Master Thesis
TVVR 22/5012

Analysis of the water quality dynamics of Lake Vomb

Interactions between water quality profile and cyanobacterial bloom in a eutrophic lake in Sweden

Wiebke Coenen

Division of Water Resources Engineering
Department of Building and Environmental Technology
Lund University

Analysis of the water quality dynamics of Lake Vomb

Interactions between water quality profile and cyanobacterial bloom in a eutrophic lake in Sweden

By
Wiebke Coenen

Master Thesis

Division of Water Resources Engineering
Department of Building and Environmental Technology
Lund University
Box 118
221 00 Lund, Sweden

Water Resources Engineering
TVVR-22/5012
ISSN 1101-9824

Lund 2022
www.tvrl.lth.se

Water Resources Engineering
TVVR-22/5012
ISSN 1101-9824

Master Thesis
Division of Water Resources Engineering
Department of Building and Environmental Technology
Lund University

Swedish title: Analys av vattenkvalitetsdynamiken i Vombsjön
English title: Analysis of the water quality dynamics of Lake Vomb
Author: Wiebke Coenen
Supervisor: Kenneth Persson
Jing Li
Examiner: Catherine Paul
Language: English
Year: 2022
Keywords: Vombsjön; Lake profile; Cyanobacteria; Drinking water; Random Forest

Abstract

Lake Vomb, located in Skåne, Sweden, provides water for groundwater infiltration, used for the drinking water supply of several municipalities, including Malmö. The lake is in a bad ecological condition with intense algae blooms during summer. Cyanobacteria dominate mentioned blooms in 2021 posing the threat of releasing cyanotoxins. The goal of this work is to asses the water quality dynamics to support the lake management. An approach to predict algae blooms and oxygen depletion to return the lake into a good ecological state and secure a long-term drinking water supply is investigated.

To assess the water quality, the profiles of the parameters pH, dissolved oxygen, and the water temperature was analysed for possible correlations with the abundance of algae represented by the chlorophyll-a concentration. Meteorological effects on the water quality dynamics were assessed. The availability of essential nutrients was evaluated by inspecting the phosphorous and nitrogen concentrations in the in- and outflow of the lake.

The pH value at the water surface showed the strongest correlation with the chlorophyll-a concentration during the summer. Besides seasonal patterns, wind and temperature fluctuations indicate a correlation with oxygen depletion. The possibility of phosphorous release supporting the algae bloom was found, but more measurements are needed to find the cause and possible preventative measures.

Random forest was used to predict the risk of high chlorophyll-a concentrations and oxygen depletion. The model shows potential, but more input data is needed to make significant predictions. Future research could focus on the regulation of phosphorous release and implementation of the phosphorous dynamic into the prediction model.

Abstract

Vombsjön, ligger i Skåne, Sverige, och ger vatten till grundvatteninfiltration, som används för dricksvattenförsörjningen i flera kommuner, bland annat Malmö. Sjön är i ett dåligt ekologiskt tillstånd med intensiv algblomning under sommaren. Cyanobakterier dominerar de nämnda blomningarna i 2021 och utgör ett hot om utsläpp av cyanotoxiner. Målet med detta arbete är att hitta en metod för att förutsäga cyanobakterieblomningar och hitta orsaken till syrebrist för att förhindra dessa och återföra sjän till ett gott ekologiskt tillstånd och säkra en långsiktig dricksvattenförsörjning.
För att bedöma vattenkvaliteten analyserades profilerna för parametrarna pH, löst syre och vattentemperatur för att se eventuella samband med algförekomsten, som representeras av klorofyll-a-koncentrationen. Meteorologiska effekter påvattenkvalitetens dynamik bedömdes. Tillgången till viktiga näringsämnen utvärderades genom att undersöka fosfor- och kvöavekoncentrationerna i sjöns in- och utflöde.
pH-värdet vid vattenytan uppvisade den starkaste korrelation med klorofyll-a- koncentrationen under sommaren. Förutom säsongsmönster visar vind- och temperatursvängningar påen korrelation med syrebrist. Möjligheten att fosforutsläpp kan stödja algblomningen har konstaterats, men det krävs fler mätningar för att hitta orsaken och eventuella förebyggande åtgärder.
Random forest användes för att förutsäga risken för höga klorofyll-a-koncentrationer och syrebrist. Modellen har potential, men det behövs mer data för att göra betydande förutsägelser. Framtida forskning skulle kunna inriktas påreglering av fosforutsläpp och genomförande av fosfordynamiken i prognosmodellen.

Contents

List of Figures

List of Tables

1 Introduction

Eutrophication is a global problem of inland waters that is anthropogenically enhanced (Rivas et al., 2020). It has been described as a complex problem to which the solution is dependent on multiple factors (Thornton et al., 2013).
Especially in the south of Sweden, the nutrient enrichment of water bodies is a problem (Naturvardsverket, unk). It is caused by excessive discharge of nutrients into the lake, for example, through agricultural run-off. Eutrophication can implicate algal bloom, which is especially problematic when it leads to oxygen deficiency and hence, loss of vegetation animal diversity or to enhanced growth of toxin-producing algae (Naturvardsverket, unk) like cyanobacteria.

Cyanobacteria can impact the environment negatively by causing instability in the ecosystem and producing toxic compounds (Drobac et al., 2013). Studies show that the uptake of cyanotoxins, both accidentally during water activities and through drinking water (Humpage and Cunliffe, 2021), can cause symptoms such as abdominal pain, vomiting and diarrhoea (Drobac et al., 2013). Mentioned health effects are widely reported; However, as of now, there is no evidence regarding the exact circumstances and the dose causing those effects (Humpage and Cunliffe, 2021).

Cyanobacterial bloom has been reported, for example, in lake Mazais Baltezers in Riga, Latvia, which is used to artificially recharge the groundwater to be used as a drinking water source. The analysis of the resulting drinking water shows that toxins can still be detected during the bloom period. This result indicates that the soil does not sufficiently protect groundwater. (dea Ric Eynard et al., 2000).

The presence of cyanobacteria does not necessarily pose a risk to public health. The toxicity depends not only on the cyanobacterial biomass but also on the taxonomic biomass.
Algae bloom (high biomass) prevails in a eutrophic environment. However, the relation between eutrophication and cyanobacteria growth is too complex to make a statement about the toxin risk. Eutrophic conditions can lead to lower numbers of certain species. Therefore, it is crucial to understand the environmental interactions leading to extreme proliferation. (Ibeligs et al., 2021)

This leads to the question of what critical factors are causing the proliferation of algae bloom and under which conditions dominate cyanobacteria.

How do the excessive algae bloom affect the variation of pH and dissolved oxygen concentration in the lake, and what effect does the water condition have on the availability of nutrients? Can any interactions be used as indicators to predict changes in the lake?

Lake Vomb is a flat lake (Alström et al., 2017) situated in Skåne, the southernmost region of Sweden. The lake water is used for drinking water production by infiltration into the groundwater through ponds (Alström et al., 2017). It supplies drinking water to the municipalities of Malmö, Burlöv, Svedala, Staffanstorp, Vellinge, and parts of Lund and Eslöv (sydvatten.se, 2021). As of 2017, the ecological status is considered to be unsatisfactory, presenting very nutritious conditions (Alström et al., 2017). The hypertrophic lake is rich in algae giving it an intense green colour in the summer months. Intense algal bloom can be observed in summer, during which algal toxins have been detected in the water (Alström et al., 2017). Blooms occur until early autumn (Li, 2020). In order to ensure a long-term drinking water supply, the water quality of Lake Vomb is of high importance.

Several projects are related to different aspects of the condition of Lake Vomb. Sydvatten, the local water supplier, started monitoring the vertical profile in 2014. During the summer month, water temperature, dissolved oxygen, conductivity and pH are measured. Kävlingeåns vattenråd, responsible for the condition of the river's catchment, performs a recipient control measuring phosphorous and nitrogen concentrations in the in- and outflow of Lake Vomb.

Furthermore, Lake Vomb is one of the case studies of the DiCyano project, a research project creating a digital platform for early warnings of cyanobacterial bloom. DiCyano provides this thesis project with sensor data on vertical concentrations of green algae, blue-green algae, diatoms and cryptophyta for autumn 2021. Satellite data over the past five years give information on chlorophyll-a on the water surface.

1.1 Objectives

As part of the DiCyano project, this thesis project contributes to a thorough analysis of lake profile data. It connects profile data with biological data such as algae groups and chlorophyll-a and the interaction with weather and nutrients data. The following points are being discussed.

- Sorting and analysing available data regarding the chemical condition, and oxygen depletion, respectively, in the lake as well as nutrient levels in the in- and outflow

- Analysing data for seasonal patterns and weather dependency
- Putting water quality and seasonal patterns into relation to cyanobacterial bloom

The compilation of a lake profile helps to find solutions to improve the ecological status of Lake Vomb to secure a long term drinking water supply. Achieving this entails supporting further analysis regarding the cause and prediction of cyanobacterial bloom and its toxicity. This study expects to improve the understanding of the stratification conditions, particularly the deepest part of the lake, which might lead to oxygen deficiency. Upon that, oxygen deficiency is expected to cause the phosphorous release from the lake bottom. Furthermore, a high abundance of nutrients is expected to, in turn, facilitate algae growth which then affects the water quality.
Overall, a cause and effect relationship between the water quality profile and algae bloom is expected.

1.2 Background

Lake Vomb is Sydvattens smallest water source (sydvatten.se, 2021) with a surface area of $12km^2$ at an elevation of 20m above sea level (Alström et al., 2017). The maximum water depth is 16m (sydvatten.se, 2021) with an average of 6,6m (Alström et al., 2017). The Kävlingeån catchment are consists of $447km^2$ (sydvatten.se, 2021) and contains mostly agricultural land (Alström et al., 2017). The dailiy extraction rate amounts to $1000l/s$ (sydvatten.se, 2021). The lake has a residence time of 1.04 years (Li, 2020). The lake has one major inflow, Björkaån. Further upstream of Björkaån is a waste water treatment plant. Additionally, two smaller streams, including Borstbäcken and Torpsbäcken enter Lake Vomb as shown on the map. Kävlingeån accounts for all natural outflow of the lake. Sydvatten regulates the outflow to ensure a stable water level that allows water extraction. The slide gate used can be opened at the bottom of the lake.

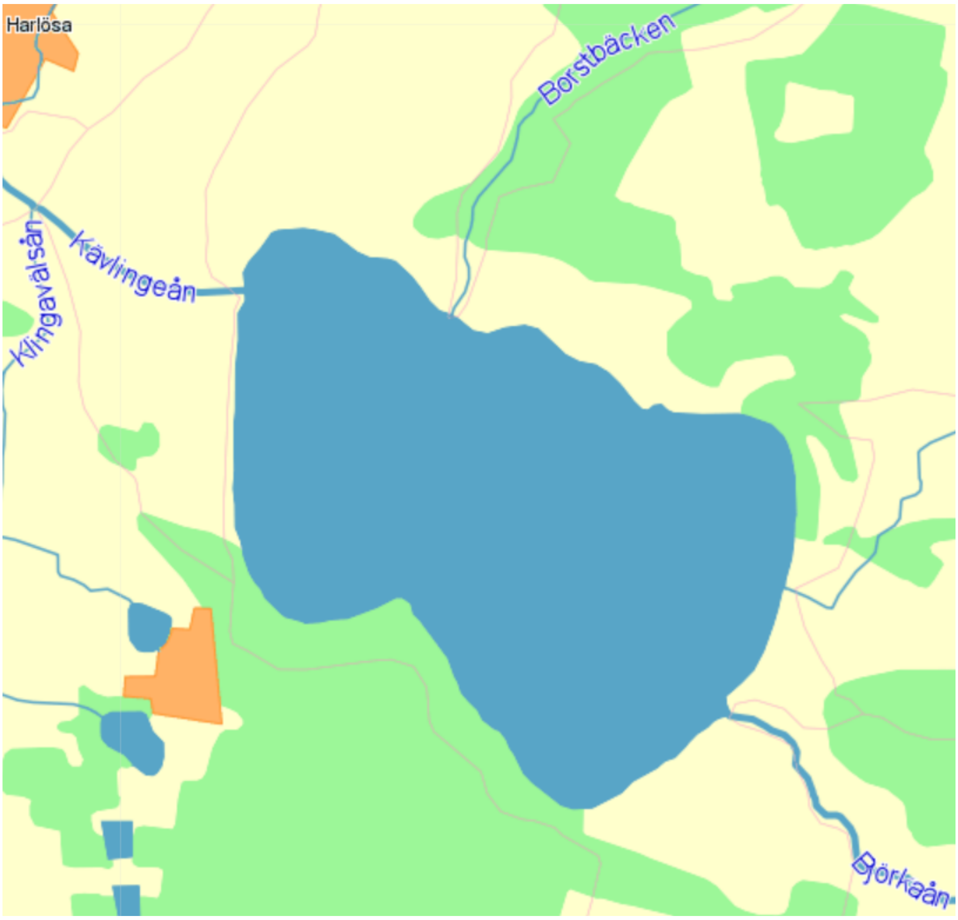


Figure 1: Lake Vomb with all its in- and outflows (SMHI); green indicates forest, beige indicates farmland and orange villages

Figure 1 shows that the catchment consists primarily of forest and farmland. The area south of the lake is mainly covered in a forest right up to the shoreline and farmland used for cultivation and grazing cattle.

2 Theory

To assess the water quality of a lake, the interaction between different processes needs to be understood. The assessment of the lake's condition includes seasonal patterns of temperature, oxygen, and nutrients, as well as factors favouring algae and cyanobacterial growth.

2.1 Limnology

Seasonal changes in the water quality can be influenced by the interplay between temperature changes and density variations at this altitude (Dodds and Whiles, 2010). The temperature distribution is affected by inflow, outflow, surface fluxes and the rate of vertical mixing (Imberger and Patterson, 1989).

In spring, the water is considered to be isothermal as a result of low air temperatures, which allows complete mixing (Dodds and Whiles, 2010). The surface layer is exposed to wind stress causing the water body to overturn (Imberger and Patterson, 1989).

Towards summer, the top layer experiences an increase in temperature, hence, decreasing the density, leading to a summer stratification since the layers of different densities can not be mixed by wind (Dodds and Whiles, 2010). In theory, the developing layers are defined as epilimnion describing the warmer upper layer, metalimnion containing the highest temperature gradient, and hypolimnion of colder water with higher density (Imberger and Patterson, 1989). This layering divides the lake into surface temperature, seasonal thermocline and bottom temperature (Imberger and Patterson, 1989). The bottom temperature is affected by cold inflows and the temperature of overturning but can be increased by vertical mixing (Imberger and Patterson, 1989).

When autumn arrives with cooler weather, the water temperature decreases and aligns with deeper water creating isothermal conditions (Dodds and Whiles, 2010). As the temperature decreases, the epilimnion deepens and allows mixing by wind (Imberger and Patterson, 1989).

Nevertheless, dissolved compounds, including salts released when sediments and organic matter are being decomposed, contribute to the stability of the density interface and can prevent the lake from mixing (Imberger and Patterson, 1989).

The depth of the epilimnion is an essential factor considering algal light availability because it influences the photosynthesis rate. Nutrient fluxes are another parameter influenced by the upper and theoretically well-mixed layer expansion. The water mass in contact with the atmosphere also determines the oxygen transfer. (Wilson et al., 2020)

2.1.1 Oxygen

The concentration of oxygen in a lake is an important parameter to provide information on its chemical condition. The saturation concentration of dissolved oxygen in a water body is dependent on the equilibrium concentration between water and atmosphere (Dodds and Whiles, 2010).

The balance of oxygen content between water and atmosphere is influenced by the water temperature; with decreasing temperature, the solubility increases (Wetzel, 2001b). At a temperature of 0°C, water can hold up to 14.6 mg/l of dissolved oxygen; at 30°C, this is already reduced to 7.6 mg/l. For good water conditions, the saturation should range between 60 and 120 percent (McCaffrey, 2000). A minimum of 5 mg/l of dissolved is necessary for fish to survive (Francis-Floyd, 2003).
Higher concentrations can remain dissolved in greater depths due to hydrostatic pressure (Wetzel, 2001b). Oxygen is added to the system through photosynthesis and can be hydromechanically distributed throughout a lake (Wetzel, 2001b). At the same time, the respiration of organisms and; however, to a minor degree, biotic and abiotic activities such as the oxidation of iron, ammonium and sulfide consume oxygen (Dodds and Whiles, 2010). The oxidation of organic matter is another oxygen reducing process (Wetzel, 2001b). As organic matter accumulates at the bottom of a lake, the oxygen consumption is highest at the sediment-water interface (Wetzel, 2001b).

During summer stratification, little to no photosynthesis takes place in the hypolimnion (Dodds and Whiles, 2010). The lack of photosynthesis leads to oxygen being present in smaller concentrations (Dodds and Whiles, 2010). Additionally, the ongoing occurrence of oxidative processes deplete the oxygen content further (Wetzel, 2001b). In eutrophic lakes, this can lead to the environment of the hypolimnion changing to anaerobic conditions during summer stratification (Wetzel, 2001b). During the fall overturn, when the epilimnion deepens and allows circulation, oxygen concentration can increase until they reach the saturation concentration (Wetzel, 2001b). Highest oxygen concentration during summer can be found in the metalimnion because the water at the surface increases in temperature leading to a reduction of solubility (Wetzel, 2001b).
The loading of many nutrients, including phosphorous is affected by the concentration of dissolved oxygen in the lake. A shift in nutrient availability can therefore be induced when the environment changes from aerobic to anaerobic (Wetzel, 2001b).

2.1.2 Phosphorus (P)

Phosphorus in lakes is mostly present in the inorganic form as phosphate, i.e. nucleic acids and lipids. Primary production is typically P-limited making phosphorus an important parameter to monitor. In the presence of oxygen, phosphate can precipitate with iron forming ferric phosphate, leading to sediment deposition. Another possible precipitation is with calcium to calcium phosphate (Dodds and Whiles, 2010). Organic-bound phosphate can also be found in sediment (Huang et al., 2005). High concentrations of phosphate and an alkaline environment, which can be enhanced by photosynthesis, can benefit this reaction. However, under anoxic conditions, for example, in the hypolimnion of a stratified lake, the formed precipitates dissociate, releasing phosphate back into the water. (Dodds and Whiles, 2010) The release of phosphorous is, moreover, affected by other factors. The pH level, redox potential, and the decomposition of organic matter are among those besides oxygen depletion. (Huang et al., 2005) Besides chemical and physical factors, the biology can impact the exchange of phosphorous too. The disturbance of sediment by animals called bioturbation can effect the environment. (Søndergaard et al., 2001)

2.1.3 Nitrogen (N)

Nitrogen is present in the aquatic environment as organic nitrogen is dissolved inorganic form. The former includes proteins, urea, amino acids and nucleic acids, whereas the latter typically refers to nitrate, nitrite and ammonium being the more biologically available forms. In a stratified lake, nitrate is primarily present in the epilimnion, whereas the hypolimnion contains ammonium. In streams, high ammonium levels can indicate pollution or the infiltration of anoxic groundwater. (Dodds and Whiles, 2010)
Nitrogen can be carried into a water body, for example, through fertilizers and atmospheric deposition. Removal happens as N_2 through denitrification, anaerobic ammonium oxidation, and when nitrate is reduced while oxidizing iron or manganese. Furthermore, sediments in an anoxic environment can detain ammonium. Under anoxic conditions, N_2 can be fixated as organic nitrogen. (Dodds and Whiles, 2010)

2.2 Eutrophication

Changes in natural circumstances, for instance, a reduced through flow or alterations of the water level, can cause lakes to reach a eutrophic state (Dokulil et al., 2010). Furthermore, an external supply of phosphorus and nitrogen can affect the stability of a lake (Prepas and Charette, 2003). Thus, eutrophic lakes are defined as having a high abundance of nutrients linked with a high production of organic matter(Wetzel, 2001b). Shallow lakes are particularly vulnerable to eutrophication (Qiang et al., 2013). Consequences of enrichment of nutrients include the reduction of the ecosystem's diversity (Qiang et al., 2013). The ratio between epilimnion and hypolimnion will likely move towards a stronger epilimnion. Lakes may shift their colour towards a green, yellow or brownish with limited visibility. (Cole and Weihe,

2015) This causes a steep light gradient and hence competition for mentioned resource (Ibeligs et al., 2021).

Further indications for a lake's eutrophic are low oxygen levels, and water blooms are common. (Cole and Weihe, 2015) Previous studies show that algal bloom is likely to happen when the ratio between nitrogen and phosphorous reaches a value of 7:1. However, the bloom of cyanobacteria can not be accurately predicted with this ratio. (Qiang et al., 2013).

2.3 Algae and Cyanobacteria

The overall function and eutrophical state of a lake can be assessed using algae as an indicator (Cole and Weihe, 2015). Algae involving processes affect the overall condition of a lake and serve as a food source (Ramaraj et al., 2013).

Algae conduct photosynthesis, removing carbon dioxide from the water and producing oxygen daily. This process leads to an increase in pH and dissolved oxygen concentration (Environmental, 2013).

When organic matter is degraded, carbon dioxide is released, having the opposite effect on the pH (Dean, 1999). Extreme values of pH can cause problems for the aquatic fauna. For freshwater, pH values should range between 6.5 and 8 (McCaffrey, 2000). Nevertheless, fish can survive in waters with a range of pH between 5 and 9 (Hach Company' H2O, 2007). However, oxygen is used to reduce the concentration of dissolved oxygen in the water body during decomposition.(Environmental, 2013).

Photosynthesis conducting algae contain chlorophyll-a (Ramaraj et al., 2013), which can be measured using remote sensing (Şeyma Merve Kaymaz, 2018), making it the most common proxy for the quantification of algae biomass (Ramaraj et al., 2013). Using this proxy comes with certain drawbacks. The concentrations of chlorophyll-a in cells differ between species (Ramaraj et al., 2013). Furthermore, the ratio of carbon to chlorophyll-a in algae is dependent on temperature and light level (Geider, 1987).

One very abundant and widespread species is the green algae, with more than 8000 freshwater species, including Chlorophyta (Cole and Weihe, 2015). Another species worth monitoring is the blue-gree algae (Cyanobacteria).

Blue-green algae (cyanobacteria) are plant-like organisms that conduct photosynthesis and possess chlorophyll-a (Vidal et al., 2021). Many different cyanobacteria taxa are present in the environment. They reproduce through cell division and form multicellular aggregates. Light energy and nutrients (particularly nitrogen and phosphorous) are essential for cyanobacterial growth. However, the bacteria has certain advantages in the competition with other algal phytoplankton over mentioned resources. (Ibeligs et al., 2021) This includes the storage of nutrients to an amount high enough for cell division. Another advantage is the ability to take up nitrogen in its molecular form and the form of nitrate, nitrite, ammonium, and urea. Certain species can fixate atmospheric nitrogen, and even taxa without this ability can benefit from this additional nitrogen input (Ibeligs et al., 2021). Another species worth monitoring is the blue-gree algae (Cyanobacteria) which can cause extensive blooms and threaten water safety and ecosystem services.

Blue-green algae can live suspended in water (plankton) or attached to surfaces (benthos). Some taxa are buoyant due to the production of aerotopes which are gas vesicles filled with air. (Vidal et al., 2021) This gives the bacteria an advantage in the competition for light. Since non-buoyant plankton sinks under calm weather conditions, buoyancy secures access to light. (Ibeligs et al., 2021)

3 Materials and Methods

Temperature, dissolved oxygen and pH condition are essential factors in describing water quality dynamics in a lake. A long term profile measurement project at a local water treatment plant, Sydvatten provides an excellent opportunity to understand spatial and temporal distributions of water quality changes. Besides, weather conditions that strongly affect surface waters' behaviour and seasonality are also included to study their correlation with water quality changes.

3.1 Data Sources

The data used in this study is provided by different projects related to Lake Vomb. The data is provided by Sydvatten, Kävlingeåns vattenråd (Vattenrad, 2022), DiCyano, and SMHI. DiCyano project (2020-2022) is a research and innovation project aiming to establish a digital tool for managing cyanotoxin risk in water. Lake Vomb is one of the case studies. The different data sets are described in detail in the following.

Data set 1 The first data set is part of Sydvatten's lake profile monitoring, and it contains vertical measurements from 2014 to 2021 at six locations in the lake. The location of the sites of measurement, as well as the corresponding depth, is shown in Figure 2.

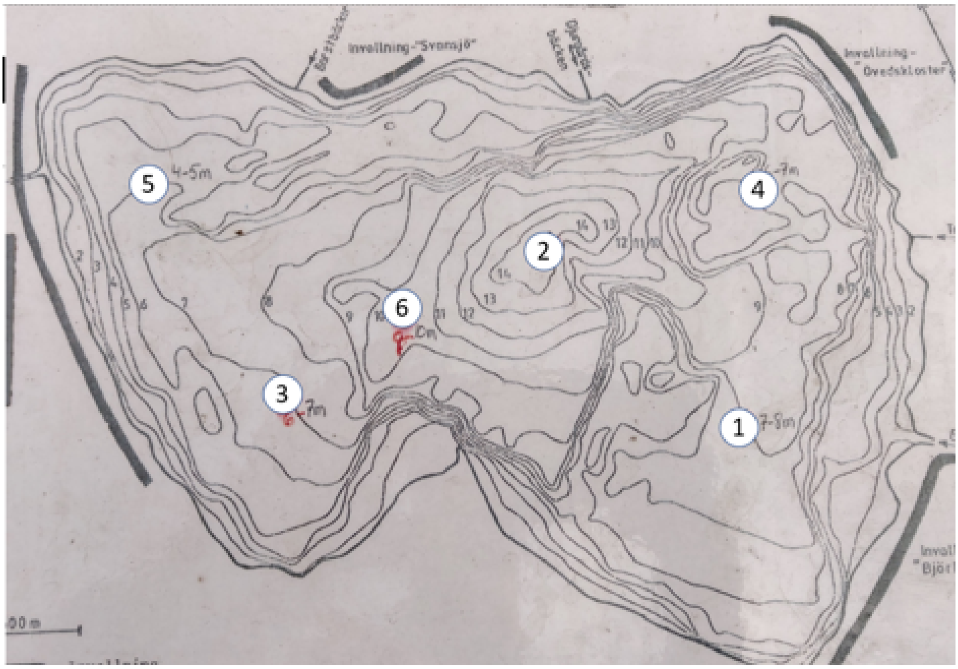


Figure 2: Locations of the measurement sites and the depths.

