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Drivers for phytoplankton community dominance of nuisance microalga *Gonyostomum semen* (Ehrenberg) Diesing in two South-Eastern Norwegian lakes

- A paleolimnological approach

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PREFACE

This thesis is written as part of the graduation requirements for the masters programme in Environment and Natural Resources at Faculty of Environmental Sciences and Natural Resource Management, Norwegian University of Life Sciences, Ås, Norway. The thesis counts 60 ECTS and was conducted during the period of April 2017 to May 2018.

Initially, I would like to thank my main supervisor Thomas Rohrlack for providing me with a study question that truly serves as an example of the complexity of freshwater ecology, perhaps especially now in an era faced with the profound impacts of climate change. Indeed, it has been a pleasure working on a study question partly concerning the state of our water bodies in a changing climate.

Also, greatly appreciated is the assistance and guidance during field and lab work and the constructive counseling during this whole process. Special thanks are also given to my co-supervisors Gunnhild Riise and Ståle Haaland. Gunnhild; thank you for your counseling and your feedbacks regarding structuring of the paper, and Ståle; your assistance during field work, your inputs and your assistance through performing and interpreting statistical analysis are very much appreciated.

A few people need to be thanked regarding supplying information on the study sites. Helge Klevengen at the municipality of Ski provided useful information on property development around lake Bindingsvann. Agricultural consultant Peder Unum at the municipality of Våler provided information on agricultural activity in drainage basin of Lake Greppérødfjorden. Your contributions and helpfulness are very much appreciated.

Finally, thank you to my family and friends for supporting me through my altogether 8 years of studies. I think I might just finally have reached my destination.

Oslo, 13.5.2018

Sunniva Sunde

ABSTRACT

Gonyostomum semen (Ehr.) Diesing has during the last decades expanded its distribution and increasingly started to dominate phytoplankton communities in Northern Europe, and particularly in Scandinavia. Several studies have recognized the species as invasive, and a recent immigration to Northern Europe within the last few decades has been hypothesized. Using paleolimnological methods, the current study aimed at using records of pigment compositions in sediment cores to investigate for phytoplankton community dominance of Gonyostomum , as well as for drivers of such development. It was hypothesized that dominance of Gonyostomum is a recent phenomenon within the last few decades and that it emerged simultaneously as changes in air temperature, precipitation and levels of allochthonous derived organic matter(DOC) in the lakes.

Sediment cores were obtained from two south-eastern Norwegian lakes belonging to the same lowland watercourse and the same climatic zone(< 200 m.a.s.l). One of the lakes, Grepperødfjorden, proved to have a dominating population of Gonyostomum since the mid-1930s, consequently contradicting prevailing assumptions of Gonyostomum as a recent invasive species to the ecoregion of South-Eastern Norway. However, as dating of the sediment cores was determined exclusively by analyzing for Cs^{137}, there are uncertainties regarding sedimentation rates, particularly for lake Grepperødfjorden, and the finding of Gonyostomum as a dominating species in the mid-1930s should therefore be considered preliminary.

The other lake, Bindingsvann, was found to have a dominating population of Gonyostomum from the mid-1990s, corresponding with increasing air temperatures and levels of allochthonous derived organic matter in the lake. It was found that increasing air temperatures in combination with elevated levels of organic matter(DOC) most likely led to an intensification and prolonging of thermal stratification, favoring Gonyostomum which performs diurnal vertical migrations between the epilimnion and the hypolimnion. In a nutrient poor lake like Bindingsvann, this allows Gonyostomum to utilize nutrients in the deep strata during thermal stratification and internal loading and thereby outcompete other phytoplankton species and form large biomasses, leading to a noticeable increase in lake productivity. The signals of temperature as a driver for Gonyostomum dominance are less evident for lake Grepperødfjorden. This lake differs from the other in that it is shallower with less potential for thermal stratification. Several factors were found to potentially could explain the initial dominance of Gonyostomum in the estimated time of the mid-1930s, such as human induced turbidity facilitating reduced light conditions, water leveling practices, high phosphorus levels and a lengthening of the growing season. As the dominance was inconsistent up until the estimated time of mid-1970s, conditions promoting Gonyostomum growth appear to have improved as time has progressed. There are indications that this might be related to water color and visibility as well as to a lengthening of the growing season.

CONTENT

1.INTRODUCTION

As the most common representative of the class Raphidophyceae, *Gonyostomum semen* (Ehrenberg) Diesing, has during the last few decades expanded its distribution and increased its biomass in Northern Europe, and particularly in the Scandinavian countries (Hongve et al.,1988; Lepistö et al.,1994; Rakko et al.,2008; Rengefors et al.,2012; Hagman et al., 2014). In many lakes it has become the dominant phytoplankton species throughout large parts of the growing season, sometimes contributing to more than 90% of total phytoplankton biovolume (Rengefors et al.,2012; Hagman et al.,2014).
Blooms of *Gonyostomum semen*(hereafter referred to as Gonyostomum only) may last for as much as three months with the seasonal maxima usually occurring in August or September (Willen, 2003; Hagman et al.,2014). No toxic effects of Gonyostomum blooms have been detected, but the alga is known to cause allergic skin reactions to bathers, caused by ejections of slime threads (Sørensen,1954; Bjørndalen&Løvstad, 1984; Cronberg et al.,1988). Experiences from Sweden have shown that the algae potentially can clog filters when lakes are used as a drinking water sources (Johansson et al.,2013a). Furthermore, few zooplankton species are known to graze on the alga, ultimately leading to trophic chain disturbances with the disruption of energy transfers to higher trophic levels (Cronberg et al.,1988; Pithart&Pechar,1997). Due to the many negative effects associated with blooms of Gonyostemum, the alga is now recognized as a nuisance species(Rengefors et al.,2012).

Gonyostomum has been known in Scandinavia since the 19th century (Levander 1894 in (Lepistö et al., 1994)) The first incident was reported in Norway in 1975, however, as monitoring regimes during this period were limited, the species may have been present at a much earlier stage (Hongve et al., 1988). Investigations of Gonyostomum prevalence during the 1980s found that most lakes inhabiting Gonyostomum were found close to the border of Sweden in the county of Østfold in the south-eastern part of Norway (Hongve et al., 1988). A 1984 study found that almost a quarter of the lakes investigated in Østfold had a dominating biomass of Gonyostomum (Bjørndalen and Løvstad, 1984). Recent research concludes that Gonyostomum has expanded its distribution in Norway since the 1980s, both geographically and to new lakes, while also showing tendencies to increasingly dominate phytoplankton communities (Hagman et al., 2014). Similar patterns of increased biomass and increased geographical spreading have been observed in other Northern European countries (Lepistö et al.,1994; Rengefors et al.,2012).
The introduction of Gonyostomum to Norway is hypothesized to have spread from neighboring country in the east, Sweden, and it is currently assumed that the alga is spreading westwards from south-east Norway (Hagman et al.,2014). The assumption of an invasion from the east is in accordance with Lebret et al. (2012) suggesting that the invasion and colonization in Northern Europe by Gonyostomum is recent within last decades.
For a specie to be considered invasive it must be non-native to an area, and adversely affect the bioregion it invades. Invasive species may according to Hagman et al. (2014) follow

different patterns; they can either bloom and disrupt the ecosystem or disappear, or they can be present in moderate amounts for extended periods and then bloom again if the conditions allow them to.
The preferable habitat for Gonyostomum is originally thought to be small, shallow, slightly acidic and humic lakes with high color and high content of phosphorous (Rosen, 1981; Willen, 1990; Willen 2003). High concentrations of total phosphorous (> 30 µg/l) and high density of nutrients have been suggested to affect the growth of Gonyostomum (Cronberg et al., 1998; Findlay et al., 2005; Hehmann et al.,2001; Hongve et al.,1988).
When exposed to fulvic acid, a common component of humic matter, Gonyostemum was also found to increase its growth rate(Rengefors et al.,2008). The preference for humic lakes with high color is supported by several studies(Bjørndalen& Løvstad, 1984; Hongve et al.,1988; Brettum and Andersen, 2005). Variables such as nutrient salts and pH are, however, factors suggested to explain the suitability of a habitat to Gonyostomum, but several studies conclude that these factors do not control the biomass to a large degree (Cronberg et al.,1988; Findlay et al.,2005; Rengefors et al.,2005).
Because cells of Gonyostemum are recruited from resting cysts at depths less than 4 meters, shallow depths are also considered to be a favorable habitat characteristic for Gonyostemum(Figueroa and Rengefors, 2006; Hansson, 1996). Additionally, the adaptability of the species to germinate in different environments has also been suggested as a driver for its success(Sassenhagen et al.,2014).
Furthermore, the ability of Gonyostomum to vertically migrate in the water column has been proposed as a mechanism acting as a competitive advantage. (Eloranta&Räike, 1995; Salonen& Rosenberg, 2000). During periods of thermal stratification and internal loading, Gonyostomum may benefit from collecting phosphorous in the deep strata otherwise not easily accessible to other phytoplankton species exclusively operating above the thermocline. By staying in the hypolimnion during nighttime, it is also hypothesized that Gonyostomum benefits from avoiding potential grazers in the epilimnion, although only a few zooplankton species have been found to feed on Gonyostomum (Lebret et al.,2012; Johansson et al, 2013).

Climatic variables water temperature, water color and dissolved organic carbon have been suspected to act as drivers for the tendency of increased biomass and phytoplankton community dominance of Gonyostomum in Scandinavia (Trigal et al.,2011; Rengefors et al.,2012). Rengefors et al. (2012) identified increased surface water temperatures as a driver for both the spreading of Gonyostomum to new lakes and the increased biomass in Swedish lakes. The link between increased surface water temperatures and increased biomass is hypothesized to be coupled with an extended growing season and intensified thermal stratification. Rengefors et al. (2012) found that increased water temperature had a positive effect on germination rates from resting cysts in the sediments. An earlier heating of the water in spring may thus result in a lengthening of the growing season. Lab experiments performed by Rengefors et al(2012) showed that growth of Gonyostomum did not occur below 6°C, and that the window of optimum growth was between 9 and 12°C. Surface water temperatures often excel above 12°C during summer, and it is therefore expected that responses in biomass to temperature increases will be most pronounced during spring and autumn (Rengefors et al.,2012).

High water color caused by humic and fulvic acids from dissolved organic carbon,and followingly reduced light climates, is hypothesized to work as a beneficial factor for the growth and dominance of Gonyostomum. The specie is sensitive to excessive insolation, and dissolved organic carbon have therefore been proposed as a factor governing Gonyostomum dominance (Findlay et al.,2005). Additionally, increased water color has been suggested to enhance stratification of lakes through reduced visibility(Eloranta&Räike, 1995; Salonen&Rosenberg, 2000).

OBJECTIVES AND HYPOTHESES

By implementing paleolimnological methods, the objectives of this study were to investigate sediment cores to further examine the assumption that Gonyostomum is a recent invasive species to the ecoregion of South-Eastern Norway, and to assess whether phytoplankton community dominance of Gonyostomum is governed by regional climatic factors rather than habitat and drainage basin characteristics. South-Eastern Norway has experienced a steady increase in both temperature and precipitation since the end of the 1980s (Norwegian Meteorological Institute, n.d) as well as increased water color due to reduced sulphate in precipitation(Hongve et al 2004; Monteith et al.,2007) It was therefore hypothesized that the increasing prevalence of Gonyostomum blooms could be due to climatic factors.

Sediment cores were obtained from two south-eastern Norwegian lakes situated in the same watercourse and located within the same climatic zone. Lakes were chosen on the background of current confirmed algal community dominance of Gonyostomum, differences in lake morphometry and drainage basin characteristics. Pigment composition analysis were performed to detect pigment compositions throughout the sediment cores corresponding with pigment compositions found in years of confirmed algal community dominance of Gonyostomum. To detect changes in total algae biomass correlated to Gonyostomum dominance, total- chlorophyll- a levels (the sum of chlorophyll- a and its breakdown product pheophytin- a) were calculated. Dating of sediment cores occurred by gamma spectroscopy analyzing for radioactive Cs137 throughout the cores.

To investigate for correlations between lake organic matter and prevalence of Gonyostomum dominance, sediments were analyzed for content of organic matter using both loss on ignition and dry sediment bulk density. The latter also provides insight into mineral contents of the sediments.

Drivers of phytoplankton community dominance of Gonyostomum were investigated both in terms of regional climatic factors, namely temperature, precipitation and sulphate depositions, and in terms of catchment area and lake characteristics. It was investigated for possible anthropogenic disturbances in drainage basins that potentially could promote

increased water color, nutrient load and reduced visibility through erosion.
Correlations were analyzed using simple multivariate statistics and regression.

The study was performed based on the hypotheses that:

(1) Gonyostomum is a recent invasive species (after 1970) to the ecoregion where the lakes are located.

(2) Phytoplankton community dominance of Gonyostomum emerged simultaneously as increases in air temperature, precipitation and levels of allochthonous derived organic matter in the lakes(NOM). The introduction of *Gonyostomum* as a dominant species led to increased productivity of the lakes.

(3) Differences in lake morphometry between the two lakes may give different responses to increased temperature, thus providing differences in competitive advantages for Gonyostomum.

2. MATERIAL AND METHODS

2.1 SITE DESCRIPTIONS

Study area comprises lakes Bindingsvann and Grepperødfjorden, both situated in the Vansjø-Hobøl watercourse in the south-eastern part of Norway. Both lakes belong to the ecoregion of Eastern Norway and situate < 200 meter above sea level.

The Vansjø-Hobøl water course is a nutritious rich lowland watercourse stretching from the Østmarka forest areas in the counties of Oslo and Akershus all the way down to Vansjø in the county of Østfold (Skarbøvik et al.,2011). More than 90% of the catchment area situates beneath marine limit. Total catchment area is 688 km^2, and approximately 15 % of the land areas are occupied by agricultural activities while the remaining are mainly forested areas (Skarbøvik et al.,2011).

Lake Bindingsvann is located at the northern end of the catchment area while Grepperødfjorden locates downstream as a relatively isolated fjord in the Vansjø lake system (see Figure 2.1). Although classified as one lake, the Vansjø lake system is often separated into three basins; an eastern, a middle and a western basin (Hauger et al.,1992). The middle basin comprises the narrow fjord arms of Grepperødfjorden and Rødsengkilen, and additionally the strait north-east of the island Bliksøya. The eastern basin is because of its size often viewed as the main basin in the lake Vansjø system. Additionally, as all four inlet rivers drains into the eastern basin, lake Storefjorden
receives much of the water supplied from the upstream watercourse(Hauger et al.,1992).

The western basin, consisting of lake Vanemfjorden, is geographically more closely linked to the middle basin of Grepperødfjorden, however, due to the relatively isolated location of lake Grepperødfjorden, the exchange of water masses between this area and the rest of the western basin is considered limited. This leads to distinct conditions regarding both water quality and biological diversity (Hauger et al.(1992).

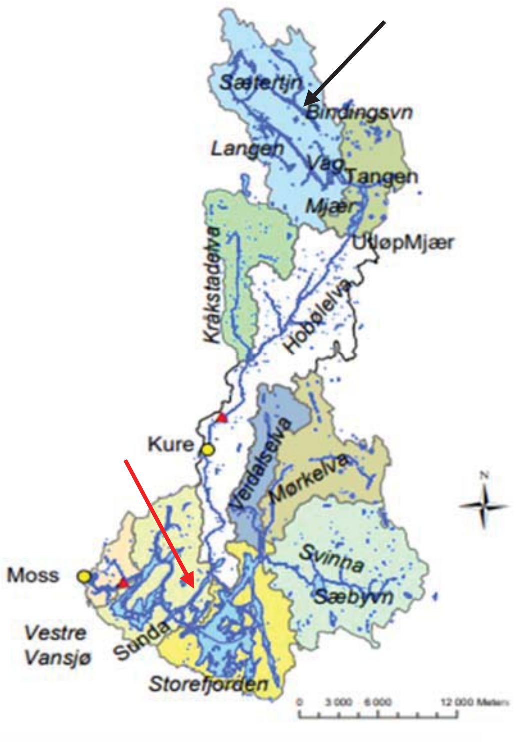


Figure 2.1: Catchment area of the Vansjø-Hobøl watercourse. Bindingsvann is located north (indicated by black arrow) while Grepperødfjorden locates downstream at the lower end of the watercourse(indicated by red arrow). Modified from Skarbøvik et al.(2011)

LAKE BINDINGSVANN

Lake Bindingsvann situates at the border between the municipalities of Ski and Enebakk in the county of Akershus. The lake occupies an area of 0,6193 km^2 and qualifies as medium large. Drainage basin area comprises in total 21,01 km^2 and predominantly locates above marine limit. Geographical and morphometric data on lake Bindingsvann are presented in table 2. Inlet creeks draining heavily forested areas enters the lake on both the eastern and western shoreline. The main inlet creek, Svartorbekken, enters the lake on the eastern side of the lake. At an elevation of 172 m.a.s.l., lake Bindingsvann is surrounded by coniferous forest as well as scattered settlements in north-east and south-west (Figure 2.2). Some agricultural land areas used for grass production are found in proximity to the farm Fjell by the northern end of the lake. Erosion risk from these areas are estimated to be in the range of small to medium, with a maximum soil loss of averagely 175 kg/ acre/ year (NIBIO, n.d.a). Several minor roads are established in relation to settlements within drainage basin, and county road no. 155 passes by near the lake on the western shoreline.

Bed rock of catchment area is predominantly consisting of bare mountain with some areas of thin soil covers. Areas of peat and swamps are found along the eastern shore (Figure 2.3). Landfills have been established in relation to the settlements in northeast and further along the eastern shore. A small area of thick lacustrine deposits is found by the area called Fjellsætra (Figure 2.3).

According to the standards of the water framework directive(WFD), the water type classifies as low in calcium carbonate (1-4 mg/L) and rich in organic matter (30-90 mg Pt/L, TOC 5-15 mg/L) (Vann-nett, n.d.a). Ecological status is by the classification system of the WFD defined as moderate. Status of total phosphorous is defined by the category of "good" while total nitrogen classifies as "very good". Nutrient load in the lake is, however, considered to be moderately affected by runoffs from surrounding scattered settlements (vann-nett, n.d.a). Monitoring of temperature and oxygen levels at different depths establishes that the lake is thermally stratified during parts of the growing season and that anoxic conditions in bottom waters frequently occur (vannmiljø,n.d.b).

Table 2.1: Geographical and morphometric data on lake Bindingsvann. Sources: kartverket.no, vann-nett.no, vannmiljo.miljodirektoratet.no

Geographic coordinates	59.7873389°N/10.9603278°E
m.a.s.l.	172 m.
Drainage basin	21,01 km^2
Water volume	Unknown
Water area	0,6193 km^2
Mean depth	Unknown
Maximum depth	> 10 m.

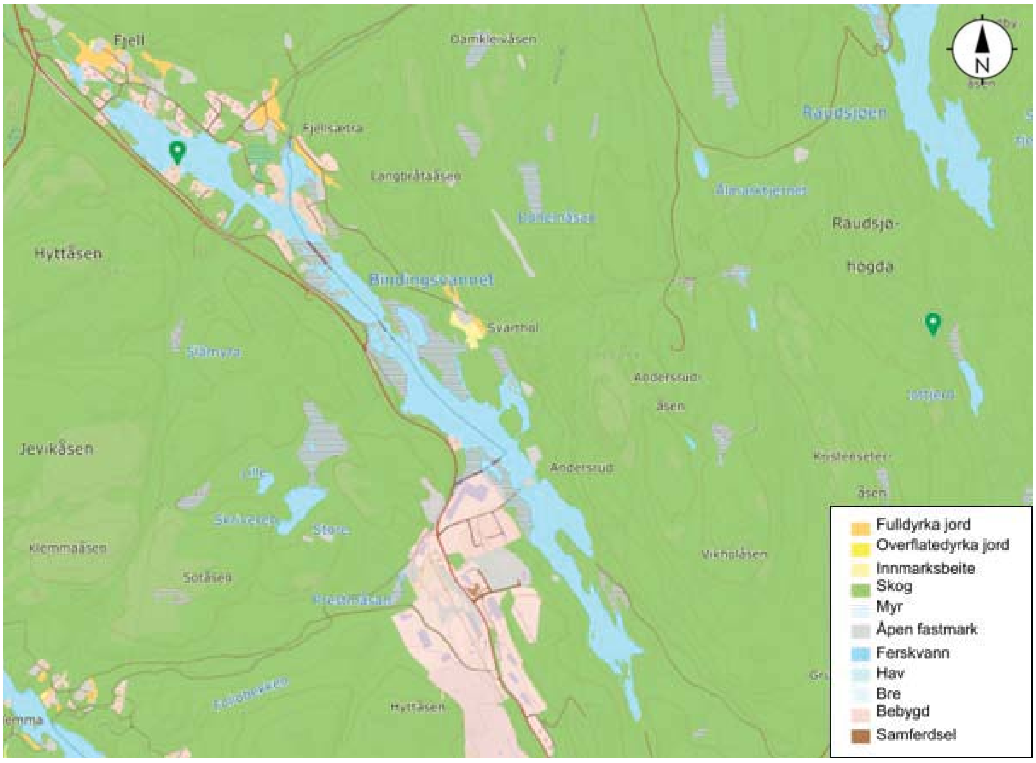


Figure 2.2: Land use map (1:40 000) for lake Bindingsvann drainage basin. Legend is given in Norwegian. A majority of catchment area is characterized as forested land (indicated by green in the map). Human settlement is concentrated in north/north-east and south-west (indicated by pink color). Map was modified from NIBIO (n.d.a).

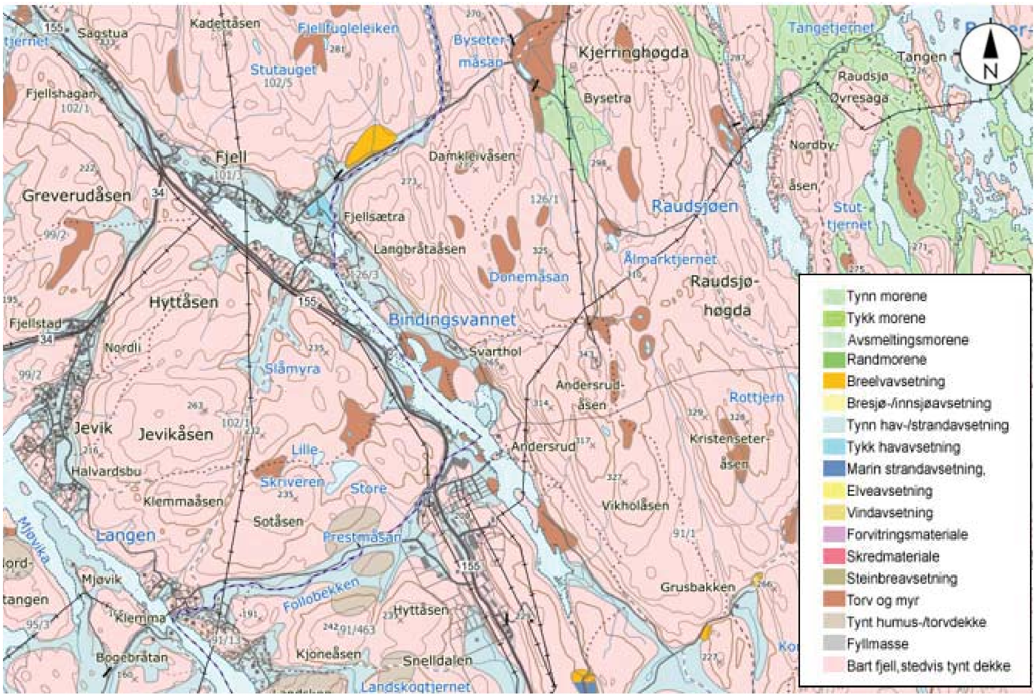
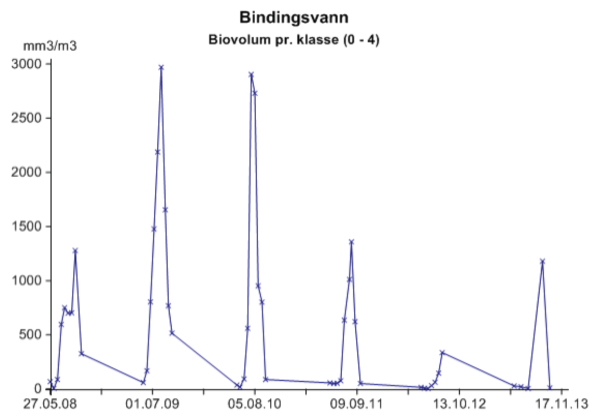


Figure 2.3: Soil map (1:50 000) of lake Bindingsvann drainage basin. Legend is given in Norwegian. Soil is predominantly consisting of bare mountain (illustrated by pink color) with some areas of thin soil cover, and areas of peat and swamps (illustrated by brown color). Landfills are established in relation to the settlements in northeast and further along the eastern shore (illustrated by grey color). A small area of thick lacustrine deposits is found by the area Fjellsætra(blue color) Map was modified from NGU (n.d.a)

GONYOSTOMUM DOMINANCE IN LAKE BINDINGSVANN

Monitoring performed in the period of 2008 to 2013 establishes that the phytoplankton community of lake Bindingsvann repeatedly is dominated by *Gonyostomum*(Figure 2.4B). Growth of Gonyostomum is usually characterized by a steady increase and by the lack of fluctuations within growth seasons (Figure 2.4A).Total phytoplankton biovolume during periods of Gonyostomum dominance noticeably exceeds what is observed for periods where Gonyostomum is not the dominating species. Biovolume of Gonyostomum during bloom periods has been observed to constitute more than 90% of total phytoplankton biovolume (Figure 2.4B).

A)



B)

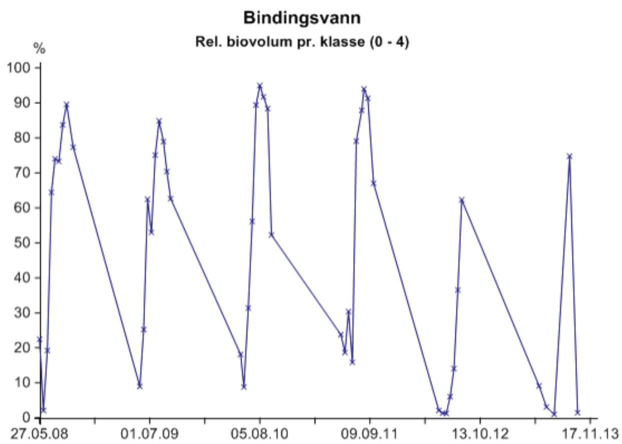


Figure 2.4: A) Biovolume (mm^3/m^3) of Raphidophyceae during the growth seasons of 2008-2013. Gonyostemum is the most common representative of this class. B) Percentage contribution of Raphidophyceae to total biovolume in lake Bindingsvann during the growth seasons of 2008-2013(Aquamonitor, n.d.a)

LAKE GREPPERØDFJORDEN

Lake Grepperødfjorden situates in the municipality of Våler in the county of Østfold. The lake occupies 0,4752 km^2 and qualifies as a small water body(vann-nett, n.d.b). With depths ranging between 2 and 7 meters(Figure 2.6) and a mean depth of approximately 2 meters, the lake is quite shallow(Hauger et al.,1992).

A large drainage basin of 679,92 km^2 is related to the connectivity of lake Grepperødfjorden to the upstream watercourse. Geographical and morphometric data on lake Grepperødfjorden are given in Table 2.2.

The Leie river enters lake Grepperødfjorden in the northern end of the lake. On its way through the landscape, it drains land areas heavily dominated by intensive grain production (Figure 2.5). Supplies of humus-rich water from lake Bjørnrødvann and lake Brønnerødtjern normally contributes to a brown water color of lake Grepperødfjorden (Hauger et al.,1992). Drainage basin is predominantly characterized by agricultural activities. Areas of grain production are especially found at the northern and north-western end of the lake (Figure 2.5). Erosion risk from these areas are estimated to be in the range of small to medium(NIBIO, n.d.b).

Minor settlements are found by Grepperød at the northern end of the lake, and by Kjærnes on the south-eastern shoreline. Runoffs from full-grown fields and sewerage are considered to be major and moderate anthropogenic disturbances, respectively (vann-nett.no, n.d.b). Situated at an elevation of 26 meter above sea level, the entire catchment area of lake Grepperødfjorden is located beneath marine limit. Northern end of catchment area is characterized by thin layers of lacustrine depositions (Figure 2.7). Eastern shoreline consists of bare mountain with some areas of thin soil covers as well as areas of landfills. Western shoreline is a mixture of lacustrine depositions, bare mountains with thin soil covers and landfills.

According to the standards of the Water Framework Directive, the water type of lake Grepperødfjorden classifies as moderately rich in calcium carbonate(Ca> 4- 20 mg/L, alkalinity 0,1 -2) as well as rich in organic matter (30-90 mg Pt/L, TOC 5-15 mg/L) (Vann-nett.no, n. d. b). Ecological status is classified as moderate, as is also levels of phosphorous and nitrogen (vann-nett.no, n. d. b). Monitoring data performed in the period of 1980 to 2013 show that total phosphorous levels often exceed 30 µg/L (Figure 8E, Appendix 8).

Table 2.2: Geographical and morphometrical data on lake Grepperødfjorden. Sources: kartverket.no, vann-nett.no, Hauger et al.(1992).

Geographic coordinates	59.4303056°N/ 10.8277139°E
m.a.s.l.	25 m.
Drainage basin	679,92 km^2
Water area	0,4752 km^2
Water volume	Unknown
Theoretical residence time	> 9 months
Mean depth	2 m.

