Interpretation of environmental changes in a long sediment core from the Sogndalsfjord, Western Norway, using benthic foraminifera as the environmental proxy

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Master Thesis in Climate Change Management

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Western Norway University of Applied Sciences

Interpretation of environmental changes in a long sediment core from the Sogndalsfjord, Wester Norway, using benthic foraminifera as the environmental proxy

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This thesis is a part of the master's program in Climate Change Management (Planlegging for klimaendringer) at the Department of Environmental Sciences, Faculty of Engineering and Science at the Western Norway University of Applied Sciences. The author(s) is responsible for the methods used, the results that are presented and the conclusions in the thesis.

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Preface

This thesis marks the end of my time as a master's student in Climate Change Management at Western Norway University of Applied Science (HVL). Although this thesis was not the initial direction I was going for, I am still grateful for saying yes to the sediment core and all that followed, good and bad. It has definitely been challenging at times due to my initial lack of experience with sedimentology, hydrology, glaciology, and most of all, benthic foraminifera.

I would therefore like to thank my superior supervisors, Marianne, Matthias and Torbjørn, for their excellent guidance, patience, and support during this process. You have all been very helpful, dedicated and, always available. I also wish to thank Laurien De Korte for cooperation in the lab and outside of the lab.

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Abstract

This study was conducted on a 291 cm long sediment core, dated to approximately 10.800 cal. BP, collected from the Sogndalsfjord. The aim of this study is to describe the past environmental conditions in the Sogndalsfjord, using the benthic foraminifera community as the environmental proxy. This was done by identify and describe the depth distribution of the foraminifera assemblages in the sediment core together with sediment properties. No previous studies in the fjord have analysed benthic foraminifera assemblages on such a long sediment core. Foraminifera assemblages and loss-in-ignition results suggests that oxygen has been continuously present, and that deep-water renewal has persisted at site throughout the core age. The changes observed in concentration of benthic foraminifera in the samples are rather explained by different sedimentation rates, then environmental stress. A higher resolution of the samples would perhaps yield more precise ecological information from the foraminifera assemblages.

Samandrag på norsk

Denne studien ble utført på en 291 cm lang sedimentkjerne, datert til omtrent 10 800 cal. BP, hentet fra Sogndalsfjorden. Målet med denne studien er å beskrive de tidligere miljøforholdene i Sogndalsfjorden, ved å bruke de bentiske foraminifera samfunnene som miljøproxy. Dette ble gjort ved å identifisere og beskrive dybdefordelingen av foraminifera-sammensetningene i sedimentkjernen sammen med sedimentegenskaper. Ingen tidligere studier i fjorden har analysert bentiske foraminifera på en så lang sedimentkjerne. Foraminifera-sammensetninger og glødetap antyder at oksygen kontinuerlig har vært til stede, og at fornyelse av bassengvannet har vedvaret på stedet gjennom kjernealderen. Endringene observert i konsentrasjon av bentiske foraminifera i prøvene forklares heller ved forskjellige sedimenteringshastigheter, enn miljøbelastning. En høyere oppløsning av prøvene vil kanskje gi mer presis økologisk informasjon fra foraminifera -samlingene.

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Table of contents

Preface I
Abstract II
Samandrag på norsk II
Table of contents III
Table of figures IV
Table of tables VI
1. Introduction 7
2. Study area & environmental settings 10
2.1 Study area 10
2.2 Holocene climate history 10
2.3 Fjord circulation 11
2.4 Present Hydrography 13
3. Materials & methods 15
3.1 Sampling design 15
3.2 Sediment dating and sedimentation rate 16
3.3 Sediment analysis of organic matter 16
3.4 Foraminifera analyses 17
3.5 Data analysis 19
4. Results 21
4.1 Sediment dating and sedimentation rate 21
4.2 Sediment analysis of organic matter 22
4.3 Planktonic foraminifera 23
4.4 Benthic foraminifera assemblages 23
4.4.1. Dominant species distribution 27
4.5 Relationship between species 29
5. Discussion 30
5.1 Limitations and justification of methodological choices 30
5.2 Environmental history 31
5.2.1 Determining the age of the core 31
5.2.2 Oxygen 33

5.2.3 *Bulimina marginata* dominated samples 34
5.2.4 *Hyalinea balthica* dominated samples 36
5.2.5 *Cassidulina laevigata* dominated samples 38
5.3.6 *Lobatula lobatula* dominated samples 40
6. Conclusion 41
7. References 42
8. Appendix 49
Appendix A 49
Appendix B 53
Appendix C 59
Appendix D 60
Appendix E 65
Appendix F 85
Appendix G 86

Table of figures

Figure 1. (a) position of the study area; (b) overview of the Sogndalsfjord area showing the approximate extent of the Sogndalsfjord highlighted in blue. 10
Figure 2. Map of the Norwegian Sea with circulation pattern of the water over the shelf from "The Norwegian Coast Current" by . AW= Atlantic water, NCC= Norwegian Coastal Current. 12
Figure 3. The three water layers of a Norwegian Fjord. From "Multi-decade warming of Atlantic water and associated decline of dissolved oxygen in the deep fjord", by Aksnes et al. 2019, Estuarine, Coastal and Shelf Science, 228. 13
Figure 4. (a) position of study area; (b) overview of the Sogndalsfjord area showing profile line (white line) and approximate location of where the core was retrieved from (red dot); (c) bathymetrical profile of the Sogndalsfjord and the Barsnesfjord, with water depth and sediment thickness, and approximate core location (red) after "Climate proxies for recent fjord sediments in the inner Sognefjord region, western Norway," by M. Paetzel & T. Dale, 2010, Geological Society, London, Special Publications 344. 15
Figure 5. The calibration curve. Y-axis showing the reservoir connected ^{14}C age, and x-axis presenting the calibrated age in BP. 21
Figure 6. Percent loss-on-ignition, bromine (Br/Fe), and magnetic susceptibility throughout the core, together with a high-resolution imaging of the core (Core image, Bromine, and magnetic susceptibility graphs: Courtesy of Matthias Paetzel, pers. comm). Light blue highlight area indicating the sand layer, red dashed line indicate the sample where the shell, presumed Acesta excavata, was found. 22
Figure 7. Relative abundance of planktonic foraminifera in relation to calcareous benthic foraminifera (black line; left y-axis), and planktonic specimens per 10 ml sediments (dotted line; right y-axis). 23

Figure 8. Total abundance of both calcareous (black line) and agglutinated (dotted line) foraminifera per 10 ml. 24
Figure 9. Species richness (dotted line; left y-axis) and the Shannon-Wiener Diversity Index values (black line; left y-axis) throughout the core. 24
Figure 10. Calcareous benthic foraminifera occurring >5 % in at least 1 sample with original references: 1. Bulimina marginata (d'Orbigny, 1826), 2. Cassidulina laevigata (d'Orbigny, 1826), 3. Cassidulina obtusa (Williamson, 1858), 4. Cibicidoides sp. 5 (genus: Thalmann, 1939), 5. Cibicidoides sp. 6 (genus: Thalmann, 1939), 6. Cassidulina sp. 1 (genus: d'Orbigny, 1826), 7. Globobulimina turgida (Bailey, 1851), 8-9. Hoeglundina elegans (d'Orbigny, 1826), and 10. Chilostomella oolina (Schwager, 1878). Photos taken by author. 25
Figure 11. Calcareous benthic foraminifera occurring >5 % in at least 1 sample with original references, continued: 1. Hyalinea balthica (Schröter, 1783), 2. Nonionoides turgidus (Williamson, 1858), 3. Nonionellina labradorica (Dawson, 1860), 4-5. Lobatula lobatula (Fleming, 1828), 6. UN-ID 33, 7. Trifarina angulosa (Williamson, 1858), 8. Stainforthia fusiformis (Williamson, 1858), 9. UN-ID 34, and 10. UN-ID 20. Photos taken by author. 26
Figure 12. Absolute abundance per 10 ml sediment (dotted line; top x-axis) and relative abundance (black line; bottom x-axis) of the dominant species, occurring >10 % in at least one sample, versus depth (cm; y-axis). From top left to bottom right: Bulimina marginata, Hyalinea balthica, Cassidulina laevigata, Lobatula lobatula, Trifarina angulosa, Nonionellina labradorica, Globobulimina turgida, and Nonionoides turgidus. 28
Figure 13. Diagram of the relationships between the most common species: Bulimina marginata, Cassidulina laevigata, Nonionoides turgidus, Nonionellina labradorica, and Lobatula lobatula. Blue dashed line= negative relationship, and green line= positive relationship (Only significant relationships) 29
Figure 14. Temporal Distribution of, from left to right, loss-on-ignition (LOI), Bromine (Br), magnetic susceptibility, concentration of benthic foraminifera per 10 ml (Black line= calcareous benthic foraminifer, black dashed line= agglutinated benthic foraminifera), planktonic foraminifera (Black line= relative abundance, black dashed line= absolute abundance), diversity (H_{log2}), and Bulimina marginata (Black line= relative abundance, dashed line= absolute abundance). Red dashed line= approximate location of bivalve shell, blue line= the sand layer, and yellow boxes= samples Bulimina marginata dominates. Bromine (Br) and Magnetic susceptibility graphs Courtesy Matthias Paetzel (2021) pers. comm. 36
Figure 15. Temporal Distribution of, from left to right, percent loss-on-ignition (LOI), Bromine (Br), magnetic susceptibility, concentration of benthic foraminifera per 10 ml (Black line= calcareous benthic foraminifer, black dashed line= agglutinated benthic foraminifera), planktonic foraminifera (Black line= relative abundance, black dashed line= absolute abundance), diversity (H_{log2}), and Hyalinea balthica (Black line= relative abundance, dashed line= absolute abundance). Red dashed line= approximate location of bivalve shell, blue line= the sand layer, and green boxes= samples Hyalinea balthica dominates. Bromine (Br) and Magnetic susceptibility graphs Courtesy Matthias Paetzel (2021) pers. comm. 38
Figure 16. Temporal Distribution of, from left to right, percent loss-on-ignition (LOI), Bromine (Br), magnetic susceptibility, concentration of benthic foraminifera per 10 ml (Black line= calcareous benthic foraminifer, black dashed line= agglutinated benthic foraminifera), planktonic foraminifera (Black line= relative abundance, black dashed line= absolute abundance), diversity (H_{log2}), and Cassidulina laevigata (Black line= relative abundance, dashed line= absolute abundance). Red dashed line= approximate

location of bivalve shell, blue line= the sand layer, and orange boxes= samples Cassidulina laevigata dominates. Bromine (Br) and Magnetic susceptibility graphs Courtesy Matthias Paetzel (2021) pers. comm. 39
Figure 17. Temporal Distribution of, from left to right, percent loss-on-ignition (LOI), Bromine (Br), magnetic susceptibility, concentration of benthic foraminifera per 10 ml (Black line= calcareous benthic foraminifer, black dashed line= agglutinated benthic foraminifera), planktonic foraminifera (Black line= relative abundance, black dashed line= absolute abundance), diversity (H_{log2}), and Lobatula lobatula (Black line= relative abundance, dashed line= absolute abundance). Red dashed line= approximate location of bivalve shell, blue line= the sand layer, and red box= samples lobatula lobatula dominates. Bromine (Br) and Magnetic susceptibility graphs Courtesy Matthias Paetzel (2021) pers. comm 40

Table of tables

Table 1. Overview of analysed samples, number of counted benthic and planktonic foraminifera, and number of objects larger than 2 mm. 19
Table 2. Results from the ^{14}C calibration. Showing the cal BP age ranges for 1 sigma and 2 sigma, and the median probability..... 21

1. Introduction

Marine ecosystems worldwide are subjected to increasing environmental pressures caused by human activities (e.g.,Breitburg et al., 2018; IPCC, 2019; Naser, 2013). As a response, many nations have passed legislations with the aim to restore and prevent further deterioration of the marine ecosystems. In Europe this included the establishment of the Water Framework Directive (WFD; Directive 2000/60/EC; European Commission, 2000) and the Marine Strategy Framework Directive (MSFD; Directive 2008/56/EC; European Commission, 2008), with the common goal of achieving and maintain good environmental and ecological status in European waters. To accomplish this, knowledge of past environmental conditions (reference conditions) is of great relevance in distinguishing between naturally and anthropogenically induced changes observed in marine environments (European Commission, 2000, 2008). However, in most areas, information on past conditions is still unknown or scarce.

Defining the state of marine environments is often complicated by the natural variabilities. In Norway, waterbodies are grouped according to ecoregions and water types to account for some of these variabilities (Direktoratsgruppen vanndirektivet, 2018). Still, the reference conditions related to different ecological parameters in most Norwegian fjords are unknown, and estimations are based on broad averages (Direktoratsgruppen vanndirektivet, 2018). Fjords exhibit very different natural hydrographic conditions in regard to the geographic region, the amount of freshwater input, and other factors such as sill depth and frequency of basin water renewal (Gade, 2004; Gade & Edwards, 1980). Consequently, even with the initial “typification,” significant differences may occur.

Benthic foraminifera (protists) have been found very useful in reflecting *in situ* environmental conditions, due to their high abundance, short life cycles, and specific environmental preferences (Bouchet et al., 2012; Murray, 2006; Schönfeld et al., 2012). Furthermore, their tests (shells) are preserved in the sediments when they die, enabling the reconstruction of past environmental conditions. In natural environments, the distributions of benthic foraminifera are mainly affected by bottom water temperature and salinity, nutrient availability, oxygen concentrations, and the type of substrate (Murray, 2006).

