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Historical development of Lake Ertevannet-studied by paleolimnological methods.

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Abstract

Paleolimnological studies of lacustrine sediment accumulation provide valuable and diverse insights into historical environmental changes, thereby offering a baseline for investigating lake conditions in line with the objectives of the Water Framework Directive (WFD). This paleolimnological study seeks to reconstruct past environmental changes in Lake Ertevannet, which is currently classified as ecologically poor under the Water Framework Directive, and to evaluate how changes in land use within the watershed have impacted lake productivity.

A sediment core, measuring 45 cm in length, was extracted from a lake encircled by areas of intensive cultivation, representing the period from 1934 to 2024. This core was analyzed for sedimentation rates, total phosphorus levels, algal pigments, and organic matter content. The results indicate that the period from 1934 to 1950 exhibited relatively low levels of algal productivity and diminished sediment deposition, reflecting a time of limited human disturbances. High-Performance Liquid Chromatography (HPLC) analysis of the sediment revealed the main carotenoids present, including Alloxanthin, Canthaxanthin, Fucoxanthin, and Lutein, suggesting the existence of diatoms, cyanobacteria, cryptophytes, and green algae, although in lower concentrations.

The sediment core indicates a period of significant changes occurring around 1960, characterized by a synchronous increase in all measured variables, such as pigment concentrations, phosphorus, organic content, and dry weight. These alterations correspond with considerable land-use changes in the catchment area, including land leveling, drainage, and the reduction of grassy buffer meadows, indicating a strong anthropogenic effect on nutrient phosphorus (P) flux to the lake, which enhances algal growth. The phosphorus profile reveals an elevated peak in 1970 (0.85 mg P/g), followed by a protracted period of stability until recent years, albeit at lower concentrations, indicating a transition from external nutrient supply to in-lake processes.

The sedimentation rate remained relatively stable from 1963 until recent years, except for 2024, when a sediment accumulation rate of 2.047 cm/year was observed, likely due to the deposition of fresh and unconsolidated materials. The concurrent increase in chlorophyll-a and organic matter from 2010, alongside a decline in dry weight, reflects an increase in autochthonous organic matter production and an enriched nutrient environment. Comparatively, it has demonstrated a broadly similar regional sensitivity to anthropogenic impact in Glomma-Sør; however, responses were site-specific due to varying catchment properties.

The simultaneous increases in Alloxanthin, Canthaxanthin, Fucoxanthin, and Lutein from 2010 suggest a positive response of multiple algal groups under eutrophic conditions. Understanding the long-term records of lake history has enabled an assessment of the ecosystem's response to anthropogenic disturbances and may provide a useful tool for the development of future measurement protocols.

TABLE OF CONTENTS

1. INTRODUCTION

1.1 BACKGROUND

Lakes are sensitive to environmental fluctuations and stress (Battarbee et al., 2002). As crucial freshwater resources, they provide vital ecological services and ecological stability. However,

Climate change and anthropogenic activities increasingly threaten the balance of these ecosystems (Battarbee, 2000). The anthropogenic pressure on the environment has a long history but has been understood to have accelerated since the onset of the Industrial Revolution in the late 1700s (Steffen et al., 2007). The deterioration of lake water quality and potential loss of ecological services have been a common environmental concern since the latter half of the 1900s (Forbord et al., 2014; (Leavitt & Carpenter, 1990). Freshwater bodies are especially vulnerable to environmental stressors and have lately been shaped by anthropogenic activities (Tonno et al., 2019).

Lake ecosystems profoundly altered through anthropogenic activities are appropriate for assessing ecosystem response to external changes and disturbances (Battarbee, 2000; Battarbee et al., 2002; Parker et al., 2008; Schindler, 2009). To estimate past conditions, however, measures must be considered within the framework of the European Water Framework Directive (WFD) from a lake that is identified as undisturbed from human activities or a reference lake (Reuss, 2005). WFD aims to restore and maintain good ecological status in European surface water bodies by 2021 (Vannportalen, 2014b). However, a report by WFD (2000) states that half of the freshwater bodies in Europe do not meet a good ecological state.

Phytoplankton, as a key primary producer in a lake ecosystem, are sensitive and respond rapidly to the shifts in environmental conditions (Reuss, 2005; Stevenson, 2003). The composition of these biota, therefore, provides an ideal insight into the historical changes in the lake productivity and trophic dynamics. Furthermore, the WFD emphasizes the use of biological indicators in studying the paleo reconstruction of a lake, and sedimentary algal pigments offer a unique opportunity to document the long-term shifts in phytoplankton composition and assemblages. The most studied biological remains include diatoms, cyanobacteria, chironomids, pollen, zooplankton subfossils, and their dormant propagules. The assessment and integration of these indicators allow paleolimnological studies to establish pre-disturbance reference conditions and track ecosystem response to external pressure.

1.2 Phytoplankton dynamics and their environmental controls

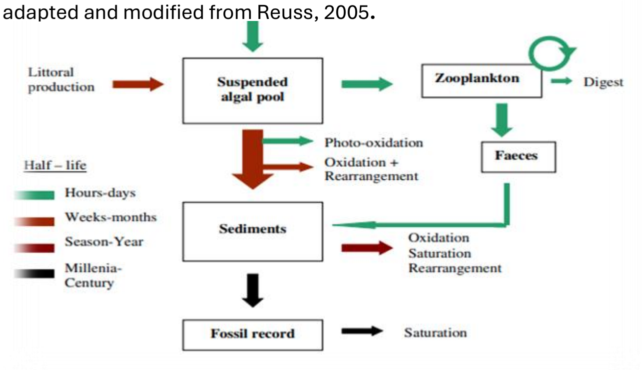
Algae are an important part of freshwater ecosystems, where they serve as the most common primary producers (Stevenson, 2003). In Northern boreal lakes, phytoplankton blooms and shifts have been observed since the mid-1900s, which coexist along with increasing browning, warmer temperatures, and humic lake water (Deshpande et al., 2014; Finstad et al., 2016; Xiao et al., 2020).

Each algae species has its own specific optimum and tolerance range (Wetzel, 2001), and a change in temperature can affect the algal growth directly by competition among the species or indirectly through the effects of thermal stratification (Leavitt & Carpenter, 1990). The growth, development, and subsequent accumulation of algae in lake sediment are determined by colonization, reproduction, death, grazing, and emigration, which are all governed by various biotic and abiotic factors (Steinman et al., 1992). Climate and Nutrient dynamics are perceived as the major influencing factors for phytoplankton development (Salmaso et al., 2012), which are mostly limited by light, temperature (Hill et al., 2009), and nutrients, particularly Nitrogen and Phosphorus (Nürnberg, 2024).

Pigments are an important source of information about long-term algal composition, with carotenoids, which are taxon-specific, serving as a vital indicator of historical phytoplankton communities (Jeffery, 1980; Leavitt & Hodgson, 2001). Paleolimnologists, therefore, rely on these biochemical markers that are stored and preserved in the sediments to reconstruct past paleo-climatic and paleoenvironmental issues (Brown, 1969; Leavitt, 1993; Sanger, 1988). However, pigments are generally labile molecules that pass through various degrees of decay before they reach the sediment (Leavitt, 1993; Reuss, 2005). Additionally, the temporal dynamics of these pigments are also strongly governed by nutrient availability (Deshpande et al., 2014), and different algal groups have different tolerance for environmental conditions (Cohen, 2003; Smol & Cumming, 2000).

Leavitt (1993) states that most of the pigment degradation occurs in the water column, however, Reuss (2005) opines that the fate of the pigments in the sediment relies on possible timed events such as latitude, lake water mixing, watershed structure, and solar irradiance.

Figure 1. Sediment pigment flux in the water column. Picture adapted and modified from Reuss, 2005.



So, the reliability of ecological interferences based on algal pigments is shaped by the degree of pigment degradation in the water column (Brown, 1969; Leavitt et al., 1999; Sangar, 1988).

However, it is unequivocal that organic remains must pass through some degree of processing before burial.

Even though algal pigments reveal past changes in lake productivity and trophic level, their interpretation and assessment are closely related to nutrient availability, particularly Phosphorus, and catchment dynamics (Bianchi et al., 2000; Jeffrey, 1980; Sterner, 2008).

1.3 Nutrient enrichment: Phosphorus as a key driver

Phosphorus (P) is the least abundant, yet one of the principal nutrients that limits biological productivity (Sterner, 2008; Elser et al., 2007), significantly affecting the composition of phytoplankton communities (Reuss, 2005). Nonetheless, the retention and release of phosphorus from the sediment into the water column is influenced by various factors and will vary across different categories of lakes (Søndergaard et al., 2001). As a critical determinant of lake productivity, the relationship between phosphorus and algal production, as measured by Chl-a, has been observed to exhibit either a positively linear relationship at low or intermediate concentrations or a sigmoidal pattern when phosphorus levels are elevated (Brown et al., 2000).

Lake sediments act as both a source and sink of phosphorus, and the trophic state of a lake can be inferred from the P profile in the lake sediments (Carey & Rydin, 2011). Phosphorus dynamics in the sediment vary over time, and its proportion will depend on both allochthonous and autochthonous sources (Kerr et al., 2011). Phosphorus in the sediment exists in various forms and often binds with other elements due to the low solubility of its compounds (Abell et al., 2013; Dunne et al., 2007). Several factors affect the P binding potential and subsequent release to the water column (Søndergaard et al., 2003). Due to natural limitations and slow mobilization of phosphorus, the primary production in a lake is, in turn, controlled by external P inputs such as agriculture, urbanization, and pasturing, which regulate the phosphorus flux from riparian or terrestrial systems into water bodies (Dunne et al., 2007).

The WFD states that member countries require good or moderate (GM) boundaries of nutrients with satisfactory ecological status for sensitive biological quality elements (BQEs) (Kelly et al., 2022). It has been shown that strategies aimed at minimizing algal biomass through P management are largely hindered by internal loading and resuspension. Furthermore, assessment and monitoring of the relationship between the Ecological quality ratio for the BQEs and nutrients, most importantly, Total P in lowland lakes and rivers, is fundamental to deriving safe ecological nutrient boundaries (Phillips et al., 2024).

1.4 Catchment changes and landscape transformations

The robust interpretation of the lacustrine sediment is governed by a detailed understanding of the lake's surrounding catchment processes and sediment sources (Schindler, 2009; Smol, 2009). Human-induced land-use changes such as agriculture expansion, wastewater discharge, and climate-driven modifications in hydrology have all significantly contributed to nutrient enrichment and subsequent changes in lake productivity (Slaymaker, 2010; Smol, 2005). Norwegian lakes, mostly oligotrophic for millennia, are turning eutrophic and have been rendered bad in ecological status after the onset of human intensification such as logging, agriculture expansion, and excessive use of fertilizer among others since the 1950s (Hagman, 2020; Finstad et al., 2016; Riise et al., 2018). As in other European countries, specialization and rationalization of farming started in Norway after the culmination of the Second World War (Lundekvam et al., 2003). The agricultural history of Norway indicates that technological development and socioeconomic and political frameworks have mainly shaped agricultural production over time (Forbord et al., 2014). During the period 1949-1995, the number of land holdings in Norway declined by 61%, which was accompanied by an almost 70% decline in labour input (Lundekvam, 2003). There was a shift in the distribution of holdings in the same period, whereby the farmland became dominated by fewer but larger holdings. Even though the total farming area diminished by around 8% in Norway since 1939, the changes are not evenly distributed, as results show that cultivated area increased in Rakkestad by 2% but declined by around 36% in western Norway farmlands. Historically, the southeastern region of Norway is the most urbanized and ideal for farming, which comprises more than 60% of the farmland in Norway (Fjellstad & Dramstad, 1999)

Although agricultural expansion and intensification endeavored to address the socioeconomic needs of the era, they also resulted in significant alterations in fertilizer application practices and exacerbated soil erosion issues (Potthoff, 2022). The predominantly silty-clayey soil in Østfold and Rakkestad was substantially enhanced with inorganic fertilizers (N, P) to boost cereal production, thereby representing the primary point source of nutrient diffusion to the adjacent aquatic environments (Bechmann et al., 2005). Once mobilized and introduced into the water body, elevated phosphorus levels stimulate phytoplankton proliferation, leading to shifts in algal communities and increased biomass (Bechmann et al., 2005).

According to the Water Framework Directive, the classification of the status of water quality in Norway shows that 51% of the water bodies are at no risk, 25% at risk, 22% at possible risk, and 2% as not defined. According to the EFTA Surveillance Authority (2025), approximately 70% of the surface water bodies in Norway have unknown anthropogenic-related stressors (Authority, 2025). It is meaningful to note that the present study area, i.e., Lake Ertevannet, is designated as poor in ecological status under the Norwegian Water Frame Directive (Vann-nett.no n.d.) and therefore offers an opportunity for paleolimnological study to highlight the direct correlation between land use practices, phosphorus enrichment, and algal growth and development.

This intricate interplay of catchment dynamics, phosphorus enrichment, and phytoplankton growth dynamics underscores the importance of a long-term integrated investigation in Lake Ertevannet in identifying the cause of lake transformations.

1.5 Paleolimnology as a tool for historical reconstruction

Lakes are an important and dynamic part of the inland aquatic environment, which continuously responds to external changes and disturbances (Battarbee, 2000). They generally act as natural repositories, where the accumulated sediments serve as a valuable archive that provides insights into historical environmental changes (Battarbee, 2000; Wetzel, 2001). Sediments are reservoirs of lakes' ecological information that have been continually accumulated over the years (Carpenter & Cottingham, 1997). Usually, reliable long-term monitoring data are often lacking, and the absence of long-term monitoring records limits in understanding of historical environmental dynamics. Thus, a paleo reconstruction becomes more necessary in environmental assessments. It is a multidisciplinary science that uses the physical, chemical, or biological information preserved in sediments of water bodies to infer past ecosystem change (Bennion & Battarbee, 2007; Smol, 2009). The undisturbed sediment profile provides information on various physical, chemical, and biological proxies such as pigments, diatoms, organic matter, pollen, pollutants, etc (Leavitt et al., 1999; Smol, 2010) stored in it, hence providing a base to reconstruct lakes past conditions and track a long-term environmental perspective from decades to millennia back (Smol, 2009).

Sediment, irrespective of the source of origin (autochthonous or allochthonous), eventually settles at the bottom of the lake. However, sediment accumulation is influenced by several factors, which subsequently determine the degree of portion and composition of materials that constitute the sediment (Cohen, 2003; Reuss, 2005).

1.6. PURPOSE OF THE STUDY

The Glomma-Sør catchment is one of the largest and most vital ecoregions in Southeastern Norway, which plays a crucial role in regional hydrology, nutrient flux, and ecological health. Lakes in this region of Norway are presumed to be heavily influenced by anthropogenic activities like agriculture expansion, urbanization, and sewage discharges (Pers. Com. Rohrlack, 03/09/2024, 14/10/25). As of January 2016, the Glomma-Sør water area consists of 134 water bodies, of which 90 are rivers or streams, 18 lakes, 21 coastal bodies, and 5 ground waters (Skarbøvik, 2022). Ertevannet is a part of a large network of the Glomma-Sør watercourse in Rakkestad municipality. While paleolimnological studies of other waterbodies in the Glomma-

Sør water region are executed extensively, Ertevannet's long-term nutrient dynamics and phytoplankton profile remain largely unexplored. So, this study aims to fill that void by reconstructing the long-term trajectories of phytoplankton composition and lake development by sediment analysis.

This study was designed to accomplish the following objectives:

- Investigate the long-term trends in algal productivity and composition using Chl-a as an expression of primary production.
- Identify and evaluate the drivers for algal composition and organic matter.
- Assess whether organic content in the Lake sediment is of autochthonous or allochthonous origin.
- Compare algal development in Ertevannet with a regional trend in the Glomma-Sør water region, thereby predicting whether the changes are local or regional.

This study aims to test the following hypothesis:

1. Catchment changes are reflected in sedimentary pigment concentration, where increased land-use activities correspond to enhanced algal production.

2. Organic matter corresponds with both lake processes and catchment disturbances.

2 STUDY AREA

2.1 SITE DESCRIPTION

The study area encompasses Lake Ertevannet, situated in Rakkestad Municipality within Østfold. This lake represents the largest body of water in Rakkestad Municipality and is located 3.5 kilometers southwest of Degernes. Lake Ertevannet is part of the Glomma River Basin District (RBD) and belongs to the Glomma-Sør for Øyeren watercourse region. It is a moderately sized lake with an area of 1.1 square kilometers. The lake features a narrow and elongated shape, extending 3.6 kilometers in length, with a relatively broader central section, possessing a maximum depth of 10.5 meters in its deepest area (Figure 2.4). The lake receives inflow from Vatvetelva, originating from Elnessjøen, along with Øverbybekken, Elgutubekken, and minor streams from Nordre Blytjern and Stomperudtjernet. Outflow from the lake is conducted through Skiselva, which ultimately connects to Rakkestadelva, a tributary of the Glomma River. The water discharge from the lake is regulated by Gjøby mill, located adjacent to Skiselva. Additionally, the lake contains two islands, Strandøya and Kollløya (Norconsult, 2018).

South-eastern Norway's landscape has a spatial heterogeneity and Ertevannet lies in a relatively flat landscape, characterized by flat open areas. Geographical and morphometric information on the lake is presented in Table 1.

Table 1: Geographical and morphometric information about lake Ertevannet. Sources: kartverket.no,vann-nett.no, vannmiljo.miljodirektoratet.no.

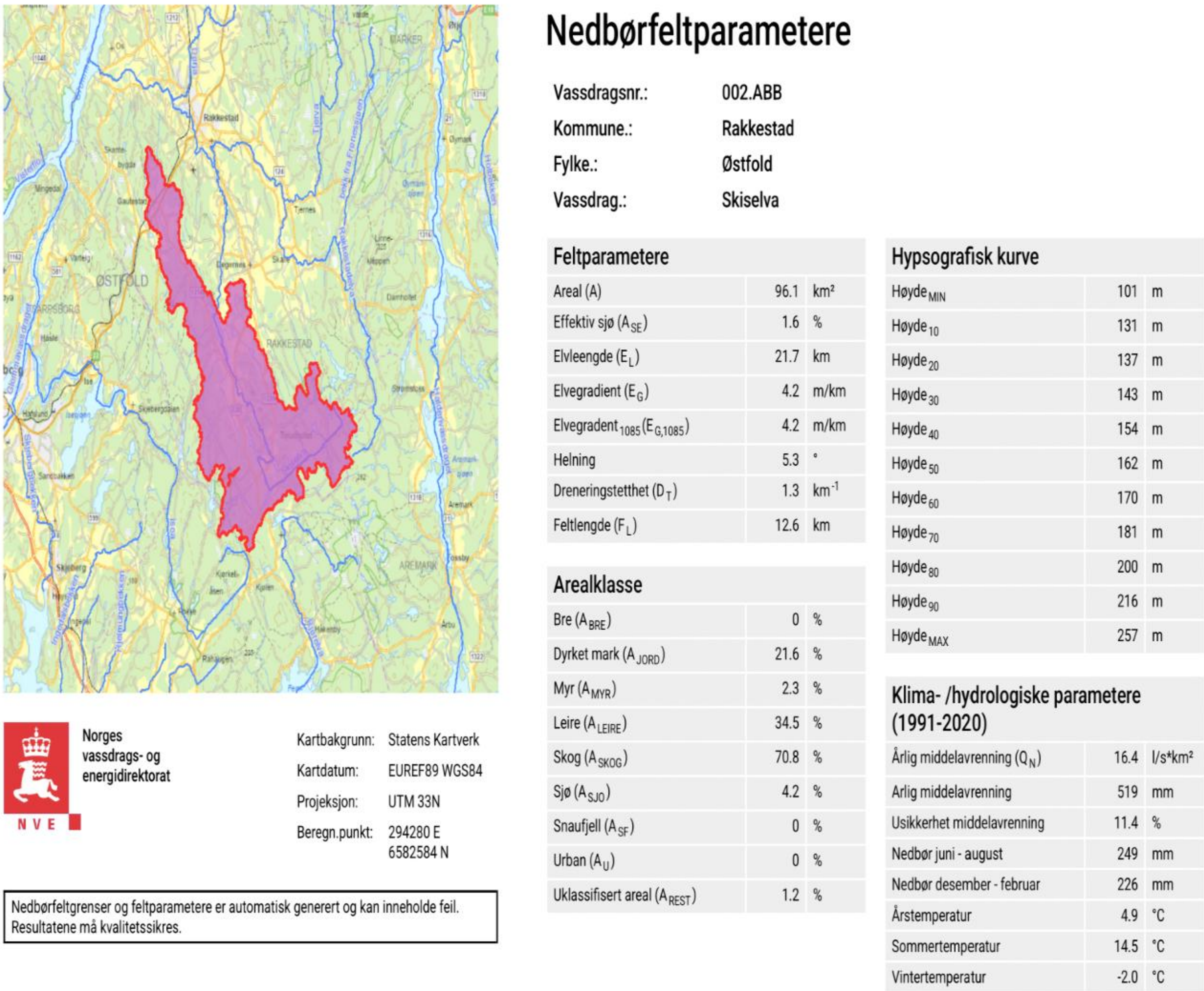
Geographic coordinates	**59°19'30" N11°23'00" Ø**
m.a.s.l.	102
Area km²	1.135
Maximum depth	10.5m.
Size	0.5-5km²
Drainage basin km²	96.09

Figure 2.1. Marked area shows the catchment area of lake Ertevannet(NVE u. å.-a)

2.2. LAKE ERTEVANNET

At an elevation of 102 m.a.s.l. Lake Ertevannet is surrounded by a scattered patch of coniferous, deciduous, mixed forest and a small proportion of pastureland on all sides.

