DIVERting the course of lake Berendonck:

IMPROVING WATER VISIBILITY

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Summary

Lake Berendonck is a recreational man-made lake in the Netherlands, it serves among other things as a diving location for a local diving association called 'De Kaaiman'. The lake has a maximum depth of 17 metres, at which a shipping container is located that serves as under water house for diving activities. The visibility in the lake is poor which decreases the diving safety and experience.

The aim of this research is to provide an overview of potential ecological solutions which could be implemented to improve water visibility. The main research question is: What ecological measures can be taken to sustainably improve the underwater visibility of lake Berendonck and what is their feasibility?

The potential solutions covered in this report are planting aquatic plants, reducing fish load, controlling crayfish, providing substrate for *Dreissena* mussels and sponges, introduction of *Daphnia*, deterrence of birds and leaf traps. Our advice to improve visibility through ecological solutions is to combine some of the solutions starting off with providing substrate for freshwater mussels and sponges to grow and function as biofilter. Aquatic plants can then actively be planted in the shallower areas of the lake with appropriate light and oxygen levels. Next to that, measures should be taken to actively control the numbers of crayfish, carp and bream, if they're overrepresented in the lake, in order to prevent overfeeding on the aquatic plants.

Our advice is based on limited knowledge of the biodiversity and nutrient load of lake Berendonck. For further research, these solutions should be studied in more detail. Before implementing any ecological measure, it is important to further assess the impact and feasibility of any of the proposed solutions and their combined functioning. A flow-chart is provided that could be used as a tool to assess which ecological measure should be pursued, when more specific information about the lake is known. Some of the solutions covered in this research seem promising and are worth further pursuit.

Samenvatting

Lake Berendonck is een recreatief aangelegd meer in Nederland en fungeert onder andere als duiklocatie voor de lokale duikvereniging genaamd 'De Kaaiman'. Het meer heeft een maximale diepte van 17 meter, waar op diepte een zeecontainer is geplaatst die dient als onderwaterhuis voor duikactiviteiten. De zichtbaarheid in het meer is slecht, wat de duikveiligheid en -ervaring vermindert.

Het doel van dit onderzoek is om een overzicht te bieden van mogelijke ecologische oplossingen die kunnen worden geïmplementeerd om de waterzichtbaarheid te verbeteren. De belangrijkste onderzoeksvraag is: Welke ecologische maatregelen kunnen worden genomen om de onderwaterzichtbaarheid van het Berendonckmeer duurzaam te verbeteren en wat is de haalbaarheid?

De potentiële oplossingen die in dit rapport worden besproken, zijn het planten van waterplanten, het verminderen van de visbelasting, het beheersen van rivierkreeften, het verschaffen van substraat voor Dreissena-mosselen en sponzen, de introductie van Daphnia, het afschrikken van vogels en bladval. Ons advies om de zichtbaarheid te verbeteren via ecologische oplossingen is om enkele van de oplossingen te combineren, te beginnen met het verschaffen van substraat voor zoetwatermosselen en sponzen om te groeien en te functioneren als biofilter. Waterplanten kunnen vervolgens actief worden geplant in de ondiepere delen van het meer met geschikte licht- en zuurstofniveaus. Daarnaast moeten maatregelen worden genomen om actief de aantallen rivierkreeften, karper en brasem te reguleren, als ze oververtegenwoordigd zijn in het meer, om overmatig voeden aan waterplanten te voorkomen.

Ons advies is gebaseerd op beperkte kennis van de biodiversiteit en de voedingsbelasting van het Berendonckmeer. Voor verder onderzoek moeten deze oplossingen gedetailleerder worden bestudeerd. Voordat een ecologische maatregel wordt geïmplementeerd, is het belangrijk om de impact en haalbaarheid van een van de voorgestelde oplossingen en hun gecombineerde werking verder te beoordelen. Een flowchart wordt verstrekt die kan worden gebruikt als een hulpmiddel om te beoordelen welke ecologische maatregel moet worden nagestreefd wanneer meer specifieke informatie over het meer bekend is. Sommige van de oplossingen die in dit onderzoek worden besproken, lijken veelbelovend en zijn de moeite van verder onderzoek waard.

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1. Introduction

1.1 Background

The quality of many water bodies in the Netherlands is under pressure from a combination of climate change and eutrophication[26] (van Halsema & Teurlincx, 2023). In 78% of the cases mentioned in the report of the NIOO-KNAW, water quality of smaller water bodies in the Netherlands is insufficient. Eutrophication, caused by an excess input of nutrients, and the rising temperature of the water together can result in an increase in phytoplankton[45] and ultimately in turbidity and possible hazardous algal blooms (Zoetemeyer & Lucas, 2007).

Lake Berendonck, located in the municipality of Wijchen, is an example of such a lake with high turbidity. The lake is divided into three smaller lakes shown in Figure 1. The smallest of them serves as a diving area and is referred to as the "diving lake". For almost 50 years, diving club 'De Kaaiman' located in Nijmegen has been leasing part of this smallest (diving) lake (van Hal & Lürling, 2004). This lake has a maximum depth of 17 metres (van Hal & Lürling, 2004). At this depth a shipping container (called the Aquavilla), on 2-metre-high stilts, can be entered from the bottom. Unfortunately, the visibility in the lake is poor, especially at lower depths, which decreases the diving safety and experience of divers that visit the Aquavilla.

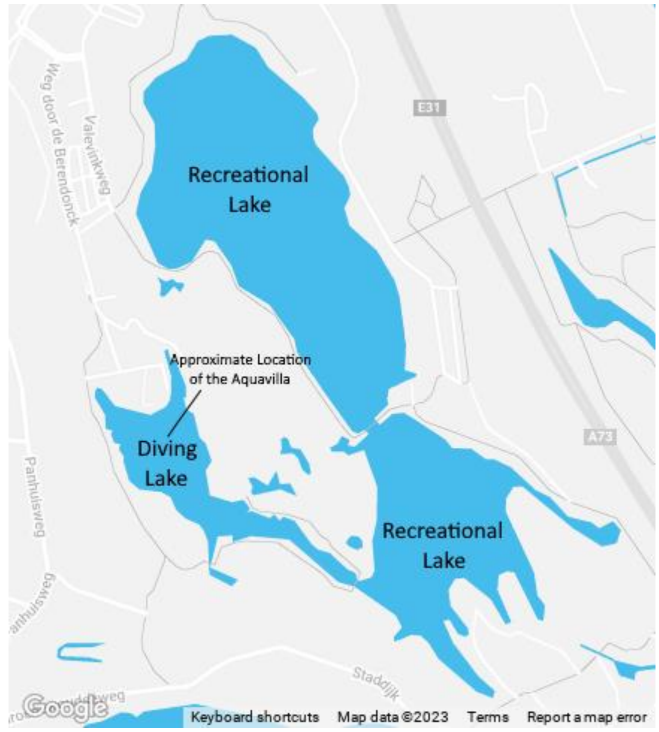

Figure 1 created with Snazzy Maps - Free Styles for Google Maps (n.d.): is a picture of the lake and the surrounding area. The Figure clearly divides which lake is defined as the diving and which as the recreational lake. Furthermore, the map also suggests the approximate location of the Aquavilla.

1.2 Problem definition

In 2004, researchers (van Hal & Lürling, 2004) conducted a study to find possible causes for the reduction in visibility and find available solutions. They discovered that the turbidity of the lake was mainly caused by algae blooms[2] in the upper part of the lake and resuspension[52] of the internal load[36] close to the bottom (van Hal & Lürling, 2004). This study reported various factors which influence the visibility in the lake and described important parameters including nutrients, sediments[54], algae[1], and other inorganic material that contribute to the visibility. Several potential ecological interventions were recommended such as biomanipulation[4] (deliberate alteration of an ecosystem[18] by adding or removing species), reducing resuspension, preventing erosion[23], and providing measures to inhibit algae growth in the lake. Despite these recommendations, none have been implemented to improve the lake's visibility or ecology[17]. This is likely due to the fact that the recommendations do not align with the needs of the Kaaiman which can be related to level 4 considering the Hierarchy of Consulting Purposes shown in Figure 2 (Turner, 2022). The Hierarchy of Consultancy Purposes represents the progressive stages consultants go through to analyse, address and sustain solutions. Our research is aimed at providing solutions which are more adapted to the needs of the commissioner. In the Hierarchy this can be related to level 5, assist implementation, since the feasibility of the solutions are given, and the advice is properly matched to lake Berendonck. During the Stakeholder Analysis, which is provided in Appendix 3, it became clear there is a

Figure 2 copied from Turner (2022): Hierarchy of Consulting Purposes (Turner, 2022).

lack of interest and high power in the visibility problem of lake Berendonck. Thus, it is necessary to create an issue which involves more stakeholders with high power. However, after discussion with the commissioner, it was agreed that we will not focus on this aspect of the problem.

Due to persistent turbidity of the lake, the diving association "de Kaaiman" reached out to Wageningen Science Shop. Wageningen Science Shop made a proposal incorporating the following objectives: (a) analyse the cause of the visibility reduction (b) analyse the cause for the deprived flora and fauna, and (c) create a plan of action to solve these problems.

The biodiversity of lake Berendonck has not yet been researched and this knowledge gap is assumed to be essential for gaining deeper insights into the problem of visibility, thereby crucial for formulating effective solutions. Consequently, this research will primarily focus on the ecological aspects of lake Berendonck and propose ecological solutions that can aid in improving water visibility.

The following research question is formed: **What ecological measures can be taken to sustainably improve the underwater visibility of lake Berendonck and what is their feasibility?** Which is subdivided into the following two sub questions.

The first sub-question is: **How does the lakes' ecosystem function?** To be able to answer this question, we will address some essential ecological components and interactions of lakes in general. The general ecology of lakes can be found in chapter 3. Chapter 4 introduces the current known biodiversity of Lake Berendonck, as well as some general characteristics of the lake.
The second sub-question is: **What ecological measures can be implemented to improve the visibility of the lake and what is their feasibility?** To understand this sub-question, we will dive into possible ecological solutions through literature studies and interviews. Per solution the feasibility of the specific solution on the lake Berendonck will be addressed from an ecological perspective.

1.3 Aim

The research provides an overview of potential ecological solutions that could aid in improving water visibility. The research is done through literature study, interviews, and an experimental survey. Based on the research, several potential measures are recommended that could be implemented in lake Berendonck. A flowchart is provided that could aid the commissioner in choosing the right ecological measure, when more detailed information about the nutrients and ecological composition of the lake is known. The goal of this research is not to definitively say what solution is feasible or not, as this would not be possible to assess in the timeframe of this project. The aim is to provide a general overview of potential ecological solutions, while taking ecological feasibility into account.

1.4 Definitions

Throughout this report several definitions will be used, some of which might be unknown to the reader. Therefore Appendix 1 will contain terms with their definition. The first time one of these words is mentioned in the text a number superscript will be added to it, so that this word can be found easier in the Appendix.

2. Approach

This chapter will concisely discuss the methodology of this research project, a detailed description of the methodology can be found in Appendix 2.

To unravel the ecology of lake Berendonck, a quantitative approach was employed. This approach focused on identifying fish types and determining the composition of plants/algae. Divers, guided by a detailed protocol and Excel documentation (protocol found in Appendix 5 & the documentation in the attached Excel file), conducted systematic dives at 2 random points along the lake's shoreline, one dive in the diving lake and the other dive in the recreation lake. A grid map facilitated the selection of these points. The divers, working in pairs, followed a 50-metre rope, documenting fish species, plant coverage estimates, and environmental conditions at each observation point. This meticulous process aimed to construct a comprehensive understanding of the lake's biodiversity.

The data collected during these dives were recorded in Excel but were not analysed since only 5 observations had been made. The divers will continue recording fish and plant species to enrich future analyses, contributing to an evolving understanding of the lake's ecology. Due to the low sample size this is considered more of a pilot study. The divers can continue with this data collection to get more knowledge about the lake’s ecology in the future. After this, the sample size per lake and the differences in the ecology of the two parts of the lake can be analysed and concrete conclusions can be drawn.

Interviews were conducted to explore ecological measures enhancing lake visibility. A structured interview guide was prepared, with two team members leading the interviews with experts. This interview guide can be found in Appendix 4.

Qualitative methodology involved literature research, utilizing platforms like Google Scholar and the WUR library, the snowballing technique and reports directly obtained from experts were used to extract a comprehensive range of information. For specific details, concerning Lake Berendonck and its stakeholders, information from websites was utilized. Potential solutions were collected through literature study and team discussions. Thereafter, each team member worked on a specific solution. This was conducted through locating scientific articles to discern insights, advantages, and drawbacks. Summaries of the relevant articles were compiled to share information.

Artificial intelligence has been occasionally used in the process of making this report. This was through the use of the program ChatGPT by OpenAI. AI has been used as a tool and not to generate any part of the text used in this report. ChatGPT has been used during the literature study phase to quickly get an overview of a potential solution or ecological interactions. AI has also been used for quick translation between Dutch and English literature, this was once again only used to share information internally and was not used as direct translation in text.

3. Ecology of freshwater lakes

This chapter will focus on the general ecology of deep freshwater lakes. Ecology in shallow lakes is distinctly different from ecology in deep lakes so only deep lakes will be covered. There will be an introduction to the concepts of stratification[56], internal and external[27] loading, and eutrophication. After that there will be a general introduction of the important types of species in a freshwater ecosystem. This will give insight into how the ecosystem of a deep freshwater lake functions and gives the necessary background information to understand the potential solutions proposed in chapter 5.

3.1 Stratification in lakes

Depending on the size and depth of a lake, in summer it can undergo stratification. Stratification is the division of different water layers with different temperatures. This happens when water becomes slightly less dense when warmed up. In lakes this means that during summer, the top water layer (epilimnion[22]) that receives the most sunlight has a higher temperature and resides on top of the deeper, cooler water layers (hypolimnion[34]). The thin water layer in between these two layers is called the metalimnion[41] (Zoetemeyer & Lucas, 2007; van Hal & Lürling, 2004). Because of insufficient light in the hypolimnion, plants can't photosynthesize and therefore can't grow in this area. This causes an imbalance in oxygen production and usage, which makes the oxygen levels in this layer very low in summer. If the ambient temperature in fall decreases, stratification of the lake stops, and the different water layers are able to mix again. This is called the turnover period[64]. After the turnover period, when ambient temperatures increase again, the lake returns to its stratified state (van Hal & Lürling, 2004).

3.2 Internal and external loading

General

The availability of nutrients in a lake ecosystem can be influenced by internal and external loading. Internal loading is the process of nutrients from the soil (the internal load) becoming available in the water, while external loading is the process of nutrients from outside of the ecosystem becoming available in the water (Pettersson, 1998). Examples of external loading are nitrogen deposition and agricultural water inflow, but also birds could impact the external loading of a lake (Birch & McCaskie, 1999).

Nutrient availability in stratified lakes

In stratified lakes, the internal load in the deep part of the lake is not accessible during the period of the year when stratification occurs. This means that the internal loading in a deep lake can gather more internal load before having an impact on the lakes' ecosystem. It also means that the upper layers of a deep lake can become nutrient poor, while the deeper parts harbour a lot of (unusable) nutrients (Zoetemeyer & Lucas, 2007).

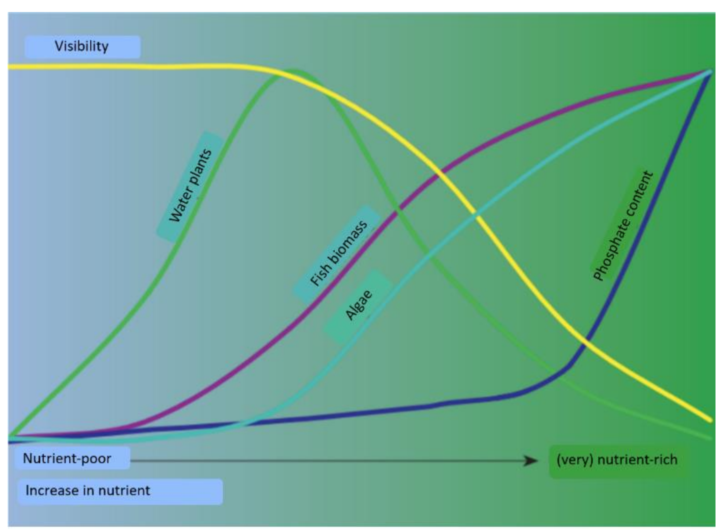

Figure 3 copied from Zoetemeyer & Lucas (2007): depiction of increased nutrient levels on the effect on visibility, water plants, fish biomass, algae and phosphate content (Zoetemeyer & Lucas, 2007).

3.3 Eutrophication

General

Lake eutrophication is water that becomes overly enriched by nutrients, often from external sources (Vollenweider, 1968). Increased water nutrient levels due to external loading make more nutrients available for plant growth, which could turn nutrient-poor water into a more plant-rich environment. However, if the nutrient content further increases, see Figure 3, they may no longer be fully absorbed by water plants, leading to increased growth of phytoplankton. More phytoplankton can result in an increase in zooplankton[66], subsequently leading to an increase in fish that feed on zooplankton, such as roach (*Rutilus rutilus,* in Dutch: blankvoorn) and bream (*Abramis brama,* in Dutch: brasem) (Zoetemeyer & Lucas, 2007). In the most extreme cases, eutrophication leads to unvegetated, turbid water with very high plankton[49] production (Jeppesen et al., 1990).

Different trophic states

The terms oligotrophic[42], mesotrophic[40] and eutrophic[25] are used to describe the trophic[63] status and nutrient content in lakes. Oligotrophic lakes are characterized by limited plant growth, low nutrient levels, especially phosphorus and nitrogen, and the water is clear with low algal biomass. The oxygen levels are high throughout the water column[65]. Mesotrophic lakes have moderate nutrient levels, a moderate number of algae and aquatic plants[3] and the oxygen levels vary, especially in deeper layers. Eutrophic lakes are rich in nutrients, have abundant algae and plant growth, but oxygen levels can be limited in deeper layers due to increased organic matter decomposition. These lakes are often shallow with mucky bottoms (New Hampshire department of environmental sciences, 2019).

Problem in deeper water layers

The upper layers of deeper waters can contain a lot of plankton, due to eutrophication. Plankton has a short life, leading to a constant 'rain' of dead plankton sinking to the bottom. Oxygen is required for the decomposition of dead organic material by fungi and bacteria, which is extracted from the water. As a result of this breakdown, the oxygen content in the lower layer of deep waters can continually decrease (Zoetemeyer & Lucas, 2007).

If oxygen deficiency or even anoxia (a total depletion in the level of oxygen) occurs in the lower layer, the decomposition of organic material continues without oxygen. This results in a decay process that produces hydrogen sulphide, which can lead to poisoning of fish and other organisms (Torrens & Clemens, 1987).

3.4 Aquatic plants

Aquatic plants, also referred to as macrophytes[39], are plants that have adapted to living in aquatic environments. They grow in or near water and are either emergent[20] (out of the water), submergent[59] (underwater), or floating. In terms of biological classification there is a distinction between algae and plants. Plants have distinct structures such as roots, stems and leaves, whereas algae do not. Algae can refer to both microscopic and macroscopic organisms. Some large algae species can resemble plants. In this report the term aquatic plant/macrophyte will refer to any aquatic plant that is visible to the naked eye and can therefore refer to both plants and macroscopic algae. The term phytoplankton will refer to all microscopic algae, this will be further elaborated on in chapter 3.4.

Light availability

The presence of aquatic plants in a lake is intertwined with light availability. Light facilitates photosynthetic capabilities for plants. These, in turn, can help improve water visibility in several ways (Scheffer, 1999; Nurminen 2003). Aquatic plants can help to combat phytoplankton in the lake, as they compete with phytoplankton for light and resources. Additionally, they can serve as an important refuge for zooplankton against fish predation. Zooplankton feeds on phytoplankton and therefore by facilitating protection, the presence of aquatic plants can directly and indirectly reduce phytoplankton levels. Plants can also reduce turbidity through resuspension of sediment, as their root systems will be able to hold the sediment in place.