The use of benthic foraminifera as marine environmental indicators dates back to the 1960s (Schönfeld et al., 2012), and have since then been increasingly studied with the aim of improving the usefulness of this group in bio-monitoring e.g., Alve (2003), Schönfeld et al. (2012), Dijkstra et al. (2013), Dolven et al. (2013), Alve et al. (2016), Dimiza et al. (2016), and Bouchet et al. (2018). However, in comparison with the more conventional use of benthic macrofauna, the use of benthic foraminifera as environmental indicators is less established (Schönfeld et al., 2012). As a response, a group of international scientists established the

FOraminiferal BIo-MOnitoring (FOBIMO) working group, with the aim to develop and standardise methods to establish benthic foraminifera in bio-monitoring (Schönfeld et al., 2012). Since then, a protocol with standardised sampling and sampling treatment methods have been developed (Schönfeld et al., 2012). Furthermore, an adaptation of the AZTI's marine biotic index (AMBI;Borja et al., 2000), Foram-AMBI, has been explored by members of the FOBIMO group, using benthic foraminifera as the environmental indicator (Alve et al., 2016). The advances in developing a biotic index, using benthic foraminifera, will make it possible to accurately define both the present ecological quality status and the pre-impacted ecological quality status (reference condition) at a given site (Alve et al., 2016; Bouchet et al., 2012; Dolven et al., 2013). Furthermore, Bouchet et al. (2018) conducted a study investigating the suitability of using fossilized benthic foraminifera as indicators of reference conditions for benthic macrofauna. However, more knowledge on the species response to environmental stress gradients, is still needed, and more species need to be assigned (Alve et al., 2016; Bouchet et al., 2018).

Although several studies in Norwegian fjords have been conducted using benthic foraminifera e.g., Kirkhus (1980), Alve & Nagy (1986), Alve (1991), Mikalsen et al. (2001), Husum & Hald (2004), and Dolven et al. (2013), only two studies are found to have been performed in the Sogndalsfjord (Grønning, 1983; Mikalsen et al., 1999). Furthermore, no previous studies in the fjord have analysed benthic foraminifera assemblages on such a long sediment core (291 cm). As a result, this thesis aims to define the past environmental conditions in the Sogndalsfjord, using predominantly the benthic foraminifera community as the environmental proxy. Furthermore, this study seeks to contribute to the current species knowledge in response to natural environmental changes, which can be useful in future management in relation to climate. One overall objective was established to answer the overall aims:

- Describe past environmental conditions/ changes in the Sogndalsfjord, both in terms of the variations in the benthic foraminifera faunal distribution and sediment properties.

The objectives were accomplished by:

a) Identify and describe the depth distribution of the foraminifera assemblages in the sediment core, i.e., concentration of benthic foraminifera, planktonic foraminifera, diversity, and dominant species.
b) Characterization of sediment properties, i.e., dating of the sediments, sediment accumulation rate, and organic matter (loss-on-ignition and bromine) and inorganic material (magnetic susceptibility).

c) Investigating relationships between selected benthic foraminifera species (species occurring more than 10 % in at least one sample)

This thesis will increase our understanding of past environmental conditions in the Sogndalsfjord. Furthermore, with expected higher temperatures and increased precipitation (Hanssen-Bauer et al., 2017) coupled with pollution from human activities, this study may facilitate in distinguishing between naturally or anthropogenically induced changes potentially observed in future bio-monitoring.

2. Study area & environmental settings

2.1 Study area

The Sogndalsfjord is a tributary fjord of the Sognefjord, located in Sogndal municipality in Vestland county, Norway (Figure 1). The fjord extends from the outlet of the Barsnesfjord and about 11 km southwest to Fimreite, where a sill area of 25-26 m water depth separates the Sogndalsfjord and the Sognefjord. Further inwards from the sill, the depth in the Sogndalsfjord increases to its deepest point at 260 m (Dale & Hovgaard, 1993; Grønning, 1983).

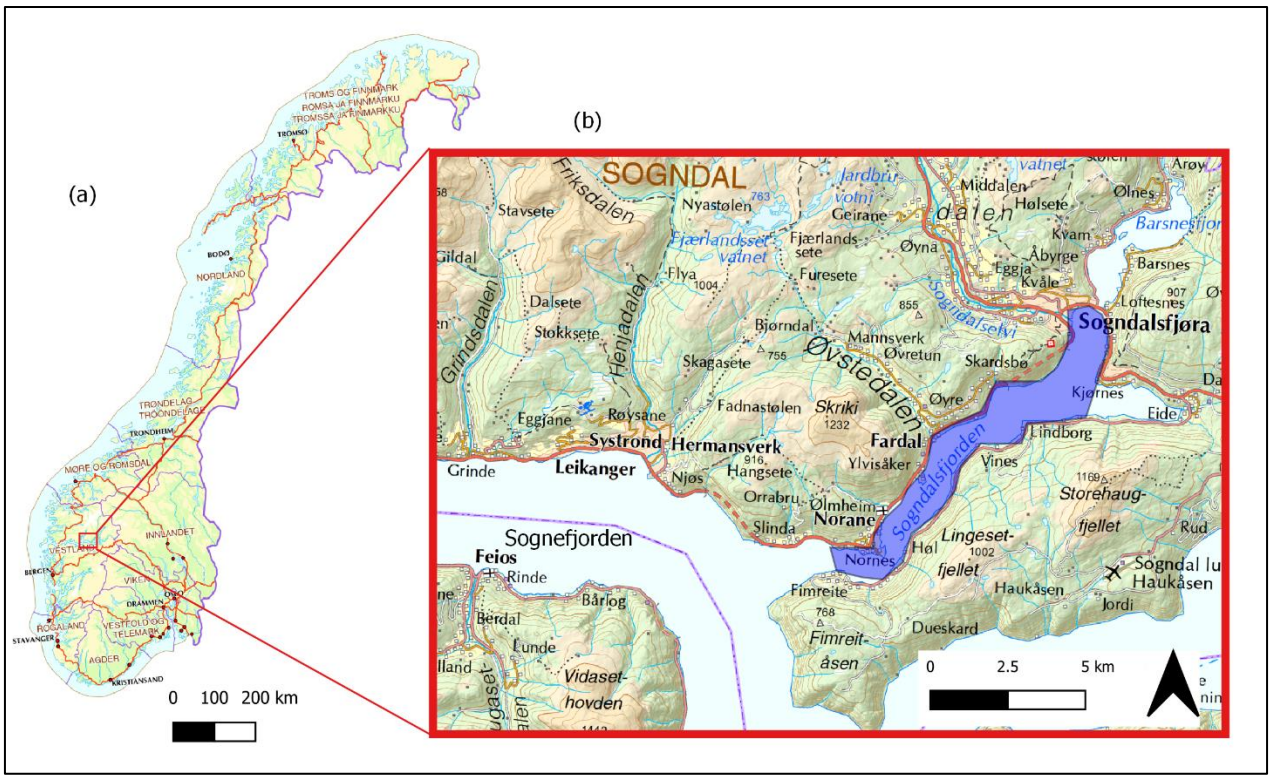

Figure 1. (a) position of the study area; (b) overview of the Sogndalsfjord area showing the approximate extent of the Sogndalsfjord highlighted in blue.

2.2 Holocene climate history

After the Last Glacial Maximum (24.000 to 22.000 BP; (Mangerud, 2004), the ice front retreated to the Norwegian mainland, re-advancing during the Younger Dryas towards the Norwegian coast. According to Anderson et al. (1995), the Younger Dryas re-advance started between 11.500 and 11.200 BP and reached its maximum extent between 10.499 to 10.300 BP. This Younger Dryas maximum extent is

represented in the Sognefjord area by the northern continuation of the Herdla end moraine at the entrance of the Sognefjord (Mangerud, 2004). Since 10.300 BP the ice retreated from the coast further inland (Aa, 1982; Bergstrøm, 1971; Vorren, 1973), leaving the mouth of the Sogndalsfjord at Fimreite ice free around 9.749 ± 120 BP (Aa, 1982). Note that the dating of Aa (1982) is not calibrated; the calibration would correspond to 10.xxx BP, corresponding to a minimum age of the ice-free conditions at Fimreite. Additionally, relative sea-level was higher than at present, after the last glaciation, due to the land still being glacio-isostatically depressed (Bondevik et al., 1997). In the Sogndalsfjord, the sea-level was as high as 120 m above present sea-level (Aa, 1982).

On a larger scale, the paleoclimate has varied considerably during the Holocene, although with a smaller amplitude than the extreme fluctuations of the glacials (Hald et al., 2007). There are several known warming and cooling periods, or events, throughout the Holocene, among them:

- The Holocene climate optimum was a remarkably warm period from approximately 9.000 to about 5.000-6.000 years BP, in northern mid- to high latitudes, with its thermal maximum around 8.000 years BP (Vinther et al., 2009; Wanner et al., 2008).
- The 8.2-kiloyear event was a short-lived cold interval, which is the largest abrupt climatic event in the past 10.000 years, and took place approximately 8.200 years ago (Kobashi et al., 2007). In Norway, this is better known as the Finse event, where evidence of decreased loss-on-ignition, have been recorded from lacustrine sediments in southern Norway (e.g., (Nesje & Dahl, 2001).
- The Medieval warming period (MWP) was as the name suggests a warm period roughly corresponding with the Middle Ages in Europa, likely consisting of three relatively short-lived warming intervals, that are comparable to the mid-20th century warming (Crowley & Lowery, 2000).
- The Little Ice Age, followed by the MWP, is the most recent and the most prominent of the periods of glacier advance during the Late Holocene (Wanner et al., 2008), and is one of the coldest periods since the onset of the Holocene (Bradley et al., 2003). Evidence from glacial advance during this period have been identified in all parts of the world, and lasted from 1300 to 1850 AD, where most glaciers reached their maximum advance in the eighteenth century in Eurasia (Grove, 2004).

2.3 Fjord circulation

The water characteristics of Western Norwegian fjords are coupled with those of the adjacent shelf (Murray & Alve, 2016, p. 219). The Norwegian coast is mainly influenced by the Atlantic Water, in the

Norwegian Atlantic Current (salinity >35), and the Norwegian coastal current (salinity ≤32; Figure 2; (Sætre, 2007). Along the western Norwegian coast, the depth of the sill(s) and the density distribution of the coastal water masses, together with wind and tides, control whether the water entering a fjord is from the NCC or Atlantic Water (Aure et al., 2007; Murray & Alve, 2016).

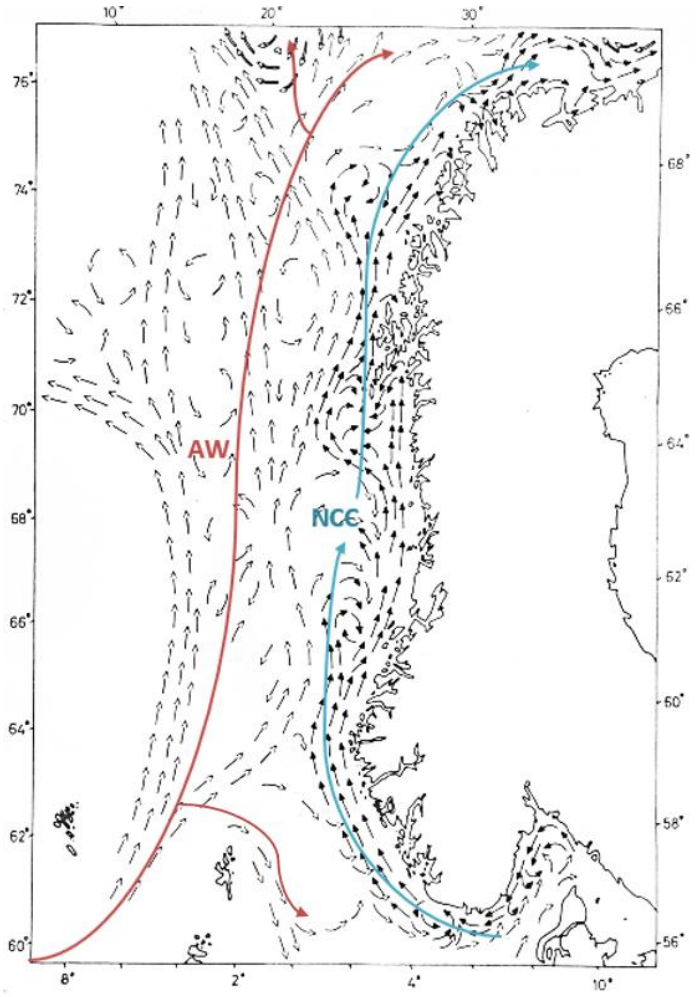

Figure 2. Map of the Norwegian Sea with circulation pattern of the water over the shelf from "The Norwegian Coast Current" by Sætre & Ljøen, 1971 . AW= Atlantic water, NCC= Norwegian Coastal Current.