The exact coordinates and depths can be found in Appendix A.1. The coordinates of the measurement sites were changed slightly throughout the years.
Dissolved oxygen, pH, and conductivity, as well as the water temperature, were being measured. The frequency of measurements varies enormously between seasons and years, emphasising the summer months. Measurements were taken mid-morning, mostly between 8.00 am and 11.00 am, except for a few. In total, 8595 values are available.

Measurements have been carried out by different employees and summer workers with a change of device used in 2018. The parameters were measured using a sensor that was slowly let into the water from a boat, collecting data while being lowered to the bottom of the lake. Hence, the data obtained is affected by weather and wave conditions and the accuracy of the person performing the measurement. These errors are likely to have influenced the accuracy of the data obtained.

Data set 2 The second data set contains in- and outflow data of nitrogen and phosphorous. The locations of in- and outlets can be seen in Figure 1.

The outflow values of Kävlingeån are provided by Kävlingeåns vattenråd as part of their recipient control. It contains information on the phosphorus and nitrogen concentration and the dissolved oxygen concentration and pH from 1004 till November 2021. The parameters were measured once a month between the 6th and 30th of each month but most often on the 14th. In 2007 no measurements were taken between August and December, and values for those months were interpolated using the moving average. In 2021, Kävlingeåns vattenråd recipient control report also contained a few measurements for the total phosphorous concentration at the surface and the bottom of the deepest location in the lake for a few days throughout the year.

The inflow data for the main inflow Björkaån, Borstbäcken and Torpsbäcken (Figure 1) are simulated values obtained from SMHI. The discharge into Kävlingeån is also based on simulated values from the same source. The data sets contain monthly values from 2004 to 2020 for discharge, nitrogen and phosphorous mass flow, and sediment transport.

Data set 3 The third data set contains satellite data taken by "Brockmann Geomatics" and provided by DiCyano (www.dicyano.com). The Data is available from 2016 to 2020 and has a timestamp between 9.00 and 10.00 am. It contains almost daily concentrations in µg/l of chlorophyll-a.

The satellite used was Sentinel-3a, launched in 2016 and has generated data since then. A twin satellite, Sentinel-3b, was launched in 2018. Both satellites overpass Sweden every day with a time-lapse of approximately one hour. The measurements of both satellites differ due to changes in local water and weather conditions.
The satellite measures the reflection of sunlight, and several water quality parameters can be derived from that. Depending on the transparency of the water, the depth to which the light enters before being scattered back differs. This depth can be influenced by, for example, cyano blooms.
The data from Sentinel 3a is available from 2016 to 2020 and has a timestamp between 9.00 and 10.00 am. Values are available for the exact six locations, as shown in Figure 2.

Data set 4 The DiCyano project contributes with a field study in Lake Vomb about different algae species measurement during autumn 2021. This study is included to see if the composition and content of algae groups are significantly different for those 6 locations. The concentrations of green algae, blue-green algae, diatoms, and cryptophyte throughout the depth were

measured using the ”FluoroProbe” sensor by ”bbe”.
The measurements were taken between 8.00 am, and 10.00 am from a boat, implying the same effect of weather and wave conditions on the measurement.

Meteorological data Weather data like precipitation, air temperature and wind speed were used from SMHI with a measurement site in Hörby located about 25 km north-north-east of Lake Vomb.

3.2 Data analysis

The analysis conducted between the different data sets is diagrammed in the following Figure.

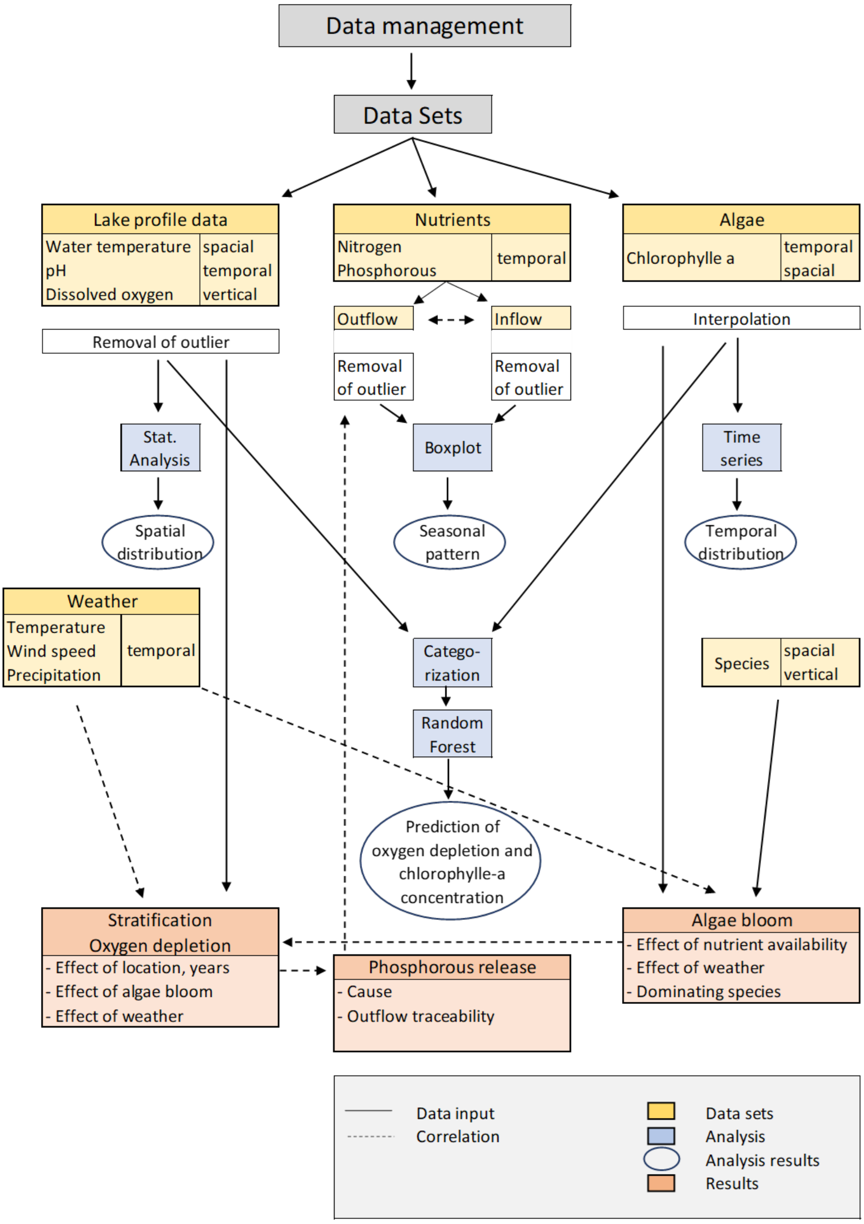


Figure 3: Methodology

The first step of the analysis conducted for this project is the comparison of the different measurement locations. This comparison is made by looking at the development of thermoclines and oxygen deficiencies, and both conditions are likely to show a substantial effect on other processes in the lake. The significance of the differences is tested with the person-chi square test.

Afterwards, the most affected locations are further investigated about their temporal differences. This differentiation is done to understand the influence of external factors such as the weather and helps narrow down the focus of the analysis. The occurrence of both thermocline and oxygen deficiency is then analysed for correlation with the meteorological data.

Furthermore, the concentration of both nitrogen and phosphorous in in- and outflow of the lake is tested for seasonality and trend. Since an oxygen deficiency at the bottom of the lake can cause a release of phosphorous, the relationship between outflow concentration of total phosphorus and oxygen concentration at the bottom is being looked at.

To make a statement of the lake's condition in regards to algae bloom, which is indicated by the concentration of chlorophyll-a , the concentration of chlorophyll-a is analysed for a seasonal pattern. Since phosphorous is typically the limiting factor to algae growth, the nutrient concentrations in the inflow to the lake in regards to algae bloom are being looked at. The weather data is also explored because algae need light to conduct photosynthesis. Algae take in carbon dioxide during the day and produce oxygen, making it likely for algae bloom to affect the water condition; hence, the profile data is tested for correlation with an algae bloom.
Since the chlorophyll-a concentration only gives information about the overall abundance of algae but not the percentage of cyanobacteria, the measurements taken in autumn 2021 are evaluated on the distribution of cyanobacteria.

Lake Profile .
The given data set is cleaned, and flawed data are excluded from the analysis. Data excluded includes measurements that give higher depths than recorded, measurements that were commented with problems with the device, and measurements containing outliers.

Water temperature, dissolved oxygen concentration, and pH values are visualised for each summer and location using RStudio. Since the data is irregularly distributed, the Akima method for bivariate interpolation was used. The interpolated values are interpolated without taking other conditions into account, and effects of weather and other external effects are not reflected in that interpolation.

Furthermore, the "rLakeAnalyzer" package in RStudio is used to determine the depth and occurrence of thermoclines. A thermocline is a temperature gradient higher than one °C over a one-meter depth. The occurrence of a thermocline and/or an oxygen deficiency, defined by a dissolved oxygen concentration below two mg/l, is plotted with the corresponding meteorological data. The Spearman test evaluates the correlation between parameters over the depth and meteorological data. The maximum temperature over the previous three days is included in this analysis to account for a time lag in the reaction of the water body to outside temperature changes.

Nutrients in in- and outflow .
Outliers in this data set were identified and replaced with interpolated values using the moving average. In- and outflow data is analysed using the "seasonal" package in RStudio to test for seasonality. The time series from 2004 to 2021 is detrended and then analysed for seasonal patterns. Additionally, a time series is plotted to see the temporal distribution.
Concentrations of phosphorous and nitrogen are plotted for in- and outflow to see if an increase of concentration in the inflow goes along with an increase in the outflow.
Additionally, a time series is plotted to see the temporal distribution.

Algae bloom .
The frequency of the chlorophyll-a concentration measured by the satellite is highly dependent on weather conditions since only clear days provide data. For this reason, missing values are interpolated with a moving average.
The chlorophyll-a concentration is plotted as a time series to visualise the temporal distribution. With the Spearman test, the data is tested for correlations with meteorological data based on daily values.

Correlations .
Besides the analysis for correlation between weather data and the profile data, chlorophyll-a, further correlations between the data sets are tested.
The concentration of dissolved oxygen at the bottom of the deepest location of the lace is plotted together with the concentration of phosphorous in the outflow and tested for correlation with the Spearmen test.
The chlorophyll-a concentration is plotted and tested, with the Spearman test, for correlations with the concentrations of nitrogen and phosphorous in the inflow. For this possible correlation, an average of hlorophyll-a over the month is calculated to match the available simulated inflow data.

Categorization .

A random forest model predicts the influence of different factors on the development of oxygen depletion. The dissolved oxygen concentration is divided into the two categories shown in Table 1. Category one is defined as an oxygen deficiency, whereas category 2 is already the lower limit of the recommended concentration for freshwater since it can be problematic for fish (Francis-Floyd, 2003).

Table 1: Categorization of the dissolved oxygen concentration into category one for depletion and category two as threshold for fish survival.

Category	Dissolved Oxygen [mg/L]
1	≤ 2
2	≤ 5

Furthermore, the profile data at one-meter depth is used to predict the concentration of chlorophyll-a. According to the World Health Organization chlorophyll-a can be used as an indicator for cyanobacteria. The chlorophyll-a concentration is categorised into alert needed and no alert needed as shown in Table 2.

Table 2: Alert levels for the cyanobacterial biomass indicator chlorophyll-a. (Organization, 2020).

Alert level	Chlorophyll-a [µg/L]
Level 1	1
Level 2	12
Recreational use	24

The Spearman rank correlation is applied to see the relationship between different parameters. A significance level of 0.05 is used in this analysis. The parameters do not follow a normal distribution, but the input values are ranked for a Spearman rank correlation, which means that this coefficient does not expect normality. The Spearman coefficient gives information about a monotonic correlation, and the correlation only shows if data co-varies but not the directionality to see which leads and which follows.

Random forest is used to predict the categorized data of oxygen depletion and high chlorophyll-a concentration.This machine learning tool in RStudio takes 70 percent of the given data to train the decision trees of

which the majority vote give the prediction. The result is then tested on the remaining 30 percent as validation. Using 70 percent for training has proven to be sufficient in other studies and leaves enough values for validating the results.
For the accuracy statistics for this model a confusion matrix is used.

Table 3: Confusion matrix.

	Actual yes	Actual no
Predicted yes	true yes	false yes
Predicted no	false no	true no

Furthermore, the sensitivity, specificity, and accuracy of the predicted values for the validation sample are calculated. Sensitivity gives the proportion of correctly predicted positives and specificity for negatives, respectively (Prabhakaran, 2017).

$$Sensitivity = \frac{true\ yes}{true\ yes + false\ no} \tag{1}$$

$$Specificy = \frac{true\ no}{true\ no + false\ yes} \tag{2}$$

Sensitivity is more important when predicting the positives is of higher importance than classifying negatives. This specification plays a role in terms of risk factors were giving a false positive is better than a false negative (Prabhakaran, 2017).
The following equation gives the accuracy of the model:

$$Accuracy = \frac{true\ yes + true\ no}{true\ yes + true\ no + false\ yes + false\ no} \tag{3}$$

The accuracy gives the percentage of the overall correctly predicted events (Prabhakaran, 2017). To take into account the chance of randomly guessing the correct answer Cohen's Kappa is calculated as follows:

$$\kappa = \frac{p_0 + p_\mathrm{e}}{1 - p_\mathrm{e}} \tag{4}$$

In this equation p_0 is the accuracy and p_e the agreement. The agreement is the sum of the products of the percentage of predicted yes' and actual yes' and noes, respectively.
This indicator takes into account the possibility of randomly agreeing with the classifier. This value ranges between 0 and 1, with 1 representing a good agreement between predicted and actual events (Widmann, 2020).

4 Results

Results from the described analysis are presented below. All datasets are visualised graphically, and figures not presented in the following can be found in the Appendix.

4.1 Lake profile

The lake profile is analysed for spatial differences within the lake and the effect of weather on the condition. The comparison is made by looking at stratification and oxygen depletion development. The statistics of the overall available data are shown in Table 4. The statistics separated for each year and each location for the surface and the bottom layer can be found in Appendix A.2.1.

Table 4: Statistics of profile data (2014-2021).

Parameter	min	max	mean	median
pH	5.2	9.4	8.5	8.6
DO [mg/l]	0	18.8	8.5	8.7
Temp. [°C]	3.5	25.0	18.0	18.8

The average pH value throughout summer is above the recommended value of 6.5 - 8 for freshwater (McCaffrey, 2000). Fish, however, can still survive at pH levels between 5 and 9 (Hach Company' H2O, 2007). The pH value can vary due to photosynthesis (McCaffrey, 2000).
The dissolved oxygen concentration is strongly dependent on the water temperature, and values below five °C can be harmful to fish (Francis-Floyd, 2003). Lower dissolved oxygen concentrations are prevalent in the deeper parts of the lake, and low oxygen concentrations can be the reason for releasing phosphorous from the sediment.

4.1.1 Spatial distribution

To see the spatial distribution of the development of a thermocline and/or an oxygen deficiency, parameters such as pH, temperature, and dissolved oxygen are plotted. The graphs for each measuring site as profiles and all measured years can be found in Appendix A.2.2,refoprofile and A.2.4. Furthermore, the percentage of days during which a thermocline or an oxygen deficiency occurred over all measurements is calculated and is shown in the Appendix A.2.1.

The significant dependence on the location regarding thermocline and oxygen depletion is visible. Comparing the six different measurement locations, it can be said that site two is the most affected regarding oxygen deficiency. This can be explained by it being the deepest part of the lake. Being the second deepest location in the lake, site six is the second most affected by oxygen deficiency.
In site five, only very few oxygen deficiencies have been measured. The proximity to the outlet is likely to cause better mixing of the water body.

Additionally, it is the second most affected after site three by thermoclines. Site three shows the highest likelihood of developing a thermocline. Its location in the lake could cause this. The area south of the lake is covered with forest, reducing the impact of wind and reducing the overturn of the water body. The lake's shape might increase this effect since the water is more stagnant in this part of the lake.

To see a more distinct difference between the locations and the years, the maximum, minimum, and means of the profile data at the bottom and the surface for each year at each location are presented in Appendix A.2.1. The bottom and the surface show the highest variation and are presented separately. The mean of each year is difficult to compare since a different amount of measurements was available, leading to a single extreme value having a different impact on the average.
Most values are relatively similar between the different sites; however, the dissolved oxygen concentration at the bottom of the lake tends to be the lowest at location 2. The same can be said about the min pH at the bottom. Comparing different years, looking at the years 2017 and 2018, it can be seen that both max. pH and the max. concentration of dissolved oxygen is higher at all locations, except 4 and 5, in 2018. The min. pH at the bottom of the lake, on the other hand, is lower in 2018 except in location 5. Another year with deficient dissolved oxygen levels at the bottom of the lake is 2016.

4.1.2 Effect of meteorological data

The thermocline and oxygen deficiency analysis shows that over several years, particularly the year 2017, temperature changes seem less affected and, hence, the development of a thermocline and oxygen deficiency. The year 2018, on the other hand, shows a higher occurrence of both in comparison to the other years. The influence of the weather could cause this. Figure 4 shows the maximum daily air temperature from 2014 to 2021 measured in Hörby.

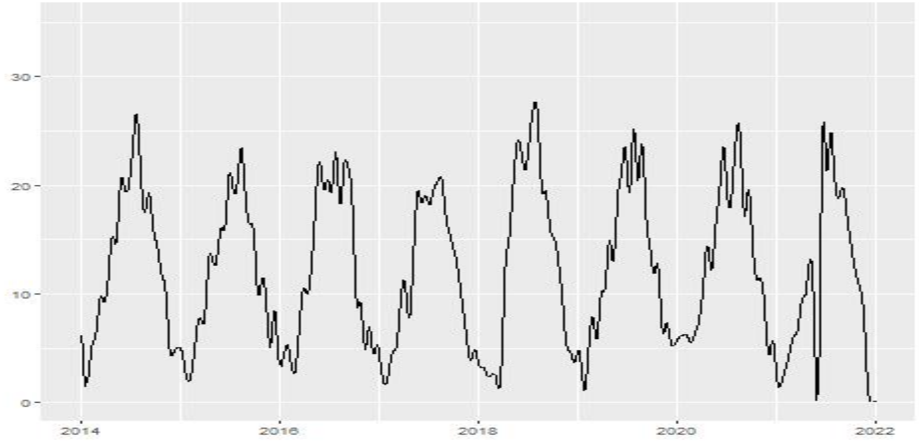


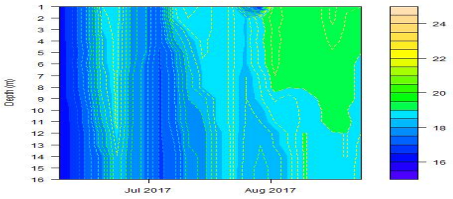
Figure 4: Maximum daily air temperature in Hörby (SMHI) in °C form 2014 to 2021

Looking at the meteorological data, the summer of 2017 was frigid, whereas the summer of 2018 was hot. This difference indicates the influence of weather on the water condition.
Since sites 2 and 3 are affected by water quality changes and the years 2017 and 2018 show the most significant differences, a focus is put on mentioned measuring locations and years.

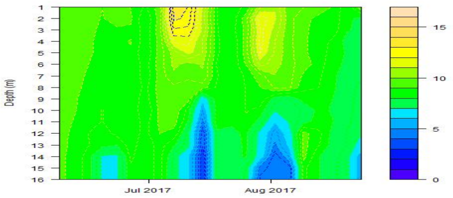
The temperature profile, the pH, and the concentration of dissolved oxygen in site two are shown in Figures5 and 6 for 2017 and 2018. The same profiles are shown for site 3 in 2018 in Figure 7.

Figure 5.a shows the temperature regime over the lake's depth at the deepest location in the summer of 2017. The top layer of the water body warms up for a short time during two events in late June and July. Only in August does the temperature increase stay for longer and reaches lower into the water body.

(a) Temperature Profile 2017 [°C]



(b) Dissolved Oxygen Profile 2017 [mg/l]



(c) pH Profile 2017

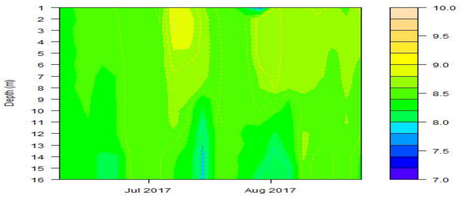
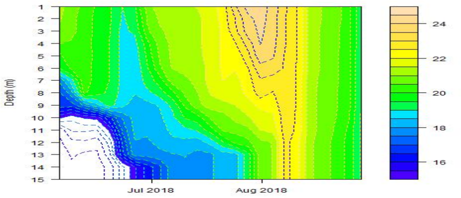


Figure 5: Profiles Site 2 in summer 2017 interpolated based on measurements taken by Sydvatten

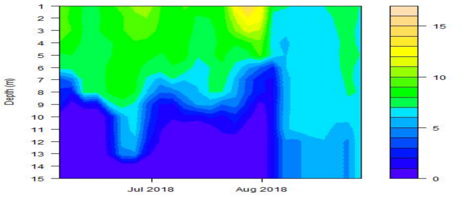
As the data shown (Figure 5.b), the concentration of dissolved oxygen shows two events with an increase at the surface followed by a decrease in the bottom layer in mid-July and early August.
As visible in Figure 5(c), the pH follows a similar pattern close to the surface as the dissolved oxygen concentration. Only the increase in late summer stays for longer, and the bottom layer seems less affected.

In 2018 the water temperature in site two warmed up in early August (Figure 6.a). This temperature increase follows through to the bottom of the lake, and overall the water temperature is higher compared to the previous year.

(a) Temperature Profile 2018 [°C]



(b) Dissolved Oxygen Profile 2018 [mg/l]



(c) pH Profile 2018

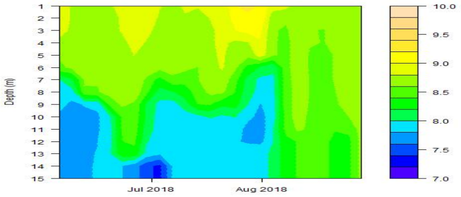
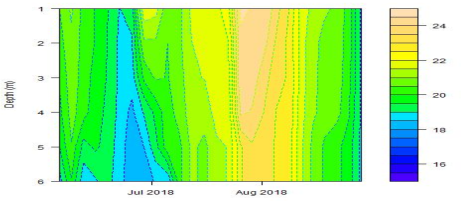


Figure 6: Profiles Site 2 in summer 2018 interpolated based on measurements taken by Sydvatten

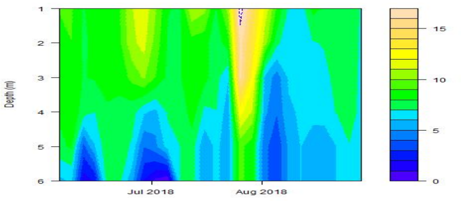
The oxygen level is low in the deeper layer of the lake and does not increase until the water temperature decreases in mid-August.
The pH shows a similar pattern to the concentration of dissolved oxygen. In comparison to the previous year, the pH is visibly less homogeneous. This behaviour can be seen for all three parameters.

In comparison, Figure 6 shows the summer of 2018 at location three. The temperature increase is visible to reach deeper into the water body, heating almost the entire depth for most of the summer.

(a) Temperature Profile 2018 [°C]



(b) Dissolved Oxygen Profile 2018 [mg/l]



(c) pH Profile 2018

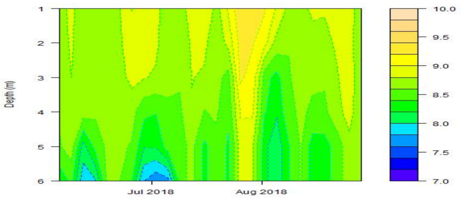


Figure 7: Profiles Site 3 in summer 2018 interpolated based on measurements taken by Sydvatten

The oxygen concentration in the bottom layer is not as strongly affected. Again, the pH follows a similar regime as the dissolved oxygen.

To illustrate the influence of meteorological data, the summers of 2017 and 2018 with the occurrence of a thermocline and an oxygen deficiency ($< 2mg/l$) are shown in Figures 8 and 9. The graph shows the maximum daily air temperature, maximum daily wind speed, and daily precipitation. For each site, the points in time taken measurement are indicated by a dot; a downwards line indicates that an oxygen concentration below two mg/l has been measured. An upwards like represents the occurrence of a thermocline. The graphs for the remaining years between 2014 and 2021 can be found in Appendix A.2.5.

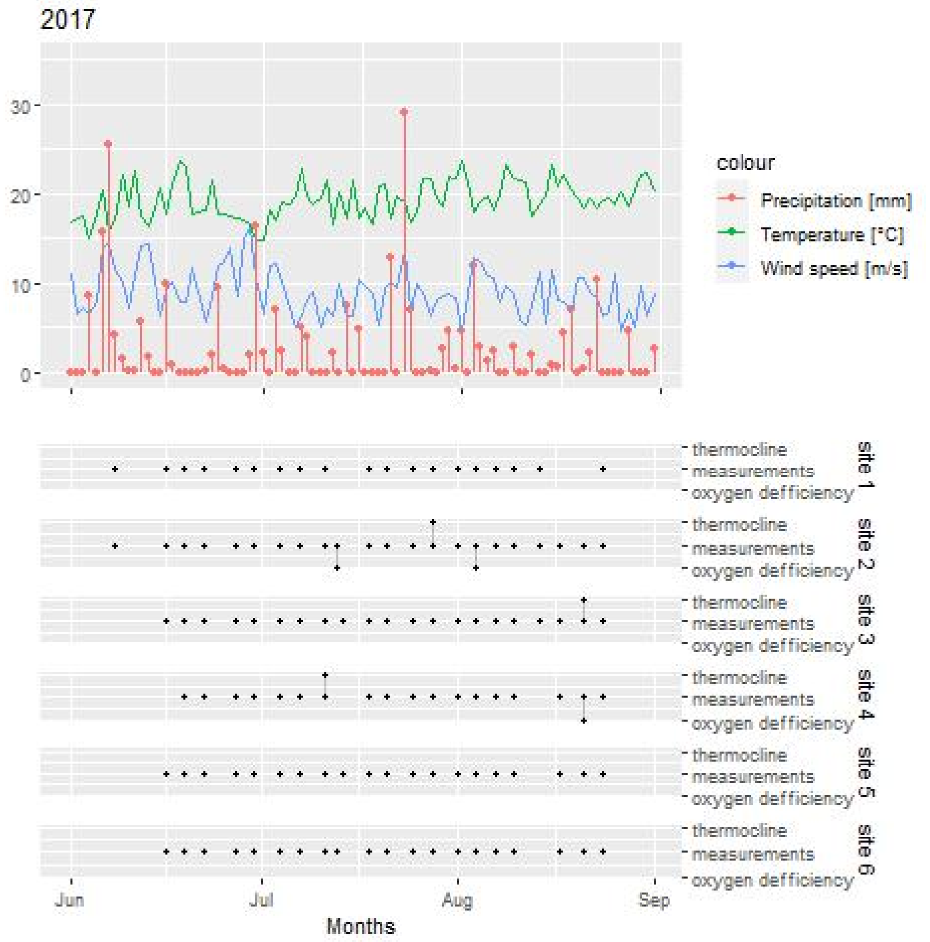


Figure 8: Meteorologial data and occurence of thermocline and oxygen deficiency in each location in 2017

In 2017 only a few days with either oxygen deficiency or the occurrence of a thermocline had been recorded. No specific pattern can be seen for mentioned occurrences, and oxygen deficiency only occurs at deeper locations.