Equilibrium shifts

The feedback loop between aquatic plants and turbidity is thought to be an important mechanism between a clear vegetation dominated state and an alternative turbid state equilibrium (Scheffer, 1999). In turbid water, light conditions are insufficient for vegetation development, but once vegetation is present, the water clears up and the improved light conditions can allow for lush vegetation. Alternatively, study has shown high sediment-driven turbidity in spring to reduce vegetation cover in summer, which has a negative effect on sediment-driven turbidity in summer, indicating potential positive feedback of sediment-driven turbidity on itself (Austin et al., 2017). This seems to indicate that these two alternative states are likely to be self-enhancing.

3.5 Plankton

Plankton is a term that refers to small and microscopic organisms that are drifting or floating in the water column. They can be divided into two subgroups: phytoplankton and zooplankton. Phytoplankton refers to microscopic algae, where zooplankton refers to microscopic animals. Phytoplankton meet their energy demand through photosynthesis, whereas zooplankton meet their energy demand through consumption of other organisms.

Daphnia (no Dutch name) is a genus of zooplankton that has a big impact on planktonic communities (Jurgens, 1994). They are a keystone species[37] in freshwater ecosystems and can strongly affect phytoplankton abundance. *Daphnia* are generally considered as the main filter feeder of an aquatic lake system because of their ability to filter a large spectrum of particles sizes (Jurgens, 1994).

3.6 Fish

Types of feeding behaviour

Fish are an important ecological player within a lake's ecosystem, mainly due to their large dietary variety. Fish can be piscivorous[48], planktivorous[50], herbivorous[32] or benthivorous[7].

Piscivorous fish mostly eat other fish species, these types of fish are often the top of the food web. Having a sufficient amount of piscivores is critical for keeping a clear water state in balance. Examples of piscivorous fish are pike (*Exos Lucius,* in Dutch: snoek), zander (*Sander lucioperca,* in Dutch: snoekbaars) and adult perch (*Perca fluviatilis,* in Dutch: baars).

Planktivorous fish feed on zooplankton like *Daphnia*. Since *Daphnia* are a keystone species, planktivorous fish can have a large influence on the state of a lake ecosystem depending on their abundance. Planktivorous fish are often juvenile fish, like those of the pike, bream, perch and zander, but also the adult fish roach is a planktivory.

Herbivorous fish include fish that graze on young aquatic plants and contribute to a reduction in their abundance. Some herbivorous fish also feed on phytoplankton, making them fall under the category of planktivorous fish as well. Examples of herbivorous fish are grass carp (*Ctenopharyngodon Idella,* in Dutch: graskarper), common carp (*Cyprinus carpio,* in Dutch: karper) and adult roach.

Benthivorous fish search in the substrate[60] for invertebrates and while doing this, stir up the sediment. When benthivorous fish occur in large numbers they could increase turbidity directly through resuspension. Disturbing the substrate also give water plants less opportunity to grow, which increases the chance of an equilibrium shift as mentioned in the aquatic plants paragraph. Examples of benthivorous fish are common carp and adult bream.

Notable fish species

Some fish species that are often mentioned in ecosystem restoration are roach, perch, bream, zander and carp. These will be shortly introduced below.

Roach (*Rutilus rutilus*, in Dutch: blankvoorn*)*: The roach is a species that occurs in all types of waters, but needs some structures underwater for reproduction. Examples of this are aquatic plants, the roots of trees or fallen branches. As mentioned before, the roach mainly feeds on zooplankton and aquatic plants as well as small invertebrates. It changes its feeding behaviour based on the availability of different types of food (Horppila & Kairesalo, 1992).
Perch (*Perca fluviatilis*, in Dutch: baars): The perch occurs, like the roach, in different water types and has a need for underwater structures for reproduction. Juvenile perches mainly feed on zooplankton and once they grow bigger will start hunting small fish. Due to their hunting nature, perches prefer to be in clear water.
Bream (*Abramis brama*, in Dutch: brasem): The bream is a fish that prefers nutrient rich water. Juvenile breams mainly filter zooplankton form the water, while adult breams are benthivorous and

thus, search the substrate for invertebrates.
Zander (*Sander lucioperca*, in Dutch: snoekbaars): The zander prefers deep, turbid water without aquatic plants. Juveniles feed on zooplankton, while adult zanders hunt near the bottom of the lake for prey fish.
Pike (*Exos Lucius,* in Dutch: snoek): The pike prefers clear water with a high abundance of aquatic plants. Juvenile pikes eat zooplankton, while adult pike eat primarily fish. For a clear water state it is the preferred large piscivore over the zander.
Common carp (*Cyprinus carpio,* in Dutch: karper): The carp doesn’t have a preferred type of water and it adapts to its environment very easily. Carps are primarily benthivores but also eat the tender parts of aquatic plants.

Fish adapting to temperature change
Fish adapt to the surrounding temperature. When the temperature drops, the fish's body temperature also decreases. As the fish's body temperature drops, metabolic processes slow down, and the fish becomes less active. This slowdown in metabolic activity leads to a halt in the growth of fish in freshwater during the cold months. Many fish species, such as roach, bream, and perch, seek deeper places in the fall. Because the temperature there is relatively constant (about 4 degrees Celsius), they can endure the winter in a state of rest. However, during the warmer months of the year, when oxygen levels are very low in the hypolimnion, living conditions for water plants and other organisms are also very low. This indirectly affects the living conditions of fish as well (Zoetemeyer & Lucas, 2007).

Oxygen levels
In still and slow flowing water, aquatic plants and phytoplankton are, under the influence of sunlight, the primary suppliers of oxygen in the water (photosynthesis). Fish can generally cope with short-term low oxygen levels in the water, partly by making stronger gill movements. Some carp-like fish may also absorb oxygen by gulping air at the water's surface or directly from the air (Kramer, 1987).

The optimal oxygen level for fish ranges between 8 and 12 mg per litre. When the concentration falls below 2 mg/l, fish encounter significant problems. The oxygen requirements vary among fish species and life stages; for instance, fish eggs and embryos typically require relatively high oxygen levels. Species adapted to shallow, plant-rich waters, such as the roach, are often well-suited to handle extreme fluctuations in oxygen levels (Kramer, 1987). However, in the hypolimnion of a lake deeper than 6 metres, little or no light penetrates, resulting in a lack of oxygen production and therefore very little fish species able to survive there (Kramer, 1987).

3.7 Fish water types

Zoetemeyer & Lucas (2007) explain and describe the different fish water types that characterize a deep lake, each will be described in the following paragraphs.

Perch-roach fish water type

The characteristic of this fish water type of having a plant-rich shoreline extending up to five to seven metres depth, occasionally up to approximately 10 metres, see Figure 4. Underwater vegetation can cover 15 to 30% of the total surface area. Additionally, it is typical for the lower layer to be cold, resulting in generally high oxygen levels. The average visibility is four to seven metres. In this type of water, perch and roach are the most distinctive fish species. Perch, being the primary predatory fish in this community, forms schools in the upper water layers of the deep water to hunt fish. Roach mostly is carnivorous, but in the absence of sufficient animal food, it may temporarily feed on plant material.

Figure 4 copied from Zoetemeyer & Lucas (2007): Sketch of Perch-Roach water type (Zoetemeyer & Lucas, 2007).

Roach-bream fish water type

This type of fish water (see Figure 5) largely corresponds to the Bream-Zander fish water type (see Figure 6), which will be described next. The difference lies in the greater potential for plant growth in the shoreline zone and the fish extending further down the water column due to ample oxygen availability. In this type of water, bream, roach, and zander are the most common fish species. They can thrive in conditions with low plant density but rich in nutrients. The average visibility depth in this type of water is typically between 1 and 3 metres.

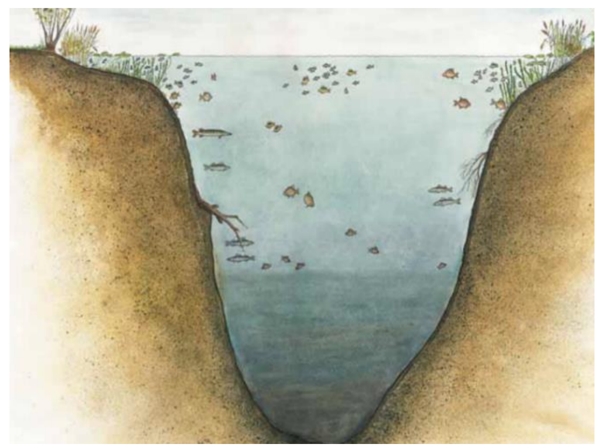

Figure 5 copied from Zoetemeyer & Lucas (2007): Sketch of Roach-Bream fish water type (Zoetemeyer & Lucas, 2007).

Bream-zander fish water type

This classification is characterized by the complete absence of water plants, or their coverage being limited to no more than 10% of the water surface, see Figure 6. Such waters are highly enriched with nutrients, making the entire nutrient content available for the production of both phytoplankton and zooplankton. A consistent yearly, seasonal, or permanent bloom of green[30] and blue-green algae is expected. The average visibility depth from May to September is notably low—typically around 40 centimetres and often as little as 10 centimetres. This limited visibility inhibits sunlight penetration, impeding the growth of underwater and floating-leaf plants. The continuous deposition of dead plankton on the bottom results in the formation of a thick sediment layer. It's important to note that this type of water is considered the least species-rich among all mentioned fish water types but has the highest density of fish. This can be explained by the fact that nutrient availability supports plankton growth, creating an abundant food source for bream and zander. However, these conditions are not ideal for predator fish like roach and perch. Herbivorous fish like bream and zander have fewer predators, enabling them to reproduce in large numbers.

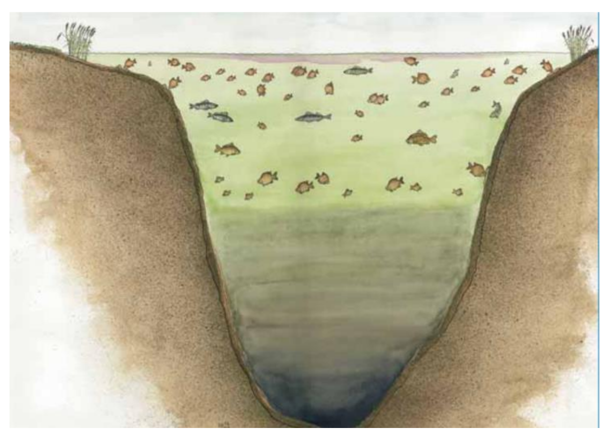

Figure 6 copied from Zoetemeyer & Lucas (2007): Sketch of Bream-zander fish water type. (Zoetemeyer & Lucas, 2007).

3.8 Other organisms that could be present in a lake

Next to the different fish species, other organisms are present in the lake as well. In this chapter, filter feeders and crayfish will be briefly introduced. These species might influence water quality, this will be addressed later in chapter 5; ecological solutions.

3.8.1 Filter feeders

Freshwater mussels

Zebra mussels (*Dreissena polymorpha,* in Dutch: driehoeksmossel) and quagga mussels (*Dreissena bugensis,* in Dutch: quagga mossel) are considered invasive species but well known for their large filtering capacity and they clarify waters in ecosystems (McLaughlan & Aldridge, 2013). See Figure 7 for the distinction between the two mussels. Zebra mussels are native to the Ponto-Caspian region of Eastern Europe and spread to large parts in Western Europe. In 1823 the species was first found in the Netherlands (bij de Vaate, 2008; McLaughlan & Aldridge, 2013). In 2006, the quagga mussel was spotted in Western Europe for the first time when collecting zebra mussels in Hollandsch Diep. Both these freshwater mussels are considered invasive since they entail a top-down mechanism on pelagic[44] primary production and there might be loss of zooplankton and ultimately a decrease in fish biomass (Goedkoop et al., 2021).

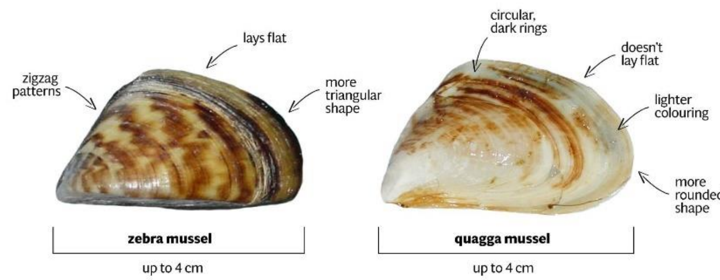

Figure 7 copied from (Invasive Species Centre, 2023). Distinction between zebra mussel and quagga mussel (Invasive Species Centre, 2023)

In the Netherlands, however, the establishment of the zebra and quagga mussel altered the effects of eutrophication in lakes and rivers and resulted in increased water visibility. Certainly, native freshwater mussels such as the painter's mussel (*Unio pictorum,* in Dutch: schildersmossel) can decrease algal densities by filtering the water (McLaughlan & Aldridge, 2013). However, due to their population decline worldwide, their complex reproductive cycle by using fish that serve as host for the larvae and the capacity to close their valves and stop filtrating for months, there is a higher interest in the use of zebra and quagga mussels (McLaughlan & Aldridge, 2013).

The living conditions in which zebra and quagga mussels can survive are very broad. In general, zebra and quagga mussels are found in almost every freshwater body in the Netherlands. In terms of depth, zebra mussels reach their highest densities in the shallower water and quagga mussels more in the deeper waters (Jones & Ricciardi, 2005). The mussels are found at depths up to 110 metres in Lake Erie, one of the Great Lakes in America, but only the quagga mussels are found at depths greater than 110 metres (Jones & Ricciardi, 2005). This might be due to the fact that quagga mussels have a lower desiccation[15] tolerance, which refers to the ability of an organism to withstand extreme dehydration or drying conditions. Oxygen is the limiting factor in the survival of freshwater mussels. They can handle most situations and survive without food for a long time, however they cannot handle too low concentrations of oxygen. In terms of temperature, according to research (Jones & Ricciardi, 2005) the water temperature needs to be at least 6 degrees for the zebra mussel to grow and 12 degrees in order for the zebra mussel to reproduce.

Sponges

Sponges[57] are simple organisms without a central gut, nerve, or muscle cells. Their body plan is one of the simplest in the animal kingdom (Lang et al., 2002). They are found mainly in coral reef ecosystems where they play a crucial role. Sponges have very fine filters with a water circulation mechanism. These filters can capture particles ranging from large algae to bacterial cells smaller than 1 µm, thus maintaining water quality. Additionally, they can process carbon, nitrogen, and phosphorus.

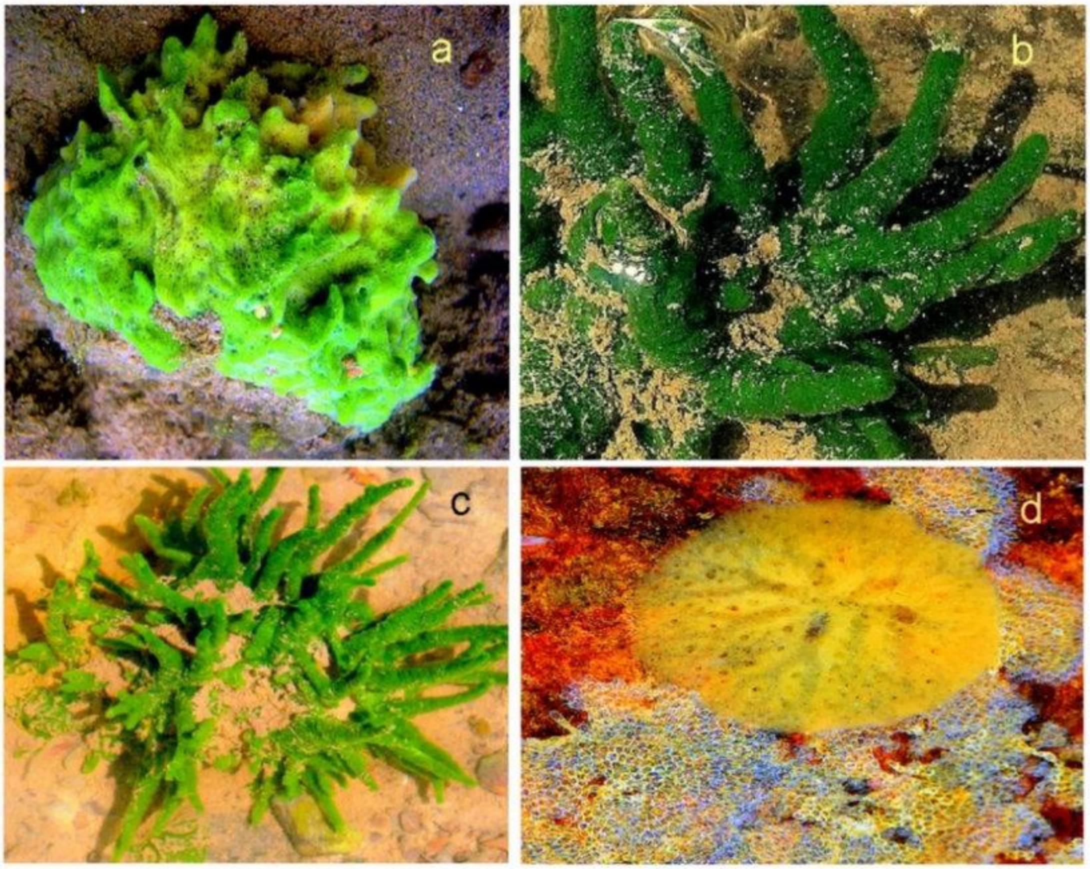

Figure 8 copied from (Dembitsky, 2022). Overview of different freshwater sponges. (a) Ephydatia fluviatilis; (b) Spongilla sp.; (c) Spongilla lacustris; (d) Ephydatia sp. (Dembitsky, 2022).

While most coral reef organisms and thus most sponge species live in saltwater ecosystems, the *Spongillidae* (no Dutch name) family is the only family that successfully adapted to freshwater habitats (Gost et al., 2023). This family is a suborder within the Demospongiae and consists of 22 species, Figure 8 shows four different species of freshwater sponges. Thriving globally, these sponges can tolerate diverse freshwater environments (Manconi and Pronzato 2008). They have developed strategies to tolerate unfavorable ecological conditions, such as rapid temperature changes and hypoxic[35] situations (Gost et al., 2023). When faced with difficulties, these sponges can create special structures called gemmules[29]. Gemmules are hard capsules with a spiky cover, containing totipotent cells[62], that can develop into different types, allowing sponges to face hard conditions and regenerate when conditions are suitable.

Freshwater sponges come in different shapes, from flat, to round and finger-like forms. Sponges in still and flowing water environments can show significant differences in their shapes. The way they grow depends on factors like water flow and how much light is available (Reiswig et al., 2010).

Freshwater sponge populations usually depend on hard substrates to survive. Many species need to attach to a substrate for growth like boulders, exposed bedrock, branches of fallen trees, and the leaves and stems of aquatic plants. Human-made structures in water, such as bridge foundations, canals, and dams, often host abundant sponge growth, particularly those offering extensive vertical surfaces. Typically, larger immovable rocks in areas with average currents are more prone to sponge colonization. Smaller rocks, often subject to movement by average currents, seldom host sponges or other sessile organisms (Gugel, 2001).

