MISSION MJØSA

The Mjøsa Assessment

A comprehensive review of the current state of knowledge on the Mjøsa Lake System and its surroundings

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Chapter 1: Setting the Scene

Elizabeth S. Barron, Preema Ranjitkar and Sajith Prabashwara Ranatunga

1.1   Executive Summary

Lake Mjøsa is Norway's largest lake and is very important to many people. It faces increasing challenges as a result of development, industry, agriculture, and climate change. The Inland County Council, the municipalities in the region and The Norwegian University of Science and Technology (NTNU) have taken the initiative for a major program to address these intertwined challenges. It is called Mission Mjøsa.

Mission Mjøsa aims to contribute to increased sustainability and value creation in the region, by implementing broad and coordinated strategies with many actors who have interests in and around Mjøsa. There is considerable interest in the lake and its surroundings due to the economic, cultural and historical significance of the lake. While Mission Mjøsa is primarily a research agenda, communication and public engagement are core tasks for the team and NTNU.

The current assessment sits at the intersection of research and public outreach. Modeled after the assessment process of the Intergovernmental Panel for Biodiversity and Ecosystem Services (IPBES, "Naturpanelet" in Norwegian), the Mjøsa Assessment is a comprehensive report on the state of knowledge on Lake Mjøsa. Through a series of six chapters, it summarizes Mjøsa's history, its social and political conditions, its hydrology, biology and ecology, and the use of various advanced technologies in better understanding the lake. In chapter six, drawing from the information presented in chapters two through five,

it addresses policy relevant questions introduced in chapter one, and used as organizing themes throughout, to tie the various chapters together. In this way the assessment is meant as an interdisciplinary "first stop" for anyone interested in understanding Lake Mjøsa and its surroundings, considering some of the most pressing topics at the science-policy interface.

We hope that this report can be a useful document for those in the public and private sectors interested in learning more about the Mjøsa area, and a valuable contribution for curious students and scholars wondering what is already known, and what knowledge gaps exist that deserve attention. On a practical level, we envision that the Mjøsa Assessment can provide a model for how to adapt the complex and expansive global environmental assessment process to more local or regional questions, and as such could serve as an example for others throughout the *EU Mission: Restore our Oceans and Waters* network, of which Mission Mjøsa is a member. Therefore, the report is made available in its entirety in both Norwegian and English.

We have taken a decidedly geographical and place-based approach to our environmental assessment, drawing as much from the social sciences and humanities as from the biophysical and technical sciences. This is evident in the framing of the policy-relevant questions, the adaptation of the IPBES conceptual model as an interdisciplinary framing guideline, and not least in the synthesis

discussions presented in chapter six. Thus, we also hope our report can provide a valuable example of the importance of interdisciplinary collaboration in assessment.

1.2 Introduction to Lake Mjøsa

"Tar du Mjøsa fra en som har vokst opp i traktene rundt innsjøen, tar du bort noe de fikk i dåpsgave" "If you take Mjøsa away from someone who grew up in the areas around the lake, you take away something they were given as a christening gift" (Bergman and Hjelpestein 2004, 9).

Many across Norway and beyond hold deep personal connections to landscape and place, and those living on the shores of Lake Mjøsa and its surroundings are no different. Christening gifts are meant as blessings, for protection and to provide spiritual guidance through a lifetime oriented to God and the Church. The gift of the lake is to orient one to place, to the waters and surrounding lands and all they hold, to support life and provide cultural, social, and perhaps even some spiritual orientation.

Lake Mjøsa, located in southern Norway, has been a resource for people for thousands of years. Currently, seven municipalities border the lake, which are split across two counties but occur primarily in Innlandet county (Figure 1.1). While only seven municipalities are on the lake, 14 are discussed within this assessment because they affect or are affected by the lake in different ways (Table 1.1) and therefore are included in the various sources reviewed here.

Lake Mjøsa is a source of drinking water for animals and humans and a prerequisite for value creation as a water source for agriculture, industry and hydropower

production. Mjøsa is biodiverse-rich, and it is highly valued as a recreational resource and fishing lake. Mjøsa has also been a transport route, and a dump. As if the lake could wash away transgressions and bad memories, it served as a dumping ground for large amounts of munitions and other waste for centuries, and it continues to be negatively affected by agricultural runoff. At irregular intervals, blooms of potentially harmful bacteria occur, initiating local mitigation measures. Due to high levels of environmental toxins such as PCBs and mercury, dietary advice has been implemented to limit the consumption of fish from the lake.

From the 1960s, Lake Mjøsa experienced strongly negative environmental development, and the danger of reaching a critical tipping point for eutrophication was met with a large-scale rescue operation to stop permanent damage to the lake – better known as "Mjøsaksjonen". The operation was expensive and extensive; many considered the resulting measures successful (Oppdrag Mjøsa 2023 internal report).

Since Mjøsaksjonen, there has been a lot of monitoring activity in Mjøsa by many national and regional actors including the Norwegian Waterways Association, The Norwegian Armed Forces (specifically Forsvarsbygg), The Norwegian Institute for Water Research (NIVA), The Norwegian Institute for Nature Research (NINA) and HIAS (a regional wastewater company established during Mjøsaksjonen). The data recorded through these ongoing monitoring efforts support broad agreement that an intensified interdisciplinary effort and the use of new technology are now needed to respond to the full range of challenges emerging in the region (Oppdrag Mjøsa, 2023 internal report).

Municipalities	Sits on lake border	County
Eidsvoll	Yes	Akerhus
Hamar	Yes	Innlandet
Lillehammer	Yes	Innlandet
Gjøvik	Yes	Innlandet
Løten	No	Innlandet
Stange	Yes	Innlandet
Østre Toten	Yes	Innlandet
Ringsaker	Yes	Innlandet
Øyer	No	Innlandet
Gausdal	No	Innlandet
Vestre Toten	No	Innlandet
Norde Land	No	Innlandet
Søndre Land	No	Innlandet
Gran	No	Innlandet

Table 1.1: Counties and municipalities (as of 2024) included in the Assessment
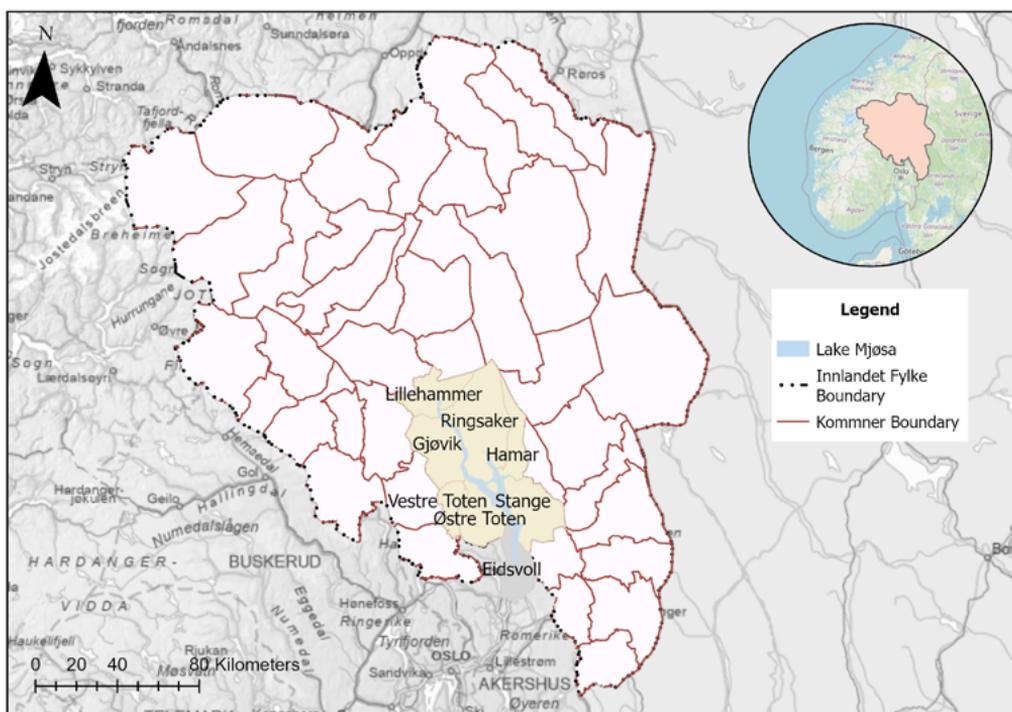
Figure 1.1: Administrative map of counties and municipalities bordering Lake Mjøsa

It is important to note that while it is possible to delineate the municipal, county and lake borders, there is no clear definition of what constitutes the "Mjøsa region". The region has been conceptualized in various ways, depending on the time period and the focus of particular studies; this is apparent in the source materials for the different chapters presented here. While Chapter 2 (The historical meaning of Mjøsa) and Chapter 3 (Social and cultural perspectives on the region of Mjøsa) look at the Mjøsa region through present and historical administrative boundaries of municipalities and counties, Chapter 4 (Biological and ecological status and trends) provides an overview of the lake based on its hydrological demarcation as a catchment area with rivers and tributaries (Figure 1.2).

Chapter 5 (Scenarios, modelling & technology), on the other hand, looks at Mjøsa based on the lake itself, and in relation to different points of interest within the lake. The result is that the assessment reflects how different fields and research interests study and understand the Lake and its surroundings differently. The implications of this for long-term management and sustainability are discussed in Chapter 6 (section 6.2).
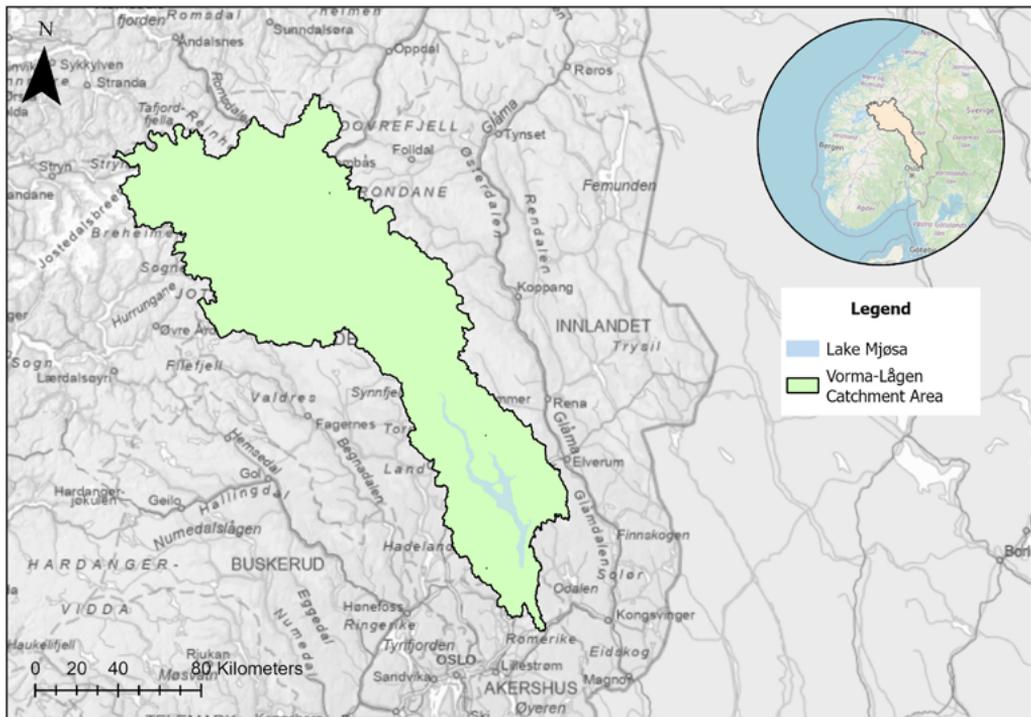
Figure 1.2: The Vorma-Lågen Catchment Area, in which Lake Mjøsa sits.

1.3   The Mjøsa Assessment

There is a range of material available on Lake Mjøsa, across academic fields and from public and private research institutions, but it has not been collated and discussed in one place. The Mjøsa Assessment is an attempt to collect and review as much relevant material as possible, to provide an overview of the state of knowledge on Lake Mjøsa and its surroundings. It is modeled after the internationally recognized strategies of global environmental assessments (GEA). GEAs are large-scale reports synthesizing existing knowledge on thematic or methodological topics meant to inform public policy (Kowarsch & Jabbour, 2017). Assessments are not meant for policy prediction or prescription, but to provide a baseline of knowledge that is readily accessible and transparent.

Mission Mjøsa is organized into six research tracks that together create a broad and interdisciplinary approach to understanding the lake and its surroundings. The current project period, 2023-2027, includes the goal of contributing to lake management with concrete solutions, new knowledge and a more sustainable model for management of Mjøsa. While the assessment is not meant to provide solutions or new knowledge, we believe it can serve as a foundation for sustainable management by providing baseline information and highlighting the need for an interdisciplinary approach to decision-making processes.

To ensure the contributions from Mission Mjøsa are evidence based, it is critical to use existing knowledge as the foundation for any further research and policy-relevant contributions. To achieve these goals, an initial group of PhD candidates was hired to assist in research tracks Water, Surroundings, People, History,

Technology, and the Digital Twin. One of the key learning outcomes for the PhD candidates is to develop tools and skills as interdisciplinary scholars alongside the development of their individual projects. Thus, this assessment fulfills two core objectives of Mission Mjøsa: (1) to provide a baseline of knowledge for current and future work, which includes identifying knowledge gaps, and (2) to serve as a team building exercise in interdisciplinary collaboration.

Mjøsa Mission draws inspiration for its interdisciplinary approach from the conceptual model developed and used by the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) (Diaz et al., 2015). In the IPBES figure starting at the top and moving clockwise the boxes represent: "Good quality of life", "direct drivers", "nature", and "nature's benefits to people". The green text is how these elements are referenced in scientific parlance. The blue text shows examples of how they are referenced among Indigenous and local communities. The central boxes are "anthropogenic assets" on the top and "Institutions and governance and other indirect drivers" below. Figure 1.3, below, is an adaptation of the conceptual model to show the relationships between different system components as they have been identified specifically for Lake Mjøsa and its surroundings. Yellow figures represent parts of the system that are societal and of special interest. Blue in the model represents natural science and biological dimensions. Green shows areas with explicit overlap and integration of social and natural components. Arrows along the outside of the box indicate the important role of changes over time and space. The figure illustrates the relationships between key aspects of the research pipeline, but it is not intended to be exhaustive.
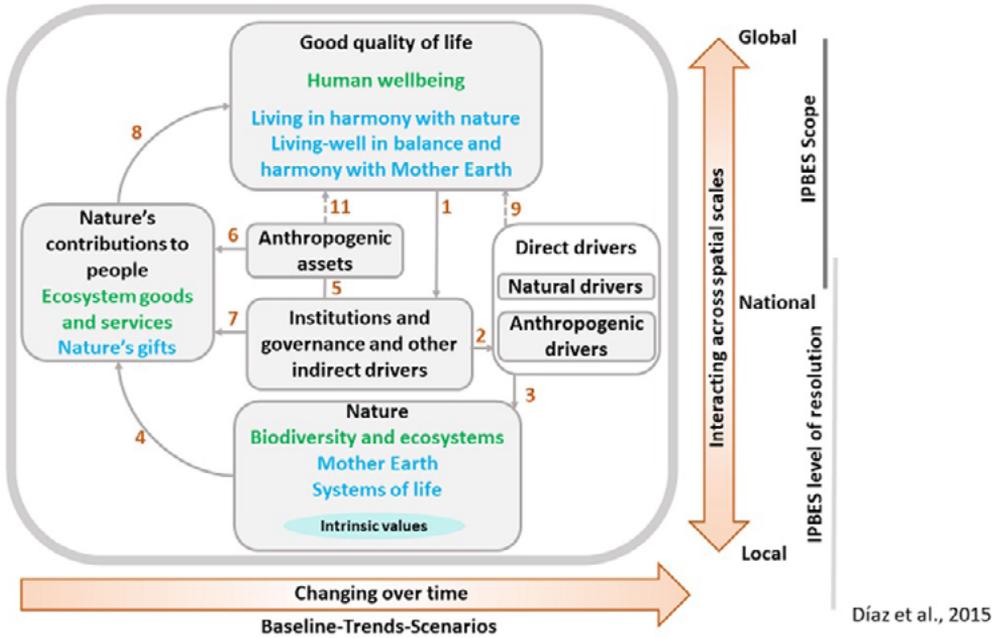
Figure 1.3: Top: IPBES conceptual model. Bottom: Interdisciplinary framework for Mission Mjøsa.

Starting at the top in the middle (Fig 1.3 top), the concept of "good quality of life" addresses elements of health, identity, gender, politics and livelihoods (chapter three). Moving clockwise, pollution, climate change, fishing pressures and land use are important drivers of change in the Mjøsa system (chapters three & four). The ecosystem around Mjøsa (the bottom blue box) includes both biotic and abiotic elements, both in the water and on land (chapter four). On the left, the IPBES system element "Nature's contribution to people" captures the many ways in which nature and human society mutually support and benefit from each other. The long legacies of this in the Mjøsa region are presented in Chapter two. The two elements in the middle are the most societal. The top one focuses on human resources, which includes education and local populations in the Mjøsa area. The bottom one includes the role of institutions, governance and other social and indirect drivers, including the role

of the state and the Mjøsaksjon. These topics are addressed in chapter two and three. Chapter five pertains to observation over time and across multiple scales, represented in the figure by the external arrows.

Policy relevant questions

The Assessment is a review of existing literature and knowledge, not an overview of current research or of the intended contributions of active projects. While the Assessment is not meant to be policy prescriptive or offer solutions to the complex problems the region is facing, based on their review and discussion with stakeholders, the research team has identified a series of policy relevant questions to which the Assessment speaks, and where there are clear knowledge gaps. The topics are demographics and human services, pollution, climate change, sustainable development, and governance. Various aspects of these topics are discussed in the different chapters, and a synthesis and knowledge gaps are presented in chapter six.

The questions are as follows:

1. What role will changing demographics play in future land management and development in the Mjøsa area? (demographic shift)

2. What are some of the implications on drinking water supply and recreational fisheries of the ways in which pollution and water contamination are managed? (pollution)

3. How will planning for climate change, both mitigation and adaptation, affect lake management and surrounding areas? (climate change)

4. How does planning to meet SDG targets by 2030, at national, county and municipal levels, affect plans for regional development and resource management? (SDGs)

5. How does the scalar mismatch between biological and hydrological delineations and jurisdictional boundaries affect monitoring and management decisions and the availability of relevant knowledge for those processes? (multi-scalar governance)

1.4   Methodology

The Mjøsa Assessment was conducted from the fall of 2024 through the summer of 2025. The scope and framing were initially designed by E.S. Barron, based on her experience working as a coordinating lead author on the IPBES Sustainable Use Assessment (Barron et al., 2022). The plan was reviewed and approved by the core leadership and senior research team of Mission Mjøsa. Barron has served as editor of the document and lead author for chapter one and six. PhD candidates working across the various research tracks of Mission Mjøsa served as lead authors on each of the four substantive chapters and supported the first and sixth chapters. Additional smaller contributions have been made by a range of colleagues and associates at NTNU and beyond. Authors and contributors for each chapter are listed alphabetically rather than in order of measured contribution. The assessment represents a key interdisciplinary output from Mission Mjøsa and the Surroundings research track during the current work program.

The review is based on scientific literature and white and grey literature located by the authors or suggested by affiliates and interested parties. Due to ongoing research and publications (not least by members of Mission Mjøsa), it is necessary in reports of this nature to specify a cut-off period after which newly recommended or published literature will no longer be reviewed for inclusion of the assessment would likely never be completed. For this report our review period extended from September of 2024 through August of 2025, which is to say anything published or recommended to the author team after August 2025 is not included in this review. At the beginning of each chapter the authors have provided more detailed information regarding their literature identification and review process. Chapter two provides an historical review of key

events happening in and around the lake, with an emphasis on elements that continue to be relevant in the contemporary period. Chapter three includes information about social services, cultural institutions, more contemporary social and cultural history, demographics, and human health. Chapter four is an overview of climate, geology, biology, key information about lake ecology, and links and references to the most current reports and online datasets. Chapter five provides a review of how technology has been used to understand the lake and its surroundings, with a focus on what technologies are being deployed as part of Mission Mjøsa to advance learning and management in real time. It includes a comprehensive list of datasets, satellites, and relevant information to help those interested in this area. Finally, in chapter six we address the policy relevant questions laid out above by drawing from the material in previous chapters. We identify key knowledge gaps and areas for future research. Appendix 1 includes the team's translations for some of the more complicated Norwegian - English translations. Appendix 2 is a list of key institutions, terms, abbreviations, and acronyms and is included so that names of agencies and such do not have to be written out in every chapter, and to assist with cross-disciplinary reading.

The assessment followed a production and review process based on global environmental assessment procedures (e.g. IPBES) adapted for our needs and conditions. While the intended audience is primarily within Norway, the initial drafts of the document were written in a mix of English and Norwegian, based on the language preferences of the authors and the source material. The authors produced first order drafts of each chapter, which were reviewed by the editor and senior scientific staff in Mission Mjøsa. Comments were collected in a single spreadsheet, which included a space for an author response on how

each comment was addressed. Completed second order drafts were compiled and edited into the current document. The second order draft underwent a similar open comment and review period, with additional participation from external reviewers. All references were collected in Zotero (a free online reference organizing software) and are publicly available; pdfs have been stored in the Mission Mjøsa digital archiving system for easy access upon request. Within this report, we follow the American Psychological Association (7th edition) standard for references, with a slight modification to in-text citations such that multiple publications with the same first author from the same year are disambiguated by adding a letter at the end of the year instead of additional author names.

The final version is available in its entirety in Norwegian and English after undergoing professional translation (i.e. not AI) by Sematrix. We felt this was a critical choice for the integrity of the report and the knowledge contained therein. Every effort was made to engage with all interested parties to produce a thorough and comprehensive assessment of the current state of knowledge about Lake Mjøsa, but of course there are always overlooked resources and missed opportunities. The authors take full responsibility for this, and kindly request the reader's understanding and patience with errors or oversights. It is not uncommon with such reports to produce updated editions at periodic intervals, at which time we hope there will be new and interesting knowledge to report.

Chapter 2: The historical significance of Lake Mjøsa

Even Næss Bergseng, with contributions by Marton Bay Wærnes

2.1 Summary

This chapter presents a review of the literature covering the historical development of Lake Mjøsa and the Mjøsa region, with emphasis on the settlement history, fishing, transportation history, regulation and flood history, pollution, environmental activism and ammunition dumping. In terms of time, the chapter spans from the first settlement in the vicinity of Lake Mjøsa around 6000 BCE up to the late 20th and 21st centuries, where it bears relevance to the topic in question. The material used for this chapter is a mix of peer-reviewed texts, general introductory books and literature of a more local historical nature.

The review shows that Lake Mjøsa has historically been of great importance to the surrounding settlements, as a source of food and drinking water, as a secondary income for farmers, and as a transport route for boats and log driving. A pinnacle was reached with steamboat traffic in the mid-19th century. The lake has also been regulated for hydropower production. In recent times, however, Lake Mjøsa's economic and transportation significance has diminished. The establishment of the railway along the eastern shore of Lake Mjøsa toward the end of the 19th century, followed by the construction of roads throughout the 20th century, gradually made the waterway less important – initially for through-traffic, and eventually also for local travel and transport. This was despite the ambitious plans to connect Lake Mjøsa to the Oslo Fjord through a system of canals. During the 20th century, fishing in Lake Mjøsa was reduced to a leisure activity. For short periods, the water in Lake Mjøsa has been exposed to severe pollution during floods, as exemplified by the Storofsen flood in 1789. However, it was not until the late 19th century and especially throughout the 20th century that pollution became a growing and persistent problem, resulting from increasing discharges from agriculture, industry and private households.

Despite much having been written about Lake Mjøsa and the Mjøsa region from a historical perspective, the review shows that there is a lack of comprehensive overviews of the history of the Mjøsa region in particular, and of the history of the Innlandet area in general. The review also highlights the need for more archaeological and historical research on Lake Mjøsa's environmental history, including prehistoric flood events and the dumping of ammunition in the 20th century.

2.2   Introduction

When the German geologist Leopold von Buch travelled through Norway in 1810, right in the midst of the Napoleonic Wars, he described Lake Mjøsa as "the small inland Sea of Norway, which appears calculated to carry commerce and prosperity into the heart of the country" (von Buch, 1810).1 Von Buch was primarily interested in the opportunities the vast lake provided for transporting goods and passengers into the otherwise difficult-to-access area of Innlandet, as it had done for over a thousand years. In addition, Lake Mjøsa has also provided people with an abundant supply of food and drinking water. In more recent times, Lake Mjøsa has served as a reservoir for energy-intensive industries further down the watercourse, as flood control for the area, and as a recipient of various forms of human and industrial waste. It is especially the latter that has strained the relationship between the lake's biodiversity and humans, not only in the Mjøsa region but also further downstream in the Oslo Fjord. Urbanisation, industrialisation and the modernisation of agriculture from the mid-19th century onward led to large and increasing discharges of organic waste, nutrients, heavy metals, chemicals and eventually plastic. The dumping of ammunition from around World War II until the 1970s, and the massive blooms of cyanobacteria (blue-green algae) in the 1950s and 1960s, represent low points in the history of humans' relationship with Lake Mjøsa.

This chapter will provide a brief introduction to the historical significance of Lake Mjøsa, how people have coexisted with it, and the historical literature that has been written about it. Ever since the Stone Age, humans' relationship with Lake Mjøsa and their ability to benefit from and influence the lake have changed in step with broader social, cultural, technological and economic developments. The same is true regarding humans' ability to understand the lake's ecological conditions and to act based on that understanding. While Lake Mjøsa was once one of the most important transportation routes in Innlandet and fishing was an important source of income for the local population, these days the lake serves as a source of drinking water, a reservoir for hydropower and a recreational area.

The material used for this chapter is a mix of peer-reviewed texts and literature of a more local historical nature. Some of the works focus directly on Lake Mjøsa, the watercourse, or the surrounding towns and villages, while others address aspects of Lake Mjøsa and the Mjøsa region in relation to a broader overarching theme. The literature was primarily found through searches in the Oria library database and the National Library of Norway's online library, but also through discussions with others in the Mission Mjøsa research programme, including Arne Julsrud Berg and Øyvind Ødegård. The vast majority of the material is available to read online through, among others, the National Library of Norway. The chapter also discusses a number of older historical sources to illustrate some of the extensive historical material available.

The reason for this mix of material is that there are relatively few peer-reviewed historical studies, articles, or books that focus directly on the history of Lake Mjøsa. One of the main findings of this

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1   Original German text: "Er tritt hier aus dem Miosensee, dem kleinen, innern Meere von Norwegen; recht gemacht Verbindung und Wohlstand bis im Herzen des Landes zu bringen." (Buch, 1810). English translation from 1813: " [...] *the small inland Sea of Norway, which appears calculated to carry commerce and prosperity into the heart of the country.*"(Buch, 1813)

chapter is that there is a complete lack of a systematic historical overview of the Mjøsa region and Innlandet, covering both earlier and more recent history. *Den store Mjøsboka* (Stensrud, 1991) is a good popular science introduction, but the historical section is limited in scope and the book lacks source referencing.

There are several ways of defining the relevant geographic area for historical studies of Lake Mjøsa, depending on what is being studied, or which time periods are involved. Currently, Lake Mjøsa lies within the administrative boundaries of two counties (Innlandet and Akershus) and seven municipalities (Eidsvoll, Østre Toten, Gjøvik, Lillehammer, Ringsaker and Hamar). Throughout history, the administrative boundaries have changed several times, both at the regional level and what corresponds to today's municipal level. In this chapter, we have chosen to use the term *Mjøsa region,* referring to what currently corresponds to the seven municipalities, as well as present-day Vestre Toten. There are three reasons for this: its geographic proximity to Lake Mjøsa, the fact that present-day Vestre Toten was historically part of the same administrative unit as Østre Toten (the Parish of Toten), and that parts of the municipality are practically considered part of the urban area of Gjøvik.

The first section addresses the main features of the settlement history around Lake Mjøsa, focusing on population development and urbanisation, as well as a brief discussion on livelihoods. The second section focuses on fishing in Lake Mjøsa from an historical perspective. The third section mainly looks at boat traffic on Lake Mjøsa and touches on the ideas of constructing a canal between the lake and the sea. Finally, the fourth section focuses

on the regulation of the lake and historical flood events. Even Næss Bergseng has written most of the text in the chapter. The fourth section, written by former master's student Marton Bay Wærnes, addresses the literature and main features related to the pollution history of Lake Mjøsa. The sections are not intended to be exhaustive on the topics, but rather to serve as introductions for further reading and research.

2.3   Settlements around Lake Mjøsa

People have lived around Lake Mjøsa for approximately 8000 years. Fishing, hunting, the fertile soil, the timber in the forests, and the easily accessible waterway formed the basis for migration and the permanent settlement that was to come. The first market town, or *kaupang*, Hamar, was most probably established in the mid-11th century but was burned down and abandoned in the 16th century. It was not until three hundred years later that the Mjøsa region once again got a town of its own, Lillehammer, which was soon followed by the reestablishment of Hamar and the founding of Gjøvik. In the first half of the 19th century, the Mjøsa region and Innlandet2 experienced major population growth and was one of Norway's most populous areas. Today, Innlandet as a whole is one of the counties with the lowest population density and slowest population growth, while the areas in and around the towns of Mjøsa continue to experience steady population growth.

This section presents some of the main features of the settlement history around Lake Mjøsa, and key works for further study. As mentioned above, there are no

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2   'Innlandet', in the definite form, is the name of the newly merged county from 2020, consisting of the former counties of Hedmark and Oppland. Historically, this area was collectively called 'Opplandene', as during the period of the administrative region 'Oplandenes amt' from 1757 to 1781. '[i]nnland' and 'oppland' in the indefinite form can refer to areas that are, respectively, some distance from the coast or surrounding a larger town. For the sake of simplicity, we use 'Innlandet', even though it is a relatively new term historically.

historical overviews of the Mjøsa region or Innlandet. However, there are published histores of individual towns, villages and landscapes such as Lillehammer (Bjørnhaug, 2000; Feiring, 2004; Rugsveen & Stang, 1996), Gjøvik (Mollgard, 1961; Ruud, 2010) and Hamar (Gjerdåker, 1998; Lillevold, 1987). Regarding the villages and landscapes, Svein-Erik Ødegaard's multi-volume work on Stange is particularly noteworthy (Ødegaard, 2006a, 2016, 2022), as well as *Hedemarks historie* (Halvorsen & Hedmark historielag, 1957), and the multi-volume *Eidsvoll Bygds Historie* (1950–1961), edited by Andreas Holmsen with contributions from several well-known historians, including

Edvard Bull and Rolf Fladby (Eidsvoll bygdebokkomite, 1952). Håvard Havin Kongsrud, on behalf of Toten historielag (*Toten Historical Society*), is writing a new book on the history of Toten, focusing mainly on the Middle Ages. There are also several local history books, such as for Brumunddal (Hedmarksmuseet og Domkirkeodden, 1986), Moelv (*Moelven*, 2019) and Helgøya (Enemo, 2021). Many local history yearbooks are published annually, with *Mjøsmuseets årbok (Mjøsmuseet's Yearbook)* being particularly noteworthy in this context, as it has published several topical issues directly related to Lake Mjøsa.

8500 BCE	The inland ice retreated from Lake Mjøsa.
6000 BCE	The first signs of humans (hunter gatherers) in the Mjøsa region.
4000 – 1800 BCE.	Neolithic period: Land cultivation and permanent settlement in the Mjøsa region.
500 BCE.	Rich archaeological finds from Åker Farm dating from the Late Iron Age.
1049	Probable year of the establishment of a mint press in Hamar by King Harald Hardrade.
1153	The establishment of Hamar diocese.
1230	The construction of Mjøsa Citadel (Mjøskastellet) at Steinsholmen in Ringsaker by King Haakon IV. Mentioned in a papal letter from 1234.
1537	The diocese moved to Oslo during the Reformation.
1563 1570	Hamar was set on fire by Swedish soldiers during the Nordic Seven Years' War. The marketplace was moved to Oslo, and Hamar was effectively abandoned as a kaupang (market town).
1789	'Storofsen', a flood disaster that affected large parts of Innlandet.
1827	Lillehammer was established as a market town with limited privileges, gaining full city status in 1842.
1848	Hamar was established as a market town.
1861	Gjøvik was established as a market town.
2010	Moelven and Brumunddal are given city status.
2020	Oppland and Hedmark are merged into Innlandet County Authority

Table 2.1: Timeline of the settlement around Lake Mjøsa

Settlement in the Mjøsa region from the Stone Age to the Iron Age

Dahl et al. write in *Mjøsområdets geologi* (*Geology of the Mjøsa Area*) that the ice retreated from the area around Lake Mjøsa approximately 9000 years ago (7000 BCE). (Dahl et al., 2017). Humans are believed to have arrived about a thousand years later (6000 BCE), drawn by the fish in the lake and rivers and the abundant wildlife in the forests, including moose, which are thought to have reached Innlandet at this time (Rugsveen & Stang, 1996). Land cultivation took place later, during the Neolithic period (4000 – 1800 BCE). (Amundsen, 2011; Dahl et al., 2017; Damlien et al., 2021; Pilø, 2005). It was primarily the calcareous soil and the favourable local climate that formed the basis for fertile agricultural communities.

Rich cultural heritage finds have been made along Lake Mjøsa's shores from both the Bronze Age (1800–500 BCE) and the Iron Age (approximately 500 BCE–1050 CE). As indicated in the 2015 *Mjøsmuseet Yearbook,* many burial mounds and hillforts located on headlands and points extending into Lake Mjøsa suggest that the lake must have played a key role during this period (Sandodden & Smiseth, 2015). They believe chieftains wanted to be buried along the waterways so that passing travellers could see the burial mounds and be impressed. According to Sandodden and Smiseth, the yield from the fertile agriculture, particularly in Toten and Hedemarken, combined with control over trade in iron, furs and other hunting products, was the source of the wealth reflected in many of these finds. The graves are also evidence that society, especially in the Late Iron Age, was socially stratified, with chieftains, farmers, tenant farmers, and slaves.

While large upheavals and periods of decline were taking place in other parts of Norway around the 6th century CE (at the transition between the Early and Late Iron Age), Sandodden and Smiseth claim that the Mjøsa region and Innlandet were instead experiencing a time of prosperity (Sandodden & Smiseth, 2015). Among the archaeological finds from this period around Lake Mjøsa, the so-called Åker assemblage located at Åker Farm in Hamar is particularly worth highlighting. The assemblage included finds such as ring-swords, belt fittings and ornate helmets, indicating a social elite – likely a chieftain's seat – which can be seen in connection with the emergence of numerous chieftain seats in Norway during this period. Other rich finds from the region in the same period are from Sveinhaug and Veldre in Ringsaker.

From the 6th century, we also find references to the people known as the 'heiner' or 'heider', which may possibly be linked to 'Hedmark', in the work *De origine actibusque Getarum* ('On the Origin and Deeds of the Goths', or *the Gothic history of Jordanes*), written by the Roman-Gothic historian Jordanes (Jordanis Gotesoga [Gothic history of Jordanes], 1932). The name is also linked to what was probably an older name for Lake Mjøsa, *Heiðsær* (*Eidsivatinget*, 2022)*.

Around the year 600 CE, the inland areas of Eastern Norway and the Mjøsa region were also affected by a period of decline. This resulted in lower production of iron and clay vessels. Plague is pointed to as a possible explanation for the decline in population (Sandodden & Smiseth, 2015). Later in the 7th century and into the 8th century, the population in Norway and Innlandet seems to increase again. The subsequent centuries leading up to the Middle Ages were characterised by gradual growth, during which more land was cleared and cultivated.

Settlement in the Mjøsa region in the Middle Ages (1000-1500)

A particularly important feature of the Mjøsa region's history in the Middle Ages is the emergence of the market town (*kaupang*) and eventually the episcopal see at Hamar. There were also other, smaller trading posts and centres of power, but Hamar's position dominated. The period from the 11th century up to the start of the 14th century was characterised by steady, gradual population growth. There are no population censuses from medieval Norway, but Stensrud estimates in *Den store Mjøsboka* that between 15,000 and 20,000 people likely lived in the areas around Lake Mjøsa at the beginning of the 14th century (Stensrud, 1991)3. This was followed by severe population decline as a result of the Black Death. The Black Death led to many farms being abandoned, and they were not placed back into use until the 16th and 17th centuries.

Åker Farm and Hamar in the Middle Ages

Towards the 11th century and the unification of Norway, the large farm and royal estate at Åker near Hamar was still a centre of power. The chieftains there had ample access to iron and hunting products from the mountain settlements, as well as grain from the lowland farming areas. Åker was strategically and centrally located in relation to traffic on Lake Mjøsa and traffic towards Østerdalen (Sandberg, 2015). It is likely that Åker was also a religious centre, and it may have been there that the Eidsivating (one of the four regional assemblies in Norway) met in the early part of the Middle Ages (Sandodden & Smiseth, 2015), before it was established at Eidsvoll (Holmsen, 1959). In 1046, Kings Magnus Olavsson and Harald Sigurdsson are said to have reached a settlement at Åker, which may indicate that the monarchy had gained control over the farm and the surrounding land (*Norsk byhistorie*, 2006). Per-Øivind Sandberg has extensively discussed Åker Farm in his book *Fra høvdingsete til herregård* (Sandberg, 2015).

The first town along Lake Mjøsa, and in many ways a kind of successor to Åker Farm, was Hamar and its market. Exactly when Hamar emerged as a *kaupang* appears to be somewhat unclear. In the sagas, Snorri Sturluson recounts the founding of towns by various kings, but does not mention Hamar. However, a coin found from Hamar dating to around 1050, with coins minted by King Harald Hardrada (1045–1066) and referencing Hamar, may indicate that a mint was established there during Hardrada's reign (*Norsk byhistorie*, 2006; Lillevold, 1987). In addition, when the episcopal see was established in 1152/1153, there is said to have already been a marketplace there (*Norsk byhistorie*, 2006).

Over time, Hamar became the central trade and power centre in the Mjøsa region during the Middle Ages, both for the king and his men, but especially for the Church. According to Helle, the founding of the episcopal see should be considered a necessary prerequisite for the emergence of Hamar in the Middle Ages (*Norsk byhistorie*, 2006). The cathedral, the bishop's residence and associated institutions are said to have had a significant impact on the townscape. The Bishop of Hamar was an important actor in the politics of the time and had significant financial interests (Hamar historielag, 2004). Among other things, the episcopal see owned rights both to the vendace fishery and to trout fishing at Fåberg (Rugsveen & Stang, 1996). More about the history of the episcopal see in Hamar is available in the book *Hamar bispestol 850 år* (Hamar historielag, 2004).

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3   Unfortunately, however, the book does not state where Stensrud obtains these figures from.

We initially have few sources on what Hamar was like during the late Middle Ages (approx. 1350 to 1537). However, in the so-called *Hamar Chronicle*, a work by an unknown author from the mid-16th century, first published in the 18th century, claims to be based on archival material from the episcopal see, late medieval Hamar is depicted in its heyday before the Black Death in the 14th century (*Hamarkrøniken*, 1986). *Historie som argument: Hamarkaupangen får nytt liv,* examines various historical texts about Hamar from the 16th to the 19th century. The Hamar Chronicle presents a city in bloom and prosperity, experiencing a kind of golden age (Høilund, 2007).

Hamar continued to be the centre of trade and power in the Mjøsa region into the late Middle Ages, but with the great upheavals in Norway during the 16th century, this came to an end. During the Reformation in Denmark-Norway in 1537, the king decreed that the episcopal see in Hamar should be moved and placed under Oslo. A few years later, during the Nordic Seven Years' War (1563–1570), the town was burned down by the Swedes, and in 1570, the marketplace in Hamar was moved to Oslo. As a result, the old Hamar was essentially abandoned as a *kaupang* and town (*Norsk byhistorie*, 2006; Lillevold, 1987). It would take several hundred years before Hamar was restored, but the memory of the town was actively kept alive, especially throughout the 18th century (Høilund, 2007).

Other important places in the Mjøsa region in the Middle Ages

While Hamar's role as a centre of power and trade is undisputed, it is less clear whether there was a permanent trading market at present-day Lillehammer or at Fåberg. Trond Feiring (Feiring, 2004) writes in the second volume of *Fåberg og Lillehammers historie (The History of Fåberg and Lillehammer)* that there is little information about any major market

activity there, but that a 'Litlikaupanger' and 'Litlihamar' are mentioned in Haakon IV Haakonsson's Saga. Feiring also writes that farmers from Gudbrandsdalen are said to have sent a letter in 1579 to the king complaining that the market at Hammer Farm (which is now in the centre of present-day Lillehammer) had been abandoned "some time ago". Based on this, Feiring believes it may be reasonable to conclude that a small trading post existed at Hammer Farm, but there is no question of any real *kaupang* or town like Hamar.