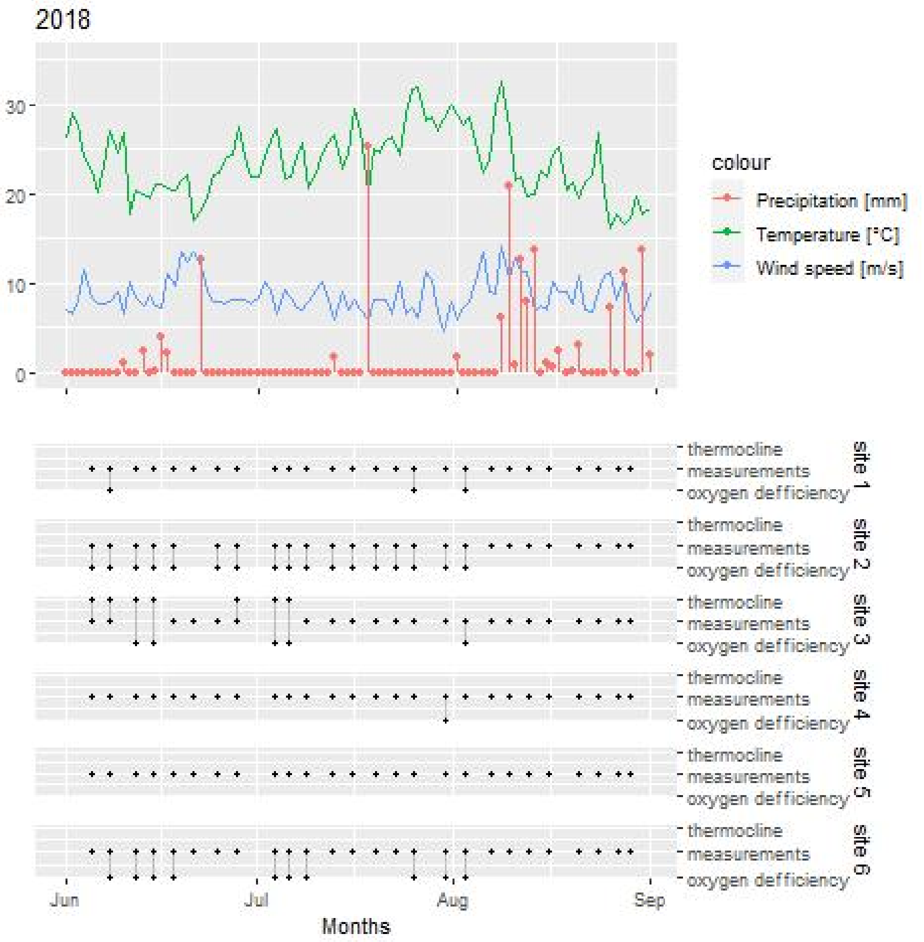


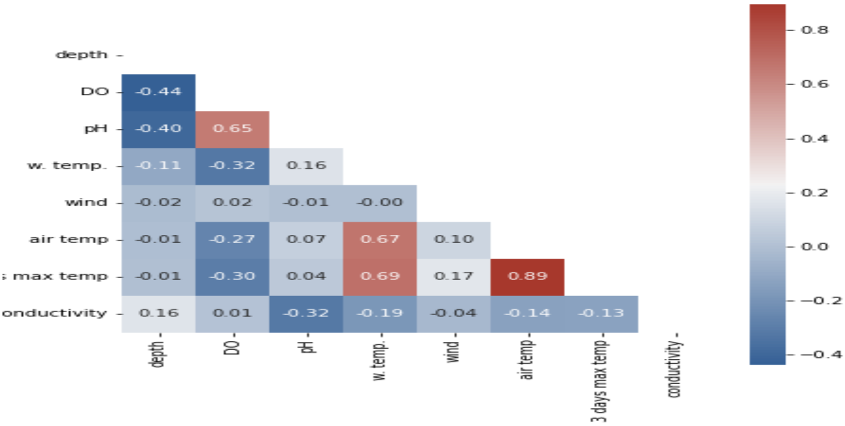
Figure 9: Meteorologial data and occurence of thermocline and oxygen deficiency in each location in 2018

The data (Figure 9) indicates that the warm summer of 2018 led to oxygen deficiencies, especially at site two, the lake's deepest point, during July. The month of July also shows high temperatures and low wind velocities.

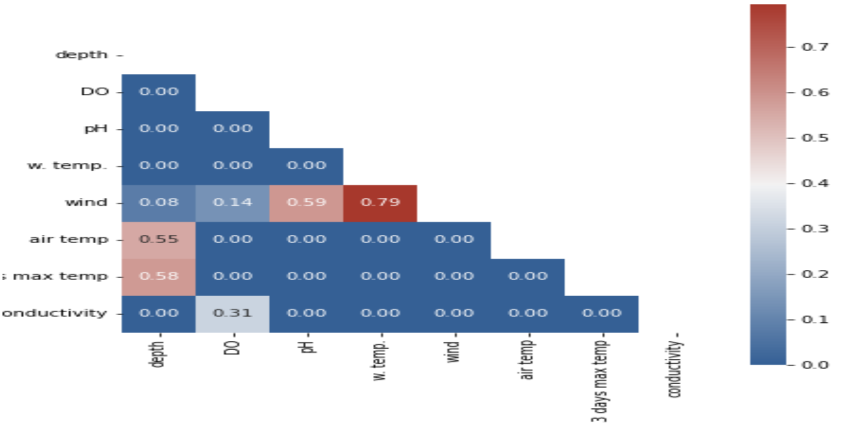
Thermoclines are primarily present at location three. The month of June starts in a thermocline, with warm temperatures, with no more than a fresh breeze. Later the same month, the temperature drops and wind speed increases, and the thermocline disappears, indicating the mixing of the water body. With an increase in temperature and a decrease in wind speed, the thermocline develops again.
To quantify the impact of weather conditions on the regime of mentioned parameters, the correlation between temperature, dissolved oxygen concen-

tration, pH, depth, wind speed, air temperature, precipitation, and the maximum air temperature over the previous three days is conducted. The maximum air temperature over the previous three days was included because the effect of the air temperature on the water temperature is expected to lag as the water body needs to take up the heat. The Spearman correlation coefficient and corresponding p-values are presented in Figure 10.

The dissolved oxygen concentration negatively correlates with the water temperature and air temperature (coeff. = -0.32/-0.27/-0.30). This correlation indicates a decreasing oxygen concentration with increasing temperature, which is conclusive that warm water can hold less oxygen. However, the oxygen saturation is lower at higher temperatures, yet during warmer weather conditions, the oxygen in the colder bottom layer is lower. This finding can be explained by how oxygen enters the water body. The warmer top layer is more likely to be mixed, and oxygen from the atmosphere enters (Wilson et al., 2020). In contrast, the bottom layer is less mixed, and oxygen can not enter the deeper layer during stratification (Wetzel, 2001b).



(a) Spearman correlation coefficient between -1 and 1



(b) Spearman correlation p value

Figure 10: Spearmen correlation of profile parameters and meteorological data

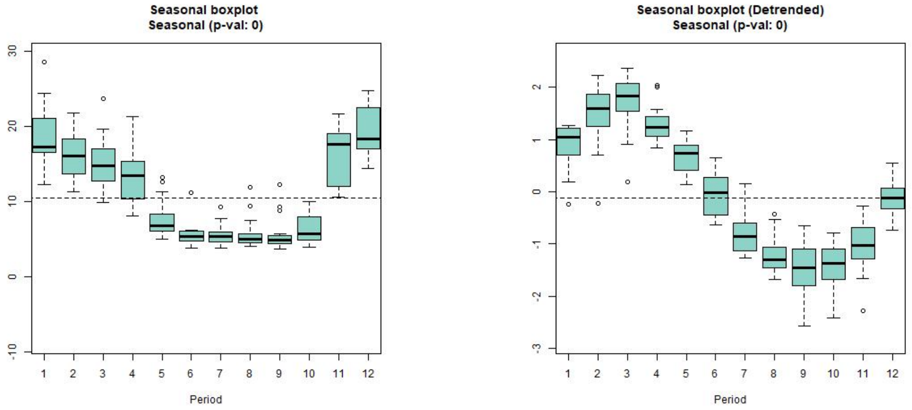
A moderate negative correlation can be seen between pH and dissolved oxygen concentration towards the depth. Looking at the processes in a lake, including photosynthesis, respiration, and degradation, both pH and dissolved oxygen concentration are involved. The zones in which mentioned processes differ over the depth, and so do both parameters. Generally, oxygen is added to the water body higher up in the water column due to the connection with the atmosphere and light-dependent photosynthesis (Wilson et al., 2020). At the same time, biomass is degraded in the lower layer. The pH increases alongside photosynthesis and decreases during degradation.

4.2 Nutrient abundance

The abundance of nutrients is analysed for seasonal patterns and differences between in- and outflow. Additionally, the potential of phosphorous being released from the sediment is examined.

4.2.1 Seasonal pattern in in- and outflow

The abundance of nutrients indicates eutrophication, with nitrogen and phosphorous limiting factors for most algae growth. To see the effect of mentioned nutrients entering the lake on the lake's condition, the concentration of both nitrogen and phosphorous in the in- and outflow are being compared and analysed for seasonal patterns. Figures 11 and 12 show boxplots of the seasonal variation of all inflow and outflow concentrations of phosphorous and nitrogen.



(a) Boxplot of the total nitrogen inflow concentration in mg/l grouped by month from 2004 to 2020.

Seasonal boxplot
Seasonal (p-val: 0)

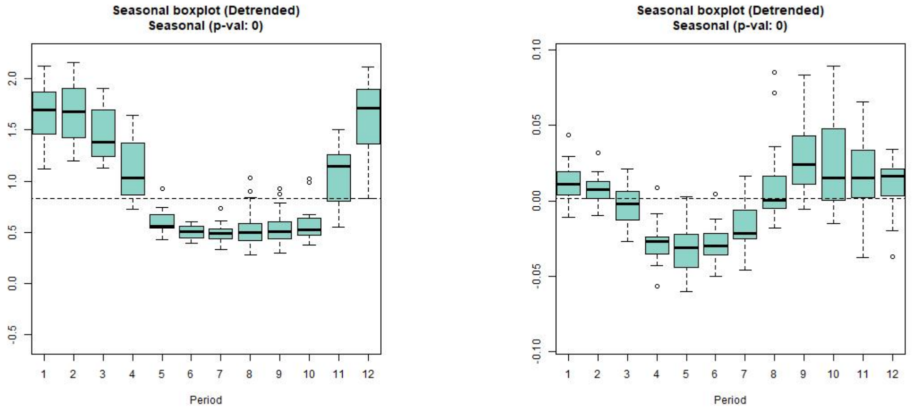
(b) Boxplot of the deviation of the total nitrogen outflow concentration in mg/l from detrended median grouped by month from 2004 till November 2021.

Seasonal boxplot (Detrended)
Seasonal (p-val: 0)

Figure 11: Seasonality of total nitrogen concentration in in- and outflow.

The outflow into Kävlingeån does not follow a natural regime because it is being used to regulate the lake's water level to ensure the water supply for groundwater infiltration. Björkaån is the biggest contributor to the inflow.

The in-and outflow and the nitrogen and phosphorous concentration show a seasonal pattern.
The nitrogen concentration in the inflow is the highest in winter and decreases over summer, as shown in Figure 11 (a). This pattern can be explained by more precipitation and thus higher flows in winter carrying nitrogen from the catchment into the water body. The concentration peaks in spring with a low point in autumn in the outflow.



(a) Boxplot of the deviation of total phosphorous inflow in percentage of the detrended median grouped by month from 2004 to 2020.

(b) Boxplot of the deviation of the total phosphorous outflow concentration in mg/l from detrended median grouped by month from 2004 to November 2021.

Figure 12: Seasonality of total phosphorous concentration in in- and outflow.

The phosphorous inflow concentration (Figure 12 .a) follows a similar regime as the nitrogen; However, the phosphorous concentration in Kävlingeån shows a distinct peak in September that does not show in the inflow. This pattern could be due to an oxygen deficiency leading to the release of previously precipitated phosphorous (Dodds and Whiles, 2010).

The following Figure shows the phosphorous concentration in the outflow from 2014 until 2021. The data from 2004 until 2004 is noisier than the more recent measurements.

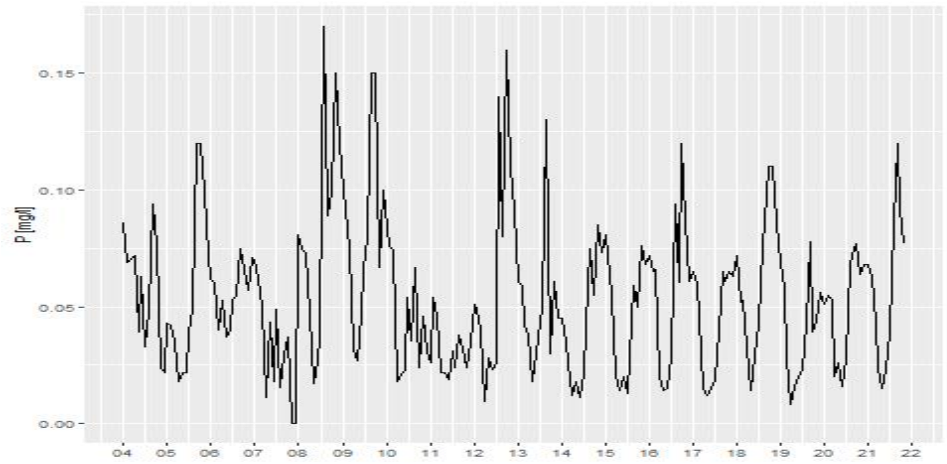


Figure 13: Total phosphorous concentration in the outflow of Lake Vomb in mg/l from 2004 to November 2021.

Looking at the timeline of the phosphorous concentration in the outflow (Figure 13), high concentrations can be seen in the warm year 2018 and lower concentrations in the cold year 2017. Another noticeable higher concentration is visible in 2016, which is not conspicuous in its temperature regime. Hence, another factor has to be the cause of this.
Going back to the development of thermocline and oxygen depletion, the measurements show a surprisingly high number of thermoclines, as shown in Figure 14 considering the air temperature,

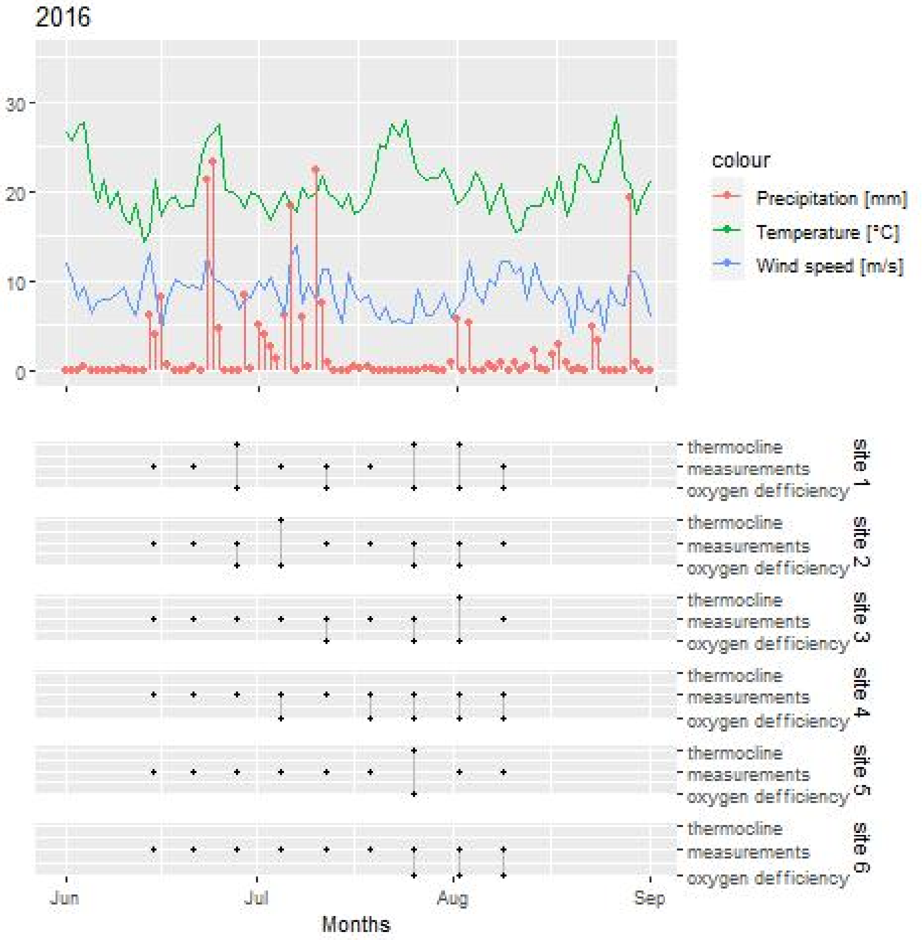
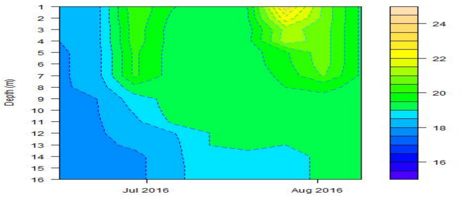


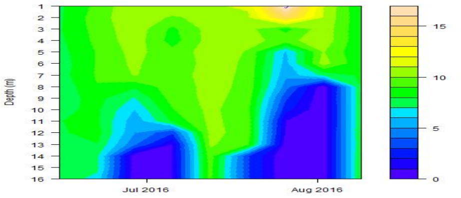
Figure 14: Meteorologial data and occurence of thermocline and oxygen deficiency in each location in 2016

The most significant difference in meteorological data between 2016 and 2017 is the lower average wind speed and less precipitation in 2016. This suggests the impact of wind and precipitation on developing an oxygen condition. Figure 15 shows the profiles of site 2 for the year 2016.

(a) Temperature Profile 2016 [°C]



(b) Dissolved Oxygen Profile 2016 [mg/l]



(c) pH Profile 2016

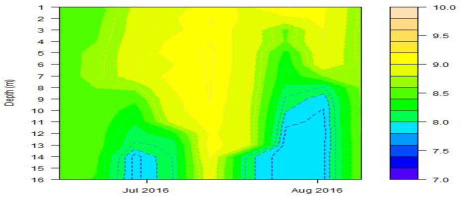


Figure 15: Profiles Site 2 in summer 2016 interpolated based on measurements taken by Sydvatten

The low dissolved oxygen content can be seen at site two, but all other measurement sites are also affected. Besides the possible effect of low wind velocities, no other parameter showed a particularly strong effect in 2016. Another noticeable year is 2019, with lower phosphorous concentrations compared to the other years.

4.2.2 Phosphorous release

The dissolved oxygen concentration at the bottom of site 2, since site 2 is most likely to develop an oxygen deficiency, is plotted in Figure 16 with the phosphorous concentration from 2014 to 2021. The red dots represent the dissolved oxygen concentration on the days they were measured, and blue shows the phosphorous concentration in µg/l.

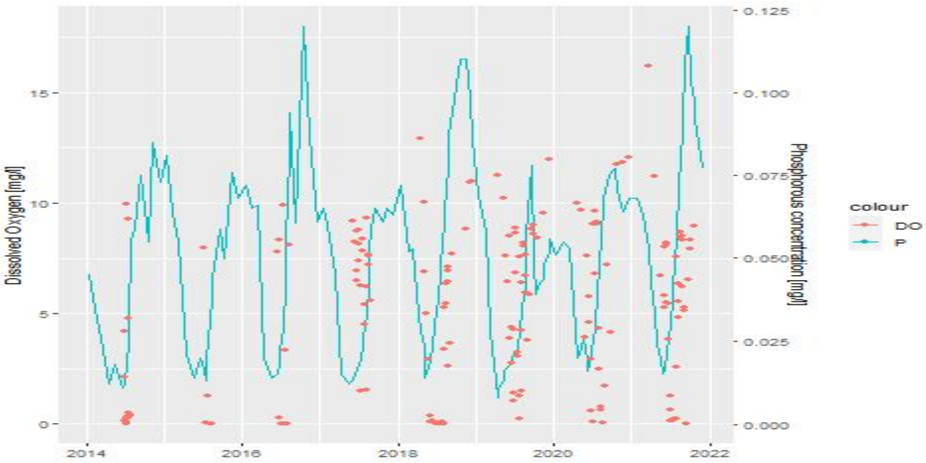


Figure 16: Total phosphorous concentration in the outflow of Lake Vomb in mg/l from 2014 to November 2021 represented by the blue line. The dissolved oxygen concentration at the bottom of site 2 in mg/l is plotted with rot dots for the available measurements.

A statistical correlation can not be seen from the data shown in Figure 16. Besides, only the summer months provide data for dissolved oxygen. Noticeable, however, is the low oxygen concentrations at the minimal turning point of the phosphorous concentration. Moreover, the phosphorous concentration is measured at the lake's outflow, whereas the dissolved oxygen concentration is measured at location 2.

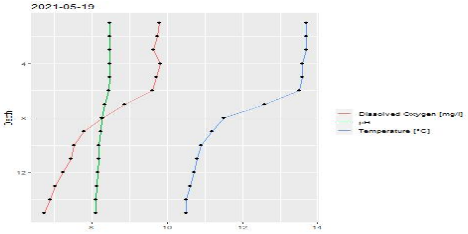
The phosphorous concentration at site 2 in the lake is available for only January till November 2021. Measured by Kävlingeåns vattenråd Table 5 shows the concentrations at the lake's surface and bottom. The phosphorous concentration increases until October before it decreases again until April, and this behaviour is the case for both surface and bottom.

Table 5: Total phosphorous concentration in 2021 in µg/l at the bottom of site 2.

Depth	Jan.	Feb.	Mar.	Apr.	May	Jul.	Oct.	Nov.
Surface	72	63	51	22	16	61	100	82
Bottom	/	53	48	23	32	96	100	79

Figure 17 shows the profile of site two on the 19th of May and the 19th of July 2021, which are the same days the phosphorous concentration was measured. The red line represents the dissolved oxygen concentration, the green line the pH value, and the blue is the temperature.

(a) Lake profile 19.05.2021



(b) Lake profile 19.07.2021

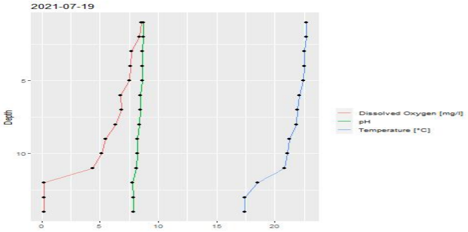


Figure 17: Profiles Site 2 in summer 2016. The red line shows the concentration of dissolved oxygen in mg/l, the green line is the pH and blue represents the water temperature in °C.

The dissolved oxygen concentration is lower in July, corresponding to higher phosphorous concentrations.

4.3 Algae bloom

The algae bloom is analysed using satellite data measuring the concentration of chlorophyll-a at the six discussed locations. As shown in Appendix A.4, the concentrations of the different locations show the same pattern. For that reason, the following comparisons are being made with an average overall of six locations. Only site one and four show more extreme peaks especially in 2018.

4.3.1 Temporal distribution of algae

Figure 18 shows the average concentration of chlorophyll-a from 2016 until 2021 to see temporal changes and seasonal patterns.

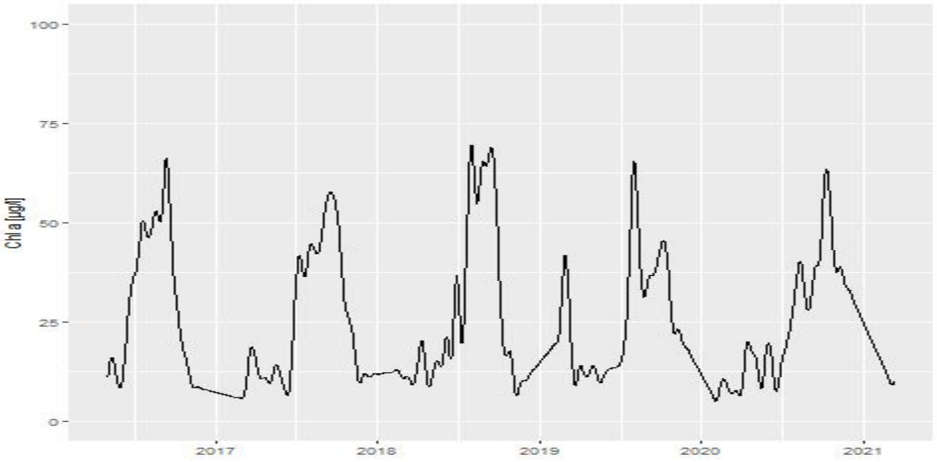


Figure 18: Average of chlorophyll-a concentration over the six measurement locations in Lake Vomb in µg/l measured by satellite Sentinel-3a from May 2016 to March 2021.