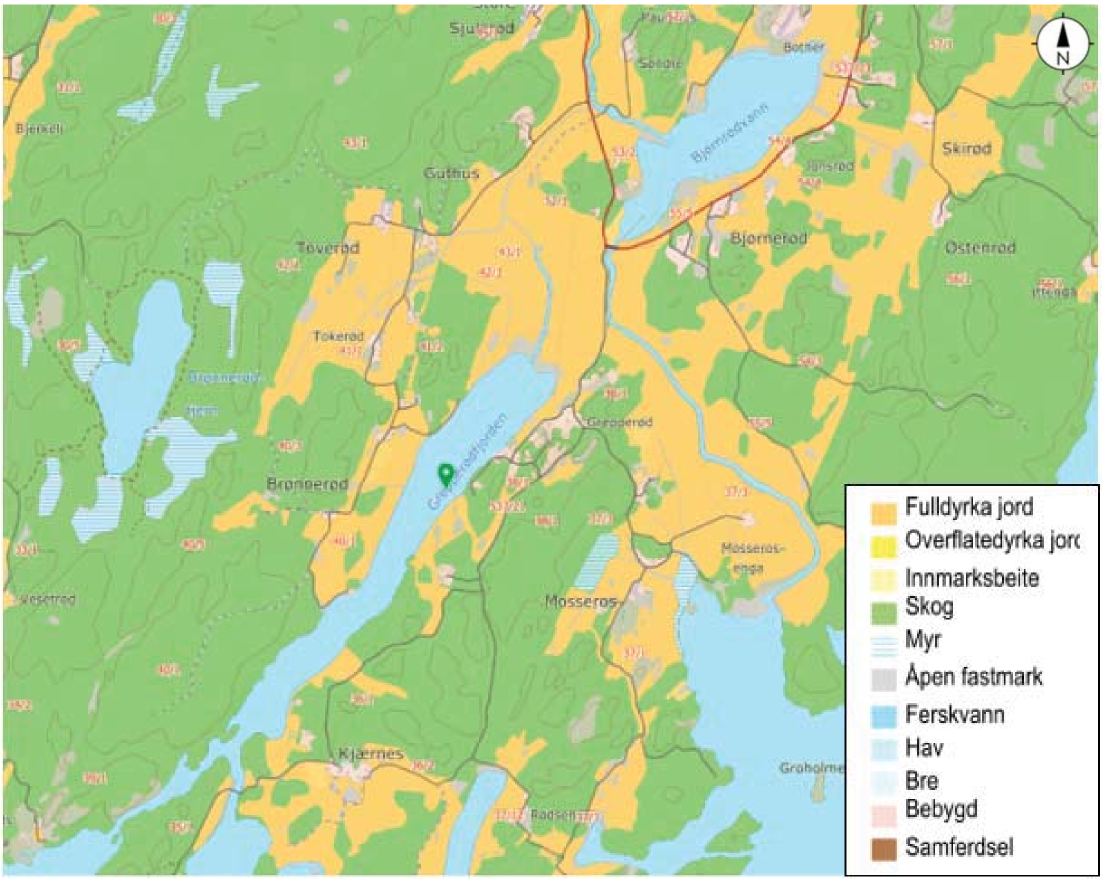


Figure 2.5: Land use map (1:40 000) of lake Grepperødfjorden drainage basin. Legend is given in Norwegian. Drainage basin area is heavily influenced by agricultural activity(orange color). Agriculture is concentrated in the northern and north-western end of the lake. Human settlement is mainly found at Grepperød in north-east and at Kjærnes in south-east. Map is modified from NIBIO(n.d.b)

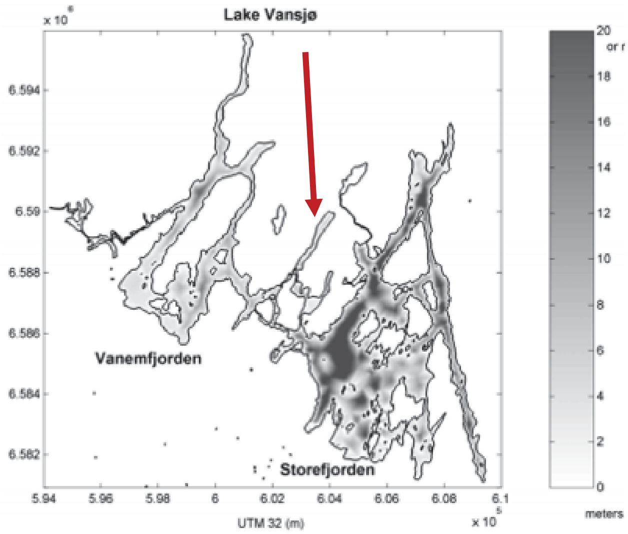


Figure 2.6: Depth map of lake Vansjø. Grepperødfjorden locates as the narrow fjord (indicated by red arrow) between the basins of Storefjorden and Vanemfjorden. Figure is adapted from Skarbøvik et al. (2011).

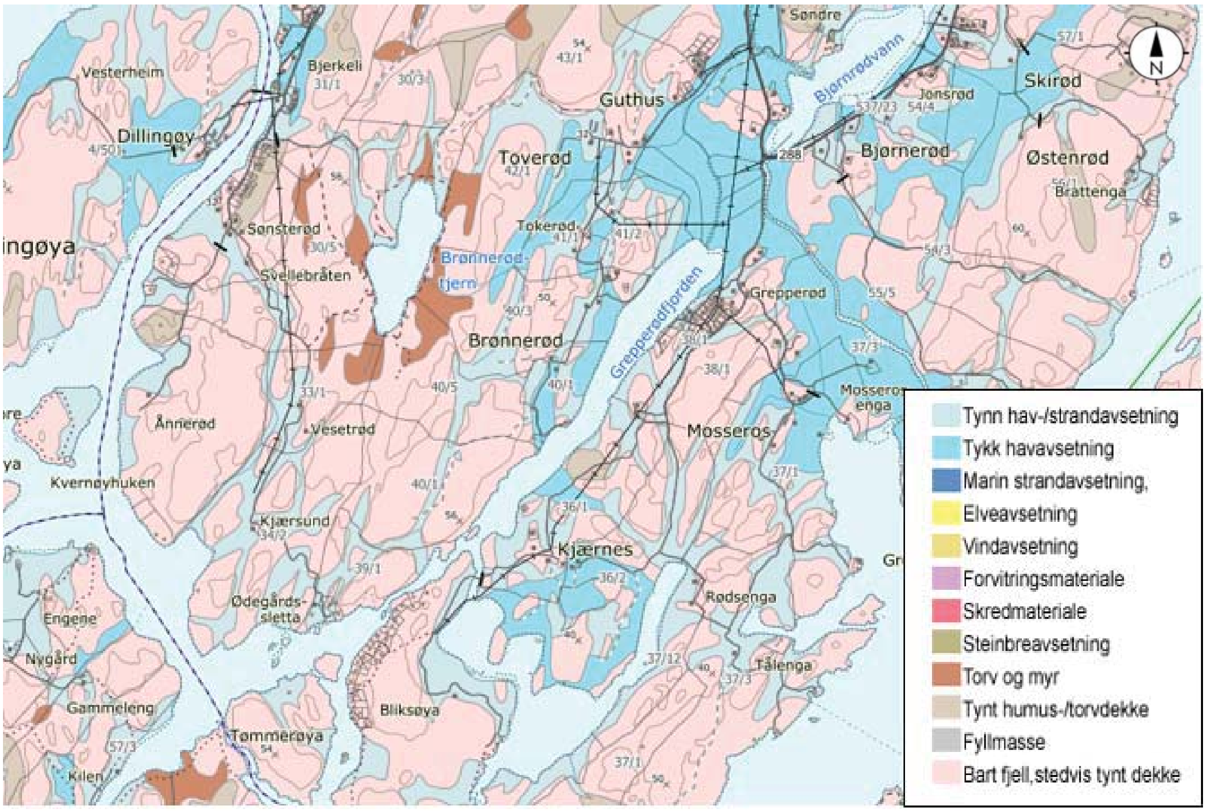
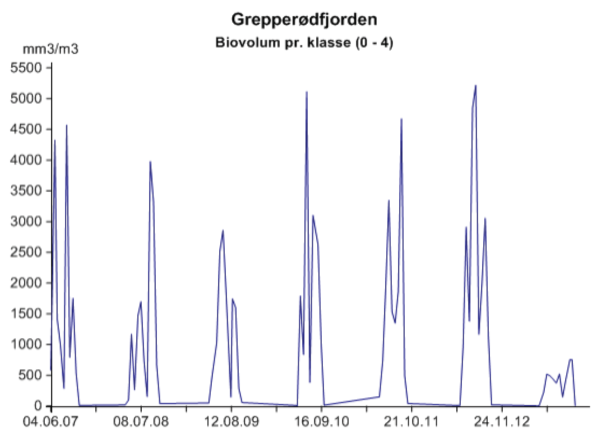


Figure 2.7: Soil map (1:50 000) of lake Grepperødfjorden drainage basin. Legend is given in Norwegian. Thick lacustrine deposits are illustrated by color blue. Pink color illustrates bare mountain with some areas of thin soil covers. Landfills are illustrated by grey color. Map is modified from NGU(n. d. b).

GONYOSTOMUM DOMINANCE IN LAKE GREPPERØDFJORDEN

A regional investigation of lakes in the county of Østfold established Gonyostomum to be present in lake Grepperødfjorden in 1984(Bjørndalen and Løvstad, 1984). Recent monitoring performed in the period of 2007 to 2013 establishes that Gonyostomum repeatedly is the dominating phytoplankton species throughout the growing season (Figure 2.8B). Biomasses of > 5000 mm^3/m^3 have been observed(Figure 2.8 A). Gonyostomum growth in lake Grepperødfjorden is characterized by intra-seasonal fluctuations with maxima normally occurring in late summer or early fall (Figure 2.8A; Figure 2.8B). Phytoplankton community is relatively homogenous for the Vansjø lake system during spring and early summer, with classes Cryptophyceae and Bacillariophyceae dominating. As the summer progresses, Gonyostomum starts dominating in Grepperødfjorden, while Bacillariophyceae and dinoflagellates are dominating in the eastern and western basin, respectively. (Hauger et al.,1992).

A)



B)

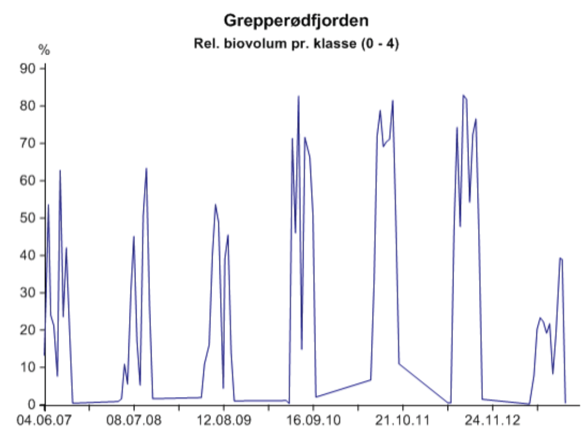


Figure 2.8: A) Biovolume distribution of Raphidophyceae in lake Grepperødfjorden during the growth seasons of 2007-2013. B) Percentage contributions of Raphidophyceae to total biomass during the growth seasons of 2007-2013(Aquamonitor, n.d.b)

2.2 FIELD WORK

Sediment core samples were obtained from lakes Bindingsvann and Grepperødfjorden on the 26th of April 2017 using an Uwitec sediment core sampler. Sampling occurred from boat while both lakes were free from ice cover. Weather conditions on the given day were clear, cold and wind still. Recorded mean temperatures for April 26th are 4,9 °C for site Grepperødfjorden and 4,0 °C for site Bindingsvann (Yr.no, n.d). Precipitation did not occur during the sampling period.

Sampling at lake Bindingsvann site was performed at a depth of 10 meters (59,78784° N / 10,95855° E, 172 m.a.s.l), illustrated in Figure 2.9, and for lake Grepperødfjorden at a depth of 4 meters (59,42921° N / 10,82600° E, 26 m.a.s.l), illustrated in Figure 2.10. Gravity core sampler attached to a rope was carefully lowered down from the rib of the boat into the water column. Sampler was then carefully dropped by letting go of the rope, allowing it to fall towards the sediments using the force of its own weight to penetrate the sediments. Before pulling the device back up from the lake bed, sediment sampler was given time to sink properly into the sediments. Sediment sampler device was then manually pulled up from the sediments making sure that it was held as straight as possible during the process. In advance to breaking the lake surface and being lifted onboard the boat, a plug was inserted at the lower end of the tube containing the core sample. To avoid mixing of sediment layers, the tubes containing sediment core samples were placed in stands making sure they were consistently vertically stabile.

To minimize risk of the sediment core samples being influenced negatively by transportation and other conditions such as temperature changes, sediment cores were decided to be processed in field. After being brought ashore, sediment cores were measured for length and consecutively split up into layers each the thickness of 1 cm. Cutting device used for this purpose was thoroughly cleansed in water prior to each cutting. Each sample was during the cutting process continuously placed in its own plastic bag container and marked with a number corresponding with its placement(cm) in the sediment core. Plastic bag containers containing sediment core samples were then followingly brought to the soil and water lab at Faculty of environmental sciences and natural resource management at NMBU and kept in the freezer at -18 °C during the consecutive night.

Figure 2.9: Sediment core sampling location for lake Bindingsvann (kartverket.no)

Figure 2.10: Sediment core sampling location for lake Grepperødfjorden (kartverket.no)

2.3 LAB WORK AND LAB ANALYSIS

Lab work and lab analysis were performed at laboratories at Faculty for environmental sciences and natural resource management, Norwegian University of Life Sciences during two periods; April/May 2017 and October 2017.

FREEZE-DRYING AND DRY SEDIMENT BULK DENSITY

Frozen sediment core samples were the following day placed in a freeze-drier to initiate the process of eliminating water from the samples. As the reduced pressure in a freeze drier allows the frozen water to sublime directly from the solid phase to the gas phase, removing water content by freeze-drying gives a much more satisfying result than by using heat only. Plastic bag containers containing samples from both lakes were opened and placed in a freeze-drier using a vacuum of 0,8 bar. Vapor coming out of the samples would attach to the freezing elements, and these would during the one week long lasting freeze-drying session have to be cleared for ice daily. After finishing the drying process, samples were placed in the freezer at -18°C awaiting further laboratory processing. Storage in freezer would prevent pigment decomposition if samples were not completely water depleted during the process of freeze-drying.

After bringing the samples out of the freezer and defrosting them in room temperature, the samples were weighed for calculating dry sediment bulk density. The use of dry sediment bulk density(g/cm^3) is a method of calculating the weight of the sediments in a given volume. The sediment volume is the combined volume of solids and pores which may contain air and/or water. Sediments containing clay have a greater proportion of smaller particles, resulting in more compacted sediments and a smaller percentage of porosity. Dry bulk density is therefore inversely correlated to the porosity, and consequently, the relationship between dry sediment weight and sample volume is greater for compacted sediments. The more pore space a sediment has, the lower the value for bulk density. Dry sediment bulk density is by that means also a way of indicating mineral contents of sediments. However, bulk density increases with compaction and tends to increase with depth.

Dry sediment bulk density calculates by finding the relationship between dry sediment weight(g) and total sediment volume(cm^3):

$$\text{Dry sediment bulk density}(\text{g/cm}^3) = \frac{\text{Dry sediment weight(g)}}{\text{Sediment volume(cm}^3)}$$

Sediment volume equals the volume of the 1 cm tall cylinder that each sample occupied in the sediment core tube. Inner diameter of the tube used for collecting sediment cores is 6 cm (radius 3 cm).

$$\text{Sediment volume}(\text{cm}^3) = \pi r^2 \times \text{tube height} = \pi 3\text{cm}^2 \times 1 \text{ cm}$$

PIGMENT ANALYSIS

Extractions for pigment analysis were prepared by using 0,1-0,3 grams of freeze-dried sediment from each sample. Separate tubes were used for each sample. Prior to placing the sample in the tube, the tube was placed on the scale and the scale was followingly nulled out so that only the weight of the sediment sample would be registered. Due to a limited sample size, sediment sample no. 1 for lake Bindingsvann contained a little less than 1 gram. After finishing the process of distributing samples in the tubes, 5 ml of ethanol (100%) was added to each sample. For optimal pigment extraction, mixtures were manually shaken and then placed in the fridge for 24 hours. Processing of sediment samples continued by centrifuging the tubes to separate sample particles from the solution. Centrifuging was performed at 2000 rpm for 10 minutes and resulted in a distinct sediment layer at the bottom of the tubes. Left in solution was the pigment extract, now vulnerable to the deteriorating effect of day light. Sample tubes were by that reason carefully protected from the direct impact of light. Protection from daylight continued during the pigment analyzing process by keeping the sample tubes in a cardboard box prior to analyzing.
Pigment analysis were performed in a spectrophotometer (UH5300 Hitachi). Spectrophotometry measures absorbance of different wavelengths in a solution to determine absorption spectrum. This is a way of measuring pigment composition optically. Absorption during analysis was measured in the range of 400 nm to 700 nm, using the resolution of 1 nm. Methodology for mathematically identifying pigments through absorption spectrum is further described in Thrane et al. (2015).
In advance to running the analysis, optical quart glass cuvettes had to be checked for any stains and spots that could affect optical measurement. Any spots were manually wiped off by a clean and dry paper. Spectrophotometer also had to be calibrated for the absorbance spectrum of ethanol, the chosen solvent for pigment extraction. Calibration involved filling all six cuvettes with 3 ml of ethanol. Absorption spectrum coming out of this analysis would automatically be withdrawn from results of all forthcoming pigment composition analysis. After finishing calibration, ethanol was removed from all quart glass cuvettes by use of a suction hose. In advance to running pigment extraction analysis, one of the cuvettes was filled with 3 ml of ethanol. To control for any systematically errors in measuring absorbance spectrum, this ethanol sample would stay in the cuvette during the whole pigment analyzing process. Remaining five cuvettes were in order filled with each its pigment extraction sample. Samples for lake Grepperødfjorden were run undiluted, while samples for lake

Bindingsvann were, due to a high concentration of algae, run diluted with 100% ethanol. Dilution was performed by the relationship of 1:2 (1 ml of pigment extraction and 2 ml of ethanol). Undiluted samples were all run using 3 ml of pigment extraction. Pipetting extraction from the sample tubes into optical cuvettes was conducted making sure that sediment swirling from the bottom of the tubes did not occur. Extraction containing particles could potentially have affected absorption spectrum measurements. Pipette tips were changed between all sample measurements. After each optical measurement, samples were removed from the cuvettes by using the suction hose. To avoid cross contamination between samples and inaccurate optical measuring, it was important making sure that the sample was removed properly from the cuvette before adding a new one.

DATING OF SEDIMENT CORES

Dating of sediment cores were performed measuring the amount of radioactive cesium(Cs^{137}) in each sample. Remaining parts of each freeze-dried sediment sample were transferred to screw cap scintillation vials. Weight of each sample for radioactive cesium analysis equals remaining weight after weight of sample for spectrophotometry had been subtracted from the full weight of freeze-dried sediment sample.
Analyzing samples for Cs^{137} was performed by operators at the isotope laboratory at the Norwegian University of Life Sciences(NMBU) using the methodology of gamma spectroscopy. Detector used in the radioactive cesium analysis was a sodium iodine(NaI) scintillation counter. Methodology of calculating sedimentation is based on locating the sediment sample representing the incidence of the Chernobyl nuclear accident of 1986(Van Metre et al.,2004). Sedimentation rate calculates by dividing depth of the sample where maxima locates(cm) on time passed since the Chernobyl incident(years). Premise for using such a calculation method is the assumption of a constant sedimentation rate throughout the whole period that the sediment samples are representing. Consequently, uncertainties regarding dating of the sediment cores follow the assumption of a constant sedimentation rate. Results of the sediment core dating, given in years for each sample(cm), must therefore be considered an approximation. Calculation of estimated dating(year) for each sample follows the equation of:

$$\text{Year of Chernobyl nuclear accident (1986)} +/- \frac{\text{year since incident(31)}}{\text{sedimentation rate}}$$

LOSS ON IGNITION

Upon returning from Cs^{137} analysis, freeze-dried sediments from screw cap scintillation vials were used to determine loss on ignition. This method consists of strongly heating, or igniting, a material at a specified temperature allowing volatile substances to escape until its

mass ceases to change. The volatile materials lost usually consists of water and carbon dioxide from organic material (Heiri et al.,2001).
0,5 - 1 gram of freeze-dried sediments from each sample were placed in its own crucible marked with a number. Weight of each crucible was registered, as was also the weight of crucibles after adding sediment samples. Due to small sample sizes, weight of sample no.1 and 2 for lake Bindingsvann contained a little less than 0,5 grams.
Crucibles were consecutively placed on trays and ignited for 4 hours on 550° C. After having cooled down, crucibles were weighed again. Weight of sediment sample both prior and post ignition was found by subtracting weight of crucible from total weight. Loss on ignition(gram) for each sediment sample was found by subtracting weight of sediment sample post ignition from weight of sediment sample prior to ignition. Percentages loss on ignition for all sediment samples were calculated by using the formula:

$$Loss\ on\ ignition\% = \frac{Loss\ on\ ignition(g)}{Weight\ of\ sample\ prior\ to\ ignition(g)} \times 100$$

Organic carbon in the sediments was calculated based on the assumption that organic C. equals 58% of loss on ignition(g). The relationship between chlorophyll a(µg/g dryweight) and the organic C fraction is used to evaluate autochthonous production in relation to allochthonous supplies. However, as algae also contains organic carbon, there are autocorrelations involved that needs to be taken into consideration.

2.4 COLLECTING DATA ON POTENTIAL DRIVERS FOR PHYTOPLANKTON COMMUNITY DOMINANCE OF GONYOSTOMUM

Data on possible drivers of phytoplankton community dominance of *Gonyostomum* have been retrieved from different sources. Regional climatic drivers and local catchment area characteristics were examined using the following sources:

- Statistics on agricultural development on municipality level was retrieved from various agricultural censuses available at statistics Norway (retrieved from https://www.ssb.no)
- Data on development of catchment area characteristics was accessed through contact with the municipalities of Våler, Ski and Enebakk.
- Existing monitoring data were accessed from the public database at the Norwegian environmental Agency (retrieved from https://www.vannmiljo.miljodirektoratet.no) and from the Norwegian Institute for Water research (retrieved from aquamonitor.no)

- Data on climatic variables temperature and precipitation was provided by the weather station BIOKLIM at Ås, Akershus(https://www.nmbu.no/fakultet/realtek/laboratorier/bioklim).
- Local history books
- Various reports produced by the Morsa water area range have provided useful information on agricultural and sewage runoffs as well as on development of water quality (retrieved from https://www. morsa.org).

2.5 STATISTICAL ANALYSIS

CLUSTER ANALYSIS

Pigment composition during years of confirmed Gonyostomum dominance was used as a marker for identifying *Gonyostomum* dominance throughout the obtained sediment cores. Identification of structures within the datasets were performed by running cluster analysis in Minitab18, comparing pigment composition in sediment samples throughout the entire sediment cores. Results are displayed in groups of clusters recognized by high similarity in pigment composition. In advance to running cluster analysis, pigment data had to be standardized against the absorption for chlorophyll *a* (666 nm). Standardizing against chlorophyll *a* is necessary to provide information on pigment composition without results being influenced by algal biomass. Standardizations were performed by Prof. Thomas Rohrlack at Faculty of Environmental sciences and natural resource management, Norwegian University of Life Sciences.

PRINCIPAL COMPONENT ANALYSIS (PCA)

Principal component analysis is a multivariate statistical analysis investigating for correlation in a dataset containing a range of variables. In principle, the purpose is to find the underlying structure of the data, and the direction where the data is the most spread out. The results of the analysis follow a successive pattern where the first component explain most of the variance within the dataset, the second component explains second most, and so forth (Abdi & Williams, 2010).

Correlations between year, chlorophyll a [µg/g), loss on ignition%, annual mean temperature(°C), total annual precipitation(mm) and sulphate in precipitation(mg/L) was performed for both lakes. Additionally, data on percentage of grain production in the drainage basin was included for lake Grepperødfjorden. In advance to running the analysis, values were standardized using minimum-maximum normalization, further described in Mohamad& Usman (2013). PCA was performed in Minitab18 by the assistance of associate Prof. Ståle Haaland at Faculty of Environmental Sciences and Natural Resource Management, Norwegian University of Life Sciences.

3. RESULTS

3.1 DESCRIPTION OF SEDIMENT CORES

Sediment core of lake Bindingsvann was characterized by a dark color indicating high content of organic matter and possibly reducing conditions. Some areas in the core appeared darker than others, some areas were almost black. Sediment core of lake Greppérødfjorden was lighter in color compared to the core obtained from lake Bindingsvann. The core appeared relatively homogenous and there were no visible layers. Both cores were 70 cm in length.

3.2 DATING OF SEDIMENT CORES

LAKE BINDINGSVANN

Results of the radioactive cesium analysis(Cs^{137}) for lake Bindingsvann show a cesium maximum for sample no. 10, representing the depth of 10 cm from the surface area of the sediment core (Figure 3.1). This sample is thought to represent the Chernobyl nuclear accident of 1986. Based on the DPM Cs^{137} maxima, annual, stable sedimentation rate is calculated by dividing number of years since the occurrence of the Chernobyl accident on depth(cm) where maxima locate. Consequently, annual sedimentation rate for lake Bindingsvann calculates to be 3,1(31/10), meaning that 1 cm of the sediment core equals 3,1 years. Annual sedimentation rate is thus 3,226 mm. The entire 70cm long sediment core of lake Bindingsvann dates as following to the period of 1803-2017(sample no. 70-1).
As dating is based upon the assumption of a stable sedimentation rate, this calculation must, however, be considered an approximation. Furthermore, as the Chernobyl nuclear accident was an isolated event, precipitation would contain cesium only for a limited time span. It is therefore expected that cs^{137} would distribute with a distinct maximum in the sediments. Cesium maxima in the sediments of lake Bindingsvann stretches over two samples, implying either swirling of sediments or delayed transportation of cesium-containing precipitation from drainage basin. Consequently, there are uncertainties regarding Cs^{137} maxima and as to which sediment core depth (cm) that represents the year of the Chernobyl nuclear accident.

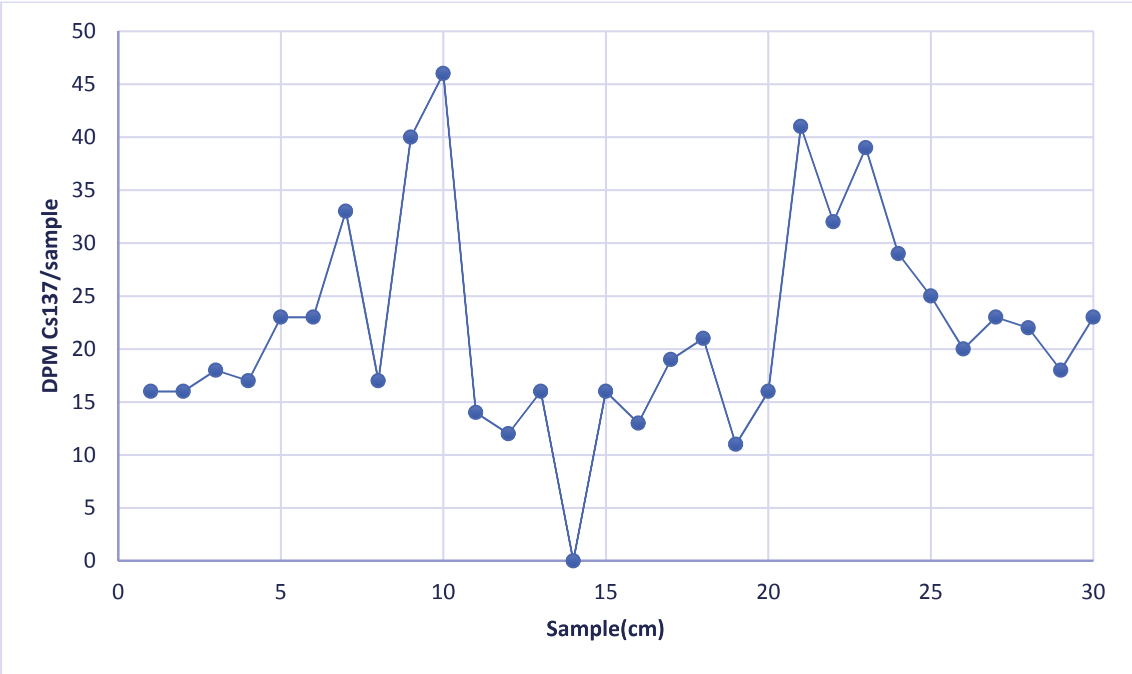


Figure 3.1: Radioactive cesium distribution down to a depth of 30 cm in sediment core obtained from lake Bindingsvann. Each sample represents 1 cm of the sediment core.

LAKE GREPPERØDFJORDEN

Distribution of Cs^{137} throughout the first 30 cm of the sediment core obtained from lake Grepperødfjorden show a cesium maximum at a depth of 22 cm (Figure 3.2). Annual, stable sedimentation rate is estimated by dividing number of years since the Chernobyl incidence on depth(cm) where Cs^{137} maxima occurs. Consequently, annual sedimentation rate estimates to be 1,4090909(31 years/22cm), meaning that 1 cm of the sediment core equals 1, 4090909 years. Annual, stable sedimentation rate is thus approximately 7,1 mm/year. The 70-cm long sediment core of lake Grepperødfjorden dates followingly by approximation to the period 1920-2017(cm 70-1).

Cs^{137} maxima stretches over two cm in the sediment core. Maxima is, however, relatively distinct. Distribution of cs^{137} in the following years contributes to a relatively wide maxima, implying swirling of sediments. Consequently, uncertainties regarding dating of the sediment core is likely related to sedimentation rate rather than the actual cs^{137} maxima.

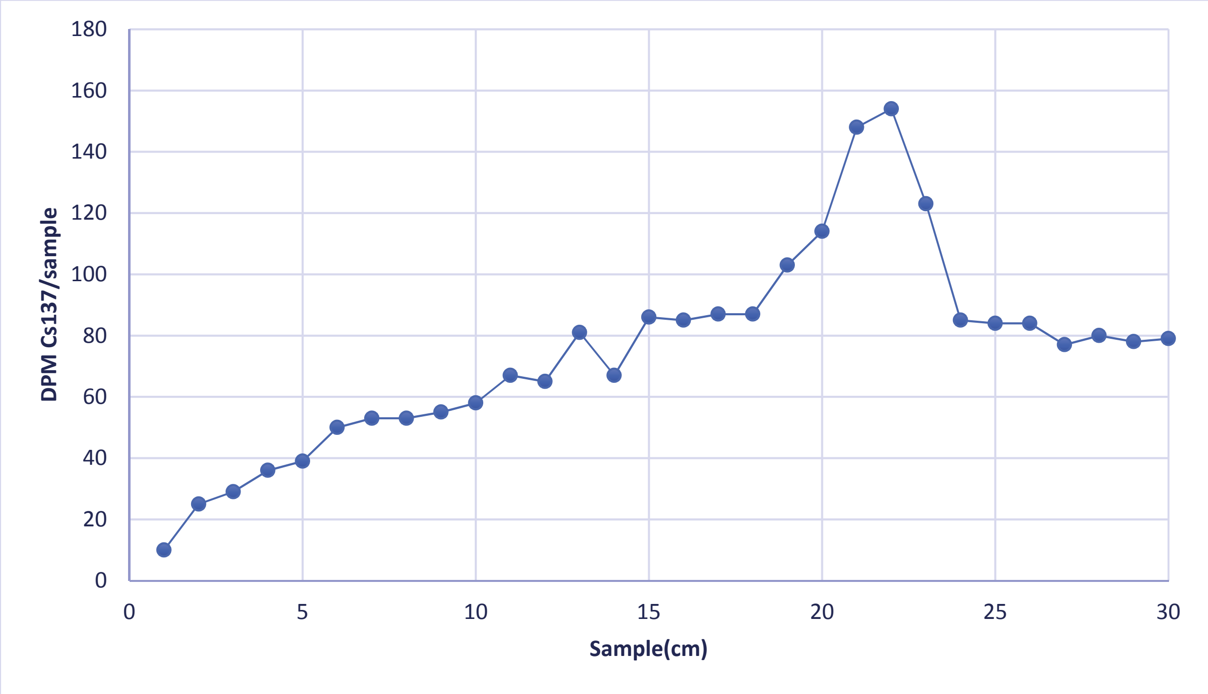


Figure 3.2: Distribution of Cs^{137} down to a depth of 30 cm in the sediment core obtained from lake Grepperødfjorden. Each sample represents 1 cm.