Although it is a small lake, the catchment area of the lake is significantly large, which is 97 km2. Seventy-one percent (71%) of the catchment area consists of native forest, 21% agricultural land, 4% lake area, and 2% bog (Figure 2.1). Settlements are not so pronounced, except for a few scattered houses in the surrounding area. Furthermore, there are significant number of pastures and open fields in the lake vicinity, which are used for grazing mostly by horses and cows (Figure 2.2).



Nedbørfeltparametere

Vassdragsnr.:	002.ABB
Kommune.:	Rakkestad
Fylke.:	Østfold
Vassdrag.:	Skiselva

Feltparametere		
Areal (A)	96.1	km²
Effektiv sjø (A_{SE})	1.6	%
Elvleengde (E_L)	21.7	km
Elvegradient (E_G)	4.2	m/km
Elvegradent $_{1085}$ ($E_{G,1085}$)	4.2	m/km
Helning	5.3	°
Dreneringstetthet (D_T)	1.3	km^{-1}
Feltlengde (F_L)	12.6	km

Arealklasse		
Bre (A_{BRE})	0	%
Dyrket mark (A_{JORD})	21.6	%
Myr (A_{MYR})	2.3	%
Leire (A_{LEIRE})	34.5	%
Skog (A_{SKOG})	70.8	%
Sjø (A_{SJO})	4.2	%
Snaufjell (A_{SF})	0	%
Urban (A_U)	0	%
Uklassifisert areal (A_{REST})	1.2	%

Hypsografisk kurve		
$Høyde_{MIN}$	101	m
$Høyde_{10}$	131	m
$Høyde_{20}$	137	m
$Høyde_{30}$	143	m
$Høyde_{40}$	154	m
$Høyde_{50}$	162	m
$Høyde_{60}$	170	m
$Høyde_{70}$	181	m
$Høyde_{80}$	200	m
$Høyde_{90}$	216	m
$Høyde_{MAX}$	257	m

Klima- /hydrologiske parametere (1991-2020)		
Årlig middelavrenning (Q_N)	16.4	l/s*km²
Årlig middelavrenning	519	mm
Usikkerhet middelavrenning	11.4	%
Nedbør juni - august	249	mm
Nedbør desember - februar	226	mm
Årstemperatur	4.9	°C
Sommertemperatur	14.5	°C
Vintertemperatur	-2.0	°C

Figure 2.1. The marked area shows the catchment area of Lake Ertevannet. Source: (NVE u.å.-a).

Ertevannet lies below the marine boundary and is influenced by marine clay. The bedrock of the catchment area predominantly consists of thin soil covers, and the soil texture is dominated by silty light clay and silty medium clay, with some proportion of marsh soil, which is notorious for high risk of erosion and phosphorus loss. The erosion risk map (Figure 2.3) of Ertevannet shows that it falls under medium erosion risk class, i.e., *classes 1 and 2* (vann.nett.n.d.).

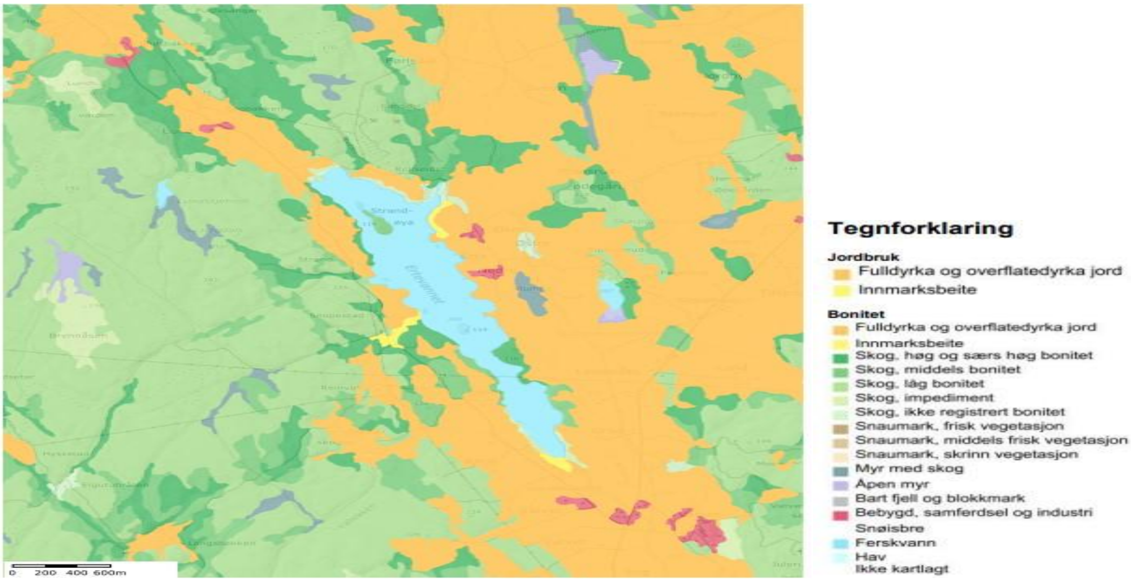


Figure 2.2. Land use map for the Ertevannet catchment area. The legends are in Norwegian. Most of the area is characterized by agricultural land. Source: (Kilden Nibio).

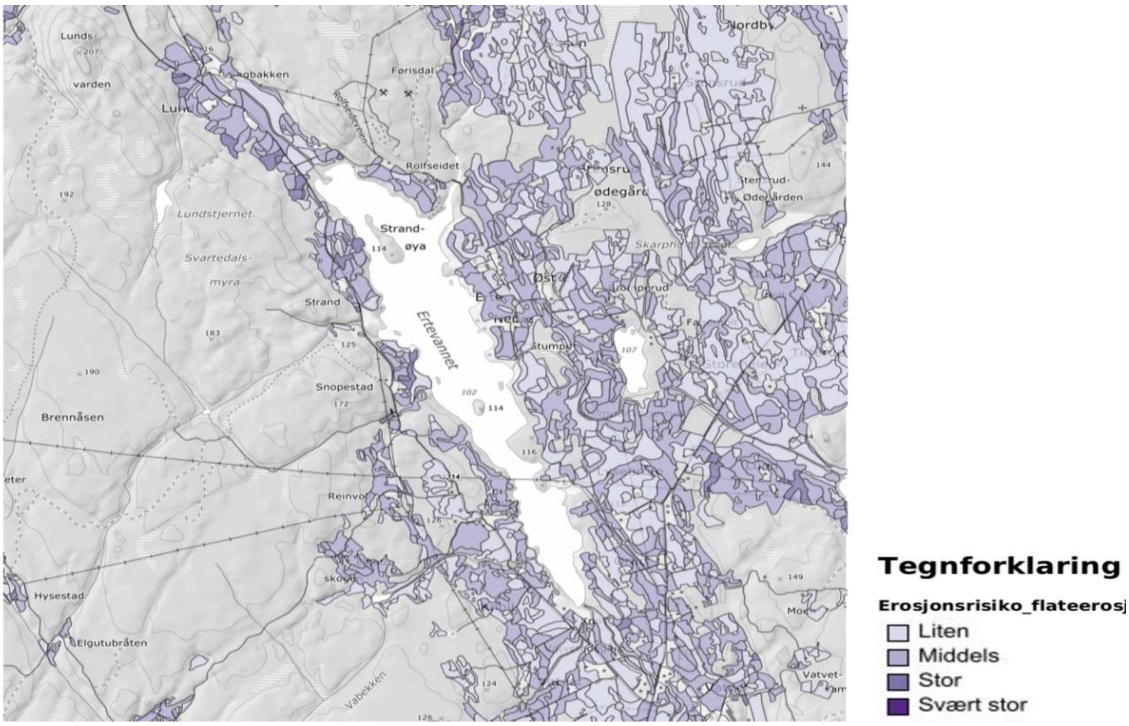


Figure 2.3: Erosion risk map of Ertevannet catchment area. The lake is at moderate erosion risk (Erosion classes 1 and 2). Source: (Kilden Nibio)

In recent decades, Ertevannet has been used as a hub for recreational activities such as, fishing, swimming. However, in recent years, it has been reported that the lake water is unfit for swimming because of the algal blooms during the summer season. A report *by Vann Milijø* states that primary production in the lake is dominated by pharyngeal flagellates, yellow algae, diatoms, and cyanobacteria since 2017. It has been reported that cyanobacteria blooms begin to proliferate in mid-summer. Norconsult (2018, 2024) and (Skarbøvik, 2022) state that transparency in Ertevannet is poor (average NEQR 0.300. According to the Water Frame Directive standards, the lake is classified as moderately calcareous (Ca≥4-20 mg/l), and humic (30-90 mg Pt/L, TOC 5-15 mg/L). Turbidity of the lake has been recorded as clear (STS ≤10 mg/L: Inorganic part at least 80%). The assessment of the lake water reveals a TP value at 40 ug/L/, which is sufficient to classify the lake as ecologically poor (vann.milijo.no n.d. Many factors are responsible for poor water quality, and among others, nitrogen and phosphorus load from the agricultural fields are considered to have an enormous influence. According to Vann.nett (n.d.), the three main anthropogenic stressors identified for the lake are diffuse dispersed settlement (small degree), diffuse farm animal production and manure (medium degree), and diffuse forestry and diffuse ploughed land (large degree). Moreover, the main source of phosphorus in the lake is from the runoff from the agricultural fields and scattered wastewater treatment plants.

3 MATERIALS AND METHODS

3.1 SEDIMENT RETRIEVAL AND SLICING

Field visit and sediment sampling were executed in the spring, on 03. May 2024, when the lake was free from ice. The weather conditions of the field excursion day were moderately cold, sunny, and calm with wind.

Figure 3.1 Preparation before sediment core sampling in Lake Ertevannet. The photo was taken on 03.05.25 by Devendra Kunwar

Figure 2 .2 Picture showing sediment core retrieved from the deep region of Lake Ertevannet. The photo was taken on 03.05.25 by Devendra Kunwar

A boat was used to reach presumably the midpoint of the lake, and the deepest point was identified by using a depth gauge. The lake's deepest point was chosen to extract the sample as it represents the sediment accumulation for the whole lake system, which is supposed to be free from mixing and bioturbation. When the boat was almost in the center of the lake and in complete balance, a gravity core sampler (UWITEC sediment corer) attached to a rope was carefully lowered down from the rib of the boat into the water column. The sample corer was then carefully dropped lower to penetrate the lake bottom. After the gravity corer had sunk into the lake bottom, it was carefully pulled up gradually. When the core reached the water surface, it was plugged at the bottom to keep the sediment material within the sediment tube and raised vertically in a stand to avoid intermixing of the sediment.

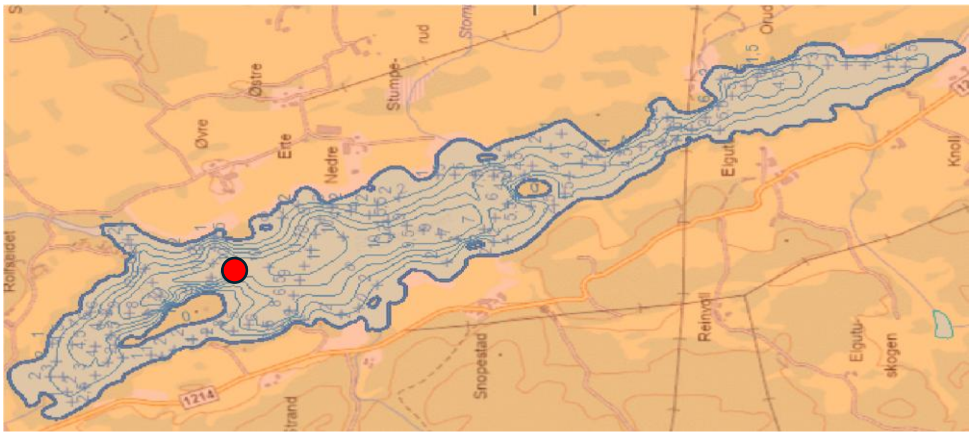


Figure 3.3: Bathymetric map of Lake Ertevannet, with red dot indicating the location of the sediment core sampled (Source: ngu. no)

When the sediment sample was brought ashore, the sediment core was measured, sectioned/split into 1-cm intervals, subsamples, and labelled. The uppermost wet layer of the sediment was rejected as a sub-sample because of its high-water content and low compaction. The slicer was carefully rinsed with clean water after slicing each layer. The individual subsamples were labelled and packed in their zip lock bags. The samples were immediately transported to the NMBU, MINA Soil and Water Laboratory, and stored in a freezer at around -20 degrees for a couple of days before the lab work started.

3.2 LAB WORK AND LAB ANALYSIS:

3.2.1 Dating and core chronology

The homogenized dry sediment samples were sent for radiometric dating in the Environmental Change Research Centre, University College London. The dating report (Appendix 3) shows the rationale and results of the sample analyzed for ^{210}Pb, ^{226}Ra, ^{241}Am, and ^{137}Cs by direct gamma assay using ORTEC HPGe GWL series well-type coaxial low background intrinsic Germanium detector (Appleby et al, 1987). The report from the lab. states that the absolute efficiencies of the detector were determined using a known calibrated source and sediment samples of known activity. The corrections were made for the effect of self-absorption of low-energy gamma rays within the sample (Appleby et al, 1992).

According to the report (Appendix 3), the ages of the sediments were inferred mainly based on the CRS, assuming a constant rate of supply of fallout ^{210} Pb (Appleby and Oldfield, 1978). The age depth model was tested and adjusted if necessary for absolute efficiency, where well-defined peaks in the ^{137} Cs activity were linked to nuclear weapons tests in 1963 and the Chernobyl accident in 1986(Appleby, 2001).

Use of CIC (Constant Initial Concentration) model was precluded by the non-monotonic features in the unsupported ^{210}Pb profile. ^{210}Pb chronologies and sediment accumulation rate were calculated by using the CRS (Constant rate of Supply) dating model (Appleby, 2001).

3.2.2 Dry weight and LOSS ON IGNITION: LOI (%)

Analysing dry weight is the first and crucial step in sediment analysis, as moisture content can vary significantly and alter measurements and calculations (Cohen, 2003). The subsamples stored in the freezer at -18 ^{0}C were then prepared for freeze-drying to remove excess moisture. The samples were then weighed to find the dry weight in grams. The ratio of dry weight and the volume of the soil sample provides information about bulk density.

The sequential LOI technique has been widely utilized to determine the soil organic matter content of sediment (Heiri et al., 2001). The method is based on sequential combustion of samples in a muffle furnace for a specific time and temperature, and the organic content is measured as the final weight of the sample after combustion. The ceramic bowls were weighed, tagged, and approximately 2-3 grams of soil sample from each sub-sample of the sediment sample was added. The ceramic bowl with soil was weighed again. All the ceramic bowls with soil sample were placed in a furnace and incinerated for 4 hours at 550 ° Celsius. The samples were left overnight to cool down and weighed again the next day, where the difference in weight measurement before and after incineration represents the proportion of organic matter that has been lost.

The LOI (%) was calculated by using the following equation:

$$LOI\ 550 = \frac{(DW_1 - DW_2) \times 100}{DW_1}$$

Where $Dw_{1(g)}$ represents dry weight of the sample before combustion and $DW_{2(g)}$ represents the weight of the sample after combustion.

3.2.3 Total phosphorus (TP)

Total phosphorus (TP) was determined according to the procedure specified by Ivan Digernes IPM, 2004. TP was measured under the Norwegian Standard NS-EN 1189. 2 ml of potassium peroxydisulfate was added as an oxidizing agent, converting the phosphorus to orthophosphate. The sample was autoclaved at 1 Atm. pressure and 121 degrees Celsius for 30 minutes. After cooling down, the samples of orthophosphate were treated with 20 microliters of antimony-molybdate, causing the formation of an antimony phosphomolybdate complex. Further, 20 microliters of ascorbic acid were added, which reduced the complex and gave it a blue colour. It was then measured in the absorbance at 880 nm, which gave the concentrations of the orthophosphate (UV-VIS Spectrophotometer UV1201. TP analysis was carried out by department experts in the IMV laboratory, Norwegian University of Life Sciences.

3.2.4 Extraction and analysis of pigments

High-Performance Liquid Chromatography (HPLC) is a widespread tool for investigating and identifying the taxonomic composition of phytoplankton (Jeffrey et al., 1999). As all chlorophylls and carotenoids have a characteristic absorption spectrum (Figure 2.5) in the wave range of 330 nm- 750 nm (Küpper et al., 2007). This method separates an array of algal and carotenoid pigments, which are indicators of biological activity and lake productivity (Smol, 2010).

Ethanol was used for the extraction of pigments. 0.2 g of the sediment sample was weighed and mixed with 15 mL of ethanol. The sample was then stored in the fridge at 4 °C overnight for almost 20 hours. The extracted sample was then shaken to ensure thorough mix/up and centrifuged in a VWR Mega Star 1.6 for 15 minutes, at 1900 revolutions per minute, which allows the particles to separate from the analytical solution. After calibration, 2 mL of each sample was extracted and kept in a cuvette in the UH5300 Hitachi Spectrophotometer.

The eluted pigments were detected by a photodiode detector at an absorbance range of 380 nm- 800 nm, and respective peaks were identified and quantified based on their absorption and retention time spectra compared to authentic standards from DHI Water and Environment, Denmark (Reuss, 2005). The pigment concentrations are presented as g/g dry weight. As photopigments are particularly sensitive to light, oxygen, and heat, the laboratory processing was performed under subdued and cool conditions to prevent any degradation and contamination.

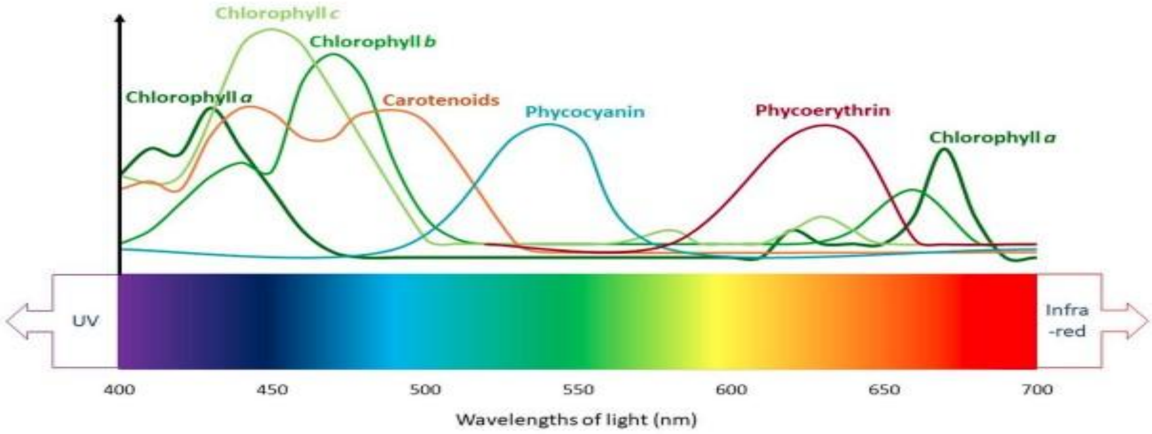


Figure 3.4: Absorption range of different algal pigments and carotenoids. Picture adapted and modified from Hagman (2020).