The chlorophyll-a regime follows a seasonal pattern with a substantial increase in concentration in summer, which drops again in late autumn. The peak in summer represents the algae bloom.

The autumn of 2018 shows an incredibly high concentration. In 2016 the average concentration in autumn seemed comparably high, and a lower peak concentration can be seen in 2017. This information coincides with similar trends of previous analysis regarding temperature and phosphorous concentration leaving the lake.

It is also observed that spring blooms are noticeable and in certain years are significantly high, such as in 2019.

4.3.2 Algae species

The presence of chlorophyll-a alone does not explicitly indicate the abundance of blue-green algae. It is instead information on algae in general.

The measurements taken in autumn 2021, when the concentration of green algae, blue-green algae, diatoms, and cryptophyta were taken, give an understanding of the distribution of the types of algae present. Figure 19 shows the concentration of green algae (green), blue-green algae (blue), diatoms (orange), and cryptophyta (pink) in µg/l over the depth of site 2 measured on the 9th of September 2021.

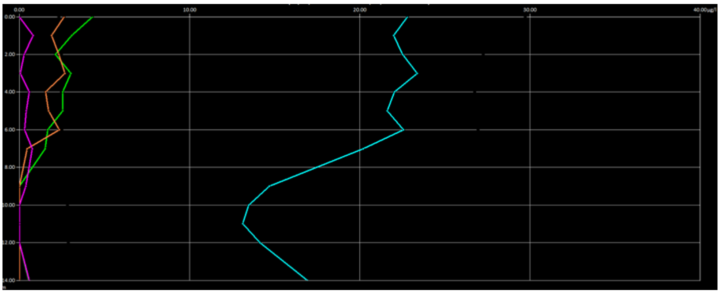


Figure 19: Concentrations of algae species including Green ALgae (green), Blue-green algae (blue), Diatoms (orange) and Cryptophyta (pink) in µg/l over the water depth in m measured on the 15.09.21 at site 2

Blue-green algae are present in the highest concentrations in all four measurements. All measuring sites show the same dominance of cyanobacteria during the study time.
Nevertheless, this only gives information for 2021, which does not mean cyanobacteria show the same dominance in previous years.

4.3.3 Nutrient supply

Algae need both nitrogen and phosphorous for growth which suggests a possible relationship between the concentration of nitrogen and phosphorous in the lake's inflow. A higher concentration in the inflow in early summer or spring could support the algae bloom. Figures 20 shows the chlorophyll-a concentration and phosphorous and nitrogen concentration in the inflow. Since the flow also affects the actual transported mass, it is also represented in the graph.

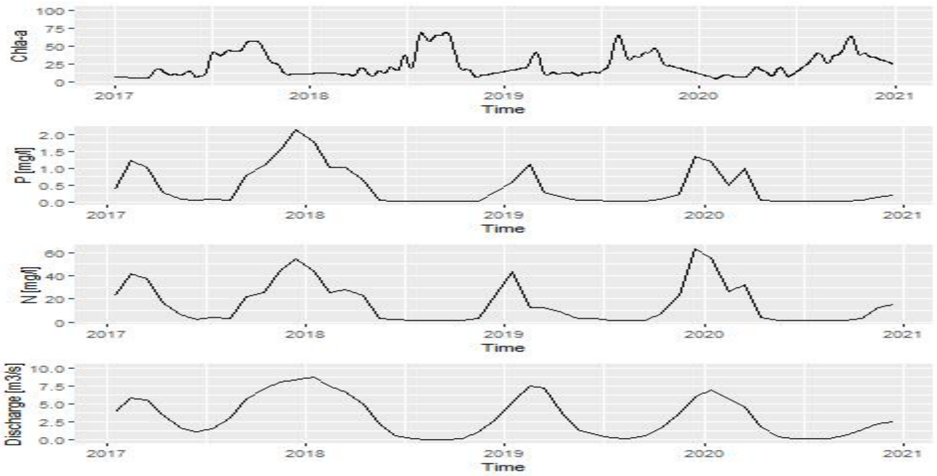
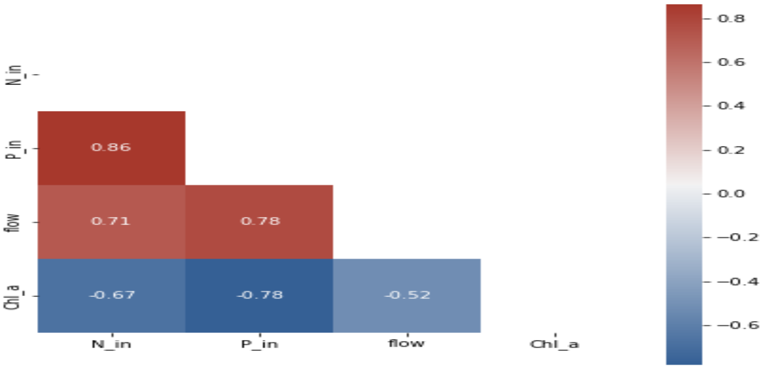


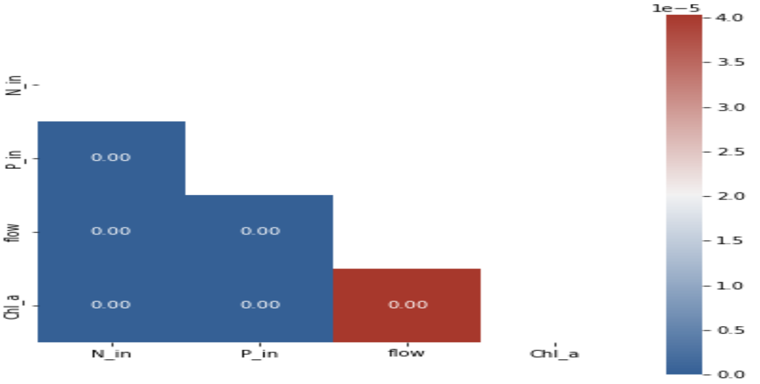
Figure 20: Average chlorophyll-a concentration [µg/l], phosphorous and nitrogen concentrations in the outflow [mg/l], and discharge [m^3/s] from 2017 to 2020.

The concentrations of nitrogen and phosphorous show a similar pattern as mentioned previously, and the regime is also very similar to the flow pattern. As a time lag is to be expected considering the transport time and the growth and other factors, high concentrations during winter could support growth in the following summer. The winter between 2017 and 2018, after a rather cold year with high precipitation, shows high concentrations, and the chlorophyll-a concentration in autumn of 2018 is also high.
The winter after the warm summer shows lower concentrations, and also, the chlorophyll-a concentration is lower the following summer.

The correlation between parameters shown in Figure 21.a is tested with the Spearman correlation. The related coefficients with their p-values are shown in Figure 21.b.



(a) Spearman correlation coefficient of monthly chlorophyll-a and phosphorous and nitrogen concentration in the outflow. The Spearman correlation coefficient can range between -1 and 1.



(b) Spearman correlation p value

Figure 21: Spearman correlation of chlorophyll-a, phosphorous and nitrogen concentration for values from 2017 to 2021.

A moderate negative correlation can be seen between chlorophyll-a and the inflow of nitrogen and phosphorous. High amounts of nutrients entering the system early in the year could facilitate the algae growth in summer, with phosphorous being the decisive factor.

The ratio of nitrogen and phosphorous can affect algae growth. Espe-

cially a ratio of 7:1 has been shown to facilitate algae bloom.
The following table shows the nitrogen concentration at site two in 2021, corresponding to the previously presented phosphorous concentration.
The nitrogen concentration follows a different regime with low values during the summer months.

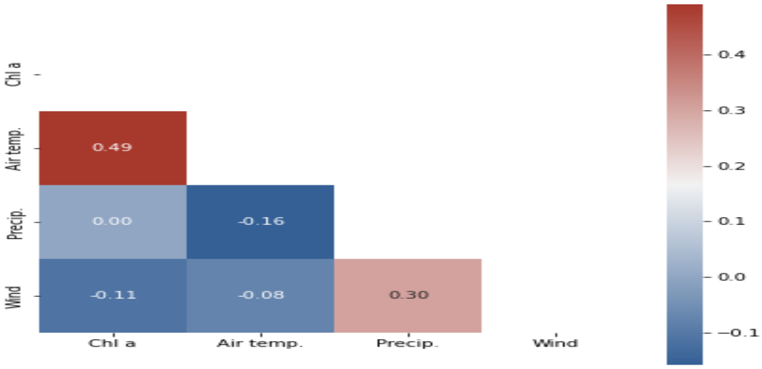
Table 6: Total nitrogen concentration in 2021 in mg/l at the bottom of site 2.

Depth	Jan.	Feb.	Mar.	Apr.	May	Jul.	Oct.	Nov.
Surface	3.8	3.7	4.7	4.0	3.6	2.3	1.0	2.1
Bottom	/	4.6	4.6	4.0	3.4	2.1	1.0	2.2

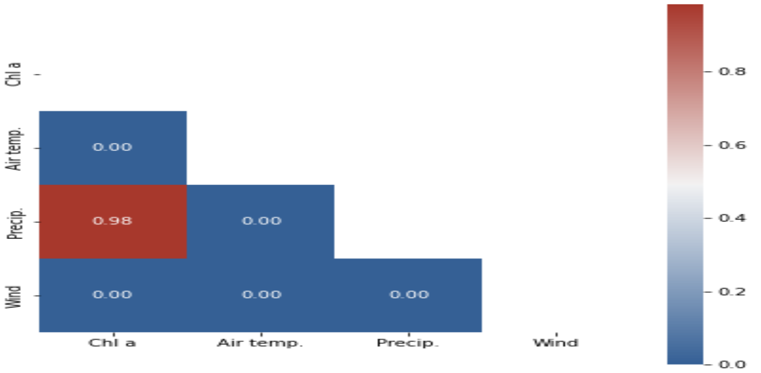
The ratio between nitrogen and phosphorous exceeds the 7:1 ratio. Especially in April, it differs a lot, and it gets the closest in October.

4.3.4 Effect of meteorological data

Besides the limiting nutrients, because algae are photosynthetic, a correlation with meteorological factors is assumed. The Spearman correlation between chlorophyll-a concentration and meteorological data is shown in Figure 22.



(a) Spearman correlation coefficient for chlorophyll-a and meteorological data including maximum daily air temperature, daily precipitation and maximum daily wind speed. The Spearman correlation coefficient can range between -1 and 1.



(b) Spearman correlation p value

Figure 22: Spearman correlation of chlorophyll-a and meteorological data from 2017 to 2021.

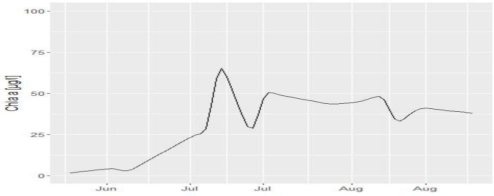
A moderate positive correlation between air temperature and chlorophyll-a can be seen in the graph. That an increase in temperature enhances the algae growth is plausible and expected.
A weak negative correlation is visible between maximum wind velocity and chlorophyll-a. A turnover or movement in the upper water body could disrupt the cyanobacteria scum at the surface, leading to lower concentrations.

4.3.5 Correlation between profile data and chlorophyll-a

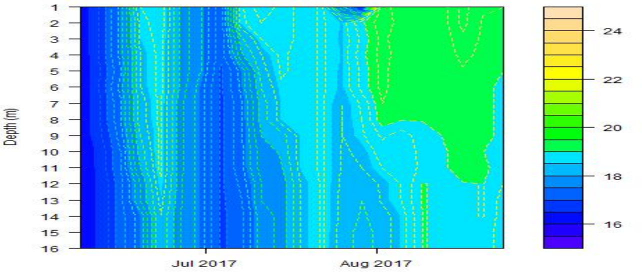
To explore a connection between chlorophyll-a concentration and the parameters measured for the water profile, the data for site two is plotted in Figures 23 and ref2018 for 2017 and 2018.
After that, the top and the bottom of the water column of site two are used to test for correlation using the Spearman coefficient. An effect is most likely visible either at the bottom of the lake or close to the surface.

In 2017 (Figure 23), the chlorophyll-a concentration peaks when the water warms up in early July. An increase in dissolved oxygen and pH can also be seen simultaneously.
In 2018 (Figure 24), the overall chlorophyll-a concentration was higher. The water heats up in late July and early August, and at the same time, the chlorophyll-a concentration increases.

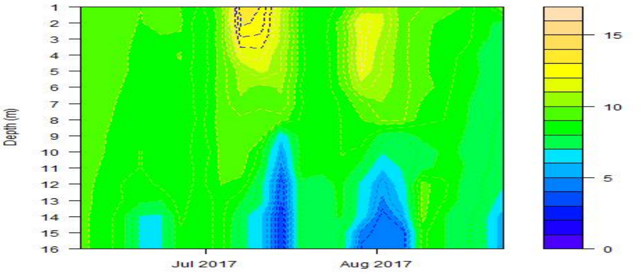
(a) Chlorophyll-a concentration at site 2 [mg/l]



(b) Temperature Profile [°C]



(c) Dissolved Oxygen Profile [mg/l]



(d) pH Profile

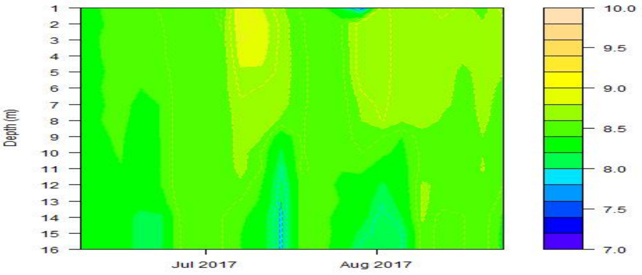
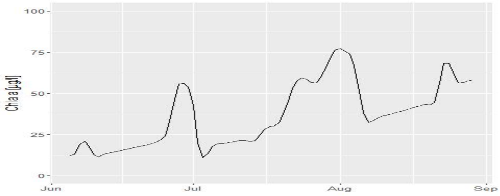
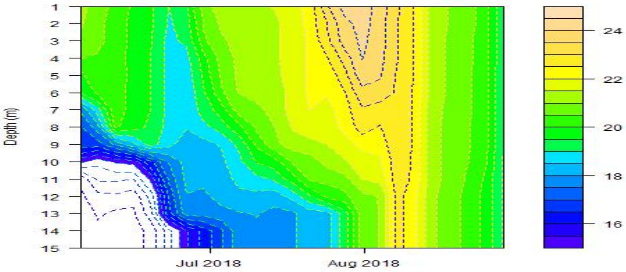


Figure 23: Chlorophyll-a concentration, temperature profile, and dissolved oxygen profile for site 2 in 2017

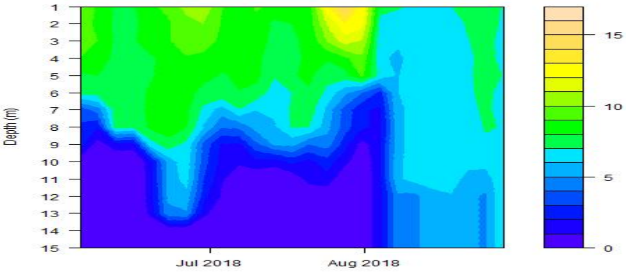
(a) Chlorophyll-a concentration at site 2 [mg/l]



(b) Temperature Profile [°C]



(c) Dissolved Oxygen Profile [mg/l]



(d) Dissolved Oxygen Profile

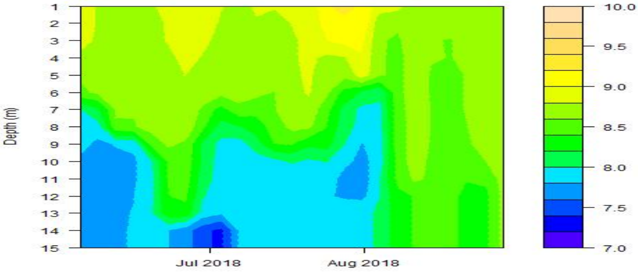
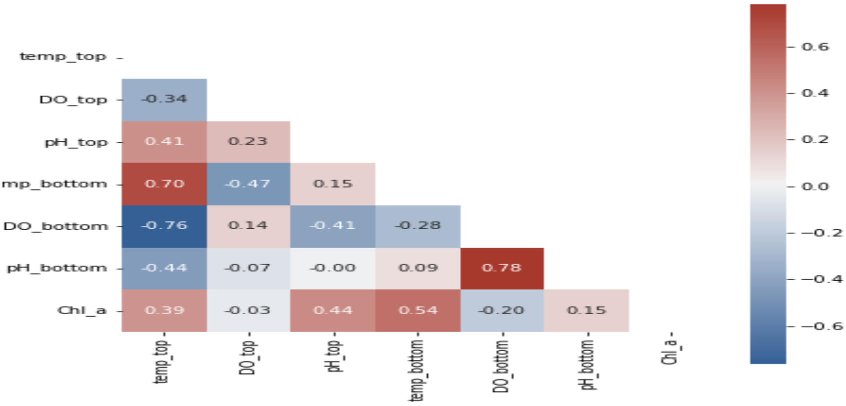
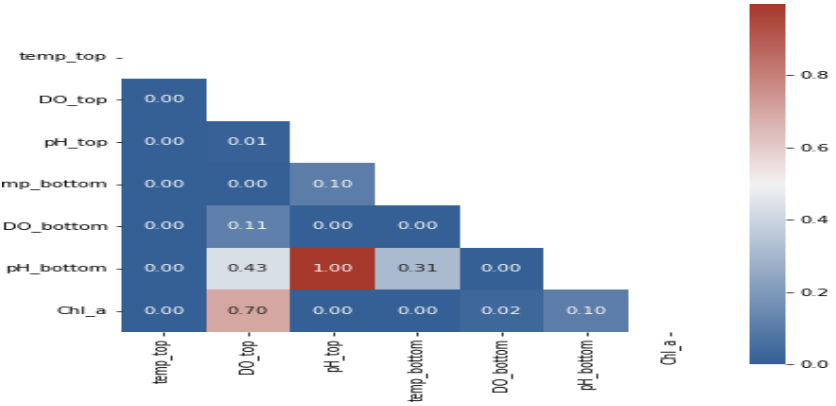


Figure 24: Chlorophyll-aconcentration, temperature profile, and dissolved oxygen profile for site 2 in 2018

The test for a correlation between the lake profile parameters and chlorophyll-a using the Spearman correlation coefficient is shown in Figure 25.



(a) Spearman correlation coefficient for chlorophyll-a and profile parameters at the surface and bottom of the lake. The Spearman correlation coefficient can range between -1 and 1.



(b) Spearman correlation p value

Figure 25: Spearman correlation of chlorophyll-a concentration and profile parameters from 2017 to 2021.

A moderate positive correlation is visible between chlorophyll-a and the pH close to the surface. Since photosynthesis can cause an increase in pH, this correlation can be explained by the higher abundance of algae conducting overall more photosynthesis.

Another moderate correlation of chlorophyll-a is visible with the water temperature at the bottom. The temperature at the bottom could be more correlated than the one close to the surface since it warms up later in summer after a long time of warm weather.

A weak and negative correlation is between chlorophyll-a and the concentration of dissolved oxygen at the bottom of the lake. Algae only produce oxygen at depths where photosynthesis is possible. When mixing of the water body does not occur, this oxygen does not reach the bottom, and oxygen is being used up for decomposition.
The strong positive correlation between the dissolved oxygen concentration at the bottom and the pH at the bottom is interesting. Oxygen is needed for respiration, which releases carbon dioxide, decreasing the pH. Biological degradation of organic matter, which can derive from depositing algae/cyanobacteria, also uses oxygen and produces carbon dioxide.

4.4 Prediction model

The depletion of oxygen and the excessive bloom of cyanobacteria are two results of the bad condition of Lake Vomb. The categorised data is modelled with random forest to determine which parameters are more relevant for the targets and what factors can be used to predict the targets' conditions. Models are run with different categorisations, and the two models with the best results are presented below. A summary is given in Table 7.

Table 7: Summary of two models presented in this work.

	Model 1	**Model 2**
Target factor	DO	Chl-a
Categorization	(no risk) > 5 mg/l	(no risk) ≤ 24 µg/l
	(risk) ≤ 5 mg/l	(risk) > 24 µg/l
Parameters	depth	conductance
	temp.	temp.
	max temp.	pH
	date	date
	Chloropyll-a	water temp.
	Site	DO
	windspeed	precipitation
	year	max temp.
	precipitation	windspeed
	month	month
		year
		Site
Values for training	564	559
Values for validation	188	187

The parameter temp. describes the maximum temperature of the day. Additionally, the water temperature (water temp.) and the maximum air temperature within the previous three days (max temp.) is included in the prediction.

4.4.1 Oxygen depletion

The Oxygen depletion as the target factor is modelled with two categories of risk ($<$5mg/l) and no risk. The parameters used for the prediction and the corresponding importance are shown in Figure 26. The prediction is solemnly based on outside factors since the pH, for example, is not a useful tool to make real time predictions. The depth represents the depth of the measurement location.

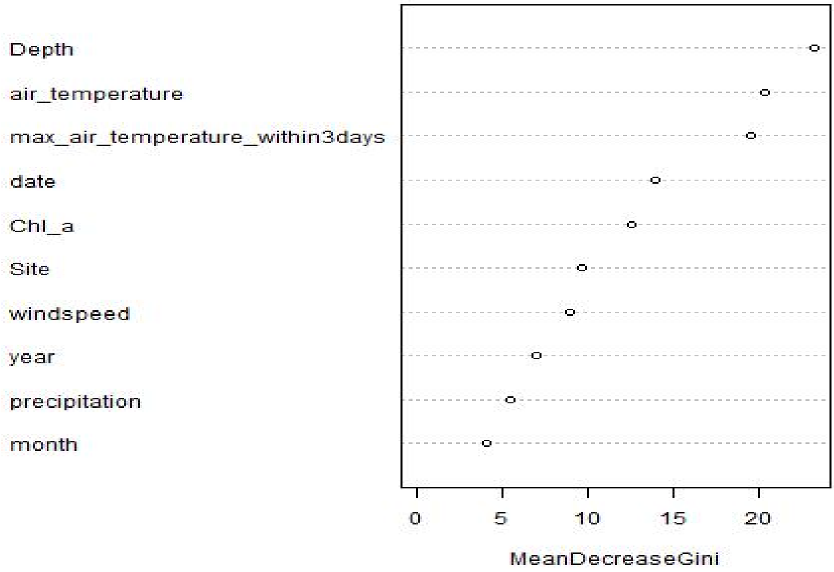


Figure 26: Importance of parameters used to predict oxygen depletion in for model 1.

The most dominant parameter is the depth which coincides with the analysis showing the biggest effect of oxygen depletion in site two.

The validation of the model to predict the risk level of dissolved oxygen concentration was tested. The 25 percent of all values not used to create the model were modelled and compared to the actual values. Following table shows the actual correctly predicted values and the amount of mistakes made by the model.

Table 8: Confusion matrix for model 1.

	risk	no risk
Predicted risk	19	12
Predicted no risk	25	132

The accuracy of the model shows 92 percent but the level of agreement between the actual and the predicted values is not as strong as can be seen in Table 9.

Table 9: Validation results for model 1.

Accuracy	0.803
Sensitivity	0.432
Specificity	0.917
Kappa	0.388

4.4.2 Chlorophyll-a

The model with chlorophyll-a as the target factor representing algal bloom is modelled using two alert categories.

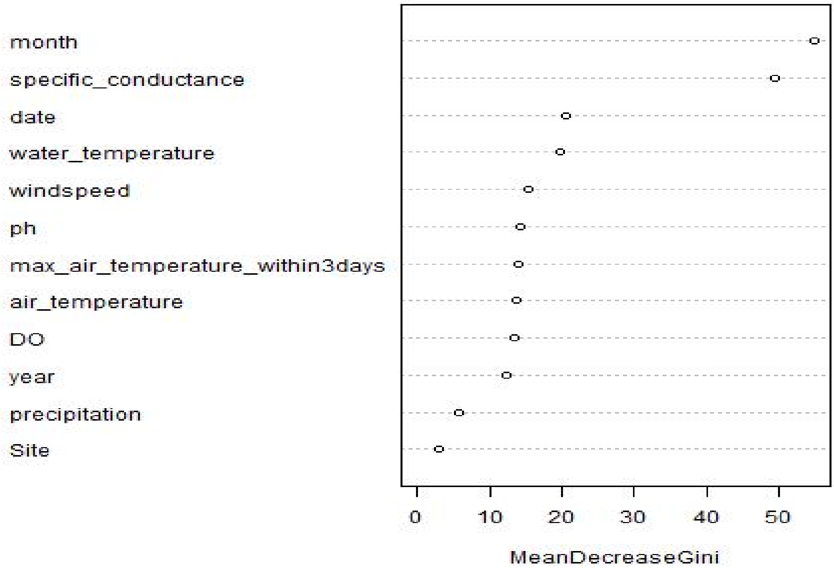


Figure 27: Importance of parameters used to predict chlorophyll-a in model 2.

The month and the specific conductance turn out to be the essential variables.

The random forest model to predict the risk level of chlorophyll-a and hence, cyanobacteria shows a slightly lower accuracy with 89 percent. With less values available, the training of the decision trees is not as strong. The model values show a moderate agreement with the actual values. The amount of correctly predicted factors is presented in Table 10.

Table 10: Confusion matrix for model 2.

	risk	no risk
Predicted risk	105	10
Predicted no risk	10	62

As can be seen in Table 11, 91 percent of all risk levels are predicted correctly.

Table 11: Validation results for model 2.

Accuracy	0.893
Sensitivity	0.913
Specificity	0.861
Kappa	0.774

5 Discussion

Given parameters are discussed with the results presented in this work. This analysis aims to aid the management of Lake Vomb to increase the quality of the water to ensure a long term drinking water supply and thwart the excessive bloom of cyanobacteria. The results are presented to give an offset to approach possible solutions.

5.0.1 Water quality dynamics

From visualising lake profile water quality parameters through space and time in Figure 23 and 24, we can easily observe how temperature affects water quality, particularly on our targeted key water quality parameters, pH and oxygen content. When the temperature increases towards to summer months, the average of pH in water is slightly higher than the recommended values of 6.5 to 8 for freshwater (McCaffrey, 2000).The increase of pH can be complicated; here it is possibly affected by the increase in photosynthetic activities of algae when the water temperature is warmer.