3.8.2 Crayfish

Crayfish (*Cambaridae,* in Dutch: rivierkreeft) play an important role in the lake ecosystems as they build up the ecosystem and are a keystone species. They bring changes in the environment through activities such as modifying habitats, processing sediment, breaking down leaves, grazing on macrophytes, filamentous algae, as well as preying on macroinvertebrates and vertebrates (Keller & Hazlett, 2010). Their diet consists of plant litter, algae, invertebrates, fish carcasses, eggs, and other crayfish (Wooster et al., 2012; Ercoli et al., 2014; Veselý et al., 2020). The main dietary component of crayfish that inhabit eutrophic lakes are invertebrates (Ercoli et al., 2014). Crayfish are mainly predated on by humans, while smaller specimens can also be consumed by birds or fish (Wooster et al., 2012; Veselý et al., 2020). One of the reasons why it is hard to get rid of them in an ecosystem is because when they deplete other food sources in a lake, they switch to cannibalism and persist until other food sources are available again. In a study done by Veselý et al. (2020) it was approximated that cannibalism consisted of 20% of the crayfish's diet.

The environmental factors that influence the crayfish's growth and behaviour are temperature, substrate size and type and population density (Keller & Hazlett, 2010; Wooster et al., 2012; Klefoth et al., 2023). Additionally, using surrounding land for farming purposes negatively affects them by addition of sediment, presence of toxic substances and water temperature rise due to global warming (Wooster et al., 2012). They are able to occur in very deep parts of lakes as long as the water is oxygenated (Veselý et al., 2020). Furthermore, there have been differences in sex distribution along depths, where females were found to occupy deeper parts than males (Veselý et al., 2020). As they are able to travel smaller distances on land as well as in water their speed of spread is increased and hard to control.

Invasive species

There are multiple invasive crayfish species in the Netherlands, for example: *Faxonius limosus (*in Dutch: gevlekte Amerikaanse rivierkreeft) and *Procambarus acutus* (no Dutch name) *and Pacifastacus leniusculus* (in Dutch: signaalkreeft) (Roessink et al., 2022*).* Invasive crayfish species can adapt better to new environments, reproduce and grow faster, and are more aggressive than native crayfish like (Ercoli et al., 2014). They are more flexible in diet changes and when there's not enough prey to catch, they are quicker to switch to an omnivorous[43] diet and consume more plants. As carriers of diseases, invasive species have the potential to displace native ones, they are more immune to the pathogens, while the native population is not. This results in massive declines in native population and local extinctions (Klefoth et al., 2023).

4. Ecology of Lake Berendonck

The main focus in this chapter is on the ecology of Lake Berendonck itself. As mentioned before, Lake Berendonck is divided into three lakes (see Figure 1). In this chapter the focus will solely be on the smallest lake – the diving lake. It is important to note that the term "The lake" refers specifically to the diving lake.

4.1 General characteristics of the diving lake

The diving lake is situated at an elevation of 7-7.5 metres above NAP (Amsterdam Ordnance Datum). The lake has a small catchment area[14] dominated by agricultural zones and an adjacent golf course (see Figure 10). The lake covers an expanse of 20,000 m^2 and a shore length of approximately 1.9 km metres (van Hal & Lürling, 2004), Lake Berendonck is a notable aquatic feature in Wijchen. The lake receives water inputs from precipitation, averaging 800 mm annually, groundwater influx, and surface runoff (coming from the catchment area). The connecting passage between the diving lake and the reference lake is both narrow and shallow. The lake is surrounded by a golf course and by pockets of woodland. The 18-hole golf course spans 27 hectares of course area and is equipped with a drainage system. This system has multiple outlet pipes leading into the lake. Approximately 15 drainage pipes discharge into the diving lake. The maximum depth of the lake is 17 metres, as can be seen in Figure 9. The deepest section, indicated by the blue parts on the map, hosts a distinctive feature—the elevated shipping container (Aquavilla), strategically positioned on 2-metre-high stilts. The structure provides an air pocket and is used as an underwater escape room. This container, accessible from the lake's bottom, adds an intriguing element to the underwater landscape, offering divers a distinctive point of exploration in the lake's deepest recesses.

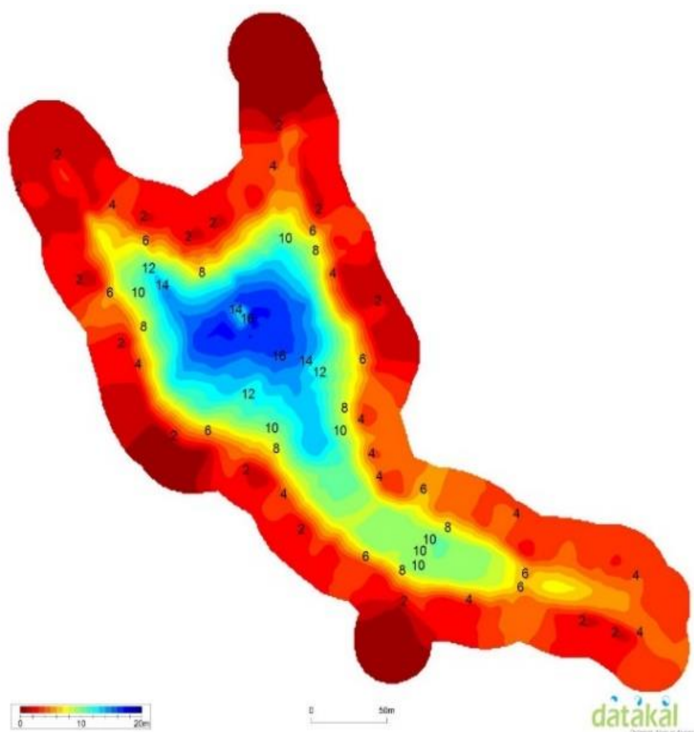

Figure 9 copied from de Laak (2010): depiction of the depth in the diving lake (de Laak, 2010).

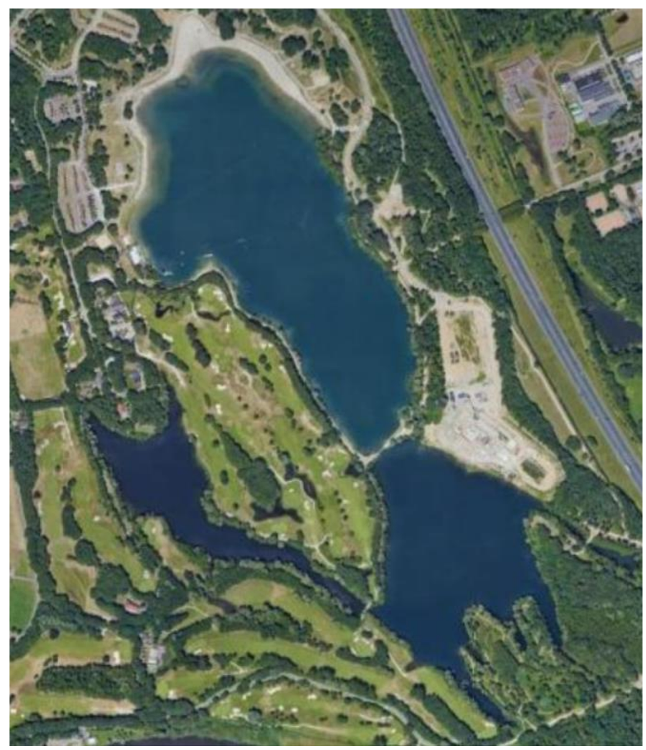

Figure 10 copied from (Google Maps, 2023): A satellite image of the area around the lake where the surrounding area depicts the golf course.

Turbidity in the lake
The report of 20 years ago, stated that turbidity in lake Berendonck was caused by resuspension of the bottom sediments and by algae, according to van Hal & Lürling, (2004). Some fish species, like carp, can stir up the bottom when they are looking for food, resulting in turbidity of the water. The divers could also resuspend the water with their fins, especially unexperienced divers (van Hal & Lürling, 2004). In spring, algae blooms occur due to eutrophication, resulting in high concentrations of phytoplankton in the upper part of the lake. This affects visibility as phytoplankton will block light penetration resulting in poor visibility (van Hal & Lürling, 2004). However, as this occurred 20 years ago, we are unaware of the current factors causing turbidity in the lake.

Oxygen level in the lake
Due to stratification in early summer, differences in oxygen levels in lake Berendonck were found by van Hal & Lürling (2004) in their research in 2004, shown in Figure 11 below. When temperature starts to rise, the warmer water with a lower density on top is able to dissolve more oxygen. The lower water layers do not mix with the top layers anymore and become completely anoxic during this period. When the temperature drops in November the water starts to mix completely and there is no measurable difference in oxygen level.

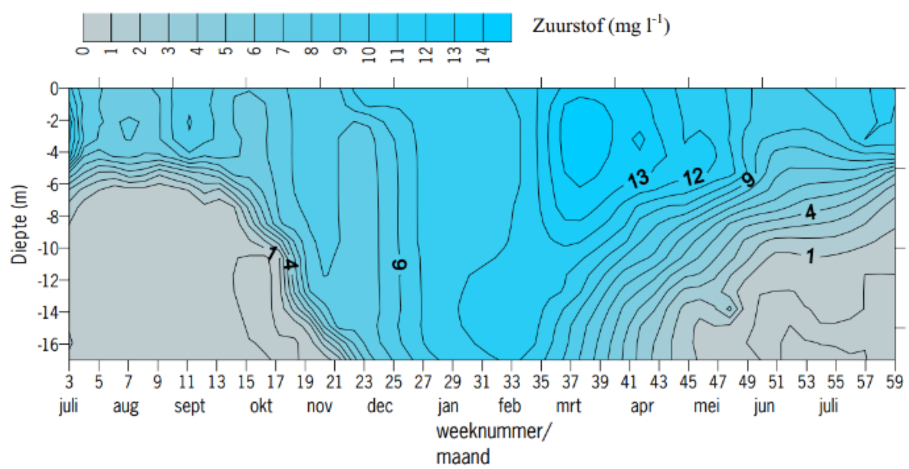

Figure 11 copied from van Hal & L Lürling (2004): Oxygen level throughout the year in lake Berendonck. On Y-axis depth, X-axis week number / month. Legend explains the oxygen level from 0-15 in mg/L (van Hal & L Lürling, 2004).

As described in chapter 3, the optimal oxygen level for fish ranges between 8 and 12 mg per litre. Fish encounter big problems when oxygen level falls below 2 mg/l. In Figure 11 can be seen that from a depth of 8 metres or more, less than 2 mg/l of oxygen is available from April till October. Additionally, from June till October the oxygen level in the whole lake is not get higher than 9mg/l and at some places at a certain time it does not even get higher than 4 mg/l. This falls out of the optimal range for fish to live there, so they will probably swim to places with higher oxygen levels. Additionally, chapter 3 touched upon fish that adapt to temperature changes in fish. In the colder months many fish species seek deeper places in the fall, due to colder upper layers. Figure 11 also indicates higher oxygen levels in the deeper parts of the lake during the winter. Together with changes in temperature and the higher oxygen levels in the lake, fish seek the deeper parts of the lake.

Bream-zander fish water type

Based on the interview with Miquel Lürling's (M. Lürling, personal communication, November 20, 2023) who noted the absence of visible plants during his visit to the lake in June 2023, coupled with the divers reporting poor visibility and the survey that was done, it is assumed that the lake falls into the Bream-zander fish water type, see Figure 6, according to Basisboek visstandsbeheer (2007).

4.2 Organisms present in Lake Berendonck

To get a better overview of the biodiversity in the lake, we asked the divers to conduct a survey and write down all the plant and fish observations. Additionally, we asked the fishermen to share their data of caught fish species with us.

Survey data

On December 2nd and 3rd, a total of two dives were conducted—one in the recreational lake and the other in the diving lake. Table 1 below summarizes the observations made during these dives. 10 crayfish (species unknown) and 5 dead shells (species unknown) were observed at a depth of 2.5 metres with a visibility of 1 -1.5 metres during the dive in the diving lake. These were the only observations from this dive. The divers that dove in the recreational lake did not observe any plants or fish species. The depth of this dive was 11.9 metres with a visibility of three metres.

Table 1 results from the two dives that took place on the 2nd and 3rd of December.

	Diving lake	Recreational lake
Depth	2.5 metre	11.9 metre
Temperature	7 degrees	7 degrees
Observations	5 dead shells and 10 crayfish	0
Visibility	1 – 1.5 metre	3 metre

Fishermen data

In 2009, an attempt was made to assess the fish population in the lake using sonar. The estimation was made between 9 and 37 kg/ha of fish. Using this sonar, the fish species were also estimated. The fish species estimated to be in the lake were; carp, bream, roach, perch, pike, and possibly some zander (Table 2). Of these species, the only individuals that were big enough to be determined for certain were common carp. Adding to this, last year the fishermen faced an outbreak of Koi Herpes Virus (KHV), likely stemming from someone clearing their pond and releasing their private koi carp into the diving lake. Approximately 70 dead carp were being retrieved and removed from the water from both the diving lake and recreational lake. From this we can conclude that carp is likely present in the lake, but in unknown numbers.

Table 2 copied from de Laak (2010): results from the report of 2010. Overview of number of fish species, the size of the fish and possible type of fish species corresponding to the size of the fish (de Laak, 2010).

Size of the fish	Number of fish	Type of fish species
0 – 5 cm	2.000	Roach, Perch, etc.
5 – 30 cm	14	Perch, Bream, Pike, Carp etc.
30 – 60 cm	5	Pike/Zander
60 – 100 cm	2	Carp

5. Potential ecological solutions

Based on literature research and interviews, multiple ecological solutions are proposed in this chapter. These solutions have been picked out after initial literature study about the problem of turbidity in stratified lakes. Based on these findings, through group discussion, several solutions that seemed promising were chosen to study in more detail. Each solution is described separately, they include background information and information on how the solution can be applied to lake Berendonck. Per solution an interaction web is made to indicate the relationship of the solution within the ecosystem. Most of the solutions discuss active ecological measures that could be taken to improve water visibility. These measures are a form of biomanipulation.

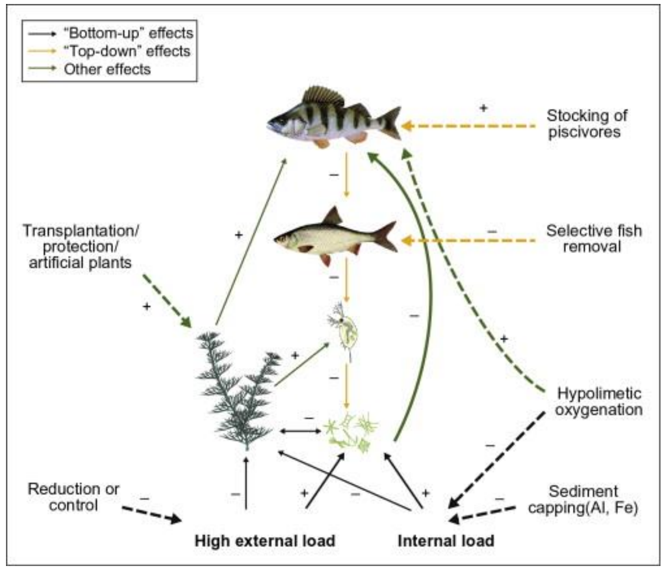

Figure 12 copied from Jeppesen et al. (2012): Conceptual model on the interactions between nutrients and the main components of a lake trophic web as affected by classic biomanipulation to enhance trophic cascade effects and other restoration measures. (Jeppesen et al., 2012).

5.1 Biomanipulation

General

Biomanipulation is a term defined by Shapiro (1975) and refers to management practices where animal or plant species are deliberately removed from or added to an ecosystem to change it from one equilibrium state to the other (Shapiro, Lamarra & Lynch, 1975). In general, biomanipulation can be applied in two ways. The first way is top-down[6], where the number of predators in the system is increased, resulting in a decrease of prey animals, which in turn, increases the abundance of their food. The other way is bottom-up[5], where accessibility of nutrients for plants is limited, resulting in a decrease of their abundance, which in turn decreases the abundance of herbivorous animals. Biomanipulation always follows this chain reaction in the food web to get desired results. Because of this, the desired results are also dependent on how the food web functions in an ecosystem (Jeppesen et al., 2012). A conceptual model that includes both top-down and bottom-up tactics is shown in Figure 1212.

Biomanipulation in deep lakes

Most research about biomanipulation has focused on shallow lakes as compared to deep lakes. In general, biomanipulation for deep lakes is less successful than shallow lakes, which is partly due to shallow lakes having a higher potential for plant growth where prey fish can find shelter more easily (Benndorf et al., 2002; Mehner et al., 2002). When top-down biomanipulation treatments were successful in stratified lakes, this was partly attributed to nutrient load reduction as well (Mehner et al., 2001). It is important to note that top-down biomanipulation is more likely to be successful in deep lakes that are in a slightly eutrophic or in a mesotrophic state (Benndorf et al., 2002). According to the lake characterization done in the 'Duikers in de mist' report, lake Berendonck can be classified as a large, deep oligo-mesotrophic medium to strongly buffered lake[11] where it leans more to the mesotrophic state (van Hal & Lürling, 2004).

5.2 Using aquatic plants

As discussed in chapter 3, aquatic plants can help against turbidity through their impact on phytoplankton through competition for light and resources and by providing habitat and protection for zooplankton. In addition, they can help against resuspension as they can keep the sediment in place. Extensive growth of aquatic plants can lead to clearwater conditions, even at higher nutrient concentrations (Jeppesen et al., 1998).

Aquatic plants can be divided into different categories that grow in different littoral[38] sections of a lake (Pokorný & Sven Björk, 2010). These are visualized in Figure 13. A littoral section refers to a certain section of a water column.

Firstly, there are emergent and submergent plants. Emergent plants refer to plants that grow out of the water but have their root systems underwater. The emergent plants are subdivided into general emergent plants (helophytes[31]) and plants with floating leaves (ephydates[21]).

The eulittoral[24] refers to the uppermost zone of the water column which is the section between the highest and lowest water level throughout the year. The upper sublittoral[58] refers to the water column down to where helophytes can grow. Ephydates can grow throughout the entire sublittoral. Submergent plants grow fully in the water and can grow in all parts of the water column if there is sufficient light and oxygen for plant growth.

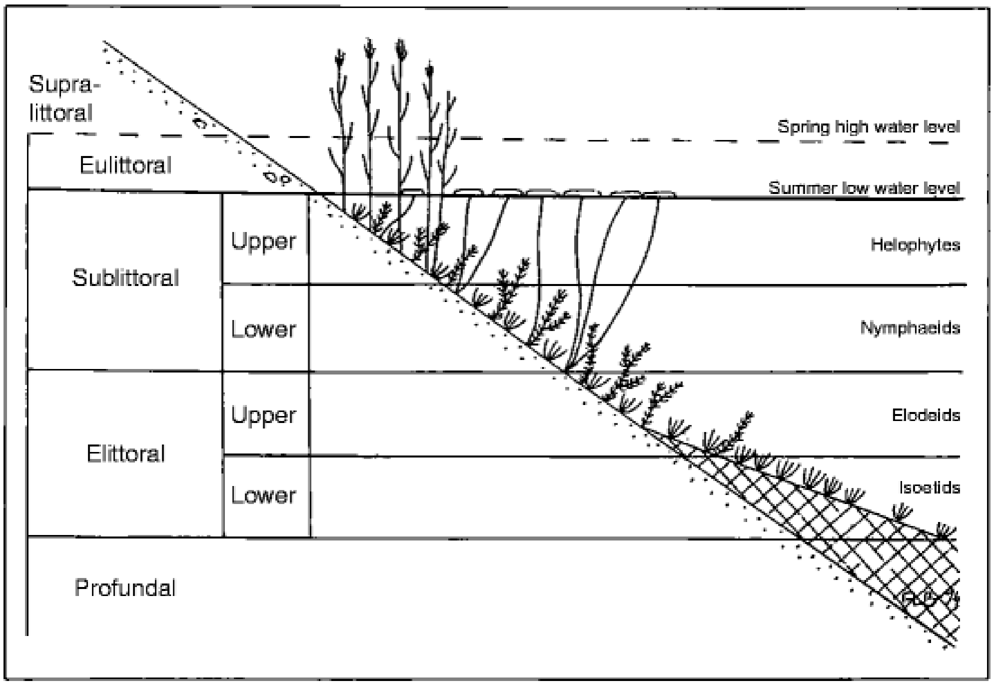

Figure 13 Schematic illustration of the littoral zonation of aquatic plants in an oligotrophic lake (Pokorný & Sven Björk, 2010).