The hydrographic conditions in western Norwegian fjord are characterised by typical estuarine circulation where the water column is stratified consisting of three layers (Figure 3; Aksnes et al., 2019; Sætre, 2007): (1) the surface layer, or the brackish water, formed by the mixing of freshwater runoff and seawater, which moves out of the fjord; (2) the intermediate layer, which extends to the depth of the sill, largely containing NCC water, and depending on the sill depth, also Atlantic Water; (3) and the basin water, bellow the sill depth, containing NCC, Atlantic Water, or a combination of both, depending on the sill depth. The dissolved oxygen concentration in the basin water is governed by the frequency of water exchange from

the denser oxygen rich water from the shelf (NCC or Atlantic Water; (Aksnes et al., 2019; Sætre, 2007). The deeper water in a shallow-silled fjord is likely to become oxygen-poor or even anoxic, without a source of oxygen resupply to the basin water (Sen Gupta & Machain-Castillo, 1993).

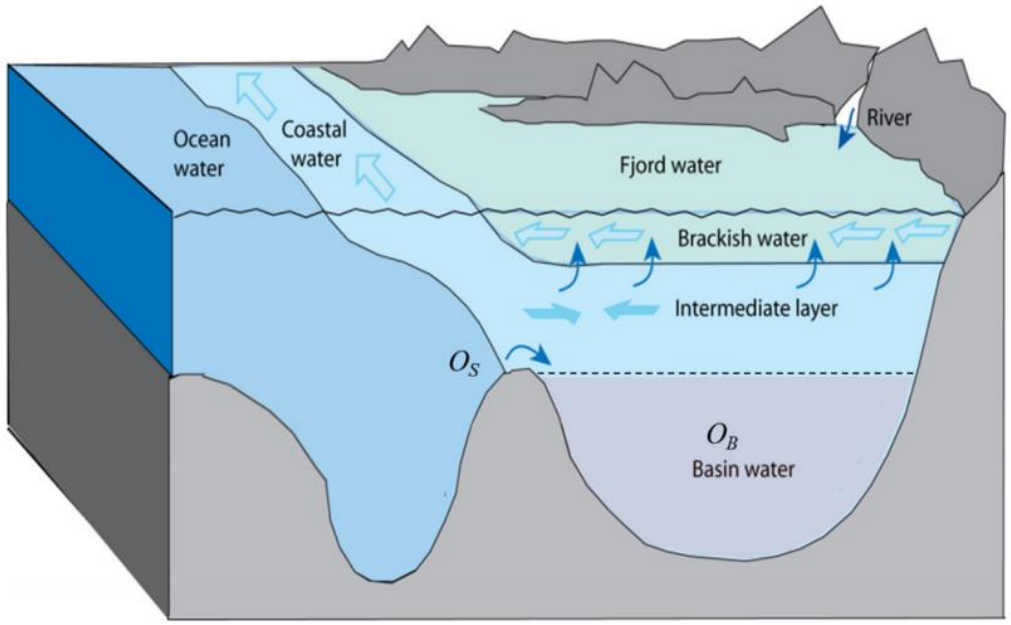

Figure 3. The three water layers of a Norwegian Fjord. From "Multi-decade warming of Atlantic water and associated decline of dissolved oxygen in the deep fjord", by Aksnes et al. 2019, Estuarine, Coastal and Shelf Science, 228.

2.4 Present Hydrography

The Sogndalsfjord is typified as a 'oxygen poor fjord', located in ecoregion North Sea (NVE, n.d.) and receives approximately 1.5 km^3 fresh water annually from the Sogndal river, the Årøy river (via the Barsnesfjord), the Fardal river, and other smaller streams (Dale & Hovgaard, 1993). The renewal of bottom waters is restricted by the sill, and the supply of oxygen to the basin water occurs by the inflow of denser oxygen rich water from the Sognefjord, and occurs approximately every 5-10 years (Dale & Hovgaard, 1993). The oxygen concentration of the basin water has significantly varied in previous studies (Johansen et al., 2007) and depends largely on the frequency of the renewal of the basin waters (Brekke et al., 2014; Dale & Hovgaard, 1993; Grieger, 2021; Johansen et al., 2007). Since the first measurements were performed in 1916, the fjord has, however, never been found anoxic (Brekke et al., 2014; Dale & Hovgaard, 1993; Grieger, 2021), however a general decrease has been observed (Grieger, 2021).

In the upper layers, the salinity varies throughout the year, while from 10 meters depth and deeper, it stays relatively stable (Dale & Hovgaard, 1993; Reß, 2015). There is a gradual mixture of more saline water

in the surface layer towards the confluence to the Sognefjord at Fimreite (Brekke et al., 2014). The temperature stays fairly stable in the bottom waters, in contrast to the upper seasonally/weather affected layers (Dale & Hovgaard, 1993). However, the average temperatures in the basin water has generally increased, in the last decades by approximately 2 degrees (Grieger, 2021; Reß, 2015).

3. Materials & methods

Detailed protocols for the treatment of the sediment cores and the identification of foraminifera can be found in Appendix A and B, respectively.

3.1 Sampling design

All the data analysed for this thesis was retrieved from a 291 cm long sediment core (ID: 03GC) sampled the 19th of June 2020 by the University of Bergen (UiB) on cruise No. GS20-299 with "R/V G.O.Sars". A standard gravity corer with a core barrel length of 320 cm and diameter of 110 mm was used to collect the sediments. The station was located in the outer part of the fjord basin (coordinated: 61°09,9133'N - 07°00,3864'E), at a water depth of 133 m (Figure 4). On the vessel, the core was cut in two sections (145.5 cm * 2) and labelled.

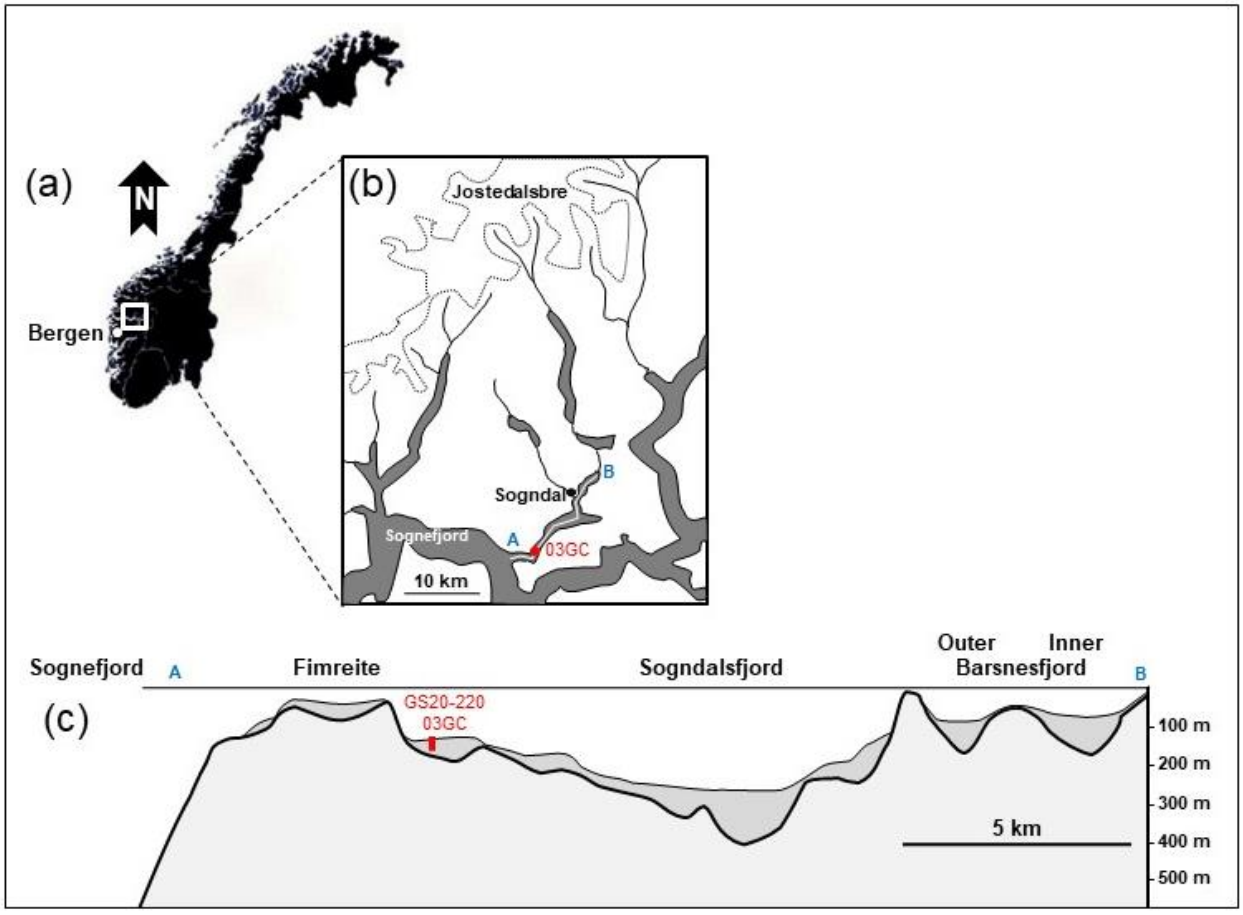

Figure 4. (a) position of study area; (b) overview of the Sogndalsfjord area showing profile line (white line) and approximate location of where the core was retrieved from (red dot); (c) bathymetrical profile of the Sogndalsfjord and the Barsnesfjord, with water depth and sediment thickness, and approximate core location (red) after "Climate proxies for recent fjord sediments in the inner Sognefjord region, western Norway," by M. Paetzel & T. Dale, 2010, Geological Society, London, Special Publications 344.

After collection, the core sections were split in half, sealed, and stored in darkness in a climate room at 4°C awaiting sampling preparation. The sampling of sediments for foraminifera analyses were made on the 23, 26, and 27th of November 2020, while the sampling of sediments for loss-on-ignition (LOI) were made the 13 and 14th of April 2021.

3.2 Sediment dating and sedimentation rate

A bivalve shell fraction, assumed to be as *Acesta excavata*, retrieved from the core depth of ~281.5 cm, was sent to Poznań Radiocarbon Laboratory, Poland, for radiocarbon (^{14}C) dating. Since the shell was retrieved from marine sediments, the ^{14}C age was calibrated using the calibration data set, marine20.14c (Heaton et al., 2020) in www.calib.org. The regional offset (ΔR = -125 +/- 47) was determined based on three samples in the Sognefjord (Mangerud, 1972; Mangerud et al., 2006) in www.calib.org/marine. This was done since the level of depletion of ^{14}C varies both spatially and temporally (Heaton et al., 2020).

An annual sedimentation rate was estimated, from the calibrated age results, assuming a linear sedimentation rate.

3.3 Sediment analysis of organic matter

An estimate of the sediment' organic content, provided as percent loss-on-ignition (LOI), was determined as the weight loss between dry weight and ash weight, expressed as percentage of dry weight. Samples of 1.6-4.7 g of wet material were extracted from the same sampling depths as the foraminifera samples. The wet material was dried at 105°C for 24h (dry weight) and subsequently burned at 550°C for 2-3h (ash weight). Since the material for organic content was collected several months after both extraction of the sediment core and the sampling for foraminifera analyses, oxidation of organic content had already started. This could result in a potential underestimation of LOI, due to oxidation. This was minimized by scraping off air exposed areas before sampling. LOI values were used to describe environmental conditions with respect to organic matter.

In addition, geochemical analyses were performed at the Earth Surface Sediment Laboratory (EARTHLAB) at UiB by Prof. Dr. Haflidi Haflidason. Magnetic susceptibility of the sediments were measured with a GEOTEK Multi Sensor Core Logger (MSCL). Magnetic susceptibility is used as an indicator of the relative amount of mineral matter in relation to organic matter, as well as an indicator of grain size, i.e., changes in sediment source (Dekkers, 1978).

The relative elemental compositions of the core was measured with a ITRAX multifunctional X-ray core scanner (XRF). The latter was also used to take high-resolution imaging of the core. From the geochemical analyses, only magnetic susceptibility, and bromine (Br) results have been used for comparison together with the LOI and the foraminifera results in this thesis.

Bromine is an indicator of marine organic matter (Ziegler et al., 2008). The Bromine values were divided by iron (Fe) to prevent the values from being masked by iron. The values were then normalized to 1 by dividing the element by its largest value. Measurements of Br stopped at 278 cm depth, consequently not including the two lowermost samples.

3.4 Foraminifera analyses

In total, 30 samples for faunal analyses were collected from different depths in the sediment core, representing different times. Due to time limitation, both sampling depths and size was determined and performed before a sedimentation rate had been established. Given preliminary assumptions, based on interpretations of the geochemical results and length of the core, a desired temporal resolution of the samples were determined. Each sample was taken at intervals of every 10 cm, consisting of 1 cm segments, with mean sample size of 9.8 ml measured volumetric. The sample that was intended at 150-151 cm depth, was incorrectly sampled at 149.5-150.5 cm. This has still been referred to as 150-151 cm, for consistency. All samples were collected at least 0.5 cm away from the tube walls to ensure that the samples taken were representative for the given depths, due to possible displacement of material along the tube walls.

The sample volumes were estimated by gently mixing the material with 20 ml water in a measuring cylinder and subtracting the 20 ml from the total volume. Subsequently, each sample was split into three fraction sizes using a standard sieve set-up consisting of four stacked sieves with mesh sizes: 63 µm, 125 µm, 250 µm, and 2 mm. The material was gently cleaned with lukewarm tap water, using a showerhead with minimum pressure to avoid damaging the fragile foraminifera tests (when the sediment would not “dissolve” in the top sieve (2 mm) with water alone, it was “dissolved” by gently using the fingertip until it would start to “dissolve” again). Clogging between the sieves became a recurring issue and was resolved by gently tapping under the bottom sieve (63 µm). The material was further transferred from the sieves into 100 ml histology beakers by backwashing the material using 75 % ethanol. Materials >2 mm were noted (Table x) and discarded. The samples were not stained. Consequently, no differentiation between

live and dead foraminifera could be made in the top sample, resulting in a total (living + dead) assemblage at this depth.