Other research states that increasing pH levels at the sediment of shallow, eutrophic lakes are a common cause of phosphorous release and is caused by excessive photosynthesis (Xie, 2006). Lake Vomb, however, mostly shows increased pH values closer to the surface and occasional decreases at the lake bottom. Mainly at the shallow locations in a few years, an increase to the bottom is noticeable. The depth until which photosynthesis is conducted is dependent on how far the light can reach. The buoyancy of some cyanobacteria species gives those an advantage over algae blocking out light for deeper depths. The type of organism conducting photosynthesis could affect the depth up to which the pH value is affected. Another possibility could be respirational and degradation processes producing carbon dioxide exceeding its consumption.

Dissolved oxygen is another key parameter of great interest for water management. Sufficient oxygen concentrations in lakes are essential for habitat maintenance, supporting fish reproduction, and ensuring reliable drinking water sources (Steinsberger et al., 2020). Oxygen concentrations are, therefore, a key parameter worth monitoring. From the results presented in Table 19, it can be seen that the concentration of dissolved oxygen reaches depletion at several locations and years.
The temporal analysis over summer shows increased temperatures of the water body in late July, accompanied by increased dissolved oxygen concentrations and values of pH at the surface. The vertical distribution shows

decreasing pH and dissolved oxygen values with increasing temperatures in late summer. The parameters of dissolved oxygen and pH follow similar patterns suggesting coherence.
As expected, the spatial analysis shows that the deepest location of the lake is affected the strongest by oxygen deficiency. Nevertheless, the measuring location in the southwest of the lake shows a high occurrence of stratification. The lake's outlet is located further north, and the area south of the lake is covered with forest making it possible that this part of the lake is less affected by circulation.

The cold year of 2017, in comparison to the warm year of 2018, show the dependency of the water dynamics on the weather. Especially, the air temperature over the previous days and the wind speed seem to affect the water body. Increased air temperatures go along with increasing water temperatures. During strong winds and colder weather, neither oxygen depletion nor stratification is typical. This relationship is not statistically proven, and more data points would be necessary.

5.0.2 Nutrient availability

From the nutrients analysis results, it is concluded that nutrients dynamics in Lake Vomb are not only dependent on the input from streams but also largely affected by the internal loading, such as phosphorus release from the sediments, which can be assumed due to a peak in the outflow of phosphorous in autumn. The phosphorous release could be facilitated by the low oxygen contents at the bottom of the lake towards the end of summer. It needs to be considered that the lake has a residence time of about one year and conditions further away from the outlet are unlikely to show immediate responses. The phosphorous measurements at the deepest location in 2021 show an increase already starting from April. This behaviour suggests the involvement of other factors, such as pH or biological factors, such as bioturbation, in the phosphorous exchange. Measurements in May show dissolved oxygen concentrations above five mg/l, higher than in July. Compared to July, the pH at the bottom in May lies above eight rather than around 7.5. Additionally, the phosphorous release seems stronger in warmer years.

According to Huang et al. (2005), the phosphorous release is also dependent on the sediment composition and pH levels of the overlying water. Their study tests different rations between iron-bound phosphate and calcium-bound phosphate in the sediment in shallow lakes regarding phosphorous release under different pH values. The study concludes that lower ratios have a maximum phosphorous release at the lowest pH, whereas high

ratios release the most at the highest pH. (Huang et al., 2005)
However, in Lake Vomb, pH levels do not reach as high as tested in the mentioned study. A good buffer capacity could reason for the moderate change in pH. The bedrock typically determines the buffer capacity of natural waters. Wastewater released into surface water can also affect the buffer capacity. Calcium and bicarbonate rich municipal wastewater support a good buffer capacity. (Grochowska, 2020)

Already in 1992, two studies investigated the phosphorous release from aerobic sediments from 15 shallows, eutrophic lakes in Denmark and found iron as a key factor (Jensen et al., 1992) (Henning Skovgaard Jensen, 1992). One study suggests that ensuring the surface sediment stays oxidised is the most effective way to control internal phosphorous loading. According to this study, this is possible when the weight ratio of iron and phosphorous is above 15. (Jensen et al., 1992)
The other study discusses the importance of temperature, nitrate, and pH on the thickness of the oxidised sediment. Hence, the phosphorous released from iron-bound compounds is analysed, concluding that a high nitrate concentration supports the oxidised layer thickness. In contrast, an increase in temperature contributes to a thinner layer. A decrease in the thickness of the oxidation layer facilitates phosphorous release. (Henning Skovgaard Jensen, 1992)

The abundance and distribution of fish species can, additionally, impact the dynamics of nutrients in a lake. Many planktivores can decrease the zooplankton grazing on algae and, therefore, reduce it. Removing planktivorous fish from a eutrophic lake in addition to removing nutrients can better the eutrophic state of a lake (Wetzel, 2001a).

Unexpected are 2016 and 2019, which do not show conspicuous temperatures. The year 2016 shows an increase in phosphorous in the outflow and a high occurrence of oxygen depletion; however, the temperature does not indicate a remarkable event. The most significant difference is the stronger winds in comparison to 2017. The effect of wind is explicitly challenging to quantify, given that the measuring station is located 20km northeast of the lake.

A year with the lower phosphorous release is 2019, with slightly higher temperatures than 2016. Besides the possible effects of wind, an explanation could be the previous years affecting the internal processes. This could be due to strong biological growth in 2018 or the early temperature increase during the spring.

Previous studies on shallow, eutrophic lakes showed that wind was the leading cause of variations in phosphorous loading between years (Søndergaard et al., 2001). Another meteorological effect that has not been analysed is the occurrence of ice covers and snowmelt. Both could influence the flows and circulations in the lake during winter with a potential effect on the availability of nutrients in summer. Ice cover extent might influence the phytoplankton and bacterial community structure (Beall et al., 2016), which is worthy of further investigation in Lake Vomb.

5.0.3 Algae abundance

The chlorophyll-a concentration can represent the abundance of algae for the largest part. In 2021, cyanobacteria dominated the algae bloom in Lake Vomb. The chlorophyll-a concentration shows a seasonal pattern with potent algae blooms during the summer months, and the bloom is extreme in warm years like 2018.

In 2021, the phosphorus measurements presented in Table 5 for the deepest location, site 2, show a continuous increase from April onwards up until October, making necessary nutrients available for algae growth.

The nitrogen concentration measured at the same location decreases in later summer towards autumn, which could be due to the uptake by algae during growth.

After years of high rainfalls and low temperatures, high nutrient availability in the inflow could also support growth. The different locations throughout the lake should benefit a different degree considering the residence time. Locations one and four show higher peaks in chlorophyll-a concentration, and their closer proximity to the inflow support this assumption.

The temporal distribution shows a noticeable event at the beginning of March 2019, where higher spring temperatures are reached compared to 2017 and 2018.

During winter, the phosphate-sorption to sediment has been shown in previous studies to be magnified by high concentrations of nitrate (Henning Skovgaard Jensen, 1992). The concentration of nitrate can increase due to the decomposition of organic matter and can accumulate under ice-cover during winter (Powers et al., 2017).

The warm summer in 2018 with strong algae bloom could cause high nitrate concentrations and, therefore, phosphate sorption. The strong algae growth could be the cause of high nutrient availability.

5.0.4 Prediction

Results from Random Forest for studying the possibilities to predict the chlorophyll-a condition and oxygen depletion first showed what factors are most relevant for the target factors.
The water depth of the measuring location was the most relevant parameter to predict the oxygen condition, and the air temperature followed the depth. The result reflects the natural connection of oxygen to the temperature in biological processes. A model using real-time weather measurements to predict the oxygen condition would be a helpful tool for lake management.
The most relevant parameter in chlorophyll-a prediction was the month the measurement was taken in. The fact that the month is such an essential factor indicates the dependency on other factors that show a seasonal pattern not in the model included.

The prediction models have potential, however, do not have the necessary accuracy for real-time predictions at this stage. Nevertheless, a random forest prediction model could be a helpful tool for lake management but certain adjustments are necessary.
More accurate wind data for the location could be a good addition because wind affects lake dynamics. A closer relationship could be seen with more applicable wind data closer to the lake. The phosphorous concentration measured at the bottom of the lake at the deepest location could be a good indicator of the nutrient supply, especially in the case of the prediction of chlorophyll-a.
The disadvantage of using a random forest categorised model in the case of the prediction of oxygen depletion is that using correlating values such as pH does not give expedient results when predicting a change in the category.

5.0.5 Possible errors and suggestions for improvement

The data provided for this study has certain drawbacks. Profile measurements were taken irregularly, with several people involved. Different sensors have been used throughout the years, and the accuracy is dependent on external conditions like waves.

The in- and outflow data has different sources with different types of measurements. The inflow consists of simulated monthly averages, whereas the outflow is measured once a month on different days.

Satellite measurements of chlorophyll-a are only possible without cloud covers; However, this is sufficient for the more critical summer months. Furthermore, the measuring time is of high importance when analysing the effect of algae on the water profile. Since algae activity shows diurnal changes by conducting photosynthesis during the day, taking in carbon dioxide and producing oxygen, and the opposite during the night, an increase in oxygen and a rise in pH at the surface during the day is possible.

The meteorological data is measured 20 km away from the lake, which could make a difference in the actual effect, especially regarding wind. Nevertheless, the results presented give a broad understanding of the patterns and interactions in the lake and how they may be related.

Based on the results and discussion, a few items are suggested to improve future measurements in Lake Vomb to aid the water management.

- Measurements should be taken at regular intervals allowing more representative interpolations.
- Starting measurements earlier in the year could help explain peaks in chlorophyll-a during spring.
- Personnel should be thoughtfully instructed and supervised in using measuring devices.
- The profile data should be taken simultaneously as the satellite passes over the lake as there are changes throughout the day. This time overlap would allow us to see more accurate effects of photosynthesis on pH and oxygen.
- Notes on the weather condition during the measurement of the profile data should be taken. This additional information could help evaluate the accuracy of the measured values.
- Measurements of water quality parameters could be combined with measurements of algae species.

Future analysis could include the effect of an ice cover on the lake and the process under the cover. Furthermore, weather data recorded closer to the lake could show a more precise picture of the effect.

Different years should be assessed regarding the dominance of cyanobacteria or algae to evaluate triggers specifically for cyanobacteria. In this regard, particular attention should be paid to nitrogen availability in different years. Since certain species of cyanobacteria can fixate nitrogen, years with less nitrogen could be the cause of the dominance of cyanobacteria.

Another advantage of cyanobacteria over algae is their buoyancy. Comparing the dominance in colder and more cloudy years when algae compete for light could help explain the difference, for example, in 2016 and 2019.

For lake management, continuous monitoring of key water quality parameters is essential to understand the dynamics of its temporal and spatial distribution. Thereafter, for instance, suitable lake restoration measures can be further investigated.
This work gives an overview and suggestions for further improvements in data collection. Furthermore, this data-driven analysis can facilitate a modelling approach.

6 Conclusion

In order to secure a water quality sufficient for recreational use and groundwater infiltration for a long term drinking water supply, the lake needs to be kept in good condition. This aim aligns with the EU water directive to achieve a good status of all waters (European, 2012). Understanding the cause and potentially predicting toxic cyanobacterial bloom is essential.

The water quality dynamics of Lake Vomb seem weather-dependent, and seasonal differences in the in- and outflow concentrations of phosphorous and nitrogen are visible. The release of phosphorous during autumn can be assumed because of increased phosphorous concentrations in the stream leaving Lake Vomb. Additionally, increased phosphorous concentrations can be seen at the bottom of the deepest location in the lake from May till late autumn in 2021. The cause of the phosphorous release can not be pinned down with the given information.

During the summer months, strong algae blooms, in 2021, dominated by cyanobacteria are visible. The high availability of nutrients are the most likely cause for that. Finding the cause of the phosphorous release and identifying specific indicators to control it could be a reasonable next step to predicting bloom.
PH levels at the water surface show a moderate correlation with the concentration of chlorophyll-a, which can be explained by photosynthesis. Other than expected, a correlation between chlorophyll-a and oxygen could not be seen, even though dissolved oxygen and pH correlate over the depth of the water column.

Inaccuracy of the data itself can be caused by the change in the measuring device and the change in people taking the measurement. Measurements are, furthermore, dependent on weather conditions, and low concentrations of phosphorous are difficult to measure precisely. Different data sources have been used, adding to a possible error in the analysis.

The conclusions show the complexity of lake systems and how multiple water qualities are intertwined. Our analysis showed indications aligning with previous studies of the impact of eutrophication on algal blooms, particularly due to the lake's internal loading. Continuously reducing the external input should be encouraged for future work and investigation of suitable in-lake measures such as biomanipulation or using certain chemicals such as aluminium to precipitate released phosphorous or ultrasonic (LGSonic) to disturb the biological activities, reducing the algae growth. However, the

problem of eutrophication does not have one perfect solution, and changes in the situation might require revisiting the choice of measures taken.
Water chemistry is connected to biological processes. Therefore, continuously monitoring key parameters is vital to observe the system's changes to help identify system shifts. Parameters such as pH, water temperature and weather conditions have the potential to indicate other water quality parameters like algal activity and oxygen depletion. Online real-time monitoring of mentioned parameters combined with advanced data-driven models such as Random Forest can support lake management decision-making.

7 Popularised Summary

Analysis of the water quality dynamics of a eutrophic lake in Sweden

Eutrophication is a global problem that can lead to excessive proliferation of algae, including toxin-producing cyanobacteria. Bad eutrophic water conditions can jeopardise the drinking water quality and the utility of surface waters for recreational use.

This case study examines Lake Vomb, located in Skane, Sweden. The lake provides water for groundwater infiltration, used for the drinking water supply of Malmö. The lake is in a bad ecological condition with intense algae blooms during summer.

The results show an effect of temperature on the water quality parameters, pH and dissolved oxygen concentration. The deeper measuring locations are more affected by oxygen depletion whereas more remote locations have the highest occurrence of thermoclines. The pH value at the water surface showed the strongest correlation with chlorophyll-a concentration during the summer. The possibility of phosphorous release supporting the algae bloom was found, but more measurements are needed to find its cause. The random forest prediction models with the targets of chlorophyll-a and oxygen depletion show potential, but more input data is needed to make relevant predictions.

Eutrophication and excessive algae blooms requires the lake management to take measures. Finding factors triggering algae bloom is necessary to make a real time prediction on water conditions which is a useful tool to find suitable solutions to return the lake into a good ecological state.

Predicting water conditions and algae blooms can facilitate the lake management's decision-making on solutions to improve the water quality and ensure a long term usage of the surface water.

The findings of this work can be used to support lake management. Measurements can be improved to facilitate further attempts at real-time predictions and assessing possible solutions. The parameter profiles were tested for correlations with the chlorophyll-a concentration and meteorological data. The availability of essential nutrients was evaluated by looking at the phosphorous and nitrogen concentrations in the in- and outflow of the lake. A categorized Random Forest model was used to predict the risk of high chlorophyll-a concentrations and oxygen depletion.

References

Alström, T., Holström, K., Holström, C., and och Hakan Bjöklund, T. D. (2017). Vombsjön Faktasammanställning. *Ekolog gruppen.*

Beall, B. F. N., Twiss, M. R., Smith, D. E., Oyserman, B. O., Rozmarynowycz, M. J., Binding, C. E., Bourbonniere, R. A., Bullerjahn, G. S., andE. D. Reavie, M. E. P., Waters, M. K., Woityra, W. C., and McKay, R. M. L. (2016). Ice cover extent drives phytoplankton and bacterial community structure in a large north-temperate lake: implications for a warming climate. *environmental microbiology*, 18(6):1704–1719.

Cole, G. A. and Weihe, P. E. (2015). *Textbook of Limnology.* Waveland Press, 5 edition.

dea Ric Eynard, F., Mez, K., and Walther, J.-L. (2000). RIsk of cyanobacterial toxins in Riga waters (Latvia). *Wat. Res.*, 34(11):2979 to 2988.

Dean, W. E. (1999). The carbon cycle and biogeochemical dynamicsin lake sediments. *Journal of Paleolimnology*, 21:375–393.

Dodds, W. K. and Whiles, M. R. (2010). *Freshwater Ecology - Concepts and Environmental Applications of Limnology.* Elsevier, 2 edition.

Dokulil, M. T., Donabaum, K., and Pall, K. (2010). *Eutrophication: causes, consequences and control*, chapter Successful Restoration of a Shallow Lake: A Case Study Based on Bistable Theory, pages 285–294. Springer, Dodrecht.

Drobac, D., Tokodi, N., Simeunovic, J., Baltic, V., Stanic, D., and Svircev, Z. (2013). Human exposure to cyanotoxins and the effects on health. *Arh Hig Rada Toksikol*, 64:305 to 316.

Environmental, F. (2013). ph of water : Fundamentals of environmental measurements. website.

European, C. (2012). Introduction to the EU Water Framework Directive . *https://ec.europa.eu.*

Francis-Floyd, R. (2003). Dissolved Oxygen for Fish Production1. *University of Floria.* Fact Sheet FA-27.

Geider, R. J. (1987). LIGHT AND TEMPERATURE DEPENDENCE OF THE CARBON TO CHLOROPHYLL a RATIO IN MICROALGAE AND CYANOBACTERIA: IMPLICATIONS FOR PHYSIOLOGY AND GROWTH OF PHYTOPLANKTON. *The New Phytologist*, 106(1):1–34.

Grochowska, J. (2020). Assessment of Water Buffer Capacity of TwoMorphometrically Different, Degraded, Urban Lakes. *water*, 12(1512).

Hach Company' H2O, U. (2007). Important Water Quality Factors. Technical report, H2OU.

Henning Skovgaard Jensen, F. O. A. (1992). Importance of temperature, nitrate and pH for phosphate release from aerobic sediments of four shallow, eutrophic lakes. *Limnol. Oceanogr.*, 37(3):577–589.

Huang, Q., Wang, Z., Wang, C., Wang, S., and Xiangcan (2005). Phosphorus release in response to pH variation in the lake sedimentswith differentratios of iron-bound P to calcium-bound P. *Chemical Speciation and Bioavailability*, 17(2):55–61.

Humpage, A. and Cunliffe, D. (2021). *Toxic Cyanobacteria in Water* , chapter Exposure to cyanotoxins, pages 295–400. WHO and CRC Press, 2 edition.

Ibeligs, B. W., Kurmayer, R., Azevedo, S. M. F. O., Wood, S. A., Chorus, I., and Welker, M. (2021). *Toxic Cyanobacteria in Water*, chapter Understanding the occurence of cyanobacteria and cyanotoxins, pages 213–294. World Health organization and CRC Press, 2 edition.

Imberger, J. and Patterson, J. C. (1989). *Advances in Apllied Mechanis*, volume 27, chapter Physical Limnology, pages 303–475. Elsevier.

Jensen, H. S., Kristensen, P., Jeppesen, E., and Skytthe, A. (1992). Iron: phsphorus ratio in surface sediment as an indicator of phosphate release from aerobic sediments in shallow lakes. *Hydrobiologia*, 235:731–743.

Li, J. (2020). *Managing Eutrophic Waters in Artifical Recharge Plants*. PhD thesis, Faculty of Engineering, Lund University.

McCaffrey, S. (2000). *WATER QUALITY PARAMETERS and INDICATORS*.

Naturvardsverket (unk). Zero eutrophication.

Organization, W. H. (2020). Cyanobacterial toxins: microcystins. *WHO*. WHO/HEP/ECH/WSH/2020.6.

Powers, S., Labou, S., Baulch, H., Hunt, R., Lottig, N., Hampton, S., and Stanley, E. (2017). Ice durationdrives winter nitrate accumulation in north temperate lakes. *Limnology and Oceanography Letters*, 2:177–186.

Prabhakaran, S. (2017). Top 15 evaluation metrics for classification models. Machine Learning +.

Prepas, E. E. and Charette, T. (2003). Worldwide Eutrophication of Water Bodies: Causes, Concerns, Controls. *Treatise on Geochemistry*, 9.

Qiang, Q. B., Guang, G., Wei, Z. G., Lin, Z. Y., Zhi, S. Y., Ming, T. X., Hai, X., and Ming, D. J. (2013). Lake eutrophication and its ecosystem response. *Chinese Science Bulletin*, 58(9):961 to 970.

Ramaraj, R., Tsai, D. W., and Chen, P. H. (2013). Chlorophyll is not Accurate Measurement for AlgalBiomass. *Chiang Mai J. Sci.*, 40(4):547–555.

Rivas, E. J. G., Pérez, G. R., Tundisi, J. G., KatherineVammen, Örmeci, B., and Forde, M. (2020). Eutrophication: A growing problem in the Americas and the Caribbean. *Brazilian journal of biology*, 80(3):688–689.

Steinsberger, T., Schwefel, R., Wüest, A., and Mülle, B. (2020). Hypolimnetic oxygen depletion rates in deep lakes: Effects of trophic state and organic matter accumulation. *Limnology and Oceanography*, 65(12):3128–3138.

sydvatten.se (2021). Vombsjön. Technical report, Sydvatten, https://sydvatten.se/var-verksamhet/rapporter-om-ravattentakter/vombsjon/.

Søndergaard, M., Jensen, J. P., and Jeppesen, E. (2001). Retention and Internal Loading of Phosphorus inShallow, Eutrophic Lakes . *The Scientific World.*

Thornton, J. A., Harding, W. R., Dent, M., Hart, R. C., Lin, H., Rast, C. L., Rast, W., Ryding, S.-O., and Slawski, T. M. (2013). Eutrophication as a ‘wicked’ problem. *Lakes and Reservoirs: Research and Management*, 18:298–316.

Vattenrad (2022). Vattenkontroller. *Kävlingeans vattenrad.*

Vidal, L., Ballot, A., Azevedo, S. M. F. O., Padisak, J., and Welker, M. (2021). *Toxic Cyanobacteria in Water*, chapter Introduction to Cyanobacteria, pages 163–2012. World Health Organization and CRC Press, 2 edition.

Wetzel, R. G. (2001a). *Limnology*, chapter PLANKTONIC COMMUNITIES: ZOOPLANKTON AND THEIR INTERACTIONS WITH FISH, pages 395–488. Gulf Professional Publishing.

Wetzel, R. G. (2001b). *Limnology - Lake and River Ecosystems.* Gulf Professional Publishing, 3 edition.

Widmann, M. (2020). Cohen's kappa: what it is, when to use it, how to avoid pitfalls.

Wilson, H. L., Ayala, A. I., Jones, I. D., Rolston, A., Pierson, D., de Eyto, E., Grossart, H.-P., Perga, M.-E., Woolway, R. I., and Jennings, E. (2020). Variability in epilimnion depth estimations in lakes. *Hydrology and Earth System Sciences*, 24:5559 to 5577.

Xie, P. (2006). Biological mechanisms driving the seasonal changes in theinternal loading of phosphorus in shallow lakes . *Science in China: Series D Earth Sciences*, 49(1):14–27.

Şeyma Merve Kaymaz (2018). Estimating Chlorophyll-A Concentration usingRemote Sensing Techniques. *Annals of Reviews and Research*, 4(2).

A Appendices

A.1 Information on Data

A.1.1 Measurement Locations

Table 12: Coordinates and depth of each measurement location in Lake Vomb.

Location	Longitude	Latitude	Depth [m]
1	55.67135	13.60501667	7-8
2	55.68491667	13.59465	14-16
3	55.6825	13.56628333	6-7
4	55.68525	13.61496667	6-7
5	55.6971	13.5651	4-5
6	55.68611667	13.57646667	9-10

A.1.2 Data sources

Table 13: In- and Outflow.

	Location	Source	Device	Timeframe
Kävlingeån	Outflow	Kävlingeåns vattenråd		2004-2021
Björkaån	Inflow	SMHI	Simulated	2004-2020
Borstbäcken	Inflow	SMHI	Simulated	2004-2020
Torpsbäcken	Inflow	SMHI	Simulated	2004-2020
Weather Data	Hörby	SMHI	Measured	1996-2021
Profile data	Vombsjön	Sydvatten		2014-2021
Satellite data	Vombsjön	Brockmann Geomatics	Sentinel	2016-2020

A.2 Lake profile

A.2.1 Statistics

Table 14: Statistical values of profile data at the surface for the years 2014 to 2021 of the sites 1 -3.

Year	Site	pH			DO [mg/l]			Temp [°C]		
		min	max	mean	min	max	mean	min	max	mean
2014	1	8.47	8.95	8.74	8.72	15.72	11.48	18.70	24.10	21.20
2016	1	8.65	9.28	8.96	8.19	17.10	10.97	17.90	23.10	19.77
2017	1	8.29	8.94	8.63	7.37	13.52	9.54	16.20	19.60	18.39
2018	1	7.97	9.16	8.75	6.78	16.47	9.26	3.60	24.40	18.63
2019	1	8.13	8.70	8.45	6.77	11.70	9.07	4.90	22.00	17.45
2020	1	6.04	8.84	8.48	7.19	13.70	10.58	4.80	22.00	16.79
2021	1	8.22	9.16	8.73	7.59	16.72	9.62	4.00	23.00	18.31
2014	2	8.40	8.91	8.70	7.72	14.68	11.02	18.70	24.00	21.36
2016	2	8.47	9.19	8.86	7.81	17.74	10.81	18.00	23.40	19.82
2017	2	7.29	8.96	8.53	7.98	13.42	9.67	14.90	19.50	18.37
2018	2	8.15	9.29	8.78	6.38	15.83	9.21	3.70	24.30	18.71
2019	2	8.17	8.75	8.45	6.76	12.24	8.96	4.90	21.80	17.57
2020	2	7.67	9.14	8.51	6.96	14.13	10.45	4.60	22.80	16.89
2021	2	8.22	9.10	8.74	7.74	16.18	9.52	3.90	22.70	18.32
2014	3	8.43	8.94	8.74	8.11	14.39	11.45	18.70	24.10	21.46
2016	3	8.49	9.18	8.88	8.12	18.76	11.16	18.10	23.30	19.88
2017	3	7.53	8.86	8.55	8.22	13.17	9.68	16.90	19.40	18.52
2018	3	8.22	9.39	8.84	6.24	17.57	9.53	3.70	24.60	19.27
2019	3	8.18	8.83	8.47	6.37	12.14	8.96	4.90	22.50	17.62
2020	3	7.86	8.90	8.51	7.07	14.24	10.51	4.70	23.80	17.05
2021	3	8.25	9.24	8.75	6.97	15.78	9.62	3.90	23.50	18.29

Table 15: Statistical values of profile data at the surface for the years 2014 to 2021 of the sites 4 -6.

