Investigating environmental change in the micro-organism distribution of anoxic Ikjefjord sediments since the 1960s, Western Norway

Bachelor Thesis

Western Norway University of Applied Sciences

van hall larenstein university of applied sciences

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Abstract

The Ikjefjord is a side branch of the Sognefjord, located in the Municipality of Høyanger, western Norway. Local people are concerned about the impact of building activities in the 1970s on the environmental conditions of the Ikjefjord, namely the building of the Ikjefjord bridge and the building of dams in the area for hydropower production. No earlier investigations have been conducted concerning the consequences of the building activities on the fjord environment. The Ikjefjord currently got the ecological classification ‘good’, but it should be emphasized that this classification of The Norwegian Water Resources and Energy Directorate is mainly based on historical data of the area. It is an ambition for this thesis to provide more natural science based aspects as basis for an ecological classification, especially in the light of the complaints of the local people. In this thesis, freshwater and planktonic marine diatoms and benthic foraminifera are used as proxies for the evolution of environmental conditions.

Two sediment cores were sampled in the inner Ikjefjord basin. The sediment cores were dated using the method of Paetzel and Dale (2010), which makes use of the relation between annual precipitation and the total amount of freshwater diatoms. For the diatom counting, smear slides were made using the method of Rothwell (1989). They were investigated on a 40x magnification. For the foraminifera counting, the 250µm - 125µm fraction of the sediment was sieved and placed in a 75% ethanol solution. The samples were investigated on a 25x magnification. To be able to investigate the influence of organic matter on the species abundancies, Loss On Ignition measurements were carried out. The precipitation data necessary for the dating method has been gathered from the eKlima database from the Norwegian Meteorological Institute.

Bivariate pearsons correlation tests have been used in combination with visual interpretation to interpret the results.

In both cores, the ratio of the abundancy of arenaceous versus the abundancy of calcareous foraminifera species increases over time. Secondly, a decline in foraminiferal abundancies is observed in the downer part of both sediment cores. Furthermore, a decline in foraminiferal abundancies is observed in a period where the amount of organic matter was low.

In both cores, the ratio of *Skeletonema costatum* versus all diatom species eventually increases. The ratio of freshwater diatoms versus all diatoms eventually decreases.

The dating method of Paetzel and Dale (2010) was confirmed to work after relating historic precipitation data to the ratio of freshwater versus marine diatoms. The timescale was added to the benthic foraminifera and freshwater and planktonic marine diatom results. The changing compositions of foraminifera then indicate a reduction in oxygen concentrations in the benthic environment from the late 1950s to now. A decrease in oxygen concentrations is expected to be caused by a regional process. This is expected because in the Barsnesfjord and the Sogndalsfjord, which are also side branches of the Sognefjord, oxygen concentrations in the deep water have been decreasing since the mid/late 1950s due to deep water temperature increases. Next to a regional process causing reductions in the oxygen concentration, the building of a bridge in 1975 to 1977 possibly resulted in a restriction of basin water renewal and could therefore have caused oxygen concentrations to decrease faster.

The period of low organic matter was between the early 1980s to late 1990s, and is expected to be caused by an overflow event in 1983.

The ratio increase of *Skeletonema costatum* versus all diatoms seems to start in the early/mid 1970s, with a peak in the mid/late 1990s. This could have been caused the building of dams for hydropower

production in 1971, which possibly reduced the stratification strength and turbidity in the inner basin of the Ikjefjord. Securing of the dam at Stølsvatnet (a lake) in 1983 and the low average annual precipitation in 1996 could have reduced the turbidity and stratification strength in the inner basin further.

The ratio of freshwater diatoms versus all diatoms slightly decreased after the early 1970s, while the average annual precipitation increased. This is a further indication that the damming of the rivers affected the diatom community.

It is recommended to use the results of this thesis as a basis to reconsider the current ecological status of the Ikjefjord. There are most likely more waterbodies where there is no (historic) information about the possible influences of anthropogenic pressures on the environmental conditions and where therefore the ecological status is based on no information. In those cases, it is recommended to add an investigation of micro-organism records in sediments to the current method for ecological classification.

Acknowledgements

Firstly, we would like to sincerely thank Matthias Paetzel, our supervisor at the Western Norway University of Applied Sciences in Sogndal (HVL). His knowledge, dedication and enthusiasm made this thesis better and made the process of writing it way more interesting. Matthias always had time for us when we needed it, if not the same day, then the day after. We have learned a lot from him. Not only how to investigate and interpret sediment records, but also about scientific writing.

We also want to express our gratitude to Jasper van Belle and Astrid Valent, our supervisors from our home university, Van Hall Larenstein University of Applied Sciences (HVHL). Their feedback and tips made us think more about how to handle the thesis, and therefore led to more thought over decisions.

Our thanks also goes to Torbjørn Dale from the HVL. He provided us with relevant foraminifera literature and helped us with laboratory methods. His enthusiasm was contagious, providing us with positive energy in the process of writing the thesis.

We would also like to thank the From Mountain to Fjord 2017 group. They gathered some of the data we were using in this thesis and did a great job. Without them, writing this thesis would have been impossible.

Our gratitude also goes to Manon van Rossum, who wrote a parallel bachelor thesis about the Ikjefjord. She helped us with preparing smear slides. We also discussed problems we encountered and discussed results to see if they were showing more or less the same.

Furthermore we would like to thank Vivian Sinnen, a graduated bachelor student in geology from the University of Halle, Germany. She was doing a traineeship at the Western Norway University of Applied Sciences, and helped us with Loss on Ignition measurements.

Last we would like to thank the international coordinators from the university in Sogndal and our home university, Gunhild Sølvberg and Sjoukje Steinhovden-Kootstra respectively. Their work made it possible for us to go to Sogndal.

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1 Introduction

The Ikjefjord is a side branch of the Sognefjord (Figure 2) and located in the Municipality of Høyanger, western Norway (Figure 1). The fjord is silled, meaning that there is a threshold located at the fjord outlet physically restricting water circulation. Silled fjords are often stratified and the basin water is consequently periodically or permanently low or even depleted in dissolved oxygen, ultimately leading to anoxic bottom water conditions (Gustafsson & Nordberg, 2002).

Massnes (2016) indicates in a personal open letter that the fish stock in the Ikjefjord declined after the impact of human building activity during the 1970s. According to Massnes, these impacts are: (a) Reduction of freshwater input into the Ikjefjord due to the building of a dam at Stølsvatnet in 1970 (Figure 2); please note that Solbakken et al., (2011) referred to this year as 1971. (b) Restricted fjord water circulation due to the raising of the sill when building the Ikjefjord bridge (Figure 2) in 1977 (Brun, 2003).

Before these building activities, i.e. before 1971 (Figure 2, left picture), the drainage direction of the fresh water runoff and rivers was oriented towards the Ikjefjord. Since the redirection of the freshwater through dams and a tunnel (Figure 2, right picture), more than half of the freshwater, formerly running into the Ikjefjord via the Storelva and the Øystrebøelva, is now running to the Matre Hydropower Plant in the opposite direction (Solbakken et al., 2011). No earlier investigations have been conducted concerning the consequences of the redirection on the fjord environment.

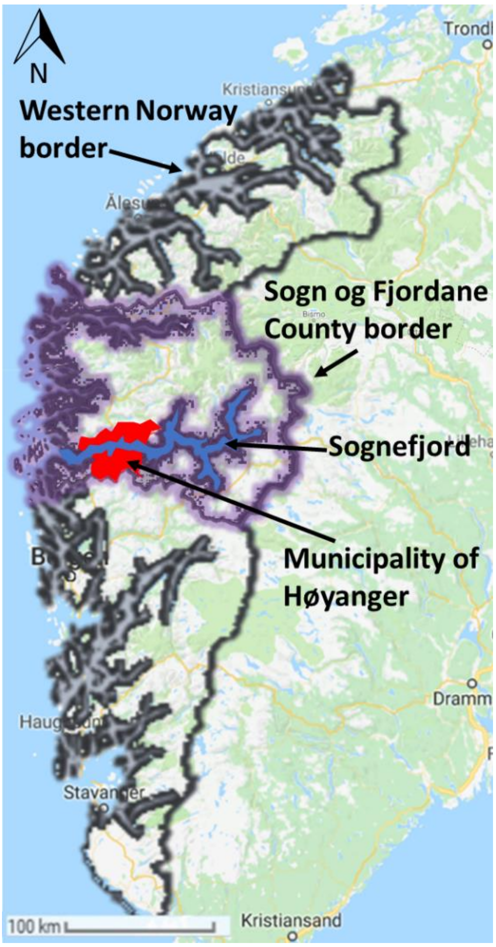


Figure 1: Location overview. The black border indicates the boundaries of Western Norway. The purple border indicates the boundaries of the Sogn og Fjordane County. In red the Municipality of Høyanger is pointed out. In dark blue the Sognefjord, crossing the Municipality of Høyanger (Høyanger Municipality, Map data ©2018 Google).

The Ikjefjord is considered to have a good ecological status according to the European Union Water Framework Directive (after this called WFD). Norway implemented the WFD in 2001 and added the WFD in the national water management framework (Vannforskriften) in 2007 (Vannportalen, 2015). The directive's main objective is to ensure a good status of surface and ground water by the deadline of 2015, which in Norway has been extended to 2021 (NIVA, 2017). Coastal waters are a part of surface waters, according to the definition of surface water given in article 2(1) of Directive 2000/60/EC (EU, 2000). The Ikjefjord is classified as 'coastal water' (Appendix I), and therefore must have the status 'good' by 2021. Although the Ikjefjord currently got the ecological classification 'good', it should be emphasized that this classification of The Norwegian Water Resources and Energy Directorate is mainly based on historical data of the area (Appendix I).

It is an ambition of this thesis to provide more natural science based aspects as basis for an ecological (and consequently environmental) classification, especially in the light of the complaints of the local people (Massnes, 2016).

Before 1971 After 1977

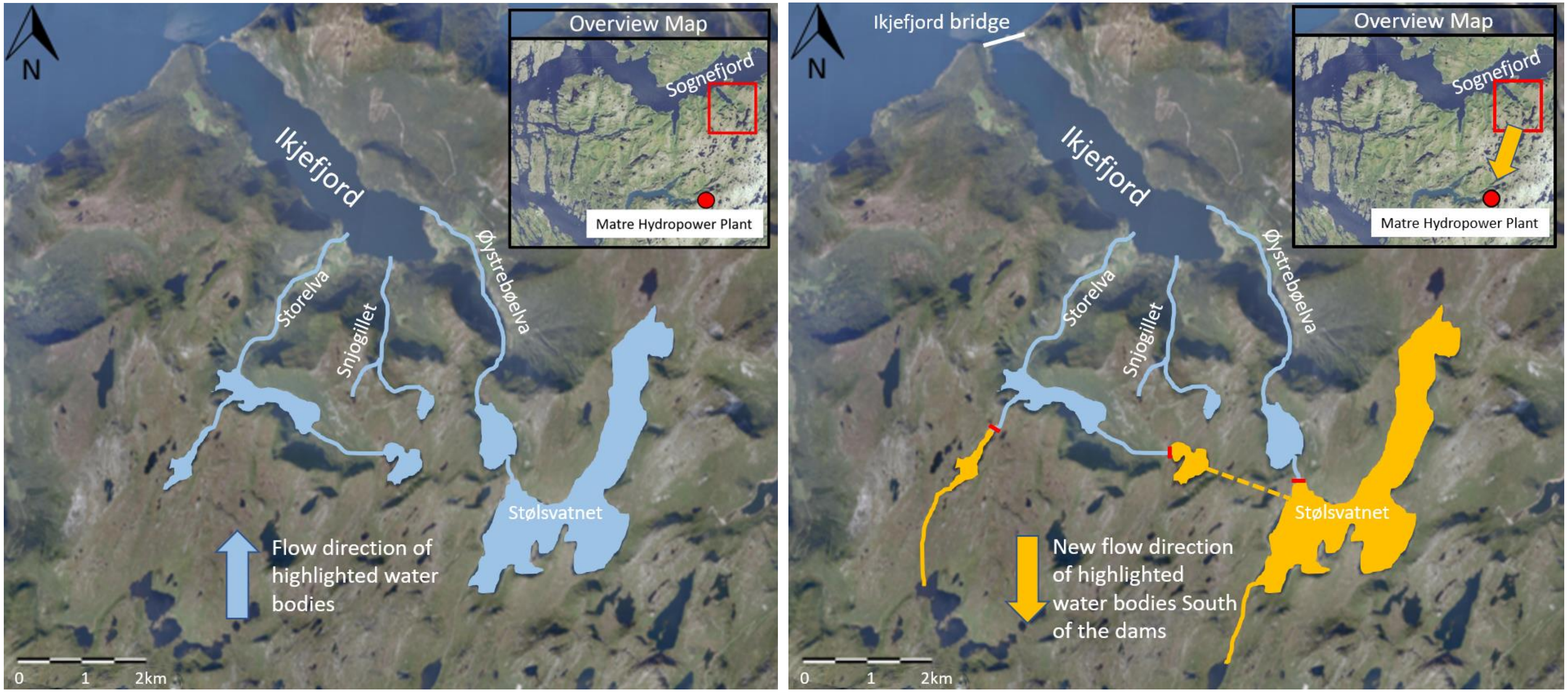


Figure 2: Ikjefjord before 1971 on the left, and after 1977 (with anthropogenic influences) on the right (Norge i Bilder, Ytre Sogn 2007 map). North of the Ikjefjord: the Ikjefjord bridge has been build at the fjord outlet. South of the Ikjefjord: changes have occurred in the river system supplying the Ikjefjord with freshwater. In blue the water bodies with a flow direction towards the Ikjefjord in the direction of the blue arrow. In orange the rivers and tunnel (dotted line) with a new flow direction towards the Matre Hydropower Plant, which is shown in the overview map, in the direction of the orange arrow. The overview maps also show the Ikjefjord as a side branch of the Sognefjord. In red, the dams are shown (BKK, 2018). Due to the dams and tunnel, more than half of the freshwater, formerly running into the Ikjefjord has been redirected to the Matre Hydropower Plant (Solbakken et al., 2011).

1.1 Objectives and research questions

Benthic *foraminifera*, e.g. Alve (2002), and freshwater and planktonic marine diatoms, e.g. McQuoida & Nordberg (2002), Barber & Haworth (1981), and Paetzel & Dale (2010), have been proven useful proxies for environmental change in marine coastal and fjord environments. In this thesis, benthic *foraminifera* will be used to investigate variations in oxygen conditions in the Ikjefjords benthic, i.e. bottom water, environment. Freshwater and planktonic marine diatoms will be used to investigate the effect of a reduction of freshwater inflow into the Ikjefjord.

The major emphasis will concentrate on the impact of historically documented environmental change on the Ikjefjord, mostly adding on a dataset gathered at the Western Norway University of Applied Sciences (HVL) during autumn 2017 (Sogn Avis, 2017).

Results are expected to show that investigating the microfossil record of anoxic sediments is useful for indicating effects of building activity on the environmental conditions in the Ikjefjord. If so, this investigation might help the Sogn og Fjordane County Governor to re-evaluate the current methods for ecological classification of fjord environments, according to the demands formulated in the EU Water Framework Directive.

This leads to the following main question:

'Does the distribution of micro-organisms from the sediment record of the anoxic Ikjefjord sediments indicate effects from the building of freshwater dams, the building of the Ikjefjord bridge or other change on the benthic and pelagic Ikjefjord environment?'

To resolve this question, the following sub-questions have to be answered:

Sub-question 1: Is it possible to date the anoxic sediments of the Ikjefjord?
Dating of the sediment cores is necessary to provide a timescale to the dataset of benthic foraminifera and freshwater and planktonic marine diatoms. With this information, observed changes in environmental conditions can be linked to a timeline. This provides knowledge to determine the cause(s) of the change. Dating recent sediments usually includes the radiometric ^{210}Pb or ^{137}Cs dating methods, or similar. Paetzel & Dale (2010) established an inexpensive and less time consuming alternative dating method in recent Norwegian fjord sediments. This method uses the relationship between the historically documented precipitation record of the area and the successive transport of freshwater diatoms and mineral matter into the marine fjord environment. This thesis will use the alternative dating method of Paetzel & Dale (2010).

Sub-question 2: Does the composition of benthic foraminifera indicate a shift in the benthic environment?
A change in the composition of benthic foraminifera gives information about changes in the benthic environment. Numerous investigations have shown that benthic foraminifera, which leave a fossil record in most coastal marine and fjord sediments, are well suited for monitoring environmental change over time; see Alve (2002) and references therein.

Sub-question 3: Does the composition of freshwater and planktonic marine diatoms indicate a shift in the planktonic environment?
Changes in the abundancy and species distribution of diatoms give information about changes in the marine (McQuoida & Nordberg, 2002) and freshwater (Barber & Haworth, 1981) environments. The peak appearance of freshwater diatoms relates most likely to the peak appearance of the historic precipitation data, as introduced in the first sub-question. However, it is expected that the total number of freshwater diatoms will decline after 1971 due to the damming of the lakes. The peak relationship with precipitation will most likely still be there, but the total number of freshwater

diatoms will be less, compared to the abundance of planktonic marine diatoms. Further, planktonic marine diatom species that are dominant in weakly stratified waterbodies, like *Skeletonema costatum*, are likely to get a higher abundancy after 1971.

Sub-question 4: If the microorganism composition changes, is it possible to find the sources of these variations by relating these variations to documented historic natural or human induced environmental change?
The type and speed of change will give information about how the environmental conditions changed over the years.

The year the change started to occur will then be compared with dates of historic events, i.e. the building of the bridge, the damming of the rivers, changes in precipitation and natural events. This might lead to an indication of the source(s) of the variations in the microorganism composition.

Sub-question 5: Do the results suggest that investigating the microorganism distribution in anoxic sediments are useful to complement on the current methods for ecological classification required by the EU Water Framework Directive?
The European Commission (2016) allows giving the classification of "good ecological status" to water bodies if the executing agency expects only slight deviations in ecology due to minimal anthropogenic pressure. Such expectations have to be subjective. They would possibly improve greatly if based on objective scientific data.

If the Ikjefjord sediments can be dated, and if the microfossil record indicates changes in environmental conditions, and if the sources of these changes can be determined, a recommendation will be given to investigate further how the microorganism distribution in anoxic sediments can be used to complement on the current methods for ecological classification.

1.2 Thesis products and relevance

This thesis contributes to a further understanding of environmental conditions in fjords. The thesis is relevant for the following parties:

- The County Governor (Fylkesmannen), who is responsible for implementing the EU Water Framework Directive in the Sogn og Fjordane County (Figure 1)
- The local people of the Ikjefjord region, who are worried about the influence of anthropogenic activities on the Ikjefjord
- The managers of the hydropower production plant, if the damming of the rivers caused changes in the environmental conditions of the Ikjefjord
- The Høyanger Municipality, if the building of the bridge caused changes in the environmental conditions of the Ikjefjord
- Parties that wish to conduct further research in the Ikjefjord

2 Theoretical background

This chapter gives insight in the environmental setting of the Ikjefjord now and in the past by showing the depth profile of the fjord and explaining the water circulation processes, and by summarizing historic building activities and natural events. In addition, this chapter provides some relevant background information about the European Water Framework directive.

2.1 Bathymetry

The Ikjefjord is divided into the inner and the outer basin (Figure 3). The inner basin has a maximum depth of around 90 meters while the outer basin has a maximum depth of around 120 meters

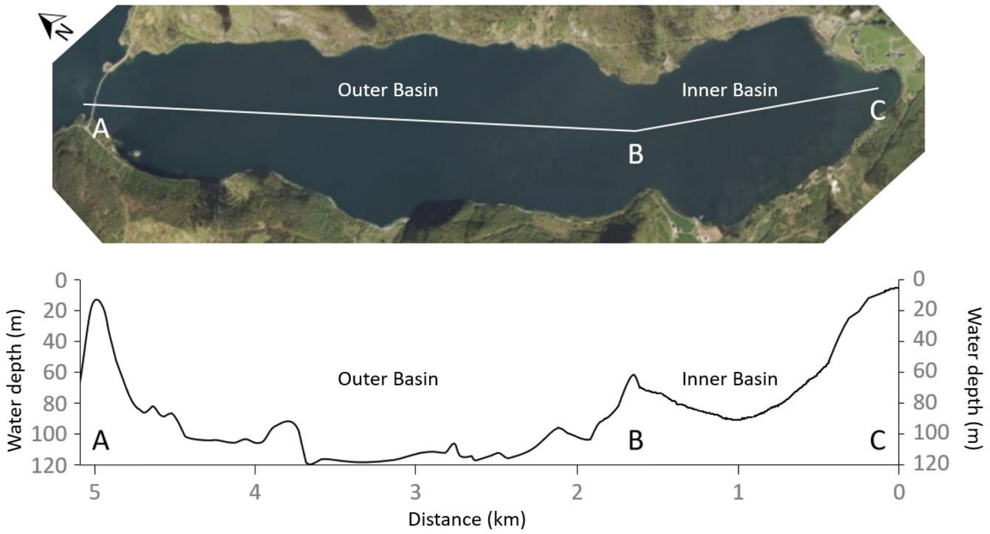


Figure 3: White line of a cross section (above) of the Ikjefjord, showing the depth profile (below) through positions A, B, and C of the fjord. The outer basin is located between positions A and B. The inner basin is located between positions B and C (Personal communication with Matthias Paetzel, 2017*).*

2.2 Hydrography

First, basin water renewal is explained. Secondly, an explanation of estuarine circulation is given, followed by an explanation of vertical convection. These processes provide a basic understanding of oxygen supply into silled fjords and oxygen depletion in fjord deep-water environments.

2.2.1 Fjord basin water renewal

The Norwegian Coastal Current

The Norwegian Coastal Current follows, combined with the Atlantic waters of the Gulfstream, the Norwegian Coast all the way from the Skagerrak in the south to the Barents Sea in the north (Figure 4). The coastal surface water masses are less saline than offshore surface waters due to the outflow of brackish water from the Baltic Sea and river runoff from the Swedish and Norwegian coast (Institute of Marine Research, 2014).

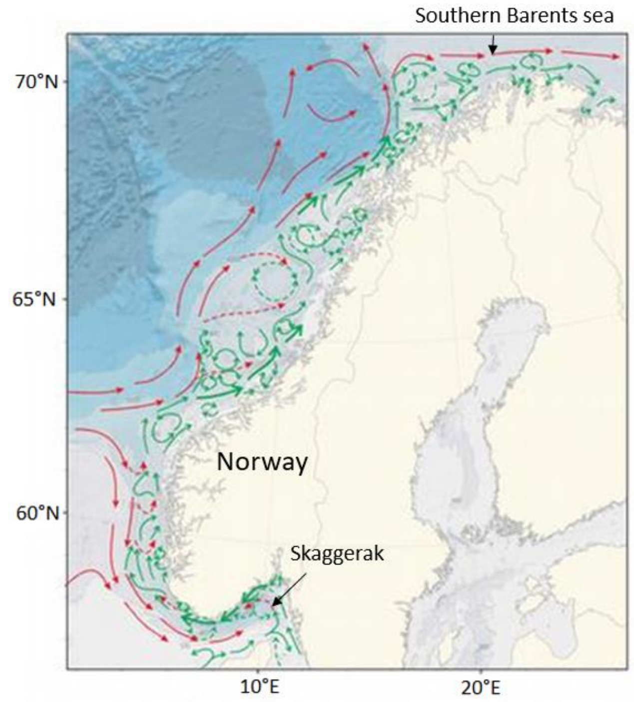


Figure 4: The Norwegian Coastal Current with green arrows, and the Atlantic water masses of the Gulfstream with red arrows (Institute of Marine Research, 2014).

Due to the lower density, the less saline coastal water lies as a wedge (the coastal wedge) on top of the Atlantic water as indicated in Figure 5.

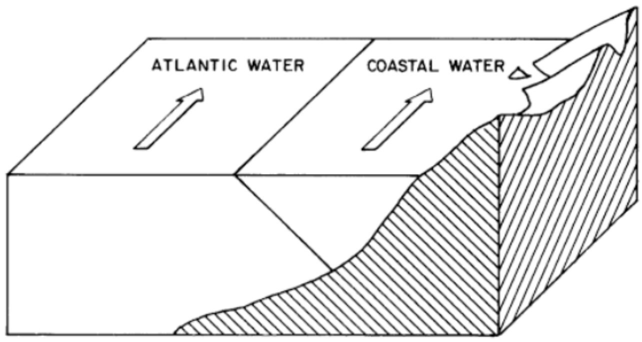


Figure 5: Wedge of low-salinity Coastal Water overlying water of Atlantic origin during winter, when the direction of the prevailing wind (as well as the current) is coming from a south-westerly direction as indicated by the arrows (Hurdle, 1986).

In winter, the coastal water spreads towards the Norwegian coast. This causes the coastal water, and therefore the coastal wedge, to be deep and narrow in winter (Figure 5). In summer, the coastal water spreads away from the Norwegian coast. This causes the coastal wedge to become wide and shallow (Hurdle, 1986; Dickson et al., 2008).

Basin water renewal

The exchange of fjord bottom water occurs when the water above sill level outside the fjord is denser than the residing deep water and pushed over the sill into the fjord (Figure 7). Being denser, new deep water descends along the bottom of the fjord basin, by which old basin water is pushed away and lifted to higher levels (Arneborg et al., 2004). This means basin water renewal is not constant, but happens from time to time by inflow events. This is due to oscillations of the coastal wedge. Oscillations of this wedge may cause inshore upwelling of the dense Atlantic water, which may occasionally spill over the sill into the fjord basins (Syvitski et al., 1986).

One of the factors pushing Atlantic water towards the coast is the wind direction. When the wind blows from south to north, it moves the Atlantic surface water to the right, i.e. towards the east. The Coriolis force is responsible for this deflection to the right in the northern hemisphere (De Coriolis, 1832; De Coriolis, 1835). According to Ekman (1905) the surface layer will move with an angle of 45° from the wind direction (Figure 6). Due to friction, the water layers below the surface water move slower. Those layers are more influenced by Coriolis per unit of distance. The angle of movement of water layers therefore changes from top to bottom (Figure 6). This is called the Ekman's spiral (Ekman, 1905)

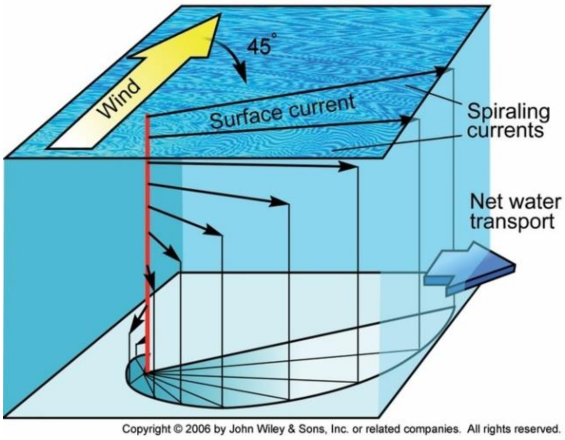


Figure 6: Ekman spiral (National Oceanic and Atmospheric Administration, 2017; modified from Ekman, 1905).

The net effect of the Ekman's spiral is that the net water transport has a 90° angle from the wind direction. This means that if the wind moves from south to north, following the Norwegian coast, Atlantic water is pushed towards the coast to the east.

2.2.2 Estuarine circulation

Rivers and streams within the Ikjefjord drainage system, supply freshwater to the fjord that forms an upper brackish water layer ('surface water' in Figure 7). This brackish water moves out of the fjord. A compensation current is created, where coastal water moves back into the fjord. Because the compensation current and the upper brackish water layer have opposite directions, there is friction between them. This friction causes the two water masses to slightly mix (Syvitski et al., 1986). This is called entrainment (Figure 7).

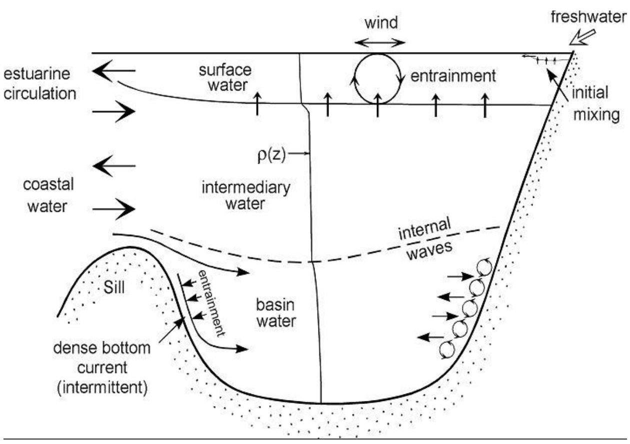


Figure 7: Estuarine circulation (Ecasa, 2007)

The total of outgoing brackish water, incoming coastal water and entrainment is called the estuarine circulation (Hansen & Rattray, 1966). One of the biological effects of the estuarine circulation is that biological material such as phytoplankton may be passively transported into fjords and may account for the deposition of allochthonous marine organic matter (Syvitski et al., 1986).

2.2.3 Vertical convection

Vertical convection or thermohaline circulation (Figure 8); first defined for ocean currents (see review of Rahmstorf, 2003) mixes deeper fjord water with higher located water masses (Syvitski et al., 1986). This often happens during cold periods where there is a small freshwater surface layer and therefore weak to no stratification at the water surface. If there is not a strong stratification, and the surface water layer is cooled, the density increases. Eventually (at the highest density of water, i.e. at 4^{o}C, and in relation to increased and homogenized salinity), the surface water starts sinking. It does not sink all the way to the bottom, since the water still has a lower salinity than the deep water. Hence, the density difference in salinity causes a stratification. Warmer water goes back up to the surface, and vertical convection is created. Vertical convection provides deeper water with oxygen and brings nutrients up to the euphotic zone.