3.3 PIGMENT ANALYSIS

LAKE BINDINGSVANN

CHLOROPHYLL A

Reconstruction of chlorophyll a distribution (the sum of chlorophyll a and its breakdown product pheophytin a) in the sediment core of lake Bindingsvann represents total production of photoautotrophic phytoplankton. Values range between approximately 87 µg/dry weight(g) and 648 µg/dry weight(g). Lowest value is found in the estimated year of 1803, while highest value registers for the estimated year of 2017(Figure 3.3). 2017 value should, however, not be considered representative as this sample contains pigments that have not sufficiently been decomposed, resulting in particularly high values.
Chlorophyll- a values stayed rather stabile throughout the 1800s, with values ranging from approximately 87 µg/dry weight(g) in the estimated year of 1803 to around 200 µg/dry weight(g) in the estimated year of 1896(Figure 3.3). A slight increase is seen from the estimated period of around 1900, culminating in 1933 with a value around 207 µg/dry weight(g). This period marks the beginning of a reduction in lake productivity, lasting all the way up until the mid-1970s. Except for a particularly high value in the estimated time of 1983, chlorophyll a values followingly fluctuates in the range of 150-200 µg/dry weight(g) up until around 1992. From the estimated period of 1992 to 1995 chlorophyll- a levels rapidly increase, excelling from approximately 145 µg/dry weight(g) to 326 µg/dry weight(g). In the following years, chlorophyll a- levels stabilize at a much higher level than previously observed, ranging from around 230-330 µg/dry weight(g) (Figure 3.3). Productivity of the lake appear thus to have increased during the last 25 years.

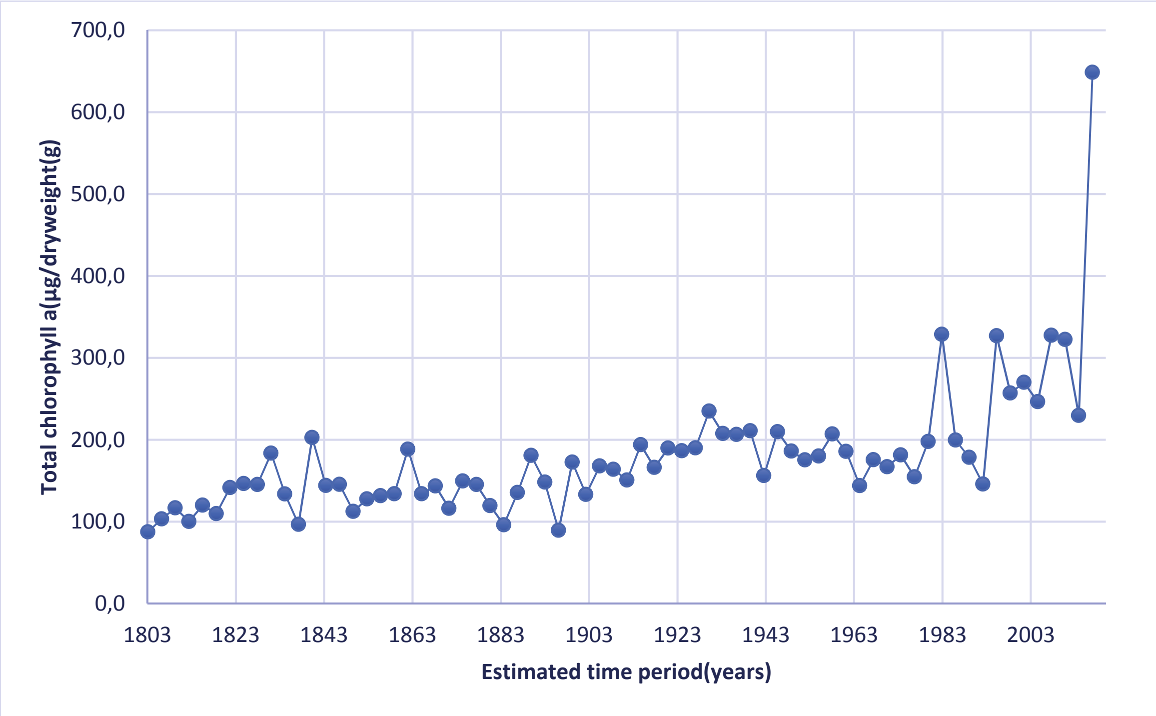


Figure 3.3: Estimated sediment core distribution of total chlorophyll a (the sum of chlorophyll a and its breakdown product pheophytin a) for lake Bindingsvann.

CLUSTER ANALYSIS

Results of cluster analysis for lake Bindingsvann separates pigment compositions throughout the sediment core into four clusters (Figure 3.4). Cluster displayed by blue in Figure 3.4 includes the years 2017, 2014, 2011, 2008, 2005, 2002, 1998, 1995(Table 3.1). These years all share the same pigment composition as found in years with confirmed algal community dominance of *Gonyostomum* . The assumption is therefore that Gonyostomum started to dominate the phytoplankton community of lake Bindingsvann around the mid- 1990s. Simultaneously, productivity of the lake increased rapidly, measured by the increase in chlorophyll a- levels from approximately 145 µg/dry weight(g)in 1992 to approximately 326 µg/dry weight(g) in 1995. Phytoplankton community dominance of Gonyostomum appear thus to be a driver for the increased productivity of lake Bindingsvann during the last 25 years.

The close correlation between cluster 1 and 2 implies that Gonyostomum may have been present also during the years represented by cluster 2. However, as cluster 1 and 2 form two subgroups, the evidence for this is relatively weak.

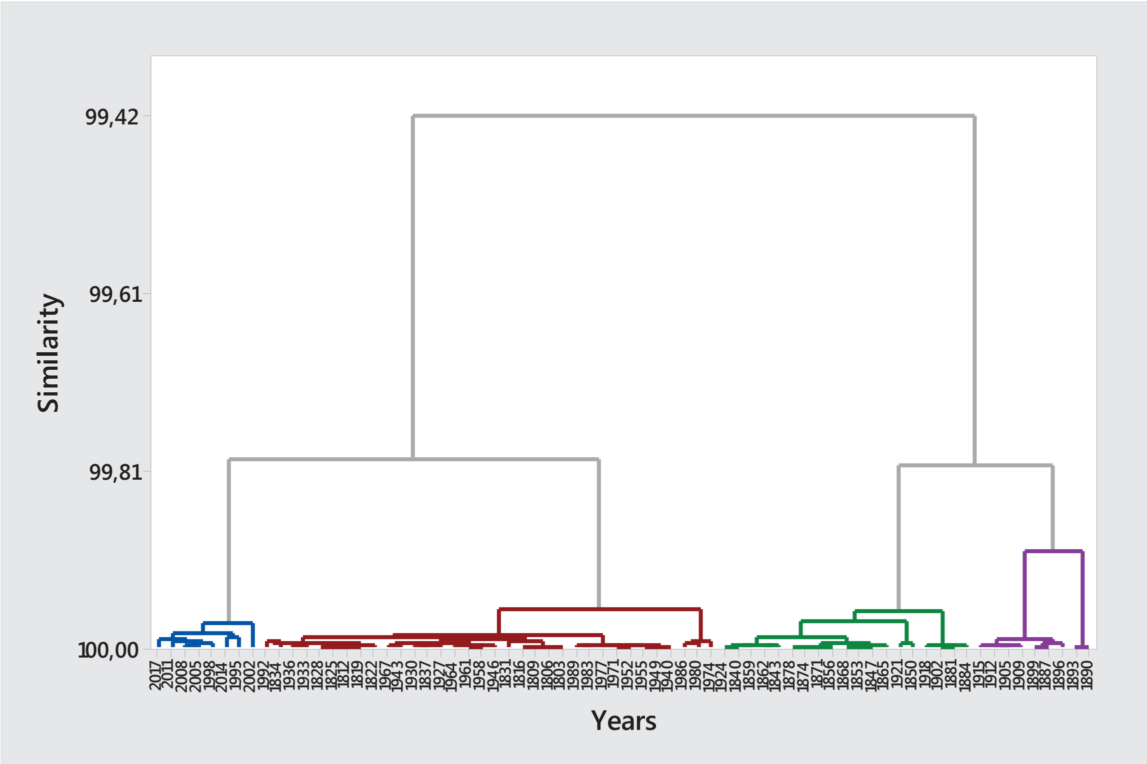


Figure 3.4: Cluster analysis for lake Bindingsvann, separating pigment compositions throughout the sediment core into four clusters. Cluster 1, marked with color blue, illustrates the estimated period of 1995-2017. Gonyostomum is with high probability the dominating species throughout this period.

Table 3.1: Cluster analysis on pigment compositions separates the sediment core of lake Bindingsvann into four clusters. Cluster 1 gives years of phytoplankton community dominance of Gonyostomum .

Cluster 1: 2017 2014 2011 2008 2005 2002 1998 1995
Cluster2: 1992 1989 1986 1983 1980 1977 1974 1971 1967 1964 1961 1958 1955 1952 1949 1946 1943 1940 1936 1933 1930 1927 1837 1834 1831 1828 1825 1822 1819 1816 1812 1809 1806 1803
Cluster3: 1924 1921 1918 1915 1912 1909 1905 1902 1899 1896 1887 1884 1881 1878 1874 1871 1868 1865 1862 1859 1856 1853 1850 1847 1843 1840
Cluster 4: 1893 1890

CHLOROPHYLL A

Reconstruction of total algae biomass for lake Grepperødfjorden shows chlorophyll a -levels ranging from around µg/dry weight(g) to around 150 µg/dry weight(g) (Figure 3.5). Highest value is found in 2017, however, this sample should not be considered representative as it contains levels of chlorophyll- a not fully decomposed.
Algae biomass stays rather stabile in the estimated period of 1920-1960 with values of chlorophyll a ranging around 20 µg/dry weight(g). From around the estimated time of 1960 level of chlorophyll *a* exceeds 20 µg/dry weight(g) and for the most part continuous to rapidly increase up until approximately 1980, reaching chlorophyll a -levels of around 65 µg/dry weight(g). The next period during the 1980s is characterized by an initial stagnation in lake productivity before chlorophyll- a levels ultimately decreases to around 50µg/dry weight(g) in the estimated year of 1990. This point marks the beginning of an increase in chlorophyll -a up until around year 2000, reaching a value of around 85 µg/dry weight(g). The estimated period of year 2003-2004 sees a relatively steep increase in lake productivity, elevating from around 85 to 110 µg/dry weight(g). Productivity of the lake continuous to increase during the next years, and a relatively sudden increase in chlorophyll-a is seen for the estimated period of 2010 to 2011 with values elevating from around 117 µg/dry weight(g) to 135 µg/dry weight(g). Values have decreased slightly from 2013 to 2016, but this might, however, be natural fluctuations not affecting the general trend. Productivity of the lake, measured by the increase in chlorophyll-a values, is slightly higher during the estimated period of 2000-2017 compared to what is observed for the estimated period of 1990-2000.

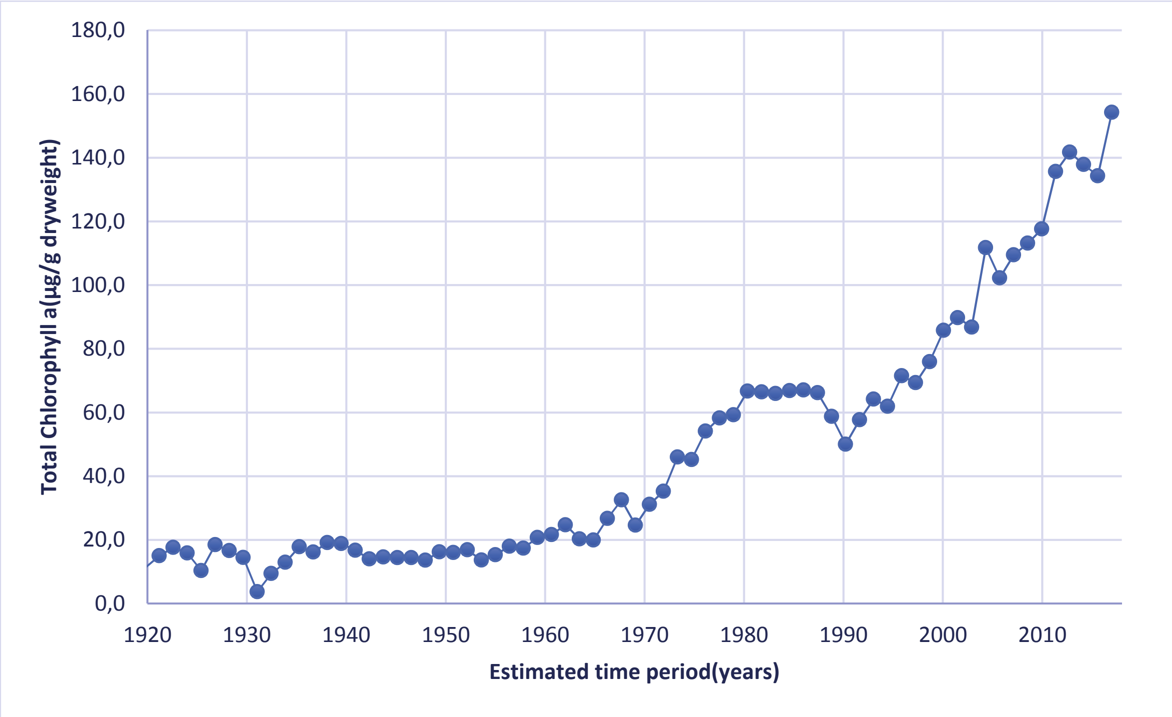


Figure 3.5: Estimated sediment core distribution of total chlorophyll a (the sum of chlorophyll a and its breakdown product pheophytin a) for lake Grepperødfjorden.

CLUSTER ANALYSIS

Cluster analysis for lake Grepperødfjorden separates estimated sediment core period into two main clusters (Figure 3.6). Cluster indicated in red comprises the years 2016-1975 and additionally the years 1972, 1952, 1944, 1940, 1935. These years all share the same pigment composition as found in years of confirmed phytoplankton community of Gonyostomum . Seemingly, Gonyostomum dominance first emerged in the mid-1930s. Comparing with the chlorophyll *a*- graph, *G. semen* dominance did not immediately result in increased lake productivity. From 1935 to around year 1970, Gonyostomum dominance may be characterized as sporadic, appearing with years in between. A reflection of this is observable on the chlorophyll a- graph, as total biomass of algae stays rather consistently around 20 µg/dry weight(g). From around 1965 total algae biomass increases. Gonyostomum dominance appear consistent from the estimated time of 1975 up until recent time, corresponding with the chlorophyll a – graph which reveals a rapid increase in lake productivity from that point on, only haltered by a stagnation and decrease from 1980-1990.

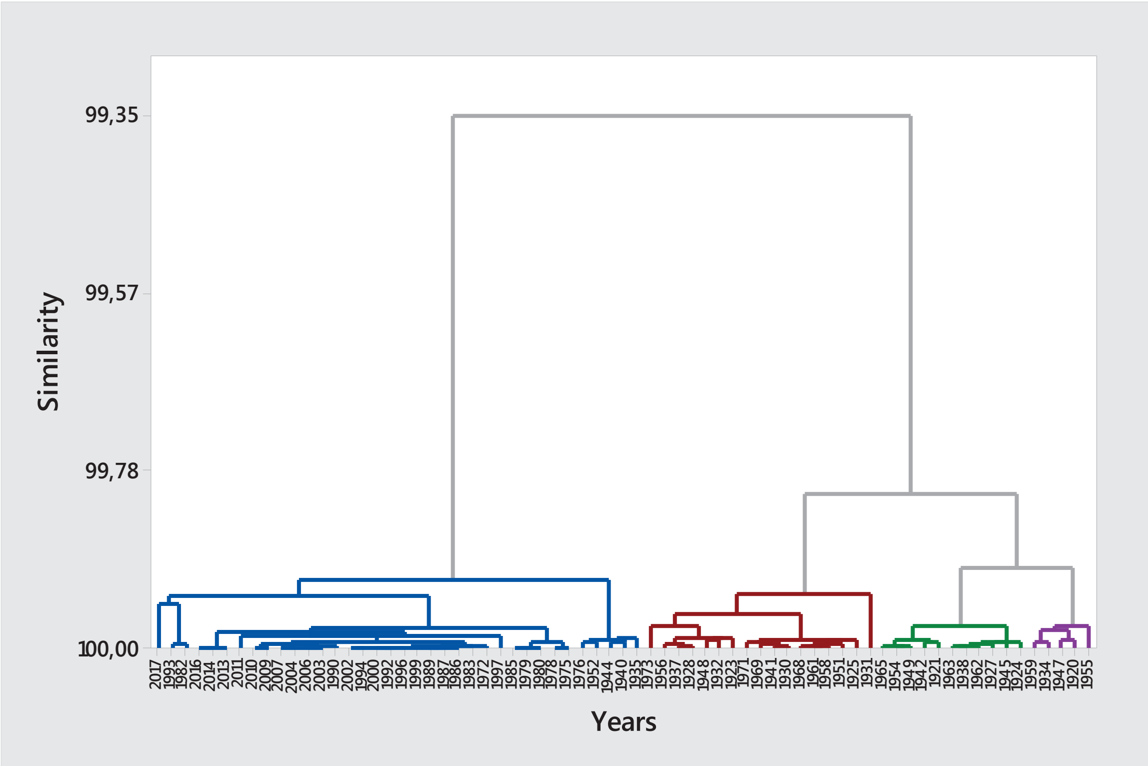


Figure 3.6: Cluster analysis for lake Greppérødfjorden, separating pigment compositions throughout the estimated period into four clusters. Cluster 1(marked by blue) comprises the years 1972-2017 as well as the years 1935, 1940, 1944 and 1952. Gonyostomum is by high probability the dominating species of the phytoplankton community throughout this period.

Table 3.2: Results of cluster analysis on pigment compositions throughout the sediment core of lake Greppérødfjorden. Estimated years are distributed in four separate clusters.

Cluster 1:
2017 2016 2014 2013 2011 2010 2009 2007 2006 2004 2003 2002 2000 1999 1997 1996
1994 1993 1992 1990 1989 1987 1986 1985 1983 1982 1980 1979 1978 1976 1975 1972
1952 1944 1940 1935

Cluster 2:
1973 1971 1969 1968 1961 1958 1956 1951 1948 1941 1937 1932 1931 1930 1928
1925 1923

Cluster 3:
1965 1963 1962 1954 1949 1945 1942 1938 1927 1924 1921

Cluster 4:
1959 1955 1947 1934 1920

3.4 LOSS ON IGNITION

LAKE BINDINGSVANN

Analysis for content of organic matter by loss on ignition finds that levels of organic matter have been greatly fluctuating throughout the estimated period of 1803-2017(Figure 3.7). During the estimated period of 1803- 1837, organic matter in the sediments is characterized by an increase from approximately 35% to 52%(Figure 3.7). Loss on ignition followingly decreases to under 40% during the estimated period of 1837-1850. The period of 1850-1915 is relatively stable with regards to content of organic matter in the sediments, with values fluctuating between 40 and 50%. An abnormally high value is observed for the estimated year of 1896(Figure 3.7). From the estimated time of 1915, loss on ignition increases from around 43% to 58% in 1933. The following period sees a decrease in loss on ignition reaching approximately 40% in 1964. Loss on ignition elevates with approximately 10% during the next ten years. The estimated year of 1974 marks the beginning of a significant reduction in organic matter in the sediments, reaching a low point of 25% in the estimated time of 1992. From this point on, lake organic matter has been increasing, although disrupted by minor fluctuations (Figure 3.7).

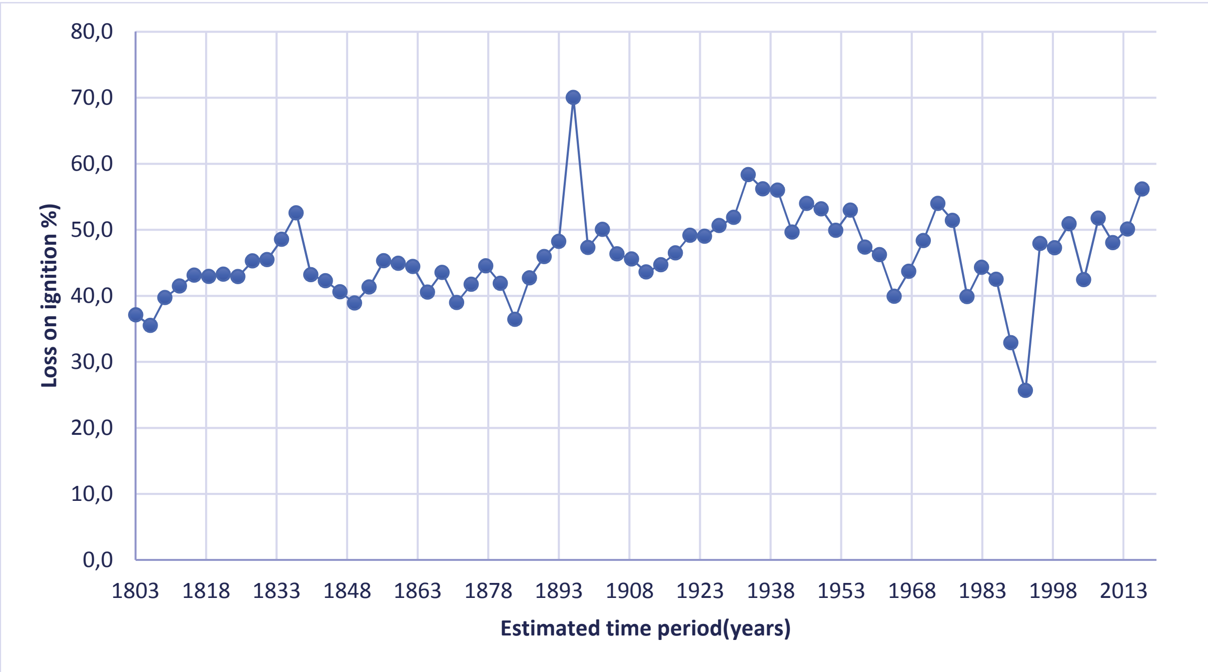


Figure 3.7: Loss on ignition (%) for lake Bindingsvann during the estimated period of 1803-2017.

Loss on ignition analysis for the sediments of lake Grepperødfjorden show relatively low values of organic matter in the sediments, with values ranging between approximately 5% and 14%(Figure 3.8). During the estimated period of 1920-1960, values for loss on ignition for the most part fluctuate between 5% and 10%. Except for minor fluctuations, the period of 1960-1982 sees an increase in organic matter in the sediments, with values increasing from 7% to 12%(Figure 3.8). The estimated year of 1982 marks the beginning of a period of decrease in organic matter in the sediments, reaching a low point in 1990 with a value of approximately 10%. The period of 1990- 2000 is characterized by an increase in loss on ignition, only haltered by minor fluctuations. Following this period, a steady increase in loss on ignition from 11% to 13% is observed during the estimated period of 2000-2009. Increase in loss on ignition is less clear after 2009 and levels have decreased slightly after 2013(Figure 3.8).

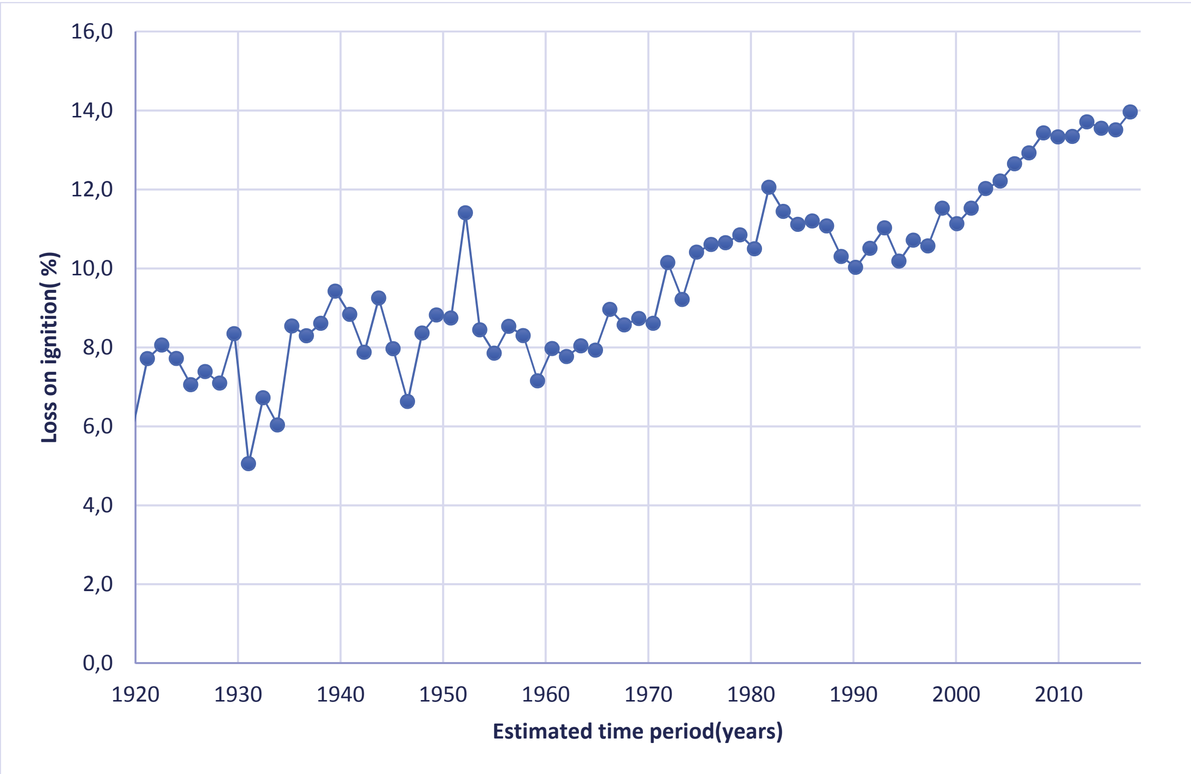


Figure 3.8: Loss on ignition (%) for lake Grepperødfjorden during the estimated period of 1920-2017.

3.5 DRY SEDIMENT BULK DENSITY

LAKE BINDINGSVANN

Dry sediment bulk density(g/cm^3) values for the estimated time span of the sediment core obtained from lake Bindingsvann ranges between 0,009 g/cm3 to 0,193 g/cm3(Figure 3.9). Relatively low values for bulk density are related to high percentages of organic matter in the sediment core. In the estimated period of 1803 to 1838, bulk density values decrease from around 0,15 g/cm^3 to under 0,1 g/cm^3(Figure 3.9). The next period up until 1850 is characterized by a steady increase, with bulk density values culminating at around 0,19 g/cm^3. Following period up until approximately year 1900 displays large fluctuations, however, in general there is a trend of decreasing values of bulk density. From the estimated period of 1900 to 1940 there is stable declining trend of bulk density. Following period up until the mid-1960 show an increase, while the next 20 years up until the mid- 1980s is characterized by fluctuations with a general trend of decreasing values. Bulk density values have in general decreased from this point on and up until now, except for a steep increase during the second half of the 1980s (Figure 3.9).

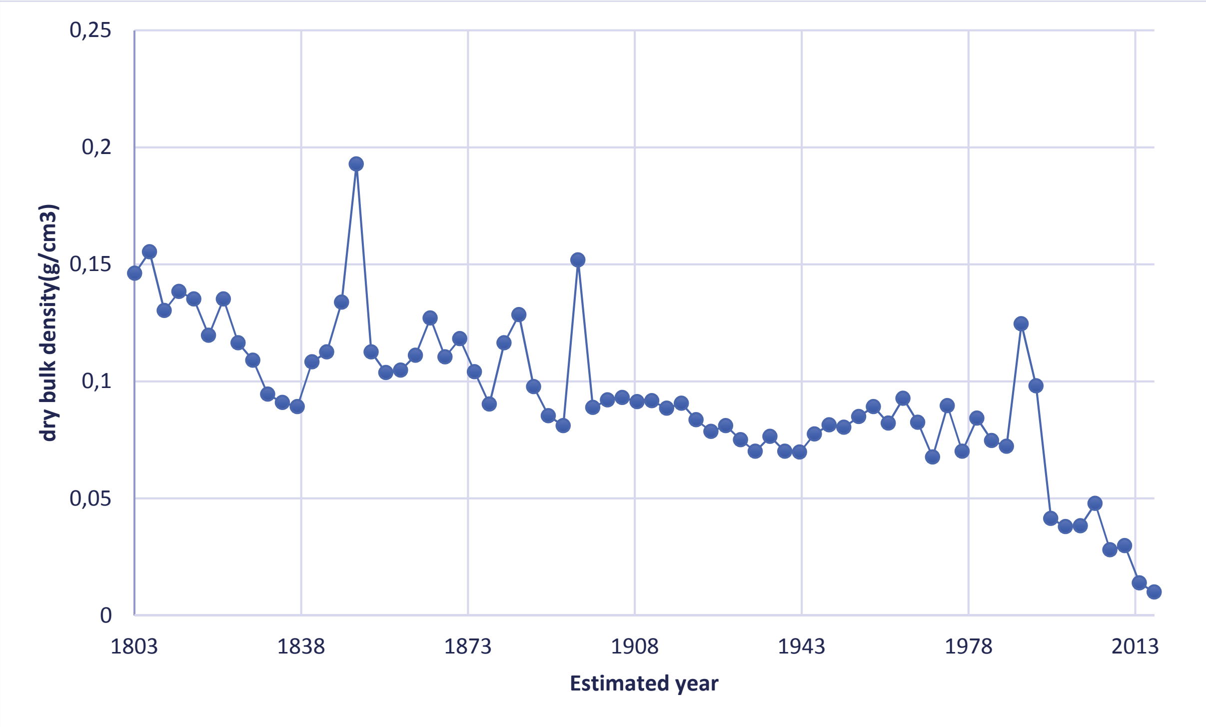


Figure 3.9: Dry sediment bulk density(g/cm^3) distribution throughout the estimated time span of the sediment core obtained from lake Bindingsvann. Bulk density values have in general declined as time has progressed, especially after the estimated time of 1995, suggesting higher content of organic matter in the sediments

LAKE GREPPERØDFJORDEN

Dry sediment bulk density values for lake Grepperødfjorden ranges between 0,03 g/cm3 to 1,15 g/cm^3. High values of bulk density indicate a smaller fraction of organic matter in the sediments. Due to a greater proportion of clay particles, sediments of lake Grepperødfjorden have a smaller percentage of porosity and the relationship between dry sediments weight and sample volume is consequently greater. The less pore space a sediment has, the higher the value for bulk density.