Year	Site	pH			DO [mg/l]			Temp [°C]		
		min	max	mean	min	max	mean	min	max	mean
2014	4	8.43	8.89	8.69	7.95	14.97	10.95	18.70	24.40	21.24
2016	4	8.50	9.14	8.85	8.08	16.30	10.46	17.70	23.90	19.79
2017	4	6.43	8.91	8.43	8.04	13.54	9.65	16.80	20.60	18.83
2018	4	8.05	9.26	8.82	5.97	16.26	9.53	3.80	24.60	19.30
2019	4	8.13	8.61	8.42	6.38	12.52	9.10	4.80	21.90	17.60
2020	4	8.00	9.01	8.51	7.28	13.34	10.59	4.80	22.90	16.97
2021	4	8.24	9.09	8.75	7.88	16.09	9.54	4.10	22.90	18.41
2014	5	8.48	8.93	8.71	8.25	14.90	11.05	18.70	24.30	21.74
2016	5	8.48	9.15	8.84	8.36	16.93	10.51	17.70	24.50	19.80
2017	5	8.25	8.86	8.61	7.24	13.06	9.74	17.00	19.70	18.53
2018	5	8.21	9.34	8.81	6.44	15.51	9.27	3.50	24.80	19.22
2019	5	8.21	8.74	8.47	6.87	12.09	8.94	4.90	22.30	17.59
2020	5	7.98	8.88	8.53	7.60	14.27	10.41	4.80	23.80	17.09
2021	5	8.29	9.25	8.75	7.00	15.81	9.61	3.90	23.60	18.26
2014	6	8.42	8.90	8.74	7.85	14.15	11.40	18.80	24.20	21.55
2016	6	8.53	9.22	8.88	7.95	17.87	10.69	17.90	23.90	19.82
2017	6	8.39	8.85	8.59	8.10	13.25	9.84	17.00	19.40	18.60
2018	6	8.19	9.41	8.84	6.30	17.44	9.57	3.80	25.00	19.28
2019	6	8.24	8.80	8.48	6.85	12.04	9.11	4.80	22.40	17.69
2020	6	8.00	8.90	8.56	6.78	14.42	10.52	4.70	23.80	17.08
2021	6	8.25	9.24	8.73	6.73	15.99	9.60	3.90	23.30	18.34

Table 16: Statistical values of profile data at the bottom for the years 2014 to 2021 of the sites 1 - 3.

Year	Site	pH			DO [mg/l]			Temp [°C]		
		min	max	mean	min	max	mean	min	max	mean
2014	1	7.63	8.59	7.94	0.06	10.47	2.87	18.10	22.10	20.16
2016	1	8.03	9.12	8.44	0.24	8.74	3.91	17.80	19.70	18.84
2017	1	8.18	8.63	8.41	2.59	9.73	7.37	16.20	19.00	18.06
2018	1	7.80	8.90	8.45	0.12	13.35	6.58	3.60	23.20	17.85
2019	1	7.98	8.59	8.28	3.31	11.59	7.78	4.90	21.80	17.06
2020	1	5.16	8.83	8.21	1.00	12.52	8.25	4.80	20.30	16.20
2021	1	7.89	9.00	8.44	2.64	16.03	7.51	3.90	22.90	17.44
2014	2	7.59	8.59	7.83	0.03	9.96	1.99	17.70	21.10	19.90
2016	2	7.81	9.01	8.24	0.01	9.89	4.10	17.60	19.30	18.48
2017	2	7.74	8.63	8.32	1.50	9.34	6.83	16.10	19.10	18.05
2018	2	7.33	8.87	8.10	0.00	12.94	3.47	3.70	22.80	15.59
2019	2	7.57	8.61	8.12	0.22	11.98	6.18	4.90	21.10	16.73
2020	2	7.54	8.72	8.11	0.06	12.08	5.84	4.60	19.30	15.66
2021	2	7.71	8.85	8.23	0.02	16.12	5.28	4.00	21.30	16.38
2014	3	7.71	8.53	8.07	0.04	8.90	4.52	18.00	21.90	20.21
2016	3	7.71	8.88	8.36	0.02	9.41	4.99	17.90	19.10	18.69
2017	3	8.20	8.68	8.48	4.79	10.11	8.00	16.90	19.00	18.17
2018	3	7.55	9.30	8.44	0.03	13.50	6.30	3.70	23.70	18.15
2019	3	8.13	8.69	8.38	4.10	11.74	7.88	4.90	22.20	17.17
2020	3	7.89	8.82	8.40	0.10	13.05	7.99	4.70	20.80	16.24
2021	3	7.93	9.12	8.49	2.31	15.96	7.71	3.90	22.20	17.49

Table 17: Statistical values of profile data at the bottom for the years 2014 to 2021 of the sites 4 -6.

Year	Site	pH			DO [mg/l]			Temp [°C]		
		min	max	mean	min	max	mean	min	max	mean
2014	4	7.84	8.63	8.16	0.53	9.81	6.05	18.40	22.20	20.12
2016	4	7.86	8.52	8.25	0.31	8.34	3.40	17.50	19.60	18.72
2017	4	8.22	8.92	8.54	0.36	13.15	8.30	16.70	19.50	18.48
2018	4	7.79	8.97	8.57	0.54	14.18	7.01	3.80	24.40	18.38
2019	4	8.05	8.73	8.36	3.90	11.99	7.82	4.80	21.60	17.17
2020	4	7.73	8.84	8.32	0.06	12.54	7.46	4.80	20.30	16.15
2021	4	7.86	9.03	8.47	1.90	16.01	7.55	4.00	22.70	17.44
2014	5	7.69	8.79	8.44	1.08	12.93	8.63	18.30	23.40	21.17
2016	5	7.95	8.98	8.59	0.90	9.80	6.62	17.60	20.00	19.01
2017	5	7.76	8.80	8.46	4.96	12.23	8.57	16.70	19.60	18.19
2018	5	8.20	9.30	8.69	5.34	15.04	8.17	3.50	24.60	18.53
2019	5	8.19	8.80	8.45	6.36	11.99	8.51	4.90	22.20	17.38
2020	5	7.99	8.89	8.47	5.68	13.87	9.07	4.80	22.40	16.54
2021	5	8.03	9.19	8.57	3.55	16.01	8.20	3.80	22.50	17.61
2014	6	7.66	8.45	7.90	0.06	9.04	2.66	18.50	21.60	20.04
2016	6	7.83	8.84	8.29	0.14	8.28	3.62	17.40	19.40	18.62
2017	6	7.96	8.60	8.39	3.41	9.37	7.35	16.90	18.90	18.11
2018	6	7.72	8.99	8.29	0.00	13.25	4.99	3.80	23.10	17.49
2019	6	7.90	8.62	8.28	3.49	11.86	7.38	4.70	21.20	16.99
2020	6	7.61	8.76	8.28	0.03	12.22	7.30	4.70	19.50	16.01
2021	6	7.76	9.04	8.38	0.62	15.66	6.90	3.90	21.90	17.09

Table 18: Percent of thermoclines each year and site on all measurements.

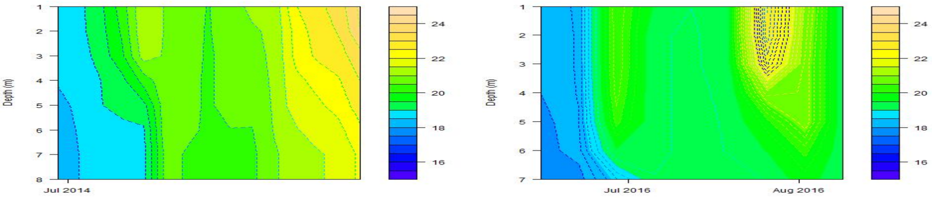
Percent	1	2	3	4	5	6
2014	0	0	7	0	0	7
2015		0	17	0		
2016	33	11	11	0	11	0
2017	0	5	5	6	0	0
2018	0	0	19	0	0	0
2019	0	3	9	0	0	0
2020	0	24	4	0	0	8
2021	19	11	14	11	14	8
SUM	6	7	11	3	3	3

Table 19: Percent of oxygen deficiencies each year and site on all measurements.

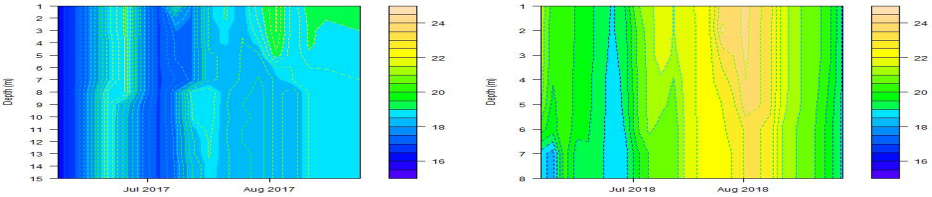
Percent	1	2	3	4	5	6
2014	60	76	27	6	7	57
2015		83	83	100		
2016	56	44	33	33	11	33
2017	0	9	0	28	0	0
2018	8	47	14	3	0	28
2019	0	14	0	3	0	0
2020	4	24	4	0	0	12
2021	0	24	0	3	0	8
SUM	10	33	10	11	1	15

A.2.2 Temperature Profiles

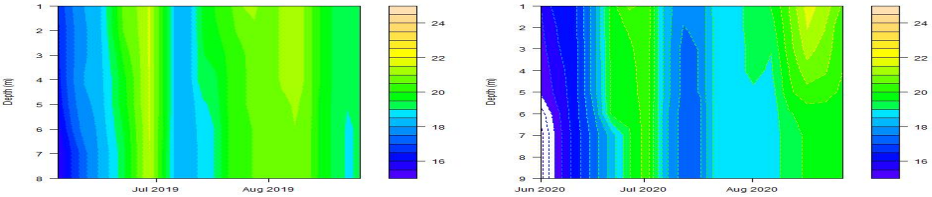
The temperature profiles show the interpolated values based on measurements from Sydvatten from 2014 to 2021 in °C.


(a) Temperature Profile 2014

(b) Temperature Profile 2016


(c) Temperature Profile 2017

(d) Temperature Profile 2018


(e) Temperature Profile 2019

(f) Temperature Profile 2020

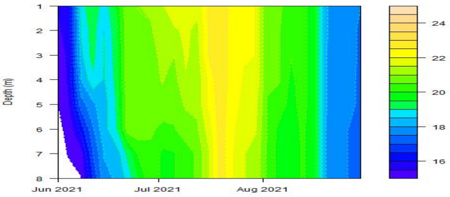
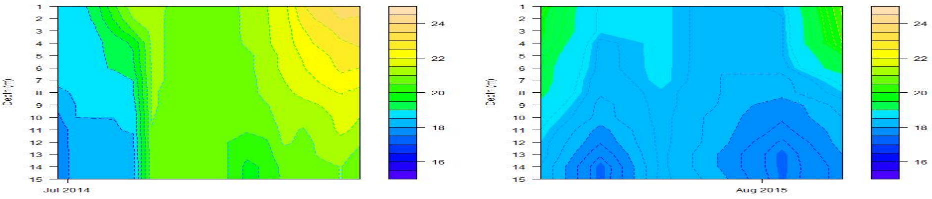
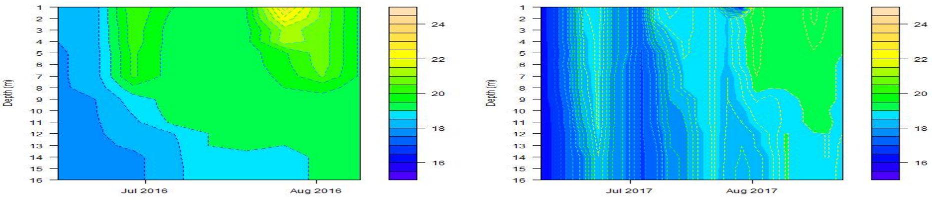

(g) Temperature Profile 2021

Figure 28: Temperature profile at site 1 for the years from 2014 till 2021



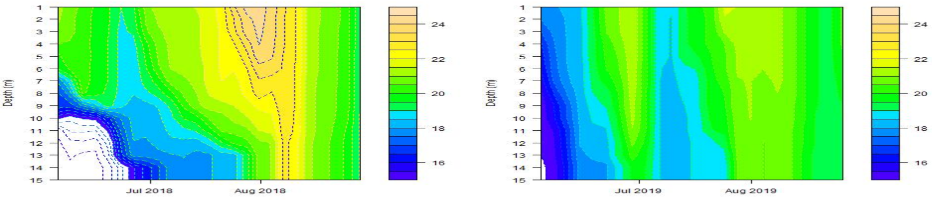
(a) Temperature Profile 2014

(b) Temperature Profile 2015



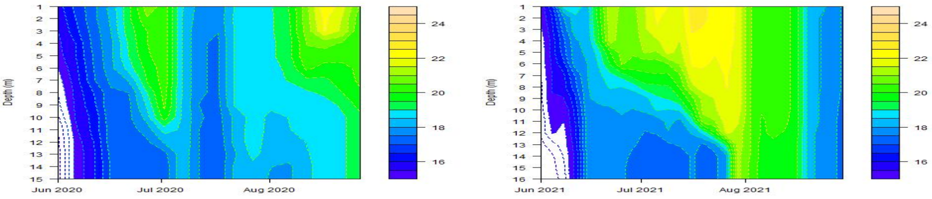
(c) Temperature Profile 2016

(d) Temperature Profile 2017



(e) Temperature Profile 2018

(f) Temperature Profile 2019

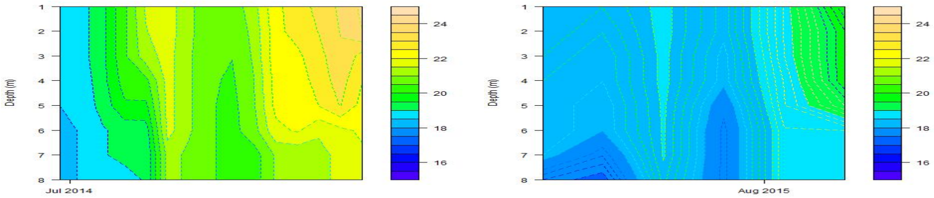


(g) Temperature Profile 2020

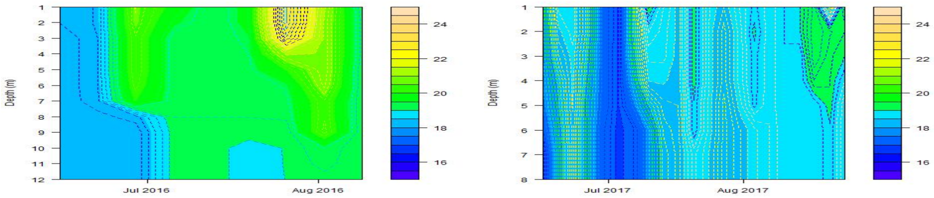
(h) Temperature Profile 2021

Figure 29: Temperature profile at site 2 for the years from 2014 till 2021

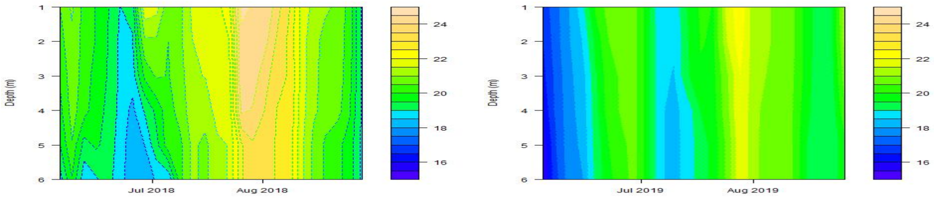
(a) Temperature Profile 2014 (b) Temperature Profile 2015



(c) Temperature Profile 2016 (d) Temperature Profile 2017



(e) Temperature Profile 2018 (f) Temperature Profile 2019



(g) Temperature Profile 2020 (h) Temperature Profile 2021

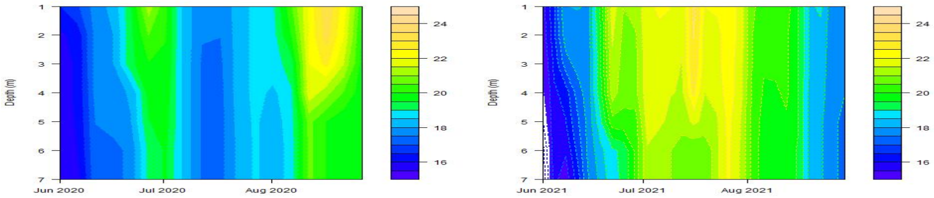
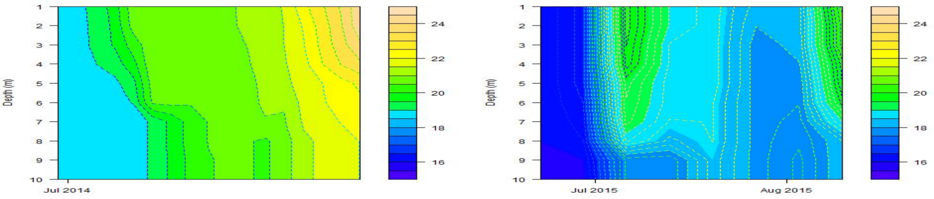
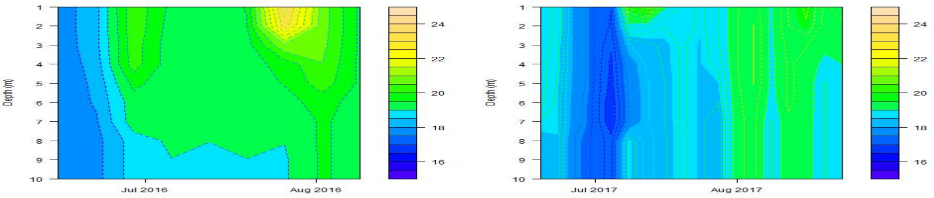


Figure 30: Temperature profile at site 3 for the years from 2014 till 2021

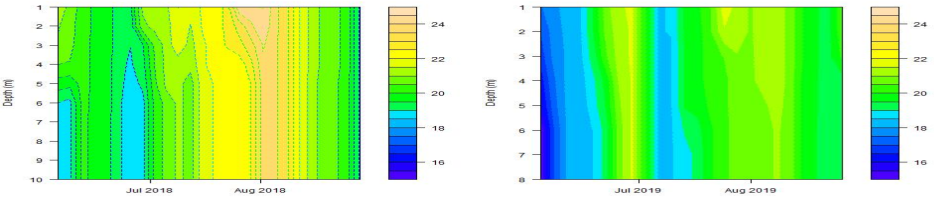
(a) Temperature Profile 2014 (b) Temperature Profile 2015



(c) Temperature Profile 2016 (d) Temperature Profile 2017



(e) Temperature Profile 2018 (f) Temperature Profile 2019



(g) Temperature Profile 2020 (h) Temperature Profile 2021

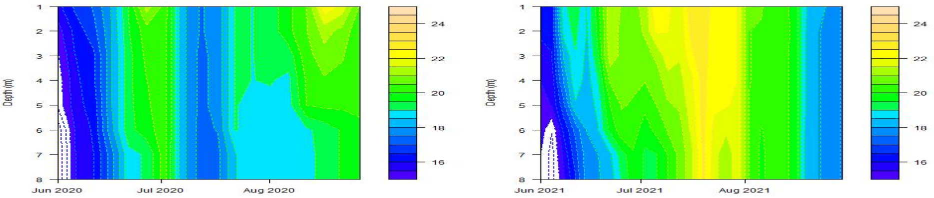
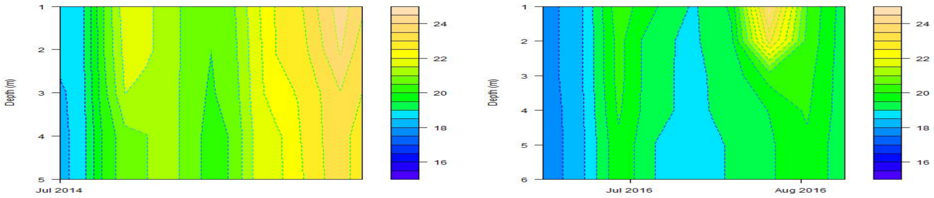
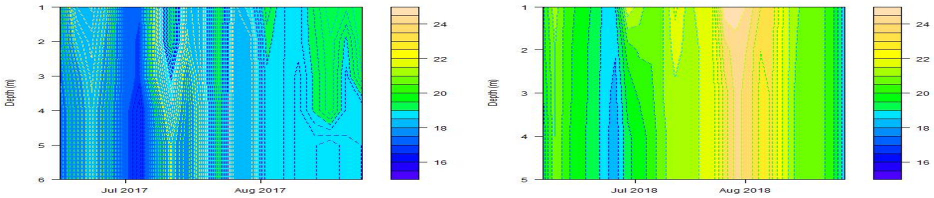


Figure 31: Temperature profile at site 5 for the years from 2014 till 2021

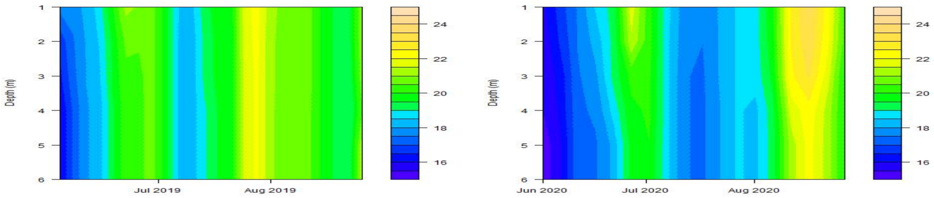
(a) Temperature Profile 2014 (b) Temperature Profile 2016



(c) Temperature Profile 2017 (d) Temperature Profile 2018



(e) Temperature Profile 2019 (f) Temperature Profile 2020



(g) Temperature Profile 2021

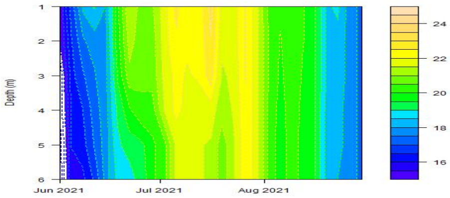
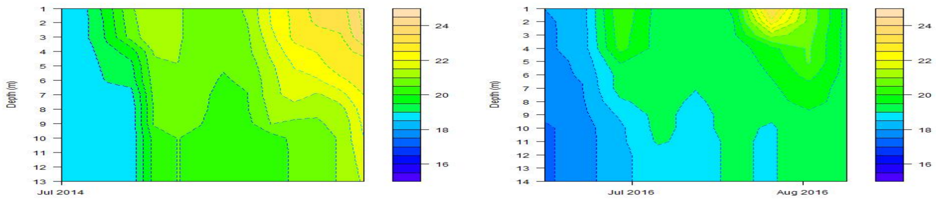
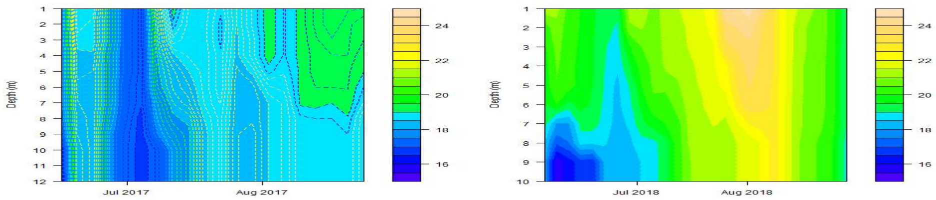


Figure 32: Temperature profile at site 5 for the years from 2014 till 2021



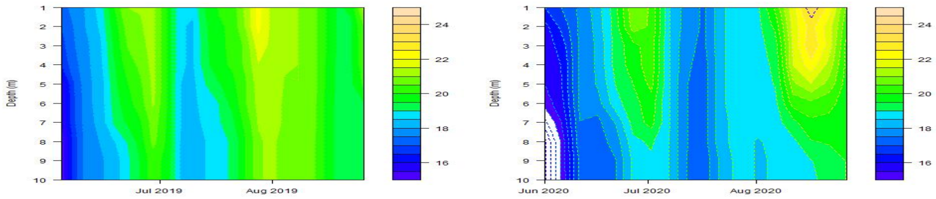
(a) Temperature Profile 2014

(b) Temperature Profile 2016



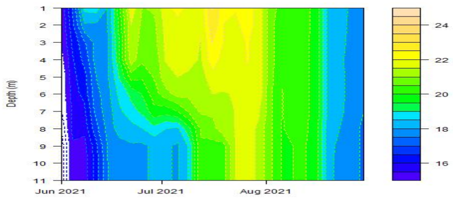
(c) Temperature Profile 2017

(d) Temperature Profile 2018



(e) Temperature Profile 2019

(f) Temperature Profile 2020

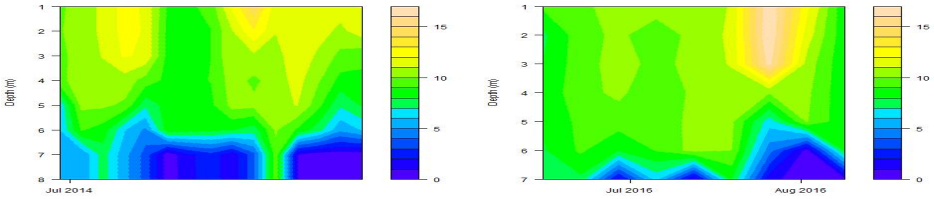


(g) Temperature Profile 2021

Figure 33: Temperature profile at site 6 for the years from 2014 till 2021

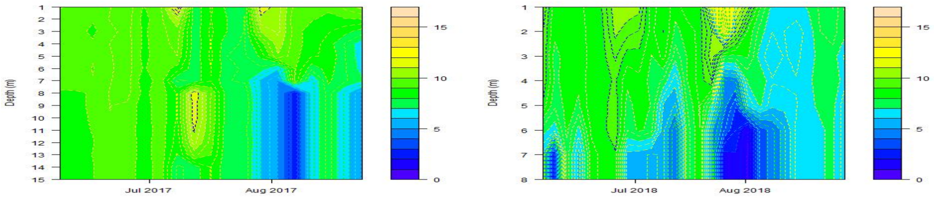
A.2.3 Dissolved Oxygen Profile

The dissolved oxygen profiles show the interpolated values based on measurements from Sydvatten from 2014 to 2021 in mg/l.