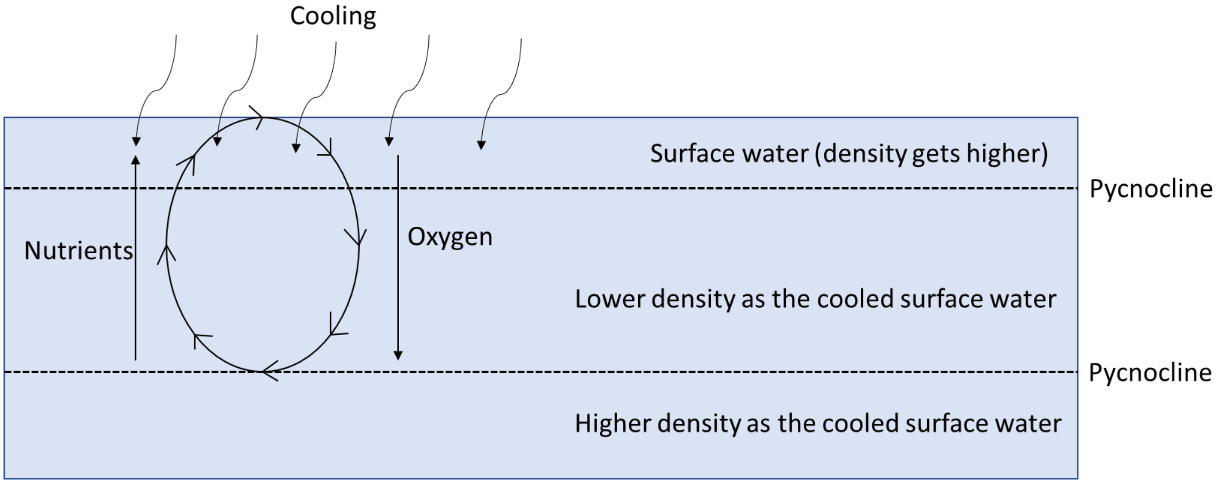


Figure 8: Deep vertical convection

How deep vertical convection reaches, depends on the acquired density of the surface water layer by cooling and the densities of the underlying water masses. In winter, the amount of freshwater released from the rivers is low compared to summer, which leads to a thin surface layer (not a strong stratification of the surface layer). The temperature is also coldest, which means the density of the surface layer increases relatively much. This is why the deep vertical convection is mainly a winter phenomenon (Syvitski et al., 1986).

2.2.4 Oxygen depletion in fjords

The bottom of a fjord outlet often consists of a sill (or threshold) built of bedrock or glacial moraine material. Shallow sills leave a narrow gap for water exchange and might therefore effectively restrict water circulation and water renewal in fjords (Syvitski et al., 1986; Woodroffe, 2003). A restriction in water renewal means that the old oxygen in the basin water has a longer residence time. A restriction in water circulation means that organic matter also has a longer residence time. This combination can lead to anoxic conditions in the fjord bottom waters when the oxygen consumption rate (by persistent organic matter decomposition) exceeds the rate of oxygen renewal.

2.3 Recent history and relevant building activity

Recent history is in this paragraph defined as the last 60 years. Recent historical events and building activity might have caused a change in environmental conditions in the Ikjefjord.

2.3.1 Natural events

In 1983, a freshwater overflow occurred over the dam at Stølsvatnet and down the Øystrebøelva (Figure 2 for location overview). This caused unknown masses of freshwater to be released very quickly into the Ikjefjord. According to Asbjørn Massnes and Matthias Paetzel (Personal communication between Paetzel and Massnes, 2017) fields and forests in the river valley were flooded. The Ikjefjord was coloured white of undefined detritus material, suggesting a visible impact of this event in the fjord sediment (Personal communication between Paetzel and Massnes, 2017). Unfortunately, the responsible people of the Matre Hydropower Plant could not provide written documentation of this event (Bøe, 2017). However, Massnes (Personal communication between Paetzel and Massnes, 2017) mentions some extensive work in the valley of the Øystrebøelva in 1983 to secure the river valley and the dam at Stølsvatnet against future flooding. This resulted in an extensive damming of the riverbanks, as also indicated in the photograph from the valley of the Øystrebøelva taken in 2017 (Figure 9). It is likely that the rocks used to adjust the riverbanks are not originally from places along the river but retrieved from elsewhere. The rocks are currently partly covered with young vegetation.

Figure 9: Adjusted riverbank in the Øystrebøelva. Picture taken by Matthias Paetzel in 2017

The number of additional overflow events prior to 1983 is not documented and thus unknown. After 1983, only four minor overflow events are documented across the dam at Stølsvatnet in December 2011, January 2012, November 2012, and December 2015 (Appendix II). These overflow events did not cause any recorded damage.

2.3.2 Hydropower production

Figure 2 shows the network of rivers and lakes in the drainage area of the Ikjefjord. The re-direction of the freshwater outflow from Stølsvatnet reduced the freshwater runoff via the river Øystrebøelva into the Ikjefjord by over 60% (Schedel et al., 2015; Åtland et al., 1998) since 1971. In addition, the redirection activity reduced the freshwater runoff through the river Storelva by over 40% (Schedel et al., 2015; Åtland et al., 1998). The reason for redirecting the water masses was to maximise the hydropower production of the Matre Hydropower Plant (Figure 2).

2.3.3 Building of the bridge

The building of the Ikjefjord bridge occurred across the outlet of the Ikjefjord (Figures 2 and 10), starting in 1975 (Massnes, 2016). The construction of the bridge was finished in 1977 (Brun, 2003). During the construction of the bridge, the 150m long eastern part of the sill was filled in to above surface water level (Figure 10). According to Massnes (Personal communication between Paetzel and Massnes, 2017), this part of the sill was the deepest, with a depth of approximately 20 meters. In addition, Massnes (2016) states that the water current used to be quite strong.

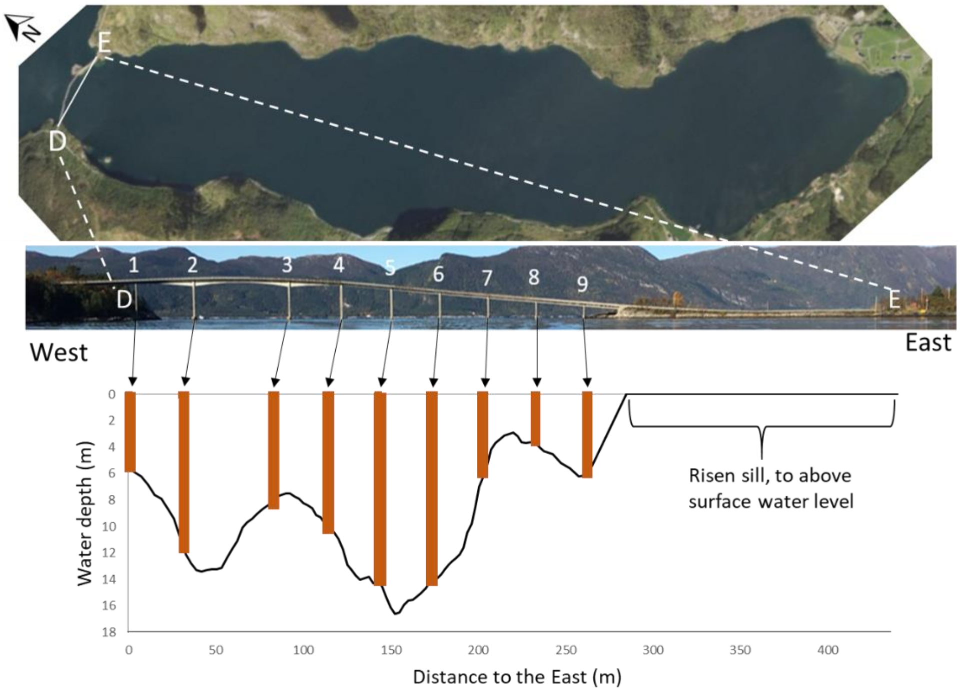


Figure 10: White line of a cross section (above) of the sill across the outlet of the Ikjefjord, showing the depth profile (below) through positions D and E of the fjord. Middle picture of the bridge and the echo sounder data from Matthias Paetzel, taken in October 2017. Orange bars indicate the numbered pillars of the bridge.

If the eastern part of the sill indeed was the deepest part of the sill, the building activity might have led to a decrease in deep water circulation. The narrowing of the sill and the reduction of the deepest sill point from 20m to 16m might have resulted in a restriction of basin water renewal. It also could have restricted the compensation current. This would explain the observation of Massnes (2016), who stated that the water currents decreased in strength.

Høyanger municipality and the building authorities could not provide any written documentation on the building activity of the bridge. It was thus not possible to provide a documentation of the original sill depth for this thesis.

2.3.4 Regional oxygen concentration decrease

There are datasets available showing historic oxygen concentrations of the Sogndalsfjord and the Barsnesfjord (personal communication between Torbjørn Dale, Peter Hovgaard, and Matthias Paetzel, 2018). The Barsnesfjord and the Sogndalsfjord are northern tending side branches of the Sognefjord (Figure 11).

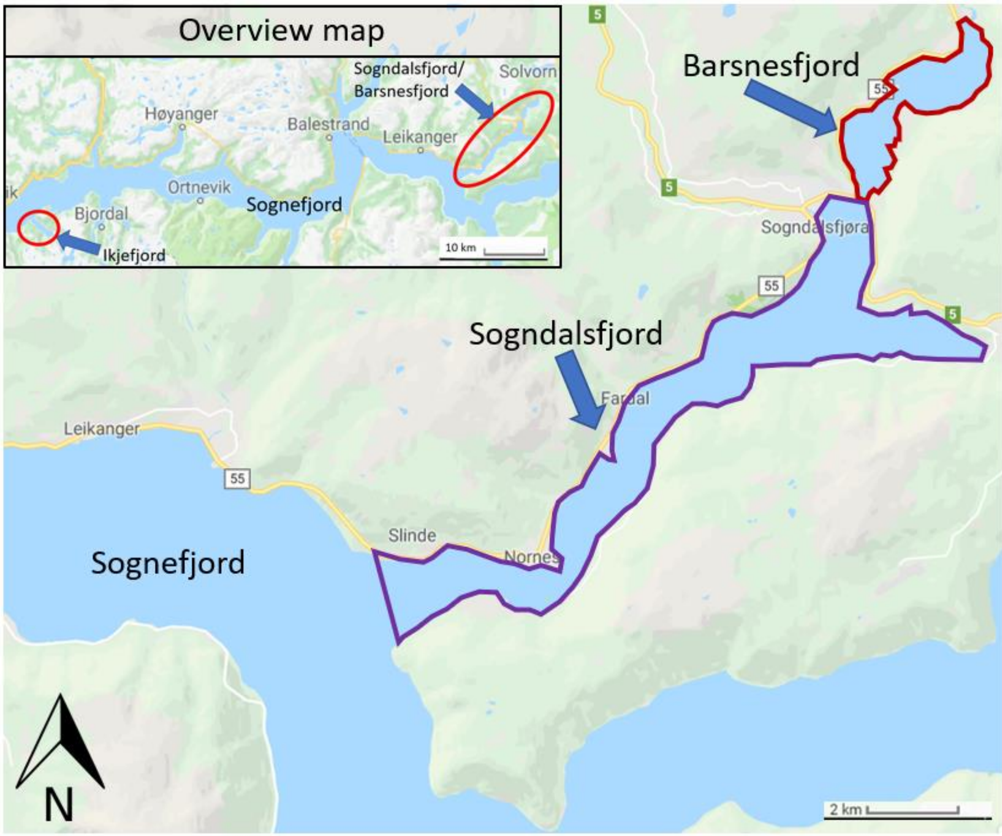


Figure 11: Location Sogndalsfjord and Barsnesfjord (Google, 2018)

In both fjords, the temperatures of the deep water increase since the mid/late 1950s, causing the oxygen concentrations in the deep water to decrease (Figures 12 and 13). In addition, a variety of shorter time records exists to confirm the general decrease in the bottom waters of the Sognefjord since the mid/late 1950s (Personal communication with Matthias Paetzel, 2018). These shorter time records are not available. This general decrease in oxygen concentrations of fjord bottom waters might thus also have affected the Ikjefjord.

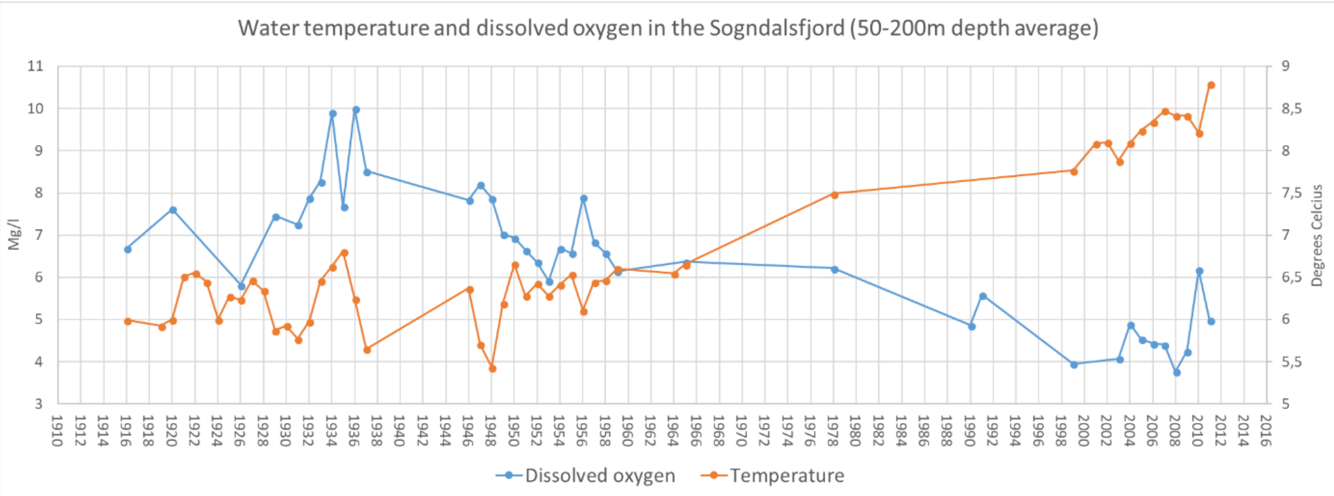


Figure 12: Yearly averaged oxygen concentrations over time of the Sogndalsfjord (Personal communication between Torbjørn Dale, Peter Hovgaard and Matthias Paetzel, 2018)

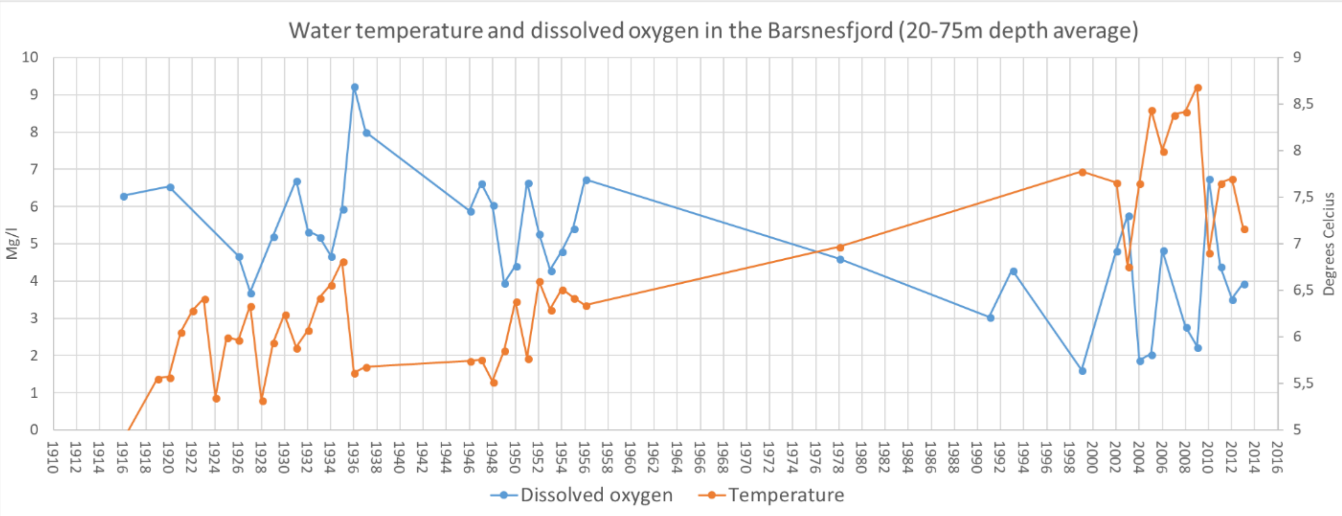


Figure 13: Yearly averaged oxygen concentrations over time of the Barsnesfjord (Personal communication between Torbjørn Dale, Peter Hovgaard, Matthias Paetzel, 2018)

2.4 Residents

According to Bøe (2017), who is an environmental protection manager (miljøvernleiar) at Høyanger Municipality, there are 40 residents registered in the Ikjefjord surrounding of which 20 are permanent residents. The houses are not connected to the sewage. Bøe (2017) states that residents make use of a septic tank for sewage disposal (Figure 14).

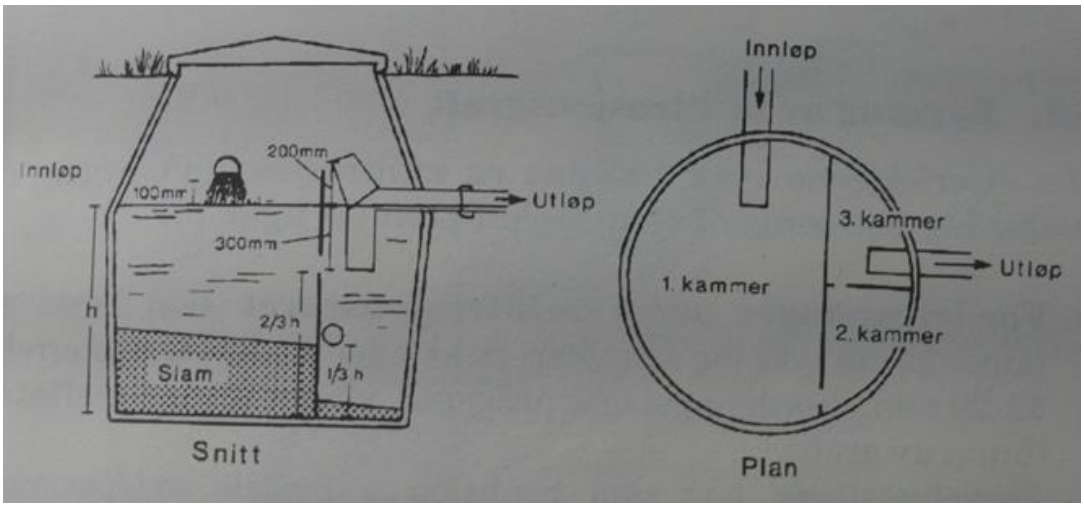


Figure 14: System for treating sewage water, used by the residents in the Ikjefjord area (Bøe, 2017)

It seems as if the treatment system is a system where the different chambers are used for pre-settling, nitrification/BOD (=Biological Oxygen Demand) removal by aeration and settling of suspended solids and sludge.

Those types of treatment systems only work when they get a consistent inflow of water. The 20 permanent residents probably make us of this treatment unit, while the remaining 20 residents most likely make use of an outhouse.

Because the number of residents is low and the permanent residents make use of a septic tank to treat the sewage, it is expected that the influence of sewage on the water quality of the Ikjefjord is negligible.

2.5 Benthic foraminifera and freshwater and planktonic marine diatoms

In this thesis, benthic foraminifera and freshwater and planktonic marine diatoms are used as proxies for changes in environmental conditions. This paragraph gives information about how they can be used.

2.5.1 Foraminifera

Foraminifera are heterotrophic amoeboid protists, which are present in almost all modern marine biotopes, see summary of Alve (2018). Different species have different tolerances to environmental change.

Scott et al., (2001) states that decreasing oxygen concentrations are indicated by an increase in the abundancy of arenaceous (or agglutinated) foraminifera species and a decrease in the abundancy of calcareous foraminifera species. The indication is stronger when the abundancy of species *Spiroplectammina biformis* increases (Scott et al., 2001). This is for example observed in the Drammensfjord (Alve, 1995).

The species *Stainforthia fusiformis* is often used as an indicator for rapid changes in environmental conditions (Alve, 2002). Alve (2002) states that this species is also tolerant for low oxygen concentrations. That *Stainforthia fusiformis* can survive during times of low oxygen concentrations is for example observed in the the Gullmar fjord basin. During a period of low oxygen concentrations the foraminifera *Stainforthia fusiformis* dominated (Davidsson, 2014). *Stainforthia fusiformis* can also get high abundancies when the oxygen concentrations suddenly rise. High abundancies of *Stainforthia fusiformis* were observed in the Drammensfjord after the conditions changed from anoxic to oxic (Alve, 1995). This is due the opportunistic properties of the species (Alve, 2002).

Every foraminifera species has its own tolerances for oxygen concentrations and therefore gives indications for certain oxygen conditions when their abundancies are high compared to the abundancies of other foraminifera species. Next to this, the absence of any benthic foraminifera indicate prolonged anoxia (Rohling et al., 1993). In this thesis, benthic foraminifera will therefore be used as proxies for changes in environmental conditions in the benthic environment.

2.5.2 Diatoms

Diatoms (Bacillophyceae) are eukaryote algae which use silica to build their cell wall (Gross, 2012).

Diatom assemblages have been used to investigate past environmental conditions (e.g. Mackay et al., 2003; Hassan, 2013). For example, influences of organic pollution can be indicated by investigating the abundancy of different species. Species like *Sellaphora pupula* and *Navicula cryptocephala* are for example more tolerant to organic pollution than the *Eunotia species* or *Gomphonema parvulum* (Salomoni et al., 2005).

In fjord sediments, planktonic marine diatoms and freshwater diatoms are present. Freshwater diatoms live in the freshwater environment and are transported to the fjord by the rivers. Planktonic marine diatoms live in the marine environment and are therefore already present in the fjord. Besides changing species distributions, changing ratios of freshwater versus planktonic marine diatoms can be investigated. A bigger volume of freshwater transported from the rivers leads to higher ratios of freshwater versus planktonic marine diatoms and the other way around.

In this thesis, diatoms will therefore be used as proxies for changes in environmental conditions in the pelagic environment.

2.6 The ecological status of the Ikjefjord

The Ikjefjord is classified as not heavily modified. If a waterbody is classified as a Heavily Modified Water Body (HMWB), the ecological potential is investigated instead of the ecological status (European Commission, 2005). HMWB's are waterbodies which are significantly changed in character due to anthropogenic activity (EU, 2000)

The ecological status is determined by investigating certain 'quality elements'. These quality elements are defined in Annex V of the EU WFD (EU, 2000). The quality elements are categorized in three groups:

- Biological elements
- Hydromorphological elements (supporting the biological elements)
- Chemical and physico-chemical elements (supporting the biological elements)

In Annex V, table 1.2.4 of the WFD the biological quality elements are given:

- Phytoplankton
- Macroalgae and angiosperms
- Benthic invertebrate fauna

In table 1.2.4 of Annex V of the WFD, descriptions are given when an element has a 'high', 'good' or 'moderate' status (Appendix III). The status depends for example on if the composition and abundancy are consistent with undisturbed conditions or if taxa indicating pollution are present.

Only a slight deviation in ecology, which would be expected in conditions of minimal anthropogenic pressure, is allowed to get the classification 'good ecological status' (European Commission, 2016). Diatoms and benthic foraminifera are a part of the biological elements (phytoplankton and benthic invertebrate fauna). Since hydromorphological, chemical –and physico-chemical elements are not investigated in this thesis, benthic foraminifera and diatoms can not be used to make a solid ecological classification. They can however be used as indicators if they suggest significant changes in environmental conditions due to anthropogenic pressures.

3 Materials and methods

This chapter describes which data was used, how it was gathered and how it was analysed.

3.1 Sampling of the sediments

On the 29th of August 2017, two sediment cores were taken in the inner basin of the Ikjefjord: MF2017-1 at 86 meter depth and MF2017-2 at 82 meter water depth (Figure 15). Since the sediment in the outer basin of the fjord was too muddy, sampling of a sediment core did not succeed in the outer part. Due to technical reasons, a seismic survey could not be carried out, and thus, no sediment core samples were retrieved from the Outer Ikjefjord basin.

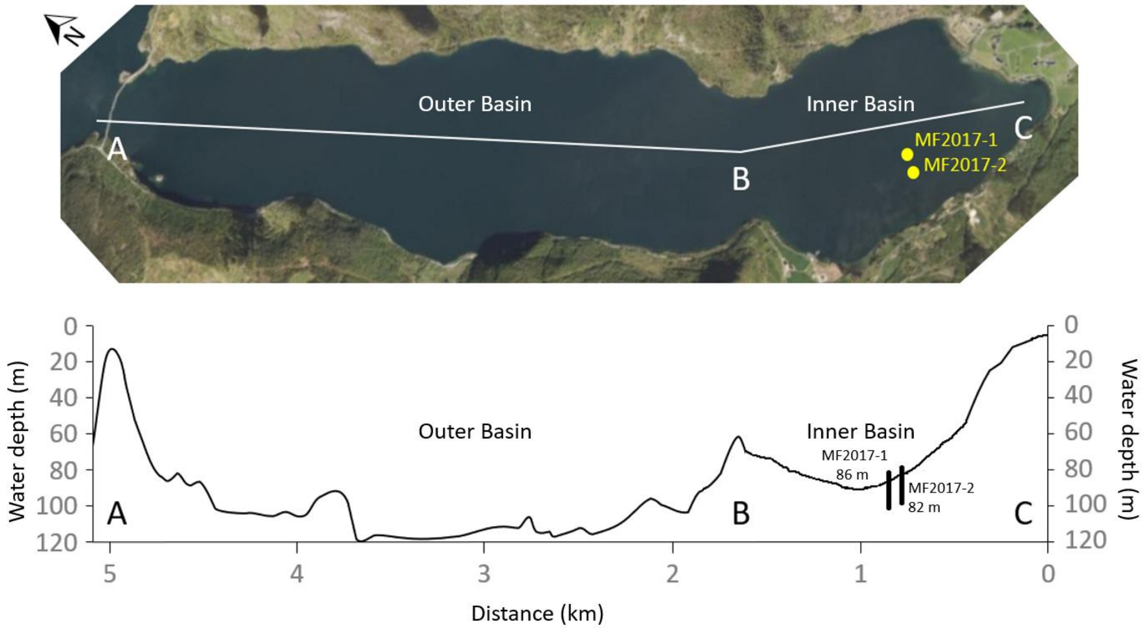


Figure 15: White line of a cross section (above) of the Ikjefjord, showing the depth profile (below) through positions A, B, and C of the fjord. *Sampling locations MF2017-1 and MF2017-2, from above (upper picture) and the depth (MF2017-1 at 86 meter depth and MF2017-2 at 82 meter depth) in the cross section of the Ikjefjord (lower picture). (Personal communication with Matthias Paetzel 2017*)

Sediment cores MF2017-1 and MF2017-2 were taken in 6,8cm diameter plastic pipes using a modified Niemistö (1974) gravity corer. The Niemistö corer samples up to 60cm bottom sediment with an intact sediment water interface (Niemistö, 1974). The sediment cores were taken, sealed, and transported vertically with the fjord bottom water on top of the sediment. This prevented the surface of the sediment from drying out and from getting disturbed during transport.

The biotic fraction of both cores was analysed in the laboratories of the Western Norway University of Applied Sciences, Campus Sogndal. After the opening of the still vertically handled core, the water was carefully siphoned off. Then, OASIS® Floral Foam was used to seal and secure the still wet sediment surface. The core was then placed horizontally. A metal saw was used to cut the plastic pipe of the core in two halves. A fishing rod was used to divide the sediment core, from the bottom to the top, into two halves. In storage, the core halves were continuously cooled.

3.2 Freshwater and planktonic marine diatoms

To be able to analyse the cores on diatoms, first smear slides were made.

3.2.1 Preparing smear slides

For the preparation of the smear slides for both cores, the method of Rothwell (1989) has been used.

Continuous subsamples were taken in 0,5cm steps downcore:

- Microscope slides were labelled and put in position on a heating plate.
- Using a thin metal spatula, roughly 0,5cm^3 sediment was taken across the respective 0,5cm segment of the core. The sediment was sampled a bit away from the side. Sediment was not taken at the side of the sediment core because the sediment might have been mixed up a little bit on the sides due to friction during sampling. A ruler was used to put the metal spatula in the correct position.
- This subsample was then homogenised with a droplet of distilled water and a toothpick (Figure 16A)
- A small amount (<1mm, size of a needle head) of the homogenised material was taken with the tip of a toothpick and put onto a cover glass (Figure 16B). One drop of distilled water was added to disintegrate the sediment

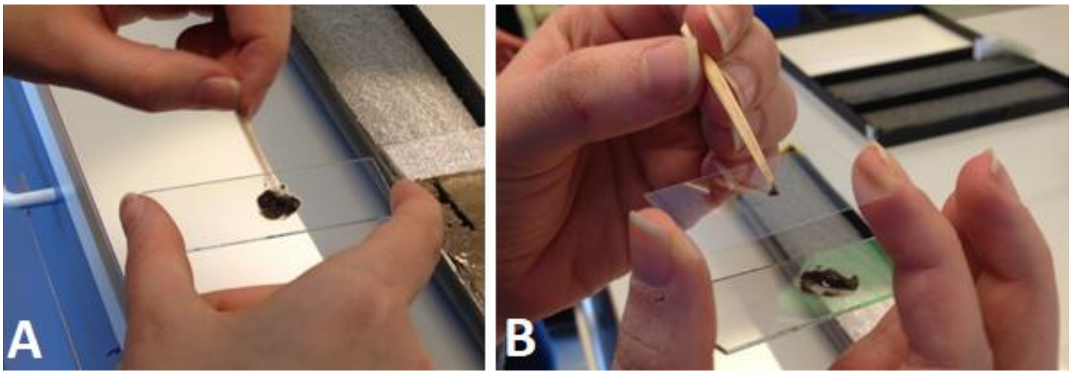


Figure 16: Homogenising the sediment sample (A) and putting a small amount of sediment on a cover glass (B)

- One drop of Kodak Photo Flo Wetting Agent was added to get rid of the surface tension of the water, preventing the waterdrop to move back and forth when smearing.
- A toothpick was used to smear the sample over the cover glass. Half a centimetre on both sides of the slide was left empty, preventing the wet sample from running off along the fingers that are holding the slide.
- The sample was dried on a heating plate on temperatures lower than 50°C. The heating plate was localised in a ventilated fume hood cupboard.
- Naphrax (Brunel Microscopes Ltd) mounting agent was added on the cover glass. Naphrax has a refraction index of 1,73 which is ideal for the identification of even finely silicified diatom skeletons and structures.
- The microscope slide was put on the cover glass and flipped over, positioning the cover glass on top of the slide (Figure 17).