3.3. DATA COLLECTION

Contemporary and historical data of the study area and its catchment were obtained from relevant literature and through contact and correspondence with related persons. In this study area, regional factors such as climate variability and land use change are broad controls, while urbanization, agriculture intensification, fertilizer use, and sewage treatment are local controls. The following data were retrieved and examined using the respective sources:

- The historical development of land use changes and agriculture evolution is retrieved from various digital sources such as Statistisk Sentralbyrå (ssb.no), *Kilden Nibio, ngu.no*, and norgeibilder.no
- Ecological status monitoring reports of the lake are accessed from the database at the Norwegian Environmental Agency (Vann-nett), and NIVA.
- Regional climatic data from weather station BIOKLIM, Ås, were used for the study area, as continuous long-term climatic data were lacking in a nearby weather station.
- Norsk Institutt for Bioøkonomi (Nibio)

The process of data collection and categorization proved to be both demanding and challenging due to the substantial volume and diversity of sources involved. Nevertheless, the necessary data was meticulously retrieved, ensuring that no significant sources were overlooked. Although not all anticipated data were collected, it was ensured that the dataset obtained is adequate to support the objectives of the thesis.

3.4 DATA UNCERTAINTIES

Despite several preventive measures, uncertainty in sediment analysis is inevitable, both during the extraction and processing of the sediment sample, which can affect the result. There are several potential sources of error while processing and analysing the sediment sample. Contamination of the sub-sample while slicing and weighing can still occur due to human error. Pigments are sensitive to light and oxygen; exposure to them during sampling and processing can lead to degradation. Therefore, each step from sampling and slicing in the field to laboratory analysis was carefully carried out.

4 RESULTS

4.1 LONG-TERM REGIONAL AND LOCAL DRIVERS OF PHYTOPLANKTON DYNAMICS

REGIONAL DRIVERS

Long-term weather data for Lake Ertevannet were obtained from the weather station BIOKLIM at Ås Municipality, Akershus. The direct line distance between BIOKLIM, Ås, and Lake Ertevannet is approximately 45 km. Even though several meteorological stations (Rygge, Rakkestad, and Askim) are in the proximity of the study area, they do not provide a long-term and uninterrupted historical record on climatic variables. Consequently, a slightly distant BIOKLIM Ås station is preferred, as it enables an uninterrupted time series for temperature and precipitation. Despite spatial discrepancies, it is assumed that the general trendlines for climatic data in south-eastern Norway exhibit coherence and serve as a reliable representative of the whole eco-region. In this study, exclusively climatic data from 1930 -2024 were analysed, as this period represents the age of the sediment retrieved from the study area.

TEMPERATURE

The long-term annual mean temperature records display distinct notable warming trends and several periods of large fluctuations (Figure 4.1). After fluctuating throughout the 1930s, it reached a record low in 1941 with a value of 3.75 °C. The period between 1950 and 1970 demonstrated a relatively cool period with an annual mean temperature of around 4.5 ° C. Temperature continues to greatly fluctuate throughout the 1980s albeit reaching a definite low in 1985 with a value 3.43 ° C. Post 1990, a sustained increase in temperature was observed that continues into the 21st century and aligns with broader regional and global shift in warmer climate.

The growth season (April-September) mean temperature calculated for the period 1930-2024 follows the same trajectory as the annual mean temperature (Figure 4.1). Early fluctuations were seen from 1930 to 1950, reaching a peak in 1947 and continuing to fluctuate further in the late 1970s. A pronounced and sustained warming trend was observed post-1990, with peaks consistently reaching above 12 °C in recent decades.

PRECIPITATION

The annual total precipitation exhibits significant fluctuations between 600 mm and 1100 mm during the calculated period from 1930-2024 (Figure 4. 2). While a notable dip was observed in 1946 and a period of variability until 1980, it displays increasing trends after 1980, with peaks in late 1990 and early 2000.

Growth season total precipitation(mm) fluctuates between 400 mm and 600 mm and exhibits less variability. Just like total annual precipitation, a similar dip was observed in 1946, which is again followed by a slight variability until the 1990s, after which it gradually increases until the recent year, except for a notable dip in 2010, when total annual mean precipitation declined to around 800 mm. (Figure 4.2).

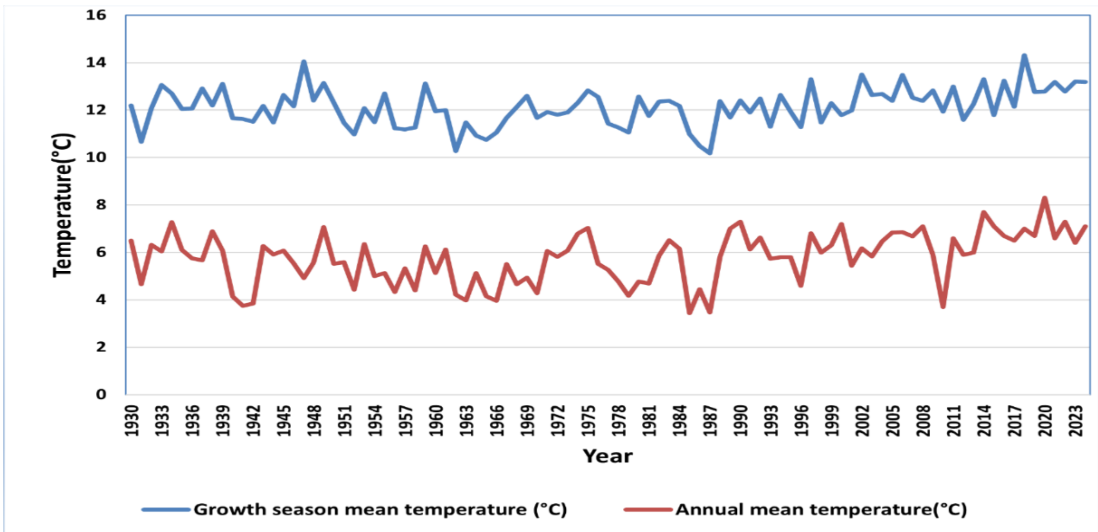


Figure 4.1: Annual mean temperature(°C) and annual growth season (April- September) mean temperature from 1930 to 2024. The figure is produced based on data provided by the weather

station BIOKLIM at Ås in Akershus. Values for annual mean temperature and growth season temperature are given in Appendix 1.

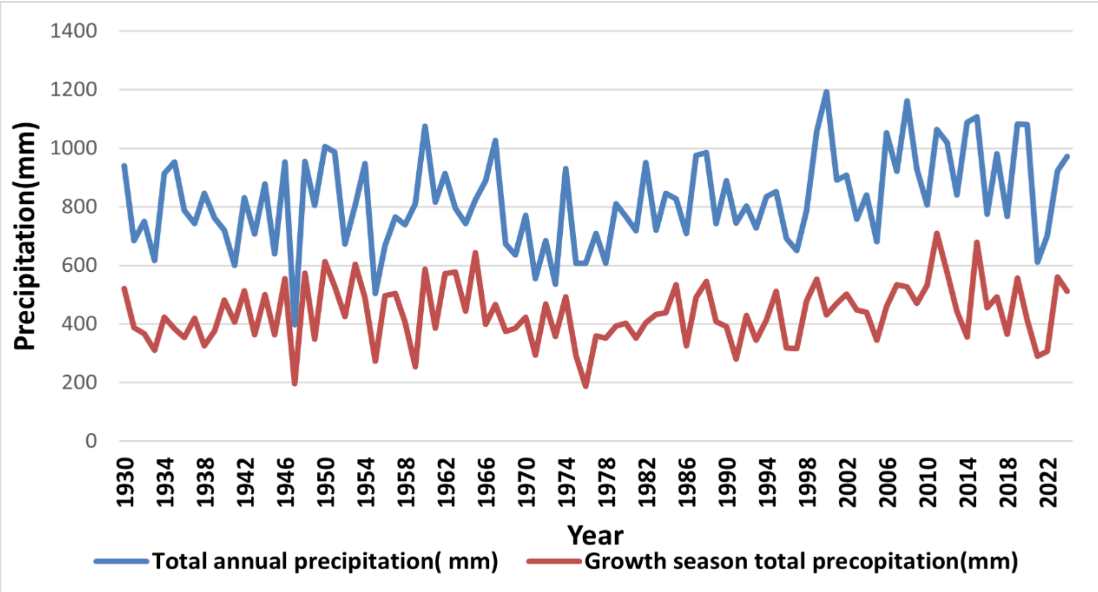


Figure 4.2: Total annual precipitation(mm) and growth season precipitation(mm) (April-September) from 1930-2024. The figure is produced based on data provided by the weather station BIOKLIM at Ås in Akershus. Values for total annual mean temperature and growth season temperature are given in Appendix 1.

4.2 LOCAL DRIVERS

1. TEMPORAL CHANGES IN LAKE WATER CHEMISTRY AND AQUATIC VEGETATION

As of January 2016, the Glomma-Sør water area consists of 134 water bodies, of which 90 are rivers or streams, 18 lakes, 21 coastal bodies, and 5 ground waters. Ertevannet is a part of a larger network of the Glomma-Sør watercourse in Rakkestad municipality, which boasts altogether 32 various water bodies. These water bodies collectively govern the hydrology and nutrient flux in the region; therefore, their long-term monitoring and assessment are essential to understand the health of the aquatic ecosystem and the long-term trends.

Water bodies in Glomma-Sør have been a subject of various ecological assessments over the years, however, environmental monitoring of Lake Ertevannet started only after 1990. So, long-term environmental monitoring records are lacking. Systematic water quality monitoring data for

Ertevannet has been entered into the vannmiljø since 1992 under location code 002-38240. Significant studies carried out by various limnological research institutions such as Nibio, Norconsult, and NIVA, over the years, will be used in interpreting the results in the discussion to see the changes and potentially their relevance to current environmental management under the WFD.

Water quality monitoring records by NIBIO from 2013 to 2021(NIBIO, 2022) reveal relative stability in most of the water parameters. Chl-a value remained stable at an average of 21ug/l, which is double the environmental target of 10.5ug/l. Similarly, total phosphorus (tot-P) averaged 38 µg/L, which is also almost double the environmental target of 20 µg/l. Norconsult (2018) states that the ecological condition of Ertevannet has been moderate, and the tot-P value shows a downward trend.

However, long-term water quality assessment records in vannmiljø (2023) reveal a different fluctuating trend at different depths, where chl-a value was 90 ug/l in 1999 to an all-time high of 150ug/l in 2015. Similarly, the TP value exhibits a fluctuating trajectory where the TP was high in 1992, and a rather stable increasing trend after 2012.

Ertevannet is a shallow, small/medium-sized calcareous lake, where long shoot plant species were not recorded (Ruben Alexander Pettersen, 2019). During the growth season, several floating mats of creeping bent grass (*Agrostis stolonifera*) were observed in various places of the lake. The occurrence of lush stands of helophyte vegetation is dominated by reed (*Phragmites australis*), sea sedge (*Schoenoplectus lacustris*). In addition to these macrophytes, species *of Equisetum fluviatile, Carex virosa*, *Cicuta virosa*, and *Typha latifolia* were also recorded. The areas outside the helophytic belt were dominated by floating leafy vegetation of various species of water lilies (Skarbøvik, 2022).

Phytoplankton records, as suggested by Niva (2012), reveal an algal community dominated by both pharyngeal flagellates and golden flagellates, and additionally a significant content of needle flagellates *(Gonyostomum semen*) and diatoms. The pharyngeal flagellates and golden flagellates are dominated by the genus *Cryptomonas and Synura,* respectively. The report further uncovers the fact that *Gonyostomum* biomass increases in August and reaches a maximum in September.

Furthermore, it is imperative to take note that approximately 3 km downstream of Ertevannet, there is a dam connected to the old mill in Skiselva (Figure Appendix 2A), which has had the same water level for many years. Although the water level in the dam has not been lowered, there is uncertainty if an accidental lowering of the dam might lead to higher concentrations of nitrogen and phosphorus in lake water.

2. Settlement in the drainage basin and population trends

Settlements within the drainage basin are predominantly agrarian, with dwellings typically concentrated around the farm holdings. According to Maria Ystrom Bislingen (Project leader, Glomma Sør, water region), there are approximately 100 households in the lake periphery (Personal communication by email, 04.04.2025).

Demographic evolution in Rakkestad kommune exhibits a long continuum of human settlement. It has been reported that the population growth in Rakkestad escalated after the establishment of Rakkestad station in 1882, and the demographic trajectory exhibits minor changes from 1930 to 2024, except for a slight rise around 1950 (Figure 4.3). At present, Rakkestad is home to approximately 8527 individuals, and at this growth rate, the number is expected to increase to 8656 in 2030 and 9392 in 2050, respectively (Statistics Central Bureau 2017a).

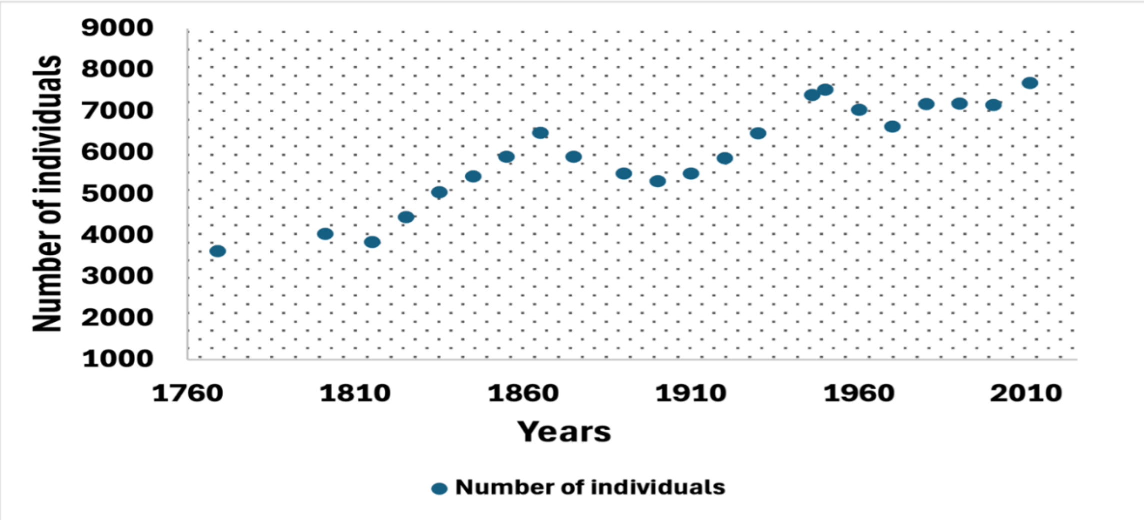


Figure 4.3: Population growth in Rakkestad Kommune in the period from 1769-2011. The graph is based on data taken from Statistics Norway's website (Statistics Central Bureau 2017a)

3. AGRICULTURE AND OTHER LAND TRANSFORMATIONS

As the municipality of Rakkestad in Eastern Norway is known for grain production, the drainage basin of Lake Ertevannet has likewise been heavily dominated by agricultural activities for ages (Pothoff & Dramstad, 2022). The most recent data shows that approximately 25 farmland units are currently operating in the lake periphery and its tributary streams (Maria Ystrom Bislingen, personal communication by email, 04.04.2025).

Rakkestad is principally an agrarian area where almost 80% of the land area is used for grain and oil crops (Store Norske Leksikon, n.d.). Among the cereal-producing areas, 41% is used for wheat cultivation, and approximately 51% is used for barley and oats (Figure 4.4) In line with broader continental (Potthoff, 2022) and National trends, similar regional and local patterns of distinct land-use transformation have been observed with the onset of 1950, with the introduction of new agricultural practices and land consolidation (Forbord et al., 2014). This agronomic approach adopted widespread use of fertilizers after the culmination of the Second World War, which effectively reduced the dependency on off-field sources by increasing in-field yields (Pothoff and Dramstad, 2022;(Ulén et al., 2007).

The archival records suggest that, until 1950, the Rakkestad landscape was characterized by small-scale farming, but with a high level of landscape heterogeneity (Lundekvam, 2003). While the total agricultural land area remained relatively stable since 1969, agricultural production (Grain and oilseeds) significantly increased after 1979 (Figure 4.15), which can be attributed to an interplay of factors, including liberalization of farming policies, advancements in technology, and intensification of land use (Lundekvam et al., 2003). Interestingly, the rented agricultural land increased progressively between 1969 and 2019, while total land holdings decreased significantly from 639 in 1969 to 272 in 2019 (Appendix 2G). Furthermore, in the post-1969 period, the green fodder and silage area also declined remarkably and consistently (Appendix 2F).

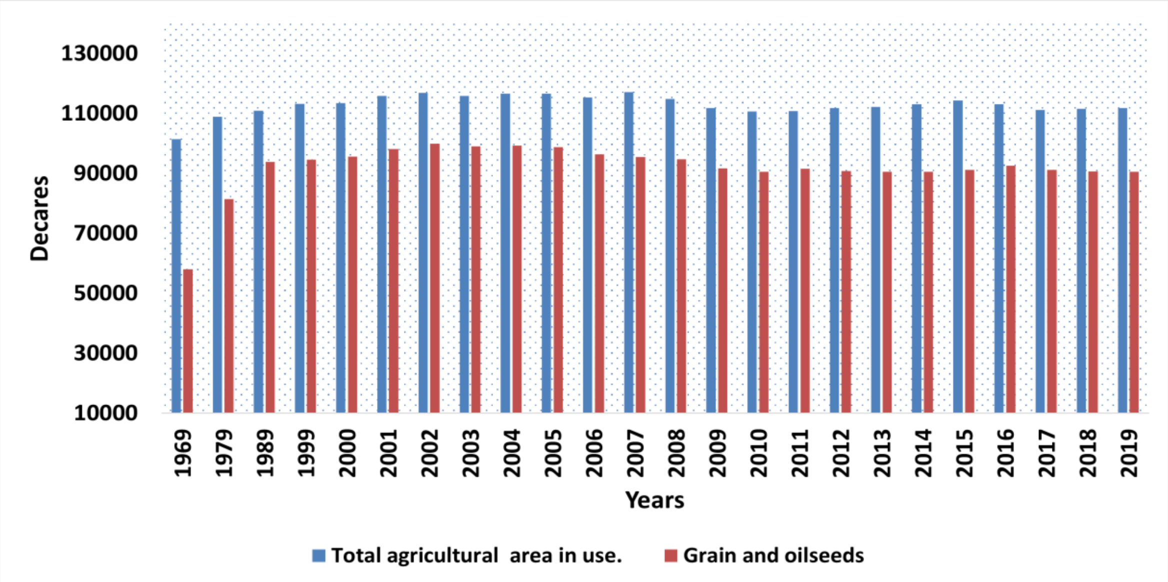


Figure 4.4: Total agriculture area in use and areas for grain and oilseeds in Rakkestad Kommune during the period of 1969-2019. The graph is based on data taken from Statistics Norway's website (SSB, 2021d). (da=1000m2).

Although agriculture was specialized as early as 1953 in Rakkestad, most of the changes took place over the next decades until 1992, as local agriculture became mechanized with further upscaling in production. A steady trend in agricultural expansion coincided with the removal of traditional field boundaries and the disappearance of a vast network of grassy banks (Figure 4.5). Another vital land use change observed was diminishing meadows for mowing and pastures after 1969 (Appendix 2H).

Figure 4.5: Farming landscape in Rakkestad in 1953 and 1992. White and black arrows show the disappearance of grasslands and grassy banks, respectively. The picture is adopted and modified from NIBIO, 2018 (Lokal tiltaksplan for Rakkestadelva).