Fossilised benthic foraminifera were only quantified and identified in the intermediate (125-250 µm) and coarse (250 µm-2 mm) fractions, due to time limitations. The fine fraction (63-125 µm) has been kept for future assessment. Samples were examined wet, using a Wild M5 stereomicroscope, with both dark and bright field illumination, and an apochromatic lens. Samples were screened using a magnification at predominantly x25 and x50. A simple splitting chamber was used for splitting the fractions, manually, before counting and identifications, due to high abundance of both individuals and other particles. For the coarse fraction 50% (n=18) and 100% (n=12) of the samples were analysed, while 6.25% (n=5), 12.5% (n=22), 25% (n=2), and 34.38% (n=1) of the sample sizes were analysed for the intermediate fraction (Table 1).

A minimum of 200[1] individuals were counted for each sample for statistically viable comparison, and to assure representative samples for diversity and abundance purposes (Alve, pers. comm.). However, due to removal of agglutinated and planktonic individuals, the abundance of calcareous individuals represented for statistical analyses resulted in six samples with <200 individuals (see Table 1). The agglutinated species were omitted from statistical analyses due to the poor preservation of their tests (taphonomic processes; (Knudsen, 1998; Murray, 2006), resulting in an underrepresentation of these species down-core. Hence, agglutinated foraminifera have only been presented and discussed as total-stock. Calcareous species are also affected by taphonomic processes; however, their tests are overall well preserved in the sediments in comparison (Knudsen, 1998; Murray, 2006).

The planktonic foraminifera were used as an environmental parameter for the water masses. The percentage of planktonic foraminifera is given in relation to the total number of foraminifera in each sample (benthic calcareous + planktonic). A high percentage of planktonic foraminifera means that there was a connection to the open ocean, as planktonic foraminifera require normal marine and stable salinity (Knudsen, 1998, p. 11). Species identification of planktonic species was not performed.

[1] One exception: sample 210-211 cm had a total of 195 individuals counted.

Table 1. Overview of analysed samples, number of counted benthic and planktonic foraminifera, and number of objects larger than 2 mm.

Sample (cm)	Objects >2 mm	% Analysed 250 µm-2 mm	% Analysed 125-250 µm	Calcareous counted	Agglutinated counted	Planktonic counted	Total counted
0-1	0	50%	6.25%	498	166	15	679
10-11	0	100%	12.50%	188	111	6	305
20-21	1	50%	6.25%	146	107	0	253
30-31	0	50%	6.25%	300	103	1	404
40-41	1	100%	6.25%	494	90	1	585
50-51	1	100%	6.25%	504	92	2	598
60-61	1	50%	12.50%	389	154	1	544
70-71	0	50%	12.50%	472	106	11	589
80-81	0	50%	12.50%	424	91	7	522
90-91	0	50%	12.50%	357	100	5	462
100-101	0	50%	12.50%	275	104	10	389
110-111	0	50%	12.50%	229	52	17	298
120-121	3	50%	12.50%	336	40	4	380
130-131	0	50%	12.50%	280	28	3	311
140-141	0	50%	12.50%	187	21	6	214
150-151	1	50%	12.50%	270	20	8	298
160-161	0	50%	12.50%	204	9	5	218
170-171	0	50%	12.50%	188	11	5	204
180-181	0	100%	12.50%	293	9	5	307
190-191	0	100%	34.38%	212	19	10	241
200-201	0	100%	12.50%	189	2	11	202
210-211	0	100%	12.50%	180	1	14	195
220-221	0	100%	12.50%	291	4	15	310
230-231	0	100%	12.50%	454	5	9	468
240-241	0	100%	12.50%	594	6	6	606
250-251	0	50%	12.50%	717	2	18	737
260-261	0	50%	12.50%	573	0	26	599
270-271	1	100%	12.50%	289	2	17	308
280-281	15	50%	25.00%	421	1	0	422
290-291	0	100%	25.00%	207	0	0	207
				10161	1456	238	11855

3.5 Data analysis

Before analysis, planktonic individuals, and species with agglutinated tests, were omitted from the dataset. All samples were standardised to 100 % and divided with the corresponding volumes (ml). The concentration of individuals were then converted to per 10 ml.

Statistical analysis was performed using R, version 4.0.4 (R Core Team, 2021). To estimate species diversity, the Shannon-Wiener index (H_{log2}; (Shannon & Weaver, 1963) was calculated using the vegan package, version 2.5-7 (Oksanen et al., 2020). H_{log2} expresses both species richness and how evenly the individuals are distributed between the species. High dominance of individual species reduces the $H'log_2$ (Shannon & Weaver, 1963). A high diversity would, generally, indicate favourable conditions whereas low diversity would be the faunal response to severe conditions. Following the Norwegian classification system, good environmental status is characterised by H_{log2} >3.1, and moderate or worse is H_{log2} <3.1 (Direktoratsguppen vanndirektivet, 2018).

Furthermore, to investigate relationships between the most common species (species occurring >10 % in at least one sample), Spearman's rank correlation coefficient (r_s) was performed.

4. Results

Raw data can be found in appendix E (foraminifera) and F (Loss-on-Ignition). The identified foraminifera species are listed alphabetically in Appendix D.

4.1 Sediment dating and sedimentation rate

The Radiocarbon (^{14}C) dating of the shell, presumably *Acasta excavata*, found at ~281.5 cm, gave a ^{14}C age of 9630 ±50 BP (Appendix C). The Marine20 calibration provided a probable age of the shell to be approximately 10510 cal BP (Table 2; Figure 5). Accurate sediment accumulation rates could not be obtained due to only having one dating point. Consequently, the age of the core has been assumed based on a linear sedimentation rate, ≤0.03 cm/yr. This resulted in a dating of the bottom sediments in the core to be approximately 10800 years old, and each sample covering roughly 36 years, and a time span of approximately 360 years between each sample.

Table 2. Results from the ^{14}C calibration. Showing the cal BP age ranges for 1 sigma and 2 sigma, and the median probability.

% Area enclosed	cal BP age ranges
68.3 (1 sigma)	10390-10650
95.4 (2 sigma)	10260-10750
	Median probability: 10510 cal BP

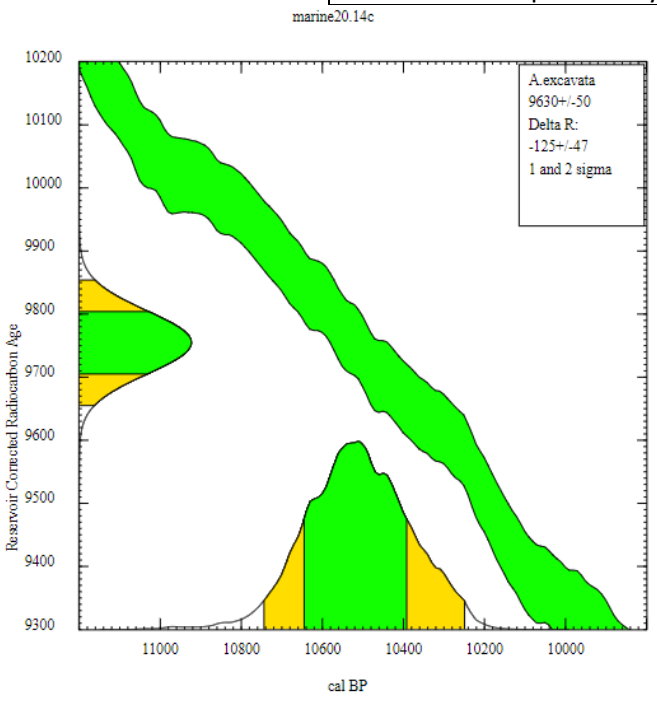

Figure 5. The calibration curve. Y-axis showing the reservoir connected ^{14}C age, and x-axis presenting the calibrated age in BP.

4.2 Sediment analysis of organic matter

The lower ca. 18 cm consisted of light gray sediments, followed by an approximately 1 cm thick sand layer, showing a distinct increase in magnetic susceptibility and bromine (Br), however a decrease in loss-on-ignition (LOI; Figure 6). From the sand layer and up core, the sediments gradually darkens, LOI and Br increase, while magnetic susceptibility decreases, suggesting a gradual increase in organic matter. The loss-on-ignition (LOI) ranged from 1.2 to 8.1 %, where the top sample (0-1 cm) had the greatest LOI with 8.1 %. The lowest LOI value, 1.2 %, was found in the sample including some of the sand layer (270-271 cm). From approximately 120 to 45 cm a general increase in LOI was observed, consistent with browner sediments. A distinct decrease in percent LOI was found at the sample depth of 30-31 cm, corresponding to sediments having a slightly lighter colour and an increase in magnetic susceptibility, suggesting a higher input of minerals. Further up the core at around 10 cm a distinct decrease in marine organic matter (Br) is observed. The noticeable decrease in magnetic susceptibility at approximately 280 cm depth corresponds with the location of the bivalve shell (inorganic=no magnetism; Figure 6).

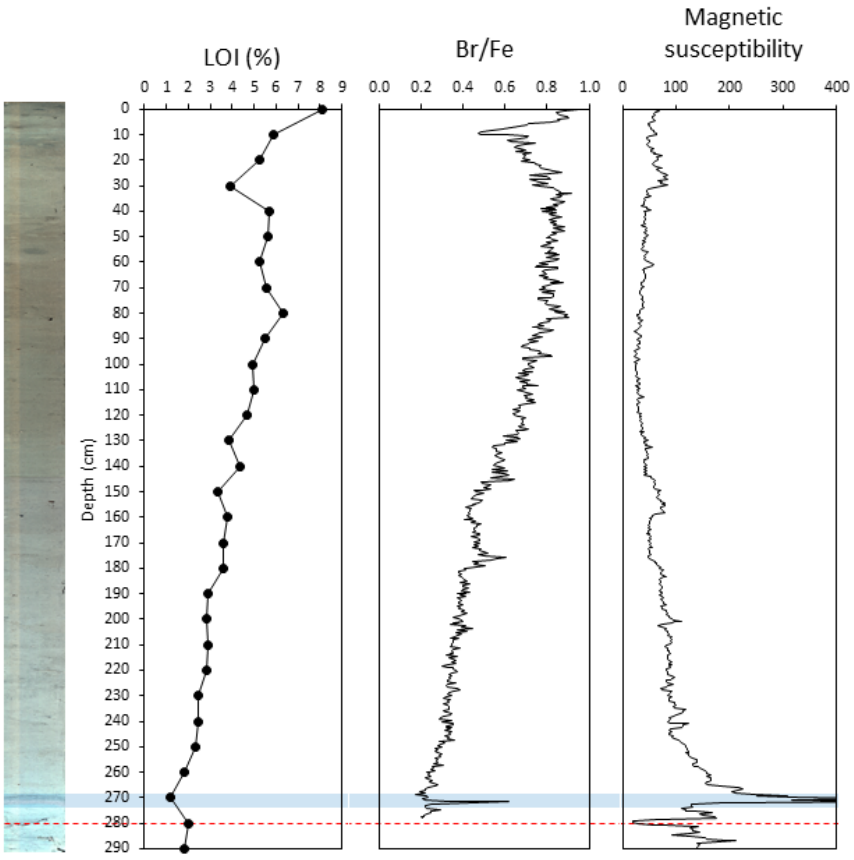

Figure 6. Percent loss-on-ignition, bromine (Br/Fe), and magnetic susceptibility throughout the core, together with a high-resolution imaging of the core (Core image, Bromine, and magnetic susceptibility graphs: Courtesy of Matthias Paetzel, pers. comm). Light blue highlight area indicating the sand layer, red dashed line indicate the sample where the shell, presumed Acesta excavata*, was found.*

4.3 Planktonic foraminifera

The relative abundance of planktonic foraminifera in relation to calcareous benthic foraminifera ranged from 0 to 10 % (Figure 8). The planktonic foraminifera fluctuated throughout the core, with three distinct peaks at 270-271 cm (9.3 %), 210-211 cm (10.0 %), and 110-111 cm (9.6 %). The high percent of planktonic specimens at 210-211 cm, is not as evident in the absolute abundance (Figure 7). In contrast, the somewhat high absolute abundance at 0-1 cm is not apparent in the relative abundance (5 %), presumably due to a high abundance of benthic calcareous foraminifera. Planktonic foraminifera were completely absent in the two lower samples, with gray sediments, and followed with a peak at the sample taken in and above the sand layer. Furthermore, planktonic species were also absent at sample depth 20-21 cm (Figure 7).