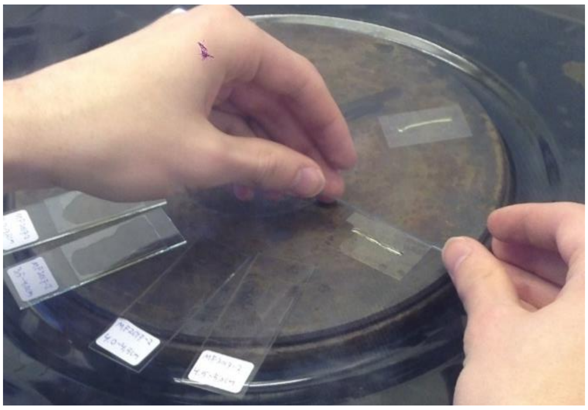


Figure 17: The microscope slide was put on the with Naphrax covered cover glas and flipped over.

- The heating plate was put on a temperature between 100 and 120°C to evaporate the solvent of the mountant, i.e. toluene. This caused the glue to dry.
- The smear slide was removed from the heat plate and cooled down to room temperature.

3.2.2 Diatom counting and data analysis

Diatom counting

The smear slides were analysed using a Leitz Aristoplan microscope. A 40x magnification was used. About 250 diatoms per slide were counted with an absolute minimum of 100 diatoms to get a statistically robust number of specimens. From the freshwater diatoms and marine diatoms, the most abundant ones were distinguished, the other ones were called: “other”. The characteristics of the following species were learned before counting:

Planktonic marine diatoms

- *Skeletonema costatum*
- *Round diatom species*
- *Thlassiosira nordenskiöldii*
- *Chaetoceros species*
- *Licmophora species*
- *Paralia sulcate*

Freshwater diatoms

- *Eunotia species*
- *Fragilaria constricta*
- *Navicula lyratae*
- *Cymbella aspera*
- *Tabellaria flocculosa*
- *Tetracyclus lacustris*
- *Cocconeis species*

Counting a maximum number of diatoms and not all the diatoms in the sediment, gives the advantage of time efficiency. Ratios between species of diatoms can be used for both the dating method (ratio of freshwater versus planktonic marine diatoms) and as proxies for environmental change. The disadvantage of this method is that differences in diatom abundancies (in total amounts of diatoms over time) are not investigated.

Data analysis

Depth profile graphs were made of the ratio of freshwater diatoms, planktonic marine diatoms and unidentified diatoms versus all diatoms. Depth profile graphs were made for all individual species as well.

Correlations between species were tested with IBM SPSS version 23 (IBM, 2018). Bivariate pearsons correlations tests were used with a two-tailed significance. Diatom species with a ratio below 4% were left out of the tests. Correlations between species and the amount of organic matter were tested with the same test, but with a one-tailed significance. The results of the statistical tests have been used as a basis for visual interpretation of the graphs.

3.3 Benthic foraminifera

This paragraph explains how the foraminifera samples were prepared and how they were analysed using a microscope.

3.3.1 Preparing samples

MF2017-1

The sediment core was cut continuously down-core into 1cm segments using a spatula. A ruler was put next to the sediment core to be sure the right centimetre layer was sampled (Figure 18A). About 20% of the sediment core was sampled. The sediment that was closest to the plastic tube was not sampled, due to possible frictional disturbances (Figure 18A).

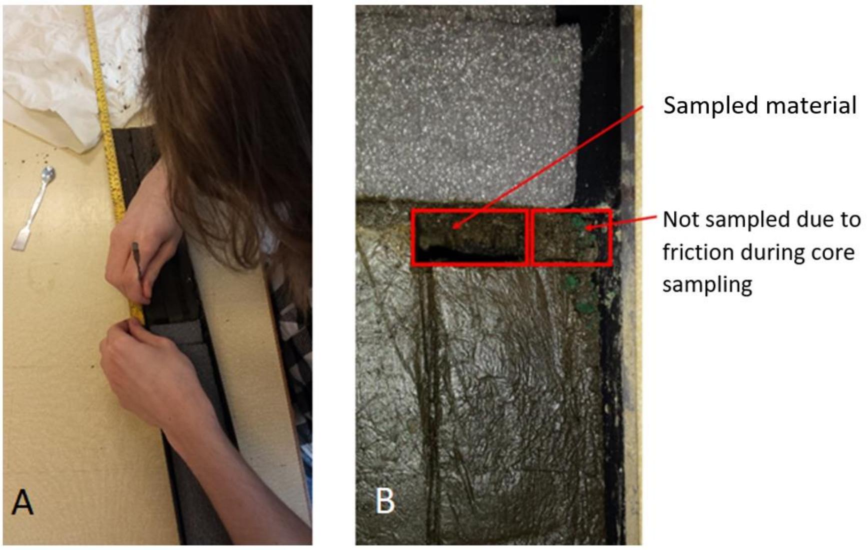


Figure 18: Cutting the sediment

The sampled material got placed in a measuring cylinder containing 20ml of water. The difference in volume was noted. The sample was then sieved to retrieve three fractions:

- 2,0mm – 250µm (coarse fraction)
- 250µm – 125µm (medium fraction)
- 125µm – 63µm (fine fraction)

To sieve the sample, the sample was put on three stacked Geonor laboratory sieves, with sieve openings of respectively 2,00mm, 250µm, 125µm and 63 µm (Figure 19A). The sample was washed per sieve with a showerhead (Figure 19B). The water beam was flushed first on the top of a hand, so that the water would not hit down too hard on the sieve and destroy the skeletons of the *foraminifera* (Figure 19B). The sieved sediment fractions were flushed into a cup using a 75% ethanol solution (Figure 19C). Ethanol was used so it was possible to store the samples more permanently (Scott et al., 2001).

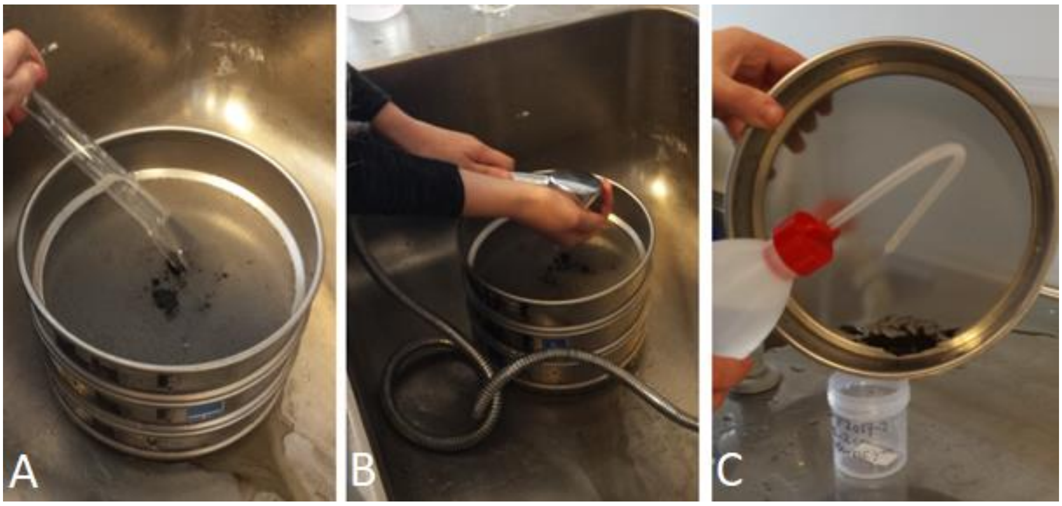


Figure 19: Sieving the sediment sample to different fractions

MF2017-2

The same method as for core MF2017-1 was used, with a few exceptions:

- Only the medium fraction (250µm - 125µm) was sampled. This choice has been made because the coarse fraction in core MF2017-1 did barely contribute to the total amount of *foraminifera*
- The sieve of 2,00mm was only used for standardization, since this sieve was also used for MF2017-1, where the coarse fraction (2,00mm-250µm) was sampled.

After the sieving, the samples were split (to 50%, 25%, 12,5% and sometimes even lower percentages down to 1,61%) to make the counting more reliable. If the samples would not be split, too much sediment could cause small foraminifera to be overlooked. Samples were split with a splitter (Figure 20A). After splitting, a sample was put in a Petri dish with wooden bars (Figure 20B). This made counting easier, since the wooden bars act as reference points.

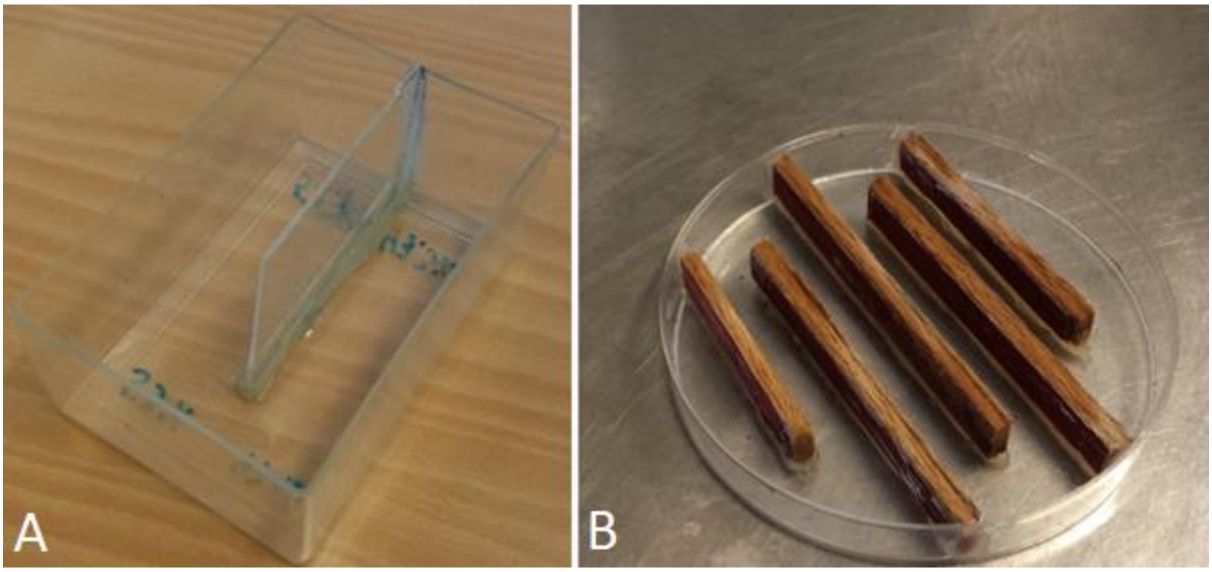


Figure 20: The used splitter (A) and petri dish (B)

3.3.2 Foraminifera counting and data analysis

Foraminifera counting

The method of microscope analysis was the same for core MF2017-1 and MF2017-2. Only the medium fraction of both cores has been analysed.

The samples were analysed with a Wild M5A binocular microscope on a 25x magnification. The numbers of foraminifera and the names of the corresponding species were written down, as well as the amount of times a sample was split before analysis. In excel, the number of foraminifera/ml sediment was calculated.

The characteristics of the following species were learned before counting:

- *Stainforthia fusiformis*
- *Bulimina marginata*
- *Nonionella labradorica*
- *Leptohalysis species*
- *Cribrostomoides crassimargo*
- *Globobulimina auriculata*
- *Ammodiscus gullmarensis*
- *Textularia earlandi* or *Spiroplectammina*. Their structure is so similar they were counted as one species
- *Reophax species*
- *Liebusella goësi*
- *Adercotryma species*

If species could not be distinguished, they were distinguished as either 'other arenaceous' or 'other calcareous', which could be determined visually.

Data analysis

Depth profile graphs were made of the foraminifera species distributions, arenaceous versus calcareous species and total foraminifera. Depth profile graphs were made for all individual species as well.

Correlations between species were tested with IBM SPSS version 23 (IBM, 2018). Bivariate pearsons correlations tests were used with a two-tailed significance. Correlations between species and the amount of organic matter were tested with the same test, but with a one-tailed significance. The results of the statistical tests have been used as a basis for visual interpretation of the graphs.

3.4 Loss on ignition (LOI)

The loss on ignition (LOI) method has been used to determine the amount of organic carbon in the sediment. The method is as follows:

The LOI technique was applied continuously down-core on 0,5cm sediment segments:

- 12 small, empty porcelain jars were numbered with a lead pencil. Loose lead particles were brushed off
- The porcelain jars were washed and put in an oven at 150°C for two hours. This, to get rid of moisture in the porcelain jar.
- When the jars were taken out of the oven, they were put in a vacuum desiccator to cool down. This has been done to prevent the porcelain taking up atmospheric moisture.
- The porcelain jars were weighted. The weight per jar was noted as 'weight of empty jar'.

- Sediment from the core was sampled and added to the jars. The first 12 cm were used for the first shift, the second 12 in the second shift and the last 8 centimetres in the last shift with 8 jars.
- The porcelain jars were put in the oven at 105°C for four hours. This to get rid of the water in the sediment. The vacuum desiccator was used to let the jars cool down.
- The porcelain jars were weighted again. The weight per jar now noted as 'dry weight, jar included'.
- Then the porcelain jars were put in the oven at 550°C for 24 hours and after that cooled down in the vacuum desiccator.
- When the jars were cooled down, they were weighted again. It was noted as 'dry weight organic carbon, jar included'

The following calculations were made:

$$Organic\ carbon\ (g) = Dry\ weight, jar\ included - \ Dry\ weight\ organic\ carbon, jar\ included.$$

$$Dry\ weight\ (g) = Dry\ weight, jar\ included - weight\ of\ empty\ jar.$$

$$Organic\ carbon\ (\%) = \frac{Organic\ carbon\ (g)}{Dry\ weight\ (g)} * 100.$$

Loss on Ignition data was already available from core MF2017-1. In that core, the burning time was reduced to 4 hours instead of 24.

3.5 Historic precipitation data

Precipitation data of the Ikjefjord area was retrieved from the eKlima climate database from the Norwegian Meteorological Institute. The data consists of monthly precipitation values, which are recalculated to annual average precipitation. Detailed information about the stations from which precipitation data was retrieved, being a map of the station locations and a table with operating times, is given in Appendix IV. The precipitation data from all the stations was averaged. Most of the stations are located East of the Ikjefjord. Data from the nearest station Lavik and the average of all stations were compared, and there were no significant differences. The choice has been made to use the average of all stations to nuance local differences.

Daily precipitation data from station Lavik was gathered from the Norwegian Water Resources and Energy Directorate (2018) to investigate if peaks in precipitation could be found in 1983, where Massnes (2017) states the overflow event occurred. Daily precipitation data from other nearby weather stations could not be found.

3.6 Dating of the sediments

Radiometric dating is a common method to date sediment cores, where the known decay of radioactive isotopes is used to provide a dating. This absolute dating method is not used to date the sediment cores of this thesis, due to:

- Sample material. Normally, the material of an entire sediment core would be required; due to technical reasons, it was not possible to sample an additional core per location.
- Costs. Radiometric dating is expensive.
- Time. Radiometric dating is time consuming and should ideally be applied earliest 1,5 years after core retrieval to allow the sediment surface to settle. The earliest time for radiometric dating would thus be in spring 2019.

Paetzel & Dale (2010) introduced an alternative dating method, using a correlation between regional precipitation and the number of freshwater diatoms. This relationship proved to be a valid relative dating method for most recent (<100 year old) sediments originating from western Norwegian fjords. Layers deposited during events do not have a negative effect on this dating method, since it is easy to subtract these from the total record. Therefore, the method of Paetzel & Dale (2010) has been used in this thesis.

The changing ratios of freshwater diatoms versus marine diatoms throughout the cores MF2017-1 and MF2017-2 have been visually correlated with historic regional precipitation data.

The application of this method is based on the similarity of the precipitation record with the succession of freshwater diatoms and grain sizes. The parallel thesis of Van Rossum (2018) discusses the independent grain sizes versus precipitation relationship of the Ikjefjord sediment cores.

Different moving average trendlines were constructed in the precipitation graph (different periods), to adjust the graph for different time slots, corresponding to different sedimentation rates in the sediment record. The sand layer in core MF2017-1 was observed at a lower depth, indicating a faster sedimentation rate than MF2017-2. This meant that the data from MF2017-2 should match with a floating average trendline which averaged a higher amount of periods. When the best matching floating average trendline was found, matching peaks and valleys were visually inspected.

4 Results

In this chapter all results are presented. First, a short description of the sediment cores is given. Secondly, graphs of the changing abundancies of foraminifera are given, with a table of the oxygen tolerances of each foraminifera species. Thirdly, graphs of freshwater and planktonic marine diatoms are presented, with a table containing diatom descriptions. Fourthly, the Loss On Ignition results are stated. This chapter concludes with the presentation of historic precipitation data

4.1 Description of the sediment cores

Figure 21 shows the sediment cores MF2017-1 and MF2017-2. Note that the picture of core MF2017-2 is an optical image and therefore the colours are different (brownish) from core MF2017-1 (greyish).

Both sediment cores seem to have a lighter grey layer in the core at different depths (Figure 21). In core MF2017-1 the layer can be seen at a depth between 16 and 14 centimetres, and in core MF2017-2 the layer can be seen at a depth between 14 and 10 centimetres. Van Rossum (2018), who investigated the grain size compositions of the sediment cores, states that these layers consist of coarser material. During the microscope analyses (both foraminifera and diatom), coarser and lighter/glassy grains were seen at the depths of the layers. From now on these light grey layers will be called sand layers.

The parallel thesis of Van Rossum (2018), contains a detailed description of the changing grain sizes in the sediment cores.

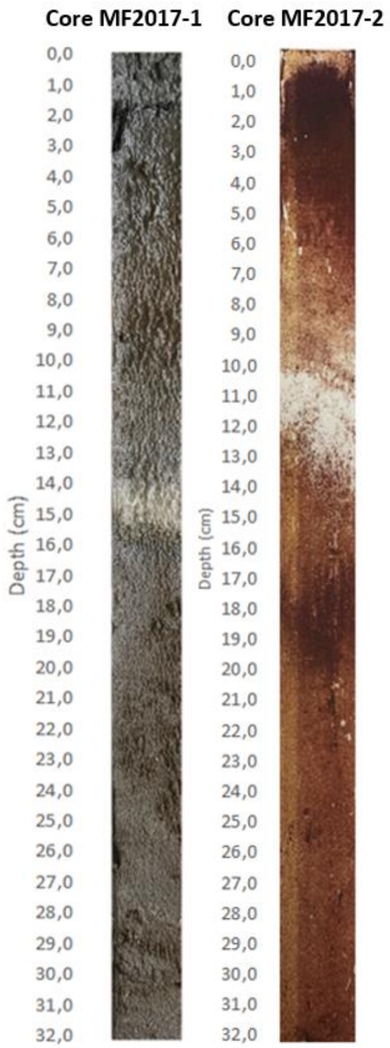


Figure 21: Pictures of the half sediment cores MF2017-1 and MF2017-2. The picture of MF2017-2 differs in colour from MF2017-1 because it is an optical image.

4.2 Benthic foraminifera

This paragraph contains results of the foraminifera species distribution, the total amount of foraminifera and the ratio of arenaceous species versus calcareous species. Graphs of individual species are given in Appendix V.

MF2017-1

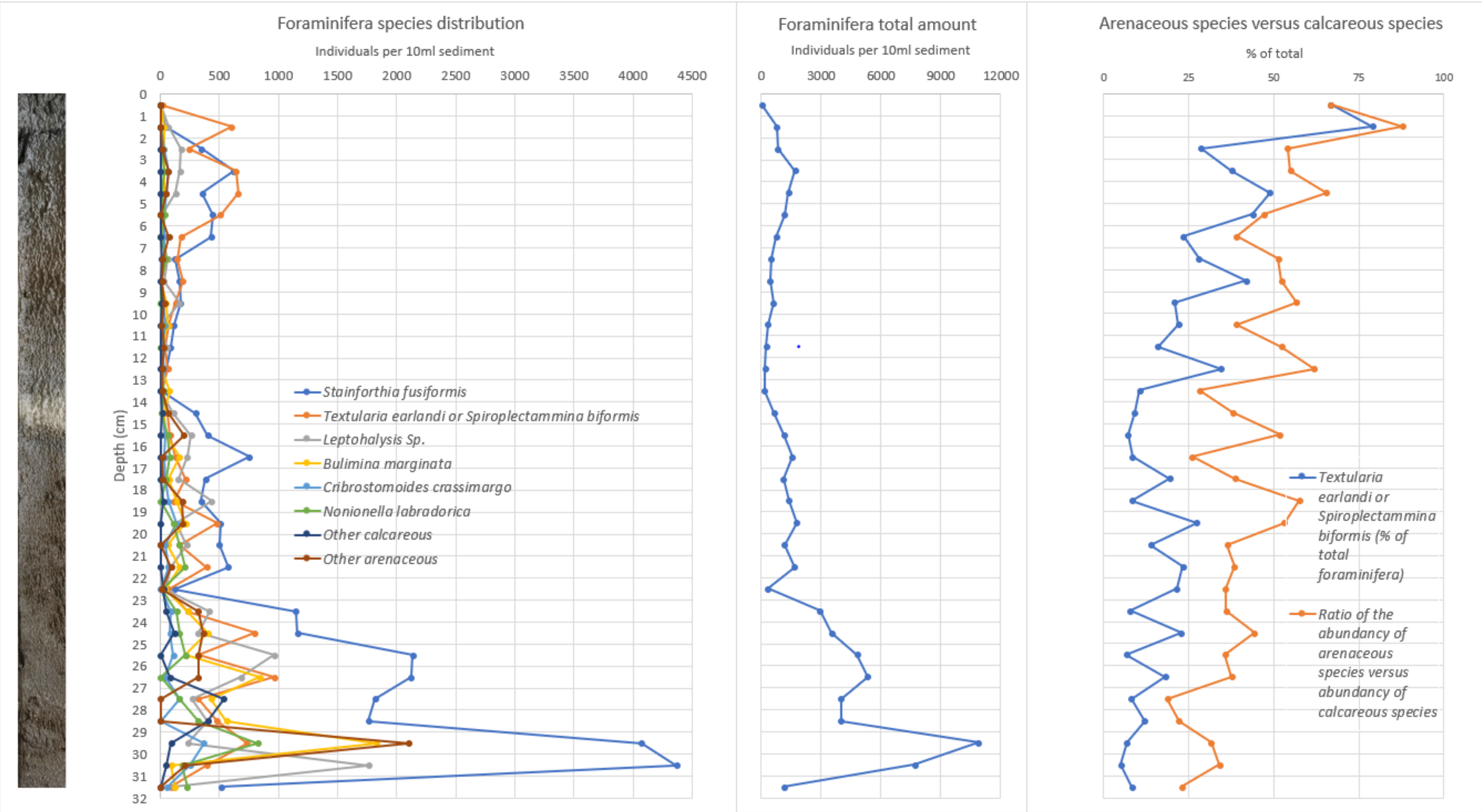


Figure 22: Foraminifera results MF2017-1: species distribution, total amount and arenaceous versus calcareous species. One species is called Textularia earlandi or Spiroplectammina biformis because during counting of the foraminifera it was unclear which of the two species was observed. This, due to their very similar structures.

MF2017-2

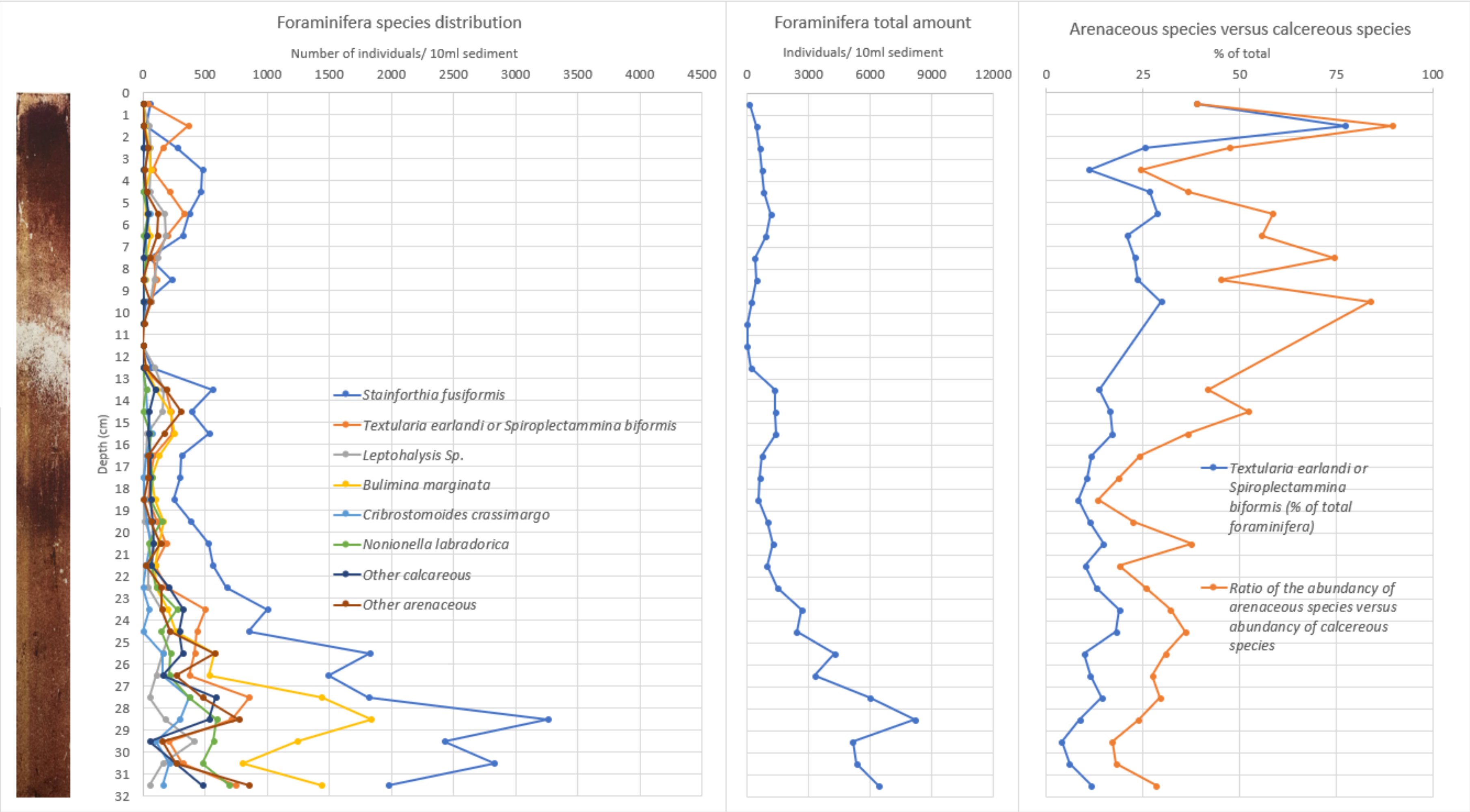


Figure 23: Foraminifera results MF2017-2: species distribution, total amount and arenaceous versus calcareous species. One species is called Textularia earlandi or Spiroplectammina biformis because during counting of the foraminifera it was unclear which of the two species was observed. This, due to their very similar structures.

Descriptions of benthic foraminifera below are given from the bottom of the sediment cores (oldest) to the top of the sediment cores (youngest).

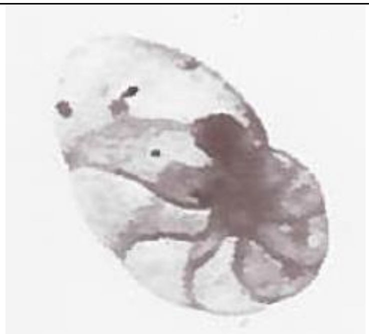
- The total amount of foraminifera is highest at the lower centimetre layers. The total amount decreases and does not reach this level again throughout the sediment core. The species *Stainforthia fusiformis* is the most abundant in these parts of the sediment core (Figures 22 and 23).
- For core MF2017-1, a minimum in the total amount of foraminifera is observed right after the sand layer (lighter gray part of the sediment core, Figure 22). For core MF2017-2, a minimum in the total amount of foraminifera is observed at the upper part of the sand layer (lighter part of the sediment core, Figure 23)
- All species seem to change in abundancies the same way (Figures 22 and 23). A notable difference is that the species *Textularia earlandi or Spiroplectammina biformis* becomes more abundant compared to other species (in % of total foraminifera, Figures 22 and 23)
- The ratio of the abundancy of arenaceous species versus calcareous species eventually starts to increase in both cores (Figures 22 and 23). This is mainly caused by the abundancy of the species *Textularia earlandi or Spiroplectammina biformis* (Figures 22 and 23).

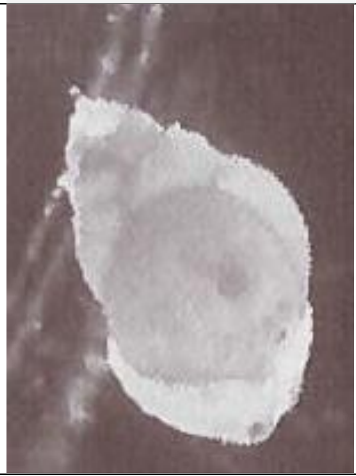
Notable differences between core MF2017-1 and MF2017-2 are:

- Core MF2017-2 has a slightly smaller total amount of foraminifera at the lower centimetre layers than core MF2017-1
- In core MF2017-2 the ratio of the abundancy of arenaceous species versus calcareous species increases less linear than core MF2017-1
- In core MF2017-2 the foraminifera minimum corresponds more with the presence of the sand layer than core MF2017-1

4.3 Oxygen tolerances of the observed foraminifera

Table 1 gives insight in the oxygen tolerances of the observed foraminifera.

