Title:

Diatoms as proxies for recent (0-20 years) environmental change as recorded in Inner Nærøyfjord sediments, Western Norway

An Honours thesis submitted to Carl von Ossietzky Universität Oldenburg and Høgskulen på Vestlandet (Western Norway University of Applied Sciences) in fulfillment of the requirements for the degree of Bachelor of Science in Biology.

Supervisor from Western Norway University of Applied Sciences (Sogndal):
Prof. Dr. Matthias Paetzel

Supervisor from Carl von Ossietzky Universität (Oldenburg):
Dr. Wilko Ahlrichs

submitted by: Nele Schewe
Gaststraße 11
26122 Oldenburg
+49 176 97635324
E-Mail: nele.schewe@uni-oldenburg.de

Date of submission: 26.04.2022

Abstract

Three sediment cores, retrieved at three different stations in the inner Nærøyfjord, Western Norway, are analysed for their diatom assemblage. The dating of the cores is based on the distribution of coarse silt, the occurrence of freshwater diatoms, and precipitation data. The sediments of these cores are dated to have been deposited over a period of 13 years from 2008 to 2021. Based on the dating, the calculated sedimentation rate for the inner Nærøyfjord is approximately ±1cm/year.

Several changes in the distribution of the diatoms in the sediment layers can be observed. The majority of diatom peaks matches the recorded precipitation peaks. Besides variations due to differences in freshwater diatom supply, a constant decrease of freshwater diatoms is recorded at the station in the Basin since 2015. This can be connected to effects of climate change in the Nærøyfjord region. A steady increase of marine benthic diatoms at the sampling station in the Basin since 2016 indicates an improvement towards less near-shore erosion caused by ships. Less benthic erosion favours the growth of marine benthic diatoms. Generally low numbers of marine benthic diatoms close to the quay of the harbour at Gudvangen are interpreted as a sign of deteriorating growing conditions due to turbulences and the deposition of mined Anorthosite during its loading on cargo ships.

It is possible to use diatoms to detect ongoing environmental change as recorded in Inner Nærøyfjord sediments. The status as proxies for environmental change is partly restricted by the determination to genus level instead of species level, which would narrow down possible sources for occurring changes in the distribution of diatoms in the sediments.

Acknowledgements

Many thanks to my supervisor in Norway, Matthias Paetzel, who invested a lot of time, effort, and patience in guiding me from the fieldwork, through the laboratory work and the writing of this thesis. In terms of his tremendous commitment, he helped me with the translation of Norwegian texts, help with the determination of the diatoms only seconds after my request and taught me how science works. I have learned a lot from you during the process of creating this thesis and I am really grateful for your never-ending encouraging attitude towards me. I would also like to thank Katharina Schmidt, my laboratory partner, who soon became more than just a working partner. Without you, many hours in mornings, evenings and weekends in the laboratory would not have been as fine and excited as they finally were. I also thank all students of "From Mountain to Fjord" 2021 for collecting and analysing data that I could use for this study. A sincere thank you goes to my German supervisor Wilko Ahlrichs for the uncomplicated handling of all formalities.

Table of content

List of figures

List of tables

Glossary

This glossary lists an explanation of terms that are not fully explained in the respective chapter (for the purpose of clarity). Corresponding terms in the main text are marked with an asterisk (*).

Climate change

A long-term natural or human caused shift in weather or temperatures on the earth. It is mostly, but not exclusively associated with anthropogenic influenced climate warming that modifies the amount and distribution of precipitation (Hauck et al., 2019).

Convergent evolution

The development of similar features in unrelated species, caused by adaptions to similar environmental conditions or functional needs (Sadava et al., 2019).

Environmental change

Long- or short-term transformation of parameters and characteristics in any environment. Environmental change can be caused by human induced or natural processes. Thus, there is no judgement connected with the term (Oldfield, 2005).

Estuarine circulation

Water circulation in estuaries that is caused by differences in the density of water layers. The less dense surface freshwater is flowing out, balanced by a more salty and thus denser compensation current flowing into an often silled coastal or fjord basin. Estuarine circulation results in the upwelling of water from the intermediate water layer (Aksnes et al., 2019).

Palaeic surface

The Palaeic surface is a result of the erosion of the Norwegian mainland down to sea level. This palaeic surface was elevated up to 2.000m during a tectonic uplift that took place during the middle of the Tertiary period around 35 million years ago. Today, the palaeic surface describes the flat landscape on top of these uplifted highland plaeteaus (named “vidda”) in the southern parts of Norway (Ramberg et al., 2008).

1. Introduction

The following thesis discusses changes in the distribution of freshwater and marine diatoms in the surface sediment of the Nærøyfjord, Western Norway, which might indicate local environmental change*.

Diatoms are aquatic microalgae that occur in marine and freshwater related ecosystems worldwide. They are important for the world ocean oxygen production, accounting for 40% of the global marine primary production (Benoiston et al., 2017). Thus, the global oxygen and CO_2 balance is greatly connected to the occurrence of diatoms, forming a significant basis for nutrient and greenhouse gas budget calculations (Romero & Armand, 2010). Although diatoms are used as indicators of ecological change in rivers (Srivastava et al., 2016) and lakes (Bennion et al., 2010; Dixit et al., 1992), it is not common to used them to provide evidence of ongoing changes in recent (0-20 years) marine ecosystems. Newly published research suggests a diatom/dinoflagellate ratio as environmental indicators to identify recent marine ecological change (Wasmund et al., 2017). However, the thesis at hand will use diatom distributions alone to try figuring out local environmental change and its sources in the Nærøyfjord.

The Nærøyfjord is a southwest tending tributary of the West Norwegian Sognefjord, classified as a coastal water body (Miljøforvaltningen og Norges Vassdrags- og energidirektoratet, 2021). According to the guidelines for water quality of the European Water Framework Directive (WFD) all surface waters, including fjords, should have the status of a pre-industrial, naturally good water quality by 2021, newly extended to 2025 (European Commission, 2014). Listed in its Norwegian implementation, the Vannforskriften (Direktoratsgruppen for gjennomføringen av vannforskriften, 2018), the inner Nærøyfjord has a poor ecological status, based on benthic invertebrates, i.e. foraminifera (Miljøforvaltningen og Norges Vassdrags- og energidirektoratet, 2021). The flora, which diatoms belong to, is not mentioned in the classification of the Nærøyfjord. The last registered data is from 2013 and an improvement of the knowledge base is demanded, hence investigations must be done to find out current environmental conditions in the inner Nærøyfjord (Miljøforvaltningen og Norges Vassdrags- og energidirektoratet, 2021).

Current environmental conditions in the Nærøyfjord are of interest to the respective environmental management agencies because these agencies can only elaborate concepts of protecting an environment, if knowing what there actually is to protect and what endangers the system that should be protected. For contributing to the improvement of the existing environmental dataset, the Western Norway University AS (HVL) implemented the Nærøyfjord environmental inventory project in 2021, which investigated hydrographical, ecological, and chemical parameters in the water column and the sediments of the inner Nærøyfjord, as well as the land-fjord transition.

Considering that diatoms are ubiquitous and strongly related to their environment (Compton, 2011), it is reasonable to consider them as an additional parameter for the classification of coastal water bodies included in the WFD. Their silicious (SiO_2*2H_2O) frustules remain well preserved in the sediments for millions of years (Suzuki & Oba, 2015). Thus, diatoms have a reasonable potential to interpret environmental change in fjords over the past few decades (Paetzel & Dale, 2010). Therefore, a study about diatoms in the inner Nærøyfjord was embedded in the Nærøyfjord environmental inventory project. This thesis is based on this embedded diatom study and can be considered as an approach to investigate if and how diatoms can contribute to indicate local environmental change in the inner Nærøyfjord.

1.1 Objectives

This thesis aims to answer the following main question: *Do diatoms indicate a local environmental change in the inner Nærøyfjord in recent (0-20) years?*

"Recent years" is pre-defined as 0-20 years based on a calculated sedimentation rate of approximately 0.8cm/year in the Nærøyfjord which is derived from a study of Dybo et al. (2016).

To answer that questions, three objectives are set as follows:

(1) Dating sediment cores of three stations in the inner Nærøyfjord and calculate sedimentation rates.

Dating the sediment cores is necessary to provide a timescale for variations in the diatom compositions in the sediments of the inner Nærøyfjord. Thus, observed changes in the distribution of diatoms can be linked to a certain time and sources and reasons can be tried to find within this time frame. The dating is based on a method established by Paetzel and Dale (2010) in recent Norwegian fjord sediments. This method connects local recorded precipitation with the transport of mineral matter and freshwater diatoms into the fjord, resulting in a relative dating approach of the sediment cores. The amount of coarse silt in the sediment is the basis for the dating approach, while the occurrence of freshwater diatoms in the sediment is used to confirm or modify this dating approach.

(2) Investigate, if and how the distribution of diatoms has changed in different sediment layers.

Changes in the abundancy of marine (McQuoid & Nordberg, 2003) and freshwater diatoms (Smol et al., 2003) might indicate shifting local environmental conditions (Paetzel & Dale, 2010). To make potential changes visible, graphs with relative numbers of marine planktonic, marine benthic, total marine and total freshwater diatoms (in percentage of the total diatom counts) are created downcore at each station within continuous one centimetre sediment depth intervals. According to the dating method of Paetzel and Dale (2010), it is expected that more freshwater diatoms occur in years with higher precipitation.

If changes in distributions can be detected, the additional aim is to:

(3) Link changes in the distribution of the diatoms to their respective sources.

Noticeable changes in the diatom distribution most likely have a reason. To find out what causes these variations, the distribution of the genera in some sediment layers and their habitat preferences is further investigated. These distributional changes will then be compared to potential sources or events that took place during the corresponding years, e.g., variations in precipitation, natural events like landslides and floods, anthropogenic impacts on the inner Nærøyfjord or hydrographical impacts.

2. Settings

As fjords are per definition estuaries extending the transition region between land and the open sea (Bianchi et al., 2020), they are affected by both land and sea. Looking at the environmental settings (Chapter 2.1) it is important to include the geology of the area and while looking at previous scientific studies (Chapter 2.3) to include studies about the transport pathways to the fjord as well. To attain a better understanding of diatoms, this chapter will also include information about their classification, morphology, habitats, and their application as bioindicators (Chapter 2.2).

2.1 Environmental settings

The occurrence of diatoms strongly depends on their direct environment. Geological features of the area, the history, including the usage of (in this case) the fjord and landscape around, the bathymetry and hydrography, as well as the recent climate contribute to the formation of the currently prevailing conditions in the Nærøyfjord. Especially the hydrography can have an impact since diatoms can be found in a wide array of pH, salinity and temperature regimes (Smol & Stoermer, 2010). Various studies were carried out independently in different parts of the world, providing strong indications that diatoms react to a changing climate, e.g. Paetzel and Dale (2010); Bopp et al. (2005); Chen et al. (2014). Hence it is important, if talking about diatoms as proxies for environmental change, to provide information about the recent regional climate in the Nærøyfjord and its surrounding area.

2.1.1 Geology

Bedrock geology:

The 20km long Nærøyfjord is located in the Western Norwegian Fjord region at the south-eastern end of the Sognefjord and has an intersection with the Aurlandsfjord (Figure 1a).

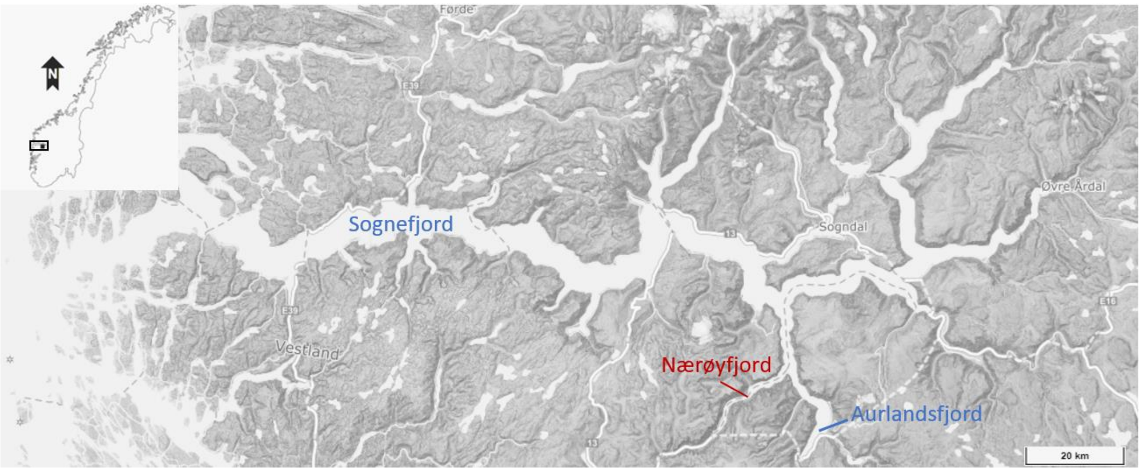


Figure 1a: Map of the Sognefjord including the intersection of the Nærøyfjord and Aurlandsfjord (modified after Norwegian Mapping Authority (2022))

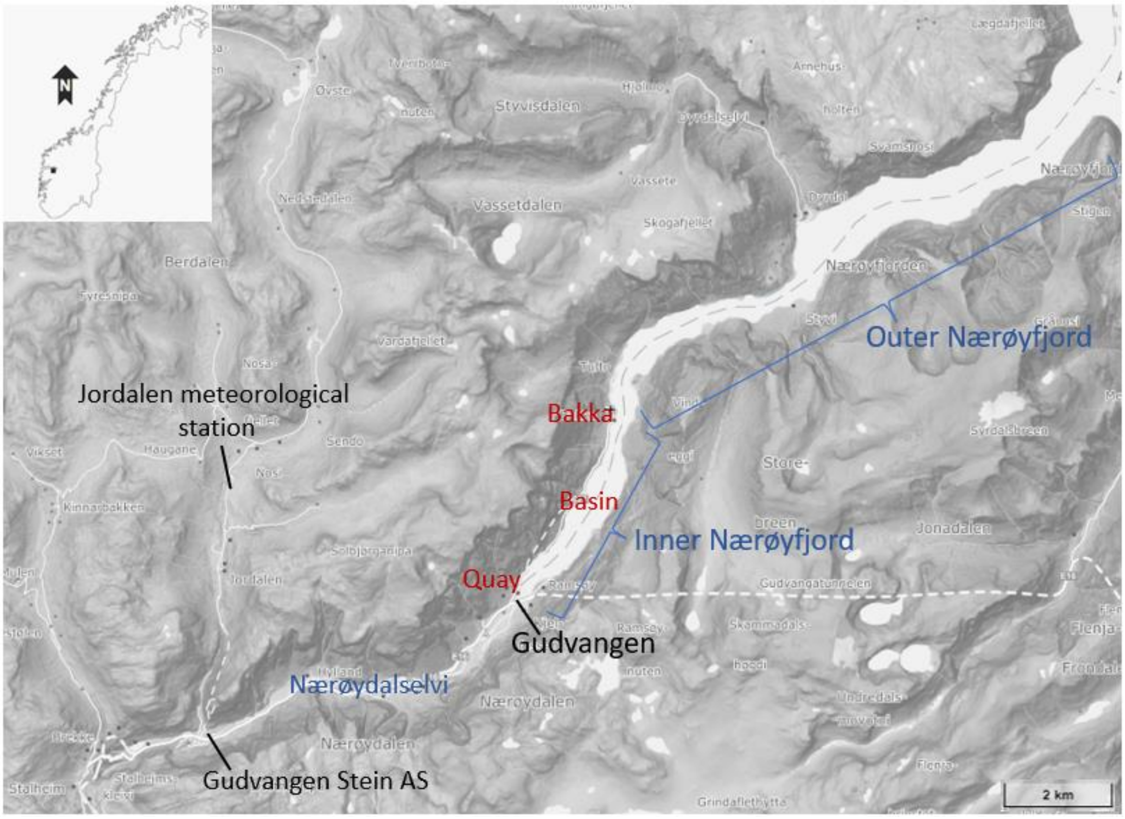


Figure 1b: Location map Nærøyfjord and Nærøydalen. Waterbodies are written in blue, places mentioned in the text in black, places of importance for the sampling in red (modified after Norwegian Mapping Authority (2022))

The surrounding landscape is characterized by glacial U-shaped valleys and hanging valleys with cliffs of up to 1499m height close to Gudvangen, the village marking the southern end of the Nærøyfjord (Figure 1b). The surrounding bedrock belongs to the Jotun Nappe Complex which had been formed during the Caledonian orogeny, i.e., the Caledonian mountain formation in the Silurian period (443-417 million years ago). During this orogeny, Ordovician ocean sediments were thrusted as phyllite nappe rocks onto the Baltic continent (the Fortun-Vang Nappe in the stratigraphic position of the Lower Allochthon), overlain by folded and metamorphized Precambrian anorthosite nappe rocks (the Jotun Nappe Complex in the stratigraphic position of the Middle Allochthon), and covered by ophiolite nappe rocks (the Solund-Stavfjord Ophiolite Complex in the stratigraphic position of the Upper Allochthon), as summarized by Ramberg et al. (2008). The anorthosite rocks of the Middle Allochthon Jotun Nappe Complex are nowadays the remaining layer of the Caledonian mountains in the inner Nærøyfjord area, consisting of over 90% plagioclase feldspar, while the other Nappe rocks are eroded away in the area, though still visible in other parts of Western Norway (Ramberg et al., 2008). There is a strong commercial interest in the anorthosite for aluminium production, making the inner Nærøyfjord region and Nærøydalen area particularly interesting for mining (Wanvik, 2007).

Tertiary and Quaternary geology

Due to the opening of the North Atlantic in the Tertiary (ca. 60 million years ago), the Norwegian landmasses were tectonically lifted up by about 2,000m. Rivers, that followed pre-existing weak zones in the bedrocks, started to erode V-shaped valleys into the flat palaeic surface*.

During repeated glaciations in the Quaternary (about 23 glaciations since ca. 2.6 million years ago), the characteristically U-shaped valleys were formed by glaciers that followed the pre-existing V-shaped river valleys of the palaeic surface, while digging into the landscape. By so-called “over-deepening processes”, the glaciers eroded further into the palaeic surface and finally even below sea level (Ramberg et al., 2008).

After the majority of glaciers melted over 10,000 years ago, they left deep fjords with shallow thresholds behind, called sills (Aarseth et al., 2014). Nowadays, some glaciers are still present in the surrounding area of the Sognefjord. The glaciers flow activity leads to the grind of its bedrock, resulting in the supply of mineral matter and nutrients in the surrounding fjords by its meltwater (Bianchi et al., 2020). Note that the inner Nærøyfjord is not directly exposed to glacial influence nowadays.

2.1.2 History and usage of the inner Nærøyfjord

The village of Gudvangen (Figure 1b) is known as a touristic spot since the 19th century with cruise liners plying in the fjord (Knagenhjelm, 2007/2019). After recognizing potential erosional environmental problems in connection to cruise ship traffic, authorities set a speed limit for ships on less than 10 knots in 2002 (Terrje Eggum, 2015). In addition to that, no big cruise liners are allowed in the Nærøyfjord nowadays. Instead, a hybrid vessel was put into operation in 2016, followed by a fully electric vessel two years later (Ship Technology, 2018), that are now arriving up to 6 times a day at the Gudvangen port (figure 2).

Due to its high amount of almost monomineralic anorthosite, the Nærøyfjord area is of high interest when it comes to mining, because plagioclase feldspar is a well requested mineral, especially for aluminium as well as for rock-wool production (Wanvik, 2007). The anorthosite mining, carried out by Gudvangen Stein AS, leads to a usage of the fjord by cargo ships. According to MarineTraffic.com (2022), up to three cargo ships (partial of an age >31 years), are arriving at the Gudvangen port at peak times (Figure 2). In 2021, Gudvangen Stein AS published plans of an inside-mountain quay for their mining cargo ships that is still under consideration (Johannes Sverdrup, 2021).

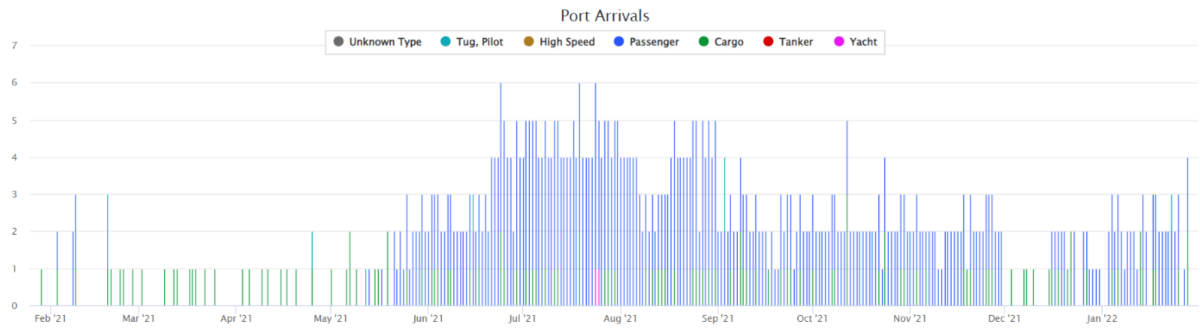


Figure 2: Gudvangen port arrivals 2021; cargo ships arrivals in green (myShipTracking, 2022)

An anthropogenic change within the Nærøyfjord area occurred in 1991 when the delta of the river Nærøydalselvi became channelized, resulting in a decrease of the natural delta area of 96.67%, increasing the outflowing water current speed and including a change in the water current direction (Klamer, 2017).

In 2005, the "West Norwegian Fjords – Geirangerfjord and Nærøyfjord" got their status as a UNESCO natural world heritage site (World heritage convention, 2005). A periodic report for the UNESCO by Erling Oppenheim (2014) points out different factors concerning the Nærøyfjord and challenging the world heritage status , e.g. mining activities, large numbers of ferries and boats trafficking the fjords, landslides and avalanches.

2.1.3 Bathymetry

The inner Nærøyfjord between Bakka and Gudvangen is marked by a 11m deep sill at Bakka and followed by a 70m deep basin southward towards Gudvangen (Figure 3). The width of the Nærøyfjord at Bakka is 250m, making it the narrowest fjord in Norway. The inner Nærøyfjord is 4km long and approximately 750m wide (World heritage convention, 2004).

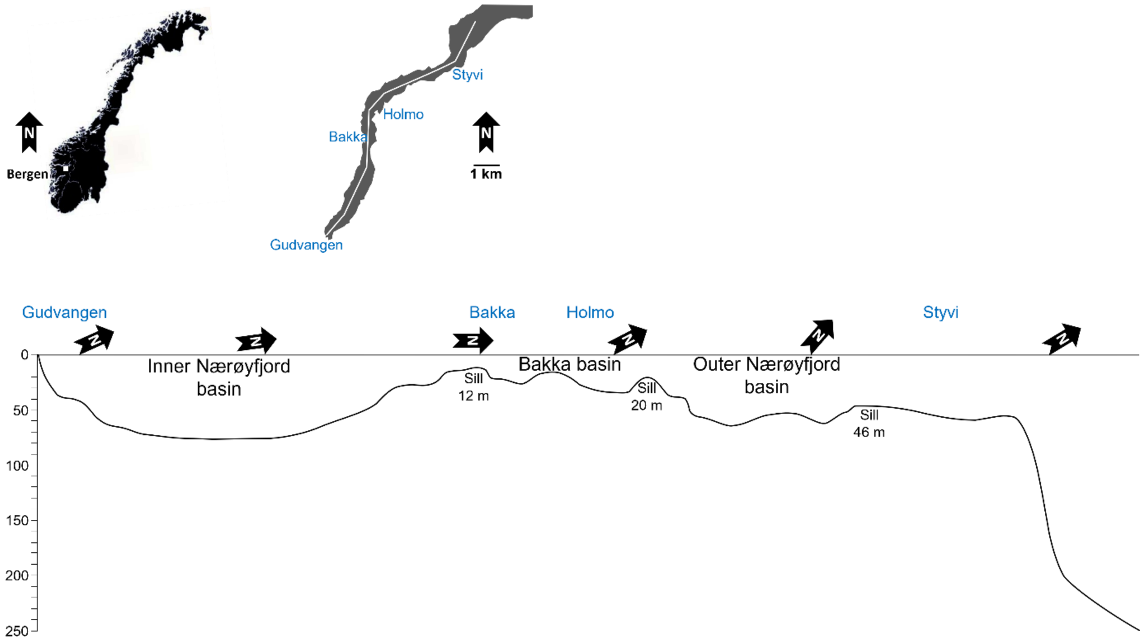


Figure 3: Depth profile (in m) of the Nærøyfjord, including sill depth

2.1.4 Hydrography

The hydrography of a fjord describes the physical features of its water column. As shown in Figure 4, the water masses of fjords are stratified in three distinct layers during summer (April to September), caused by differences in temperature, pressure, and salinity, which influence the density of the water.

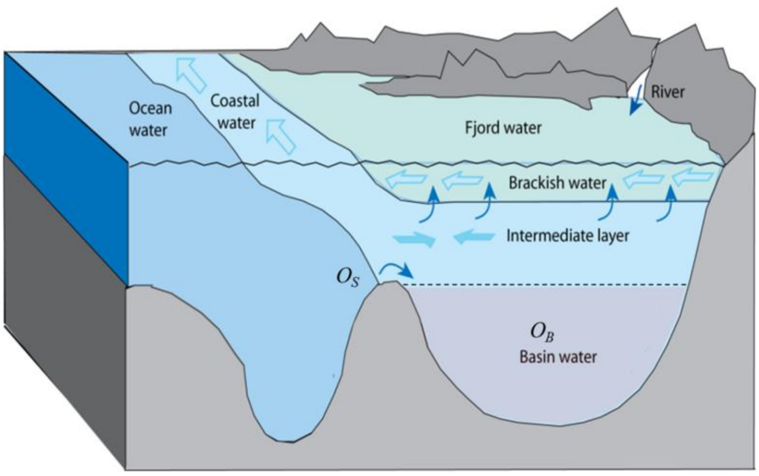


Figure 4: Principle summer stratification into three vertical layers in a Norwegian fjord (Aksnes et al., 2019)

The first, less than a few meters thick, brackish water layer consists of water with low salinity (<20PSU) due to the freshwater inflow from land. The intermediate layer extends down to sill depth and carries coastal (and partly oceanic) water and therefore has a higher salinity (20-

30PSU) and density than the brackish water layer (Aksnes et al., 2019). Different types of circulation, e.g., the wind-driven intermediate layer circulation, estuarine circulation* and/or tidal currents, might supply the upper layers of the fjord with nutrients and oxygen (Hansen & Rattray, 1966; Pritchard, 1952) . The basin water layer extends from the bottom to the sill and is prone to stagnation as it is mostly isolated by the sill from free water exchange, resulting in naturally oxygen poor conditions (Bianchi et al., 2020). New oxygen might only be transported into the basin water every few years when a bottom water renewal takes place. The youngest recorded major bottom water renewal in the inner Nærøyfjord happened in 1996 (visible as a peak of oxygen in Figure 5), while another, but smaller oxygen inflow event is recorded in 2019. There are also indications that a minor water exchange might have happened during the sampling of the material for the thesis at hand in 2021 (*Torbjørn Dale 2022, personal communication*). Circulation ceases towards a more homogenous upper water column during winter when temperature (and thus density) driven thermohaline circulation might take over before the fjord freezes at the surface (Aksnes et al., 2019).

The critical free oxygen level in water masses is 2.0mg/l. Below this value the water masses become more anoxic. Macroscopic life is only supported above that level (Elliott et al., 2013). Regarding this, the inner Nærøyfjord has naturally anoxic conditions which are extending to gradually shallower depths within the last 25 years, as illustrated in Figure 5 (Grieger, 2021).

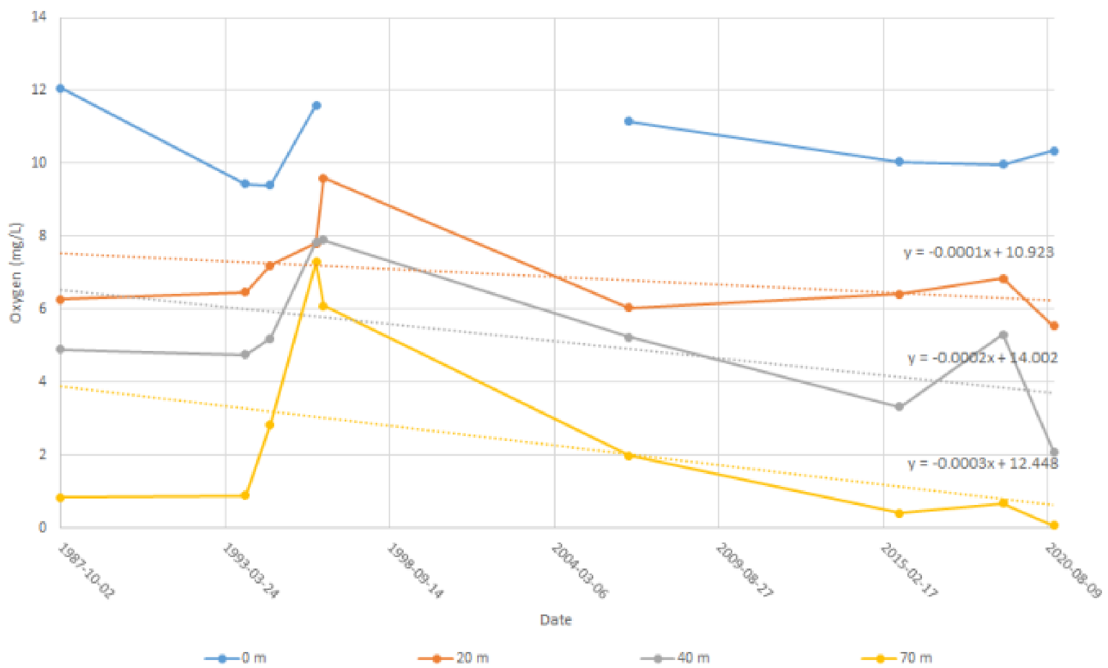


Figure 5: Oxygen concentration in the inner Nærøyfjord; note the tendency of declining oxygen levels during the last 25 years (Grieger, 2021)

According to Grieger (2021), water temperatures are steadily increasing parallel to the decreasing oxygen levels in both water surface and at basin depths (Figure 6).