The alternative states of a clear vegetation dominated state and an alternative turbid state appear to be self-enhancing (Scheffer, 1999; Austin et al., 2017). Without intervention, a turbid lake will stay turbid, as it won't be able to facilitate plant growth. Therefore, to alter a turbid lake to a clear lake, intervention is required. Within this solution will be discussed whether this would be achievable through increasing vegetation.

Previous studies

In Lake Scharmützelsee, a deep and stratified freshwater lake in East-Germany, submerged aquatic plants indicated a potential contribution to the stabilization of a clear-water regime (Hilt et al., 2010). A sudden change in phytoplankton mass caused an increase in light availability, which caused a significant increase in submerged plant coverage and the return of Characeae meadows.

The maximum colonization depth of submerged aquatic plants in the lake increased from about 2 m on average up to 4.3 metres in 8 years time. This study indicates that using submerged aquatic plants can also be beneficial in the restoration and maintaining clear-water regimes in deep lakes. Other studies have shown aquatic plants to play an important role in the transition to a clear state and in preventing a switch back to a turbid state (Jeppesen et al., 1998; Shui et al., 2021; van Donk and Gulati, 1995)

Lake Berendonck
In lake Berendonck, we estimate submergent plant presence to be little to none, this is based on the findings in the research 'Duikers in de mist' (van Hal & Lürling, 2004), from the interview with M. Lürlings as well as from the survey data discussed in Chapter 4. The establishment of submerged aquatic plants is traditionally considered essential in the restoration of eutrophicated lakes (Nurminen, 2003). Actively planting submergent aquatic plants in lake Berendonck could be a potential solution, but it's important to first get a better insight into the current presence of aquatic plants in the system, an overview of potential threats which might explain the distribution of aquatic plants in the current situation. This will be further discussed in the paragraph below and in chapter 6.

Potential role of Aquatic plants in improving water visibility
Visibility is a big factor in facilitating plant growth, and because visibility in lake Berendonck is low, it is expected to limit plant presence in the lake. Submergent aquatic plants can only grow up to depthse where there is enough sunlight penetration for them to be able to photosynthesize; this is their colonization depth. In lakes with poor visibility, planting aquatic plants might therefore not be a good solution. Emergent aquatic plants however, such as helophytes and floating vegetation, can help filter nutrients out of the water while not being affected by the lack of sunlight penetration. This subgroup of plants won't be able to help against resuspension but can be the first step in competing with phytoplankton, limiting their presence and thus clearing up the water. Whereas helophytes are already present at lake Berendonck. Filtering capacity could be improved by planting more helophytes and adding floating plants. Nurminen (2003) demonstrates that emergent vegetation can reduce sediment resuspension and reduce inorganic turbidity and internal P-loading.

Emergent plants could be a potential initiator to start the process of improving water visibility in the upper parts of the water column. This would allow for sunlight to penetrate deeper into the water, improving the colonization depth of aquatic plants which could facilitate submerged plant growth in the shallow parts of the lake. Which would, in turn, improve filtering capabilities of the system and would allow for a self-enhancing improvement of the maximum colonization depth. This positive feedback loop could over time lead to increasing coverage of submerged aquatic plants. This would be a relative slow process, for instance, in lake Scharmützelsee the maximum colonization depth improved by over 2 metres in 8 years time (Hilt et al., 2010).

Drawbacks/limitations/unknowns
To recommend introducing/planting aquatic plants to the system more information is required on the current presence and filtering capacity of aquatic plants in lake Berendonck. This could be achieved by continuing ecological surveys. Furthermore, more information is required on other ecological factors that could influence plant growth, such as the presence of herbivores and nutrient availability of the soil. Aquatic plants could be actively introduced and planted, but to choose which plant species to introduce also more information is needed. There are some potential fast-growing species of aquatic plants, for example, the family *Characeae* (in Dutch: kranswieren). Characeae is a type of green algae that is known to be a rapid colonizer (Hilt et al., 2010). Alternatively, active planting of aquatic plants might not be required as seeds could be present in the lake already. Seeds of Characeae, for instance, are known to be able to survive long periods in the sediment and therefore this species is able to quickly reestablish during a change in conditions. When introducing new species to the lake, more study of native species and their growing rates will need to be done. Additionally, the effects of these species specifically on the ecosystem would have to be studied in more detail.

A drawback of using emergent aquatic plants is that they can only grow in the upper parts of the water column (in the sublittoral). Many nutrients have sunk down to the deep parts of the lake and these nutrients won't be able to be directly filtered by emergent plants. Floating plants (epydates) can also have a negative effect on light penetration as they will block some of the sunlight, their presence needs to be controlled so they don't block the sunlight for submerged aquatic plants. They might be beneficial for starting the process of increasing water visibility, but it is worth considering their removal once submerged aquatic plants start to develop. Turbidity in the lower parts of the lake is not able to be solved directly through aquatic plants as they can't grow in the deeper parts of the lake, as there are light and oxygen limitations. Therefore, aquatic plants are only useful against resuspension in shallower parts of the lake. Still their presence in the shallow parts would limit the amount of floating matter in the upper parts of the water column, which would reduce the amount of floating matter that can descend into the deeper parts of the lake.

Ethical concerns
Introducing any species into a system will raise ethical concerns, especially when introducing species that are non-native to the lake. Aquatic plants are a natural part of freshwater ecosystem and therefore are native to the system. This of course depends on which species aquatic plants are introduced. While filtering capacity between aquatic plants differs and some aquatic plants would be able to turn around a system more quickly, overall, many plant species compositions with sufficient coverage will be able to sustain a clear water state. Therefore, when further studying this solution, we recommend only considering introducing plants that are native to the system.

Summary
Aquatic plants will compete with phytoplankton for nutrients. More aquatic plants will result in less phytoplankton and therefore less algal blooms. Additionally, macrophytes will help against resuspension of the sediment as their root system will keep it in place. Finally, aquatic plants facilitate refuge for zooplankton that feed on phytoplankton. All of these interactions lead to improved water visibility. Figure 14 indicates the interaction web of macrophytes.

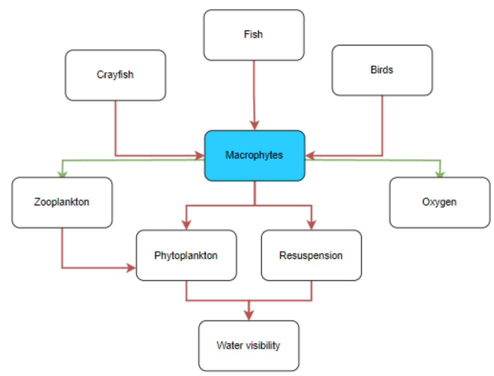

Figure 14 interaction web of macrophytes. Green arrows indicate a positive relation, red arrows indicate a negative relation.

5.3 Biomanipulation of fish population in the lake
Fish are an important ecological player within a lakes 'ecosystem. The influence of fish on ecosystems makes them very interesting for biomanipulation measures. If visibility in a lake is decreased by resuspension or algae, introducing certain fish species through biomanipulation could decrease algal growth or resuspension via the aforementioned chain reaction. Specific ways this can be done will be discussed below.

Types of top-down biomanipulation using fish in deep lakes
The most common types of biomanipulation using fish are controlling fish stock, controlling specific fish species or increasing abundance of specific fish species.

Controlling the general fish stock is done to restore the balance of the food web in the lake, a high density of fish means that there are fewer possibilities for other types of animals or plants to grow or reproduce. This high fish density mostly consists of herbivores and benthivores, as these are lower in the food chain than piscivores. Removing a substantial number of fish also means removing a part of the nutrients within the lake, which especially for eutrophic lakes could be beneficial (Griffiths, 2006). If the fish population density in lake Berendonck is high, it is a possibility that this measure could help to decrease turbidity.

Controlling a specific type of fish is a method used in lake ecosystems where one fish species is significantly more abundant than other species, and this species uses a foraging method that could be harmful to the lake's ecosystem. When this type of biomanipulation is used, the species is either fully removed from the ecosystem, or their population is decreased by a drastic amount (>80%). The latter option often has to be combined with other measures to stop the species from becoming too dominant again (Meijer & Hosper, 1997; Triest, Stiers & van Onsem, 2016; Eilers et al., 2011). According to the 'Duikers in de mist' research and a sonar survey done in 2010, common carp (*Cyprinus carpio*) and possibly bream (*Abramis brama*) are present in the lake (van Hal & Lürling, 2004; de Laak, 2010; M. Lürling, personal communication, November 21, 2023). Common carp is a species that can have a negative impact on water visibility, and even at low densities can, over a longer period of time, cause an equilibrium shift in the lake (Zambrano and Hinojosa, 1999; Chumchal et al., 2005; Weber & Brown, 2009). Bream are also proven to play an important role in keeping a lake in a turbid state due to their benthic feeding behaviour (Hansen et al., 2019). If the presence of common carp or bream in the lake is proven to be problematic, a decrease or removal of these species could benefit the lake's water visibility (Huser et al., 2022).

Increasing the abundance of a specific type of fish is a less labour-intensive measure where a species higher in the food chain is introduced to alter the food web below it. Often this is done by introducing piscivores to decrease herbivorous fish numbers, which would give aquatic plants a better chance to grow. A species often used for this measure is the pike (*Esox Lucius*) (Craig, 2008). In lakes where light is blocked by an overabundance of floating aquatic plants, a measure to introduce more herbivorous fish could also be considered. A known example of this is the grass carp (Dibble & Kovalenko, 2009). Introducing herbivorous fish to lake Berendonck is certainly not necessary, since no previous research on the lake mentions overly abundant aquatic plants as a problem, and during the visit to the lake, the abundance of plants in the water seemed notably low rather than high (Wijmans, Bosman & van Emmerik, 2010).

While increasing the number of piscivores in a system could be beneficial to lake Berendonck if the abundance of their prey animals is high, research shows that adding piscivores in lakes that stratify often result in only short periods of algal control, after which non-grazable algae started taking over and total algal biomass returned to pre-manipulation conditions (McQueen, 1998).

Method with highest potential

Looking at the different options, no concrete 'best' method can be chosen. This is largely because a lot of knowledge about fish in the lake is unknown. As mentioned in paragraph 4.2, the sonar survey in 2010, sent by the fishermen, showed that perch, roach, bream and pike could be present and carp are definitely present in the lake (de Laak, 2010). This survey did only look at parts of the lake with a depth of >5 metres, which accounts for 19% of the total surface. From the results, average fish stock was also calculated to be between 9 and 37 kg per ha. This is a very low estimate, because only the deepest part of the lake has been used to survey the fish population. Most of the fish population is expected to be in the shallower areas so the calculated estimate is likely to be lower than the reality (de Laak, 2010). It is known that common carp and possibly bream are present in the lake, and due to their high rate of substrate resuspension and grazing, it is a possibility that the low plant presence is caused by this. This does imply that the estimated fish density calculated in 2010, and the estimate given by the fishermen, is a lot lower than the reality. Taking all known factors into account, the most likely method to increase water visibility through biomanipulation with fish is removal of common carp and bream from the diving lake. An interaction web on how removal of carp and/or bream could improve water clarity can be seen in Figure 15. Fish stock represents the stock of carps and bream in the lake, the arrows deriving from this represent the positive or negative relations to a change in this number.

In research, carp was often removed by adding piscicide[47] (pesticide made to mainly kill fish) to the water (Huser et al., 2022), which in the case of lake Berendonck could be harmful to not only the rest of the aquatic wildlife, but also to people that use the lake for recreation. Research done by Gilligan, Gehrke and Schiller (2005) concludes that the best fishing method for large-scale carp removal is through the use of small mesh fyke nets. They do mention that for the most efficient use of fyke nets, a slow water flow must be present, which for lake Berendonck is unlikely to be the case. The relatively steep gradient of the lake could also prove problematic in deploying the fyke net set-up. So further research is necessary to determine the feasibility of this method. But this research can be done once the high benthivorous fish stock is proven to be the problem in the lake.

Ethical concerns
Removal of fish without harming them is difficult, but the ethics of the methods used will have to be considered. Using piscicide is out of the question as this could affect recreationists and other species as well. If carps are removed from the lake, fishing in the lake will be a less enjoyable experience for the fishers, as carp is often used for sports fishing. If carps are removed from the diving lake, the other parts of the lake still need to house carps so that the fishers still have places to fish for them.

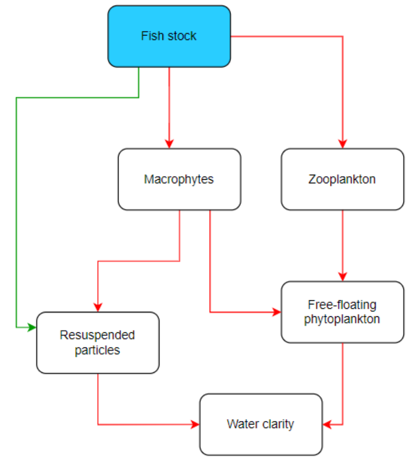

Figure 15 Interaction web of the effects of benthivorous fish stock on different factors regarding water clarity. Green arrows indicate a positive relation, while the red arrows indicate a negative one.

Summary
To summarize, removal of benthivorous/herbivorous fish, which for lake Berendonck are likely common carp and bream, increases the underwater visibility if these species are present in high numbers. Common carp and bream stir up the sediment which increase turbidity and decreases the chances for aquatic plants to settle. On top of this, carp can also graze on aquatic plants which makes it even harder for them to compete with phytoplankton, as increased phytoplankton also increases turbidity. So, decreasing the numbers of these fish will decrease turbidity as well. All this is visualised in Figure 15. Once turbidity is decreased, more macrophytes are able to grow which makes the lake more preferable for species that are favoured in a clear water ecosystem like perch, roach and pike (see paragraph 3.7).

5.4 Controlling crayfish methods

In chapter 3 the ecology of crayfish was briefly touched upon. However, they can have a big impact on ecosystems, and this requires further explanation. This chapter will focus on the reasons behind their influence on ecosystems and methods to remove them.

Impact of crayfish on the ecosystem
Crayfish may have negative impacts on the lake's ecosystem in multiple ways. At higher temperatures they are more active which means that they consume more feed and produce more waste which can result in ammonia accumulation (Klefoth et al., 2023). Furthermore, they directly impact the water turbidity in multiple ways. When foraging for prey in the sediment as well as in the pelagic zone they stir up the sediment (Veselý et al., 2020). When finding shelter the crayfish dig and bury themselves in sediment which causes sediment disruption. As they predate on plants and algae their consumption has a long-term negative impact on the sediment stability. Lastly during some parts of the year, for example the breeding season, there can be more sediment stir up due to certain specific mating behaviour.

Impact of crayfish on fish population

Crayfish can have an impact on fish in several ways. Crayfish are omnivorous animals, meaning that are able to eat everything. Therefore, they pose a threat by preying on fish eggs and juvenile fish. This affects the reproduction and early life stages of fish species (Reynolds, 2011). Additionally, crayfish compete with fish for food and shelter. Acting as ecosystem engineers[19], crayfish change the environment where they live, which can have an impact on other animals and plants. This affects the variety of living organisms in the area, making it less diverse (Reynolds, 2011). So, crayfish can have a big influence on the fish and the whole underwater community.

Methods to control

There are different methods to control crayfish species, but none is effective enough to wipe out an entire population. Additionally, every method has a downside to it, see Table 3 for an overview of the methods.

Table 3 copied from Freeman et al. (2010): Overview of crayfish control methods, highlighting the negative and positive aspects and final conclusion per method (Freeman et al., 2010).

Control method	Negative aspects	Positive aspects	Conclusion
Mechanical			
Netting	Very labour intensive and site sensitive.	Removes crayfish and also effective against juveniles.	Unlikely to eradicate a population. Not sustainable.
Trapping	Very labour intensive and site sensitive. Not effective against juveniles. May risk encouraging a market for non-native crayfish, and hence increase illegal introductions.	Removes crayfish effectively and reduces population density in the short term.	Unlikely to eradicate a population. Not sustainable. In the long term tends to promote earlier sexual maturity in the population and lead to a state of 'sustainable harvest'.
Electrofishing	Very labour intensive and site sensitive. Potential to harm non-target organisms and potential vector.	Effective against all age classes.	Only removes a portion of a population. Too site sensitive to be practical.
Chemical			
Biocides	Not endorsable in large areas such as river systems, hence very site sensitive.	Can cause high crayfish mortality. Not as labour intensive as mechanical methods.	Most biocides seriously affect non-target organisms. Scope for future development of novel crayfish biocides.
Semiochemicals	Expensive to develop and purify. Dependent on trapping.	Species specific, increases the efficiency of trapping.	Not sustainable and not effective against juveniles and sub-adult crayfish.
Physical			
Habitat alterations	Extremely site sensitive. Causing excessive damage to the environment.	An option for small ponds or closed systems.	With unlimited resources may work for certain sites. Not practical.
Biological			
Microbial	Possible impact on native and aquaculture species. Current lack of scientific knowledge and techniques.	Potentially very host specific, and self-maintaining in the environment. Both acutely and chronically acting pathogens have potential.	Burdened with legislative issues, but could, given the research effort, provide a long-term strategy for the control of invasive crayfish.
Predators	Site / habitat sensitive. Native species not always good candidates.	Native predators pose a low risk to the environment.	Difficult to evaluate, may have a role in an IPM strategy for some sites.

As mentioned by (Peay et al., 2014), trapping is a commonly used method, yet it hasn't led to the eradication of invasive crayfish populations, though localized reduction is achievable. However, trapping effectiveness varies with crayfish sizes. Peay et al. (2014) explores an alternative approach: electric shock treatment. Unlike conventional electrofishing for fish, this method demonstrates higher mortality for small crayfish compared to larger ones. Adjusting the device's power and enhancing bank treatment could improve effectiveness, although complete eradication seems unlikely. Nevertheless, it might help in controlling the crayfish population, particularly in habitats with limited crayfish shelter. Notably also in this report, 80% of the crayfish population has a carapace[13] length (this is the hard upper shell, see Figure 16) smaller than 30 mm, making this method more efficient than trapping. However, there are some disadvantages which are similar to biocide treatments. This method may impact other aquatic animals, such as fish, potentially leading to high fish mortality. Additionally, its suitability is restricted to very shallow waters, which will not work for the deeper part of the lake (Peay et al., 2014).

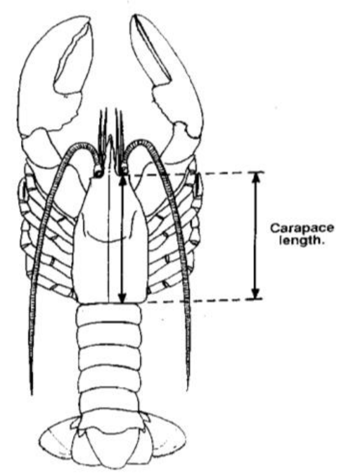

Figure 16 copied from (The Undersized Lobsters Order 1993 No. 1178, 2023). Schematic view of the carapace length. Which begins at the front edge where their horns begin, till the rear edge, this excludes soft tissue (The Undersized Lobsters Order 1993 No. 1178, 2023)

Another study (Peay et al., 2019) recently achieved eradication of crayfish populations in small ponds and short lengths of small watercourses. They used different non-selective biocides, like synthetic pyrethroid, cypermethrin, deltamethrin and natural pyrethrum. According to Table 4, which is from the research done by Peay et al. (2019), deltamethrin and cypermethrin are most effective against crayfish.