Species	**Pictures (50x magnification, made by AUTHORS, 2018)**	**Oxygen tolerance**
Stainforthia fusiformis		In south Norwegian fjords, this species is common in basins which are dysoxic (defined as 0,1–0,3ml/l dissolved oxygen by Drinia et al., 2003) or periodic anoxic (defined as waters that have no dissolved oxygen by Millero (2000). The species is common in environments where the dissolved oxygen concentration is below 1,5 mg/l. As an opportunist, it predominates in areas with rapid changes in environmental conditions (Alve, 2002). The species is also observed as one of the first to colonize formerly anoxic sediments (Alve, 1995)
Nonionella labradorica		Large avoidance reactions from 3,5 mg/l dissolved oxygen (Moffit et al, 2013). With avoidance reactions, declines in abundances are meant.

Leptohalysis species		*Leptohalysis catella* seems to have an affinity with lower oxygen levels (Blais-Stevens and Patterson, 1998) *Leptohalysis scotti* seems to have a limited tolerance to oxygen deficiency (Ernst, 2002)
Textularia earlandi or *Spiroplectammina biformis*		*Spiroplectammina biformis* often replaces calcareous foraminifera when oxygen levels are depressed (Scott et al, 2001) *Textularia earlandi* survives hypoxic (≤ 2 ml/l) conditions (Davidsson, 2014).
Bulimina marginata		Observed in areas where dissolved oxygen is low (e.g. Davidsson, 2014; Rohling et al, 1993)

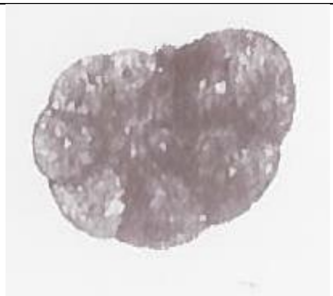
Cribrostommoides crassimargo		Unknown
Example of ‘other calcereous’		Cannot be determined since it is an unknown species
Example of ‘other arenaceous’		Cannot be determined since it is an unknown species

Table 1: Oxygen tolerances of the observed foraminifera

4.4 Freshwater and planktonic marine diatoms

Graphs of species with an abundancy higher than 4% of total diatoms are given. Results of species with an abundancy lower than 4% of total diatoms are given in Appendix VI.

MF2017-1

Figure 24: Ratio's of freshwater diatoms, marine diatoms and unidentified diatoms versus all diatoms in MF2017-1

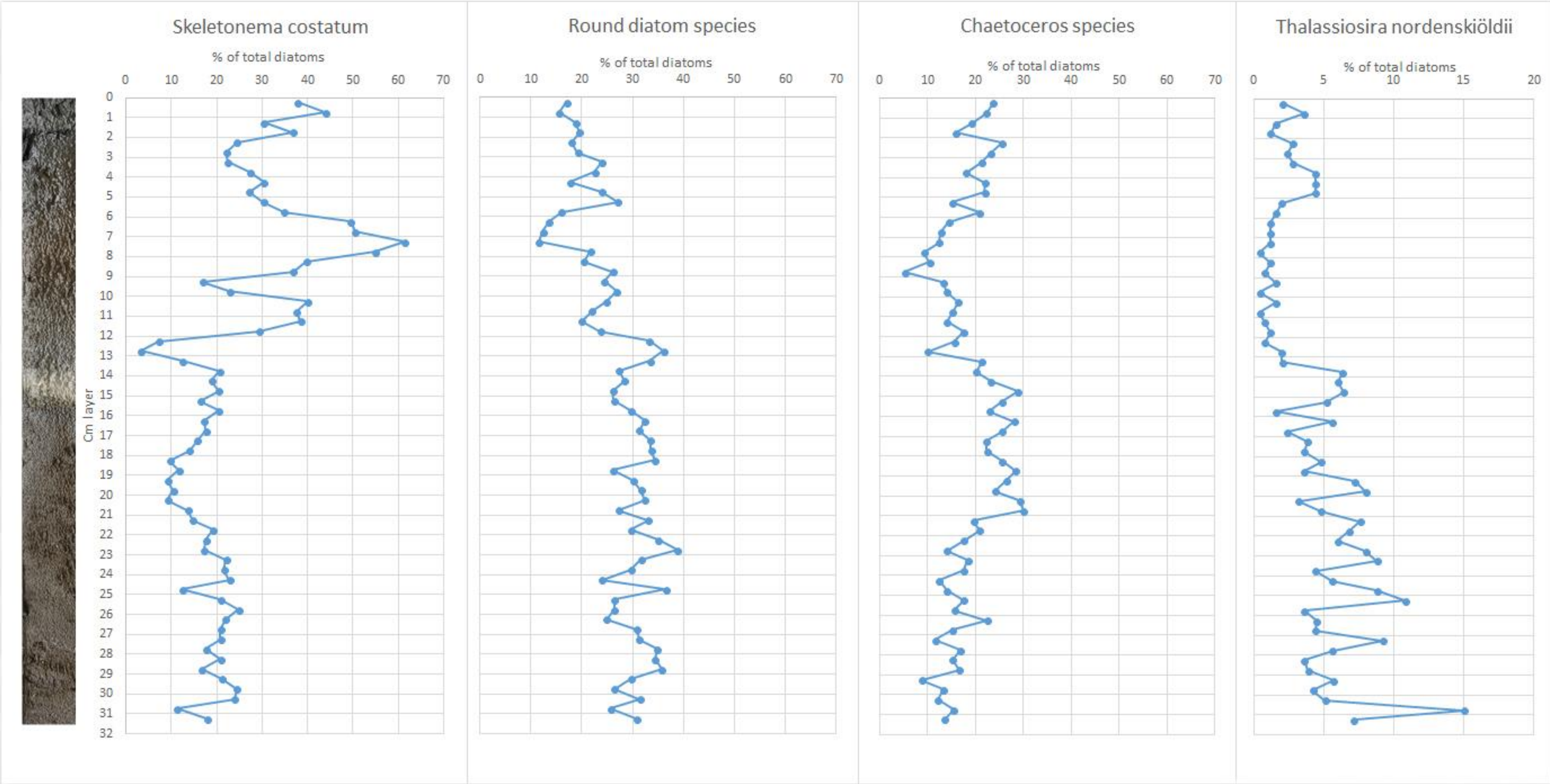


Figure 25: Ratio's of Skeletonema costatum, Round diatom species, Chaetoceros species and Thalassiosira nordenskiöldii versus all diatoms in core MF2017-1

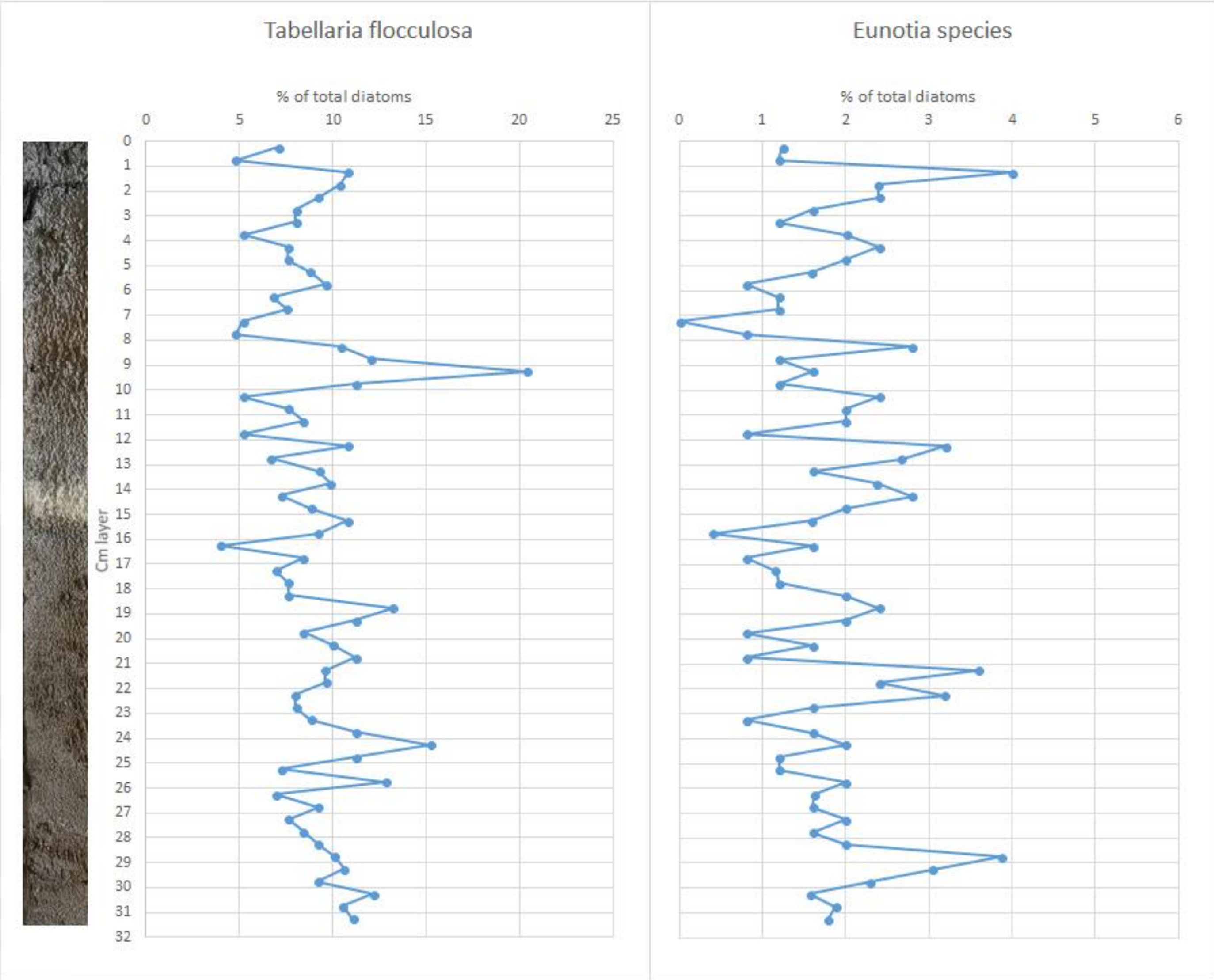


Figure 26: Ratio's of Tabellaria flocculosa,and Eunotia species versus all diatoms in core MF2017-1

MF2017-2

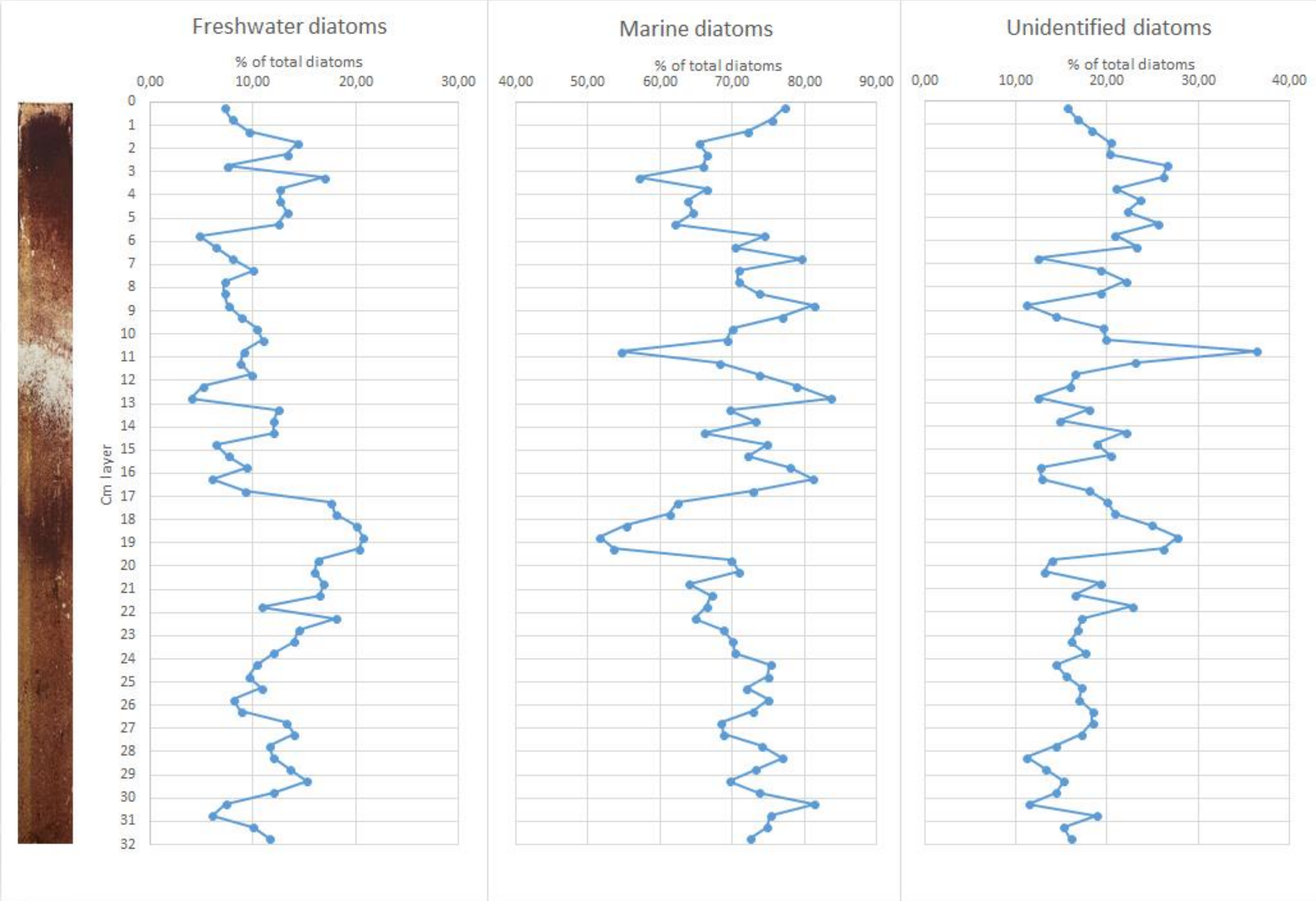


Figure 27: Ratio's of freshwater diatoms, marine diatoms and unidentified diatoms versus all diatoms in core MF2017-2

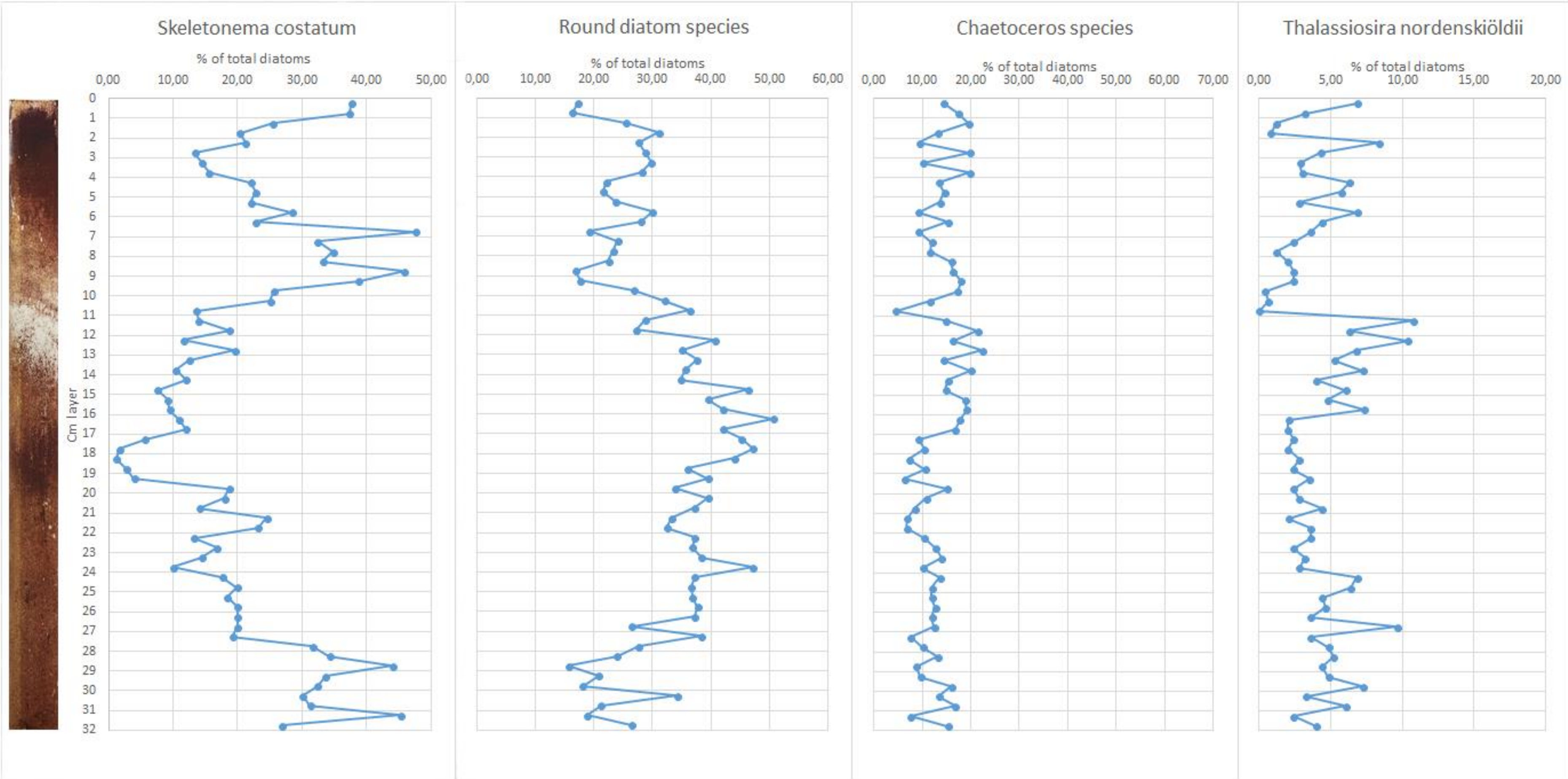


Figure 28: Ratio's of Skeletonema costatum, Round diatom species, Chaetoceros species and Thalassiosira nordenskiöldii versus all diatoms in core MF2017-2

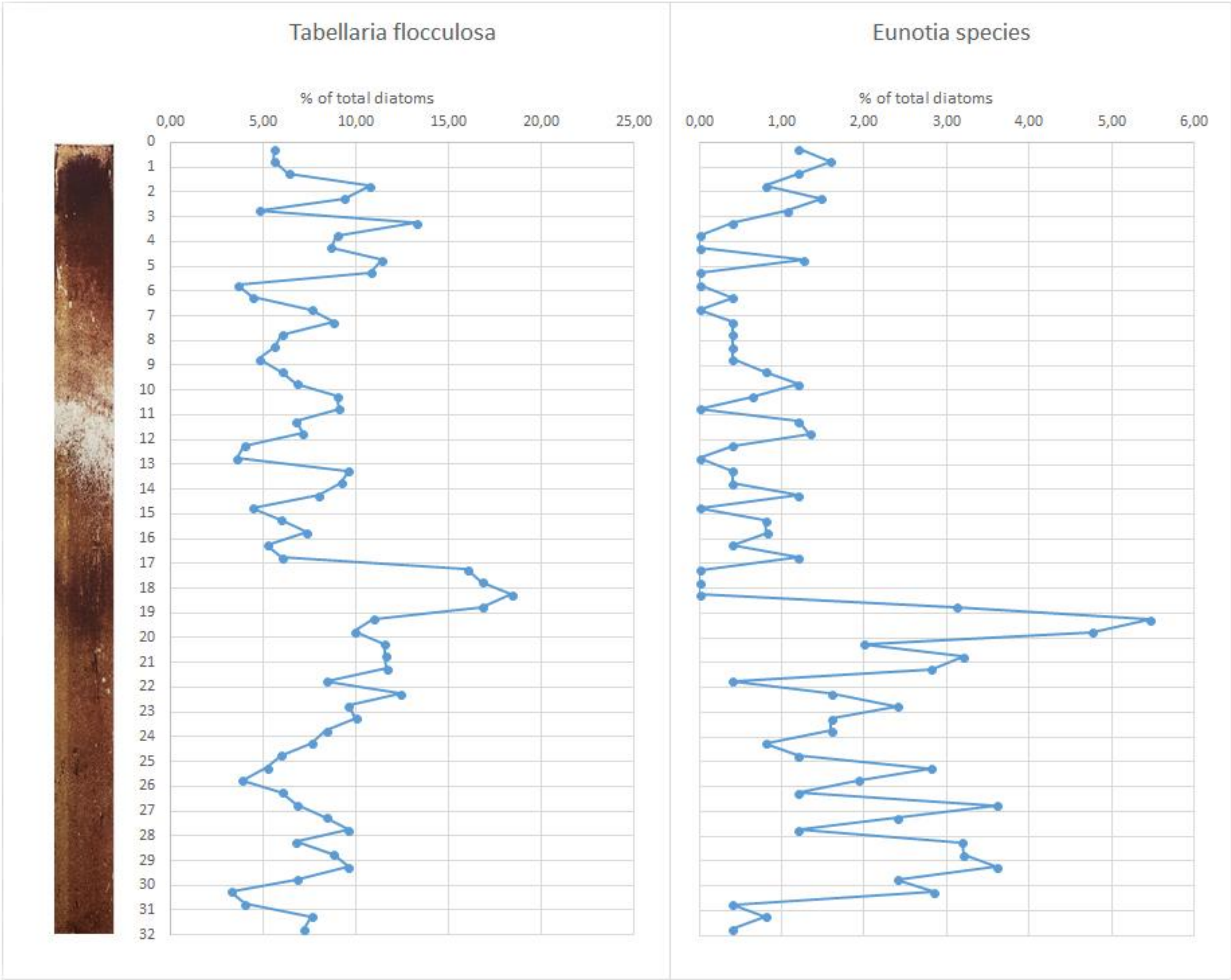


Figure 29: Ratio's of Tabellaria flocculosa and Eunotia species versus all diatoms in core MF2017-2

Descriptions of the diatoms below are given from the bottom of the sediment cores (oldest) to the top of the sediment cores (youngest).

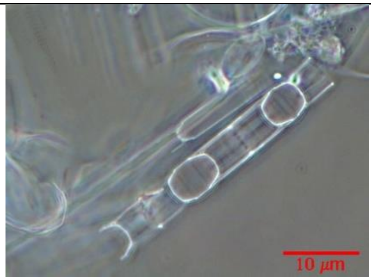
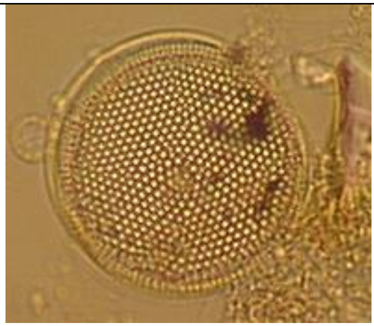
- The amount of freshwater diatoms and the amount of planktonic marine diatoms fluctuate throughout the sediment core (Figures 24 and 27). There is a general slight decrease in the amount of freshwater diatoms throughout the core and a slight increase in the amount of planktonic marine diatoms (Figures 24 and 27).
- The most abundant planktonic marine diatoms are *Skeletonema costatum, Round diatom species*, *Chaetoceros species and Thalassiosira nordenskiöldii* (Figure 25 and 28)
- The most abundant freshwater diatoms are *Tabellaria flocculosa* and *Eunotia species (Figures 26 and 29)*. *Tabellaria flocculosa* is the most abundant, which is probably due to its planktonic nature.
- There is an increase in the abundancy of *Skeletonema costatum* from the 20th/18th centimetre layer (Figure 25) in core MF2017-1. In core MF2017-2 there is an increase in the abundancy of *Skeletonema costatum* from the 18th centimetre layer (Figure 28)
- *Skeletonema costatum* seems to have a negative relation with *Round diatom species* (Figures 25 and 28)

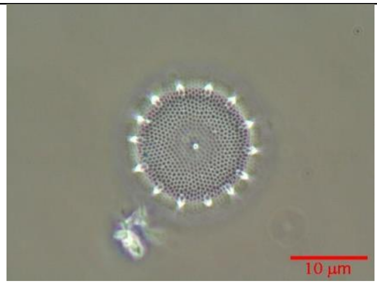
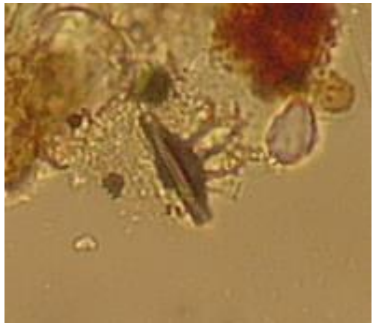
Notable differences between core MF2017-1 and MF2017-2 are:

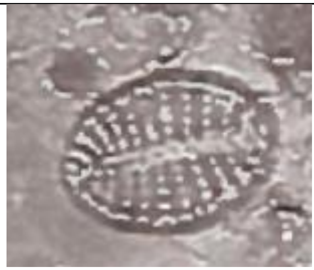
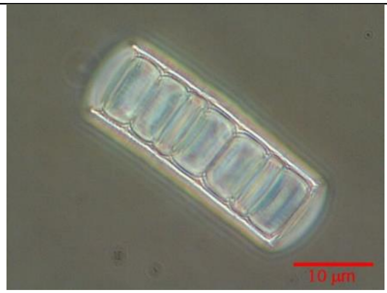
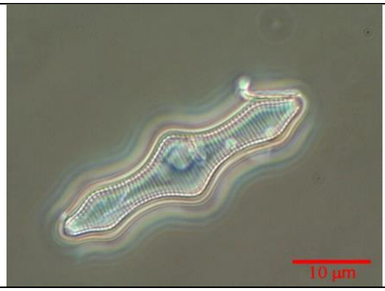
- *Skeletonema costatum* seems to have a stronger negative relation with round diatom species in core MF2017-2 than in core MF2017-1
- *Skeletonema costatum* also has high abundancies in the bottom of sediment core MF2017-2

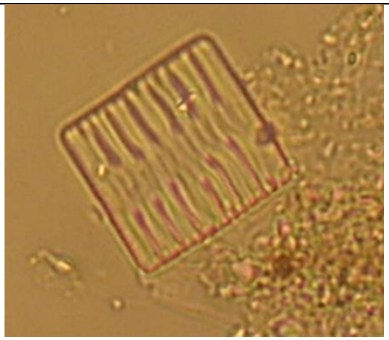
4.5 Descriptions of the observed freshwater and planktonic marine diatoms

Table 2 gives insight in the different properties of the observed freshwater and planktonic marine diatoms.

Species	**Pictures (40x magnification, made by AUTHORS and Matthias Paetel, 2018)**	**Description**
Skeletonema costatum		Planktonic marine diatom. Indicator for poorly stratified but stable waterbodies (Syvitski et al., 1986). Needs a favourable combination of nutrients (including Si, and the limiting nutrients NO_3^- and PO_4^{2-}). This has been observed especially in upwelling areas where nutrient rich bottom waters reach the surface water layers. (Hu et al., 2010). Also needs good light conditions, and good temperature conditions. Blooms from spring to fall (Tian et al., 2002).
Round diatom sp.		Planktonic marine diatom. Round diatoms (centric diatoms, or centrales) usually are of marine origin, with only few exemptions (Not et al., 2012): Thus, the round diatoms can be added to the marine fraction of the total diatom count.

Thalassiosira nordenskiöldii		Planktonic marine diatom. Occurs in temperate to cold climate (Cupp, 1943), but not polar. Contributes often extensively to the spring and the fall bloom (UBC Department of Earth, Ocean and Atmospheric Sciences, 2012).
Chaetoceros species	 	Planktonic marine diatom. Common species that occurs mostly between the spring bloom and the fall bloom, i.e. during the summer month. Forms resting stages under unfavourable conditions. (UBC Department of Earth, Ocean and Atmospheric Sciences, 2012)
Licmophora species		Planktonic marine diatom. Can also occur in freshwater. The species is epiphytic and epilithic, i.e. it grows on algae and rocks, indicating its origin from shore environments when found in deeper fjord sediments. (Barber & Haworth, 1981)

Cocconeis species		Mostly planktonic marine, but also brackish. Occurs epiphytic on algae, or benthic. Like the *Licmophora species*, it indicates its origin from shore environments. (Barber & Haworth, 1981)
Paralia sulcata		Planktonic marine diatom. Occurs planktonic and benthic. Large populations might indicate high nutrient and high salinity conditions (typical in upwelling areas). The species declines at low nutrient (especially PO_4^{2-}) concentrations (McQuoida & Nordberg, 2002).
Eunotia species		Freshwater diatom. A benthic species and most common in acidic waters. (Barber & Haworth, 1981)
Fragilaria constricta		Freshwater diatom. A benthic species and most common in acidic waters. (Barber & Haworth, 1981)

Navicula lyratae		Freshwater diatom.
Cymbella aspera		Freshwater diatom. Could also be marine. Epilithic and epilitic. So this diatom could be attached to plants and rocks. (Barber & Haworth, 1981)
Tabellaria flocculosa	 	Freshwater diatom. Planktonic, thus not attached to rocks or plants. (Barber & Haworth, 1981)

Tetracyclus lacustris		Freshwater diatom. Planktonic and common in nutrient poor waters. (Barber & Haworth, 1981)

Table 2: Descriptions of the observed freshwater and planktonic marine diatoms.