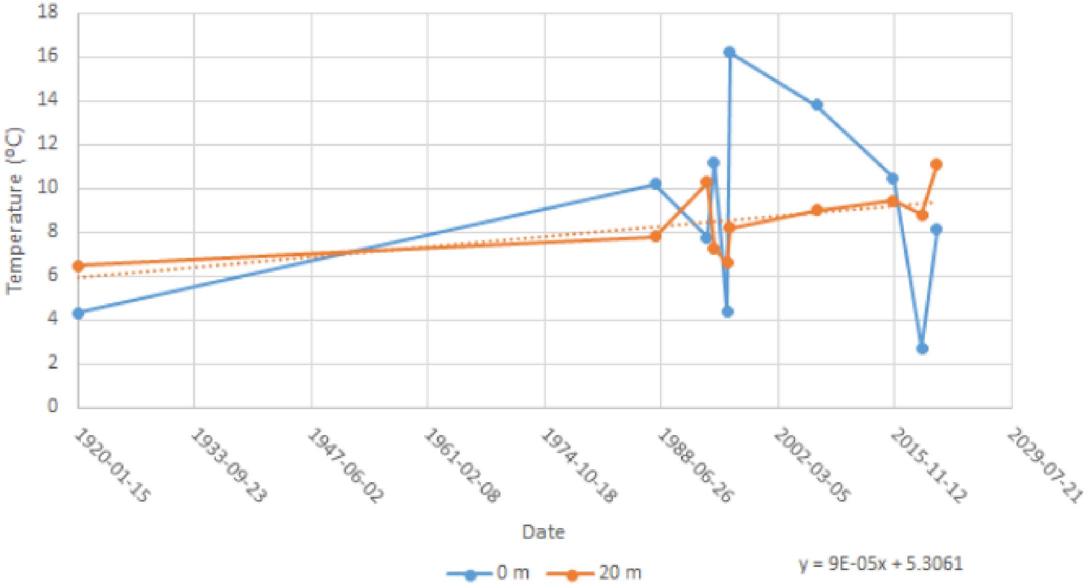


Figure 6: Temperatures in the inner Nærøyfjord; note that no temperature measurements exist between 1920 and 1988 (Grieger, 2021)

The salinity in the inner Nærøyfjord shows a decreasing trend over the same 25-year period, interrupted by a distinct peak in 2019 that affected not only the surface water but also water in 20m depth (Figure 7).

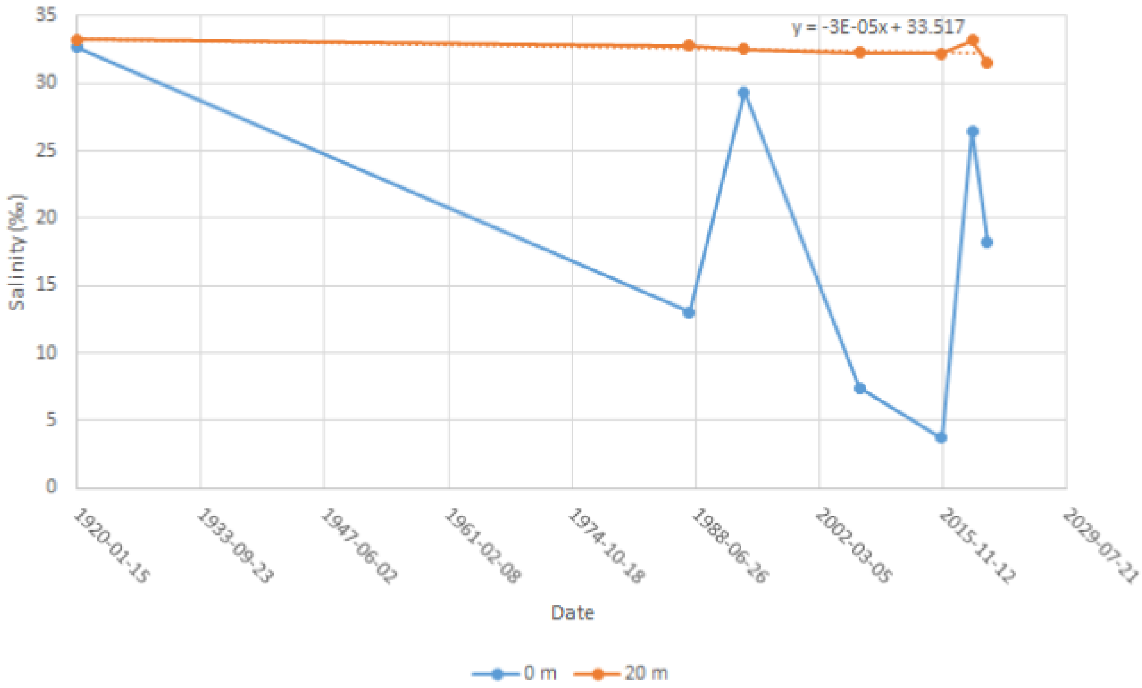


Figure 7: Salinity in the inner Nærøyfjord; note that no salinity measurements exist between 1920 and 1988 (Grieger, 2021)

2.1.5 Recent climate

The climate of the west Norwegian region Vestlandet, where the Nærøyfjord is located, is marine. Meaning it is influenced by the sea and therefore comes along with relatively cool summers, mild winters and a an elevated mean precipitation of 2047mm/year between 2000 and 2021 (The Norwegian Meteorological Institute, 2021). Even though the winters are mild in comparison to East Norway, the Nærøyfjord is one of the few fjords in Western Norway that might freeze in wintertime (Claudino-Sales, 2019).

Especially precipitation is of importance in terms of the supply of freshwater diatoms into the fjord. There are no precipitation measurements available for Gudvangen or the Nærøydalen itself, hence the presented precipitation data (Figure 8) is recorded at the Jordalen meteorological station, which is located in a neighbour valley of the Nærøydalen (Figure 1b). The riverine water from Jordalen directly runs into the river Nærøydalselvi and the data can therefore be used as an appropriate precipitation reference.

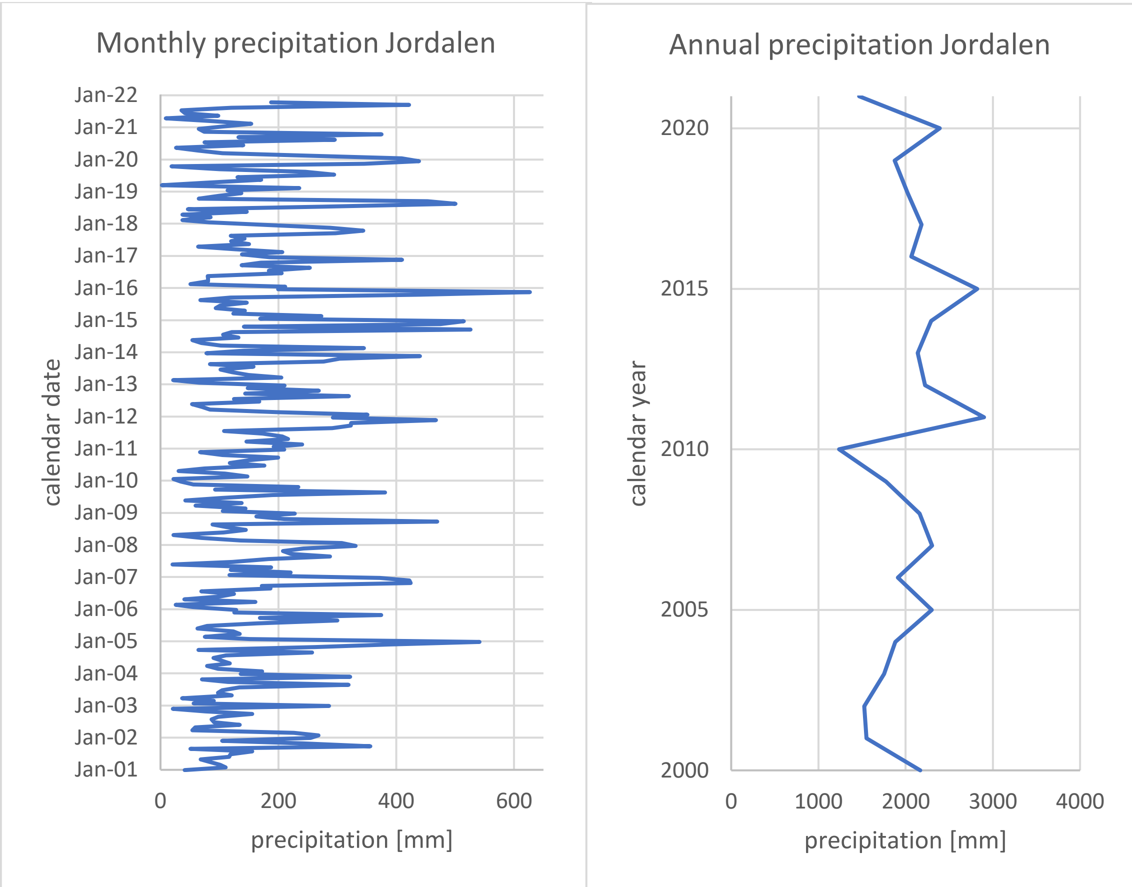


Figure 8: Monthly and annual precipitation in Jordalen, based on data from The Norwegian Meteorological Institute (2021)

The distribution of the monthly precipitation slightly changed during the past years. Especially since 2018 there were several months with less than 40mm precipitation, culminating in a monthly precipitation of only 2.4mm in April 2018. On the other hand, months with a precipitation of 400 to 500mm during fall and winter became more common since 2015 (The Norwegian Meteorological Institute, 2021). Hence, there is more extreme precipitation, but also more droughts in the Nærøyfjord area. In addition, the mean annual precipitation increased from 1870mm/year between 2000 and 2010 to 2216mm/year between 2011 and 2021.

2.2 What are diatoms?

Diatoms are unicellular microalgae which sizes are varying between 2 and 200µm in diameter, belonging to the class Bacillariophyceae (Seckbach & Kociolek, 2011). Their cell walls contain silica, making them remain in their original shape for a long time after the organic cell itself died. Therefore it is possible to determine diatoms even in sediment cores that represent millions of years (Ohtsuka et al., 2015). They occur in freshwater, marine water and brackish water environments while living either planktonic or benthic (Seckbach & Gordon, 2019).

2.2.1 Morphology

The distinct cell wall of diatoms, called frustule, is composed of opaline silica (SiO_2*2H_2O) and encloses a eukaryotic protoplast. Diatom frustules consist of two different sized valves connected with girdle bands that fit together, mostly forming differently shaped boxes and mostly round and elliptical cylinders. The diatom morphology is commonly described from two views, the girdle, and the valve view, depending on which feature is visible from the respective perspective. The bigger and older valve is called epitheca, while the smaller and younger valve is called hypotheca (Seckbach & Kociolek, 2011). While reproducing asexual via mitosis, both the epitheca and hypotheca of the mother cell will become the epitheca of the daughter cell, followed by the new building of a smaller epitheca in the next generation. To avoid the problem of a gradually decreasing mean cell size in the mean cell size of the population, the cell is restored by sexual reproduction (Smol & Stoermer, 2010). Some studies (e.g. Mizuno and Okuda (1985); Perez-Martinez et al. (1992)) suggest that environmental factors, such as irradiance and temperature could have an influence on the sexual reproduction and thus also on the frustule size (Cherpunov, 2004/2004).

It is common to differ between centric and pennate diatoms, depending on the valve shape. While centric diatoms have radiating patterns in the valve, pennate have elongated valves with a long axis of bilateral symmetry and perhaps a sternum, which is a longitudinal silica element in the valve (Seckbach & Kociolek, 2011). The sternum often contains two symmetrically arranged raphe branches, which are slits through the siliceous cell wall. The central nodule is located between the two raphe branches and consist of nodule-like silicified wall thickenings. Further characteristics are striae which are areola foramen in the porous membrane, extending from the apical axis to the margin. They can either appear as a row of punctae or as one line, then called lineola (Spaulding et al., 2022). Even though there are several other morphological characteristics within a diatom frustule, the mentioned ones are the most important for the identification of diatoms connected to this thesis. They are exemplary visualized in Figure 9 on a scanning electron microscope (SEM) image of a pennate diatom.

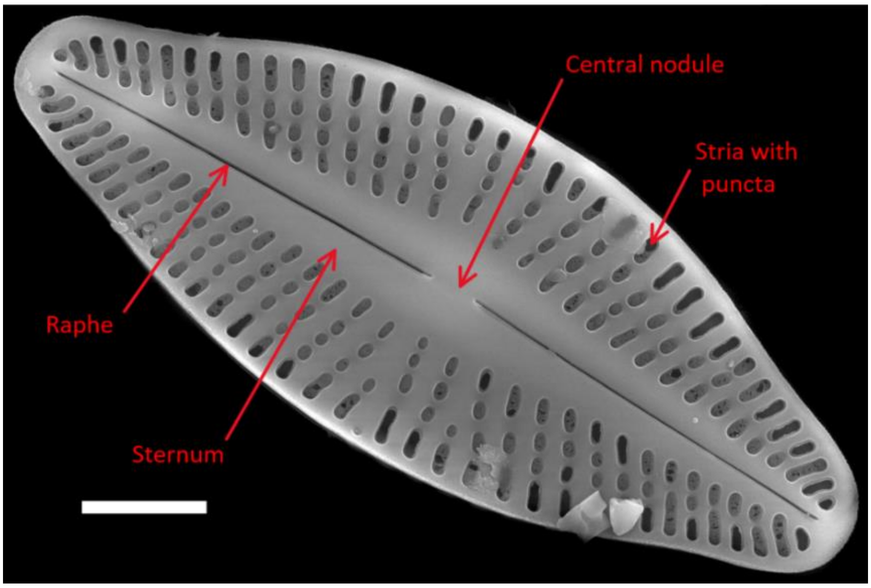


Figure 9: SEM image of the inner side of the raphe valve of Karayevia clevei; the white line corresponds to 2µm (modified after (Marina Potapova [Photograph], 2022))

2.2.2 Classification

There are several hundred genera of diatoms and, according to Kociolek and Williams (2015), more than 60,000 named species, while the estimated total number of species might be between 100,000 and 200,000 (Mann & Vanormelingen, 2013). Hence, diatoms are the most species-rich group of autotrophic algae worldwide (Archibald, 2017).

In the past, diatoms were classified according to their shape as either Centrales or Pennates. This method is no longer applicable because centric diatoms are discovered to be not monophyletic. Thus, Medlin & Kaczmarska (2004) suggested a new classification (Figure 10), later deviated by Mann (in Adl et al., 2005), based not only on morphology but also on genetic relationships. Given that diatoms belong to the Bacillariophyceae they cluster them into the subdivision Coscinodiscophytina and Bacillariophytina as illustrated in Figure 10, nodes 1 and 2, while node 3 represents the new class Mediophyceae and node 4 includes the altered class of Bacillariophyceae.

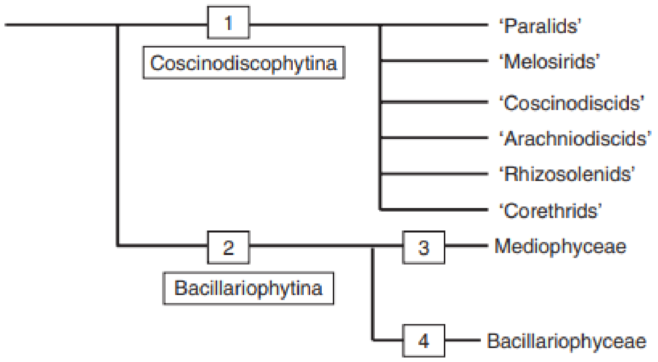


Figure 10: Classification of diatoms derived from Medlin and Kaczmarska (2004) as a branching diagram; node 1, 2,3 and 4 are explained in the text (D. Williams & Kociolek, 2007)

This classification, called CMB hypothesis, is still discussed (Williams & Kociolek (2010); Williams & Kociolek (2007); Sorhannus (2004); Theriot et al. (2009)) because it is unlikely that Coscinodiscophytina or Mediophyceae are monophyletic in their present form, but still it is a valid approach to include molecular data in the diatom classification (Seckbach & Kociolek, 2011). Therefore, the CMB hypothesis is used as a basis in the following to classify diatoms.

2.2.3 Habitats and Ecology

Diatoms are living in freshwater, brackish water and marine water related habitats. Many similarities can be found between genera of the different habitats, e.g. the convergent evolution* of forming zig-zag colonies between *Tabellaria* or *Diatoma* and *Grammatophora* (Archibald, 2017). Thus, diatoms live either as single cells or they are attached to each other in colonies. In general, they occur in two community types: planktonic, in the open water mass, or benthic, associated with underwater surfaces, e.g., soils, rocks or plants. Having only a limited range of motility by using a gliding system connected to the raphe (Bedoshvili & Likhoshway, 2021), they are mostly exposed to water currents and turbulences. Each species has its own ecological niche for optimal growth. However, salinity is more relevant when it comes to the tolerance of ecological factors in the marine environment while pH is the more important factor in freshwater related environments. In general, light is the limiting factor for diatom growth based on the photosynthetic activity of the microalgae. Regarding this, they can only be found alive in the euphotic zone (of generally 30-40 meters water depth) below the water surface, where light still penetrates the water. Silica is the other controlling factor on the growth rate, next to other nutrients, especially Nitrogen, Phosphorus and Iron, and the water temperature (Archibald, 2017).

2.2.4 Applications in science

Having the various growth controlling factors and narrow ecological niches of each genus or species in mind, the usage of diatoms as bioindicators is reasonable and already often applied in aquatic studies (Seckbach et al., 2019). Diatoms can be used in various ways: Interpreting fossil diatom assemblages is a valid approach on reconstructing long term environmental change, while a short-term environmental change can be investigated by means of diatoms as constituents of benthic and pelagic communities, because they are long known sensitive indicators for small modifications of environmental factors. Practically it means that a change of environmental factors can be visible in a species shift (Smol & Stoermer, 2010). A diatom-based biological condition gradient for streams was published by Hausmann et al. (2016), suggesting a correlation between nutrient concentrations, anthropogenic land usage and the occurrence of some specific diatom genera and species. Whereas Vilmi et al. (2015) used the (freshwater) species morphology, e.g. the valve size, to evaluate the effect of eutrophication.

The implementations and measurements of the water quality standards in the EU-Water Framework Directive are different in each country. For example, the United Kingdom already uses diatoms to evaluate the ecological status of a waterbody, as diatoms are a significant component of the phytobenthos (Kelly et al., 2007). Another new approach of benthic diatoms as indicator of local coastal eutrophication comes from Kafouris et al. (2019), suggesting that the genera *Cocconeis* and *Tryblionella* are efficient bioindicators of coastal eutrophication. The shown potential of diatoms as bioindicators should be kept in mind while assessing and discussing the results of this thesis.

2.3 Scientific setting

The Nærøyfjord environmental inventory project of 2021 resulted in a wide spectrum of data about the inner Nærøyfjord, which is summarized in a, yet unpublished, report of Bollingberg (2022). The following aspects are based on the results that can be reviewed in that report.

While looking at previous studies and data of the Nærøyfjord it is also important to include investigations of the pathways, meaning mainly the material supply from the discharging river Nærøydalselvi, which is a protected rain supplied river due to its importance for salmon. All discharging water goes directly into the Nærøyfjord and therefore also directly influences the fjord and the life in it. Turbidity, conductivity, temperature, and pH were measured at several stations along the Nærøydalselvi. The results show an increased turbidity and conductivity close to both the Anorthosite mining pit of Gudvangen Stein AS (Figure 1b) and a campsite, where dust and sewage enter the river. Downstream, the temperature was constantly rising, while the pH decreased, most likely because of an increasing photosynthesis rate caused by a higher number of algae the closer it gets to the estuary. Consequently, the current ecological status of the Nærøydalselvi is moderate, while the target is to achieve a good water quality (Norges Vassdrags- og energidirektorat, 2022).

When looking at the **hydrography,** a trend to an almost complete anoxia in the deeper water becomes visible with oxygen values below the critical value of 2.0mg/l starting at a depth of approximately 30m. That is also confirmed by geochemical analyses of recent fjord sediments and measurements of the redox potential and loss on ignition, which revealed that the fjord also becomes more anoxic the closer it gets to the quay at Gudvangen (Figure 1b). The water temperature in the inner Nærøyfjord (Figure 6) is constantly increasing over the past 100 years, leading to an increase of almost 3°C in all water layers since the first data sampling in 1920 (Grieger, 2021). Even considering that the Nærøyfjord is naturally anoxic, there is a clear trend that, together with a rising temperature, the oxygen concentrations are decreasing, and are thus deteriorating living conditions.

Beside those measured invisible effects of an environmental change, a pioneer investigation with an underwater drone revealed the visible parts of it. With the usage of the Ecological Quality Ratio (EQR) it is possible to determine the water quality according to the occurrence of **macroalgae**. The EQR is the ratio between the observed and expected biological parameter value for a given surface water body (van de Bund & Solimini, 2007). The calculated EQR indicates a moderate status for the Nærøyfjord in 2021 while, according to the EU-WFD, it needs to be improved until the status is either good or very good.

Foraminifera are already well used bioindicators within the European Water Framework Directive (2000), and therefore investigated within the Nærøyfjord environmental inventory project in 2021. The results indicate that the ecological status of the Nærøyfjord close to Bakka is moderate, with a low but constant oxygen supply, while the conditions worsen closer to the Quay with ecological conditions that are even too bad to be classified, because almost no foraminifera were found.

Besides the Nærøyfjord environmental inventory project in 2021, Dybo et al. (2016) among others investigated the hydrography and sediment geochemistry of the inner Nærøyfjord . A marine biological investigation took place in the Nærøyfjord in 2007 and 2009, with measurements of hydrography and benthic macroscopic fauna (Johansen et al. 2007). Relevant results from both investigations are included in the graphs of Grieger (2021), Figures 5, 6, and 7.

No diatoms were investigated during these investigations. Hence it might be meaningful to finally take diatom variations in the Nærøyfjord into account when investigating ongoing environmental change and evaluating ecological conditions to see, if they provide useful information that can set into context with other presented results.

3. Material and methods

The analysis of the diatoms is based on sediment samples of the inner Nærøfjord. Sampling sites and further procedure after the sampling are described in this chapter.

3.1 Data collection

The data collection includes the sediment sampling in the fjord, as well as the preparation of smear slides and the determination of diatoms within the slides.

3.1.1 Sampling

The sampling took place on September 1st, 2021, when three sediment cores were retrieved from the inner Nærøyfjord at three different stations (Figure 11 and 12, red marked locations). The first sampled station is located south of the sill close to Bakka at a water depth of 38m. Station 2 is at 68m water depth in the inner Nærøfjord basin, while the third sample was taken close to the Quay at Gudvangen at 55m depth. From now on the sampling stations will be called Bakka, Basin and Quay, respectively.

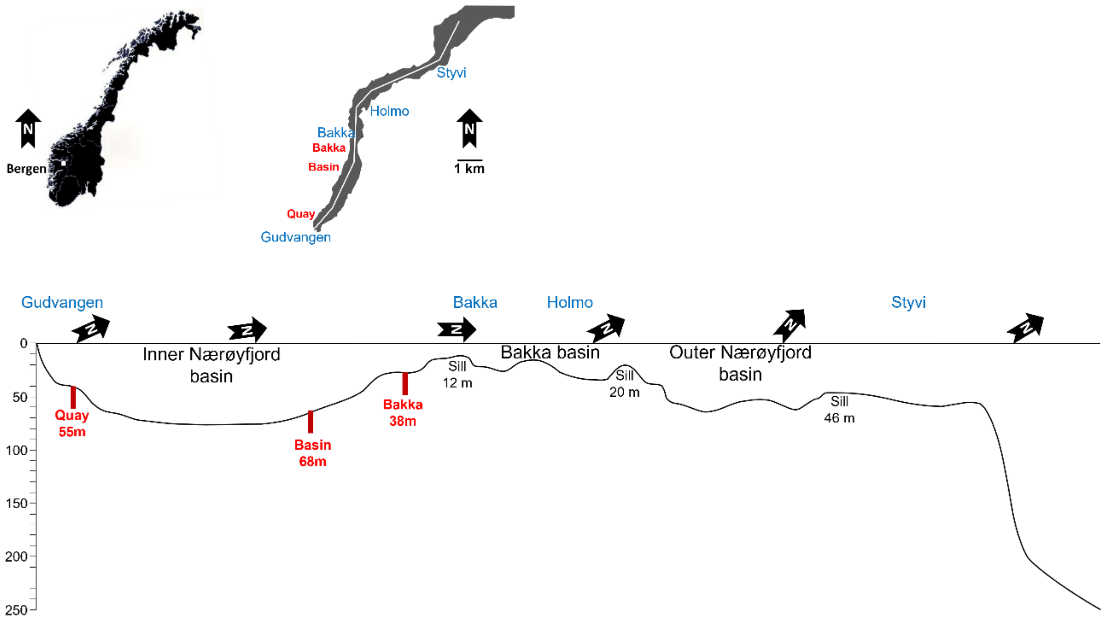


Figure 11: Depth profile of the Nærøfjord with sampling locations and depths

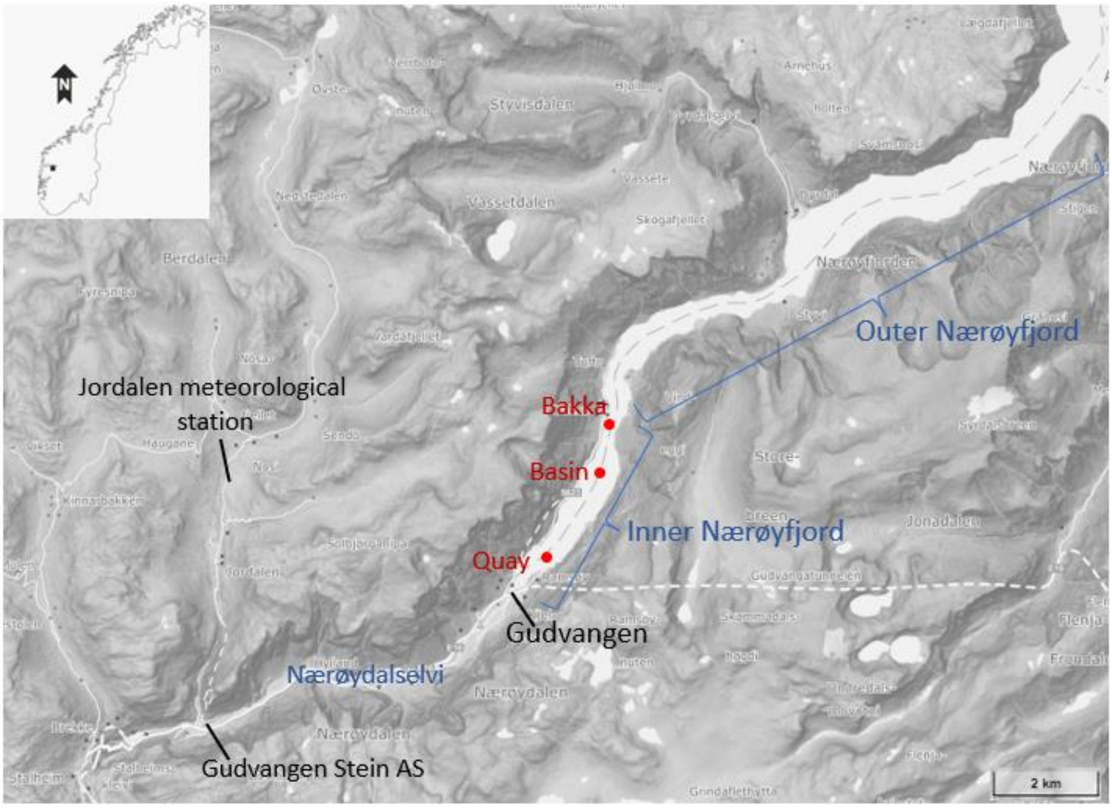


Figure 12: Location map Nærøydalen with sampling locations in red (modified after Norwegian Mapping Authority (2022))

The tubing of the cores happened immediately after retrieving the sediment sample with a box corer (15x15x30cm, Figure 13).

Figure 13: Box corer filled with sediment

3.1.2 Smear slide method

Diatoms were investigated using the smear slide method according to Rothwell (1989). Diatom analysis from smear slides is favourable as smear slides would reveal the *in situ* distribution of the investigated particles mainly on silt grain sizes between 4 and 63µm (including the size of diatoms) in high resolution. Smear slides were taken continuously downcore in 1cm slices. These 1cm increments were chosen based on the average sedimentation rates of 0.8cm/year in the Inner Nærøyfjord basin estimated by Dybo et al. (2016). Thus, a 1cm homogenized sediment sample will contain the average sediment composition of about one year deposition. The 1cm subsamples are homogenized and from this homogenized sample another subsample with the size of a needle head is extracted using the tip of a toothpick. The needle head sized subsample is then placed onto a clean microscope cover glass and dispersed in a drop of distilled water. The step is followed by the application of a wetting agent, e.g., Kodak Foto-Flo, to break the surface tension of the distilled water. After that, the toothpick is used to smear the dispersed sediment particles out, creating a thin film on the cover glass. To make sure that all liquids are evaporating, the cover glasses are warmed up on a heating plate.

Due to their opaline silica cell walls, diatoms have a low refractive index of 1.43 (Fuhrmann et al., 2004) which is similar to glass. To make the frustule structures visible, a mounting medium with a higher refractive index is needed. In this case Naphrax (Brunel Microscope Ltd) high resolution diatom mountant with a refractive index of 1,73 is used. After adding Naphrax, the cover slide is mounted on top of a standard 75x26mm microscope slide. Note that Naphrax is dissolved in toluene, which is highly carcinogenic and cancerogenic and thus needs to be treated in a foam cupboard. During the following heating process, the toluene is evaporated. The Naphrax mounting cures when it is dry, making the sample remaining long-term in its position. Care is required to avoid bubbles between the microscope slide and the cover slip. The final smear slide (Figure 14B) can be reused in future research. It is a rapid, simple and cheap method with the advantage that only a very small sample size ($1mm^3$) is required to get appropriate results (Rothwell, 1989). It reveals the *in-situ* distribution of diatoms and the sediment particles and thus sets diatoms into relation of the entire sediment fraction (Paetzel & Dale, 2010).

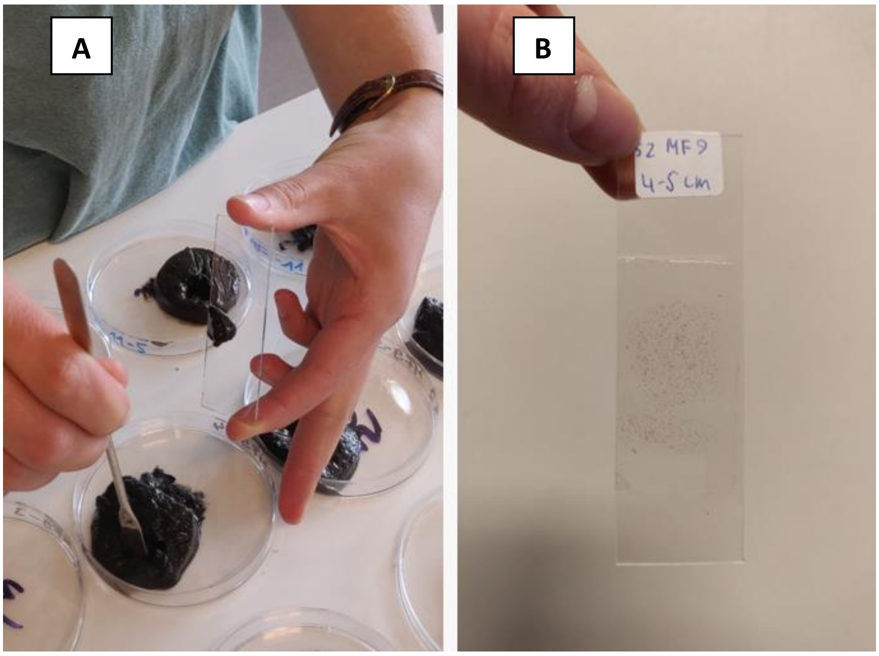


Figure 14: Smear slide preparation (A) and final slide (B)

3.1.3 Determination of diatoms

The smear slides were investigated with a translucent light microscope with 40x magnification (Figure 10).