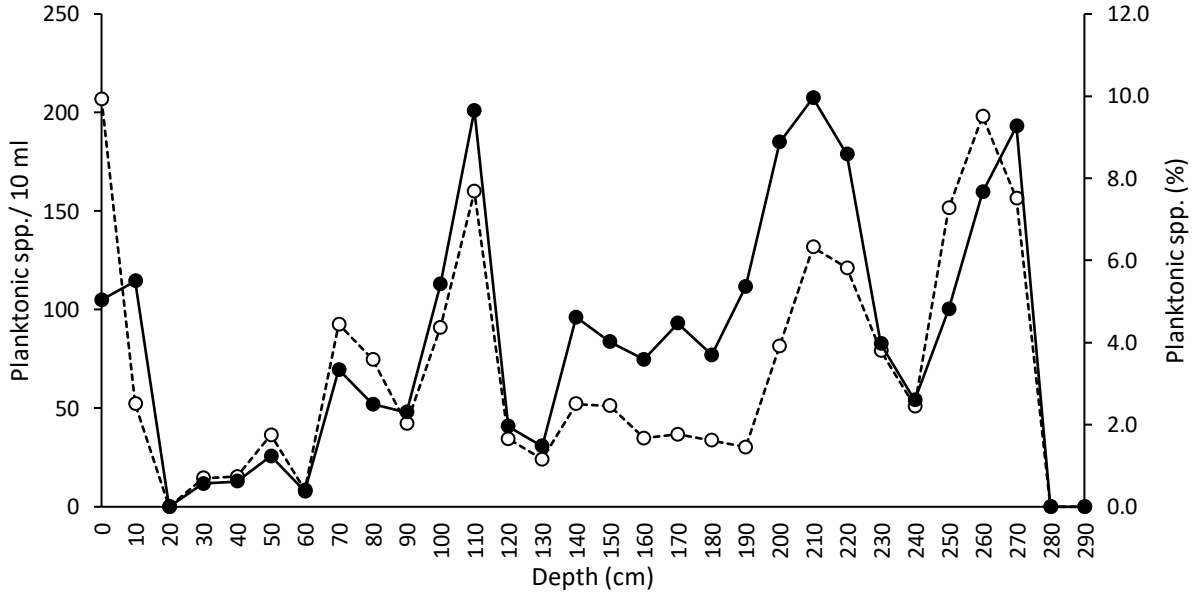

Figure 7. Relative abundance of planktonic foraminifera in relation to calcareous benthic foraminifera (black line; left y-axis), and planktonic specimens per 10 ml sediments (dotted line; right y-axis).

4.4 Benthic foraminifera assemblages

The abundance of benthic foraminifera with agglutinated tests decreased noticeably with depth and was generally lower than calcareous, with the exception of sample depth 20-21 cm, with 87 more specimens per 10 ml sediments (Figure 8). The abundance of calcareous foraminifera varied between 535.2 and 3900 individuals per 10 ml, and with 17 to 44 species per sample (Figure 8 & 9). Diversity (H_{log2}) varied between 2.3 (210-211 cm) and 4.1 (0-1 cm) of the Shannon-Wiener Index. In general, the highest diversity values were observed in the upper samples, and the three lower most samples (Figure 9). The youngest sediments

(sample depth 0-1 cm) had the highest abundance of both calcareous and agglutinated specimens, and highest number of species recorded.

The abundance of calcareous species produced three periods with high concentrations of specimens, and three periods with low concentrations (Figure 8).

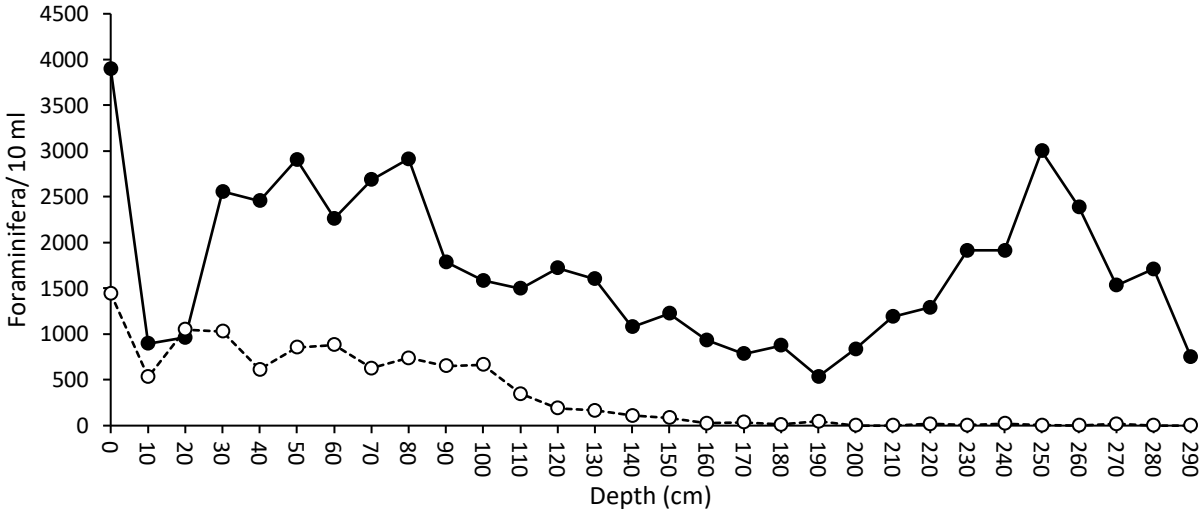

Figure 8. Total abundance of both calcareous (black line) and agglutinated (dotted line) foraminifera per 10 ml.

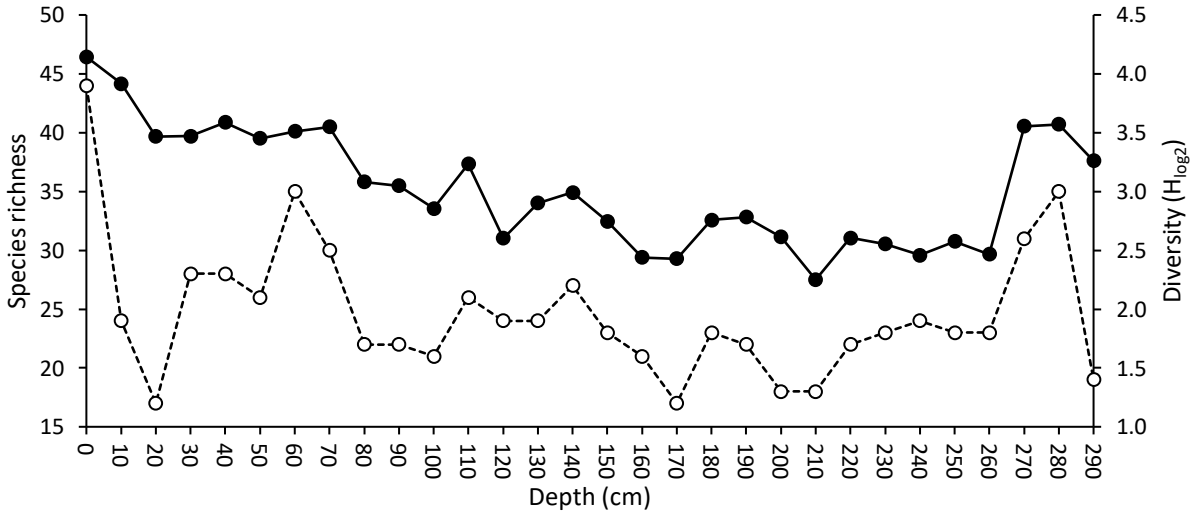

Figure 9. Species richness (dotted line; left y-axis) and the Shannon-Wiener Diversity Index values (black line; left y-axis) throughout the core.

A total of 110 calcareous foraminifera species were identified: 42 at the species level, 30 at the genus level, and 38 assigned to unidentified ID groups. Only 18 of these species had a relative abundance of >5 % in at

least one sample, and together described 89 % of the total assemblage. Photos with names of these can be seen in Figure 10 and 11. Among these, three "species" were unidentified: UN-ID 20 (0-5.4 %), UN-ID 33 (0-12.6 %), and UN-ID 34 (0-6.8 %). Furthermore, UN-ID 33 was the 2nd most abundant in sample depth 10-11 cm (12.6 %), with 113 individuals per 10 ml.

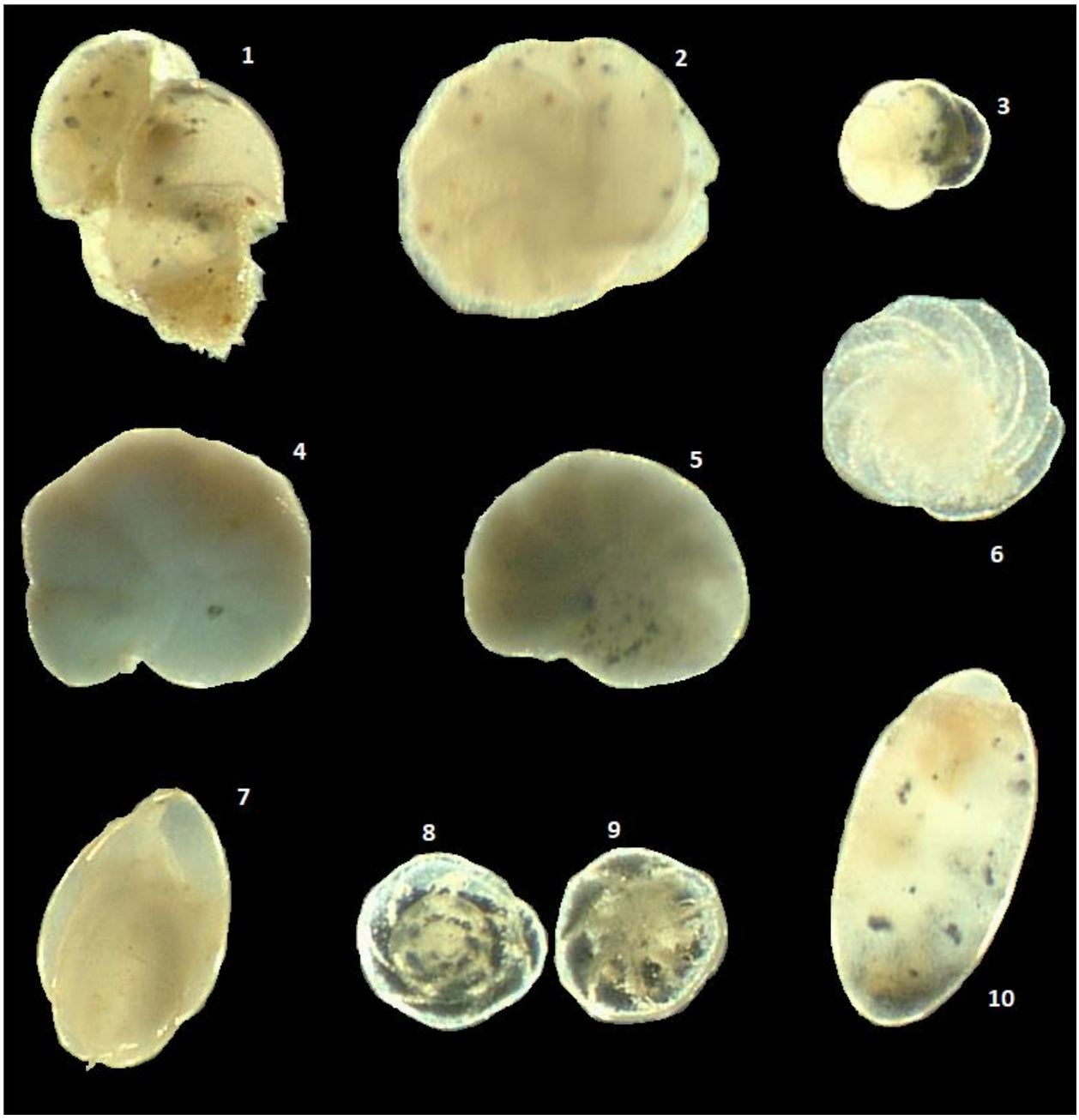

Figure 10. Calcareous benthic foraminifera occurring >5 % in at least 1 sample with original references: 1. Bulimina marginata *(d'Orbigny, 1826), 2.* Cassidulina laevigata *(d'Orbigny, 1826), 3.* Cassidulina obtusa *(Williamson, 1858), 4.* Cibicidoides *sp. 5 (genus: Thalmann, 1939), 5.* Cibicidoides *sp. 6 (genus: Thalmann, 1939), 6.* Cassidulina *sp. 1 (genus: d'Orbigny, 1826), 7.* Globobulimina turgida *(Bailey, 1851), 8-9.* Hoeglundina elegans *(d'Orbigny, 1826), and 10.* Chilostomella oolina *(Schwager, 1878). Photos taken by author.*

Figure 11. Calcareous benthic foraminifera occurring >5 % in at least 1 sample with original references, continued: 1. Hyalinea balthica *(Schröter, 1783), 2.* Nonionoides turgidus *(Williamson, 1858), 3.* Nonionellina labradorica *(Dawson, 1860), 4-5.* Lobatula lobatula *(Fleming, 1828), 6. UN-ID 33, 7.* Trifarina angulosa *(Williamson, 1858), 8.* Stainforthia fusiformis *(Williamson, 1858), 9. UN-ID 34, and 10. UN-ID 20. Photos taken by author.*

4.4.1. Dominant species distribution

The relative and absolute abundance of the most abundant and frequent species (occurring >10 % in at least one sample) is plotted in Figure 12. The samples were predominantly dominated by *Bulimina marginata* (5.8-54.8%), *Hyalinea balthica* (0-44.9%), *Cassidulina laevigata* (0-24.8%), and *Lobatula lobatula* (0.2-18.6%; Figure x), together accounting for 66.3 % of the total assemblage. In addition, *Trifarina angulosa* (0-22.3%), *Nonionellina labradorica* (0-11.9%), *Globobulimina turgida* (0-10.5%), and *Nonionoides turgidus* (0-13.1%) were common species, all occurring more than 10 % in at least one sample.