The estimated period of 1920 to 1955 show values of bulk density fluctuating at around 0,4-0,6 g/cm^3. A particularly high value of approximately 0,85 g/cm^3 is observed for the estimated year of 1931. Values of bulk density show a downward trend during the estimated period of 1960 to 1980, declining from approximately 0,6 g/cm^3 to 0,3 g/cm3. A high value registers for the estimated year of 1955. Bulk density values increase during a ten-year span from 1980 to 1990, culminating at around 0,4 g/cm^3. A relatively stable decline in bulk density is observed from around 1990 and up until recent time (Figure 3.10).

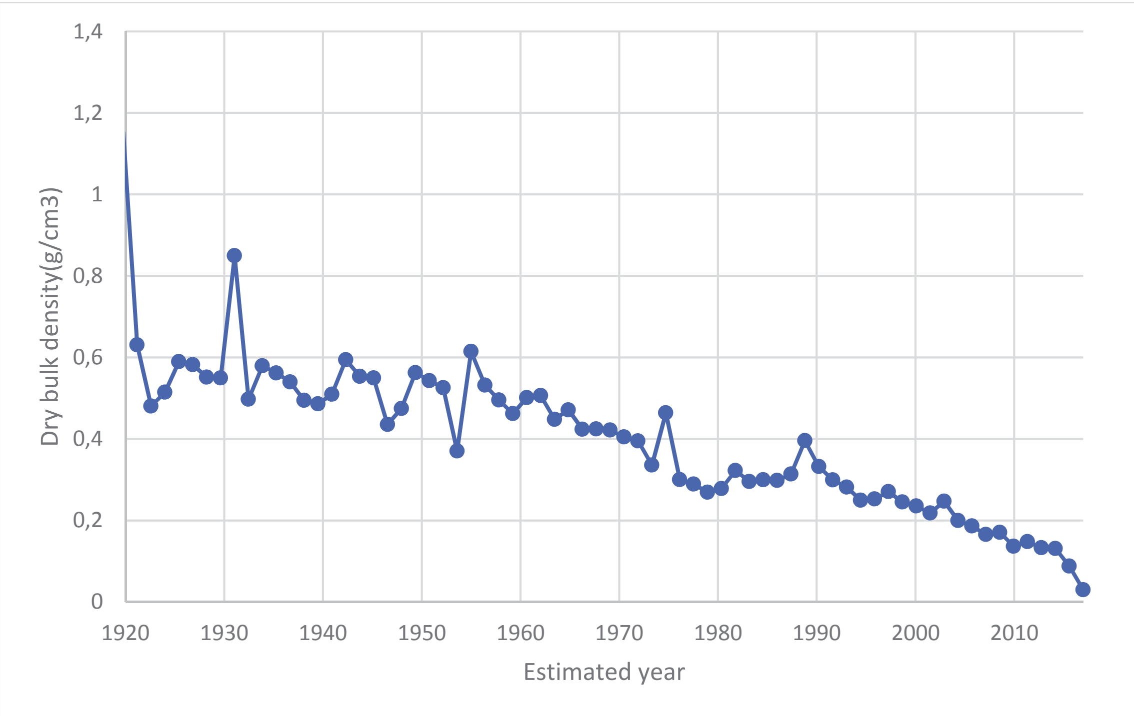


Figure 3.10: Dry sediment bulk density(g/cm^3) distribution throughout the estimated time span in the sediment core obtained from lake Grepperødfjorden. Bulk density values have in general declined as time has progressed, suggesting increasing levels of organic matter in the sediments.

3.6 POTENTIAL DRIVERS FOR PHYTOPLANKTON COMMUNITY DOMINANCE AND INCREASED BIOMASS OF GONYOSTOMUM

3.6.1 REGIONAL DRIVERS

Temperature and precipitation data for both lakes are represented by data obtained from the weather station BIOKLIM at Ås in the county of Akershus. Weather station locates 17 km from lake Bindingsvann and around 40 km in a direct line from lake Grepperødfjorden. It is assumed that the general trendlines for temperature and precipitation are representative for the region of South-Eastern Norway. Several weather stations do, however, locate in closer proximity to lake Grepperødfjorden, namely stations locating at Huggenes, Rygge and Råde, but these do not provide long, disrupted time-series for both temperature and precipitation. Weather station at Ås was by that reason considered to be a preferable option in representing both lakes regarding development of temperature and precipitation. However, due to the position of lake Grepperødfjorden in an area affected by spring floods and frequent changes in water supplies from inlet rivers, there might be uncertainties related to these data and as to which they are representative for lake Grepperødfjorden. Sulphate in precipitation for both Grepperødfjorden and Bindingsvann are represented by historical data on emissions in Europa up until 1973(Schöpp et al.,2003). Actual rainfall data from a station at Løken, Norway, are used for the period of 1973- 2017(S. Haaland, personal communication, 10.3.2018). Data on sulphate in precipitation is given in Appendix 3.

TEMPERATURE

In the period of 1897 to 2017, annual mean temperature graph displays several periods of large fluctuations (Figure 3.11). After fluctuating from 1897- 1927, temperature appear to increase until 1934 with a mean annual value of 7,3 °C. Following ten years are characterized by decreasing temperatures, reaching a minimum in 1941 with a value of 3,75°C. Temperatures continuous to greatly fluctuate until 1985 reaching a definite low point with a value 3,43 °C. Next fire years reveals a distinct rise in mean annual temperatures, culminating in 1990 at 7,94°C. From this point on temperatures continuous to fluctuate, however, they stay in general well above the line representing the normal temperature of 5,3°C (Figure 3.11).
Mean temperatures during the growth season(April-September) were calculated for the period of 1897-2017(Figure 3.11). Fluctuations are seen during the period of 1897- 1987, reaching a peak in 1947 with the value of 14,1 °C during the growth season. The period of around 1990 marks a point where trendline excels and stays above 12°C. Fluctuations are observed during the whole period of 1990-2017, however, it is consistently warmer during

the growth season than in previous years. Growth season temperatures follow to some extent the same pattern as annual mean temperatures.

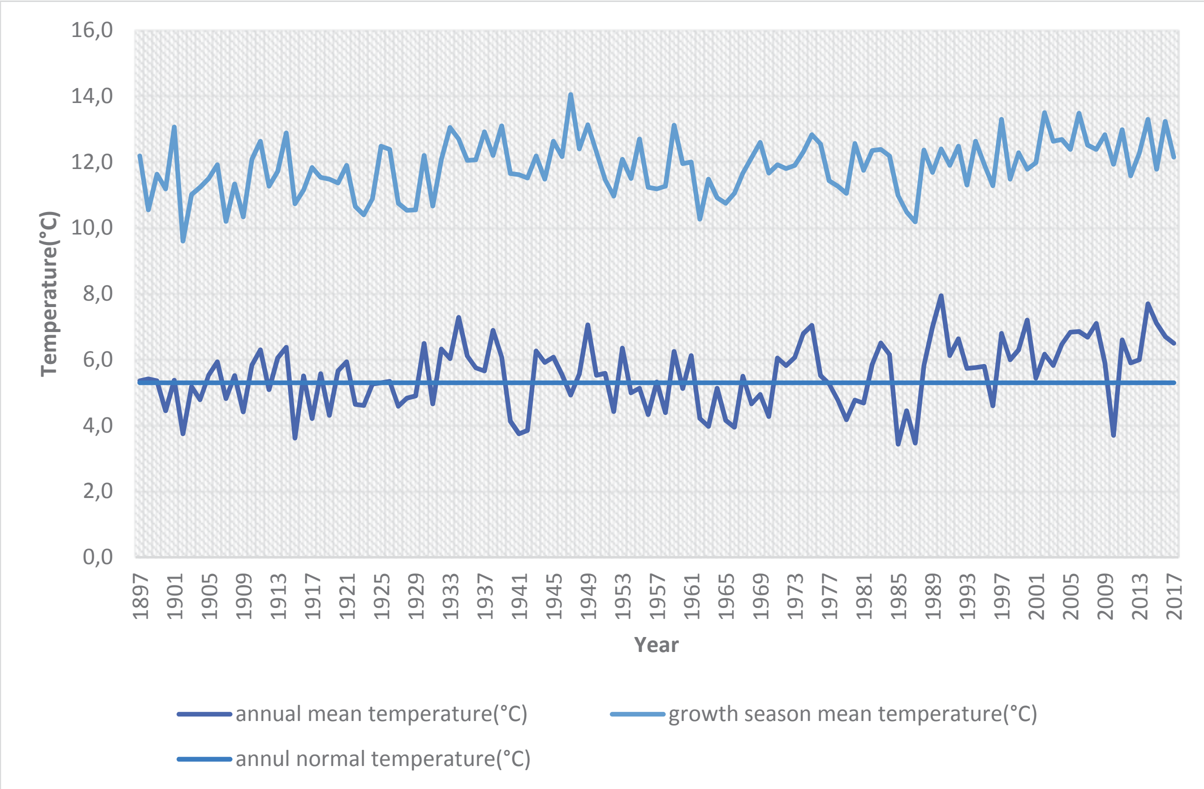


Figure 3.11: Annual mean temperature(°C), annual normal temperature(°C) and growth season (April-September) mean temperature during the period of 1897- 2017. Figure is produced based on data provided by weather station BIOKLIM at Ås in Akershus. Values for annual mean temperature and growth season temperature are given in Appendix 6.

PRECIPITATION

Total annual precipitation(mm) is characterized by large fluctuations during the period of 1897-2017(Figure 3.12). Precipitation fluctuates at values ranging from approximately 600-1000 mm/year. The following period sees an increase in annual precipitation, culminating in 1927 at a value of approximately 1100 mm/year. Annual precipitation values decline until 1941 when yet another increase starts, lasting up until 1960. From this point on there is a decrease until 1973(Figure 3.12). From around 1970 a trend of stable, increasing annual precipitation levels are observable (Figure 3.12). Maxima occurs around year 2000 with a value of approximately 1200 mm/ year. Values decrease slightly in the following years but remain elevated compared to previous periods. Values for total growth season precipitation follow to a large extent the same pattern as annual, total precipitation (Figure 3.12).

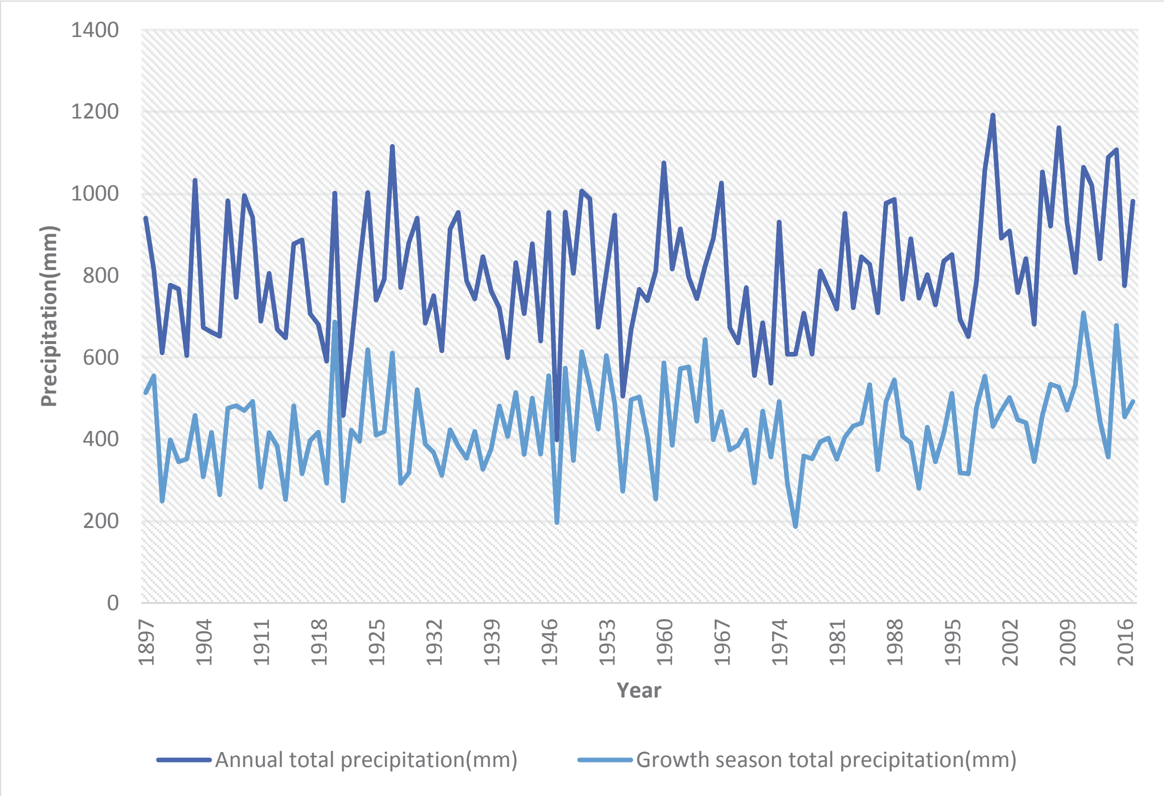


Figure 3.12: Annual total precipitation(mm) and growth season(April-September) total precipitation(mm). Figure is produced based on data provided by weather station BIOKLIM.

3.6.2 LOCAL DRIVERS: ANTHROPOGENIC DRAINAGE BASIN AND LAKE DISTURBANCES

3.6.2.1 LAKE BINDINGSVANN

Cluster analysis performed on pigment compositions throughout the obtained sediment core from lake Bindingsvann suggests that phytoplankton community dominance of Gonyostomum with high probability has been present since the estimated time of the mid-1990s. To investigate for drivers of such development, this chapter addresses drainage basin developments since the 1980s.

AGRICULTURE AND SETTLEMENTS/ SEWAGE EFFLUENTS IN DRAINAGE BASIN

Drainage basin of lake Bindingsvann consist of 88,5% forested areas and 4,8% swamp areas. 0,29% is occupied by settlements and 0,22% by agricultural fields(Figure 3.13). Agricultural fields are limited to the northern end of the lake in connection with the farm Fjell. Written sources for this farm goes back to 1723(Østlid, 1930), and as such there appear to have been settlements around the lake for several hundred years. According to Tormod Solem, agricultural consultant at Follo Agricultural Office, there are currently two units of the farm Fjell operating in the drainage basin(personal communication by email, 29.4.2018). Farm unit 101/3 comprises 26 acres of full-grown field used for grass production. Farm unit 101/8 constitutes 16 acres of full-grown fields also used for grass production. No records of change of use since the 1980s have been found for these areas.
Most of the residentials in drainage basin of lake Bindingsvann is located near the lake (see Figure 2.2). Current number of residentials surrounding the lake equals 92 permanent residentials and 25 cabins. Population is determined to be 150 people (see Figure 3.14).

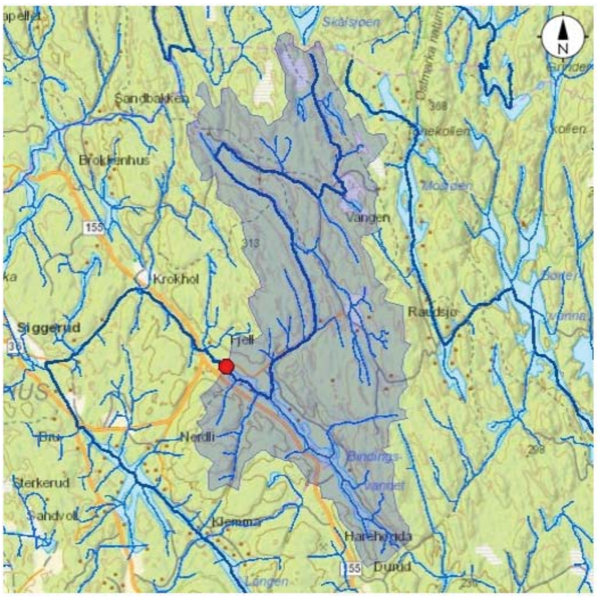


Figure 3.13: Catchment area of lake Bindingsvann is highlighted in grey (1:80 000). Adapted from NVE(n.d)

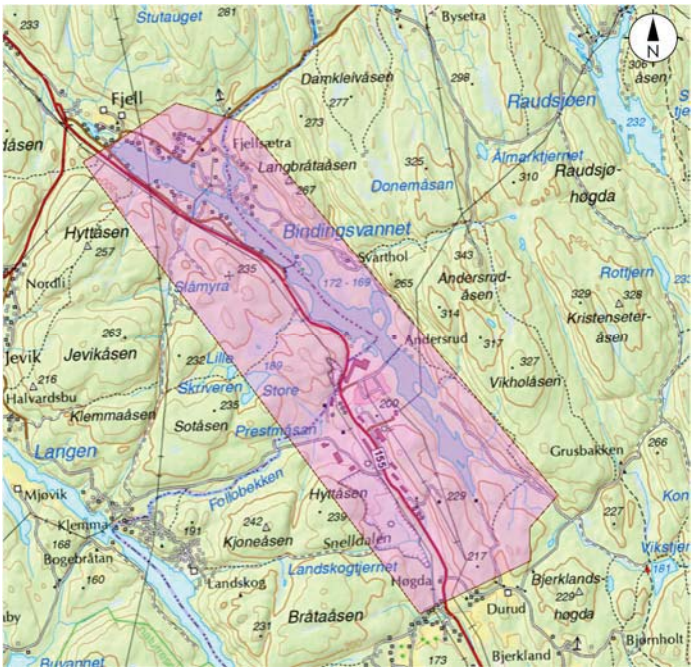


Figure 3.14: Polygon area used to calculate number of current residentials is highlighted (pink color). 92 permanent residences and 35 cabins is located within the polygon. Population is determined to be 150 people. Map and calculations were supplied by chief engineer Helge Klevengen at the Department of Technical Environment, Ski municipality.

Residentials surrounding lake Bindingsvann originate according to chief engineer Helge Klevengen at the municipality of Ski from the time span between the 2nd world war and up until the beginning of the 1980s(personal communication at his office at Ski municipality, 25.02.2018).Most of these properties were approved as farmhouses requiring very few technical solutions regarding sewerage. Leading up to the 1980s, an increasing amount of these properties were being used illegally as permanent residences. In the period of 1985-1988 the municipality of Ski conducted what has been referred to as a “cabin-amnesty”. This was part of an effort to reduce illegal settlements and unsatisfactory sewerage, and it meant that owners of the residentials could apply the municipality for permission to change of use if the sewerage was upgraded and improved. Most of the owners applied for change of use while also fulfilling the conditions of improved sewerage by installing mini treatments(H. Klevengen , personal communication, 25.02.2018). Moreover, due to its location within forested areas reserved for outdoors recreational purposes (Markaloven, 2009), further property development around the lake has been prohibited since 2009. Because of the cabin amnesty, there were no property development between 1980 and 2009.
After the implementation of the European water framework directive, the municipality of Ski initiated inspections of residentials around lake Bindingsvann. A 2013 inspection of the sewerage revealed that mini treatments installed in the 1980s no longer satisfied function

and capture rate requirements. 69 residentials with mini treatments that did not meet current requirements were imposed to perform an upgrade (H. Klevengen, personal communication, 25.2.2018). The process of upgrading the sewerage has just recently finished.

The municipality of Enebakk has yet to the same extent as the municipality of Ski to follow up on the challenge of unsatisfactory sewerage. Anne Marie Solsvik Heidenreich in the municipality of Enebakk informs that residentials on the Enebakk side of the lake counts 15 permanent residentials and 10 cabins not connected to public sewerage (personal communication by email, 3.3.2018). Residentials are from the 60s, 70s and 80s, and sewerage systems are mainly septic tanks with poor cleansing ability, and a few mini treatments.

Additionally, the Andersrud field includes 30 residentials and some commercial buildings (storehouse/ offices), but these are, however, connected to public sewerage system and do not have effluents to lake Bindingsvann (A.M. Heidenreich, personal communication by email, 3.3.2018).

WATER LEVEL REGULATIONS IN LAKE BINDINGSVANN

Lake Bindingsvann is dammed at the river outlet in the northern end of the lake. During the period of 1913-1960 water levels in lake Bindingsvann were regulated for providing hydropower for a sawmill and for a private hydropower plant downstream. Currently, it is the municipality of Oslo that owns the water rights in lake Bindingsvann. Special consultant Daniel Lyngholm Jacobsen in the Urban environment agency of the municipality of Oslo informs that water regulations during the 80s and 90s were done by the purpose of avoiding flooding of the road Bindingsveien, and to secure minimum flow in downstream river(personal communication by email, 11.4.2008). It was thus granted permission to lower water levels beneath the lowest point on the Bindingsveien road. Minimum flow in downstream river is currently secured through bottom drainage flow at an elevation of 169 m.a.s.l. Additional water flow in the river is self-regulating through overflow.

3.6.2.2 LAKE GREPPERØDFJORDEN

Cluster analysis performed on pigment compositions throughout sediment core obtained from lake Grepperødfjorden suggests algal community dominance of Gonyostomum to first emerge in the mid-1930s, however, dominance was inconsistent up until the estimated time of 1975. Based upon the time scale of Gonyostomum dominance provided by the Cs^{137} analysis, the following chapter addresses drainage basin and lake disturbances since around year 1900.

AGRICULTURE AND SETTLEMENTS

Catchment area of lake Grepperødfjorden comprises 66,8% forest and 18,7 % agricultural area. Lake area constitutes 10,2 % of total catchment area (NVE, n.d.). Drainage basin is given in Figure 3.15.

Areas of agricultural activity are found in proximity to the shoreline on the western side and northern end of lake Grepperødfjorden. However, inlet river in the northern end of the lake drains areas heavily dominated by grain production (see Figure 3.15). Settlements within drainage basin area are mainly found in relation to the farms, however, smaller settlements are found at Grepperød on the north-eastern side of the lake, and at Syverød, north-west of lake Grepperødfjorden.

Agricultural consultant Peder Unum at the municipality of Våler informs that Syverød originally was an area developed for leisure properties during the first half of the 1970s, but that it now has transformed to a residential area facilitating a joint sewage treatment plant. (personal communication at his office, 26.2.2018). Sewerage prior to 2004 consisted of private septic tanks with sand filters. Settlements at Grepperød consists mainly of leisure properties developed during the 1970s. The sewerage systems in this area were according to Peder Unum upgraded to mini treatments approximately ten years ago, around 2008.

All farms in the drainage basin of lake Grepperødfjorden had upgraded their sewerage to mini treatments within 2006/2007. Drainage basin of lake Grepperødfjorden is heavily dominated by agricultural activity, and it is therefore considered not to be representative of the general trends of population growth in the municipality of Våler (P. Unum, personal communication, 26.2.2018).

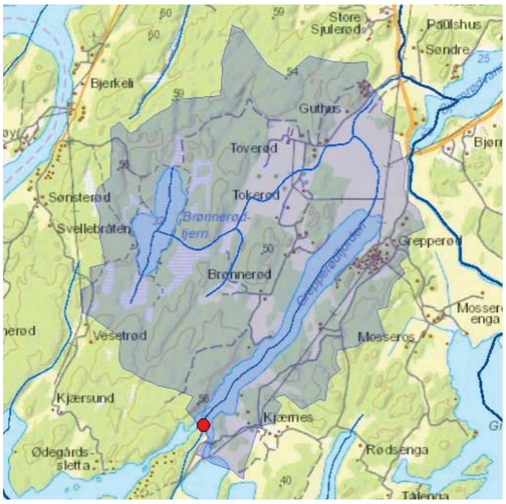


Figure 3.15: Catchment area of lake Grepperødfjorden (1:40 000) (NVE, n.d.b).

Total farmland within drainage basin area of lake Gredderødfjorden currently equals 1344 000 m^2. Majority of the 12 farm units operating in this area are producing grains by conventional methods (see Table 3.3). Grain production in the municipality of Våler saw an increase from around 1950, culminating in year 2002 with > 90% of the agricultural area being used for grain production (Figure 3.16). Areas used for grain production have decreased after 2001(Figure 3.17). Development of agricultural areas used for grain production in the municipality of Våler are assumed to be representative for drainage basin of lake Grepperødfjorden (P. Unum, personal communication, 26.2.2018).

Table 3.3: Farm units and agricultural land use within drainage basin of lake Grepperødfjorden. Table is produced based on information provided by agricultural consultant Peder Unum in the municipality of Våler.

Farm unit	Farm name	Size(m^2)	Current land use
40/1	Brønnerød	113 000	Conventional grain production
40/3	Brønnerød	156 000	Conventional grain production
41/1	Tokerød	157 000	Conventional grain production
41/2	Tokerød	41 000	Conventional grain production
42/1	Toverød	236 000	Conventional grain production
43/1	Guthus	205 000	Conventional grain production
45/1	Syverød	38 000	Ecological grass and grain production
53/2	Utengen	15 000	Conventional grain production
52/1	Paulshus	130 000	Conventional grain production
38/1	Grepperød	153 000	Conventional grain production
44/1	Mosseros	24 000	Conventional grain production
36/1	Kjærnes	91 000	Conventional grain production

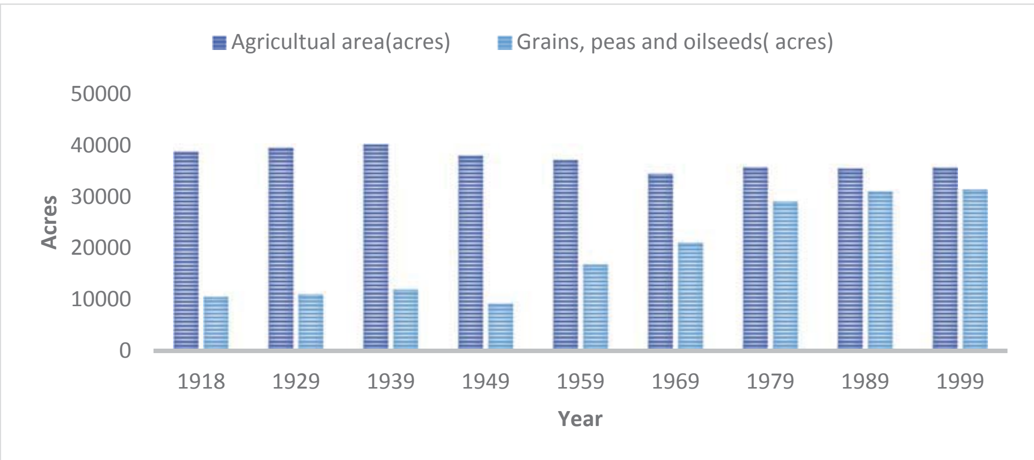


Figure 3.16: Development of total agricultural areas and areas used for total grain, peas and oilseed production in the municipality of Våler during the period of 1918-1999. (SSB 1918; SSB 1929; SSB 1939; SSB 1949; SSB 1959; SSB 2017).

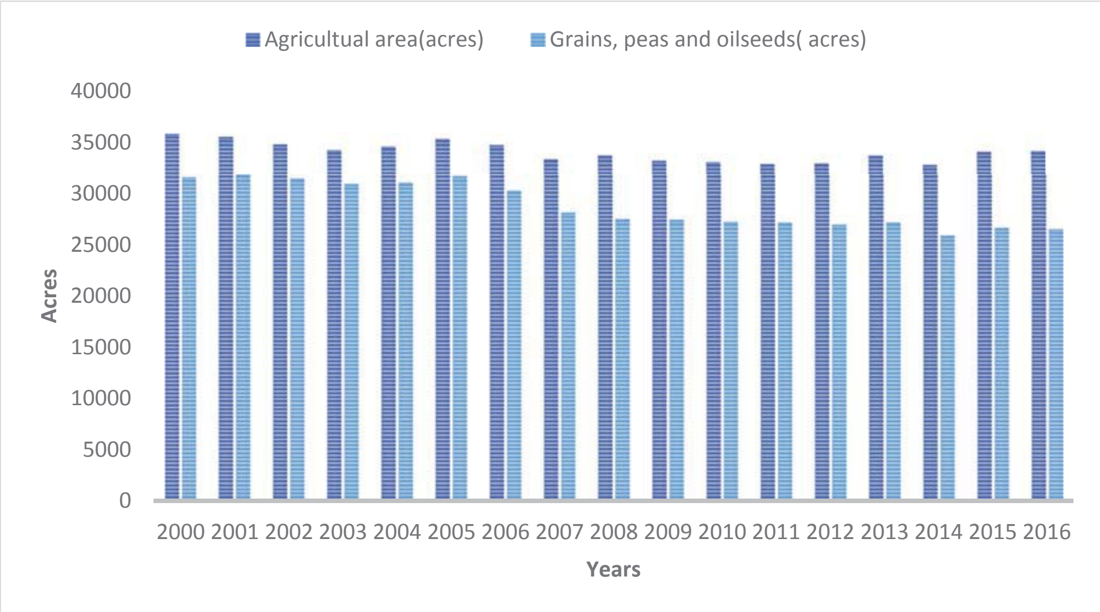


Figure 3.17: Development of total agricultural area and areas used for grain, peas and oilseeds in the municipality of Våler during the period of 2000-2016. (SSB 2017).

LAND USE IN A HISTORICAL CONTEXT

Agricultural traditions in drainage basin of lake Grepperødfjorden go several hundred years back in time. Most of the farms appear to have been established in early medieval age (Pedersen, 2005). Prior to this time, high water levels in lake Vansjø most likely would have made the area inadequate for agricultural activity (Pedersen, 2005). The soil in the area is currently a mixture of clay, sand and swamp material.

FARM BRØNNERØD

Farm unit 40/1(Southern Brønnerød), bordering Vansjø in the south and east, is established in early medieval age.). Leading up to 1802, the farm has suffered from deforestation. Live stocking is reported to have decreased around the turn of the 20th century, and is last reported in 1918(Andersen,2005). Simultaneously, grain and potato production increased. 7 acres of wheat, 3 acres of barley, 29 acres of oats and 8 acres of potatoes are reported to be sowed in 1918(Andersen, 2005).