Table 4 copied from Peay (2019): Overview of biocide treatments on signal crayfish in UK (first six locations), Sweden (the 7th, 8th and 9th location) and Norway (last two locations). Py = natural pyrethrum, delt = deltamethrin, cyp = cypermethrin (Peay et al., 2019).

Location (See Figure 1 and Figure 2)	Mortality of Caged Crayfish During Treatment (Number of Cages × Number of Crayfish/Cage)	Days Until Not Toxic (Bioassay [1])	Veg. Increase [2])	Signal Crayfish Caught in Post-Treatment Monitoring (5 + Years)	Target Dosage Active Ingredient [2] µg/L
1 Gravel pit	31% in 48 h, 100% < 5 days (20 × 10)	<24 (site obs.)	+	None	py 150
2 Mains ponds	80% in 48 h, 100% < 5 days (13 × 25)	21–24	++	Year 2	py 200
3 Castle pond	35% dead in 48 h, 100% < 5 days (20 × 10)	21	+	Year 2	py 200
4 Farm reservoir Pocklington	97% in 48 h, 100% < 4 days (16 × 20, 2 × 25)	115–134	+	None	py 200
5 Ballintuim ponds and stream	garden pond 83% in 48 h (22 × 15), lower pond 91% in 48 h (5 × 10); stream section 100%, 56%* (*section was re-dosed after this result), 74%, 85%, 71% in 24 h (per section 5 × 10, plus eight burrows × 4)	Pond (garden) 23, stream and lower pond 7–11 (flushed)	++ (garden pond) 0 (lower pond)	Year 3 (garden pond)	py 1000 (ponds), py 2000 (stream)
6 Ballachulish quarry	65% in 24 h, 100% in 48 h (13 × 10)	34–60	+	None	py 500
Smöjen	100% < 24 h (5 × 3/pond)	27 (not toxic to crayfish)	na	None and no crayfish plague	delt 0.5
Stenkyrka,	100% < 24 h (5 × 3/pond)	16 (not toxic to crayfish)	na	None and no crayfish plague	delt 0.5
Hangvar	100% < 24 h (4 × 3/pond)	<60 (not toxic to crayfish)	na	None and no crayfish plague	delt 0.5
Dammane ponds	100% < 24 h (4 × 3/pond)	No data (pond drained)	na	None and no crayfish plague.	cyp 20
Ostøya golf course ponds	100% < 24 h (4 × 3/pond)	No data (pond drained)	na	None and no crayfish plague.	cyp 20

[1] U.K. sites bioassay using *Gammarus pulex*, except site (3), where *Asellus aquaticus* (Linnaeus, 1758) was used. [2] Increase in cover of submerged aquatic vegetation in years 1 and 2 after treatment: ++ = increase to abundant (>50% cover), + = increase, na = not available.

Ethical concerns

If crayfish would be removed from the ecosystem, it is important to minimize the harm to non-target species. Other stakeholders should be involved in the decision-making. Due to laws and legislation, it might be necessary to obtain permission or approval to remove crayfish, since it will change the ecosystem.

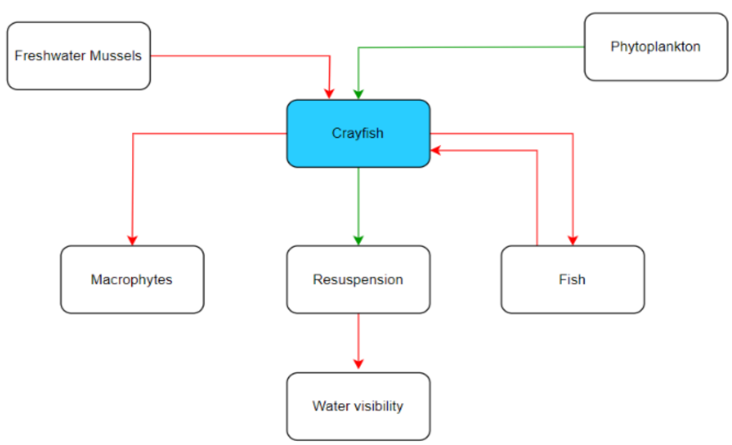

Figure 17 interaction web that represents the relationship and connections between various organisms or factors in the ecosystem and crayfish (in blue box). Green arrows indicate a positive relation, while the red arrows indicate a negative one.

Summary

Crayfish can disturb ecosystems in multiple ways, like changing the habitat, eat everything they encounter from plants to even juveniles of fish, and stir up the sediment. Since the data from the divers already indicated 10 crayfish individuals, it might be that there are a lot more present in the lake and that they could be a big problem to the turbidity. There are different methods to control crayfish, like trapping, using biocides or electrofishing. Every method has a downside to it though, so it is important to take these into consideration.

Figure 17 indicates the relationship between crayfish and other organisms or ecosystem problems. As described in the ecology of crayfish in Chapter 3, crayfish have a negative effect on macrophytes, since they eat and cut them. Crayfish can change habitat in such a way that fish species not prefer to live there anymore. Additionally, crayfish can eat encountered eggs or juvenile fish. However, carnivorous fish may eat young crayfish as well.

5.5 Filter feeders

5.5.1 Freshwater Mussels

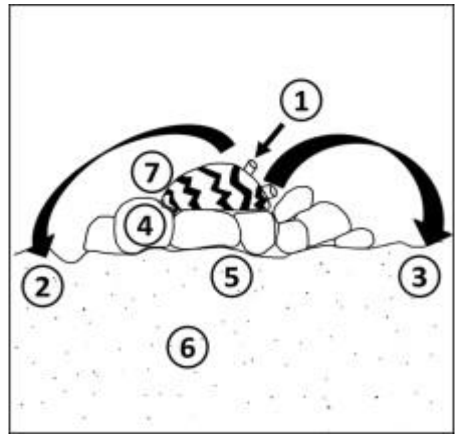

Figure 18 copied from McLaughlan Aldridge (2013): "Schematic of the ecosystem-engineering role of a zebra mussel. 1. Suspended particles >0.7 μm, including phytoplankton, are removed from the water column, entering the mussel through its inhalant siphon. 2. Material that is not ingested is bound in mucus and ejected from the inhalant siphon as negatively buoyant pseudofaeces. 3. Undigested material that has passed through the gut is ejected from the exhalant siphon as negatively buoyant faeces. 4. The shells provide substrate for attachment by other biota, including other zebra mussels, sponges, hydrozoans and bryozoans. Shells affect flow dynamics in the water column, changing near bed flows and shear stress. 5. Shells of living/dead mussels build up on the surface of the sediment, creating habitat for invertebrates and reworking sediment structure. 6. Filter feeding and depositing of faeces and pseudofaeces can change sediment grain size, organic matter content, porosity and water holding capacity. 7. The growth of bivalves locks nutrients into tissue biomass and calcium into shell biomass." Description copied from McLaughlan & Aldridge (2013)

Innovative and ecological solutions to the problem of eutrophication and turbidity in water are causing many opportunities but also challenges (McLaughlan & Aldridge, 2013). One of the proposed ecological solutions is the use of natural filter feeders which include bivalves[9], sponges and bryozoans[10]. For freshwater bodies it is interesting to consider bivalves and in particular mussels to filter the water and reduce eutrophication and turbidity. There is a lot of research done on the use of mussels for filtering the water, especially on the use of the *Dreissena* species, zebra mussels (*Dreissena polymorpha*), or quagga mussels (*Dreissena bugensis*) (Elliott et al., 2008; McLaughlan & Aldridge, 2013; Waajen et al., 2016; Goedkoop et al., 2021). The use of freshwater mussels for filtering the water is believed to be a promising solution to improve water quality and they are often considered as keystone organisms, see Figure 18 (McLaughlan & Aldridge, 2013). These filter feeders are able to process large volumes of water in order to trap and concentrate suspended particles from their environment. The mussels are attached to a hard substrate e.g., dead wood or rocks by their byssus threads[12] (McLaughlan & Aldridge, 2013). Suspended particles move from the water column and enter the mussel through the inhalant siphon (Figure 18: 1). The material that cannot be ingested by the mussel is bound in mucus and removed from the inhalant siphon as pseudofaeces[51] which ends up in the sediment (Figure 18). Material that cannot b e digested and has passed the gut is removed from the exhalant siphon as faeces which also ends up in the sediment (Figure 18: 3). The nutrients that are used for growth are turned into tissue biomass and calcium into the shell biomass (Figure 18: 7). The shells of the mussels can provide new substrate for other mussels but also for sponges and bryozoans (Figure 18: 4). According to bij de Vaate (2008) the filtration capacity of zebra and quagga mussels does not significantly differ from each other at flow rates of <20 cm/s. They can filter water at a rate of 60/70 ml/h for mussels of 11 mm. Another study found a clearance rate of approximately 180 ml/h for a zebra mussel of 22 mm at flows of 50 ml/s (Elliott et al., 2008).

Lake Berendonck

To implement this ecological solution in lake Berendonck there are two approaches that can be used. The first one is to introduce the zebra and quagga mussels in the lake by using mussel crates. The *Dreissena* mussels are grown on crates that provide an appropriate surface for larval settlement in another lake where the freshwater mussels are already present in great numbers (Waajen et al., 2016). The benefit of this approach is that many crates can be placed in lake Berendonck at the same time and the time needed to clear the water can be very short (days to weeks). However, factors that need to be considered are the regional and national legislation with regard to the introduction of species. Currently, it is not allowed in the Netherlands to introduce species anywhere in nature. However, it is possible for the Dutch Food Safety Authority to make an exemption considering the beneficial characteristics of zebra and quagga mussels (BuRO, 2017). This can be realistic since lake Berendonck is a closed system and the risk of the spread of the zebra and quagga mussels is quite low. The other benefit of using mussel crates is the opportunity to move them around and place them, for instance in the deeper part of the lake when the oxygen conditions are more preferable, see Figure 11. This way the internal loading in the deeper part of the lake can also be filtered by the mussels. However, it might not be needed to move them around since there is full mixing of the water layers in the colder period of year. To add, even if the mussels do not reproduce in the lake and die after several years, the process can be repeated again.

The second approach is to simply provide substrate for the zebra and quagga mussels that are already present in lake Berendonck. This can, for instance, be dead wood, rocks or biodegradable structures for the mussels to grow on. The benefit of this approach is that there are no issues concerning legislation and it is not very costly. The downside to this approach is that it might take a longer time before the water becomes clear if, for instance reproduction of the mussels is low. Next to that, the zebra and quagga mussels need to be already present in the lake in order for this approach to work.

For both approaches it is advised to place the substrates, either crates with mussels or the recommended substrates, at a depth of at least 1 metre to prevent them from drying out due to direct air exposure and at a certain distance from the bottom to prevent the oxygen depleted area close to the bottom. Important to note is that the freshwater mussels are very mobile. If they do not prefer their current location, they can detach themselves from the substrate and fall to the bottom where they might die due to lack of oxygen. A crate or substrate close to the bottom gives then the opportunity for the mussels to crawl back again.

Number of freshwater mussels needed in lake Berendonck

Considering the report by de Laak (2010) the average depth in the diving lake of the Berendonck is 6 metres. Knowing the surface area, 20,000 m^3, the total volume can be calculated which is then 120,000 m^3 or 120,000,000 L. Taking a mean filtration rate of 70 ml/h per mussel and a year to filter the water approximately 80 crates or 200,000 mussels are needed to filter the water. The calculations for the crate is based on the assumption that one crate weighs about 25 kg and one mussel weighs about 10 g. Important to note is that if the time to filter the water should be shorter, more mussels are needed to filter the water.

Ethical concerns

There are some ethical concerns to keep in mind. As mentioned above, zebra and quagga mussels are considered invasive and therefore could harm the ecosystem, so a permit is needed for its introduction or addition of more individuals. Stakeholders' perceptions need to be considered for instance the fishermen, Leisurelands, the golf course, waterboard Rivierenland, the municipality of Wijchen and the residents that live around the lake. If the species is already present (permit is not needed) in the lake and the solution is to provide substrate to encourage their growth, this can also be discussed with the stakeholders.

Summary

The addition of substrate or actively adding zebra and quagga mussels in lake Berendonck improves the visibility because of their filtering capacity. Figure 19 shows the overall interactions of the mussels in the lake's ecosystem. The most important part of the web is the reduction of floating particles and the phytoplankton due to water filtration which then has a positive effect on the water visibility.

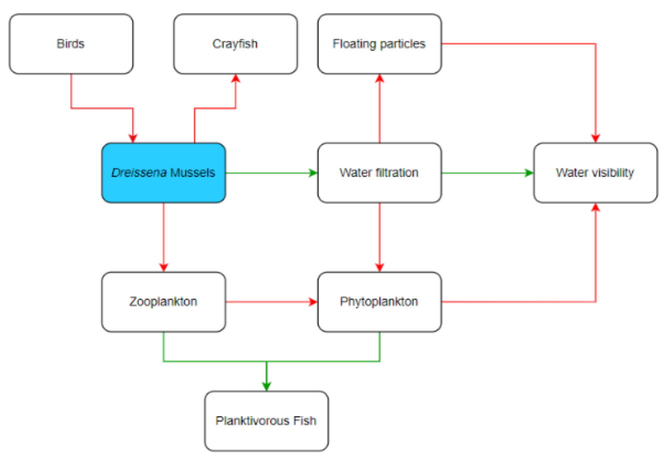

Figure 19 interaction web of Dreissena mussels in the ecosystem of lake Berendonck. The red arrows represent the negative effects and the green arrows the positive effects.

5.5.2 Sponges

Sponges were also mentioned to filter and clear the water. In this chapter we will explore the use of sponges and if it is possible to place them in Lake Berendonck.

Lake Berendonck

Sponges are great at filtering water, and during the summer, a finger-sized *Spongilla lacustris* (no Dutch name), can filter over 125 litres in a day. However, this filtering ability also suggests that sponges might use up all the nearby available food in some situations. This could happen, especially in calm water or places with not many floating particles to eat. An example is lake Baikal in Russia, where sponges consumed a lot of tiny picoplankton[46], and it seemed like they ran out of feed sometimes (Pile et al., 1997).

In lake Vinkeveense Plassen in Utrecht, The Netherlands the sponge *Ephydatia fluviatilis* (in Dutch: echte zoetwaterspons) is already present (Costa et al., 2012). This species is the only species in the freshwater sponge family that can survive throughout the entire year. In the winter, only the gemmules of this species have been found, but in the early spring months of March and April, young sponges hatch from overwintering gemmules. Their growth continues until midsummer (July-August), with the potential for sexually produced larvae occurring from May to July. Asexual gemmules are generated consistently throughout the year, with a more pronounced frequency towards autumn. Come September-October, the colonies experience a decline, leading to disintegration and the production of overwintering units (Gugel, 2001).

As discussed in chapter 3, sponges need hard substrates in order to settle and survive. In the lake, there are already some hard substrates like the Aquavilla and some other small structures. However, placing more substrates like boulders, exposed bedrock or just branches, results in a higher chance for sponges to settle. Sponges are in symbionts[61] with algae and cyanobacteria, resulting in individuals often exhibiting greenish tones. This collaboration with algae contributes to photosynthesis to the sponge but requires light to do so and they also play a crucial role in protecting the sponge against UV radiation. Placing hard substrates where the water is clearer might be beneficial for sponges with algae symbiose to grow there.

Ethical concerns

As with the zebra mussels, introducing non-native freshwater sponges would impact the current ecosystem, therefore, possible negative consequences need to be taken into account. It is therefore good to consider the legislation of introducing a new species in an ecosystem and managers should carefully consider potential consequences when introducing sponges into the system. Additionally, sponges are living organisms and can therefore also experience stress, it is therefore important to minimize their stress levels and take care of not harming them. Otherwise, they will die very quickly.

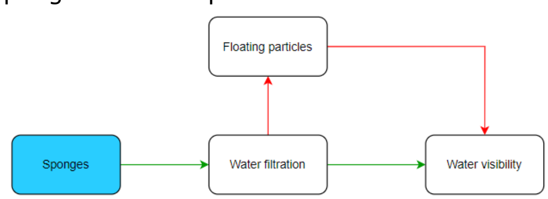

Figure 20 interaction web of sponges on different factors in the ecosystem. Green arrows indicate a positive relation, the red arrows indicate a negative one.

Summary

Sponges are great filter feeders, some species are able to filter 125 Liter of water per day when they are just the size of a finger. Almost all sponge species live in saltwater except for one family of sponges. They have evolved to survive in freshwater and are able to withstand extreme conditions. Sponges need hard substrates to be able to grow, it is therefore beneficial to place more substrates in the lake to give the sponges a higher chance of survival. Figure 20 indicates the interaction between sponges and water filtration in an ecosystem and what the consequences are.

5.5.3 *Daphnia* grazing

Daphnia is a species of zooplankton. They play an essential role in controlling phytoplankton as a key grazer due to their comparative size, indiscriminate feeding behaviour and excessive reproduction success (Rahman et al., 2011). Other than *Daphnia,* other zooplankton species, such as rotifers[53] (*Rotifera*, in Dutch: raderdieren) can fulfil similar filtering capabilities, however *Daphnia* are generally considered as main filter feeder of an aquatic lake system. Grazing effects of *Daphnia* have been shown to be evident under elevated nutrient condition (Rahman et al., 2011). Findings of Rahman et al. (2011) suggest that *Daphnia* can play a role in phytoplankton controlling, as their study demonstrated clear grazing effects of zooplankton in nutrient rich waters.

In lake Zwemlust, in the Netherlands, introduction of *Daphnia* led to reduced phytoplankton density and improved water transparency (van Donk and Gulati, 1995). When *Daphnia* became abundant in the Dutch Lake Volkerak-Zoommeer, transparency increased significantly as the *Daphnia* controlled phytoplankton biomass by grazing (Ligtvoet & De Jong, 1995; Scheffers 1999). A 4-year study of a Danish Lake documented a shift from turbid to clear water which was related to a strong increase in *Daphnia* numbers (Jeppesen et al., 1998; Scheffers, 1999). These results support the view that lakes can be more turbid due to a lower zooplankton grazing potential.

Although a mix of factors will be responsible for reducing phytoplankton productivity, grazing may often help in driving phytoplankton biomass to an extremely low level (Scheffers, 1999). Zooplankton are a key player in a lake ecosystem and as of 20 years ago were already present in lake Berendonck (van Hal & Lürling, 2004). Whereas (field)experiments have shown *Daphnia* to be able to play a role in transitioning a lake from a turbid to a clear state, it remains unclear how big of an impact they have on the process by themselves. As zooplankton are likely already present in the lake, the numbers of *Daphnia* need to be studied to assess whether there is an underrepresentation of *Daphnia* in the lake. If that is the case, the root cause of this underrepresentation needs to be determined. After this has been done and the root cause is no longer deemed to be a problem, breed and releasing *Daphnia* could be considered as an intervention.

Ethical concerns
Introducing any species into a system will raise ethical concerns, especially when introducing species that are non-native to the lake. Luckily, the *Daphnia* genus has species native to freshwater lakes in Western-Europe. It's highly likely that *Daphnia* species are already present in the lake. When considering releasing captive bred *Daphnia* into the lake, it's important to ensure that these are native *Daphnia* species. The effect of releasing *Daphnia* on the ecosystem as a whole should also thoroughly be studied before implementing this measure.

Summary
Daphnia will graze on phytoplankton limiting their numbers. As phytoplankton floating in the water limits visibility, presence of *Daphnia* will increase visibility. Figure 21 indicates the interaction web of *Daphnia.*

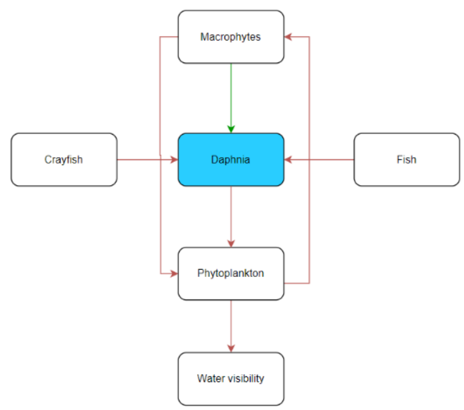

Figure 21 Ecological web of Daphnia. The red arrows represent a negative effect and the green arrows a positive one on the relevant component of the ecosystem.