The two most dominant species in total were *B. marginata,* and *H. balthica,* with a total dominance (all samples combined) of 27.1% and 24.3%, respectively. *B. marginata* dominated 17 out of the 30 samples investigated, while *H. balthica* dominated in nine of the samples. *B. marginata* occurred in all samples, while *H. balthica* was completely absent in the lowermost sample. The high relative abundance of *B. marginata* in samples between 200 and 170 cm, and at 290 and 140 cm is not visible in the absolute abundance of the species (Figure 12). Furthermore, the absolute abundance of all species is low at these samples (Figure 8 & 12). Likewise, the high relative abundance of *H. balthica,* in particularly sample depths 200 to 180 cm, were higher than what the absolute abundance would suggest (Figure 12).

C. laevigata dominated in three samples, with a total dominance of 10.1 %, and had its highest occurrence in the samples between 61 and 30 cm (21.2-23.7 %), and at 280-281 cm (24.8 %; Figure 12). Furthermore, *C. laevigata* was the most dominant species in sample depth 10-11 cm, despite the low absolute abundance of this specie. Likewise, the absolute abundance was low among all species at this sample depth (Figure 12).

L. lobatula only dominated in the top sample, and had a generally low abundance (Total dominance 4.9 %), compared with the three other dominating species, with the exception of sample depth 280-281 cm where it peaked (14.3 %), although, the absolute abundance was not as evident (Figure 12).

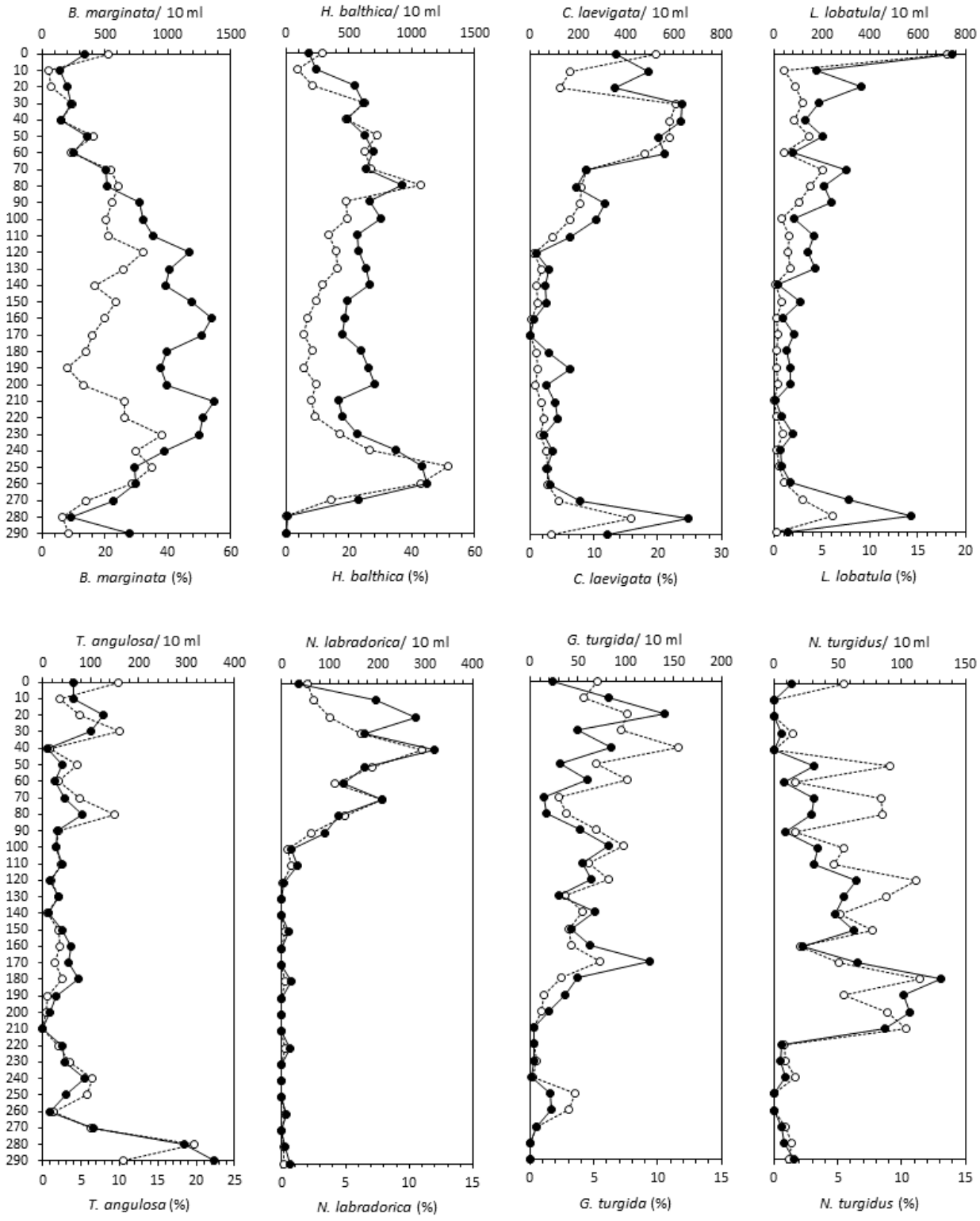

Figure 12. Absolute abundance per 10 ml sediment (dotted line; top x-axis) and relative abundance (black line; bottom x-axis) of the dominant species, occurring >10 % in at least one sample, versus depth (cm; y-axis). From top left to bottom right: Bulimina marginata, Hyalinea balthica, Cassidulina laevigata, Lobatula lobatula, Trifarina angulosa, Nonionellina labradorica, Globobulimina turgida, *and* Nonionoides turgidus.

4.5 Relationship between species

Correlation tests were conducted on eight selected species of calcareous benthic foraminifera to look for relationships. These species are among the most common species in the core, and all occur >10 % in at least one sample.

From the correlation test (Spearman's corelation coefficient=r_s), eight significant relationships were observed. All correlation results can be found in Appendix G. *B. marginata* showed invers relationships with *C. laevigata* (r_s= -0.85, p= <0.001), *L. lobatula* (r_s= -0.61, p= <0.001), and *N. labradorica* (r_s= -0.72, p= <0.001), and a positive relationship with *N. turgidus* (r_s= 0.58, p= 0.001; Figure x). In contrast, *C. laevigata* showed a positive relationship with *L. lobatula* (r_s= 0.56, p= 0.002), and *N. labradorica* (r_s= 0.74, p= <0.001), while there was a weak negative relationship with *N. turgidus* (r_s= -0.43, p= 0.02). There was, furthermore, a weak significant positive correlation between *L. lobatula* and *N. labradorica* (r_s= 0.55, p= 0.002). No significant relationship could be found between *H. balthica, T. angulosa* or *G. turgida* and the other species.

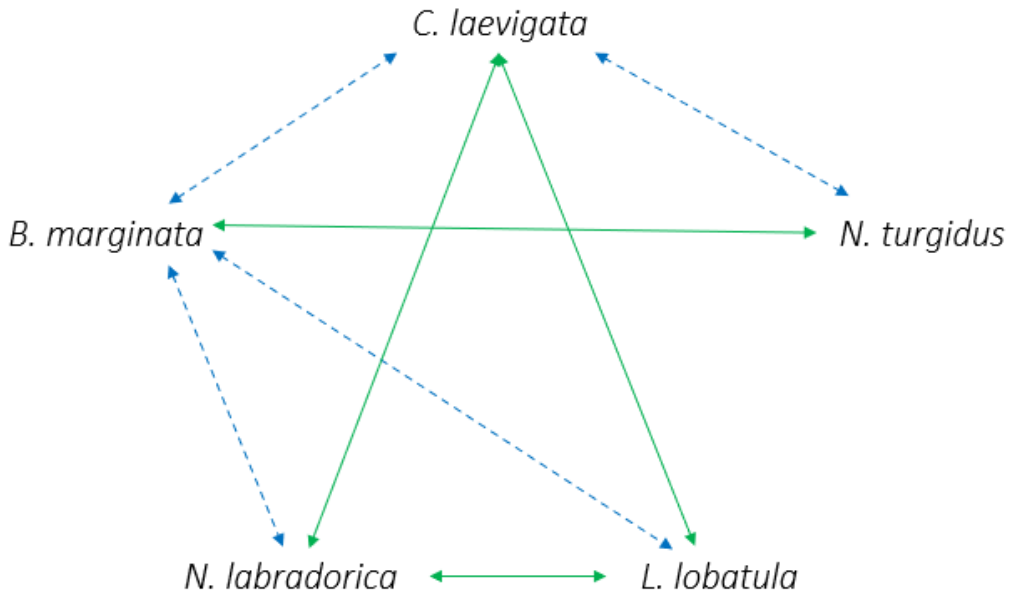

Figure 13. Diagram of the relationships between the most common species: Bulimina marginata, Cassidulina laevigata, Nonionoides turgidus, Nonionellina labradorica, and Lobatula lobatula. *Blue dashed line= negative relationship, and green line= positive relationship (Only significant relationships)*

5. Discussion

The objective of this thesis is to describe past environmental changes in the Sogndalsfjord, both in terms of the variations in the benthic foraminifera faunal distribution and sediment properties. This has been accomplished through analysing a 291 cm long sediment core collected from the Sogndalsfjord at a water depth of 133 m.

5.1 Limitations and justification of methodological choices

Some consideration regarding the methodology of this study must be taken into account when interpreting the results.

Only calcareous foraminifera species were included in this thesis, neglecting ecological information that some agglutinated species may provide, moreover potentially resulting in a lower diversity, particularly in the upper samples. Despite this, diversity values were still at the highest in these samples. Furthermore, as the sediment core stretches so far back in time, there is reason to interpret the gradual decrease in agglutinated tests as that of taphonomic processes (Knudsen, 1998; Murray, 2006), this reasoning is further supported when considering the low sedimentation rate, exposing the fragile tests for a prolonged time.

Only fraction size 125 µm-2 mm was analysed, due to time limitations. By not including the smallest fraction size (63-125 µm), underrepresentation of smaller and juvenile species may have occurred, potentially causing significant loss in abundance and false diversity values (Schönfeld et al., 2012; Sen Gupta et al., 1987). Furthermore, opportunistic responses in some species may not have been detected, as opportunistic species are commonly small (Alve et al., 2016; Mojtahid et al., 2006; Schönfeld et al., 2012). The 63-125 µm fraction has therefore been retained and archived for more detailed investigations in the future.

The samples were not stained with Rose Bengal, meaning that no differentiation between the living (at the time of sediment core sampling) and dead (fossil) foraminifera could be made (Murray, 2006). Consequently, the abundance and diversity in the youngest sediments (0-1 cm) sample could be lower if only the fossil individuals were included. Furthermore, since this 1 cm includes many years, establishing present conditions was not possible.

Only one replicate has been used for this study, due to what was available, neglecting spatial variability, as the distribution of benthic foraminifera is known to be patchy (Bernstein et al., 1978; Fontanier et al.,

2003; Griveaud et al., 2010). However, in the present investigation, benthic foraminifera tests have accumulated over a long time-span (+/- 36 years in each sample). This should therefore not be too big of an issue in comparison with studies of living benthic foraminifera, where three replicates is recommended (Bouchet et al., 2012; Schönfeld et al., 2012). However, it would have been preferred to have one or two replicates from the same area, to give more accurate "values" for the area.

Furthermore, the use of gravity corers (method used for the present study), may result in a loss of the surface layer due to both the impact and when being raised through the water column, as it does not seal once the sample has been taken (Murray, 2006). Gravity corers are therefore deemed as unsatisfactory for sampling sediments for benthic foraminifera analysis (Murray, 2006). However, this is of greater concern when studying present and live foraminifera, rather than past foraminifera assemblages. Even So, it is unknown how much sediments have been lost, and without a dating of the top sediments, it is not possible to accurately determine the age of the youngest sediments.

Lastly, the taxonomic level regarding benthic foraminifera was not at an advanced level when species identification was conducted. Hence, some misidentification and unintended clustering of different species as single species may have occurred and must be considered.

5.2 Environmental history

5.2.1 Determining the age of the core

The dating of the bivalve shell fraction embedded in the sediment core corresponds well with a shell dated by Aa (1982) at the mouth of the Sogndalsfjord, which suggested minimum age of the retreat of the glacier from the Sogndalsfjord area. However, in contrast to the shell from Aa (1982), the shell found in the present study, identified as *Acesta excavata,* does not have its habitat in soft bottom sediments but rather on steep or overhanging hard substrata and cold-water coral reefs at water depths between 40 and 3200 m (usually between 200 to 800 m (Correa et al., 2005). Consequently, the shell has most likely been deposited there post-mortem. However, determining how long after is hindered by the lack of other dating points in the core for comparison. The shell was, additionally, accompanied by other small shell fragments, small intact mussel shells (roughly 2-3 mm), and a calcified lump of annelid worms of the Serpulidae family.