Farm unit 40/3(Northern Brønnerød) suffered, like unit 40/1, from deforestation in 1802. Around the turn of the 20th century there appear to be a shift towards increased grain production. 8 acres of spring wheat, 10 acres of barley, 32 acres of oats, 10 acres of potatoes and 2 acres of peas were sowed in 1918. In the period of 1866- 1976 both cultivated and uncultivated land seem to have increased. Cultivated land increases from 109 acres to 188 acres, while uncultivated land increases from 470 to 499 acres (Andersen, 2005).

FARM TOKERØD

The Farm is established in early medieval age, and it was later split up into two units. Grain production on unit 41/1 appear to have increased in 1918 with the sowing of 14 acres of spring wheat, 12 acres of autumn rye, 7 acres of barley and 28 acres of oats. Livestocking continued up until 1964. From this point of the farm is exclusively producing grains, while also having some forestry in the winter season (Andersen, 2005). Unit 41/2 shifted its operational structure in 1970 from traditional agriculture with livestocking to exclusively producing grains and potatoes. Size of cultivated land appear to be relatively unchanged from year 1866(Andersen, 2005).

FARM TOVERØD

Farm is established in early medieval age. Unit 42/1 is reported to have had traditional agriculture with livestocking, grain production and forestry from 1965. From 1968, production of broilers gradually took over. The farm is currently being used for grain production and forestry. Cultivated land is reported to have slightly decreased from 278 acres in 1866 to 250 acres in 1976(Andersen, 2005).

FARM GUTHUS

This farm is like its neighboring farms likely established in the early medieval age. Most of the cultivated land stretches south on the western side of the Leie river. Farm unit 43/1 is reported to have had both grain production and livestocking in 1919. From the 1970s the farm is exclusively producing grains after having downscaled livestocking from around 1961. Poultry production is part of the operational structure during the period of 1980-1990. Size of cultivated land decreases from 238 acres in 1866 to 193 acres in 1976(Andersen, 2005).

FARM UTENGEN

This unit locates east of the Leie river and north of Grepperød. For a long period of time the area was presumably a swamp area perhaps used as pasture for multiple farm units. Utengen was likely established as a meadow in the 1600`s (Andersen, 2005).

FARM SYVERØD

Farm Syverød is established in early medieval age. Unit 45/1 first appeared when Syverød was split up into two units in 1823. In the 1920s the farm is reported to have had traditional operation in the form of livestocking. The entire farm was trenched in the 1960s, and forestry occurred during the 1990s. (Andersen, 2005) Syverød farm is the only unit in drainage basin of lake Grepperødfjorden that currently produces grains and grass by ecological methods (P. Unum, personal communication, 26.2.2018).

FARM PAULSHUS

The farm is likely to have been established in early medieval age or even a bit earlier. Paulshus was split up into two units in 1866. From 1915 farm unit 52/1 is reported to have had traditional operations with livestocking and some grain productions (Andersen, 2005). Grain productions appear to have had an increase with the sowing of 12 acres of autumn rye, 15 acres of barley, 36 acres of oats and 28 acres of mixed grains in 1918. From the 1960s the farm is for the most part producing grains.

FARM GREPPERØD

Grepperød is likely established in medieval age. Unit 38/1 is currently used for grain production; however, production of eggs was a significant part of the operational structure during the period of 1984-1997. Like its neighboring farms, unit 38/1 experienced a slightly increase in grain production in 1918. 8 acres of spring wheat, 10 acres of autumn rye, 8 acres of barley and 79 acres of oats were sown. Cultivated land decreased from 288 acres in 1866 to 196 acres in 1976. Uncultivated land increased from 136 acres in 1866 to 408 acres in 1976.

FARM MOSSEROS

Age of the farm is difficult to establish, however, considering all the other farms in the area are established in medieval age, it is rather unlikely that this farm is significantly older (Andersen, 2005). Unit 44/1 is reported to have had livestocking and production of grains up until 1952. From this point on it gradually transforms to exclusively producing grains.

FARM KJÆRNES

Age of the farm is difficult to establish; however, it likely originates from the Viking era or even a bit earlier. Up until 1955 the farm is reported to have had both livestocking and grain production, but currently it is exclusively producing grains. Like many of the other farms in

the area, farm Kjærnes appears to have had an increase in grain production around the beginning of the 1900s**.** 8 acres of spring wheat, 10 acres of autumn rye, 8 acres of barley and 60 acres of oats were sown in 1918.
Cultivated land have decreased from 236 acres in 1866 to 186 acres in 1976. Uncultivated lands(forest)increased from 273 acres in 1866 to 456 acres in 1976(Andersen, 2005).

DOCUMENTED NUTRIENT SUPPLIES TO THE WESTERN BASIN OF VANSJØ

The first thorough investigations of water quality in lake Vansjø was conducted in the mid-1960s, and it was then established that the lake was changing in the direction of a more eutrophic character(Holtan,1966). New investigations around the mid-1970s revealed that the lake during a ten-year period quickly had undergone eutrophication, especially in the western basin (Brettum, 1977). Runoffs from agriculture and sewerage had resulted in increased supplies of plant nutrients to the lake.
Effect of agricultural and sewage runoffs on eutrophication in the western basin of lake Vansjø has in recent time been well documented through the Morsa project - a 1999 initiative to restore water quality in the Vansjø lake system.
After a flooding in lake Vansjø in year 2000, the water quality of the western basin strongly deteriorated. The eastern and the western basin are relatively separated, and it was thus assumed that local supplies of plant nutrients could be an explanatory factor for the increasingly poor water quality of the western basin (Bechmann et al.,2006). Investigations of local supplies of phosphorous to the western part of Vansjø and the Moss river were conducted in the period of 2004-2007(Bechmann et al., 2006; Bechmann &Eggestad, 2007; Bechmann, 2008).
Results of the 2004-2005 examinations suggested that phosphorous supplies from 14 investigated drainage basin creeks were in twice the magnitude as originally expected (Bechmann et al.,2006). Phosphorus content in the creek Guthusbekken, draining into lake Grepperødfjorden, was found to exceed the environmental goals by more than 50%, and normalized loss of total phosphorous based on acres of agricultural land in drainage area showed that Guthusbekken had the greatest loss of total phosphorous out of all the investigated creeks (Bechmann, 2008). Amount of phosphate out of total phosphorous in Guthusbekken was in 2007 determined to be 21%, a number corresponding with results of similar measurements conducted in other heavily agricultural dominated drainage basins in eastern Norway where erosion is the main pathway for supplies of phosphorous(Bechmann et al.,2008). Concentration of total nitrogen was found to be 1,0 mg/L in 2007 for creek Guthusbekken. In general, there was a positive correlation between percentage of agricultural land in the drainage basins and registered values of total nitrogen in the creeks (Bechmann et al.,2008).

Calculated values of phosphorous supplies to the western basin was approximately the same in 2006 as in 2004/2005 when accounting for rainfalls and runoffs. Estimated normalized supplies on an annual basis was calculated to be 3- 3,5 tons of phosphorous. Due to heavy rainfalls and runoffs, the actual supplies of P were greater in 2006 compared to those found in 2004/2005. In total, 4-4,5 tons of phosphorous were supplied to the western basin from the local drainage basin in 2006 (Bechmann and Eggestad, 2007). Precipitation and runoffs was found to have a significant impact on supplies of phosphorous to the western basin (Bechmann, 2008). Highest average concentration of phosphorous (235-415 µg TP/L) were in 2007, as in previous years, measured in runoff draining areas featuring the highest percentage of agricultural area(Bechmann,2008).
Several measures have been performed after 2007 to reduce supplies of phosphorus to the western basin, such a decreasing amount of phosphorous in fertilizers and upgrading sewerage(Bechmann et al.,2006b)

In addition to phosphorous supplies from drainage basin, internal loading of phosphorous was hypothesized to be a contributing factor to the eutrophication of the western basin. However, a 2006 research project evaluating the probability for internal loading of phosphorous in the western part of Vansjø found that internal loading was significantly less than hypothesized (Andersen et al.,2006). The investigations showed that phosphorous release from the sediments during anoxic conditions occurred in very small areas of the lake and in a limited magnitude, and the process was thus evaluated to not contribute to the input- output phosphorous budget of the lake.
Phosphorous release from swirled sediments in shallower waters of the lake potentially could have an impact during shorter periods in midsummer, but the netto effect on an annual basis was thought to be insignificant (Andersen et al.,2006). Due to large areas of shallow waters and its location in a wind exposed area, lake Vansjø has relatively few areas for hypolimnion hypoxia to develop. Phosphorous contents in the sediments of lake Greppørødfjorden are calculated to be higher than those found in the sediments of lake Vanemfjorden. However, areas for anoxic conditions to develop are very limited. There is, however, a possibility for resuspension of sediments and phosphorous through sediment swirling from wind exposure and bioturbation from bottom dwelling fish (Andersen et al., 2006).

WATER LEVELS REGULATIONS IN THE VANSJØ BASIN

The Lake Vansjø system is dammed at the river outlet by Moss, at the lower end of the water course. The first serious attempt to dam the lake was made in the years of 1866-1868, and the purpose of the damming was allegedly to recover approximately 5000 acres of agricultural land. In conjunction with the damming of the lake, the first reservoir regulation schedule was introduced in 1868. Highest allowed regulated water level was set to be 9,5 feet (Hauger et al.,1992). A further lowering of the water level was decided in the 1880s, and

the construction works finished in 1887 with the repositioning of the dam to Sponvika. There have been no further regulation interventions in lake Vansjø since 1887, however, the dam was repositioned from Sponvika to Klova in 1941. A new reservoir regulation schedule was introduced in 1966 which in principal only was a clarification of the 1868 schedule. Environmental considerations were for the first time incorporated in 1983 when yet a new regulation legislation was implemented. The most significant change was that water level during summer could not be lowered beneath 2,30 meters (Hauger et al. 1992).
The water reservoir schedule later became a topic as the water quality of lake Vansjø increasingly deteriorated (Skarbøvik, 2008). As part of the Morsa project to restore water quality of the lake, a temporary change of the regulation practices was granted for the years 2005-2010 and from 2011-2015. The purpose was to research for more environmentally friendly regimes of maneuvering the water levels in lake Vansjø. Results of the temporarily changes in water leveling of the lake indicate that heavy draining at the dam may lead to 1) supplies of nitrogen-rich water from the eastern basin (lake Storefjorden) to the western basin, promoting increased algal growth, and 2) low water levels in the lake, possibly resulting in resuspension of phosphorous-rich sediments, although such incident has not been detected (Skarbøvik and Rohrlack, 2009). Consequences of water leveling practices have not been discussed solely for lake Grepperødfjorden, rather for the western basin in general.

LAKE BINDINGSVANN

A principal component analysis using variables annual mean air temperature, annual precipitation(mm), chlorophyll- a(µg/g) in the sediments, loss on ignition (%) and sulphate in precipitation(mg/l) found that PC1 and PC2 altogether explained 60,2% of variation within the dataset of lake Bindingsvann (Figure 3.18). All variables except for sulphate in precipitation are positively correlated along the PC1 axis. Chlorophyll a, annual precipitation and annual mean air temperature show a positive correlation, while sulphate in precipitation is negatively correlated to loss on ignition. This should be interpreted as increase in loss of ignition as a cause of decrease in sulphate in precipitation. Chlorophyll a and annual precipitation are the two variables with the highest correlation. Loss on ignition appear to be relatively weakly correlated to chlorophyll a in the sediments.

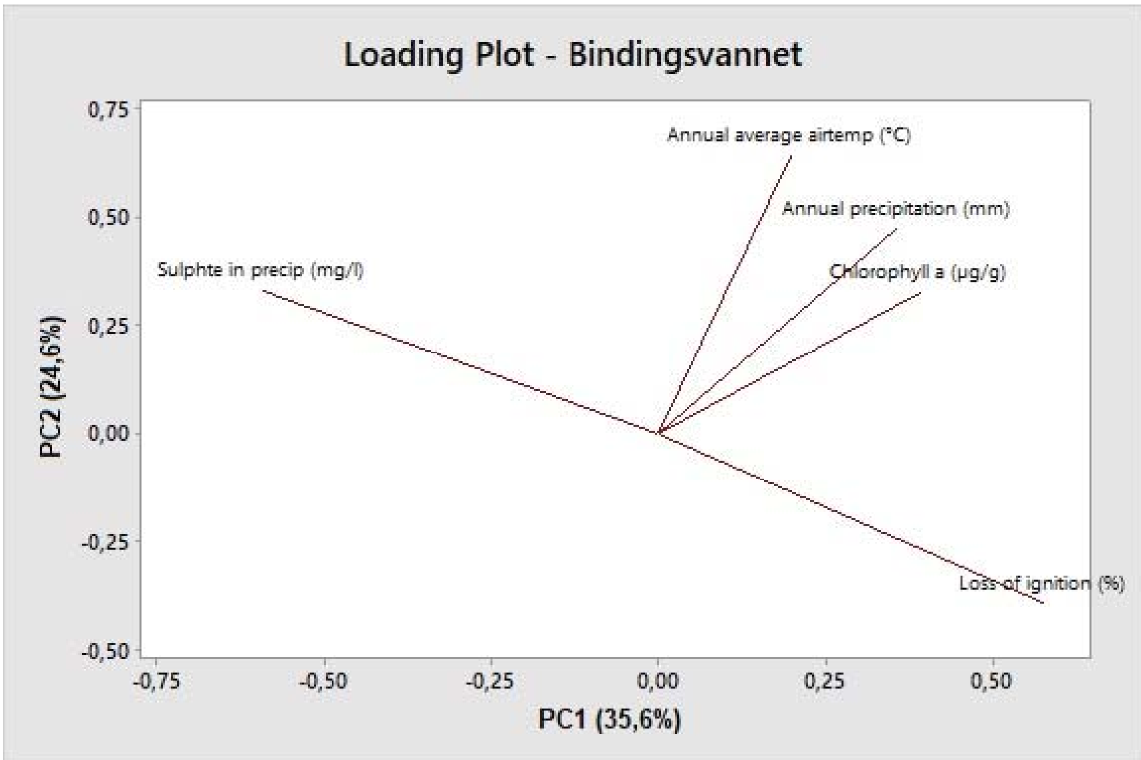


Figure 3.18: Principal component analysis of the variables annual mean air temperature(°C), annual precipitation(mm), chlorophyll- a(µg/g), loss of ignition (%) and sulphate in precipitation(mg/l) for lake Bindingsvann. PC1 and PC2 explain in total 60,2% of variance within the dataset.

LAKE GREPPERØDFJORDEN

Principle component analysis was performed for lake Grepperødfjorden using the same variables as in PCA for lake Bindingsvann while also adding a new variable for percentage of agricultural area used for grain production (Figure 3.19). Results of the PCA show that all variables are positively correlated along the PC1 axis, except for sulphate in precipitation that shows a zero correlation (Figure 3.19). Chlorophyll-a (µg/g) and loss of ignition (%) are closely positively correlated along the PC1 axis. Agricultural area correlates to these two variables in slightly the same direction. Consequently, productivity of the lake (total chlorophyll a) and levels of organic matter in the sediments correlates to agricultural area used for grain production.

Annual precipitation(mm) and annual mean air temperatures positively correlate along the PC1 axis, but they do not go in the same direction or stretch as far out on the PC1 axis as chlorophyll a, loss on ignition and percentage of agricultural area used for grain production. PC1 and PC2 explain in total 74,1% of the variance within the dataset of lake Grepperødfjorden (Figure 3.19).

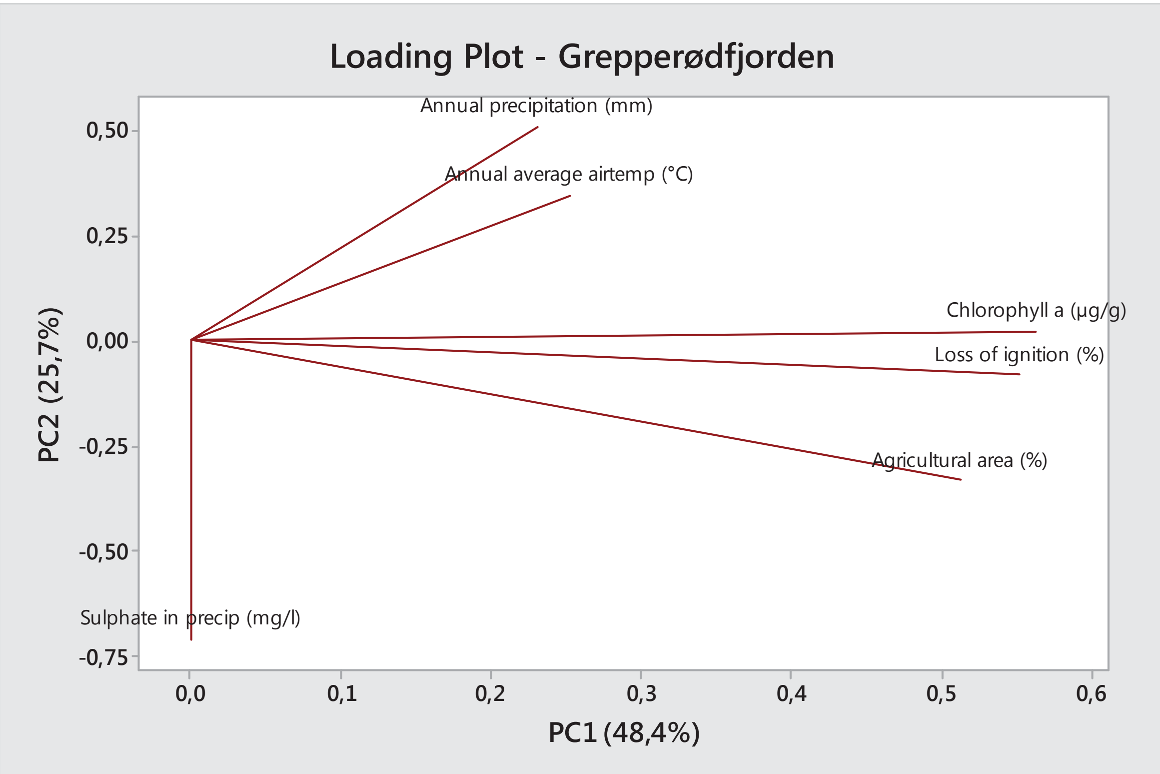


Figure 3.21: Principal component analysis(PCA) of the variables annual precipitation(mm), annual mean air temperature(°C), chlorophyll-a(µg/g), loss of ignition (%), agricultural area used for grain production (%) and sulphate in precipitation(mg/l) for lake Grepperødfjorden. PC1 and PC2 explain in total 74,1% of the variance within the dataset

4. DISCUSSION

4.1 PHYTOPLANKTON COMMUNITY DOMINANCE OF GONYOSTOMUM AND LAKE PRODUCTIVITY

Cluster analysis indicate that *Gonyostomum* first emerged as a dominant species in the phytoplankton community of lake Grepperødfjorden in the estimated time of the mid-1930s and in lake Bindingsvann in the mid-1990s. However, as this study only examines for Gonyostomum dominance, it may have been present in both lakes at a much earlier stage. The finding of *Gonyostomum* as a dominating species in lake Grepperødfjorden in the mid-1930s contradicts the hypothesis of Lebret et al. (2012) that invasion and colonization of *Gonyostomum* in Northern Europe in recent within the last decades. However, due to uncertainties regarding sedimentation rate and dating of the sediment core, this finding should be considered preliminary.

Phytoplankton community dominance of the Gonyostomum population in lake Grepperødfjorden appear, however, inconsistent up until the estimated time of the mid-1970s. The behavior of this species in Grepperødfjorden appear thus to follow the pattern as suggested by Hagman et al.(2014) of adapting and blooming once the conditions approve. No information is available whether the dominating Gonyostomum population up until the mid-1970s is in fact genetically identical to the current population. Lebret et al.(2013) found evidence of genetic differentiation among Gonyostemum populations in Fenno-Scandinavia,suggesting adaptation to different environments.

Results of the cluster analysis performed on the sediments of lake Bindingsvann showed that clusters one and two were closely positively correlated, indicating that Gonyostomum may have been present throughout the entire period that the sediment core is representing. However, cluster one and two form two subgroups and the evidences are therefore relatively weak for dominance of Gonyostomum throughout this period. Phytoplankton community dominance of Gonyostomum is with high probability present from the estimated time of the mid-1990s.

Although being present as a dominating species in the phytoplankton community of lake Grepperødfjorden since the estimated time of the mid-1930s, Gonyostomum did not immediately contribute to an increase in total algal biomass of the lake, as expressed by chlorophyll-a distributions in the obtained sediment core. A steady increase in chlorophyll-a levels is first observed during the 1960s, and from this point on algae biomass continuous to increase only haltered by a stagnation and decrease during the estimated time of the 1980s. Monitoring data support the findings of increased productivity, as chlorophyll -a levels in the water phase appear to have increased from the 1980s(Figure 8A, Appendix 8).

The graph of chlorophyll a µg/ g Org. C (Figure 2A, Appendix 2) follow to a large extent the same pattern as the graph for Chlorophyll a µg/ g dryweight, suggesting that there has been an increase in lake productivity. The same applies for lake Bindingsvann. Graph on chlorophyll a µg/ g Org. C (Figure 1 A, Appendix 1) follows the same pattern as Chlorophyll a µg/ g dryweight with an increase around the 2000s. The emergence of Gonyostomum as a dominant species in lake Bindingsvann in the estimated time of 1995 corresponds with a noticeably increase in lake productivity, increasing from approximately 145µg chlorophyll a/ dry weight in 1992 to approximately 326 µg / dry weight in 1995. In the following years and throughout the 2000s, chlorophyll- a levels stabilize at a considerably much higher level than seen in previous periods. The introduction of Gonyostomum as a dominant species appear thus to noticeably have increased the productivity of the lake. Monitoring performed in the period of 2008-2013 lends support to the finding of increased productivity as a cause of Gonyostomum dominance. Total phytoplankton biovolume during periods of Gonyostomum blooms are observed to increase considerably, and Gonyostomum biovolume during blooms periods are observed to constitute as much as 90% of total phytoplankton biovolume(Figure 2.4B)

4.2 REGIONAL DRIVERS OF GONYOSTOMUM DOMINANCE AND INCREASED BIOMASS

AIR TEMPERATURES

Temperature is hypothesized to influence Gonyostomum growth rates in several ways. Figueroa and Rengefors (2006) found that G. semen cyst germination was positively affected by temperature while Rengefors et al. (2012) found that higher temperature may promote larger biomasses of Gonyostomum by increasing the length of the Gonyostomum growing season. Lab experiments have demonstrated that Gonyostomum growth starts at temperatures above 6°C, is optimal at temperatures between 9 and 12 °C and decreases rapidly with increasing temperatures above 19°C (Rengefors et al.,2012). Elevated spring temperatures leading to intensified and prolonged thermal stratification are also hypothesized to influence the size of Gonyostomum populations (Salonen and Rosenberg, 2000).

The introduction of Gonyostomum as a dominant species and the correlating increased productivity of lake Bindingsvann correspond with air temperatures significantly higher during the period of 1990-2017 than those registered during the period 1920-1989(Figure 4.1), lending support to the principal component analysis suggesting that air temperatures positively correlates to productivity of the lake.

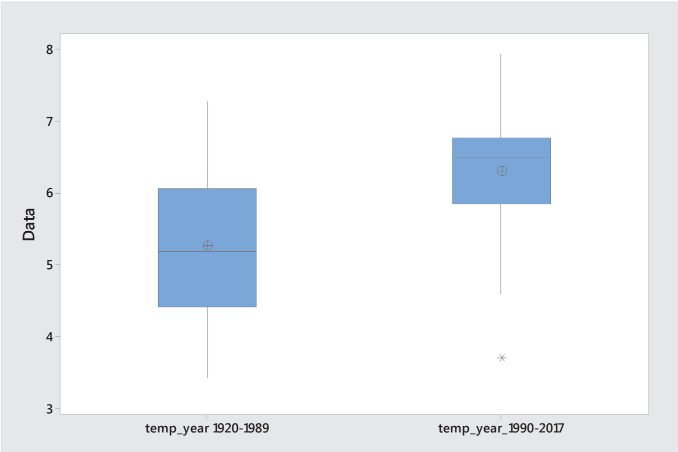


Figure 4.1: Boxplot demonstrating significant difference in means of annual air temperatures between the period of 1920-1989 and 1900- 2017. T-Test of difference = 0 (vs ≠): T-Value = 4,05 P-Value = 0,000 DF = 37.

Increasing air temperatures may have supported Gonyostomum growth in lake Bindingsvann both by extending the growing season and by fasciliating earlier and more stable thermal stratification. Monitoring data have shown that lake Bindingsvann is thermally stratified during summer and that anoxic conditions in bottom waters frequently occur. Periods of thermal stratification promote anoxic conditions in bottom waters with the potential of internal loading of soluble reactive phosphorous. This may work as an advantage for a species like Gonyostomum that vertically migrates in the water column utilizing nutrients in the deeep strata.

Due to its location above marine limit, phosphorous is likely a limiting factor for algae growth in lake Bindingsvann, and the ability to utilize phosphorous in the deep strata during conditions of internal loading would benefit growth rates of Gonyostomum. Intra-seasonal distributions of Gonyostomum indicate that the algae may be profiting on resources not easily accessible for other phytoplankton species, as biovolume during blooms periods of Gonyostomum dramatically exceeds what is found earlier in the growing season(Figure 2.4A; Figure 2.4B).Monitoring data show a persistent increase in Gonyostomum biovolume from around mid-summer, contributing to a noticeably increase in lake productivity, some years constituting to as much as 90% of total phytoplankton biovolume (see Figure 2.4; Figure 2.5). This could suggest that stable stratification over a long period promote the dominance and biovolume increase of Gonyostomum. Similar results of pronounced Gonyostemum dominance during thermal stratification have been found by Salonen&Rosenberg(2000) and Karosiene et al.(2016).

The signal of air temperature as a driver for phytoplankton community dominance of Gonyostomum appear less strong for lake Grepperødfjorden than that found for lake Bindingsvann. The PCA show a positive correlation between temperature and precipitation, but they do not stretch in the same direction or go as far out on the PC1- axis as parameters chlorophyll-a, loss on ignition and percentage of agricultural area used for grain production. However, recorded temperatures show a trend of increasing temperatures around the time

Gonyostomum rose to dominance in the mid -1930s. During the period of 1897 to 1989, annual mean temperature reaches maxima in 1934 with a value of 7,3°C. The following period reveals fluctuating temperatures, but in general there is trend of decreasing values up until 1970, coinciding with inconsistency of Gonyostomum dominance during the same period. Dominance of Gonyostomum appear from the cluster analysis to be inconsistent up until the estimated time of 1975, appearing with years in between. Entering year 2000 there appear to be a relatively steep increase in primary production, expressed by chlorophyll- a values increasing from approximately 86 µg / dry weight in 2003 to 117 µg/ dry weight in 2004. This coincides with significantly higher air temperatures during the same period (Figure 4.1).

The relatively weak signal of temperature as a driver for Gonyostomum dominance in lake Grepperødfjorden could be associated with the limited possibilities of thermal stratification. Although lakes Grepperødfjorden and Bindingsvann locate in the same watercourse and within the same climatic zone, they possess different traits and morphometric characteristics possibly making them unevenly susceptible for the competitive advantages hypothesized to be provided by increased air temperatures.

Grepperødfjorden is relatively shallow (mean depth < 2 m) and wind exposed and consequently there are fewer areas for hypolimnion hypoxia to develop (Andersen, 2006). However, although limited scenarios for reducing conditions in bottom waters, internal loading may occur as a cause of sediment swirling caused by wind exposure and/or bioturbation. Lake Vansjø is exposed to wind from the south and west, and shallow areas of the lake may thus be completely mixed throughout the entire summer season. Shallower depths contribute to a more homogenous body of water, and the heating of the waters in spring occurs more rapidly. This is confirmed by monitoring data saying that lake Grepperødfjorden is an altogether warmer lake compared to lake Bindingsvann (vannmiljø,n.d.a). Warmer spring temperatures could work as an advantage for Gonyostomum by extending the growth season. Rengefors et al. (2012) found that optimal growth of Gonyostomum was in the temperature range of 9 and 12°C, and that it rapidly decreased when temperatures exceeded 19°C. The beneficial effects of temperature were therefore hypothesized to mainly be seen in spring and autumn. Intra-seasonal distribution of Gonyostomum biovolum in lake Grepperødfjorden supports this hypothesis. Distribution is normally characterized by an increase in biovolume in spring, a decline during mid-summer and a maximum during late summer or fall (see Figure 2.9A and Figure 2.9B). July temperatures of lake Grepperødfjorden often exceeds 20°C (vannmiljø,n.d.a). This is well above the threshold limit value of 19°C where adverse effects on growth have been observed. There are, however, several variables potentially causing these intra-seasonal fluctuations, like e.g. competition from other phytoplankton species, accessibility to nutrients and interruptions from floodings and wind exposure.

PRECIPITATION, SULPHATE DEPOSITION AND WATER COLOR

Several studies have found that Gonyostomum prefers humic lakes with high color (Bjørndalen and Løvstad, 1984; Hongve et al.,1988; Brettum and Andersen, 2005). Rengefors et al. (2008) also found that G. semen grew better when exposed to fulvic acid, and Peczula et al.(2014) demonstrated that additions of peat extract had a positive impact on spring recruitment of Gonyostemum from the sediments. Both Findlay et al. (2005) and Lepistö et al. (1994) found that Gonyostemum growth rates were positively correlated to concentration of DOC in the water.

Additionally, increased color has been suggested to enhance stratification through reduced visibility in the water column(Eloranta& Räike, 1995; Salonen& Rosenberg, 2000).

Principal component analysis for lake Bindingsvann suggests that lake productivity (total chlorophyll- a) and total annual precipitation are closely correlated along the PC1 axis. The emergence of Gonyostomum as a dominating species in lake Bindingsvann coincides with increased precipitation during this period (Figure 3.12). From year 1997 there is a trend of increasing values of both annual and growth season precipitation lasting all the way up until today. Runoffs of precipitation works as a pathway for both plant nutrients and organic matter to the recipient, and increased precipitation may thus have increased both supplies of nutrient and organic matter.

Drainage basin of lake Bindingsvann is heavily dominated by forested areas as well as with contributions of peat areas along the shoreline. Runoff of organic matter is thus though to be of a greater magnitude here compared to lake Grepperødfjorden. An indicator of the relative contribution of allochthonous organic matter is reflected in the correlation between chlorophyll a in the sediments and loss on ignition.