5.6 External nutrient inputs management strategies

5.6.1 Birds

Lakes are part of the habitat of aquatic birds and their role in the ecosystem can be seen in Figure 22. They use the lake to forage in as well as for breeding purposes (Birch & McCaskie, 1999). Furthermore, feeding by humans leads to the attraction of more birds as well as feed rotting in the water. They also impact the lakes ecosystem with phosphorus addition mainly from their droppings (Birch & McCaskie, 1999). A study done by van Oosterhout et al. (2021) approximated that from all the external nutrient load to the water (which was 15% from the overall nutrient load) contribution from the birds was the largest. Some techniques to reduce their impact on the water quality were implemented by Birch & McCaskie (1999) and included: physical exclusion, habitat modification and population management. Physical exclusion included using fences to prevent access to the birds in preferred breeding and feeding spots. Another strategy is to make the birds habitat less favourable by introducing certain plant species and building fences. Additionally, the population can be managed through egg picking, moving of birds to other sites and bird culling.

There are some ethical concerns linked to this solution. Birds are overall very well protected animals in the Netherlands and so any interventions affecting their welfare or behaviour would be hard to approve from the government. Furthermore, any modifications of their habitat might have long term consequences, for example affecting their breeding behaviours and effectivity. Therefore, this solution would require weighing both of these ethical aspects of legislation and individual welfare and considering if it is worth implementing.

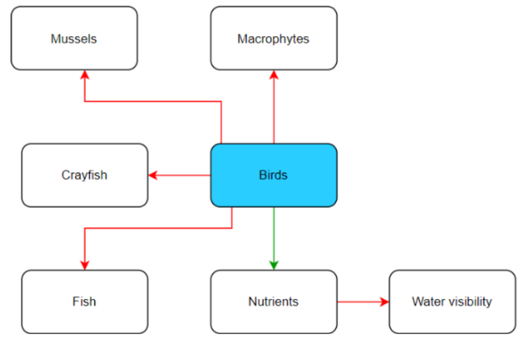

Figure 22 Interaction web representing the interaction of birds with other relevant species in the ecosystem of our diving lake. The red arrows represent a negative effect and the green arrows a positive one on the relevant component of the ecosystem.

Summary
To summarize, controlling the birds around the lake would be useful to limit the external nutrient loading and their role in the ecosystem can be seen in Figure 22. As less nutrients would be released in the lake this would have an indirect impact on the internal nutrient loading. This solution should only be implemented if it is discovered that the external loading from the birds is a problem.

5.6.2 Leaves

Around the diver's part of lake Berendonck there are a lot of trees on the banks covering around 80% (estimated by eye) of the surrounding area. Most of the trees are deciduous which results in a lot of leaf litter especially during autumn. The leaves can fall to the ground where they decompose, and the nutrients produced can end up in the water when it rains. They can also end up directly in the water where they decompose, creating high oxygen demand and eventually sink to the bottom adding to the sediment accumulation (Birch & McCaskie, 1999). This process is vital for the ecosystem creating highly accessible and soluble nitrogen and phosphorus into the water (Bratt et al., 2017). Additionally, leaves from different species (e.g., size and fibre content) decompose at different rates and release different nutrients (Dudley et al., 2014). Furthermore, there is some evidence that leaf decomposition first releases phosphorus and at a later stage nitrogen. A study done by Quintão et al. (2013) found that leaf decomposition can occur at faster rates when: there's high nutrient availability, and diverse O_2 availability with varying temperature which leads to overall enhanced microbial metabolic rate in a eutrophic water body. A summary of the processes mentioned above can be found in Figure 23.

To prevent this addition to the nutrient pool of the lake there are several solutions. First, leaf traps can be installed on the trees to prevent them from falling in the water (Birch & McCaskie, 1999). Cylinder shaped nets can be hung from the lower branches to collect the falling leaves (Wantzen et al., 2008). Leaf vacuums can be used to collect fallen leaves from the ground. Second, regular management practices can be applied to collect the fallen leaves from the water (Birch & McCaskie, 1999). This can be done manually from the banks of the lake with a big landing net. Another way would be to install a small robotic device with a net behind it and put that in the water to swim around the lake and collect the leaves that fell in the water.

The leaves do play a role in contributing to the nutrient pool in the lake, but the internal nutrient loading is a bigger problem to tackle. Preventing the leaves from ending up in the water would not make a significant difference on its own but it would help the other solutions implemented to be more efficient (van Oosterhout et al., 2021).

Summary

To end, looking at all of the problems and solutions, leaves are not that important and their interaction in the ecosystem can be seen in Figure 23. It is mentioned as a solution this extensively because we only found out that they do not contribute that much to the problem at a later stage during the literature research. Therefore, due to the reasons stated above we conclude that it is an intervention that would not have enough impact to deal with the visibility issue.

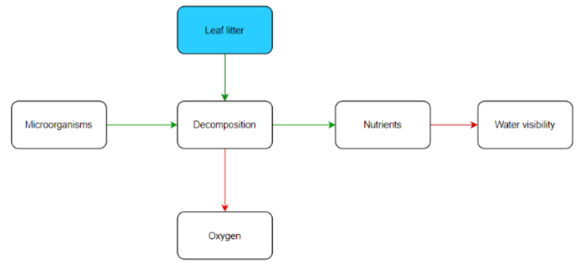

Figure 23 This interaction web shows how the leaves play a role in the ecosystem. The red arrows represent a negative effect and the green arrows a positive effect on the relevant component of the ecosystem.

5.7 Summary of the current ecological state and solutions impact on lake ecology

To summarize on all the potential solutions mentioned above, Figure 24 shows for each potential solution, the worst-case scenario for the state of the lake (on the left side) and how the proposed solution could change the state of the ecosystem (on the right side of the lake). All of the solutions would help with clearing up the water (watercolour gradient change). As can be seen in the current state of the ecosystem there's a lot of birds and leaf litter adding to the internal nutrient load of the lake. There are not that many water plants, a small number of *Daphnia* and a high number of carps and crayfish present. Considering this worst-case state of the lake, applying all of the solutions proposed the following changes to the lake would occur. There would be less external nutrient input by controlling the bird populations and trapping leaves. Additionally, more macrophytes and *Daphnia* would be present. Furthermore, the number of crayfish and carp would be reduced, and more fish species would then be present in the lake. Lastly, substrate would be provided for freshwater mussels and sponges to grow on. All of these solutions, as mentioned above, would theoretically contribute to improving the water clarity, although the magnitude of their impact varies depending on the current state of the lakes' ecosystem in reality.

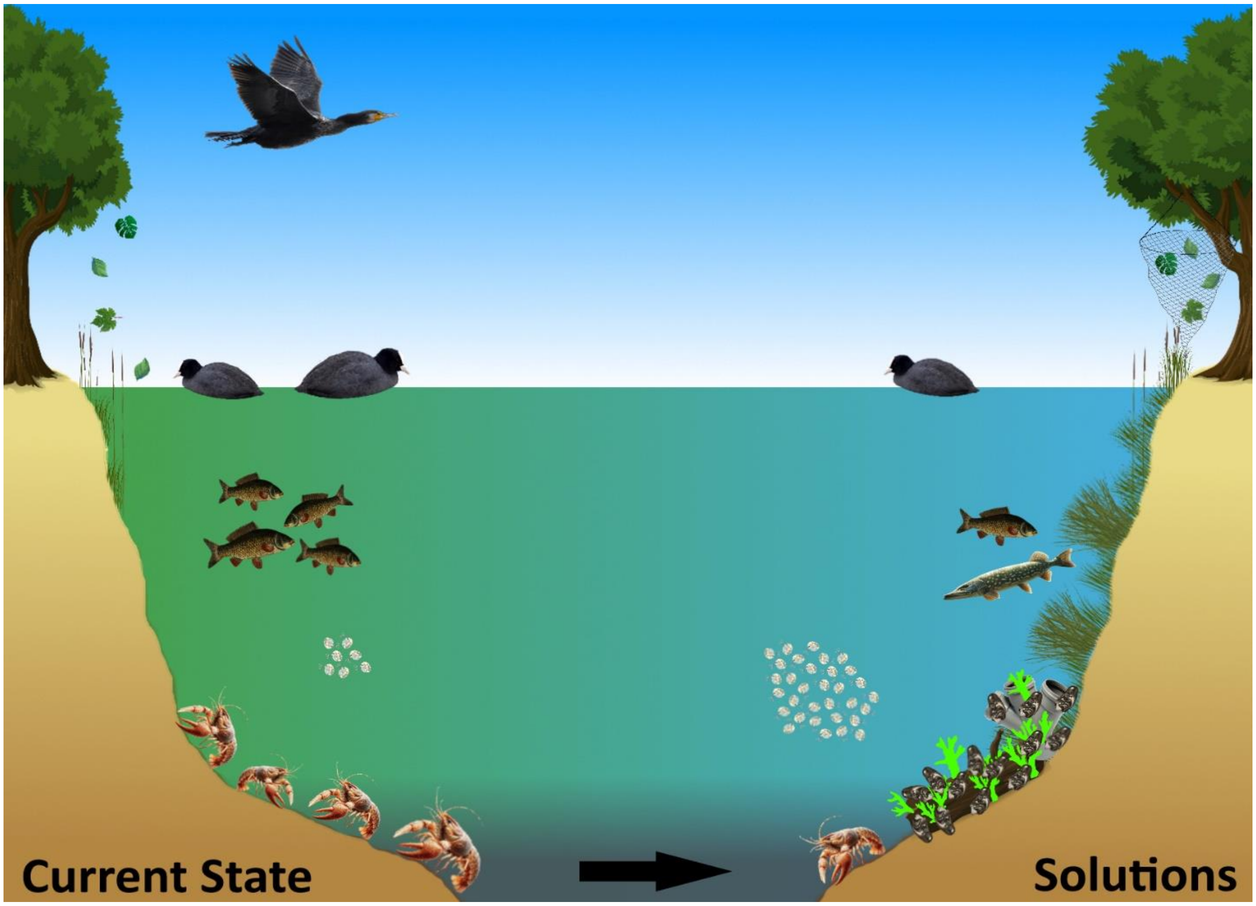

Figure 24 Depiction of the current state of the ecosystem (left side) and how would it look if all discussed solutions would be applied (right side). All pictures were taken from free image sources from the internet. At the bottom of the lake crayfish (in orange) are depicted, on the right-side sponges (in neon green) together with mussels (in black with a little grey) are visualized and above that some plants can be seen. In the middle of the lake there are some Daphnia (depicted as the whiteish dots), above the daphnia some fish can be seen and on the surface of the lake are some birds (in black and one flying bird). On the right and left top part of the Figure some trees are depicted; the right tree has a leaf trap underneath it to capture all the leaves.

5.8 Ecological interactions between key players in different solutions

Each solution provided in this research has at least some interaction with one another or is dependent on one another. Aquatic plants for instance, cannot grow well in turbid waters, whereas *Daphnia*, sponges and *Dreissena* mussels clarify the water (reduce the internal loading). The water purification then enhances the growth of aquatic plants. Once the aquatic plants are established and the clear water state is reached, it is more likely that the lake stays in this state and so the ecosystem stabilizes. To add, the reduction of leaves that end up in the lake as well as the reduction of bird faeces decreases the external loading and can contribute to the visibility of the water in the lake.

The number of crayfish in the lake has a negative impact on the growth of aquatic plants since they are grazed on by the crayfish. According to the research (Arslan et al., 2022) the *Dreissena* mussels are able to attach themselves on the narrow-clawed crayfish which had an influence on their growth, reproduction and health. This might be a way to control the numbers of the crayfish species in lake Berendonck, however their effectiveness is not known and thus another approach is needed to control their numbers. Next to the crayfish, herbivorous fish such as carp can have a negative effect on the growth of aquatic plants due to grazing and benthic behaviour. Their numbers should therefore be controlled in order for the ecological solution to work. However, a better insight in the number of fish and fish species is needed to draw a conclusion on this.

Once the number of *Dreissena* mussels, so the zebra and quagga mussels, has increased due to the addition of substrate or crates, it is possible that they alter the ecosystem in the lake. The number of zooplankton, including *Daphnia*, can decrease as a result of the filtering of the water and thus not function as a solution together. The effect of the *Daphnia* on the clearance of the water, however, is uncertain so it is more favourable in this case to use the *Dreissena* mussels.

5.9 Non-ecological solutions

Whereas ecological solutions are feasible in maintaining a clear lake state, they might prove difficult to implement as an ecological regime shift. Often when ecological solutions are discussed, interventions on a non-ecological scale are recommended, either to speed up the process or to solve the underlying problem. The problem of resuspension in the deeper part of the lakes is especially difficult to solve through ecological solutions as the conditions don't allow plant growth and are anaerobic for some time during the year (see Figure 11). Some of these non-ecological measures will be briefly discussed below.

Dredging and sediment capping

Non-ecological solutions that could aid against resuspension in the deeper parts of the lake are dredging[16] and sediment capping[55] (Waajen et al., 2018; Lürling et al., 2023). The former involves scooping up the upper (and most turbid) part of the sediment and removing this from the lake, the latter involves adding a layer of sand over the sediment. While both of these solutions are costly, they are a quick method to tackle the problem of resuspension.

Flocculant

To aid in the removal of floating particles in the water, flocculant[28] could be used to induce particles to clump together and form larger particles (Waajen et al., 2018). These clumps can then settle or be more easily removed from the lake through filtration. The use of flocculent has a negative impact on macrofauna present in the lake shortly after application, but once lake conditions have improved due to the flocculant, macrofauna can recover and increase in numbers (van Oosterhout & Lürling, 2010; Han et al., 2021; Waajen et al., 2017).

Circulation pumps

To tackle the problem of anaerobic conditions, water circulation pumps could be considered, this would prevent stratification and facilitate water flow which will aid ecological measures taken in the upper parts of the water column to be more effective for the lower part of the water column.

Change in diving practices
Finally, from a practical point of view, a change or adaptation in diving practices could also help in solving the visibility problem. Prohibiting diving to the deeper parts of the lake for a prolonged period could aid in allowing particles to settle down without being disturbed through resuspension. This might lead to particles being compressed down and less likely to be resuspended. A different propelling technique for diving near the sediment could aid in reducing the resuspension through divers. This technique is easy to implement and would be beneficial regardless of other measures taken to improve visibility.

Relocation
Finally, relocation of the Aquavilla to a shallower part of the lake or even just a bit higher in the water column would be the measure with the highest certainty of improving diving quality.

6. Discussion

6.1 Limitations

As with any study, due to constraints in time and manpower, there are limitations that should be acknowledged. This will be discussed in the paragraphs bellow.

We haven't discussed all ecological solutions, and we were limited in the extent to which we could study the individual solutions. Therefore, this research won't be able to yield a total and definitive overview of the ecology and potential solutions also due to a lot of unknowns.

A major limitation in the study is that the exact source of the turbidity in lake Berendonck is unknown. It is known that turbidity is a problem, probably due to resuspension and algal bloom. Of which the algal bloom is a result of the nutrients present in the lake which are introduced into the lake by internal loading and nutrient inflow. The 2004 report (van Hal & Lürling, 2004) described this, but as this was over 20 years later, the current state of the lake is unknown.

To get a professional opinion and advise on each of the solutions it was planned to interview more experts. Due to the short time span of the project and experts being too busy or not interested in the end, we didn't interview as many people as we were hoping for. Therefore, the information provided by the two experts might be biased in the way that not all of variation of opinions in the population is covered and experts were not randomly drawn.

Due to the short timeframe of this project, weather conditions and other circumstances, only 2 dives have taken place. Those dives have yielded a limited amount of data, which has confined our understanding of the current ecological state of the lake. Thus, no concrete conclusions can be drawn from the data we have, and the specific ecological state of the lake is still unknown. However, this study served as a pilot study, to get at least some sort of idea on the status of the lake, to familiarize the divers with the protocol and to motivate them to keep going with the data collection. Therefore, by continuing with these observations with the updated protocol, a better understanding and more evidence of the species present can be obtained.

Observational data from divers and fisherman are at risk of species being misidentified, due to lack of knowledge, or overrepresentation. Observations by fishers for instance will mainly consist of fish that are, of interest to, and therefore caught by fisherman. This can yield biased estimation of the ecosystem; however, this was taken into account when interpreting the data.

In order to recommend specific source-oriented ecological solutions and identify their impact and feasibility, it is vital to get a better insight into the ecology of the lake, the visibility throughout the water column as well as how this changes throughout the year, and the nutrient load throughout the lake. Ultimately, no ecological system will ever be understood completely, but gaining knowledge on the distribution and abundance of key players in the ecosystem is essential to be able to support an ecological measure with a degree of certainty. Nevertheless, this research has provided a more detailed understanding of the general ecology of a freshwater lake and based on this knowledge provide some ecological solutions that could be used to improve water visibility.

6.2 Ethical aspects

There are several ethical aspects that need to be discussed related to this project. First of all, as mentioned previously, it has not been possible yet to find any other party involved with this problem that has the means to invest in the solution and take responsibility. The situation will probably lead into a conflict between the needs of the lake and divers and the unwillingness to get involved by the other parties with more power. It is a problem that most do not consider the lake to be in a problematic state and have a general mindset that we should not interfere with the current situation. Second of all, we need to make sure that every intervention we propose is still safe enough so that the divers can still dive in the lake, the fishermen can still fish and the there's no big impact on the adjacent recreational area. The adjacent golf course surrounding the lake also needs to be in agreement with whatever would be implemented if it would influence their land.

7. Advice

This report has been structured in a way where each solution has been studied on its own. Any ecological intervention likely affects the entire ecological web and its key players. Some of their interactions are explained in the discussion. Ultimately, to tip a lake from a turbid state into a clear water state, multiple solutions need to be combined to initiate a shift in the ecological regime. A resulting clear water state would be able to sustain itself if the stabilized ecosystem can support it.

This means that to restore the state of the ecosystem, several ecological solutions should be implemented together, as long as their effects have been studied in detail. Non-ecological methods might also be required to initiate a regime shift, after which the system could sustain itself if the ecosystem is in a healthy state (van Oosterhout & Lürling, 2010). The implementation of non-ecological methods combined with ecological methods is proven to be complementary (Han et al., 2022; Lürling et al., 2023).

Our advice for the commissioner is that an initial ecological intervention would be to provide substrate for freshwater mussels and sponges to grow and function as biofilter[8]. Based on literature study we expect freshwater mussels and sponges to be present in the lake, adding substrate could be an effective way to increase filtering capacity of the lake. Based on the survey and literature study, crayfish are expected to be present in high numbers in lake Berendonck which will need to be verified. When high numbers of crayfish are present in the lake, measures should be taken to reduce and actively control the number of crayfish.

Additionally, the following measures could be considered when the prior mentioned methods don't have the expected results. Aquatic plants could actively be planted in the shallower areas of the lake with appropriate light and oxygen levels. We don't recommend this immediately as it is likely that when visibility improves macrophytes will settle the lake by themselves. If it is proven from ecological surveys that carp are overrepresented in the lake, measures could be taken to actively control their numbers in order to keep the aquatic plants from being overfed on.

Finally, there are some solutions that we expect not to be very effective based on a limited amount of knowledge about the ecology and nutrients of lake Berendonck. We expect *Daphnia* to already be present in the lake, however if *Daphnia* or zooplankton in general is found to be underrepresented in the lake, captive breeding and release could be considered. Furthermore, we expect external nutrient inflow to be relatively small compared to the internal loading. However, if a study about the nutrients influx to the lake results in external loading being a considerable factor, ecological measures should be taken to decrease the external loading in the lake as well. These active measures can include working with leaf traps and studying potential deterrence and management of birds in the area.