Eidsvoll played a role in the Middle Ages as the meeting place for the Eidsivating, one of the four regional assemblies in Norway, each with its own provincial law. The location of the assembly site at Sundfossen in Eidsvoll, not far from the mouth of Lake Mjøsa, formed a hub in the judicial district that encompassed Hedmarken, Hadeland and Romerike, and eventually also Gudbrandsdalen and Østerdalen. The location near Lake Mjøsa reflects the importance the lake had in the Middle Ages. In more recent times, two new historical works on the Eidsivating have been published: *Eidsivatinget: den norske tingtradisjonen gjennom 1000 år,* edited by Jørn Øyrehagen Sunde and Brage Thunestvedt Hatløy (*Eidsivatinget*, 2022) and *Landslov og lagting - Eidsivatinget etter 1274* by Miriam Jensen Tveit (Tveit, 2022)

Another example of a centre of power by Lake Mjøsa in the Middle Ages is the so-called Mjøsa Citadel *(Mjøskastellet)* at Steinsholmen, two kilometres south of present-day Moelv. Mjøsa Citadel was a fortified tower with a base measuring 18 by 20 metres, most likely five storeys high, making it the foremost example of fortresses built next to Lake Mjøsa. It is possible that Mjøsa Citadel was a piece in the power struggle between Haakon IV Haakonsson, who had the fortress built in the 1230s, and Bishop Pål of Hamar. King Haakon is said to have wanted to control

shipping on Lake Mjøsa to strengthen his power in the inland areas of Eastern Norway (Olden, 2022; Sæther, 2005). Mjøsa Citadel's location along the shipping route in the northern part of Lake Mjøsa reflects the importance of attempting to control traffic on the lake. Furthermore, Olden points out that Mjøsa Citadel's secular function sets the structure apart from most other known medieval ruins in Norway, which are primarily church ruins (Olden, 2022).

Settlement in the Mjøsa region in the period 1500-1900

Population development in the Mjøsa region from the 16th to the 18th century

Despite recurring waves of plague, the period from the 16th century onward was characterised by steady population growth in the Mjøsa region. Stensrud writes that while there were probably no more than 10,000 inhabitants around Lake Mjøsa at the beginning of the 16th century, the population had doubled to 20,000 by 1650 (Stensrud, 1991). According to Hutchison, the increase is partly due to the fact that Norway was able for a long time to increase agricultural production in step with population growth in the 16th and 17th centuries. The reason for this was that previously deserted land areas, abandoned after the Black Death in the mid-14th century, were brought back into use (Hutchison, 2019). Such re-establishment of deserted farms can be seen around Lake Mjøsa, for example in Fåberg (Rugsveen & Stang, 1996) and Stange (Ødegaard, 2006b).

So-called *manntall* censuses were conducted in Norway in the 1660s and in 1701 (counting men aged 12 and older), but the first complete population census in

Norway was not carried out until 1769. At that time, 723,000 people were counted in Norway and approximately 33,966 people lived in the Mjøsa region, depending somewhat on how the region's boundaries are defined (Statistisk sentralbyrå [Statistics Norway], 1980).4 The *manntall* censuses and population censuses are available on the Digital Archives *(Digitalarkivet)* website.

The growth of forestry (1500-1800)

Forests and timber have always been a resource for the people living in the Mjøsa region, but it was after the Middle Ages that the timber trade really expanded. The introduction of the water-powered gate saw in Norway in the 16th century made it possible for farmers to produce far more timber than before (Fryjordet, 1992; Hutchison, 2019). International demand for Norwegian timber increased, and as the forests along the coast were felled, timber merchants in export towns began looking further inland for timber. This included new areas around Lake Mjøsa and up the valleys of Gudbrandsdalen and Østerdalen, where logs could be floated across Lake Mjøsa and then further down the Vorma and Glomma rivers (Rugsveen & Stang, 1996).

During the 17th century, the authorities feared that low timber prices, overharvesting and deforestation would begin to have a negative effect on the inland areas as well – a concern more related to conservation of resources rather than caring for the natural environment. As a result, they introduced ordinances and regulations that limited how much timber could be harvested. In 1688, the king introduced a system of sawmill privileges, distinguishing between sawmills permitted to saw a certain quantity of timber for export and those permitted to saw timber only for the village's own

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4   I have chosen to include all parishes bordering Lake Mjøsa but have excluded Hurdalen from the Parish of Eidsvoll. If the parishes of Hurdal (697), Gausdal (3101) and Løten (1952) are included, the total is 39,716.

needs (village sawmills) (Fryjordet, 1992; Rugsveen & Stang, 1996). This led to approximately a 50 per cent reduction in both the number of sawmills and the amount of timber sawn. The sawmills that survived were the large and profitable ones, often owned by the bourgeoisie (Dyrvik, 1979, 2011). In practice, this meant that farmers were excluded from sawmill operations, apart from what they needed for their own use. With regard to the Mjøsa region, the timber trade was dominated by citizens from Christiania (Oslo) and Fredrikstad (Fryjordet, 1992). Most of the timber floated on Lake Mjøsa was subsequently exported from there. As highlighted in section 2.5.4, there were strong interests among the merchant bourgeoisie in Christiania to facilitate the transport of timber to the capital by canalising the waterways up to Lake Mjøsa.

The lack of a market town in the Mjøsa region

After the discontinuation of the episcopal see and the market at Hamar in the 16th century, the Mjøsa region and Innlandet remained without their own town for a long time. However, there were visiting merchants with whom the farmers could conduct limited trade, and seasonal markets such as the Grundset Market near Elverum.

Until well into the 19th century, trade and craft production were largely reserved for men with a burgher's license, who were affiliated with the official towns (market towns and trading posts) under the privileges system. The town councils, together with the guilds, regulated who was permitted to engage in trade or crafts by issuing burgher's licenses. Exports to foreign countries, especially timber, had to pass through the towns, as the monarchy wanted to ensure as much control as possible over customs and taxation

(Dyrvik, 1979; Hutchison, 2019). During this period, towns were found mainly along the coast because of foreign trade, with the exception of the mining towns of Kongsberg and Røros, which only had limited town privileges.

The markets in Christiania and at Røros were particularly important for the grain farmers around Lake Mjøsa, but the journey there was long. Discontent with the long distance can be found among many writers in the 18th and early 19th centuries, including the county governor Christian Sommerfeldt (1746–1811), who believed it reduced agricultural efficiency. Sommerfeldt wrote that "so much time is spilt on long travels to the market towns for buying grain, that one must truly wonder if the farmer at all in this area has got time to improve the soil5" (Sommerfeldt, 1795).

For the most part, there was agreement on the benefits for the farmers around Lake Mjøsa of establishing a town in the region; there was also agreement that the Mjøsa region had a large enough population base for it (*Norsk byhistorie*, 2006). For example, the Dane Niels Sevel Hoffmann Bloch (1761–1829) wrote the following when he visited Lake Mjøsa in 1808:

> *That the Opplands (all districts bordering Lake Mjøsa), whose Population amounts to over 80,000 Souls, should be granted a Market town within their own Borders; and that Hammer was the most convenient Location for this: this is something all enlightened Patriots have long agreed upon as useful and beneficial. (Bloch, 1808)*

Looking at Kristians amt (Oppland) and Hedemarkens amt together, they had a combined population of 129,000 in 1815. This was highlighted as a key argument by

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5 English translation: "[…] so much time is spilt on long travels to the market towns for buying grain, that one must truly wonder if the farmer at all in this area has got time to improve the soil."

the advocates for establishing a town in the Mjøsa region.

The establishment of Lillehammer, Hamar and Gjøvik

There were different opinions about where a possible Mjøsa town should be located. The authorities could grant market town privileges to existing settlements that they believed could become viable towns. Alternatively, they could designate new locations that previously had little urban infrastructure but were believed, for other reasons, to have the potential to grow and develop.

A total of eleven possible locations for a new town by Lake Mjøsa were considered. Many people expressed a desire for the reestablishment of Hamar, which was merely an agricultural landscape at the beginning of the 19th century (Lillevold, 1987). The idea of the town of Hamar was something many people felt strongly about (Høilund, 2007), and many farmers in Hedemarken had a strong interest in its establishment in the area. In addition, locations were also considered at the mouth of the River Lena *(Lenaelva)*, where the town of Skreia is today, and at the mouth of the River Hunn *(Hunnselva)*, where a settlement had already begun to develop around the glassworks (and later the nail factory) in Gjøvik. In the 1790s, the aforementioned Sommerfeldt had envisioned a town at Lillehammer, based on the fact that several mills and sawmills already existed along the River Mesna *(Mesnaelva)*. Like many others, Sommerfeldt also associated the establishment of a Mjøsa town with the idea of constructing a navigable canal from Lake Mjøsa to the coast (see 2.5.4 for more on this topic). (Feiring, 2004; Sommerfeldt, 1795). Regardless of where the new town in Innlandet would be located, all parties agreed that it had to be situated along the shores of Lake Mjøsa.

The process of deciding the location of a Mjøsa town took place over several decades. Several commissions of inquiry were appointed, and the Storting considered the matter on multiple occasions. Finally, in 1827, the choice stood between Hamar and Lillehammer, and a majority in the Storting ended up favouring the latter. Some of the arguments supporting Lillehammer were the industrial potential of the River Mesna and the fact that the distance to the capital was greater than from Hamar. According to those in favour of Lillehammer, its location at the northern end of Lake Mjøsa and at the entrance to Gudbrandsdalen valley made it a transportation hub where both water transport and land transport met (Feiring, 2004). Initially, Lillehammer received only limited town privileges, and it was not until 1842 that full privileges were granted.

The establishment of a town in Lillehammer did not diminish the desire to reestablish Hamar. In 1842, County Governor and Member of the Storting Fredrik Heidmann (1777–1850) and Professor Gregers Fougner Lundh (1786–1836) argued that Lillehammer would not be able to serve as a trading centre for all of Oppland (Innlandet). When the Storting discussed the matter and passed the *Act on the Establishment of the Market Town of Hamar* in 1848, it was considerations relating to trade that were decisive, rather than industry, which had been important in the previous round (Lillevold, 1987).

Gjøvik was granted town privileges by the Storting in 1860. Although the glassworks in Gjøvik had been closed down in 1843, there was emerging industrial activity along the River Hunn *(Hunnselva)*, including Holmen Distillery and Mustad factories, and it was considered a suitable location for further development. Advocates for a town in Gjøvik were criticised by supporters of Hamar for the idea that yet another town along Lake Mjøsa would only undermine the other two, but proponents

of a town in Gjøvik argued that the farmers in the densely populated areas of Toten, Land, Valdres and Hadeland (with a total population of 72,000 in 1866) needed a market where they could sell their products. In addition, the newly established steamboat traffic on Lake Mjøsa was highlighted as an argument (Mollgard, 1961).

As shown in the table below, Hamar quickly became the largest of the three towns, while Gjøvik and Lillehammer developed to be roughly equal in size by the end of the 19th century *(Statistisk sentralbyrå [Statistics Norway], 1878, 1902; Statistiske Tabeller for Kongeriget Norge: : R. 8: Ottende Række : Indeholdende Tabeller over Folkemængden i Norge Den 31te December 1845 Samt over de i Tidsrummet 1836-1845 Ægteviede, Fødte Og Døde, 1847 [Statistical Tables for the Kingdom of Norway: R. 8: Eighth Series: Containing Tables on the Population of Norway on 31 December 1845 As well as on Marriages, Births and Deaths in the Period 1836–1845, 1847]).* Gjøvik in particular experienced an upswing toward the end of the century due to increased employment in industry (Haugstøl, 1954; Mollgard, 1961; Wicken, 1982). In Hamar's case, the growth was closely linked to the town's development as a hub in the railway network (Lillevold, 1987; Stensrud, 1991). According to Feiring, Lillehammer's 'golden age' was from 1842 to the early

1860s (Feiring, 2004). This was related to the growth of steamboat traffic, as well as Lillehammer being granted full town privileges in 1842. After a period of stagnation and some decline, partly due to emigration to America, Lillehammer began to grow again in the 1890s, following the arrival of the railway in the town.

Population development in the 19th and 20th centuries

Den store Mjøsboka, (Stensrud, 1991) includes a table of the later development in the population around Lake Mjøsa from 1815 to 1983, unfortunately without defining which municipalities he includes and which he does not.

Stensrud's table shows that the population increased dramatically in the first half of the 19th century. The large population increase both in the Mjøsa region and in Norway in general during the 19th century was likely due to several factors. Firstly, birth rates were still very high, while child mortality declined, and the smallpox vaccine became particularly important after 1820. Secondly, there were fewer demographic crises than before: the recurring plague epidemics had disappeared from Norway around the mid-17th century, and after 1814 the country experienced neither war nor years of widespread crop failure. Thirdly,

Census	LILLEHAMMER	HAMAR	GJØVIK
1835	254	-	-
1845	695	-	-
1855	1256	1025	-
1866	1627	1868	626
1876	1551	2188	1051
1891	1832	4170	1416
1900	3111	6046	3153

Table 2.2: Population change in the Mjøsa towns 1835-1900

agriculture produced better yields and potato cultivation from the 1820s onwards contributed to better nutrition (Myhre, 2012).

In the second half of the 19th century, population growth in the Mjøsa region came to a halt due to emigration to America and migration to the larger cities, especially the capital. According to Stensrud, while Norwegian emigration to America began in the 1830s, people from the Mjøsa districts tended to emigrate a bit later. Stensrud highlights that conditions in the Mjøsa region were better than in other parts of the country, and that there had long been access to arable land reserves that could accommodate population growth (Stensrud, 1991). Later in the century, however, things also became more difficult for people living around lake Mjøsa due to increased agricultural competition caused by grain imports from other countries. Lower transport costs resulting from the introduction of railways and steamboats further reduced grain prices, and the mechanisation of agriculture led to less of a need for hired labour (Myhre, 2012; Stensrud, 1991). As a result, it became harder for those who did not already own land to make a living, and many therefore chose to emigrate.

Towards the end of the 20th century, the population began to grow again. In the sparsely populated parts of the region, the population remained fairly stable until after the 1950s, when it began to decline. The major growth occurred in the towns and urban settlements, such as Kapp and Raufoss near Gjøvik, Brumunddal, Moelv, Stange and Ilseng in Hedemarken, and Jørstadmoen on the outskirts of Lillehammer. In most of these small towns, industry or trade had been the driving force behind population growth, while at Jørstadmoen, it had been the military. The growth of the towns throughout the 20th century is linked to additional trade and industry, as well as to the expansion of public services such as education and healthcare (Bjørnhaug, 2000; Gjerdåker, 1998; Ruud, 2010; Stensrud, 1991). For more information on recent demographic developments see Chapter 3.

PERIOD	Population at the beginning of the period	Average annual growth, percent
1815-1865	45,576	1.3
1865-1890	85,596	-0.2
1890-1946	82,290	0.9
1946-1980	133,010	0.7
1980-1983	170,440	0.1

Table 2.3: Population around Lake Mjøsa 1815-1983 (Stensrud, 1991)

2.4   Fishing in Lake Mjøsa from a historical perspective

With a total of 20 different species of fish, Mjøsa is one of the most species-rich lakes in Norway. Currently, fishing in Lake Mjøsa is primarily a recreational activity and of little economic significance. In the past, however, Lake Mjøsa was an important source of food for the surrounding population, and fishing provided people with an additional source of income alongside farmwork for both farmers and bishops. Unlike the coastal areas, Innlandet has not been home to professional fishermen or seen the establishment of permanent settlements because of fishing.

For a long time, vendace was the most profitable species, followed by trout, but the opposite is true regarding the current relationship between the two species (Dervo et al., 2017; Stensrud, 1991). The living conditions of the fish have been affected by human construction, regulation and pollution, both in Lake Mjøsa and in its tributary rivers, but measures have also been taken to improve the natural habitat.

Approx. 4000 BCE.	Finds of petroglyphs in Fåberg with fish motifs.
1459	The construction of 'Fiskekapellet' (the Fishermen's Chapel) at Øyra in Fåberg
1855	The establishment of an inspector for the freshwater fisheries.
1863	The Act of 6 June 1863, which regulated the use of equipment/gear in inland fishing
1883	Mjøsens Fiskeriforening (the Mjøsa Fisheries Association) is founded.
1908	The ban on otter board fishing and trolling in Lake Mjøsa is lifted.
1917	Hartvig Huitfeldt-Kaas published his research in Mjøsens fisker og fiskerier.
1961	The construction of Hunderfossen power station. Period of human encroachment that has had the greatest negative impact on the Hunder trout.
1964	Act on salmonid and inland fishing
1965	Production of Hunder trout fry starts for stocking purposes.
1978 1981	Extensive biological fisheries studies in Lake Mjøsa in connection with the Mjøsa Campaign (Mjøsaksjonen).
1992	Act relating to salmonids and freshwater fish. Applicable legislation in 2025
2006	Regulations on fishing in Lake Mjøsa, including its tributary rivers and streams in Akershus, Hedmark and Oppland.

Table 2.4: Timeline related to fishing in Lake Mjøsa

Fishing in Lake Mjøsa in pre-modern times

Fishing in Lake Mjøsa up to the Middle Ages

There is good reason to believe that fishing has been carried out for as long as humans have lived around Lake Mjøsa and its tributary rivers. Fish bones have been found at some Stone Age settlements in Innlandet (Rugsveen & Stang, 1996), and petroglyphs in Fåberg dating from around 4000 BCE also feature fish motifs (Rugsveen & Stang, 1996).

Fishing in Lake Mjøsa and its tributary rivers was also significant during the Viking Age and the Middle Ages. Our main sources on fishing in the Middle Ages come from property transfers and from settlements and agreements regarding fishing in specific locations. According to Rugsveen and Stang, there is also information indicating that fish were used as a form of tax payment. Late medieval Hamar is described in the Hamar Chronicle *(Hamarkrøniken)*, a work by an unknown author from the mid-16th century that was first published in the 18th century, where it is noted that the town's "citizens and inhabitants obtained a lot of fine fish" there (*Hamarkrøniken*, 1986). As mentioned in Chapter 2.2, the episcopal see in Hamar held fishing rights for both vendace and trout in Fåberg, and the Bishop of Hamar's interest in vendace fishing is also reflected in the construction of the so-called 'Fiskekapellet' *(the Fishermen's Chapel)* at Øyra in Fåberg in 1459.

Descriptions of fishing in Lake Mjøsa in the 17th and 18th centuries

From the 17th and 18th centuries, there are numerous descriptions of the diversity of species in Lake Mjøsa by typographers and Enlightenment scholars such as Peder Claussøn Friis (1545–1614), Jens Lauridsen Wolf (1583–1660), Erik Pontoppidan (1698–1764), Johan Ernst Gunnerus (1718–1773)

and Gerhard Schøning (1722–1780), among others (Friis, 1881; Nye samling af Det Kongelige norske videnskabers selskab Skrifter, 1784; Pontoppidan, 1752; Schøning, 1980; Wolf, 1651) (Norges naturlige historie 1752 vol. 2)

In Schønning and Pontoppidan, we find several descriptions of the 'Lake-herring fishery' at Fåberg and in Hedemarken. However, Pontoppidan does not describe the species in the best light, as he believes it is "[...] almost like another Herring, but not nearly as large. In terms of taste, it is also far inferior and is not particularly Fatty, which is why it is not highly valued by those who have a Choice". In contrast, Pontoppidan describes Lake Mjøsa as "one of the most fish-rich freshwater Lakes in the World" and claimed that at least 23 "Types of Fish" were found there (Norges naturlige historie 1752, vol. 2).

The picture outlined by the typographers of Lake Mjøsa being a rich fishery is challenged and nuanced in reports from the same period by officials in the Mjøsa region, including in the large 1743 survey issued by the authorities in Copenhagen. Here it is claimed that fishing has little economic significance for several of the areas around the lake, such as the Hedmark judicial district, Toten, or the Parish of Vang. This is attributed partly to low fish stocks, and partly to the fact that fishing gear was very expensive. The district judge in Toten has another explanation, claiming that the poor abundance of fish is due to the farmers' "ignorance of fishing and somewhat [sic] poor ability to maintain fishing gear". In Fåberg and in the Parish of Gausdal, however, it was reported that fishing for vendace and Hunder trout was significant and profitable *(Norge i 1743: Innberetninger Som Svar På 43 Spørsmål Fra Danske Kanselli : 2: Akershus Stift: Hedmark, Oppland, 2004). (Norway in 1743: Reports in Response to 43 Questions from the Danish Chancellery: 2: Akershus Diocese: Hedmark, Oppland, 2004).*

In addition to the descriptions of the fish in Lake Mjøsa, the Hamar Chronicle *(Hamarkrøniken)* and many topographical works from the 17th and 18th centuries also contain accounts of another, more mythical creature in the lake, the so-called Mjøsa serpent (*or Mjøsa serpents, depending on the source*). In the Hamar Chronicle, it is described as "a terribly large serpent that was dreadful to lay eyes on. [...] Its eyes were as large as barrel hoops, and it had a large black mane like a horse, hanging down its neck" (*Hamarkrøniken*, 1986). In the 17th century, the sea serpent is mentioned by Claussøn Friis (1881) and Wolf (1651) as an omen that foretells major changes. The sea serpent was said to have foretold both the Reformation in Europe and the downfall of Hamar. The serpent is also often associated with the vast and still largely unknown depths of Lake Mjøsa. The later topographers of the 18th century, such as Erich Johan Jessen (1705-1783) (1763) and Gunnerus (*Nye samling af Det Kongelige norske videnskabers selskab Skrifter*, 1784), are more critical of the sea serpent's existence, but Jessen does not completely rule out the possibility. The very fact that they devote space in their books to mention the sea serpent highlights the creature's significance and prevalence as a cultural concept. As late as 1917, Hartvig Huitfeldt-Kaas also chose to mention the sea serpent in his book *Mjøsens fisker og fiskerier*, but more for cultural than scientific reasons. For a general introduction to the cultural and intellectual-historical significance of the Mjøsa serpent, the second volume of *Norsk idéhistorie is recommended: Tankeliv i den lutherske stat* (Gilje, 2002)*.

Fishing in Lake Mjøsa from the 1800s onwards

Commercial fishing in Lake Mjøsa continued throughout the 19th century, with both governmental and professional efforts to strengthen the industry. In his overview of Norwegian salmonoid and freshwater fisheries, Magnus Berg (1986) writes about how in the 19th century, Lake Mjøsa was considered particularly suitable from an economic standpoint for stocking fish species. This was due to its proximity to the capital and the densely populated surrounding areas. Magnus Gabriel Hetting (1811–1892), the first inspector of freshwater fisheries from 1855 to 1874, sought to make freshwater fisheries more profitable. Together with the zoologist Halvor Heyerdahl Rasch (1805–1883), Hetting carried out groundbreaking work in artificial fish breeding in Norwegian freshwater lakes. Salmon fry were released into Lake Mjøsa as early as 1866–67, without much success. Later, several other species were also released, such as rainbow trout, Arctic char and Vänern salmon from Sweden, but none of these species succeeded in establishing themselves (Berg, 1986).

The profitability of vendace in Lake Mjøsa and the River Lågen led to attempts in the mid-19th century to transfer it to other lakes such as Tyrifjorden, Randsfjorden and Krøderen. Although the distance from Lake Mjøsa to these lakes was short, the work was challenging, as vendace cannot withstand being transported when fully grown, and hatching new eggs proved difficult. In 1879–1880, the attempt succeeded, and vendace roe was transferred to the hatchery in Vestfossen, and later to other locations. However, vendace has only managed to establish itself in a few other lakes (Berg, 1986).

Berg also writes about how fisheries inspector Hetting established fishing regulations in Lake Mjøsa and its tributaries to prevent overfishing of the stocks, particularly trout. This included fishing quotas and regulations on the type of fishing gear used. In the 1860s, the Storting also passed laws regulating the use of fishing gear, for example prohibiting the use of dynamite in fishing (Berg, 1986).

Huitfeldt-Kaas and Mjøsens fisker og fiskerier (Lake Mjøsa's Fish and Fisheries)

A particularly important source on fishing in Lake Mjøsa at the end of the 19th and beginning of the 20th century is Hartvig Huitfeldt-Kaas' book *Mjøsens fisker og fiskerier* (1917), thoroughly discussed in the article 'Mjøsens fisker og fiskerier gjennom 100 år' (*Lake Mjøsa's Fish and Fisheries Through 100 Years*) by Dervo et al. (2017). Biologist Huitfeldt-Kaas is considered a pioneer in the field. In the period 1900–1902, the Storting granted him NOK 8000 to carry out fisheries surveys in Lake Mjøsa, where, in addition to describing the diversity of species and mapping the fishery, he also conducted temperature measurements, depth measurements and new rectangular surveys of the water surface. Huitfeldt-Kaas' calculations increased the measured surface area of the lake by 3 km2. Huitfeldt-Kaas (1917) describes a commercially successful fishery, but also notes that the catch volume in his time was declining. The reason for this is partly due to overexploitation, for example of the vendace, but Huitfeldt-Kaas also suggests that in the case of the grayling, it may be due to environmental problems and pollution. He also considered the increase in water levels in Lake Mjøsa, caused by the Sundfossen dam in 1858, as a negative environmental factor (Dervo et al., 2017).

Dervo et al. (2017) provide a concise overview of the further development of Lake Mjøsa's fisheries history in the hundred years following Huitfeldt-Kaas' surveys. The main trend during this period is that threats to the fish stocks increased, and that economically profitable commercial fishing declined. Commercial fishing continued up until World War II, but declined during the post-war period in step with broader economic development (Dervo et al., 2017).

Several of the challenges Huitfeldt-Kaas pointed out at the time were amplified during the 20th century. The population around Lake Mjøsa doubled during this period, and both industrial and agricultural activities brought increasingly large discharges of nutrients into the lake and its tributaries, which continued unabated until the 1970s. Fertilizer runoff from agriculture caused many tributary rivers and streams to become unsuitable for spawning. Many of the challenges were remedied through the Mjøsa Campaign (*Mjøsaksjonen*), and the current water quality is significantly improved. Other human activities, such as further expansion of the railway and the massive investment in road construction, have also affected the living conditions of the fish. The two expansions of the water regulation system at Svanfossen in 1947 and 1961 contributed to poorer living conditions for fish species associated with the shoreline zone, such as roach, perch, pike and trout (Dervo et al., 2017). Similarly, the construction of the Hunderfossen power station in the 1960s had a major negative impact on the Hunder trout (Næstad et al., 2023).

2.5   Lake Mjøsa as a transport route and power source

For many years, Lake Mjøsa has served as a transport route for trade and passenger traffic, both on the water during the summer months and over the ice in winter. Unlike the rest of Europe, Norway is largely characterised by rivers that are naturally difficult to navigate with many large falls and rapids. With a length of 117 kilometres, Lake Mjøsa constitutes a significant contribution to the inland waterways.

For a long time, travel across Lake Mjøsa was both faster and safer than by road, as improved roads along the shores of the lake were not established until the 17th and 18th centuries. In addition, these roads were not considered particularly good, even by contemporary standards. So when steamboat traffic began in the mid-19th century, most travellers chose to use the boat services instead. Similarly, timber has been floated on Lake Mjøsa and its tributaries for several centuries, right up until the last raft in 1980. Traffic across the lake has been important for the local population, as well as for visitors from other parts of the country. Its central location in Innlandet and the long navigable stretch made the lake a key hub connecting routes from Oslo in the south, to Trondheim and Romsdalen in the north via Dovre or Østerdalen, Bergen in the west via Valdres, and to Sweden in the east. Since the 20th century, train and car traffic have outcompeted boat traffic, and the current use of boats on Lake Mjøsa is mainly recreational.

1743	Parish priest Ole H. Hoff in the Parish of Toten mentioned the "immense benefit" it would have been for Oppland, Christiania and Fredrikstad if Lake Mjøsa were made "navigable from the sea".
1805	The royally appointed canal commission proposed building a canal between Lake Mjøsa and Christiania. The plan was halted due to the Napoleonic Wars.
1824	The Canal Inspectorate launched a plan to canalise the stretch from Lake Mjøsa to Rælingssund.
1841	The first steamboat traffic on Lake Mjøsa: Jernbarden (Lillehammer and Minnesund)
1843	Establishment of a communications committee appointed by the government to work on the question of connecting Lake Mjøsa to Christiania, either by canal or railway.
1848	Farmers gathered at Nordli Farm in Sørum to discuss the question of canalising the Lågen and Rauma rivers all the way to Romsdalen, as well as a connection down to Øyeren and the Oslo Fjord.
1854	The Trunk Line opened: a railway connection between Oslo (Christiania) and Eidsvoll. Previously called the Mjøsa Line.
1856	The steamboat Skibladner was put into service.
1858	First regulation of Lake Mjøsa in the River Vorma at Sundfossen. Built to make the River Vorma navigable between Eidsvoll and Lake Mjøsa.
1862	The Hamar-Grundset Line opened: Connected Lake Mjøsa with Østerdalen.
1877	The Røros Line opened between Hamar and Trondhjem.
1880	The Hedmark Line completed: Railway connection between Eidsvoll and Hamar. Norway's first main railway line (between two regions), along with the opening of the Minnesund railway bridge.
1894	Extension of the Hedmark Line to Lillehammer and up Gudbrandsdalen valley.
1902	The Gjøvik Line opened: Railway connection between Oslo (Kristiania) and Gjøvik.
1910	Second regulation of Lake Mjøsa, at Svanfoss. Built with the aim of improving boat traffic and the power supply in the Glomma watercourse.
1918	Glommens og Laagens Brukseierforening was founded. An interest organisation for hydropower producers in the Glomma and Gudbrandsdalslågen river basins. A continuation of Glommens Brukseierforening from 1903.
1923	The Mjøsa Ferry between Ringsaker and Gjøvik was put into operation (discontinued in 1988).
1940	The Watercourse Act of March 15, 1940
1951	The Hamar-Kapp Ferry was put into service (discontinued in 1970).
1980	The last timber raft on Lake Mjøsa
1985	The Mjøsa Bridge (Mjøsbrua) between Moelv and Biri opened.
2023	Opening of Minnevika railway bridge, Norway's longest railway bridge. Built in connection with the establishment of the double track between Hamar and Eidsvoll.

Table 2.5 Timeline: Transport and water regulation

Figure 2.1: Horse racing on the ice on Lake Mjøsa (1890-1910?). (Photo credit: Ole Hansen Løken, Anno Domkirkeodden, downloaded from digitalmuseum.no 16 January, 2026).

Traffic on Lake Mjøsa before the 1800s

Boat traffic in the Iron Age and Middle Ages

Goods transport across Lake Mjøsa was extensive and organised as early as the Iron Age and the Middle Ages, especially during Hamar's heyday in the High Middle Ages. In the Iron Age, there were no roads, only simple footpaths and riding trails, so it was much faster to transport goods by boat on Lake Mjøsa. From the saga literature that exists, we have many accounts of boats being used on Lake Mjøsa, including the naval battle at Ekornholmen off Feiring in the 13th century. However, few sources exist from the period before the Viking Age and the saga literature regarding the use of boats on Lake Mjøsa (Sandodden & Smiseth, 2015). To date, no site-specific finds of ships from the Iron Age or Middle Ages have been made in Lake Mjøsa (Sandodden & Smiseth, 2015). However, in 2022, researchers associated with Mission Mjøsa discovered an old shipwreck in the Storfjorden area of Lake Mjøsa.

Marine archaeologist Øyvind Ødegård has estimated that the wreck may date from the period 1300–1900, but does not rule out that it could be older (Bergstrøm, 2024; Kjørstad, 2023). More accurate dating is planned as part of Mission Mjøsa.

'Føringsbåter' (transport vessels) and royal boats in the early modern period (1500-1800)

From the 16th century up until the mid-19th century, so-called *føringsbåter (a local type of boat used for everything from freight to passenger traffic)* dominated goods transport on Lake Mjøsa. They transported textiles, tobacco, coffee, grain, meat, dairy products, ore, spirits and glassware. This type of boat is discussed in detail in Andersen-Øzkaraman's master's thesis, *Føringsbåtene på Mjøsa* (2024), written in connection with Mission Mjøsa. In the thesis, he bases his work on the data collected during the investigations of the so-called *Torgunrud wreck (Torgunrudvraket)* in 1980 and 2023. This is a *føringsbåt* that is said to have sunk sometime in the early 19th century. Andersen-Øzkaraman argues

that these types of local boats were crucial for trade and social development in the Mjøsa region (Andersen-Øzkaraman, 2024). He also advocates for more wreck investigations in Lake Mjøsa, as he believes that the lake's size and history, and the fact that it is freshwater, suggest good chances of finding ancient wooden boats there.

So-called *kongsbåter (royal boats)* are highlighted in the literature as another type of important vessel in the period 1600–1800. These were boats that the farmers along Lake Mjøsa were obligated to build and crew, and that were used to transport officials and authorities on official journeys. The oldest written source mentioning such royal boats dates from 1662 (Andersen-Øzkaraman, 2024; Berg & Nordsveen, 1996).

Traffic on Lake Mjøsa from the 19th century onwards

The introduction of steamboats on Lake Mjøsa

The most comprehensive work on Lake Mjøsa's boat history in the 19th and 20th centuries is *Damp- og motorbåter på Mjøsa* (1996) *(Steam and motorboats on Lake Mjøsa)*, by Arne Julsrud Berg and Arve Marthinus Nordsveen. The book provides a general overview of the development of boat traffic across Lake Mjøsa during the period, as well as a detailed review of the individual boats that have operated scheduled services.

The main focus of the book centres on the steamboats, which according to Berg and Nordsveen, constituted a transportation revolution on Lake Mjøsa. The steamboats were faster than the sailing vessels and less vulnerable to weather conditions, and therefore more predictable. In 1840, *Jernbarden* was the first steamboat to sail on Lake Mjøsa, followed seven years later by *Dronningen*. The arrival of steamboats on Lake Mjøsa

coincided with the establishment and growth of the towns of Lillehammer (1828), Hamar (1849) and Gjøvik (1861), as well as with the construction of Norway's first railways, including the Trunk Line between Christiania and Eidsvoll (1854) and the Hamar–Grundset Line (1862).

With the first regulation of Lake Mjøsa at Sundfossen in 1858, the upper part of the Vorma River was made navigable for larger vessels between Eidsvoll and Minde. As a result, the steamboats could receive the goods and passengers arriving by train to Eidsvoll and transport them up Lake Mjøsa and further toward Gudbrandsdalen, Valdres and Østerdalen. The peak year for steamboats on Lake Mjøsa was 1874, with a total of 105,000 passengers transported, accounting for roughly half of the national lake traffic (Berg & Nordsveen, 1996).

Steamboat traffic on Lake Mjøsa also played a role in tourism in the region. The boats offered higher speeds for tourists travelling toward Gudbrandsdalen and the mountains for fishing and hunting, as well as greater comfort for those wishing to take pleasure trips around Lake Mjøsa, for example to view the Skreifjell mountains, the cathedral ruins at Hamar, or the burial mound on the island of Helgøya. In the 1880s, the tourism industry was extensive, and hotels and farm guesthouses were built in the towns and villages around Lake Mjøsa. In competition with the railways and automobile traffic, the ship *Skibladner* focused more and more on tourist services (Berg & Nordsveen, 1996). For more specific information about the history of 'Skibladner', see *Skibladner 1856–1981* by Jan H. Olstad (1981).

Mjøsa jakt boats

Steamboats were not the only vessels to be seen on Lake Mjøsa after 1840. The second half of the 19th century was also the period of the so-called Mjøsa jakt boats (mjøsjaktene), which can be read about in Gjermund Høiby Motland's master's thesis

(2024), also written in connection with Mission Mjøsa. Motland writes that the old cargo vessels (føringsbåter), which had previously handled the transport of bulk cargo across the lake, were outcompeted by the steamboats in terms of speed, cost and reliability. The emergence of brickworks, distilleries and other industrial enterprises created a demand for efficient bulk transport which was cheaper than the more expensive steamboats. According to Motland, this laid the foundation for the development of the cheaper jakt boats. These vessels had a small crew and could transport goods that were not urgent to deliver, such as potatoes, spirits or bricks. This type of boat was developed by individuals who were familiar with the latest shipbuilding technology along the coast. According to Motland, the jakt boats formed a unique boatbuilding community at Lake Mjøsa for nearly a hundred years, from the first boat built in 1859 until the last one was dismantled in 1958.

Boat traffic in a military context

Boat traffic on Lake Mjøsa has also been considered in a military context. In the period 1895–1905, when tensions within the union between Norway and Sweden escalated and there were fears of war, specific plans existed to equip the steamboats on Lake Mjøsa and Lake Øyeren with cannons (Berg & Nordsveen, 1996). The idea was that the gunboats would engage in delaying actions as part of the defence of the capital and prevent the Swedes from transporting soldiers and equipment across to the western side of Lake Mjøsa (Berg & Nordsveen, 1996). *Skibladner* was considered the most important gunboat, due to its high speed. The plans were never carried out, and the potential threat from Sweden disappeared after the peaceful dissolution of the union in 1905.

This was not the only time Lake Mjøsa has been considered in a military-strategic context. In the work *Almindelig Udkast af*

Krigens Skueplads from 1785, Heinrich Otto Scheel (1745–1808) wrote about the use of Lake Mjøsa in wartime situations, highlighting the narrow stretch between Morskogen and Lake Mjøsa as being particularly important to guard (Scheel, 1785). The later Bredo Henrik von Munthe af Morgenstierne (1774–1835) also described the importance of military boat operations on Lake Mjøsa in his work on Bernhard Ditlef von Staffeldt's campaign against Sweden in 1814 (Morgenstierne, 1827).

Railway and automobile traffic challenge steamboat traffic

The gradual expansion of the rail network challenged the position of steamboat traffic. In 1880, the line to Eidsvoll was extended to Hamar, and further on to Lillehammer and up through Gudbrandsdalen in 1894. In 1902, the railway from Kristiania reached Gjøvik. Railway traffic outcompeted the longitudinal traffic between Eidsvoll and Lillehammer, but boat traffic on the shorter routes and the ferry crossings across the lake continued for a long time. The number of boats on Lake Mjøsa increased until 1930, and total passenger and cargo transport was probably at its peak around 1920.

Initially, cars were not a threat to boat traffic. However, during the 1920s, lorries and bus services became serious competitors, and an increasing number of scheduled boats had to cease operations in the 1930s. World War II temporarily halted the growth of automobile traffic, but with the removal of import restrictions on heavy goods vehicles in 1951, the end of private car rationing in 1960, and the massive investment in road construction, automobile traffic exploded.

The number of passengers using the car ferries, such as between Gjøvik and Mengshol, increased sharply right up until the opening of the Mjøsa Bridge

(Mjøsbrua) in 1985. However, the establishment of the bridge put an end to the Mjøsa ferries, and the current use of boats on Lake Mjøsa is primarily for recreational purposes. The lake, which previously connected people, is now perceived by many as a barrier (Berg & Nordsveen, 1996). For more information about the Mjøsa Bridge and the rest of the road history, see *Mjøsbrua: en vandring i veghistorien* by Erik Johnson (Johnsen, 1992)

Ice roads over Lake Mjøsa

It is not only boats that have taken advantage of Lake Mjøsa as a transport route; there is a long tradition of sleds being used to cross the lake when the water froze. The ice roads were preferred well into spring, while the land roads were still soft and difficult to travel on.

The ice roads were important for trade and passenger traffic, but were also dangerous because of open leads and meltwater on the ice. (Sandodden & Smiseth, 2015). We also have written sources from the 18th and 19th centuries claiming that travellers risked being chased by large packs of wolves across the ice (*Norge i 1743: Innberetninger Som Svar På 43 Spørsmål Fra Danske Kanselli : 2 : Akershus Stift : Hedmark, Oppland*, 2004; von Buch, 1813), although no deaths resulting from such attacks have been confirmed (Bjerke & Linell, 2002; Furseth, 2005).

Perhaps the most well-known text dealing with the ice roads across Lake Mjøsa is Christian Krohg's short story 'Paa Isa paa Mjøsa' from the book *Omkring Mjøsa: Interviewer og Skisser* (Krohg, 1909), which humorously depicts a visitor's somewhat anxious encounter with winter traffic across Lake Mjøsa.

From the 1920s, private cars and lorries also drove on the ice across the lake (Berg & Nordsveen, 1996). Since there were few bridges across Lake Mjøsa for a long time,

the ice roads were seen as shortcuts, for example between Hamar and Helgøy or Moelv and Biri. For many years, public funding was used to clear the ice roads of snow and mark them with poles (Johnsen, 1992). However, the opening of the Mjøsa Bridge reduced the need for ice roads, and it is also the case that the lake now freezes less frequently due to milder and more unstable winters as a result of climate change. According to the Innlandet County Archives, public ice roads are now considered history (Innlandet fylkeskommune [Innlandet County Authority], n.d.).

Log driving on Lake Mjøsa

Log driving has also been an important part of Lake Mjøsa's transportation history. The most comprehensive book dealing with log driving on Lake Mjøsa is *Fløting gjennom århundrer: fløtingas historie i Glomma- og Mjøsvassdraget* by Øivind Vestheim (1998), but Berg and Nordsveen also touch on the topic. Vestheim writes that it is difficult to say when log driving began, as few written sources from the Middle Ages address the topic directly. From the 16th century, we have several sources, such as district accounts and customs records, and from the late 18th century, there are more or less continuous archives from the log driving associations in the various main watercourses (Vestheim, 1998).

According to Berg and Nordsveen, log driving was an economically efficient mode of transport, both for businesses and for society. Like commercial boat traffic, log driving eventually had to give way to automobile transportation. The last timber raft on Lake Mjøsa took place in 1980, when *Glomma Fellesfløtingsforening* ceased its operations on the lake (Figure 2.2) (Berg & Nordsveen, 1996).

Figure 2.2: The last log drive on lake Mjøsa (1980). Photo credit: Ole-Thorstein Ljøstad, Anno Norsk skogmuseum SJF-F.014427

The actual floating of timber rafts causes little harm to the surrounding environment, except that it can disrupt other boat traffic and fishing. However, the adaptation of watercourses for log driving – through clearing riverbeds and building dams, especially in smaller rivers and streams – has negatively affected fish habitats (Vestheim, 1998).