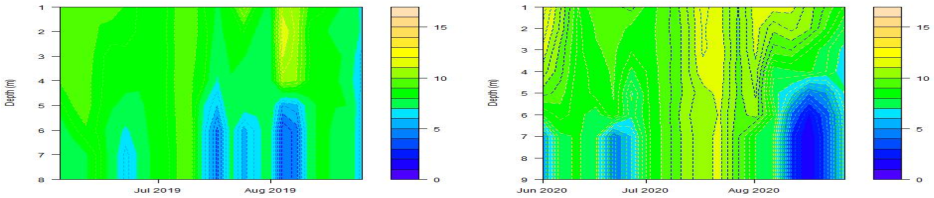
(a) Dissolved Oxygen Profile 2014

(b) Dissolved Oxygen Profile 2016



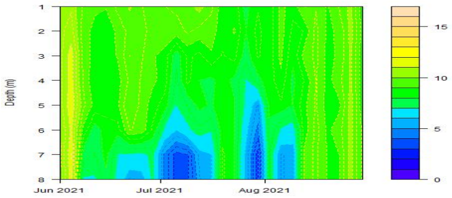
(c) Dissolved Oxygen Profile 2017

(d) Dissolved Oxygen Profile 2018



(e) Dissolved Oxygen Profile 2019

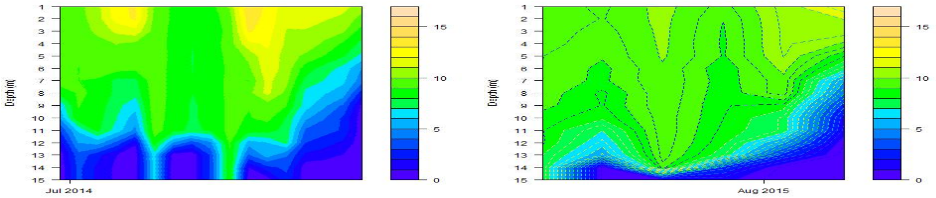
(f) Dissolved Oxygen Profile 2020



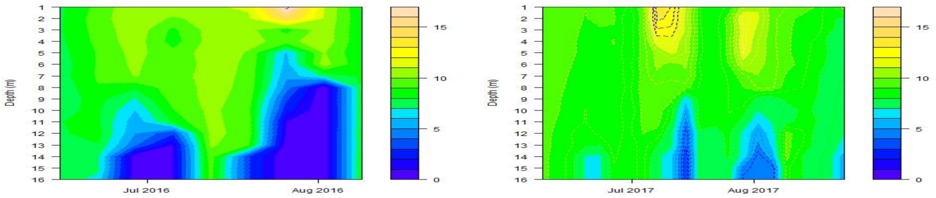
(g) Dissolved Oxygen Profile 2021

Figure 34: Dissolved Oxygen profile at site 1 for the years from 2014 till 2021

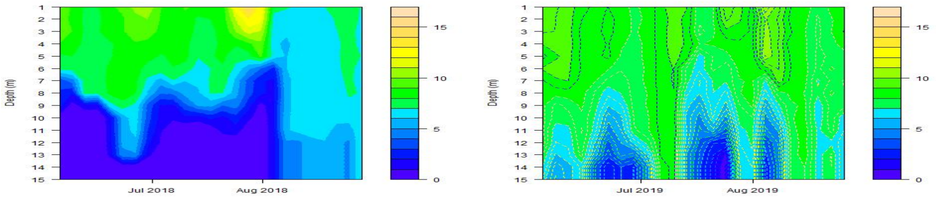
(a) Dissolved Oxygen Profile 2014 (b) Dissolved Oxygen Profile 2015



(c) Dissolved Oxygen Profile 2016 (d) Dissolved Oxygen Profile 2017



(e) Dissolved Oxygen Profile 2018 (f) Dissolved Oxygen Profile 2019



(g) Dissolved Oxygen Profile 2020 (h) Dissolved Oxygen Profile 2021

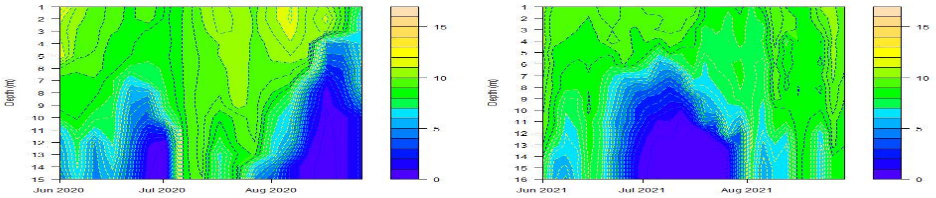
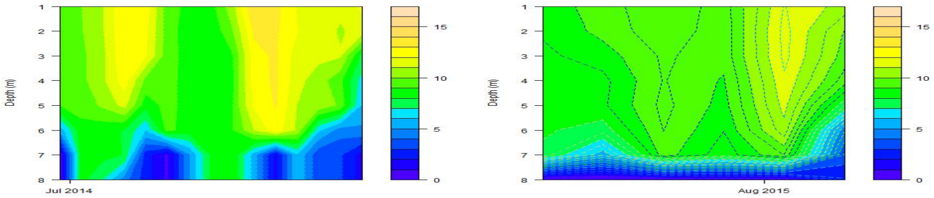
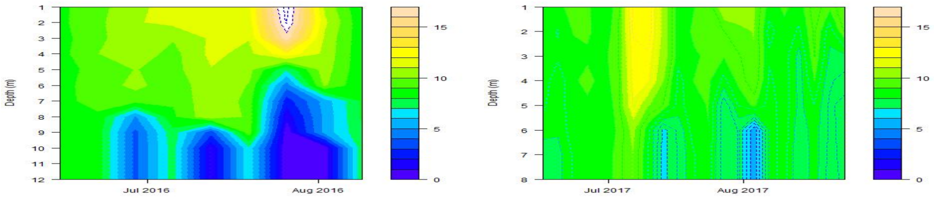


Figure 35: Dissolved Oxygen profile at site 2 for the years from 2014 till 2021

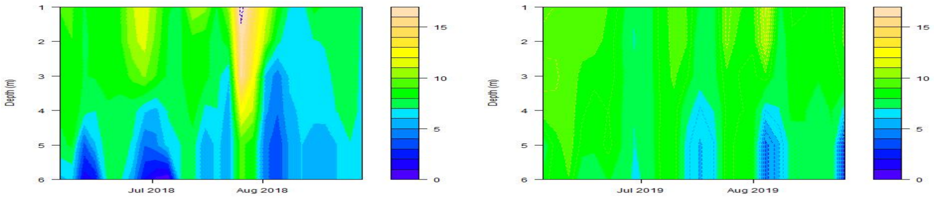
(a) Dissolved Oxygen Profile 2014 (b) Dissolved Oxygen Profile 2015



(c) Dissolved Oxygen Profile 2016 (d) Dissolved Oxygen Profile 2017



(e) Dissolved Oxygen Profile 2018 (f) Dissolved Oxygene Profile 2019



(g) Dissolved Oxygen Profile 2020 (h) Dissolved Oxygen Profile 2021

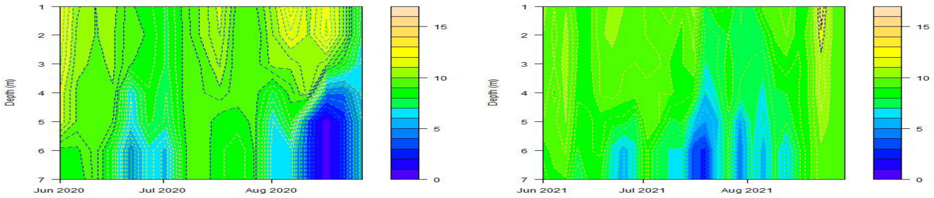
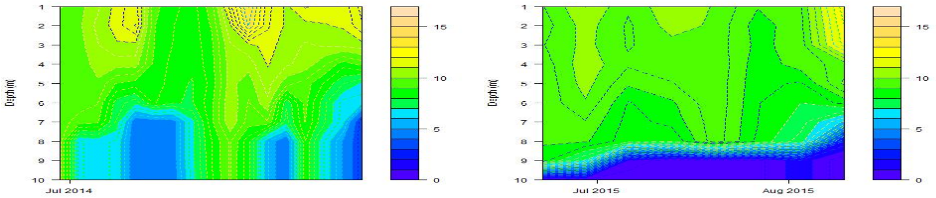
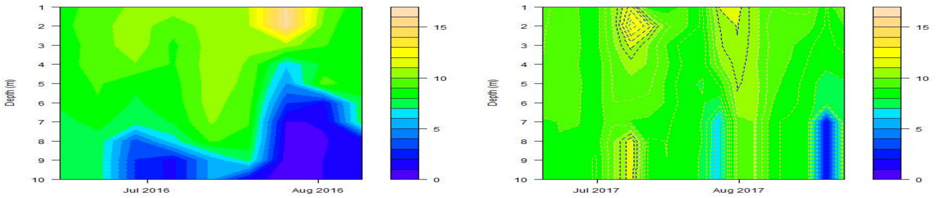


Figure 36: Dissolved Oxygen profile at site 3 for the years from 2014 till 2021



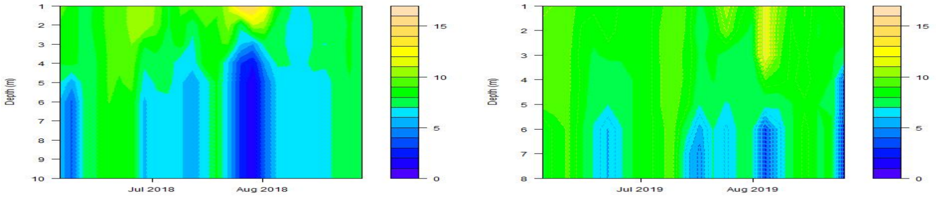
(a) Dissolved Oxygen Profile 2014

(b) Dissolved Oxygen Profile 2015



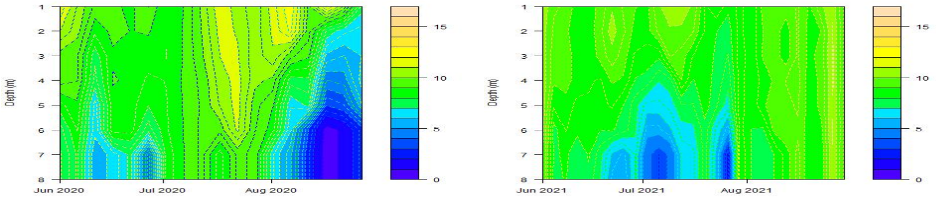
(c) Dissolved Oxygen Profile 2016

(d) Dissolved Oxygen Profile 2017



(e) Dissolved Oxygen Profile 2018

(f) Dissolved Oxygen Profile 2019

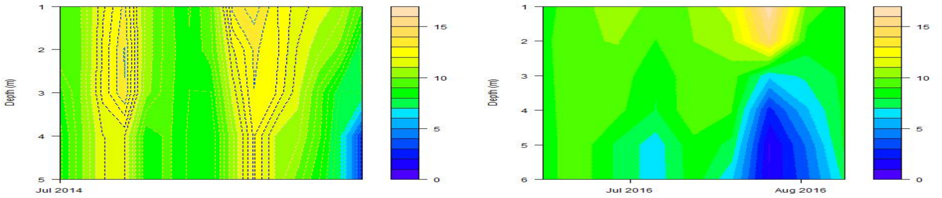


(g) Dissolved Oxygen Profile 2020

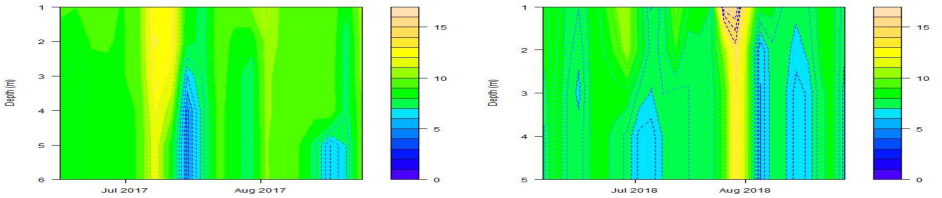
(h) Dissolved Oxygen Profile 2021

Figure 37: Dissolved Oxygen profile at site 4 for the years from 2014 till 2021

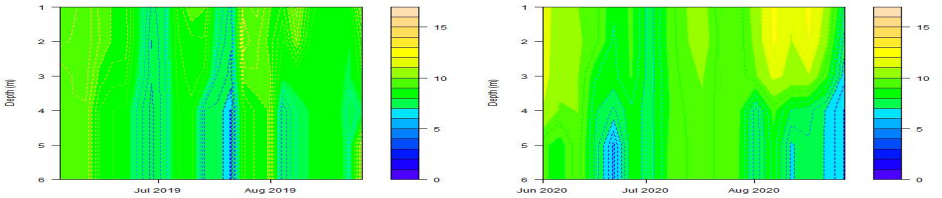
(a) Dissolved Oxygen Profile 2014
(b) Dissolved Oxygen Profile 2016



(c) Dissolved Oxygen Profile 2017
(d) Dissolved Oxygen Profile 2018



(e) Dissolved Oxygen Profile 2019
(f) Dissolved Oxygen Profile 2020



(g) Dissolved Oxygen Profile 2021

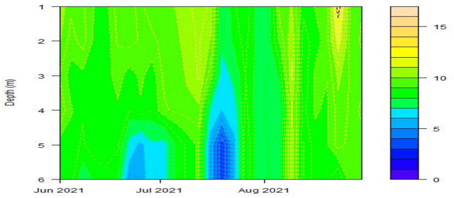
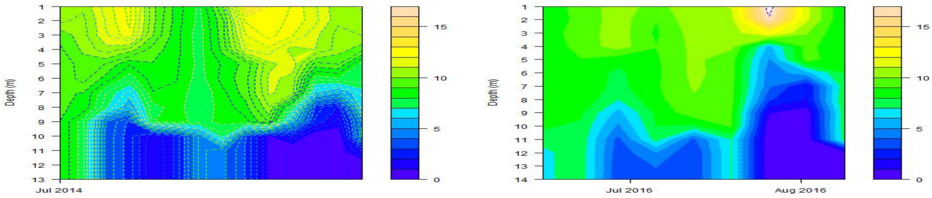
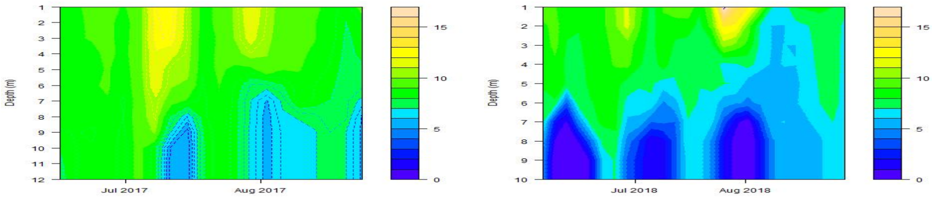


Figure 38: Dissolved Oxygen profile at site 5 for the years from 2014 till 2021

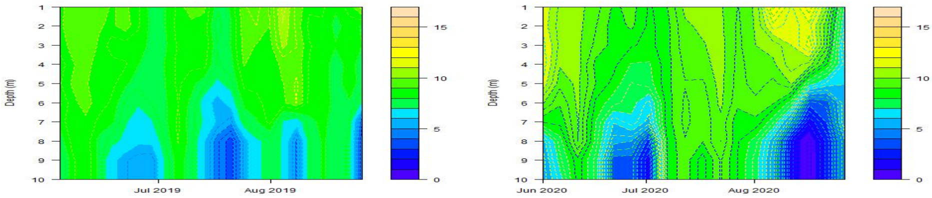
(a) Dissolved Oxygen Profile 2014 (b) Dissolved Oxygen Profile 2016



(c) Dissolved Oxygen Profile 2017 (d) Dissolved Oxygen Profile 2018



(e) Dissolved Oxygen Profile 2019 (f) Dissolved Oxygen Profile 2020



(g) Dissolved Oxygen Profile 2021

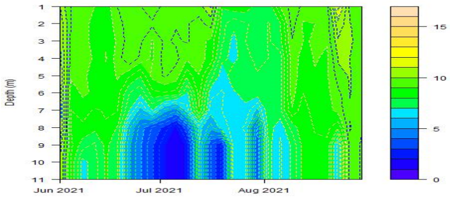
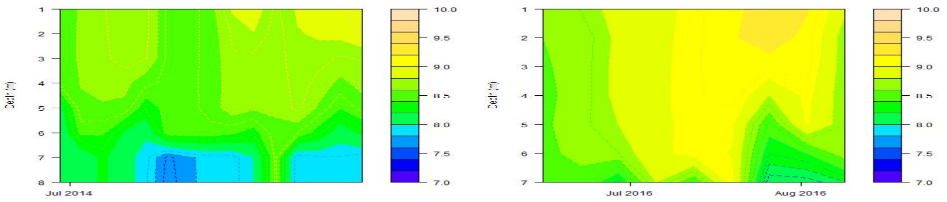


Figure 39: Dissolved Oxygen profile at site 6 for the years from 2014 till 2021

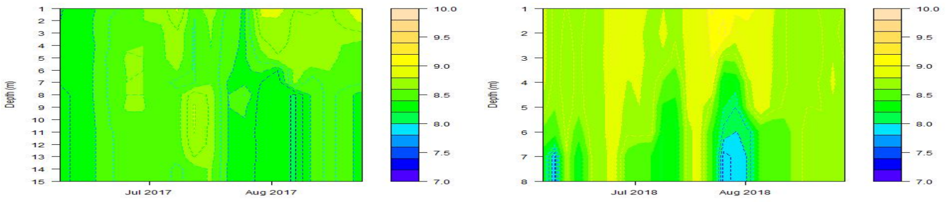
A.2.4 pH profiles

The pH profiles show the interpolated values based on measurements from Sydvatten from 2014 to 2021.



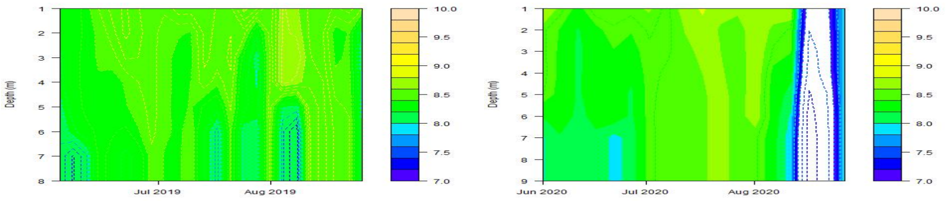
(a) pH Profile 2014

(b) pH Profile 2016



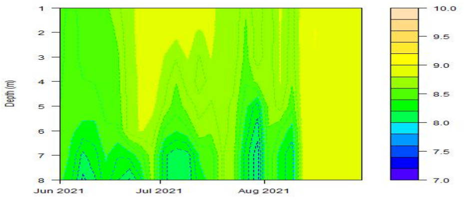
(c) pH Profile 2017

(d) pH Profile 2018



(e) pH Profile 2019

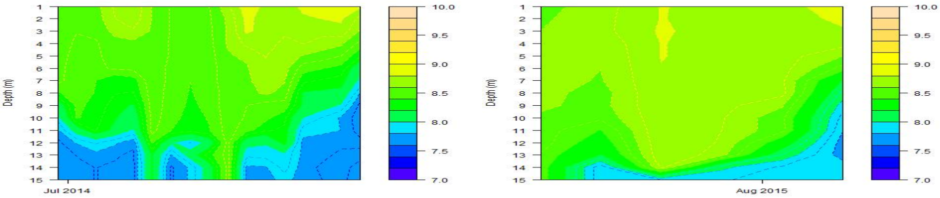
(f) pH Profile 2020



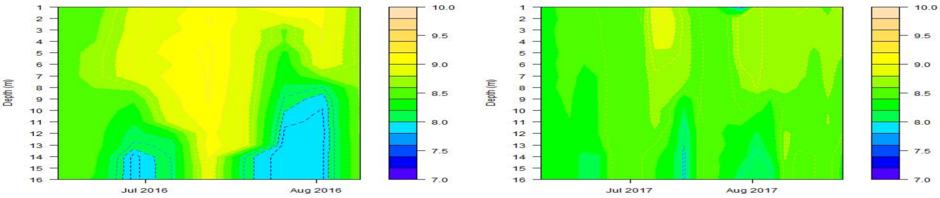
(g) pH Profile 2021

Figure 40: pH profile at site 1 for the years from 2014 till 2021

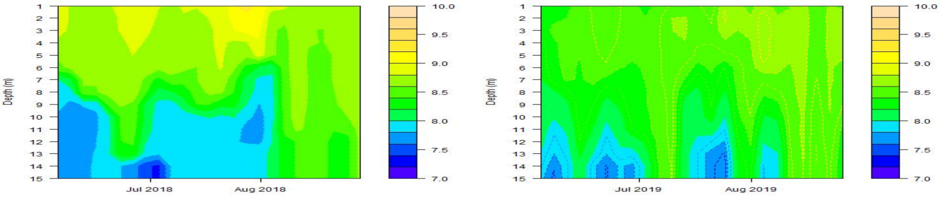
(a) pH Profile 2014 (b) pH Profile 2015



(c) pH Profile 2016 (d) pH Profile 2017



(e) pH Profile 2018 (f) pH Profile 2019



(g) pH Profile 2020 (h) pHProfile 2021

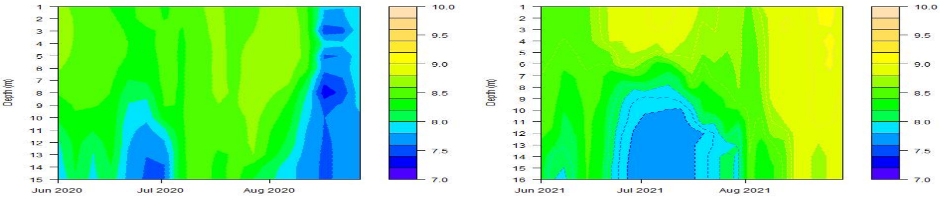
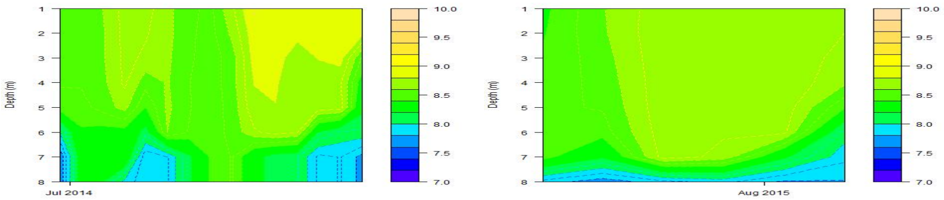
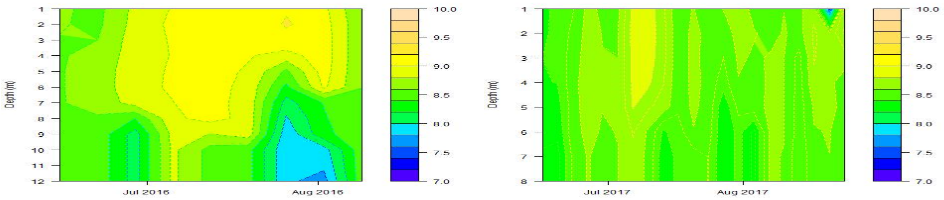


Figure 41: pH profile at site 2 for the years from 2014 till 2021

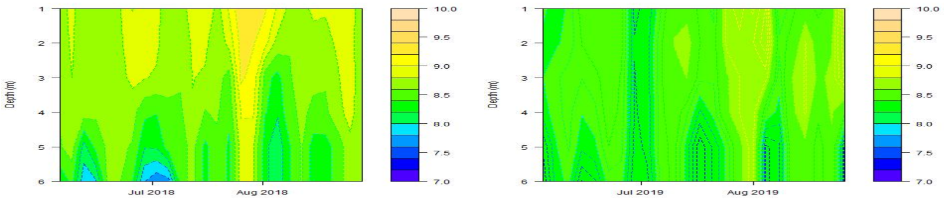
(a) pH Profile 2014 (b) pH Profile 2015



(c) pH Profile 2016 (d) pH Profile 2017



(e) pH Profile 2018 (f) pH Profile 2019



(g) pH Profile 2020 (h) pH Profile 2021

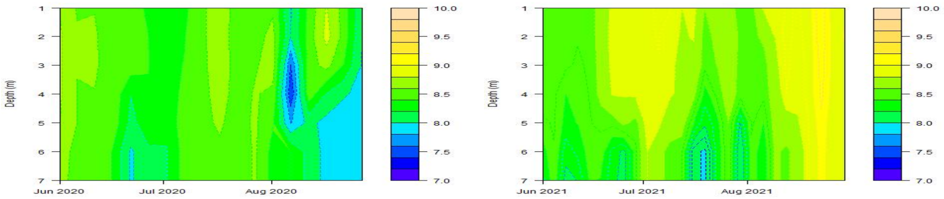
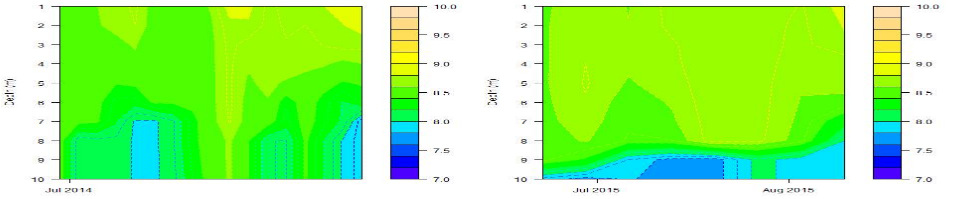
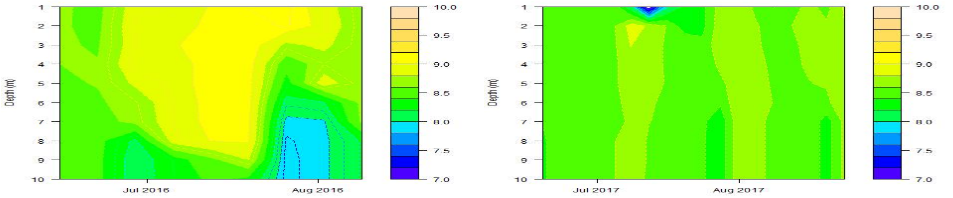