The expected feasibility of the recommendations we have made is based on the limited amount of knowledge of the ecology and nutrient load of the lake. It is therefore important to emphasize that whereas some of these solutions seem promising, to implement any of these solutions more detailed study to this particular measure is required. An ecosystem is a complex web of interactions, any intervention in a system should be studied to determine whether such an intervention could have negative impacts on the ecological web of a whole.

When more information about the lake becomes available, the feasibility of solutions might change. Therefore, we provide the flow chart as a tool that can be used to assess which ecological measure might be worth pursuing. If there is interest in implementing any of these proposed solutions, any solution should be studied in more detail to gauge the impact, effects and feasibility of the particular solution.

7.1 Flowchart

Due to unclear cause of the problem, it is hard to find an effective solution. The only thing that is known is that the visibility is very poor Potential causes are outlined below in the flowchart, (Figure 25). For each possible cause of bad visibility, it suggests a solution that fits best. Bad visibility can result from various factors such as resuspension, algal blooms, limited aquatic plants, and high external loading. The Figure distinguishes between different solutions based on our advice and perceived importance. The most recommended solutions are indicated in dark green (remove crayfish and add substrate for mussels + sponges), followed by lighter green options. The grey boxes are considered to have a lesser impact on the problem but could still be a solution. In cases where there are multiple issues, such as resuspension and a lack of aquatic plants, multiple solutions may exist, but not all may be necessary to solve the problem. Further investigation is required for confirmation.

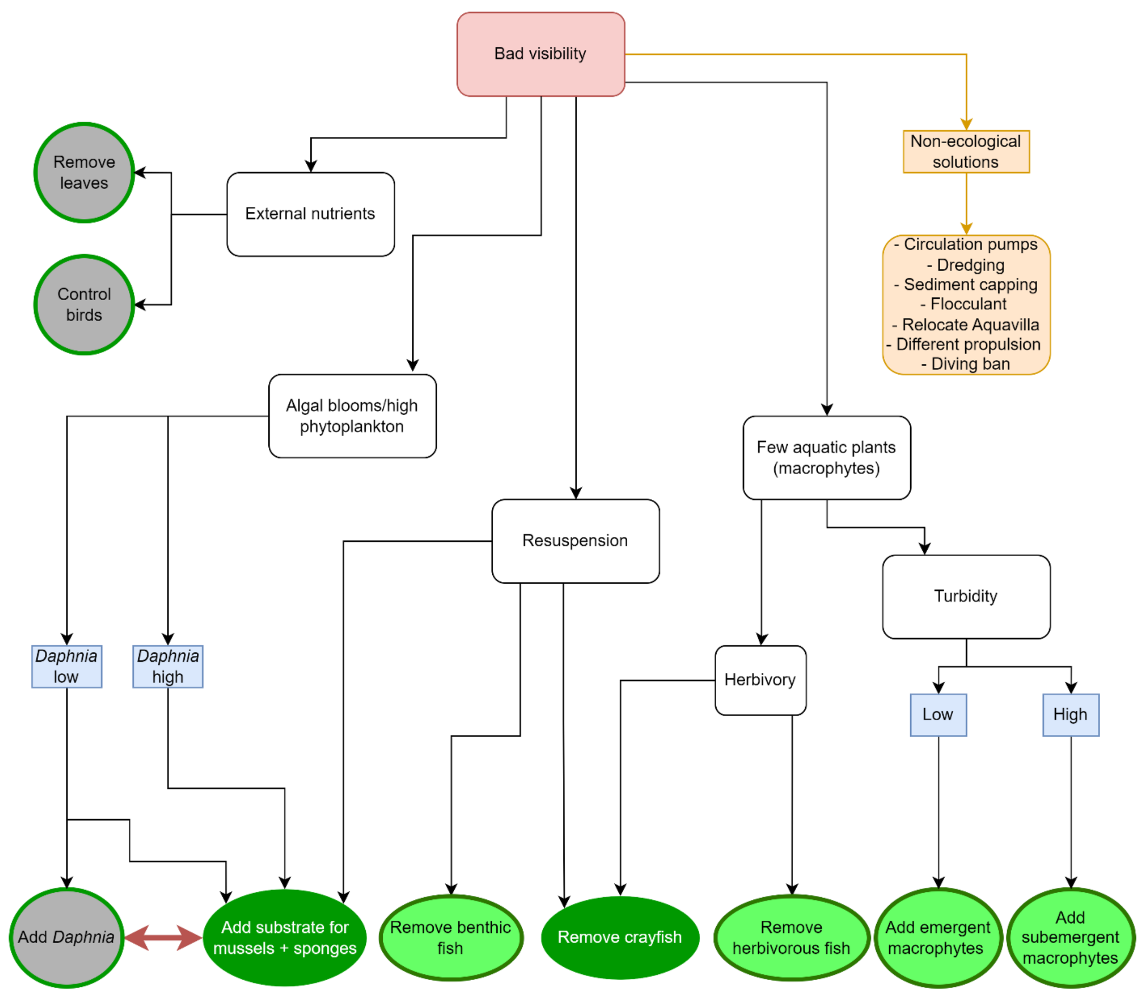

Figure 25 Flowchart illustrating potential solutions (varied shades of green and some in grey) corresponding to identified causes (in white boxes). Blue boxes signify a distinction between high and low problems. The red box denotes the known main problem. Dark green highlights our optimal solution, followed by other green solutions, and lastly, grey boxes are expected to have lower impact on the problem. In addition to ecological solutions, non-ecological alternatives are presented in orange. A red arrow from Daphnia to the mussels + sponges means that these solutions do not go together. A red arrow from Daphnia to the mussels + sponges means that these solutions do not go together. Herbivory[33] in the flowchart indicates organisms eating plants. Turbidity signifies large numbers of particles in the water. External nutrients refer to nutrients that are coming from outside the water, like leaves and bird poop.

7.2 Further study

Several times in this report we have mentioned limitations in specific knowledge about lake Berendonck. We recommend as following steps that the lake ecology and nutrient load should be studied in more detail. In addition, a detailed stakeholder analysis could be performed to better be able to assess the feasibility of any solution from a social and legal perspective. In the following paragraph we will briefly discuss information that could be collected that would help in getting a better insight into the specifics of lake Berendonck.

Ecology

We have provided a survey protocol that the divers could follow that gains better insight in the lake's ecology. For this, the more data the better. The survey will give an overview of the plants and fish species present in lake Berendonck. Although these results will not yield a total understanding of the ecosystem, it will help in understanding two key components: aquatic plants and fish. Just knowing their representations will help in understanding the state of the lake. Additionally, taking catch bias into consideration, information for fisherman about their catch would help in confirming / understanding the fish water type in lake Berendonck. Furthermore, insight into the number of crayfish in the lake, as well as the presence and abundance of freshwater mussels & sponges will help in understanding the current state of the lake. Just having a rough estimation of the relative abundance of key species in freshwater lakes will help a lot to assess the feasibility of potential solutions.

Resuspension

We know resuspension is a big issue in the deep parts of the lake, however ecological measures are difficult to implement in the deeper parts of the lake. Therefore, whether tackling the specific problem of resuspension is worth pursuing, the amount of resuspension in the shallow parts of the lake needs to be studied.

Algal blooms

More information on the severity of algal blooms needs to be available to judge the effects of this specific problem on the overall problem of turbidity. This could be done by measuring visibility in the shallow parts of the lake during the phases in summer when algal blooms occur.

Nutrients

To assess the level of eutrophication in the lake, the amount of nutrients in the water needs to be studied. To assess the feasibility of planting submerged macrophytes the nutrient load in the sediment of the shallow parts of the lake needs to be studied.

Stakeholder analysis

A problem that has become apparent from the stakeholder analysis is that there are no stakeholders that have high power and high interest in this specific case. This is an issue if the diving association wants to involve other stakeholders in the problem. To gain the interest of uninterested high-power stakeholders, it is recommended to do a more detailed stakeholder analysis that focusses on finding an issue that could help in gaining the interest of high-power stakeholders. Additionally, to assess the feasibility of making changes to an ecosystem from a legal perspective, this should be studied in more detail as well.

8. Conclusion

This report discussed lake ecology in general, specific information on Lake Berendonck and potential ecological solutions that could improve water quality. Ultimately, improving water visibility requires a shift from a turbid to a clear water state of the lake. This could be achieved by implementing and combining some of the discussed solutions. However, more knowledge on the ecology and nutrient load of lake Berendonck is required to assess the impact and feasibility of any of the proposed solutions. This report could be used to get a general overview of lake ecology, to introduce possible ecological solutions and to aid in the choice of which solution to pursue. Whereas the problem of turbidity in lake Berendonck is a complex problem, this report showed that there are several ecological measures that could be seriously considered to improve water visibility.

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Appendix 1: Definitions

1. **Algae:** A diverse group of photosynthetic organisms, ranging from microscopic to macroscopic size, algae have simple cellular structures and lack complex systems.

2. **Algal bloom**: Rapid growth of phytoplankton in water.

3. **Aquatic plants:** Plants have adapted to living in aquatic environments. They grow in or near water and are either emergent (out ofthe water), submergent (underwater), or floating.

4. **Biomanipulation:** Refers to management practices where often fish or plant species are deliberately removed from or added to an ecosystem to change it from one equilibrium state to the other (Shapiro, Lamarra & Lynch, 1975).

5. **Biomanipulation bottom-up:** Accessibility of nutrients for plants is limited, resulting in a decrease of their abundance, which in turn decreases the abundance of herbivorous animals (Jeppesen et al., 2012).

6. **Biomanipulation top-down:** The number of predators in the system is increased, resulting in a decrease of prey animals, which in turn, increases the abundance of their food (Jeppesen et al., 2012).

7. **Benthivore:** A fish or invertebrate that feeds on material located in or on the bottom of a water body.

8. **Biofilter:** Removal of organic particles from air or water.

9. **Bivalves**: Aquatic mollusks which have a compressed body enclosed within a hinged shell.

10. **Bryozoans**: Bryozoa with the common name "moss animals" are microscopic aquatic invertebrates that live in colonies and have tentacles used for filter feeding.

11. **Buffered lake**: High internal loading.

12. **Byssus threads**: Strong, silky fibers that are made from proteins used by mussels but also other bivalves to attach to certain substrates (Kennedy, 2021).

13. **Carapace**: The hard upper shell of a crustacean.

14. **Catchment area:** Area of surrounding ground of a water body that collects all the water after rainfall and ends up in it.

15. **Desiccation:** The elimination of moisture from something.

16. **Dredging:** Scooping up the upper (and most turbid) part of the sediment and removing this from the lake (Waajen et al., 2018; Lürling et al., 2023).

17. **Ecology**: The relationship between living organisms and their environment.

18. **Ecosystem**: Community of livings organisms and their environment.

19. **Ecosystem engineers**: Species that creates significant changes in a habitat.

20. **Emergent plant:** Aquatic plants that grow out of the water but have their root system submerged in the water.

21. **Ephydates**: Plants with floating leaves.

22. **Epilimnion:** The top water layer.

23. **Erosion**: Geological process in which earthen materials are worn away and transported by natural forces.

24. **Eulittoral**: Uppermost zone of the water column which is the section between the highest and lowest water level throughout the year.

25. **Eutrophic lake:** Are rich in nutrients, have abundant algae and plant growth, but oxygen levels can be limited in deeper layers due to increased organic matter decomposition (New Hampshire department of environmental sciences, 2019).

26. **Eutrophication**: Enrichment of water by a building up of nutrients, often from outside sources (Vollenweider, 1968).

27. **External load**: Nutrients being introduced into the water from an external source.

28. **Flocculant:** A substrate that stimulates the clumping of particles.

29. **Gemmules:** Are hard capsules with a spiky cover, containing totipotent cells, that can develop into different types, allowing sponges to face hard conditions and regenerate when conditions are suitable (Gost et al., 2023).

30. **Green algae:** Photosynthetic eukaryotic algae mostly living in freshwater that contain chlorophyll and use chloroplasts for starch storage.

31. **Helophytes:** Macrophyte that grows out of the water but has its root system submerged in the water.

32. **Herbivorous fish:** Fish that only eats plant material.

33. **Herbivory:** Act of eating plants.

34. **Hypolimnion:** Deeper water layer.

35. **Hypoxic:** A hypoxic zone is an area of low oxygen.

36. **Internal loading**: Nutrients being introduced into the water from the lake sediment.

37. **Keystone species:** Species that contribute to maintaining the ecosystem running. If this species would be missing from the ecosystem it would lead to substantial changes in the ecosystem and even could lead to disappearance of the ecosystem.

38. **Littoral:** A certain section of a water column.

39. **Macrophyte:** Aquatic plants that can be seen with the naked eye. These plants have adapted to living in aquatic environments. They grow in or near water and are either emergent (out of the water), submergent (underwater), or floating.

40. **Mesotrophic lake:** Have moderate nutrient levels, a moderate number of algae and aquatic plants and the oxygen levels vary, especially in deeper layers (New Hampshire department of environmental sciences, 2019).

41. **Metalimnion:** Water layer in between epilimnion (top layer) and hypolimnion (bottom layer).

42. **Oligotrophic lake:** Are characterized by limited plant growth, low nutrient levels, especially phosphorus and nitrogen, and the water is clear with low algal biomass. The oxygen levels are high throughout the water column (New Hampshire department of environmental sciences, 2019).

43. **Omnivorous**: Animals that are able to eat plant material but also animal material.

44. **Pelagic zone:** Open and free waters that are off the shore and were fish and other organisms are able to swim freely.

45. **Phytoplankton:** Photosynthetic plankton.

46. **Picoplankton**: fraction of plankton composed by cells between 0.2 and 2 µm.

47. **Piscicide:** Pesticide made to specifically kill fish.

48. **Piscivore:** A carnivorous animal that feeds on fish.

49. **Plankton**: Microscopic organisms drifting or floating in the sea or fresh water.

50. **Planktivorous fish:** Fish that primarily eat on plankton.

51. **Pseudofaeces**: Pseudofaeces are a specialized method of excretion that bivalves use in order to get rid of suspended particles which cannot be used as food.

52. **Resuspension:** The suspension and redistribution of previously deposited sediment particles in the water column due to a certain force.

53. **Rotifers**: Type of zooplankton.

54. **Sediment:** Particles that sink down in a liquid and settle down at the bottom.

55. **Sediment capping:** This process involves covering the contaminated sediment in a water body with a clean coat of materials or liner. For example, adding a layer of sand over the sediment (Waajen et al., 2018; Lürling et al., 2023).

56. **Stratification:** Is the division of different water layers with different temperatures. This happens when water becomes slightly less dense when warmed up. In lakes this means that during summer, the top water layer (epilimnion), that receives the most sunlight, floats on top of the deeper, cooler water layers (hypolimnion). The thin water layer in between these two layers is called the metalimnion (Zoetemeyer & Lucas, 2007; van Hal & Lürling, 2004).

57. **Sponges:** Are simple organisms without a central gut, nerve, or muscle cells (Lang et al., 2002). They are natural filter feeders living in freshwater or saltwater.

58. **Sublittoral**: Water column just below the shore.

59. **Submergent plant:** Aquatic plants that grow fully underwater.

60. **Substrate:** An object or surface where an organism lives and feeds from.

61. **Symbiont:** When two organisms are in symbiosis. Symbiosis means that two organisms are living in a state that is beneficial for both of them.

62. **Totipotent cells:** It is an individual cell that is capable alone producing a fertile adult individual (Gost et al., 2023).

63. **Trophic zone:** Position an organism occupies in a food web.

64. **Turnover period:** When the outside temperature in fall decreases, stratification of the lake stops, and the different water layers are able to mix again (van Hal & Lürling, 2004).

65. **Water column:** Concept of describing the characteristics of a water body at a certain geographical point.

66. **Zooplankton:** Microscopic plankton that feeds on other planktonic organisms.

Appendix 2: methodology

2.1 Survey approach

Related to the first sub-question (what is the ecology of the lake?) quantitative methodology was used. Our focus was on answering a few questions that are a part of the first sub-question: What types of fish live in the lake? And what is the composition of plants/algae in the lake? To unravel these questions, we asked the divers to perform an investigation. We set up a plan and a set of instructions in a protocol, made in a word document, to make sure every dive was done the same way (protocol can be found in appendix 5). Furthermore, an Excel document was created, with an overview of the potential fish species and an overview of the code of coverage of plants, along with a sheet for each dive, enabling divers to record their observations for each specific dive. This document can be found in the attached Excel file.

To facilitate the random points along the lake's shoreline, we initially created a grid map. This map was generated for the lake to illustrate the coordinates situated along the shoreline of the diving lake and the recreational lake. These coordinates were compiled in an Excel sheet, and utilizing the random function within Excel, 20 random samples were selected for both the diving lake and the recreational lake. In total, 40 random samples were collected to establish the locations where divers are required to conduct observations of the water. The divers, working in pairs, entered the water together at one of these designated points and followed a 50-metre rope. One person, acting as the navigator, guided the underwater path and was equipped with a compass and depth measuring device to determine the observation point's depth in the lake. The second person recorded each observation with corresponding depth on a board. When they encountered a fish, they wrote down the species and the depth of the observation on the board. For plant observations, they estimated the coverage of the plant species withing a 1 by 1 metre area. Every 5 metres, they took a picture of the board, their surroundings and observed plant/fish species. In the end, each dive resulted in 10 of these observations. After each dive, the divers analysed the photos taken and documented the coverage of plants/algae, encountered amount per fish species, visibility during the dive, and the depth per observation in an Excel sheet. This precise process allowed us to paint a detailed picture of the lake's ecology, identifying the various fish and plant species that inhabit its waters.

In the end the data was collected in the excel sheet by the divers. Unfortunately, due to not enough samples and problems with the experimental execution there was not enough data to be analysed. The divers will continue to record fish and plant species to gain a better understanding of the lake's ecology. In future projects, this data can then be analysed.

2.2 Interviews

Interviews were conducted to gain a better understanding of the second sub-question (What ecological measures that can be implemented to improve the visibility of the lake and what is their feasibility?) and the ecology of the lake. In preparation of each interview, an interview guide was formulated with all relevant questions. To optimize the interviewing process, it was decided that only two team members would conduct the interview with an expert. This was recommended during a methodology consultation meeting with Jurian Meijering, who is teaching sociology and knows how to do interviews. The interview guide, detailed in its structure and question overview, is provided in appendix 4. During the interview, one person was leading the interview and asked the questions, while the second person was taking notes but could also ask following up questions. The interview was recorded, but this was asked before the start of the interview.

Throughout the interview, one team member led the conversation, posing questions, while the second member took notes and also had the opportunity to ask follow-up questions. It is noteworthy that permission to record the interview was asked before its beginning. Subsequently, recorded interviews were transcribed.

2.3 Literature research

The qualitative methodology employed for this study involves literature research to address the sub-questions. To facilitate this literature research, platforms such as Google Scholar and the WUR library were utilized to maximize the breadth and depth of the literature review. Additionally, the snowballing technique and reports directly obtained from experts were employed to extract a comprehensive range of information. In the case of specific details about Lake Berendonck, stakeholders, and the social/legal environment, scientific literature was not available, but instead websites were used for this information. Initially, the team discussed potential solutions for the problem. Subsequently, each team member was assigned to a particular solution and tasked with locating scientific articles that provided insights, clarification, and delineated the pros and cons of the assigned solution. Following the obtained relevant articles, each team member independently reviewed and summarized the content of the respective articles.