Chlorophyll- a distribution in the sediments of lake Bindingsvann appears to have a relatively weak correlation to loss on ignition (Figure 4.3). This finding further strengthens the assumption that loss of ignition, hence organic matter in the sediments, are strongly affected by allochthonous supplies of organic matter.

The negative correlation between sulphate in precipitation and loss on ignition in PCA suggests that a decrease in sulphate deposition during the last two to three decades have promoted increased water color in lake Bindingsvann. Scatterplot of loss on ignition and sulphate in precipitation appear to give a relatively strong correlation, lending support to the PCA suggesting that reduced sulphate depositions inversely correlates to levels of organic matter in the sediments (Figure 4.5).

Also supporting the negative correlation between sulphate in precipitation and loss of ignition for lake Bindingsvann is dry sediment bulk density values. Values show a decreasing trend from about a depth of 10 cm (year 1986) to the sediment surface, illustrating that content of organic matter has increased during this period. The period before 1986 is characterized by an increase in dry sediment bulk density values, suggesting that organic matter has decreased. This is confirmed by data from the loss of ignition analysis, illustrating

that content of organic matter in the sediments follow a downward trend during a 20 year-period from 1972-1992. In the following period from 1992 and up until today, values of organic matter in the sediments follow an upward trend. Monitoring data also suggest that water color in the lake follows the patterns of precipitation. A high water color of almost 130 Pt/L in 2011 coincide with heavy rainfall as observed in 2011(See Figure 9B in Appendix 9). Likely, the combination of increased air temperatures and increased supplies of allochthonous organic matter in lake Bindingsvann have led to poor visibility and a more rapid heating of the water masses in the spring, resulting in an intensified and more prolonged stable stratification. Earlier heating of the water due to elevated levels of organic matter may also have promoted increased recruitment from resting cysts.
Allochthonous supplies of organic matter appear to have had less impact on levels of organic matter in the sediments of lake Grepperødfjorden. Scatterplot of chlorophyll a in the sediments and loss on ignition show a relatively strong positive correlation. Using a linear regression line, chlorophyll a in the sediments explain 84,7% of the variance in loss on ignition (Figure 4.2). The importance of autochthonous production on levels of organic matter in the sediments is supported by a weak correlation between sulphate in precipitation and loss on ignition (Figure 4.4) and by the PCA suggesting that there is a zero-correlation regarding sulphate in precipitation and loss on ignition. Altogether, it appears like levels of organic matter in the sediments are heavily influenced by autochthonous production, and that lake Grepperødfjorden is a much more productive lake compared to lake Bindingsvann. However, the stagnation and decrease in lake productivity observed during the 1980s suggests that sulphate depositions may have impacted productivity of the lake. This stagnation and decrease is also observable in dry sediment bulk density, as it is slightly increasing throughout the 1980s. Although most of the production in the sediments originates from autochthonous production, the water in lake Grepperødfjorden has a high color, influenced by supplies of humic acids from upstream lake Bjørnrødvann (Hauger et al.,1992). Monitoring data for lake Grepperødfjorden suggests that water color has been increasing since year 2000, although disrupted by minor fluctuations(Figure 8B, Appendix 8). This development coincides with both growth season and annual rainfalls, as these have been increasing during the same period(Figure 3.12). Furthermore, distribution of total chlorophyll a in the sediments of lake Grepperødfjorden suggest that the estimated years of 2003 and 2010 are characterized by a noticeably increase in lake productivity. Accounting for uncertainties in sedimentation rate, the estimated year of 2003 could represent the period after the flooding of lake Vansjø in year 2000. Water quality in the western basin strongly deteriorated in the aftermath of the year 2000 flooding, likely caused by supplies of nutrients from the local drainage basin. Increased productivity after year 2000 in lake Grepperødfjorden may therefore be a cause of allochthonous supplies of organic matter in combination with nutrient salts.
Principal component analysis for lake Grepperødfjorden suggests a relatively weak correlation between precipitation and lake productivity (chlorophyll a) for lake

Grepperødfjorden. The productivity of the lake is in PCA closely linked to percentage of agricultural area used for grain production. Transportation and runoffs of phosphorous and nitrogen from the drainage basin will depend on precipitation patterns and amount of precipitation. This is also supported by monitoring data from the inlet creek Guthusbekken, draining into lake Grepperødfjorden. The weak correlation in PCA between precipitation and lake productivity suggests therefore that precipitation data obtained from the weather station at Ås is not representative for lake Grepperødfjorden. The lake situates in an area highly affected by spring floods and frequent changes in water supplies ,and it is therefore to be expected that it would be influenced by local precipitation patterns.

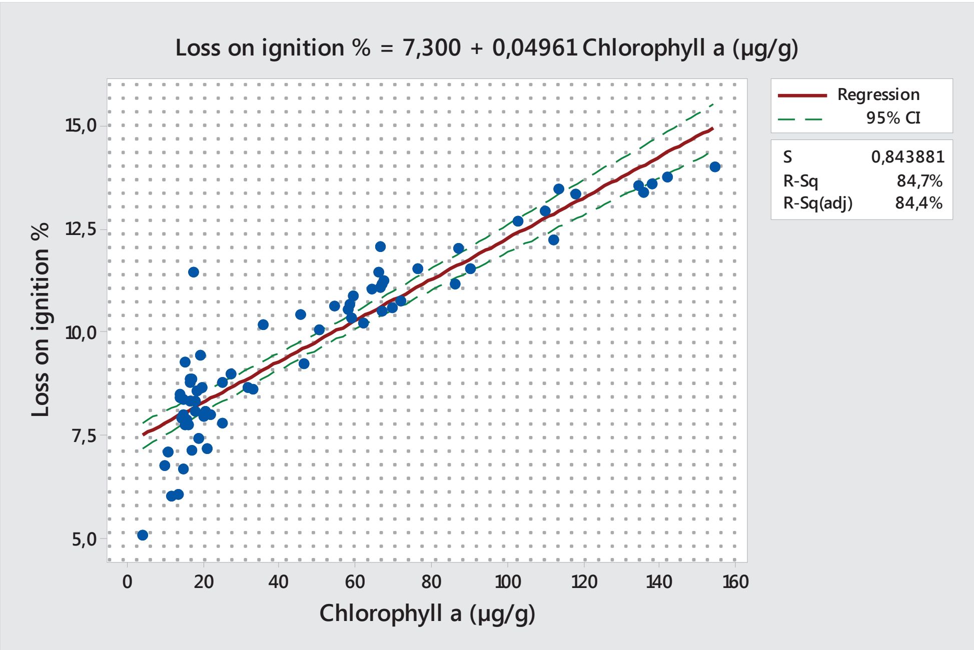


Figure 4.2: Scatterplot of chlorophyll a(µg/g) vs. loss on ignition (%) in the sediments of lake Grepperødfjorden indicate a positive correlation between the two variables. A fitted linear regression line explains in total 84,7% of the variance in loss of ignition.

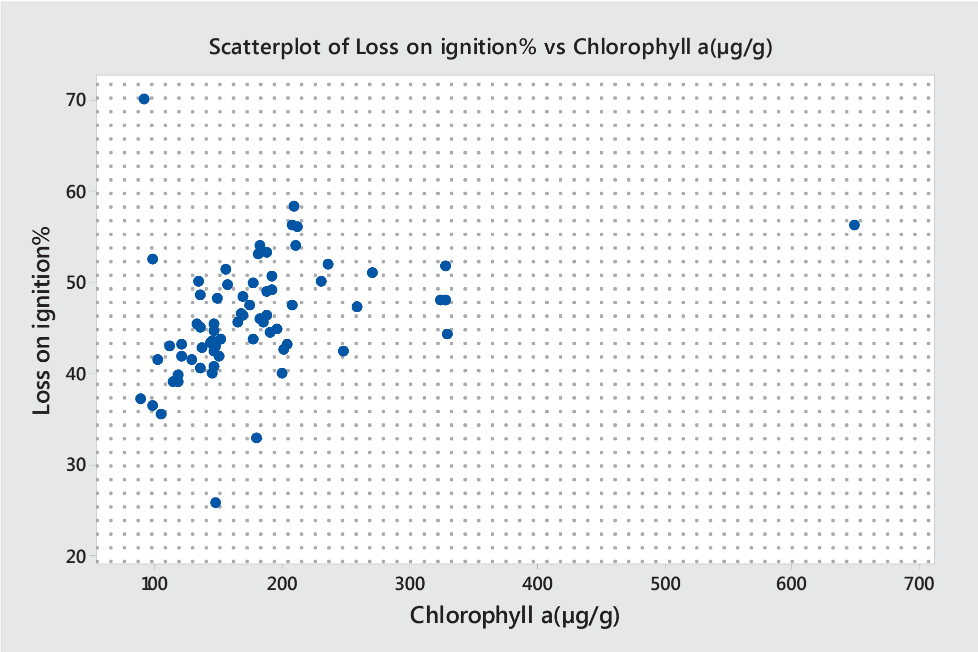


Figure 4.3: Scatterplot of chlorophyll a(µg/g) vs. loss on ignition (%) for lake Bindingsvann show a weak correlation between the two variables, suggesting low lake productivity.

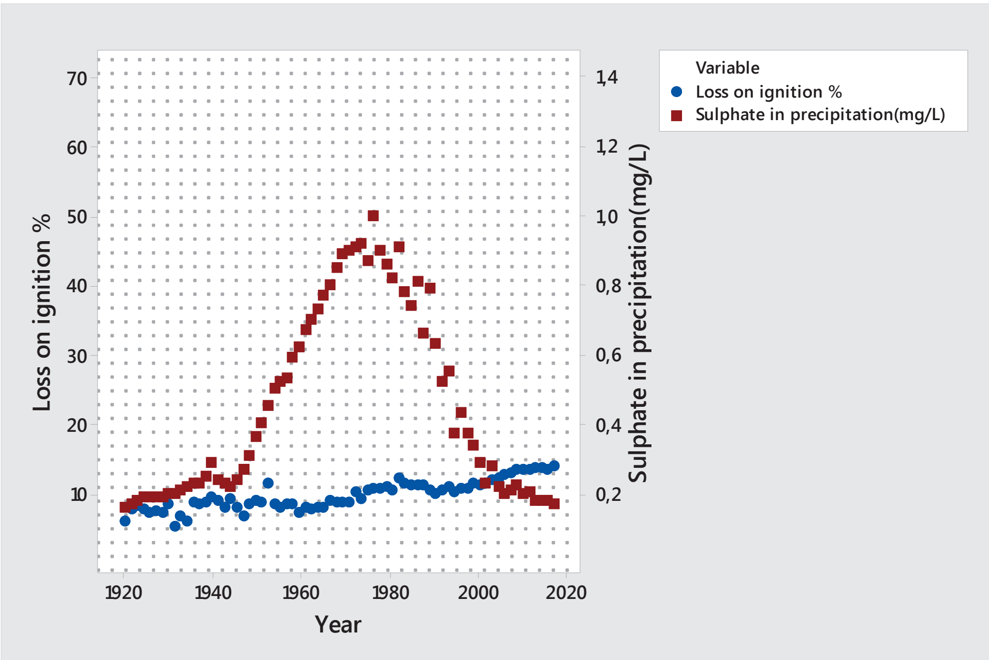


Figure 4.4: Scatterplot of loss on ignition (%) vs. sulphate in precipitation(mg/L) for lake Grepperødfjorden show a weak correlation. If levels of organic matter(loss on ignition) was dependent on levels of sulphate in precipitation, it would have displayed as an inverse correlation on the graph.

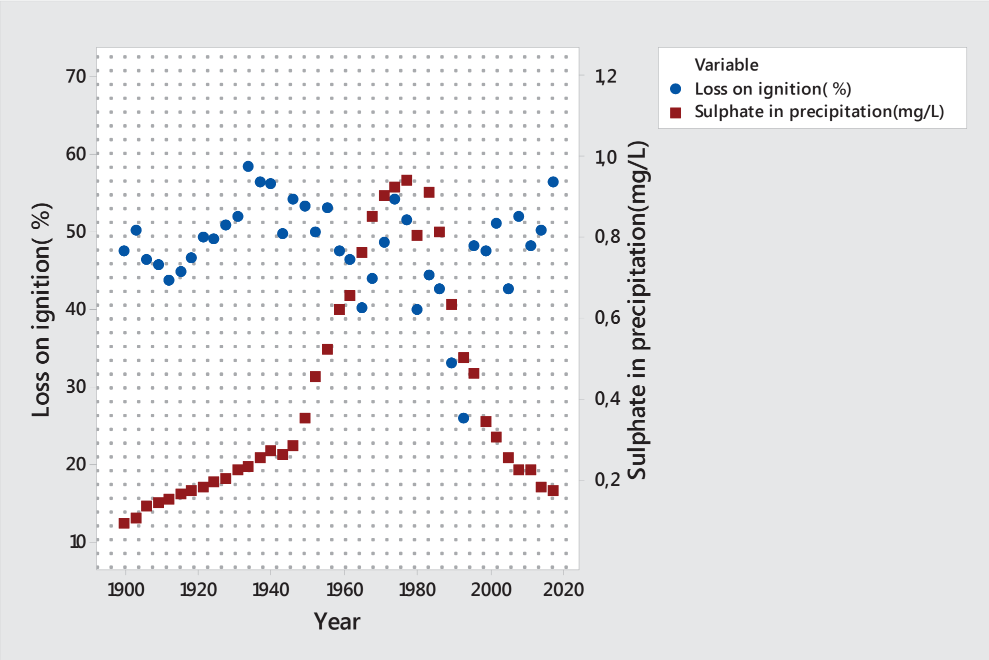


Figure 4.5: Scatterplot of loss on ignition (%) vs. sulphate in precipitation(mg/L) for lake Bindingsvann show a relatively strong correlation between the two variables. Levels of organic matter in the sediments appear to be inversely correlated to sulphate in precipitation.

4.3 LOCAL DRIVERS: HABITAT CHARACTERISTICS AND DRAINAGE BASIN AND LAKE DISTURBANCES

The finding of Gonyostomum as a dominating species in lake Grepperødfjorden already in the estimated time of the mid-1930s implies that certain local habitat characteristics are perhaps inherently favorable for this species. Lake Grepperødfjorden is part of a lake system, but the limited exchange of water masses between this area and the rest of the water body fascilitates distinct conditions regarding both water chemistry and biological diversity. This reflects among others in composition of phytoplankton community, as Grepperødfjorden is the only area of lake Vansjø where Gonyostomum is the dominating species.

Without further knowing, Gonyostomum may have been present long before it emerged as a dominating species, or it may have colonized the lake in the mid-1930s and quickly started to dominate the phytoplankton community.

Morphometric characteristics, like the small size of the water body and the shallow depths, coincides with was has been referred to as preferable habitats for Gonyostomum . The shallow areas (mean depth < 2m) may have promoted a larger population because the cells are recruited from resting cysts at less than 4 meters (Figueroa and Rengefors, 2006; Hansson, 1996). Water level regulations during the 1880s lead to a general lowering of the water levels in lake Vansjø, possibly facilitating lake Grepperødfjorden as a suitable habitat for Gonyostomum. However, inconsistency in dominance up until the estimated time of

1975 suggests that conditions facilitating Gonyostomum dominance have improved as time has progressed.

TURBIDITY

Turbidity may be a factor facilitating light climates that are suitable for G. semen growth. Sedimentation rates of lakes Grepperødfjorden and Bindingsvann was by the Cs^{137} analysis estimated to be approximately 7 mm and 3 mm, respectively. Sedimentation rate of lake Grepperødfjorden is thus considered to be more than twice as high as that observed for lake Bindingsvann. This reflects in calculated values for dry sediment bulk density. Values for lake Grepperødfjorden are much higher than those observed for lake Bindingsvann, suggesting that a larger proportion of the sediments consists of minerals rather than organic matter. This is also confirmed by results of the loss of ignition analysis; percentage of organic matter for lake Grepperødfjorden never excels above 14% while the values for lake Bindingsvann for the most part stay in the range of 40-55%.

Hence, turbidity caused by erosion of clay particles could be a factor influencing light conditions in lake Grepperødfjorden, especially during rainfalls in spring and autumn. Due to its location in a wind exposed area, clay particles are also known to be able to resuspend from the lake bed in shallow areas (not deeper than 3 meters) of lake Grepperødfjorden (Hauger et al.,1992). A general lowering of the water levels in lake Vansjø in the 1880s may have provided more areas in lake Grepperødfjorden < 3 meters, and thereby promoted increased resuspension of clay particles from shallow areas during wind incidents.

Hauger et al. (1992) suggests that the lake Vansjø system probably has been influenced by runoffs of clay material even before humans settled in the drainage basin. However, increased erosion rates are now related to the structural changes of the agricultural areas beginning around the 1950s. Statistics show that agricultural area used for grain production increased from around 25% at the beginning of the 1900s to over 90% in the beginning of the 2000s. This led to an industrialization of agriculture with altered tillage patterns promoting increased erosion(Hauger et al.,1992).

Analyses have shown that 80-90% of total transportation of clay particles to lake Vansjø occurs during floodings (Hauger et al.,1992). During such incidents, the entire lake Vansjø is characterized by sludgy water, and the visibility in the waters may in some areas reduce to < 30 cm. The waters gradually clear up after flooding incidents, but the smallest particles may stay in the water column up until the beginning of June, which is one and a half month after the flooding normally is over (Hauger et al.,1992). As Gonyostemum has been found to avoid the greatest light intensities, increased turbidity of the lake may be a significant contributor in facilitating light climates suitable for Gonyostomum growth. Positive effects of flooding incidents on Gonyostomum growth was found by Findlay et al., (2005), but this was, however, related to DOC and phosphorous concentrations in the water. Blooms of Gonyostomum developed when light decreased and when levels of total phosphorous increased. Gonyostomum biomass was found to be significantly correlated with total P and DOC concentrations (Findlay et al.,2005). Poor light climates as a competitive advantage for Gonyostomum is related to the species poor acceptance to excessive insolation(Findlay et

al.,2005). Adaptability to poor light climates was also found by Sassenhagen& Richardsson(2014) who detected photoprotective functions in Gonyostomum. Amount of chlorophyll -a generally decreased as light intensity increased.
Records of land use show that there was an increase in grain productions around 1920 for most of the farms operating in the drainage basin of lake Grepperødfjorden. Although this did not represent an industrialization of agricultural methods, increased grain production may have resulted in tillage patterns possibly impacting erosion rates. This could have been a factor facilitating the first dominance of Gonyostomum in the mid-1930s. However, transportation of clay particles is dependent on precipitation patterns, and as such, turbidity caused by erosion from agricultural land is an interplay between local and regional drivers. Drainage basin of lake Bindingsvann is to a lesser extent influenced by agriculture, and the operational structures are limited to grass production in the northern end of the lake. Monitoring data show that visibility in the waters in general is lower in lake Grepperødfjorden as compared to lake Bindingsvann. During the monitored period of 2005-2013, secchi depth never exceeded 1,5 m. in lake Grepperødfjorden, and for the most part it stayed under 1,25 m. (Figure 8D, appendix 8). Secchi depth in lake Bindingsvann ranged between 2 and 1 m. (Figure 9C, appendix 9).

NUTRIENT SALTS: PHOSPHOROUS AND NITROGEN

High total- P concentrations (> 30 µg/l) and high nutrient- density have been suggested to influence the growth of Gonyostomum (Cronberg et al., 1998; Findlay et al., 2005; Hehmann et al.,2001; Hongve et al.,1988). In the monitoring period of 1980-2013, total phosphorous levels in lake Grepperødfjorden often exceeded 30 µg/l P during the growth season (Figure 8E, appendix 8). This may indicate that high concentrations of total phosphorous may be a contributing factor to the success of this alga. Due to redevelopment measures taken to reduce agricultural runoffs of P, total- P content has decreased in lake Grepperødfjorden since around 2007(Figure 7E, appendix 7). Reduced total- P content could also be related the declining effects of the 2000 flooding.
Total- P concentrations are considerably lower in lake Bindingsvann compared to those found in lake Grepperødfjorden. Values of total-P stays in general well beneath the value of 30 µg/l which have been suggested to influence Gonyostomum growth (Figure 9D, appendix 9). There is, however, a trend of increased total-P since year 2011. This could be due to either increased biomass during the growth season, or increased runoff to the recipient. Knowing that the upgrading of separate sewerage systems surrounding lake Bindingsvann just finished in 2017, there likely have been increasing effluents from these to the recipient. Moreover, since many of the leisure properties that were built following the 2nd world war was being used illegally as permanent residences, the impact of settlements and sewerage on lake Bindingsvann may have been increasing already at a much earlier stage. No measurements of phosphate or nitrate and ammonium have been conducted in lake Bindingsvann, and as such is difficult to evaluate any phosphorous or nitrogen limitation of algae growth.

Phosphorous is normally considered to be a limiting nutrient for phytoplankton growth in lakes. However, there are indications that algae growth in lake Grepperødfjorden may be limited by nitrate. During the monitored period of 2000-2013, the NO3-N fraction in the water phase usually follows a pattern of increasing values in spring before it steadily drops and ultimately reaches close to detection limit (Figure 8C, appendix 8). Unlike the case of phosphorous, there has been no reduction in the use of nitrogen in fertilizers. Content av phosphorous has reduced, while nitrogen has stayed the same. The close positive correlation in PCA between chlorophyll- a and percentage of agricultural area used for grain production for lake Grepperødfjorden suggests that an excess of nutrients supplied by intense grain production allows the algal community to grow larger biomasses than it would have without the additional supplies. The rapid increase in lake productivity beginning at around 1950 coincides with the industrialization of agriculture and the gradually transforming to a drainage basin more heavily dominated by grain production. Monitoring of inlet creeks supports the assumption that agriculture has promoted supplies of nutrients to lake Grepperødfjorden. Phosphorus content in the creek Guthusbekken, draining into lake Grepperødfjorden, was found to exceed the environmental goals by more than 50% in 2005, and normalized loss of total phosphorous based on acres of agricultural land in drainage area showed that Guthusbekken had the greatest loss of total phosphorous out of all the investigated creeks (Bechmann, 2008). Levels of total nitrogen in the investigated creeks also showed a positive correlation to percentage of agricultural land in the drainage basin. As found by Bechmann (2008), precipitation and runoffs had a significant impact on supplies of phosphorous to the western basin.
Consequently, increased supplies of nutrient salts and suspended solids may be interpreted as an interplay between regional drives and anthropogenic drainage basin disturbances.

5. CONCLUSION

By implementing paleolimnological methods, this study finds that *Gonyostomum semen*(Ehrenberg) Diesing first emerged as a dominating species of the phytoplankton community of lake Grepperødfjorden in the estimated time of the mid-1930s and in lake Bindingsvann in the estimated time of the mid-1990s. The finding of Gonyostomum in lake Grepperødfjorden as early as the mid-1930s contradicts hypothesis (1) of a recent invasion of this species to the ecoregion of south-eastern Norway. Furthermore, as this study only examines for Gonyostomum dominance, the alga may have been present in both lakes at a much earlier stage. However, there are uncertainties regarding dating of the sediment cores, particularly for lake Grepperødfjorden, and the estimated time span for the first encounter of Gonyostomum dominance in lake Grepperødfjorden must therefore be considered preliminary.
The emergence of Gonyostomum as a dominating species in lake Bindingsvann in the mid-1990s coincides with a trend of increasing precipitation and air temperatures. Introduction of Gonyostomum as a dominating species also corresponds with a noticeably increase in lake productivity. The emergence of Gonyostomum as a dominating species and the rapid increase in lake productivity is likely a cause of competitive advantages provided by intensified thermal stratification induced by warmer spring temperatures and increased water color. It appears unlikely that human disturbances in the drainage basins of lake Bindingsvann have facilitated conditions that are considered to act as competitive advantages for Gonyostomum. The sediment analyses show that Bindingsvann is a lake of low productivity, and that most organic matter found in the sediments originates from allochthonous production. Thus, Bindingsvann is a humic and less nutrient rich lake that likely is limited by phosphorus in its production. The ability to collect phosphorous in the deep strata during periods of internal loading will act as a benefit for the vertically migrating Gonyostomum. The results from the paleolimnological investigations in lake Bindingsvann lends support to hypothesis (2) that increased air temperatures and increased levels of allochthonous derived DOC in the lake led to the emergence of Gonyostomum as a dominating species and an increased productivity of the lake.

Evidence for temperature as a driver for Gonyostomum dominance is less evident for lake Grepperødfjorden. Phytoplankton community dominance of Gonyostomum appeared inconsistent up until the estimated time of the mid-1970s, appearing with years in between. This implies that conditions facilitating Gonyostomum dominance have improved as time has progressed. Records of temperature suggests that Gonyostomum emerged as a dominant species in a time of particularly high air temperatures. The following period with inconsistency in dominance up until the mid-1970s coincides with declining temperatures during the same period. The introduction of Gonyostomum as a dominating species in the mid-1930s did not, however, result in increased productivity of the lake. The trend of increased productivity coincides with the transformation of the drainage basin to be more

heavily dominated by grain productions.
There are several characteristics of lake Grepperødfjorden suggesting that this lake might be inherently suitable as a habitat for Gonyostomum . The shallow depths facilitate recruitment of resting cysts in the spring and high water color and reduced visibility through turbidity fascilitates light climates that are suitable for this species. Human activities in the drainage basin may have promoted increased erosion and thereby paving the way for Gonyostomum as a consistently dominating species. The visibility in the waters of lake Grepperødfjorden is in general poor, and it may indicate that phytoplankton community dominance of Gonyostomum is promoted by adaptability to, and preference for, poor light climates. Visibility in the water column is related both to supplies of humic acids from upstream waters and erosion of clay materials from the drainage basin.
The shallow waters and the limited possibilities for internal loading possibly exclude vertical migration as a competitive advantage, although it may occur in some areas of the lake. Increased spring temperatures may have reinforced Grepperødfjorden as a beneficial habitat by expanding the length of the growing season and increasing spring recruitment. The pattern of intra-seasonal fluctuations as observed in the monitoring data may be explained with the hypothesized window of optimal growth, suggesting that there is a threshold limit value regarding the positive effect of temperature on growth.
The increased productivity of the lake appears, however, to be governed by allochthonous supplies of nutrients, and it appears that the NO3-N fraction could be a limiting factor for algae growth. Consequently, factors like poor light climates, high phosphorous levels and elevated temperatures may favor Gonyostomum dominance but the rapid increase in lake productivity as observed from around the 1960s is likely a consequence of supplies of nutrient salts induced by human activity in the drainage basin.
Altogether, the investigations paint a complex picture of several factors interplaying. Lake Grepperødfjorden may have been an inherently suitable environment for Gonyostomum to colonize in the 1930s or it may have been human disturbances or climatic changes that caused its emergence as a dominating species. Nevertheless, the evidence suggests that conditions for Gonyostomum have improved as time has progressed.
Based on this study, there are not enough evidence to conclude that climatic variables enabled Gonyostomum to emerge as a dominant species in the estimated time of the mid-1930s in lake Grepperødfjorden. Further paleolimnological studies of lake Grepperødfjorden should focus on providing accurate sedimentation rates to determine the reliability of the preliminary finding of Gonyostomum as a dominant species in the mid-1930s. This could be done by implementing methods such as analyzing for radioactive lead(Pb-210).
Investigations of distribution of total phosphorous and total nitrogen throughout sediment cores could also shed light on the role of these nutrients in phytoplankton community dominance of Gonyostomum .
Finally, lake morphometry appears to be an important factor in determining which beneficial factors that plays out. Gonyostomum seem to benefit considerably from stratification and

the ability to migrate downwards in its quest for phosphorous. This adaptability might be particularly beneficial in a nutrient poor lake like Bindingsvann that stratifies during summer. The beneficial effect of temperature on Gonyostomum dominance in a shallow and nutrient rich lake like Grepperødfjorden might be more directed towards the lengthening of the growing season. However, as shown by monitoring data, the dominance level during Gonyostomum blooms are greater in lake Bindingsvann compared to what is seen in lake Grepperødfjorden, suggesting that stratification in nutrient poor lakes gives pronounced advantages for this species. Consequently, the differences between lakes Bindingsvann and Grepperødfjorden, as shown in this study, support hypothesis (3) of lake morphometry as a factor giving differentiated responses to increased air temperatures.

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7. APPENDIX

APPENDIX 1- TOTAL CHLOROPHYLL A BINDINGSVANN

		Total chlorophyll a	
Sample no.(cm)	Estimated year	µg/g dry weight	µg/g org. C
1	2017	648,5	27269,73
2	2014	229,6	7250,03
3	2011	322,5	2287,26
4	2008	327,5	1907,62
5	2005	246,4	1016,25
6	2002	270,0	1261,74
7	1998	257,0	1280,86
8	1995	326,9	1405,56
9	1992	145,8	514,13
10	1989	178,5	565,63
11	1986	199,5	618,77
12	1983	328,7	1021,06
13	1980	197,9	582,28
14	1977	154,6	396,17
15	1974	181,3	384,56
16	1971	167,0	446,44
17	1967	175,5	472,69
18	1964	143,9	372,06
19	1961	185,7	520,71
20	1958	207,1	458,92
21	1955	180,0	576,79
22	1952	175,3	416,94
23	1949	186,2	705,41
24	1946	209,7	542,93
25	1943	156,2	495,06
26	1940	210,9	537,17
27	1936	206,4	528,68
28	1933	207,6	529,49
29	1930	234,9	819,83
30	1927	190,1	471,51
31	1924	186,5	662,97
32	1921	189,8	595,12
33	1918	166,1	723,10
34	1915	193,8	677,93
35	1912	150,8	516,92

36	1909	163,9	510,96
37	1905	167,9	440,73
38	1902	133,2	447,63
39	1899	172,7	519,70
40	1896	89,5	154,53
41	1893	148,1	460,99
42	1890	180,8	756,65
43	1887	135,5	486,60
44	1884	96,1	337,41
45	1881	119,5	396,06
46	1878	145,2	565,09
47	1874	149,5	452,32
48	1871	116,3	499,89
49	1868	143,5	623,35
50	1865	133,9	481,13
51	1862	188,5	582,33
52	1859	133,9	409,34
53	1856	131,5	392,40
54	1853	127,6	347,57
55	1850	112,5	420,83
56	1847	145,4	468,50
57	1843	144,2	615,41
58	1840	202,8	747,03
59	1837	96,7	437,56
60	1834	133,8	430,54
61	1831	183,6	502,33
62	1828	145,3	489,33
63	1825	146,4	520,37
64	1822	141,6	362,24
65	1819	109,8	301,84
66	1816	120,0	468,28
67	1812	100,2	306,95
68	1809	116,7	436,39
69	1806	103,3	516,38
70	1803	87,5	273,25

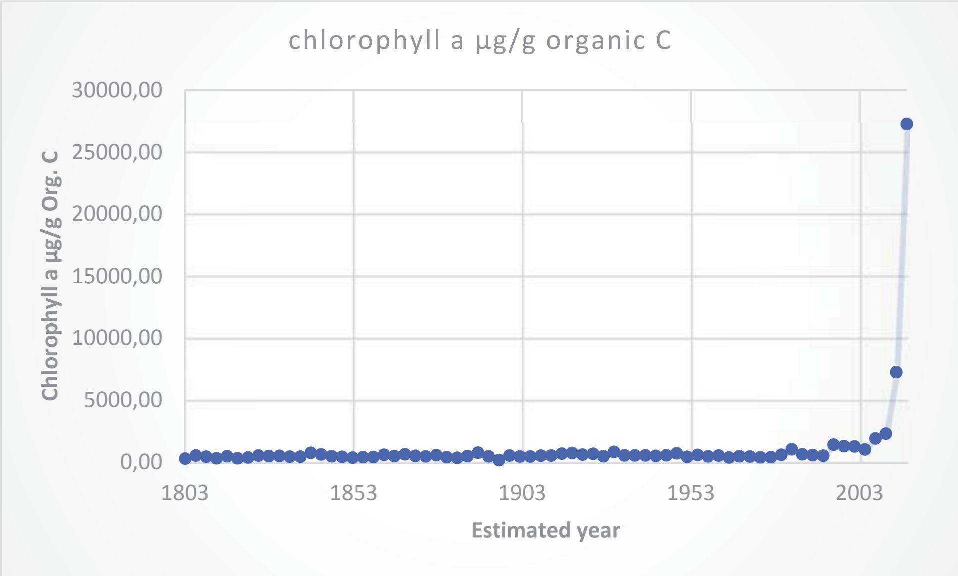

Figure 1A: Chlorophyll a µg/ g Organic Carbon. Calculations are based upon the assumption that Organic C. equals 58% of loss on ignition.