Proposal for a canal between Lake Mjøsa and the sea

From the 18th century, throughout the 19th century, and into the early 20th century, several actors, both within the Mjøsa region and beyond, advocated for the creation of a navigable canal from Lake Mjøsa down to the sea. The canal ideas have not been the subject of dedicated articles or books, but they are mentioned in several works, for example in connection with forestry and log driving history (Andersen, 1996; Bødtker, 1945; Fryjordet, 1992; Olsen, 1993), Bård Frydenlund's biography of Peder Anker (Frydenlund, 2009), or in Åge Olav Olsen's

book on Romerike's waterways (Olsen, 1993). Even Næss Bergseng, the author of this chapter and a participant in Mission Mjøsa, plans to address the canal ideas in his PhD thesis.

One of the earliest instances where the idea of a Mjøsa canal was proposed came from parish priest Ole H. Hoff in the Parish of Toten in 1743. Inspired by canal construction in Sweden, he wrote to the authorities in Copenhagen that the "Great Mjøsa, if it were or could be made navigable from the sea, would doubtless provide invaluable benefits to all the inland areas (*oplandene*), Christiania and Frederikstad, just as it does for Stockholm and all the towns and provinces around Lake Mälaren." *(Norge i 1743: Innberetninger Som Svar På 43 Spørsmål Fra Danske Kanselli: 2: Akershus Stift: Hedmark, Oppland*, 2004). Similarly, in 1795, County Governor Christian Sommerfeldt believed that "a canal to facilitate transport to the coastal towns, and a market town in the inland areas (o*plandene*), both connected, would support each other and strongly contribute to achieving the

goal" (Sommerfeldt, 1795). *(Norge i 1743: Innberetninger Som Svar På 43 Spørsmål Fra Danske Kanselli: 2: Akershus Stift: Hedmark, Oppland*, 2004). Similarly, in 1795, County Governor Christian Sommerfeldt believed that "a canal to facilitate transport to the coastal towns, and a market town in the inland areas (o*plandene*), both connected, would support each other and strongly contribute to achieving the goal." (Sommerfeldt, 1795).

At the beginning of the 19th century, landowner and former road director Peder Anker (1749–1824) took the initiative to investigate a canal connection between Øyeren and Christiania, the so-called Øyeren Canal (*Øyerenkanalen*) (Frydenlund, 2009). The motivation was largely related to facilitating the transport of timber, as Anker and many other Christiania-based businessmen owned large areas of forest in the Mjøsa and Glomma watercourses.

With the help of the Swedish master builder Pohl and engineer Samuel Bagge (1774–1814), both of whom had been involved in the Trollhättan Canal project, Anker had a proposal drawn up for a canal connecting Øyeren with Bjørvika via the Nittelva river and Nordmarka. The King appointed a canal commission to assess the proposal. The plan received support, but on the condition that a connection further upstream toward Lake Mjøsa was also investigated. Despite this, the plan stalled due to the blockade and the situation during the Napoleonic Wars.

The Mjøsa Canal later appears several times. In 1814, Anders Lysgaard (1756–1827), a farmer representative from Christians amt, advocated at the Constituent Assembly at Eidsvoll that a market town should be established at Lake Mjøsa and that a canal should be constructed at the same time. In 1824, the Canal Inspectorate proposed a plan to canalise the stretch from Lake Mjøsa to Rælingssund, but the Ministry of Finance considered the costs too high,

and the plan was set aside. In 1843, the government established a committee to work on the question of connecting Lake Mjøsa with Christiania. They considered a canal but ultimately decided on a railway.

The idea of constructing a canal resurfaced at the beginning of the 20th century. In 1913, Canal Director Sætren, together with Hans Maximilian Graff, presented a new canal plan in the publication Teknisk Ukeblad (Sætren, 1913). This time, the plan was for the canal to empty into Bekkelaget, southeast of Kristiania, and for the boats to travel through tunnels running through the mountains. Sætren and Graff were convinced that this canal would provide much lower transportation costs than the railway could offer.

An even more ambitious idea was to canalise the Lågen and Rauma rivers all the way out to the Romsdal Fjord. According to Tollef Kilde, this idea was discussed in 1848 by farmers who gathered at Nordli Farm in Sørum (*Østlendingen*, 1975). The farmers are said to have wanted this in addition to a canal system down to the Oslo Fjord. If such a plan had been realised, Lake Mjøsa would have formed the centre of a waterway running straight through all of the southern part of Norway.

2.6 The water level of Lake Mjøsa: historical regulation and flood events

The water level of Lake Mjøsa is, and has historically been, of great interest and concern to the population around the lake and further downstream. The water level naturally fluctuates in step with weather conditions, ranging from drought to flooding as the two extremes, the latter with the 1789 *Storofsen* flood as the largest in recorded history. At the same

time, human intervention has also made it possible to regulate the level by several metres since the first dam was built at Sundfossen in the River Vorma in 1858. Since 1910, Lake Mjøsa has also served as a water reservoir for hydropower production further downstream.

Excessively high water levels, in the form of flooding, pose obvious challenges, including the potential destruction of property and, in the worst case, loss of life. However, excessively low water levels like those in May 2025 also create challenges, such as irrigation difficulties for farmers around Lake Mjøsa who rely on pumping water from the lake (Nordby, 2025). Excessively low water levels can also cause problems for boats trying to dock, particularly on the Gjøvik side. This was a factor in the debate over the construction of the first dams on the River Vorma.

The following sub-chapter will provide a brief introduction to the main water regulations of Lake Mjøsa and the most significant flood events that have affected the lake.

Regulation of Lake Mjøsa 1858-1993

The first regulation of Lake Mjøsa (1858) at Sundfossen, as mentioned in section 2.4, was built to increase the water depth in the Vorma River, thereby facilitating year-round traffic between Minnesund and Eidsvoll so that steamboat services could connect with trains from Christiania (Kanalkontoret, 1881; Olsen, 1993). The dam at Sundfossen allowed for a 2.5-metre regulation height of Lake Mjøsa. In the decades that followed, Sundfossen was the subject of much debate, including concerns about whether it caused higher flood levels and damage to fishing, especially the vendace fishery (Table 2.6).

The second regulation, further south in the River Vorma at Svanfossen, was completed in 1910. The purpose of this regulation was partly to address challenges caused by the dam at Sundfossen, but primarily to regulate the water supply for power production further downstream in the Vorma and Glomma watercourses. The construction of this new dam, referred to as the *Mjøsa Regulation (Mjøsreguleringen)*, was not without controversy. Firstly, several municipalities along Lake Mjøsa and the Vorma and Glomma rivers feared its impact on fishing, agriculture and ice roads, as well as the compensation costs that would result from the increased water level in Lake Mjøsa (*Elektrisitetens forvaltningshistorie* 1877-1921, 2020; *Stortingsforhandlinger*, 1907; Fuglum, 1988; Thue, 2006). However, the regulation became far more controversial due to its constitutional and political aspects: In 1907, the Michelsen government granted Glommens Brugseierforening permission to carry out the regulation without going through the Storting. This led to intense confrontations, and the government was instructed not to grant licences without consulting the Storting. The matter was a major factor contributing to the resignation of the Michelsen government in 1907.

Among the older and larger hydroelectric power stations further downstream along the River Glomma, for which Lake Mjøsa serves as a reservoir, are Rånåsfoss (1921) in Sørum Municipality, Solbergfoss (1924), Kykkelsrud (1903) and Vamma (1915) in Askim Municipality, as well as the power stations at Sarpefossen in Sarpsborg, including Borregård Power Station (1898) and Hafslund Power Station (1899).

More recently, the dam at Svanfossen has been upgraded twice, in 1947 (called Mjøsa II) and 1961 (Mjøsa III), without the same conflicts as in 1907. This time, the licences were granted to the merged association, Glommens and Laagens Brukseierforening. The regulations at

1824-1827	The first regular measurements of the water level in the River Vorma at Minnesund.
1858	The first regulation of Lake Mjøsa in the River Vorma at Sundfossen. Constructed to make the River Vorma navigable between Eidsvoll and Lake Mjøsa. Regulation height 2.5 metres.
1903	Glommen Brugseierforening is founded.
1906	The Michelsen government allowed Glommen Brugseierforening to regulate the water level in Lake Mjøsa at Svanfoss without consulting the Storting.
1907	The Storting criticised the government for its decision to authorise the regulation of Lake Mjøsa and decided that the government could not grant new licences without going through the Storting.
1910	The second regulation of Lake Mjøsa completed at Svanfoss, featuring a dam and locks. Built with the aim of improving boat traffic and the power supply in the Glomma watercourse. Regulation height 2.2 metres.
1917	Section 1 of Act No. 16 of 14 December 1917 relating to acquisition of waterfalls, mines and other real property etc. (Industrial Licensing Act), and Act No. 17 of 14 December 1917 relating to regulations of watercourses.
1918	Glommens og Laagens Brukseierforening is founded. An interest organisation for hydropower producers in the Glomma and Gudbrandsdalslågen river basins. A continuation of Glommens Brukseierforening from 1903.
1940	The Watercourse Act of March 15, 1940
1947	Mjøsa II: the third regulation of the River Vorma/Lake Mjøsa (Svanfoss). Additional regulation height of 0.66 metres.
1961	Mjøsa III: the fourth regulation of the River Vorma/Lake Mjøsa (Svanfoss). Additional regulation height of 0.73 metres.
1973	The lock at Sundfossen was removed due to maintenance costs and reduced boat traffic.
1993	A new lock was built at Svanfossen due to growing interest in recreational boating.

Table 2.6: Timeline, regulation

Svanfossen involved a regulation height of 2.2 metres in 1907, Mjøsa II increased the height by an additional 0.66 metres, and Mjøsa III by a further 0.73 metres. (Glommen og Laagens Brukseierforening, n.d.). In total, this corresponds to a regulation height of 3.61 metres, with the highest regulated water level (HRWL) at 123.15 metres above sea level and the lowest regulated water level (LRWL) 119.54 metres. (Holmqvist & Hamududu, 2022).

For more literature on Glommen Brugseierforening and Glommens og Laagens Brukseierforening (GLB) (merged in 1918) and their role in the regulation of Lake Mjøsa, see (Furuholmen, 1938) for the period 1903–1938 and the three jubilee volumes covering up to 1993 (*Glommens Og Laagens Brukseierforening : [B. 1] : 1918-43,* 1947; *Glommens Og Laagens Brukseierforening : B. 2 : 1943-1968,* 1975; *Glommens Og Laagens Brukseierforening : B. 3 : 1968-1993,* 1995). For Norwegian hydroelectric history in general, *De temmet vannet* is recommended: *Statkrafts tekniske kulturhistorie* (Sekne, 2011) and the NVE report (*Elektrisitetens forvaltningshistorie 1877-1921,* 2020), written by Per Einar Faugli.

Historical floods in Lake Mjøsa

Lake Mjøsa and the Mjøsa region have historically been prone to floods, some of which have been large and destructive. The biggest flood in Lake Mjøsa's history is the so-called *Storofsen* flood in 1789, closely followed by the *Storflaumen/ Ofsen* flood in 1860. More recently, the *Vesleofsen* flood in 1995 and the flood that followed *Storm Hans* in 2023 are the most well-known (Figure 2.3). Major flood events are among the natural disasters that cause the greatest economic losses in Norway each year. This also applies to the population and built-up areas around Lake Mjøsa, even though the extent of the damage is far smaller than in major historical floods in other parts of the world, such as China or India, where the number of victims can be counted in the tens or hundreds of thousands. This is due to larger and denser populations and greater destruction of fertile topsoil. Another damaging effect of floods is the pollution of the water caused by sediments, trees and vegetation carried along by floodwaters, as illustrated during the *Storofsen* flood described below, or by plastic-wrapped silage bales in more recent times, such as during *Storm Hans* (Engesmo et al., 2024).

The most severe flood levels in the tributary rivers, especially the River Lågen, will often be reduced and spread out over time in a basin as large as Lake Mjøsa. Similarly, the regulation of Lake Mjøsa in more recent times has helped reduce the peak levels of most floods (Holmqvist & Hamududu, 2022), but it has less impact on the very largest floods, which will be roughly the same as if the watercourse had not been regulated (Roald, 2013).

The introductory report *Flom i Norge (Floods in Norway)* by Lars Andreas Roald (Roald, 2013) contains several descriptions of floods that have affected the Mjøsa region and includes references to further literature on floods in general and on flooding in the Mjøsa watercourse in particular. The NVE report *Flomberegning for Mjøsa/Vorma (Flood calculations for Mjøsa/Vorma)* (Holmqvist & Hamududu, 2022) also provides a brief historical overview of the largest floods in Lake Mjøsa. Local historical yearbooks and town histories often address flood damage at specific locations. For a general introduction to the history of flood protection in Norway, see (Andersen, 1996).The introductory report *Flom i Norge (Floods in Norway)* by Lars Andreas Roald (Roald, 2013) contains several descriptions of floods that have affected the Mjøsa region, and includes references to further literature on floods in general and on flooding in the Mjøsa watercourse in particular. The NVE report *Flomberegning for Mjøsa/Vorma (Flood calculations for Mjøsa/Vorma)* (Holmqvist & Hamududu, 2022) also provides a brief historical overview of the largest floods in Lake Mjøsa, with calculations of .. Local historical yearbooks and town histories often address flood damage at specific locations. For a general introduction to the history of flood protection in Norway, see (Andersen, 1996).

Timeline: Prehistoric and observed historical flood events

YEAR		WATER LEVEL[1]
50-1 BCE	Gammelofsen. Major flood event in the Lågen watercourse. Unknown how much impact it had on Lake Mjøsa.	Unknown
600-800	Merovingerofsen (Merovingian flood). Major flood event in the Lågen watercourse. Unknown how much impact it had on Lake Mjøsa.	Unknown
1789	Storofsen: Highest observed water level in Lake Mjøsa in historical times. Observation 24 July.	128.00 metres above sea level.
1795	The so-called Thesenraset landslide in the River Vorma caused the water level in Lake Mjøsa to rise eight metres.	
1808	Fourth highest observed water level in Lake Mjøsa. Unknown observation date.	126.40 metres above sea level.
1827	Third highest observed water level in Lake Mjøsa. Water level observed on 5 June. The first for which direct daily measurements exist.	126.50 metres above sea level.
1846	Observation date 23 June	125.70 metres above sea level.
1860	Storflaumen or Ofsen. Second highest observed water level in Lake Mjøsa.	127.97 metres above sea level.
1863	Flood event in Lake Mjøsa. Observed on 26 June.	125.80 metres above sea level.
1910	Flood event in Lake Mjøsa. Observed on 18 June.	125.60 metres above sea level.
1927	Flood event in Lake Mjøsa. Observed 11 July.	126.21 metres above sea level.
1967	Flood event in Lake Mjøsa. Observed on 7 June.	125.62 metres above sea level.
1995	Vesleofsen. Observed on 11 June.	125.84 metres above sea level.
2011	Pinseflommen. Observed on 16 June. Between a 10- to 20-year flood.	124.24 metres above sea level.
2013	Observed on 5 June.	124.49 metres above sea level.
2023	Storm Hans. Largest flood since Vesleofsen.	125.14 metres above sea level.
	(The zero point on Hamar's water level marker.)	(117.69 metres above sea level)
	(Lowest regulated water level LRWL)	(119.54 metres above sea level)
	(Normal summer water level after last regulation)	(122.80 metres above sea level)
	(Highest regulated water level after last regulation HRWL)	(122.94 metres above sea level)

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1   Flood water levels indicated in the NN2000 vertical reference system.

Figure 2.3: The flood stone in Hamar. Photo: Øyvind Holmstad

Prehistoric flood events

It is not until the Middle Ages that we begin to find written records of flood events in Norway. However, archaeological evidence shows that larger floods have occurred in the Mjøsa watercourse in prehistoric (pre-literate) times, such as Gammelofsen (50–1 BCE) and the Merovingian flood (600–800 CE) in the Gudbrandsdalslågen watercourse. These events have been discussed by Quaternary geologists Atle Nesje, Ingar M. Gundersen and Rebecca J.S. Cannell in the chapter 'Flommer og flomskred i Gudbrandsdalen i et værmessig og klimatisk perspektiv' in the book *Gård og utmark i Gudbrandsdalen : arkeologiske undersøkelser i Fron 2011-2012* (Gundersen & Kulturhistorisk museum [The Museum of Cultural History], Oslo, 2019). No studies have been conducted on how these floods in Gudbrandsdalen affected Lake Mjøsa, but it is reasonable to assume that the consequences were similar to those of the Storofsen flood in 1789.

The 1789 Storofsen flood in Lake Mjøsa

In historical times, the *Storofsen* flood in 1789 was the largest flood in Lake Mjøsa and in Eastern Norway in general. This is reflected in its frequent mention in literature from the time. The flood was caused by extensive snowmelt due to high temperatures and heavy rainfall. The previous summers had been unusually cold, with less snowmelt than usual, resulting in larger amounts of snow in the mountains in 1789. In addition, there was a thick layer of frozen ground that had thawed slowly, so the topsoil absorbed little water when the rainfall began. In Lake Mjøsa, the water level reportedly reached 128.00 metres above sea level on 24 July, ten metres above what was considered normal at the time (Hagen, 1995;

Holmqvist & Hamududu, 2022; Nordstoga, 2004; Østmoe, 1985; Roald, 2013).

The Storofsen flood did not claim any lives in the communities around Lake Mjøsa, unlike in Gudbrandsdalen, where the damage was immense and 61 people lost their lives. Several flood victims were found in Lake Mjøsa, carried there by the River Lågen, who could not be identified (Roald, 2013). The flood caused extensive damage to farms and reportedly flooded some churches. Publicly appointed commissions travelled to the farms and documented the damage. Some of the damage reports have been preserved, providing insight into the extent of the destruction.

Gunnhild Kolstad (Kolstad, 1988) and Arne Haave (Haave, 1990) have written about the damage caused by the *Storofsen* flood in the various parts of what today constitutes Ringsaker Municipality, based on bailiff records and the damage reports collected by officials. In the Parish of Nes, 29 farms were damaged, totalling 784 riksdaler6 and 36 skilling7; in Ringsaker, 29 farms were also damaged, totalling 940 riksdaler; and in Vang, 13 farms were damaged, totalling 3987 riksdaler. Farms that suffered damage could not apply for direct financial compensation from the authorities, but they could be granted a tax reduction for a certain period. On the west side of Lake Mjøsa, 21 farms applied for tax reductions, as water from Lake Mjøsa and flood streams had reportedly cut channels in the fields and washed away the soil (Lauvdal, 1951; Roald, 2013).

In addition to the official damage reports, other sources on the historical flood events are from public and private records, as well as numerous newspaper articles. For example, Kolstad cites the churchwarden Niels Samulelsen, who reportedly wrote about food shortages

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6   An historical currency unit in Sweden
7   An historical monetary unit in Scandinavia

following the Storofsen flood, partly because, after the water receded, an *"indescribable Number of so-called Lemmings appeared, which ate up both grain and hay, with very little left for Anyone on the shores of Lake Mjøsa".* (Kolstad, 1988)

Another source for the damage caused by the *Storofsen* flood in the Mjøsa region is the previously mentioned county governor Sommerfeldt. In 1790, he wrote that during the *Storofsen* flood the year before, Lake Mjøsa "was almost hidden by Debris and filthy refuse, so that the Fish became sick and inedible". Sommerfeldt also says that at the time of writing, one year after the flood peak, the lake had still not "regained its clarity". At the same time, Sommerfeldt emphasised that the damage from the flood disaster was not irreparable, and that the flooded fields "would, in time, become as good as they had previously been, or perhaps better."(Sommerfeldt, 1795).

The *Storofsen* flood intensified the already ongoing migration of farmers from Gudbrandsdalen and Østerdalen, especially from the areas that were hard hit, to Bardu and Målselv in the inland parts of Troms County, which is reflected in the local dialects (Andersen, 1996; *Troms*, 1979; Roald, 2013).

An indirect consequence of the *Storofsen* flood was that a position as canal director was established in 1804, and eventually a separate Canal Directorate. The directorate was initially located in Copenhagen but was transferred to Norway in 1813. The Canal Directorate can be regarded as one of the predecessors of the Norwegian Water Resources and Energy Directorate (NVE) (Andersen, 1996; Roald, 2013).

19th century floods in Lake Mjøsa

Lake Mjøsa was again hit by major floods in 1808 and 1827. The flood in 1827 is the first for which direct daily measurements were taken of the water level. These measurements were taken under the supervision of Captain Gerhard Schive, who, on behalf of the Canal Directorate, had taken measurements at Minnesund since 1824. (Roald, 2013)

The biggest flood in Lake Mjøsa during the 19th century was the so-called *Storflaumen* or *Ofsen* in 1860, which affected large parts of Eastern Norway. This is the second-highest flood in Lake Mjøsa in recorded history, with a water level of 127.97 metres above sea level observed on 22 June. However, the extent of the damage was less than what the 3-centimetre difference below the *Storofsen* flood in 1789 would suggest, due to the preparations that had been made.

It was in connection with this 1860 flood that the first flood warning in Norway was issued, first in Buskerud on 6 April, and then in Kristians amt (Oppland), based on the large volumes of snow in the mountains. The warning made preparations possible, and in the vicinity of Lake Mjøsa, quays and jetties were weighed down with stones.

However, the damage caused by the 1860 flood in the Mjøsa region was still significant, particularly in the rebuilt town of Hamar, where the floodwaters rose high up the walls of houses and Strandgaten road was submerged. Local historian Lillevold describes the flood as a disaster for Hamar (Lillevold, 1987). For the somewhat younger town of Gjøvik, the damage was less extensive, as it was primarily the higher-lying parts of the town that had been developed at the time, while the plots closer to the shoreline of the lake had only been marked out and not yet built upon when the flood occurred (Mollgard, 1961; Roald, 2013). With regard to Lillehammer, which is largely situated well above the shoreline of the lake, the greatest damage was linked to the log boom giving way in the River Mesna, which sent large quantities of timber into Lake Mjøsa. (Feiring, 2004; Roald, 2013). At Eidsvoll Station, the flood is said to have

risen one and a half metres above the tracks (Andersen, 1996).

20th and 21st century floods in Lake Mjøsa

The next major flood to hit Lake Mjøsa was in 1927, when the water level peaked at 126.21 metres above sea level on 11 July. This was far lower than the 1860 flood, but higher than the *Vesleofsen* flood in 1995. The 1927 flood once again caused Strandgaten road in Hamar to be submerged, and resulted in damage in Lillehammer (Roald, 2013). Compared to the 1860 flood, considerably less has been written about the 1927 flood and its impact on Lake Mjøsa. The same applies to the 1967 flood, where a water level of 125.62 metres above sea level was observed on 7 June.

The *Vesleofsen* flood in 1995 has been more extensively covered in the literature, but the focus is more often on Gudbrandsdalen and the Glomma area than on the Mjøsa region (Hagen, 1995; Lundquist, 1996; Nordstoga, 2004; Roald, 2013).8 The *Vesleofsen* flood peaked in Lake Mjøsa on 11 June at 125.84 metres above sea level. The total damage from the *Vesleofsen* flood amounted to NOK 1.8 billion (1995), and one person died in Gudbrandsdalen while attempting to drive on a flooded road. The flood led to an increased need for gathering knowledge about floods. Among other measures, the government established a committee that submitted a report on floods and flood management in 1996 (Njøs, 1996), and a multidisciplinary research project, HYDRA, was initiated, submitting its final report in 2000 (Norwegian Water Resources and Energy Directorate & HYDRA (research programme), 2000).

Since the *Vesleofsen* flood, there have been three major floods in Lake Mjøsa, with *Storm Hans* in 2023 being the largest (125.14 metres above sea level), followed by the 2013 flood (5 June at 124.4 metres above sea level) and the *Pinseflommen* on 16 June 2011 (124.24 metres above sea level). (Roald, 2015). For more information on flood monitoring see Chapter 4.

2.7 Pollution, the Mjøsa Campaign and ammunition dumping

This section was written by Marton Bay Wærnes and presents literature addressing pollution and dumping, as well as the Mjøsa Campaign that took place in the 1970s.

The pollution of Lake Mjøsa has previously been addressed in studies on the rise of environmental policy in Norway in the post-war period, a time when new perspectives of nature and the natural environment were spreading and pollution was being politicised, understood and managed in new ways. The fact that the pollution situation in Lake Mjøsa coincides with and is part of the story of the rise of Norwegian environmental policy has meant that the early phase of Lake Mjøsa's pollution history is the best documented. In the Mjøsa region, the local pollution problems culminated in a large-scale environmental campaign, and the Mjøsa Campaign became a key focal point for historical research on pollution in Lake Mjøsa. However, the ammunition dumping that took place in the lake, which has recently received increased attention and relevance, illustrates that Lake Mjøsa's pollution history involves more than just

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8 Despite the geographical proximity, floods do not always occur simultaneously in the western part of the Glomma watercourse (the Gudbrandsdalslågen river, Lake Mjøsa and the River Vorma) and in the eastern part (the River Glomma north of the River Vorma's mouth) (Gundersen & Kulturhistorisk museum (Oslo), 2019; Roald, 2013)

the lead-up to and execution of the Mjøsa Campaign in the 1970s. Here we focus on the causes and lead-up to the Mjøsa Campaign, as well as the campaign itself.

The master's thesis *Forurensning av Mjøsa: Mjøsas helsetilstand forsket frem, formidlet og forstått* documents Lake Mjøsa's pollution history after the Mjøsa Campaign by drawing on scientific reports and newspaper articles from the period 1946–2024. (Wærnes, 2025).

Pollution in Lake Mjøsa leading up to the Mjøsa Campaign

Eutrophication, environmental policy and detergent campaign

As a consequence of urban growth and increasing industrial and agricultural activity in the Mjøsa region during the 20th century, pollution in Lake Mjøsa steadily increased. The intensity increased particularly during the post-war period. In the 1960s and 1970s, it became clear that the environmental condition of the lake was poor. Runoff from agriculture, industry and the population in the Mjøsa region brought elevated levels of nutrients to the lake (especially phosphorus), leading to increased algal growth. This process is called eutrophication, which means over-fertilisation.

Pollution increased in several water areas during this period as a consequence of post-war societal growth. Eutrophication and acidification were quickly identified as the main problems in polluted water areas throughout Norway. (Berntsen, 1994). By the late 1960s, the water in Lake Mjøsa had become so murky and foul-smelling that it drew reactions from local residents, authorities and experts. The processes that took place in Lake Mjøsa, as the lake shifted from being considered oligotrophic (nutrient-poor) to eutrophic (nutrient-rich), are described in (Nashoug, 1999; Økland & Økland, 1995). This literature also provides

descriptions of technical terms related to the *trophic state* of lakes.

Magnus Løken's 2019 master's thesis in Technology and Science Studies, '*Blanke Mjøsa klar og rein? Vannforurensningenes veger inn i politikken 1945-1973*' (*Shiny Mjøsa clear and clean? Water pollution and Norwegian politics 1945-1973*) focuses on the pollution of Lake Mjøsa and investigates water pollution as it became part of Norwegian post-war politics from 1945 to 1973. The thesis focuses on the period from the founding of Hamar in 1849 to the launch of the Mjøsa Campaign in 1973, takes a broad approach, and addresses topics such as urbanisation, opposition to pollution, and environmental policy. (Løken, 2019). The thesis has a broad periodisation and illustrates how pollution issues developed in the period leading up to the Mjøsa Campaign, as also described in the history of water book *Det viktige vannet.* (Johansen, 2004).

Per Østby focuses on the pollution of Lake Mjøsa in his studies on the integration of environmental science into politics and the development of pollution research in Norway. A working paper authored by Østby in 1997 is the first in a series of works dealing with the topic øs (Østby, 1997). Østby closely examines the role of the Norwegian Institute for Water Research (NIVA) in mapping and managing the adverse condition of Lake Mjøsa. NIVA continues to play a key role in monitoring Lake Mjøsa today, as it has conducted annual surveys of the lake's environmental condition since 1972. NIVA was established in 1958, partly as a result of severe pollution problems in the Oslo Fjord during that period. The key role NIVA came to play in Lake Mjøsa's pollution history is described by Østby and is reflected in the prominence Lake Mjøsa holds in accounts of NIVA's development (Baalsrud, 1996, 2004). Other key environmental policy institutions established during this period include the Ministry of the Environment (1972) and the Norwegian Pollution Control Authority (1974). Østby

1864	Typhoid epidemic in Gjøvik, 8 people died.
1871-1881	Annual outbreaks of typhoid in Hamar.
1887	The Watercourse Act of 1887 adopted: Ban on waste emissions from industry, but few provisions on how the ban should be enforced
1899	Hartvig Huitfeldt-Kaas carried out the first plankton surveys in Lake Mjøsa
1931	Typhoid epidemic in Gjøvik, 19 people died.
1958	NIVA (Norwegian Institute for Water Research) established
1970	Strong algal bloom in Lake Mjøsa.
	NIVA submitted their first report on the condition of Lake Mjøsa.
	The Water Protection Act is adopted.
1972	Ministry of the Environment established.
	NIVA submitted their second report on the condition of Lake Mjøsa.
1973-1980	The Mjøsa Campaign (Mjøsaksjonen)
1973	Draft resolution No. 2. 'Measures against the pollution of Lake Mjøsa' presented by the Ministry of the Environment. Led to what is referred to as 'The Minor Mjøsa Campaign' (Den lille Mjøsaksjonen). With state support, NOK 200 million kroner was invested in new treatment plants and sewage pipelines in Hedemarken and in Lillehammer, Gjøvik, and Vestre Toten.
1974	SFT (the Norwegian Pollution Control Authority) established: Finances and administers the Mjøsa surveys (1974-1995).
1977	Draft resolution No. 89 (1976-77): Continuation of the action plan for reducing the pollution of Lake Mjøsa'. The case was allocated NOK 1 billion. Initiated the so-called 'Major Mjøsa Campaign' (Store Mjøsaksjonen)
1993	Lake Mjøsa's first 'clean bill of health': In its 1993 monitoring report, NIVA concludes that the water quality in Lake Mjøsa was once again as good as in 1950, before pollution truly began to accelerate.
1996-2002	Responsibility for monitoring Lake Mjøsa becomes intermunicipal under the designation 'Action-oriented monitoring for Lake Mjøsa and its tributary rivers". The monitoring was administered by the 'Steering Committee for Intermunicipal Monitoring of Lake Mjøsa and its Tributary Rivers.
2001 2004	'The toxin scandal' In 2001, the presence of a number of environmental toxins were detected in fish from Lake Mjøsa.
2003-	The non-profit foundation 'Vassdragforbundet for Mjøsa med tilløpselver' (The Watercourse Association for Lake Mjøsa and its Tributary Rivers) was given responsibility to administer the monitoring. The association also serves as the water area committee and coordinator for work on integrated water management in the Mjøsa water area.
2009	SFT changes its name to KLIF (The Climate and Pollution Agency)
2013	The Norwegian Environment Agency is established following the merger of KLIF and DN (Directorate for Nature Management).

Table 2.7: Pollution, disease and the Mjøsa Campaign (Mjøsaksjonen)

describes the environmental policy conflicts that arose when environmental science became part of national politics in connection with the Mjøsa Campaign (Østby, 2004; Østby 2008) (Østby, 2004, 2008).

The Detergent Campaign

The opposition to pollution in the Mjøsa region, as expressed through the housewives' campaign or 'Detergent Campaign' (Vaskemiddelaksjonen), is discussed, among other sources, in the aforementioned master's thesis by Løken, in a working report written for the Norwegian Institute for Consumer Research in 1999, and in Silje C. Fylkesnes' article in *Mjøsmuseet's Yearbook* from 2015 (Løken, 2019; Throne-Holst, 1999). As those primarily responsible for clothes washing at the time, housewives (Løken, 2019; Throne-Holst, 1999). As those primarily responsible for clothes washing at the time, hHousewives in the Mjøsa region joined forces to reduce the use of phosphate-containing detergents, as these had been shown to negatively affect the condition of Lake Mjøsa. The Detergent Campaign is an early example of consumer behaviour changing in response to environmental considerations, and of women based in the home influencing broader political movements through social action. It also serves as an example of how concern for the preservation of Lake Mjøsa spread widely among the general population, even though industrial and agricultural pollution had an equally significant impact on the lake's condition.

The Mjøsa Campaign

In the second half of the 20th century, the pollution of Lake Mjøsa got out of control. This culminated in the Mjøsa Campaign, which took place from 1973 to 1980, followed by later measures to address the pollution problems in the lake. Large sums of money were allocated, and wide-ranging measures were launched to tackle the problem of eutrophication.

A report published by NIVA in 1973 stated that Lake Mjøsa had reached a point where eutrophication could spread, and it called for active, wide-ranging efforts to prevent further inflows of pollution to the lake. The newly established Ministry of the Environment, under the leadership of Gro Harlem Brundtland, presented a government funding proposal in 1973 for an action programme to achieve this (Nashoug, 1999). As a result, the condition of Lake Mjøsa gained national significance. The summer of 1976 was particularly warm, leading to a strong growth of cyanobacteria (blue-green algae) *Oscillatoria bornetii*. (Nashoug, 1999).

The fact that this massive algal growth occurred while pollution-mitigating measures were already being implemented led to a significant intensification of the Mjøsa Campaign. In a draft resolution from 1976–77, the action plans were continued (Johansen, 2004; Nashoug, 1999). The Mjøsa Campaign was concluded in 1980. By then, the pollution-mitigating measures had decreased the phosphorus inflow to the lake by approximately 60 percent (Nashoug, 1999; Økland & Økland, 1995).

Four reasons why the Mjøsa drama died down after the Mjøsa Campaign are:(1) Unknown variables had been mapped, (2) management-related knowledge had increased, (3) the relationship between nature and culture could be balanced with technological measures, and (4) the population had undergone a learning process that led to greater environmental awareness (Østby, 2008).

Sociologist Arvid Hallén prepared memos, reports and studies in 1981 on behalf of the Norwegian Institute for Urban and Regional Research, directly following the Mjøsa Campaign. Hallén's work provides insight into the legislation and economic

aspects that formed the basis for the action plans and the concluding phases of the Mjøsa Campaign. It is also part of the project 'Local Consequences of Central Decisions' (*Lokale konsekvenser av sentrale vedtak*), which covers various aspects of the implementation of the campaign. This literature review refers to four of Hallén's works, which can be used in various ways as a starting point for studies of the Mjøsa Campaign, including its background, goal attainment, opinions on it, and implementation processes (Hallén, 1981).

The practical implementation of the campaign extended beyond its formal conclusion in 1980. Over time, the eutrophication problem proved to be a recurring one, as algal blooms reappeared in the mid-1980s, showing that pollution-mitigating measures had to be fully implemented and continuous efforts were required to protect Lake Mjøsa (Berntsen, 1994; Johansen, 2004); Nashoug, 1999). It was not until 1993 that Lake Mjøsa could once again be considered an oligotrophic lake, but even in recent times, algal growth occurs sporadically during the summer months. The pollution of Lake Mjøsa following the Mjøsa Campaign has not been closely addressed historically, but Lake Mjøsa's successive pollution problems are discussed in Wærnesæs master's thesis (Wærnes, 2025).

Ammunition dumping

The dumping of ammunition in Lake Mjøsa lacks historical research and is a case marked by uncertainty regarding both its level of danger and its extent. With that said, some details are known. The practice of dumping ammunition in Lake Mjøsa most likely took place over a 30-year period from the 1940s to the 1970s, if not longer. In the archives of Raufoss Ammunition Factory (Raufoss Ammunisjonsfabrikks (RA)), the start of the practice is dated to 1942/43 and ended in 1971. However, *Mjøsmuseet* has contemporary witnesses who date the last dumping of ammunition to 1976. Therefore, there is uncertainty about the exact time period during which this practice took place.

In 1999, ammunition was found in Lake Mjøsa, close to the water intake at Gjøvik. Following these discoveries, the matter was investigated further, revealing that large amounts of ammunition had been dumped into the lake. Wærnes' master's thesis discusses press coverage of the ammunition dumping to illustrate how environmental perspectives and understanding of pollution changed over time. From the 1940s to the 1960s, the presence of ammunition was mentioned with casual indifference, but when it was rediscovered in 1999, it sparked a flurry of calls to local newspapers, and the Mayor of Gjøvik demanded clarity on the matter. Raufoss Ammunition Factory was required to account for the practice while Norske Veritas conducted investigations. However, the reports that were issued were called

Figure 2.4: Ammunition dumping on lake Mjøsa. From the local newspaper Samhold, July 30 1965

into question and have since been shown to be incomplete (Wærnes, 2025).

In connection with the historical research efforts involved in Mission Mjøsa, several master's theses will be written focusing on Raufoss Ammunition Factory. In addition, PhD candidate Vilde Antonie Haug Slottemo at OsloMet is currently working on the topic.

Books about the history of Raufoss Ammunition Factory have also been published. In 1996, Thor Wang wrote Raufoss Ammunition Factory's history from a hundred-year perspective, but since the book was written three years before the dumping became an issue, it contains no information about the dumping (Wang, 1996). Steinbakken et al. have written two volumes on the Norwegian Army's ammunition service in the early 2000s. The first volume describes the practice of ammunition dumping after World War II, noting that lakes were considered particularly suitable dumping sites, but Lake Mjøsa is not mentioned in detail (Steinbakken et al. 2000). Lake Mjøsa is mentioned in the second volume, but not in connection with dumping (Steinbakken et al. 2001).

Further information on ammunition dumping can be found in chapters 3 and 5.

2.8   Conclusion

This chapter has provided an overview of the history of Lake Mjøsa and the Mjøsa region from prehistoric times up to the late 20th century, on topics of population developments around Lake Mjøsa, fishing, transportation, water regulation, flooding, pollution, ammunition dumping, environmental activism and environmental monitoring. Historically, the Mjøsa region has been a relatively densely populated area by Norwegian standards, but it has only become urbanised in more recent times, with the exception of the medieval town of Hamar. Lake Mjøsa has been an important transportation hub in Innlandet County, but the lake's significance as a transport route has changed. In the past, much of the transport of passengers and goods across Lake Mjøsa took place on boats, with steamboat traffic as the pinnacle. However, throughout the 20th century, railways and automobiles outcompeted waterborne traffic, with the construction of the Mjøsa Bridge serving as a symbolic endpoint. The once-important sled traffic across the Mjøsa ice in winter has also come to an end, mainly as a result of climate change. Nowadays, Lake Mjøsa is experienced more as a barrier than as something that connects people. Recreational boating, however, remains popular, and the *Skibladner* steamship is still in operation for tourists. Similarly, fishing in Lake Mjøsa is no longer as important in terms of an additional food supply or as a source of livelihood as it was for several centuries, but remains a popular recreational activity.

Lake Mjøsa has always been prone to major flood events, with the *Storofsen* flood in 1789 and the *Ofsen* flood in 1860 being the largest. Warning routines and watercourse regulation have made floods less dangerous than in the past, but the extent of flood damage can still be significant today, as seen during *Storm Hans* in 2023.

The pollution problems in Lake Mjøsa, linked to the discharge of nutrients, organic waste, chemicals and heavy metals, emerged toward the end of the 19th century but only became truly problematic in the postwar period. The successful Mjøsa Campaign has become an important focal point in Lake Mjøsa's environmental history in particular, and in Norwegian environmental history in general.

Lake Mjøsa is one of many lakes in which ammunition has been dumped in Norway. However, the large volume, the long duration and the proximity to densely populated areas make this dumping particularly notable. It is still unclear when the practice of dumping ammunition from Raufoss Ammunition Factories in Lake Mjøsa began, and when it actually ended.

This literature review highlights the need for more research, particularly on the ammunition dumping in Lake Mjøsa, but also on the lake's earlier environmental history. Furthermore, it emphasises the need for a comprehensive, accessible overview of the history of the Mjøsa or Innlandet regions.

Chapter 3: Socio-political and cultural knowledge about Mjøsa

Preema Ranjitkar and Sindre Johan Cottis Hoff, with contributions by F. Chantel Nixon, Chris Storie, and Joni Storie

3.1 Executive Summary

This chapter presents an overview of the social, cultural, and political dimensions of the Lake Mjøsa region, with a focus on the recent past and present. It includes details on the economy, sports, governance, demographics, and health in the area from approximately 2000 through to 2025. Material for this review was identified based on search with the keyword "Mjøsregionen" in the digital database of the Norwegian National Library for the specified time period. Supplementary material was collected by Google search with related keywords, and from contributions from knowledgeable experts. All identified sources were qualitatively screened for relevance.

Mjøsa is a region where sports is deeply ingrained into society, providing individual and collective benefits, and with a long history of cultural traditions, many of which are intimately connected to Lake Mjøsa. Yet, Mjøsa is not isolated. It is a region with strong internal characteristics, and one firmly connected to conditions nationally and internationally. This is especially true with regards to in-migration, resource governance, and tourism.

The economy has traditionally been characterized by the natural resources available, with timber and arable soil being the most important. In recent decades, the largest increase in jobs has taken place in urban centres, and this has

been strongly influenced by fluctuations in the Norwegian national economy. The population growth in the region has consequently been largest in urban areas. Hence, similar to trends across Norway, there has been an increasing centralization in terms of where people live and work, and the services they rely upon. In line with the trend of national centralization, a growing number of residents in the region, particularly the southern parts, commute to Oslo and the surrounding areas for paid employment.

In a changing world with constant new challenges, the region faces challenges in maintaining prosperity and the wellbeing of the residents; two of the largest are the aging population and pollution in the lake. Both issues demand costly action. It is unclear how the people and the politicians of the municipalities and counties will respond to these challenges.