The sediments in which the shell was found were gray in colour followed by a sand layer of approximately 1 cm thickness. The samples retrieved from the gray sediments are dominated by *B. marginata* (from

bottom up: 27.8-9.4 %), *C. laevigata* (12.2 and 24.8 %), *T. angulosa* (18.4-22.3 %) and *L. lobatula* (1.5 and 14.3 %).

Previous studies have found that the species *C. laevigata, L. lobatula* and *T. angulosa* are all associated with coarse grained sediments (Dijkstra et al., 2013; Harloff & Mackensen, 1997; Mackensen et al., 1993; Mackensen & Hald, 1988; Mackensen et al., 1985; Murray, 2003), fitting well with the higher magnetic susceptibility values. Furthermore, both *L. lobatula* and T*. angulosa* are commonly connected with strong bottom currents (Dijkstra et al., 2013; Grønning, 1983; Mackensen et al., 1985), in particular *T. angulosa* (Dijkstra et al., 2013; Mackensen et al., 1985), which has its strongest presence in these samples. Moreover, *H. balthica* is barely present in these sediments (0 and 0.3 %). Grønning (1983) suggested that *H. balthica* favour calm hydraulic conditions in finer sediments in the Sogndalsfjord.

Furthermore, all dominant species, in these samples, are commonly regarded as species associated with warmer waters (Hald & Steinsund, 1992; Klitgaard Kristensen & Sejrup, 1996; Mackensen & Hald, 1988; Murray & Alve, 2016; Sejrup et al., 2004). *C. laevigata*, *T. angulosa,* and *L. lobatula* have all been classified as sensitive to organic matter in the Foram-AMBI (Alve et al., 2016), while *B. marginata* is classified as tolerant to organic enrichment, however still occurring in sediments with low organic matter (Alve et al., 2016).

In conclusion, the foraminiferal species dominating in the gray sediments, B*. marginata, C. laevigata, T. angulosa,* and *L. lobatula*, reflect coarse-grained sediments, high hydrological activity, low organic flux, and warm bottom waters.

Moreover, gray-coloured sediment layers are typical for deposits in front of glaciers without large quantities of organic matter. However, marine landslide materials are also characterised by this coloration (Paetzel, pers. comm.). Furthermore, it is difficult to distinguish between sediment deposits from mass movement and moraines since there may be larger grains in the horizon that the small diameter of the core has not captured (Paetzel, pers. comm.). Nevertheless, the deposition can also represent a continuous sedimentation process that began in the gray layer, corresponding with the gradually darker colour of the sediments above the sand layer, indicating a gradual increase of organic matter. This would fit the theory that the gray layer was deposited in a shallow marine environment with little or no added material from the outside, suggested by the lack of planktonic foraminifera, and possibly when the glacier was still nearby. However, this would not explain how a, usually, deep-water marine bivalve shell (preferred salinity: 33.4 to 38.5 %; (Correa et al., 2005) has made it into the sediments unless the identification is

wrong and the species is, in fact, a soft bottom species. Since the shell was not intact, identification has been made without all the typical species characteristics present.

An alternative theory could be that these sediments were deposited by a tsunami which occurred approximately 8.200 BP, generated by one of the largest known Holocene sub-marine slides: the Storegga slide (Bondevik et al., 2005; Bryn et al., 2005; Bugge et al., 1988). It is expected that evidence from this tsunami would reveal itself in a sediment core dating that far back in the Sogndalsfjord (Stein Bondevik, pers. comm.), as the tsunami propagated in all directions from the slide, inundation most coastlines around the North Sea/Norwegian Sea with various run-ups (Bondevik et al., 2005; Bondevik et al., 2003; Bryn et al., 2005).). On the Norwegian coast, the tsunami first began as a sea withdrawal before a positive wave propagated towards the coast (Bondevik et al., 2005). The tsunami could explain how the bivalve shell and other larger marine particles made their way into the sediments. Furthermore, the foraminifera assemblages, indicating strong bottom currents in these sediments, could have been transported from a more exposed area, such as the sill.

5.2.2 Oxygen

Norwegian fjords tend to develop dysoxic to anoxic conditions (Sen Gupta & Machain-Castillo, 1993) due to restricted circulation. Despite this, the low loss-on-ignition (LOI) values from the investigated sediment core (maximum 8.1 % in the top sample) strongly suggest that oxygen is continuously present. Moreover, deep-water renewal has persisted at the site throughout the Holocene, as organic matter is only preserved under conditions of limited oxygen availability (anaerobic conditions;Nichols, 2009). The assumption is further strengthened when comparing the present study's LOI values with the findings from a 182 m long sediment core from the Ikjefjord, SW Norway (125 water depth; (Kirkhus, 1980). Here, Kirkhus (1980) found between 16 to 20 % LOI in the upper 135 cm of the core, characterized as gyttja sediments (coprogenous sediment), which he linked to oxygen-depleted conditions.

Stainforthia fusiformis is one of the foraminifera species that have been strongly linked to severe oxygen depletion (e.g., Alve, 1991; Alve, 2003) with high tolerance to increased organic enrichment (Alve et al., 2016). In a study from the Drammenfjord, SE Norway, *S. fusiformis* strongly dominated (>95 %) in the oxygen deficient living foraminifera assemblages (Alve, 1991). However, in the present study, *S. fusiformis*, only exceeds a relative abundance of >5 % on three occasions, and never more than 7 %. This suggests that no prolonged periods of severe oxygen depletion in the water masses has taken place in the fjord throughout the investigated time span. However, it should be noted that opportunistic species, such as *S. fusiformis*, are small and elongated species, which easily wash through the 125 µm sieve (Alve, 2003). By

not including the smallest fraction (63-125 µm) underrepresentation of these species may occur (Alve, 2003; Mojtahid et al., 2006; Schönfeld et al., 2012). In fact, the relative abundance of *S. fusiformis* were found 14 times higher in the >63 µm fraction compared to the >125 µm fraction at a site in the Oslofjord, SE Norway, while the other common species multiplied by 1.1-2.8 in relative abundance (Cited unpublished data from Alve 1999 in (Alve, 2003). Consequently, this must be considered for the interpretation of the results. However, as this fraction size has yet to be investigated it is, at present, impossible to know whether the relative abundance of *S. fusiformis* would significantly increase in the samples or stay relatively the same.

Furthermore, the inverse relationship found between *B. marginata* and *C. laevigata* (r_s= -0.85, p= <0.001) strongly indicate that these two species have distinctly different environmental preferences. In resent surface samples from the Sognefjord and the Voldafjord, both Mikalsen et al. (1999) and Mikalsen et al. (2001) found the same correlation and suggested that this trend may be related to the amount of dissolved oxygen in the basin water masses, and subsequently the frequency of exchange of the basin water. A study from the North Sea also showed that *B. marginata* occurred in high percentage in stratified waters with low oxygen concentrations, while high values of *C. laevigata* were found in better ventilated areas (Klitgaard Kristensen & Sejrup, 1996). Additionally, these two species have been found to respond differently to organic fluxes, where *C. laevigata* has been classified as sensitive to organic matter, and *B. marginata* is describes as tolerant to organic enrichment, however still occurring in sediments with low organic matter (Alve et al., 2016).

Given the strong inverse relationship between *B. marginata* and *C. laevigata* and their evident relation to oxygen, one could also assume that the species in which they are significantly correlated to may also be, to some extent, driven by oxygen: *Nonionoides turgidus* could be tolerant to low oxygen levels, while *L. lobatula* and *N. labradorica* require well-oxygenated conditions. These correlations, however, are rather conflicting with the Foram-AMBI classifications of sensitivity/ tolerance to organic matter (Alve et al., 2016), implying that organic matter is not the main driver of the distribution of these species.

5.2.3 *Bulimina marginata* dominated samples

Bulimina marginata is a deep infaunal species tolerant to organic enrichment (Alve et al., 2016; Murray, 2003) in fine sediments (Conradsen, 1993; Murray, 2003). *B. marginata* is found in warm, marine waters (Risdal, 1963; Sejrup et al., 2004) and is regarded as an opportunistic species able to respond to high food availability (Jorissen et al., 1992) and persist in low oxygen conditions (Alve, 1991; Jorissen et al., 1998;

Sen Gupta & Machain-Castillo, 1993). *B. marginata* is found in all samples, where it has its highest relative abundance between approximately 241 to 90 cm core depth (31-54.8 %), in which it dominates (Figure 14). However, it must be noted that the absolute abundance of *B. marginata* is lower than the relative abundance would suggest in these samples (Figure 14). Furthermore, these samples are characterised by comparatively low concentrations of calcareous benthic foraminifera and some of the lowest diversity values in the core (H_{log2} ≤3.2). The low concentrations are presumably due to a higher sedimentation rate in these samples.

The lowermost sample, which *B. marginata* dominates (27.8 %; Figure 14), is mainly accompanied by *Cassidulina laevigata* (12.2 %) and *Trifarina angulosa* (22.3 %), and is characterised by low concentrations of calcareous foraminifer. Both, *C. laevigata* and *T. angulosa*, are associated with coarse grained sediments (Dijkstra, 2013; Harloff & Mackensen, 1997; Murray, 2003), where the latter is commonly connected with strong bottom currents (Dijkstra, 2013; Mackensen et al., 1985). Moreover, both *B. marginata* and *C. laevigata* have been found to be superior competitors of food-rich sediments (Alve, 1991; de Stigter et al., 1998; Sen Gupta & Machain-Castillo, 1993). Where *C. laevigata* indicates this behaviour in oxygen-rich sediments (de Stigter et al., 1998), *B. marginata* does so in sediments with lower oxygen concentrations (Sen Gupta & Machain-Castillo, 1993). Lastly, all three species are commonly associated with warmer waters (Klitgaard Kristensen & Sejrup, 1996; Mackensen et al., 1985; Sejrup et al., 2004).

In conclusion, this sample is characterised by coarse sediments, which fit with the magnetic susceptibility readings, warm temperatures, high energy and possibly food rich-sediments.

The assemblages from the samples between 241 to 90 cm, where *B. marginata* dominates for a prolonged time (31-53.7 %; Figure 14), are mainly accompanied by *Hyalinea balthica* (16.7-34.8 %). Both species are associated with opportunistic behaviours in relation to food-supply and oxygen concentrations (Alve, 1991; Hess & Jorissen, 2009; Jorissen et al., 1998; Mikalsen et al., 2001; Rosenthal et al., 2011; Sen Gupta & Machain-Castillo, 1993), deviating in the response to organic matter (Alve et al., 2016) and temperature (Murray, 2006; Rosenthal et al., 2011; Sejrup et al., 2004).

In conclusion, these sediments can roughly be characterised as possibly lower oxygen concentrations with a presumably higher sedimentation rate.

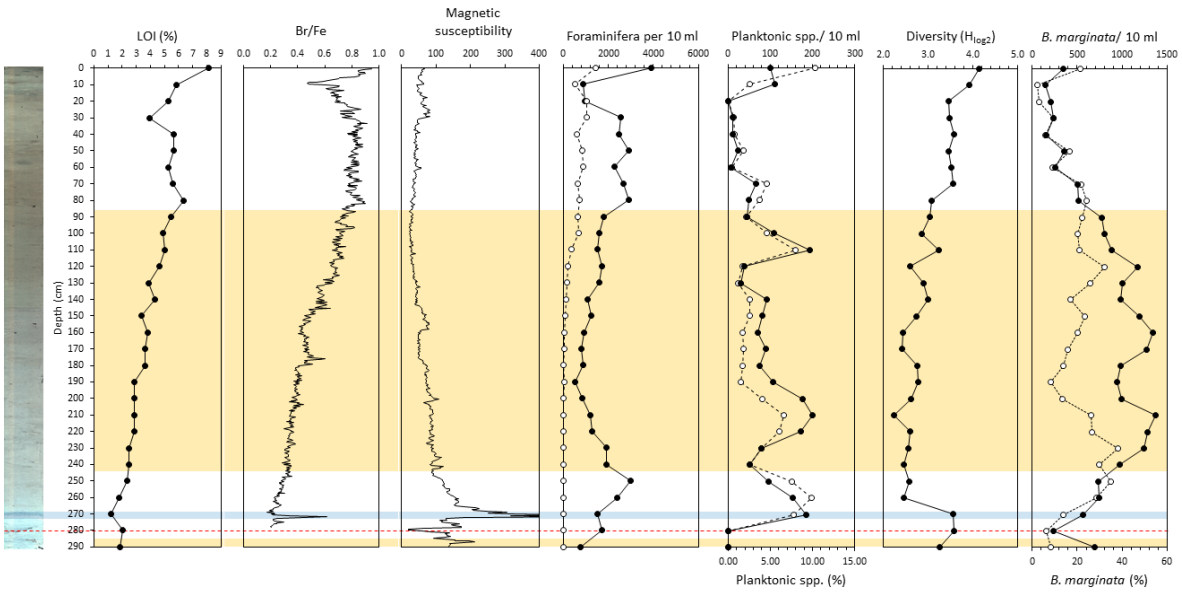

Figure 14. Temporal Distribution of, from left to right, loss-on-ignition (LOI), Bromine (Br), magnetic susceptibility, concentration of benthic foraminifera per 10 ml (Black line= calcareous benthic foraminifer, black dashed line= agglutinated benthic foraminifera), planktonic foraminifera (Black line= relative abundance, black dashed line= absolute abundance), diversity (H_{log2}), and Bulimina marginata *(Black line= relative abundance, dashed line= absolute abundance). Red dashed line= approximate location of bivalve shell, blue line= the sand layer, and yellow boxes= samples* Bulimina marginata *dominates. Bromine (Br) and Magnetic susceptibility graphs Courtesy Matthias Paetzel (2021) pers. comm.*

The assemblages from the samples between 241 to 90 cm, where *B. marginata* dominates for a prolonged time (31-53.7 %; Figure 14), are mainly accompanied by *Hyalinea balthica* (16.7-34.8 %). Both species are associated with opportunistic behaviours in relation to food-supply and oxygen concentrations (Alve, 1991; Hess & Jorissen, 2009; Jorissen et al., 1998; Mikalsen et al., 2001; Rosenthal et al., 2011; Sen Gupta & Machain-Castillo, 1993), deviating in the response to organic matter (Alve et al., 2016) and temperature (Murray, 2006; Rosenthal et al., 2011; Sejrup et al., 2004).