Figure 15: Smear slide under transmitted light microscope with 40x magnification

High numbers of genera and similarities between species and genera are the main obstacles in the determination of diatoms. The features used to identify and classify diatoms rely on the morphology and ornamentation of their valves: A first differentiation can be made between Pennales and Centrales. The shape of the valve can be, amongst other shapes, arcuate (Figure 16: 8,9,11), straight (Figure 16: 1,6,7,12) or sigmoid (figure 16: 5) and their apices might be apiculate (figure 16: 2,11) meaning that the apex area is narrow and widens to the middle of the frustule (Spaulding et al., 2022), round or straight. Other distinguishing features are the occurrence of a raphe, if a raphe exists, the centrale nodule with or without a pore and the number, density and orientation of striae (e.g. figure 16: 2) and puncta (e.g. figure 16: 1) (Salido et al., 2020). In addition, the formation of colonies (figure 16: 7) can be used as an identification feature.

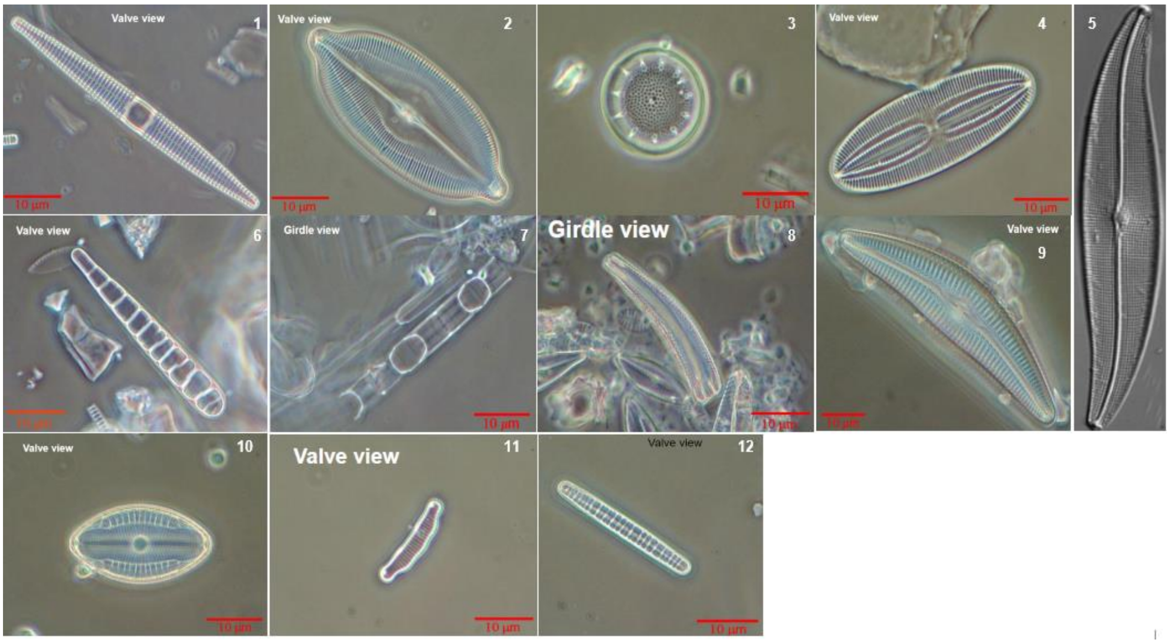


Figure 16: Diversity of diatom valves (modified after Paetzel (personal communication, 2021): (1) Fragilaria pulchella (2) Caloneis amphisbaena (3) Thalassiosira nordenskioeldii (4) Navicula lyratae (5) Gyrosigma acuminatum (6) Meridon circulare (7) Sceletonema costatum (8) Rhoicosphenia curvata (9)Cymbella aspera (10) Mastogloia elliptica (11) Eunotia diadon (12) Diatoma tenuis

Pictures, like those in Figure 16, are used for the final determination of the genus by matching the distinguishing features of the observed diatom and the exemplary picture of the species. The determination is only made at genus level, because the main interest of this thesis is to distinguish between the origin of the diatoms, and diatoms within a genus mostly have similar salinity preferences (Seckbach & Kociolek, 2011) and thus a similar origin. If less than 50% of a frustule is visible, the diatom is not considered due to the risk of misidentification. To minimize the error of wrong determinations, diatoms are counted to a minimum of 600 individuals per smear slide, which is feasible considering their abundance. Any abnormalities (e.g., noticeable valve sizes, increased occurrence of colonies) are noted while examining the smear slides under the microscope.

3.2 Dating

To detect when changes happened it is necessary to date the sediment cores. Precipitation diagrams of the Jordalen weather station, as shown in detail in Appendix II A (The Norwegian Meteorological Institute, 2021), are used to compare the annual precipitation with the relative amount of coarse silt (grain size up to 63µm (Wentworth, 1922)) on mineral matter in the same smear slides that are used for determining the diatoms on it. The method is based on a study of Paetzel and Dale (2010) in the Barsnesfjord and Sogndalsfjord, two northern tributaries of the Sognefjord, where grainsizes and the ratio between organic and terrestrial matter, as well as freshwater diatoms are used to date sediment cores. The more precipitation occurs, the coarser material is flushed into the fjords, because the time of transport is too short to grind the particles into smaller grain sizes. This holistic method is feasible, because it is based on parallel data on the same smear slide, which allows to transfer the dating for diatom investigations. The distribution of coarse silt is taken from unpublished graphs within the project, illustrated in detail in the Appendix II B (Marie-Sophie Kind, 2022, *personal communication*).

The sedimentation rates are calculated between all dated peaks of coarse silt. The unit of centimetre per year is derived by dividing the depth difference of these peaks by the time difference between these peaks. In addition to that, the results of the occurrence of freshwater diatoms in the sediment is used in the discussion to verify or modify the precipitation related dating, because freshwater diatoms do not grow in the brackish fjord waters, hence need to be flushed in secondary by precipitation through rivers or streams.

3.3 Data processing

The collected data is transferred into tables, depending on the diatom's habitat, differing between "marine planktonic", "marine benthic", "freshwater/ brackish water", and "other diatoms" that are not possible to clearly identify (Appendix I). The genus *Thalassiosira* is normally settled in a marine environment, with the exception of *Thalassiosira Weissflogii*, which is found in marine water, as well as in freshwater, but is not a brackish species (WoRMS Editorial Board, 2022). That makes it difficult to assign that species to one of the listed groups above. Therefore, *Thalassiosira Weissflogii* is determined to species level and grouped to "other diatoms”. If it was not possible to clearly identify centric diatoms, they are counted as “round diatoms” and assigned to the category “marine diatoms”, because centric diatoms are typically of marine origin (Not et al., 2012).

It is not necessary to differ between “freshwater planktonic diatoms” and “freshwater benthic diatoms”, because freshwater diatoms are flushed into the fjord through rivers and water runoff from land and it is not of importance for this thesis, where exactly freshwater diatoms grew before they are transported into the fjord. Brackish water species are not separately counted, because they rather have salinity preferences, but, according to Smol and Stoermer (2010), there are only a few genera worldwide that have a true brackish water distribution. Real brackish water species would only be endemics found in land-locked brackish waters, which can be neglected for fjords.

The total number of counted diatoms is set into a relative value, coming out with a percentage of total diatoms for each genus. 100% equals the total number of all counted individuals.

All genera found are displayed in tabular form in the results with percentage information about their relative abundance of all counted diatoms. Diatom genera that are common, abundant or that become relevant at a later point in this thesis are further described with their morphology, classification, and pictures. The categories of diatom abundance are based on suggested categories of Scherer and Koc (1996) and adjusted to relative numbers of the diatom occurrence used in this work (Table 1).

Table 1: Definition of categories for relative diatom abundance (modified after Scherer and Koc (1996))

Abundance description	Definition
barren	No diatom debris evident
rare	>2% diatoms
few	2% to 5% diatoms
common	5% to 20% diatoms
abundant	20% to 60% diatoms

All tables with total and relative diatom counts are attached in the Appendix I and the distributions of freshwater, marine planktonic, marine benthic and total marine diatoms are presented in graphs with their relative frequencies. The graphs are described and compared to each other to answer the question if it is possible to detect a change in the composition of diatoms in recent years. All graphs, regardless of their station and type of diatoms presented in it, have the same y-axis scale, going down to 14cm depth, even though two sediment cores are only 6cm long. That makes it easier and more uniform when it comes to comparing the graphs to each other. The data points have 1cm depth between each other because subsamples were taken continuously in 1cm sediment slices down the sediment core. A subsample of exemplary 2-3cm sediment depth will be displayed as a data point at 2.5cm depth. All graphs of one category of diatoms (freshwater, marine planktonic, marine benthic, total marine) also have the same x-axis scale, making them again better to compare to each other.

3.4 Linking changes in the distribution of the diatoms to their respective sources

After finding out what exactly has changed in the diatom composition in recent years, the third objective of this thesis is to link these changes to their respective sources. Hence, it is necessary to know what influences the observed diatom change in general. This is done by using the results of previous studies about influencing biotic and abiotic factors of diatom occurrence and variations. The next step is to find out which factors can be transferred to the results of the Nærøyfjord investigations and which factors can be excluded. This is done under consideration of results from previous local studies, e.g., temperature regimes or salinities. The usage of the fjord also belongs to potential influencing factors as well as past weather events.

4. Results

The sampling of sediment with a box corer results in three parallel tubed sediment cores (Table 2). All following results are based on material retrieved from these cores.

Table 2: Coordinates, water depth and sediment penetration of three sediment cores

Core/ station name	**Longitude (north)**	**Latitude (east)**	**Water depth**	**Sediment penetration (core length)**
Bakka	60°54'28.9"	6°52'14.7"	38m	6cm
Basin	60°54'14.7"	6°52'08.5"	68m	13cm
Quay	60°53'10.1“	6°50'59.0“	55m	6cm

4.1 Dating approach

The precipitation in 2010 was exceptionally low with only 1236.7mm/year, which can be seen as a remarkable low point in Figure 17. Transferring it to the relative amount of coarse silt, the low precipitation is reflected in a minimum of approximately 10% coarse silt. Contrary to 2010, next year's precipitation of 2898.9mm is the highest value since 2000, which is also reflected in a marked increased amount of coarse silt with over 40% on total mineral matter. 2019 was another year with little precipitation below 2000mm, which is also reflected in coarse silt with less than 20%. The peaks of coarse silt between these years are not as distinct as the mentioned ones, but still following the principal trend of the amount of precipitation, visible for example in 2016 when annual precipitation was decreasing in comparison to 2015 and coarse silt is also decreasing in the sediments. Hence, the dating approach is feasible and can be used to transfer the dating on all following results about the diatoms distribution within the sediments if the inner Nærøyfjord.

Based on this dating approach, a sedimentation rate year for the inner Nærøyfjord of ±1cm per year can be calculated, corresponding well to the given relative sedimentation rate of about 0,8 cm/year of Dybo et al. (2016). Exemplary calculated with numbers taken from Figure 17: The coarse silt peak of 2017 is located at 2.5cm sediment depth and the coarse silt peak of 2011 is located at 8.5cm sediment depth, resulting in a sedimentation rate of:

$$\frac{8.5cm-2.5cm}{2017\ years-2011\ years} = 1cm/year.$$

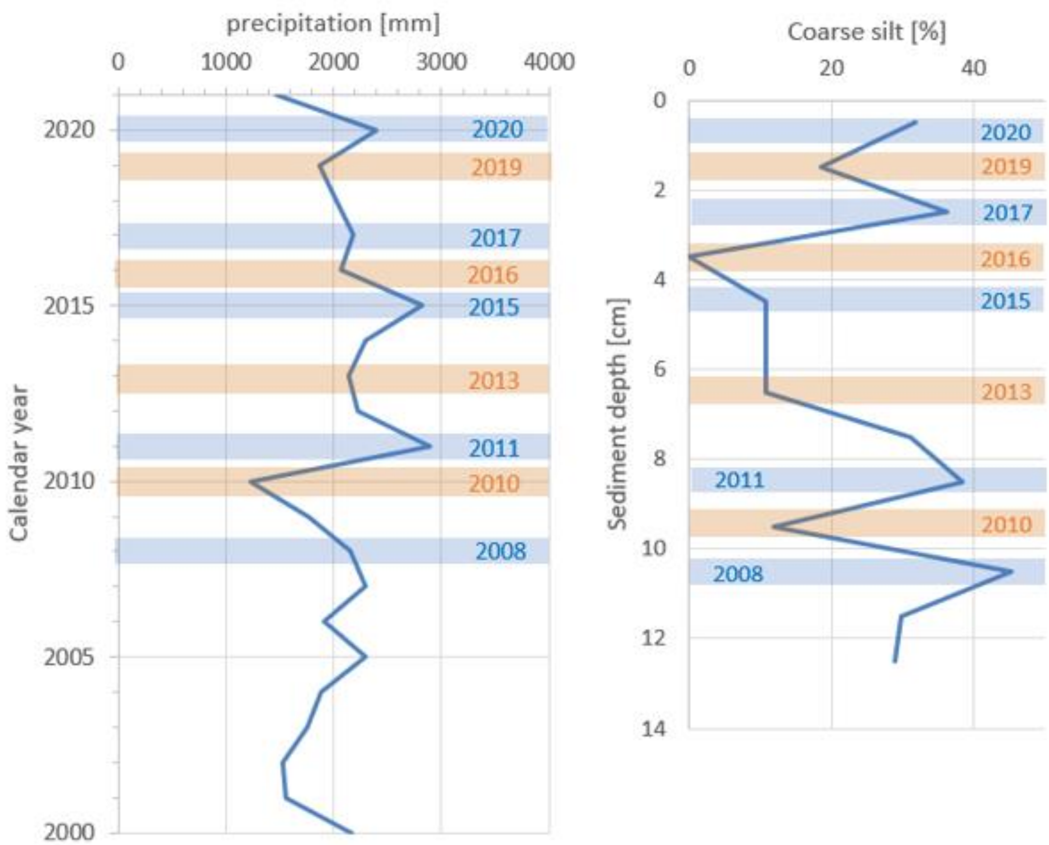
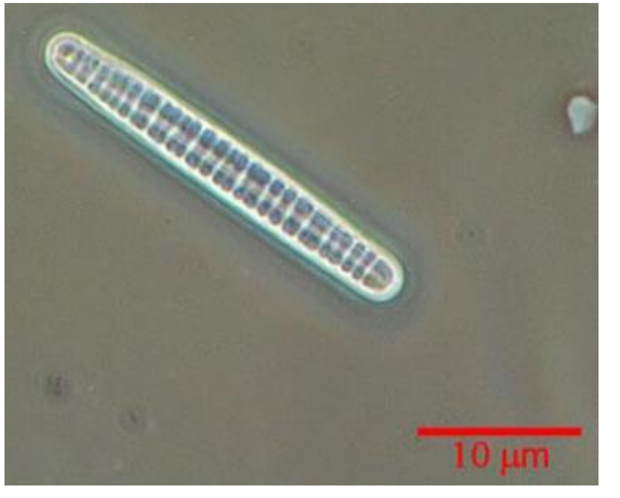


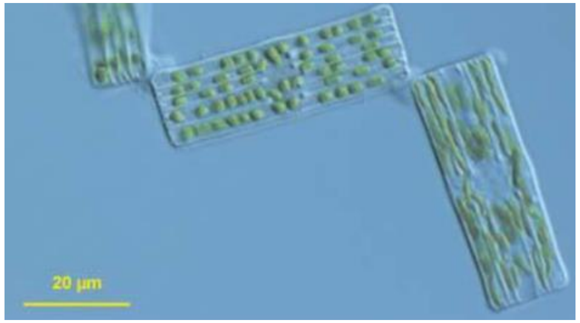
Figure 17: Dating approach of the Basin sediment core based on coarse silt and annual precipitation at the Jordalen weather station

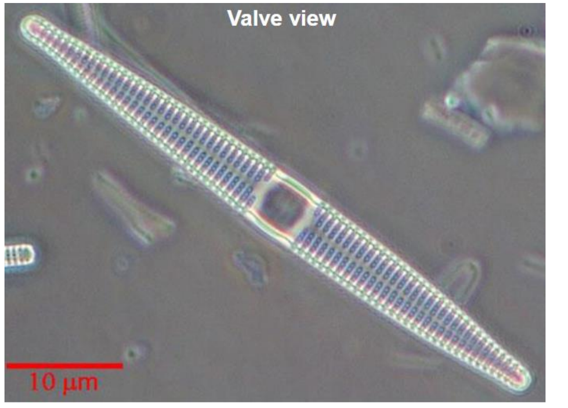
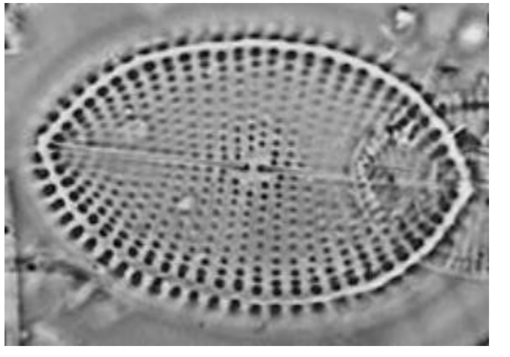
4.2 Commonly found diatoms

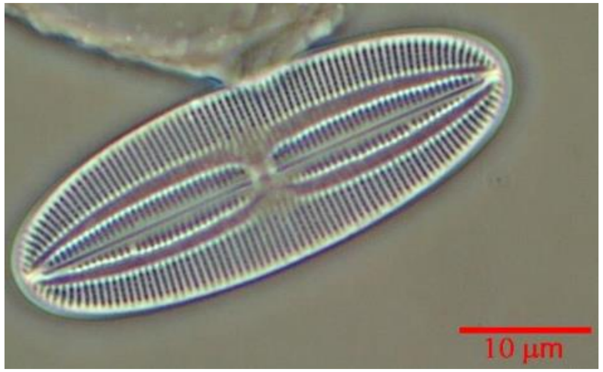
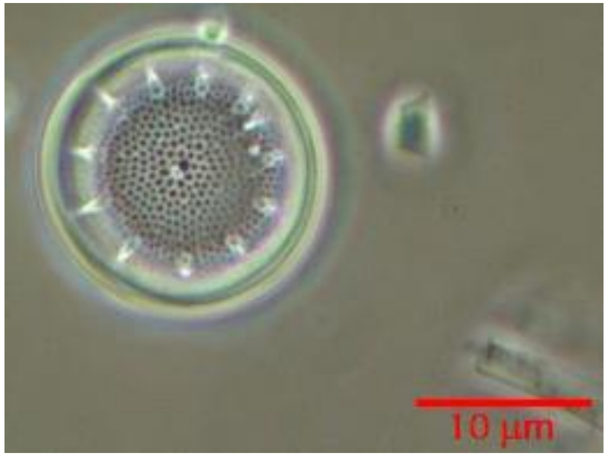
To get a better idea of the identified diatoms, common genera are presented in Table 3. The information about morphology, classification and habitat is taken from Round et al. (2000), Spaulding et al. (2022), WoRMS Editorial Board (2022) and own observations. The pictures are made available by the curtesy of Matthias Paetzel (2022, *personal communication*) or taken as own documentary during this study. Diatoms that are few or rare are listed in table 4 with their percentual mean occurrence of all counted diatoms.

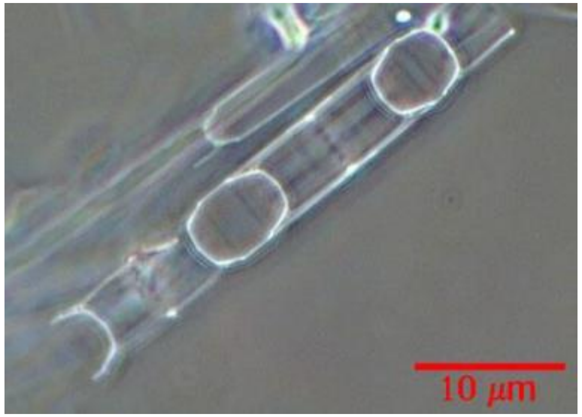
Table 3: Description of the identified diatom genera in the Inner Nærøyfjord sediments. Diatoms with an abundance of >5% are of relevance for this thesis and described in greater detail. Exception is the marine benthic genus Achnanthes that occurs at only 1.72%.

Genus	Mean occurrence [%]	Morphology	Classification	Picture
Freshwater diatoms	**60.82**			
Diatoma	17.63	- Araphid (no raphe system) - Elliptical to elongate valves - Capitate ends (valve end with the shape of a rounded knob) - Uniseriate striae, lying in right angles to narrow central sternum	Class: Bacillariophyceae Subclass: Fragilariophycidae Order: Fragilariales Family: Fragilariaceae	

Tabellaria	10.2	- Araphid - Elongated valves, slightly capitate - Wide central valve inflation - Uniseriate, irregular spaced striae - Often found in zig-zag colonies *(first picture)*	Class: Bacillariophyceae Subclass: Fragilariophcidae Oder: Taberllariales Family: Tabellareaceae	 
Eunotia	7.92	- Arcuate form - Apices broadly rounded - Short raphe - Striae uniserate (arranged in single lines)	Class: Bacillariophyceae Subclass: Bacillariophycidae Order: Eunotiales Family: Eunotiaceae	

Fragilaria	6.03	- Rectangular to lanceolate capitate frustules - Araphid - Transapical striae - Distinct central nodule - Rib-like colonies	Class: Baccilariophyceae Subclass: Fragilariaphycidea Order: Fragilariales Family: Fragilariaceae	
Cocconeis	5.57	- One valve with a distinct raphe, one without - Oval shaped valve - Well distinguished puncta	Class: Bacillariophyceae Subclass: Baccilariophycidea Order: Achnanthales Family: Cocconeidaceae	

Navicula	5.37	- Naviculoid (boat-shaped) valve - Sternum central and thickened - Striae composed of lineate areolae - Capitate ends - Biraphid, thickened sternum	Class: Bacillariophyceae Subclass: Bacillariophycidae Oder: Naviculales Family: Naviculaceae	
Marine planktonic diatoms	35.79			
Thalassiosira	18.2	- Centric - Mostly discoid valves - Several areolae arranged in radial/ tangential rows or arcs	Class: Bacillariophyceae Subclass: Coscinodiscophycidae Order: Thalassiosirales Family: Thalassiosiraceae	

Sceletonema	8.53	- Cylindrical shaped -Forming long colonies connected with external tubes	Class: Bacillariophyceae Subclass: Thalassiosirophycidae Oder: Thalassosirales Family: Skeletonemaceae	
Chaetoceros	6.33	- Cells joined in filamentous colonies - Elliptic valves with one seta from each pole - Single Resting with long spines	Class: Bacillariophyceae Subclass: Coscinodiscophycidea Order: Chaetocerotales Family: Chaetoceraceae	 Resting spore, filled with Pyrite (dark part)

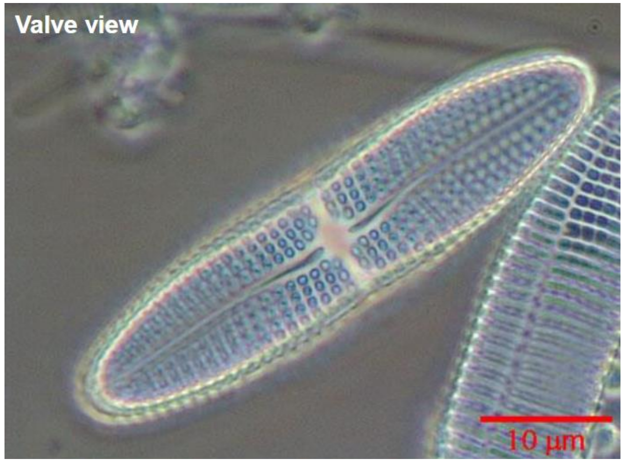
Marine benthic diatoms	1.85			
Achnanthes	1.72	- Linear valve, slightly constricted at the centre - Heterovalvar: one raphid and one araphid valve - Raphe valve with thickened central area - Ornamented with puncta	Class: Bacillarophyceae Subclass: Bacillariophycidea Order: Achnanthales Family: Achnanthaceae	

Table 4: List of identified diatoms in the Inner Nærøyfjord sediments with an abundance of <5%

Freshwater diatoms	Mean occurrence [%]	Marine planktonic diatoms	Mean occurrence [%]	Marine benthic diatoms	Mean occurrence [%]
Melosira	2.24	*Other round diatoms*	1.32	*Suriella*	0.07
Diatomella	1.46	*Porosia*	1.27	*Caloneis*	0.03
Rhoicosphenia	0.95	*Licmophora*	0.14	*Paralia*	0.03
Tetracyklus	0.87	*Asteromphalus*	0.04		
Meridon	0.81				
Cymbella	0.52				
Amphora	0.41				
Gomphonema	0.33				
Mastogloia	0.19				
Nitzschia	0.14				
Pinnularia	0.10				
Denticula	0.06				
Gyrosigma	0.06				

4.3 Distribution of diatoms

The following graphs will show percentages of freshwater, marine planktonic, marine benthic and total marine diatoms in relation to the total counts of diatoms within each subsample. The sediment depth on the y-axis corresponds to the calendar year dating in chapter 4.1. Marine planktonic and marine benthic diatoms are additionally summed up to create graphs with relative numbers of total marine diatoms.

4.3.1 Freshwater diatoms

Freshwater diatoms at **Bakka** are increasing to 64% at 4.5cm, followed by a decrease about 10% at 3.5cm sediment depth (Figure 18). After that low point, the numbers of freshwater diatoms are rising steadily until they reach a maximum of 65% in 1.5cm depth. A recent trend to fewer freshwater diatoms at Bakka becomes visible with a decrease to 60% in the most recent sediment layer.

In the first deepest sediment subsample at 12.5cm of the **Basin**, 55% freshwater diatoms are counted and 60% are reached at 10.5cm and 7.5cm. The lowest number of freshwater diatoms is detected at 9.5cm sediment depth with 51.6% on all counted diatoms. The number increases again, culminating in a climax of 65% at 4.5cm. Above that depth, the number of freshwater diatoms is steadily decreasing by about 10%, resulting in 52.8% freshwater diatoms in the most recent sample.

The distribution of freshwater diatoms at the **Quay** is again, corresponding to marine diatoms, marked by several distinct peaks. Starting with 56% at 5.5cm sediment depth, freshwater diatoms are increasing to 70% at 3.5cm, followed by a sudden decrease to a minimum of 56% at 2.5cm sediment depth. A strong increase of 20% leads to a peak in the number of freshwater diatoms at 1.5cm with 76%. Above that sediment depth, the numbers are only declining, leading to a relative number of 58% freshwater diatoms in the most recent sediment subsample. In general, the number of freshwater diatoms at the Quay is characterized by distinct peaks and strong variations within a short time period. Furthermore, freshwater diatoms are most abundant at the Quay in comparison to the other stations with an average occurrence of 64% on all diatoms (Bakka: mean value of 60.6%, Basin: 57.9%).

Comparing the graphs to each other, a similarity between Bakka and the Quay becomes visible with high and low numbers of freshwater diatoms in almost the same sediment depths. The first peak in common is also visible in the Basin at 4.5cm. Above these 4.5cm, the freshwater diatoms are decreasing, and the continuation of the Bakka graph does not match the continuation of the Basin and Quay graphs anymore.

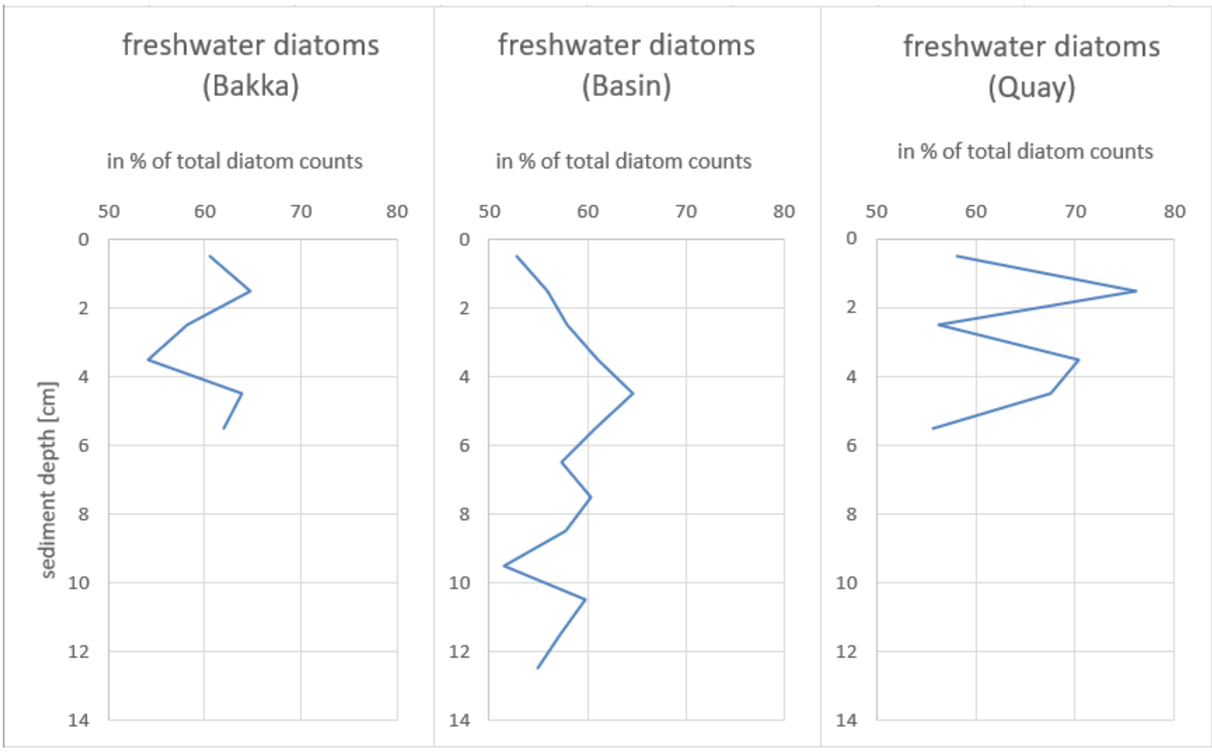


Figure 18: Distribution of freshwater diatoms in Inner Nærøyfjord sediments. Note that percentages start at 50% and end at 80%.