The review also reveals a notable lack in knowledge about the significance of Mjøsa and aspects of Mjøsa for private and collective goods such as identity, cohesion, and wellbeing. This makes decision makers poorly equipped to assess if policies and projects risk diminishing Lake Mjøsa's ability to provide these immaterial values.

3.2 Introduction and Methodology

This chapter is a review of published work on the topics of: (1) economic landscape, (2) sports, (3) lake governance and (4) demographics and (5) health in the region around Lake Mjøsa in southern Norway, spanning from the year 2000 to 2025. Searches for these key words in scientific and academic databases, however, suggested that there was little peer-reviewed literature specifically focusing on these topics. Therefore, efforts were re-directed towards gray literature and a literature search was conducted using the National Library (Nasjonalbiblioteket, n.d.-b). The National Library is responsible for storing and continuously making available to the Norwegian public all material that has been published in Norway. Beginning in 2006, they have made their collection of material digitally available and searchable online (Nasjonalbiblioteket, n.d.-a), making the collection an accessible and powerful tool for identifying relevant literature outside of academic and scientific databases.

The keyword "Mjøsregion" was searched for amongst material published in the period of 2000- 2025. A secondary literature search was performed on Google to scout for literature not listed in the National Library database, such as literature not officially published for the Norwegian public. Keywords "mjøsa" OR "mjøsregion" were used. Only peer-reviewed journals, books, reports and papers by research institutes, or municipalities and county authorities were selected. After this, qualitative assessment of each document was done with respect to whether it related to the scope of this review. The documents considered to be unrelated were excluded from further review. Documents that did not largely use primary sources, such as bachelor's and master's theses affiliated with different universities as well as works of fiction and memoirs, were excluded from the review. We acknowledge that this is a different literature review strategy than Chapter 2, which references several master's theses. This was an intentional choice by the author team based on the available literature and the style of master's theses in the relevant disciplines. The Mission Mjøsa research team as well as Mission Mjøsa partners were also asked for recommendations for relevant documents.

While Lake Mjøsa and its immediate surroundings are the main scope of this review, several of the sources included also refer to areas further out across the larger region. These sources are included as they together provide a picture of the region of Mjøsa, or they provide information that is applicable to the Mjøsa region and the country more generally. The different regions discussed in this chapter include: Innlandet (one of the two counties where Mjøsa is located), Akershus (one of the two counties where Mjøsa is located), Hedmark (the county on the eastern side of Mjøsa, which as of 2020 became part of Innlandet county), Oppland (the county on the western part of Mjøsa, which as of 2020 became part of Innlandet county), and the areas including and surrounding the region's largest cities of Hamar, Gjøvik, and Lillehammer.

3.3 Economic Landscape

Existing literature indicates that the region of Mjøsa has economic characteristics rooted in its industrial and agricultural past. The bulk of the research on economy relates to mainstream industries and markets divided by economic sectors (agricultural, manufacturing, service and knowledge sectors) and is organized by county and city. There is some material on challenges and opportunities for future development, which is also organized this way.

Economic characteristics of the region of Mjøsa

Historically, the region of Mjøsa has had a strong industrial base, which is linked to its strong agricultural potential and technological advancements. During the 19th and 20th centuries, the region was a leading hub for industrial activities, for manufacturing parts, metalworking, and aquavit distillation among others. The shift away from subsistence production and towards sales-oriented agriculture was a significant factor, with the region of Mjøsa being a pioneer in commercial food production (Merok, 2015). The establishment of distillery enterprises, including Atlungstad Brænderi, signified the economic strength of the region. The industry's growth was connected to farmers seeking outlets for their potato crops. The timber and paper industries also flourished, something which was enabled by abundant forest resources in the area (Kristoffersen et al., 2007). More details about this period are included in chapter 2.

The cities of Gjøvik, Hamar, and Lillehammer are frequently discussed in the literature; this is much less the case with the smaller towns and settlements. The economic structure of Gjøvik, for example, is characterized by a mix of private and public sector activities, with a notable emphasis on certain industries (Hauge et al., 2014). In the private sector, the dominant industries include trade and retail, manufacturing, metal and motor vehicle production, and construction. The public sector includes health and social services, employing approximately a quarter of the workforce. The education sector is also notably larger than the national average. Between 2000 and 2013, employment in the Gjøvik region grew by six percent, significantly lower than the national growth rate of 16 percent during the same period. Economic development in the region is largely shaped by national trends and remains heavily reliant on the provision of public services. This dependence also makes Gjøvik particularly vulnerable to fluctuations in the national economy (Hauge et al., 2014).

Hamar is a key regional centre and maintains 20% of the region's total concentrated employment (Gløtvold-Solbu et al., 2014). Hamar is also categorized as an administrative, financial, and service centre of Innlandet county. It was the administrative centre of the previous county of Hedmark. Hamar has net in-commuting, meaning that it has more jobs than residents and people commute into the city for work (Leknes et al., 2016). Hamar is also listed as one of the ten regions with the strongest growth in out-commuting towards other medium sized regional cities (Leknes et al., 2016).

Like Gjøvik and Hamar, Lillehammer is also identified as a key regional centre, accounting for 17% of the region's employment (Gløtvold-Solbu et al., 2014), and is a key tourist destination for Norwegians and international visitors. Lillehammer and Hamar both have a relatively high share of inhabitants with higher education in many fields including but not limited to natural sciences and technology. The University of Innlandet's largest campus is in Lillehammer, based at the site of the previous television and radio centre built for the 1994 Olympic Games. The city maintains other facilities from the Olympics including a museum dedicated to the games and the large downhill ski jump near the centre of town. Maihaugen, Norway's largest open-air museum, is also located in Lillehammer and draws large international crowds throughout the year.

Economic challenges of the region of Mjøsa

According to a 2004 report by Norwegian Institute of Urban and Region Research (NIBR), the Innlandet region

is characterized by a relatively small population, large geographical area, and a history of lagging development compared to the rest of Norway (Johnstad, 2004). Despite having access to rich natural resources in the form of arable land, forest and wilderness areas, the report suggested that Innlandet county had relatively weak business development compared to the rest of Norway. The report also suggested that Innlandet had relatively few research and development (R&D) environments, and low investment in R&D in higher education, leading to a weak regional innovation system. However, government welfare policies and increased commuting to the Oslo region have contributed to a personal services sector that is in line with the national average.

Østlandforskning (2009) considered the attractiveness of Hamar as a city people would want to live in (*bolyst*), and found that future challenges in this area, particularly the aging population and its impact on the labour market (Alnes et al., 2009) were primary concerns for economic development. Innlandet's persistent structural challenges have been referred to as the 'Innlandet Syndrome'. Some argued that the region's stagnation was partly due to being in the 'oil shadow' of Norway's petroleum economy (Johnstad, 2004). There was also concern about proximity to Oslo, referred to as the 'Oslo Shadow', although more recently the southern parts of Innlandet have benefited from increased commuting to Oslo. Hauge et al. (2014) suggested linking towns along the shore more closely to increase labour markets in smaller cities.

Economic development in Innlandet was traditionally focused in the agricultural and forestry sectors. However, a report by Østlandsforskning analyzed the timber house industry in Innlandet and found that it faced challenges in recruiting skilled labour and the need for increased process industrialization (Kristoffersen et al.,

2007). It recommended comprehensive and strategic reform involving innovation, competence building, and networking to foster the development of the timber construction (Kristoffersen et al., 2007). There is also an emphasis on collaboration with educational institutions for growth of timber industry.

Economic opportunities in the region of Mjøsa

A report by NIBR published in 2004 recommends two strategies for fostering economic growth and value creation in the Innlandet region: developing a commuter-based population and fostering export-oriented industries (Johnstad, 2004). Infrastructure development, like the current E6 expansion, allows more people to participate in surrounding labour markets by making commuting easier. Lein et al. (2003) investigated how investment in transport infrastructure could lead to economic growth in Hedmark and Oppland. A survey of businesses in Hedmark and Oppland regions highlighted the importance of freight transport, the need for reliability and predictability, and the high significance of transport options for customers. The survey further indicated that car transport was the most important mode of transport for both employees and customers, but other forms of transport were also significant.

Alnes et al. (2009) found that Hamar's attractiveness as a place to live was dependent on people commuting to and from work. Similarly, 'Gardermoen 2040: Strategic development for Gardermoen' details how changes at Gardermoen Airport could make positive contributions in the development of the region, considering its proximity. Individuals from Gjøvik, Hamar, Lillehammer and Eidsvoll were invited to participate as resource groups for this report. The report suggested that travel time between Hamar and Gardermoen could be reduced to as

little as 35 minutes, which could result in various opportunities for economic development (Akershus Fylkeskommune, 2007). As of this writing, these transportation improvements have not been made, and it still takes approximately an hour and twenty to an hour and thirty minutes to travel between Gjøvik and the international airport at Gardemoen.

A report by the Transport Economics Institute defines the region of Mjøsa as the Hamar, Lillehammer and Gjøvik regions (Strand & Engebretsen, 2005). If transportation and commuting times within the region serve as an indicator of regional interaction and taking the relative stability of the population in Hedmark and Oppland between the 1980s to the 2000s, there has been a relative and absolute increase in regional interaction. By regional interaction, we refer to the ways in which different places connect and influence each other. At the same time, the change is characterized by growth in commuting towards Oslo, especially from Hamar and Gjøvik. This trend is also supported by a 2014 report by Østlandsforskning, which found that the interaction between Mjøsa cities is not particularly extensive

when compared with commuting to Oslo/Akerhus (Gløtvold-Solbu et al., 2014). One point of note, commuting between Hamar and Gjøvik has increased significantly, likely related to the Mjøsbrua, which opened in 1985 (Strand & Engebretsen, 2005).

Collaboration within and outside of the region of Mjøsa is another recurring theme in literature reviewed for this report. The NIBR report recommended the development of an export-based business sector, focusing on traditional industries and the development of new industries (Johnstad, 2004). The document stressed the importance of region-strengthening measures, including developing basic institutions and infrastructure for culture, research and education. The establishment of University of Innlandet in 2020, for example, was one of the outcomes of such recommendations. Emphasis was also placed on strengthening connections with the communities around the lake and up into the surrounding valleys. The document also stresses the importance of strategic partnerships and coalitions in influencing the direction and form of development

Figure 3.1: Recreational sailing on the lake. Photo credit: Jan Tore Bern

1994 Winter Olympics in Lillehammer

The Winter Olympics in 1994 and Paralympics were the biggest sporting events in the history of Lillehammer and the surrounding region (Haugerud, 2015). The organization of the Olympics was a large and challenging undertaking for the small city. Hosting the Olympics meant that the municipality was not only building new, international standard sporting facilities, but also larger medical facilities, housing facilities, and water management systems, communication channels, art and cultural monuments, and transport facilities like the Lillehammer bus station (Haugerud 2015). The Lillehammer Olympics were planned and carried out before the concept of 'legacy' was a goal for major sporting events. Nevertheless, the concern for post-use was central to local actors from the moment the Olympic idea was proposed. Post-use was, in fact, an important motivation for bringing the Olympics to Lillehammer and the Innlandet region, along with the idea that it would trigger investments and facilities that would create longer-term benefits. A report by the University of Inland Norway (INN) details how the different sports, culture, media and accommodation facilities built for the 1994 Olympics have been adapted and repurposed for current use (Lesjø & Syversen, 2021). The 25th anniversary of the OL was celebrated in February 2019 in Lillehammer to highlight the significance of the event for all of Innlandet, and to showcase the importance of voluntary work and further develop the Olympic legacy in the future. Other municipalities with Olympic arenas such as Gjøvik, Hamar, Ringebu and Øyer also held anniversary celebrations. Attended by 10,000 people for the main event and costing NOK 1,174,000, this celebration indicates the ongoing significance of the 1994 Olympics for the people in the area. The details of the organisation of this celebration along with press coverage are found in a report by Lillehammer Municipality (2019).

Text box 3.2: The European Union Water Framework Directive (EU WFD)

in Innlandet (Johnstad, 2004). The county plan for Hedmark (2009-2012) contained similar sentiments regarding policies for the county, regional cooperation, regional cooperation and regions in the county (Hedmark Fylkeskommune, 2008).

A document detailing Hedmark's regional policies and planning for 2009 – 2012 (with a long-term vision to 2020) included strategies for economic opportunities (Hedmark Fylkeskommune, 2008). The document emphasized the importance of research and development as a driver for innovation and economic growth. It called for strengthening collaboration between research institutions, businesses, and regional authorities through initiatives like the establishment of University of Innlandet. The plan also highlighted the importance of collaboration among the Østland region, the Innlandet region, and neighbouring areas in Sweden.

In the past decade the two university colleges in the Mjøsa region have transitioned to universities. The University college of Gjøvik merged with Norwegian University of Science and Technology (NTNU) in 2016, and the University college of Innlandet became University of Innlandet in 2024 (Regjeringen, 2024). As indicated above, research and educational institutions in the region have been of great importance for value creation, and it is widely agreed that the transition to university status and the opportunities that follows from this will enable these institutions to contribute notably to regional development (Jenssen, 2016).

3.4 Sports and its importance for the region of Mjøsa

A report by Østlandsforskning assessed the value of sports in Innlandet, detailing how sports are organized and funded in Norway (Malasevska, 2024). The report included a detailed list of facilities and their ownership, and the economic value of sports in monetary and non-monetary terms. As of 2022, all of Innlandet had 688 sports clubs with 124,944 members and 107,593 active participants. There were 5,928 sports facilities in Innlandet of which 67% were 'ordinary facilities' and 32% were local facilities. In 2022, the total economic value creation in the sports industry in Innlandet was 1.15 billion NOK, an 18% increase since 2018. The estimated value of volunteer work was approximately 1.3 billion NOK. The report estimated the value of health benefits from increased physical activity among sports members using the concept of QALY (Quality-Adjusted Life Years) which is an evaluation to assess the value of medical interventions. The report also calculated the value-creation per member in sports at approximately 89,000 NOK annually in 2022. The report also estimates the value of volunteer work in Innlandet was approximately 1.3 billion NOK (Malasevska, 2024).

While the Østlandsforskning sports report did not specifically focus on the region of Mjøsa, it did include information specific to the largest cities on the lakeshore, Gjøvik, Hamar and Lillehammer (Malasevska, 2024). For example, the economic value created from events such as NM ski på Vind 2023 was approximately 10 million NOK for the Gjøvik region. Lillehammer received a total of 34.47 million NOK in grants between 2018 and 2022. The non-monetary value of sports in Innlandet are in their ability to increase life expectancy, provide health benefits, social development and well-being, support mental health, foster a sense of community, and foster volunteerism.

3.5 Governing Lake Mjøsa

Ownership of land and forests surrounding the lake

Lindstad & Solberg (2012) show that international policy influences Norway's national forest program, forest protection, public participation and policy evaluations. International sustainable forest management policies intensified national focus on protection of productive forests, potentially due to knowledge about the negative effects of forest practices on biological diversity (Lindstad & Solberg, 2012). Helseth, et al. (2023) state there are value asymmetries in Norwegian forest governance, focusing on the role of institutions and power dynamics in shaping perceptions and preferences related to forest ecosystem services and values. In their study, most respondents prioritize ecosystem services with relational and intrinsic values, such as recreation and biodiversity, over those with instrumental values like timber; women and non-forest owners show higher appreciation for relational values compared to men and forest owners, who value instrumental services more. In contrast, timber markets and cost-benefit analyses dominate Norwegian forest governance, favouring utility, efficiency, and instrumental values.

Forestry in Norway is characterized by small-scale farmers, combining forestry and agriculture. This structure is based on the Norwegian topography, varying production conditions and the ownership

structure of Norwegian forests. According to Statistics Norway (2024a), forests (49.7%) represent almost half of the landscape in Innlandet, followed by open firm ground/bare rock, gravel and blockfields (31.9%), bogs (6.5%), inland waters (5.3%), agriculture (4.3%), built up areas (1.8%) and permanent snow and glaciers (0.6%). With the existing level of timber harvest and forest management, the growing stock and its increment in 2011 is more than twice the level documented by the first National Forest Inventory in 1932. The amount of dead wood, old forest and deciduous trees, which is important for biological diversity, has increased considerably during the same period.

Norwegian forest policy is based on a wide range of measures including legislation, taxation, financial support schemes, research and advisory bodies. Norway's obligations under international agreements have also been incorporated in Norwegian law, i.e. the criteria for sustainable forest management that have been negotiated in the framework of forest policy cooperation in Europe. The main objectives of the Forestry Act are to promote sustainable forest management with a view to promoting active, local and national economic development, and to secure biological diversity, consideration for the landscape, outdoor recreation and the cultural values associated with the forest. The Forestry Act applies to all categories of forest ownership (det norske skogselskapet, 2011).

A regulation under the Forestry Act requires forest owners to reinvest a part of the revenue from forestry into a government administrated fund, the Forest Trust Fund. This fund was established to secure long term investment in sustainable forest management such as silviculture, building and maintenance of roads, forest management planning and environmental measures. A forest owner is required to deposit between 4 and 40 % of the gross

revenue from the sale of timber and firewood to a trust fund that remains with the forest holding. The forest owner is stimulated to use the trust fund actively as only a part of the money invested in the property will be subject to taxes. Some regions, mainly the western and the northern part of Norway have no traditions for commercial forestry. These regions are prioritized when aid is allocated, which means that regions that do prioritize commercial forestry, such as the areas around Mjøsa, receive less aid. These support schemes are administered on regional and local levels.

With 46 municipalities and at least 12 common areas (almennings) identified (using online sources) in Innlandet, the management of the Lake Mjøsa watershed and its surroundings needs to overcome analysis and decision-making challenges to achieve a more holistic approach that underlies sustainable ecology. Departments within the municipalities report and manage forest and open fields, agriculture, livestock husbandry, welfare schemes, concession and property, and agriculture-based business development. In the Innlandet region, like many mountain and rural areas of Norway, there are also informal rights and management by communal rule of the historically recognized common land and water. The commons are primarily managed by local farmers for a range of activities including, for example, pasture and forest management, fishing and hunting access and rights, and more recently, cabin development. The Vang Commons on the east side of Lake Mjøsa provides this description (Vang Almenning, 2024) (Accessed 10October2024 https://vangalmenning. no/wp/almenningsbestyrer-gar-av-med-pensjon /):

> *Vang Almenning is a village almenning in Hamar municipality and a recognized forest and range manager in Innlandet. The business is organized as an association (FLI) and*

The European Union Water Framework Directive (EU WFD)

The European Union Water Framework Directive (EU WFD) is a comprehensive legal instrument designed to maintain good water quality that supports both ecological integrity and human needs in its signatory countries. Norway adopted the WFD in 2008, prompting a major reorganisation and restructuring of its national water management system (Norwegian Government, 2025). A key feature of EU WFD is its ecosystem-based management approach (Hanssen et al., 2016), which emphasises organising water governance around natural watershed boundaries-referred to as River Basin Districts (RBDs), rather than traditional administrative divisions such as municipalities, counties, or states. Each RBD is then further divided into several Sub-River Basin Districts, again based on natural hydrological boundaries. Lake Mjøsa, under this system of organisation, is within the Mjøsa Sub-RBD which is within the Glomma RBD. Each RBD is also appointed a county as a River District Authority. For Lake Mjøsa, this is Østfold County (Norwegian Environment Agency, 2020). The EU WFD is operationalised into the Norwegian legal framework through the Water Regulation (Vannforskriften). While the Ministry of Climate and Environment and the Norwegian Environment Agency are the central authorities for water governance in Norway, the decentralised and polycentric system of Norwegian governance means that the municipalities and sectoral authorities have the duty and authority to carry out requirements stipulated in the Water Regulations' (Lovdata, 2006). The EU WFD is implemented through six-year cycles. Each cycle, RBDs and sub-RBDs are required to submit documents on plans for water management as well as key challenges in their respective areas. The documents from 2016 to 2023 are available at vannportalen.no.

Text box 3.2: The European Union Water Framework Directive (EU WFD)

is owned by 356 landowners entitled to use it. [Vang] Almenningen has an area of 221,500 acres, of which 108,000 acres are productive forestry land and 53,000 acres are protected areas. Active grazing with sheep and cattle is practiced throughout the community. The business is diverse and includes forestry, arranging for cabin development, property development, letting, selling and hunting and fishing, production of gravel and, not least, arranging for outdoor life, sports and activity - all year round.

In total, Vang Almenning had a turnover of approx. 31 million [NOK] in 2023 and has a solid economy, with good liquidity and profitability.

Almenningen has its office in a new, beautiful building at Gåsbu in Hamar, and the area is one of the biggest departure points in the region, especially in winter. Vang Almenning wants to be an active collaboration partner and positive social actor for all stakeholders and is based on a long-term and sustainable development and operation of the business.

From 2013 to 2023, on average, individuals or private owners other than individuals owned 96% of the national forested properties (SSB, 2024). The State, municipalities and counties own approximately 1% while approximately 2% is in deceased estates. While communal organizations own less than 0.045% of

forest lands themselves, their members are part of the individuals who own forested land in the areas. In 2009 Norway had 120 000 forest owners with more than 2.5 hectares of forest. Ninety-seven percent of these properties are privately owned and constitute 80 % of the total productive forest area. The average size of privately owned farms with forest resources is 45 hectares. In 2021 there were registered almost 125 000 forest properties in Norway, with an average size of 560 decares of productive forest land. Most of them are individual owners that own a smaller forest area, that together represent about 75% of the forest. While the last 25% is mostly owned by private institutions, state, municipality, or county (Aasetre & Bele, 2009). National ownership of forested lands is relevant for the Mjøsa area because what happens in one part of the country affects other areas with regards to distribution of benefits, support services, resources, and taxes.

Who owns the water?

There are conflicting reports regarding who technically owns the water in Lake Mjøsa, which is an issue because the lake functions as a reservoir for drinking water for many communities in the area. It is also used for irrigation and hydropower. Beyond these instrumental uses, it is important to preserve the natural environment, cultural landmarks, and cultural landscapes in the region of Mjøsa, and this includes the lake itself. There is a necessity to ensure that the water is clean enough to support plant and animal life as well as recreational activities like fishing and swimming.
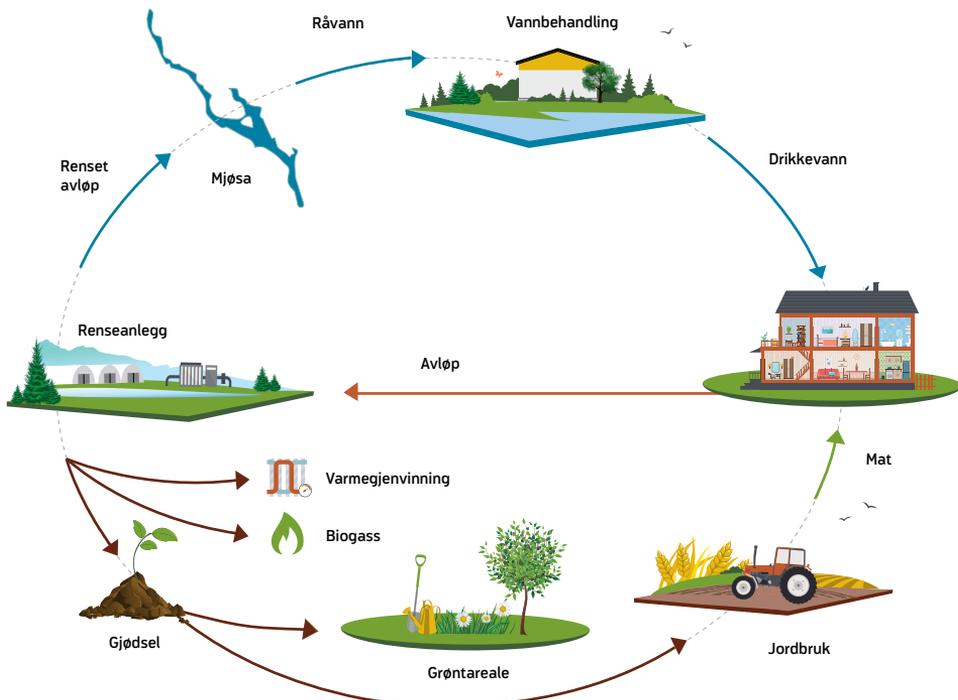
Figure 3.2 Lake Mjøsa as a source of drinking water and recipient of wastewater and the processes of ensuring a good quality of drinking water through this circular process. Source: (HIAS, n.d.-a)

While ownership and management of the lake water is quite complicated, we were able to find a report titled 'Det gode liv ved Mjøsa' detailing a 2007-2008 project aimed at creating unified guidelines for the sustainable development of Lake Mjøsa's shoreline (Styringsgruppa for Prosjekt strandsone Mjøsa, 2008). The project involved multiple municipalities and counties, updating 1995 guidelines to balance environmental protection and increased public access. The report includes an analysis of shoreline land use, accessibility, and obstacles to public access. The report also offers ideas for future sustainable development initiatives focusing on tourism, recreation, and community engagement. It emphasizes the need for balanced growth around the lake, based on the principles of sustainable development. A major theme is increasing public access to Mjøsa's shoreline. There is a need for footpaths, bicycle paths, and access points for canoes, kayaks, and boats to make the shoreline more accessible to the general public. The report aims to provide guidance for land use planning in the shoreline area. It establishes a 100-meter zone from the shoreline with specific building restrictions, while also allowing for certain kinds of development outside of this zone. The report suggests that municipalities should consider the creation of 'consideration zones' that extend beyond this 100-meter zone, where the unique characteristics of the shoreline can be considered. (Styringsgruppa for Prosjekt strandsone Mjøsa, 2008).

Before the adoption of the European Union Water Framework Directive (EU WFD) in Norway (Text box 3.2), Helleberg and Nordhagen (2003) proposed the creation of a watershed association for Lake Mjøsa and its tributaries in Norway. Assessing the fragmented governance structure, the authors highlight the need for a unified organization to manage water resources effectively through the creation of a watershed association for Lake Mjøsa. The primary focus of establishing the association would be to achieve compliance with EU WFD and address stakeholder interests. The document details the organizational structure, financial planning and collaboration needs for the proposed association. There is an emphasis on the necessity of a coordinated and unified approach to water management through the establishment of a 'vassdragforbund' or a water board. (Helleberg & Nordhagen, 2003). The water board exists today as a central coordinating body to oversee the water management and monitoring activities in the Mjøsa watershed and Mjøsa sub-river basin district.

The Legacy of the Mjøsa Campaign (1972-1883) regarding drinking water treatment

Although half a century has passed since the lake restoration project known as Mjøsaksjon, translated here as the Mjøsa Campaign, it remains relevant for communities around the lake. This is explored in depth in Chapter 2. The Mjøsa Campaign is frequently referenced in different kinds of reports and planning documents produced by interest groups, research institutions and the municipalities around the lake (Forbord et al., 2022; M. F. Johansen, 2002; Ratnaweera, 2013; Vittersø, 2000). It is also frequently referenced in Norwegian and English language peer-reviewed journal articles (Brox, 2016; Gooch et al., 2010; Lund et al., 2024; Moe et al., 2020, 2022; Oliversen & Deborah, 2021; Venkatesh, 2013). Over the 50 years since the Mjøsa Campaign, municipalities and sector authorities have invested significant resources to maintain the lake as source of drinking water, as a wastewater and sewage recipient, and a space for recreational activities such as fishing, swimming and boating. Following the Campaign, stricter requirements were generally imposed on industry in the areas surrounding the lake than in the rest of the country. Wastewater from dairies, slaughterhouses, breweries, mineral water and canning factories was largely directed to municipal treatment plants after first undergoing internal treatment processes in the different companies (Nashoug, 1999). Additionally, the local requirements of concentration of chlorophyll A (2.0 µg/l) are stricter than the local target set by the Water Regulation's goal of 4.0 µg/l (Vassdragsforbundet for Mjøsa med tilløpselver, n.d.). More recently, in March 2025, catalysed by a large algal bloom in Lake Mjøsa in 2019, the Innlandet county governor issued new regulations on regional environmental requirements for agriculture in Innlandet County. One of the more tangible legacies of the Mjøsa Campaign is the annual monitoring carried out by NIVA, commissioned and funded by the Mjøsa Water Board (Vassdragsforbundet for Mjøsa med tilløpselver, n.d.). This annual monitoring and reporting is explained further in Chapter 4. These reports are also used to develop recommendations on management strategies for the lake.

Text box 3.3: The Legacy of Mjøsaksjon

3.6   Mjøsa and drinking water

While Lake Mjøsa is used for different purposes, drinking water is, arguably, its largest and the most important use. Many of the municipalities surrounding the lake draw water from it, supplying approximately 80,000 - 150,000 people (HIAS, 2023; Vassdragsforbundet for Mjøsa med tilløpselver, n.d.). While Lake Mjøsa is a source of clean water to the people surrounding the lake, it is also a recipient of wastewater.

There are different steps undertaken to ensure that drinking water is of acceptable quality. For the municipalities of Hamar, Løten, Ringsaker, and Stange, HIAS, an inter-municipal organization, provides water services. At HIAS VBA Sandvika, water is treated through four steps: coagulation with an iron coagulant, filtration through a three-media filter that also contains marble to adjust pH and reduce corrosion, and disinfection using both ultraviolet light and small amounts of chlorine. At HIAS VBA Vestbyda, water treatment involves three steps: screening to remove particles, corrosion prevention by adding sodium silicate to raise pH, and disinfection using the same two methods – UV light and small amounts of chlorine (HIAS, n.d.-b).

Nationally, the drinking water regulations require that the water supplied is safe for health, clear and without a prominent odour, taste or colour (Hamar Municipality, 2025). The key to maintaining the drinking water quality of Lake Mjøsa is ensuring the wastewater is treated before being discharged into the lake. HIAS, established after the Mjøsa Campaign to ensure water quality, implements measures such as continuous monitoring of the water, laboratory tests of water at water treatment plants and distribution networks, reserve water stored in

elevated reservoirs corresponding to approximately one day's normal supply, doubling of necessary process and pumping equipment, emergency power for necessary process and pumping equipment, systematic preventive maintenance and rehabilitation of facilities, and updated emergency plans and risk analyses. The Mjøsa water board is responsible for carrying out a yearly monitoring of the lake with one of the main concerns being drinking water quality.

The discharge of pollution in water is regulated nationally by the Pollution Control Act (Pollution Act (Forurenseningloven), 1983) . The goal of the act is to "protect the environment against pollution and reduce existing pollution, ensure good environmental quality, and promote the health and well-being of people, plants, and animals". Locally, HIAS, for instance, uses a two-step process to treat water before releasing to Lake Mjøsa. The first step is the mechanical treatment that removes large solids, sand and grease. The second step is the biological treatment which removes phosphorus using bacteria. These bacteria are exposed to anaerobic and aerobic conditions to enhance phosphorus removal. Both steps produce sludge, which is treated and reused as fertilizer, and generates gas used for energy. The final treated water is then released into Lake Mjøsa (HIAS, n.d.-a).

3.7 Demography

In Norway, there was population growth all across the country in the 1970s, but in the following decades the population growth was increasingly associated with regional and national centralization and therefore more related to population redistribution (Alnes, 2019). The region of Mjøsa is no exception to this; the main population growth has taken place in the cities.

When looking at the population changes in the Eastern part of the region, the Hamar region (Hamar, Stange, Ringsaker, Løten), from 1990-2000 and from 2000-2010, there was a marked increase in the population growth from 2000-2010 compared to 1990-2000. The growth rate in these decades, respectively, was 0.48 % per year and 0.3% per year (Ørbeck et al., 2010). Between 2000-2010 differences in population growth were seen across the municipalities in the region. In Hamar, the population growth equalled 0.68% per year, and in Stange it equalled 0.66 per year. In Løten and Ringsaker, on the other hand, a markedly lower population growth was seen, with 0.12% per year in Løten, and 0.29% per year in Ringsaker.

Comparing Hamar to the other cities in the region of Mjøsa between 2000-2010, Hamar had larger population growth than Lillehammer and Gjøvik, but slightly lower population growth than Elverum (Ørbeck et al., 2010). However, when extending the time period by two years, 2000-2012, Alnes et al. (2009) found that Gjøvik had an annual population growth of 0.7% which is right above that which Hamar had from 2000-2010.

Gløtvold-Solbu et al. (2014) explored the population growth in the municipalities surrounding Mjøsa, except for Eidsvoll, between 2009 and 2014. They found that Hamar and Elverum had the largest population growth in this five-year period.

The population of Hamar grew by 4.6%, which equals an annual increase of 0.92, and Elverum grew by 4,4%, which equals an annual increase of 0.88. The authors underline that there is a process of urbanization going on in Innlandet county, and this process is most visible in urban areas. However, while urbanization was increasing in the region of Mjøsa, the population growth in the bigger cities and urban regions in Norway was higher (Gløtvold-Solbu et al., 2014; Leknes et al., 2016).

To understand the underlying dynamics of the changes in population, it is worth noting that at the start of the current millennia, the rate of natural increase in the Eastern and Western part of the region of Mjøsa has been negative, meaning that there has been a net loss of population due to fewer births than deaths (Alnes et al., 2012; Ørbeck et al., 2010). This is mainly the result of an aging population, the share which has been higher in the region of Mjøsa than the national average (Alnes et al., 2012). Based on this, Alnes and colleagues (2012) argued that the biggest challenge to population growth in the municipalities around Mjøsa is the aging population. By looking at data from Statistics Norway from 2024 (SSB 2024), it is evident that the issue of an aging population is still present in the region of Mjøsa, and more so than it is in Norway as a whole. The population growth observed in the region is in fact a result of increased in-migration.

The migration to Innlandet County is primarily constituted of foreign migrants, and secondarily from domestic migrants. Foreign migrants have been important for population growth in Norway as a whole as well (Gløtvold-Solbu et al., 2014). Gløtvold-Solbu et al. (2014) finds that from 2006 to 2014, there was a marked increase in immigration from Eastern Europe, a slight increase in immigration from Western Europe and the Nordics, and a stable level of migration from Africa

and Asia. This increase of migration from Europe was critically important for the population growth in the region. In 2014, migrants from Europe constituted 5% of the total population in Innlandet County, whereas in 2008 they constituted only 3% (Gløtvold-Solbu et al., 2014).

There has also been substantial migration within the Mjøsa region, particularly from rural urban areas, but also from sub-region to sub-region. By looking at the period 2008-2012, Alnes and colleagues (2012) found that the migration from the Gjøvik region to the Hamar region was in balance, whereas there were more people moving from the Lillehammer region to the Gjøvik region than the contrary.

3.8 Human health in the region of Mjøsa

The population in the region of Mjøsa generally has good health and access to good health care systems. Despite this, there are different challenges for the present and the future, particularly regarding the proportion of elderly compared to the national average (Gløtvold-Solbu et al., 2014) and some specific economic challenges (Alnes et al., 2009).

Self-reported health of the population

Different survey-based studies have been conducted to provide insights into the health of the population in Innlandet county, including the region of Mjøsa. The Folkelseundersøkelsen i Innlandet survey in 2023 by the Norwegian Institute of Public Health divided the county into nine regions, of which three are of relevance here. The first is the Hamar region, which includes Hamar, Løten, Stange and Ringsaker. The second is the Lillehammer region, which includes

Lillehammer, Gausdal, and Øyer. The third is the Gjøvik region, which includes Gjøvik, Vestre-Toten, Østre-Toten, Nordre Land, Søndre Land, and Gran (the three latter municipalities are not a part of the region of Mjøsa, and numbers from the Gjøvik region thus ought to be interpreted with caution).

Overall, there appear to be small regional variations in health, but the Lillehammer region appears to have a particularly healthy population (Leino et al., 2023). Results of the survey show that 66% of respondents in the Gjøvik region reported to have "good" or "very good" health. For the Hamar region the number was 68%, whereas in the Lillehammer region the number was 73%. . Twenty-two percent of the respondents in both the Gjøvik region and the Hamar region answered in such a way as to be considered obese (KMI30+), whereas in the Lillehammer region only 17% got this label. Additionally, the Lillehammer region had the highest proportion of respondents that exercised at least 30 minutes four days a week. For dental health, 71% in the Gjøvik region, 73% in the Hamar region, and 75% in the Lillehammer region reported "good" or "very good" health. When asked about when they last went to the dentist, 12% of respondents in the Gjøvik region, 13% in the Hamar region, and 11% in the Lillehammer region reported it to be more than 2 years ago

Another survey, the Folkehelse- og Levekårsunersøkelse of Oppland county, was administered during fall 2018 (Alnes, 2019) . This survey did not capture the entirety of the region of Mjøsa, only the areas around Lillehammer and Gjøvik. However, it complements the findings from the Folkelseundersøkelsen i Innlandet 2023 by showing that the population in the region generally had good health, but that it was particularly good in Lillehammer and surrounding areas.

Hospitals

Hospitals in the region of Mjøsa have been a topic of public debate for a long time, and they are a critical part of planning for an aging population. The location of hospitals continues to be a contested issue (Amdal, 2021). As of 2025, there are four general hospitals in the region of Mjøsa, located in Gjøvik, Hamar, Lillehammer, and Elverum. In addition, there are mental health care facilities at Sanderud in Stange municipality and at Reinsvoll in Vestre Toten municipality. In 2019, it was agreed by the board of the Southeastern Norway Regional Health Authority that these different hospitals should be partially closed and replaced by a larger "Mjøssykehus" located in Moelv in Ringsaker municipality (Helse Sør-Øst RHF). In 2023, the Norwegian government supported this, yet held that the hospital in Elverum had more activity than what the board of the Southeastern Norway Regional Health Authority originally proposed (Regjeringen, 2023). This will mark a major change in the structure of hospitals in the region.

Health threat of Mjøsørret consumption

Fishing is a common recreational activity in Mjøsa, and people normally eat what they catch. Due to pollution from polychlorinated biphenyls (PCBs) and dioxins in the lake, such consumption is considered a health risk. Knutsen et al. (2011) found that frequent consumption of fish from Mjøsa, particularly trout, was associated with higher concentrations of polychlorinated biphenyls (PCBs) and dioxins in the blood. At the time of study, the Norwegian Food Control Authorities advised people to avoid eating trout from Mjøsa bigger than 1 kg more than once a month, as individuals above this size were likely to have high concentration of PCBs. Pregnant and breastfeeding women were advised not to eat trout above 1 kg at all (Knutsen et al., 2011). Today, concentrations of PCBs and dioxins in the fish in Mjøsa are still considered the primary source of pollution in the fish population. The Mjøsa specific guidelines have been replaced by nationwide advice from the Norwegian Food Safety Authority (Mattilsynet) to avoid consumption of pike or perch longer than 25 cm and trout larger than 1 kg. For Mjøsa specifically, guidelines recommend against eating burbot in Furnesfjorden (see Mattilsynet. no for most up-to-date guidelines).

3.9   Conclusion

Between 2000 to 2025 the Mjøsa region has experienced interesting social and cultural development. Increasing economic challenges have been met with economic opportunities in the form of regional collaborations and easier commutes to bigger cities such as Oslo. Sports continue to be of cultural importance and provide people with financial, physical and mental well-being while facilitating social cohesion. Governance of the lake itself has also changed over the years; it now reflects international frameworks and collaboration between local actors and local governments. Demographically, the Mjøsa region reflects the national trends of centralization and growth in urban areas, while also working to address concerns related to a growing elderly population. The importance of understanding demographic shifts is very notable with regards to the importance of health and services planning, such as where to locate key public services and facilities such as hospitals and schools. In this same time period, there has been increasing concerns regarding ecological contamination in the lake and its impact on fishing culture and fish consumption, especially trout.

Mjøsa, with its aesthetic qualities, can provide peace and calmness to the soul of humans. While there is material on these cultural qualities in arts and literature, the literature review completed for this assessment suggests there is a lack of research on these non-extractive values of the lake. Future research may consider the extent to which this is an atypical or typical way of relating to Mjøsa, and the extent to which Mjøsa provides people with peace and calm, consciously or subconsciously.
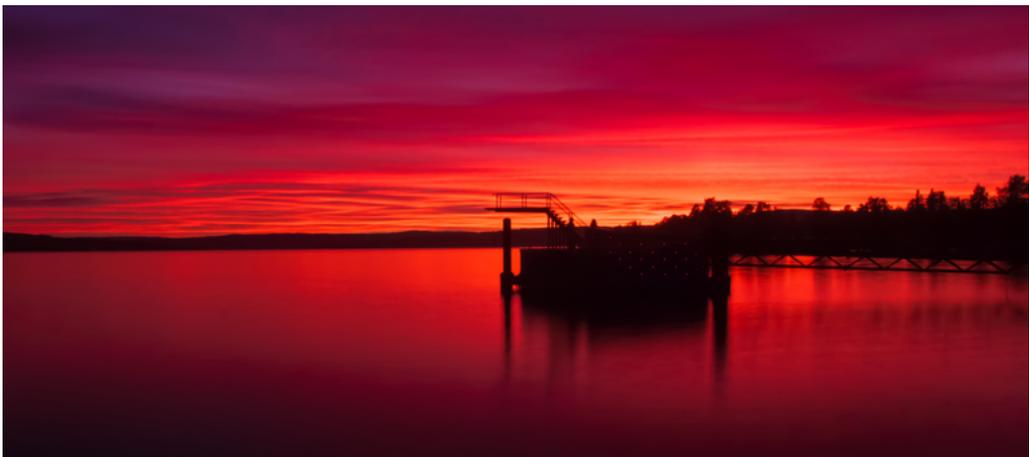
Figure 3.3: Divetower at sunset on Lake Mjøsa. Photo credit: Aleksander Bern

Chapter 4: Ecological and Hydrological Overview

Mikkel Emil Lange Friis, Elizabeth Barron, F. Chantel Nixon, Chris Storie, and Joni Storie

4.1 Executive Summary

This chapter includes an overview of the climate conditions in and around Lake Mjøsa, the geology and hydrology, the available data on the biological system within and around the lake, and the ecological information about the lake system and its surroundings. It aims to provide a comprehensive overview of ecosystem change, its key drivers and the implications for management and conservation. One of the key findings from this chapter is that there is abundant data on the biological, ecological and hydrological dimensions of Lake Mjøsa and its surroundings. However, two main challenges persist: (1) how to best use the existing data and communicate it to the public, and (2) rapidly changing conditions due to development and climate change.