Small water bodies are prone to disturbances, particularly in the form of infrastructure development, intensification of farming, drainage, and filling in, all of which can potentially lead to their ecological isolation. Hydrological and landscape transformation was evident as early as 1790 in the drainage basin of the lake; however, it was accelerated after 1960, when the government grants were introduced ((Forbord et al., 2014). The archival records since late 1700 show that lakes were either extensively ditched or reclaimed, and streams were culverted to consolidate agricultural expansion (Figure 4.6). In Østfold alone, more than 1500 kilometers of streams and ditches have been blocked since 1960 (Kålås, 2010). Land levelling and sub-surface draining (tile-drainage) of mires and peats were rampant from 1950 until the early 1960s, to improve and expand farming conditions as a part of a broader push for agricultural intensification (Pers. Com., Thomas Rohrlack, March 2025). Moreover, this period also coincides with both regional and national challenges with sewage treatment and the transition from horses to tractors (Forbord, 2014).

Likewise, Kløve (1999) opines that both the flood-sensitive catchments of Glomma mires and the vast expanse of peatlands in Østfold have been drained for forestry, which was particularly rampant in the decades of the 1950s and 1960s.

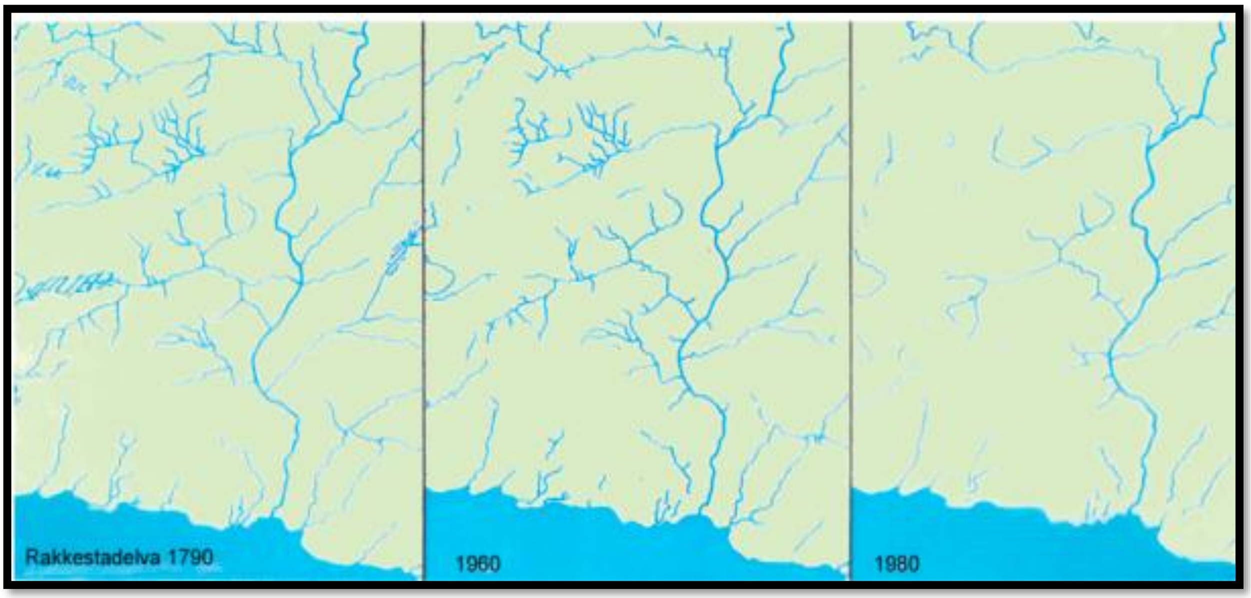


Figure 4.6: Overview of the disappearance of the canals and open streams in Rakkestadelva: Drainage basin of lake Ertevannet from 1790-1980. The picture is adopted and modified from Environmental Conditions and Impacts for Red List Species by Kålås et al (2010), PP 98.

4.3 SEDIMENT CORE ANALYSIS

1 DESCRIPTION OF THE SEDIMENT CORE

The 45 cm long sediment core from Lake Ertevannet appeared relatively homogenous with faint laminations. The surface layer was characterised by moist, dark brown, and fine-textured clay sediment, suggesting recent sediment accumulation that is rich in organic matter.

2 CORE CHRONOLOGY AND SEDIMENT ACCUMULATION

Figures 4.7 and 4.8 display the lake chronology and sediment accumulation profile of Lake Ertevannet. The ^{210}Pb-dated sediment core represents 90 years of sediment accumulation (Figure 4.8). The deepest part of the sediment core (45cm) was dated as 1934, while the uppermost section (1cm) represents 2024. Appendix 3 contains all the details of core chronology, a report from The Environmental Change Research Centre at University College London.

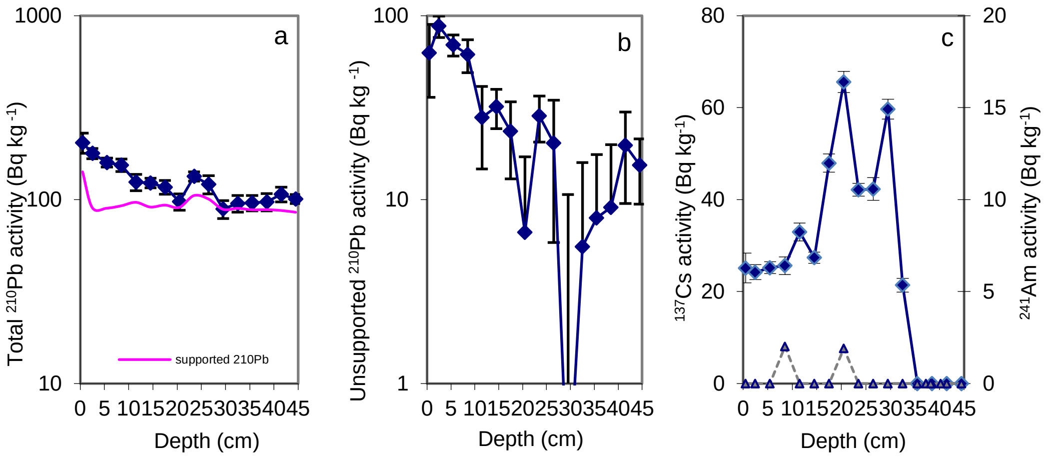


Figure 4.7. Fallout radionuclide concentrations in core ETNV taken from Ertevannet, showing (a) total ^{210}Pb, (b) unsupported ^{210}Pb, and (c) ^{137}Cs and ^{241}Am concentrations versus depth.

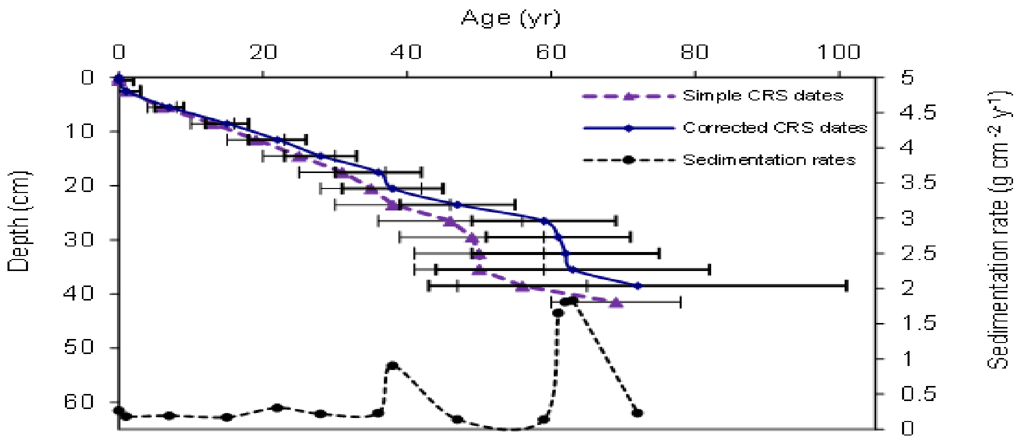


Figure 4. 8 Radiometric chronology of sediment core taken from lake Ertevannet showing the CRS model ^{210}Pb dates and sediment accumulation rates.

The ^{210}Pb activity profile shows a decreasing trend (Appendix 3) and does not reach equilibrium depth with the relevant supported 210 Pb activity. The total 210 Pb activity is higher in the shallow depth (0-10 cm), while the supported ^{210}Pb activity remains relatively constant throughout the profile. Unsupported ^{210}Pb generally decreases exponentially with depth in the top 17.5 meters with minor fluctuations, suggesting small changes in the sedimentation rates. The sedimentation rate of the lake remains low, displaying minor oscillations from 1934 to 1960, which is followed by a dramatic increase in 1961 by 2.707cm yr$^{-1.}$ The period 1961 to 1963 represents a high sedimentation rate (Appendix 3). Sedimentation rate remained consistently low after 1963, with the exception in 1986 and 2024, when a notable increase was observed (Appendix 3).

Furthermore, the age validation by ^{137}Cs depth showed two significant peaks at 20.5 and 29.5, which correspond to Chernobyl fallout in 1986 and the atmospheric testing of nuclear weapons in 1963 (Appendix 3). The corrected CRS model for 210 Pb dating closely aligns with the Simple CRS model except for some divergence at greater depth (Appendix 4). Moreover, there is greater uncertainty with increasing depth, which is a general characteristic of radiometric dating.

3 SEDIMENT DRY WEIGHT AND ORGANIC MATTER (LOI)

The LOI values, which reflect the organic content in the lake sediment, remain low (7%-17%) and relatively stable until 1960, but increase slightly and steadily, reaching a peak in the uppermost layer dated at 2024 (Figure 4.7). In contrast, dry weight, which reflects mineral-rich, compact sediment, declines consistently until the present day after peaking dramatically in 1960(Figure 4.2). Dry weight value exponentially decreased from 16.57 g in 1934 to 0.33 g in 2024. In addition to this, dry weight and LOI values of Lake Ertevannet exhibit a clear inverse relationship throughout the sediment core (Figure 4.8).

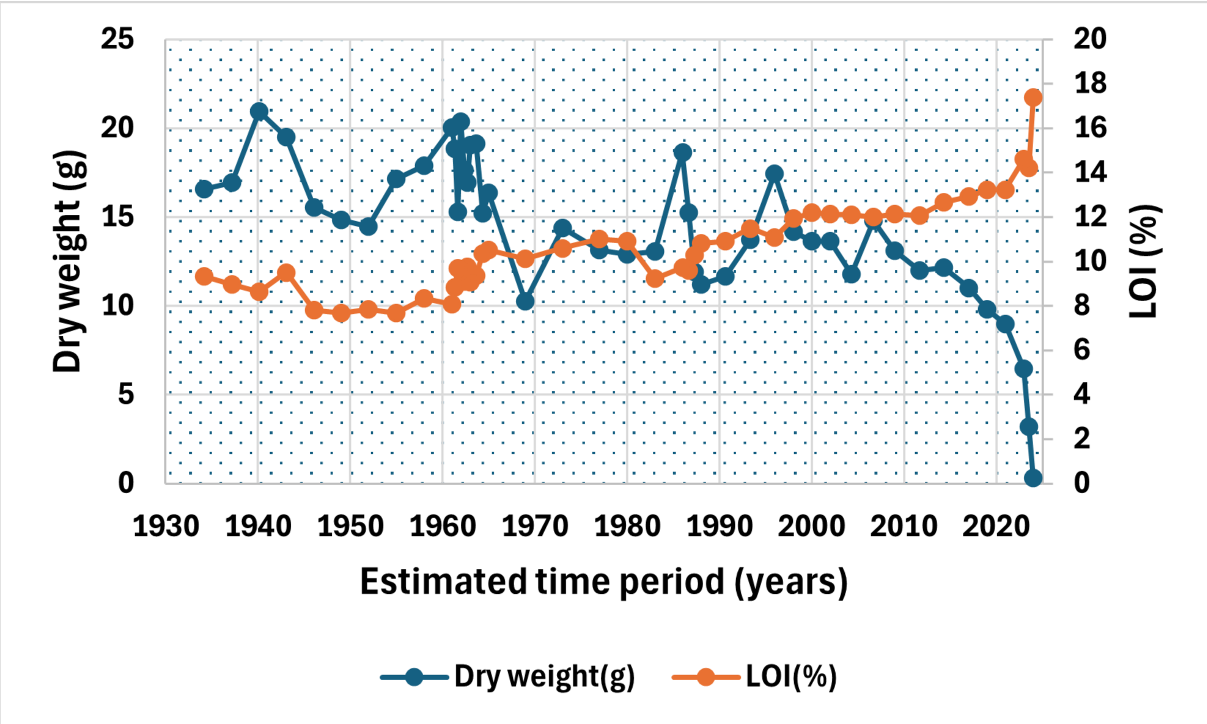


Figure 4.9. Dry weight (g) vs LOI (%) for Lake Ertevannet from 1934 to 2024.

4 TOTAL PHOSPHORUS (TP)

The phosphorus concentration in the lake sediment reveals key historical trajectories (Figure 4.10). The pre-1950 period exhibits a relatively low and stable phosphorus concentration, which fluctuates around 0.5 mg P/g to 0.6 mg P/ g.

The phosphorus concentration started to increase after 1950, but a rapid increment was observed from 1960 (Figure 4.10). Phosphorus concentration consistently increased after 1960, reaching a highest value of 0.9 mg P/g dry weight in 1969 (Figure 4. 10). After peaking in 1970, the P level declined slightly and remained consistently stable until the present date, with the P concentrations around 0.8mg P/ g throughout this period (Figure 4.10).

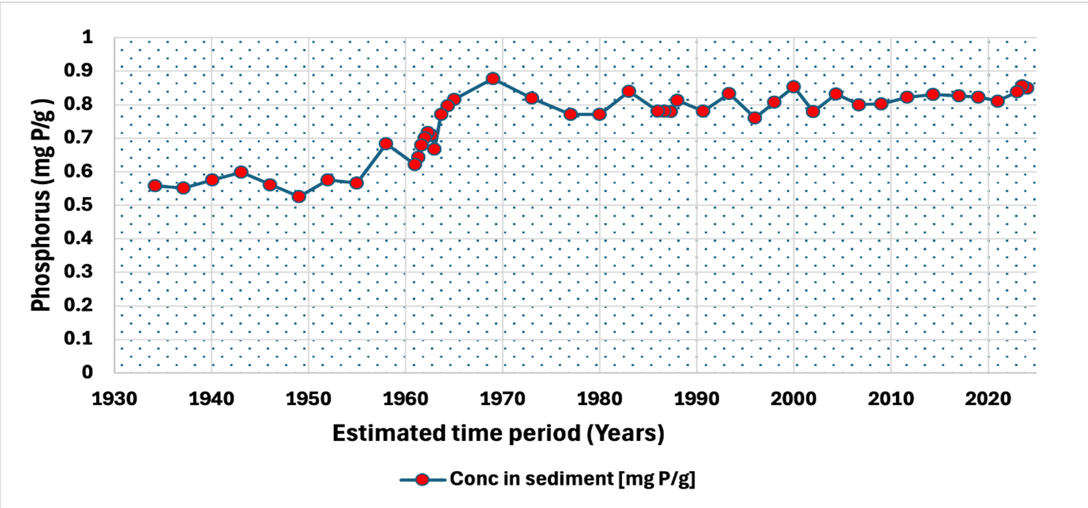


Figure 4.10: Stratigraphic profile of Phosphorus for Lake Ertevannet from 1934-2024.

5 PIGMENT ANALYSIS

The lake sediment samples contained a variety of sedimentary pigments (Figures 4.11-4.14), which confirmed the presence of nine algal pigments, primarily Chl-a and its derivatives (Chlorophyll and its breakdown, Pheophytin-a and its degradation products), and carotenoids. The recorded carotenoids include fucoxanthin (from diatoms and chrysophytes), lutein (Chlorophytes), alloxanthin (from cryptophytes), and canthaxanthin (from cyanobacteria). The pigments were quantified as µg/g dry weight.

Generally, the pigments are well documented throughout the sediment core, and at the same time, they exhibit distinct trajectories with depth and corresponding period (Figures 4.11 4.14).

CHLOROPHYLL-A AND ITS DERIVATIVES IN SEDIMENT CORE

Chlorophyll-a and its diagenetic products exhibit relatively lower values in pre 1950 period, which is followed by a dramatic surge from the early 1960s. From the result, it is apparent that there were some unusual or specific events around the early 1960s to 1980s and in recent years (Figure 4.12). The sediment record reveals a high total chl-a value in the uppermost layers, which corresponds to recent years after 2010 (Figure 4.12. At depths between 31cm-24cm, which corresponds to the period 1963-1980, total chl-a value remained consistently high (23.56 µg/ g -39.44 µg/g/ g). Total chl-a value decreases dramatically after 1980 and fluctuates in lower concentrations until 2010, from then on, a rapid escalation is observed, forming an all-time high value in 2022 (Figure 4.12). Similarly, chl-a value remains consistently low until 2010, after which it increases dramatically until recent years (Figure 4.11).

The chlorophyll degradation products reflect post-depositional changes in the organic content of the sediment. In the uppermost layers, which correspond to recent years, the value of degradation products is relatively high, however, the value gradually lowers consistently with depth, except for fluctuations in 1960 and the late 1980s.

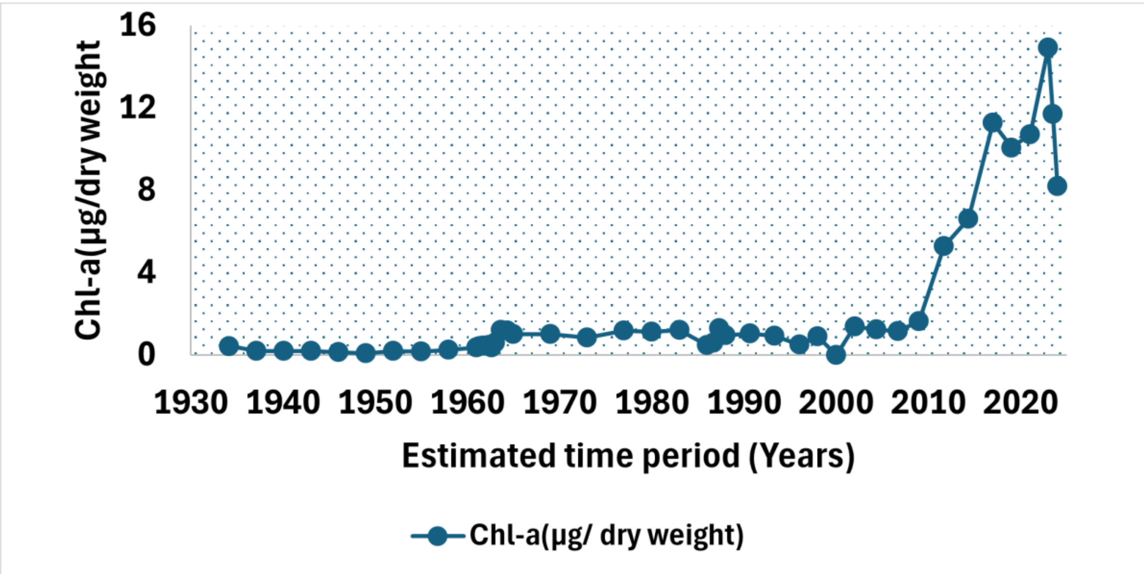


Figure 4. 11. Stratigraphic profile of Chl-a µg/ g dry weight for Lake Ertevannet from 1934 to 2024.

