pesticide-filters for surface runoff. *Water Science and Technology*, *51*(3–4), 63–71. https://doi.org/10.2166/wst.2005.0576

Tsiafouli, M. A., Thébault, E., Sgardelis, S. P., de Ruiter, P. C., van der Putten, W. H., Birkhofer, K., Hemerik, L., de Vries, F. T., Bardgett, R. D., Brady, M. V., Bjornlund, L., Jørgensen, H. B., Christensen, S., Hertefeldt, T. D., Hotes, S., Gera Hol, W., Frouz, J., Liiri, M., Mortimer, S. R., . . . Hedlund, K. (2014). Intensive agriculture reduces soil biodiversity across Europe. *Global Change Biology*, *21*(2), 973–985. https://doi.org/10.1111/gcb.12752

USGS. (z.d.). *USGS*. Available at: <https://www.usgs.gov/special-topic/water-science-school/science/dissolved-oxygen-and-water?qt-science_center_objects=0#qt-science_center_objects> [Accessed 21 May 2021].

Vuister, L. (2010, april). *Handreiking natuurvriendelijke oevers*. Hoogheemraadschap van Rijnland. https://www.rijnland.net/over-rijnland/wat-doet-rijnland/downloads-taken/handreiking-natuurvriendelijke-oevers.pdf

Waterschap Hollandse Delta. (2019, 4 oktober). *Natuurvriendelijke oever* [Illustration]. wshd. https://www.wshd.nl/plan-natuurvriendelijke-oever-strijense-haven