4.6 Loss On Ignition (LOI)

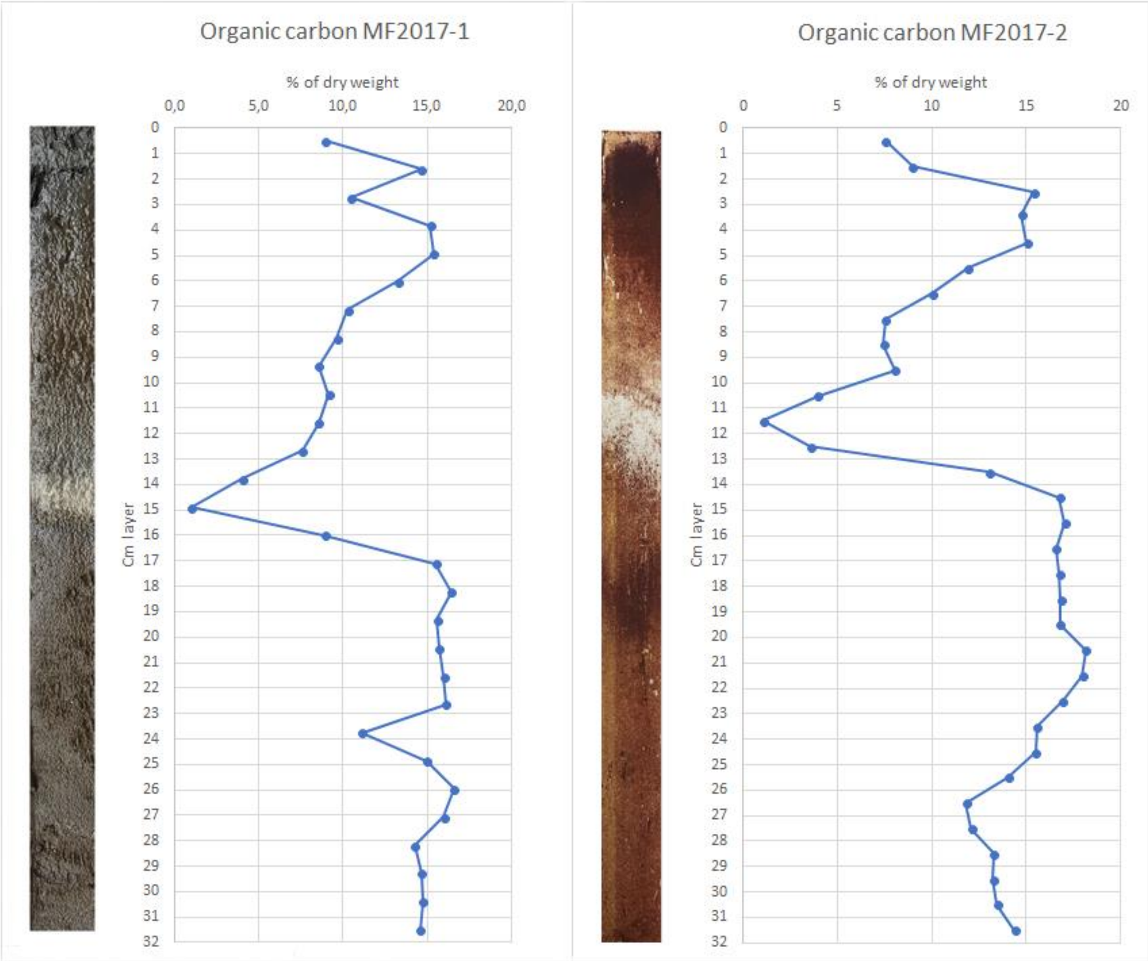


Figure 30: LOI of core MF2017-1 (left) and LOI of core MF2017-2 (right)

The amount of organic matter (Figure 30) has small fluctuations in both cores until the presence of the sand layer. The amount of organic matter then rapidly decreases. After the middle of the sand layer, the amount of organic matter gradually increases again. At the top of the sediment cores a decline is observed.

4.7 Historic precipitation

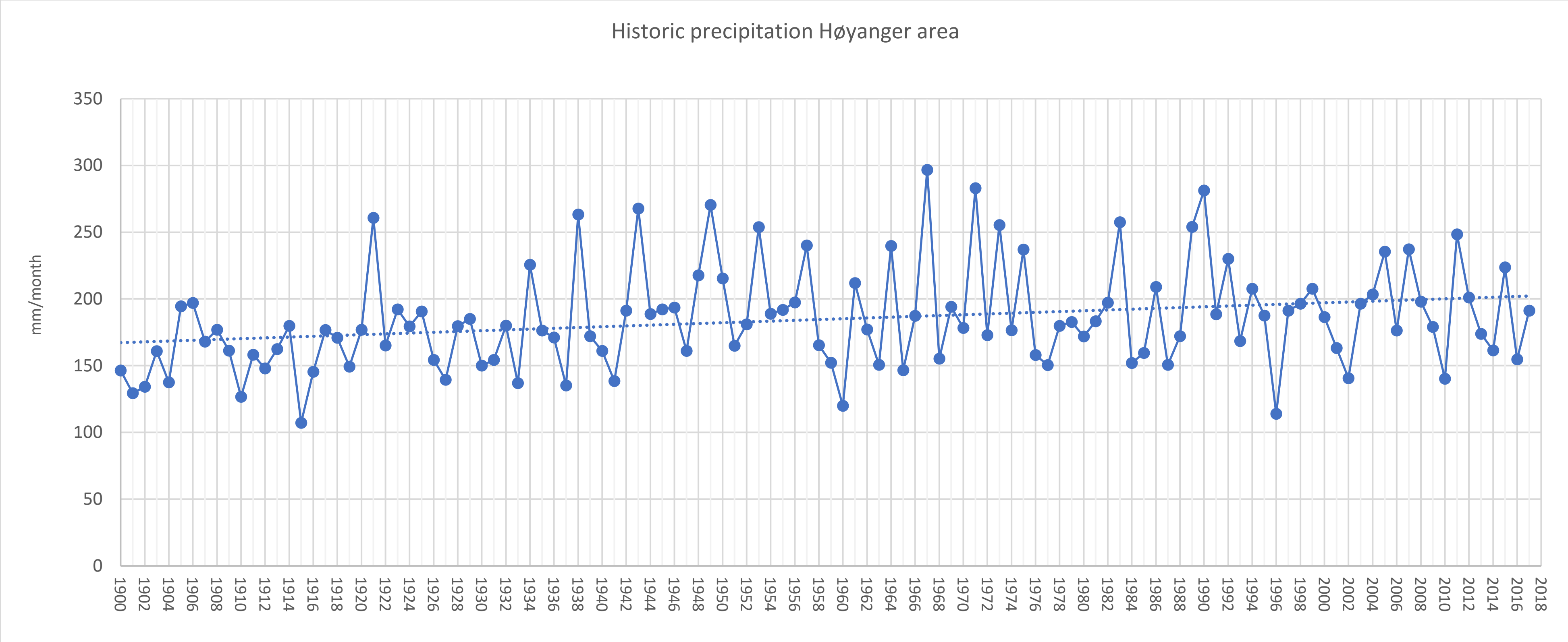


Figure 31: Annual average precipitation of the Høyanger area, in mm/month

There is a general increase in annual average precipitation in the Høyanger area, looked at a timescale from 1900-2018 (Figure 31). The highest value of annual average precipitation is observed in 1967 and the lowest value in 1996.

The highest peak in daily precipitation after the building of the dam in 1971, is in 1983 (Figure 32) which is an additional argument for Massnes (2016) observation of the overflow in 1983. Having a closer look at the year 1883, the highest peak in daily precipitation is in March (Figure 33), which is also a month in which snow and ice melt has started to increase. The combination of the peak in precipitation and the increase of melt water transport from the mountains to the rivers (and therefore the Ikjefjord) has most likely led to the overflow event.

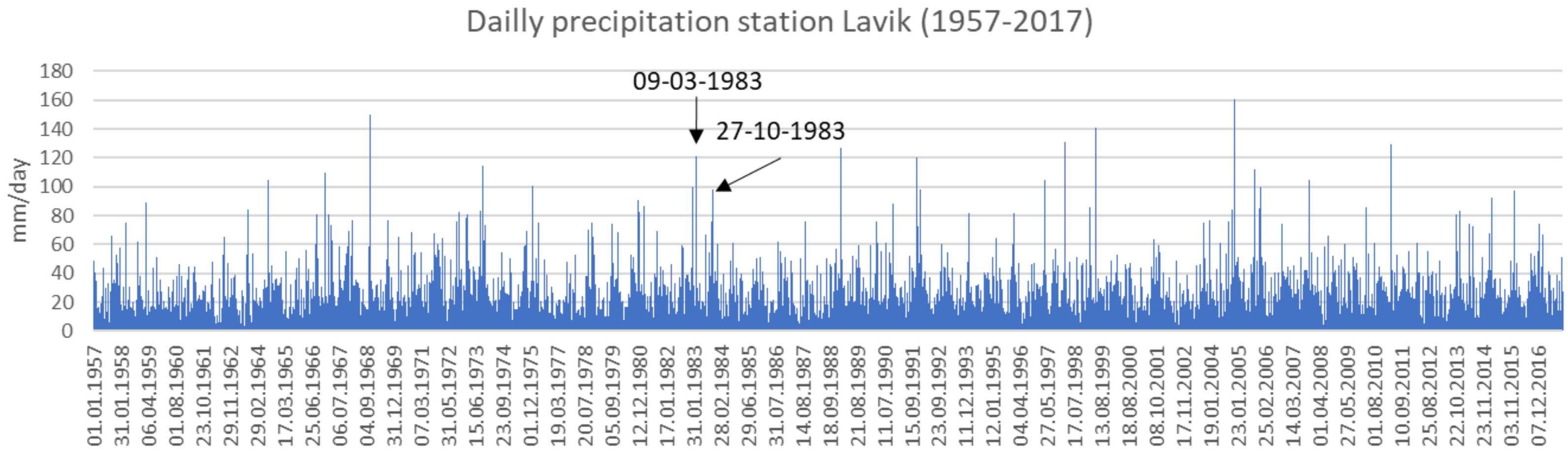


Figure 32: Daily precipitation from 1957 to 2017

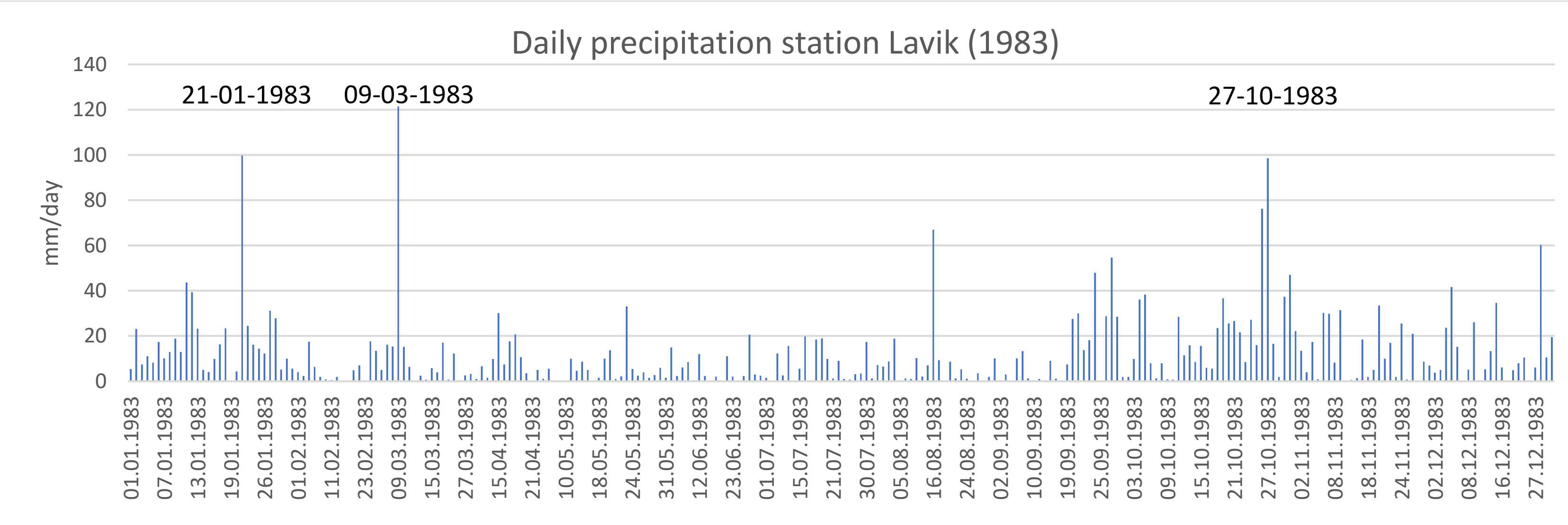


Figure 33: Daily precipitation in the year 1983

5 Discussion

5.1 Dating the sediment cores

Visual correlation between historic precipitation data and the ratio of freshwater versus planktonic marine diatoms leads to the following dating of the sediment cores.

MF2017-1 (Figure 34):

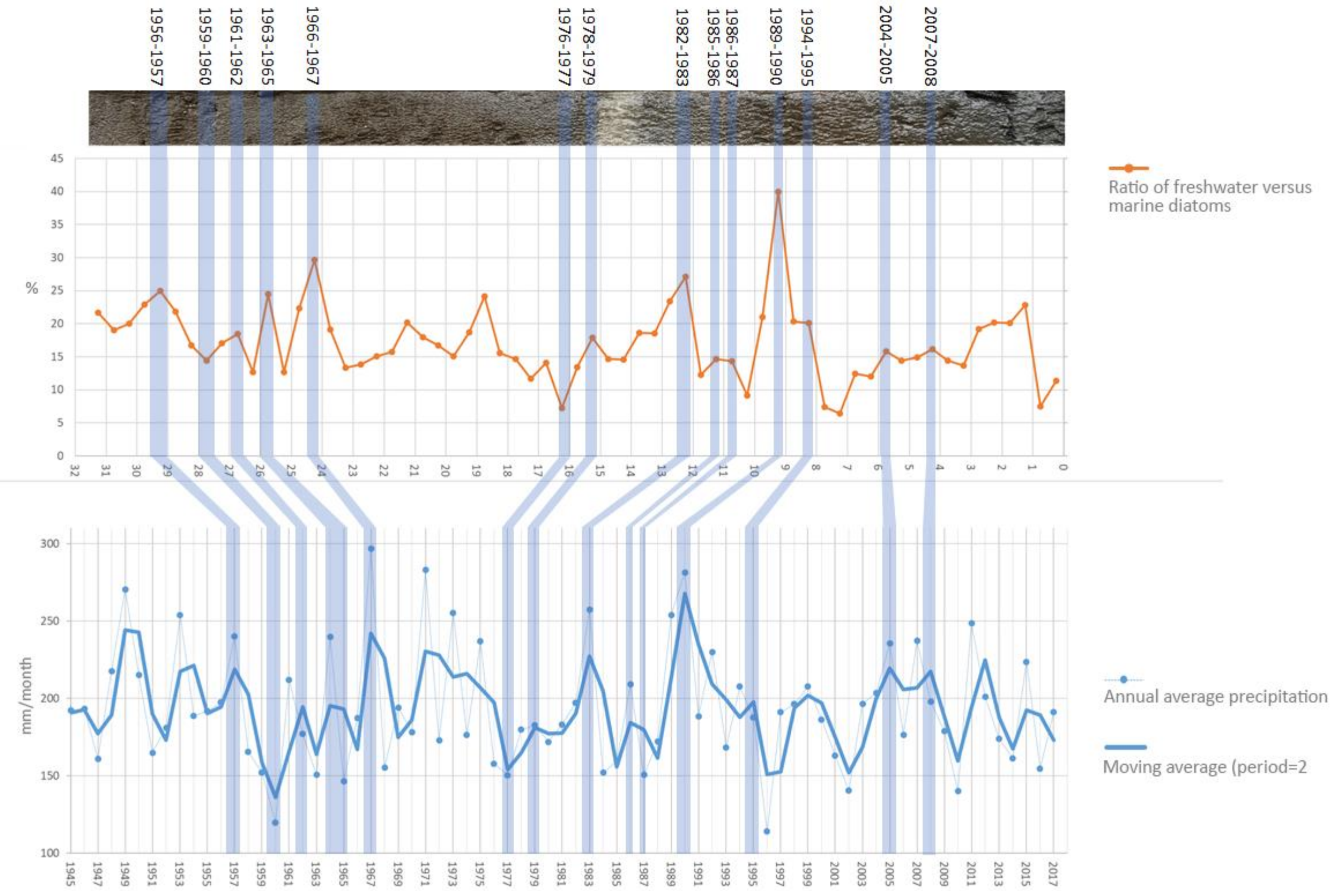


Figure 34: Dating of the sediment core MF2017-1

Since a 2-point moving average trendline is used, the dated year is always somewhere between 2 years. For example, the precipitation point in the year 1951 is the average of the precipitation in the years 1950-1951.

Due to the varying nature of sedimentation rates and the use of moving average trendlines, this dating is supposed to be used as a rough guideline. It is not possible to pinpoint specific years and therefore the dating should be used in a more decadal way (e.g. early 1950s, late 1980s).

MF2017-2 (Figure 35):

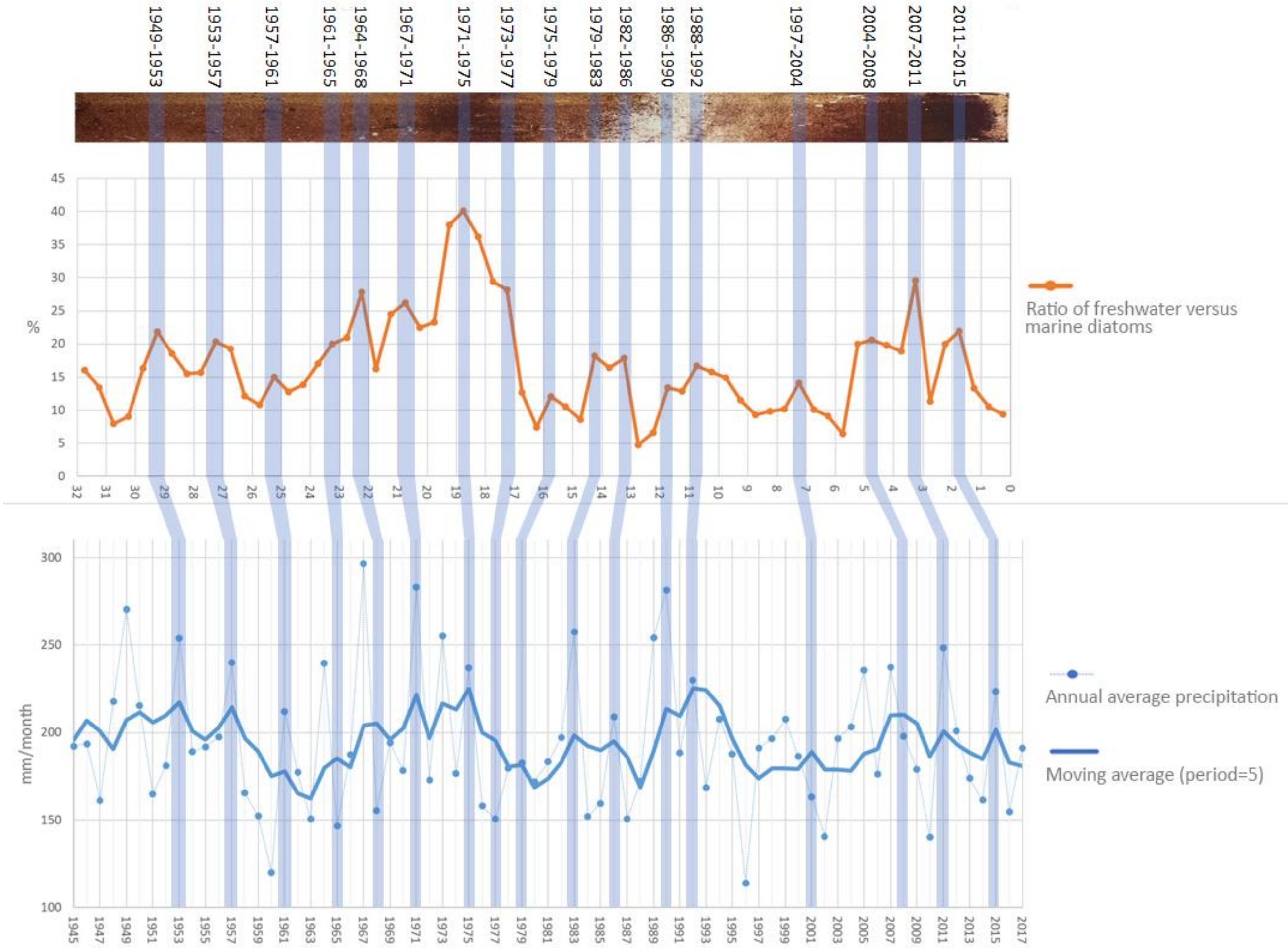


Figure 35: Dating of the sediment core MF2017-2

Since a 5-point moving average trendline is used, the dated year is always somewhere between 5 years. For example, the precipitation point of the year 1951 is the average of the precipitation in the years 1947-1951.

Due to the varying nature of sedimentation rates and the use of moving average trendlines, this dating is supposed to be used as a rough guideline. It is not possible to pinpoint specific years and therefore the dating should be used in a more decadal way (e.g. early 1950s, late 1980s).

5.2 The influence of the overflow event on the amount of organic carbon

Time of sand deposition

The year 1983 is the year Massnes (2017) stated as the year of an overflow event. The highest peak in daily precipitation after the building of the dam in 1971 is also in 1983 (Figures 32 and 33), which makes a stronger argument that an overflow event occurred in 1983.

The dating of core MF2017-1 indicates that sand deposition started to occur in the late 1970s/early 1980s. The year 1983 of the overflow is dated after the sand layer. The dating of core MF2017-2 indicates that sand deposition started to occur in the early 1980s. The year 1983 is dated at the start of the sand layer.

It is unlikely that sand deposition started to occur earlier in MF2017-1 than in MF2017-2. As stated before, the dating should be interpreted in a more decadal scale. This, in combination with the statement of Massnes (2017) and the peak in daily precipitation, leads to the interpretation that sand deposition started to deposit in both sediment cores from 1983.

The ratio of freshwater diatoms versus planktonic marine diatoms keeps relating to the historic precipitation data throughout the sand layer. This gives reason to believe that the material of the sand layer was not all deposited during the overflow event, but also deposited throughout the years after.

Effect on the amount of organic carbon

During the overflow event, there was more erosion. This would theoretically lead to an increase in the amount of organic matter. However, the amount of organic matter in the sediment quickly decreases. The organic matter then gradually increases back to its normal level (Figure 36).

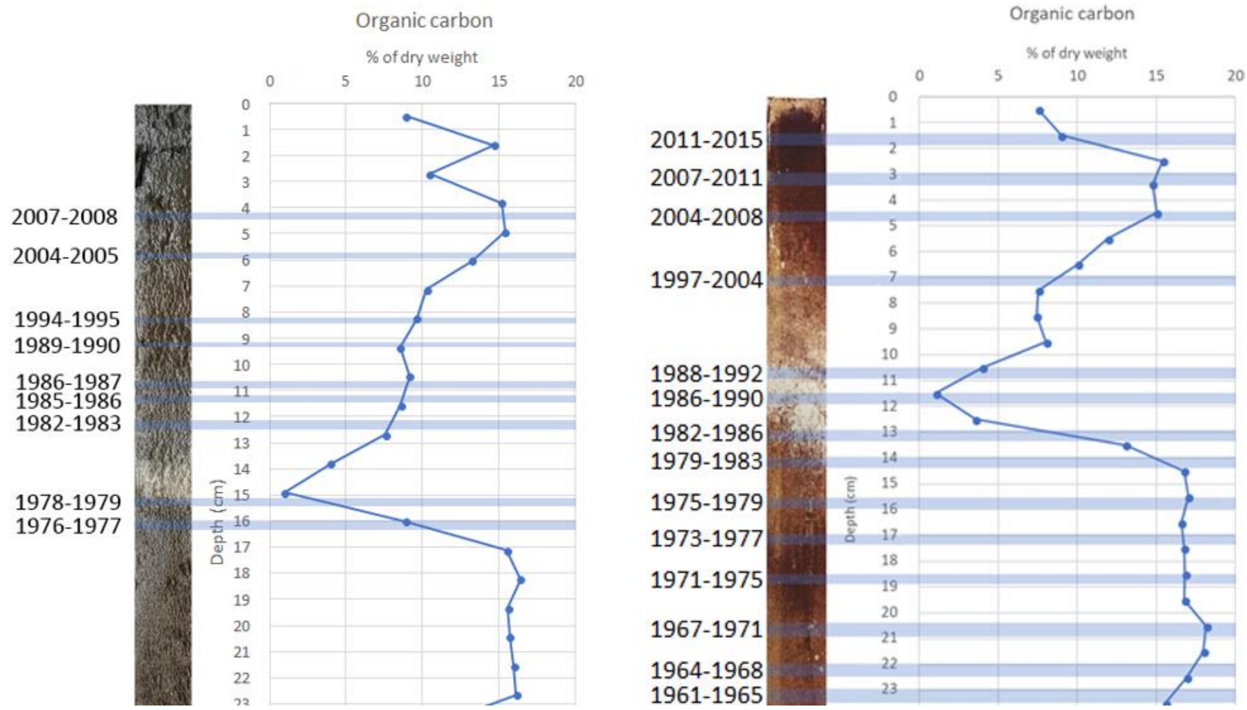


Figure 36: Amount of organic matter during the deposition of the sand layer of core MF2017-1 left and MF2017-2 right

It is expected that this is the result of the adsorption capacity of the sediment. There is a well-known correlation between the amount of organic carbon in coastal sediments and the surface area of coastal sediments, namely that the amount of organic carbon increases with finer-grained sediments (Bergamaschi et al., 1996). This gives the particles better characteristics for organic matter adsorption (Rojas & Silva, 2005). In the case of the Ikjefjord, sand deposited during the overflow event, giving the sediments a worse adsorption capacity for organic carbon. Therefore, there was a quick decrease in the amount of organic carbon. As stated before, not all of the sand probably deposited during one event. The Loss on Ignition data gives the same indications. First, there was a sudden decrease in the amount of organic carbon, due to the deposit of sand during the overflow event. Sand did not only deposit in the Ikjefjord, but also in the riverbeds. It is expected that throughout the years after the overflow event, sand present in those riverbeds was transported to the Ikjefjord. Over time, increasingly less sand was present in the riverbeds and therefore increasingly less sand deposited into the Ikjefjord. This probably led to an increasing adsorption capacity of the sediments and therefore a gradual increase in the amount of organic matter.

An important notice is that the reduction of organic matter in the benthic environment does not mean the supply of organic matter to the Ikjefjord changed. Actually, since there was more erosion during the overflow event, an increase in organic matter supply to the pelagic environment is expected in 1983.

5.3 Benthic foraminifera

MF2017-1:

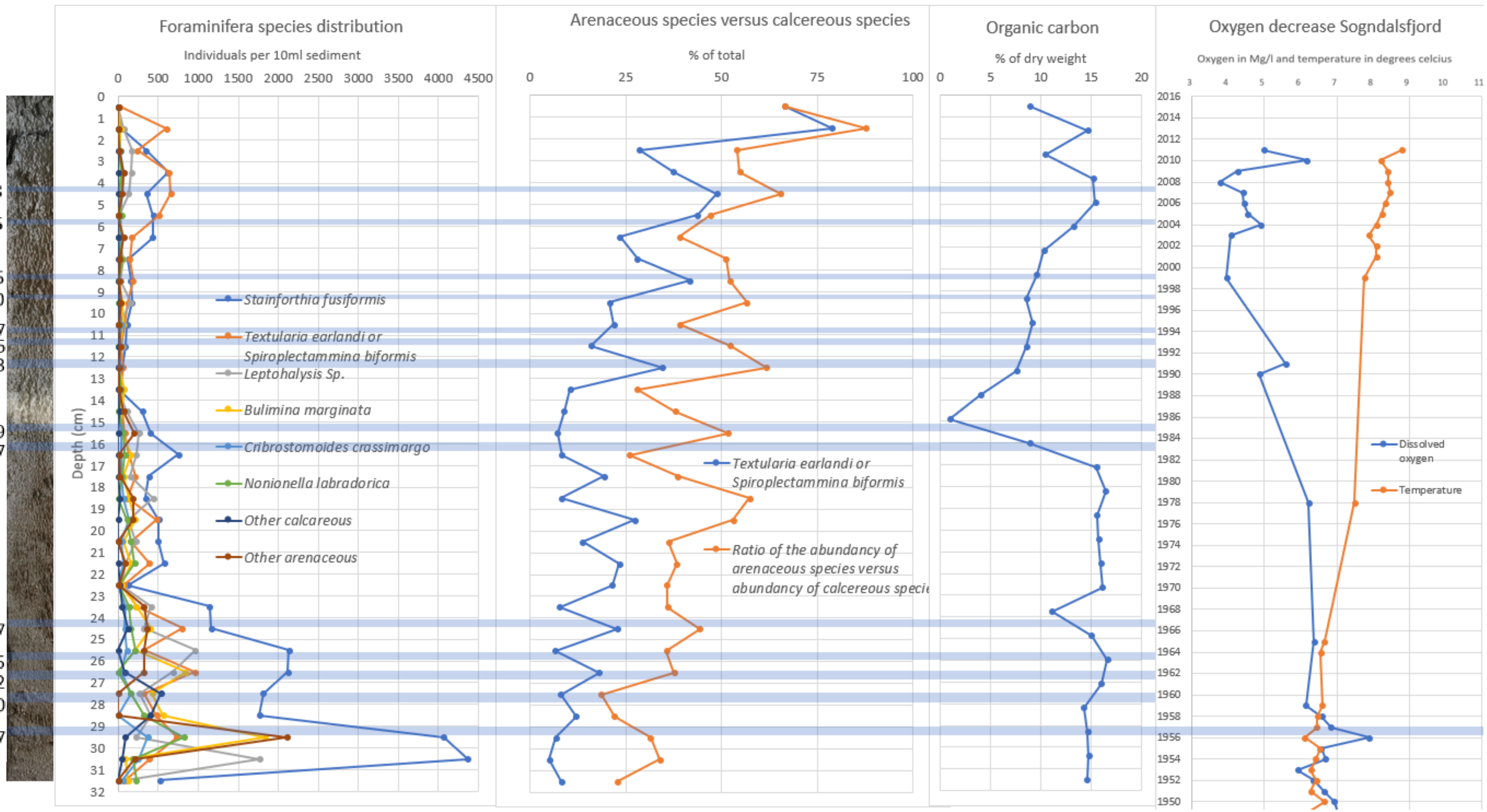


Figure 37: MF2017-1 benthic foraminifera and organic carbon results with added timescale, compared with oxygen declines in the Sogndalsfjord. Temperature and oxygen data of both the Sogndalsfjord and Barsnesfjord from 1916 to 2013 is given in figures 12 and 13.