4.2 Climate

Extensive information is available on the past, present and future climate conditions through the Norwegian Centre for Climate Services (NCCS), a collaboration among the Norwegian Meteorological Institute (Meteorologisk institutt), the Norwegian Water Resources and Energy Directorate (NVE), The Norwegian Research Centre (NORCE), Kartverket (NMA), and the Bjerknes Centre for Climate Research. NCCS strives "to be the preferred supplier of knowledge about climate change and hydrology and the effects of climate change on natural hazards [in Norway]," (Nilsen et al., 2022).

There is extensive information available about climate and climate change in Norway, which can be extrapolated to the Mjøsa region, and some more detailed climate data are also available. For the purposes of this assessment, we begin with a brief overview about micro-climatic conditions in the lake itself and then present future climate scenarios for the region. The information in this section is based primarily on selected reports from the Norwegian Climate Service Centre (Hanssen-Bauer et al., 2017; Norsk Klimaservicesenter, 2022b, 2022b).

In 2018 the Norwegian government updated their guidelines regarding climate change adaptation, placing greater responsibility on municipalities to take an evidence-based approach to climate change in all future planning. As a result, these reports and the associated fact sheets are widely used and form an important knowledge basis for planning at the municipal and county levels. Three reasons for uncertainty in the reports are highlighted: the unknown future of anthropogenic behaviours, uncertainties related to natural climate variability, and uncertainties in the models used for the analysis. Nevertheless, there is detailed information contained therein regarding the methods, datasets, and analyses, which are an important source of information for planning at multiple levels.

Lake Mjøsa micro-climate

Since 1972 Lake Mjøsa has experienced an increase in yearly average and maximum surface water temperatures of, respectively, 0.41 and 0.61 °C per decade (Thrane et al., 2024), which is comparable to other lakes across the globe (O'Reilly et al., 2015; Thrane et al., 2024). This change in habitat conditions, along with other factors, seems to be affecting the composition of the planktonic community, which may in turn affect the fish communities of the lake (Moe et al., 2022).

Mjøsa is heavily influenced by winds, strong water currents, and relatively cold surface waters from glacial melt in Jotunheimen. These factors contribute to a mix of the water column, often leading to a weak thermocline that in summer can extend over a depth of 20–30 m (Holtan et al., 1979; Thrane et al., 2024). Over the last decades, there has been an increased duration of summer stratification due to an extension of the stratification period further into autumn (Hobæk et al., 2012).

Water temperatures were measured over the course of one year in 1977 in central Lake Mjøsa at 1 m, 20 m, and 400 m water depths. Water temperatures at 1 m depth ranged from around 2°C in February to 18°C in July, and from approximately 3-12°C in February and July, respectively, at 20 m depth (Holtan, 1979). At 400 m depth, temperatures are just below 4°C, year-round (Holtan, 1979). Lake ice usually forms in northern Mjøsa by January and although the entire lake can freeze over during cold winters, central zones are more often ice-free, year-round. Ice melt usually begins in April (Nashoug, 1999). For more information on water temperatures, levels, and discharge at all hydrometric stations around Lake Mjøsa and in its watershed, see NVE Sildre (NVE, n.d.-d).

The number of ice-covered winters has decreased in the last six decades, but the duration of ice-cover (in ice-covered winters) has not changed and varies between 50 and 125 days (Hobæk et al., 2012).

The surrounding climate

The NCCS, in 2017, prepared a national report, *Climate in Norway 2100,* based on the then most recent report from the Intergovernmental Panel for Climate Change (IPCC). The report was prepared by downscaling and bias adjusting regional climate models (c.f. (Wong et al., 2016). At the request of the Norwegian Environmental Agency, they used scenarios based on RCP8.5 and RCP4.5.9 In addition to the national report, climate profiles for all counties in Norway were developed, which include detailed summaries of current conditions, expected changes up to the year 2100, and related challenges which could occur during this period due to climate change (Hanssen-Bauer et al., 2017).

Of note for planning, the report suggests that natural variations will largely dominate climatic patterns over the next 10 – 20 years (up to approximately 2037), and therefore when planning shorter builds and projects with a lifespan to be completed during this time, recent statistics rather than downscaled model simulations should be used (Hanssen-Bauer et al., 2017). An updated version of the *Climate in Norway 2100* report was released in late October 2025 (Irene Nilsen, personal communication, August 2025) but was unavailable at the time of this writing.

Last updated in 2022, the county reports are based on the organization of the

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9   RCP stands for representative concentration pathway, and is used to represent different levels of concentration of greenhouse gases in the atmosphere. Current emissions are tracking close to the RCP 8.5 pathway, leading to increases in average global temperature of 3-7 °C.

counties prior to 2020. Here we draw primarily from the Oppland and Hedmark reports, supplemented by the national report. While the southern part of the lake sits in Akershus county, that report includes and is more focused on areas around Oslo and therefore is only briefly referenced here. In 2020 Oppland and Hedmark were merged to form Innlandet, which is how this area is referenced in primary documents published after 2020.

Weather and climate observations between 1971 – 2000 were used as a baseline to develop predictions for expected changes up to 2071 – 2100. The most likely increases are related to the changing nature of rainfall events, which will become more intense and more frequent, which may lead to increased risks of flooding, landslides, and mudslides (Figure 4.1). Increased drought due to higher summer temperatures, shorter periods of solid ice, increased chance of avalanche, and in Hedmark only, increased risks of quick clay landslides are also likely.

The mean air temperature for mainland Norway increased approximately 1 °C between 1900 – 2014 (Nilsen et al., 2022). Nationally, "the medians of the dynamically downscaled projections indicate that annual temperature for Norway will increase by 2.7 °C (for emission scenario RCP4.5) and by 4.5 °C for RCP8.5 until the end of the century," (Hanssen-Bauer et al., 2017). In Oppland and Hedmark temperatures are expected to increase an average of 4 °C by 2100, with larger increases in temperature observed during the winter period (5 °C) than the summer period (3.5 °C). It is predicted that the growing season in the region will increase between one and two months, and the heating season will decrease.

Precipitation increased across Norway by approximately 20% from 1900-2022, with higher average changes in coastal Norway (Lutz et al., 2024). This is noteworthy because precipitation is expected to increase additionally in the coming period, an average of 18% under emissions scenario RCP8.5, but only 8% under RCP4.5. In the Mjøsa region annual precipitation is expected to increase noticeably, with greater increases in the winter season and greater likelihood of winter precipitation falling as rain rather than snow, especially at lower elevations. In fact, the snow season is predicted to become one to four months shorter around the lake in the coming period. For the three largest cities in the region, the following average temperature and rainfall increases are expected:

Hamar: 4.3 °C / 575 millimeters

Gjøvik: 4.2 °C / 685 millimeters

Lillehammer: 3.3 °C / 660 millimeter

Overall, the importance of rainfall for flooding regimes is increasing across Norway, while the importance of snowfall is decreasing. Despite the projected increases in precipitation in the Mjøsa region, there is no change recommended for the climate safety margin in the updated flood zone maps (flomfarekart/ flomsonekart) for areas surrounding Lake Mjøsa. In Hedmark there is an increased risk of erosion along rivers, especially in areas with quick clay.

SANNSYNLIG ØKNING

Ekstrem nedbør	Det forventes at episoder med kraftig nedbør øker vesentlig både i intensitet og hyppighet. Dette vil også føre til mer overvann
Regnflom	Det forventes flere og større regnflommer, og i mindre bekker og elver må man forvente en økning i flomvannføringen
Jord-, flom- og sørpeskred	Økt fare som følge av økte nedbørmengder

MULIG SANNSYNLIG ØKNING

Tørke	Til tross for mer sommernedbør, kan høyere temperaturer og økt fordampning gi økt fare for tørke om sommeren
Isgang	Kortere isleggingssesong, hyppigere vinterisganger samt isganger høyere opp i vassdragene
Snøskred	Med varmere og våtere klima vil det oftere regne på snødekt underlag. Dette kan redusere faren for tørrsnøskred og øke faren for våtsnøskred i skredutsatte områder
Kvikkleireskred	Økt erosjon som følge av kraftig nedbør, og økt flom i elver og bekker, kan utløse flere kvikkleireskred. Dette gjelder små områder lengst sør og sørvest i Hedmark

SANNSYNLIG UENDRET ELLER MINDRE

Snøsmelteflom	Snøsmelteflommene vil komme stadig tidligere på året og bli mindre mot slutten av århundret

USIKKERT

Sterk vind	Trolig liten endring
Steinsprang og steinskred	Hyppigere episoder med kraftig nedbør vil kunne øke hyppigheten av disse skredtypene, men hovedsaklig for mindre steinspranghendelser
Fjellskred	Det er ikke forventet at klimaendringene vil gi vestentlig økt fare for fjellskred

Figure 4.1 Hedmark climate fact sheet. Summary of expected changing trends from 1971 – 2000 to 2071 – 2100 in climate, hydrological conditions and natural hazards with direct impacts on safety. The possible likely concern for quick clay landslides is the only difference between the Hedmark and Oppland tables (Norsk Klimaservicesenter, 2022a).

4.3 Geology, Hydrology, and Flooding

Hydrology

Lake Mjøsa, Norway's largest lake, is a low-calcium, clear, deep, non-alpine lake (as classified by the Norwegian Institute for Water Research) (NIVA, n.d.-b) . The surface area of Lake Mjøsa is 369 km2, its mean depth is 150 m (with a max. depth of 453 m), and its volume is 55.361 km3 (Norwegian Water Resources and Energy Directory NVE, n.d.-b). The main inflow to Mjøsa is Gudbrandsdalslågen (also referred to as River Lågen), which has a mean discharge of 256 m3/second (NVE, n.d.-b). River Lågen has its source areas in the mountain ranges of Dovre, Rondane, and Jotunheimen (>2000 m above sea level). These mountains support numerous, small cirque glaciers and ice patches. Seasonal glacial meltwater is therefore a relatively important source for the River Lågen via its tributaries, depending on precipitation fluxes. As such, water discharge to Lake Mjøsa from its main inflow is clear with low nutrients, and carries fine glacial sediments (i.e. silt, also known as 'rock flour') in the spring and summer, which seasonally cools and colours northern parts of the lake (Holtan, 1979).

There are approximately 40 rivers that flow into Mjøsa in addition to River Lågen, including the Gausaelva, Hunnevla, and Svartelva rivers (Figure 4.2). These rivers flow through the catchment surrounding Mjøsa, called the Glomma watershed, which is 16,568 km2 and consists of mostly forests and mountains, but also glaciers, lakes, bogs, and agricultural, industrial, and urban areas (the latter including Hamar, Gjøvik, and Lillehammer). Mjøsa's outlet is the Vorma River, which is located at the southernmost tip of the lake and
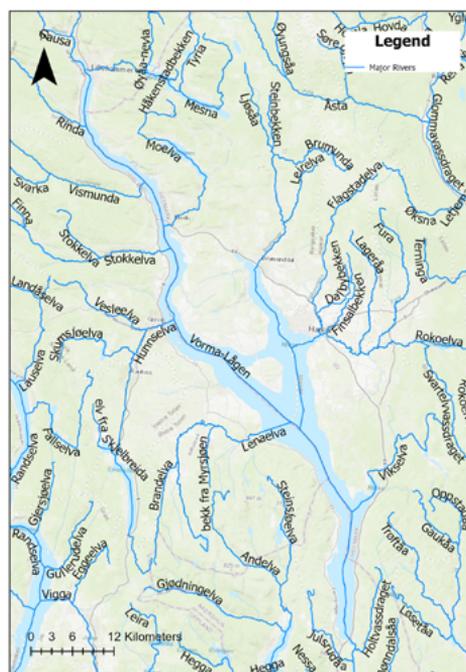
Figure 4.2: Major rivers in the Lake Mjøsa Region. Map credit: Sajith Ranatunga

flows into the Glomma River (Norway's largest river) approximately 30 km to the south-southeast. Mean outflow from Mjøsa is 321 m3/second (NVE, n.d.-b).

Presented in detail in section 3.6, Lake Mjøsa serves as the drinking water supply for a population of approximately 80,000 and its downstream river supplies another 150,000. The lake nevertheless receives discharge from wastewater treatment plants (WWTPs) in urban areas as well as runoff from industry and agriculture.Microplastics are widespread in lakebed sediments, with the highest concentrations near rivers, urban areas (including roads), and WWTPs (Lusher et al., 2018). Water quality and biological conditions in Mjøsa have been monitored annually since 1972 by NIVA, and their reports are available on NIVA's official website, niva.no, under their publications section. The current ecological status of Lake Mjøsa is rated as 'good' to 'moderate'

(Bechmann et al., 2021c; Løvik & Moe, 2016), which is a significant improvement from the 1970s and 1980s when it experienced severe eutrophication. Improvements in ecological conditions and water quality are primarily a result of implementing "Mjøsaksjonen" (Mjøsa Action Plan) between 1973-1982 (Miljøverndepartementet, 1979) (Chapters 2 and 3 include more information on Mjøsaksjonen).

When considering the risk of contamination to and/or from intake and outlet water, Tjomsland et al. (2009) emphasizes the importance of considering movements of water masses, at different seasons and different weather conditions, and how modelling can be used to assess this, as shown for Furnesfjorden (Tjomsland et al., 2007), Biri, Moelv, Gjøvik and Østre Toten (Tjomsland & Tryland, 2008), and Hamar and Stange (Tjomsland et al., 2012b). Modelling can also be used to assess the consequence of particle dispersion following dumping of loose sediments (Tjomsland et al., 2012a). Risks one should consider in relation to water inlets security: sewage leaks, contamination from accidents involving cars, trucks, trains, planes etc., building of infrastructure and housing, enabling of agriculture, water-based recreation use of water resources, in addition to consequence, reaction time and how a changing climate could change the lake properties (Tjomsland et al., 2009).

Flooding

Lake Mjøsa experiences flooding occasionally although it is regulated by over 20 regulation reservoirs and is itself a winter reservoir for power plants in Glomma (Hobæk et al., 2012). Free reservoir capacity in Mjøsa's catchment has resulted in reduced flood sizes, however, this effect decreases with increasing flood size (Holmqvist & Hamududu, 2022). Highest lake levels

normally occur between May and July in connection with snowmelt in the upper parts of the watershed (Holmqvist & Hamududu, 2022). Autumn floods can occur but are less common (Pettersson, 1997). The highest known flood in historical times occurred in July 1789, which was caused by heavy late winter snow in eastern Norway, late snowmelt, and more or less continuous rain in July followed by a torrential rainstorm beginning on July 20th, which brought water levels up 7 m above normal in the River Lågen and 10.10 m above normal in Lake Mjøsa (measured at Hamar) (Nesje et al., 2001; Pettersson, 1997). River Lågen was at one point during this flood dammed by soil, gravel, bushes, and trees, that eventually gave way, allowing the floodwaters and debris to enter Lake Mjøsa.

The oldest hydrological measuring station in connection with Lake Mjøsa is a water mark located slightly below the outlet, Vorma, and dates to May 1824 (Pettersson, 1997). Frequency analysis of water stages and discharge (i.e. Q; m3/second) based on data from the period 1961-1995, showed that the 100-year flood stage is 8.23 m and water discharge 1742 m3/second at Mjøsa (Pettersson, 1997). The highest observed flood discharge by 1995 was 1650 m3/second. Recent and historical measurements of water levels (stage) and discharge from hydrometric stations around Lake Mjøsa, some of which date to the earliest 20th century can be retrieved from NVE Sildre (NVE, n.d.-d). Additional information and data on flooding is available in Holmqvist and Hamududu (2022).

The timing and magnitude of the spring flood in River Lågen affects the physicochemical conditions (e.g. turbidity, phosphorus transport, and temperature) in Mjøsa – especially in the northern parts of the lake. Particle transport in connection with flooding is often so significant that the increased turbidity in

Key findings in 2023 summary report on operational monitoring (Thrane et al., 2024)

- The water quality from late summer and throughout the rest of the year was heavily influenced by the extreme weather event Hans.

- The overall ecological condition was assessed as good at the stations Skreia, Furnesfjorden, and Brøttum, and moderate at station Kise (due to low Secchi depth, high turbidity, and a high concentration of organic material).

- The mean concentration of total phosphorus (tot-P) did not exceed normal levels at Skreia, Furnesfjorden, or Brøttum. At Kise, however, it was the highest mean concentration recorded in the last decade.

- The measured biomass of phytoplankton remained at normal levels.

- Some locally elevated levels of cyanobacteria were observed along the shoreline, but no large blooms occurred.

- The evaluation of benthic invertebrates and periphyton growth as indicators of eutrophication and organic load showed good or very good conditions in the rivers Gausa, Mesna, Moelva, and Brumunda—except in the lower parts of Brumunda, where the condition was determined to be moderate.

Text box 4.1: State of the Lake 2023

Mjøsa can be captured on satellite images well south of the lake (Thrane et al., 2023). Floods and inputs from the medium-sized tributaries around Mjøsa also have an impact on the physicochemical conditions (especially nutrient inputs) in the lake, particularly locally (Thrane et al., 2023).

Geology

A wide variety of bedrock lithologies outcrop around Lake Mjøsa, but broadly, Late Precambrian sandstones dominate in the north and northeast, Cambro-Silurian shales in the central-east, and Precambrian crystalline bedrock (e.g. gneiss, gabbro), Cambro-Silurian (shale, sandstone, limestone) and Permian (syenite, granite) in the south and southwest (Nordgulen, 1999).

The surficial geology surrounding Lake Mjøsa (where surficial geology refers to unlithified material, including sediments and landforms, known as 'løsmasse' in Norwegian) is well described in the literature and on maps produced by the Geological Survey of Norway (NGU, n.d.-a). From central to northern regions adjacent to Lake Mjøsa, thick, continuous till mantles the bedrock, though there are some smaller patches of glaciofluvial, glaciolacustrine, lacustrine, and modern fluvial sediments, particularly along river valleys. Underlying bedrock structures are masked beneath the thick cover of till except where the structures are large (Follestad et al., 2014). From central Mjøsa and south, the till becomes thinner and discontinuous, with numerous exposures of weathered bedrock. At the southernmost point of Lake Mjøsa (on either side of its outlet, the Vorma River), the surficial geology comprises glaciofluvial, marine, and aeolian (sand dune) deposits (NGU, n.d.-a). Similarly, where the Gausa and Lågen rivers flow

into the northwest arm of Lake Mjøsa (immediately northwest of Lillehammer), glaciofluvial and fluvial deposits overlie till and bedrock. Bogs containing peat are also common in the hinterland around the lake, occupying small basins in the till and bedrock.

From 1972 to 1985, NGU performed Quaternary geological mapping of the area around Lake Mjøsa, which resulted in a number of Quaternary maps at the scale of 1:50,000 and 1:20,000 (Follestad et al., 2014 and references therein). Extensive petrographic and geochemical characterisations of the till surrounding Lake Mjøsa have since been analysed for the purposes of evaluating the usefulness of till geochemistry in mineral prospecting (see Reimann et al. (2014) for references to these large datasets).

More detailed information about geology of the area surrounding Lake Mjøsa area can be found on individual maps and in reports published by the Geological Survey of Norway (Norges geologiske undersøkelse (NGU) on their website (NGU, n.d.-b).

Geomorphology

Lake Mjøsa is a fjord lake that occupies an ancient valley where subsequent glacial erosion was concentrated over multiple glacial cycles during the Quaternary Period. An ice sheet divide immediately north of Mjøsa, that likely formed repeatedly during glacial periods, would have directed ice flow southwards (Follestad et al., 2014). Additional glacial landforms that confirm past south- and south-eastward flowing ice have been mapped east and west of Lake Mjøsa, and include drumlins, flutings, and striae (Aa, 1979; Bargel, 1983; Follestad, 1973, 1974; Mangerud et al., 2018; Olsen, 1979, 1983, 1985; Sveian, 1979), however, most of these likely date to the most recent glaciation, the Last Glacial Maximum (LGM;

ca. 20,000 years before present), when the Fennoscandian Ice Sheet (FIS) covered all of Norway. Other glacial landforms, some of which indicate vertically down-wasting ice, have also been mapped in the vicinity of Lake Mjøsa, including hummocky moraines, kettle-holes, eskers, and lateral meltwater channels (Follestad et al., 2014).

End moraines and ice-front deposits marking the northward-retreating FIS were mapped across the southern end of Lake Mjøsa (dated to between 10,600-10,800 years BP) (Mangerud et al., 2018) and from seismic data across the northwestern arm of Mjøsa near the town of Moelv (Aagaard & Holtan, 1976; Mangerud et al., 2018). Deglaciation of the FIS at the north end of Lake Mjøsa occurred by 10,500 years BP (Mangerud et al., 2018) and meltwater, including some from the spectacular glacial lake outburst floods that occurred between 10,200-10,500 years BP (Høgaas & Longva, 2016; Longva, 1994), would have flowed through the Mjøsa basin (Aurand et al., 2024).

Most of the region surrounding Lake Mjøsa today is hilly terrain up to 600 m above sea level, however, an area of lowlands (150-200 m asl) borders its central-eastern shore (the Hedemarken area), known as one of Norway's best agricultural districts (Løvik & Kjellberg, 2003). Mass movements occur on the slopes that border the lakeshore, especially along the narrow southern and northern areas and steep western shore, with rockfalls being the most common (NVE, n.d.-c). Since Lake Mjøsa, at 122 m above mean sea level, sits below the local marine limit of approximately 200 m above sea level (Mangerud et al., 2018), it is no surprise that marine clay, including quick clay, has been mapped in many of the lower-lying areas around the lake, and quick clay slides are known to occur (NVE, n.d.-c) Other documented mass movements around Mjøsa include snow avalanches, slush flows, landslides, and debris-flow slides (NVE, n.d.-c).

Finally, the coastal geomorphology of Lake Mjøsa includes sandy to rocky beaches and coastal cliffs, while submarine sediments are mostly fine-grained (silty clay) and organic-rich in places (Lusher et al., 2018). Sediment sources for the Mjøsa lakebed include rock flour (fine silt) transported from the glaciated uplands of the watershed via a network of rivers and lakes, eventually reaching Lake Mjøsa (see 4.3.1), landslides, coastal erosion, fluvial inputs, other runoff, and lakeside construction activities. The underwater slopes of the lake generally show gradients of 15–20° but exceed 30° in places (Forsberg et al., 2016). Numerous channels and several slide scarps, approximately 2 m high, have been mapped (Forsberg et al., 2016) and underwater mass movements have caused utility pipeline breakages in the past (Forsberg et al., 2016). Sedimentation rates for the central lake basin are approximately 2 mm/year (Forsberg et al., 2016) .

The reader is again directed to NGU's surficial geology map (løsmassekart NGU, n.d.-a) for a detailed overview of the glacial geomorphology and other landforms that can be found in the vicinity of Lake Mjøsa.

4.4 Aquatic monitoring programs in Mjøsa

For assessing the biological and ecological trends, ongoing and previous monitoring programs are vital. This section aims to introduce the most relevant ongoing ecological monitoring programs, as well as other monitoring programs surveying in the Mjøsa catchment area. There are currently three larger monitoring programs surveying the water quality and ecological communities in Lake Mjøsa:

Operational Monitoring of Lake Mjøsa

The water properties of Mjøsa are monitored regularly by NIVA on contract from Vassdragsforbundet. The current monitoring programs are a continuation of previous monitoring efforts dating back to 1972. Results from the current monitoring program are published through the NIVA report series, as well as being available from the Norwegian Environment Agency (Miljødirektoratet, n.d.-h).

Four stations at different key locations in the lake are sampled regularly for water quality and ecological condition six times a year from May to October, with the main station *Skreia* being sampled with six additional reduced in-between samplings. Station *Brøttum* in the middle part of Ringsakerfjorden, *Kise* in the outer part of Ringsakerfjorden, *Furnesfjorden* in the outer part of Furnesfjorden and the main station *Skreia* in the southern part of Storfjorden. The main station, *Skreia*, is monitored for water chemical properties, Secchi depth, temperature, oxygen properties, abundance and diversity of phyto- and zooplankton, and abundance and biomass of mysis (*Mysis relicta*). In addition, water chemical and bacteriological monitoring are checked regularly (24 times a year) at the outlet of the rivers Gudbrandsdalslågen, Gausa, Hunnselva, Lena, Flagstadelva and Svartelva, and at the inlet of outlet river Vorma. Biological monitoring is done at Gudbrandsdalslågen, Gausa, Moelva, Stokkelva, Hunnselva, Brumunda, Flagstadelva, Svartelva, Lena, Vikselva and Vorma at a rotating schedule of three years.

In Mjøsa, monitoring is conducted to assess the presence and potential sources of contaminants in a lake significantly impacted by anthropogenic activity. Zooplankton, Mysis, European smelt (*Osmerus eperlanus*), Vendace (*Corgenous Albula*) and brown trout

(*Salmo trutta*) are sampled yearly. The Monitoring of Environmental Contaminants in Freshwater Food Webs Program (MILFERSK) surveys a set of large Norwegian lakes, with a special emphasis on lake Mjøsa (along with the comparable Lake Femunden), for organic environmental contaminants, providing an early warning system. The current monitoring program began in 2013 and is led by NIVA on contract from The Norwegian Environment Agency. The latest report from MILFERSK is: Monitoring of environmental contaminants in freshwater food webs (Økelsrud et al., 2024). Additional information on the MILFERSK program can be found on the NIVA homepage (NIVA, 2021a) and from the Norwegian Environment Agency (Miljødirektoratet, n.d.-e)

The Surveillance Monitoring of Large Norwegian Lakes Program (ØKOSTOR) surveys a set of large Norwegian lakes to determine ecological conditions. The current monitoring programs are conducted by NINA, NIVA and Akvaplan-niva on contract from The Norwegian Environment Agency. It should be noted that due to the contract nature of this arrangement, it is possible that other organizations could take over this monitoring at any point if they "win the bid" for services. Changes in organization could affect long-term data quality due to possible changes in monitoring methodologies, temporal incompatibility, and data availability.

Mjøsa is surveyed annually, with a full survey every fourth year. Annual sampling includes water chemistry (done in the MILFERSK program), phytoplankton and zooplankton. The full survey also includes aquatic plants, littoral crustaceans, benthic invertebrates and fish. For monitoring of fish communities, Nordic survey gill nets are used along the bottom, pelagic trawling is used to catch fish in the open waters and hydroacoustic (Echo sounding) is used to determine location,

depth and biomass of pelagic fish. The combinations of methods used to monitor the fish communities vary. Additional information on the ØKOSTOR program can be found at the homepage of The Norwegian Environment Agency (*Økosystemovervåkning i store innsjøer*, n.d.), at the homepage of NIVA (NIVA, n.d.-e), and at the homepage of NINA (NINA, n.d.-b)

- The latest main report: ØKOSTOR 2023: Surveillance monitoring of large Norwegian lakes. Testing of methodology for monitoring and classification of ecological status according to the Water Framework Directive (Haande et al., 2024)

- The latest report on fish surveying: Fiskeundersøkelser i store innsjøer i ØKOSTOR-programmet 2023 (Eikland et al., 2024).

- The latest report on fish surveying with pelagic trawling: Fiskeundersøkelser i store innsjøer i ØKOSTOR-programmet 2022 (Eikland et al., 2023).

- The latest report on fish surveying with gill-nets (and pelagic trawling): Overvåkning av fisk i store innsjøer – FIST 2018 (Gjelland et al., 2020).

- The latest main report with a full ecological surveying of Mjøsa: ØKOSTOR 2021: Basisovervåking av store innsjøer. Utprøving av metodikk for overvåking og klassifisering av økologisk tilstand i henhold til vannforskriften (Haande et al., 2022).

Monitoring Programs with localities in the Mjøsa watershed

There are several monitoring programs surveying areas in the Mjøsa watershed. This section introduces and highlights their relevance to lake Mjøsa.

The River Monitoring Program (Elverovervåkningsprogrammet)

On contract from the Norwegian Environment Agency, NIVA monitors several stations in a set of rivers for water quality, nutrients and pollutants to aseess ecological conditions; these include lower parts of Mjøsa's outlet river, Vorma.

On a three-year interval, Vorma is surveyed for ecological and chemical condition by sampling benthic algae for PIT, benthic invertebrates for ASPT and phosphorus. In Vorma, high-frequency monitoring is used to survey short-term effects of climate variability. Sensors continuously monitor temperature, pH, conductivity, turbidity and FDOM.

- The latest report on ecological and chemical conditions from the river monitor program: River Monitoring Programme 2023. Classification of ecological and chemical status in Norwegian rivers according to the Water Framework Directive (Kile et al., 2024).

- The latest report on water quality and trends from the river monitor program: The Norwegian River Monitoring Programme 2023 – water quality status and trends (Kaste et al., 2024).

- Additional information on the river monitoring program can be found at the homepage of The Norwegian Environment Agency (Miljødirektoratet, n.d.-c), and the homepage of NIVA (NIVA, n.d.-a).

NIVA currently monitors 75 rivers, referred to as "reference rivers" because of limited anthropological influence for ecological and chemical parameters, five of which are in the Mjøsa drainage area. In the Mjøsa drainage area rivers draining into Gudbrandsdalslågen – Jora, Otta, Sjoa and Store Ula – and Lera, which drains into Brumunda, are included in the program. The monitoring programs survey each river for fish, benthic invertebrates, benthic algae, contaminants and water chemistry every second year. Over the year nutrients and other physical-chemical parameters are sampled monthly and metals quarterly. Some rivers are sampled for benthic algae, benthic invertebrates and fish. Additional information on the Monitoring in Reference Rivers program can be found at the homepage of The Norwegian Environment Agency (*Overvåkning i referanseelver*, n.d.), and the homepage of NIVA (NIVA, 2021b).

- The latest report from the monitoring of reference rivers: Overvåking i referanseelver. Oppsummering av data for perioden 2017-2023(Eriksen et al., 2024).

The Monitoring of Microplastics in the Norwegian Environment Program (MIKRONOR, (Overvåkning av mikroplast i det norske miljø) surveys levels and types of microplastics in aquatic systems in Norway; including in lake Mjøsa. NIVA, on contract from the Norwegian Environment Agency has monitored microplastics since 2021. In 2022, the following samples were tested: water samples from water pumps outside Moelv and Hamar, urban runoff water and effluent from wastewater treatment plant in Hamar, plankton samples from outside Skreifjella, sediment samples by Moelv, Hamar and Skreifjella, and duck mussels. Additional information on the MIKRONOR program can be found at the homepage of The Norwegian Environment Agency (Miljødirektoratet, n.d.-d) and the homepage of NIVA (NIVA, n.d.-c).

- Data are available through Vannmiljø (Miljødirektoratet, n.d.-h) and mikronor-data (NIVA & Miljødirektoratet, n.d.).

- The latest report from the monitoring of microplastics program: Monitoring of microplastics in the Norwegian environment (MIKRONOR) 2023 (Alling et al., 2024).

- The latest report from MIKRONOR with more extensive surveying of Mjøsa: Monitoring of microplastics in the Norwegian environment (MIKRONOR) (Alling et al., 2023).

The Spatially Representative Nature Monitoring Program for Terrestrial Ecosystems (Arealrepresentativ naturovervåkning (ANO) av terrestriske **økosystemer** i Norge) is monitoring more than a thousand localities and assessing the ecological conditions; several of these localities are around Mjøsa. ANO started in 2019 and surveys on a five-year rotation. The program can, in the future, be a useful tool to assess the ecology of lake Mjøsa in relation to changes in terrestrial ecology. Additional information on the Spatially Representative Nature Monitoring Program for Terrestrial Ecosystems program can be found at the homepage of The Norwegian Environment Agency (Miljødirektoratet, n.d.-a). The data should be available through the homepage of The Norwegian Environment Agency (Miljødirektoratet, n.d.-b), however this has been shown to be somewhat unreliable and can require a lot of time.

Report Series Surveying in the Mjøsa watershed

(1) Monitoring of Lakes in the Innlandet region (Overvåkning av innsjøer i Innlandet fylke) is a report series which has included the Mjøsa region. Monitoring from 2020 – 2023 was conducted by Norconsult on behalf of Statsforvalteren i Innlandet. Eriksrudtjernet,

Steffensrudtjernet, Sjusjøen, Helsettjernet, Silongen, Kauserudtjernet and Slomma are surveyed for physical-chemical properties as indicators of water quality, including phytoplankton taxonomy, examination and visual estimation of colour by the Forel-Ule colour comparator scale, Chlorophyl A and ToP, in addition concentration of other compounds. Data are available through Vannmiljø (Miljødirektoratet, n.d.-h). The latest report is Overvåking av innsjøer i Innlandet fylke, 2023 (Stabell et al., 2024b).

(2) Monitoring of Rivers and Streams in region Innlandet (Overvåkning av elver og bekker i Innlandet fylke) is a report series including nine rivers from "vannområde Mjøsa". The monitoring from 2021 – 2023 has been conducted by Norconsult on behalf of Statsforvalteren i Innlandet. In "Vannområde Mjøsa" the sampled rivers vary between years. Rivers are sampled for TotP, benthic invertebrates and benthic algae. Not all rivers are sampled for all factors. The data is available through Vannmiljø (Miljødirektoratet, n.d.-h). The latest report is Overvåking av elver og bekker i Innlandet fylke, 2023 (Stabell et al., 2024a).

(3) Hydropower Regulations and Fish in Innlandet (Reguleringer og fisk i Innlandet) is a project by the county governor, which surveys fish biology in regulated watercourses including Mjøsa. The project focuses on brown trout recruitment. In the Mjøsa area, the current project surveys the rivers Våla, Moksa, Gausa, Gudbrandsdalslågen, Moelv, Brumunda, Hunnselva and Lenaelva by use of electro fishing and fish trap passings where available. In addition, the project gathers voluntary reports on fish caught and effort spent fishing by recreational trolling fishermen (Norsk: "dreggefiskere/trollingfiskere"). Standalone surveys are reported in a common summary report, while the surveying of the regularly surveyed rivers is reported individually. Additional information on the Hydropower Regulations and Fish in

Innlandet can be found on the homepage of the County Governor of Innlandet (Statsforvalteren i Innlandet, n.d.). The latest summary report including the standalone surveys is Reguleringer og fisk i Innlandet- Fagrapport 2023 (Thorkildsen & Ustvett, 2024). The latest report from the regularly surveyed rivers Gausavassdraget (Norum et al., 2025c), Gudbrandsdaslågen (Norum et al., 2025b), Hunnselva (Norum et al., 2025d), Lenavassdraget (Norum et al., 2024a), Moelva (Moelva: Overvåkning 2022, 2022), Moksa (Norum et al., 2025e), Vinstra (Norum et al., 2024b) and Vålå (Norum et al., 2025a).

4.5 Biological Status and monitoring

This section summarizes knowledge on the aquatic communities in and around lake Mjøsa.

Phytoplankton

With phosphorous being the limiting factor for phytoplankton growth in Mjøsa, there has been a decrease in phytoplankton biomass since Mjøsaksjonen in the late 1970s, with the total biovolume and chlorophyll *a* concentrations being halved (Thrane et al., 2024), likely attributed to the reversal of eutrophication process (Nashoug, 1999). The reduction in nutrients has also caused a shift in the phytoplankton community (Thrane et al., 2024), with a large reduction of the more nutrient-demanding species of cyanobacteria, and a higher presence of more nutrient-poor species of golden algae (*Chrysophyceae* sp.) and Cryptophyceae earlier in the season. The medium nutrient-demanding species of diatoms (*Bacillariophyta* sp.) are reduced earlier in the season, but still dominant later in summer and autumn. Generally, later peaks of phytoplankton production have been observed, however Cryptophyceae displayed earlier peaks, likely as an effect of increased surface water temperatures (Moe et al., 2022).

Zooplankton

The biomass and species composition of the zooplanktonic community in lake Mjøsa have varied considerably since the accelerating eutrophication in the 1950s to 1970s with the following oligotrophication from the 1980s. Zooplanktonic monitoring is now a part of the operational monitoring of Mjøsa (Thrane et al., 2024). Total crustacean zooplankton biomass has decreased along with decreasing algal biomass (Løvik & Kjellberg, 2003). Bottom-up regulation appears to be the main influencer on crustacean zooplankton biomass, however a top-down control on cladocerans has been observed in years with large numbers of vendace (Løvik & Kjellberg, 2003). Generally, the earlier onset of zooplankton population growth could be explained by climatic changes such as increased temperatures, or indirectly by earlier available phytoplankton as a food source (Moe et al., 2022).

Invertebrates

European Crayfish *(Astacus astacus)*
The European crayfish are used as an indicator species for freshwater ecosystem conditions as they are sensitive to acidification and contamination, and experience morphological alterations from changes in river flow and the introduction of non-native species such as signal crayfish (*Pacifastacus leniusculus*) (Miljødirektoratet, 2025a). The European crayfish is known to reside in Hunnselva, Svartelva and Vikselva (Johnsen et al., 2021), which drains into Mjøsa. Occasional observations in Åkersvika (Kjellberg et al., 1994, p. 19), by Gjøvik, in Furnesfjorden, and by Hamar are likely individuals from these populations

(Myrvold et al., 2020). Being a regulated lake, populations in Mjøsa would likely be limited by recruitment, as lowered water levels reduce the opportunity for shelter from predators (Myrvold et al., 2020). European crayfish have also been observed in Tangenvika, with higher densities in the inner part of the bay, in Måsåbekken (likely wandered from Tangenvika) and in Vikselva (Myrvold et al., 2020). About 85 % of the European crayfish caught in Tangenvika were larger than 95mm, indicating low harvest pressure and a population which likely depends on recruitment from the population in Vikselva (Myrvold et al., 2020).

Glacial Relict Crustaceans

In Mjøsa, the species of ice-age immigrants *Gammaracanthus lacustris*, along with *Limnocalanus macrurus*, *Pallaseopsis quadrispinosa*, *Myoxocephalus quadricornis*, and *Cyclops lacustris*, and *Mysis relicta*, have naturally occurring populations (Spikkeland et al., 2016). With the exception of Mysis, none of the ice-age immigrants are targeted for regular monitoring today. The density of *Gammaracanthus lacustris* (earlier *G. loricatus*) was reported to be relatively high in 2001 with 5 individuals per square meter, but then none in 2002 (Kjellberg, 2004), low in 2004 with maximum of 4 juvenile and 1 adult, and 3 juvenile and 1 adult per square meter in 2005 (Kjellberg, 2006). The presence of adult European smelt could be a possible explanation for the lower numbers in later years. *Limnocalanus macrurus* showed small numbers in 2007 and 2008, with an increase in 2009 (Løvik et al., 2010).

Operational monitoring in Mjøsa has included measurements of *Mysis relicta* biomass since 1976. The results show that both the density and biomass of Mysis are now approximately half of what they were in the 1970s. (Thrane et al., 2024). Earlier, a predominant top-down control on Mysis in Mjøsa was observed, but there were no correlations between the biomass of

Mysis and phytoplankton or zooplankton prey species (Kjellberg et al., 1991). Since the earlier study in 1967-80, there has been a large reduction in the biomass of phytoplankton and zooplankton (Thrane et al., 2024), and an increase in abundance of European smelt (Gjelland et al., 2020), likely contributing to the change in Mysis biomass as their food availability decreased and the risk of being eaten by smelt increased. Kjellberg et al. (1991) emphasize a flexible life history to buffer against year-to-year fluctuations for the Mysis in Mjøsa, with a predominant 2-year life history and reproduction during winter.

Benthic Crustaceans

The composition of benthic invertebrates in riverine communities is often used as an indicator of ecosystem health, of acidification, eutrophication and organic load (Miljødirektoratet, 2025a). Riverine benthic invertebrates are regularly assessed in relation to eutrophication and organic load in a set of rivers associated with Mjøsa, and as part of the operational monitoring of Mjøsa program (4.4.1). In 2023, the communities of benthic invertebrates were determined to be in *good* or *very good* ecological condition in Gausa, Mesna, Moelva and Brumunda (Thrane et al., 2024). In 2022, the communities of benthic invertebrates in Flagstadelva were determined to be *very good*, *good* and *moderate*, *very good* in Stokkelva, *moderate* (2/4) and *good* (2/4) in Lenaelva, and *good* and *moderate* in Vorma with the classifications being uncertain because unsuitable substrates sampled in Vorma (Thrane et al., 2023). In 2021, riverine benthic invertebrates were determined to be in good ecological condition in Gudbrandsdalslågen, Hunnselva, Svartelva and Vikselva (Thrane et al., 2022). In Åkersvika surveying from 1974-75, 1900-91 and 2010 showed a decline in biomass of benthic invertebrates, possibly as a result of improved water quality, decreased organic load and increased mineralization of the

sediments, leading to increased diversity (Eriksen & Løvik, 2011).