APPENDIX 2- TOTAL CHLOROPHYLL A GREPPERØDFJORDEN

		Total chlorophyll a	
Sample no.	Estimated year	µg/g dryweight	µg/g org. C
1	2017	154,2	5026,41
2	2016	134,3	964,64
3	2014	137,8	1467,89
4	2013	141,7	1277,79
5	2011	135,6	1177,61
6	2010	117,6	1017,69
7	2009	113,1	906,21
8	2007	109,5	771,83
9	2006	102,2	910,83
10	2004	111,7	825,35
11	2003	86,8	701,06
12	2002	89,8	697,08
13	2000	85,8	595,7
14	1999	75,9	575,2
15	1997	69,3	483,82
16	1996	71,5	501,89
17	1994	61,9	435,24
18	1993	64,1	347,69
19	1992	57,7	409,48
20	1990	50	348,7
21	1989	58,8	396,05
22	1987	66,2	375,83
23	1986	67	583,42
24	1985	66,9	515,74
25	1983	65,9	378,23
26	1982	66,4	380,59
27	1980	66,7	528,07
28	1979	59,3	287,16
29	1978	58,3	357,84
30	1976	54,1	278,33
31	1975	45,2	191,84
32	1973	46	247,98
33	1972	35,3	148,39
34	1971	31,2	163,41
35	1969	24,6	140,08
36	1968	32,5	150,69
37	1966	26,7	101,8
38	1965	19,9	98,11
39	1963	20,3	119,73

40	1962	24,7	156,65
41	1961	21,6	105,15
42	1959	20,7	130,17
43	1958	17,4	82,62
44	1956	18	71,69
45	1955	15,3	57,56
46	1954	13,6	72,97
47	1952	16,9	52,48
48	1951	16	69,55
49	1949	16,2	79,64
50	1948	13,6	67,07
51	1947	14,4	106,75
52	1945	14,4	69,27
53	1944	14,6	64,71
54	1942	14	58,4
55	1941	16,7	87,11
56	1940	18,8	76,02
57	1938	19,1	90,05
58	1937	16,1	69,92
59	1935	17,8	74,67
60	1934	13	71,79
61	1932	9,4	42,04
62	1931	3,7	27,63
63	1930	14,5	70
64	1928	16,6	83,45
65	1927	18,5	88,52
66	1925	10,3	65,32
67	1924	15,9	60,26
68	1923	17,6	79,25
69	1921	15	63,87
70	1920	11,3	62,77

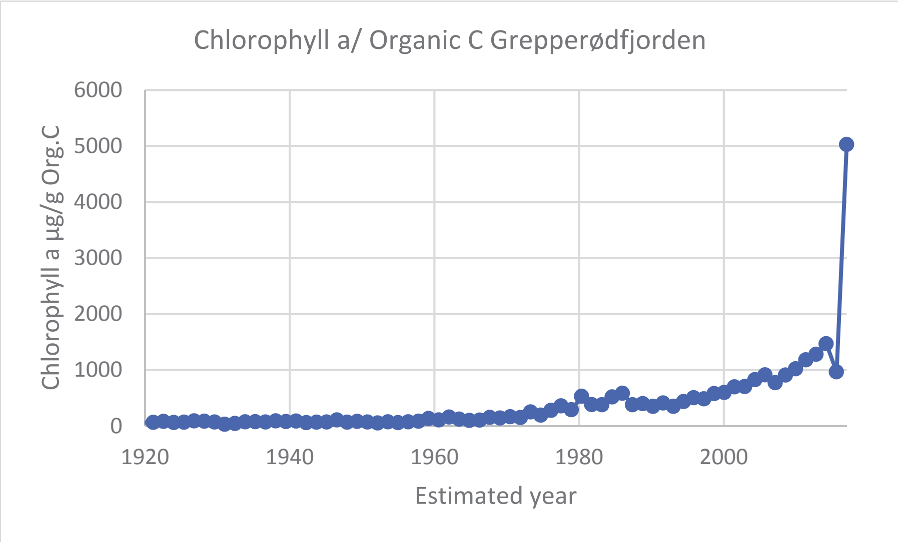

Figure 2A: Chlorophyll a µg/g Organic Carbon. Organic carbon was estimated to be 58% of loss on ignition.

APPENDIX 3- SULPHATE IN PRECIPITATION

Bindingsvann Estimated year	Sulphate in precipitation(mg/L)	Grepperødfjorden Estimated year	Sulphate in Precipitation(mg/L)
1899	0,09	1920	0,16
1902	0,10	1921	0,17
1905	0,13	1923	0,18
1909	0,14	1924	0,19
1912	0,15	1925	0,19
1915	0,16	1927	0,19
1918	0,17	1928	0,19
1921	0,18	1930	0,20
1924	0,19	1931	0,20
1927	0,20	1932	0,21
1930	0,22	1934	0,22
1933	0,23	1935	0,23
1936	0,25	1937	0,23
1940	0,27	1938	0,25
1943	0,26	1940	0,29
1946	0,28	1941	0,24
1949	0,35	1942	0,23
1952	0,45	1944	0,22
1955	0,52	1945	0,24
1958	0,62	1947	0,27
1961	0,65	1948	0,31
1964	0,76	1949	0,36
1967	0,85	1951	0,40
1971	0,90	1952	0,45
1974	0,92	1954	0,50
1977	0,94	1955	0,52
1980	0,80	1956	0,53
1983	0,91	1958	0,59
1986	0,81	1959	0,62
1989	0,63	1961	0,67
1992	0,5	1962	0,70
1995	0,46	1963	0,73
1998	0,34	1965	0,77
2002	0,30	1966	0,80
2005	0,25	1968	0,85
2008	0,22	1969	0,89
2011	0,22	1971	0,90
2014	0,18	1972	0,91
2017	0,17	1973	0,92
		1975	0,87

		1976	1,00
		1978	0,90
		1979	0,86
		1980	0,82
		1982	0,91
		1983	0,78
		1985	0,74
		1986	0,81
		1987	0,66
		1989	0,79
		1990	0,63
		1992	0,52
		1993	0,55
		1994	0,37
		1996	0,43
		1997	0,37
		1999	0,34
		2000	0,29
		2002	0,23
		2003	0,28
		2004	0,22
		2006	0,20
		2007	0,21
		2009	0,22
		2010	0,20
		2011	0,21
		2013	0,18
		2014	0,18
		2016	0,18
		2017	0,17

APPENDIX 4- PIGMENT COMPOSITION BINDINGSVANN

Pigment compositon(µg/ g dryweight)																				
Cm	year	Allo	bb.Car	c.Neo	Cantha	Chl.a	Chl.b	Chl.c1	Chl.c2	Diadino	Diato	Dino	Echin	Fuco	Lut	Myxo	Peri	Phe.a	Phe.b	Viola
Cm1	2017	0,00	0,00	22,81	0,00	40,36	30,97	0,00	50,45	328,53	0,00	0,00	33,03	0,00	0,00	0,00	30,55	608,12	98,59	101,10
Cm2	2014	0,00	0,00	4,70	0,00	0,00	16,59	0,00	15,85	99,47	0,00	0,00	11,51	0,00	0,00	0,00	7,28	229,59	43,45	42,66
Cm3	2011	0,00	0,00	9,53	0,00	0,00	23,55	0,00	23,73	154,30	9,11	0,00	12,99	0,00	0,00	0,00	10,00	322,50	63,26	71,56
Cm4	2008	0,00	5,96	15,34	0,00	0,00	26,09	0,00	24,44	133,65	23,15	0,00	0,00	0,00	0,00	0,00	29,25	327,50	66,07	59,54
Cm5	2005	0,00	8,67	3,56	0,00	0,00	18,49	0,00	14,97	72,68	46,24	0,00	0,00	0,00	0,00	0,00	15,85	246,38	44,09	60,30
Cm6	2002	0,00	12,53	0,00	0,00	0,00	27,20	0,00	17,21	83,34	60,56	0,00	0,00	0,00	0,00	0,00	15,97	270,04	48,09	76,57
Cm7	1998	0,00	11,89	0,00	0,00	0,00	22,13	0,00	15,52	73,54	54,46	0,00	0,00	0,00	0,00	0,00	14,78	257,04	42,08	66,58
Cm8	1995	0,00	16,92	0,00	0,04	0,00	39,53	0,00	17,89	93,94	55,07	0,00	0,00	0,00	0,00	0,00	14,81	326,91	59,10	73,19
Cm9	1992	0,00	7,42	4,87	0,00	0,00	11,46	0,00	7,75	40,91	13,76	0,00	0,00	0,00	0,00	0,00	2,65	145,82	24,62	22,00
Cm10	1989	0,00	15,35	3,23	0,00	0,00	10,91	0,00	9,69	46,50	14,32	0,00	0,00	0,00	0,00	0,00	7,85	178,47	32,22	25,28
Cm11	1986	0,00	23,06	0,00	0,00	0,00	9,56	0,00	12,06	56,07	12,04	0,00	0,00	0,00	0,00	0,10	15,25	199,54	36,73	31,15
Cm12	1983	0,00	33,40	0,00	0,00	0,00	17,46	0,00	19,06	90,65	18,05	0,00	0,00	0,00	0,00	0,01	19,38	328,68	61,91	46,08
Cm13	1980	0,00	18,03	0,00	0,00	0,00	10,93	0,00	11,88	55,73	16,07	0,00	0,00	0,00	0,00	0,00	10,59	197,91	38,94	33,37
Cm14	1977	0,00	15,62	0,00	0,00	0,00	12,88	0,00	8,89	46,66	0,00	0,00	0,00	0,00	0,00	0,73	6,36	154,64	27,93	18,42
Cm15	1974	0,00	24,94	0,00	0,00	0,00	11,44	0,00	10,37	50,89	2,85	0,00	0,00	0,00	0,00	2,56	4,72	181,33	36,77	25,14
Cm16	1971	0,00	20,19	0,00	0,00	0,00	8,85	0,00	8,47	40,23	9,92	0,00	0,00	0,00	0,00	0,00	9,28	167,01	34,06	21,47
Cm17	1967	0,00	18,40	0,00	0,00	0,00	11,73	0,00	9,05	48,39	0,00	0,00	0,00	0,00	0,00	1,09	5,67	175,46	34,17	19,35
Cm18	1964	0,00	13,50	0,88	0,00	0,00	10,34	0,00	7,37	38,66	10,40	0,00	0,00	0,00	0,00	0,00	4,31	143,93	27,67	18,05
Cm19	1961	0,00	18,19	0,00	0,00	0,00	12,82	0,00	10,20	56,02	0,00	0,00	0,00	0,00	0,00	1,53	0,57	185,74	41,97	21,53
Cm20	1958	0,00	18,09	0,00	0,00	0,00	14,67	0,00	11,11	62,02	0,00	0,00	0,00	0,00	0,00	0,00	8,79	207,09	43,76	25,28
Cm21	1955	0,00	20,38	0,00	0,00	0,00	8,09	0,00	10,19	51,23	1,64	0,00	0,00	0,00	0,00	1,04	10,53	179,98	38,55	25,17
Cm22	1952	0,00	19,88	0,00	0,00	0,00	11,03	0,00	9,82	52,14	0,00	0,00	0,00	0,00	0,00	1,52	3,09	175,32	36,10	21,09
Cm23	1949	0,00	19,24	0,00	0,00	0,00	10,91	0,00	10,64	57,50	0,00	0,00	0,00	0,00	0,00	2,65	4,63	186,16	39,73	24,83

Cm24	1946	0,00	17,74	0,00	0,00	0,00	16,60	0,00	11,58	60,89	0,00	0,00	0,00	0,00	0,00	2,46	4,38	209,72	42,62	25,67
Cm25	1943	0,00	11,72	0,00	0,00	0,00	14,00	0,00	7,85	45,36	0,00	0,00	0,00	0,00	0,00	1,06	8,43	156,20	33,35	18,51
Cm26	1940	0,00	19,17	0,00	0,00	0,00	16,12	0,00	11,30	68,05	0,00	0,00	0,00	0,00	0,00	2,77	4,62	210,92	46,14	28,63
Cm27	1936	0,00	15,83	0,00	0,00	0,00	16,70	0,00	11,57	66,26	0,00	0,00	0,00	0,00	0,00	1,84	6,88	206,36	46,16	29,60
Cm28	1933	0,00	11,20	0,00	0,00	0,00	23,63	0,00	11,67	73,29	0,00	0,00	0,00	0,00	0,00	2,64	5,47	207,60	47,88	28,50
Cm29	1930	0,00	13,81	0,00	0,00	0,00	30,93	0,00	11,75	74,67	0,00	0,00	0,00	0,00	0,00	1,90	16,16	234,90	49,44	28,84
Cm30	1927	0,00	11,75	0,00	0,00	0,00	27,29	0,00	8,77	58,02	0,00	0,00	0,00	0,00	0,00	0,63	17,09	190,07	42,12	21,86
Cm31	1924	0,00	4,88	0,00	0,00	0,00	32,38	0,00	6,57	49,83	0,00	0,00	0,00	0,00	0,00	0,00	19,78	186,49	40,77	14,86
Cm32	1921	0,00	6,89	0,00	0,00	0,00	28,41	0,00	7,28	51,26	0,00	0,00	0,00	0,00	0,00	0,00	19,82	189,84	43,50	18,38
Cm33	1918	0,00	3,76	0,00	0,00	0,00	33,01	0,00	4,39	36,14	0,00	0,00	0,00	0,00	0,00	1,70	6,30	166,08	38,80	9,37
Cm34	1915	0,00	3,06	0,00	0,00	0,00	45,44	0,00	3,59	36,63	0,00	0,00	0,00	0,00	0,00	0,75	11,76	193,85	44,98	7,45
Cm35	1912	0,00	2,20	0,00	0,00	0,00	30,53	0,00	3,36	28,70	0,00	0,00	0,00	0,00	0,00	1,04	5,77	150,81	33,83	6,77
Cm36	1909	0,00	3,18	0,00	0,00	0,00	29,50	0,00	3,71	29,97	0,00	0,00	0,00	0,00	0,00	0,00	14,16	163,88	36,75	8,43
Cm37	1905	0,00	4,10	0,00	0,00	0,00	27,35	0,00	3,88	30,25	0,00	0,00	0,00	0,00	0,00	0,93	9,97	167,94	37,34	8,90
Cm38	1902	0,00	3,94	0,00	0,00	0,00	24,94	0,00	3,31	26,40	0,00	0,00	0,00	0,00	0,00	2,46	0,00	133,19	32,86	7,67
Cm39	1899	0,00	3,03	0,00	0,00	0,00	35,06	0,00	2,95	30,91	0,00	0,00	0,00	0,00	0,00	1,95	2,29	172,72	40,26	7,58
Cm40	1896	0,00	0,17	0,00	0,00	0,00	22,64	0,00	1,34	16,36	0,00	0,00	0,00	0,00	0,00	1,30	4,66	89,45	20,20	2,26
Cm41	1893	0,00	0,00	0,00	0,00	0,00	32,85	0,00	1,46	24,06	0,00	0,00	0,00	0,00	0,00	0,00	15,06	148,13	33,32	2,68
Cm42	1890	0,00	0,00	0,00	0,00	0,00	42,67	0,00	1,56	29,56	0,00	0,00	0,00	0,00	0,00	1,33	9,29	180,81	40,32	1,86
Cm43	1887	0,00	2,36	0,00	0,00	0,00	29,39	0,00	2,45	25,53	0,00	0,00	0,00	0,00	0,00	2,37	0,00	135,47	31,66	3,89
Cm44	1884	0,00	3,36	0,00	0,00	0,00	19,57	0,00	2,17	19,97	0,00	0,00	0,00	0,00	0,00	1,07	0,00	96,09	24,71	6,10
Cm45	1881	0,00	3,84	0,00	0,00	0,00	22,47	0,00	2,96	25,17	0,00	0,00	0,00	0,00	0,00	0,90	4,69	119,45	28,11	6,87
Cm46	1878	0,00	3,90	0,00	0,00	0,00	24,87	0,00	4,82	35,51	0,00	0,00	0,00	0,00	0,00	0,75	9,98	145,20	32,13	9,02
Cm47	1874	0,00	4,02	0,00	0,00	0,00	25,61	0,00	4,96	36,58	0,00	0,00	0,00	0,00	0,00	0,77	10,27	149,54	33,09	9,29
Cm48	1871	0,00	3,46	0,00	0,00	0,00	21,01	0,00	3,55	27,66	0,00	0,00	0,00	0,00	0,00	2,04	1,72	116,26	26,72	7,03
Cm49	1868	0,00	2,86	0,00	0,00	0,00	22,92	0,00	5,20	34,60	0,00	0,00	0,00	0,00	0,00	0,00	12,07	143,53	33,32	11,02
Cm50	1865	0,00	4,50	0,00	0,00	0,00	16,06	0,00	4,65	29,77	0,00	0,00	0,00	0,00	0,00	0,04	9,19	133,95	30,99	12,32
Cm51	1862	0,00	6,82	0,00	0,00	0,00	18,25	0,00	7,52	44,75	0,00	0,00	0,00	0,00	0,00	0,00	16,50	188,47	40,46	19,85

Cm52	1859	0,00	5,18	0,00	0,00	0,00	22,19	0,00	4,26	31,77	0,00	0,00	0,00	0,00	0,00	1,10	5,18	133,90	30,41	10,96
Cm53	1856	0,00	4,01	0,00	0,00	0,00	23,61	0,00	3,95	30,75	0,00	0,00	0,00	0,00	0,00	1,62	0,00	131,55	30,08	8,11
Cm54	1853	0,00	4,26	0,00	0,00	0,00	21,27	0,00	4,06	31,95	0,00	0,00	0,00	0,00	0,00	0,74	1,93	127,61	30,30	9,71
Cm55	1850	0,00	4,60	0,00	0,00	0,00	18,25	0,00	4,21	31,21	0,00	0,00	0,00	0,00	0,00	0,44	2,41	112,52	28,18	11,34
Cm56	1847	0,00	3,86	0,00	0,00	0,00	21,48	0,00	4,85	36,81	0,00	0,00	0,00	0,00	0,00	0,00	7,84	145,38	33,94	11,76
Cm57	1843	0,00	3,91	0,00	0,00	0,00	21,03	0,00	5,40	38,58	0,00	0,00	0,00	0,00	0,00	0,00	12,04	144,20	32,73	13,31
Cm58	1840	0,00	7,84	0,00	0,00	0,00	32,70	0,00	7,00	51,88	0,00	0,00	0,00	0,00	0,00	1,47	5,90	202,77	46,04	14,87
Cm59	1837	0,00	5,02	0,00	0,00	0,00	16,90	0,00	4,40	33,22	0,00	0,00	0,00	0,00	0,00	0,78	1,62	96,69	22,31	9,29
Cm60	1834	0,00	7,79	0,00	0,00	0,00	24,20	0,00	6,73	49,33	0,00	0,00	0,00	0,00	0,00	0,60	1,44	133,85	33,79	18,86
Cm61	1831	0,00	8,88	0,00	0,00	0,00	29,26	0,00	8,20	59,93	0,00	0,00	0,00	0,00	0,00	0,18	10,20	183,55	43,03	20,72
Cm62	1828	0,00	7,30	0,00	0,00	0,00	19,95	0,00	7,39	53,13	0,00	0,00	0,00	0,00	0,00	0,00	7,28	145,31	35,93	18,67
Cm63	1825	0,00	8,18	0,00	0,00	0,00	20,08	0,00	7,38	52,88	0,00	0,00	0,00	0,00	0,00	0,38	2,76	146,38	35,72	19,44
Cm64	1822	0,00	6,64	0,00	0,00	0,00	26,38	0,00	6,37	48,91	0,00	0,00	0,00	0,00	0,00	0,04	0,00	141,61	39,64	17,78
Cm65	1819	0,00	5,59	0,00	0,00	0,00	18,61	0,00	5,33	41,11	0,00	0,00	0,00	0,00	0,00	0,23	2,14	109,77	30,25	14,91
Cm66	1816	0,00	6,01	0,00	0,00	0,00	15,77	0,00	5,56	40,30	0,00	0,00	0,00	0,00	0,00	0,00	7,97	120,05	30,31	16,61
Cm67	1812	0,00	5,50	0,00	0,00	0,00	15,22	0,00	4,85	36,51	0,00	0,00	0,00	0,00	0,00	0,03	3,35	100,23	27,59	13,34
Cm68	1809	0,00	4,61	0,00	0,00	0,00	17,03	0,00	5,44	41,52	0,00	0,00	0,00	0,00	0,00	0,59	1,42	116,68	29,58	13,79
Cm69	1806	0,00	5,28	0,00	0,00	0,00	15,84	0,00	4,84	35,45	0,00	0,00	0,00	0,00	0,00	0,24	0,00	103,33	27,16	13,04
Cm70	1803	0,00	4,99	0,00	0,00	0,00	11,94	0,00	3,97	29,99	0,00	0,00	0,00	0,00	0,00	0,13	1,13	87,48	23,55	11,76

APPENDIX 5- PIGMENT COMPOSITION GREPPERØDFJORDEN

Pigment composition(µg/g dryweight)

Cm	year	Allo	bb.Car	c.Neo	Cantha	Chl.a	Chl.b	Chl.c1	Chl.c2	Diadino	Diato	Dino	Echin	Fuco	Lut	Myxo	Peri	Phe.a	Phe.b	Viola
Cm1	2017	0,00	6,70	8,44	0,00	4,31	15,37	0,00	6,38	40,92	0,00	0,00	5,89	0,00	0,00	0,00	3,69	149,91	41,12	13,10
Cm2	2016	0,00	5,79	7,68	0,00	0,00	11,38	0,00	6,16	35,91	0,23	0,00	0,00	0,00	0,00	0,00	6,46	134,28	32,44	8,59
Cm3	2014	0,00	5,64	7,29	0,00	0,00	9,94	0,00	5,94	29,76	8,26	0,00	0,00	0,00	0,00	0,00	6,57	137,84	31,16	10,23
Cm4	2013	0,00	5,32	7,45	0,00	0,00	10,74	0,00	6,27	30,92	8,94	0,00	0,00	0,00	0,00	0,00	5,32	141,70	29,62	10,19
Cm5	2011	0,00	6,03	3,21	0,00	0,00	7,63	0,00	7,21	36,76	0,00	0,00	0,00	0,00	0,00	0,69	4,46	135,65	26,86	10,68
Cm6	2010	0,00	4,49	4,78	0,00	0,00	7,53	0,00	5,07	23,11	11,41	0,00	0,00	0,00	0,00	0,00	4,29	117,58	22,01	10,72
Cm7	2009	0,00	3,24	5,62	0,00	0,00	7,72	0,00	4,89	23,03	10,91	0,00	0,00	0,00	0,00	0,00	3,02	113,11	19,46	9,77
Cm8	2007	0,00	3,21	5,21	0,00	0,00	7,15	0,00	4,88	21,75	12,80	0,00	0,00	0,00	0,00	0,00	2,82	109,45	18,71	9,94
Cm9	2006	0,00	3,03	4,94	0,00	0,00	6,89	0,00	4,71	22,04	10,85	0,00	0,00	0,00	0,00	0,00	1,98	102,22	17,08	9,64
Cm10	2004	0,00	3,21	4,85	0,00	0,00	8,89	0,00	5,31	25,59	8,63	0,00	0,00	0,00	0,00	0,23	0,00	111,73	19,32	9,78
Cm11	2003	0,00	2,58	3,94	0,00	0,00	6,40	0,00	3,82	17,67	10,70	0,00	0,00	0,00	0,00	0,00	0,35	86,77	13,87	8,78
Cm12	2002	0,00	1,98	4,86	0,00	0,00	6,63	0,00	3,90	19,36	9,20	0,00	0,00	0,00	0,00	0,15	0,00	89,76	13,34	7,91
Cm13	2000	0,00	1,03	5,52	0,00	0,00	5,95	0,00	3,69	18,76	9,14	0,00	0,00	0,00	0,00	0,00	0,58	85,79	11,92	7,18
Cm14	1999	0,00	0,91	4,45	0,00	0,00	6,35	0,00	3,48	19,74	3,98	0,00	0,00	0,00	0,00	0,00	0,00	75,93	11,01	5,50
Cm15	1997	0,00	1,58	3,79	0,00	0,00	5,32	0,00	2,47	12,30	9,28	0,00	0,00	0,00	0,00	0,17	0,00	69,34	10,91	5,83
Cm16	1996	0,00	1,83	3,38	0,00	0,00	5,42	0,00	3,04	16,54	5,74	0,00	0,00	0,00	0,00	0,23	0,12	71,49	10,79	6,11
Cm17	1994	0,00	1,94	2,93	0,00	0,00	5,05	0,00	2,37	12,58	6,72	0,00	0,00	0,00	0,00	0,06	0,00	61,92	9,46	5,96
Cm18	1993	0,00	2,73	2,68	0,00	0,00	4,95	0,00	3,24	17,65	5,16	0,00	0,00	0,00	0,00	0,22	0,20	64,15	10,09	7,05
Cm19	1992	0,00	0,85	2,97	0,00	0,00	5,00	0,00	2,52	15,50	2,87	0,00	0,00	0,00	0,00	0,05	0,00	57,69	8,31	5,00
Cm20	1990	0,00	0,75	2,41	0,00	0,00	4,53	0,00	2,36	14,75	2,29	0,00	0,00	0,00	0,00	0,06	0,00	50,04	7,51	4,56
Cm21	1989	0,00	0,69	2,54	0,00	0,00	4,97	0,00	2,42	14,94	3,29	0,00	0,00	0,00	0,00	0,00	0,00	58,76	7,85	5,51
Cm22	1987	0,00	0,93	2,81	0,00	0,00	5,91	0,00	2,72	17,68	2,74	0,00	0,00	0,00	0,00	0,00	0,00	66,18	9,76	6,11
Cm23	1986	0,00	0,87	3,34	0,00	0,00	6,09	0,00	2,74	17,80	2,33	0,00	0,00	0,00	0,00	0,22	0,00	67,03	10,76	6,66
Cm24	1985	0,00	0,45	3,50	0,00	0,00	6,32	0,00	2,49	16,75	2,16	0,00	0,00	0,00	0,00	0,15	0,00	66,86	10,79	6,21