MF2017-2

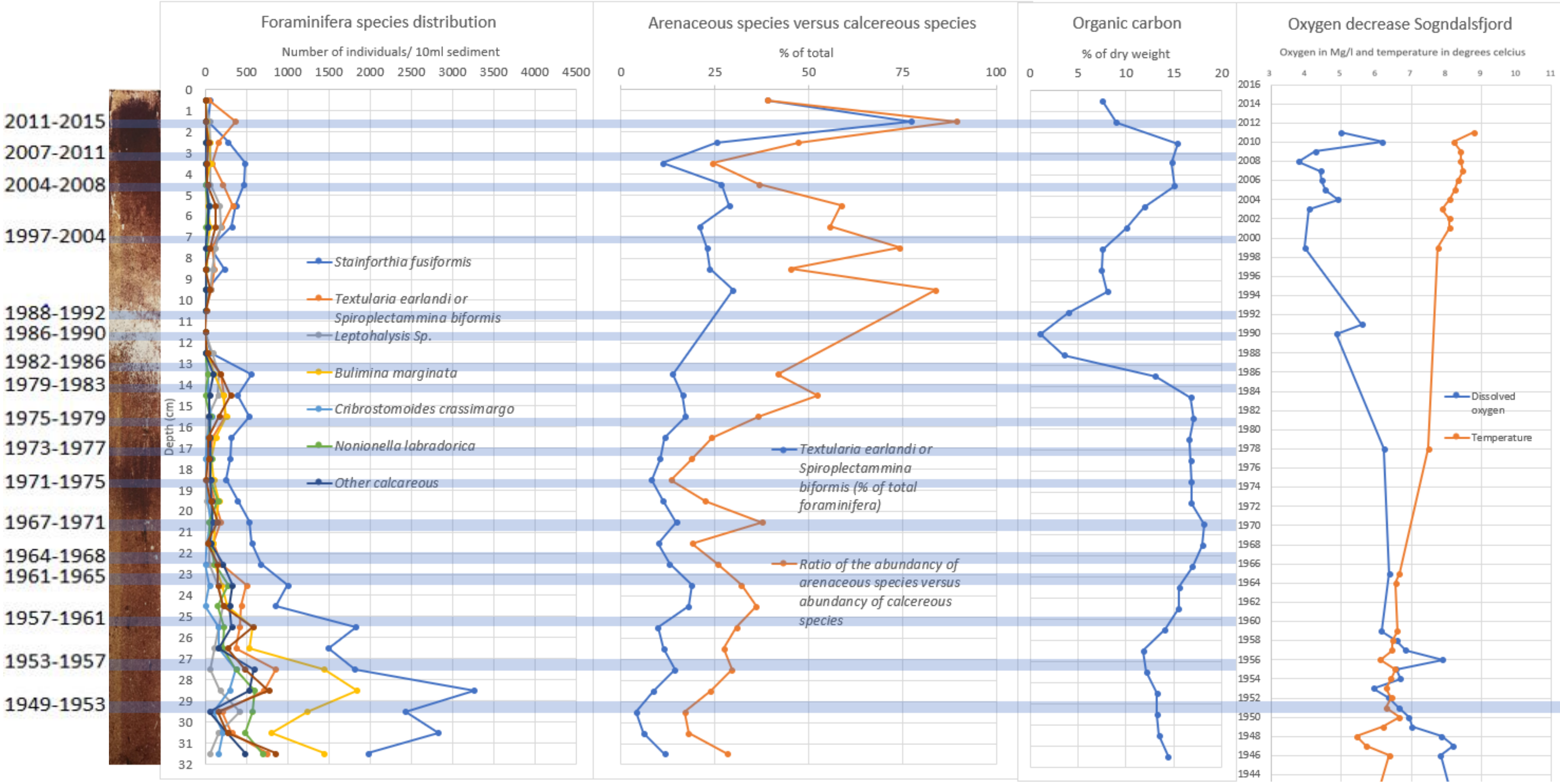


Figure 38: MF2017-2 benthic foraminifera and organic carbon results with added timescale compared with oxygen and temperature data declines from the Sogndalsfjord. Temperature and oxygen data of both the Sogndalsfjord and Barsnesfjord from 1916 to 2013 is given in figures 12 and 13.

Significant positive correlations between foraminifera abundancies
In both cores, most of the foraminifera abundancies change the same way. In core MF2017-1, the species *Textularia earlandi or Spiroplectammina biformis, Bulimina marginata, Cribrostomoides crassimargo*, *Nonionella labradorica*, other arenaceous and *Stainforthia fusiformis* all have significant positive correlations with each other*. On average, the abundancy of those species combined is 86% of the total abundancy (minimum of 64,9%, maximum of 100%). The species other calcareous and leptohalysis sp. have significant positive correlations with some of the species, but not all*. In core MF2017-2, the same species plus other calcareous have a significant positive correlation*. On average, the abundancy of those species combined is 91% of the total abundancy (minimum of 55,6%, maximum of 100%). That most of the foraminifera abundancies change the same way can also be seen in figures 37 and 38. Leptohalysis sp. is the only species which does not have significant positive correlations with all species*. This might be because Leptohalysis sp. are small and thin foraminifera and therefore the easiest of all to oversee during the counting. Thereby it is a possibility that because of their shape they could easier flow through the sieve from the medium to the small fraction.

Reduction in foraminiferal abundancies from the mid- 1950s to the 1970s
From the mid-1950s to the 1970s, there is a big decrease in the abundancies of foraminifera. It is possible that this is caused by decreasing oxygen concentrations in the deep water. Decreasing oxygen concentrations in the deep water are expected because the deep water oxygen concentrations in the Barsnesfjord and Sogndalsfjord decreased since the mid/late 1950s due to a water temperature increase (Figure 38). A regional process (for example a climate oscillation) most likely caused this phenomenon and probably had the same effect on the Ikjefjord.

Increase in the ratio of the abundancy of arenaceous species versus calcareous species from the mid-1970s to 2017
An increasing ratio of the abundancy of arenaceous species versus calcareous species is an indicator for depressed oxygen concentrations (Scott et al., 2001). In core MF2017-1, the ratio fluctuates between the early 1950s and the middle of the 1970s. From the mid-1970s to 2017, the ratio increases (Figure 37). In core MF2017-2, the ratio fluctuates between the late 1940s and the early 1970s. From the early/mid-1970s to 2017, the ratio increases (Figure 38). The arenaceous species *Spiroplectammina biformis* is especially an indicator for depressed oxygen concentrations (Scott et al., 2001). In both cores (Figures 37 and 38) the ratio increase of the abundancy of arenaceous species versus calcareous species is mainly caused by an increasing abundancy of *Spiroplectammina biformis or Textularia earlandi (*in % of total foraminifera). Even though it is unknown if this species was *Spiroplectammina biformis* or *Textularia earlandi*, it is still seen as a stronger indicator of oxygen concentrations getting depressed.

As stated before, the oxygen concentrations are expected to have decreased in the deep water since the mid- 1950s. It is expected that the observation of an increasing ratio of the abundancy of arenaceous species versus calcareous species from the mid-1970s is due to the reach of a ‘critical’ dissolved oxygen concentration for calcareous species.

A possible source which might have accelerated the decrease in oxygen concentrations in the Ikjefjord is the building of the bridge from 1975 to 1977. The narrowing of the sill and the reduction of the deepest sill point from 20m to 16m for the construction of the bridge might have resulted in a restriction of basin water renewal and could therefore have caused oxygen concentrations to decrease faster.

***Tables with results of the statistical tests are included in Appendix VII**

Correlation of foraminifera abundancies with the amount of organic matter after the 1970s
From the 1970s to now, the abundancies of foraminifera relate with the amount of organic matter. When the cases before 1970 are excluded from the bivariate pearsons test (>21cm in core MF2017-1>19,5cm in core MF2017-2) the following correlations are found*:

- MF2017-1: significant positive correlations between the amount of organic matter and *Textularia earlandi* or *Spiroplectammina biformis*, *Bulimina marginata*, *Cribrostomoides crassimargo*., *Nonionella labradorica* and *Stainforthia fusiformis*
- MF2017-2: significant positive correlations between the amount of organic matter and *Textularia earlandi or Spiroplectammina biformis, Bulimina marginata, Cribrostomoides crassimargo, Nonionella labradorica, other calcareous, other arenaceous* and *Stainforthia fusiformis*

This indicates that the foraminifera abundancies partly depend on the amount of organic matter. The only species which does not have a significant correlation with the amount of organic matter in both cores is *Leptohalysis sp*. This gives another explanation why its abundancy does not correlate with the abundancies of most foraminifera.

As explained earlier, the amount of organic carbon in the benthic environment decreased from the early 1980s, probably because of the overflow event and the transport of remaining sand in the riverbeds to the Ikjefjord throughout the years after. This period, where the sediments contained a low amount of organic matter, corresponds with low foraminifera abundancies in the early 1980s to late 1990s.

***Tables with results of the statistical tests are included in Appendix VII**

5.4 Freshwater and planktonic marine diatoms

MF2017-1

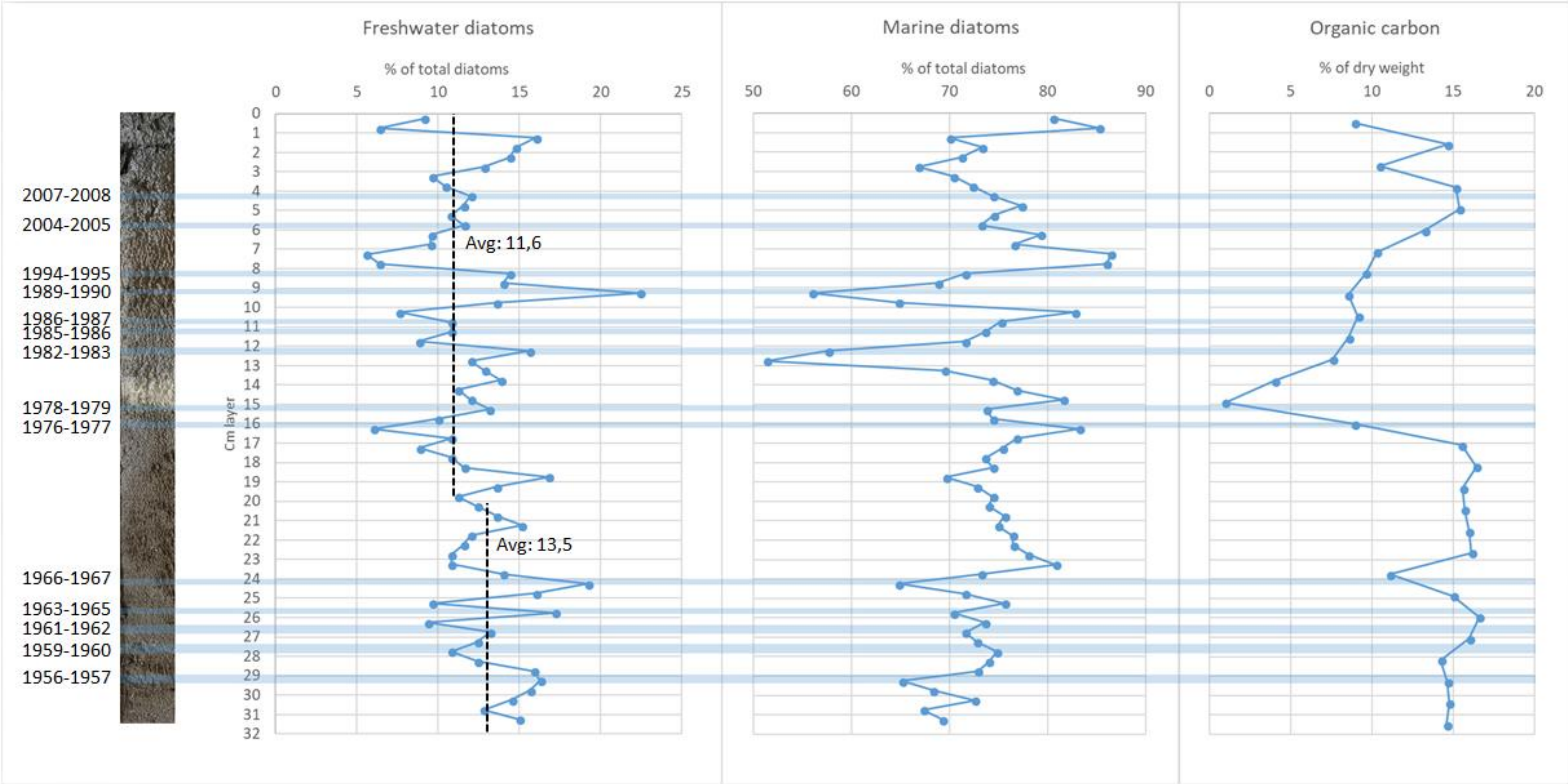


Figure 39: Ratio's of freshwater and marine diatoms versus all diatoms and the amount of organic carbon in MF2017-1 with added timescale

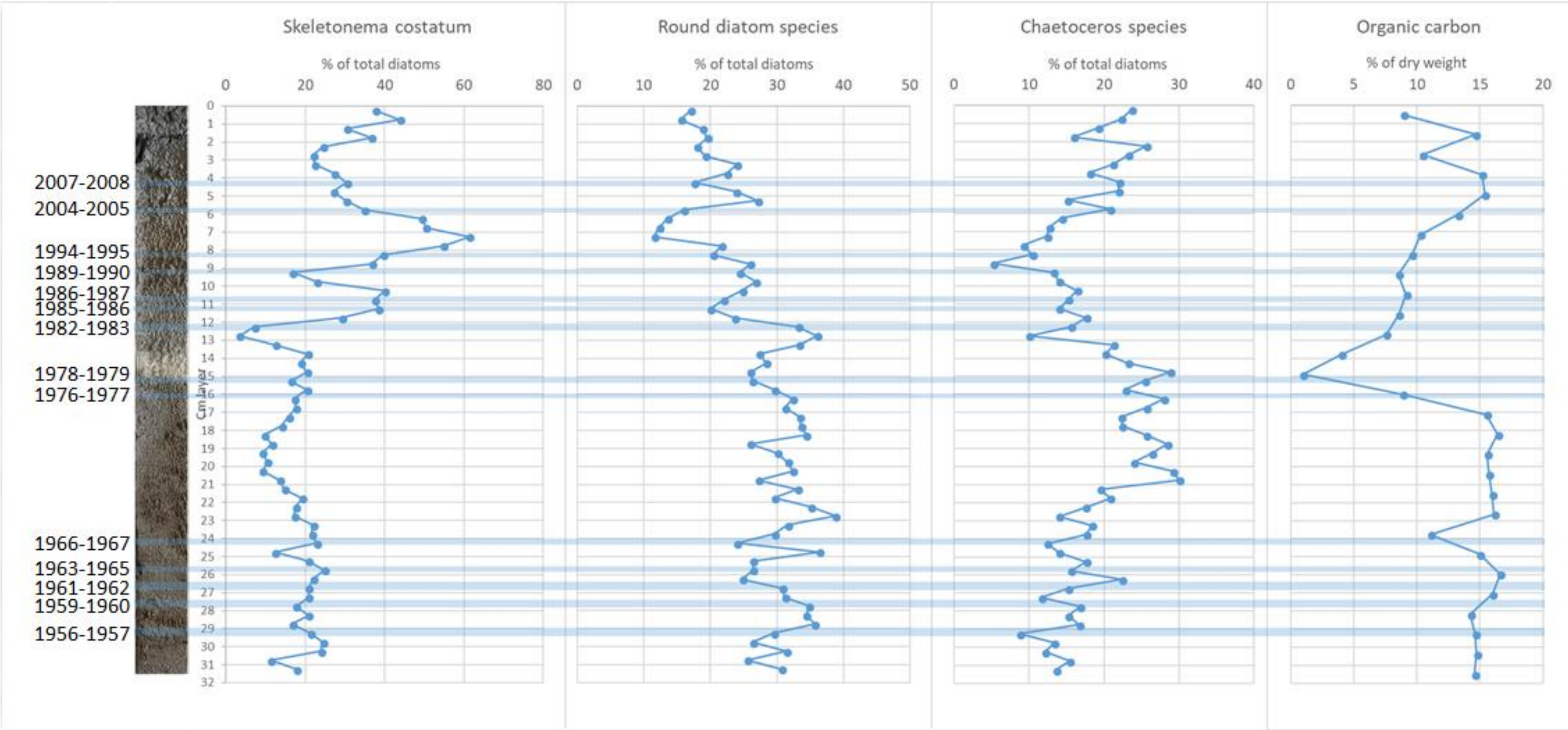


Figure 40: Ratio's of Skeletonema costatum, Round diatom species and Chaetoceros species versus all diatoms and the amount of organic carbon in MF2017-1 with added timescale

MF2017-2

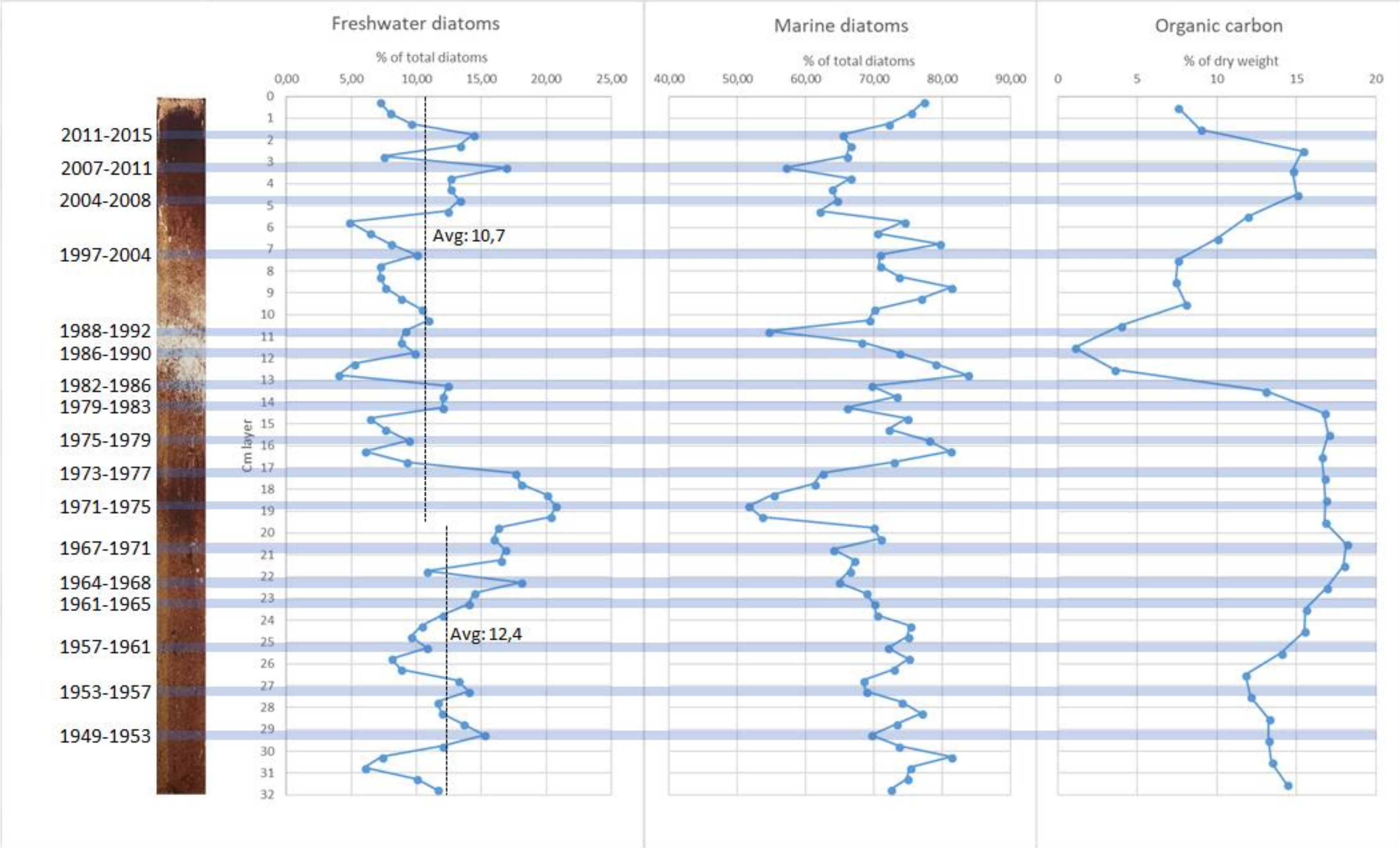


Figure 41: Ratio's of freshwater and marine diatoms versus all diatoms and the amount of carbon organic carbon in MF2017-2 with added timescale

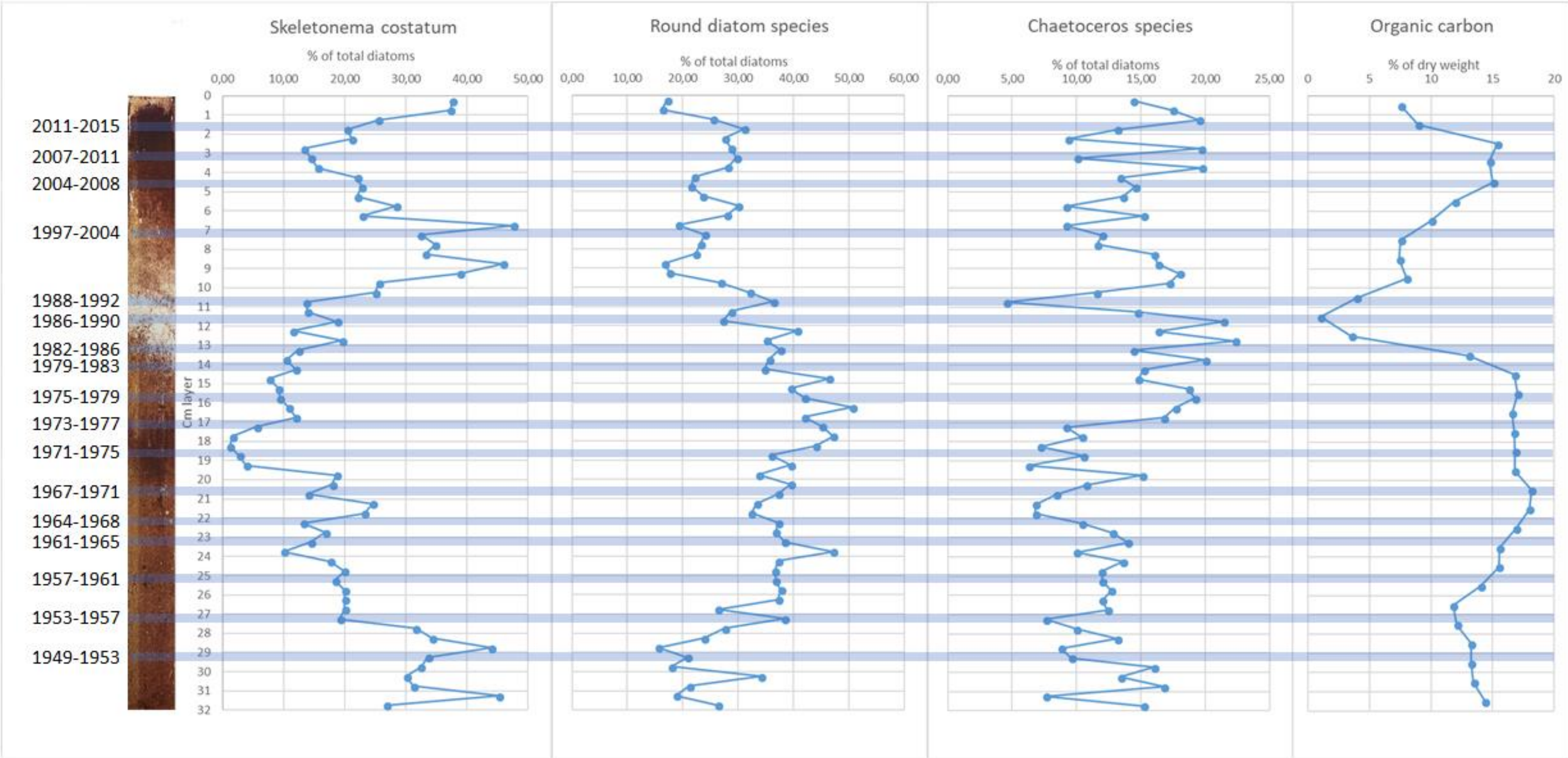


Figure 42: Ratio's of Skeletonema costatum, Round diatom species and Chaetoceros species versus all diatoms and the amount of organic carbon in MF2017-2 with added timescale

Interspecific competition between planktonic marine diatom species
In both cores, the species *Skeletonema costatum* has a strong significant negative correlation with Round diatom species*:

- MF2017-1: p=-0,741, s=0,002
- MF2017-2: p=-0,851, s=0,000

In core MF2017-1 *Skeletonema costatum* also has significant negative correlations with *Chaetoceros species* (p=-0,386, s=0,002) and *Thalassiosira nordenskiöldii* (p=-0,483, s=0,000)*.

As stated earlier, the reduction in organic matter during sand deposition probably did not occur in the pelagic environment but only in the benthic environment. To test for correlations between species abundancies and the amount of organic matter, two test have been run*:

- A pearsons bivariate test where the centimetre layers of sand deposition are included (>5,25cm and <17,25m in core MF2017-1 and >4,75cm and <15,25cm in core MF2017-2)
- A pearsons bivariate test where the centimetre layers of sand deposition are excluded

Both tests show that the species *Skeletonema costatum* has a significant negative correlation with the amount of organic matter in both cores and that *round diatom species* has a significant positive correlation with the amount of organic matter in both cores. Next to this, the species *Thalassiosira nordenskiöldii* has a significant positive correlation with the amount of organic matter in MF2017-1 and the species *Chaetoceros sp.* has a significant negative correlation with the amount of organic matter in MF2017-2. All of the correlations mentioned are stronger in the test where the centimetre layers of sand deposition are excluded, with the exception of the correlation between the amount of organic matter and *Thalassiosira nordenskiöldii* in MF2017-1.

Skeletonema costatum can be dominant in poorly stratified water due to its physical properties (Syvitski et al, 1986). It is therefore likely that the interspecific competition *between Skeletonema costatum, Round* (mostly marine) *diatom species* and *Thalassiosira nordenskiöldii* is due to changes in stratification strengths. Rivers are the main supply of organic matter in fjords. Low amounts of organic matter in the sediment is probably often due to low river flow rates. If less freshwater is transported to the fjord, the fresh water surface layer is thinner. This probably causes weaker stratification and therefore a better environment for *Skeletonema costatum* (hence the significant negative correlations with the amount of organic carbon). Competition between *Skeletonema costatum* and *Chaetoceros species* is probably due to other reasons, since *Chaetoceros species* does not have a significant positive correlation with the amount of organic matter.

Influences of hydropower production
In core MF2017-1, the ratio of *Skeletonema costatum* versus all diatoms increases from the early 1970s, arguably from the early 1980s (Figure 40). In core MF2017-2 it is clearly visible that the ratio of *Skeletonema costatum* versus all diatoms increases from the early/mid-1970s (Figure 42). The highest ratio is present in the mid/late 1990s in both cores. There are two explanations for this ratio increase:

- Damming the rivers in 1971 reduced the stratification strength in the inner basin of the Ikjefjord. The stratification might have been reduced more after 1983, when the dam at Stølsvatnet was secured against future flooding. The low average annual precipitation in 1996 possible contributed in reducing the stratification strength too, explaining the observation of the highest ratio's of *Skeletonema costatum* versus all diatoms in the mid- or late 1990s

***Tables with results of the statistical tests are included in Appendix VII**

- Damming the rivers in 1971 reduced the freshwater supply to the Ikjefjord. A reduction in the freshwater supply could have led to the transport of less sediment to the Ikjefjord and therefore a decreased turbidity. A lower turbidity could have led to better light conditions (and therefore better growing conditions) for *Skeletonema costatum.* Securing of the dam at Stølsvatnet in 1983 and the low average annual precipitation in 1996 could have caused an even further reduction in freshwater supply and therefore could have reduced the turbidity even more

It is expected that the ratio of *Skeletonema costatum* versus all diatoms increased due to a combination of both explanations.

In core MF2017-2 the ratio of *Skeletonema costatum* versus all diatoms was high in the late 1940s/early 1950s. This is not confirmed in core MF2017-1. This is probably the case because core MF2017-1 does not date back as far as core MF2017-2. No indications can be given why this ratio was high at that time, since the history of building activity and natural events in this thesis goes only back to the 1970s.

The total amount of freshwater diatoms versus all diatoms slightly decreases after the 1970s in both cores when comparing the averages before and after the early 1970s (Figures 39 and 41). This, while the average annual precipitation increases. This is a further indication that the damming of the rivers affected the diatom community.

6 Conclusion and recommendations

Dating the sediment cores

It is possible to date the anoxic sediments of the Ikjefjord, using the dating method of Paetzel and Dale (2010) as an alternative for radiometric dating. The dating is supposed to be used as a rough guideline due to changing sedimentation rates and the use of moving average trendlines.

Changes in the benthic environment

From the mid-1950s to the 1970s a big decrease in the abundancies of foraminifera is observed. From the mid-1970s to 2017 the ratio of the abundancy of arenaceous species versus calcereous species increases. Both observations are expected to be caused by decreasing oxygen concentrations in the deep water. A decrease in deep water oxygen concentrations is expected to be caused by a regional process (for example a climate oscillation), since oxygen concentrations in the Barsnesfjord and Sogndalsfjord, which are also side branches of the Sognefjord, have been decreasing since the mid/late 1950s due to deep water temperature increases. The specific process causing this is unknown.