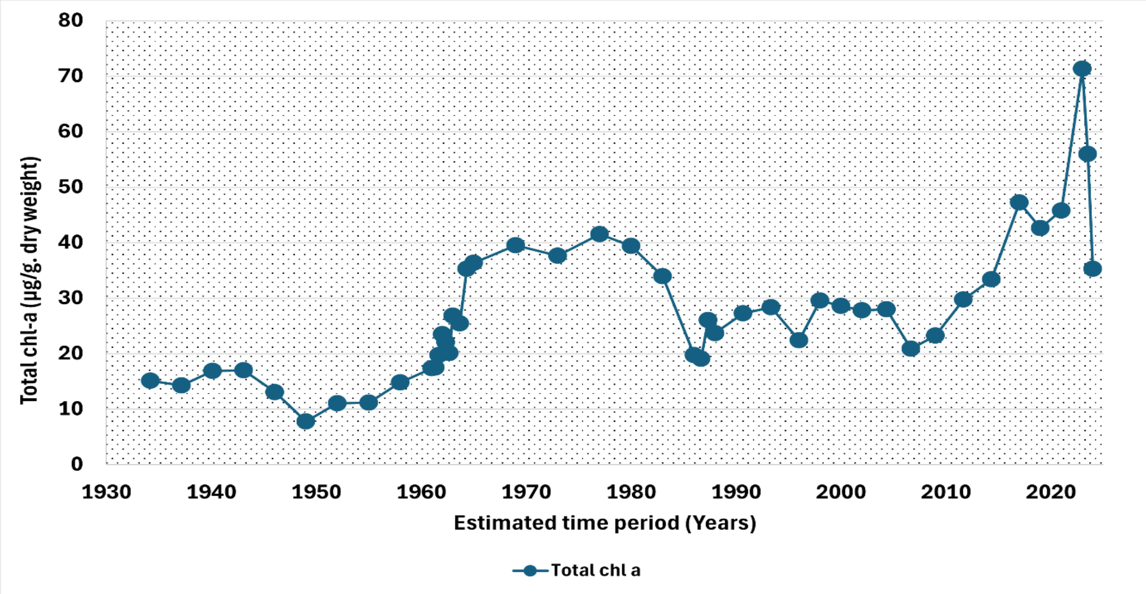


Figure 4.12 Stratigraphic profile of Total Chl-a (µg/ g dry weight) for Lake Ertevannet from 1934 to 2024.

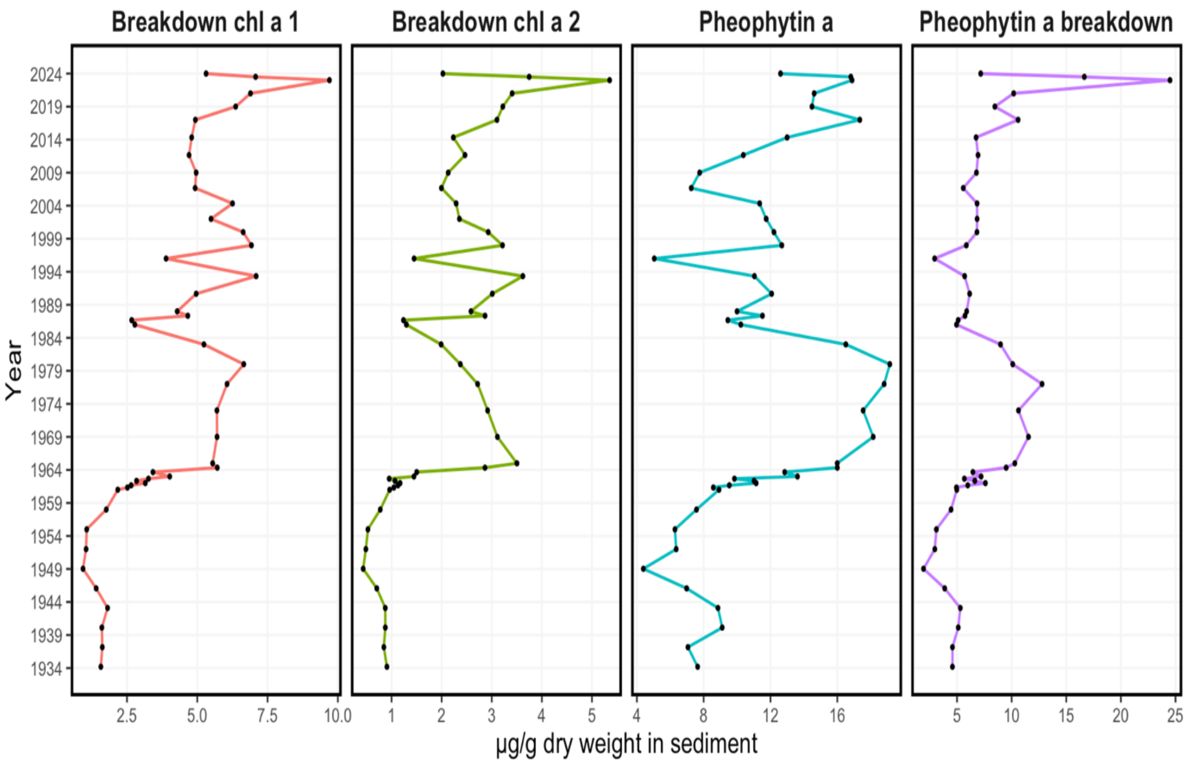


Figure 4.13 Stratigraphic profile of Chl-a degradation products, including breakdown chl-a1, chl-a2, pheophytin, and pheophytin breakdown µg/ g dry weight for Lake Ertevannet from 1934-2024.

CAROTENOIDS IN THE SEDIMENT CORE

The taxon-specific carotenoids measured in MAU * min and µg/g dry weight display almost identical trajectories at similar depth, with relatively low values until 1950 with minor variations (Figure 4.14). The pigment value rises dramatically from 1960 to 1980 in both datasets, followed by a moderately stable phase until early 2000, and again culminates with an ascending value in recent decades (Figure 4.14).

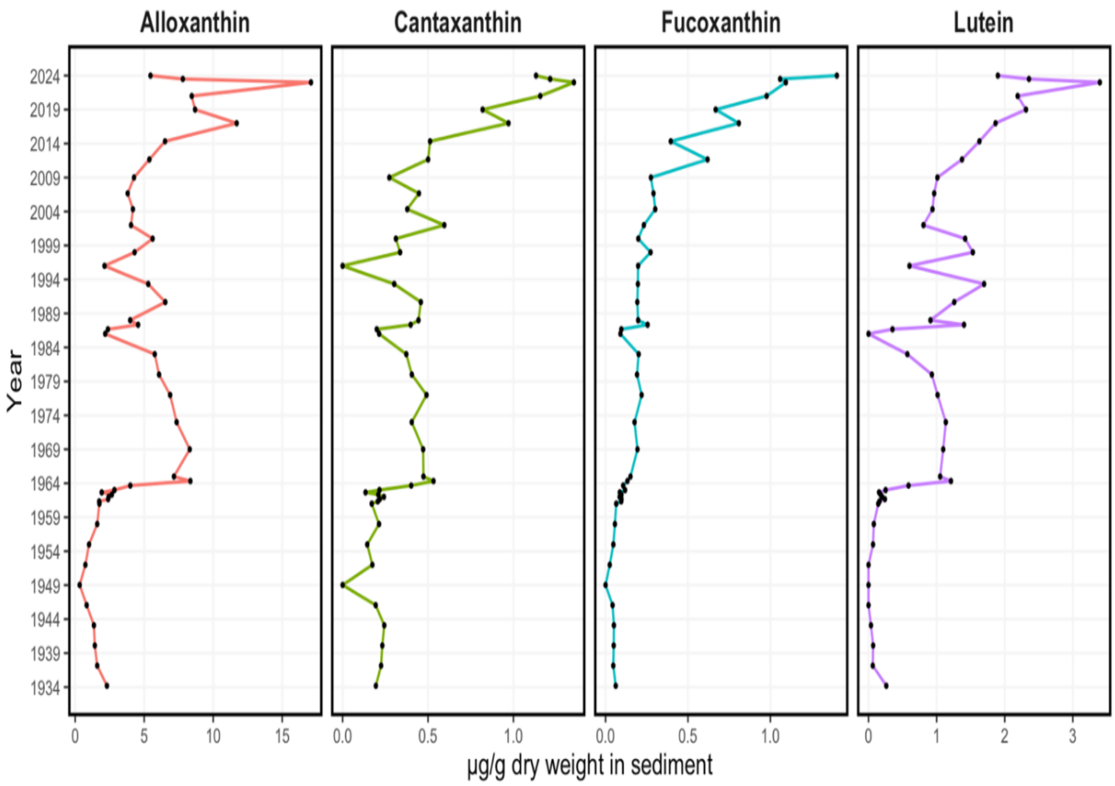


Figure 4.14 Stratigraphic profiles of carotenoids (Alloxanthin, Cantaxanthin, Fucoxanthin, and Lutein) (µg/ g dry weight) for Lake Ertevannet from 1934-2024.

The concentration of Fucoxanthin was 1.403 µg/ g in the surface sediment layer and decreased gradually with depth (Figure 4.14). Pigment value was lowest (0.026µg/ g) in 1952, at 40 cm, however, it was absent in 1949 at 40 cm. The concentration of lutein shows a strong presence in the upper layers, with the highest value of 3.4 µg/g dry weight in 2023, thereafter consistently declines with depth until 1961, followed by a relatively low value (Figure 4.14). Alloxanthin, associated with Cryptophytes, follows a similar trend, with higher concentration in the upper layers (2011-2024) and a gradual reduction after 1960 to a minimum concentration in the deeper layers (Figure 4.14). Alloxanthin concentration is highest in 2023 (17.082 μg/g dry weight and lowest in 1949 (0.325 μg/g dry weight, Appendix 5B). Canthaxanthin, a marker for cyanobacteria, was also in lower concentration before 1960, but rose dramatically from the early 1960s up to the late 1980s. After displaying a sustained plateau from the late 1980s to 2000, the value shoots up dramatically, with the highest values in recent years. (Figure 4.14).

5. DISCUSSIONS

5.1 HUMAN IMPACT ON CATCHMENT TRANSFORMATIONS

As catchment-lake interactions lead to changes in the ecological balance of an aquatic ecosystem(Carpenter et al., 2011). Lake Ertevannet, located within an agriculturally dominated landscape (Norconsult, 2017; vann-nett, n.d.), is expected to have undergone substantial transformations over the years. Since lakes surrounded by agricultural land are more prone to increased runoff and nutrient load (Romaheim et al., 2015), large amounts of soil-bound nutrients such as nitrate and phosphate are mobilized upon events of intense precipitation and surface runoff (Wetzel, 2001). These changes have been reflected in the sedimentary record of Lake Ertevannet, as shown by the temporal variability in sediment accumulation, P concentrations, and phytoplankton composition.

For many years, due to its productive soil, Norwegian policy has been to enhance cereal cultivation in this part of Norway. However, there is some degree of uncertainty due to limited information on land-use disturbances before 1950 in Rakkestad. Nevertheless, it is assumed that the catchment of Lake Ertevannet was relatively undisturbed, with intact forest cover and limited human interferences. This limited catchment disturbance before 1950 was mirrored by the consistently low level of P and Chl-a concentration (Figures 4.10 and 4.11). These trends are comparable to other regional lakes, such as Lake Skjeklesjøen (Hagman, 2020) and Lake Hersjøen (Rohrlack & Haaland, 2017), which suggests a broader regional baseline of low anthropogenic impact.

In contrast, the post-1950 period in Rakkesatd, another part of Østlandet, is characterized by profound landscape modifications. This period is characterized by widespread agricultural expansion, increased use of inorganic fertilizers, land levelling (Galloway and Cowling, 2002), and the disappearance of natural buffer zones (Figure 4.1). These interventions substantially increased soil erodibility by 3 to 13 times (Lundekvam, 2003) and manifested in quick transport of organic matter and particulate P from exposed agricultural fields into surface waters (Galloway & Cowling, 2002; Kragh et al., 2022 and Slaymaker, 2010), which coincides with the onset of dramatic rise in sedimentation rate, and P concentration (Figures 4.8 and 4.10). Furthermore, tile drainage during the early 1960s (pers.com.Rohrlack, 09/03/2024, 14/10/25), and intense draining of flood-sensitive catchment of Glomma mires in the 1950s and 1960s (Ecke, 2009;(Kløve, 1999), likely have intense transport of nutrient-rich soil from the catchment, further contributing to algal growth.

Here, it is important to take a note from the historical maps from 1964 and 1965 (Appendix 2B, 2C), which reveal a major hydrological reconfiguration. In 1964, Blytjernsbekken flows into Stomperudtjernet before it pours into Ertevannet. But in 1965, the flow path was altered and the Blytjernsbekken poured directly into Ertevannet, which may be one of the reasons for the high sedimentation rate, as a shortened watercourse has reduced water residence time. As the

Ertevannet catchment area is classified under erosion class 2 (vannmiljo n.d.), high sediment accumulation rate with increased nutrients flow is expected in this period, which was also observed by Shyika (2017) in lake Øyern, suggesting a regional pattern.

The forest volume at the National and regional level shows a clear increase during the 1900s). Lake Ertevaannet, which predominantly consists of forest (71%) in the catchment area, is expected to be a part of this increase. However, Logging has emerged as a recent and significant disturbance in Ertevannet catchment area (Norconsult, 2018). Forest clearance not only increases phosphorus and nitrogen leakage from soil but also is expected to promote holomictic mixing of the lake's water column, which results in both nutrient resuspension and oxygenation of deeper layers, ultimately enhancing internal nutrient cycling and productivity (Makri et al., 2020; Zander et al., 2021). Such developments are supported by the findings of Norconsult (2024), which revealed that Ertevannet has shifted from a moderately impacted to eutrophic state following a marked increase in logging activities between 2015 to 2016.

5.2 LONG-TERM PHOSPHORUS DYNAMICS

Phosphorus (P), along with climatic factors, light availability, and oxygen, has long been recognized as the primary limiting nutrient for phytoplankton growth in freshwater ecosystems, provided nitrogen levels are adequate (Cohen, 2003; Schindler, 2009; Sterner, 2008; Smol et al., 2005). The sedimentary record of Ertevannet indicates a moderate but statistically significant correlation (R^2 = 0.53) between phosphorus concentration and total Chl-a (Appendix, 6B), emphasizing the central role of P in regulating phytoplankton biomass and productivity.

Before the 1950s, phosphorus levels were characterized as low and stable (Figure 4.10), indicative of an ecosystem with limited anthropogenic disturbance and effective natural phosphorus retention. This era likely represents the natural baseline condition of the system, in which probably intact forest cover, grassy field banks, and minimal soil disruption curtailed nutrient runoff into the lake. However, the period following 1960 demonstrated a pronounced upward trend in phosphorus concentrations, particularly a dramatic increase after 1960 (Figure 4.10), which corresponds with the escalation of agricultural practices, land levelling, and land modifications as we mentioned earlier, that might have collectively contributed to external P loading into Lake Ertevannet, thereby enhancing algal proliferation. This trend mirrors the views and findings of Kronvang et al (2001), Makri et al (2020), and (Szpakowska et al., 2022), who observed comparable patterns, thereby emphasizing the broader applicability of this trend.

The phosphorus concentration that peaked around 1970, followed by a period of stabilization—a post-disturbance plateau—indicates a transition from externally driven inputs to internal nutrient cycling processes. In lakes that are seasonally stratified or experience hypoxia, phosphorus can be released from sediments under anoxic conditions through the reductive dissolution of iron-phosphate complexes (Søndergaard et al., 2003). This internal loading and legacy phosphorus stored in sediments can sustain eutrophic conditions for decades (Flower et al., 1988). The slightly declined, yet consistently high sedimentary P after 1980 may reflect changes in soil chemistry. It can be explained by the fact that elevated soil pH in the surrounding catchment immobilizes P and reduces its mobility (Bechmann et al., 2005; Kopáček et al., 2000). Additionally, the introduction of the National Action Plan against Agricultural Pollution from 1985-1988, and the National Agro-Environmental Scheme in 1991 might have played a crucial role in mitigating external loading, with measures such as reduced autumn tillage and the restoration of grassy buffer zones (Kollerud, 2005; Arnoldussen, 2005b).

Although the examination of nitrogen dynamics was not included in this study, its potential role in influencing lake productivity cannot be disregarded. The interactions between phosphorus and nitrogen compounds also impact nutrient dynamics within aquatic ecosystems (Andersen, 1982). The fluctuating nitrate concentrations from 2013 to 2023 in the water column of Ertevannet (vann-miljø, n.d.) are not excessively high, yet they surpass ecological thresholds (Appendix 3B). This nitrate profile further indicates that anthropogenic influences, particularly from agriculture, surface runoff, and sewage, remain significant. Nevertheless, Bostrom & Pettersson (1982) and Frostad (2018) illustrated the coupling between the presence of NO3- and the prevention of P-leaching from the sediments in lake Årungen, suggesting that the supply of NO3- to lake Ertevannet might have impacted its ability to retain P in the lake sediments.

However, it is essential to acknowledge that the phosphorus record represents long-term accumulation, and elevated nitrate reflects more recent occurrences in the water column; therefore, the direct relationship between these two variables remains uncertain.

Nonetheless, it is plausible to mention that nitrate conditions in Ertevannet should be playing a crucial role in modulating internal P retention or release. Despite recent reductions in external inputs, persistent nutrient delivery from catchment, legacy phosphorus in sediments, and changing climate conditions will continue to influence phosphorus dynamics in Ertevannet.

Another crucial factor that needs considerable attention is sewage-derived P. According to Norconsult (2024), 104 treatment plants for dispersed wastewater in the Ertevannet catchment area are operational (Appendix 1A), which account for an estimated 84 kg/ year P into Lake Ertevannet (Norconsult, 2018). So, it is reasonable to assume that even though Rakkestad commune has applied measures to reduce diffuse P from sewage by 100% in 2021(Norconsult, 2018; vann.nett. n.d.), P leaching from these treatment plants is a long-term process contributing to elevated lake productivity.

Thus, the persistent catchment-driven P delivery will continue to influence the lake's biological response, regulating both lake productivity and algal composition. Given the rising temperatures and anticipated extreme weather events, such as increased rainfall and flooding, are expected to amplify phosphorus transport in the future. Rohrlack & Haaland (2019) reported similar patterns in Lake Lundebyvann, where total phosphorus delivery exceeded natural background levels during extreme events. Consequently, ongoing climate variability, combined with catchment processes, is likely to drive future changes in lake productivity and ecosystem structure.

5.3 LAKE PRODUCTIVITY AND PHYTOPLANKTON SHIFTS: CAROTENOIDS AS A FUNCTIONAL INDICATOR

Chlorophyll-a is the most common primary pigment used to estimate primary production in lake sediments (Leavitt & Hodgson, 2001) while carotenoids offer taxon-specific insights, as they are often associated with specific algal groups, allowing for more detailed reconstruction of past phytoplankton communities (Jeffrey, 1980; Leavitt and Hodgson, 2001; Reuss, 2005; Sanger, 1988). Although algal pigments undergo various degrees of degradation before being preserved in sediment, they are the key elements to characterize OM sources and lake productivity dynamics (Bianchi et al, 2000), and even to interpolate the environmental changes in the aquatic ecosystems (Schouten et al, 2001).

The results demonstrated long-term variability in primary production and algal composition that can be attributed to persistent alterations in external forcings (Dakos et al., 2015). The nearly nine-decade changes in phytoplankton composition can be structured and discussed across distinct periods, each reflecting specific environmental conditions.

1. Pre-Industrial period: 1930-1950.

The pigment profile in this period is characterized by consistently low concentrations of Chl-a and other pigments, indicating limited primary productivity and subdued algal development (Figures 4.11 and 4.12). This low concentration of algal pigments during this period completely aligns with an extremely low value of LOI and P, suggesting an environmental setting with minimal anthropogenic influences. Consistently low algal production until 1960 aligns with low Chl-a/ Chl-a breakdown ratio and P concentration, suggesting either limited nutrient input from the drainage basin or complete degradation of organic pigments before burial. Furthermore, this reduction in algal production may be attributed to a cooler temperature, as temperature is an important factor in primary production (Wetzel,2001). This phenomenon is consistent with the framework of Leavitt et al (1990), who noted that environmental influences work on lakes via coupled influxes of energy and mass.

2. Agriculture intensification and Catchment modification period: 19560- 1990.

Beginning with the onset of the 1950s and continuing through the next two decades, a notable, unusual event unfolded around 1960, marking an abrupt rise in algal production and pigment profile (Figures 4. 11, 4.15, 4.16, 4.17, 4.18). Fucoxanthin, which is associated with diatoms, remained consistently low, suggesting that diatoms, which often proliferate in well-mixed and nutrient-poor conditions, were still not a dominating algal community in that period. On the other hand, the clustering of Chl-a and the variable increasing trajectory of alloxanthin, lutein, and canthaxanthin indicate the onset of a growing dominance of cryptophytes, green algae, and cyanobacteria, which further implies a transition towards a nutrient-rich eutrophic lake condition. Dakos et al (2015) have identical observations, suggesting that the variability of primary producers probably reflects a persistent increase in external forcings. This coincides with the intense land modifications and farm expansion in the drainage basin, as we mentioned earlier, when land levelling, ditching, and trenching began with the canalization policy, which continued until the 1980s. Similar trends of elevated phytoplankton production during the mid-20th century were observed by Makri et al (2019 & 2020), and Tu et al (2020 & 2021) in Swiss plateau lakes and Zander et al (2021) in small polish lakes, suggesting an enhanced aquatic productivity as a response to land use transformations.