4.3.2 Marine planktonic diatoms

As displayed in Figure 19, the percentage of marine planktonic diatoms in relation to all counted diatoms ranges in general between 20 and 50%. In the deepest sediment layer at **Bakka,** they account for about 30% of all diatoms (left graph, Figure 19), followed by an increase to almost 40% in 3-4cm sediment depth. Coming to upper (accordingly younger) sediment layers, the numbers decrease to 32% between 3.5 and 1.5cm sediment depth. Above 1.5cm a trend to more marine planktonic diatoms at Bakka becomes visible, ending with about 32% in the most recent sediment layer.

In the **Basin**, at 63m depth (middle graph, Figure 19), the relative amount of marine planktonic diatoms varies between 12.5 and 6cm sediment depth around 40%, interrupted by one maximum peak at 9.5cm with 45.5% marine planktonic diatoms of all diatoms. The number of marine planktonic diatoms decreases to a minimum of 32% at 4.5cm depth. Above that sediment depth, marine planktonic diatoms are increasing again to ~40% at 2.5cm, followed by a small low point (38.7%) at 1.5cm sediment depth. As at Bakka, the recent trend in the Basin is towards slightly more marine planktonic diatoms with a percentage of 41% on all diatoms at that station at the sediment surface.

The number of marine planktonic diatoms at the **Quay** (right graph, Figure 19) starts with 42.5% at 5.5cm sediment depth and decreases about 15% until 3.5cm. A maximum is reached 2.5cm sediment depth with over 40% marine planktonic diatoms. This peak is followed upward by a decrease to a minimum of about 20% at 1.5cm sediment depth. As already observed at the other stations, the recent trend of an increase in marine planktonic diatoms can also be seen at the Quay with a strong increase, leading to almost 40% in the youngest sediment layer.

Comparing the graphs to each other it is noticeable that all three graphs follow a similar course: a relative low number of marine planktonic diatoms around 4cm depth, a peak between 2 and 4cm sediment depth, followed by a reduction at 1.5cm and a rise in numbers towards the sediment surface.

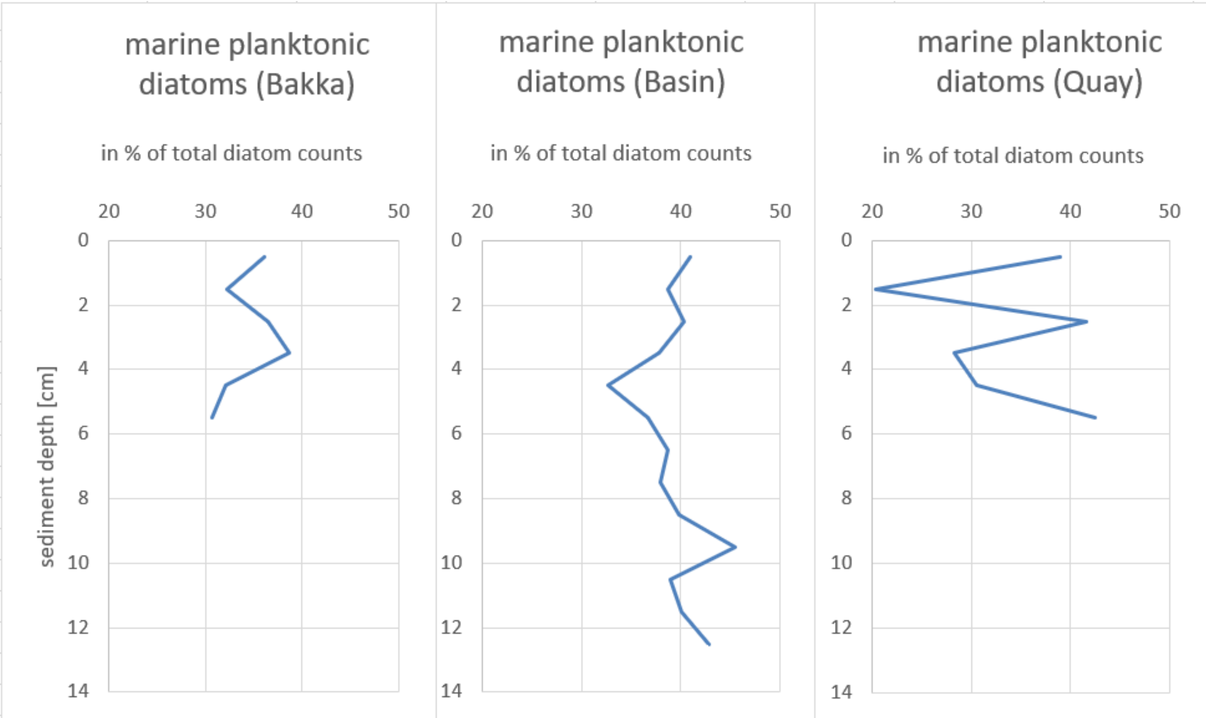


Figure 19: Distribution of marine planktonic diatoms in Inner Nærøyfjord sediments. Note that percentages start at 20% and end at 50%.

4.3.3 Marine benthic diatoms

Marine benthic diatoms are generally represented with significantly lower numbers at all stations than marine planktonic diatoms, with variations between 0 and 5%. Hence, the data might be not as representative as the numbers in the other categories. The distribution of marine benthic diatoms at **Bakka** (left graph, Figure 20) looks similar to the corresponding graph of the marine planktonic diatoms in Bakka, but with lower percentages varying between ~1.5 and 5%. The graph starts with a relative number of 3.4% in 5.5cm sediment depth and is then decreasing to less than 2% at 4.5cm sediment depth. A strong increase of marine benthic diatoms leads to a peak of 5.1% in 3.5cm sediment depth, followed by a minimum of 1.6% that is reached at 1.5cm sediment depth. A trend of slightly increasing numbers of marine benthic diatoms can be seen in the upper sediment layer.

The percentage of marine benthic diatoms in the **Basin** (middle graph, Figure 20) fluctuates a lot between 0.5 and 2% within 12.5 and 3.5cm sediment depth, with two small peaks reaching a bit over 2% at 9.5 and 6.5cm sediment depth. Above the peak over 2% at 6.5cm sediment depth, the numbers of marine benthic diatoms are declining again to 1.4% at 5.5cm sediment depth, followed by a small increase to 1.7% at 4.5cm. A minimum of 0.4% marine benthic diatoms can be seen at 3.5cm, which is followed by a strong increase between that sediment depth and the sediment surface layer resulting in 3.7% of marine benthic diatoms.

Starting with 0.4% at 5.5cm sediment depth, the number of marine benthic diatoms at the **Quay** (right graph, Figure 20) increases a little bit to 0.7% followed upward by a decrease to 0.3% in 3.5cm sediment depth. The highest percentage of marine benthic diatoms at the Quay are found (2%) at more shallow sediment depths.

Even if the graphs look quite different from each other at the first view, all graphs from the three stations are similar in their course: A peak is visible at 4.5cm at the Basin and Quay and marine benthic diatoms reaching their matching peak at 3.5cm at Bakka. The percentages are declining at all stations above that peak, reaching a minimum at 3.5cm sediment depth in the Basin and at the Quay, and at 1.5cm at Bakka, followed by an increase at all stations, even though the increase is by far the most in the Basin.

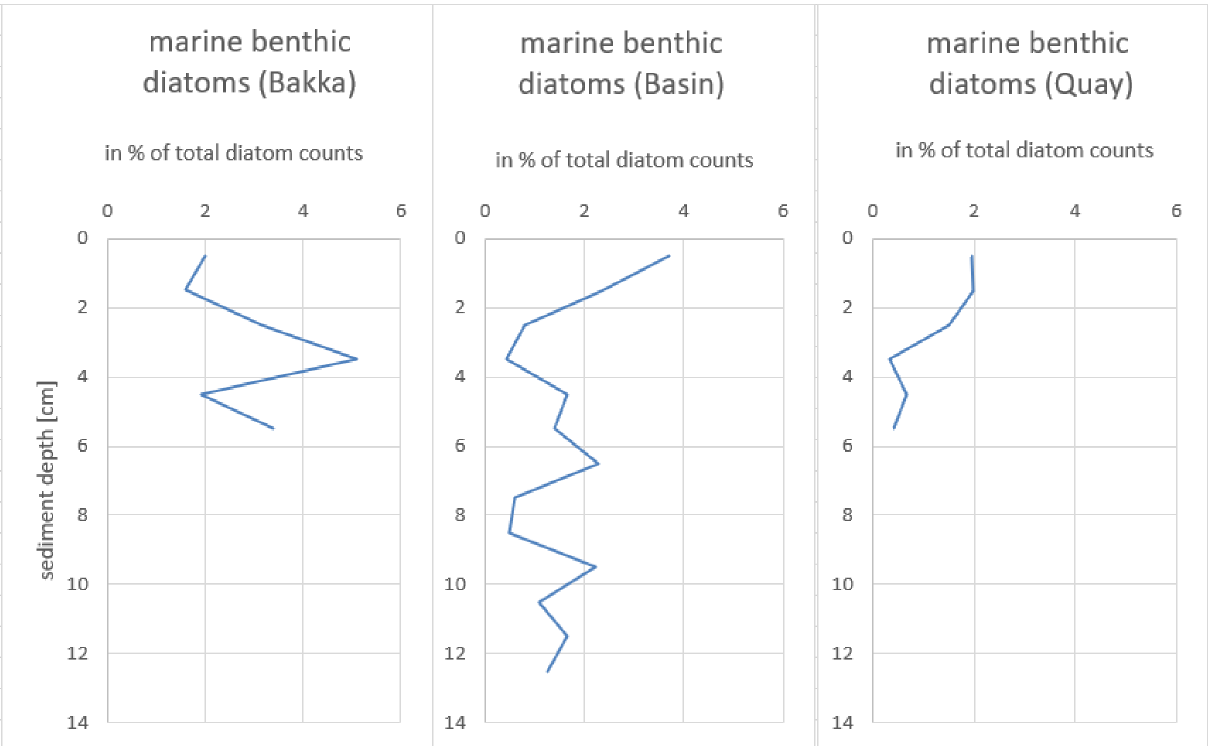


Figure 20: Distribution of marine benthic diatoms in Inner Nærøyfjord sediments. Note that percentages start at 0% and end at 6%.

4.3.4 Total marine diatoms

Due to the processing of the data of counted diatoms as relative numbers, the percentages of total freshwater diatoms and marine diatoms add up to 100%. Hence, the graphs of marine diatoms are opposite to the graphs of total freshwater diatoms.

All graphs of the relative amounts of total marine diatoms (Figure 21) resemble the corresponding graphs of marine planktonic diatoms which can be explained by the low percentage on marine benthic diatoms that adds only a little number on the total marine diatoms in comparison to the marine planktonic diatoms. Hence, the graph of total marine diatoms at **Bakka** (left graph, Figure 21) corresponds to the Bakka marine planktonic graph but with more distinct peaks because marine benthic diatoms at Bakka have similar peaks to the marine planktonic diatoms. The number of total marine diatoms starts with 34% at 6.5cm sediment depth and increases from 4.5cm to 3.5cm sediment depth to a maximum of 43.8%. Above 3.5cm sediment depth, the percentage of total marine diatoms is decreasing to less than 34% at 1.5cm sediment depth followed by a recent trend to increasing marine diatom percentages (38% in the upper sediment layer).

The graph of total marine diatoms in the **Basin** (middle graph, Figure 21) also looks very similar to the one of planktonic diatoms, only with more distinct peaks. In general, the percentage of marine diatoms in the basin varies around 40%, except a maximum of almost 48% in 9.5cm sediment depth and a minimum of 34% at 4.5cm sediment depth. A recent trend to an increase of marine diatoms to around 45% can be seen in the basin, too.

Percentages of marine diatoms are fluctuating a lot at the **Quay** (right graph, Figure 21) with three maxima of about 43% in the deepest sediment layer, in the middle (2.5cm) and in the surface sediment layer, and two minima with 28.6% at 3.5cm and 22.3% at 1.5cm sediment depth. Again, the most recent trend is an increase in the number of marine diatoms.

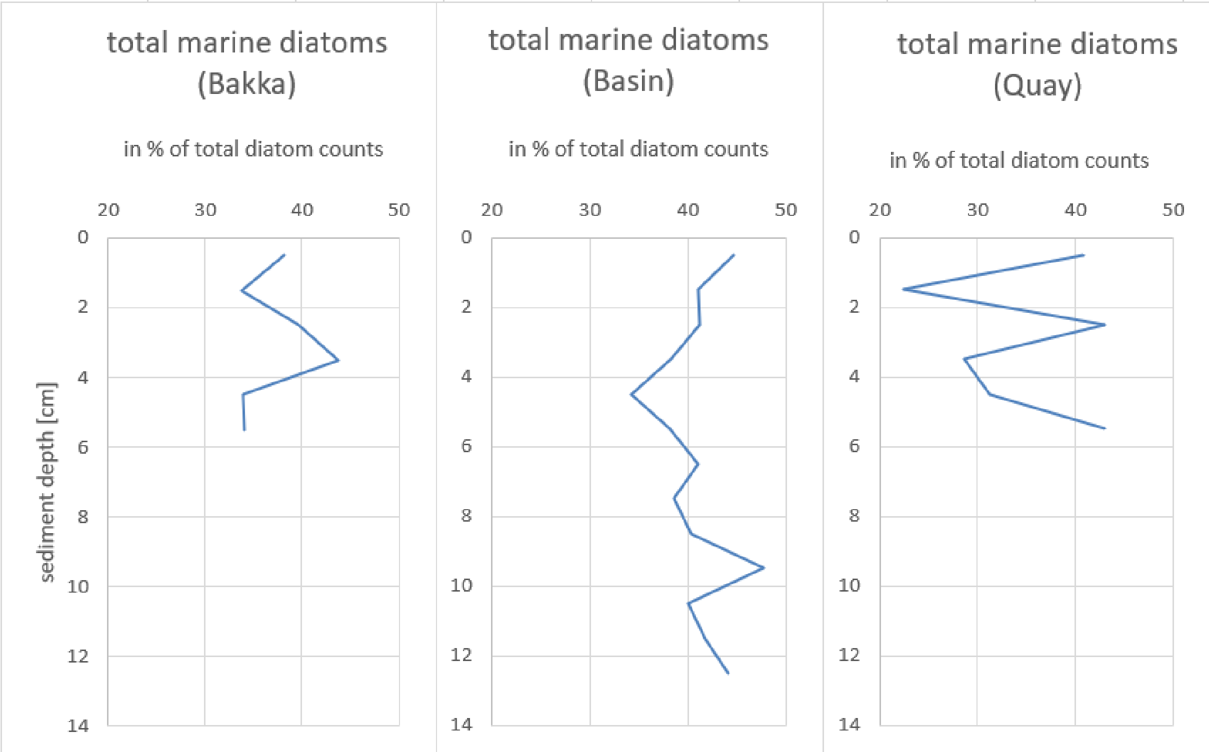


Figure 21: Distribution of total marine diatoms in Inner Nærøyfjord sediments. Note that percentages start at 20% and end at 50%.

4.4 Additional observations

In comparison to the other station, many diatoms of the Eunotia genus (up to 14.5% in 2-3cm) are found in the smear slides of the sediment at the Quay, and their valves are noticeably enlarged (with about 42µm of the length axis and 18µm of the width axis) compared to the size of Eunotia individuals found at the other stations. During the microscopic investigation of the smear slides of the sediments at the Quay, it was noticed that enhanced numbers of colonies of *Fragilaria* and *Diatomella* occur in all sediment depths, while both genera are mainly found as single frustules at the other stations in the Basin and at Bakka. In general, the diatoms frustules in all smear slides at the Quay station are better preserved than at Bakka and in the Basin. Furthermore, many frustules at the Quay station are heavy silicified.

However, the statements must be put into perspective because the aim of the smear slide investigation was to count and determine diatoms to genus level, hence the focus was not on noting sizes of diatom frustules or differentiate in counting between single frustules and colonies. Therefore, further investigations would be necessary, to achieve statistically valid statements about these additional observations.

5. Discussion

The discussion tries to figure out if the distribution of the different diatom genera can be related to local documented environmental and/or climate change*, according to the objectives formulated in Chapter 1.1.

5.1 Freshwater diatom composition as an additional dating

The relative grain size related dating, resulting in sedimentation rates around 1,0cm/year, confirms the relative dating of Dybo et al. (2016) with sedimentation rates around 0,8cm/year.

Given that the freshwater diatom record in fjords depends on the local runoff pattern, as documented by Paetzel and Dale (2010) in recent sediment cores from the Barsnesfjord and Sogndalsfjord, their similar distribution pattern supports the dating of the sediment cores of the inner Nærøyfjord. The dating is transferred to the diatom distribution graphs as shown in Appendix II B.

The Basin core is most reasonable to use for the dating purposes because it is the longest core, and hence has the highest resolution of peaks that can potentially correlate with the precipitation graph of Jordalen. The following dating relationship is based on the peaks in the abundancy of freshwater diatoms that seemingly match the peaks in the precipitation graph as displayed in Figure 22.

Coming from a precipitation peak in 2007 and 2008 (ca. 2200mm/y), that can also be seen as a peak in the percentage of freshwater diatoms in the Basin, the most distinct minimum in precipitation and freshwater diatoms is reached in 2010. This minimum is followed by a precipitation maximum in 2011 (almost 3000mm/y) that is also reflected in a peak in freshwater diatoms between 7.5 and 8.5cm, while it is not possible to clearly determine which of the two (or if possible both) peaks belong to the year 2011. After 2011 the precipitation is decreasing to ca. 2100mm/y which can be seen in less freshwater diatoms in 6.5cm sediment depth. A decrease in precipitation in 2013 is reflected in less freshwater diatoms as well. The year 2015 has the second highest precipitation since 2000 which can also be seen in the highest abundance of freshwater diatoms within the entire Basin sediment core. After 2015 the distribution of freshwater diatoms for some reason does not match the precipitation data anymore, apart from a less strong decrease between 1 and 2cm, which could be referred to a precipitation peak in 2020.

The freshwater diatom peak in the Basin and precipitation peak in 2015 is also visible at Bakka and the Quay, with the restriction that it is not possible to determine whether the first peak (4.5cm sediment depth) at the Quay, the second (3.5cm) at the Quay, or both belong to the year 2015. The precipitation decreases in 2016 which can be seen as a minimum of freshwater diatoms at Bakka and the Quay as well. After 2016 there is one distinct maximum in the precipitation graph, hence the freshwater diatom peak at 1.5cm might as well corresponds to the year 2020. The low precipitation in 2021 can be seen as a decrease in freshwater diatoms at all stations. The sampling took place in the beginning of September, hence not a full year sediment layer accumulated at this time of a year. However, it seems reasonable that 2021 sediments equal approximately one centimetre, because most sediments accumulates in the spring time during the melt season, when sediment material is flushed into the fjord with the meltwater runoff (Cowan et al., 1999).

The minimum of freshwater diatoms at the Quay in 2016 is also found one-centimetre closer to the sediment surface at Bakka. This leads to the assumption of a lower sedimentation rate at the Quay in comparison to the other stations. That can be explained with the energy of the water current originating from the river Nærøydalselvi that might transport material further away into the fjord. Furthermore, mineral matter from the storage of Anorthosite at the Quay can lead to a consolidation of sediment layers in the sampling area. Compacted particles of mineral origin compress loose particles of organic origin and leading to a compression of sediment layers. This theory can be confirmed by x-ray pictures of the sediment cores that show a stronger lamination of the sediment at the Quay in comparison to the Basin and Bakka cores (Figure 22, pictures to the right of corresponding diagrams).

Another dating approach connects the freshwater diatom peak at 1.5cm to the small precipitation peak in 2017. This would result in a higher sedimentation rate at Bakka with two centimetres between 2016 and 2017. A higher sedimentation rate at Bakka is generally possible because the sampling station is located just behind the sill which separates the inner from the outer Nærøyfjord, thus deposits might slide down from the sill to the 38m deep sampling station. Tidal currents, coming from the outer Nærøyfjord, could also transport additional sediment material to the sampling station at Bakka, which would result in a higher sedimentation rate. According to this dating approach the decrease of freshwater diatoms in the most recent sediment layer would belong to the year 2018, where a decrease in precipitation is recorded. Still, it is unlikely that the most recent peak belongs to 2017, because that would indicate a sediment loss from the last three years (equivalent to approximately 3cm) on top of the sediment cores, which could not be observed while sampling the cores.

Considering those arguments against the hypothesis of the peak in 1.5cm sediment depth belonging to 2017, it can be assumed that the maximum in the number of freshwater diatoms in that sediment layer is assigned to the year 2020. Thus, the first described dating approach can be set as the most correct dating for all three sediment cores.

Some differences in the dating of certain peaks are reasonable due to naturally occurring differences in the sedimentation rate at different locations and years.

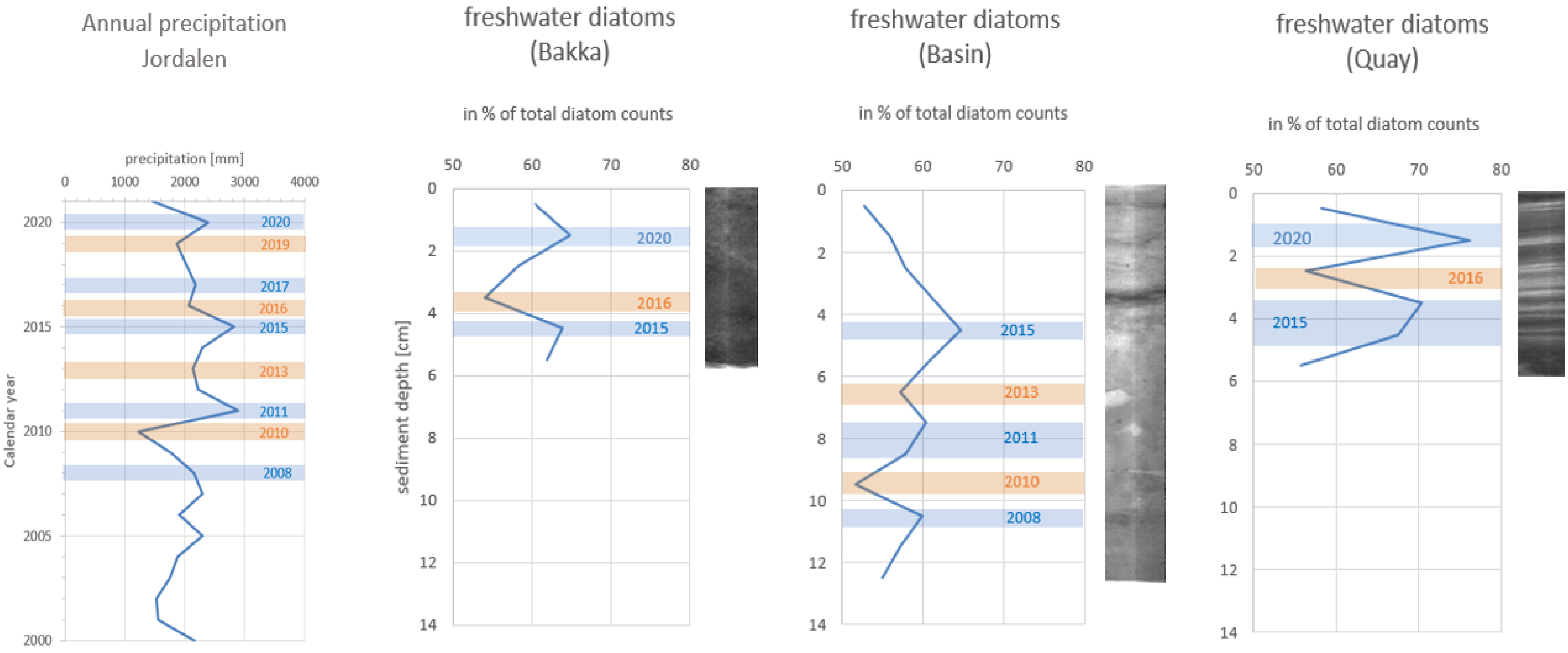


Figure 22: Dating of Inner Nærøyfjord sediment cores based on precipitation, freshwater diatom occurrence and x-ray pictures of sediment cores

5.2 Linking changes in the distribution of the diatoms to their respective sources

While looking for potential sources of certain changes in the diatom distribution, differences in seasonality can be disregarded. The sampling material that is preserved on the smear slides consists of homogenised material of approximately one year sediment, hence different diatom blooms within one year and their reaction of certain events are all represented within one smear slide.

The Nærøyfjord is exposed to tidal currents and changes in the layering of water masses throughout the year. Tidal currents move the intermediate layer which extends 15m from the water surface to the depth of the sill (Aksnes et al., 2019). The shallowest sampling station is at 38m water depth at Bakka, and thus tidal currents will not create turbulences that might swirl the sediment layers. Diatoms that live in the estuarine fjord are most likely adapted to constantly occurring tidal currents, and thus salinity differences caused by tides are not considered when linking changes in the distribution of diatoms to their possible sources.

5.2.1 Source variations of freshwater diatoms

Freshwater diatoms generally have the highest abundance at all three stations. This is most likely caused by freshwater inflow of the river Nærøydalselvi into the inner Nærøyfjord (Figure 1b). The shallow sill at Bakka limits the water exchange and the inflow of more saline coastal water. Hence the inner Nærøyfjord can be characterized as a fjord with low marine water inflow and varying terrestrial runoff (Bianchi et al., 2020), with diatom assemblages dominated by freshwater diatom frustules. Generally, a decline of freshwater diatoms can also be caused by the increase of marine diatoms, because the collected data are relative numbers.

Bakka: The sampling station at Bakka is located further in the direction of the outer fjord and thus the least impacted by the river Nærøydalselvi. Hence, the lowest percentages of freshwater diatoms are expected at Bakka, which is not the case. With averaged 60.6%, there are slightly more freshwater diatom frustules at Bakka than in the Basin sediments (57.9%). Most likely this is caused by freshwater inflow from occasionally existing streams and rainwater runoff from the shores at Bakka, while the Basin is furthest away from shores and from freshwater input that flushes freshwater diatoms into the fjord.

Basin: The freshwater diatom assemblage in the Basin differs significantly from the other stations since 2015: While the freshwater diatom distribution at Bakka and the Quay follows the precipitation graphs, a steady decrease of freshwater diatoms of more than 10% is recorded in the Basin between 2015 and 2021. One reason for that might be a decrease in precipitation in the last six years. Looking at the precipitation data, this theory is not applicable. However, the distribution of the total annual precipitation changed since 2015, resulting in very dry springs and summers (e.g., 2.4mm precipitation in April 2019) and single months with high precipitation (e.g., 627.0mm in December 2015). To set these values into relation: the mean monthly precipitation since 2000 is 169.7mm. If the summers are dry, rivers and streams carry less water, leading to less discharge in the fjord, thus fewer freshwater diatoms. This can be an explanation for a decrease in freshwater diatoms, but due to its short distance to the river outlet, less freshwater diatoms would be expected at the Quay as well, which is not the case.

On the other hand, there are more months with exceptional high precipitation since 2015, resulting in rivers and streams having a higher flow velocity, thus carrying high amounts of water within a short time. Higher velocities lead to stronger outflowing currents and therefore freshwater diatoms carried in the water are getting flushed further into the fjord, away from the Quay sampling station. Based on this, it could be assumed that there are also more diatoms flushed in the Basin in months with exceptional high precipitation. However, looking at the distribution of the precipitation, it is noticeable that extreme precipitation since 2015 only occurs between September and January. Due to the location and its high latitude, irradiance is very low in the late autumn and winter months. Hence, diatom blooms are the strongest in spring and summer time (Paulino et al., 2018). When there is no diatom bloom in freshwaters, there are less diatoms in the water column. Thus, even when there are months with exceptionally high precipitation but they do not correlate with diatom blooms, only a few diatoms are expected to be exported into the fjord (Lalande et al., 2020). Considering that, a changing distribution of annual precipitation, with noticeable dry summers, is a reasonable explanation for the steady decrease of freshwater diatoms in the basin. Dry summers and extreme precipitation events are consequences of climate change, concerning many parts of the world, including northern Europe (Seneviratne et al., 2012; Tabari, 2020). Thus, the steady decrease of freshwater diatoms in the Basin can be considered to potentially indicate the effect of ongoing climate change in the Nærøyfjord.

Quay: Comparing the freshwater diatom distributions of all stations to each other it is noticeable that peaks at the Quay are more distinct than at Bakka and in the Basin. The Quay region is highly impacted by the river outflow, which is reflected in the highest abundance of freshwater diatoms of all stations: 64% of all counted diatoms at the Quay are freshwater diatoms. Hence variations in precipitation directly influence the freshwater input and have a stronger impact on the diatom distribution at the Quay than at other stations. Tidal currents in the intermediate layer and a potential transport of marine diatoms from the outer fjord buffer the impacts from precipitation and river runoff at the other stations.

Another noticeable observation is a distinct peak in freshwater diatoms in the year 2015 at all stations. This can either be explained by generally high precipitation or a flood event in that year. Looking at precipitation graphs, an increased precipitation is visible in 2015. Furthermore, a so-called century flood in October 2014 (Langsholt et al., 2015) transported high amounts of terrestrial material to the shores of the Nærøyfjord. Heavy rainfalls in 2015 (Figure 8) probably cause a flushing of the deposited flood material with attached freshwater diatoms into the fjord. Exceptional high snowfalls in the winter of 2014/15 (The Norwegian Meteorological Institute, 2021) additionally leads to an increased freshwater inflow as soon as the springtime melting starts. This favours the transport of material with attached freshwater diatoms into the Nærøyfjord in 2015.

The highest number of freshwater diatoms at all stations in all years is observed at the Quay in 2020 with over 76%. Generally, distinct peaks in the occurrence of freshwater diatoms might be caused by heavy precipitation within a short period of time. Looking at the weather data in 2020 no month or day with exceptional high precipitation can be observed. Nevertheless, a high annual precipitation in 2020 (ca. 2400mm) can also lead to increased freshwater, hence freshwater diatom, input. This trend can also be observed at Bakka in sediment depths corresponding to the calendar year 2020.

Another reason for the exceptional high occurrence of freshwater diatoms at the Quay that year might be an avalanche that came down in January 2020 close to the village Gudvangen (Fauske, 2020). Together with the snow, also terrestrial matter and attached freshwater diatoms are transported either close to the shores or directly into the fjord. In case of the avalanche in January 2020 it is not possible to say whether the snow and its carried material reached the fjords water or only the surrounding shores. In the latter case, freshwater diatoms would secondarily be flushed into the fjord by precipitation events later that year.