The abundancies of almost all foraminifera species correlate with the amount of organic matter from the 1970s to 2017. A minimum of the amount of organic matter in the early 1980s to late 1990s most likely caused the observed minimum in foraminiferal abundancies. The period of low organic matter is expected to be caused by the overflow event in 1983. A period of sand deposition most likely reduced the adsorption capacity of the sediment, causing a period of low organic matter in the benthic environment.

Changes in the pelagic environment

From the early/mid 1970s the ratio of *Skeletonema costatum* versus all diatoms increases. It is expected that the ratio increased due to the damming of the rivers in 1971. The damming of the rivers might have reduced the stratification strength in the inner basin of the Ikjefjord. It also reduced the freshwater supply to the Ikjefjord. This could have led to the transport of less sediment to the Ikjefjord and therefore could have decreased the turbidity. Securing the dam at Stølsvatnet in 1983 and a year of low average annual precipitation in 1996 could have caused an even further reduction in the freshwater supply and could therefore have reduced the stratification strength and turbidity even more.

The total amount of freshwater diatoms versus all diatoms slightly decreases after the 1970s when comparing the average before and after the early 1970s. This, while the average annual precipitation increases. This is a further indication that the damming of the rivers affected the diatom community.

Recommendations concerning ecological status classification required by the EU Water Framework Directive

The results show that the investigation of micro-organism records from the sediment record indicate effects from building activity and natural events on the environmental conditions in the inner Ikjefjord. They give information about the biological quality elements, namely phytoplankton (diatoms) and benthic invertebrate fauna (benthic foraminifera). Formally, the EU WFD requires the investigation of hydromorphological, chemical and physico-chemical elements to support the biological elements. When all quality elements are investigated, an ecological classification can be made. However, the Ikjefjord is currently classified based on 'no information' (Appendix I), admitting a 'low reliability' (Appendix I). It is therefore recommended to use the results of this thesis as a basis to reconsider the current ecological status. At least, this thesis provides arguments for increasing the reliability of the information the ecological status is based on.

There are most likely more waterbodies where there is no (historic) information about the possible influences of anthropogenic pressures on the environmental conditions and where therefore the ecological status is based on no information. In those cases, it is recommended to add an investigation of micro-organism records in sediments to the current method for ecological classification.

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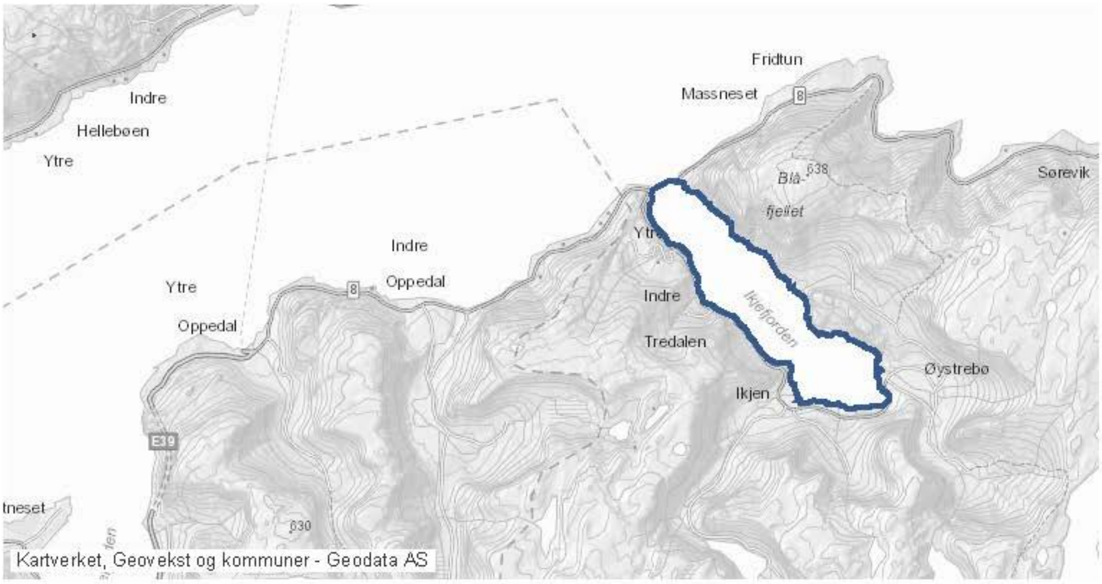
Appendix I: Current classification of the Ikjefjord

Ikjefjorden

Map



General info

Name	Ikjefjorden	**Waterbody Id**	0280020300-C
Water category	en-CW		
River Basin	069	**Catchmentarea**	
Area km²	4		
Competent authority	Sogn og Fjordane	**River basin district**	Sogn og Fjordane
Sub unit	Ytre Sogn	**County**	Sogn og Fjordane
Municipality	Høyanger		

Environmental goals ⚠ en-Miljømålet er automatisk endret i.h.t unntak eller mangel på sådant

Ecological	Good	
Chemical	Good	
Risk	Risk	Usikker risiko grunnet manglende data

Watertype

Watertype name	Fjord poor in oxygen	**Salinity**	Mesohaline (5 - 18)

Watertypecode	CM6323231	**Wave exposure**	Protected
Water category	en-CW	**Tide**	Small (< 1 m)
Ecoregion	North Sea North	**Water column mixing**	Partially layered
Retention time bilge water	Long (months/years)	**Flow velocity**	Weak (< 1 knot)

Pressure

	DEGREE OF IMPACT	EFFECT
Agriculture		
Diffuse pollution		
Diffuse Agricultural source	Unknown degree	en-NUTR - Nutrient pollution
Energy - hydropower		
Hydromorphological		
Hydromorphological alteration Physical loss Diversions	Medium degree	en-OTHE - Other significant impact type

Measure

MEASURES ID	MEASURE NAME	MEASURE TYPE	PRESSURE	EXCEPTION	STATUS

Effect from measures on other waterbodies

MEASURES ID	MEASURE NAME	MEASURE TYPE	PRESSURE	EXCEPTION	STATUS

Ecological status

Ecological status	**en-Pålitelighetsgrad**	Low
Good	**Status based on**	No Information

QUALITYELEMENTS	STATUS	VALID	SOURCE

Riverbasin specific substances

QUALITYELEMENTS	STATUS	COUNT

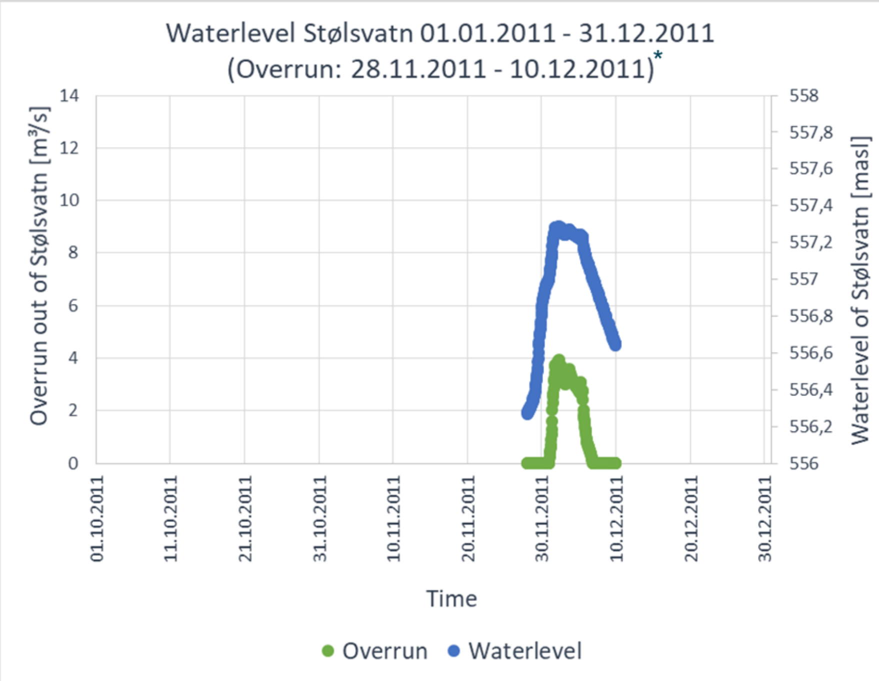
Chemical status

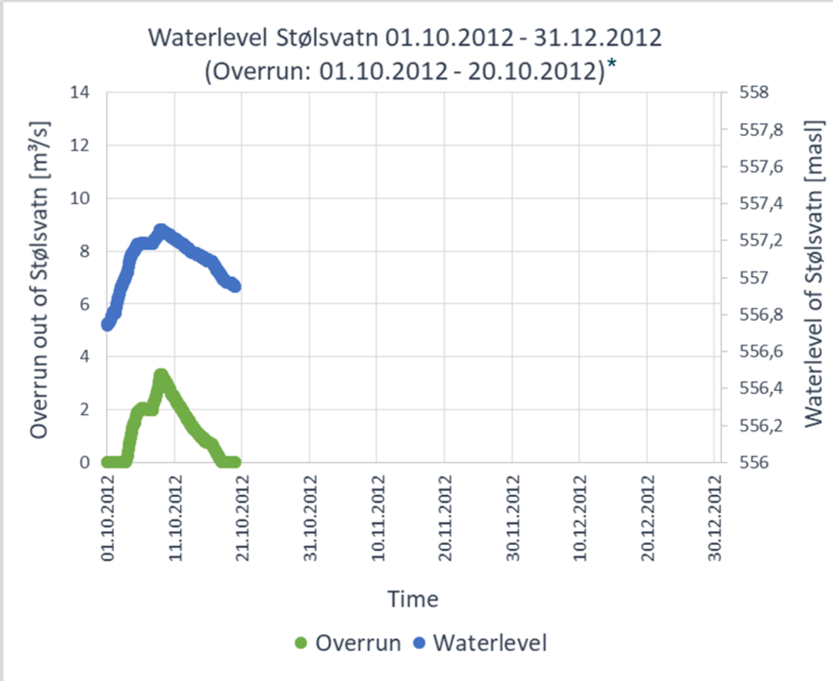
Chemical status	en-Pålitelighetsgrad	No information
Unknown		

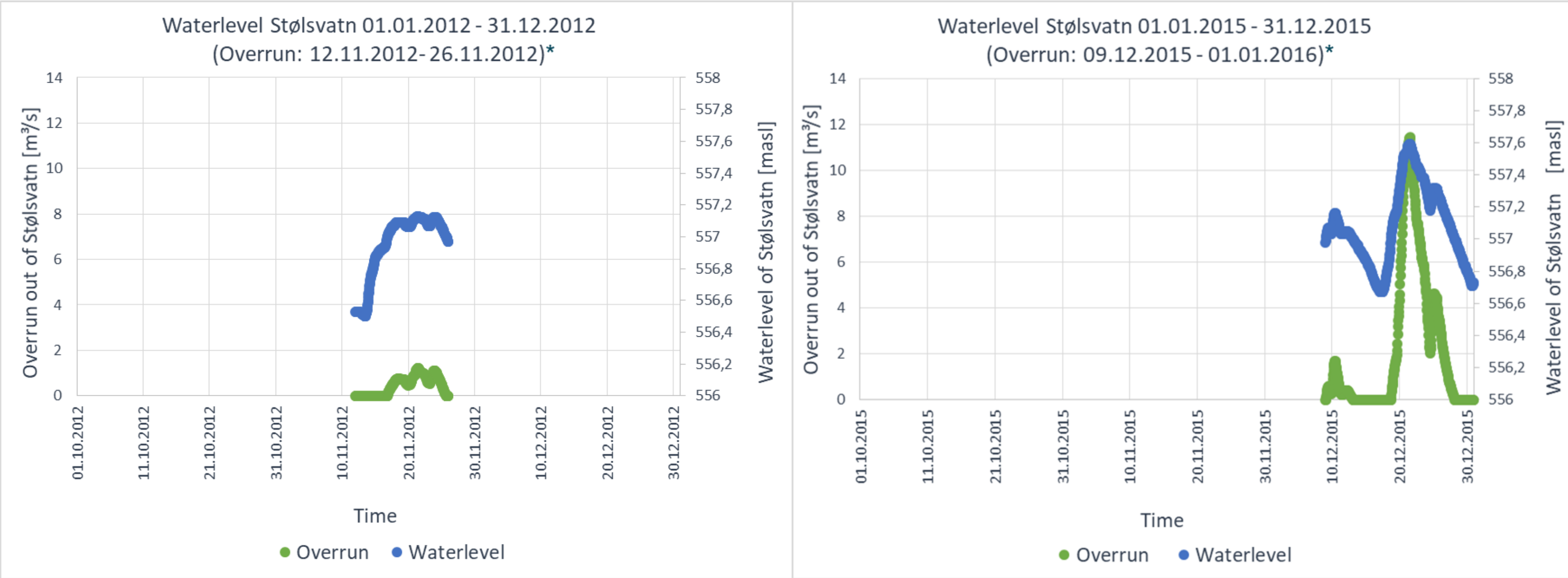
QUALITYELEMENTS	STATUS	COUNT

Information from Miljøforvaltningen og Norges Vassdrags- og energidirektoratet (2017).

Appendix II: Overflows of the Stølsvatnet in the period 2008-2017







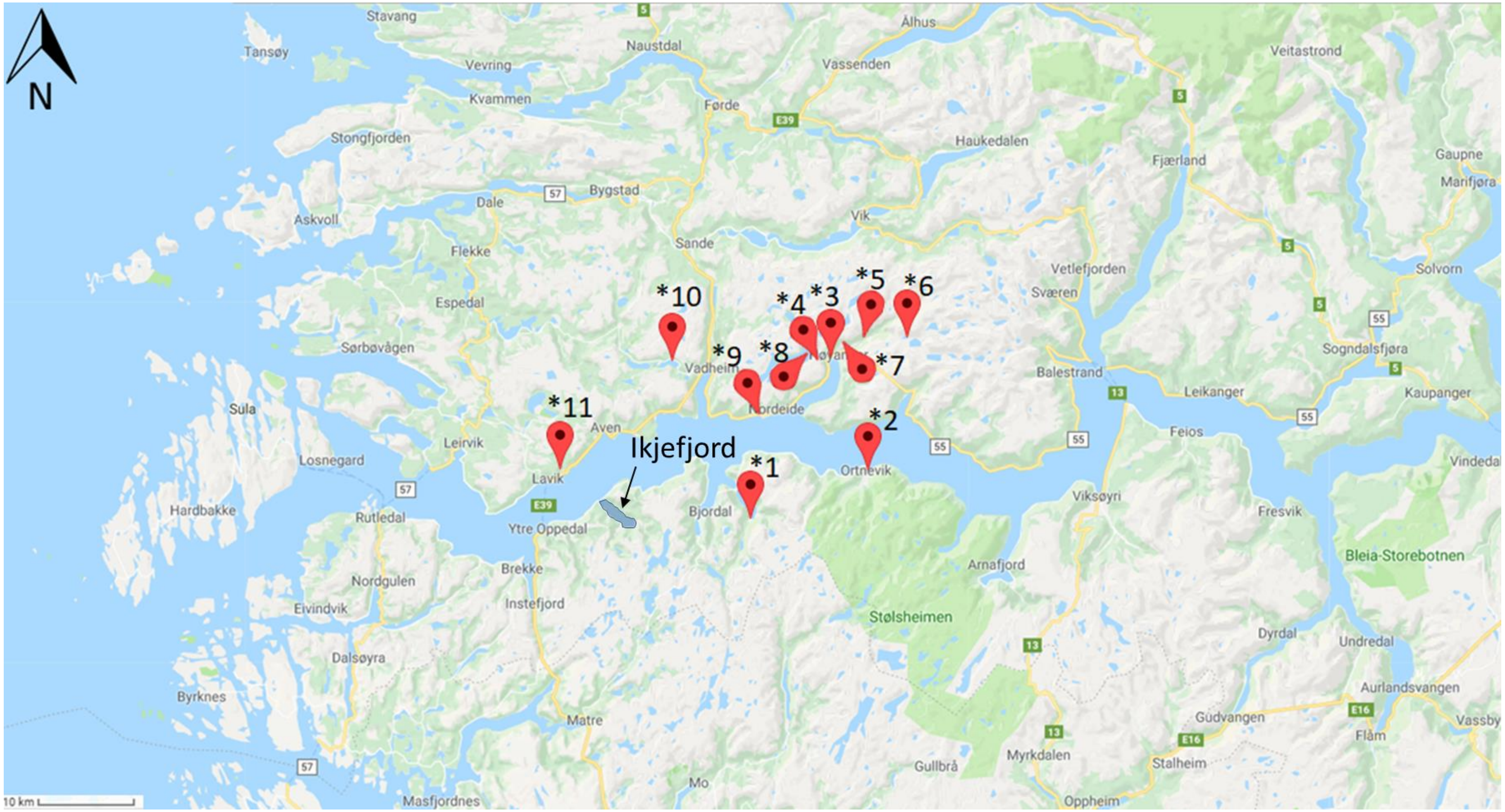
Dataset has been provided to the From Mountain to Fjord group in 2017 by the hydropower company BKK (Bergenshalvøens Kommunale Kraftselskap, 2017)

Appendix III: Definitions for high, good and moderate ecological status in coastal waters – biological elements

Element	High status	Good status	Moderate status
Phytoplankton	The composition and abundance of phytoplanktonic taxa are consistent with undisturbed conditions. The average phytoplankton biomass is consistent with the type-specific physico-chemical conditions and is not such as to significantly alter the type-specific transparency conditions. Planktonic blooms occur at a frequency and intensity which is consistent with the type specific physico-chemical conditions.	The composition and abundance of phytoplanktonic taxa show slight signs of disturbance. There are slight changes in biomass compared to type-specific conditions. Such changes do not indicate any accelerated growth of algae resulting in undesirable disturbance to the balance of organisms present in the water body or to the quality of the water. A slight increase in the frequency and intensity of the type-specific planktonic blooms may occur.	The composition and abundance of planktonic taxa show signs of moderate disturbance. Algal biomass is substantially outside the range associated with type-specific conditions, and is such as to impact upon other biological quality elements. A moderate increase in the frequency and intensity of planktonic blooms may occur. Persistent blooms may occur during summer months.
Macroalgae and angiosperms	All disturbance-sensitive macroalgal and angiosperm taxa associated with undisturbed conditions are present. The levels of macroalgal cover and angiosperm abundance are consistent with undisturbed conditions.	Most disturbance-sensitive macroalgal and angiosperm taxa associated with undisturbed conditions are present. The level of macroalgal cover and angiosperm abundance show slight signs of disturbance.	A moderate number of the disturbance-sensitive macroalgal and angiosperm taxa associated with undisturbed conditions are absent. Macroalgal cover and angiosperm abundance is moderately disturbed and may be such as to result in an undesirable disturbance to the balance of organisms present in the water body.
Benthic invertebrate fauna	The level of diversity and abundance of invertebrate taxa is within the range normally associated with undisturbed conditions. All the disturbance-sensitive taxa associated with undisturbed conditions are present.	The level of diversity and abundance of invertebrate taxa is slightly outside the range associated with the type-specific conditions. Most of the sensitive taxa of the type-specific communities are present.	The level of diversity and abundance of invertebrate taxa is moderately outside the range associated with the type-specific conditions. Taxa indicative of pollution are present. Many of the sensitive taxa of the type-specific communities are absent.

Table from Annex V table 1.2.4 from the EU WFD (EU, 2000)

Appendix IV: Details of the precipitation stations in the Ikjefjord area



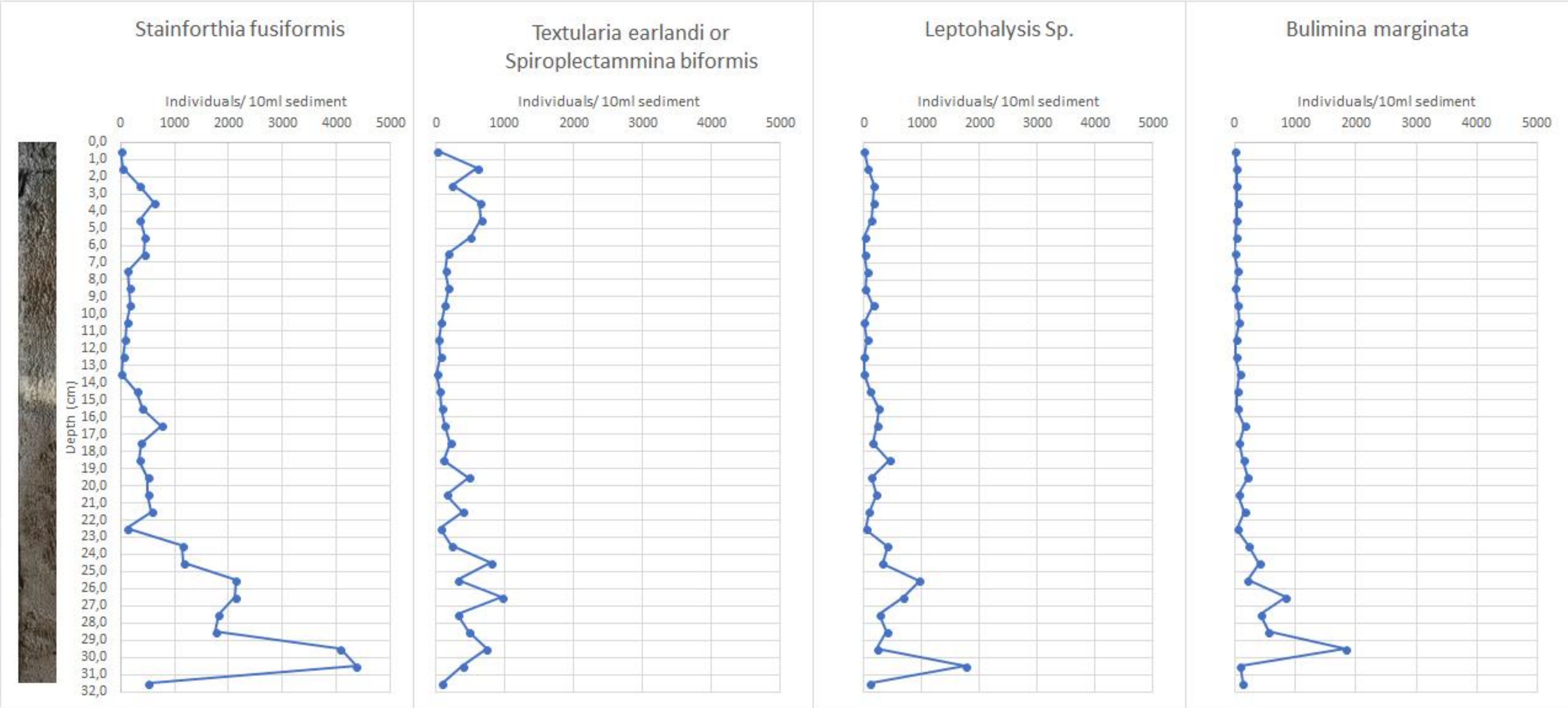
Map retrieved from Google (2018). Locations of the weather stations retrieved from the Norwegian Meteorological Institute (2018).

Number	Station name	Operates from	Operates until	Altitude	Latitude	Longitude
*1	Sørebø	1 July 1996	Still operating	4	61,0657	5,9063
*2	Ortnevik	January 1972	Still operating	4	61,1095	6,134
*3	Høyanger Verk	August 1981	Still operating	5	61,2178	6,0647
*4	Høyanger	March 1996	June 2007	20	61,2172	6,0595
*5	Dale i Høyanger	November 1906	June 1967	55	61,2333	6,1167
*6	Roesvann i Høyanger	August 1939	September 1971	631	61,2348	6,2103
*7	Høyangshaland	September 1907	November 1992	243	61,2315	6,083
*8	Grimsosen i Høyanger	February 1926	April 1978	584	61,2208	6,04
*9	Ramsien	July 1896	December 1915	51	61,1648	5,9257
*10	Rørvikvatn ved Vadheim	January 1929	March 2013	350	61,2163	5,7513
*11	Lavik	July 1895	Still operating	31	61,1122	5,5413

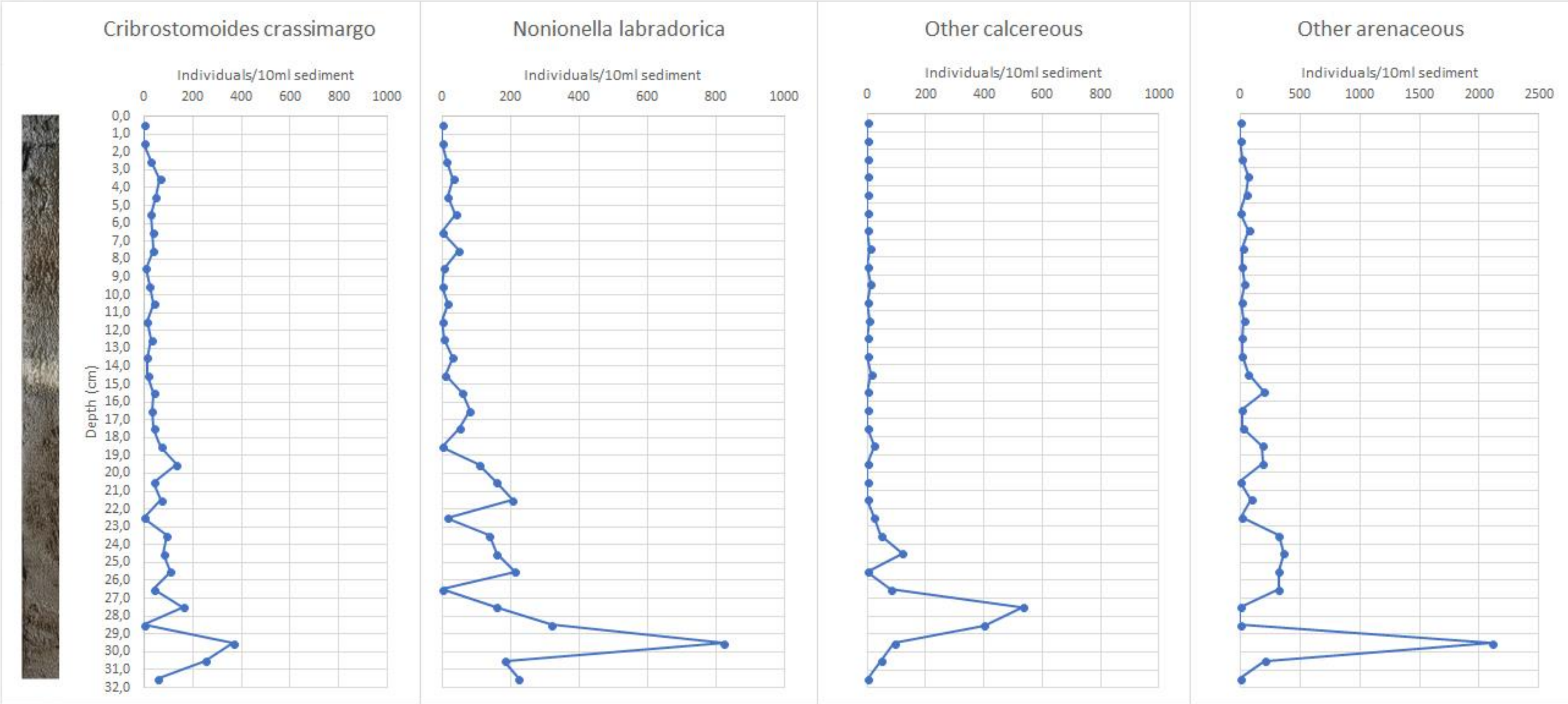
Details of the weather stations has been retrieved from the Norwegian Meteorological Institute (2018)

Appendix V: Abundancies of individual foraminifera species

Core MF2017-1

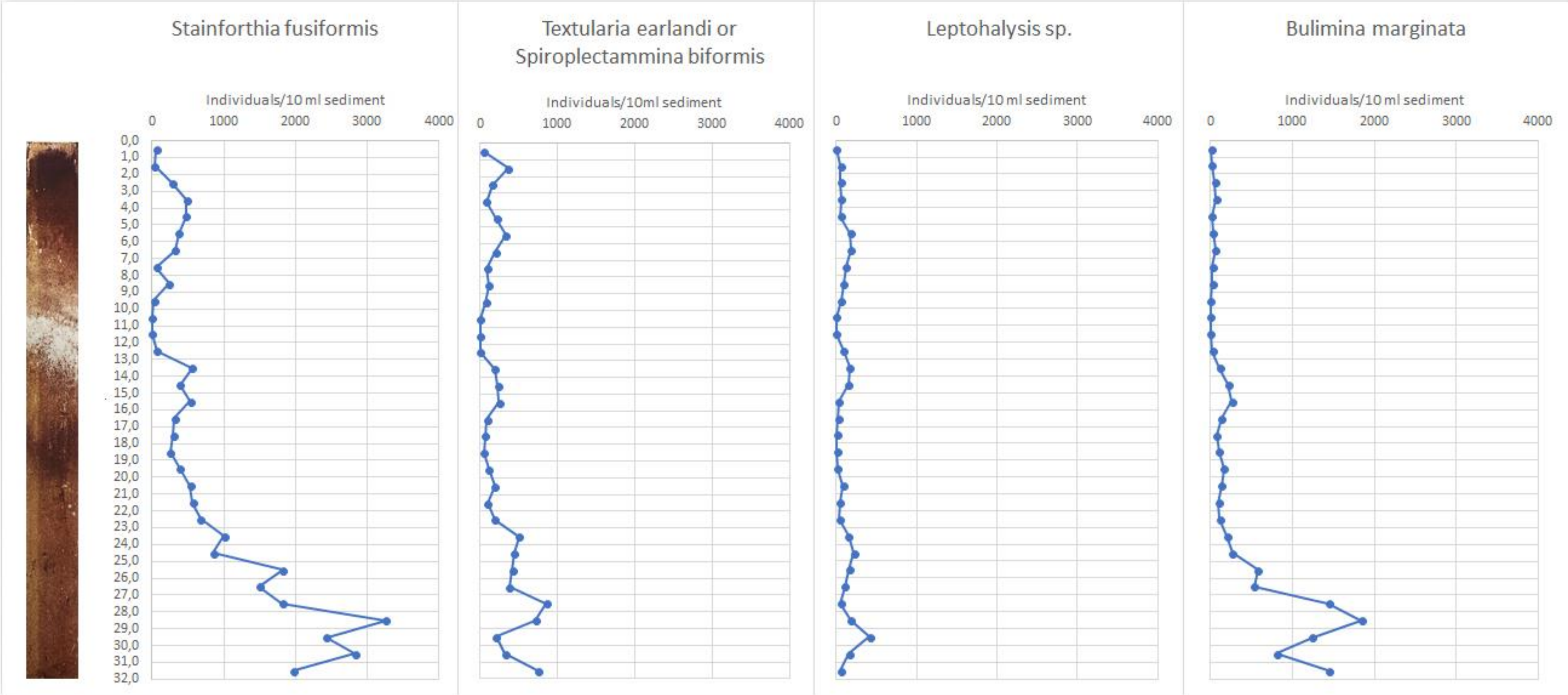


Abundancies of Stainforthia fusiformis, Textularia earlandi or Spiroplectammina biformis, Leptohalysis sp. and Bulimina marginata in MF2017-1