Key words used, ranked per solution:

General:	Lake, solution, visibility, turbidity
Macrophytes:	Macrophytes; algae; water plants; phytoplankton; turbidity; submerged; emergent
Fish:	Phytoplankton; ecology; lakes in the Netherlands; resuspension; turbidity; eutrophication; biomanipulation; ecological impact; deep lake; the Netherlands; Western Europe; water quality; algivores; stratified lakes; benthivorous; herbivorous; piscivorous; algae
Sponges:	Sponges; porifera; freshwater; in the Netherlands; spongillidae
Zebra mussels:	Zebra mussels; filtering; turbidity
Crayfish:	Crayfish; lobster; Pacifastacus leniusculus; Astacus astacus; lake; ecosystem; controlling; management
Daphnia:	Daphnia; water fleas; zooplankton; turbidity; lake
Leaf:	Leaf; trap; eutrophication; lake; ecology
Birds:	Birds; nutrients

Appendix 3: Stakeholders

- **Leisurelands**: Leisurelands is the owner of the recreation area the Berendonck, including the lake where the Aquavilla is placed (*Recreatiegebied Berendonck*, 2023). They provide recreational activities such as water skiing and golfing. Due to their ownership, they are of big influence and their power is considered to be high. Their interest in the improvement of the visibility of the lake is considered to be somewhat low. Their interest is in the quality of the water, because the visibility is better in the other parts of the lake.
- **Diving club the Kaaiman**: Diving club the Kaaiman was founded in 1969 and has been the most active in lake Berendonck (*Onze Club – Duikteam de Kaaiman*, 2023). They placed the underwater house 'Aquavilla' in the lake to improve the diving experience in this lake. The Kaaiman has the most interest in the improvement of the visibility in the water, but does not have much power since they are limited to a certain budget and have to obey the rules that are set by e.g., governmental organizations.
- **Golf club**: The golf club which is located around lake Berendonck influences the lake as their drainage system is connected with the lake and thus is an important stakeholder in this system (van Hal & Lürling, 2004). Their interest in the improvement of the visibility of the lake is considered low because it does not bother the golf court itself. Their power is not considered to be high either.
- **Recreationists**: Recreationists around lake Berendonck include swimmers, hikers and people that come into the area to seek relaxation. Their interest in increasing visibility is considered low as these people are mostly in the other part of the lake. They are not considered 'high power' as the recreationists do not have the power to solve the problem.
- **Waterboard Rivierenland**: The waterboard has interest in keeping sufficient and clean surface water in the area between the rivers 'Lek' and 'Maas' including the municipality of Wijchen (Rivierenland, 2019). Their specific interest in the visibility of lake Berendonck is relatively low, higher in the quality of the water. Their power is considered high since they manage the waters in the area and have the power to change the water systems.
- **Municipality of Wijchen**: The municipality of Wijchen takes initiatives to improve areas that belong to the municipality, this may include lake Berendonck (*Projecten | Gemeente Wijchen*, 2023). Their interest in improving the visibility in the lake is relatively low, higher in the quality of the water. Their power is considered high since they have the power to take initiatives in these types of recreational areas. They should be kept satisfied when developing solutions for the improvement of visibility in the lake.
- **Dutch underwater sport association (NOB):** The Dutch underwater sport association (NOB) is a Dutch dive training organization, and their objective is to improve diving in the Netherlands and support dive clubs (*Missie En Visie*, n.d.). Their interest in the improvement of the visibility of lake Berendonck can be high, however they are not involved. Their power is considered to be in the middle.
- **Fishers:** The fishers are fishing in lake Berendonck and therefore are related to the quality of the water of the lake. If the visibility of the water in the lake increases, it is assumed that the fishers will have a benefit of that since probably the biodiversity in the lake will also change.
- **Province Gelderland**: The Province of Gelderland is concerned with the protection and restoration of multiple areas together with nature-based organizations (*Welkom Bij Provincie Gelderland*, n.d.). The province is considered to be of high power and low interest since they have many other things on their agenda. They should be kept satisfied when developing solutions for the improvement of visibility in the lake.
- **Natuur Wijchen:** The local nature society, they are committed to increasing the quality of nature in Wijchen (*Natuur Wijchen – Voor Een Mooiere Natuur*, 2023). This is mostly done through volunteer work, and sometimes, legal pursuit. Their interests in increasing water quality and biodiversity in the lake are higher than just water visibility. The power of the nature group is limited, but they can be a nuisance to governing bodies when they make changes that are not in line with the groups values.

3.1 Stakeholder Analysis

Figure 26 represents a stakeholder analysis. The stakeholder analysis tool is used for creating a matrix that describes the power of each stakeholder in relation to interest. This tool is used to help identify the stakeholder's involvement and interaction in the system of lake Berendonck. Each stakeholder is positioned on the gradient of the matrix, see Appendix 3 for a complete description of each stakeholder. Power in this analysis is defined as the 'Positional' power to change the situation at the lake and interest as the stakeholder's benefits in the improvement of the lake's visibility. During the project we will contact the following stakeholders: Diving club Kaaiman which is our most important stakeholder; the fishers for their ecological input; leisurelands for the legal and social input and Natuurgroep Wijchen for their previous input to the lake Berendonck and possible views for the future. Noticeable in the stakeholder analysis is the lack of stakeholders with a high power and high interest in this case. It is possible that this caused a challenge in solving the problem before, especially with finding responsible parties and financial help.

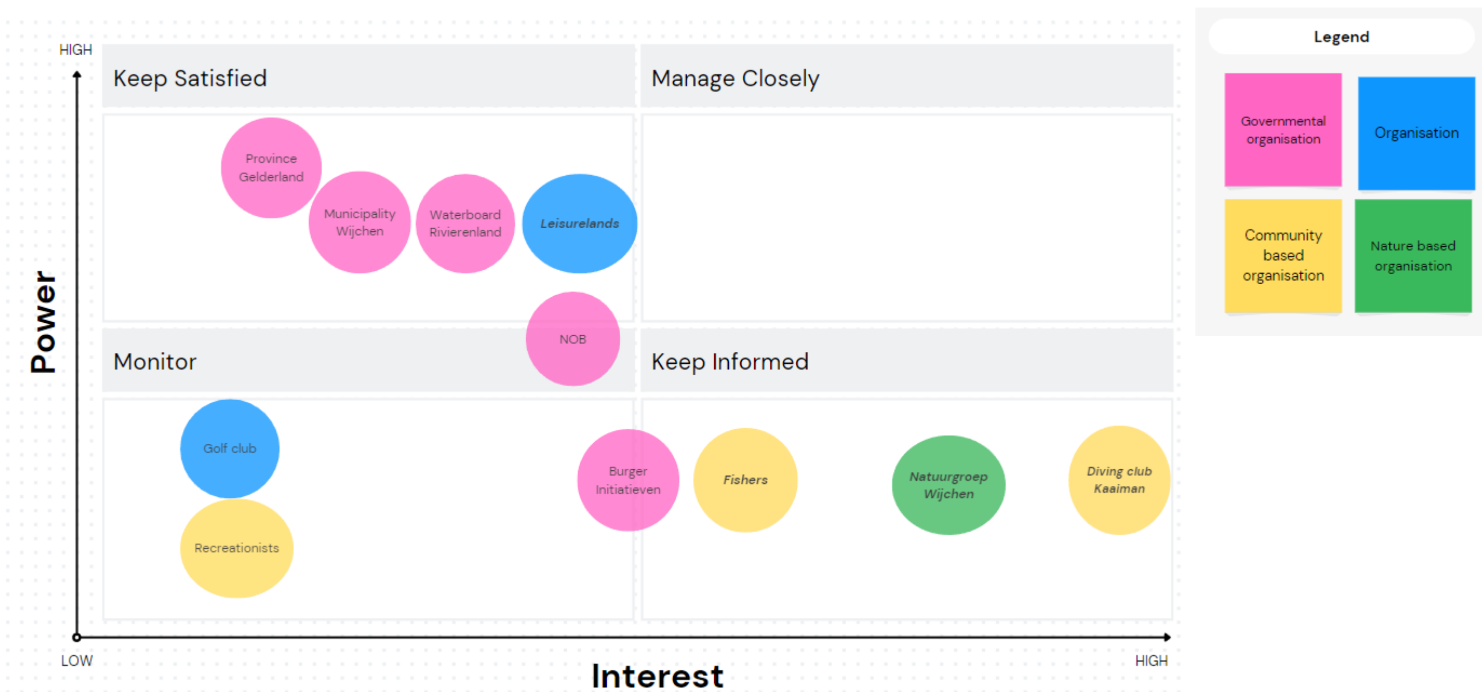

Figure 26 Stakeholder Analysis: Power vs Interest matrix on the lake Berendonck

Appendix 4: Interview guide

--Introduction--

Introduction:

- Thanking for your time and participation
- Introducing ourselves
- Purpose: gaining more knowledge about our project
- Role differentiation: I will ask the questions and "name" will help me with writing key words down and ask some questions that pop up.
- Time duration: 45-60 minutes
- Is it ok to audio record this interview?
- These recordings will only be heard and analysed by our research group.

Background:

- Introduce our project by explaining our research question and mention the sub-questions.
    - Poor water visibility
    - Stakeholders
    - Aquavilla

Research Topic:

Diving deep: improving underwater visibility for a pleasant and safe recreational dive in lake Berendonck.

Our Research question:

What ecological measures can be taken to sustainably improve the underwater visibility of lake Berendonck and what is their feasibility?

The Sub-questions are:

1. What is the ecology of the lake?

a. What is the structure of the lake and the catchment area?

b. What fish species are present in the lake?

c. What is the plant and algae composition in the lake?

d. What other factors influence the ecology of the lake?

2. What ecological measures that can be implemented to improve the visibility of the lake and what is their feasibility?

a. What are some of the potential ecological measures that improve water visibility?

b. What are the expected effects of implementing potential solutions on the ecology of the lake?

c. What is the feasibility of the potential solutions, taking the social and legal environment into account?

d. What is the feasibility of the potential solutions, taking the budget into account?

Explain what we are going to do:

- Looking from an ecological perspective
- Observing fish and plant species in the lake

---Start with the Questions---

Main questions:

Identifying the core issue in lake Berendonck:

- What would you identify as the main problem facing lake Berendonck?
- Regarding the plant and fish species in the lake, are there any specific interactions among them that can be crucial for the lake's ecosystem?

- Regarding the lakes tipping point do you think it has reached a point where the situation is not reversible through small measures but requires large interventions (such as dredging etc.) or is it still reversible? Especially taking into account, the lakes ecosystem.
- What impact do the different layers/zones have on the ecology of the lake? As it is small and deep.

Our ecological measures:

- Do you think our experimental setup will gain useful insight into the biodiversity in the lake?
- Do you have any suggestions on how to visualize the biodiversity in the lake?
- In terms of resuspension, do you think bottom stirring fish (such as bream) will have a high impact on resuspension or would divers have a bigger impact (assuming 1 dive per week)

Proposing optimal solutions:

- In your expert opinion, what do you think is the most effective solution to the problem in the lake?

Research experience:

- Considering your extensive research in various lakes, are there any successful case studies where similar water quality issues were effectively addressed?
- Are there any lakes comparable to lake Berendonck in terms of water quality that have undergone successful interventions?
- Are there specific challenges or unique characteristics in Lake Berendonck that make it different from other lakes you've studied?

Impact of events:

- In terms of the ecological impact, how do events like the Strong Viking and Emporium affect the lake?
- Are there any mitigation measures that could be considered?

<u>Follow up questions:</u>

1. Talk about the report 'Duikers in de mist' and relate those questions:

- In the summer months every week a monster, October November once per two weeks and the winter months till April once a month, why?
- Do you think much has changed in regard to water visibility and quality since the report in 2004.
- The report had quite some recommendations; do you feel like this report was already sufficient for the diving association. I.e. is there value in more study or is it more a case of the solution not being able to implemented from a financial point of view?
    - Considering a lot of time has passed since this report would you add anything to the list of recommendations to improve the lakes visibility?

--Ending--

- We have reached the end of the interview.
- Thank you for participating in this interview.
- Do you have anything to add?
- Explain what we will do with the recording: use it analyse and write down what have been said.
- Mention that the recording will be stopped now.

Appendix 5: Duikprotocol

5.1 Initial version

Het doel van deze duiken is het verkrijgen van een overzicht van de vis- en plantensoorten die tijdens de duik worden waargenomen. We vragen jullie om zowel in de duikplas als in de recreatieplas te duiken om eventuele verschillen in ecologische samenstelling tussen de plassen vast te stellen.

De duikplas en het zuidelijke deel van de recreatieplas zijn opgedeeld in kwadranten. Uit deze secties zijn willekeurige punten langs de kustlijn geselecteerd om een onbevooroordeelde inventarisatie van de verschillende soorten te verkrijgen. De duiken zullen plaatsvinden in buddy-paren, waarbij nauwe samenwerking wordt aangemoedigd om tot goede resultaten te komen. Idealiter worden de duiken op een dag evenredig over de twee plassen verdeeld, zo wordt voorkomen dat er een bias ontstaat tussen de meren die gebaseerd is op externe factoren zoals weer, temperatuur etc.

5.1.1 Stappenplan

1. Voor aanvang van iedere duik moeten verschillende constante waarnemingen worden genoteerd, waaronder de locatie, de datum, starttijd, en het weer. Onder het stappenplan is een overzicht te vinden van de betekenis van deze constanten.
2. Voor elk gekozen punt vragen wij jullie om van de oever af te duiken en daarbij de bodem te volgen.
3. Voor het uitvoeren van het onderzoek wordt een touw van 50 meter gebruikt. Het touw wordt dan vastgemaakt aan een stok of boom die dicht bij de oever staat.
4. Beide duikers gaan dan vanaf de oever af het water in, houden het andere uiteinde van het touw vast en zwemmen onder een hoek van ongeveer 90 graden ten opzichte van de oever. Duiker 1 zwemt dus aan de ene kant van het touw en duiker 2 aan de andere kant van het touw, beide duikers noteren de observaties aan hun eigen kant van het touw zodat observaties niet dubbel worden gedaan.
5. Tijdens deze duik is het de bedoeling om alle aangetroffen plantensoorten/algen en vissoorten van begin tot eind te noteren.
6. Indien mogelijk, lees de diepte tijdens de duik af van een apparaat en registreer per waarneming de diepte waarop elke gevonden plant, alg of vis zich bevindt.
7. Tijdens de duik kunnen de waarnemingen genoteerd worden op een schrijfbord of tablet naar keuze. Noteer uiteindelijk, na uit het water te zijn gekomen, de waarnemingen in een Excel bestand dat wij beschikbaar zullen stellen (vis- en plantsoortenformulier).
8. Als het mogelijk is, graag tijdens de duik ook een korte video of foto maken van het water en eventuele gevonden planten- en vissoorten.
9. Tijdens de duik moet er een schatting gemaakt worden van de horizontale zichtbaarheid in het water per observatie. In het aangeleverde excel bestand onder tabblad “Plantsoorten” zijn codes te vinden over hoe goed zichtbaar het water is. Als het zicht dus tussen de 0-1 meter is dan is dat code A.
10. Noteer vissoorten per waarneming, inclusief de vissoort, het aantal individuen en de diepte van de observatie.
11. Let op! Als een vissoort voor een tweede keer wordt waargenomen op een ander moment tijdens de duik, beschouw dit dan als een nieuwe waarneming.
12. Plant- en algensoorten zijn soms moeilijker te identificeren. Indien identificatie niet mogelijk is, deel deze waarnemingen in naar de mate van bedekking. De mate van bedekking is ingedeeld in 5 categorieën, zoals beschreven in het vis- en plantsoortenformulier. Doe dit zowel voor algen als planten.
13. Zwem door tot je het einde van het touw hebt bereikt. Voor sommige punten kom je niet verder dan 25 meter vanwege de overkant van het meer. Noteer in dit geval hoeveel touw is gebruikt om naar de overkant van het meer te komen.
14. Voor het invullen van het excel bestand let erop dat elk tabblad 1 duik is! Voor het gemak hebben wij alvast de eerste 6 duiken, in de duikplas, erin gezet. A betekent de duikplas (waar de aquavilla staat) en B betekent de recreatieplas.

5.2.2 Een overzicht van de betekenis van de constanten

- **Locatie**: Dit betreft de coördinaten van het geselecteerde punt, zoals aangegeven in het protocol, en geeft aan in welk van de twee plassen de duik plaatsvindt (duikplas/recreatieplas).
- **Datum en starttijd**: De datum en tijd waarop de duikers zich op de gekozen plek bevinden en beginnen met het noteren van plant- en vissoorten.
- **Weer**: Of het zonnig, bewolkt of regenachtig is, evenals de temperatuur en windsnelheid. Deze parameters kunnen worden opgezocht via een weerapp.

Het aantal uitvoerbare duiken tijdens ons project zal gelimiteerd zijn, echter kan dit protocol gebruikt worden in toekomstige duiken om een goed beeld van de onderwaterecologie te krijgen.

5.2 Updated version

Het doel van deze duiken is het verkrijgen van een overzicht van de vis- en plantensoorten die tijdens de duik worden waargenomen. We vragen jullie om zowel in de duikplas als in de recreatieplas te duiken om eventuele verschillen in ecologische samenstelling tussen de plassen vast te stellen.
In verband met regelgeving en bereikbaarheid mogen jullie zelf punten kiezen langs de oever die bereikbaar zijn. De duiken zullen plaatsvinden in buddy-paren of met drie personen, waarbij nauwe samenwerking wordt aangemoedigd om tot goede resultaten te komen. Idealiter worden de duiken op een dag evenredig over de twee plassen verdeeld, zo wordt voorkomen dat er een bias ontstaat tussen de meren die gebaseerd is op externe factoren zoals weer, temperatuur etc.

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2. Voor het uitvoeren van het onderzoek wordt een touw van 50 meter gebruikt. Het touw wordt eerst vastgemaakt aan een stok of boom die dicht bij de oever staat. Voor elk gekozen punt vragen wij jullie om eerst het touw van 50 meter uit te zwemmen (gewoon boven water, zonder metingen) in een hoek van ongeveer 90 graden ten opzichte van de oever.
3. Daarna zwemmen alle duikers naar beneden tot de bodem wordt bereikt en zich bevinden aan het einde van het touw.
4. Als er drie duikers samen werken, zorg er dan voor dat het voor elke duiker duidelijk is wat zijn/haar taak is onderwater. Zo kan een duiker zich bezig houden met de coordinatie van het volgen van het touw terug naar de oever, de andere duiker kan zich dan bezig houden met licht en camera en de laatste duiker kan dan de waarnemingen noteren op ee leibord.
5. Zodra elke duiker er klaar voor is begint het onderzoek. Het is dan de bedoeling dat alle drie de duikers het touw volgen via de bodem totdat de oever bereikt wordt.
6. Tijdens deze duik is het de bedoeling om alle aangetroffen plantensoorten/algen en vissoorten van begin tot eind te noteren.
7. Indien mogelijk, lees de diepte tijdens de duik af van een apparaat en registreer per waarneming de diepte waarop elke gevonden plant, alg of vis zich bevindt.
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codes te vinden over hoe goed zichtbaar het water is. Als het zicht dus tussen de 0-1 meter is dan is dat code A.

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12. Let op! Als een vissoort voor een tweede keer wordt waargenomen op een ander moment tijdens de duik, beschouw dit dan als een nieuwe waarneming.
13. Plant- en algensoorten zijn soms moeilijker te identificeren. Indien identificatie niet mogelijk is, deel deze waarnemingen in naar de mate van bedekking. De mate van bedekking is ingedeeld in 5 categorieën, zoals beschreven in het vis- en plantsoortenformulier. Doe dit zowel voor algen als planten.
14. Voor sommige punten kan je niet het touw uitzwemmen omdat je dan de overkant van de oever bereikt. Zwem in dit geval van de ene oever naar de andere oever via de bodem en noteer dat het niet de volle 50 meter zijn geweest.
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