Preliminary conclusion: Concluding the aspects mentioned before, it can be said that the decrease of freshwater diatoms since 2015 might be a proof for ongoing effects on the Nærøyfjord and its surrounding area caused by climate change. Furthermore, freshwater diatoms in fjord sediments seem to be suitable indicators for past events on land affecting the fjord (e.g., floods, landslides, or avalanches).

5.2.2 Source variations of marine planktonic diatoms

Generally, the percentages of marine planktonic diatoms evolve opposite of the freshwater diatoms because all results of diatom assemblages are relative numbers that add up to 100%. Small deviations occur due to marine benthic diatoms that are separately counted.

Diatoms are reacting very sensitive to changing environmental factors, like salinity, temperature, or ice coverage (Smol & Stoermer, 2010). Therefore, beside precipitation events leading to more freshwater diatoms, and thus fewer marine diatoms, the reason for the decline or increase of marine planktonic diatoms might additionally be caused by changes in the marine environment.

Bakka: A noticeable peak of marine planktonic diatoms is observed in 2016, especially in Bakka and at the Quay but also partly in the Basin. Investigating the distribution of the genera, it is noticeable that *Thalassiosira* species account for over 30% of all diatoms at Bakka in 2016. To set this into relation: The mean occurrence of *Thalassiosira* species at Bakka is 22.5%. Even if the diatoms are only determined up to genus level, their morphology indicate that the main fraction of the genus *Thalassiosira* belongs to the *Thalassiosira nordenskioldii* species. This species favours cold water conditions with temperatures up to maximum 8.5°C (Rynearson et al., 2020). Looking at available water temperature data (Grieger, 2021), a surface water temperature decrease to less than 8°C can be observed. This suggests favourable growth conditions for *Thalassiosira nordenskioldii*.

Surface temperatures varying depending on the air temperature, thus measurements of the surface water temperature are only the documentation of a temporary situation. However, a decrease of water temperature is measured even in 20m water depth. *Thalassiosira nordenskioldii* is a planktonic diatom, thus occurs in the photic zone of the open water column where the most light is available, which is between the water surface and approximately 20m depth in the Nærøyfjord (Bollingberg, unpublished/2022). Therefore, the low temperature in 2016 can reasonable be used as an approach to explain the high number of *Thalassiosira* at Bakka in that year.

Basin: The distinct minimum of marine planktonic diatoms in the Basin in 2015 correlates with the maximum of freshwater diatoms that are flushed in 2015 with the remaining debris of the century flood 2014. Looking at the distribution of the genera, noticeable less *Thalassiosira* individuals are observed. The mean occurrence of *Thalassiosira* species of all counted diatoms in the Basin is 20.7%, while only 11.7% of the counted diatoms in 2015 belong to the *Thalassiosira* genus. Some *Thalassiosira* species favour ice coverage (Smol & Stoermer, 2010) and the Nærøyfjord, unlike most Norwegian fjords, has the tendency to be periodically ice covered in wintertime (Claudino-Sales, 2019). However, there is no available data about ice coverage of the fjord in 2015. Accordingly, no clear statement can be made on this issue.

According to Smol and Stoermer (2010), *Thalassiosira* diatoms occur more frequently during storms and flood events. Hence, more *Thalassiosira* individuals are expected to occur in 2014, which can be confirmed by the existing data of 28.6% *Thalassiosira* in the Basin in 2014. There are no exceptional flood or storm events recorded in 2015. Thus, it could contribute to unfavourable growth conditions for *Thalassiosira* species.

In addition to that, the genus *Thalassiosira* has salinity preferences varying between 17.94 and 37.76 PSU (EOS, University of British Columbia, 2022). The surface water salinity of the inner Nærøyfjord reached a minimum of 3.73 PSU in 2015 (Grieger, 2021), which is below the salinity preference of *Thalassiosira*. This value must be assessed critically, as it is only a salinity at a given instant. Increased freshwater input or outgoing tidal water currents at the sampling time can influence the measured salinity, resulting in a very low value. However, marine planktonic diatoms occur not only at the water surface but also deeper in the water column, where the salinity still ranges around 33 PSU at 20m depth in 2015 (Grieger, 2021). At this depth, the decline of salinity can be recorded, too, compared to previous years, which might be a reason for less *Thalassiosira* in the Basin sediments of 2015.

In principle, the decline of the *Thalassiosira* genus, and at the same time the minimum in marine planktonic diatoms, may be due to low salinity and less storm or flood events. However, the increased flush-in of freshwater diatoms with the remnants of the century flood has probably a bigger impact on the decrease of marine planktonic diatoms in 2015, due to its negative relation. Unfavourable growth conditions, such as low salinities, could additionally decrease the number of marine planktonic diatoms in the Basin in 2015.

Quay: Looking at the Quay sampling station, it is unlikely that decreased water temperatures (as at Bakka) explain the peak in marine planktonic diatoms in 2016. Due to its proximity to the mouth of the river it is most likely rather impacted by precipitation and consequently the ratio of increasing freshwater diatoms.

An exceptional low number of marine planktonic diatoms (20.4%) is found at the Quay in 2020. An increased precipitation in 2020 can explain the general leak of marine planktonic diatoms due to increased numbers of freshwater diatoms. But the occurrence of 20.4% marine planktonic diatoms is the lowest abundance at all stations in the entire core, dating back to 2008. Therefore, significantly higher precipitation would be expected as a reasonable explanation for such few marine planktonic diatoms, than it was the case in 2020.

Regarding the distribution of the genera at the Quay in 2020, noticeably few individuals are detected of the genus Sceletonema, with only 4.4% on all diatoms in the associated smear slide. For comparison, 17.4% of all diatoms belong to the *Sceletonema* genus in 2019 and 15.4% of all diatoms belong to *Sceletonema* in 2021. Enhanced precipitation in 2020 and thus more run-off from land leads to a more pronounced freshwater layer. This results in a stronger stratification which is, according to Syvitski et al. (1987), an unfavourable condition for *Sceletonema* species. Together with the negative relation with the increase of freshwater diatoms, a precipitation effect might be a reasonable explanation for the exceptionally low abundance of marine planktonic diatoms at the Quay in 2020.

Preliminary conclusion: Salinity differences influence the occurrence of marine diatoms: higher salinities suggest the increased occurrence of some marine planktonic diatoms. The freshwater inflow does not only supply the fjord with freshwater diatoms but causes a stratification of water, which negatively influences the growth conditions of some marine planktonic diatoms.

5.2.3 Source variations of marine benthic diatoms

Marine benthic diatoms are generally the least abundant diatoms in the sediment assemblages. However, they show some distinct distribution patterns that should be discussed.

Bakka: A peak with 5.1% of all counted diatoms is observed at Bakka in 2016. The sampling station at 38m water depth most likely does not receive enough light to provide favourable growing conditions for marine benthic diatoms, although the exact depth of the euphotic zone in the inner Nærøyfjord is not known. There is no available data about irradiance in the inner Nærøyfjord in 2016, therefore no statement can be made about this hypothesis.

If *in situ* growing condition can be excluded, marine benthic diatom frustules that are found in the sediments in 38m water depth need to be transported from their growing habitat close to the shores before depositing. A transport of the frustules might happen due to erosion.

Oppenheim (2014) assessed erosion as a negative influencing factor on the Nærøyfjord with an increasing trend. Generally, erosion in the inner Nærøyfjord can be caused by waves produced by cargo- or cruise ships and ferries that are entering the fjord daily. Episodic high energy events, like ship generated waves, are even more effective at transporting sediment than wind generated waves (McConchie & Toleman, 2003). Hence ship traffic probably has mayor impacts on erosion in the Nærøyfjord.

Floods with terrestrial material suddenly entering the fjord can also cause erosion, as well as avalanches. All listed sources of erosion are classified as factors with increasing trends negatively affecting the Nærøyfjord (Oppenheim, 2014).

No data about ship traffic is available for the year 2016, that could explain the distinct peak in marine benthic diatoms at Bakka. However, a big avalanche came down close to Bakka in the beginning of 2017 (Brakstad & Svarstad, 2017) and, according to the World heritage convention (2005), the surrounding slopes are very active with frequent avalanches occurring in the wintertime. Due to the calculated sedimentation rate of ±1cm/year it is reasonable, that the beginning of 2017, and thus the exceptional big avalanche, is captured in the sediment layer of 3-4cm sediment depth. However, it is not possible to determine exactly where the avalanche came down and how much snow and debris was deposited into the fjord. Anyway, the results of the thesis on hand clearly point out a distinct peak in marine benthic diatoms at Bakka in 2016, thus it most likely is an indication of increased erosion, probably caused by either one big avalanche or several small ones.

A strong decrease of marine benthic diatoms at Bakka is recorded in the sediments above the peak of 2016. Only *Achnanthes* species are contributing to marine benthic diatoms since 2016. Investigations of benthic communities by Boer et al. (2014) point out that the *Achnanthes* species decrease strongly at increasing water temperatures. Regarding the water temperature trendlines in the inner Nærøyfjord there is a steady increase in water temperature since the beginning of records in 1920 (Grieger, 2021). These are unfavourable conditions for *Achnanthes* which can explain its decrease.

However, the temperature is probably not only decreasing at Bakka but everywhere in the inner Nærøyfjord, and marine benthic diatoms are not decreasing at the other sampling stations. As already pointed out, erosion is an influencing factor of the transport of marine benthic diatoms to the sampling station. Hence, less benthic diatoms might indicate less ongoing erosion at the habitat of *Achnanthes* species. Comparing the decrease with local changes, it is noticeable that the introduction of a diesel-electric hybrid powered catamaran ferry in 2016, that operates frequently between Flåm in the neighbouring Aurlandsfjord and Gudvangen (Ship Technology, 2018), correlates with the reduction of marine benthic diatoms at Bakka. Thus, it is possible that the results of the benthic marine diatom investigation indicate a reduction of erosion on shore zones by the usage of the passenger-catamaran ferry that replaced a conventional car-ferry.

Basin: There is a steady increase of marine benthic diatoms in the Basin since 2016, that is partly visible at the Quay too. Generally, the increase could be caused by deeper light penetration and thus the expansion of the marine benthic diatom's habitat in deeper benthic areas. This would result in more total marine benthic diatoms in the fjord, which is not verifiable with the existing data, because these are relative numbers. However, "deeper benthic areas" would not include the sampling station itself at 63m depth due to the fjord's turbidity and the absence of light. Climate data about monthly sun hours at the Jordalen weather station show that there are months with more sun hours since 2018 in comparison to previous years (The Norwegian Meteorological Institute, 2021). Based on this hypothesis, more marine diatoms would also be expected at Bakka, which is not the case.

Changing salinities can also potentially cause a changing distribution in the diatom assemblage. Marine benthic diatoms in the Basin since 2016 are mainly represented by *Achnanthes* species, which have salinity optima ranging between 17 and 36 PSU (Parr et al., 2014). Accordingly, changing salinities might contribute to the steady increase of marine benthic diatoms in the Basin since 2016. The surface salinity is increasing between 2015 and 2019 from 3 to 27PSU and down to 18PSU in 2019. In comparison to the years before 2015, there are indeed higher salinities and thus favourable conditions for *Achnanthes* species.

The genus *Achnanthes* does not only occur in the benthos close to the surface, but also in the deeper benthos, if there is enough light available. The salinity at 20m water depth is increasing too, with a peak of 33PSU reached in 2019 (Grieger, 2021). However, the surface salinity can still be taken into account, because Achnanthes species most likely occur there as well as on the benthos at 20m water depth. Thus, changing salinities since 2015 can reasonably contribute to the steady increase of marine benthic diatoms in the Basin.

Achnanthes uses high amounts of silicate (Boer et al., 2014), so silicate concentrations also need to be considered as a potential reason for the occurrence of marine benthic diatoms. Looking at the silicate record in the discussed time period (Matthias Paetzel, 2021. *Personal communication*), no matching trend to the increase of *Achnanthes* species is observed.

Also, changing temperatures might influence the abundance of *Achnanthes*. The water temperatures in the inner Nærøyfjord are steadily increasing since 2016, but at no time since the first year that is represented in the sediment core they were below 2.6° or above 18.5°C, which are the temperature minima and maxima for *Achnanthes* (Parr et al., 2014). Hence, the factor temperature probably has no, or only a limited influence on the steady increase of marine benthic diatoms in the Basin since 2016.

Because it is not a single peak, but rather a steady increase in marine benthic diatoms, single events like landslides or avalanches, can be ruled out. Especially in the basin, where particulate material and diatom frustules are deposited from all sides, erosion has a major impact on the number of occurring marine benthic diatoms in the sediment. Generally, it might be possible that increased wake waves of ships (produced by the ship's propellor) lead to more erosion at the shores and thus increased transport of marine benthic diatoms in the basin. Hence, either more ships in total or ships with more powerful wake waves might enter the Nærøyfjord since 2016. A combination of both factors could also influence the erosion rate. According to Erling Oppenheim (2014), anorthosite mining activities are increasing and thus more cargo ships are expected to enter the fjord on a regular basis. This would mean more wake induced waves and thus more erosion.

The UNESCO nomination paper of the World heritage convention (2005) additionally stated that it is uncertain whether waves generated by tourist vessels in the fjord create erosion in the shore zones. On the other hand, speed limits for all ships entering the fjord were established in 2002 (Terrje Eggum, 2015) which should result in less disturbances, hence less erosion and less benthic diatoms in the basin on a long term scale. Additionally, old car ferries which entered the fjord daily are fully replaced by catamaran ferries since 2018 (Ship Technology, 2018). The usage of catamarans suggest a decrease of erosion at the shore zones (Jonason & Stumbo, 1993).

These facts rather suggest a development of erosion the other way around: living conditions for near-shore communities improve with decreasing speed and reduced wake waves (Meyers et al., 2021). Accordingly, if there are less near shore disturbances, marine benthic diatoms find better growing conditions and occur in higher numbers (Shaffer & Sullivan, 1988).

The redistribution of precipitation due to climate change (resulting in more frequent short-term precipitation in Norway (Norwegian Meteorological Institute, 2017)) leads to occasionally high water runoff from land. That causes periodic erosion at shore zones which transports more marine benthic diatoms in the basin since 2016.

Due to the implementation of the speed limit in 2002, less near-shore disturbances (thus more marine benthic diatoms) might be expected in earlier years than in 2016. However, investigations show that five years after its implementation, the vegetation in shore zones just was in the process of being restored (Terrje Eggum, 2015). If that needs five years already, a full restoration of the original environment, accompanied by increased growth of benthic diatoms, most likely take several more years. Therefore, it is reasonable to interpret the increase of marine benthic diatoms since 2016 as a sign of improved living conditions for marine benthic communities at shore-zones. Thus, the steady decrease of marine benthic diatoms in the Basin since 2016 might be a proof for the succession of the implementation of a speed limit in the inner Nærøyfjord.

Quay: In general, the least marine benthic diatoms are found at the Quay, with an average of 1.1% of all counted diatoms in all sediment depths at that station. The low abundance is most likely caused by the proximity to the quay and the river mouth. Disturbances due to arriving and departing ships as well as outflowing river currents cause unfavourable growing conditions for marine benthic diatoms. The extent to which this applies is not verifiable with the available data.

A strong lamination, as captured in the x-ray picture of the sediment core (Figure 22), indicates an increased input of mineral matter in the Quay region, where mined Anorthosite is loaded onto cargo ships. This contributes to disturbances at the benthos and most likely creates unfavourable conditions for marine benthic diatoms at the Quay.

The exceptional low occurrence of marine benthic diatoms in 2015 (0.3%) can additionally be explained with the century flood. During heavy precipitations, when debris from the flood got flushed into the fjord in 2015, the benthic diatoms growing at the Quay are probably transported further into the fjord and disturbances from entering material additionally create unfavourable growing conditions.

Looking at the data of marine benthic diatoms in the basin in 2015, a slight increase is recorded, which would confirm the hypothesis of marine benthic diatoms from the Quay are getting transported further into the fjord into the Basin with remnants of the century flood.

Preliminary conclusion: Marine benthic diatoms are generally suitable to indicate erosion at shore zones. The living conditions for them improve with less long-term erosion, while permanent disturbances of the benthos create unfavourable growing conditions. The design of operating ships, their speed, the frequency of arrivals and departures of ships and deposition of material into the fjord while loading cargo ships can be associated with the abundance of marine benthic diatoms in the Nærøyfjord.

5.2.5 Source variations of additional observations

One notable observation is the increased occurrence of *Fragilaria* and *Diatomella* colonies in all sediment depths at the Quay, while those diatoms are rather found as single cells at the other stations. Solitary cells are dominating during nutrient-limited conditions because the nutrient uptake per single cell in colonies is decreasing (Kenitz et al., 2020). Hence, diatoms living in colonies in nutrient poor conditions have a disadvantage compared to solitary cells in the same conditions. Therefore, the occurrence of many colonies might indicate nutrient rich conditions. On the other hand, existing variations in cell shapes complicate that theory. For example, one chain of small cells has a similar nutrient flux as one large elongated cell of the same species (Kenitz et al., 2020). Both *Fragilaria* and *Diatomella* are freshwater diatoms, so there is no data about nutrient conditions on land close to the fjord available. Colonies are heavier than single cells, so they sink faster to the ground. Hence, coming with freshwater input from land, colonies are found more frequently close to the river outlet at the Quay sampling station than at the other stations.

The enhanced occurrence of very long *Sceletonema* colonies at the Quay can be considered as a resistance against turbulences (Kenitz et al., 2020). After the natural delta of the Nærøydalselvi became channelized, the outflowing river current strongly increased (Klamer, 2017). Also, cargos ships and ferries create turbulences with their ship propellers. These turbulences might force *Sceletonema* cells to form colonies to avoid being carried away.

Another observation at the Quay is the occurrence of bigger and heavier silicified *Eunotia* frustules. The increased sizes might be caused by enhanced nutrient conditions (Kenitz et al., 2020). But there is no information about nutrient conditions available in the inner Nærøyfjord, thus it is not possible to verify that hypothesis. The reproduction might also influence the size of diatoms. Bigger frustules can generally indicate more ongoing sexual reproduction than asexual, because there is no loss of cell size throughout the generations (Smol, 2010). There is no literature found about favourable conditions for the sexual reproduction of *Eunotia* species and thus no conclusion about conditions in the water can be drawn from this.

The heavy silicification can be caused by a higher availability of silica at the Quay that diatoms use to stabilize their frustules (Jeon, 2004). Silica is composed of Silicon (Si) and Oxygen, hence available measurements of Silicon concentrations in the inner Nærøyfjord (Bollingberg, unpublished/2022) are reasonable to use as an explanation approach for the heavy silicification of frustules. The mean Silica concentration in all sediment depths at the Quay is 133.69 (all values come without a unit due to the usage of the x-ray fluorescence method that investigates the mineralogy and describes a proportion). Compared to the Basin it is a high value that can explain heavy silicification of diatom frustules, but the mean concentration of silicate at Bakka is even higher with 151.96. Thus, heavy silicified diatom frustules would be expected at Bakka too, which is not the case. The heavy silicification of *Eunotia* frustules at the Quay might have other reasons. Further research would have to be done to find out more about this observation.

5.6 Error discussion

Scientific investigations are prone to potential errors that can occur along the research. Within the underlying scientific research on which this thesis is based, errors can have occurred too. Starting with the sampling in the Nærøyfjord on September 1st, 2021, it is possible, that sediment layers were disturbed while the box corer was hitting the sediment, thus the sediment samples might be contaminated with younger or older material. When towing the filled box corer up to the water surface, sediment can also get lost. However, if this would be the case, then only very liquid sediment material could have been lost along the way up, because the box corer was still completely closed when it was towed up to the deck of the boat. Also, the dating is reasonable applicable and does not indicate errors of sediment layers worth mentioning that were lost.

While taking subsamples, no complications occurred and due to the simpleness of making smear slides no noticeable mistakes were made. Even if there is only a very thin sediment layer on one smear slide, it still happens that diatoms are overlying by each other or by other particles. But due to their high abundance, the error of missing out individuals can be rejected.

The laboratory work was done by two persons, which can be accompanied with potential differences in determining the diatoms. However, this error can be rejected, because both persons have the same pre-knowledge about diatoms, used the same pictures to identify the genera and investigated individuals together if uncertainties about the genus determination occurred. Furthermore, all smear slides of one station were always microscopically investigated by one person, without switching persons within the investigation of one station. Still, a wrong determination of some individuals is possible. This error is minimized by counting to a minimum of 600 individuals per smear slide. Marine benthic diatoms were in the minority, hence even the wrong determination of one individuum would have an impact on the results of marine benthic diatoms. At all times, the two persons investigating the smear slides were aware of that potential error, hence if uncertainties about, especially *Achnanthes* species, occurred, the diatom was counted as “other diatom” instead of “marine benthic diatom”.

The dating is also prone to errors, but another dating approach is only explainable with a huge loss on sediment on top of the core, which was already rejected. Additionally, the distributional graph of freshwater diatoms is following the peaks of the precipitation graph which can be considered as a confirmation of the coarse silt versus precipitation dating.

While processing the data, mistakes in transferring the numbers of the genera in each smear slide into excel sheets could have been made. Two persons independently checked the transferred data to minimize that potential error in this step.

When evaluating and discussing the results of the study only abiotic factors were considered. Biotic factors, like herbivores, that influences the occurrence of marine diatoms (Nicotri, 1977) are not taken into account because there is no data available about biotic factors influencing the diatom assemblage in the inner Nærøyfjord.

5.3 Summary and future perspective

Figure 23 summarises the environmental and climate change interpretation that can be drawn from the diatom composition of the inner Nærøyfjord sediments.

The freshwater inflow is the main supply of **freshwater diatoms** into the Nærøyfjord because the brackish fjord water is too saline to provide living conditions for freshwater diatoms. Precipitation and thus rivers, streams, and run-off from land are the main sources of the delivery of freshwater diatoms into the fjord. Events which occur on land and influencing the fjord, e.g., avalanches, landslides, and floods additionally contribute to the supply of freshwater diatoms into the inner Nærøyfjord (Figure 23).

The steady decrease of freshwater diatoms in the Basin since 2015 can be interpreted as a sign of ongoing effects of climate change, which are expressed in the form of exceptional dry months on the one hand and very high precipitation within short periods of time on the other hand.

The occurrence of **marine planktonic diatoms** depends (apart from the negative relation to freshwater diatoms) on the specific genus and its preferences. Based on the high abundance of *Thalassiosira* and *Sceletonema* as marine planktonic diatoms, it is reasonable to use the preferences of that genus to generalize connections between environmental parameters in the fjord and the abundance of marine planktonic diatoms. Increasing water temperatures seem to negatively influence the occurrence of marine planktonic diatoms. Also, the stratification of the fjord's water seems to influence marine planktonic diatoms: A less stratified water column due to very dry summers favours the occurrence of marine planktonic diatoms.

Some marine planktonic diatoms might additionally flush in with fjord water currents that transport marine water from the outer Nærøyfjord region into the inner Nærøyfjord (Figure 1b). Tidal currents in the brackish and estuarine circulation in the intermediate water layer also provide the inner Nærøyfjord with nutrients (Bianchi et al., 2020) that might also influence the occurrence of the marine planktonic (and benthic) diatoms. However, it is not possible to make a statement about that with the available dataset, hence nutrients are not shown in Figure 23. Further related research would be necessary to establish the relation of nutrients to the occurrence of marine diatoms.

The same applies to turbidity and irradiance. Both are possible factors that influence the occurrence of marine diatoms and should be considered because the depth and intensity of light penetration of the water is a limiting factor for the growth of diatoms. However, it is not possible to record the influences of turbidity and irradiance with the available data set.

Erosion has an impact on the occurrence of **marine benthic diatoms**. Speed limits for ships in the Nærøyfjord (Figure 23) and a ships shape with less water resistance reduce near-shore benthic erosion which favours the growth of marine benthic diatoms. Frequent disturbances (as in the Quay region) are reflected in less marine benthic diatoms.

The marine benthic diatom assemblage in the inner Nærøyfjord is dominated by *Achnanthes*. Increasing water temperature leads to the decline of the genus, and thus marine benthic diatoms in general, while *Achnanthes* prefers favours higher salinities.

Marine benthic diatoms do not grow in the depths of the sampling stations due to the lack of light. Short-term events, like landslides, heavy precipitation over a short time or avalanches will transport them into deeper water zones of the fjord. Thus, the positive relation of marine benthic diatoms with avalanches and landslides, as illustrated in Figure 23, refers to the caused transport and occurrence of the frustules at the sampling depth, but not to an influence of the actual marine benthic diatom growth.

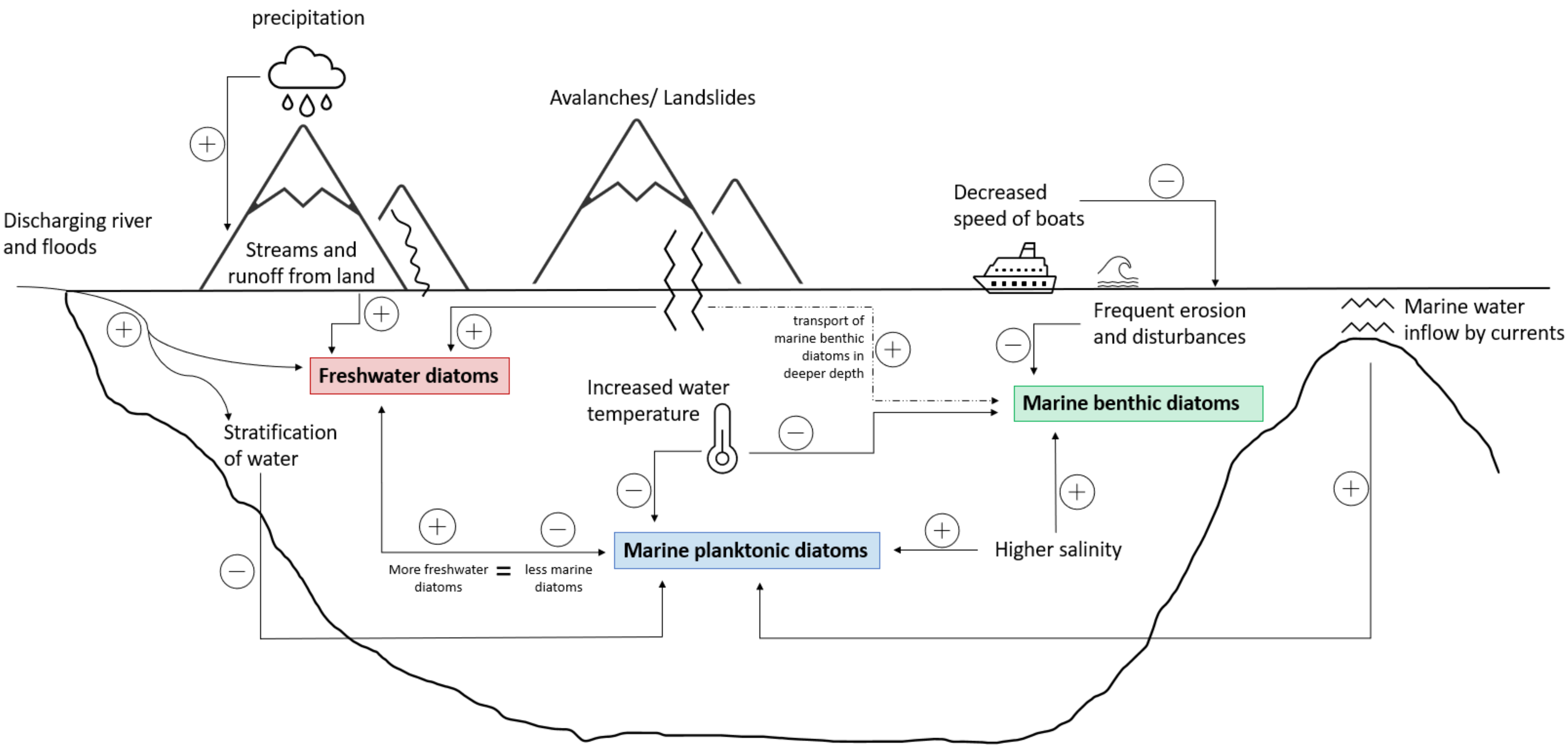


Figure 23: Summarized sources that influence the occurrence of freshwater and marine diatoms in the inner Nærøyfjord. A "+" means "leads to an increase of…". A "-" means "leads to a decrease of…". Continuous arrows indicate the shown relations between different parameters and/or the occurrence of diatoms. Stippled arrows indicate an influence on the transport of diatom frustules and thus indirectly the occurrence of diatoms.

With an ongoing climate change, and thus more periods of drought and more heavy short-term precipitation (Norwegian Meteorological Institute, 2017) the percentage of freshwater diatoms in the inner Nærøyfjord will probably further decrease in the future.

The implementation of a speed limit for ships in the Nærøyfjord is already a good approach to protect near-shore benthic communities against erosion. If further restrictions, e.g., a limit for the number of operating vessels or restrictions for sizes of vessels, would be established, the amount of marine benthic diatoms would probably further increase in the future.

Generally, preferences in environmental conditions vary between different diatom species within one genus. Accordingly, it would be necessary to determine the diatoms in the sediment samples to species level to narrow down the sources for the change in the diatom distribution in the inner Nærøyfjord sediments in the last 20 years.

6. Conclusion

(1) Based on the distribution of coarse silt in sediments of the inner Nærøyfjord and its comparison to precipitation, it is possible to date sediment cores and calculate a sedimentation rate of ±1cm/year for the inner Nærøyfjord. The occurrence of freshwater diatoms confirms the dating. Peaks in the distribution can thus be assigned to certain years, reaching back to the year 2008.

(2) The existing dataset reveals several changes in the distribution of the diatoms in inner Nærøyfjord between 2008 and 2021. Beside several minima and maxima in the occurrence of freshwater diatoms, marine planktonic and marine benthic diatoms, especially the steady decrease of freshwater diatoms since 2015 and the increase of marine benthic diatoms since 2016 are noticeable.

(3) Due to the analysis of the results in relative numbers, linking changes in the distribution of the diatoms to their respective sources is somewhat limited possible. Especially changing environmental factors in the water column are difficult to detect without absolute numbers of marine diatoms. However, the distribution of freshwater diatoms indicates effects of a climate change concerning the inner Nærøyfjord. The distribution of marine benthic diatoms reflects changes in near-shore erosion throughout the years with a trend to less erosion in some parts of the inner Nærøyfjord. To narrow down possible reasons for changes in the distribution of

the diatoms a determination to species level would be necessary because many species of the same genus favour different conditions.

In general, it can be concluded that diatoms in sediments of the inner Nærøyfjord indicate local environmental change in recent (0-20) years.