Mollusks

Freshwater pearl mussel are used as an indicator species for riverine ecosystem conditions as they are sensitive to acidification, contamination, changes in river flow and morphological alterations (Miljødirektoratet, 2025a). The freshwater pearl mussels are present as a moderately small populations in the Hunnselva river draining into lake Mjøsa, estimating 2500 individuals in 2008 (Larsen, 2017). The ecological condition of freshwater pearl mussels in Hunnselva has been considered moderate since monitoring began in 1998 (Larsen & Magerøy, 2024), as a part of the national monitoring program for freshwater river mussels (Miljødirektoratet, n.d.-g).

Recruitment in freshwater pearl mussel populations in Norway has been shown to be negatively correlated with increasing summer temperatures (Gosselin et al., 2023). In Hunnselva, the freshwater pearl mussels had an average annual growth of 0,6 mm from 2001 to 2008, which was below average (Larsen, 2017). No freshwater pearl mussels less than 50 mm in length were found in surveys between 1998 and 2008, indicating recruitment halted or stopped completely during the 1970s (Larsen, 1998, 2017). In 2019, 1% of surveyed mussels were below 50 mm in length, however no new recruitment was observed (Larsen & Magerøy, 2024). In Hunnselva, possible efforts to improve the conditions are, among others, to reduce the nutrient input into the river, establish regimes for "flushing" the river of sediments, establish vegetation to decrease the water temperature and reduce the amount of sediments entering the river, move mussels from the lower to upper parts, and improve recruitment by improving the local brown trout population (Larsen, 2010). As of 2015, no morphological habitat improvement has been conducted (Larsen, 2016).

Duck mussels are observed in Mjøsa north of Storfjorden (Ottestad – Skreia), and in rivers Vikselva, Lenaelva, Svartelva, Flagstadelva, and streams on the Nes peninsula (Artsdatenbanken, n.d.; Larsen, 1998).

Not much is reported on other freshwater clams, family *Sphareiidae*, in Mjøsa. Reports of *Sphaeriidae* are mainly detections in sediment samples, such as in the southern parts of the lake (Aanes et al., 2014) and in Svartelva (Rustadbakken et al., 2009). In Åkersvika, *Sphaeriidae*, (likely) pea clams (*Pisidium* sp.) and Fingernail clams (*Spaherium* sp.), increased in biomass from 1990-91 compared to 2010 (Eriksen & Løvik, 2011).

Fish

Mjøsa is a species rich lake with 20 registered fish species (Thorsnæs et al., 2024). The knowledge on the populations of species in Mjøsa varies considerably, with the most studied species in lake Mjøsa being the brown trout. Most species are only reported in terms of catches or presence, with a few being compared to previous catches. Some species have been subject to sampling regarding environmental contaminants.

Brown trout (*Salmo trutta*)

Lake Mjøsa is well known for its populations of large-sized brown trout – *Storørret* – which is defined as "… a brown trout population that is naturally reproducing with a steady occurrence of piscivorous individuals, and where the transition to a piscivorous diet gives A) a shift in growth, or B) continued growth" (Museth et al., 2018).

Brown trout (*Salmo trutta*) is one of the most studied fish species in Norway (Vøllestad, 2023). The existing literature on the brown trout populations in general in Mjøsa is vast compared to other species. However, population

Figure 4.3: Fish monitoring activities on Lake Mjøsa. Photo credit: Mikkel Emil Lange Friis

specific knowledge varies greatly as more efforts have been directed towards the population of the largest growing individuals in Gudbrandsdalslågen, and the more abundant populations such as in Brumunda. Therefore, this section focuses on the knowledge better representing the population as a whole. Museth et al. (2018) summarizes the more recent knowledge on some of the brown trout populations in Mjøsa through the report "Storørret i Norge. Definisjon, status, påvirkningsfaktorer og kunnskapsbehov".

There are 58 rivers and streams connected to Mjøsa to a varying extent, which function as spawning and nursery habitats for large brown trout (Gregersen, 2009). Most of the surveyed streams were considered to be in good ecological condition, while many of the rivers had deteriorated spawning habitats. In 11 investigated rivers, no genetic differences were found between riverine and lake-migrating brown trout that would suggest genetic differentiation within rivers (Wollebæk et al., 2011), indicating that riverine and lake migrating brown trout are interbreeding and that strategies are important for the population as a whole.

In Mjøsa, lake migrating trout generally return to their natal rivers to spawn, leading to genetic differentiation among rivers. This differentiation increases with river distance and there are clear differences between rivers on opposite sides of the lake (Linløkken et al., 2014; Skaala et al., 1991; Wollebæk et al., 2011). From analysis of brown trout from the 11, assumed, most important rivers for reproduction, the populations had a large degree of natural genetic variation and no substantial signs of reduction of genetic variation in recent times, suggesting that the lasting genetic effect of earlier reductions in populations and stocking of non-native brown trout is small (Wollebæk et al., 2011).

For large-sized brown trout populations, the availability of prey species of appropriate size is essential (Museth et al., 2018). Brown trout in Mjøsa appears to have a shift in diet at approximately 25 cm in length, as no sampled stomach content from brown trout smaller than 25 cm contained fish, while all sampled fish larger than 25 cm had fish in their stomachs (Sandlund & Næsje, 1984). European smelt (*Osmerus eperlanus*), and partly vendace (*Coregonus albula*) and common whitefish

(*C. lavaretus*) were previously identified as the most important prey species for large-sized brown trout (Sandlund & Næsje, 1984; Taugbøl, 1995; Taugbøl et al., 1989).

Mjøsa is one of two Norwegian lakes that have large-sized brown trout populations of good ecological condition (Museth et al., 2018). Stocking of brown trout in Mjøsa from the Hunderfossen population was a compensatory measure started in 1965, developed in method and abundance through the decades, and had its last deployment in 2022 (Næstad et al., 2023). Through the fish passage in Hunderfossen, the yearly average of upstream migrants from 2002 – 2023 was higher than in the period 1978 – 2001, with an average of 753 and 233 individuals per year, respectively (Norum et al., 2025b). Since monitoring began, 2024 was the third year in a row with record numbers of upstream migrants at Hunderfossen in Gudbrandsdalslågen, with 1626 brown trout larger than 44 cm registered migrating upstream using video surveillance (Norum et al., 2025b). The increased number of upstream migrants is likely a result of reduced catch mortality in Mjøsa and in the river, high density of European smelt, and altered sluice gate maneuvering (Museth et al., 2023). From voluntary reporting, catches (in relation to effort) in Mjøsa have approximately doubled from the period 1987 – 1992 to 2002 – 2022 (Statsforvalteren i Innlandet, 2022).

As a lake with a rather substantial history of human influence, the different substances and groups of environmental contaminants in the large-sized brown trout have varied greatly. Environmental contaminants in large-sized brown trout in Mjøsa are monitored through the MILFERSK program. From the latest monitoring effort, Økelsrud et al. (2024), reports that PBDEs and siloxanes are currently the dominating environmental contaminants in large-sized brown trout from Mjøsa, and that the concentrations of BDE6 (PBDE), PFOS and PFTrDA (PFAS) and Hg are slowly decreasing.

Pelagic fish

The species most commonly found in the open water masses of lake Mjøsa are European smelt, vendace and common whitefish.

European smelt (*Osmerus eperlanus*)
Sandlund et al. (2017) summarizes existing knowledge on European smelt and highlights the species importance to the Mjøsa ecosystem through the report "Variabel livshistorie hos krøkle (*Osmerus eperlanus*) i Mjøsa og Randsfjorden". The age of maturation for *E. smelt* in Mjøsa varies with cohort, and is usually between 2-3 years, with most spawning individuals measuring from 100 to 130 mm (Sandlund et al., 2017). While the growth of most individuals stagnates at 11-12 cm, some, likely specializing in cannibalism, might continue to grow to a length of 30 cm (Sandlund et al., 1980).

Despite being an important prey species for large-sized brown trout, little is known about the European smelt ecology. In Mjøsa, the European smelt is omnivorous, experiencing an ontogenetic diet shift from phytoplankton, to zooplankton, to *Mysis* to fish (cannibalistic) (Sandlund et al., 2005).Using pelagic trawling, European smelt is determined to be the most abundant pelagic species in Mjøsa (Gjelland et al., 2020). The average length of European smelt caught with trawl in pelagic masses has decreased from 11 – 14 cm since the period 1978 – 1981 to 10 – 11 cm in 2018 (Gjelland et al., 2020). However, the total biomass appears to be approximately the same because the abundance has increased.

Vendace (*Coregonus albula*)
The historical importance of vendace is discussed in chapter 2. The abundance of vendace was lower in 2018 compared to

the period 1978 – 1981 based on pelagic trawling (Gjelland et al., 2020). Since the period 1978 – 1981, vendace appears to have had a shift in depth preference towards deeper waters. There has been a substantial increase in catches of vendace, using bottom nets, at depths from 0-50 m (Gjelland et al., 2020; Sandlund et al., 1980, 2021), which could be a response to increasing surface water temperatures in Mjøsa (Solheim et al., 2019). In 2019, after a few years of relatively slim catches, reduction in size and fewer larger individuals, the population of vendace experienced a collapse (Linløkken & Rukan, 2020). The coinciding increase in Eurasian cormorant (*Phalacrocorax carbo sinensis*) leading up to the collapse were questioned by some, but estimates on the cormorants effect on the vendace population suggest only a minor impact (Andersen et al., 2018; Linløkken & Rukan, 2020).

Common whitefish (*Coregonus lavaretus*)
The common whitefish in Mjøsa is known to exhibit two niche changes during their life cycle, with a change in habitat and diet: juveniles (<25 cm) tend to stay in the shallow epibenthic zone (0 – 30 m) preying on small and medium sized zooplankton and insects, medium sized individuals (25 – 35 cm) also used deeper epibenthic (0 – 90 m) as well as pelagic habitats, feeding on zooplankton and insects, as well as the larger amphipod *Pallasea quadrispinosa*, and occasionally European smelt. Larger individuals (>35 cm) are restricted to the deeper epibenthic zone (30 – 90 m) and feeding on *P. quadrispinosa* (Sandlund et al., 1992). A seasonal change from epibenthic to pelagic habitat use for whitefish with body lengths between 25 and 35 cm during summer, as the seasonal increasing zooplankton densities at depths between 0 – 50 meters increased with pelagic gillnet catches of common whitefish (Næsje et al., 1991). The abundance of common whitefish appears to be lower in 2018 compared to the period 1978 – 1981 based on pelagic trawling (Sandlund et al., 2021). The length

of mature common whitefish is around 30 cm in 2018, which is the same as in the late 1970s (Gjelland et al., 2020). As with vendace, the number of small common whitefish (<15-20 cm) caught with bottom nets have increased substantially since the period 1978 – 1981 (Gjelland et al., 2020).

Littoral, benthic and riverine fish

Littoral, benthic and riverine fish in Mjøsa are more closely related to the shore, the bottom of the lake and to the connected rivers and streams.

Northern pike (*Esox lucius*)
In Mjøsa, the Northern pike is reported to be able to reach Gudbrandsdalslågen up towards Hunderfossen (and with parts of Gausa), as well as the outlet river Vorma (Hesthagen & Sandlund, 2012). Tangenvika and Åkersvika are identified to be important spawning and nursery habitat for northern pike (Johnsen et al., 2014; Myrvold et al., 2020), as is Lågendelta. In Lågendelta, the spawning migration of northern pike increased with increasing water level in Mjøsa, and appears to have a low harvest pressure, as 34% of the sampled individuals were older than 10 years (Eggebø, 2024). In Mjøsa, PFAS is shown to be the dominating contaminant in pike (Jartun et al., 2023).

European perch (*Perca fluviatilis*)
Northern perch is common in Mjøsa in the epibenthic sone, with higher densities in shallower waters (Gjelland et al., 2020). The number of northern perch caught during the sampling efforts in 2018 were substantially higher than in 1979 (Gjelland et al., 2020), as an increase in size of perch in the age group of 4 – 7 years suggested better growth for the perch sampled in 2018 compared to 1979 (Gjelland et al., 2020; Sandlund et al., 2021). PFAS was the dominating contaminant in perch (Jartun et al., 2023). Åkersvika and Tangenvika are identified as important spawning

and nursery habitats for European perch (Johnsen et al., 2014; Myrvold et al., 2020), as is Lågendelta. In Lågendelta, the spawning migration of northern perch increased with decreasing water levels in Mjøsa, after the spring flood, indicating the necessity of flooding to initiate the spawning migration (Eggebø, 2024). At Moelv in Lake Mjøsa, from June to October, perch exhibited little diel variation in depth and showed reduced activity at night (Tofte, 2025). Perch maintained an overall mean depth close to eight meters throughout the day, with daily mean depth increasing later in the season. Activity of the perch increased from June to early August before declining towards mid-October.

Ruffe (*Gymnocephalus cernua*)
When sampling with Nordic multi-mesh survey nets, ruffe appears to be the most abundant fish species in the littoral area in Mjøsa (Gjelland et al., 2020). Concentrations lead, nickel, cadmium, zinc, chromium, copper, and arsenic in liver of ruffe were low, and as expected for a lake with no known local points of discharge, as were levels of PAH metabolites (Garmo et al., 2017). Among the tested biota, the highest concentrations of contaminants were found in the stomach content of ruffe, and in whole body samples of ruffe the dominating contaminant group was the same as in the sediments, QAC, siloxanes and UV-compounds (Jartun et al., 2023).

Grayling (*Thymallus thymallus*)
Populations of grayling in the Mjøsa watercourse have declined in recent years (NINA, 2019). Surveys in Gudbrandsdalslågen in 2014 revealed lower densities of grayling compared to earlier (Johnsen et al., 2015). In addition to Gudbrandsdalslågen and it's connected rivers, grayling is reported to be connected to many of the larger rivers, such as Moelva, Hunnselva, Vikselva (Kjellberg, 2004), Svartelva and Flagstadelva (Kraabøl & Museth, 2008), in Lenaelva (Westly &

Rustadbakken, 2006) and Brumunda (Kjellberg et al., 2001), as well as other rivers and streams (Linløkken, 2012). There are 58 rivers and streams which, to a varying extent, function as spawning and nursery habitats for grayling (Gregersen, 2009). Most of the surveyed streams were considered to be in good ecological condition, while many of the rivers had deteriorated spawning habitats.

Cyprinids

Seven species of cyprinids are described in lake Mjøsa: bleak *(Alburnus alburnus)*, common bream (*Abramis brama*), common dace (*Leuciscus leuciscus*), crucian carp (*Carassius carassius*), Eurasian minnow *(Phoxinus phoxinus)*, ide (*Leuciscus idus*), and roach (*Rutilus rutilus*). Reported knowledge of the local populations is limited, largely related to observations in regard to spawning migration.

At Moelv in Lake Mjøsa, from June to October, ide exhibited clear diel vertical migration, residing in deeper waters during the day and moving into shallower areas at night, with stable activity levels throughout the day (Tofte, 2025). Ide generally maintained a daily mean depth of less than two meters, with a slight increase in mean depth was observed later in the season. Activity of the ide increased from June to early August before declining towards mid-October.

Åkersvika is an important spawning and nursery habitat for roach, ide, bream, bleak, crucian carp and Eurasian minnow (Johnsen et al., 2014; Kjellberg et al., 1994; Museth et al., 2010), as is Tangenvika (Myrvold et al., 2020). Lågendelta is another important area for cyprinids in Mjøsa. Common dace are only observed in small numbers in lower Gudbrandsdalslågen, and in much larger numbers further upstream in the river above Hunderfossen (Johnsen et al., 2015). Ide and bream in Gudbrandsdalslågen

appear to be more closely associated with backwaters and flood channels throughout the season, while roach and common dace use these habitats in relation to spawning (Johnsen et al., 2015). Common dace could also be spawning in the main channel (Johnsen et al., 2015), as they are known to spawn on sand and gravel in faster flowing waters (Kraabøl & Museth, 2008; Vriese et al., 1994). In Lågendelta, the spawning migration of roach and bream is observed to increase with decreasing water level after the spring flood, indicating the necessity of flooding to initiate the spawning migration (Eggebø, 2024).

In 2018, most roach were caught in Furnesfjorden, and individuals ranging from 210 – 270 mm were most abundant (Gjelland et al., 2020). The number of roach caught during the sampling efforts in 2018 were substantially lower than in 1979 (Gjelland et al., 2020).

Nine-spined Stickleback (*Pungitius pungitius*)
Not much is reported on the nine-spined stickleback in Norway (Vøllestad, 2023) or in Mjøsa. Nine-spined stickleback use Åkersvika during spawning migration in summer (Kjellberg et al., 1994). A few individuals were caught during electro-fishing by boat in Tangenvika in May 2019 (Myrvold et al., 2020).

Burbot (*Lota lota*)
Burbot ecology in lake Mjøsa is described by Sandlund et al. (1985). The burbot is most commonly found from 10 to 80 meters depth, which coincides with findings from ØKOSTOR where burbot was caught only below 15 meters, and showed the highest CPUE at 30-45 meters depth (Gjelland et al., 2020). The burbot showed a growth rate and age of maturation fairly similar to other oligo/mesotrophic lakes. In Mjøsa, they mainly preyed upon *Pallasea quadrispinosa* and European smelt. Their diet contributes to the transfer of energy from the pelagic to the benthic ecosystem by preying on the semi-pelagic European smelt.

Concentrations of lead, nickel, cadmium, zinc, chromium, copper, and arsenic in the livers of burbot were low, and as expected for a lake with no known local points of discharge, as were levels of PAH metabolites, while the concentration of mercury in muscle was the same level as large-size brown trout, more than 4 times the EQS limit (Garmo et al., 2017). Levels of PCBs, DDTs and PBDEs were about 10, 15 and 300, respectively, times higher in burbot from Mjøsa compared to Losna, as a reference lake, in samples from 2005-2008 (Berg et al., 2013), highlighting the high anthropogenic impact on fish in Mjøsa. The burbot in Mjøsa also showed higher numbers of lesions, higher numbers of infections and lower hepatic lipid content (Berg et al., 2013), as well as altered physiological processes (Olsvik et al., 2013), compared to lake Losna, suggests that the higher levels of contamination could be having a negative impact on fish health in Mjøsa (Berg et al., 2013; Olsvik et al., 2013).

Alpine bullhead sculpin (*Cottus poecilopus*)
Alpine bullhead is a species which has received little attention in research in Norway (Vøllestad, 2023), and not much is reported about the alpine bullhead population in lake Mjøsa except for its presence in Åkersvika (Johnsen et al., 2014; Kjellberg et al., 1994) and a small number of individuals caught during ØKOSTOR in Ringsakerfjorden (Brøttum), Furnesfjorden (Jessnes) and Tangen (Trosvika) (Gjelland et al., 2020).

Fourhorn sculpin (*Myoxocephalus quadricornis*)
The fourhorn sculpin is only known to exist in two lakes in Norway, one of which is lake Mjøsa, which was the first observation in Norway in 1979 (Sandlund, 1979). Based on video surveillance fourhorn sculpin reside on mud substrate, and their density increases with depth The population is

estimated to be approximately 2 million individuals (Kraabøl et al., 2012).

European river lamprey (*Lampetra fluviatilis*)

The European River Lamprey is the subject of minimal attention or scientific research in Norway (Vøllestad, 2023). Flagstadelva, Finsalbekken and Svatelva have been identified as spawning habitats for lamprey, likely migrating upstream during autumn (Vøllestad, 2023). Five lamprey were caught in Åkersvika on 22 September 2014, likely on spawning migration (Johnsen et al., 2014). Six individuals were caught during pelagic trawling in Ringsakerfjorden by Moelv in 2012, which constituted 0.7% of the number of fish caught (Gjelland et al., 2013). In 2018, 10 and 4 individuals were caught during pelagic trawling in Ringsakerfjorden and Furnesfjorden, respectively, while none were caught in Storfjorden (Gjelland et al., 2020).

Amphibians

Of the six reproducing amphibian species in Norway many have relatively wide geographic distributions except the pool frog (*Pelophylax lessonae*), which is only registered at a handful of locations in southern Norway (Dolmen, 2012). Amphibians, especially newts, are vulnerable to introduction of species into ecosystems (especially fish), habitat fragmentation, reduction of forests and wetlands between agriculture units, increasing infrastructure, contamination from agriculture, industrial and urban development, vegetation encroachment from dams, and wetland drainage, among other things (Handlingsplan for Stor Salamander Triturus Cristatus, 2008; Wyman, 1990).

The smooth newt (*Lissotriton vulgaris*), the northern crested newt (*Triturus cristatus*), the common frog (*Rana temporaria*), the moor frog (*Rana arvalis*) and the common

toad (*Bufo bufo*) are found along the eastern shore of Mjøsa (Strand, 2008). On the western side, only smooth newt and common frog are present (Jensen, 1996; Strand, 2007). In the Lillehammer region smooth newt, crested newt, common frog and common toad are found (Strand, 2007).

4.6 Ecological Trends

There are two national means of evaluating biological diversity and ecosystem trends in freshwater systems in Norway, Vannforskriften (Miljødirektoratet, 2025a) and the Nature Index for Norway (Miljødirektoratet, n.d.-f). For evaluation of freshwater systems there is a need for better representation of indicators sensitive to hydropower regulation, changing climate and alien species (Jakobsson & Pedersen, 2020), and a need for better coordination and cooperation between the reporting schemes (Sandvik, 2019).

In the latest surveying, the overall ecological conditions based on eutrophication and organic load (PIT and ASPT) were determined to be *good* or *very good* in Gausa, Mesna, Moelva and Brumunda, with the exception of the lower most station in Brumunda, which was determined to be *moderate* (Thrane et al., 2024); in Flagstadelva *moderate/very good*, *good/very good* in Stokkelva, *moderate/good* in Lenaelva, and *moderate/good* in Vorma, with constraining factors being benthic invertebrates and benthic algae at varying locations (Thrane et al., 2023). The river monitoring program classified the lower parts of Vorma to have *moderate* ecological condition in 2023 (and in 2020 and 2017), with good levels of ToP and PIT, and moderate levels of ASPT (Kile et al., 2024). In Gudbrandsdalslågen *good/very good*, *moderate/good* in Hunnselva, *moderate/good* in Svartelva and *moderate* in Vikselva were recorded, with constraining factors being growth in

relation to eutrophication (Thrane et al., 2022).

In Mjøsa, the overall ecological condition based on phytoplankton, Tot-P, Secchi-depth and physical-chemical factors was determined to be *good* at Brøttum, Furnesfjorden and Skreia, and *moderate* at Kise (due to lower Secchi-depth from the extreme weather event "Hans") in 2023 (Thrane et al., 2024). All stations had *good* ecological conditions in 2022 and 2021. In 2023, the lake was determined to be in *good* ecological condition (0,79) according to the WS-FBI index, which takes into account fish biomass as a result of eutrophication (Haande et al., 2024). This is a slight reduction from *very good* (0,81) in 2021 (Haande et al., 2022).

Mjøsa is exposed to environmental contaminants through a variety of pathways: air, industry, and runoff from transportational infrastructure, wastewater, urban areas, and agriculture. From the latest report on operational monitoring of Mjøsa, Thrane et al. (2024) presents some of the central environmental goals for lake Mjøsa:

1. The concentration of total phosphorus (Tot-P) in late winter should not exceed 5 µg/l.

2. The mean values for total phytoplankton biomass and chlorophyll-a during the algal growing season should not exceed 0.4 mg/l and 2.0 µg/l, respectively.

3. The mean Secchi depth in the central waters of Lake Mjøsa should be more than 8 m.

Nutrients and Eutrophication

The latest results from the operational monitoring of Mjøsa (Thrane et al., 2024) show a trend of decreasing phosphorus and increasing nitrogen. The Tot-P concentrations of late winter/early spring have decreased from 8 – 12 to 2 – 4 µg/l since monitoring began in the 1970s, due to The Mjøsa Campaign and later efforts to reduce eutrophication (Nashoug, 1999). Since 1998, the late winter (or spring) concentrations have satisfied the environmental goal of 5 µg/l, except for Brøttum station in 2012. The decrease in Tot-P concentrations is also visible for the yearly mean, decreasing from 7 – 10 µg/l to 4 – 6 µg/l the last decade, which classifies to *good* ecological quality in accordance with Vannforskriften (Miljødirektoratet, 2025a). In Mjøsa, the Tot-N concentrations are classified as *moderate* ecological condition at the stations Kise (450 µg/l), Furnesfjorden (541 µg/l) and Skreia (475 µg/l), and *good* at Brøttum (330 µg/l) for 2023. The Tot-N concentrations of late winter (or spring) have increased with 24 µg/l per decade since the 1970s, with a higher increase the last two decades. The authors emphasize that the increase in Tot-N is likely a result of local runoff, mainly from agriculture. The lower concentrations measured at Brøttum, where the water is heavily influenced by the less agriculturally influenced Gudbrandsdalslågen river reflects the effect on nitrogen from runoff from agricultural land. The Tot-N concentration is not attributed to the overall ecological status classification of the lake as eutrophication processes in Mjøsa are limited by phosphorous.

In 2023, the average of registered Secchi-depths was relatively low as a consequence of increased turbidity after the extreme weather event "Hans" (Thrane et al., 2024). The average registrations at Skreia (6,9 m) and Furnesfjorden (6,8 m) qualified for *good* ecological condition, while the average registrations at Kise station (5,8 m) were *moderate*. The registered Secchi-depts of 2023 did not reach the central environment goal of minimum 8 m average at Skreia. At Skreia, the average Secchi depth has increased from 4 – 6 meters in the 1970s to 9 – 11 meters in the 2000s, largely due to the decrease in algal biomass. Over the last

decade the average Secchi-depths have varied between 7 and 9 meters, more often than not reaching more than 8 meters and reaching the local goal.

At the monitoring stations in Mjøsa, the Cyanomax has been classified as *very good* and *good* at Skreia monitoring station since the end of the 1970s, and in 2023 the Cyanomax was classified as *very good* at all four stations (Thrane et al., 2024). In large lakes, harmful algal blooms can occur locally in shallow bays and at beaches without being detectable at the offshore monitoring stations, which is the case in Mjøsa (Solheim et al., 2022).

Symptoms of eutrophication in Mjøsa peaked in the 1970s (Hobæk et al., 2012), and have shown a general decrease since then. However, in the last decade there has been an increasing trend in chlorophyll *a*, an indicator of eutrophication, in Furnesfjorden and at Skreia station, as well as several local blooms observed by the shore (Bechmann et al., 2021i; Solheim et al., 2022). Over the last 20 years, there has been an increase in agricultural animals in the Mjøsa watershed, as well as an increase in phosphorus runoff from the application of livestock manure (Bechmann et al., 2021i). In some of the larger river watersheds draining into Mjøsa (Lenaelva, Hunnselva, Flagstdelva, Svartelva, Moelva and Tingnes-Brøttum, Heggshuselva, Skanselva and Bausbakkelva and Gausa), decentralized wastewater is the largest contributor of bioavailable phosphorous (Bechmann et al., 2021i). For Gudbrandsdalslågen, the highest contributor is forests and outlying land (2,5 tons estimated), followed by decentralized wastewater (2,4 tonnes estimated). For most of these rivers, the largest contributor to Tot-P is agriculture. The local algal blooms could be attributed to increased local loads of phosphorous, increases surface water temperatures and increased frequency of heavy rainfall events.

Contaminants

The history, knowledge and proposed actions for the major groups of contaminants in Mjøsa is summarized in "Miljøgiftene i Mjøsa – historikk, kunnskap og tiltaksplan" (Fjeld, 2019). The latest results from the current MILFERSK monitoring, as well as trends, are reported in "Monitoring of environmental contaminants in freshwater food webs (MILFERSK), 2023" (Økelsrud et al., 2024).

Metals

Mercury, Hg, in piscivorous fish, such as large-sized brown trout, northern pike, large northern perch and burbot is known to exceed the EQS limit of 0.2 mg/kg wet weight and the Food and Safety Authorities limit of 0.5 mg/kg wet weight for sale for consumption (Fjeld, 2019). Historically, local industry has been an important source of mercury contamination (Fjeld, 2019) while in recent times, the main source of mercury to aquatic systems is long distance atmospheric contamination (Wang et al., 2004). The average length-adjusted mercury concentration in brown trout for the period 2015 – 2023 is lower than that of the period 2006 – 2014, suggesting deceasing mercury concentration for average fish length in which they reach 0.5 mg/kg wet weight, which is approximately 56 cm (Økelsrud et al., 2024).

Organic Contaminants

The latest results from the MILFERSK program (Økelsrud et al., 2024) shows that PFAS, siloxanes (D5) and PBDE are the organic contaminants with the highest concentrations in fish at higher trophic levels. PBDE concentrations in brown trout peaked in the early 2000s and have shown a significant decrease since then, however they are still above the EQS limit. Siloxane D5 concentrations are below the EQS limit, as is the PFAS group for the majority of individuals of tested brown trout. Both

siloxane D5 and PFASs show a weak decreasing trend in concentrations. In lower trophic levels the non-biomagnifying UV-compound octocrylene is dominating, with higher concentrations in the pelagic than the benthic communities.

Microplastics

It is estimated that 35.9 (7.4 – 119.4) tons of microplastic is released annually into Mjøsa, and that about 10% of this settles into the sediments of the lake, with the majority of microplastics (70 – 90%) originating from urban waste mismanagement and sewage sludge application on crops (Clayer et al., 2021). Fragments from historical plankton samples suggest input of microplastics from the 1970s (Lusher et al., 2018).

Sites in Mjøsa influenced by rivers, urban areas, roads, and wastewater treatment plants have shown higher concentrations of microplastics compared to lake Femund (as a reference lake) and sediment accumulation areas of lake Mjøsa representing sites with fewer potential sources of microplastic input (Lusher et al., 2018). In one study, out of ten duck mussel individuals, one had one microplastic fragments (Lusher et al., 2018). In this study samples were sieved on a 36-micron siew. Concentrations in nearly all substrates and animals are increasing substantially, some sources say exponentially and with decreased sizes and lower thresholds. Therefore, false negatives for microplastics contamination compared to actual concentrations are a very real possibility. This is especially the case in areas with a heavy car traffic where there is a lot of dust that is less then 36-microns (dust from cars is normally measured at 10- and 2.5-micron levels), which is the case around much of Mjøsa.

Alling et al. (2023) report that tire wear particles were present in the highest concentrations in the urban runoff samples (Hamar and Oslo combined)

among the water samples, and showed the second highest concentrations in freshwater sediments (following blue mussels from the Norwegian shore) (Alling et al., 2023). In Mjøsa, the highest tire wear particle concentrations in sediments were found outside Hamar, followed by Mjøsbrua (by Moelv), while the concentration in the samples outside Skreifjella was not detectable. This coincides with the highest reported concentrations of microplastic values close to Hamar, followed by Mjøsbrua, and very low concentrations outside Skreifjella (Lusher et al., 2018). High concentration of tire wear particles in the sediment samples by Hamar likely relates to urban runoff. The wastewater effluent and urban runoff samples (from Oslo and Hamar) showed 1000 – 10 000 times higher concentrations of particles of microplastics than their controls. The authors emphasize a large variation between samples, and that no strong conclusions should be drawn, however it is clear that effluent from wastewater treatment plants seem to be an important source for microplastics, apart from tire wear particles.

4.7 Land Use and landcover change

Selective logging was at its peak in the 19th century due to corresponding population growth; more intensive logging practices occurred as farmers sold logging contracts to companies beginning around 1860 (Aasetre & Bele, 2009). Since the 1950s, clear-cutting has been the dominant logging regime creating a fragmented landscape with even-aged forest patches.

Helseth et al. (2022) provides a summary of forest ecosystem services in Norway, focusing on trends, conditions, and drivers of change from 1950 to 2020. The main drivers of forest transformation in Norway from 1950 to 2020 include industrial forestry, large-scale re- and afforestation,

and infrastructure development (e.g., roads and recreational homes). Since the 1950s, clear-cutting has been the dominant logging regime creating a fragmented landscape with even-aged forest patches (Aasetre & Bele, 2009). Figure 4.4 – 4.6 shows recent land cover change in the area around Lake Mjøsa, with an approximately 1% decrease in forest area.

Deep transformations in the Norwegian economy, including a shift towards the tertiary (service) sector and mechanization of forestry, have significantly influenced trends in forest ecosystem services (Helseth et al., 2022). The primary value of Norwegian timber was 3 billion NOK in 2008. The same year timber and wood products had a gross value of approximately 48 billion NOK, corresponding to 5 % of the total gross domestic product in Norway (det norske skogselskapet, 2011). Norwegian forestry and the wood industry continue to have great financial importance today, at national, regional and local levels. Direct sales of raw timber in 2024 totalled 8.3 billion NOK (Bern et al., 2025).

The Dynamic World dataset (https://dynamicworld.app/) , accessible on Google Earth Engine (https://developers.google.com/earth-engine/datasets/catalog/GOOGLE_DYNAMICWORLD_V1) , offers a powerful, near-real-time tool for monitoring global land use and land cover (LULC) changes like changes in forest cover. Using medium-resolution 10-meter Sentinel-2 satellite imagery, the dataset can generate LULC predictions with class probabilities for nine categories (water, trees, grass, flooded vegetation, crops, shrub and scrub, built, care, and snow and ice) every 2-5 days. However, it should be noted that since Sentinel-2 is an optical satellite, data availability and quality can be affected by cloud cover, therefore it is common practice to generate multi-date composites to ensure cloud free data products.

These data products are vital for detecting rapid shifts from natural disasters like wildfires or floods, or human activities such as deforestation or urban expansion, which traditional annual or five-year LULC maps often miss. For example, while the change detected between 2019 and 2024 images may be minimal for forest cover, this dataset demonstrates how even subtle shifts can be identified and monitored across vast areas (Fig 4.4 – 4.6) (For tables associated with these figures see Appendix 3).

While its single-image, per-pixel classification can present limitations for long-term analysis as the data catalog is still limited (launched 2015), the dataset's utility is growing as more data becomes available, allowing for more comprehensive monitoring over longer periods. Establishing a baseline is crucial for this long-term tracking. By generating LULC maps for specific areas and time periods, its key strength is the ability to monitor landscape changes at a 10m scale over large geographic areas. The dataset allows scientists, governments, and organizations to quantify changes as they happen, supporting timely decision-making in environmental management, disaster response, and climate research.

For example, while the change detected between 2019 and 2024 images may be minimal for forest cover, this dataset demonstrates how even subtle shifts can be identified and monitored across vast areas. Figure 4.4 illustrates the LULC for a specified area in 2024, providing a current snapshot of the landscape. By contrast, Figure 4.5 shows the same area in 2019, serving as a critical baseline for comparison.

Comparing these two images highlights the dynamic nature of the environment. The dataset's ability to quantify these changes is one of its key strengths. For instance, the percentage of land covered by each category can be calculated, as

shown in Table 1 for 2024 and Table 2 for 2019 (Appendix 3).

The true potential of the dataset lies in its ability to quantify changes over time. Figure 4.6 visually represents the change in forest cover from 2019 to 2024, showing both areas of loss and gain. While table 3 (Appendix 3) further quantifies this specific change, making it easy to see the net change. This is crucial for supporting timely decision-making in environmental management, disaster response, and climate research.
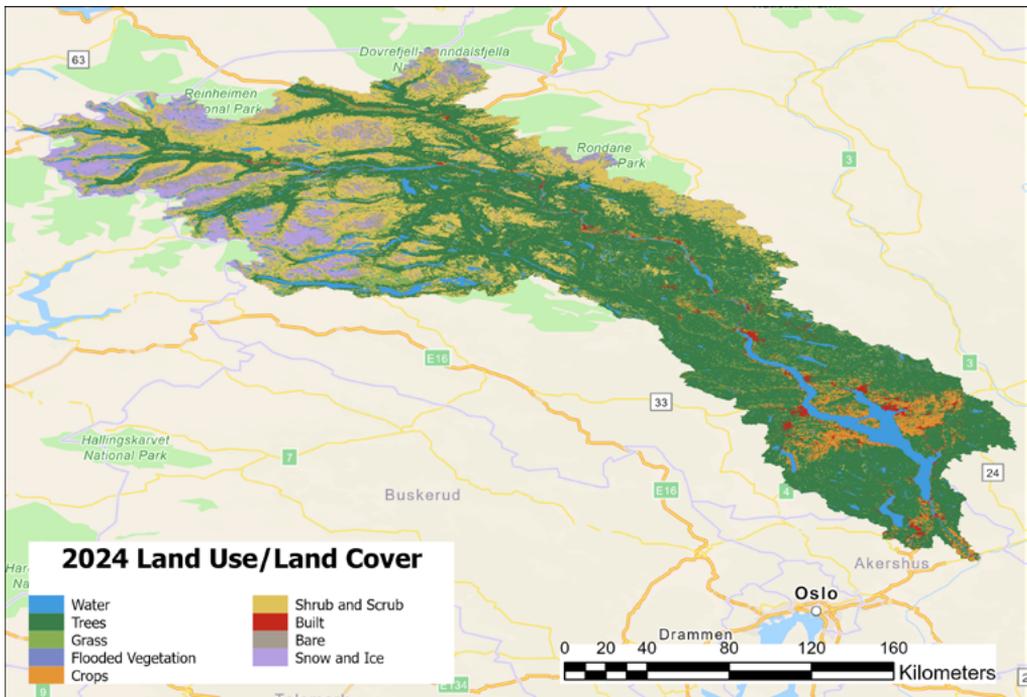
Figure 4.4: 2024 Land Use Land Cover Change in area surrounding Lake Mjøsa

Data Sources: Brown, C.F., Brumby, S.P., Guzder-Williams, B. et al. Dynamic World, Near real-time global 10 m land use land cover mapping. Sci Data 9, 251 (2022). doi:10.1038/s41597-022-01307-4

This medium-resolution land use and land cover (LULC) map, generated from the Google Earth Engine Dynamic World dataset, provides a detailed 2024 snapshot of the landscape at a 10-meter resolution. It leverages near-real-time Sentinel-2 satellite imagery to classify the Earth's surface into nine distinct categories, from built-up areas to forests and water bodies. This LULC product is a mosaiced summer composite (June-August) thereby ensuring a cloud-free image.
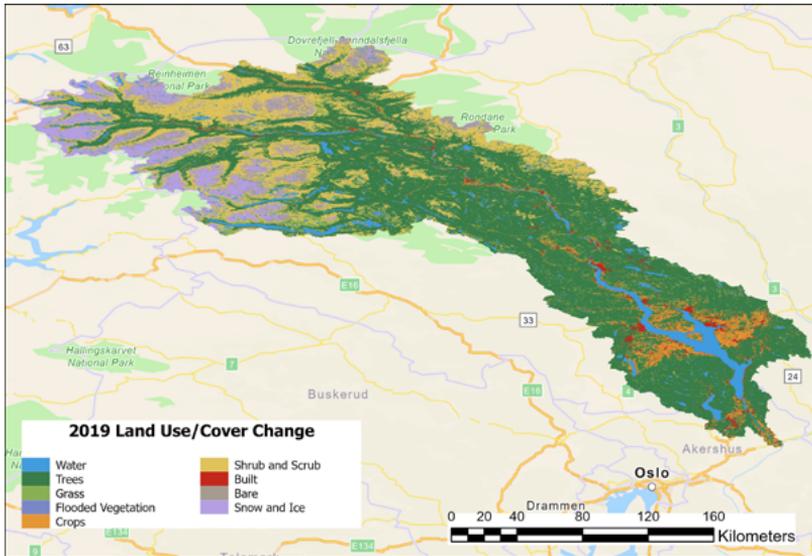
Figure 4.5: 2019 Land Use Land Cover

Data Sources: Brown, C.F., Brumby, S.P., Guzder-Williams, B. et al. Dynamic World, Near real-time global 10 m land use land cover mapping. Sci Data 9, 251 (2022). doi:10.1038/ s41597-022-01307-4
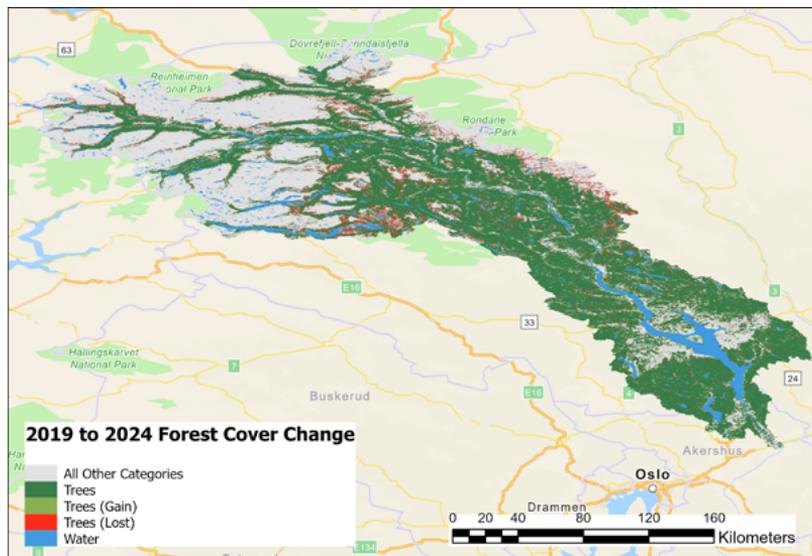
Figure 4.6: 2019-2024 Forest Cover Change

Data Sources: Brown, C.F., Brumby, S.P., Guzder-Williams, B. et al. Dynamic World, Near real-time global 10 m land use land cover mapping. Sci Data 9, 251 (2022). doi:10.1038/s41597- 022-01307-4

This map represents the total change from 2019 to 2024 for the forest category only. The change was assessed by determining all pixels that remain as forest between the two data years, those areas of forest that were lost (changed to another category), and those areas that gained forests.