Moreover, the variability of primary producers probably reflects a persistent increase in external forcings (Dakos et al., 2015). Supporting this view, recent studies (Kyle et al., 2015; Sunde, 2018) found that insufficient sewage management, agriculture, and urbanization are important drivers of phytoplankton abundance. Nevertheless, it is believed that, together with human-induced alterations and climate-driven changes, such as length of ice-cover period, duration of growing season, oxygen consumption, and chemical weathering, can also affect lake dynamics and production (Douglas et al, 1994; Overpeck et al, 1997).

3. Nutrient enrichment: 2000-present day.

After an unstable but persistent productivity from 1980 to 2000, the lake productivity began to rise dramatically specifically after 2010, which is evident by a marked increase in total chlorophyll and other pigments (Figure 4.11). A similar increase in Chl-a and cyanomax has also been observed in the water column of Ertevannet in recent years (Appendix 3A and 3C). While fucoxanthin and lutein exhibit relatively stable but elevated concentrations from 1990, canthaxanthin and alloxanthin show a pronounced rise from 2010 until 2024, which aligns with the findings of Rohrlack *et al* (2008), who observed cyanobacteria expansion in nutrient-rich and thermally favorable conditions. It can be reasoned that the episodic rise and fall of cyanobacteria and cryptophytes from 1990 to 2010 can be attributed to a transient lake ecosystem, when re-establishment of internal feedback mechanisms like nutrient cycling, loss of macrophytes, and shading influence major parameters (Carpenter et al, 2011; Dakos et al, 2015).

The elevated Chl-a together with recorded piments suggests a more productive system with a dynamic and diverse phytoplankton community, where early spring diatoms proliferation is believed to be followed by cryptophytes and late-summer cyanobacterial expansion (Skarbøvik, 2022a). This is further supported by the findings from Norconsult (2018) and Vann-nett (n.d), both of which classify Ertevannet to be in poor ecological condition based on TP concentrations in the water column, which exceeds the threshold set by the Water Framework Directive (WFD). However, NIBIO (2019) revealed that Ertevannet was moderate in ecological conditions until 2018, with the dominant algal groups of *Cryptomonas and Synura*. However, Gonyostomum started to dominate only after 2018.

It can be inferred that the elevated productivity observed after 2010 might reflect a warming-induced stratification regime and enhanced nutrient recycling, a pattern indicative of higher algal biomass and cyanobacterial dominance due to forcing by climate change and eutrophication (Kosten et al., 2012; Richardson et al., 2019). This trend is prevalent despite the stable sedimentary P concentrations, suggesting a dominant role of lake internal processes as a key driver. Nevertheless, as we mentioned earlier, the persistent diffuse sewage load and P flux from agricultural land also holds a notable influence on the algal composition and development (Norcosult 2017,2018; vann- nett, n.d). The recent prevalence of algal blooms can also be explained by the observations of Rohrlack (2022), who highlighted high pH values due to algal blooms as lakes are caught in a positive feedback loop where a lot of algae leads to the release of phosphate from the sediment. The other possible explanation for algal development and blooms in recent years may be because of increased flushing (Padiask et al., 1999; Reynolds and Lund, 1988), as it promotes phytoplankton growth due to enhanced nutrient availability.

Alternatively, Ulen et al. (2007) observed long-term increased P accumulation in south Norwegian agricultural fields from 1960-2005, possibly reflecting continued inputs from manure and mineral fertilizers. This increased soil P suggests a legacy effect, where excess P is stored in catchment soils and may continue to leach or drain off during precipitation. As the drainage basin of Ertevannet is heavily cultivated and several livestock units are in the catchment, it is expected that the recent elevated algal growth is not only influenced by the internal lake processes but also by diffused P losses from the catchment (vann. miljo.n.d). It is further supported by the fact that despite the regulatory requirements for 90% P purification, the mini-treatment plants have a lower purification efficiency, suggesting that ineffective treatment may be a contributing factor to continued P loading to the lake, resulting in pronounced phytoplankton growth.

Nevertheless, it is ambiguous whether the observed elevated pigment values and Chl-a decay ratio in recent years are the result of either reduced oxygen values in the lake bottom (Rohrlack and Haaland 2017), grazing pressure (Leavitt and Carpenter, 1990; Reuss, 2005), or better preservation conditions (Reuss, 2005). It is also equally plausible that although Regional Environmental Program (RMP) shows that grassed zones in cultivated field edges has doubled in recent years from 6.3 km in 2019 to approximately 14.4 km in 2023, and limited tillage practice in the fall (Norconsult, 2024), it is observed that P from the drainage basin is still finding a way to Ertevannet and together with lake internal P processes accelerates algal blooms.

5.4 ORGANIC MATTER VARIATION AND SEDIMENT TRANSPORT

The organic matter accumulated in the lake sediment reflects the amount of OM deposited and the extent of alteration and degradation of the OM, its origin, transport, deposition, and preservation (Meyers, 2003). The near-millennia sediment accumulation records of Lake Ertevannet are characterized by relatively low, yet varied and distinct contrasting temporal trends of OM deposition, punctuated by a striking anomaly centered around the early 1960s and in recent years (Figure 4.8), indicating a specific event of lake development. This suggests that organic matter in Lake Ertevannet is both autochthonous as well as influenced by allochthonous inputs. The high and variable dry weight value before 1950 contrasts with relatively low LOI, suggesting a period dominated by mineral-rich sediment deposition facilitated by limited catchment disturbances and primary production. Decline in OM during this period has also been recorded in several lakes in Europe (Cunningham et al., 2011) and Sørli (2015) in Lake Jarenvatnet, reflecting a wider regional trend of reduced OM, controlled by driving forces of identical regional nature, such as climate and anthropogenic activities.

Unusual events around 1960.

An abrupt and gradual increase in LOI after 1960 likely points to an increased organic matter accumulation along with the prominent rise in pigment concentrations, potentially triggered by diverse driving forces. As mentioned earlier, several events happened in the lake catchment throughout this period, which are believed to have resulted in high sediment deposition and raised lake productivity. The spike in OM content, which is also mirrored by a period of high sediment accumulation (2.707cm year^{-1} in 1961) and lake phytoplankton production (Figure 4.11), is believed to be a combined result of elevated terrestrial input and enhanced erosion. The co-occurrence of elevated pigment concentrations, higher dry-weight values, and enhanced LOI during this interval suggests that the 1960s represent an event when catchment disturbance, hydrological transport, and lake productivity converged.

There is a pronounced shift observed post-1970, as dry weight decreases while LOI increases, specifically after 1980, which signifies a change in sedimentary processes from dominance of external sources to in-lake processes. It is plausible to argue that the modest rise in LOI in recent decades coincided with the implementation of the National Agro-Environmental Scheme in 1991, which targeted mechanisms to a soil erosion from agricultural areas by reducing tillage in autumn ploughing, establishment of grassy buffer zones (Kollerud, 2005; Arnoldussen, 2005b).

The synchrony between LOI, DW, and total-Chl-a, notably in recent decades, reveals a tightly coupled association between those two variables, suggesting a system with high productivity and autochthonous OM production, which agrees with the findings of Sørli (2015) in Lake Jarenvatnet. The apparent high sediment accumulation rate of 2.084 cm yr $^{-1}$ in 2024 can be attributed to either a fresh unconsolidated soil layer that hasn't settled well or a combined effect of high lake productivity and anthropogenic input. This contradicts the findings of Riise et al (2013), who observed relatively high, i.e., 7.5 cm yr $^{-1}$ annual sedimentation rate in lake Årungen since 1986, and suggest an equal contribution of both autochthonous and allochthonous OM sources to the lake bottom.

Although climate remains largely secondary to human-driven land-use disturbances, it considerably amplifies the runoff and subsequent deposition on the lake bottom (Flower, 1988; Slaymaker, 2010). While Freeman et al (2001) argue that OM increases with temperature rise, Schindler et al (1996a) suggest that the supply of OM is greatly reduced. As the climatic variables vary in this period, it is challenging to ascertain and conclude the extent to which climatic variables contributed to variations in OM deposition.

Bogen (2022) opined that temperature and events with heavy rainfall will significantly increase in the coming years, likely to elevate the magnitude of flooding and sediment transport to the water bodies. This argument is further supported by the findings of Norconsult (2024), which states that periods of cocoa colored water that are rich in organic content were reported in the lake during periods of excessive precipitation.

5.5 FILLING THE GAPS- FUTURE DEVELOPMENT

Apart from the recent and infrequent monitoring records conducted by Norconsult and NIVA, the long-term findings of Lake Ertevannet will provide additional insight into its historical ecological development. Furthermore, in the context of the Water Framework Directive (WFD), which aims to achieve 'good ecological and chemical status' for all water bodies, these findings might offer a valuable historical perspective to assess the long-term trends in phytoplankton composition and development, likely governed by catchment area disturbances.

The observed trajectories in lake productivity and phytoplankton composition indicate a period of recent elevated lake productivity and pronounced algal composition, which are mirrored by ongoing nutrient transportation likely due to catchment disturbances. Given that agricultural activities in the lake catchment are intense and a major source of P flux into Lake Ertevannet, management activities should be considered carefully, as episodic flooding and landslides might affect the lake water quality and algal growth. As bogs constitute 2.1% of the catchment area, restoration of the drained mires can be a measure that can reduce flooding and sediment transport. On the other hand, a reduction in local catchment flooding from 2-3 times a year to once every second year was observed in the Vansjø-Hobel catchment due to the implementation of a water retention pond (Couture et al., 2018). Therefore, creating water retention ponds in the agricultural area is suggested as it captures and diverts the surface run-off, soaks nutrients, and ultimately alleviates gully erosion in a moderately erosion risk landscape (Syversen, 2002).

Besides the ecological consequences, increasing algal blooms affect the local community and reduce recreational values. As signs of skin irritation are already evident, activities like swimming and fishing will be greatly threatened if proactive drainage basin management plans are not taken seriously.

The sediment core we examined was short (45 cm), spanning from 1934 to 2024. However, considering the variability in climate and magnitude of human-induced TP, a paleolimnological investigation beyond that date is imperative to uncover the ecological setting in light of the reference value for Lake Ertevannet before 1934. Therefore, an extensive paleolimnological study beyond 1934 is suggested, which might discern useful information on realistic reference values for the lake (Battarbee et al., 2011). Additionally, finding a way to combine more robust and specific paleolimnological tools, such as diatoms or cyanobacteria (*Gonyostomum semen*) analysis in monitoring programs, will both bridge the gap in existing knowledge and simultaneously improve mitigation measures and define reference conditions (Bigler et al, 2006). Moreover, this study of Lake Ertevannet is more focused on long-term changes in phytoplankton composition with P as a major nutrient from a drainage basin; therefore, investigating the role of atmospheric S deposition and nitrate-phosphorus coupling will further expand our understanding of the lake's environmental setting

6. CONCLUSION

This study has examined a range of sediment-based variables, reflecting both in-lake production and catchment processes, to reconstruct long-term environmental changes in Lake Ertevannet. The deepest part of the core was supposed to represent a period with a low impact from human-induced disturbances such as modern agriculture, extensive industrialization, and urban proliferation. The long-term reconstructions revealed that the period 1934-1950 was characterized by a relatively stable algal composition, with consistently low concentrations, that is mirrored by declined nutrient (particularly, P) and OM, suggesting limited phytoplankton growth and catchment disturbances (Figures 4.11, 4.12, 4.13, 4.13).

A marked transition happened around 1960, signaling the onset of rapid and dramatic changes in the catchment area triggered by anthropogenic activities. This period is characterized by a dramatic rise in sediment accumulation and enhanced primary production, which is also accompanied by a significant increase in phosphorus amount in lake sediment. The increase further coincides with major human impacts such as ditching, canalizing, increased tillage, logging, road expansion, and increasing amounts of sewage discharged. It is evident from the results that human-induced influence was the main driver for the variation in dramatic shifts in TP and algal production in that period. The influence from natural driving forces, however, cannot be ruled out either. However, the period of enhanced lake production and nutrients persisted until 1980, after which TP concentration began to level off, even though algal growth varied. This nutrient concentration levelled off after 1980 until recent years, suggesting the establishment of a new ecological baseline, potentially reflecting an equilibrium between sustained P flux and lakes' adaptive response mechanisms.

The recent resurgence in algal production after 2000 (Figure 4.11) indicates a renewed, enhanced phytoplankton growth, potentially linked to persistent external nutrient inputs under warm temperatures and unusual extreme precipitation. Nevertheless, even though land reform measures began around 1990, the consistent rise in phytoplankton production implies persistent sewage discharge, and agriculture continues to contribute as the main driving factor.

In the context of the Water Framework Directive, which mandates water bodies to maintain good ecological status, these findings clearly illustrate that the current state of Lake Ertevannet is below its environmental objective. Although this study did not aim to explain the nitrogen budget, the reduction in nutrient flux, especially phosphorus to the lake, is of paramount importance to improve and achieve good ecological status. Based on the results, it can be concluded that catchment-related influences have been the pivotal driver of phytoplankton growth and development in Lake Ertevannet, supporting hypothesis 1.

It is expected that in a rapidly changing world, the paleolimnological study of Lake Ertevannet will serve as a crucial link, offering vital insights into how a moderately shallow temperate lake responds to a wide array of anthropogenic disturbances in the catchment. Furthermore, the findings will support the limnological and conservation stakeholders to understand, compare, and construct the lake trajectories in the Glomma-Sør Watercourse in the context of nutrient mitigation and WFD ecological objectives.

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8. APPENDICES

APPENDIX 1 - CLIMATIC DATA

Year	Total annual precipitation (mm)	Growth season total precipitation (mm)	Annual mean temperature (°C)	Growth seasons mean temperature(°C))
1930	940,2	521	6,49	12,20
1931	683,7	387,7	4,66	10,67
1932	750,7	367,5	6,33	12,08
1933	616,1	311,5	6,03	13,05
1934	913,3	422,9	7,28	12,70
1935	954,1	383,2	6,11	12,05
1936	787,1	353,5	5,75	12,07
1937	742,7	419,1	5,66	12,92
1938	845,9	326,4	6,89	12,20
1939	761,9	376,4	6,08	13,10
1940	720,4	481,1	4,13	11,65
1941	599,3	406,6	3,75	11,62
1942	831,3	514,1	3,85	11,52
1943	706,6	363	6,27	12,18
1944	877,6	500,4	5,92	11,48
1945	639,8	363,5	6,08	12,63
1946	954,1	555	5,54	12,17
1947	398,3	196,2	4,93	14,05
1948	954,9	573,9	5,57	12,40
1949	805,4	348	7,06	13,13
1950	1006,5	613,7	5,53	12,30
1951	987,5	529,4	5,58	11,47
1952	673,7	424,5	4,43	10,97
1953	807,2	604,3	6,35	12,08
1954	947,6	488,6	4,99	11,50
1955	505	273	5,13	12,70

1956	667,6	496,5	4,33	11,23
1957	766,2	503,5	5,33	11,18
1958	738,9	406,1	4,39	11,27
1959	810,8	254	6,25	13,12
1960	1075,5	587	5,13	11,95
1961	816	385,2	6,13	12,00
1962	914,1	572,3	4,22	10,27
1963	796	576,7	3,98	11,48
1964	743,4	444,3	5,13	10,92
1965	823,8	643,3	4,16	10,75
1966	890,2	398,8	3,95	11,05
1967	1026,1	467,5	5,50	11,67
1968	672,7	374	4,66	12,13
1969	635,6	385	4,94	12,60
1970	770,6	422,7	4,28	11,67
1971	555,7	293,5	6,05	11,92
1972	684,6	468,7	5,82	11,80
1973	536,6	356,8	6,07	11,90
1974	930,9	492,3	6,79	12,30
1975	607,6	292,6	7,04	12,83
1976	608	186,8	5,52	12,55
1977	708,1	359,3	5,27	11,43
1978	608,1	352,3	4,78	11,27
1979	811,2	393,6	4,18	11,05
1980	767,1	402,9	4,78	12,57
1981	718,1	351,1	4,68	11,75
1982	951,9	405,4	5,86	12,35
1983	721,2	432,4	6,51	12,38
1984	846,1	439	6,16	12,18
1985	827,5	533,4	3,43	10,98
1986	709,3	325,5	4,45	10,48
1987	976,6	492	3,47	10,18
1988	986	544,8	5,82	12,37
1989	742,2	407,5	7,00	11,68
1990	889,6	391,4	7,30	12,40
1991	744,8	279,9	6,13	11,90
1992	802,3	429,5	6,63	12,48
1993	728,4	344,9	5,73	11,30
1994	835	413,9	5,79	12,63
1995	850,9	512,2	5,80	11,93
1996	692,7	318,1	4,60	11,28

1997	650,8	315,5	6,80	13,30
1998	786	478,3	6,00	11,48
1999	1057,8	553,9	6,30	12,28
2000	1192	431,1	7,20	11,78
2001	891,3	470,1	5,44	11,98
2002	909	502	6,17	13,50
2003	758,5	447,5	5,83	12,63
2004	841,2	440,3	6,47	12,68
2005	681	345,2	6,83	12,38
2006	1053,2	458,8	6,86	13,48
2007	920,6	534,4	6,68	12,52
2008	1161,2	527,4	7,10	12,38
2009	929,5	471,2	5,90	12,83
2010	807,3	532,8	3,70	11,93
2011	1064,2	708,7	6,60	12,98
2012	1019,9	575	5,90	11,58
2013	841	444,9	6,00	12,27
2014	1089,2	356,5	7,70	13,30
2015	1107,5	678,3	7,10	11,78
2016	775,1	454,9	6,70	13,23
2017	981,6	492,4	6,50	12,15
2018	767,7	364,4	7,00	14,32
2019	1082,5	556,9	6,70	12,77
2020	1080,9	413,5	8,30	12,78
2021	611,6	290,3	6,60	13,18
2022	701,5	307,6	7,30	12,78
2023	923,6	560,2	6,40	13,20
2024	972,2	511,3	7,10	13,18

APPENDIX-2 HISTORICAL CHANGES IN THE CATCHMENT AREA

Figure 2A- Dam in Skiselva, Ertevannet. Source: www. norgeibilder.no. Picture retrieved on 25.02.2025

Figure 2 B- Blytjernsbekken in 1964.The map shows a stream from Nordre-Blytjen pouring directly into stomperudtjernet . Source: norgeibilder.no. Picture retrieved on 25.12.2024

Figure 2 C- Blytjernsbekken in 1965.The map shows a stream from Nordre-Blytjen diverting towards Lake Ertevannet without pouring into stomperudtjernet. Source: norgeibilder.no. Picture retrieved on 25.12.2024

Figure 2D-Scattered wastewater treatment plants in the Ertevannet catchment. Source: Figure is modified and adapted from the Norconsult report, 2024.Picture retrieved on 15.03.2025

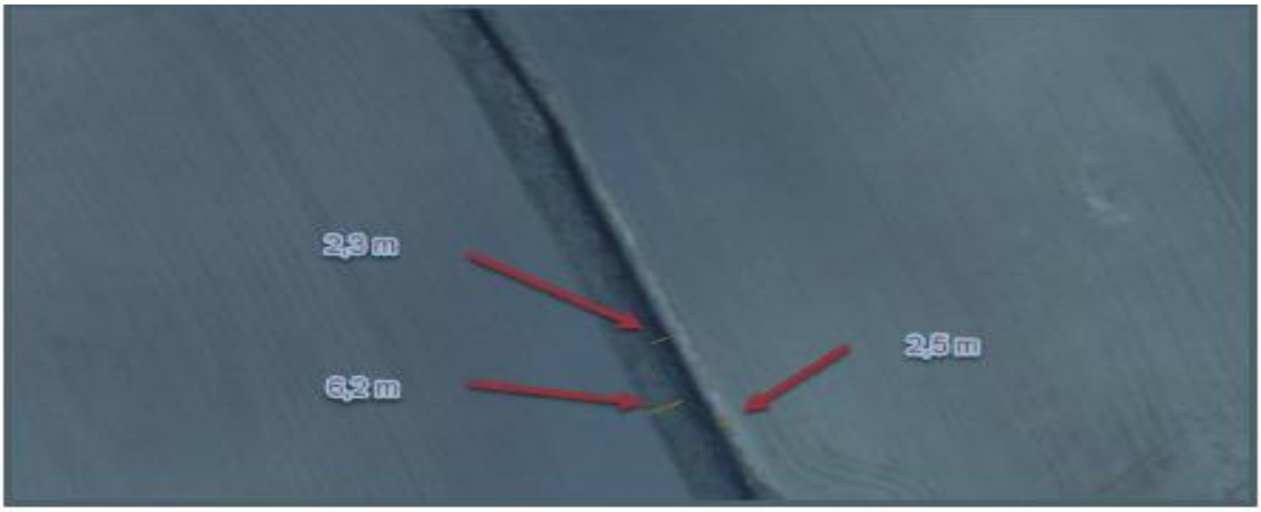

Figure 2E: Vegetation cover in the buffer zone along a stream in the Ertevannet catchment. Source: Picture adapted and modified from Norconsult Report 2024.Picture retrieved on 15.03.2025