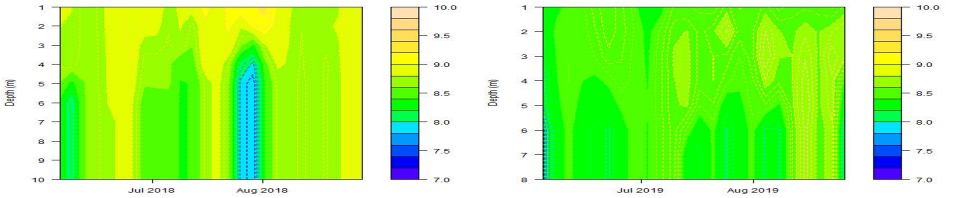
Figure 42: pH profile at site 3 for the years from 2014 till 2021


(a) pH Profile 2014

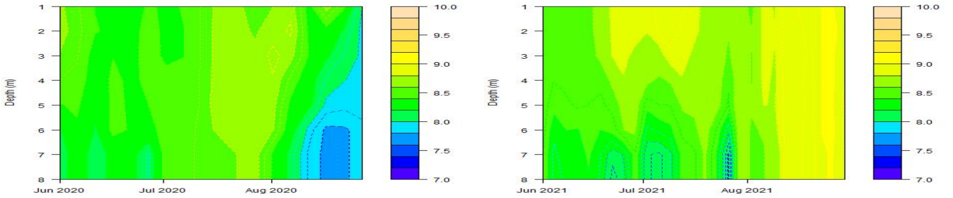
(b) pH Profile 2015


(c) pH Profile 2016

(d) pH Profile 2017

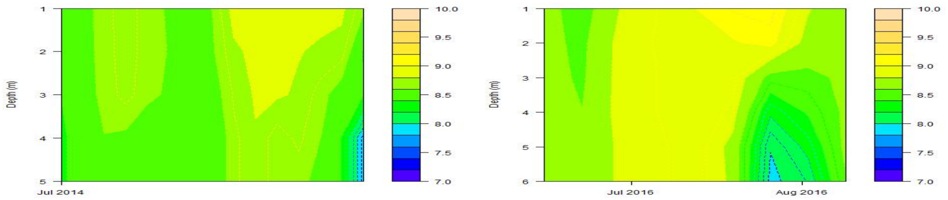

(e) pH Profile 2018

(f) pH Profile 2019

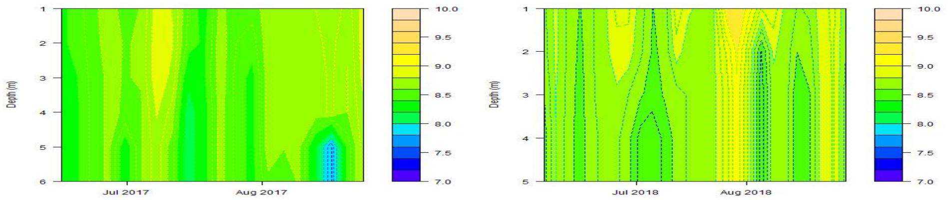

(g) pH Profile 2020

(h) pH Profile 2021

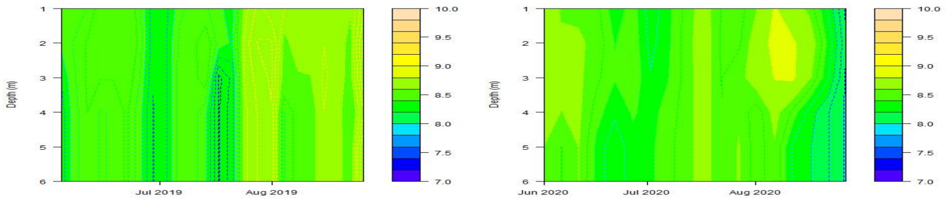
Figure 43: pH profile at site 4 for the years from 2014 till 2021


(a) pH Profile 2014

(b) pH Profile 2016


(c) pH Profile 2017

(d) pH Profile 2018


(e) pH Profile 2019

(f) pH Profile 2020

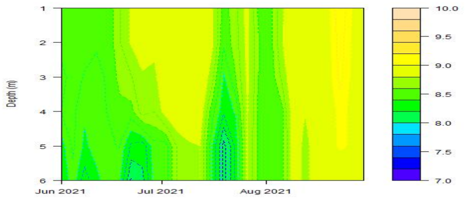
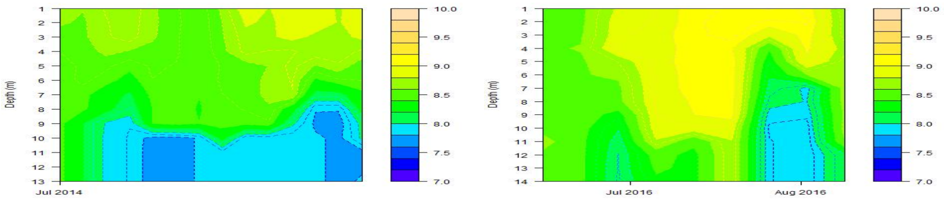
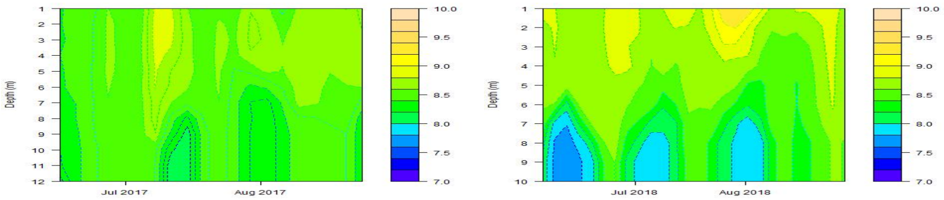

(g) pH Profile 2021

Figure 44: pH profile at site 5 for the years from 2014 till 2021

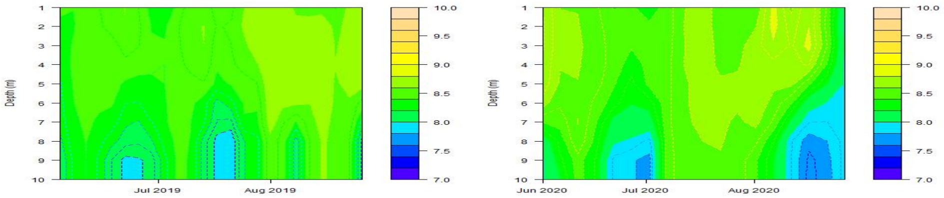
(a) pH profile 2014 (b) pH profile 2016



(c) pH profile 2017 (d) pH profile 2018



(e) pH profile 2019 (f) pH profile 2020



(g) pH profile 2021

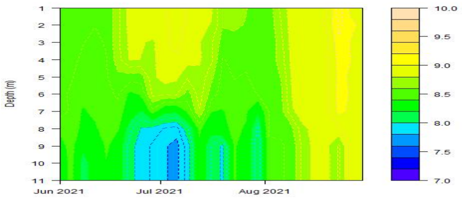


Figure 45: pH profile at site 6 for the years from 2014 till 2021

A.2.5 Meteorological data with thermocline and oxygen deficiency

Figure 46: Meteorologial Data and thermocline, oxygen deficiency

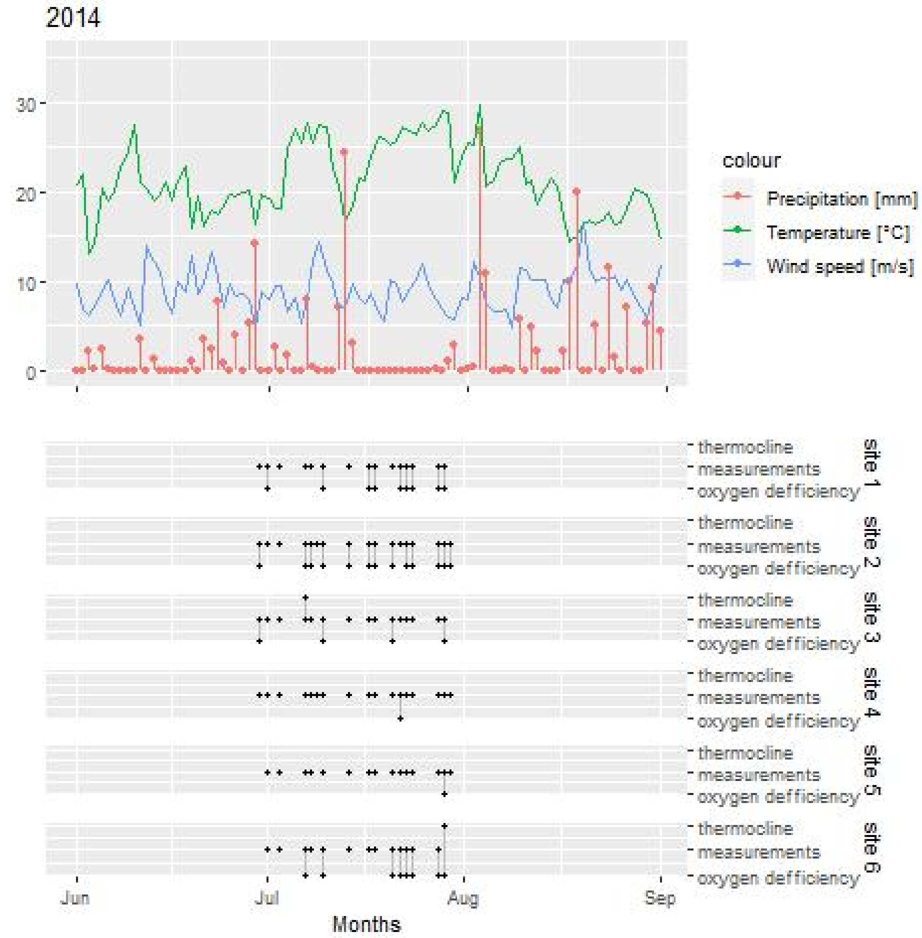


Figure 47: Meteorologial Data and thermocline, oxygen deficiency

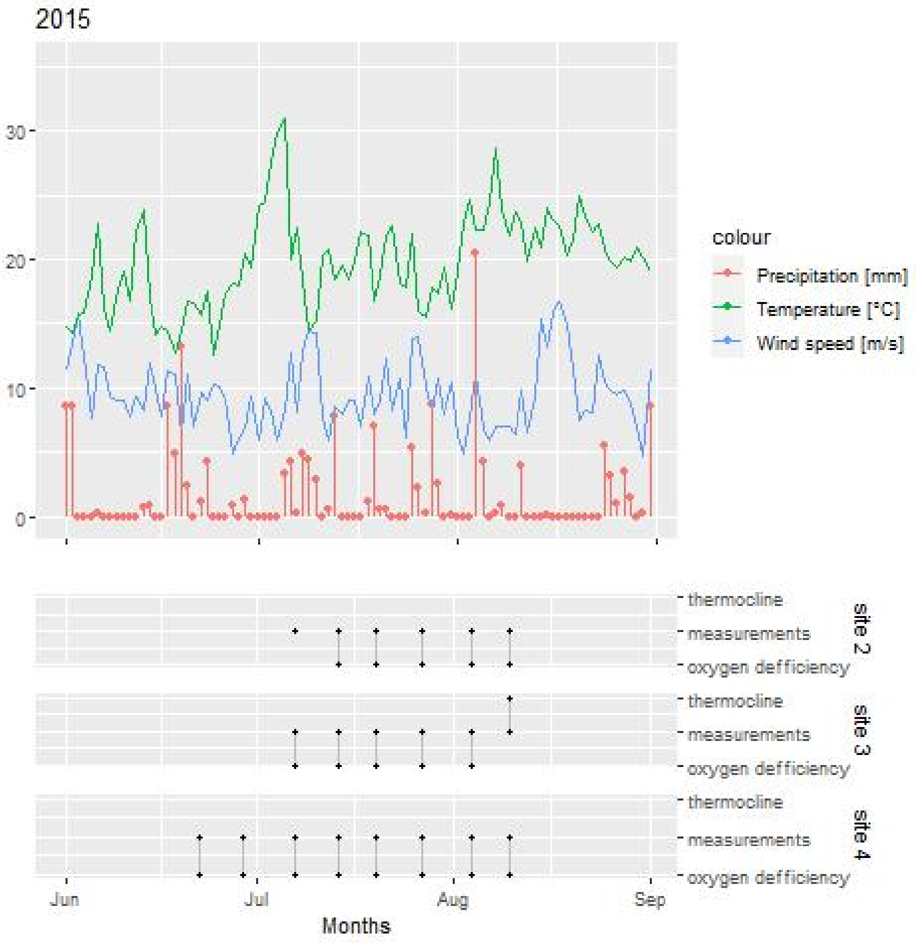


Figure 48: Meteorologial Data and thermocline, oxygen deficiency

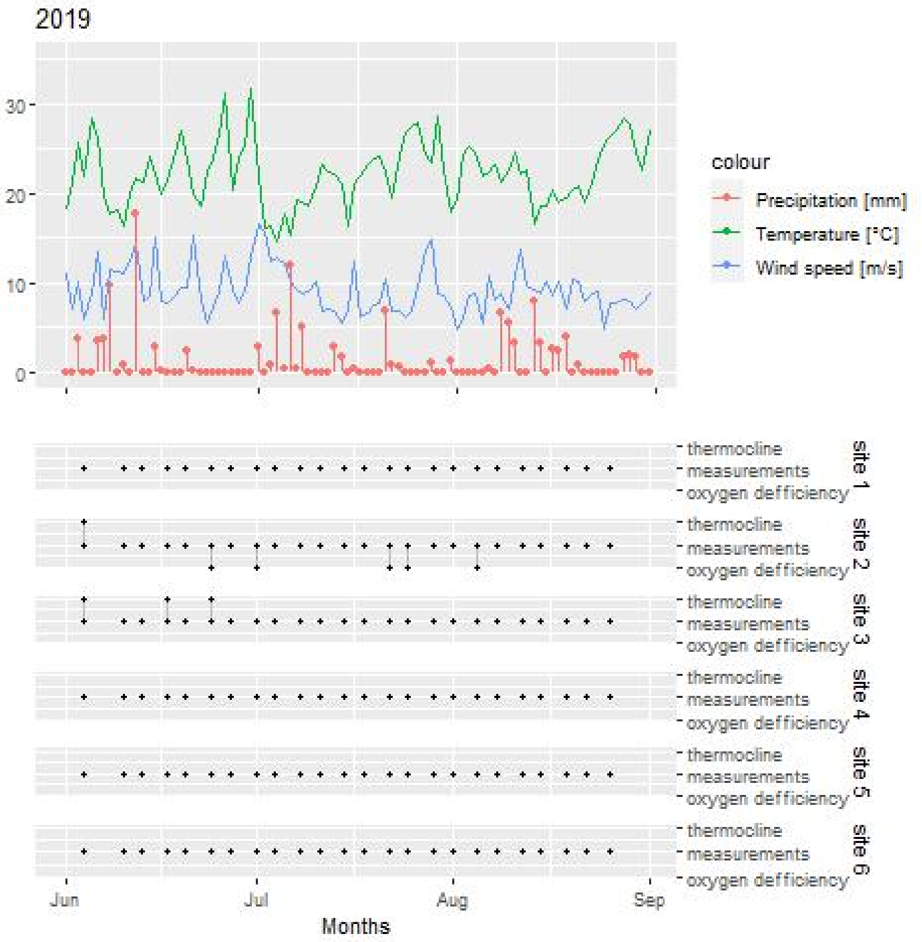


Figure 49: Meteorologial Data and thermocline, oxygen deficiency

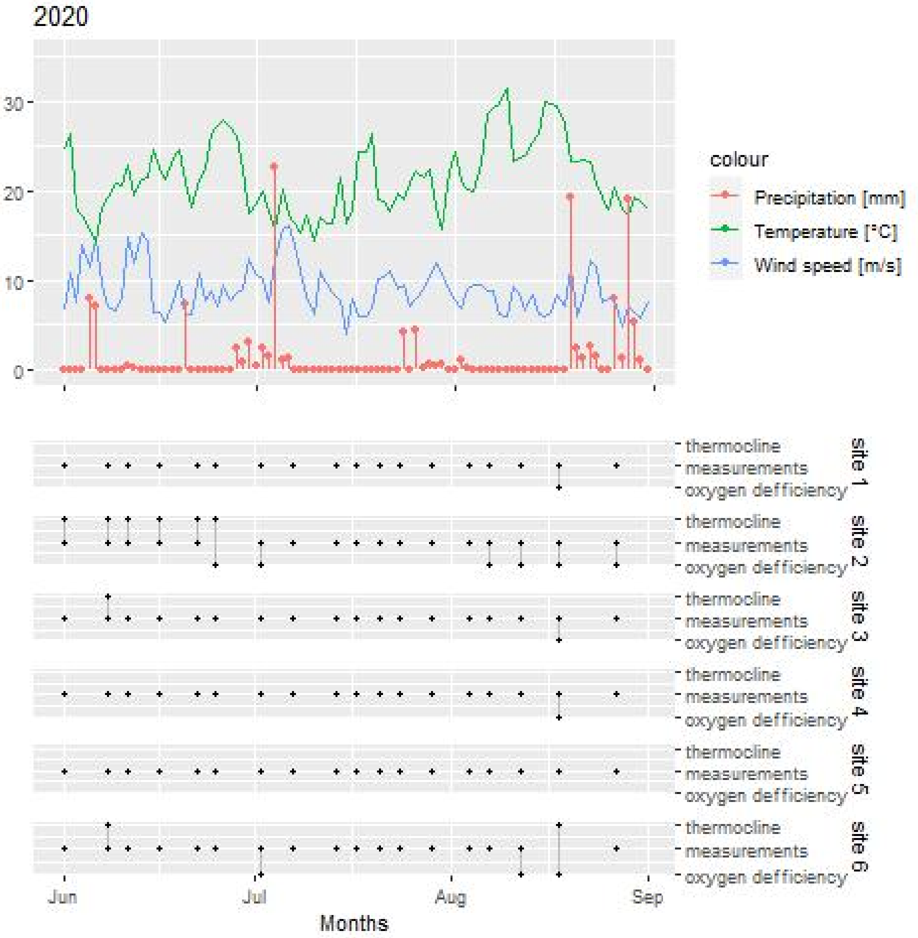
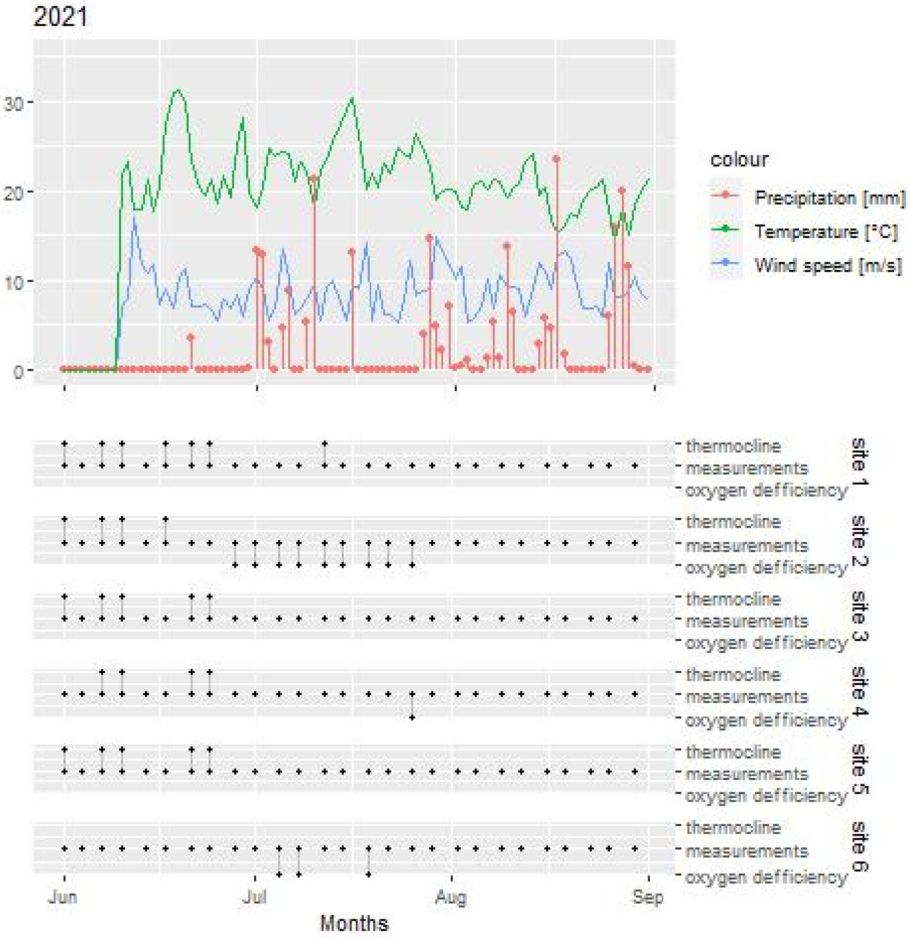


Figure 50: Meteorologial Data and thermocline, oxygen deficiency



A.3 In- and Outflow Data

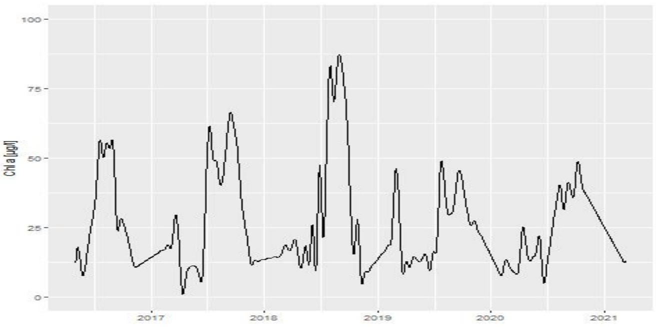
Table 20: Statistics of in- and outflow data.

Parameter	min	max	mean
Nitrogen	55.67135	13.60501667	7-8
Phosphorous	55.68491667	13.59465	14-16

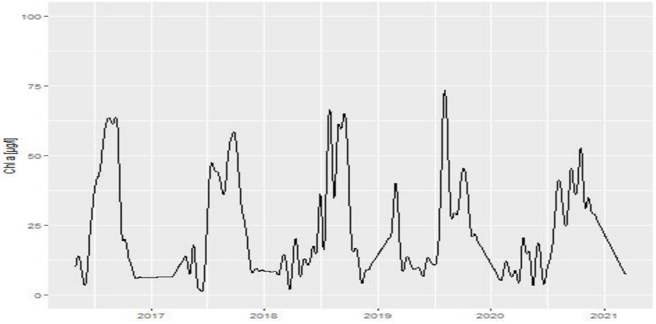
A.4 Satellite Data

Table 21: Statistics of profile data.

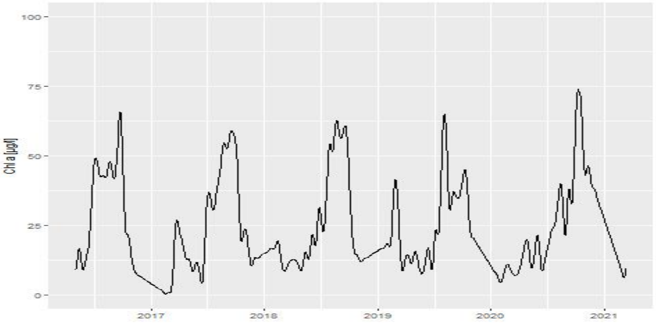
Parameter	min	max	mean
Chl-a	55.67135	13.60501667	7-8



(a) Clorophylle-a concentration at site 1 from 2016 to 2020



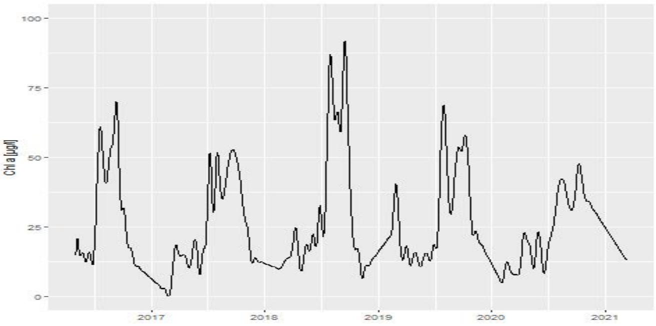
(b) Clorophylle-a concentration at site 2 from 2016 to 2020



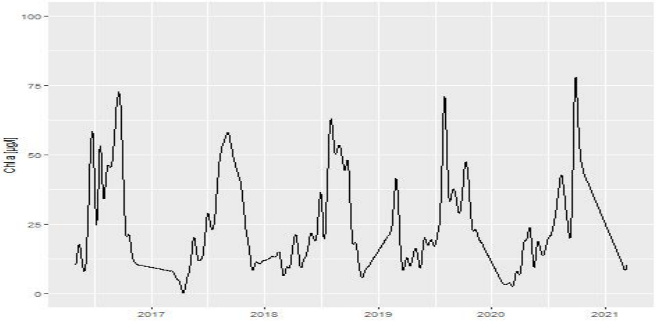
(c) Clorophylle-a concentration at site 3 from 2016 to 2020

Figure 51: chla

(a) Clorophylle-a concentration at site 4 from 2016 to 2020



(b) Clorophylle-a concentration at site 5 from 2016 to 2020



(c) Clorophylle-a concentration at site 6 from 2016 to 2020

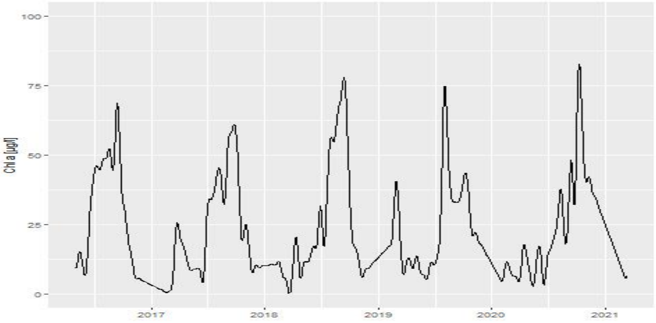


Figure 52: Clorophylle-a concentration measured by a satellite from 2016 to 2020