References

Aarseth, I., Nesje, A., & Fredin, O. (2014). *West Norwegian Fjords: UNESCO world heritage guid to to geological excursion from Nærøyfjord to Geirangerfjord* (No. 3). Geological Society of Norway. https://doi.org/10.13140/RG.2.1.3390.7924

Adl, S. M., Simpson, A. G. B., Farmer, M. A., Andersen, R. A., Anderson, O. R., Barta, J. R., Bowser, S. S., Brugerolle, G., Fensome, R. A., Fredericq, S., James, T. Y., Karpov, S., Kugrens, P., Krug, J., Lane, C. E., Lewis, L. A., Lodge, J., Lynn, D. H., Mann, D. G., . . . Taylor, M. F. J. R. (2005). The new higher level classification of eukaryotes with emphasis on the taxonomy of protists. *The Journal of Eukaryotic Microbiology*, *52*(5), 399–451. https://doi.org/10.1111/j.1550-7408.2005.00053.x

Aksnes, D. L., Aure, J., Johansen, P.-O., Johnsen, G. H., & Vea Salvanes, A. G. (2019). Multi-decadal warming of Atlantic water and associated decline of dissolved oxygen in a deep fjord. *Estuarine, Coastal and Shelf Science*, *228*, 106392. https://doi.org/10.1016/j.ecss.2019.106392

Archibald, J. M. (2017). *Handbook of the protists*. Springer Berlin Heidelberg. https://link.springer.com/content/pdf/10.1007%2F978-3-319-28149-0_29.pdf

Bedoshvili, Y. D., & Likhoshway, Y. V. (2021). Cellular Mechanisms of Raphid Diatom Gliding. In S. Cohn, K. Manoylov, & R. Gordon (Eds.), *Diatom Gliding Motility* (pp. 65–75). Wiley. https://doi.org/10.1002/9781119526483.ch3

Bennion, H., Sayer, C. D., Tibby, J., & Carrick, H. J. (2010). Diatoms as indicators of environmental change in shallow lakes. In J. P. Smol & E. F. Stoermer (Eds.), *The Diatoms* (pp. 152–173). Cambridge University Press. https://doi.org/10.1017/CBO9780511763175.009

Benoiston, A.-S., Ibarbalz, F. M., Bittner, L., Guidi, L., Jahn, O., Dutkiewicz, S., & Bowler, C. (2017). The evolution of diatoms and their biogeochemical functions. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *372*(1728). https://doi.org/10.1098/rstb.2016.0397

Bianchi, T. S., Arndt, S., Austin, W. E., Benn, D. I., Bertrand, S., Cui, X., Faust, J. C., Koziorowska-Makuch, K., Moy, C. M., Savage, C., Smeaton, C., Smith, R. W., & Syvitski, J. (2020). Fjords as Aquatic Critical Zones (ACZs). *Earth-Science Reviews*, *203*, 103145. https://doi.org/10.1016/j.earscirev.2020.103145

Boer, M. K. de, Moor, H., Matthiessen, B., Hillebrand, H., & Eriksson, B. K. (2014). Dispersal restricts local biomass but promotes the recovery of metacommunities after temperature stress. *Oikos*, *123*(6), 762–768. https://doi.org/10.1111/j.1600-0706.2013.00927.x

Bollingberg, I.-M. (2022). *unpublished report about the Nærøyfjord.*

Bopp, L., Aumont, O., Cadule, P., Alvain, S., & Gehlen, M. (2005). Response of diatoms distribution to global warming and potential implications: A global model study. *Geophysical Research Letters*, *32*(19), n/a-n/a. https://doi.org/10.1029/2005GL023653

Brakstad, T., & Svarstad, S. (2017, March 26). Snøskred stenger fylkesveg – bygdefolket fortvilar. *NRK*. https://www.nrk.no/vestland/snoskred-stenger-fylkesveg-_-bygdefolket-fortvilar-1.13445657

Chen, C., Zhao, L., Zhu, C., Wang, J., Jiang, J., & Yang, S. (2014). Response of diatom community in Lugu Lake (Yunnan–Guizhou Plateau, China) to climate change over the past century. *Journal of Paleolimnology*, *51*(3), 357–373. https://doi.org/10.1007/s10933-013-9760-4

Cherpunov, V. (2004). Experimental Studies on Sexual Reproduction in Diatoms. In K. W. Jeon (Ed.), *International Review of Cytology: A Survey of Cell Biology.* Elsevier Academic Press. (Original work published 2004)

Claudino-Sales, V. (2019). West Norwegian Fjords: Geirangerfjord and Nærøyfjord, Norway. In V. Claudino-Sales (Ed.), *Coastal World Heritage Sites* (pp. 87–92). Springer Netherlands. https://doi.org/10.1007/978-94-024-1528-5_13

Compton, J. C. (2011). *Diatoms: Ecology and Life Cycle: Ecology and Life Cycle*. Nova Science Publishers, Incorporated. http://ebookcentral.proquest.com/lib/hogskbergen-ebooks/detail.action?docID=3018022

Cowan, E. A., Seramur, K. C., Cai, J., & Powell, R. D. (1999). Cyclic sedimentation produced by fluctuations in meltwater discharge, tides and marine productivity in an Alaskan fjord. *Sedimentology*, *46*(6), 1109–1126. https://doi.org/10.1046/j.1365-3091.1999.00267.x

Direktoratsgruppen for gjennomføringen av vannforskriften. (February 2018). *Klassifisering av miljotilstand i vann: Økologisk og kjemisk klassifiseringssystem for kystvann, grunnvann, innsjøer og elver.* Miljødirektoratet. https://www.vannportalen.no/veiledere/klassifiseringsveileder/

Dixit, S. S., Smol, J. P., Kingston, J. C., & Charles, D. F. (1992). Diatoms: powerful indicators of environmental change. *Environmental Science & Technology*, *26*(1), 22–33. https://doi.org/10.1021/es00025a002

Dybo, M. H., Sundheim, M. L., & Sognesand, M. A. (2016). *Analyse av resente sedimentkjerner i den anoksiske Nærøyfjorden, Vest-Norge.* Høgskulen i Sogn og Fjordane.

Elliott, D. T., Pierson, J. J., & Roman, M. R. (2013). Predicting the effects of coastal hypoxia on vital rates of the planktonic copepod Acartia tonsa Dana. *PloS One*, *8*(5), e63987. https://doi.org/10.1371/journal.pone.0063987

EOS, University of British Columbia. (2022, February 28). *EOS Phytoplankton Encyclopedia Project.* Department of Earth, Ocean and Atmospheric Sciences. https://www.eoas.ubc.ca/research/phytoplankton/diatoms/centric/thalassiosira/thalassiosira_genus.html

Erling Oppenheim. (2014, May 19). *Periodic Report - Section II- West Norwegian Fjords - Geirangerfjord and Nærøyfjord.*

Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, OJ L 327 (2000 & rev. 20.11.2014).

Fauske, R. R. (2020, February 18). Snøskredfaren er stor – trass i uvêrspause. *NRK*. https://www.nrk.no/vestland/stor-snoskredfare-i-fjellheimen-1.14907844

Fuhrmann, T., Landwehr, S., El Rharbi-Kucki, M., & Sumper, M. (2004). Diatoms as living photonic crystals. *Applied Physics B*, *78*(3-4), 257–260. https://doi.org/10.1007/s00340-004-1419-4

The Geological Survey of Norway. (2021, July 15). *Grunnkart Vestland*. https://geo.ngu.no/kart/minkommune/?kommunenr=4641

Grieger, J. (2021). *Hydrographical History of 7 Fjord Basins Along the Norwegian Sognefjorden with Emphasis on Oxygen Conditions.*

Hansen, D. V., & Rattray, M. (1966). New Dimension in Estuary Classification. *Limnology and Oceanography*, *11*(3), 319–326. https://doi.org/10.4319/lo.1966.11.3.0319

Hauck, M., Leuschner, C., & Homeier, J. (2019). *Klimawandel und Vegetation - Eine globale Übersicht*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-59791-0

Hausmann, S., Charles, D. F., Gerritsen, J., & Belton, T. J. (2016). A diatom-based biological condition gradient (BCG) approach for assessing impairment and developing nutrient criteria for streams. *The Science of the Total Environment*, *562*, 914–927. https://doi.org/10.1016/j.scitotenv.2016.03.173

Jeon, K. W. (Ed.). (2004). *International Review of Cytology: A Survey of Cell Biology*. Elsevier Academic Press.

Johansen, P.-O., Heggøy, E., & Johannessen, P. (2007). *Marinbiologisk miljøundersøkelse av Sognefjorden i 2006* (No. 7). Bergen. University Bergen.
Jonason, O., & Stumbo, S. (1993). *Ferry Wake Study*. http://depts.washington.edu/trac/bulkdisk/pdf/331.1.pdf
Kafouris, S., Smeti, E., Spatharis, S., Tsirtsis, G., Economou-Amilli, A., & Danielidis, D. B. (2019). Nitrogen as the main driver of benthic diatom composition and diversity in oligotrophic coastal systems. *The Science of the Total Environment*, *694*, 133773. https://doi.org/10.1016/j.scitotenv.2019.133773.
Kelly, M., Juggin, S., Gurthrie, R., Pritchard, S., Jamieson, J., Rippey, B., Hirst, H., & Yallop, M. (2007). Assessment of ecological status in U.K. rivers using diatoms. *Freshwater Biology*, *0*(0). https://doi.org/10.1111/j.1365-2427.2007.01903.x
Kenitz, K. M., Orenstein, E. C., Roberts, P. L. D., Franks, P. J. S., Jaffe, J. S., Carter, M. L., & Barton, A. D. (2020). Environmental drivers of population variability in colony-forming marine diatoms. *Limnology and Oceanography*, *65*(10), 2515–2528. https://doi.org/10.1002/lno.11468
Klamer, T. (2017). *River Deltas of the Inner Sognefjord (Inner Sogn Region): Consequences of Anthropogenic Change*. https://hvlopen.brage.unit.no/hvlopen-xmlui/bitstream/handle/11250/2456017/klamer_thomas.pdf?sequence=1
Knagenhjelm, T. K. (2019, June 4). *The village of Gudvangen.* Fylkesarkivet i Sogn og Fjordane. https://encyclopedia.fylkesarkivet.no/article/31342d9e-817b-4c50-a458-0aec3b680c26/
Kociolek, J., & Williams, D [D.] (2015). How to define a diatom genus? Notes on the creation and recognition of taxa, and a call for revisionary studies of diatoms. *Acta Botanica Croatica*, *74*(2), 195–210. https://doi.org/10.1515/botcro-2015-0018
Lalande, C., Dunlop, K., Renaud, P. E., Nadaï, G., & Sweetman, A. K. (2020). Seasonal variations in downward particle fluxes in Norwegian fjords. *Estuarine, Coastal and Shelf Science*, *241*, 106811. https://doi.org/10.1016/j.ecss.2020.106811
Langsholt, E., Roald, L. A., Holmqvist, E., & Fleig, A. (2015). *Flommen på Vestlandet oktober 2014* (No. 11). https://publikasjoner.nve.no/rapport/2015/rapport2015_11.pdf
Mann, D. G., & Vanormelingen, P. (2013). An inordinate fondness? The number, distributions, and origins of diatom species. *The Journal of Eukaryotic Microbiology*, *60*(4), 414–420. https://doi.org/10.1111/jeu.12047
Marina Potapova. (2022, January 26). *SEM image of the inner side of the raphe valve of Karayevia clevei*. https://diatoms.org
MarineTraffic.com. (2022, January 29). *Port of Gudvangen: Departures, Expected Arrivals and Port Calls | AIS MarineTraffic*. https://www.marinetraffic.com/en/ais/details/ports/24606?name=GUDVANGEN&country=Norway
McConchie, J., & Toleman, I. (2003). Boat wakes as a cause of riverbank erosion: a case study from the Waikato River, New Zealand. *Journal of Hydrology (New Zealand)*, *42*(2), 163–179. http://www.jstor.org/stable/43944869
McQuoid, M., & Nordberg, K. (2003). The diatom Paralia sulcata as an environmental indicator species in coastal sediments. *Estuarine, Coastal and Shelf Science*, *56*(2), 339–354. https://doi.org/10.1016/S0272-7714(02)00187-7
Medlin, L., & Kaczmarska, I. (2004). Evolution of the diatoms: V. Morphological and cytological support for the major clades and a taxonomic revision. *Phycologia*, *43*(3), 245–270. https://doi.org/10.2216/i0031-8884-43-3-245.1
Meyers, S. D., Luther, M. E., Ringuet, S., Raulerson, G., Sherwood, E., Conrad, K., & Basili, G. (2021). Ship wakes and their potential shoreline impact in Tampa Bay. *Ocean & Coastal Management*, *211*, 105749. https://doi.org/10.1016/j.ocecoaman.2021.105749

Miljøforvaltningen og Norges Vassdrags- og energidirektoratet. (2021, December 7). *indre Nærøyfjorden*. https://vann-nett.no/portal/#/waterbody/0280020800-2-C
Mizuno, M., & Okuda, K. (1985). Seasonal change in the distribution of cell size of cocconeis scutellum var. ornata (bacillariophyceae) in relation to growth and sexual reproduction. *Journal of Phycology*, *21*(4), 547–553. https://doi.org/10.1111/j.0022-3646.1985.00547.x
myShipTracking. (2022, January 29). *Port of GUDVANGEN, [NO] Norway (NOGUD). Arrivals*. https://www.myshiptracking.com/ports/port-of-gudvangen-in-no-norway-id-5119
Nicotri, M. E. (1977). Grazing Effects of Four Marine Intertidal Herbivores on the Microflora. *Ecology*, *58*(5), 1020–1032. https://doi.org/10.2307/1936922
Norges Vassdrags- og energidirektorat. (2022). *Nærøydalselvi*. https://vann-nett.no/portal/#/waterbody/071-43-R
Norwegian Mapping Authority. (2022, March 29). *Norgeskart.* Kartverket. https://www.norgeskart.no
Norwegian Meteorological Institute. (2017). *It will become wetter*. https://www.met.no/en/weather-and-climate/It-will-become-wetter
The Norwegian Meteorological Institute. (2021). *Precipitation Jordalen.*
Not, F., Siano, R., Kooistra, W. H., Simon, N., Vaulot, D., & Probert, I. (2012). Diversity and Ecology of Eukaryotic Marine Phytoplankton. In *Advances in Botanical Research. Genomic Insights into the Biology of Algae: Diversity and Ecology of Eukaryotic Marine Phytoplankton* (Vol. 64, pp. 1–53). Elsevier. https://doi.org/10.1016/B978-0-12-391499-6.00001-3
Ohtsuka, S., Suzaki, T., Horiguchi, T., Suzuki, N., & Not, F. (Eds.). (2015). *Marine Protists: Diversity and Dynamics*. Springer Japan.
Oldfield, F. (2005). *Environmental change*. Cambridge University Press. https://doi.org/10.1017/CBO9781139165266
Paetzel, M., & Dale, T. (2010). Climate proxies for recent fjord sediments in the inner Sognefjord region, western Norway. *Geological Society, London, Special Publications*, *344*(1), 271–288. https://doi.org/10.1144/SP344.19
Parr, C. S., Wilson, N., Leary, P., Schulz, K. S., Lans, K., Walley, L., Hammock, J. A., Goddard, A., Rice, J., Studer, M., Holmes, J. T. G., & Corrigan, R. J. (2014). The Encyclopedia of Life v2: Providing Global Access to Knowledge About Life on Earth. *Biodiversity Data Journal*(2), e1079. https://doi.org/10.3897/BDJ.2.e1079
Paulino, A. I., Larsen, A., Bratbak, G., Evens, D., Erga, S. R., Bye-Ingebrigtsen, E., & Egge, J. K. (2018). Seasonal and annual variability in the phytoplankton community of the Raunefjord, west coast of Norway from 2001–2006. *Marine Biology Research*, *14*(5), 421–435. https://doi.org/10.1080/17451000.2018.1426863
Perez-Martinez, C., Cruz-Pizarro, L., & Sanchez-Castillo, P. (1992). Auxosporulation in Cyclotella ocellata (Bacillariophyceae) under natural and experimental conditions. *Journal of Phycology*, *28*(5), 608–615. https://doi.org/10.1111/j.0022-3646.1992.00608.x
Pritchard, D. W. (1952). Estuarine Hydrography. In H. E. Landsberg (Ed.), *Advances in Geophysics: v. 1. Advances in geophysics* (Vol. 1, pp. 243–280). Academic Press. https://doi.org/10.1016/S0065-2687(08)60208-3
Ramberg, I. B., Bryhni, I., Nøttvedt, A., & Rangnes, K. (2008). *The Making of a Land: Geology of Norway*. Geological Society Publishing House. https://books.google.de/books?id=rMVNE0F2SckC
Romero, O. E., & Armand, L. K. (2010). Marine diatoms as indicators of modern changes in oceanographic conditions. In J. P. Smol & E. F. Stoermer (Eds.), *The Diatoms* (pp. 373–400). Cambridge University Press. https://doi.org/10.1017/CBO9780511763175.021
Rothwell, R. G. (1989). *Minerals and mineraloids in marine sediments: An optical identification guide*. Elsevier Applied Science.

Round, F. E., Crawford, R. M., & Mann, D. G. (2000). *The diatoms: Biology & morphology of the genera* (Reprinted.). Cambridge Univ. Press.

Rynearson, T. A., Flickinger, S. A., & Fontaine, D. N. (2020). Metabarcoding Reveals Temporal Patterns of Community Composition and Realized Thermal Niches of Thalassiosira Spp. (Bacillariophyceae) from the Narragansett Bay Long-Term Plankton Time Series. *Biology*, *9*(1), 19. https://doi.org/10.3390/biology9010019

Sadava, D., Hillis, D. M., Heller, H. C., & Hacker, S. D. (2019). *Purves Biologie* ((A. Held, B. Jarosch, L. Seidler, M. Niehaus-Osterloh, E. Sixt & M. Delbrück, Trans.)) (J. Markl, Ed.) (10. Aufl. 2019). Springer Berlin Heidelberg.

Salido, J., Sánchez, C., Ruiz-Santaquiteria, J., Cristóbal, G., Blanco, S., & Bueno, G. (2020). A Low-Cost Automated Digital Microscopy Platform for Automatic Identification of Diatoms. *Applied Sciences*, *10*(17), 6033. https://doi.org/10.3390/app10176033

Scherer, R. P., & Koc, N. (1996). Late Paleogene Diatom Biostratigraphy and Paleoenvironments of the Northern Norwegian-Greenland Sea. In J. Thiede, A. M. Myhre, J. V. Firth, G. L. Johnson, & W. F. Ruddiman (Eds.), *Proceedings of the Ocean Drilling Program. Proceedings of the Ocean Drilling Program, 151 Scientific Results* (Vol. 151). Ocean Drilling Program. https://doi.org/10.2973/odp.proc.sr.151.155.1996

Seckbach, J., & Gordon, R. (Eds.). (2019). *Diatoms: Fundamentals and Applications: Fundamentals and applications*. Wiley. https://onlinelibrary-wiley-com.proxy02a.bis.uni-oldenburg.de/doi/pdfdirect/10.1002/9781119370741 https://doi.org/10.1002/9781119370741

Seckbach, J., & Kociolek, P. (Eds.). (2011). *Cellular origin, life in extreme habitats and astrobiology: Vol. 19*. *The Diatom World*. Springer Netherlands. https://link.springer.com/content/pdf/10.1007%2F978-94-007-1327-7.pdf https://doi.org/10.1007/978-94-007-1327-7

Seneviratne, I, S., Nicholls, N., Easterling, D., Goodess, C. M., Kanae, S., Kossin, J., Luo, Y., Marengo, J., McInnes, K., & Rahimi, M. Changes in Climate Extremes and their Impacts on the Natural Physical Environment. In *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (pp. 109–230). (Original work published 2012)

Shaffer, G. P., & Sullivan, M. J. (1988). Water column productivity attributable to displaced benthic diatoms in well-mixed shallow estuaries. *Journal of Phycology*, *24*(2), 132–140. https://doi.org/10.1111/j.1529-8817.1988.tb04226.x

Ship Technology. (2018). *Fjords receives all-electric ferry Future of The Fjords*. https://www.ship-technology.com/news/fjords-receives-electric-ferry-future-fjords/

Smol, J. P. (2010). *The Diatoms: Applications for the Environmental and Earth Sciences* (2nd ed.). Cambridge University Press. https://ebookcentral.proquest.com/lib/kxp/detail.action?docID=581089

Smol, J. P., Birks, J. B., Last, W. M., Bradley, R. S., & Alverson, K. (Eds.). (2003). *Developments in paleoenvironmental research: Vol. 3*. *Tracking Environmental Change Using Lake Sediments: Terrestrial, algal, and siliceous indicators* (Repr with corrections). Kluwer.

Smol, J. P., & Stoermer, E. F. (2010). *The Diatoms: Applications for the Environmental and Earth Sciences* (Second Edition). Cambridge University Press.

Sorhannus, U. (2004). Diatom phylogenetics inferred based on direct optimization of nuclear-encoded SSU rRNA sequences. *Cladistics: The International Journal of the Willi Hennig Society*, *20*(5), 487–497. https://doi.org/10.1111/j.1096-0031.2004.00034.x

Spaulding, S. A., Potapova, M. G., Bishop, I. W., Lee, S. S., Gasperak, T. S., Jovanoska, E., Furey, P. C., & Edlund, M. B. (2022). *Diatoms.org: supporting taxonomists, connecting communities*.

Srivastava, P., Jyoti, V., Grover, S., & Sardar Khan, A. (2016). *On the importance of diatoms as Ecological Indicators in River Ecosystems: A Review* (Vol. 5).

https://www.researchgate.net/publication/320056908_On_the_importance_of_diatoms_as_Ecological_Indicators_in_River_Ecosystems_A_Review
Suzuki, N., & Oba, M. (2015). Oldest Fossil Records of Marine Protists and the Geologic History Toward the Establishment of the Modern-Type Marine Protist World. In S. Ohtsuka, T. Suzaki, T. Horiguchi, N. Suzuki, & F. Not (Eds.), *Marine Protists: Diversity and Dynamics* (pp. 359–394). Springer Japan. https://doi.org/10.1007/978-4-431-55130-0_15
Sverdrup, Johannes. (2021). *Melding om oppstart av planarbeid, Nærøyfjorden næringskai, Aurland Kommune*. https://opus.no/plannotice/melding-om-oppstart-av-planarbeid-naeroyfjorden-naeringskai-aurland-kommune/
Syvitski, J. P. M., Burrell, D. C., & Skei, J. M. (1987). *Fjords*. Springer New York. https://doi.org/10.1007/978-1-4612-4632-9
Tabari, H. (2020). Climate change impact on flood and extreme precipitation increases with water availability. *Scientific Reports*, *10*(1), 13768. https://doi.org/10.1038/s41598-020-70816-2
Terrje Eggum (2015, December 16). Fartsgrensa har verka. *Sogn Avis*(244).
Theriot, E. C., Cannone, J. J., Gutell, R. R., & Alverson, A. J. (2009). The limits of nuclear encoded SSU rDNA for resolving the diatom phylogeny. *European Journal of Phycology*, *44*(3), 277–290. https://doi.org/10.1080/09670260902749159
van de Bund, W., & Solimini, A. G. (2007). *Ecological Quality Ratios for Ecological Quality Assessment in Inland and Marine Waters*. Luxembourg. Institute for Environment and Sustainability.
Vilmi, A., Karjalainen, S. M., Landeiro, V. L., & Heino, J. (2015). Freshwater diatoms as environmental indicators: Evaluating the effects of eutrophication using species morphology and biological indices. *Environmental Monitoring and Assessment*, *187*(5), 243. https://doi.org/10.1007/s10661-015-4485-7
Wanvik, J. E. (2007). *Assessment of anorthosite at Gudvangen Stein's property in Nærøydalen Aurland from a resource geology perspective* (NGU-Rapport). https://openarchive.ngu.no/ngu-xmlui/bitstream/handle/11250/2664797/2007_040.pdf?sequence=1&isAllowed=y
Wasmund, N., Kownacka, J., Göbel, J., Jaanus, A., Johansen, M., Jurgensone, I., Lehtinen, S., & Powilleit, M. (2017). The Diatom/Dinoflagellate Index as an Indicator of Ecosystem Changes in the Baltic Sea 1. Principle and Handling Instruction. *Frontiers in Marine Science*, *4*, 22. https://doi.org/10.3389/fmars.2017.00022
Wentworth, C. K. (1922). A Scale of Grade and Class Terms for Clastic Sediments. *The Journal of Geology*.
Williams, D., & Kociolek, P. (2007). Pursuit of a natural classification of diatoms: History, monophyly and the rejection of paraphyletic taxa. *European Journal of Phycology*, *42*(3), 313–319. https://doi.org/10.1080/09670260701419921
Williams, D. W., & Kociolek, J. P. (2010). Towards a comprehensive diatom classification and phylogeny (Bacillariophyta). *Plant Ecology and Evolution*, *143*(3), 265–270. https://doi.org/10.5091/plecevo.2010.401
World heritage convention. *Norwegian Nomination: The West Norwegian Fjords.*
World heritage convention. (May 2005). *World Heritage Nomination – Iucn Technical Evaluation Geirangerfjord & Nærøyfjord (Norway) Id N° 1195* (World Heritage Evaluation Report). UNESCO.
WoRMS Editorial Board. (2022). *World Register of Marine Species.: Thalassiosira weissflogii (Grunow) G.Fryxell & Hasle, 1977*. https://www.marinespecies.org/aphia.php?p=taxdetails&id=163513 https://doi.org/10.14284/170

Appendix I: Diatom distribution

A: Results smear slide analysis

Smear slides: diatoms

Core number: 1
Location: Bakka
Water depth: 38m

depth range (cm)	average depth (cm)	Diatoms (#) Marine genera Planktonic Chaetoceros	Sceletonema	Thalassiosira	Licmophora	Asteromphalus	Porosia	Other round	Total marine planktonic genera	Marine genera Benthic Achnanthes	Caloneis	Surirella	Paralia	Total marine benthic genera	Freshwater/b Tabellaria
0,0-1,0	0.5	34	39	171	0	0	5	3	252	14	0	0	0	14	71
1,0-2,0	1.5	67	33	102	1	1	9	10	223	11	0	0	0	11	74
2,0-3,0	2.5	29	28	148	1	0	5	8	219	19	0	0	0	19	74
3,0-4,0	3.5	25	18	185	0	0	4	4	236	31	0	0	0	31	75
4,0-5,0	4.5	43	24	135	4	0	5	7	218	12	0	0	1	13	69
5,0-6,0	5.5	24	27	143	1	0	8	5	208	23	0	0	0	23	45

depth range (cm)	average depth (cm)	Diatoms (%) Marine genera Planktonic Chaetoceros	Sceletonema	Thalassiosira	Licmophora	Asteromphalus	Porosia	Other round	Total marine planktonic genera	Achnanthes	Caloneis	Surirella	Paralia	Total marine benthic genera	Freshwater/ Tabellaria
0,0-1,0	0.5	4.9	5.6	24.5	0.0	0.0	0.7	0.4	36	2.0	0.0	0.0	0.0	2	10.2
1,0-2,0	1.5	9.7	4.8	14.7	0.1	0.1	1.3	1.4	32	1.6	0.0	0.0	0.0	2	10.7
2,0-3,0	2.5	4.8	4.7	24.6	0.2	0.0	0.8	1.3	36	3.2	0.0	0.0	0.0	3	12.3
3,0-4,0	3.5	4.1	3.0	30.3	0.0	0.0	0.7	0.7	39	5.1	0.0	0.0	0.0	5	12.3
4,0-5,0	4.5	6.3	3.5	19.9	0.6	0.0	0.7	1.0	32	1.8	0.0	0.0	0.1	2	10.1
5,0-6,0	5.5	3.5	4.0	21.1	0.1	0.0	1.2	0.7	31	3.4	0.0	0.0	0.0	3	6.6
mean		5.6	4.2	22.5	0.2	0.0	0.9	0.9	34.4	2.8	0.0	0.0	0.0	2.9	10.4

brackish genera

Eunotia	Navicula	Amphora	Diatomella	Cymbella	Mastogloia	Rhoicosphenia	Diatoma	Meridon	Melosira sp	Cocconeis	Tetracyklus	Nitzschia	Pinnularia	Denticula
31	31	5	13	6	0	9	150	5	17	44	13	0	0	0
57	40	6	25	1	0	8	139	5	10	47	5	0	0	4
29	30	4	14	0	1	6	88	1	21	35	10	1	0	0
21	27	5	8	1	0	8	68	1	15	40	13	3	4	2
37	48	5	7	3	0	12	110	1	16	63	10	0	0	0
54	45	1	0	1	0	8	133	5	18	58	9	0	0	0

brackish genera

Eunotia	Navicula	Amphora	Diatomella	Cymbella	Mastogloia	Rhoicosphenia	Diatoma	Meridon	Melosira sp	Cocconeis	Tetracyklus	Nitzschia	Pinnularia	Denticula
4.4	4.4	0.7	1.9	0.9	0.0	1.3	21.5	0.7	2.4	6.3	1.9	0.0	0.0	0.0
8.2	5.8	0.9	3.6	0.1	0.0	1.2	20.1	0.7	1.4	6.8	0.7	0.0	0.0	0.6
4.8	5.0	0.7	2.3	0.0	0.2	1.0	14.6	0.2	3.5	5.8	1.7	0.2	0.0	0.0
3.4	4.4	0.8	1.3	0.2	0.0	1.3	11.1	0.2	2.5	6.6	2.1	0.5	0.7	0.3
5.4	7.1	0.7	1.0	0.4	0.0	1.8	16.2	0.1	2.4	9.3	1.5	0.0	0.0	0.0
8.0	6.6	0.1	0.0	0.1	0.0	1.2	19.6	0.7	2.7	8.6	1.3	0.0	0.0	0.0
5.7	5.6	0.7	1.7	0.3	0.0	1.3	17.2	0.4	2.5	7.2	1.5	0.1	0.1	0.2

			Total freshwater/ brackish			Control
				Other	Total	Total
Gomphonema	Gyrossigma	Fragilaria	genera	Diatoms	diatoms	diatoms
0	0	27	**422**	10	698	698
0	0	28	**449**	10	693	693
0	1	35	**350**	13	601	601
1	0	38	**330**	13	610	610
13	0	40	**434**	15	680	680
3	0	40	**420**	27	678	678

			Total freshwater/ brackish			Control
				Other	Total %	Total %
Gomphonema	Gyrossigma	Fragilaria	genera	Diatoms	diatoms	diatoms
0.0	0.0	3.9	**60**	1.4	100	100
0.0	0.0	4.0	**65**	1.4	100	100
0.0	0.2	5.8	**58**	2.2	100	100
0.2	0.0	6.2	**54**	2.1	100	100
1.9	0.0	5.9	**64**	2.2	100	100
0.4	0.0	5.9	**62**	4.0	100	100
0.4	0.0	5.3				

(cm)	Bakka ma	Bakka m	Bakka total marine	freshwater
0.5	36.1	2.0	38.1	60.5
1.5	32.2	1.6	33.8	64.8
2.5	36.4	3.2	39.6	58.2
3.5	38.7	5.1	43.8	54.1
4.5	32.1	1.9	34.0	63.8
5.5	30.7	3.4	34.1	61.9
		2.9		60.6