Chapter 5: Scenarios, Modelling & Technology

Simen Berg, Sabine Fischer, and Sajith Prabashwara Ranatunga

5.1 Executive Summary

This chapter presents an introduction to available data on Lake Mjøsa, the technologies used to collect it, and emerging innovations such as digital twins that promise to revolutionize environmental monitoring. It highlights the dispersed nature of Mjøsa-related data across different studies, institutions, and formats, posing challenges to integrated environmental analysis and policymaking. The chapter presents past and ongoing data collection efforts, focusing on use cases in scientific research, ecosystem restoration, pollution tracking, and climate impact assessment.

Data has been collected in Lake Mjøsa through various coordinated initiatives, often involving institutions such as NINA (Norwegian Institute for Nature Research), NIVA (Norwegian Institute for Water Research), and NVE (The Norwegian Water Resources and Energy Directorate) among others. Historical research includes assessments of eutrophication, sedimentation, aquatic biodiversity, underwater mass movements, and contaminant bioaccumulation. Annual reporting on Lake Mjøsa has been coordinated since 1972, with Vassdragsforbundet taking responsibility from 2003 onward. These reports, often spanning water chemistry, biological diversity, meteorological inputs, and tributary dynamics, offer valuable longitudinal datasets. Recent extreme events, such as storm Hans in 2023, have prompted supplementary data collection efforts, reflecting the growing role of responsive environmental monitoring.

Recent and ongoing campaigns and collaborations with NIBIO have extended environmental studies to include chemical contamination, fish ecology, and broader ecosystem health. These efforts have increasingly incorporated advanced technologies including satellite-based remote sensing from platforms such as Sentinel-2 and Sentinel-3. Optical imagery aids in monitoring vegetation and water quality, while Synthetic Aperture Radar (SAR) provides reliable, cloud-penetrating data suitable for land surface and water body assessment.

Mission Mjøsa, launched in 2020, marks a significant advancement in coordinated research. One of its primary objectives is to develop a digital twin of Lake Mjøsa: a dynamic, virtual model that reflects real-time environmental conditions. As part of this initiative, researchers have used Remotely Operated Vehicles (ROVs), Autonomous Underwater Vehicles (AUVs), and hyperspectral satellite systems, as well as various optical and acoustic sensor to gather high-resolution data on lakebed conditions, water chemistry, biological activities, and historical artifacts like shipwrecks and dumped ammunition.

These instruments are part of the "observational pyramid" – a layered technological system of systems in which different sensors and platforms collectively

contribute to knowledge about the Mjøsa region (Figure 5.1). Human input still drives much of the system's coordination and analysis, but future integration through automation and feedback mechanisms could increase efficiency and provide even deeper insights.

The concept of the digital twin plays a central role in this work. In the context of Lake Mjøsa it could unify real-time data streams from sensors, historical datasets, simulation models, and AI-based analytics. Applications include water quality monitoring, flood risk modelling, fish population tracking, and scenario-based simulations for ecosystem management. While not yet fully implemented for Mjøsa, international examples like Digital Twin of the Ocean (DTO) in Trondheim Fjord, the Chaohu Lake platform in China, and Korea's K-Twin SJ platform demonstrate practical implementations of real-time integrated monitoring, interactive 3D visualization, and predictive analytics. These efforts illustrate approaches to and challenges of managing data integration, stakeholder collaboration, and visualization from which Mission Mjøsa can

learn. Other emerging technologies, like deep-learning based 3D reconstruction, could support photorealistic visualization in the future digital twin of Lake Mjøsa, offering enhanced tools for education, decision-making, and public engagement.

In conclusion, this chapter provides an overview of Lake Mjøsa's environmental monitoring history, current data infrastructure, and technological developments that form the foundation for realizing a holistic digital twin. While challenges remain in standardization, integration, and coordination, the synergy of historical datasets, cutting-edge technology, and multi-stakeholder engagement presents a transformative opportunity for sustainable freshwater ecosystem management. Mission Mjøsa is positioned to become a model initiative for other large-lake digital twins globally, demonstrating how digital technologies can support adaptive, resilient, and informed environmental stewardship**.**
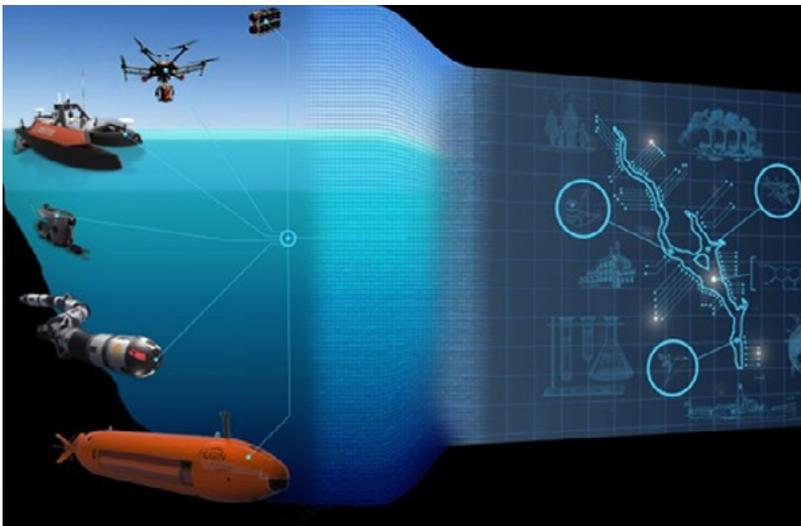

Figure 5.1:
Visualization of the observational pyramid and Lake Mjøsa. Image credit: Øyvind Ødegård

5.2   Introduction

Lake Mjøsa, the surrounding vegetation, ecology, and tributary rivers have been an important part of the livelihood of people living close to it for a long time. In the 1950s and 1960s, the water quality of lake Mjøsa suffered from pollution and severely declined the health of the lake, but was later restored through *Mjøsaksjonen* (Nashoug, 1999). From the European Union water framework directive: *"The water framework directive focuses on ensuring good qualitative and quantitative health, i.e. on reducing and removing pollution and on ensuring that there is enough water to support wildlife at the same time as human needs"* (European Commission, 2023). Monitoring efforts have been integral to detecting a deterioration in water quality, ecology, and being able to restore them, and technological advancements enable enhancements of current capabilities. This chapter considers the role of technology in understanding lake Mjøsa.

The goal of this chapter is to introduce available data related to Lake Mjøsa and key technologies for its acquisition, processing, and distribution. Data about Mjøsa has been collected in various contexts. It is spread across various sources and is hence challenging to locate. To mitigate this problem and ease the planning of future data collection efforts, this chapter aims to provide a starting point for locating relevant pre-existing data and selecting suitable technology.

To this end, this chapter summarizes previous and ongoing data collection efforts that cover lake Mjøsa and its surroundings. Then, it describes key technologies used to collect such data. Lastly, emerging technologies and their use in other lake observation efforts are presented.

5.3   Methods

As noted by Per Even Johansen et al. (Nashoug, 1999), previous collection campaigns at Lake Mjøsa are spread across a large variety of sources, thus making the work challenging to locate. Although considerable effort has been put into locating relevant data for this work, it should not be viewed as a complete overview of previous and ongoing data collection efforts. Instead, we hope to guide readers towards relevant data sets and technologies for a variety of use cases.

The information about previous and ongoing data collection efforts and relevant technologies presented in this chapter was collected using multiple techniques with various degrees of formalization. To gain insight into data collection efforts by the overall research community, google scholar, web of science and Scopus were queried in both English and Norwegian. In addition, we queried google for relevant public reports and news articles. We limited search to the first two to five pages of results. As Norway's biggest lake Mjøsa is an integral part of the water body network within Norway. So, we also utilized the databases of local research institutes connected to water bodies (NINA, NIVA) as well as on governmental projects. The queries included keywords covering the region of interest (Mjøsa OR Mjoesa OR Mjosa), lakes within Norway (lake Norway OR innsjø Norge), or bodies of water more broadly when targeting emerging technologies (lake OR water OR underwater). Additional relevant governmental programs and the associated data collection efforts were identified based on the funding source acknowledgments in the reports we found. Results that did not collect or provide data from/about the Mjøsa region, or investigate emerging technologies with clear transferable capabilities for this lake, were excluded from further analysis based on the abstracts. Since the goal is

to provide a broad selection of potentially relevant data sources and technologies, the further qualitative analysis of the literature focused on grouping them based on the characteristics of the involved data and potential application. In addition, this chapter draws on the authors' pre-existing literature collections, informal conversations with other people involved in Mission Mjøsa, and internal campaign plans. Because of the recency and ongoing nature of data campaigns directly connected to Mission Mjøsa, their descriptions are largely based on internal plans and information provided by researchers involved in the planning and execution of these data collection efforts.

5.4 Previous studies

Extensive data collection and analysis efforts have been conducted in and around Lake Mjøsa in various contexts, including research, monitoring, and public service applications. This section introduces past and ongoing data collection efforts to give an impression of what kinds of data have been collected in connection with research studies, and how they have been used.

Lake Mjøsa has been the focus of extensive environmental research and data collection due to its ecological importance and history of pollution. From the 1950s to the 1970s, the lake suffered from severe eutrophication, prompting the Norwegian Institute for Water Research to undertake a multi-year study, which identified phosphorus pollution as the primary cause. This led to the Mjøsa Campaign in 1977, a government-supported initiative that introduced advanced wastewater treatment and public awareness efforts. By the early 1980s, monitoring revealed a significant reduction in phosphorus levels and a return to oligotrophic conditions, underscoring the success of these interventions (Baalsrud, 1982).

Complementing this, research from the 1970s and 1980s provided critical baseline data. For example, bottom fauna samples were collected in 1975–1976 across 93 stations at various depths using Ekman grabs to assess pollution levels via oligochaete communities (Milbrink, 1994). Similarly, (Frøslie et al., 1985) examined mercury and selenium levels in fish, highlighting bioaccumulation risks.

Further studies continued to build on this foundation. Nordli et al. (2007) reconstructed historical temperature trends using ice break-up records from 1758 to 2006, demonstrating long-term climate variability using observations from Lake Mjøsa. Forsberg et al. (2016) investigated underwater mass movements that had damaged utility pipelines, using modern multibeam bathymetry and sub-bottom profiling. Hobæk et al. (2012) explored changes in algal biomass, lake stratification, and nutrient decline through sediment core analysis and radiometric dating, reinforcing evidence of Mjøsa's ecological recovery.

More recent efforts have embraced emerging environmental challenges and technological advances. Aro et al. (2021) tested fluorine mass balance to detect unidentified organofluorine compounds in the lake and results show that several times higher in extractable organofluorine than reported values in othernations. Moe et al. (2022) conducted extensive monitoring of nutrients, phytoplankton, zooplankton, and sediment to evaluate the ongoing impact of human activity and support evidence-based policy-making. Høyberget et al. (2023) focused on paleontological exploration, documenting the Skyberg Biota, a newly discovered Cambrian fossil assemblage through fieldwork and advanced imaging.

Together, these studies contribute to a comprehensive and evolving understanding of Lake Mjøsa's environmental condition from early pollution crises and recovery efforts to modern monitoring using cutting-edge tools (see Table 5.1). They provide an essential knowledge base for ongoing and future initiatives and support for the development of sustainable lake management.

Study	Research Focus	Data Collected
Baalsrud, 1982	Eutrophication	Water- and algal samples
Milbrink, 1994	Pollution and eutrophication	Lakebed fauna samples
Ibrekk et al., 1991	Pollution-abatement assessment methodology	Summary and interpretation of previously collected data
Frøslie et al., 1985	Mercury and selenium levels in fish	Fish specimens
Aro et al., 2021	Fluorine mass balance analysis	Surface water samples
Berglind et al., 1983	Algae, underwater mass movement	Water samples
Forsberg et al., 2016	Underwater mass movement	Multibeam bathymetry, sub bottom profiles, sediment samples
Hoyberget et al., 2023	Biodiversity in the Cambrian era	Rock samples, fossils,
Moe et al., 2022	Ecological effects of climate change	Weekly samples of water temperature, Secchi depth, total phosphorus, total nitrogen, nitrate, and silicate. Samples of biomass per species of phytoplankton and zooplankton every two weeks.
Hobæk et al., 2012	Sediment-based reconstruction	Sediment samples
Nordli et al., 2007	Reconstruction of temperature records back to 1758	Farm diary records, ship observations, modern temperature measurements

Table 5.1: Previously collected data of Lake Mjøsa

5.5 Research Institutions and Governmental Initiatives

As described in 4.4, there have been continuous efforts in monitoring the hydrology, biology, and ecology of Lake Mjøsa and connected bodies of water by Norwegian research institutions since at least 1972 (Løvik, 2007). Annual reports on these topics, as well as additional studies about Mjøsa and its tributary rivers, are available in the *Research Institute for Water and the Environment*'s (NIVA), *Norwegian Institute for Nature Research*'s (NINA), *Norwegian Institute of Bioeconomy Research*'s (NIBIO), and *Vassdragsforbundet's* own publication catalogs (Bechmann et al., 2021c, 2021b, 2021h, 2021h, 2021f, 2021g, 2021d, 2021a, 2021e; NINA, n.d.-a; NIVA, n.d.-d; Vassdragsforbundet, n.d.). They are a good source for studying long-term trends and changes in Lake Mjøsa. The websites of the *MILFERSK* and *ØKOSTOR* programs similarly collect more recent reports the ecological and chemical state of water bodies in Norway, including Mjøsa (Miljødirektoratet, n.d.-e; NINA, n.d.-b).

There have also been efforts to utilize satellite data to aid in the monitoring efforts of Lake Mjøsa. Harvey & Sørensen (2021) describe the use of data from the Sentinel-2 and Sentinel-3 satellites to aid in the Økostor programme. Results from the work were optimistic about it being realistic, but that it still required further work to assess the need of possible adjustments and corrections. GeoNorge (Geonorge, n.d.), Norway's national website for map data and other location-based information, offers topographic, land cover, and administrative boundary data for Norway including the Mjøsa region. Similarly, Norwegian Water Resources and Energy Directorate (NVE) (NVE - Norges vassdrags- og energidirektorat, n.d.) provides hydrological data, including

water levels, river discharge, and flood risk assessments. Kartverket (Kartverket. no, 2025), Norway's national mapping authority, supplies high-resolution terrain models, aerial imagery, and bathymetric data. The SeNorge website is a collaboration among NVE, NPRA, NMA, and The Meteorological Institute.

In addition, GeoNorge (*Geonorge*, n.d.), Norway's national website for map data and other location-based information, offers topographic, land cover, and administrative boundary data for Norway, including the Mjøsa region. Kartverket (*Kartverket.no*, 2025), Norway's national mapping authority, supplies high-resolution terrain models, aerial imagery, and bathymetric data. The *Norwegian Water Resources and Energy Directorate* (NVE) (*NVE - Norges vassdrags- og energidirektorat*, n.d.) (NVE - Norges vassdrags- og energidirektorat, n.d.) provides historival and nera real-time hydrological data through their *SLIDRE* portal (NVE, n.d.-a)

5.6 Open-source satellite data

There is a large amount of satellite data acquired of lake Mjøsa. It is possible to request and buy commercial satellite images, but a large selection of openly available satellite data covering the target region is also available. There are multiple commercial actors utilizing these openly available satellite images as a data source and offering processed data products from them but here we focus on openly available data. Open-source satellite data utilizes optical and radar imaging. Optical imagers can cover a wide variety of use cases both in the water and

in the vegetation surrounding the lake. However, data coverage can be limited due to lighting conditions and cloud cover. Satellites performing radar imaging cannot provide much insight into the water quality, but their coverage is much more reliable due to not requiring sunlight in order to image and being able to image through clouds. It is more commonly used for imaging vegetation and water level. The following is a list of satellites with coverage of Mjøsa, and which providing openly accessible data. The data itself can be located through a variety of web viewers and APIs.

Table 5.2 shows an overview of satellites providing openly accessible optical satellite images with coverage of Lake Mjøsa. Note that the different satellites have varying spectral, spatial, and temporal resolutions, and different spectral bands and spectral ranges. Series of satellites – like the Landsat series – have evolved and changed payload instruments (i.e. the scientific sensors installed on the satellite) on the different satellites, and many of these satellites have multiple payload instruments. Different instruments can also have distinct acquisition modes. These factors affect data parameters like spatial, spectral and temporal resolution. The revisit frequency of a location – meaning the time from one image acquisition to another – is dependent on the satellite orbit and the instrument swath width. Additionally, optical imagers cannot image through clouds, leading to varying data availability. In general, multispectral and hyperspectral optical data can be utilized for monitoring vegetation and water quality. For more specific data parameters the reader is directed towards the sources provided in the second-to-last column in the table.

Table 5.3 shows an overview of radar satellites providing open access to data. Most of them utilize Synthetic Aperture Radar (SAR) imaging techniques. Note that the different satellites have different revisit times and spatial resolution, and different imaging modes which can affect these parameters. They also use different wavelengths for imaging, something that affects how deep they penetrate the vegetation and how high spatial resolution they can achieve. SAR satellites commonly have different acquisition modes to accommodate the trade-off between coverage and spatial resolution. The higher the coverage, the lower the spatial resolution. SAR data is generally not used for ocean color monitoring, but it is used for detection of oil spills in water. Instead, SAR is more commonly used for vegetation monitoring with use-cases such as wildfires, land subsidence, and agriculture. It can be used for GIS applications. For more specific data parameters the reader is directed towards the sources provided in the second-to-last column in the table.

Satellite name	Payload instrument type	Active	Source and more specification	Comment
Landsats 1 to 9	Multispectral	1972 -	See (NASA, n.d.) for more specifications.	Landsat 6 had a failed launch
MODIS (Terra & Aqua)	Multispectral	Terra 1999 – Aqua 2002 -	See (NASA, 2025) for more specifications	
Envisat	Multispectral	2002 – 2012	See (ESA, n.d.-b) for more specifications	Also equipped with other payload instruments
VIIRS	Multispectral	2011 -	See (NASA, 2024) for more specifications	Instrument onboard the Suomi-NPP, NOAA-20, and NOAA-21 satellites
Proba-V	Multispectral	2013 – 2020 Experimental phase from 2020 to 2021	See (ESA, n.d.-d), (ESA, n.d.-a) for more specifications	Intended for vegetation
Sentinel-2	Multispectral	2015 -	See (ESA, 2025b; Fernandez et al., 2013) for more specifications.	
Sentinel-5P	Spectrometer and SAR altimeter	2016 -	See (ESA, 2025c; Mecklenburg et al., 2017) for more specifications.	Atmospheric measurements
PACE	Hyperspectral	2024 -	See (PACE, 2025) for more specifications.	

Table 5.2: Table of optical satellites providing openly available satellite images with coverage of Lake Mjøsa

Satellite name	Payload instrument type	Active	Source and more specification	Comment
RADARSAT-1	SAR	1995 – 2013	See (NASA, 2016) for more specifications	
ALOS PALSAR	SAR	2006 – 2011	See (Earth Science Data Systems, 2024) for more specifications	Only partially covered Norway
RADARSAT-2	SAR	2007 -	See (CSA, 2021) for more specifications	
Sentinel-1	SAR	2014 -	See (ESA, 2025a) for more specifications.	
ICEYE Open Data	SAR	2018 -	See (ESA, n.d.-c) for more specifications	Restricted access to some data through ESA.
Sentinel-6	SAR altimeter	2020 -	See (ESA, n.d.-e) for more specifications.	Weather satellite

Table 5.3: Table of optical satellites providing openly available satellite images with coverage of Lake Mjøsa

Campaign dates	Goals	Data	Locations
30.11. – 03.12.2020	Mapping parts of the bed of the lake, object detection	Acoustic reflection images, positions	Between Gjøvik and Mengshol, Mjøsbrua, Totenvika
	Shipwreck inspection	RGB images, navigational data	Between Gjøvik and Nordlien, Mjøsbrua
	Ammunition inspection	Acoustic reflection images, RGB images, hyper-spectral images, navigational data	Between Gjøvik and Mengshol
22.06. – 24.06.2021	Learn about shallow water ecosystem	Water column parameters, hyper-spectral images, navigational data, acoustic reflection images	Kapp, between Gjøvik and Lillehammer
	Shipwreck inspection	Acoustic reflection images	Hamar
07.11. – 19.11.2022	Object detection	Acoustic reflection images, positions	Between Totvika, Skreia and Helgøya
	Ammunition inspection	RGB images	Between Totvika, Skreia and Helgøya
28.03. – 30.03.2023	Shipwreck inspection	RGB images	Wega, Dølen, Torgunrudvraket, Korslundvraket, Ekornholmen, Stofjordvraket
Sep 2023 –	Fish observation	acoustic signal time series of IDs	Increasing number of locations mostly along the shore
23.10. – 31.10.2024	Ammunition inspection	RGB images, hyperspectral images, acoustic reflection images, water column parameters	Between Gjøvik and Mengshol
	shipwreck inspection	RGB images	Storfjordvraket

Table 5.4: Timeline of the dedicated data collection activities of Mission Mjøsa

5.7   Mission Mjøsa data collection efforts

In addition to the research and available resources described in the previous sections, Mission Mjøsa has launched dedicated data collection activities to further explore the lake. The goals are twofold, to facilitate a comprehensive and interdisciplinary understanding of the lake and its surroundings, and to test technology that could facilitate the integration of relevant data into a single model of lake Mjøsa, a Digital Twin.

Data collection efforts directly linked to Mission Mjøsa started in 2020 (see Table 4). Most of them have focused on the detection and investigation of dumped ammunition and shipwrecks. Other campaigns are related to the investigation of ecosystems, including a long-term, ongoing data collection campaign about fish behaviour. In accordance with these goals, different areas within the lake itself have been visited (see 5.2). Similarly, various types of data were collected. The acoustic and optical images in various spectrums of the lake floor, shipwrecks, and dumped ammunition recorded between 2020 and 2023 capture the structure and appearance of the lake floor and these objects. Ongoing time series have been recording the presence of fish near multiple locations spread throughout the lake. In 2021 the characteristics of the water column have been measured, i.e., the amount of Chlorophyll, conductivity, and temperature. In addition to data connected to the specific goal of each data collection effort, navigational data was logged to capture the positions at which other data types have been collected and the movement of the sensors.

Additional data has been collected by secondary school pupils in connection with the project *"Under ei ferje over Mjøsa"*. This initiative by *Mjøsmuseet* and *Vitensenteret Innlandet,* two museums in the Mjøsaregion, brings secondary

school pupils to Lake Mjøsa to contribute to underwater archaeology, limnology, geology, and biology research, utilizing underwater remotely operated vehicles (*Under ei ferje over Mjøsa*, n.d.).
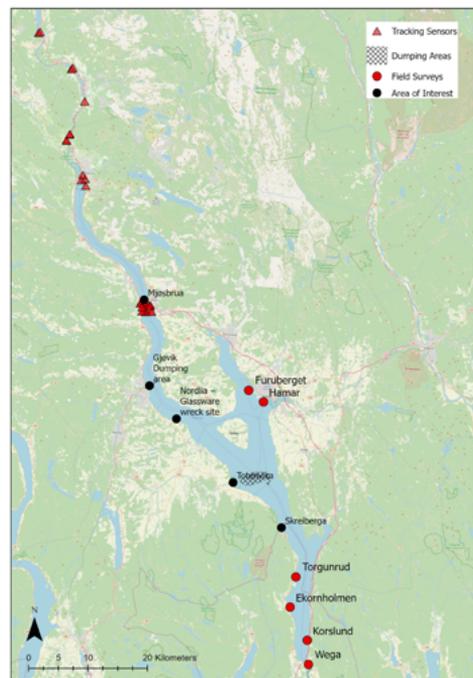
Figure 5.2: Research sites for ammunition dumping

Observational Pyramid

So far, most data collection in and about the Mjøsa region relies on the presence of humans who make decisions about the deployment of different sensors and vehicles in real-time, steer the vehicles involved, and sometimes place the sensors. At the same time, collecting and processing the data also involves various kinds of technology, i.e. software, sensors, and vehicles. The technology utilized in recent and ongoing data collection efforts in connection with Mision Mjøsa forms

a technological system for observing the lake and its surroundings, which we call the observational pyramid.

Sensors

Different sensors are utilized to record different kinds of data. Hence, they can be broadly categorized by the type of output they produce. The first category of sensors is optical cameras. They can capture colour and texture. Optical cameras are passive sensors, i.e., they only receive signals but do not send out any. Underwater, optical cameras are limited to recording close-range parts of the scene (Huy et al., 2023; McConnell et al., 2022). Optical cameras can be further differentiated by the light spectrum they detect. RGB cameras produce images showing colours in the human-visible spectrum. The images consist of pixels that each save three values, the intensities of light we perceive as red, green, and blue, respectively. The built-in camera of the Blueye ROVs (utilized in 2020, 2022, 2023, and 2024), of the Eely ROV (utilized in 2024), and GoPro cameras (utilized in 2020 and 2023) belong to this category. In contrast, hyperspectral cameras detect light from a broader spectrum, including wavelengths not visible to humans. They use additional channels (values for each pixel) to encode the amount of light across this larger spectrum.

The second category of sensors is acoustic sensors. They detect mechanical waves in a medium, some of which we can experience as sound. Underwater active acoustic sensors, i.e., acoustic sensors that both send and receive a signal, are commonly used to detect objects at a longer range than possible with optical sensors (Huy et al., 2023). Side Scan Sonars (SSS) are a type of active acoustic sensors (Huy et al., 2023). They send out arrays of acoustic pulses to both sides (Huy et al., 2023). For seabed mapping, an SSS is pulled behind a vehicle with a known
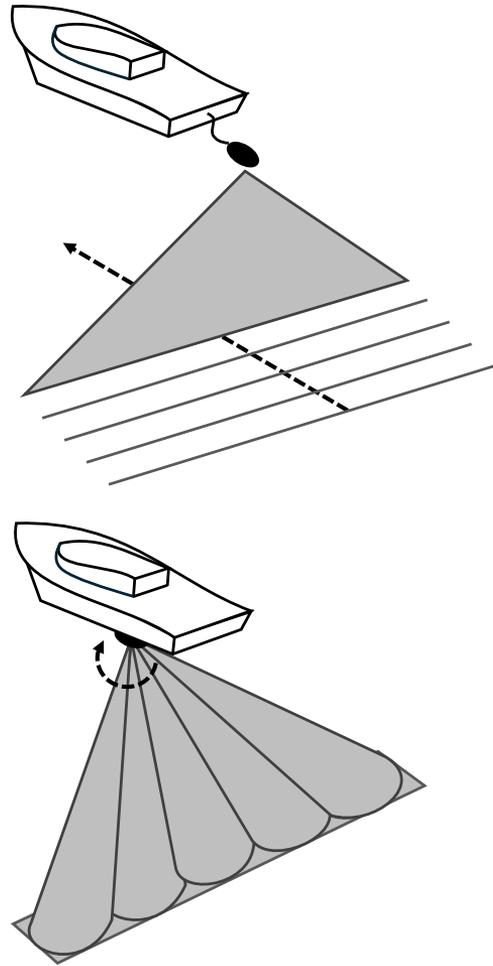
Figure 5.3: Process of imaging process of the lake floor with a Side Scan Sonar (top) and a Multibeam Echosounder (bottom), graphic adapted from Shang et al., 2019

movement pattern, and then the resulting lines of signals are stitched together into images that can cover relatively big areas of seabed (see 5.3) (Huy et al., 2023; McConnell et al., 2022). The Deep vision Sidescan Sonar utilized in 2020, and the MSRL Sidescan Sonar utilized in 2021 are SSSs. Multibeam Echosounders (MBES) are another type of active acoustic sensor. In contrast to an SSS, an MBES can steer the direction of the pulses it sends out independently of the transporting vehicle

(see Figure 5.3) (Huy et al., 2023; Shang et al., 2019). MBEs generally produce acoustic reflection images at higher resolutions but cover smaller regions (Huy et al., 2023; *Kongsberg EM 2040 Multibeam Echo Sounder Product Description*, n.d.). Kongsberg EM 2040 belongs to this second category of sonars and has been deployed to inspect the seafloor and underwater objects in 2020 and 2022.

Besides sonars, active acoustic sensors also include smaller transmitter-receiver pairs (acoustic telemetry) that can be used to track fish. The transmitters used in connection with Mission Mjøsa are used to track fish and send signals at 69 kHz. These signals encode an ID number and can be detected when the fish are within range of the receivers. To get data on fish behaviour, acoustic tags can be equipped with different sensors. In lake Mjøsa, sensors for temperature, acceleration and depth have been used. To build a time series capturing the movement of fish, the IDs and sensor data are saved together with a timestamp of their detection. In Mjøsa several receiver types (InnovaSea models VR2W and VR2AR, Telma Biotel models TBR700 and TBR 800R) have been

in use. In addition to these models, which all log data but need physical access for downloads, live stations (Thelmabiotel model TBR700 live) have also been used to allow real time detections of tracked fish to be accessed. During the period August 2023 – November 2025, nine different species (Brown trout (*Salmo trutta*), European perch (*Perca fluviatilis*), Ide (*Leuciscus idus*), European white fish (*Coregonus lavaretus*), European greyling (*Thymallus Thymallus),* Common bream (*Abramis brama*), Pike (*Esox lucius*), European smelt (*Osmerus eperlanus*) and Vendace (*Coregonus albula*)) have been tagged and tracked.

Lastly, many data collection efforts log data from the navigational systems, mostly to capture the location at which other kinds of data were collected or the movement of the vehicles involved. Navigational data can include geographical coordinates calculated from GPS (global positioning system), or information about acceleration collected via an Inertial Measurement Unit.

	Underwater	On the Lake's Surface
Autonomous	AUVs OceanScan-MST LAUV "Fridtjof": 2020 HYDROID Remus 100: 2021 OceanScan-MST LAUV "Roald": 2021 Kongsberg HUGIN HUS: 2022 Eelum 500M »Eely«: 2024	USVs Maritime Robotics Otter "Otter 2": 2021 Maritime Robotics Mariner "Ratatosk": 2022
Remotely operated	ROVs Blueye X1: 2020 Sperre Sub-Fighter 10K: 2020 Blueye X3: 2022, 2023, 2024	
Locally operated		Boats Polarcircle: 2020

Table 5.5: Vehicles utilized in the dedicated data collection efforts of Mission Mjøsa between 2020 and 2024

Vehicles

Sensors are usually mounted on vehicles that transport them to a location or object of interest. They can be categorized based on the space they operate in and the amount of human oversight necessary (see Table 5.5). Underwater vehicles are utilized to collect data by diving below the surface of the lake. They include Autonomous Underwater Vehicles (AUVs) that are programmed to explore a given region before the operation, and Remotely Operated Vehicles (ROVs) whose movement during data acquisition is controlled by a human operator in a different location. A combination of both types of underwater vehicles has been used for data collection multiple times since 2020. In addition, data from underwater has also been collected directly by human divers, e.g., with handheld optical cameras in spring 2023.

Surface vehicles navigate on the lake surface. This includes both manned surface vehicles, which are directly controlled by a human operator on board, and Unmanned Surface Vehicles (USVs), which can involve remote operation or autonomous control to varying degrees. Data collection efforts connected to Mission Mjøsa have utilized various types of surface vehicles.

Besides these vehicles, NTNU is also operating two satellites that have occasionally been used to record Mjøsa. HYPSO-1 was launched in January of 2022, and HYPSO-2 was launched in August of 2024. The satellites are equipped with a hyperspectral imaging payload. Thus, they enable data collection from above the surface of the earth, capturing information about phenomena above, on, or closely below the surface of the lake and its surroundings.

The observational pyramid as a system of systems

All these sensors and vehicles contribute to the overarching goal of exploring and monitoring Mjøsa by providing different types of data from various locations. They form the observational pyramid that can hence be considered a system of systems. A system of systems is a collection of systems that collaborate to achieve a common goal, but that are also operated and developed to each fulfil a purpose of their own, independently from the overarching system (Maier, 1998). For a system of systems to flourish, the benefits of cooperating need to outweigh the cost (Maier, 1998). This can be achieved by facilitating emergent behaviours for a shared purpose while preserving each system's autonomy, and adapting connections between the sub-systems (Boardman & Sauser, 2006). In the case of Mission Mjøsa, combining the information from different parts of the observational pyramid and using information from other sub-systems to guide further data collection can facilitate a more comprehensive understanding of Mjøsa than what could be inferred from the data collected by each sub-system alone. However, the need for human involvement at each data collection step so far limits the synergetic effects. Potentially, a tighter connection between the sub-systems, e.g., through automated communication and feedback loops, might increase the benefits of utilizing a system of systems. Constructing a digital twin is one approach to solving this challenge.

5.8   Digital Twin

The concept of Digital Twins has gained significant attention across various domains, including urban planning, manufacturing, and environmental sciences. A digital twin is a virtual representation of a physical entity that integrates real-time data, simulations, and

ID	Reference	Interpretation
1	(Digital Twin Overview | Interagency Modeling and Analysis Group, n.d.)	"A digital twin is a digital replica of a living or non-living physical entity, such as a manufacturing process, medical device, piece of medical equipment, and even a person. Utilizing sensor data, digital twins combine simulation and analytics to gain insight into present and future operational states of each physical twin."
2	(Armstrong, 2020)	"A digital twin is a virtual representation of an object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning and reasoning to help decision-making."
3	(Grieves, 2015)	"Virtual products are rich representations of products that are virtually indistinguishable from their physical counterparts.", "It contains three main parts: a) physical products in Real Space, b) virtual products in Virtual Space, and c) the connections of data and information that ties the virtual and real products together."
4	(Grieves & Vickers, 2017)	"Digital Twin is a set of virtual information constructs that fully describes a potential or actual physical manufactured product from the micro atomic level to the macro geometrical level. At its optimum, any information that could be obtained from inspecting a physical manufactured product can be obtained from its Digital Twin."
5	(Schluse et al., 2017)	"It is a virtual representation of a real world subject (person, software system,…) or a real world object (machine, component, part of the environment,…). A Digital Twin contains models of its "data" (geometry, structure,…), its functionality (data processing, behavior,…) and its communication interfaces."

Table 5.6: Different interpretations of the concept of digital representations

advanced analytics to enhance decision-making and monitoring processes. In the context of lakes and water bodies, digital twins provide a framework for real-time environmental monitoring, predictive modelling, and ecosystem management.

As climate change and anthropogenic activities increasingly impact freshwater ecosystems, digital twins can aid in mitigating risks, optimizing water resources, and ensuring sustainable environmental management. This section explores the use of digital twins for lakes, highlighting key applications, technologies, and real-world examples, with a particular focus on Lake Mjøsa..

The evolution of digital twins can be traced back to the field of astronomy where NASA in the 1960s used a similar concept called the "living model" for the Apollo mission. They employed multiple computer-aided designs (CAD) and simulations to evaluate the failures of its previous Apollo 13 mission. This digital representation of a physical model is a first of its kind, where they were initially used to model and simulate complex events that lead to accidents and explosions (Allen, 2021). Over time, the concept and scope of digital representations have expanded to encompass a wide range of applications, including manufacturing, urban planning, transportation, and environmental monitoring. With that development, many interpretations of digital representations emerged into the open world. Many of them are focused on the term "digital twin," which is the most advanced type of digital representation. Most of these interpretations are based on the manufacturing industry. Table 6 presents a few different interpretations of the concept of digital representations.

Digital representations and level of integration

This section is not specifically about Mjøsa. It is provided here for those wishing to learn more about digital twins, as it is a significant contribution of the current Mission Mjøsa work program (2022 – 2027).

Based on exploring various interpretations of the term "Digital Twin" in different contexts, the key idea of digital twins is that they are digital replicas of a physical object or system. However, depending on the level of integration between digital replica and physical object, different terms such as *'Digital Model'*, *'Digital Shadow'*, and *'Digital Twin'* are often used interchangeably (Kritzinger et al., 2018). In one extreme, digital representation is created manually and is not linked to any real-world objects, while the opposite extreme is fully integrated with bi-directional real-time data exchange. Figure 5.4 presents the different levels of data integration on digital representations.

A "digital model" is the most primitive version of digital representations, which is used to interpret an actual or potential physical entity. This model does not involve any automated data exchange between the physical entity and the digital one interchangeably (Kritzinger et al., 2018). The digital representation may contain a detailed or incomplete description of the physical entity. The available data of physical systems may still be used for the development of digital models, but all data exchange is done manually in both directions (digital entity to physical entity and physical entity to digital entity). A change in the state of the physical entity has no direct impact on the digital entity and vice versa. Digital models are being used in many geospatial data domains (Figure 5.4). In the middle ground, a "digital shadow" exists. It is based on a digital model foundation, but the physical entity to digital entity data integration is automated. Therefore, a change in the state of the physical entity changes the state of the digital representation. But not the other way around interchangeably (Kritzinger et al., 2018). Figure 4 shows some examples in geospatial domain. In most extreme cases of digital representations, it is the "digital twin". For this model, data exchange is automated in both ways. Therefore, any change in physical entity changes the state of the digital model, and the same is true for the other way around interchangeably (Kritzinger et al., 2018). Some example use cases are presented in Figure 5.5. Section 2.2 explores more of these digital representations and some example use cases for each type of representation.

In the context of spatial data management, spatial digital representations (spatial digital twins) serve as dynamic models that mirror real-world spatial object (e.g. a road, a lake etc.) or phenomena (e.g. ecosystem around a lake, environmental monitoring etc.). This integration of digital representations with existing GIS technologies involves capturing and integrating various data streams,
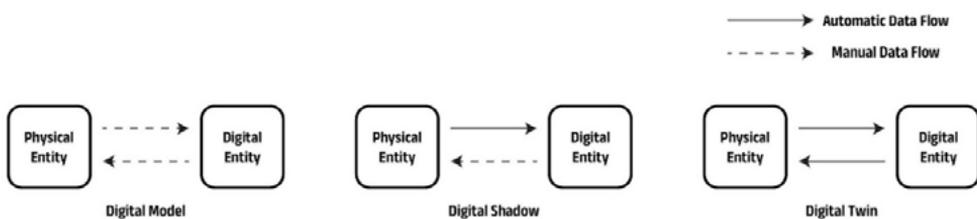

Figure 5.4:Level data integration between digital entity and physical entity

including geospatial data, sensor data, and environmental data, to create a comprehensive virtual representation for collaborative decision-making (Shahid et al., 2023). These systems enable continuous monitoring, analysis, and simulation of spatial data, allowing decision-makers to gain insights into spatial relationships, patterns, and trends in real time.

Digital Representations for Geospatial Domains

In geospatial domains, the spread of spatial data sources, such as satellite imagery, sensor networks, and geographic information systems (GIS), has highlighted the need for more efficient and scalable data management and representation solutions to support spatial decision-making. So far traditional solutions like standalone GIS applications have offered significant support for spatial decision-making. However, with steep technological advancement and big data production, traditional approaches to spatial data management and representation often face challenges related to data integration, interoperability, and real-time processing (Correia et al., 2023). The emergence of novel technologies, including machine learning (ML), artificial intelligence (AI), cloud computing, web services and technologies, and interactive visualisation tools, has opened new possibilities for addressing these challenges (Meschini et al., 2022; Saifi & Anandakumar, 2024; Tengtrairat et al., 2021).

A digital model for the geospatial domain is a digital representation of a real-world geospatial entity. It is static and doesn't interact with real-time data or updates interchangeably (Kritzinger et al., 2018). Geospatial digital models can include 3D city models to represent buildings, infrastructure, and terrain of urban environments for planning and visualisation. Moreover, topological maps

to represent terrain and land features and geological models to depict subsurface structures for resource management and exploration can be considered for digital models. For data collection and integration, digital models begin with static data from surveys, remote sensing and GIS databases. It usually performs fundamental spatial analysis and is primarily used for the visualisation of geospatial entities. It also provides fundamental information for initial decision-making processes. Example use cases are presented in Figure 5.4.

Digital shadow for the geospatial domain is an advanced digital representation that includes real-time data feeds from a real-world geospatial entity. It bridges the gap between a static model and fully interactive digital twins of the geospatial entity. This concept incorporates real-time information to reflect the actual state of the geospatial entity at a given time interchangeably (Kritzinger et al., 2018). In digital shadows, data collection and integration are usually done by incorporating Internet of Things (IoT) devices, sensors and real-time data streams to update the digital representation dynamically. For the analysis and simulations, digital shadow performs real-time monitoring and updates to reflect the current conditions of the real-world geospatial entity. Digital shadow can be used to improve situational awareness and offer reactive collaborative decision-making based on real-time data. Example use cases are presented in Figure 5.6.

Digital twins for the geospatial domain are the most advanced digital representation. These dynamic virtual systems for real-world geospatial entities continuously update with real-time data and simulate various scenarios. Therefore, the digital twins are being used not only for monitoring but also for predictive analytics and optimisation (Brucherseifer et al., 2021) . For data collection and integration

Example Use Cases for Digital Models in the Geospatial Doamin

Urban Planning

Visualizing existing infrastructure to plan new developments.

Environmental Monitoring

Creating baseline models for analyzing changes over time.

Disaster Management

Preparing models of at-risk areas to plan for potential natural disasters.

Figure 5.5: Example use cases of Digital Models in the geospatial domain

Example Use Cases for Digital Shadow in the Geospatial Doamin

Traffic Management

Integrating real-time traffic data with road networks to optimize flow and reduce congestion.

Environmental Monitoring

Using live sensor data to monitor air quality, water levels, or weather conditions.