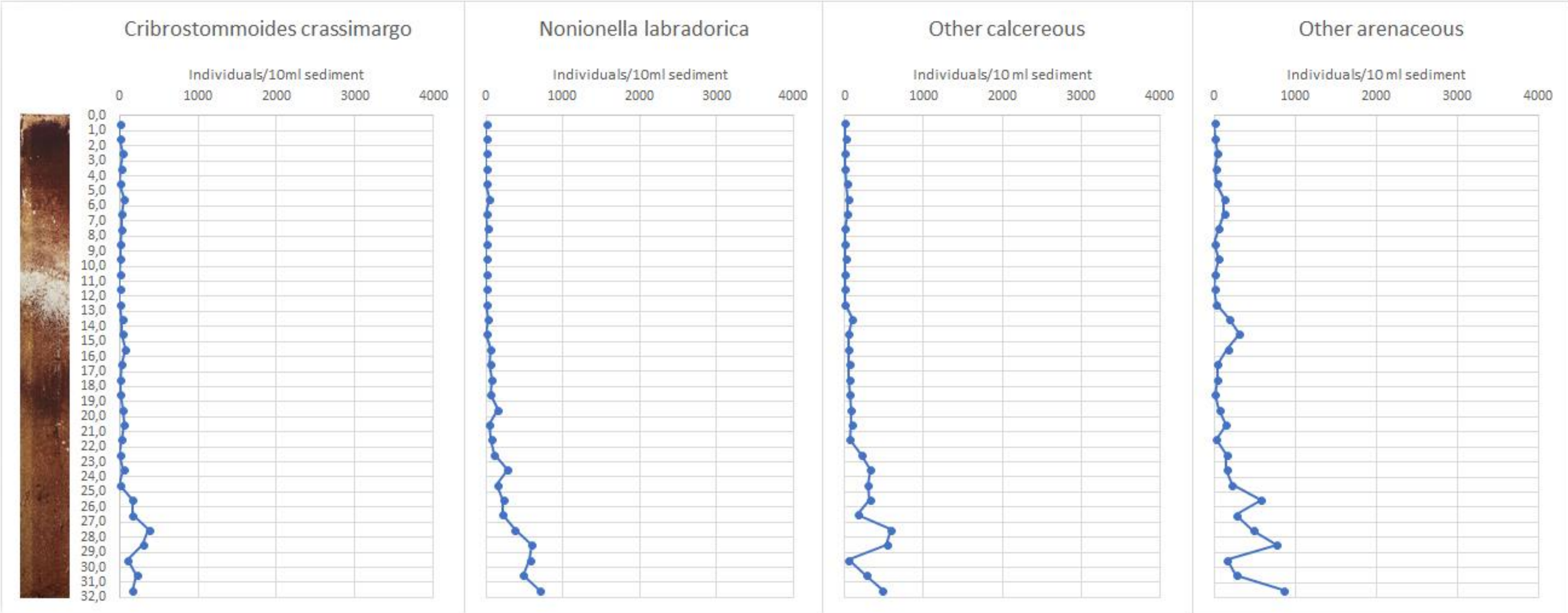


Abundancies of Cribrostomoides crassimargo, Nonionella labradorica, other calcareous and other arenaceous in MF2017-1. Keep in m ind the y-axis maxima differ compared with the y-axis maxima used in. Furthermore, the y-axis maxima of other arenaceous is heightened to 2500 individuals/10ml sediment

Core MF2017-2



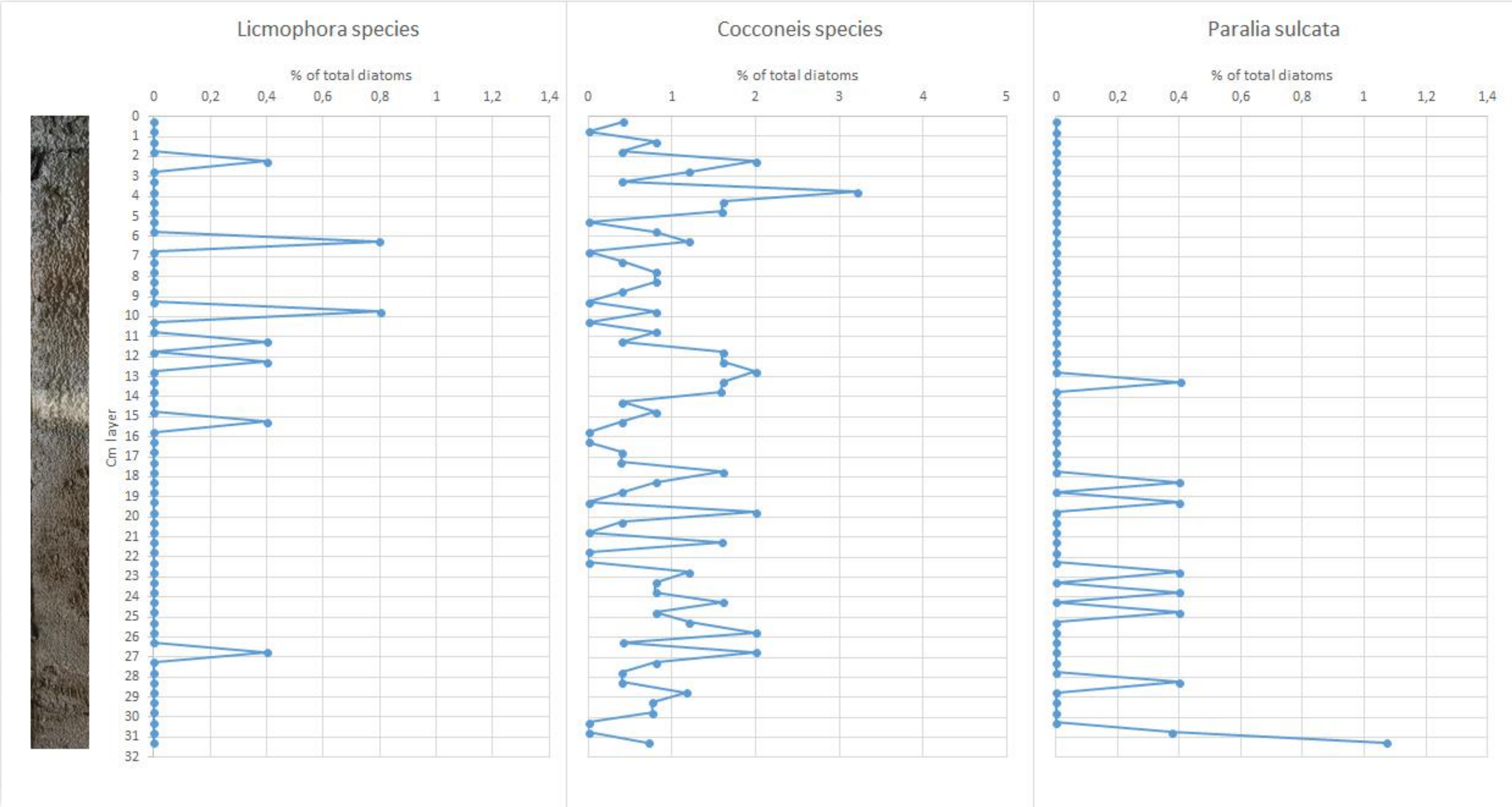
Abundancies of Stainforthia fusiformis, Textularia earlandi or Spiroplectammina biformis, Leptohalysis sp. and Bulimina marginata in MF2017-2



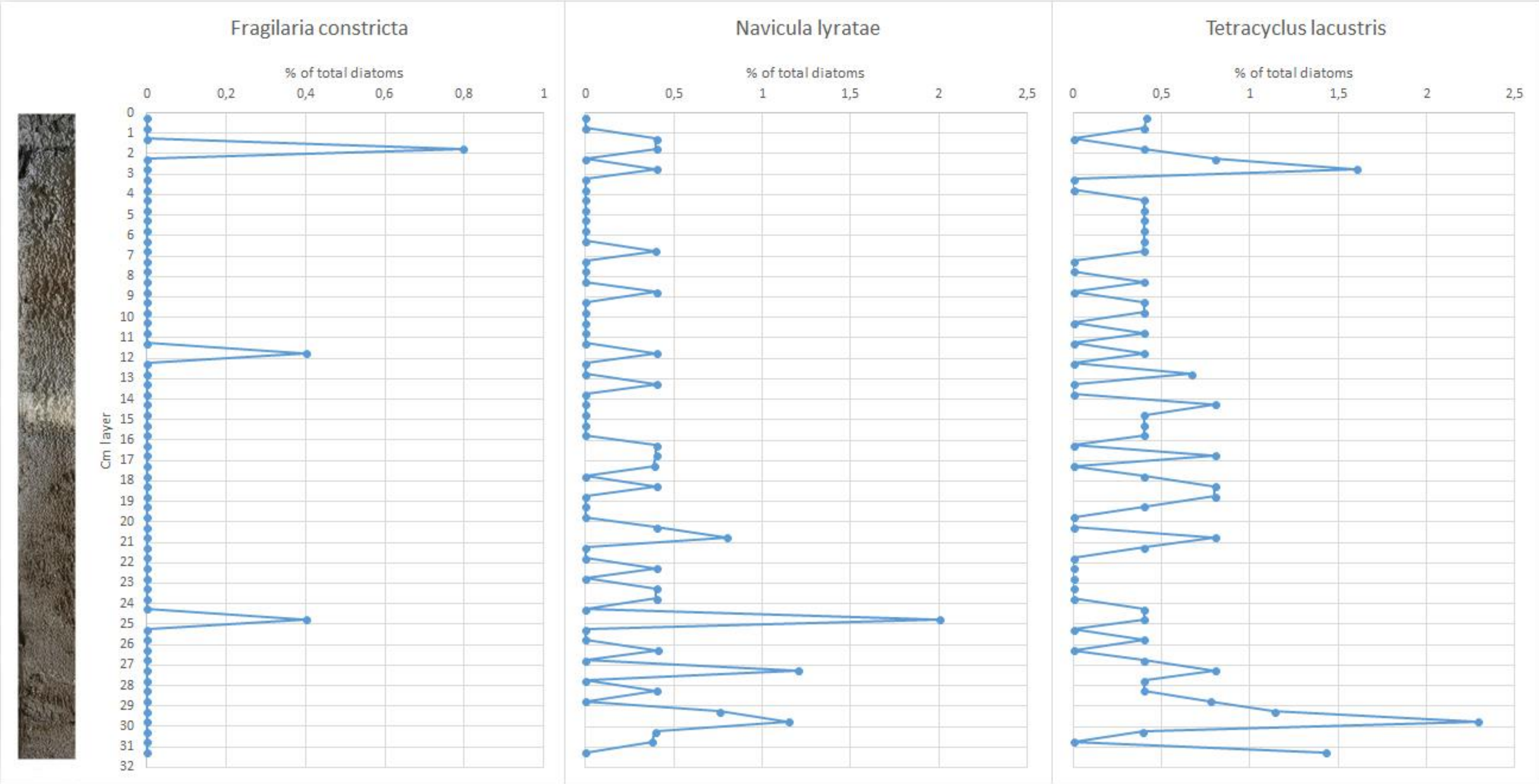
Abundancies of Cribrostomoides crassimargo, Nonionella labradorica, other calcareous and other arenaceous in MF2017-1. Keep in mind the y-axis maxima differ compared with the y-axis maxima used in. Furthermore, the y-axis maximum of other arenaceous is heightened to 2500 individuals/10 ml sediment

Appendix VI: Abundancies of individual diatom species which have a low abundancy

Core MF2017-1

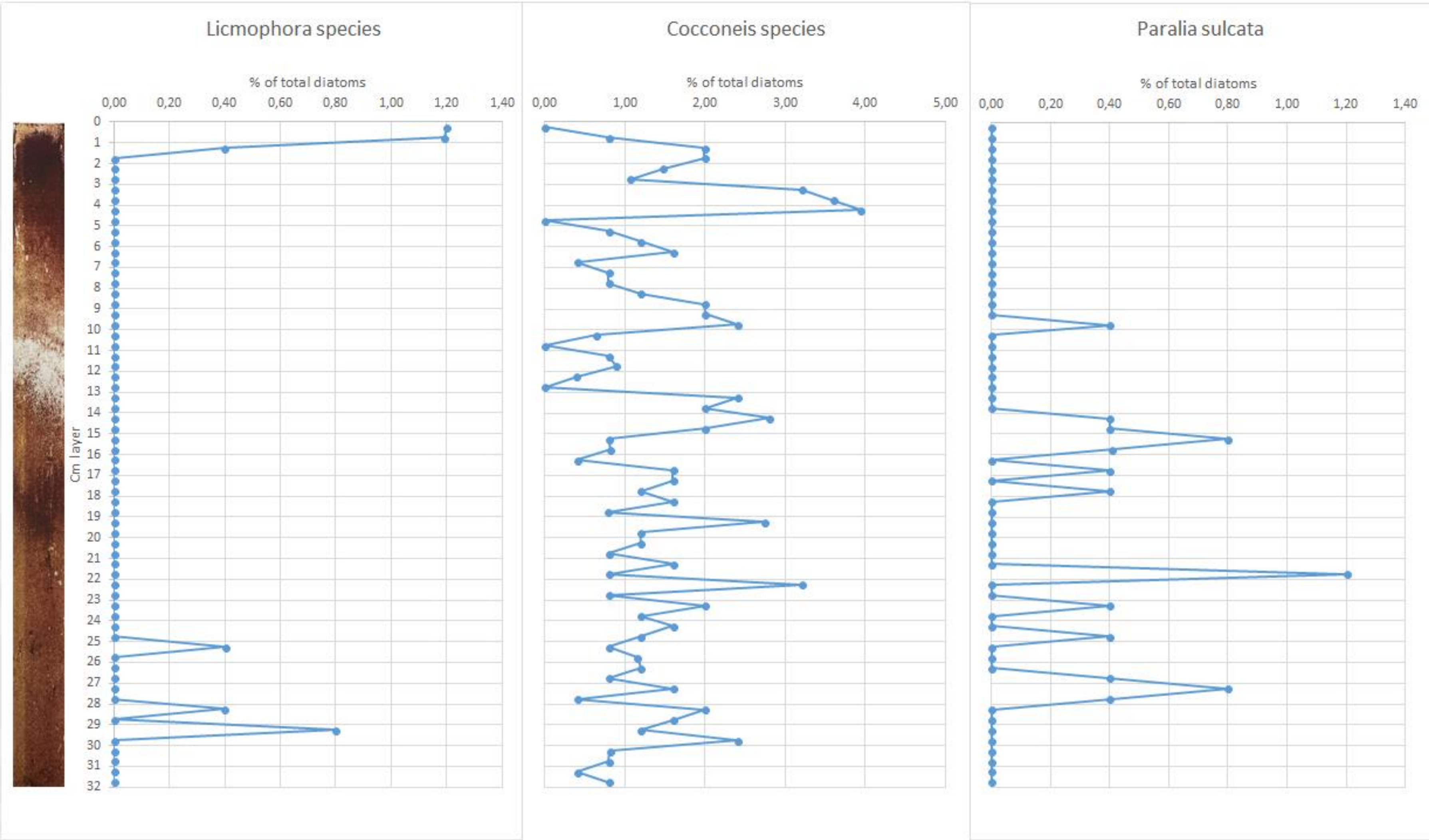


Ratio's of Licmophora species, Cocconeis species and Paralia sulcata versus all diatoms in core MF2017-1.

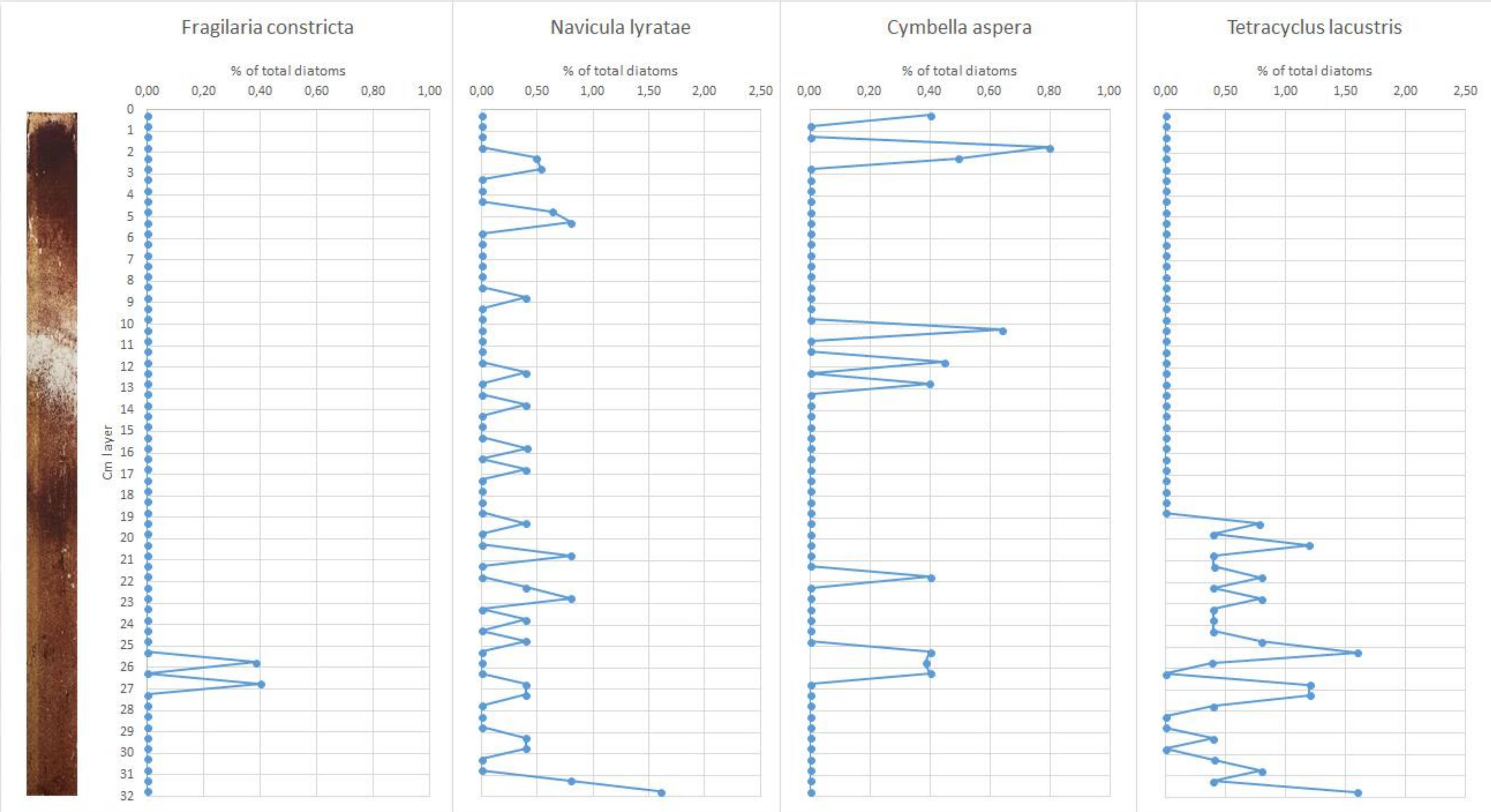


Ratio's of Fragilaria constricta, Navicula lyratae and Tetracyclus lacustris versus all diatoms in core

Core MF2017-2



Ratio's of Licmophora species, Cocconeis species and Paralia sulcata versus all diatoms in core MF2017-2



Ratio's of Fragilaria constricta, Navicula lyratae, Cymbella aspera and tetracyclus lacustris versus all diatoms in core MF2017-2

Appendix VII: SPSS results

MF2017-1

- Benthic foraminifera

Significant correlations are marked green (significance ≤ 0,05).

Correlations

		T.earlandi.S.bifo rmis	Leptohaly sis	B.margin ata	C.crassima rgo	N.labrador ica	Other.calcere ous	Other.arenace ous	S.fusifor mis
T.earlandi.S.bifo rmis	Pearson Correlation	1	,277	,561	,388	,358	,241	,422	,501
	Sig. (2-tailed)		,125	,001	,028	,044	,184	,016	,003
	N	32	32	32	32	32	32	32	32
Leptohalysis	Pearson Correlation	,277	1	,182	,507	,232	,156	,171	,775
	Sig. (2-tailed)	,125		,319	,003	,201	,393	,348	,000
	N	32	32	32	32	32	32	32	32
B.marginata	Pearson Correlation	,561	,182	1	,697	,838	,387	,890	,703
	Sig. (2-tailed)	,001	,319		,000	,000	,029	,000	,000
	N	32	32	32	32	32	32	32	32
C.crassimargo	Pearson Correlation	,388	,507	,697	1	,780	,233	,793	,843
	Sig. (2-tailed)	,028	,003	,000		,000	,199	,000	,000
	N	32	32	32	32	32	32	32	32
N.labradorica	Pearson Correlation	,358	,232	,838	,780	1	,328	,838	,721
	Sig. (2-tailed)	,044	,201	,000	,000		,067	,000	,000
	N	32	32	32	32	32	32	32	32
Other.calcereou s	Pearson Correlation	,241	,156	,387	,233	,328	1	,062	,384

	Sig. (2-tailed)	,184	,393	,029	,199	,067		,736	,030
	N	32	32	32	32	32	32	32	32
Other.arenaceous	Pearson Correlation	,422	,171	,890	,793	,838	,062	1	,657
	Sig. (2-tailed)	,016	,348	,000	,000	,000	,736		,000
	N	32	32	32	32	32	32	32	32
S.fusiformis	Pearson Correlation	,501	,775	,703	,843	,721	,384	,657	1
	Sig. (2-tailed)	,003	,000	,000	,000	,000	,030	,000	
	N	32	32	32	32	32	32	32	32

For the organic carbon test, cases after 1970 are selected

Correlations

		T.earlandi.S.biformis	Leptohalysis	B.marginata	C.crassimargo	N.labradorica	Other.calcereous	Other.arenaceous	S.fusiformis	Organic.carbon
Organic.carbon	Pearson Correlation	,636	,338	,398	,543	,413	-,092	,111	,506	1
	Sig. (1-tailed)	,001	,062	,033	,005	,028	,342	,311	,008	
	N	22	22	22	22	22	22	22	22	22

- Freshwater and marine diatoms

Significant correlations are marked green (significance ≤ 0,05).

Marine species

Correlations

		Skeletonema.costatum	Chaetoceros.sp	Round.sp	Thalassiosira.nordenskiöldii
Skeletonema.costatum	Pearson Correlation	1	-,386	-,741	-,483
	Sig. (2-tailed)		,002	,000	,000
	N	63	63	63	63
Chaetoceros.sp	Pearson Correlation	-,386	1	,089	,125
	Sig. (2-tailed)	,002		,488	,329
	N	63	63	63	63
Round.sp	Pearson Correlation	-,741	,089	1	,478
	Sig. (2-tailed)	,000	,488		,000
	N	63	63	63	63
Thalassiosira.nordenskiöldii	Pearson Correlation	-,483	,125	,478	1
	Sig. (2-tailed)	,000	,329	,000	
	N	63	63	63	63

Freshwater species

Correlations

		Eunotia.sp	Tabellaria.flocculosa
Eunotia.sp	Pearson Correlation	1	,195
	Sig. (2-tailed)		,125
	N	63	63
Tabellaria.flocculosa	Pearson Correlation	,195	1
	Sig. (2-tailed)	,125	
	N	63	63

Correlations with organic carbon (all centimetre layers included)

Correlations

		Eunotia.sp	Tabellaria.flocculosa	Total.marine	Total.freshwater	Skeletonema.costatum	Chaetoceros.sp	Round.sp	Thalassiosira.nordenskiöldii	Organic.carbon
Organic.carbon	Pearson Correlation	,025	,065	,043	,105	-,209	,072	,286	,364	1
	Sig. (1-tailed)	,424	,307	,368	,207	,050	,286	,011	,002	
	N	63	63	63	63	63	63	63	63	63

Correlations with organic matter (centimetre layers > 5,25 and < 17,25 excluded)

Correlations

		Organic.carbon	Eunotia.sp	Tabellaria.flocculosa	Total.marine	Total.freshwater	Skeletonema.costatum	Chaetoceros.sp	Round.sp	Thalassiosira.nordenskiöldii
Organic.carbon	Pearson Correlation	1	,149	,157	-,224	,171	-,654	,028	,534	,284
	Sig. (1-tailed)		,185	,173	,088	,152	,000	,433	,000	,042
	N	38	38	38	38	38	38	38	38	38

MF2017-2

- Benthic foraminifera

Significant correlations are marked green (significance ≤ 0,05).

Correlations

		S.fusiformis	T.earlandi.S.biformis	Leptohalysis	B.marginata	C.crassimargo	N.labradorica	Other.calcereous	Other.arenaceous
S.fusiformis	Pearson Correlation	1	,713	,534	,909	,841	,920	,774	,780
	Sig. (2-tailed)		,000	,002	,000	,000	,000	,000	,000
	N	32	32	32	32	32	32	32	32
T.earlandi.S.biformis	Pearson Correlation	,713	1	,291	,791	,803	,730	,908	,841
	Sig. (2-tailed)	,000		,106	,000	,000	,000	,000	,000
	N	32	32	32	32	32	32	32	32
Leptohalysis	Pearson Correlation	,534	,291	1	,402	,250	,445	,197	,287
	Sig. (2-tailed)	,002	,106		,023	,167	,011	,280	,111
	N	32	32	32	32	32	32	32	32
B.marginata	Pearson Correlation	,909	,791	,402	1	,884	,930	,820	,850
	Sig. (2-tailed)	,000	,000	,023		,000	,000	,000	,000
	N	32	32	32	32	32	32	32	32
C.crassimargo	Pearson Correlation	,841	,803	,250	,884	1	,763	,824	,779
	Sig. (2-tailed)	,000	,000	,167	,000		,000	,000	,000
	N	32	32	32	32	32	32	32	32
N.labradorica	Pearson Correlation	,920	,730	,445	,930	,763	1	,784	,788
	Sig. (2-tailed)	,000	,000	,011	,000	,000		,000	,000

	N	32	32	32	32	32	32	32	32
Other.calcereous	Pearson Correlation	,774	,908	,197	,820	,824	,784	1	,862
	Sig. (2-tailed)	,000	,000	,280	,000	,000	,000		,000
	N	32	32	32	32	32	32	32	32
Other.arenaceous	Pearson Correlation	,780	,841	,287	,850	,779	,788	,862	1
	Sig. (2-tailed)	,000	,000	,111	,000	,000	,000	,000	
	N	32	32	32	32	32	32	32	32

For the organic carbon test, cases after 1970 are selected

Correlations

		S.fusiformis	T.earlandi.S.biformis	Leptohalysis	B.marginata	C.crassimargo	N.labradorica	Other.calcereous	Other.arenaceous	Organic.carbon
Organic.carbon	Pearson Correlation	,781	,398	,074	,691	,528	,571	,667	,417	1
	Sig. (1-tailed)	,000	,046	,382	,001	,010	,005	,001	,038	
	N	19	19	19	19	19	19	19	19	19

- Freshawter and marine diatoms

Significant correlations are marked green (significance ≤ 0,05).

Marine species

Correlations

		Skeletonema.costatum	Round.sp	Thalassiosira.nordenskiöldii	Chaetoceros.sp
Skeletonema.costatum	Pearson Correlation	1	-,851	-,068	-,004
	Sig. (2-tailed)		,000	,592	,975
	N	64	64	64	64
Round.sp	Pearson Correlation	-,851	1	-,065	-,124
	Sig. (2-tailed)	,000		,610	,331
	N	64	64	64	64
Thalassiosira.nordenskiöldii	Pearson Correlation	-,068	-,065	1	,229
	Sig. (2-tailed)	,592	,610		,069
	N	64	64	64	64
Chaetoceros.sp	Pearson Correlation	-,004	-,124	,229	1
	Sig. (2-tailed)	,975	,331	,069	
	N	64	64	64	64

Freshwater species

Correlations

		Eunotia.sp	Tabellaria.flocculosa
Eunotia.sp	Pearson Correlation	1	,104
	Sig. (2-tailed)		,414
	N	64	64
Tabellaria.flocculosa	Pearson Correlation	,104	1
	Sig. (2-tailed)	,414	
	N	64	64

Correlations with organic carbon

		total.marine	total.freshwater	skeletonema.costatum	round	Thalassiosira.nordenskiöldii	Chaetoceros.sp	Eunotia.sp	Tabellaria
Organic.carbon	Pearson Correlation	-,255	,518	-,404	,442	-,082	-,226	,273	,404
	Sig. (1-tailed)	,022	,000	,001	,000	,261	,038	,015	,001
	N	63	63	63	63	63	63	63	63

Correlations with organic carbon (centimetre layers >4,75 and <15,25 excluded)

		total.marine	total.freshwater	skeletonema.costatum	round	Thalassiosira.nordenskiöldii	Chaetoceros.sp	Eunotia.sp	Tabellaria
Organic.carbon	Pearson Correlation	-,385	,458	-,617	,617	-,207	-,268	,015	,465
	Sig. (1-tailed)	,005	,001	,000	,000	,092	,041	,463	,001
	N	43	43	43	43	43	43	43	43