Smear slides: diatoms

Core number: 2

Location: Basin

Water depth: 68m

depth range (cm)	average depth (cm)	Diatoms (%) Marine genera Planktonic Chaetoceros	Sceletonema	Thalassiosira	Licmophora	Asteromphalus	Porosia	Other round	Total marine planktonic genera	Achnanthes	Caloneis	Surirella	Paralia
0,0-1,0	0.5	46	47	91	2	0	5	41	232	15	3	2	1
1,0-2,0	1.5	22	49	160	0	0	0	16	247	12	0	2	1
2,0-3,0	2.5	51	69	158	3	0	5	15	301	6	0	0	0
3,0-4,0	3.5	51	51	108	2	0	7	40	259	3	0	0	0
4,0-5,0	4.5	34	82	78	3	0	2	18	217	11	0	0	0
5,0-6,0	5.5	27	23	184	2	0	0	0	236	9	0	0	0
6,0-7,0	6.5	29	39	171	1	0	15	16	271	15	1	0	0
7,0-8,0	7.5	43	59	124	0	0	14	9	249	4	0	0	0
8,0-9,0	8.5	22	59	137	0	0	14	8	240	3	0	0	0
9,0-10,0	9.5	50	99	109	1	0	34	12	305	15	0	0	0
10,0-11,0	10.5	22	83	134	2	0	6	4	251	6	0	0	1
11,0-12,0	11.5	19	60	171	0	0	9	7	266	9	1	1	0
12,0-13,0	12.5	29	94	138	0	1	9	4	275	7	1	0	0

depth range (cm)	average depth (cm)	Diatoms (%) Marine genera Planktonic Chaetoceros	Sceletonema	Thalassiosira	Licmophora	Asteromphalus	Porosia	Other round	Total marine planktonic genera	Achnanthes	Caloneis	Surirella	Paralia
0,0-1,0	0.5	8.1	8.3	16.1	0.4	0.0	0.9	7.2	41	2.7	0.5	0.4	0.2
1,0-2,0	1.5	3.4	7.7	25.0	0.0	0.0	0.0	2.5	39	1.9	0.0	0.3	0.2
2,0-3,0	2.5	6.8	9.2	21.2	0.4	0.0	0.7	2.0	40	0.8	0.0	0.0	0.0
3,0-4,0	3.5	7.5	7.5	15.8	0.3	0.0	1.0	5.8	38	0.4	0.0	0.0	0.0
4,0-5,0	4.5	5.1	12.3	11.7	0.5	0.0	0.3	2.7	33	1.7	0.0	0.0	0.0
5,0-6,0	5.5	4.2	3.6	28.6	0.3	0.0	0.0	0.0	37	1.4	0.0	0.0	0.0
6,0-7,0	6.5	4.1	5.6	24.4	0.1	0.0	2.1	2.3	39	2.1	0.1	0.0	0.0
7,0-8,0	7.5	6.6	9.0	18.9	0.0	0.0	2.1	1.4	38	0.6	0.0	0.0	0.0
8,0-9,0	8.5	3.7	9.8	22.8	0.0	0.0	2.3	1.3	40	0.5	0.0	0.0	0.0
9,0-10,0	9.5	7.5	14.8	16.2	0.1	0.0	5.1	1.8	45	2.2	0.0	0.0	0.0
10,0-11,0	10.5	3.4	12.9	20.8	0.3	0.0	0.9	0.6	39	0.9	0.0	0.0	0.2
11,0-12,0	11.5	2.9	9.0	25.8	0.0	0.0	1.4	1.1	40	1.4	0.2	0.2	0.0
12,0-13,0	12.5	4.5	14.6	21.5	0.0	0.2	1.4	0.6	43	1.1	0.2	0.0	0.0
mean		5.2	9.6	20.7	0.2	0.0	1.4	2.3	39.3	1.4	0.1	0.1	0.0

Total marine benthic genera	Freshwater/ brackish genera												
	Tabellaria	Eunotia	Navicula	Amphora	Diatomella	Cymbella	Mastogloia	Rhoicosphenia	Diatmona	Meridon	Melosira sp	Cocconeis	Tetracyklus
21	86	44	2	2	13	8	19	6	38	13	6	3	0
15	62	43	9	5	2	0	11	3	104	8	9	28	0
6	68	52	3	6	6	11	1	7	98	15	19	94	0
3	80	49	10	0	3	4	0	4	101	8	8	67	3
11	65	51	18	2	15	7	0	8	87	8	20	90	1
9	44	50	17	1	12	6	2	8	143	9	29	41	0
16	30	64	15	2	1	6	0	9	154	14	34	41	4
4	55	43	8	0	0	2	0	1	159	11	13	65	2
3	39	46	32	2	5	1	2	4	125	10	20	36	3
15	41	35	18	0	1	6	0	0	135	4	17	46	4
7	30	50	24	3	2	1	2	4	168	6	28	32	5
11	32	58	37	2	5	2	0	3	161	4	16	38	3
8	50	38	18	3	11	1	1	7	138	2	15	44	2

Total marine benthic genera	Freshwater/brackish genera												
	Tabellaria	Eunotia	Navicula	Amphora	Diatomella	Cymbella	Mastogloia	Rhoicosphenia	Diatmona	Meridon	Melosira sp	Cocconeis	Tetracyklus
4	15.2	7.8	0.4	0.4	2.3	1.4	3.4	1.1	6.7	2.3	1.1	0.5	0.0
2	9.7	6.7	1.4	0.8	0.3	0.0	1.7	0.5	16.3	1.3	1.4	4.1	0.0
1	9.1	7.0	0.4	0.8	0.8	1.5	0.0	0.9	12.5	2.0	2.5	12.6	0.0
0	11.7	7.2	1.5	0.0	0.4	0.6	0.2	0.6	14.8	1.2	1.2	9.8	0.4
2	9.8	7.7	2.7	0.3	2.3	1.1	0.0	1.2	13.1	1.2	3.0	13.5	0.2
1	6.8	7.8	2.6	0.2	1.9	0.9	0.3	1.2	22.2	1.4	4.5	6.4	0.0
2	4.3	9.1	2.1	0.3	0.1	0.9	0.0	1.3	22.0	2.0	4.9	5.9	0.6
1	8.4	6.6	1.2	0.0	0.0	0.3	0.0	0.2	24.2	1.7	2.0	9.9	0.3
0	6.5	7.6	5.3	0.3	0.8	0.2	0.3	0.7	20.8	1.7	3.3	5.8	0.5
2	6.1	5.2	2.7	0.0	0.1	0.9	0.0	0.0	20.1	0.6	2.5	6.7	0.6
1	4.7	7.8	3.7	0.5	0.3	0.2	0.3	0.6	26.0	0.9	4.3	5.0	0.8
2	4.8	8.7	5.6	0.3	0.8	0.3	0.0	0.5	24.3	0.6	2.4	5.7	0.5
1	7.8	5.9	2.8	0.5	1.7	0.2	0.2	1.1	21.5	0.3	2.3	6.9	0.3
1.5	8.1	7.3	2.5	0.3	0.9	0.6	0.5	0.8	18.8	1.3	2.7	7.1	0.3

					Total freshwater/ brackish			Control
						Other	Total	Total
Denticula	Gomphonema	Gyrosigma	Fragilaria	genera	Diatoms	diatoms	diatoms	
0	0	0	59	299	14	566	566	
0	0	0	75	357	20	639	639	
0	0	0	58	433	6	746	746	
0	0	0	80	417	5	684	684	
0	0	0	58	430	7	665	665	
0	0	4	25	391	7	643	643	
0	0	2	25	401	12	700	700	
0	0	0	37	396	7	656	656	
0	0	0	24	348	11	602	602	
0	0	2	38	346	5	671	671	
0	0	0	31	386	1	645	645	
0	0	0	16	379	7	663	663	
0	0	1	19	353	6	642	642	

				Total freshwater/ brakish			Control					
					Other	Total %	Total %	depth				
Denticula	Gomphonema	Gyrosigma	Fragilaria	genera	Diatoms	diat/silic	diat/silic	(cm)	Basin marine pl	Basin marine be	Basin marine	Basin freshwater
0.0	0.0	0.0	10.4	53	2.5	100	100	0.5	41.0	3.7	44.7	52.8
0.0	0.0	0.0	11.7	56	3.1	100	100	1.5	38.7	2.3	41.0	55.9
0.0	0.0	0.0	7.8	58	0.8	100	100	2.5	40.3	0.8	41.2	57.9
0.0	0.0	0.0	11.7	61	0.7	100	100	3.5	37.9	0.4	38.3	61.1
0.0	0.0	0.0	8.7	65	1.1	100	100	4.5	32.6	1.7	34.3	64.7
0.0	0.0	0.6	3.9	61	1.1	100	100	5.5	36.7	1.4	38.1	60.8
0.0	0.0	0.3	3.6	57	1.7	100	100	6.5	38.7	2.3	41.0	57.3
0.0	0.0	0.0	5.6	60	1.1	100	100	7.5	38.0	0.6	38.6	60.4
0.0	0.0	0.0	4.0	58	1.8	100	100	8.5	39.9	0.5	40.4	57.8
0.0	0.0	0.3	5.7	52	0.7	100	100	9.5	45.5	2.2	47.7	51.6
0.0	0.0	0.0	4.8	60	0.2	100	100	10.5	38.9	1.1	40.0	59.8
0.0	0.0	0.0	2.4	57	1.1	100	100	11.5	40.1	1.7	41.8	57.2
0.0	0.0	0.2	3.0	55	0.9	100	100	12.5	42.8	1.2	44.1	55.0
0.0	0.0	0.1	6.4							1.5		57.9

Smear slides: diatoms

Core number: 3
Location: quay
Water depth: 55m

depth range (cm)	average depth (cm)	Diatoms (#) Marine species Planktonic Chaetoceros	Sceletonema	Thalassiosira	Licmophora	Asteromphalus	Porosia	Other round	Total marine planktonic species	Marine benthic Achnanthes
0,0-1,0	0.5	64	110	82	0	1	14	6	277	11
1,0-2,0	1.5	37	29	55	0	0	8	5	134	10
2,0-3,0	2.5	16	104	111	2	0	11	5	249	9
3,0-4,0	3.5	53	70	35	0	0	9	6	173	2
4,0-5,0	4.5	83	61	63	0	1	10	6	224	4
5,0-6,0	5.5	84	100	108	0	1	9	3	305	3

depth range (cm)	average depth (cm)	Diatoms (%) Marine species Planktonic Chaetoceros	Sceletonema	Thalassiosira	Licmophora	Asteromphalus	Porosia	Other round	Total marine planktonic species	Marine species benthic Achnanthes
0,0-1,0	0.5	9.0	15.4	11.5	0.0	0.1	2.0	0.8	39	1.5
1,0-2,0	1.5	5.6	4.4	8.4	0.0	0.0	1.2	0.8	20	1.5
2,0-3,0	2.5	2.7	17.4	18.5	0.3	0.0	1.8	0.8	42	1.5
3,0-4,0	3.5	8.7	11.5	5.7	0.0	0.0	1.5	1.0	28	0.3
4,0-5,0	4.5	11.3	8.3	8.6	0.0	0.1	1.4	0.8	31	0.5
5,0-6,0	5.5	11.7	13.9	15.1	0.0	0.1	1.3	0.4	43	0.4
mean		8.2	11.8	11.3	0.1	0.1	1.5	0.8	33.7	1.0

Caloneis	Surirella	Paralia	Total marine benthic species	Freshwater species Tabellaria	Eunotia	Navicula	Amphora	Diatomella	Cymbella	Mastogloia
0	2	1	**14**	69	53	29	0	34	4	0
0	3	0	**13**	109	90	60	4	11	4	0
0	0	0	**9**	49	87	45	0	11	4	1
0	0	0	**2**	90	62	49	4	10	5	0
0	1	0	**5**	87	63	59	2	5	6	0
0	0	0	**3**	81	71	82	0	0	2	1

Caloneis	Surirella	Paralia	Total marine benthic species	Freshwater species Tabellaria	Eunotia	Navicula	Amphora	Diatomella	Cymbella	Mastogloia
0.0	0.3	0.1	**2**	9.7	7.4	4.1	0.0	4.8	0.6	0.0
0.0	0.5	0.0	**2**	16.6	13.7	9.1	0.6	1.7	0.6	0.0
0.0	0.0	0.0	**2**	8.2	14.5	7.5	0.0	1.8	0.7	0.2
0.0	0.0	0.0	**0**	14.7	10.1	8.0	0.7	1.6	0.8	0.0
0.0	0.1	0.0	**1**	11.9	8.6	8.0	0.3	0.7	0.8	0.0
0.0	0.0	0.0	**0**	11.3	9.9	11.4	0.0	0.0	0.3	0.1
0.0	0.1	0.0	1.1	12.1	10.7	8.0	0.3	1.8	0.6	0.1

Rhoicosphenia	Diatoma	Meridon	Melosira sp	Cocconeis	Tetracyklus	Nitzschia	Pinnularia	Denticula	Gomphonema	Gyrosigma
7	114	5	10	12	7	1	0	0	0	1
3	106	2	12	13	4	0	0	0	0	1
4	82	2	11	9	6	4	0	0	0	0
9	133	5	15	12	5	2	4	0	0	0
5	183	5	4	25	6	0	3	1	13	0
4	64	8	7	29	3	3	0	0	12	0

Rhoicosphenia	Diatoma	Meridon	Melosira sp	Cocconeis	Tetracyklus	Nitzschia	Pinnularia	Denticula	Gomphonema	Gyrosigma
1.0	16.0	0.7	1.4	1.7	1.0	0.1	0.0	0.0	0.0	0.1
0.5	16.1	0.3	1.8	2.0	0.6	0.0	0.0	0.0	0.0	0.2
0.7	13.7	0.3	1.8	1.5	1.0	0.7	0.0	0.0	0.0	0.0
1.5	21.8	0.8	2.5	2.0	0.8	0.3	0.7	0.0	0.0	0.0
0.7	24.9	0.7	0.5	3.4	0.8	0.0	0.4	0.1	1.8	0.0
0.6	8.9	1.1	1.0	4.0	0.4	0.4	0.0	0.0	1.7	0.0
0.8	16.9	0.7	1.5	2.4	0.8	0.3	0.2	0.0	0.6	0.0

Fragilaria	Total freshwater brackish species	Other Diatoms	Total diatoms	Control Total diatoms
68	**414**	7	712	712
82	**501**	10	658	658
22	**337**	4	599	599
25	**430**	6	611	611
29	**496**	9	734	734
32	**399**	10	717	717
			672	

Fragilaria	Total freshwater brackish species	Other Diatoms	Total % diatoms	Control Total % diatoms
9.6	**58**	1.0	100	100
12.5	**76**	1.5	100	100
3.7	**56**	0.7	100	100
4.1	**70**	1.0	100	100
4.0	**68**	1.2	100	100
4.5	**56**	1.4	100	100

6.4

(cm)	Quay marine pla	Quay marine be	Quay marine	Quay freshwater
0.5	38.9	2.0	40.9	58.1
1.5	20.4	2.0	22.3	76.1
2.5	41.6	1.5	43.1	56.3
3.5	28.3	0.3	28.6	70.4
4.5	30.5	0.7	31.2	67.6
5.5	42.5	0.4	43.0	55.6

1.1 64.0

depth range (cm)	average depth (cm)	Diatoms (%) Marine genera Planktonic Chaetoceros	Sceletonema	Thalassiosira	Licmophora	Asteromphalus	Porosia	Other round	Total marine planktonic genera	Achnanthes	Caloneis	Surirella	Paralia
0,0-1,0	0.5	4.87	5.59	24.50	0.00	0.00	0.72	0.43	36.10	2.01	0.00	0.00	0.00
1,0-2,0	1.5	9.67	4.76	14.72	0.14	0.14	1.30	1.44	32.18	1.59	0.00	0.00	0.00
2,0-3,0	2.5	4.83	4.66	24.63	0.17	0.00	0.83	1.33	36.44	3.16	0.00	0.00	0.00
3,0-4,0	3.5	4.10	2.95	30.33	0.00	0.00	0.66	0.66	38.69	5.08	0.00	0.00	0.00
4,0-5,0	4.5	6.32	3.53	19.85	0.59	0.00	0.74	1.03	32.06	1.76	0.00	0.00	0.15
5,0-6,0	5.5	3.54	3.98	21.09	0.15	0.00	1.18	0.74	30.68	3.39	0.00	0.00	0.00
mean		5.55	4.25	22.52	0.17	0.02	0.90	0.94	34.36	2.83	0.00	0.00	0.02

depth range (cm)	average depth (cm)	Diatoms (%) Marine genera Planktonic Chaetoceros	Sceletonema	Thalassiosira	Licmophora	Asteromphalus	Porosia	Other round	Total marine planktonic genera	Achnanthes	Caloneis	Surirella	Paralia
0,0-1,0	0.5	8.13	8.30	16.08	0.35	0.00	0.88	7.24	40.99	2.65	0.53	0.35	0.18
1,0-2,0	1.5	3.44	7.67	25.04	0.00	0.00	0.00	2.50	38.65	1.88	0.00	0.31	0.16
2,0-3,0	2.5	6.84	9.25	21.18	0.40	0.00	0.67	2.01	40.35	0.80	0.00	0.00	0.00
3,0-4,0	3.5	7.46	7.46	15.79	0.29	0.00	1.02	5.85	37.87	0.44	0.00	0.00	0.00
4,0-5,0	4.5	5.11	12.33	11.73	0.45	0.00	0.30	2.71	32.63	1.65	0.00	0.00	0.00
5,0-6,0	5.5	4.20	3.58	28.62	0.31	0.00	0.00	0.00	36.70	1.40	0.00	0.00	0.00
6,0-7,0	6.5	4.14	5.57	24.43	0.14	0.00	2.14	2.29	38.71	2.14	0.14	0.00	0.00
7,0-8,0	7.5	6.55	8.99	18.90	0.00	0.00	2.13	1.37	37.96	0.61	0.00	0.00	0.00
8,0-9,0	8.5	3.65	9.80	22.76	0.00	0.00	2.33	1.33	39.87	0.50	0.00	0.00	0.00
9,0-10,0	9.5	7.45	14.75	16.24	0.15	0.00	5.07	1.79	45.45	2.24	0.00	0.00	0.00
10,0-11,0	10.5	3.41	12.87	20.78	0.31	0.00	0.93	0.62	38.91	0.93	0.00	0.00	0.16
11,0-12,0	11.5	2.87	9.05	25.79	0.00	0.00	1.36	1.06	40.12	1.36	0.15	0.15	0.00
12,0-13,0	12.5	4.52	14.64	21.50	0.00	0.16	1.40	0.62	42.83	1.09	0.16	0.00	0.00
mean		5.21	9.56	20.68	0.19	0.01	1.40	2.26	39.31	1.36	0.08	0.06	0.04

depth range (cm)	average depth (cm)	Diatoms (%) Marine species Planktonic Chaetoceros	Sceletonema	Thalassiosira	Licmophora	Asteromphalus	Porosia	Other round	Total marine planktonic species	Marine species benthic Achnanthes	Caloneis	Surirella	Paralia
0,0-1,0	0.5	8.99	15.45	11.52	0.00	0.14	1.97	0.84	38.90	1.54	0.00	0.28	0.14
1,0-2,0	1.5	5.62	4.41	8.36	0.00	0.00	1.22	0.76	20.36	1.52	0.00	0.46	0.00
2,0-3,0	2.5	2.67	17.36	18.53	0.33	0.00	1.84	0.83	41.57	1.50	0.00	0.00	0.00
3,0-4,0	3.5	8.67	11.46	5.73	0.00	0.00	1.47	0.98	28.31	0.33	0.00	0.00	0.00
4,0-5,0	4.5	11.31	8.31	8.58	0.00	0.14	1.36	0.82	30.52	0.54	0.00	0.14	0.00
5,0-6,0	5.5	11.72	13.95	15.06	0.00	0.14	1.26	0.42	42.54	0.42	0.00	0.00	0.00
mean		8.16	11.82	11.30	0.06	0.07	1.52	0.78	33.70	0.98	0.00	0.15	0.02
total mean diatoms at	of all counted all stations	6.31	8.54	18.16	0.14	0.04	1.27	1.32	35.79	1.72	0.03	0.07	0.03

Total marine ater/ brackish genera

Total marine benthic genera	Tabellaria	Eunotia	Navicula	Amphora	Diatomella	Cymbella	Mastogloia	Rhoicosphenia	Diatoma	Meridon	Melosira sp	Cocconeis	Tetracyklus
2.01	10.17	4.44	4.44	0.72	1.86	0.86	0.00	1.29	21.49	0.72	2.44	6.30	1.86
1.59	10.68	8.23	5.77	0.87	3.61	0.14	0.00	1.15	20.06	0.72	1.44	6.78	0.72
3.16	12.31	4.83	4.99	0.67	2.33	0.00	0.17	1.00	14.64	0.17	3.49	5.82	1.66
5.08	12.30	3.44	4.43	0.82	1.31	0.16	0.00	1.31	11.15	0.16	2.46	6.56	2.13
1.91	10.15	5.44	7.06	0.74	1.03	0.44	0.00	1.76	16.18	0.15	2.35	9.26	1.47
3.39	6.64	7.96	6.64	0.15	0.00	0.15	0.00	1.18	19.62	0.74	2.65	8.55	1.33
2.86	10.37	5.72	5.55	0.66	1.69	0.29	0.03	1.28	17.19	0.44	2.47	7.21	1.53

Total marine vater/brackish genera

Total marine benthic genera	Tabellaria	Eunotia	Navicula	Amphora	Diatomella	Cymbella	Mastogloia	Rhoicosphenia	Diatmona	Meridon	Melosira sp	Cocconeis	Tetracyklus
3.71	15.19	7.77	0.35	0.35	2.30	1.41	3.36	1.06	6.71	2.30	1.06	0.53	0.00
2.35	9.70	6.73	1.41	0.78	0.31	0.00	1.72	0.47	16.28	1.25	1.41	4.07	0.00
0.80	9.12	6.97	0.40	0.80	0.80	1.47	0.00	0.94	12.47	2.01	2.55	12.60	0.00
0.44	11.70	7.16	1.46	0.00	0.44	0.58	0.16	0.58	14.77	1.17	1.17	9.80	0.44
1.65	9.77	7.67	2.71	0.30	2.26	1.05	0.00	1.20	13.08	1.20	3.01	13.53	0.15
1.40	6.84	7.78	2.64	0.16	1.87	0.93	0.31	1.24	22.24	1.40	4.51	6.38	0.00
2.29	4.29	9.14	2.14	0.29	0.14	0.86	0.00	1.29	22.00	2.00	4.86	5.86	0.57
0.61	8.38	6.55	1.22	0.00	0.00	0.30	0.00	0.15	24.24	1.68	1.98	9.91	0.30
0.50	6.48	7.64	5.32	0.33	0.83	0.17	0.33	0.66	20.76	1.66	3.32	5.81	0.50
2.24	6.11	5.22	2.68	0.00	0.15	0.89	0.00	0.00	20.12	0.60	2.53	6.71	0.60
1.09	4.65	7.75	3.72	0.47	0.31	0.16	0.31	0.62	26.05	0.93	4.34	4.96	0.78
1.66	4.83	8.75	5.58	0.30	0.75	0.30	0.00	0.45	24.28	0.60	2.41	5.73	0.45
1.25	7.79	5.92	2.80	0.47	1.71	0.16	0.16	1.09	21.50	0.31	2.34	6.85	0.31
1.54	8.07	7.31	2.50	0.33	0.91	0.64	0.49	0.75	18.81	1.32	2.73	7.13	0.32

Total marine eshwater species

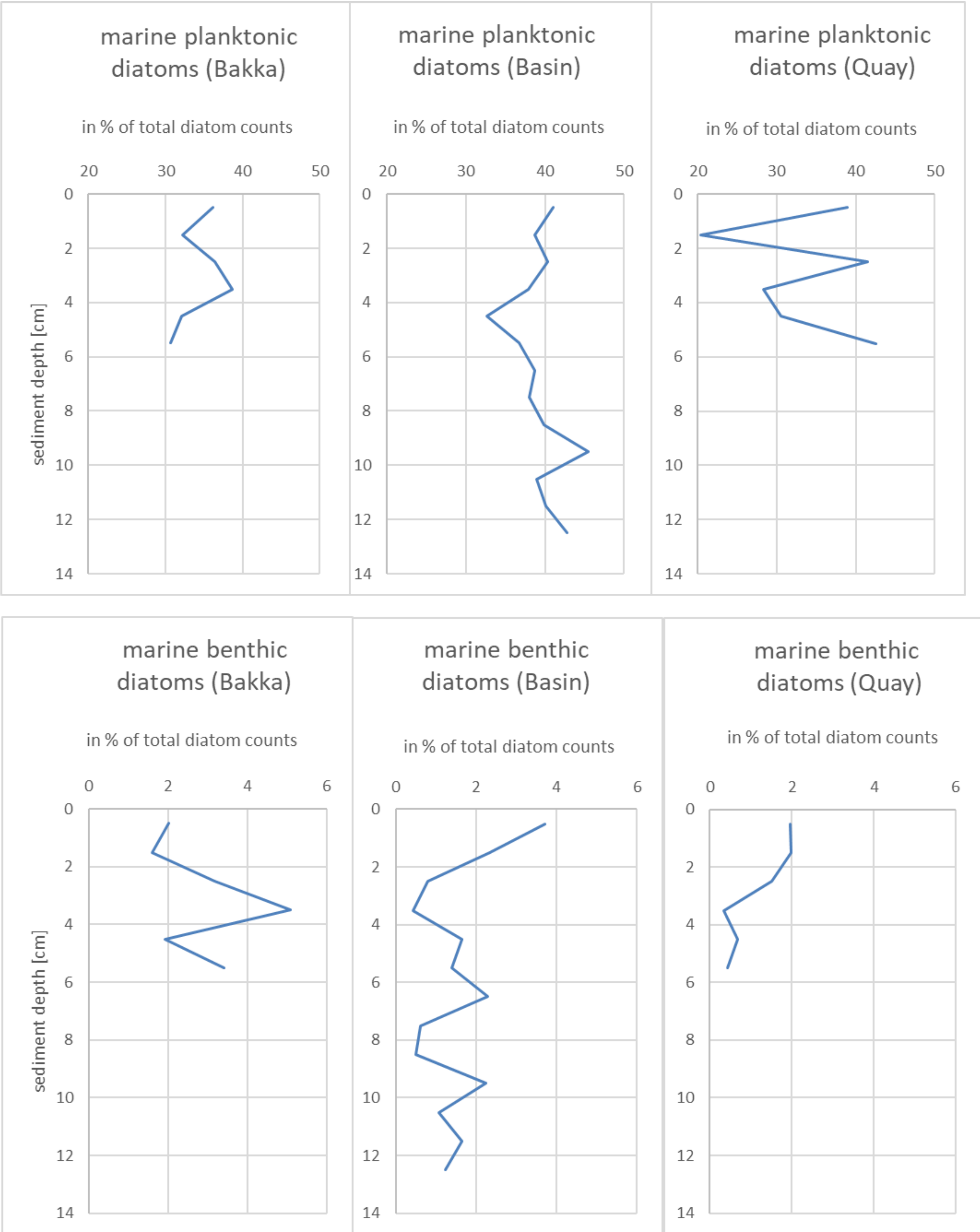
Total marine benthic species	Tabellaria	Eunotia	Navicula	Amphora	Diatomella	Cymbella	Mastogloia	Rhoicosphenia	Diatoma	Meridon	Melosira sp	Cocconeis	Tetracyklus
1.97	9.69	7.44	4.07	0.00	4.78	0.56	0.00	0.98	16.01	0.70	1.40	1.69	0.98
1.98	16.57	13.68	9.12	0.61	1.67	0.61	0.00	0.46	16.11	0.30	1.82	1.98	0.61
1.50	8.18	14.52	7.51	0.00	1.84	0.67	0.17	0.67	13.69	0.33	1.84	1.50	1.00
0.33	14.73	10.15	8.02	0.65	1.64	0.82	0.00	1.47	21.77	0.82	2.45	1.96	0.82
0.68	11.85	8.58	8.04	0.27	0.68	0.82	0.00	0.68	24.93	0.68	0.54	3.41	0.82
0.42	11.30	9.90	11.44	0.00	0.00	0.28	0.14	0.56	8.93	1.12	0.98	4.04	0.42
1.15	12.05	10.71	8.03	0.26	1.77	0.63	0.05	0.80	16.91	0.66	1.51	2.43	0.77
1.85	10.16	7.92	5.36	0.41	1.46	0.52	0.19	0.95	17.63	0.81	2.24	5.59	0.87

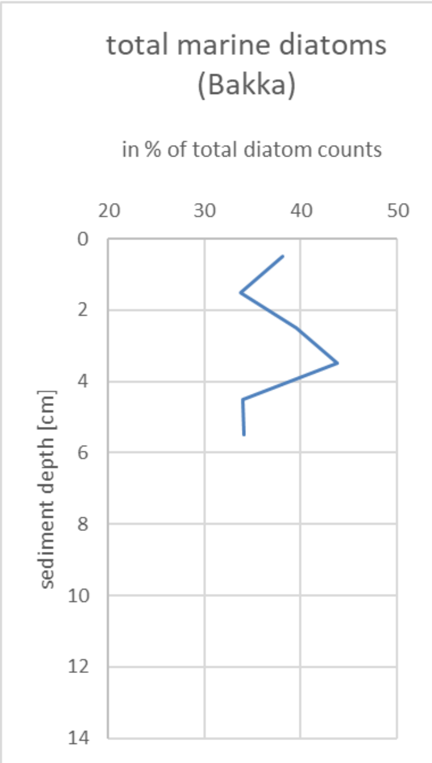
Nitzschia	Pinnularia	Denticula	Gomphonema	Gyrossigma	Fragilaria	Total freshwater/ brackish genera	Other Diatoms	Total % diatoms	Control Total % diatoms
0.00	0.00	0.00	0.00	0.00	3.87	60.46	1.43	100.00	100.00
0.00	0.00	0.58	0.00	0.00	4.04	64.79	1.44	100.00	100.00
0.17	0.00	0.00	0.00	0.17	5.82	58.24	2.16	100.00	100.00
0.49	0.66	0.33	0.16	0.00	6.23	54.10	2.13	100.00	100.00
0.00	0.00	0.00	1.91	0.00	5.88	63.82	2.21	100.00	100.00
0.00	0.00	0.00	0.44	0.00	5.90	61.95	3.98	100.00	100.00
0.11	0.11	0.15	0.42	0.03	5.29	60.56			