Infrastructure Maintenance

Tracking the real-time status of critical infrastructure like bridges, pipelines, or power grids.
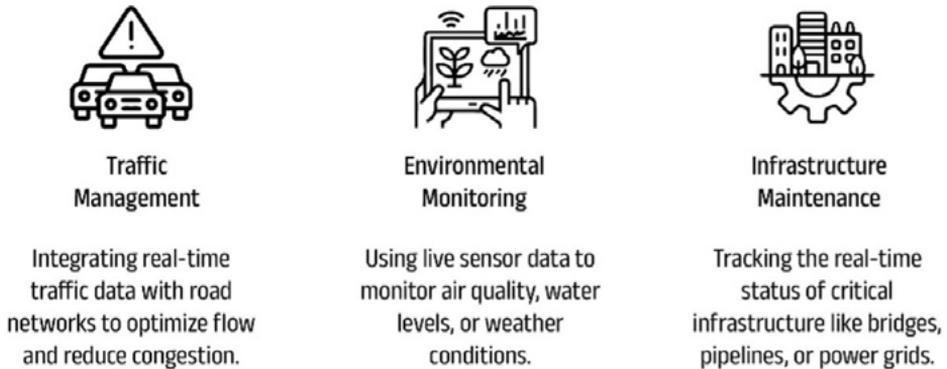
Figure 5.6 Example use cases of Digital Shadows in the geospatial domain

Example Use Cases for Digital Twins in the Geospatial Doamin

Smart Cities

Integrating various systems (traffic, utilities, emergency services) to create a cohesive and responsive urban environment.

Asset Management

Monitoring and managing the lifecycle of assets such as buildings, roads, and utilities with predictive maintenance and performance optimization.

Disaster Responses

Simulating potential disaster scenarios (earthquakes, floods) to improve preparedness and response strategies.

Figure 5.7 : Example use cases of Digital Twins in the geospatial domain.

digital twins may use integrated platforms that combine real-time data with advanced analytics, machine learning, and simulation capabilities (Dembski et al., 2020). Digital twins can be used for advanced simulations, what-if scenarios, and predictive modelling to support collaborative decision-making. Figure 5.7 presents examples of cases of digital twins in geospatial domains.

Moving forward, these integrated geospatial digital representations still lack accessibility and collaboration functionalities if they are based on standalone applications. Instead of making standalone applications, integrated geospatial digital representations can be combined with web-based technologies to unlock a set of unique features that push the boundaries of integrated geospatial digital representations even further by enhancing accessibility, interactivity, and real-time data integration on the go (Nevistić & Špoljarić, 2019).

To build these digital representations various technologies are essential. Ali et al. (2023) identified four major parts for the building spatial digital representations. Data Acquisition and Processing involves collecting and processing geospatial data from sources like satellite imagery, LiDAR, and IoT sensors. Data Modelling, Management, and Processing focuses on structuring and managing spatial data using platforms like PostgreSQL. GIS Software, Maps, and APIs integrate data with GIS tools and visualization platforms. Key Functional Components enable simulation, predictive modelling, and spatial queries, supported by AI, machine learning, and blockchain technologies (Ali et al., 2023).

Digital Twin Applications for Lakes

Digital twin applications for lakes offer advanced capabilities in environmental monitoring, modelling, and management. By integrating real-time data from sensors, satellites, and weather stations, they track key environmental parameters such as water temperature, turbidity, and dissolved oxygen, aiding in pollution detection and climate impact assessments (Chen et al., 2023). Hydrodynamic and ecological modelling helps predict lake behaviour under various conditions, including floods and droughts, while also assessing biodiversity and ecosystem health (Parasyris et al., 2024). Digital twins assist in flood risk and water level management by simulating scenarios and optimizing reservoir operations (Bartos & Kerkez, 2021). Additionally, they enhance pollution control by tracking contamination sources and enabling early warning systems. In fisheries and aquatic conservation, digital twins support sustainable management by monitoring fish migration, breeding cycles, and the impact of environmental changes on aquatic life (Føre et al., 2024; Giske et al., 2025).

Digital Twin of Lake Mjøsa, Norway

Lake Mjøsa is Norway's largest lake, covering 365 km² of land area. It is a crucial water resource for drinking, industry, fisheries, and recreation. However, pollution, climate change, and biodiversity loss pose challenges that require advanced monitoring and management strategies.

A Digital Twin for Lake Mjøsa could offer multiple ways to enhance environmental monitoring and management. One example is water quality monitoring to track seasonal changes in nutrient levels, turbidity, and pollution sources which helps to prevent eutrophication and algal

blooms. (See chapter 4 for details on various water quality monitoring schemes and programs.) Flood and hydrological modelling, which integrates meteorological data, could also be integrated into the digital twin to predict flood risks, optimize reservoir management, and support hydropower operations. Additionally, climate change impact assessment would help analyse temperature rise, water level changes, and altered hydrology, providing insights into ecosystem shifts and adaptation strategies. Lastly, fisheries management could benefit from monitoring fish population dynamics and assessing the effects of environmental changes on aquatic biodiversity, ensuring sustainable resource management in Lake Mjøsa. Landcover and land use changes of Mjøsa watershed can be analysed using remote sensing data, GIS-based modelling, and Digital Twin simulations to track near real-time urban expansion, agricultural practices, deforestation, and water body alterations over time. By integrating satellite imagery, historical land cover datasets, and real-time environmental monitoring, it is possible to assess the impacts of human activities, climate change, and policy interventions on the watershed. These insights can support sustainable land management, biodiversity conservation, flood risk assessment, and ecosystem restoration efforts around Lake Mjøsa.

Several existing data sources and research initiatives contribute to the environmental monitoring and management of Lake Mjøsa. The Norwegian Institute for Water Research (NIVA) conducts extensive water quality research, analysing pollution levels, nutrient dynamics, and ecosystem health. Hydropower and dam management is regulated by energy companies and environmental agencies, ensuring sustainable water resource utilization and flood control. Municipal water utilities play a crucial role in monitoring drinking water sources and implementing pollution control measures to maintain

water safety. Additionally, universities and research groups actively collaborate on environmental studies and the development of digital twin technologies, enhancing data-driven decision-making for watershed conservation and management.

Several geospatial and hydrological data sources provide valuable insights for monitoring land use, water resources, and environmental changes. GeoNorge, Norway's national website for map data and other location-based information in Norway, offers topographic, land cover, and administrative boundary data, supporting spatial analysis for watershed planning. Norwegian Water Resources and Energy Directorate (NVE) provides hydrological data, including water levels, river discharge, and flood risk assessments, crucial for hydropower management and climate impact studies. Kartverket, Norway's national mapping authority, supplies high-resolution terrain models, aerial imagery, and bathymetric data, aiding in land use change detection and ecosystem monitoring. Moreover, Norwegian Institute for Nature Research (NINA) is also good source of data on applied ecological research, with broad-based expertise on the genetic, population, species, ecosystem and landscape level, in terrestrial, freshwater and coastal marine environments. These data sources collectively enhance the understanding of Lake Mjøsa's watershed dynamics, supporting environmental research, flood management, and sustainable development initiatives. However, they lack integration with each other and additional data sources.

The implementation of digital twin for lake Mjøsa faces several key challenges that must be addressed to ensure their effectiveness. Data integration complexity is a major hurdle, as it requires merging diverse data sources, including IoT sensor networks, remote sensing imagery, and historical records, into a unified digital twin framework. This demands advanced

data fusion techniques and interoperability standards to ensure seamless integration. Additionally, high computational demands pose a challenge, as real-time simulations and predictive modelling require substantial processing power and storage capacity, necessitating efficient cloud computing solutions and high-performance computing infrastructures.

Another critical issue is the lack of standardized frameworks for lake digital twins. The absence of open-source, interoperable architectures hinders scalability and cross-platform compatibility, requiring the development of flexible, modular digital twin solutions. Furthermore, stakeholder collaboration remains essential for success, necessitating strong cooperation among research institutions, government agencies, local municipalities, hydropower operators, and community stakeholders. Ensuring shared access to data, defining governance structures, and aligning interests across sectors are crucial to developing a collaborative and sustainable digital twin ecosystem for lake Mjøsa management. Addressing these challenges will help unlock the full potential of digital twin of lake Mjøsa for decision support on environmental monitoring, sustainable development, and climate resilience.

Digital twins for lakes represent a transformative technology for environmental monitoring, ecosystem conservation, and sustainable water resource management. With the advancement of IoT, Artificial Intelligence (AI), and remote sensing technologies, digital twins can provide a real-time, data-driven approach to managing complex freshwater systems. Lake Mjøsa, as Norway's largest lake, offers an ideal case study for implementing a digital twin framework that integrates hydrodynamic modelling, pollution tracking, and climate adaptation strategies. Future efforts should focus on collaboration between researchers, government agencies, and

industry partners to create a robust, scalable, and actionable digital twin for sustainable lake and watershed management of the lake Mjøsa.

Other digital twin efforts and emerging technologies

To broaden the perspective on ongoing data collection and integration efforts for Lake Mjøsa, it is valuable to examine representative case studies of digital twin initiatives applied to similar environmental monitoring and management challenges. Rather than focusing broadly on technical aspects, this section highlights general implementations that offer practical insights and transferable lessons. These real-world examples demonstrate how digital twin frameworks have been used and deployed to address issues such as real-time data integration, ecosystem modelling, and decision support, key areas from which the Mission Mjøsa project can learn and adapt.

One such example is the Digital Twin of the Ocean (DTO) pilot project in Trondheim Fjord, developed as part of the EU-funded ILIAD project (Vasilijevic et al., 2024). This initiative demonstrates a federated and interoperable framework for marine environmental monitoring by integrating real-time data from surface and benthic sensors, autonomous underwater vehicles (AUVs), and other systems to track water quality and biological events. The collected data—stored in InfluxDB and accessed via APIs—is processed using AI and machine learning models, with results visualized through dashboards and interactive platforms like Unity and Cesium. Applications such as microplastic detection, algae bloom monitoring, and pollutant dispersion forecasting illustrate how DTOs can support timely decision-making. However, the need for higher-resolution models and enhanced scalability remains a key challenge. Overall, the Trondheim Fjord DTO represents a

pioneering environmental monitoring system that combines real-time data collection, AI-driven analytics, and interactive visualization, providing valuable decision-making support for policymakers, researchers, and industry stakeholders, while setting a global precedent for DTO applications in marine environments.

Similarly, a web-based digital twin platform for the Chaohu Lake Watershed in China addresses the limitations of traditional watershed models by combining real-time sensor networks, 3D geographic simulation, and interactive web technologies (Qiu et al., 2022). The platform supports dynamic data integration and spatial analysis, enabling decision-makers to manage water pollution through a suite of embedded models that assess water quality targets, pollutant loads, and reduction strategies. UAV-based terrain models, real-time dashboards, and automated alerts further enhance its utility for pollution control and watershed management.

Another notable development is the lake-oriented digital twin framework applied to Poyang Lake, China's largest freshwater body. This approach leverages IoT-based environmental sensing and high-resolution video surveillance to collect and visualize multi-dimensional lake data, including water quality, meteorology, and air pollution (Chen et al., 2023). Advanced visualization techniques such as scalar and vector field rendering, Kriging interpolation, and video fusion are used to depict hydrodynamic processes and ecological variability in real time. This comprehensive system supports conservation efforts, migratory bird tracking, and real-time monitoring, offering a scalable model for similar ecosystems.

A further illustrative example is the K-Twin SJ platform, a digital twin developed for the Sumjin River basin in Korea to support flood response and watershed

management (Park & You, 2023). This system integrates high-resolution geospatial data, facility information, and real-time hydrological inputs such as rainfall, flow rates, and water levels with AI-driven predictive models. The platform facilitates advanced decision-making through 3D visualization, flood forecasting, and optimization of dam discharge scenarios. Additional features such as geotechnical safety evaluations, drone-based infrastructure assessments, and AI-enhanced CCTV surveillance further expand its monitoring capabilities. By linking hydraulic and hydrological simulation models, K-Twin SJ provides a comprehensive solution for data-driven, real-time management of water resources and flood risks.

Varsom.no is an online platform to share natural hazards warnings. It is Norway's national warning service for natural hazards, delivering alerts and information on floods, landslides, avalanches, droughts, and hazardous weather from the Norwegian Meteorological Institute (MET). Managed by the Norwegian Water Resources and Energy Directorate (NVE) in cooperation with MET, the platform offers detailed warnings, maps, and data through its website and mobile app, supporting informed safety decisions.

Together, these examples demonstrate the diverse technological approaches and digital infrastructure required for building effective lake digital twins. Each case illustrates methods for overcoming challenges such as fragmented data sources, real-time integration, and complex environmental interactions challenges that are equally relevant to the ongoing Mission Mjøsa project. By synthesizing lessons learned from these implementations, future development of Mjøsa's digital twin can adopt proven technologies and design strategies that enhance interoperability, visualization, and collaborative decision-making.

Emerging technologies to improve 3D visualization

3D interfaces for digital twins of lakes rely on the availability of 3D representations. One way to produce such representations is image-based 3D reconstruction methods. These methods merge multiple 2D pictures of an object or scene into a single 3D model (Dalal et al., 2024). Recent machine learning-based novel view synthesis methods, especially 3D Gaussian Splatting, extend on previous approaches to 3D reconstruction by learning a combined representation of both the geometry of the scene and its appearance (its colour and texture). This enables them to directly produce photorealistic images of the scenes from new perspectives (Dalal et al., 2024).

However, recording underwater changes the appearance of images. Images of underwater scenes suffer from low visibility, a colour shift towards green/blue, and blurriness (Skarlatos & Agrafiotis, 2020). The challenges of underwater image collection and adapting imaging processing technology to the shifts in appearance have not yet been fully solved but there has been considerable progress. A key step towards successfully handling colour shifts and haze has been the introduction of a revised underwater image formation model (Akkaynak & Treibitz, 2018). It describes how different components of the optical signal, specifically the light directly reflected by an object towards the camera and the light scattered by the medium, form the recorded image (Akkaynak & Treibitz, 2018). In contrast to previous models, it considers the attenuation coefficients that describe the strength of each of these signals to be independent parameters (Akkaynak & Treibitz, 2018). This revised model has led to multiple specialized image processing methods for underwater scenes. This includes an image enhancement method (Akkaynak & Treibitz, 2018) as well as a machine learning novel view synthesis

method (Levy et al., 2023) that manage to remove a considerable part of the colour shifts and haze caused by the surrounding water. Eventually, further improvement in this domain might enable the generation of truly photorealistic 3D displays of underwater scenes.

5.9 Summary

Extensive data collection efforts have been conducted on Lake Mjøsa to monitor pollution, ecological changes, and climate impacts. Early studies in the 1970s focused on eutrophication, identifying phosphorus pollution as the main cause and leading to the Mjøsa Campaign, which improved wastewater treatment and reduced nutrient inputs. Subsequent research examined metal contamination in fish, underwater mass movements, and sediment accumulation using advanced bathymetric and geochemical analysis. Long-term monitoring programs have tracked water quality trends, algal biomass, and rising water temperatures. Recent initiatives include fluorine mass balance analysis, paleontological studies of Cambrian fossils. Moving forward, promising initiatives include to use of digital twin modelling to integrate environmental data for sustainable lake management. Satellite imagery, IoT sensors, and hydrodynamic modelling further enhance real-time monitoring and predictive analytics for sustainable water resource management. In addition, advancements in image enhancement and 3D reconstruction might provide a highly detailed 3D model of the environment and facilitate intuitive user interfaces for displaying the collected data. These collective efforts provide a comprehensive understanding of Mjøsa's environmental status and support evidence-based decision-making.

Chapter 6: Synthesis

Elizabeth Barron and Preema Ranjitkar with contributions by Joni Storie and Chris Storie

6.1   Executive Summary

Chapter one laid out a set of policy relevant questions related to cross-cutting topics and themes of great interest addressed throughout the report: demographic shift, water pollution, climate change, sustainable development, and multi-scalar governance. We address these questions here and identify others as knowledge gaps for future research.

With regards to water management and pollution, it is outside the scope of this assessment to draw any conclusions about the implications of water contamination and pollution mitigation on drinking water and recreational fishing as this is an active area of research, however it is clear that there are effects. As drinking water is a critical resource and recreational fishing contributes to the cultural and social fabric of Mjøsa, it follows that when these things are threatened the topic of pollution and contaminant mitigation take on heightened significance for both the public and public agencies. Critical questions in this regard are how and when the public becomes aware of pollution, how they have been informed (e.g. from media or the government), and how they understand the material that is communicated about the topic. The effectivity of public outreach and communication could be an active area of future research.

Climate change is one of the most pressing issues globally and in Norway. The area around Lake Mjøsa will be affected primarily by increasing variability in rainfall events, rising temperatures and precipitation levels, and increased risk of flooding and erosion events. There is a significant amount of material available for urban and rural planning in the short and long term, and this is an area of considerable research effort and outreach for the Norwegian government climate and environmental agencies. The main issue here seems to be at the user interface, and this is receiving a lot of attention.

In terms of the UN Sustainability Development Goals, there are several efforts underway in Innlandet county to contribute to and educate the public about how to achieve the SDGs. Like with climate change, it could be said that the key tension point is not a lack of information, but a lack of public awareness and uptake about the topic. This suggests that a central element of planning should be assessing how to balance the need for regulatory frames that force the public into systems of management that align with meeting goals, or if these systems should continue to be primarily voluntary.

6.2   Water management

Managing the lake involves balancing competing interests and making trade-offs. Available reports and research highlight different ways that Lake Mjøsa is used, ranging from provisioning drinking water and receiving wastewater to producing hydroelectric power and supporting recreational fishing. Some of these uses are in conflict, for instance, the need to protect water quality for

drinking water purposes is challenged by wastewater inputs, and hydroelectric operations can create negative ecosystem impacts on fish populations popular for recreational fishing. Managing the lake therefore requires balancing competing interests and making trade-offs that do not compromise environmental sustainability, community needs, or long-term resource protection. We identify this as a scalar governance issue, discussed in more detail in section 6.5.

As noted in Chapter three and four, anthropogenic pressures on Lake Mjøsa are increasing. Agricultural intensification and even relatively minimal deforestation have resulted in increased runoff, ongoing buildup of microplastics, sewage leaks, and contaminants from traffic running into the lake and its tributaries. Microplastics especially are likely highly under-reported, and they pose significant threats to both ecosystem and human health by accumulating in the food web.

Our review suggests that there is ample information available, but that it remains somewhat siloed and with variable accessibility. As noted in Chapter five, research on these topics is ongoing in Lake Mjøsa, which will inform evidence-based decision-making if it is available, easily locatable, and understandable. However, consideration and balancing of research results and addressing them through integrated water management approaches that combine regulations, monitoring and infrastructure investment is easier said than done. As Nilsen et al. (2022) point out for climate change, products and research need to be designed with the end users in mind, if not in collaboration with them, to increase the production of user-friendly and useable knowledge.

6.3 Planning for climate change

Climate adaptation nationwide in Norway is organized into four areas of concern: (1) water, (2) nature, land use and cultural heritage, (3) civil protection in a changed climate, and (4) holistic management. Nilsen et al. (2022) present a thorough and informative overview of climate reporting, planning, and engaging with stakeholders. Key messages from the paper are presented here; we refer readers to the complete paper for more details. One of their main points is the importance of working with diverse stakeholders and the intended users for various climate information products to ensure that the information presented is accessible and of interest to the proposed audiences.

The information developed at NCCS reports primary challenges to infrastructure related to extreme weather events, which will become more frequent in the coming decades (Nilsen et al. 2022). NCCS has prepared tools for use in Norway for infrastructural and building planning for climate-related challenges such as heavy precipitation, increased flooding, and storm surges. Nilsen et al. (2022) present a translation of Hamarsland's (2015) principles for climate change adaptation in Norway. These principles are crucial to consider for future spatial and urban planning in the Mjøsa region.

- i) Buildings and infrastructure with short lifespan (10-20 years) are to be designed on the basis of the current climate

- ii) Buildings and infrastructure with a long lifespan are either built to withstand projected climate change or designed based on the current climate, but which are also suitable for reinforcement at a later date.

- iii) Measures should be climate-resilient, that is, they should function as intended even if the climate develops differently from what is projected.

- iv) Climate adaptations contributing to achieving several goals are considered win-win adaptations and should be given high priority.

In the Mjøsa region, Hamar was identified by the Norwegian Environmental Agency to participate in the "I Front: Kommunenettverk for klimatilpasning" (Miljødirektoratet, 2025b) program, a municipal network for climate change adaptation. Two of the focus areas have been to support the installation of green roofs and the preservation of cultural heritage sites in the 13 cities participating in the program. This network, and others like it, represent a key way in which public agencies and researchers are working directly with users of climate data and reports. Another example is a series of collaborative participatory workshops, called Klimathons, that were held across the country in the late 2010s which facilitated the inclusion of local knowledge about climate change into maps and other various formats. These were integrated into existing web resources to support public outreach and accessibility to climate-related information and to address needs identified by user groups. These sorts of websites and resources are critical because despite an abundance of information and tools many users including municipalities and county planners, "do not know where to begin reading". This issue is made worse in the Mjøsa region by a lack of coordination amongst users divided across so many counties and municipalities (Table 1.1).

For more detailed information regarding climate conditions, risks, and possible hazards in the Mjøsa region readers are directed to the following web portals and learning networks:

- http://senorge.no for general information

- http://temakart.nve.no for general information

- https://www.miljodirektoratet. no/ansvarsomrader/klima/for- myndigheter/klimatilpasning/ om-klimatilpasningsarbeidet/ StorbynettverketIfront/ on how Hamar is participating in the iFront climate adaptation network organized by the Norwegian Environment Agency

6.4   Sustainable development goals, public and areal planning

Norway has mobilized extensive resources and planning on the UN Sustainable Development Goals (SDGs) through the United Nations Association Norway (FN-Sambandet), all sections of government, large-scale support services such as KS, an independent organization that supports government initiatives, and an active research community at universities and research institutes across the country. The government has documents, statistics and other resources about the SDGs available online in Norwegian and English dating back several years (c.f. https:// www.regjeringen.no/no/tema/fns- barekraftsmal/om-barekraftmal).

Innlandet county has a stated intention to contribute to meeting the SDGs by collaborating with Statistics Norway and KS, and by following their "taxonomy" to measure the county's efforts (Figure 6.1). The taxonomy is a tool that allows users to systematize indicators to support measurement and tracking efforts and support local participation. It is distinct from the EU taxonomy for sustainable finance.

Following from national aims and goals, Innlandet Co. has developed its own strategy, anchored with residents, inclusion, innovation, and infrastructure and stated as follows:

1. Sustainable resource management that provides development and new jobs

2. Vibrant local communities with sustainable cities, towns, and villages

3. That actors in our county gain greater national importance and visibility.

There is not scope in this assessment to review the entire strategy, which is further integrated with regional planning for safety, climate, energy and environment, and regional promotion, and is available in its entirety from the county. With regards to the question laid out in Chapter one, it is clear even from this brief overview that Innlandet Co., like so many others, has a complex set of goals to which it must attend in order to meet the demands and aims of many stakeholders at national, county, and municipal levels. Futhermore, these goals and aims are often in tension, or even direct conflict, with each other such that planning for economic development, societal changes, resource management and environmental protection is gridlocked. Below we provide an example of some of the tensions around forest management as an indicator of the many intersecting and complex variables that come into play with regards to one resource, forests. The example of forests is used because they are a major presence on the land area surrounding the lake, and demonstrate the complexity of choices that must be made to determine what is meant by sustainability – sustainable for what purpose? Sustainable for whom?

Forests have many important functions related to climate including influence on water balance and local climatic conditions. The world's forest ecosystems also represent considerable stores of

carbon that can impact global warming if the carbon is emitted into the atmosphere. On the other hand, growing stocks are important carbon sinks that can reduce the impact of man-made emissions of CO_2. Through photosynthesis the world's forests are, for the time being, capturing and storing carbon equivalent to 25 % of the total man-made emissions of greenhouse gases. As less than half of the increment in Norwegian forests is harvested today, it is possible to increase the use of wood for production of energy and as building materials to reduce the consumption of oil, coal and gas. This can contribute to a reduction of emissions in accordance with the terms set out by the IPCC to avoid a rise in temperature of more than two degrees (det norske skogselskapet, 2011) (Norwegian Forest Policy Brochure, 2011; accessed 19Sept2024, brosjyre_norsk_skogpolitikk_2011_engelsk.pdf from https://www.regjeringen.no/).

With regards to ecosystem services (a popular accounting method for nature valuation used for SDG indicators), forest management in Norway has largely favoured provisioning services (e.g., timber and bioenergy) at the expense of supporting services and some cultural and regulating services (e.g., recreational use) (Helseth et al., 2022). While Norwegian forests retain a strong capacity to deliver provisioning services, the overall ecological condition is relatively poor. The total forest biomass in Norway has tripled over the past century, and the forest area has increased by around 10%. However, this growth has been accompanied by fragmentation and changes in forest functions, leading to a decline in habitats for species and other ecological values. Halseth et al. (2022) argue that growth in forest area and biomass are insufficient indicators for sustainable forest management. Future forest policies would benefit from improved knowledge on forests' ecological condition, resilience
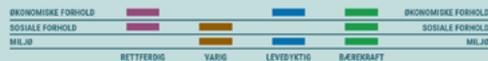
Figure 6.1: KS taxonomy for classification of indicators to meet SDGs (downloaded from ks.no 20 November 2025; www. ks.no/fagomrader/barekraftsmalene)

against climate change, and socio-cultural contributions to human well-being.

Aasetre & Bele (2009) present an historical review of forest management in Nord-Trøndelag (not in Lake Mjøsa region), and emphasize the need for an interdisciplinary approach combining historical records, biological data, and local knowledge to understand the shifting logging regimes and their ecological impacts. With almost half of the landscape identified as forest, the relationship between Community Forest Management (CFM, an established concept that encapsulates the idea of almennings management) with REDD+ is seen as an approach that can bridge the regional to national scale of CFM policy decision-making (Hajjar & Oldekop, 2018). CFM has been promoted worldwide to conserve forests, recognize community rights, and improve local livelihoods (Hajjar & Oldekop, 2018). Although the primary objective of REDD+ is climate change mitigation, it has also received considerable attention for its potential 'co-benefits', including socio-economic development through monetization of standing forests by retaining and enhancing forest carbon stocks, while also delivering co-benefits such as improved livelihoods and biodiversity conservation (Hajjar & Oldekop, 2018).

In Norway land use change, resulting in habitat conversion, is the most important factor and driver to both species and habitat biodiversity loss (Bevanger, 2018). Ecosystems and habitat types are not well defined and recognizable entities like an animal or a plant species. The ecosystem services connected to freshwater are subject to several conflicting interests, particularly because of their potential value as hydropower sources. The major threats against these ecosystem types can relate to cultural traditions, as well as fertilization, cultivation, forestation and infrastructure development and dismantling. While seen as threats to the

ecosystem, many of these practices will be necessary to meet various parts of Innlandet county's SDG plan, for example infrastructural development and support for cultural traditions.

Using data from the Norwegian national forest inventory (NFI), Vergarechea et al. (2023) simulated the development of Norwegian forests under different management regimes and defined different forest policy scenarios, according to the most relevant forest policies in Norway: national forest policy (NFS), biodiversity policy (BIOS), and bioeconomy policy (BIES). The results for all scenarios indicated that Norway will be able to satisfy wood demands of up to 17 million m3 by 2093. Vergarechea et al. (2023) observed that BIES and NFS resulted in very similar forest management programs in Norway, with a dominance of extensive management regimes. In BIOS there was an increase of set aside areas and continuous cover forestry, which made it more compatible with biodiversity indicators. They also found multiple synergies and trade-offs between the forest ecosystem services (FES), likely influenced by the definition of the policy targets at the national scale. These national and international scenarios and modelling are highly relevant with regards to how local governance responds to national priority-setting and implementation.

6.5   Issues with multi-scalar governance between the physical environment and jurisdictional boundaries

Scalar mismatch is a widely recognized issue in the scholarship on natural resource management and governance. Scalar mismatch refers to the misalignment between biophysical scales at which the environmental system operates and the institutional or governance scale at which management decisions are made (Cash et al., 2006). This concept is particularly pronounced in the case of water management where hydrological systems such as watersheds often extend beyond the administrative and political units that are meant to manage them (Moss & Newig, 2010). Scalar mismatches can contribute to a decrease in social-ecological resilience, the mismanagement of ecosystems, create a greater pressure on natural resources (Cumming et al., 2006), and affect societal well-being and livelihoods (Welsh et al., 2020). Our review suggests a possible mismatch between the scales used to understand ecological systems and their management in Lake Mjøsa region.

Throughout the document, particularly in chapters two and three, Lake Mjøsa is defined by the seven municipalities that surround the lake: Eidsvoll, Østre Toten, Gjøvik, Lillehammer, Ringsaker, Hamar, and Stange. Chapter three explains how local governance decisions are made within the jurisdictional boundaries of these municipalities. In contrast, chapter four adopts an ecological perspective of Lake Mjøsa viewing the lake not as an entity defined by municipal boundaries but as a larger watershed system. The Mjøsa

watershed includes inflows, catchment areas, and ecological processes than span 20 municipalities (Vassdragsforbundet for Mjøsa med tilløpselver, n.d.). It recognizes that biological life, pollutants and nutrients entering the lake originate from and impact areas beyond the seven lakeside municipalities.

This juxtaposition reveals a scalar mismatch in the management of Lake Mjøsa: while ecological processes occur at the scale of the lake and its watershed, key decisions are made in a fragmented manner by seven separate municipalities, misaligning governance with ecological realities. Furthermore, chapter two describes the fluidity of administrative boundaries over time. While this may seem like an historical point, the county boundaries for the entire country were significantly re-drawn as recently as 2020, with lasting effects on a range of services. With regards to water management, despite the adoption of the European Union Water Framework Directive's efforts to re-scale and match ecological units to administrative boundaries, our review suggests that management arrangements and decisions continue to be largely determined by individual municipalities, which while collaborating together, remain autonomous decision-making authorities. This has the potential to create and further disrupt fragmented lake management that does not fully align with the biophysical reality of the lake system.

Despite problems identified as results of scalar mismatch, scholars do not advise revising formal governance boundaries to match the biophysical scale (Welsh et al., 2020). Rather, there are several suggestions to address scalar mismatches: collaborations across different institutions, co-management of natural resources in terms of power and responsibility sharing between governments and local community, and the creation of "bridging organizations" which act as intermediaries between different arenas, levels, or

scales to facilitate the co-production of knowledge (Cash et al., 2006). Chapter three identifies institutions that could be identified bridging organizations in the Mjøsa region. More research is needed to analyse how well the scalar mismatch is neutralized by these organizations.

6.6 Knowledge gaps and research needs

The history of Lake Mjøsa and its surroundings are well documented in archival documents, public and historical documents, personal stories and museums. Most of this material is in Norwegian, with some in German, Swedish, and English. However, we were unable to locate any sort of comprehensive text such as a "History of the Mjøsregionen" or a "History of Innlandet". Producing some sort of text along these lines could be a valuable contribution.

The biophysical environment of Lake Mjøsa, its surroundings and climate conditions are overall well studied and monitored. While the assessment cannot claim to be completely comprehensive, it is clear that there is a wealth of knowledge and information available in Norwegian and some in English. Furthermore, history, biology, ecology, and climate all continue to be areas of great interest and active research. Based on our review, immediate and future research needs and knowledge gaps in these areas include:

1. A need for more detailed and accessible information on ammunition contamination of the water supply in the Lake Mjøsa watershed, with a special focus on the lake and downstream into the Oslo Fjørd.

2. A need for closer monitoring and information regarding pharmaceuticals contamination in the Lake Mjøsa watershed, with a special focus on the lake and downstream into the Oslo Fjørd.

3. Adaptation of early warning systems and natural hazard monitoring (including flood management) to adapt to future climate conditions.

4. For evaluation of freshwater systems, a need for better representation of indicators sensitive to hydropower regulation, changing climate and alien species (Jakobsson & Pedersen, 2020), and a related need for better coordination and cooperation between the reporting schemes (Sandvik, 2019). These would further support and enhance the existing two national means of evaluating biological diversity and ecosystem trends in freshwater systems in Norway, Vannforskriften (Miljødirektoratet, 2025a) and the Nature Index for Norway (Miljødirektoratet, n.d.-f).

5. Consideration of forest quality, with regards especially to ecological system integrity, habitat fragmentation, and species complex resilience against climate change. How these ecological dimensions affect the socio-cultural contributions of forests to human well-being is also an active area of interest.

Chapter five explores a wide range of technology used to better understand Mjøsa and its surroundings. While this is clearly a cutting edge for research, there are some specific needs with regards to the technology-society interface:

1. Querying the most appropriate and productive uses of technology for desired outcomes.

2. Consideration of data availability with regards to standardizing protocols for downloading large datasets, securing long-term availability and access of data

3. Attention to the future viability of systems with regards to server capacity, data management, and rapidly changing

technologies related to artificial intelligence (AI).

While there is a fair bit of baseline information regarding the social, cultural, and political dimensions of life in and around Lake Mjøsa, the team found a limited amount of research in these areas, which could be used to inform decision-making. Based on our review, immediate and future research needs include:

1. More in-depth consideration of the role of shifting demographics in future land management and development. This was one of the policy questions identified in chapter one that we were unable to answer satisfactorily, for while there is ample information on the actual demographics, there is little to no analysis of the meaning, significance and thoughtful ways to address these shifts that maintain personal dignity, egalitarian benefit sharing, respect for changing culture, and guidance for living in a rapidly changing socio-ecological environment.

2. The review reveals a notable lack in knowledge about the significance

of Mjøsa and its aspects for private and collective goods such as identity, cohesion, and wellbeing. This leaves decision makers poorly equipped to assess if policies and projects risk diminishing Lake Mjøsa's ability to provide these immaterial values.

3. There are few participatory arenas that exist for decision-making on forests, where local people, especially non-forest owners, can have an active role in forest governance. Meeting SDG goals will require the balancing of these values through empowering underrepresented groups (i.e., women, smallholders, and non-forest owners) in forest policy decision-making.

4. While there is significant funding and information available on how Innlandet county and various communities are taking up the call to meet SDG targets and goals, there is a lack of research on the possible effects of enacting conflicting measures, how the SDGs are communicated to the public, and how success is determined by whom and for whom. Given the resources and focus on the SDGs across Norway,

Figure 6.2: Lake Mjøsa shoreline. Photo Credit: Jan Tore Bern.

this is identified as an immediate need with social, environmental, and justice implications.

It is clear that Lake Mjøsa has a deep significance for the people of Mjøsa region. However, this significant relationship between the lake and its people, and the non-extractive value of the lake, is under-researched and missing in the academic and white literature. While it is possible to access some of this through the creative arts, one might ask how that cultural meaning and significance is being promoted and protected and if this is an area for greater participatory research and active interventions. How might research programs, for example, simultaneously engage with concerns regarding an aging population, growing threats from increasing pollution, and Mjøsa's ability to provide immaterial cultural, aesthetic, and spiritual values?

What ties many of these knowledge gaps together is the looming question of a need for a new Mjøsa Campaign, which has begun to be discussed in recent years. The parameters of this campaign are unclear, however, given the complexities of the demands on the lake system and its inhabitants. One possible outcome of the current Mission Mjøsa work program may be further insights into the need for a new campaign, and an outline of its possible parameters.

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Appendix 1: Norwegian to English translations used in the assessment

Norwegian

English translation

Norsk	English
Fiskerkapellet	The Fishermen's chapel
flomfarekart/flomsonekart	flood zone maps
Føringsbåter	Cargo boats
Hovedbanen	The Trunk Line
Hamarkrøniken	The Hamar Chronicle
Kjøpstad	Marked town
klimapåslag	climate safety margin
Lågasild	Vendace
Lagsogn	Thing district
Mattilsynet	Norwegian Food Safety Authority
Meteorologisk institutt	Norwegian Meteorological Institute
Miljødirektoratet	Norwegian Environment Agency
Mjøskastellet	The Mjøsa citadel
Mjøsormen	The Serpent of Lake Mjøsa
Norsk Klimaservicesenter	Norwegian Centre for Climate Services
Noregs vassdrags- og energidirektorat	Norwegian Water Resources and Energy Directorate
Vannregion	River Basin District
Vannområde	Sub-River Basin District
Åkerkomplekset	The Åker complex / the Åkerfind complex

Appendix 2: Glossary of acronyms, abbreviations, key programs and organizations, and technical specifications

Institutions

NIBIO: Norwegian Institute of Bioeconomy Research

NILU: Norwegian research institute with focus on air pollution

NINA: Norwegian Institute for Nature Research

NIVA: Norwegian Institute for Water Research

Organizations

Vassdragsforbundet: Vassdragsforbundet for Mjøsa med tilløpselver: "Ideell forening" ...

Programs

EU Water Framework Directive: setting out rules to halt deterioration in the status of EU water bodies and achieve good status for Europe's rivers, lakes and groundwater (*Water Framework Directive - European Commission*, 2025).

MIKRONOR: *Overvåkning av mikroplast i det norske miljø* – Monitoring of microplastics in the Norwegian environment

MILFERSK: *Miljøgifter i ferskvann* – Monitoring of environmental contaminants in freshwater food webs.

ØKOSTOR: *Basisovervåkning av store innsjøer* – Surveillance monitoring of large Norwegian lakes.

REGFINN: *Regulering og fisk i Innlandet* – Hydropower regulations and fish in Innlandet.

Definitions

Benthic: On or in the bottom sediments.

Biomagnify: Increasing concentration with higher trophic levels.

Cyanomax: Maximum biovolume of cyanobacteria in mg/l

Epibenthic: On top of or close to the bottom.

Eutrophication: Increased primary production (i.e. phytoplankton, algae and plant growth) in aquatic systems because of increased nutrient load.

Litoral: Close to the shore.

Nordic multi-mesh survey nets: Nordiske oversiktsgarn: Gill nets with mixed mesh sizes used for fish surveying.

Pelagic: In open waters.

Phytoplankton: Photosynthesizing organisms suspended in the water column, following the water current, not capable of large-scale movements.

Secchi-depth: Measurement of water transparency.

Vannområde: An administrative division for the management of water and waterways

Vannforskriften: Innføring av EU's vanndirektiv.

Zooplankton: Animals suspended in the water column, following the water current, not capable of large-scale movements.

Acronyms

AIP: Acidification Index Periphyton. An indicator for acidification.

ASPT: Average Score Per Taxon. An index based on the presence of families of macro invertebrates. An indicator for eutrophication.

CPUE: Catch – per unit effort

DDTs: Dichlorodiphenyltrichloroethanes

EQR: Ecological Quality Ratio. Deviation from reference conditions.

EQS: Environmental Quality Standard – Concentration limits for pollutants.

FDOM: Fluorescent Dissolved Organic Matter

PAH: Polycyclic aromatic hydrocarbon.

PBDEs: Polybrominated diphenyl ethers

PCBs: Polychlorinated biphenyls

PIT: Periphyton Index of Trophic Status. An index based on the presence of taxa of benthic algae. An indicator for eutrophication.

POPs: Persistent organic pollutants

PFAS: Per- and polyfluorinated alkyl substances

RAMI: River Acidifcation Macroinvertebrate Index. An indicator for acidification

WS-FBI: Weighted Stratified Fish Biomass Index. Eutrophication index based on fish biomass

Tot-P: Total Phosphorous. An indicator for eutrophication

Appendix 3: Mjøsa Land Use Land Cover Change

Numerical Values for Map generation in Figures 4.4 – 4.6
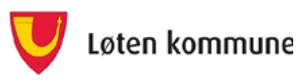
Table 1: Percent Cover 2024

Category	Percent of Total
Water	6.71
Trees	51.53
Grass	5.41
Flooded Vegetation	0.17
Crops	2.92
Shrub and Scrub	21.68
Built	1.52
Bare	4.43
Snow and Ice	5.63

Table 2: Percent Cover 2019

Category	Percent of Total
Water	6.10
Trees	53.72
Grass	4.84
Flooded Vegetation	0.16
Crops	3.59
Shrub and Scrub	18.54
Built	1.65
Bare	4.25
Snow and Ice	7.12

**Table 3: Total Change in Forests Over
5-year Period**

Category	Percent Cover
Forest Cover in 2019	53.72
Forest Cover in 2024	51.53
Net Loss	2.19 (or ~80.15 sq km)

Innlandet fylkeskommune

EIDSVOLL KOMMUNE

Østre Toten kommune

GJØVIK KOMMUNE

LILLEHAMMER KOMMUNE

Ringsaker kommune

Hamar kommune

Løten kommune

Stange kommune

NTNU Samfunnsforskning

MJØSMUSEET

ANNO Museene i Hedmark

FFI Forsvarets forskningsinstitutt
Norwegian Defence Research Establishment

OceanFront an eSEA Group Company

iNN Høgskolen i Innlandet

NIVA Norsk institutt for vannforskning

VITENSENTERET INNLANDET

NINA Norsk institutt for naturforskning

Norsk skogmuseum ANNO Museene i Hedmark

ARKIVVERKET

NORGES GEOLOGISKE UNDERSØKELSE – NGU –

Hias

Kartverket

NVE

Hafslund Eco

VASSDRAGSFORBUNDET for Mjøsa med tilløpselver

NTNU

MISSION
MJØSA

Mission Mjøsa is a cooperation between NTNU, Innlandet Fylkeskommune, eight municipalities in the Mjøsregion and a number of collaborators. Mission Mjøsa is intended to serve as a tool for both facilitating value creation, water quality, and food security, as well as maintaining the environmental values of Mjøsa.