Cm25	1983	0,00	0,81	3,56	0,00	0,00	5,88	0,00	2,77	17,96	2,19	0,00	0,00	0,00	0,00	0,29	0,00	65,92	10,82	7,10
Cm26	1982	0,00	1,33	3,21	0,00	0,00	5,35	0,00	3,23	19,88	2,55	0,00	0,00	0,00	0,00	0,51	0,36	66,44	11,26	8,40
Cm27	1980	0,00	0,62	3,09	0,00	0,00	6,44	0,00	2,43	16,22	2,85	0,00	0,00	0,00	0,00	0,09	0,00	66,71	11,14	6,70
Cm28	1979	0,00	0,70	2,46	0,00	0,00	5,72	0,00	1,97	14,09	2,37	0,00	0,00	0,00	0,00	0,16	0,00	59,26	10,23	6,40
Cm29	1978	0,00	0,57	2,28	0,00	0,00	5,83	0,00	1,92	14,20	1,41	0,00	0,00	0,00	0,00	0,00	0,00	58,26	10,00	5,36
Cm30	1976	0,00	0,78	1,60	0,00	0,00	5,56	0,00	1,74	13,61	0,00	0,00	0,00	0,00	0,00	0,00	0,00	54,13	9,38	4,28
Cm31	1975	0,00	0,94	1,49	0,00	0,00	4,43	0,00	1,30	10,08	2,23	0,00	0,00	0,00	0,00	0,07	0,00	45,20	8,23	4,20
Cm32	1973	0,00	0,65	1,59	0,00	0,00	5,42	0,00	1,01	9,31	1,69	0,00	0,00	0,00	0,00	0,00	0,00	46,01	9,11	2,95
Cm33	1972	0,00	1,12	0,91	0,00	0,00	3,47	0,00	1,27	10,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	35,26	6,79	3,79
Cm34	1971	0,00	0,31	0,84	0,00	0,00	3,62	0,00	0,57	5,77	0,00	0,00	0,00	0,00	0,00	0,00	0,00	31,15	5,44	1,07
Cm35	1969	0,00	0,45	0,53	0,00	0,00	2,71	0,00	0,51	4,59	0,00	0,00	0,00	0,00	0,00	0,00	0,00	24,58	4,02	0,99
Cm36	1968	0,00	0,60	0,70	0,00	0,00	3,58	0,00	0,67	6,07	0,00	0,00	0,00	0,00	0,00	0,00	0,00	32,51	5,32	1,31
Cm37	1966	0,00	0,67	0,64	0,00	0,00	2,83	0,00	0,61	5,04	0,00	0,00	0,00	0,00	0,00	0,00	0,00	26,73	4,62	1,20
Cm38	1965	0,00	0,26	0,84	0,00	0,00	2,30	0,00	0,22	3,10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	19,95	3,44	0,15
Cm39	1963	0,00	0,41	0,86	0,00	0,00	2,47	0,00	0,29	3,34	0,00	0,00	0,00	0,00	0,00	0,00	0,00	20,29	3,93	0,22
Cm40	1962	0,00	0,62	0,90	0,00	0,00	2,84	0,00	0,43	4,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	24,71	4,58	0,60
Cm41	1961	0,00	0,75	0,43	0,00	0,00	2,00	0,00	0,46	3,91	0,00	0,00	0,00	0,00	0,00	0,00	0,00	21,62	3,44	1,24
Cm42	1959	0,00	0,43	0,69	0,00	0,00	2,25	0,00	0,14	2,61	0,00	0,00	0,00	0,00	0,00	0,00	0,00	20,72	3,54	0,14
Cm43	1958	0,00	0,54	0,34	0,00	0,00	1,98	0,00	0,33	3,26	0,00	0,00	0,00	0,00	0,00	0,00	0,00	17,38	3,08	1,01
Cm44	1956	0,00	0,77	0,36	0,00	0,00	2,10	0,00	0,45	3,55	0,00	0,00	0,00	0,00	0,00	0,00	0,00	18,00	3,65	0,95
Cm45	1955	0,00	0,13	0,41	0,00	0,00	1,80	0,00	0,00	1,33	0,47	0,00	0,00	0,00	0,00	0,00	0,00	15,34	2,71	0,00
Cm46	1954	0,00	0,40	0,18	0,00	0,00	1,67	0,00	0,07	1,98	0,00	0,00	0,00	0,00	0,00	0,00	0,00	13,64	2,46	0,40
Cm47	1952	0,00	0,89	0,32	0,00	0,00	1,90	0,00	0,49	3,81	0,00	0,00	0,00	0,00	0,00	0,00	0,00	16,86	3,69	1,05
Cm48	1951	0,00	0,38	0,61	0,00	0,00	2,07	0,00	0,26	3,25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	16,02	3,33	0,40
Cm49	1949	0,00	0,47	0,47	0,00	0,00	2,16	0,00	0,13	2,40	0,00	0,00	0,00	0,00	0,00	0,00	0,00	16,21	3,31	0,06
Cm50	1948	0,00	0,75	0,11	0,00	0,00	1,74	0,00	0,24	2,57	0,00	0,00	0,00	0,00	0,00	0,00	0,00	13,61	3,01	0,56
Cm51	1947	0,00	0,61	0,00	0,00	0,00	1,18	0,00	0,09	1,09	0,00	0,00	0,00	0,00	0,00	0,00	0,00	14,43	2,80	0,35
Cm52	1945	0,00	0,49	0,41	0,00	0,00	1,74	0,00	0,16	2,23	0,00	0,00	0,00	0,00	0,00	0,00	0,00	14,38	2,99	0,09

Cm53	1944	0,00	0,78	0,00	0,00	0,00	1,81	0,00	0,47	3,87	0,00	0,00	0,00	0,00	0,00	0,00	0,00	14,60	2,80	0,88
Cm54	1942	0,00	0,37	0,41	0,00	0,00	1,64	0,00	0,16	1,91	0,00	0,00	0,00	0,00	0,00	0,00	0,00	13,99	2,78	0,00
Cm55	1941	0,00	0,50	0,27	0,00	0,00	2,12	0,00	0,26	3,43	0,00	0,00	0,00	0,00	0,00	0,00	0,00	16,72	3,24	0,26
Cm56	1940	0,00	0,97	0,00	0,00	0,00	2,52	0,00	0,59	5,07	0,00	0,00	0,00	0,00	0,00	0,00	0,00	18,83	3,82	0,76
Cm57	1938	0,00	0,43	0,66	0,00	0,00	2,22	0,00	0,25	3,76	0,00	0,00	0,00	0,00	0,00	0,00	0,00	19,12	3,54	0,00
Cm58	1937	0,00	0,60	0,00	0,00	0,00	2,09	0,00	0,45	4,08	0,00	0,00	0,00	0,00	0,00	0,00	0,00	16,14	3,08	0,61
Cm59	1935	0,00	0,76	0,00	0,00	0,00	2,24	0,00	0,55	4,72	0,00	0,00	0,00	0,00	0,00	0,00	0,00	17,84	3,38	0,81
Cm60	1934	0,00	0,26	0,25	0,00	0,00	1,46	0,00	0,09	1,72	0,00	0,00	0,00	0,00	0,00	0,00	0,00	12,95	2,37	0,00
Cm61	1932	0,00	0,15	0,48	0,00	0,00	1,06	0,00	0,13	2,12	0,26	0,00	0,00	0,00	0,00	0,00	0,00	9,41	1,79	0,12
Cm62	1931	0,00	0,14	0,25	0,00	0,00	0,51	0,00	0,00	0,52	0,26	0,00	0,00	0,00	0,00	0,00	0,00	3,72	1,11	0,00
Cm63	1930	0,00	0,32	0,34	0,00	0,00	1,93	0,00	0,22	3,13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	14,45	3,01	0,11
Cm64	1928	0,00	0,63	0,00	0,00	0,00	1,98	0,00	0,45	3,84	0,00	0,00	0,00	0,00	0,00	0,00	0,00	16,60	3,06	0,76
Cm65	1927	0,00	0,53	0,15	0,00	0,00	2,37	0,00	0,30	3,37	0,00	0,00	0,00	0,00	0,00	0,00	0,00	18,48	3,68	0,37
Cm66	1925	0,00	0,32	0,21	0,00	0,00	1,20	0,00	0,19	2,22	0,00	0,00	0,00	0,00	0,00	0,00	0,00	10,34	2,07	0,22
Cm67	1924	0,00	0,31	0,00	0,00	0,00	2,06	0,00	0,26	3,03	0,00	0,00	0,00	0,00	0,00	0,00	0,00	15,87	2,75	0,37
Cm68	1923	0,00	0,71	0,00	0,00	0,00	2,03	0,00	0,41	3,67	0,00	0,00	0,00	0,00	0,00	0,00	0,00	17,61	3,06	0,77
Cm69	1921	0,00	0,37	0,15	0,00	0,00	1,71	0,00	0,20	2,06	0,00	0,00	0,00	0,00	0,00	0,00	0,00	15,00	2,59	0,24
Cm70	1920	0,00	0,26	0,16	0,00	0,00	1,38	0,00	0,04	1,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	11,29	2,12	0,00

APPENDIX 6- CLIMATE DATA

Year	Mean temperature year(°C)	Mean temperature growth season(°C)	Precipitation year(mm)	Precipitation growing season(mm)
1899	5,4	11,6	611	248,7
1900	4,5	11,2	776,4	398,6
1901	5,4	13,1	767,1	344,8
1902	3,8	9,6	604,3	351,6
1903	5,2	11,0	1032,8	458,3
1904	4,8	11,2	673,3	308,1
1905	5,5	11,5	661,3	416,9
1906	5,9	11,9	651,5	264,2
1907	4,8	10,2	982,9	475,9
1908	5,5	11,3	746,6	481,9
1909	4,4	10,3	995,1	470
1910	5,8	12,1	942,2	492,7
1911	6,3	12,6	688,6	282,7
1912	5,1	11,3	805,2	416
1913	6,1	11,7	668,4	382,3
1914	6,4	12,9	647,8	252,6
1915	3,6	10,7	877,3	481,7
1916	5,5	11,2	887	315,6
1917	4,2	11,8	706,3	396,7
1918	5,6	11,5	680,1	417,3
1919	4,3	11,5	590,9	292,7
1920	5,7	11,4	1001,3	686,4
1921	5,9	11,9	457,9	249,4
1922	4,6	10,7	625,7	422,1
1923	4,6	10,4	828,9	394,8
1924	5,3	10,9	1002,6	619
1925	5,3	12,5	740,1	410,2
1926	5,3	12,4	791	418,9
1927	4,6	10,8	1115,6	610,8
1928	4,8	10,5	770,5	292,3
1929	4,9	10,6	880,3	318,1
1930	6,5	12,2	940,2	521
1931	4,7	10,7	683,7	387,7
1932	6,3	12,1	750,7	367,5
1933	6,0	13,1	616,1	311,5
1934	7,3	12,7	913,3	422,9
1935	6,1	12,1	954,1	383,2
1936	5,8	12,1	787,1	353,5

1937	5,7	12,9	742,7	419,1
1938	6,9	12,2	845,9	326,4
1939	6,1	13,1	761,9	376,4
1940	4,1	11,7	720,4	481,1
1941	3,8	11,6	599,3	406,6
1942	3,9	11,5	831,3	514,1
1943	6,3	12,2	706,6	363
1944	5,9	11,5	877,6	500,4
1945	6,1	12,6	639,8	363,5
1946	5,5	12,2	954,1	555
1947	4,9	14,1	398,3	196,2
1948	5,6	12,4	954,9	573,9
1949	7,1	13,1	805,4	348
1950	5,5	12,3	1006,5	613,7
1951	5,6	11,5	987,5	529,4
1952	4,4	11,0	673,7	424,5
1953	6,4	12,1	807,2	604,3
1954	5,0	11,5	947,6	488,6
1955	5,1	12,7	505	273
1956	4,3	11,2	667,6	496,5
1957	5,3	11,2	766,2	503,5
1958	4,4	11,3	738,9	406,1
1959	6,3	13,1	810,8	254
1960	5,1	12,0	1075,5	587
1961	6,1	12,0	816	385,2
1962	4,2	10,3	914,1	572,3
1963	4,0	11,5	796	576,7
1964	5,1	10,9	743,4	444,3
1965	4,2	10,8	823,8	643,3
1966	4,0	11,1	890,2	398,8
1967	5,5	11,7	1026,1	467,5
1968	4,7	12,1	672,7	374
1969	4,9	12,6	635,6	385
1970	4,3	11,7	770,6	422,7
1971	6,1	11,9	555,7	293,5
1972	5,8	11,8	684,6	468,7
1973	6,1	11,9	536,6	356,8
1974	6,8	12,3	930,9	492,3
1975	7,0	12,8	607,6	292,6
1976	5,5	12,6	608	186,8
1977	5,3	11,4	708,1	359,3
1978	4,8	11,3	608,1	352,3
1979	4,2	11,1	811,2	393,6
1980	4,8	12,6	767,1	402,9

1981	4,7	11,8	718,1	351,1
1982	5,9	12,4	951,9	405,4
1983	6,5	12,4	721,2	432,4
1984	6,2	12,2	846,1	439
1985	3,4	11,0	827,5	533,4
1986	4,5	10,5	709,3	325,5
1987	3,5	10,2	976,6	492
1988	5,8	12,4	986	544,8
1989	7,0	11,7	742,2	407,5
1990	7,9	12,4	889,6	391,4
1991	6,1	11,9	744,8	279,9
1992	6,6	12,5	802,3	429,5
1993	5,7	11,3	728,4	344,9
1994	5,8	12,6	835	413,9
1995	5,8	11,9	850,9	512,2
1996	4,6	11,3	692,7	318,1
1997	6,8	13,3	650,8	315,5
1998	6,0	11,5	786	478,3
1999	6,3	12,3	1057,8	553,9
2000	7,2	11,8	1192	431,1
2001	5,4	12,0	891,3	470,1
2002	6,2	13,5	909	502
2003	5,8	12,6	758,5	447,5
2004	6,5	12,7	841,2	440,3
2005	6,8	12,4	681	345,2
2006	6,9	13,5	1053,2	458,8
2007	6,7	12,5	920,6	534,4
2008	7,1	12,4	1161,2	527,4
2009	5,9	12,8	929,5	471,2
2010	3,7	11,9	807,3	532,8
2011	6,6	13,0	1064,2	708,7
2012	5,9	11,6	1019,9	575
2013	6,0	12,3	841	444,9
2014	7,7	13,3	1089,2	356,5
2015	7,1	11,8	1107,5	678,3
2016	6,7	13,2	775,1	454,9
2017	6,5	12,2	981,6	492,4

APPENDIX 7- PRINCIPAL COMPONENT ANALYSIS

Table 6A: Principal component analysis for lake Bindingsvann

Eigenanalysis of the Correlation Matrix					
Eigenvalue	1,7807	1,23	0,8031	0,6748	0,5114
Proportion	0,356	0,246	0,161	0,135	0,102
Cumulative	0,356	0,602	0,763	0,898	1
Variable	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**
Sulphate in precipitation(mg/L)	-0,329	-0,572	-0,463	-0,571	0,154
Loss on ignition (%)	0,378	0,546	-0,547	-0,193	0,472
Chlorophyll a(µg/g)	0,594	-0,131	-0,279	-0,18	-0,721
Annual precipitation(mm)	0,498	-0,201	0,604	-0,485	0,335
Annual average air temp(°C)	0,384	-0,563	-0,211	0,608	0,349

Table 6B: Principal component analysis for lake Grepperødfjorden

Eigenanalysis of the Correlation Matrix						
Eigenvalue	2,9029	1,5399	0,7872	0,603	0,1184	0,0487
Proportion	0,484	0,257	0,131	0,1	0,02	0,008
Cumulative	0,484	0,74	0,872	0,972	0,992	1
Variable	**PC1**	**PC2**	**PC3**	**PC4**	**PC5**	**PC6**
Sulphate in precipitation(mg/L)	0	-0,711	-0,125	0,571	0,281	-0,273
Agricultural area (%)	0,512	-0,333	-0,02	0,108	-0,661	0,422
Loss on ignition (%)	0,552	-0,083	0,136	-0,219	0,682	0,396
Chlorophyll a(µg/g)	0,563	0,021	0,101	-0,264	-0,111	-0,769
Annual precipitation(mm)	0,231	0,507	0,429	0,71	0,022	-0,008
Annual air temp(°C)	0,252	0,346	-0,878	0,2	0,079	-0,002

APPENDIX 8-MONITORING DATA FOR LAKE GREPPERØDFJORDEN

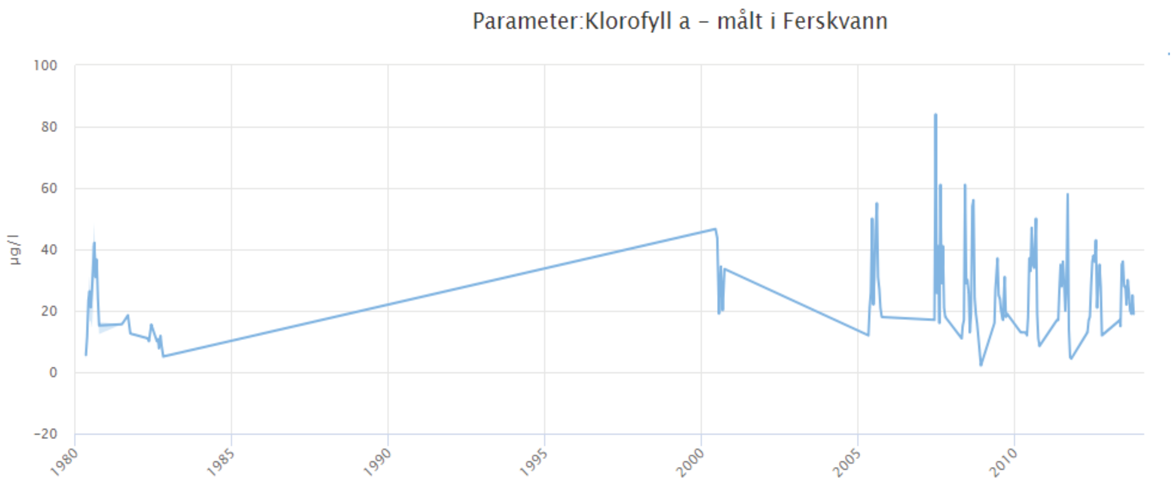

Figure 8A: Chlorophyll -a values in the water phase of lake Grepperødfjorden during the monitored period of 1980-2013. Source: vannmiljo.miljodirektoratet.no. Retrieved: 24.4.2018.

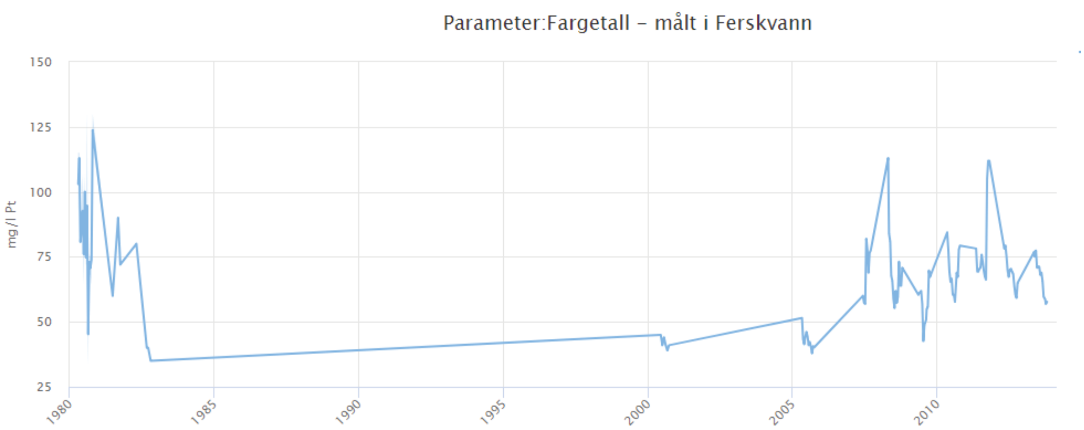

Figure 8B: Development of water color in lake Grepperødfjorden during the monitored period of 1980-1982, 2000, 2005 and 2007- 2013. Source: vannmiljo.miljodirektoratet.no. Retrieved 24.2.2018.

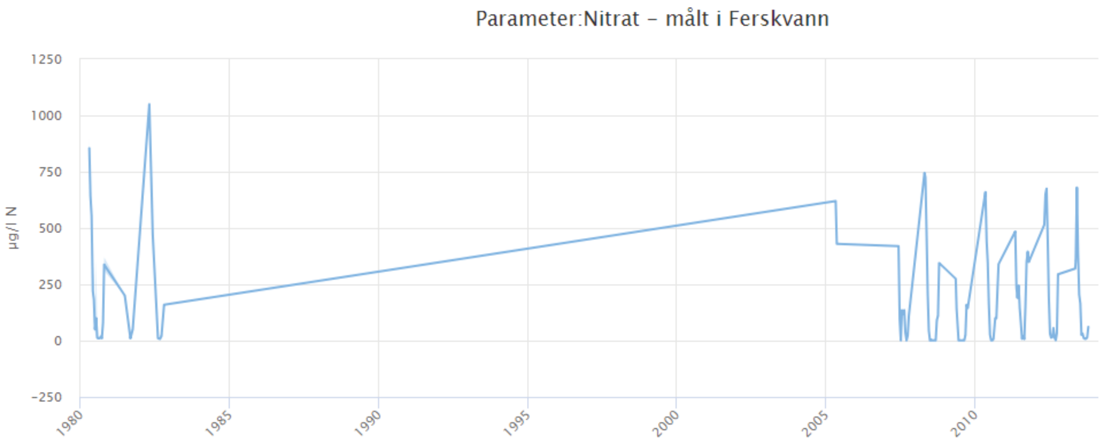

Figure 8C: Development of NO3-N in the water phase of lake Grepperødfjorden during the monitored period of 1980-1982, 2005 and 2007-2013. Source: vannmiljo.miljodirektoratet.no. Retrieved 24.4.2018.

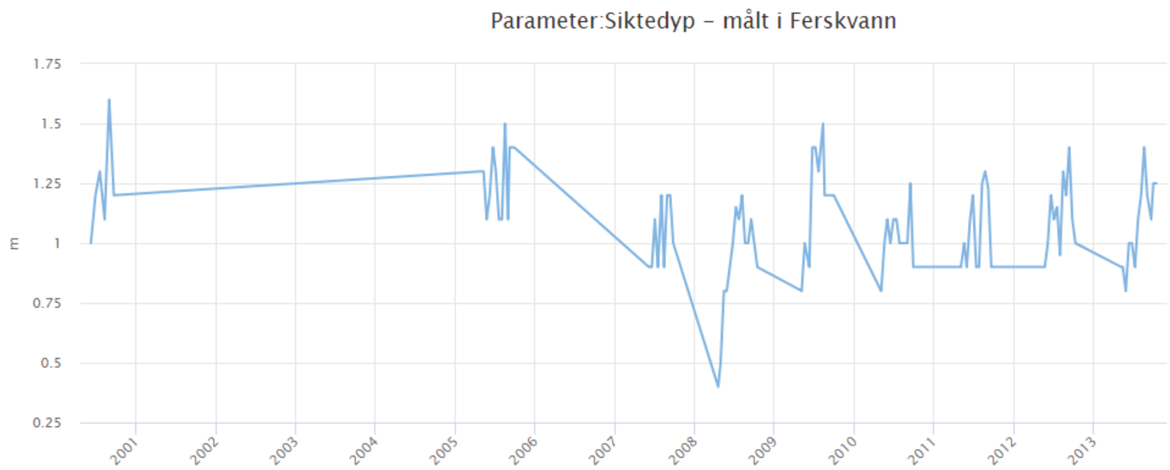

Figure 8D: Development of secchi depth in lake Grepperødfjorden during the monitored period of 2000, 2005 and 2007-2013. Source: vannmiljo.miljodirektoratet.no. Retrieved 24.4.2018.

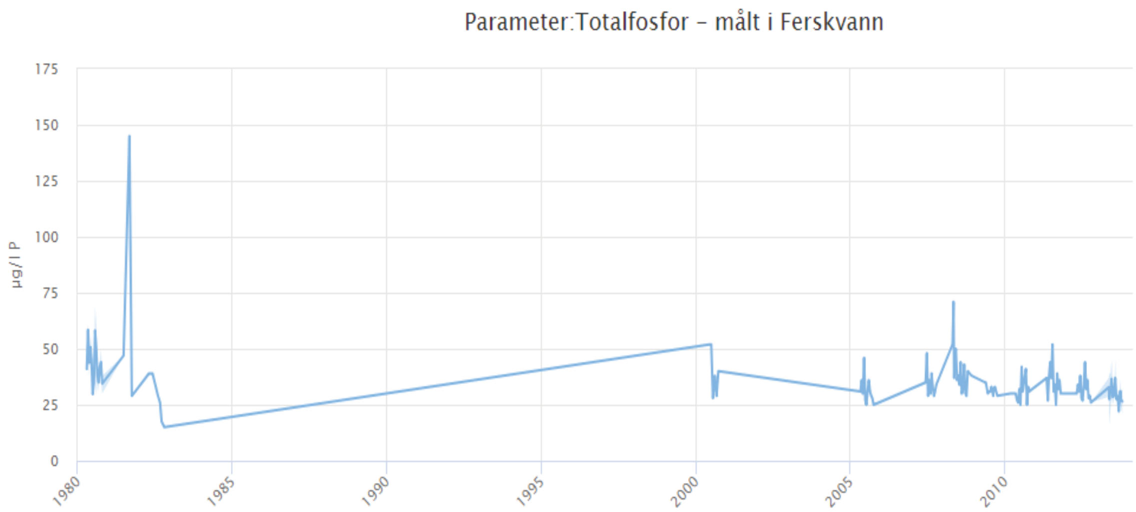

Figure 8E: Development of TOT-P in the water phase of lake Grepperødfjorden during the monitored period 1980- 2013. Source: vannmiljo.miljodirektoratet.no. Retrieved 24.4.2018.

APPENDIX 9 –MONITORING DATA FOR LAKE BINDINGSVANN: FIGURES

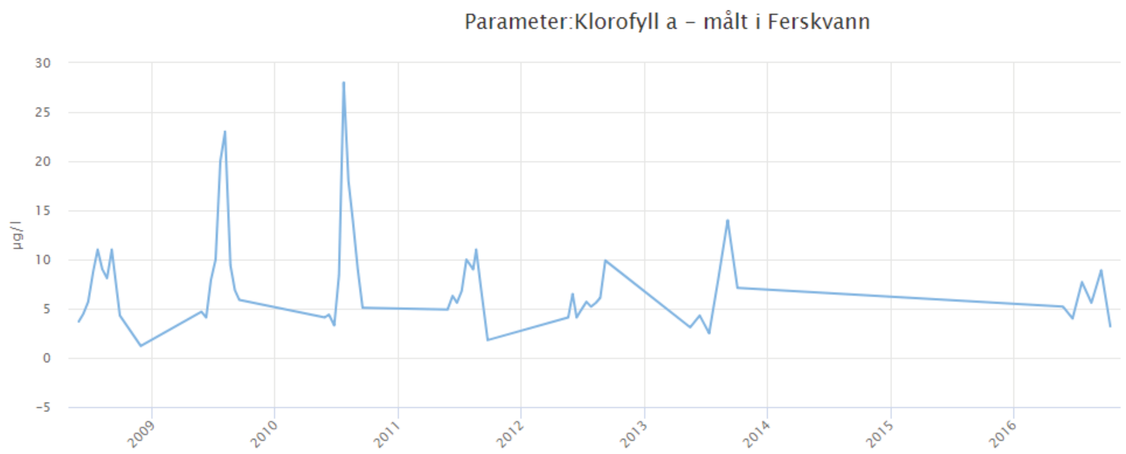

Figure 9A: Chlorophyll-a values in the water phase of lake Bindingsvann during the monitored period of 2008-2016. Source: vannmiljo.miljodirektoratet.no. Retrieved 24.4.2018.

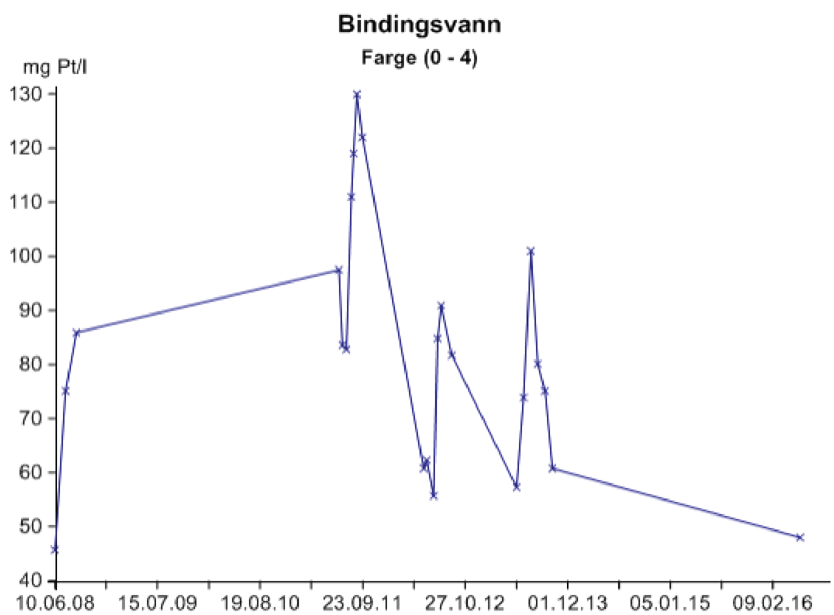

Figure 9B: Development of water color during the monitoring period 2008-2016. Source: Aquamonitor.no. Retrieved 24.4.2018

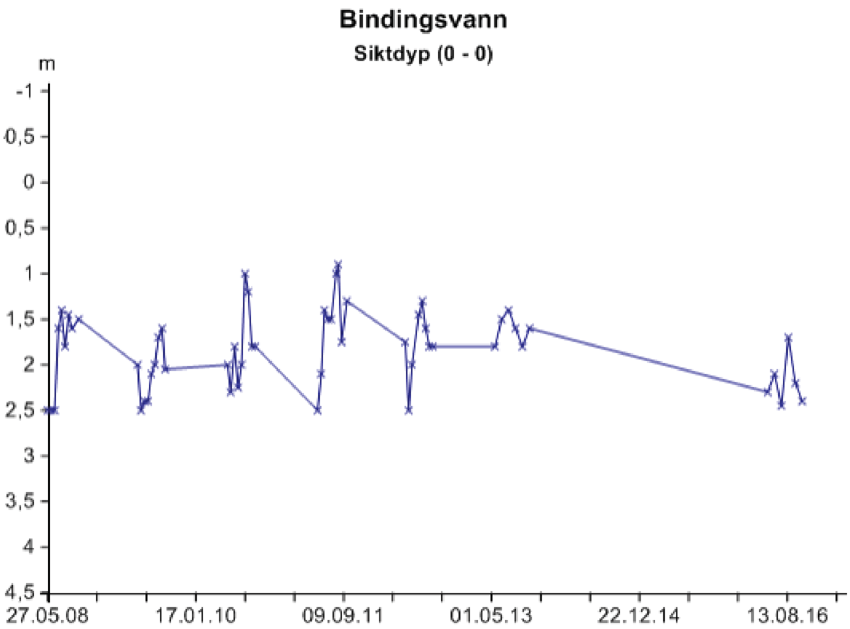

Figure 9C: Development of secchi depth in lake Bindingsvann during the monitored period of 2008-2016. Source: Aquamonitor.no. Retrieved 24.4.2018.

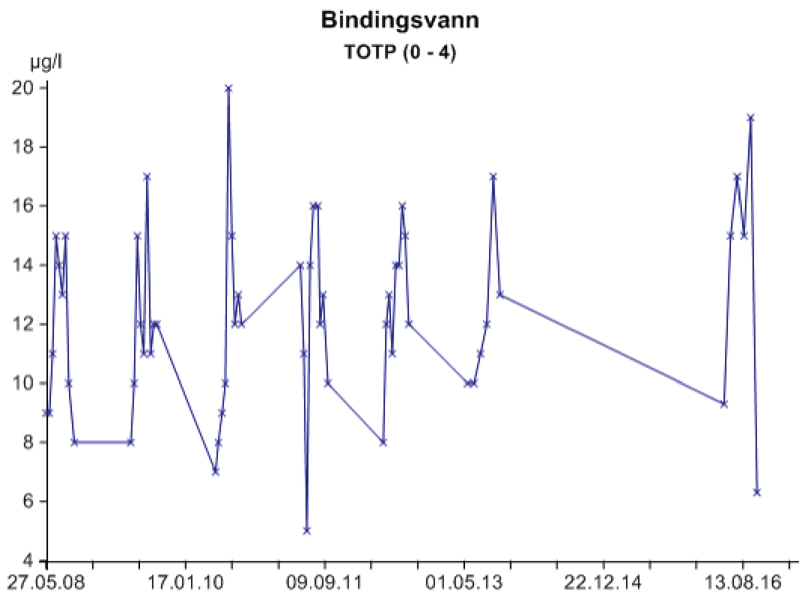

Figure 9D: Development of TOT-P in lake Bindingsvann during the monitored period of 2008-2016. Source: Aquamonitor.no. Retrieved 24.4.2018.

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