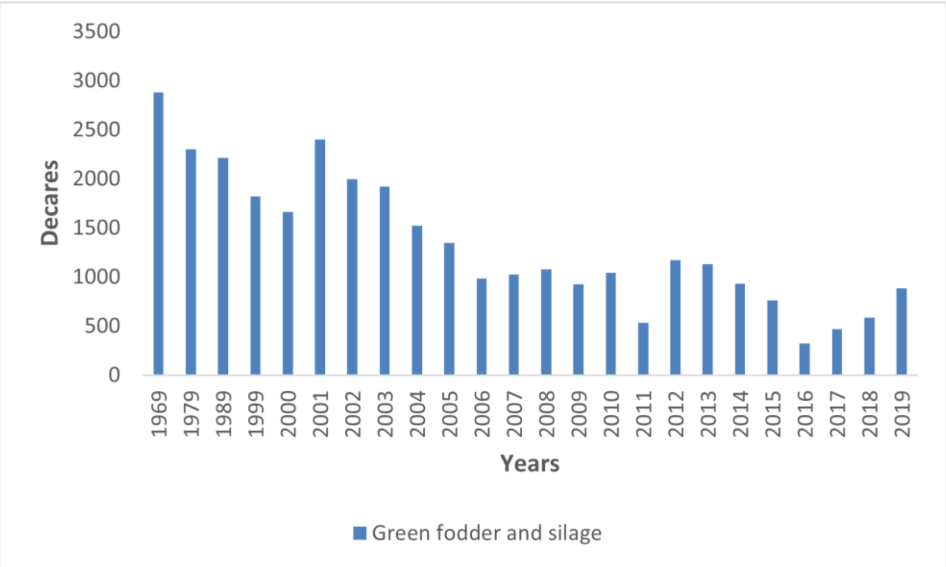

Figure 2F: Green fodder and silage in Rakkestad Kommune during the period of 1969-2019. The graph is based on data taken from Statistics Norway's website (SSB, 2021d). (da=1000m2)

Figure 2G: Total land holdings in Rakkestad Kommune during the period of 1969-2019. The graph is based on data taken from Statistics Norway's website (SSB, 2021d).

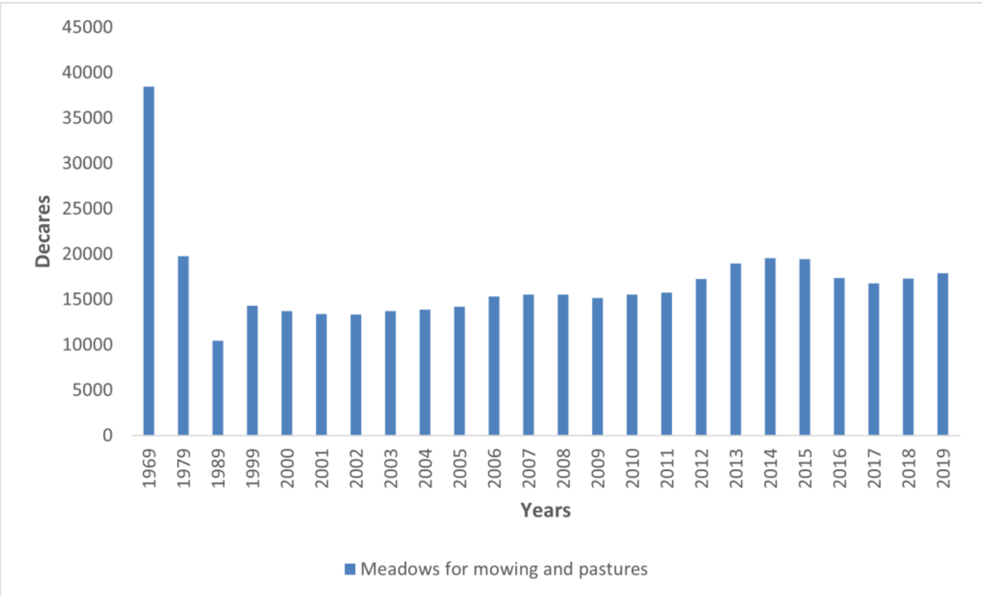

Figure 2H: Meadows for mowing and pastures in Rakkestad Kommune during the period of 1969-2019. The graph is based on data taken from Statistics Norway's website (SSB, 2021d).

APPENDIX 3- REPORT ON THE RADIOMETRIC DATING OF SEDIMENT CORE ETVN TAKEN FROM ERTEVANNET, NORWAY

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Rationale and methodology

Lead-210 (half-life is 22.3 year) is a naturally-produced radionuclide, derived from atmospheric fallout (termed unsupported ^{210}Pb). Cesium-137 (half-life is 30 years) and ^{241}Am are artificially produced radionuclides, introduced to the study area by atmospheric fallout from nuclear weapons testing and nuclear reactor accidents. They have been extensively used in the dating of recent sediments. Dried sediment samples from core ETVN taken from Ertevanne were analysed for ^{210}Pb, ^{226}Ra, ^{137}Cs and ^{241}Am by direct gamma assay in the Environmental Radiometric Facility at University College London, using ORTEC HPGe GWL series well-type coaxial low background intrinsic germanium detector. Lead-210 was determined via its gamma emissions at 46.5keV, and ^{226}Ra by the 295keV and 352keV gamma rays emitted by its daughter isotope ^{214}Pb following 3 weeks storage in sealed containers to allow radioactive equilibration. Cesium-137 and ^{241}Am were measured by their emissions at 662kev and 59.5kev (Appleby et al, 1986). The absolute efficiencies of the detector were determined using calibrated sources and sediment samples of known activity. Corrections were made for the effect of self absorption of low energy gamma rays within the sample (Appleby et al, 1992).

Results

Lead-210 Activity

Total ^{210}Pb activity does not reach the equilibrium depth with relevant supported ^{210}Pb activity even at the base of the core (45 cm, Figure 1a). Unsupported ^{210}Pb activities, calculated by subtracting ^{226}Ra activity (as supported ^{210}Pb) from total ^{210}Pb activity, are relatively low and decline irregularly with depth (Figure 1b). In the top 17.5 cm unsupported ^{210}Pb activities decline in an exponential trend with depth with some gentle fluctuations, suggesting small changes in the sediment accumulation rates. However, notable dips at 20.5 and 29.5 cm would indicate considerable increased sediment accumulation rates at the depths, respectively.

Artificial Fallout Radionuclides

The ^{137}Cs activity versus depth profile (Figure 2c) shows two peaks at 20.5 and 29.5 cm, and they should be derived from the Chernobyl accident fallout in 1986 and the 1963 fallout maximum of the atmospheric testing of nuclear weapons， respectively. Low ^{241}Am activities in two disconnected samples were detected, but they are insufficient for dating.

Core Chronology

Use of the CIC (constant initial concentration) dating model was precluded by the non-monotonic features in the unsupported ^{210}Pb profile. ^{210}Pb chronologies and sediment accumulation rates were calculated using the CRS (constant rate of 210Pb supply) dating model (Appleby, 2001). The simple CRS dating model places 1963 depth between 38.5 and 41.5 cm, which is clearly deeper than the depth suggested by the ^{137}Cs record. The final ^{210}Pb chronologies were calculated by assuming that the sediments at 29.5 cm were formed in 1963， and this put 1986 depth at 20.5 cm, in agreement with the ^{137}Cs record. The corrected results were given in Table 3 and shown in Figure 2. ^{210}Pb sedimentation rates of the core show considerable increased rates in the 1960s and 1980s, reaching 1.8 and 0.9 g cm^{-2} yr^{-1}, respectively, above the basic rates around 0.2 g cm^{-2} yr^{-1}.

Reference

Appleby, P G, 2001. Chronostratigraphic techniques in recent sediments. In W M Last and J P Smol (eds.) Tracking Environmental Change Using Lake Sediments. Vol. 1: Basin Analysis, Coring, and Chronological Techniques. Kluwer Academic Publishers, Dordrecht. Pp171-203.

Appleby, P G, Richardson, N, Nolan, P J, 1992. Self-absorption corrections for well-type germanium detectors. *Nucl. Inst. & Methods B*, 71: 228-233.

Appleby, P G, Nolan, P J, Gifford, D W, Godfrey, M J, Oldfield, F, Anderson, N J & Battarbee, R W, 1986. 210Pb dating by low background gamma counting. Hydrobiologia, 141: 21-27.

Table 1. ^{210}Pb concentrations in core ETNV taken from Ertevannet

Depth	Dry Mass	Pb-210						Cum Unsupported	
		Total		Supported		Unsupp		Pb-210	
cm	g cm^{-2}	Bq Kg^{-1}	±	Bq Kg^{-1}	±	Bq Kg^{-1}	±	Bq m^{-2}	±
0.5	0.0075	204.16	25.53	141.34	8.05	62.82	26.77	4.7	1.4
2.5	0.3181	178.31	11.33	90.42	3.14	87.89	11.76	236.6	47.8
5.5	1.3816	159.22	8.71	89.84	2.68	69.38	9.11	1069	112.1
8.5	2.7843	154.1	12.05	92.58	3.61	61.52	12.58	1986	180.9
11.5	4.3158	124.58	12.62	96.65	3.97	27.93	13.23	2637.4	265.4
14.5	5.9877	123.18	7.4	91.14	2.2	32.04	7.72	3138	331.5
17.5	7.6926	116.89	10.1	93.38	3.1	23.51	10.57	3607.7	362.5
20.5	9.4157	97.42	9.99	90.78	3.14	6.64	10.47	3837.7	405.4
23.5	11.1525	133.77	7.69	105.19	2.27	28.58	8.02	4098.7	440.6
26.5	12.675	121	13.83	100.74	4.05	20.26	14.41	4466.9	467.7
29.5	14.6082	88.78	9.93	88.55	3.21	0.23	10.44	4553.4	528.2
32.5	16.7456	95.23	9.86	89.68	3.1	5.55	10.34	4589.1	571.1
35.5	18.8006	96.01	9.18	88.06	2.76	7.95	9.59	4726.3	608.8
38.5	20.8069	97.24	10.44	88.18	2.85	9.06	10.82	4896.7	640.8
41.5	22.8661	107.06	9.76	87.33	3.04	19.73	10.22	5179	677.2
44.5	25.0156	100.84	5.73	85.44	1.63	15.4	5.96	5554.7	705.8

Table 2. Artificial fallout radionuclide concentrations in core ETVN.

Depth	Cs-137		Am-241	
cm	Bq Kg^{-1}	±	Bq Kg^{-1}	±
0.5	25.11	3.23	0	0
2.5	24.22	1.65	0	0

5.5	25.19	1.28	0	0
8.5	25.62	1.89	2.01	1.13
11.5	32.93	1.94	0	0
14.5	27.37	1.2	0	0
17.5	47.94	1.98	0	0
20.5	65.57	2.31	1.91	0.89
23.5	42.14	1.4	0	0
26.5	42.31	2.44	0	0
29.5	59.7	2.16	0	0
32.5	21.39	1.5	0	0
35.5	0	0	0	0
38.5	0	0	0	0
41.5	0	0	0	0
44.5	0	0	0	0

Table 3. ^{210}Pb chronology of core ETNV taken from Ertevanne.

Depth	Drymass	Chronology			Sedimentation Rate		
		Date	Age				
cm	g cm^{-2}	AD	yr	±	g cm^{-2} yr^{-1}	cm yr^{-1}	± %
0	0	2024	0				
0.5	0.0075	2024	0	2	0.2652	2.084	43.9
2.5	0.3181	2023	1	2	0.1813	0.66	17.5
5.5	1.3816	2017	7	2	0.1923	0.468	18.6
8.5	2.7843	2009	15	3	0.1705	0.349	25.9

11.5	4.3158	2002	22	4	0.303	0.567	50.5
14.5	5.9877	1996	28	5	0.2154	0.383	32.1
17.5	7.6926	1988	36	6	0.2314	0.405	51.3
20.5	9.4157	1986	38	7	0.902	1.564	57.3
23.5	11.1525	1977	47	8	0.1368	0.252	41
26.5	12.675	1965	59	10	0.1365	0.237	78
29.5	14.6082	1963	61	10	1.653	2.437	85
32.5	16.7456	1962	62	13	1.8104	2.591	99.8
35.5	18.8006	1961	63	19	1.832	2.707	119.4
38.5	20.8069	1952	72	29	0.2286	0.337	133.1

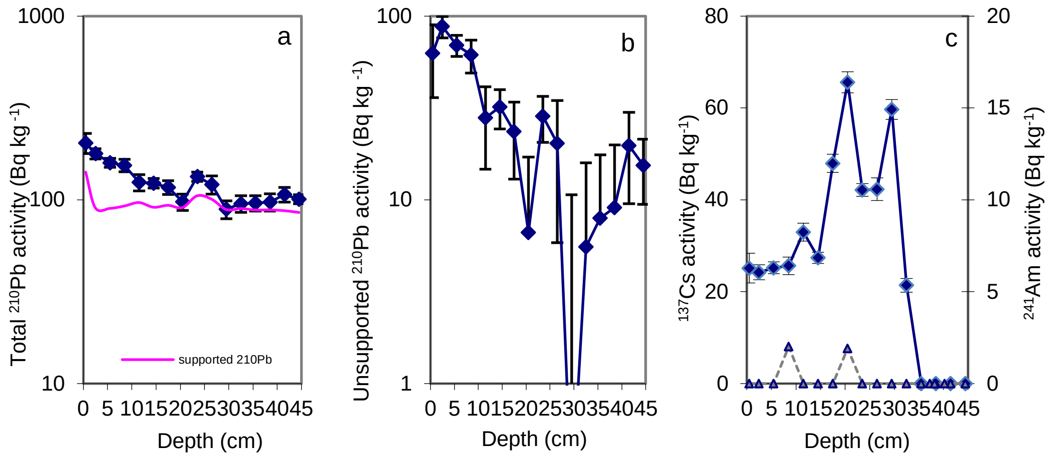

Figure 1. Fallout radionuclide concentrations in core ETNV taken from Ertevanne, showing (a) total ^{210}Pb, (b) unsupported ^{210}Pb, and (c) ^{137}Cs and ^{241}Am concentrations versus depth.

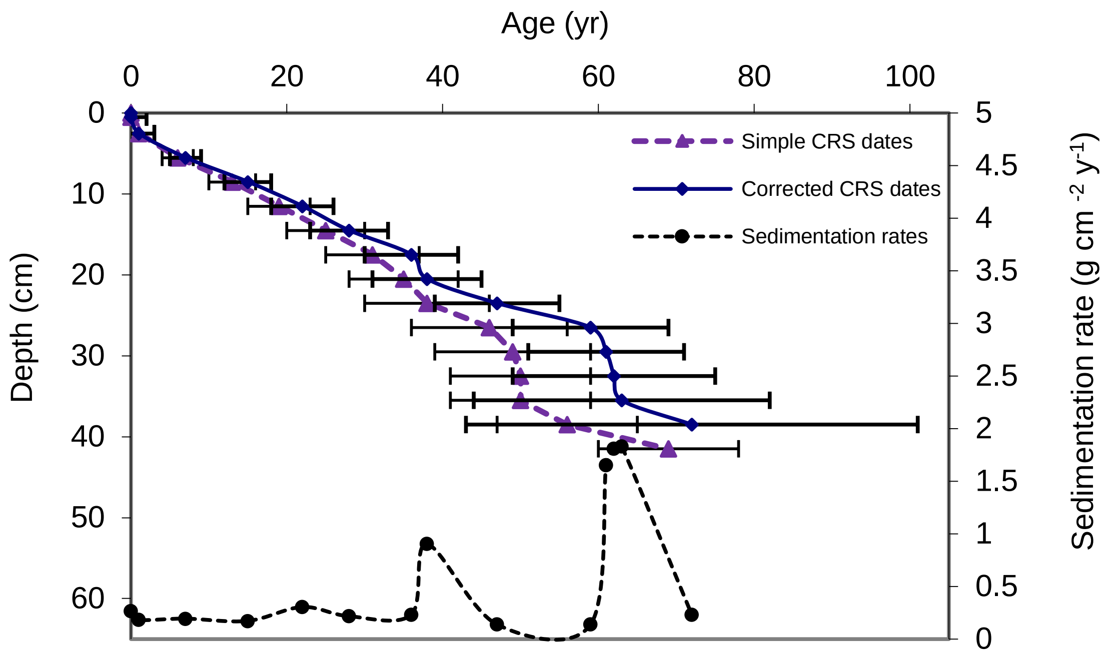

Figure 2. Radiometric chronology of core ETNV taken from Ertevanne, showing the CRS model ^{210}Pb dates and sediment accumulation rates.