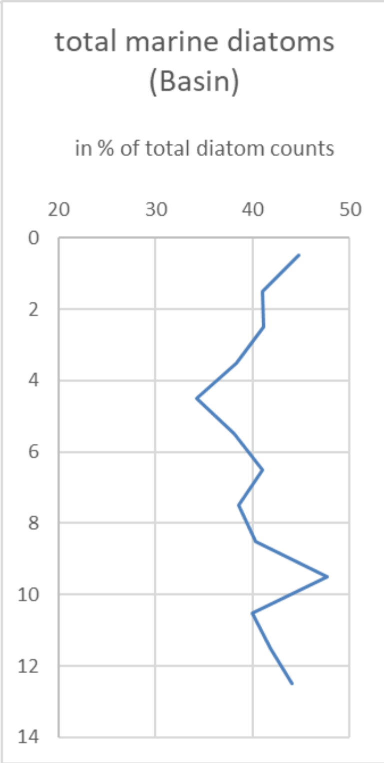
Nitzschia	Pinnularia	Denticula	Gomphonema	Gyrosigma	Fragilaria	Total freshwater/ brakish genera	Other Diatoms	Total % diat/silic	Control Total % diat/silic	depth (cm)
0.00	0.00	0.00	0.00	0.00	10.42	52.83	2.47	100.00	100.00	0.5
0.00	0.00	0.00	0.00	0.00	11.74	55.87	3.13	100.00	100.00	1.5
0.00	0.00	0.00	0.00	0.00	7.77	57.91	0.80	99.87	99.87	2.5
0.00	0.00	0.00	0.00	0.00	11.70	61.12	0.73	100.16	100.16	3.5
0.00	0.00	0.00	0.00	0.00	8.72	64.66	1.05	100.00	100.00	4.5
0.00	0.00	0.00	0.00	0.62	3.89	60.81	1.09	100.00	100.00	5.5
0.00	0.00	0.00	0.00	0.29	3.57	57.29	1.71	100.00	100.00	6.5
0.00	0.00	0.00	0.00	0.00	5.64	60.37	1.07	100.00	100.00	7.5
0.00	0.00	0.00	0.00	0.00	3.99	57.81	1.83	100.00	100.00	8.5
0.00	0.00	0.00	0.00	0.30	5.66	51.56	0.75	100.00	100.00	9.5
0.00	0.00	0.00	0.00	0.00	4.81	59.84	0.16	100.00	100.00	10.5
0.30	0.00	0.00	0.00	0.00	2.41	57.16	1.06	100.00	100.00	11.5
0.31	0.16	0.00	0.00	0.16	2.96	54.98	0.93	100.00	100.00	12.5
0.05	0.01	0.00	0.00	0.10	6.41	57.86				

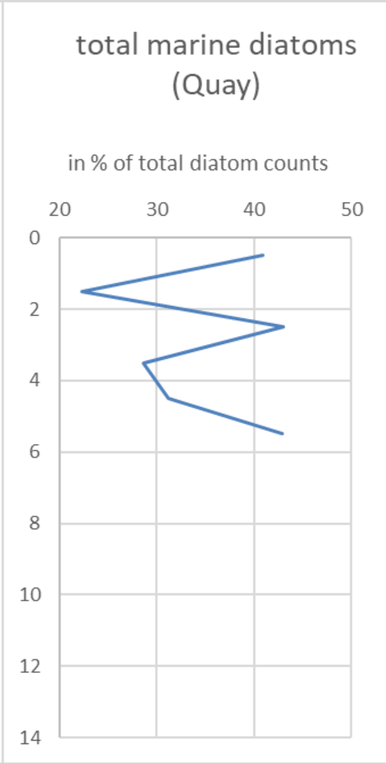
Nitzschia	Pinnularia	Denticula	Gomphonema	Gyrosigma	Fragilaria	Total freshwater brackish species	Other Diatoms	Total % diatoms	Control Total % diatoms
0.14	0.00	0.00	0.00	0.14	9.55	58.15	0.98	100.00	100.00
0.00	0.00	0.00	0.00	0.15	12.46	76.14	1.52	100.00	100.00
0.67	0.00	0.00	0.00	0.00	3.67	56.26	0.67	100.00	100.00
0.33	0.65	0.00	0.00	0.00	4.09	70.38	0.98	100.00	100.00
0.00	0.41	0.14	1.77	0.00	3.95	67.57	1.23	100.00	100.00
0.42	0.00	0.00	1.67	0.00	4.46	55.65	1.39	100.00	100.00
0.26	0.18	0.02	0.57	0.05	6.37	64.02			
0.14	0.10	0.06	0.33	0.06	6.02	60.82			

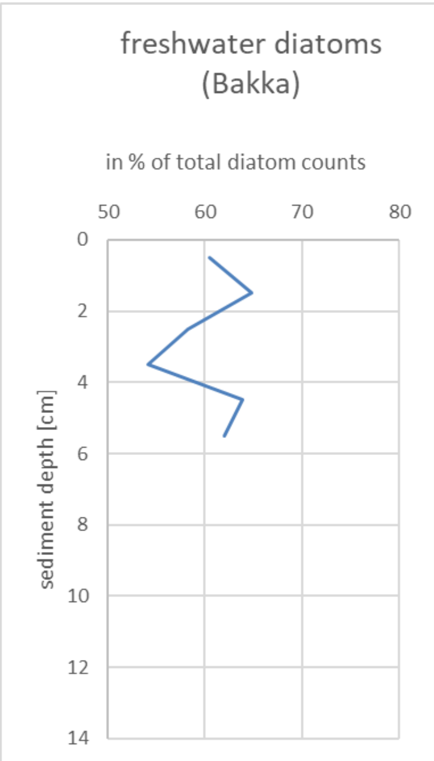
B: Graphs with the percentual distribution of diatoms and added dating

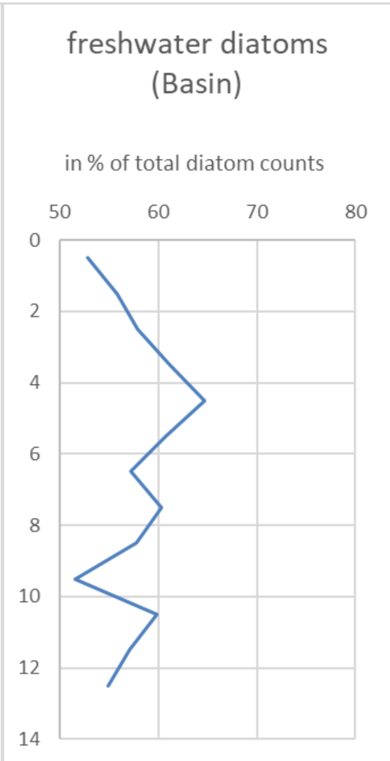


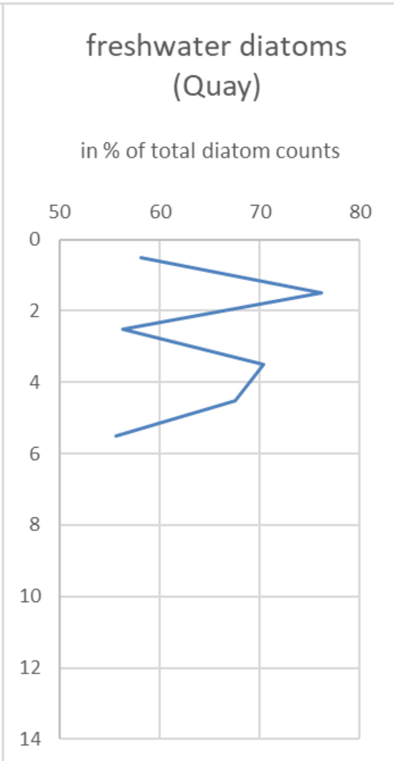

total marine diatoms
(Bakka)
in % of total diatom counts
20 30 40 50
0 2 4 6 8 10 12 14
sediment depth [cm]

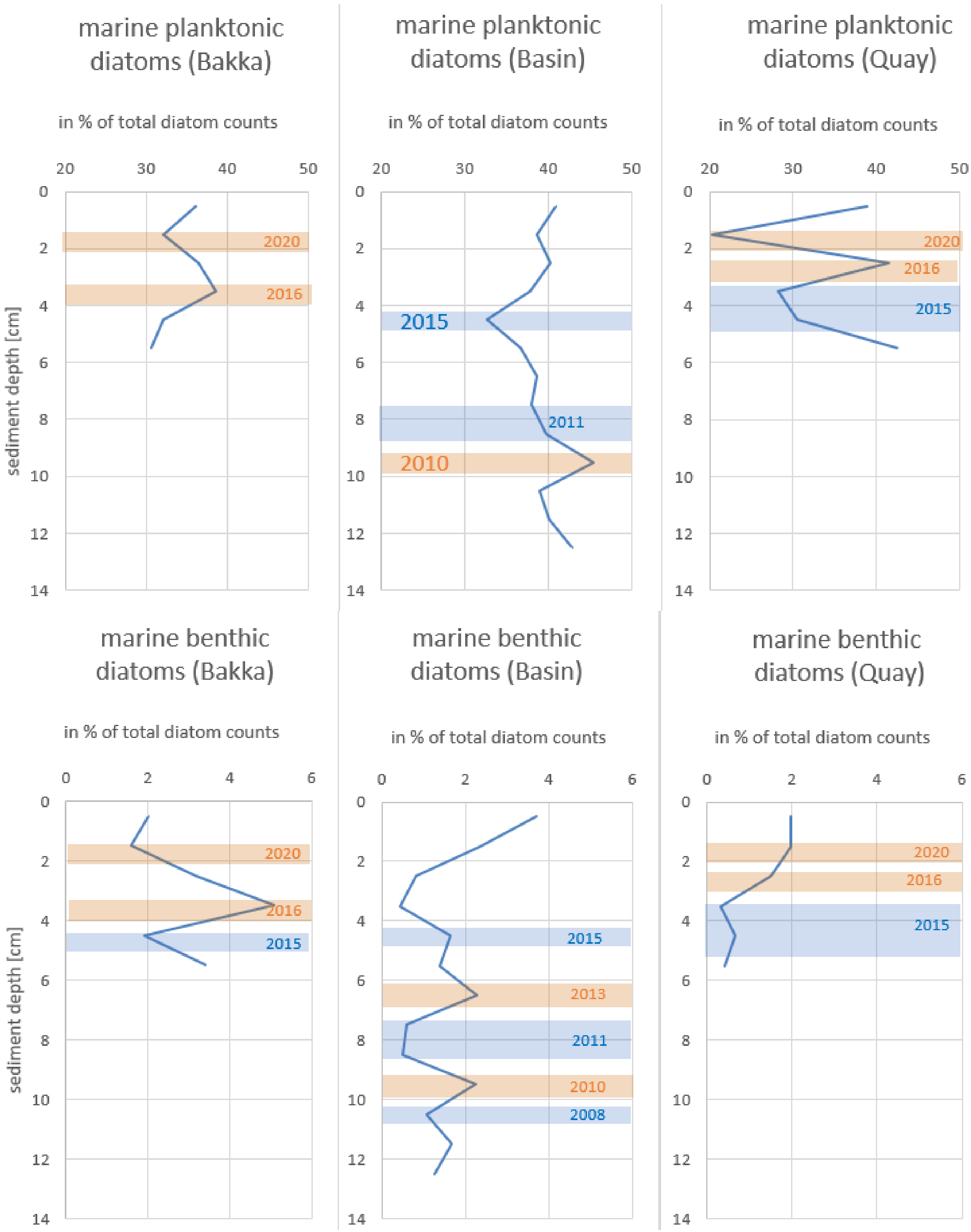

total marine diatoms
(Basin)
in % of total diatom counts
20 30 40 50
0 2 4 6 8 10 12 14

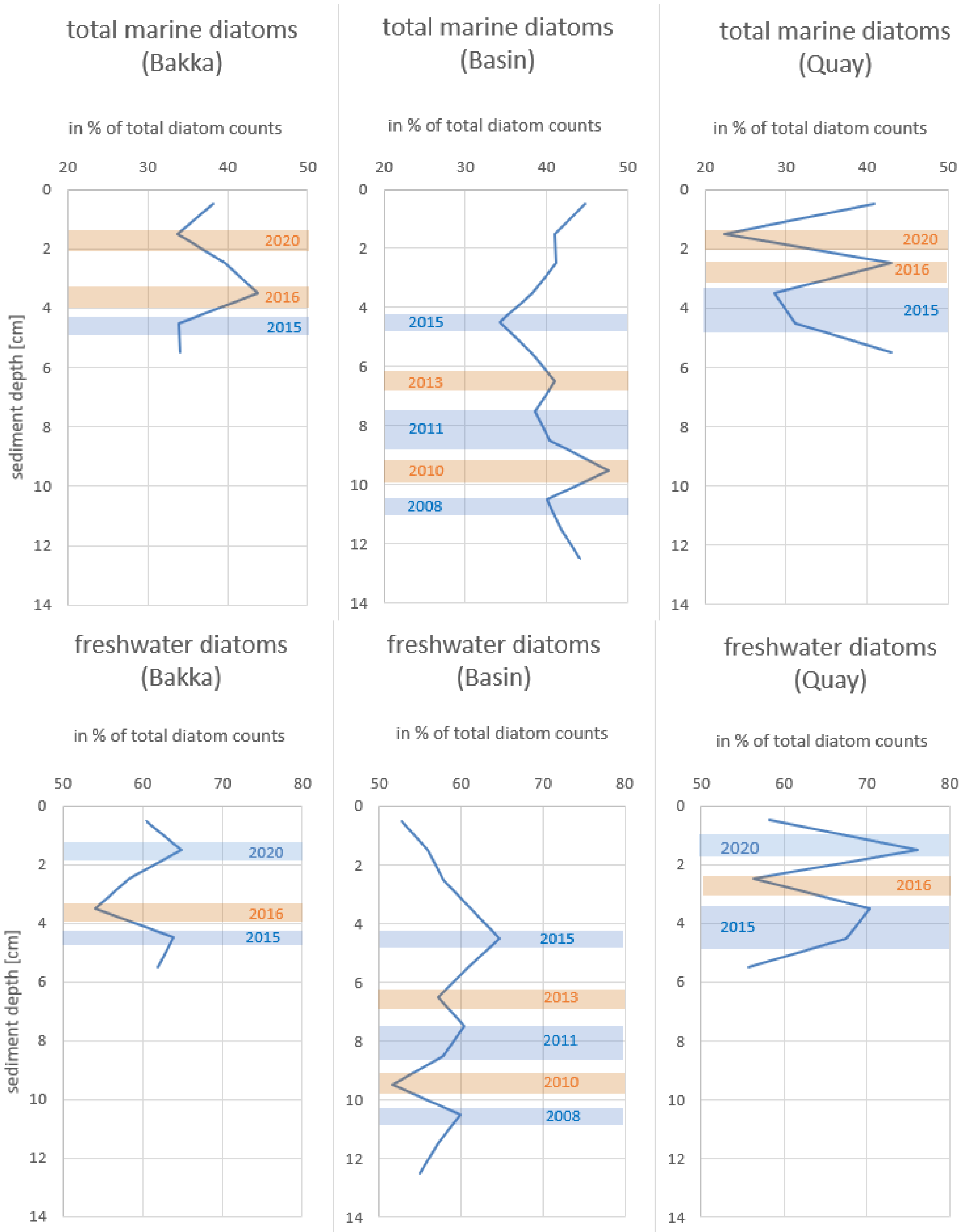

total marine diatoms
(Quay)
in % of total diatom counts
20 30 40 50
0 2 4 6 8 10 12 14


freshwater diatoms
(Bakka)
in % of total diatom counts
50 60 70 80
0 2 4 6 8 10 12 14
sediment depth [cm]


freshwater diatoms
(Basin)
in % of total diatom counts
50 60 70 80
0 2 4 6 8 10 12 14


freshwater diatoms
(Quay)
in % of total diatom counts
50 60 70 80
0 2 4 6 8 10 12 14

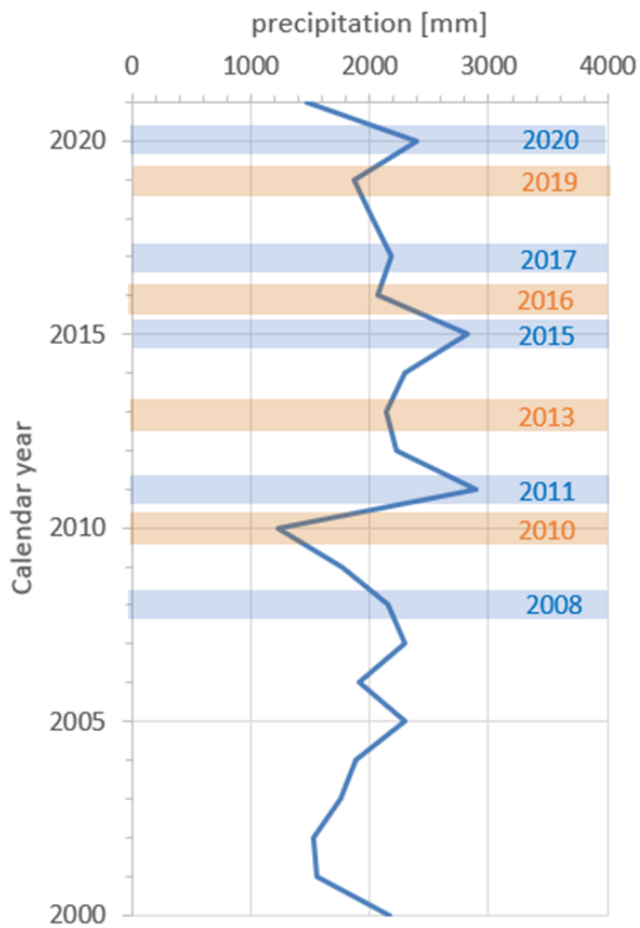

marine planktonic diatoms (Bakka)
in % of total diatom counts
2020
2016
sediment depth [cm]
marine planktonic diatoms (Basin)
in % of total diatom counts
2015
2011
2010
marine planktonic diatoms (Quay)
in % of total diatom counts
2020
2016
2015
marine benthic diatoms (Bakka)
in % of total diatom counts
2020
2016
2015
sediment depth [cm]
marine benthic diatoms (Basin)
in % of total diatom counts
2015
2013
2011
2010
2008
marine benthic diatoms (Quay)
in % of total diatom counts
2020
2016
2015


total marine diatoms (Bakka)
in % of total diatom counts
2020
2016
2015
sediment depth [cm]
total marine diatoms (Basin)
in % of total diatom counts
2015
2013
2011
2010
2008
total marine diatoms (Quay)
in % of total diatom counts
2020
2016
2015
freshwater diatoms (Bakka)
in % of total diatom counts
2020
2016
2015
sediment depth [cm]
freshwater diatoms (Basin)
in % of total diatom counts
2015
2013
2011
2010
2008
freshwater diatoms (Quay)
in % of total diatom counts
2020
2016
2015

Appendix II: Data used for dating the sediment cores

A: Precipitation data

Date	Annual precipitation [mm]
2000	2169.3
2001	1552
2002	1526.3
2003	1752.3
2004	1880
2005	2301.1
2006	1912
2007	2302.7
2008	2160.3
2009	1775.9
2010	1236.7
mean	1869.9
2011	2898.9
2012	2221.2
2013	2137.7
2014	2292.1
2015	2821.5
2016	2064.8
2017	2181.4
2018	2019.7
2019	1874.3
2020	2393.2
2021	1466.6
mean	2215.6

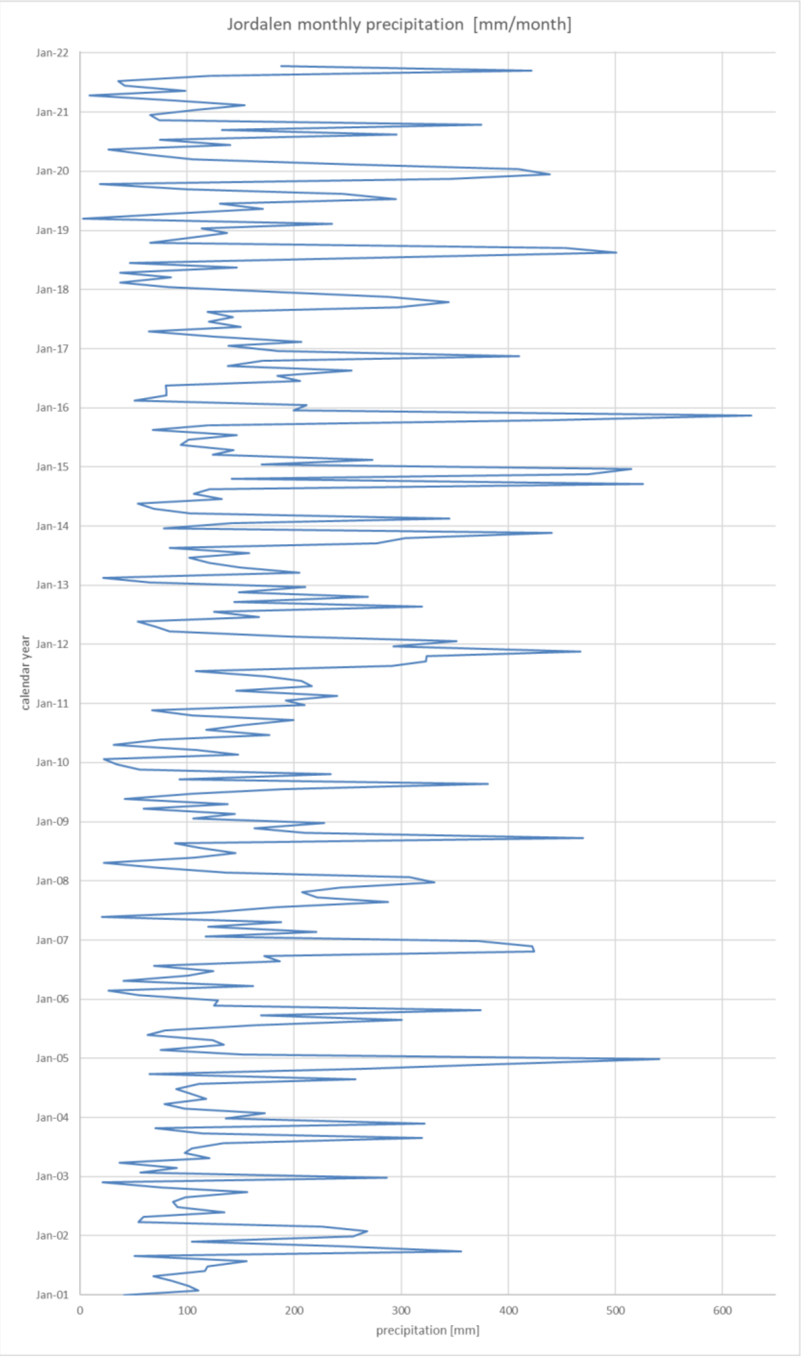


Name: Jordalen - Nåsen
Station: SN53160

Date	Precipitation [mm]		
Dec-00	122.4	Jun-04	102.9
Jan-01	40.8	Jul-04	89.7
Feb-01	110.7	Aug-04	111.3
Mar-01	101.6	Sep-04	257.2
Apr-01	85.6	Oct-04	64.6
May-01	68.5	Nov-04	263.5
Jun-01	116.5	Dec-04	387.7
Jul-01	118.7	Jan-05	541.2
Aug-01	155.7	Feb-05	151.5
Sep-01	51	Mar-05	75.3
Oct-01	356.2	Apr-05	134.4
Nov-01	242.1	May-05	123.7
Dec-01	104.6	Jun-05	63
Jan-02	254.8	Jul-05	79.3
Feb-02	268.3	Aug-05	163.9
Mar-02	226.3	Sep-05	300.3
Apr-02	54.2	Oct-05	168.8
May-02	59.2	Nov-05	374.4
Jun-02	134.6	Dec-05	125.3
Jul-02	91.1	Jan-06	128.7
Aug-02	86.8	Feb-06	55.1
Sep-02	98.1	Mar-06	26.1
Oct-02	155.9	Apr-06	161.4
Nov-02	76.1	May-06	40.6
Dec-02	20.9	Jun-06	100.6
Jan-03	286.3	Jul-06	124.7
Feb-03	56.2	Aug-06	69.3
Mar-03	90.3	Sep-06	186.9
Apr-03	36.7	Oct-06	171.9
May-03	120.8	Nov-06	424.4
Jun-03	97.5	Dec-06	422.3
Jul-03	104.6	Jan-07	372.3
Aug-03	133.9	Feb-07	117
Sep-03	319.4	Mar-07	221
Oct-03	114.2	Apr-07	119.3
Nov-03	70.5	May-07	188
Dec-03	321.9	Jun-07	20.4
Jan-04	136.2	Jul-07	121.8
Feb-04	172.8	Aug-07	183.5
Mar-04	97.4	Sep-07	287.8
Apr-04	78.9	Oct-07	221.2
May-04	117.8	Nov-07	207.6

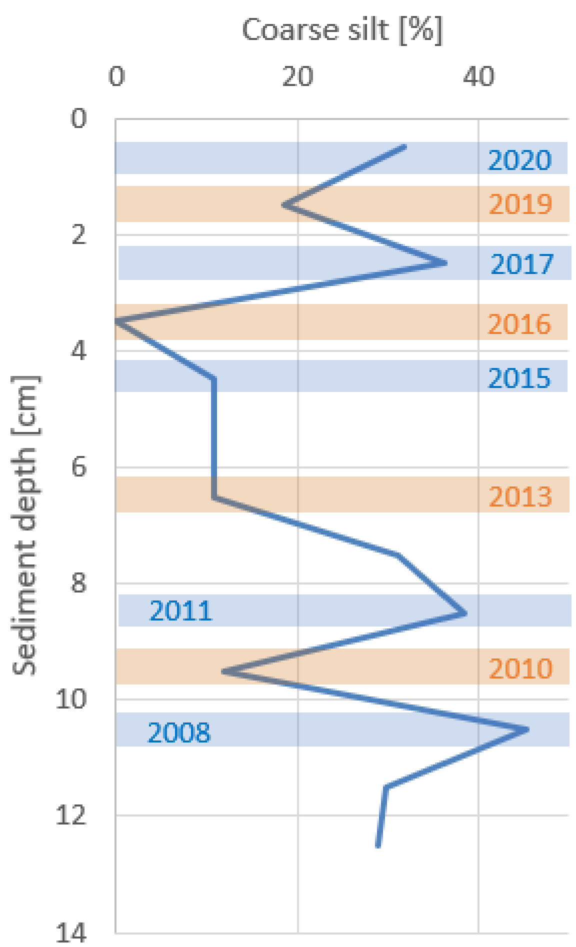
Dec-07	242.8	Oct-11	323.3
Jan-08	331	Nov-11	323.7
Feb-08	307.9	Dec-11	467.7
Mar-08	135.8	Jan-12	292.8
Apr-08	69.2	Feb-12	351.5
May-08	22	Mar-12	195.8
Jun-08	106.8	Apr-12	83.8
Jul-08	144.9	May-12	71
Aug-08	111.9	Jun-12	53.5
Sep-08	88.5	Jul-12	167.4
Oct-08	469.6	Aug-12	125
Nov-08	210	Sep-12	319.6
Dec-08	162.7	Oct-12	143.9
Jan-09	228	Nov-12	268.8
Feb-09	105.6	Dec-12	148.1
Mar-09	144.4	Jan-13	210.5
Apr-09	59.3	Feb-13	65.6
May-09	137.8	Mar-13	21.5
Jun-09	41.9	Apr-13	205.1
Jul-09	105.1	May-13	149.6
Aug-09	190	Jun-13	120.9
Sep-09	381.2	Jul-13	102.1
Oct-09	92.7	Aug-13	157.7
Nov-09	234.2	Sep-13	83.8
Dec-09	55.7	Oct-13	276.7
Jan-10	34.5	Nov-13	303.8
Feb-10	22	Dec-13	440.4
Mar-10	147.6	Jan-14	78.1
Apr-10	109.5	Feb-14	141.4
May-10	31	Mar-14	345.2
Jun-10	74.7	Apr-14	102.6
Jul-10	176.6	May-14	69.3
Aug-10	117.5	Jun-14	54
Sep-10	151.4	Jul-14	132.1
Oct-10	199.5	Aug-14	106.1
Nov-10	105	Sep-14	120.8
Dec-10	67.4	Oct-14	526.1
Jan-11	209.8	Nov-14	141.5
Feb-11	192.3	Dec-14	474.9
Mar-11	240.3	Jan-15	515
Apr-11	145.8	Feb-15	169.3
May-11	216.4	Mar-15	273
Jun-11	206.7	Apr-15	123.8
Jul-11	173.3	May-15	143.4
Aug-11	107.9	Jun-15	94
Sep-11	291.7	Jul-15	101.2

Aug-15	146.5
Sep-15	67.6
Oct-15	118.9
Nov-15	441.8
Dec-15	627
Jan-16	199.7
Feb-16	211.5
Mar-16	50.8
Apr-16	80.5
May-16	80.7
Jun-16	80.1
Jul-16	205.7
Aug-16	184
Sep-16	253.4
Oct-16	137.8
Nov-16	170.4
Dec-16	410.2
Jan-17	185
Feb-17	138.3
Mar-17	207
Apr-17	125.7
May-17	64
Jun-17	150.1
Jul-17	120
Aug-17	142.6
Sep-17	119.1
Oct-17	297
Nov-17	344.2
Dec-17	288.4
Jan-18	190.4
Feb-18	82.7
Mar-18	37.2
Apr-18	85
May-18	37.1
Jun-18	146.6
Jul-18	46.5
Aug-18	275
Sep-18	500.9
Oct-18	453.4
Nov-18	65.2
Dec-18	99.7
Jan-19	137
Feb-19	113.6
Mar-19	235.4
Apr-19	2.4
May-19	78.7
Jun-19	170.7
Jul-19	130.8
Aug-19	294.8
Sep-19	246



B: Distribution of coarse silt

Sediment depth [cm]	Coarse silt [%]	Sediment depth [cm]
0.5	31.85	0.5
1.5	18.52	1.5
2.5	36.1	2.5
3.5	0	3.5
4.5	10.75	4.5
5.5	10.75	5.5
6.5	10.75	6.5
7.5	31.02	7.5
8.5	38.38	8.5
9.5	11.9	9.5
10.5	45.25	10.5
11.5	29.89	11.5
12.5	28.99	12.5



Affidavit

Englisch	German
I hereby confirm that I have authored the present bachelor thesis independently, did not use any sources other than those indicated, and did not receive any unauthorized assistance.	*Hiermit versichere ich an Eide statt, dass ich diese Arbeit selbstständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe. Außerdem versichere ich, dass ich die allgemeinen Prinzipien wissenschaftlicher Arbeit und Veröffentlichung, wie sie in den Leitlinien guter wissenschaftlicher Praxis der Carl von Ossietzky Universität Oldenburg festgelegt sind, befolgt habe.*
Signature	*Unterschrift*