Appendix 4- Water monitoring data for Lake Ertevannet

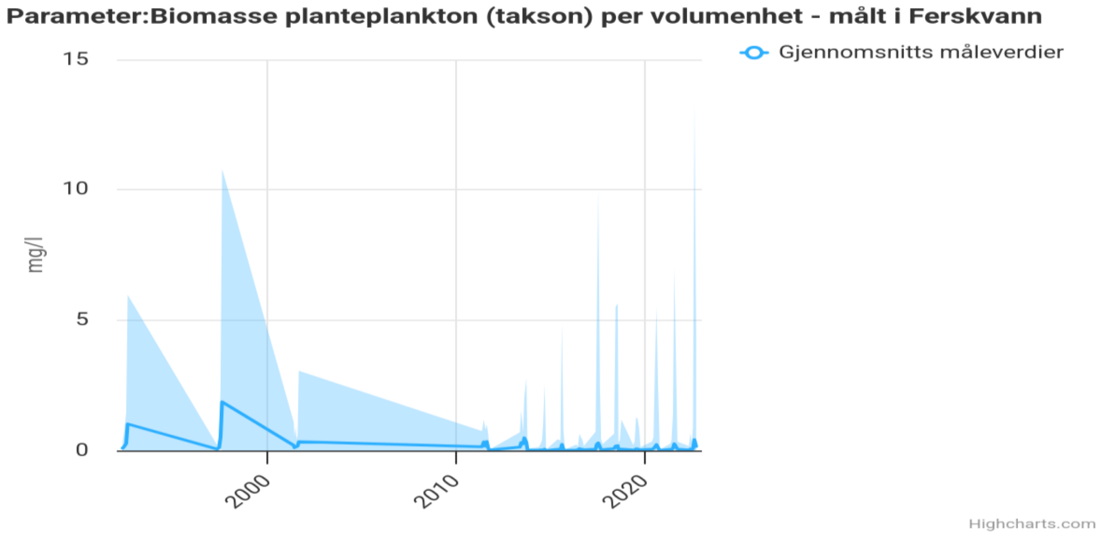

Figure 4A: Phytoplankton biomass in the water column of Lake Ertevannet during the monitoring period of 1995-2022. Source: vannmiljo. miljodirektoratet.no. Retrieved: 10.02.2025

Figure 4B: Nitrate values in the water column of Lake Ertevannet during the monitoring period of 2013- 2023. Source: vannmiljo. miljodirektoratet.no. Retrieved: 16. 12.2024

Figure 4C: Total phosphorus values in the water column of Lake Ertevannet during the monitoring period. Source: vannmiljo. miljodirektorate.no. Retrieved: 16. 12.2024

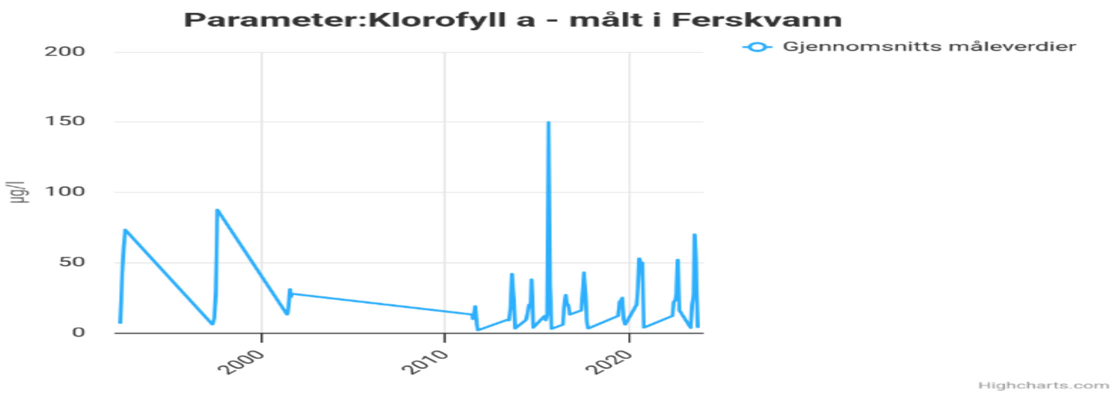

Figure 4D: Chlorophyll-a values in the water column of Lake Ertevannet during the monitoring period. Source: vannmiljo. miljodirektorate.no. Retrieved: 16. 12.202

APPENDIX 5A – PHOSPHORUS (MG P/G) IN SEDIMENT SAMPLE

Sample	Year		Absorption	Conc in extract	Volume extract	Mass extracted		Conc in sediment
				[µg P/l]	[ml]	[g]		[mg P/g]
1	2024		0,63003	875	10	0,0103		0,850
2	2024		0,6653	924	10	0,0108		0,856
3	2023		0,45299	629	10	0,0075		0,839
4	2021		0,64815	900	10	0,0111		0,811
5	2019		0,71663	995	10	0,0121		0,823
6	2017		0,73807	1025	10	0,0124		0,827
7	2014		0,72986	1014	10	0,0122		0,831
8	2012		0,63983	889	10	0,0108		0,823
9	2009		0,7276	1011	10	0,0126		0,802
10	2007		0,67988	944	10	0,0118		0,800
11	2004		0,7909	1098	10	0,0132		0,832
12	2002		1,08353	1505	10	0,0193		0,780
13	2000		0,87309	1213	10	0,0142		0,854
14	1998		0,83147	1155	10	0,0143		0,808
15	1996		0,95834	1331	10	0,0175		0,761
16	1993		0,72049	1001	10	0,012		0,834
17	1991		0,89953	1249	10	0,016		0,781
18	1988		0,81925	1138	10	0,014		0,813
19	1987		0,84666	1176	10	0,0151		0,779
20	1987		0,73673	1023	10	0,0131		0,781
21	1986		0,57896	804	10	0,0103		0,781
22	1983		0,81017	1125	10	0,0134		0,840
23	1980		1,07815	1497	10	0,0194		0,772
24	1977		0,99328	1380	10	0,0179		0,771
25	1973		0,87313	1213	10	0,0148		0,819
26	1969		0,70104	974	10	0,0111		0,877
27	1965		0,78752	1094	10	0,0134		0,816
28	1964		0,77408	1075	10	0,0135		0,796
29	1964		0,68284	948	10	0,0123		0,771
30	1963		0,83131	1155	10	0,0173		0,667
31	1963		0,62312	865	10	0,0122		0,709

32	1962		0,63488	882	10	0,0123		0,717
33	1962		0,57557	799	10	0,0114		0,701
34	1962		0,66976	930	10	0,0137		0,679
35	1961		0,53258	740	10	0,0115		0,643
36	1961		0,71662	995	10	0,016		0,622
37	1958		0,53161	738	10	0,0108		0,684
38	1955		0,74976	1041	10	0,0184		0,566
39	1952		0,58018	806	10	0,014		0,576
40	1949		0,52577	730	10	0,0139		0,525
41	1946		0,5297	736	10	0,0131		0,562
42	1943		0,49995	694	10	0,0116		0,599
43	1940		0,76626	1064	10	0,0185		0,575
44	1937		0,55982	778	10	0,0141		0,551
45	1934		0,47415	659	10	0,0118		0,558

APPENDIX 5B -STRATIGRAPHY OF PIGMENTS IN SEDIMENT SAMPLE.

					Area [mAU*min]								
Sample	Sediment depth	Year	Extr. Vol	Sediment extracted	Fucoxanthin	Lutein	Alloxanthin	Cantaxanthin	Chl a	Breakdown chl a 1	Breakdown chl a 2	Pheophytin a	Pheophytin a2
	[cm]		[ml]	[g]									
Ertevann1	1	2024,0	3	0,055	0,0767	0,0703	0,3208	0,0666	0,27	0,18	0,07	0,10	0,05
Ertevann2	2	2023,5	3	0,1362	0,1433	0,216	1,1361	0,177	0,97	0,58	0,31	0,31	0,31
Ertevann3	3	2023,0	3	0,1104	0,12	0,2524	2,0169	0,1599	1,00	0,65	0,36	0,26	0,37
Ertevann4	4	2021,0	3	0,0897	0,0871	0,1322	0,8101	0,111	0,58	0,37	0,19	0,18	0,13
Ertevann5	5	2019,0	3	0,1371	0,091	0,2134	1,2737	0,1202	0,84	0,53	0,27	0,27	0,16
Ertevann6	6	2017,0	3	0,15	0,1205	0,1883	1,8773	0,1558	1,03	0,45	0,28	0,36	0,22
Ertevann7	7	2014,3	3	0,1737	0,0683	0,1904	1,2089	0,0951	0,70	0,51	0,24	0,31	0,16
Ertevann8	8	2011,7	3	0,1192	0,0733	0,1101	0,685	0,0638	0,38	0,34	0,18	0,17	0,11
Ertevann9	9	2009,0	3	0,262	0,0716	0,1784	1,1948	0,0766	0,26	0,79	0,34	0,28	0,24
Ertevann10	10	2006,7	3	0,1931	0,0558	0,1253	0,7853	0,0923	0,14	0,58	0,23	0,19	0,15
Ertevann11	11	2004,3	3	0,1752	0,0525	0,1108	0,7839	0,0709	0,13	0,66	0,24	0,27	0,16
Ertevann12	12	2002,0	3	0,1727	0,0399	0,0937	0,7467	0,11	0,14	0,57	0,25	0,28	0,16
Ertevann13	13	2000,0	3	0,205	0,0404	0,1958	1,23	0,0683	0,00	0,82	0,36	0,34	0,19
Ertevann14	14	1998,0	3	0,1341	0,0364	0,1383	0,6175	0,0483	0,07	0,56	0,26	0,23	0,11
Ertevann15	15	1996,0	3	0,107	0,0339	0,07	0,3929	0	0,06	0,41	0,15	0,12	0,07
Ertevann16	16	1993,3	3	0,2059	0,0401	0,2352	1,1655	0,0665	0,12	0,89	0,45	0,31	0,16
Ertevann17	17	1990,7	3	0,2019	0,0386	0,1711	1,4093	0,0989	0,13	0,61	0,37	0,33	0,17

Ertevann18	18	1988,0	3	0,2197	0,0431	0,1346	0,9357	0,1043	0,13	0,57	0,34	0,30	0,18
Ertevann19	19	1987,3	3	0,2281	0,0578	0,2153	1,1121	0,0972	0,18	0,65	0,40	0,36	0,18
Ertevann20	20	1986,7	3	0,1595	0,0379	0,0945	0,6361	0,0678	0,15	0,65	0,30	0,31	0,17
Ertevann21	21	1986,0	3	0,2346	0,0526	0	0,8577	0,1067	0,17	0,99	0,46	0,49	0,24
Ertevann22	22	1983,0	3	0,2163	0,1078	0,2075	2,0988	0,1715	0,40	1,72	0,65	0,74	0,40
Ertevann23	23	1980,0	3	0,1823	0,0864	0,2854	1,8647	0,1571	0,31	1,84	0,66	0,72	0,38
Ertevann24	24	1977,0	3	0,2327	0,1266	0,3972	2,6934	0,2432	0,42	2,14	0,96	0,90	0,61
Ertevann25	25	1973,0	3	0,278	0,1214	0,5309	3,4395	0,2392	0,36	2,40	1,23	1,00	0,61
Ertevann26	26	1969,0	3	0,2837	0,1364	0,5235	3,9624	0,2845	0,44	2,45	1,34	1,06	0,67
Ertevann27	27	1965,0	3	0,3255	0,1223	0,576	3,917	0,3277	0,51	2,74	1,73	1,07	0,69
Ertevann28	28	1964,3	3	0,2236	0,0736	0,4555	3,1419	0,2531	0,40	1,94	0,97	0,74	0,44
Ertevann29	29	1963,7	3	0,4342	0,1153	0,4297	2,9165	0,3709	0,80	2,25	0,99	1,15	0,58
Ertevann30	30	1963,0	3	0,3136	0,0922	0,1325	1,5003	0,1439	0,28	1,91	0,69	0,88	0,47
Ertevann31	31	1962,7	3	0,2913	0,0625	0,0758	0,942	0,0831	0,17	1,44	0,42	0,59	0,34
Ertevann32	32	1962,3	3	0,364	0,087	0,1087	1,6281	0,1616	0,27	1,57	0,59	0,83	0,50
Ertevann33	33	1962,0	3	0,3811	0,0807	0,1284	1,555	0,1961	0,26	1,82	0,68	0,87	0,60
Ertevann34	34	1961,7	3	0,3623	0,0868	0,1468	1,4541	0,1675	0,25	1,45	0,62	0,71	0,45
Ertevann35	35	1961,3	3	0,345	0,0814	0,0933	1,0102	0,1511	0,22	1,32	0,55	0,61	0,35
Ertevann36	36	1961,0	3	0,3794	0,061	0,0914	1,1206	0,1375	0,21	1,25	0,55	0,70	0,39
Ertevann37	37	1958,0	3	0,3584	0,0505	0,047	0,9628	0,1626	0,14	0,96	0,42	0,56	0,33
Ertevann38	38	1955,0	3	0,4825	0,0565	0,0541	0,8156	0,1479	0,13	0,78	0,39	0,62	0,31
Ertevann39	39	1952,0	3	0,4162	0,0264	0	0,5169	0,1542	0,13	0,66	0,31	0,54	0,25
Ertevann40	40	1949,0	3	0,4085	0	0	0,2235	0	0,06	0,58	0,27	0,37	0,16
Ertevann41	41	1946,1	3	0,4977	0,0527	0	0,6966	0,205	0,11	1,06	0,53	0,72	0,40

Ertevann42	42	1943,1	3	0,56	0,0703	0,034	1,2803	0,2903	0,17	1,54	0,74	1,02	0,61
Ertevann43	43	1940,1	3	0,4368	0,0535	0,05	1,0455	0,2158	0,13	1,06	0,58	0,82	0,46
Ertevann44	44	1937,2	3	0,5509	0,0638	0,0579	1,4796	0,264	0,16	1,36	0,71	0,80	0,52
Ertevann45	45	1934,2	3	0,6521	0,0997	0,287	2,5229	0,27	0,44	1,55	0,90	1,03	0,62

Concentration [µg/g dry weight in sediment]										
Fucoxanthin	Lutein	Alloxanthin	Cantaxanthin	Chl a	Breakdown chl a 1	Breakdown chl a 2	Pheophytin a	Pheophytin a breakdown	Total chl a	Chla/broken down chl a
1,403	1,899	5,454	1,132	8,196	5,314	2,024	12,600	7,168		0,302
1,059	2,356	7,799	1,215	11,717	7,074	3,747	16,810	16,655	56,003	0,265
1,094	3,396	17,082	1,354	14,944	9,702	5,353	16,884	24,494	71,376	0,265
0,977	2,189	8,444	1,157	10,720	6,893	3,407	14,614	10,187	45,821	0,305
0,668	2,312	8,687	0,820	10,084	6,365	3,220	14,483	8,461	42,614	0,310
0,808	1,865	11,702	0,971	11,292	4,934	3,105	17,348	10,595	47,274	0,314
0,396	1,628	6,508	0,512	6,625	4,801	2,233	12,996	6,741	33,397	0,247
0,619	1,372	5,373	0,500	5,292	4,707	2,466	10,374	6,926	29,765	0,216
0,275	1,012	4,264	0,273	1,649	4,962	2,132	7,757	6,781	23,280	0,076

0,291	0,964	3,803	0,447	1,179	4,924	1,995	7,253	5,574	20,924	0,060
0,302	0,939	4,184	0,378	1,260	6,255	2,289	11,350	6,838	27,992	0,047
0,233	0,806	4,043	0,596	1,381	5,488	2,354	11,743	6,840	27,806	0,052
0,198	1,419	5,610	0,312	0,000	6,634	2,930	12,206	6,825	28,596	0,000
0,273	1,532	4,306	0,337	0,915	6,927	3,215	12,677	5,852	29,586	0,032
0,319	0,972	3,433	0,000	0,852	6,286	2,341	8,145	4,767	22,392	0,040
0,196	1,697	5,293	0,302	0,928	7,093	3,621	11,038	5,698	28,378	0,034
0,192	1,259	6,527	0,458	1,051	4,962	3,011	12,069	6,161	27,253	0,040
0,197	0,910	3,982	0,444	0,974	4,286	2,585	9,997	5,884	23,725	0,043
0,255	1,402	4,559	0,398	1,304	4,664	2,866	11,520	5,731	26,085	0,053
0,096	0,352	2,370	0,200	0,600	2,668	1,238	9,445	5,105	19,055	0,032
0,090	0,000	2,172	0,214	0,475	2,778	1,296	10,223	4,955	19,728	0,025
0,201	0,570	5,766	0,373	1,226	5,237	1,990	16,510	8,981	33,944	0,037
0,191	0,930	6,078	0,405	1,128	6,656	2,373	19,144	10,100	39,400	0,029
0,219	1,014	6,878	0,491	1,185	6,059	2,718	18,805	12,789	41,556	0,029
0,176	1,135	7,352	0,405	0,845	5,698	2,918	17,546	10,626	37,633	0,023
0,194	1,096	8,299	0,472	1,012	5,704	3,113	18,151	11,541	39,521	0,026
0,151	1,052	7,151	0,473	1,034	5,548	3,503	15,996	10,290	36,370	0,029
0,133	1,210	8,350	0,532	1,192	5,713	2,864	16,003	9,499	35,271	0,035
0,107	0,588	3,991	0,402	1,216	3,424	1,501	12,848	6,453	25,444	0,050
0,118	0,251	2,843	0,216	0,592	4,021	1,447	13,618	7,206	26,884	0,022
0,086	0,155	1,922	0,134	0,384	3,265	0,953	9,839	5,670	20,111	0,019
0,096	0,177	2,658	0,209	0,483	2,839	1,068	11,017	6,630	22,037	0,022

0,085	0,200	2,425	0,242	0,456	3,153	1,171	11,141	7,600	23,520	0,020
0,096	0,241	2,385	0,217	0,455	2,649	1,129	9,535	5,986	19,753	0,024
0,095	0,161	1,740	0,206	0,429	2,517	1,046	8,578	4,948	17,518	0,025
0,065	0,143	1,755	0,170	0,364	2,174	0,962	8,916	4,982	17,398	0,021
0,057	0,078	1,596	0,213	0,250	1,763	0,775	7,569	4,454	14,811	0,017
0,047	0,067	1,004	0,144	0,184	1,067	0,528	6,278	3,113	11,170	0,017
0,026	0,000	0,738	0,174	0,200	1,045	0,487	6,355	2,969	11,056	0,018
0,000	0,000	0,325	0,000	0,097	0,936	0,433	4,387	1,935	7,788	0,013
0,043	0,000	0,832	0,194	0,141	1,405	0,705	6,979	3,870	13,100	0,011
0,051	0,036	1,359	0,244	0,197	1,811	0,875	8,856	5,303	17,041	0,012
0,049	0,068	1,422	0,232	0,192	1,607	0,876	9,112	5,114	16,901	0,012
0,047	0,062	1,596	0,225	0,194	1,623	0,846	7,056	4,585	14,304	0,014
0,062	0,262	2,299	0,195	0,444	1,571	0,907	7,639	4,584	15,146	0,030

APPENDIX-6 CORELATION BETWEEN KEY VARIABLES

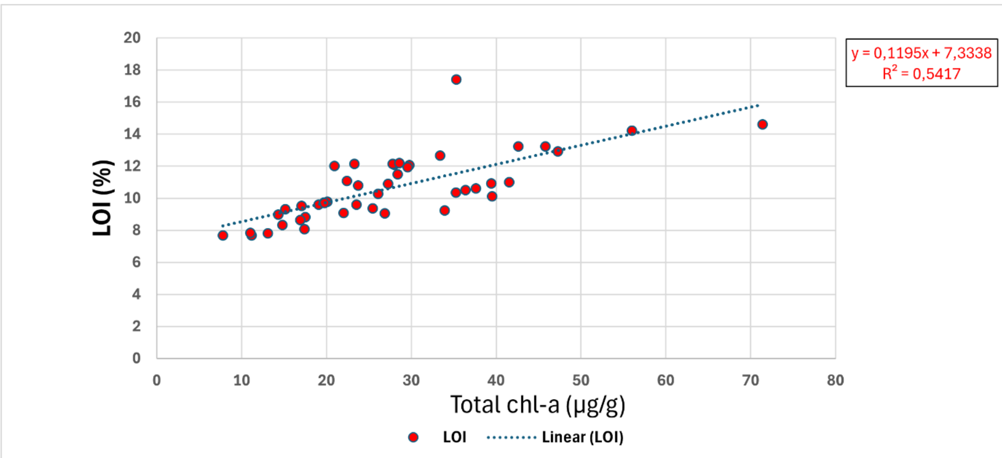

Figure 6A: Scatter plot showing the relationship between LOI (%) and Total chla-a (µg/g) in Lake Ertevannet. Here, each point represents a sediment layer.

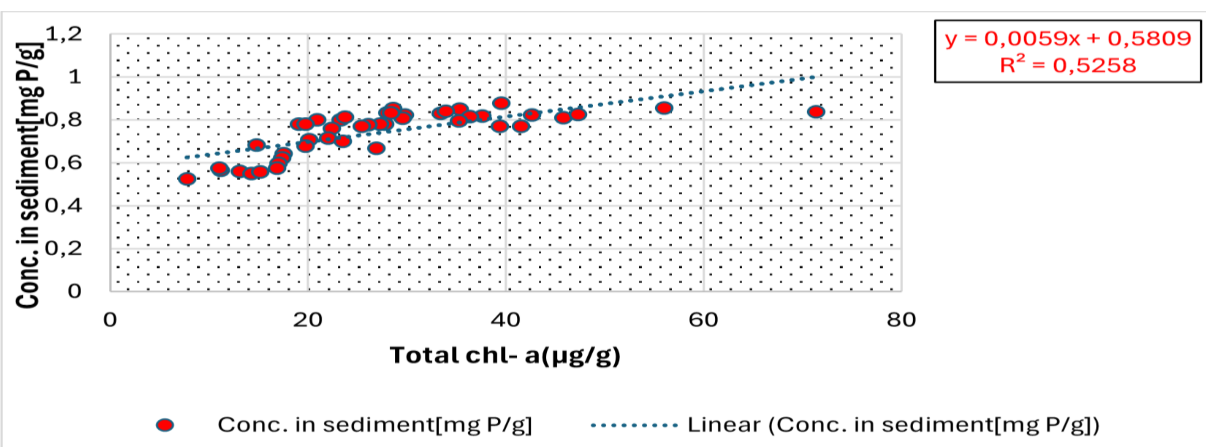

Figure 6B: Scatter plot showing the relationship between sedimentary P as TP (conc. In sediment (mg./ g) and Total chla-a (µg/g) in Lake Ertevannet. Here, each point represents a sediment layer.

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