In conclusion, these sediments can roughly be characterised as possibly lower oxygen concentrations with a presumably higher sedimentation rate.

5.2.4 *Hyalinea balthica* dominated samples

H. balthica is an infaunal species sensitive to organic enrichment (Alve et al., 2016), and is associated with low dissolved oxygen levels (Mikalsen et al., 2001; Sen Gupta & Machain-Castillo, 1993). Nevertheless, Polovodova Asteman & Nordberg (2013) relate this species to prefer normoxic conditions, suggesting that there are other factors in addition to oxygen, which controls the distribution of this species. *H. balthica* is, furthermore, a marine species, commonly connected with cold waters (Murray, 2006; Murray & Alve,

2016; Rosenthal et al., 2011). Grønning (1983) found *H. balthica* favouring calm hydraulic conditions in finer sediments in the Sogndalsfjord.

H. balthica is highly abundant throughout the core, particularly from 271-20 cm, where it ranges from 17.8 to 44.9 % (Figure 15). Samples dominated by *H. balthica* are of generally good diversity values, apart from samples 260-261 and 250-251 cm where *H. balthica* dominates 44.9 and 43.1 %, respectively, together with *B. marginata* (29.8 and 29.3 %). However, the total abundance of calcareous benthic foraminifera in these samples are high (Figure 15), suggesting opportunistic behaviour from both *H. balthica* and *B. marginata* in these samples (e.g. (Odum, 1971).

In the sample which partially include the sand layer (270-271 cm; Figure 15) *H. balthica* is accompanied by *B. marginata* (22.6 %)*, C. laevigata* (7.8 %)*, L. lobatula* (7.9 %)*,* and *T. angulosa* (6.6 %). *C. laevigata, L. lobatula,* and *T. angulosa* are all associated with coarse grained sediments (Dijkstra et al., 2013; Harloff & Mackensen, 1997; Mackensen et al., 1993; Mackensen & Hald, 1988; Mackensen et al., 1985; Murray, 2003), while *B. marginata* and *H. balthica* are linked to fine sediments (Grønning, 1983; Murray, 2003, 2006). Both *L. lobatula* and *T. angulosa* are commonly found in strong bottom currents (Dijkstra et al., 2013; Grønning, 1983; Mackensen et al., 1985). Furthermore, all but *H. balthica* are warm-waters species (Hald & Steinsund, 1992; Klitgaard Kristensen & Sejrup, 1996; Mackensen & Hald, 1988; Murray & Alve, 2016; Sejrup et al., 2004). Likewise, all but *B. marginata* are sensitive to organic enrichment (Alve et al., 2016). The contradicting environmental signals is expected, as this sample was inconveniently taken, included two distinctly different sediments.

The samples *H. balthica* dominates, in the upper half of the core (Figure 15), is furthermore accompanied by another cold-water species, *Nonionellina labradorica*. *N. labradorica* is mainly found in the Arctic parts of the Atlantic, where it dominates, preferring temperatures of <1 °C (Knudsen et al., 2004; Murray, 2006). In the core, *N. labradorica* is barely existing until it peaks in abundance from sample 80-81 cm and persists until it decreases again at around 10-11 cm (Figure 12), perhaps indicating cooler temperatures when these sediments were deposited. However, the assemblages are also well represented by species linked to warm-waters, e.g., *C. laevigata*, *B. marginata*, and *L. lobatula* (Klitgaard Kristensen & Sejrup, 1996; Mackensen & Hald, 1988; Mackensen et al., 1985; Sejrup et al., 2004).

At sample depth 20-21 cm, the calcareous, normal marine assemblages decreased distinctly and was surpassed by agglutinated foraminifera (Figure 15) who appear unaffected or profiting in this sample. Increasing river runoff in this period may have caused an increased sedimentation rate throughout the

fjord, which would explain the low concentrations of calcareous foraminifera, decrease in marine organic matter (Br), and increase in magnetic susceptibility (Figure 15). Furthermore, some agglutinated foraminifera have been found more tolerant to reduced salinity conditions and increased terrestrial influence (Alve, 1991).

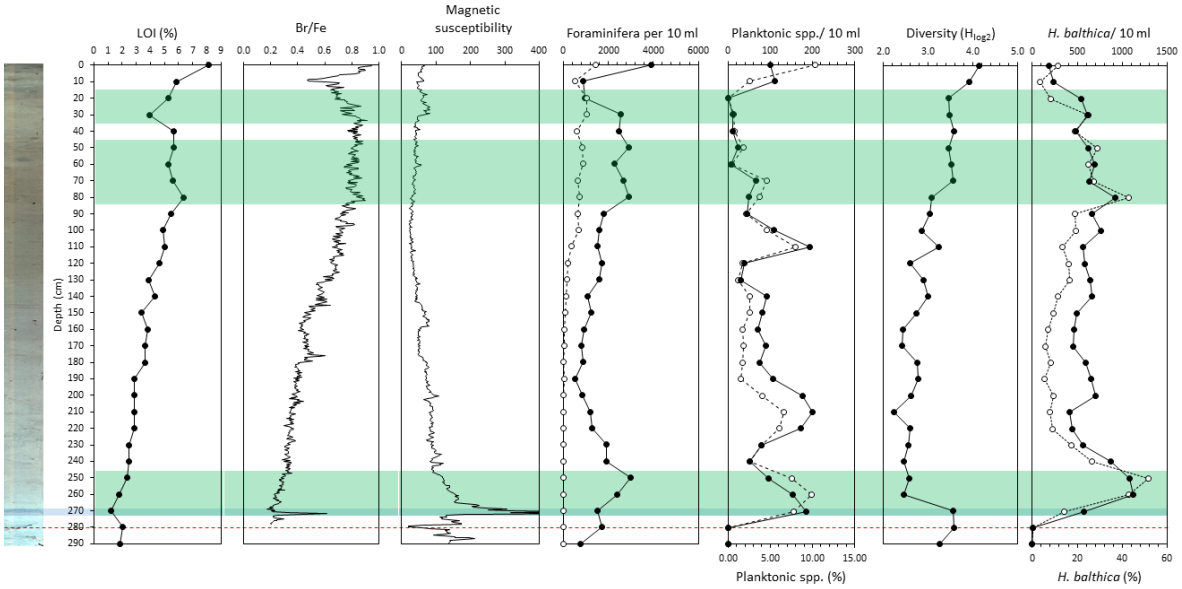

Figure 15. Temporal Distribution of, from left to right, percent loss-on-ignition (LOI), Bromine (Br), magnetic susceptibility, concentration of benthic foraminifera per 10 ml (Black line= calcareous benthic foraminifer, black dashed line= agglutinated benthic foraminifera), planktonic foraminifera (Black line= relative abundance, black dashed line= absolute abundance), diversity (H_{log2}), and Hyalinea balthica *(Black line= relative abundance, dashed line= absolute abundance). Red dashed line= approximate location of bivalve shell, blue line= the sand layer, and green boxes= samples* Hyalinea balthica *dominates. Bromine (Br) and Magnetic susceptibility graphs Courtesy Matthias Paetzel (2021) pers. comm.*

5.2.5 *Cassidulina laevigata* dominated samples

C. laevigata is a typical warm-water species dominating boreal to Listerine waters (Klitgaard Kristensen & Sejrup, 1996; Mackensen & Hald, 1988; Sejrup et al., 2004) found in coarse sediment with low organic matter concentrations (Alve et al., 2016; Grønning, 1983; Murray, 2003). *C. laevigata* is, furthermore, an indicator of well-oxygenated water-masses (e.g.,(Bouchet et al., 2018; de Stigter et al., 1998; Polovodova Asteman & Nordberg, 2013), and a superior competitor in food and oxygen-rich sediments (de Stigter et al., 1998).

C. laevigata appears in all but one sample (170-171 cm), displaying the highest abundance in the three lowermost samples, and from sample 110-111 cm and up to the most recent deposited sediments (Figure 16). Moreover, all samples where *C. laevigata* dominates has a high diversity (H_{log2} >3.6; Figure 16), suggesting good environmental conditions in these samples.

Sample 280-281 cm, dominated by *C. laevigata* (24.8 %; Figure 16) has fairly similar species composition and, hence, ecological information as showed in sample 290-291 cm, dominated by B. marginata (5.2.1), i.e., species associated with coarser grains, strong bottom currents, and warm temperatures. Given that the fractured bivalve shell, together with other marine organism >2 mm, were found in this sample (180-181 cm) strongly suggests high energy deposits in these gray-coloured sediments with high, fluctuating magnetic susceptibility.

The presumed higher sedimentation rate in sample 20-21 cm, dominated by *H. balthica*, appear to have persisted into the following sample (10-11 cm), i.e., still low concentrations of calcareous foraminifera (Figure 16). LOI values have further increased, despite marine organic matter experiencing a distinct decline (Figure 16). This decline could furthermore reflect a higher sedimentation rate, as less marine organic matter will have time to accumulate. This could furthermore explain the decrease in percent LOI at sample 30-31 cm. Species common in this sample apart from *C. laevigata,* are *H. balthica* (9.6 %), *N. labradorica* (7.4 %) and *Globobulimina turgida* (6.2 %). Little ecological information could be found on *Globobulimina turgida,* however, the genus is linked to cold temperatures (Murray, 2006), suggesting, together with *H. balthica* and *N. labradorica* that temperatures may have been cold at this time.

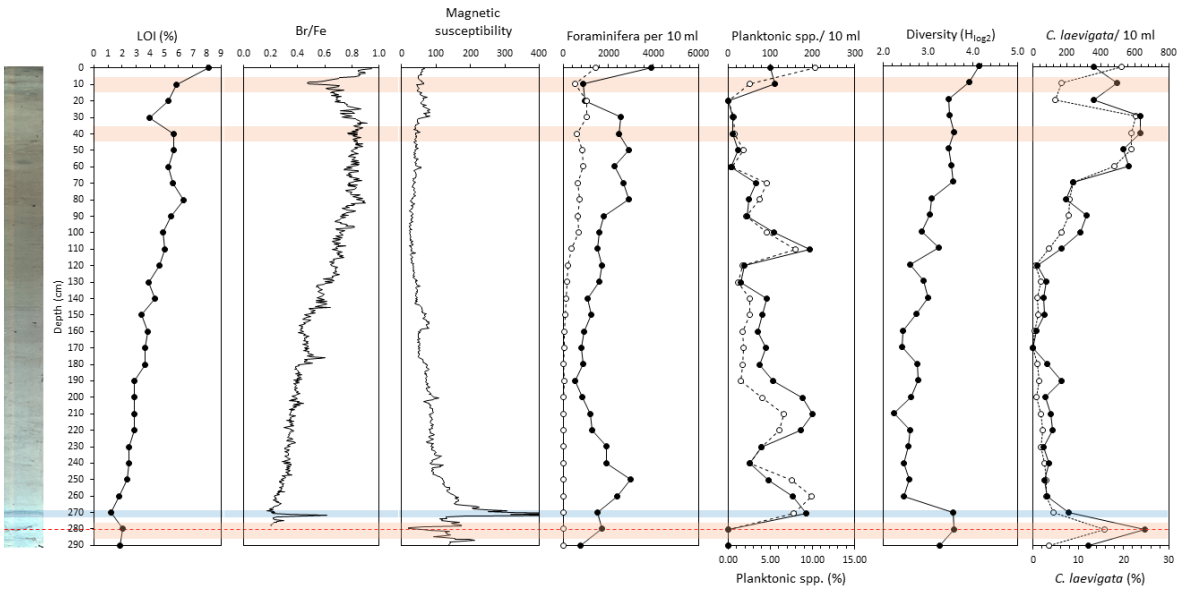

Figure 16. Temporal Distribution of, from left to right, percent loss-on-ignition (LOI), Bromine (Br), magnetic susceptibility, concentration of benthic foraminifera per 10 ml (Black line= calcareous benthic foraminifer, black dashed line= agglutinated benthic foraminifera), planktonic foraminifera (Black line= relative abundance, black dashed line= absolute abundance), diversity (H_{log2}), and Cassidulina laevigata *(Black line= relative abundance, dashed line= absolute abundance). Red dashed line= approximate location of bivalve shell, blue line= the sand layer, and orange boxes= samples* Cassidulina laevigata *dominates. Bromine (Br) and Magnetic susceptibility graphs Courtesy Matthias Paetzel (2021) pers. comm.*

5.3.6 *Lobatula lobatula* dominated samples

L. lobatula is an immobile epifaunal specie (Murray, 2006) found in warm saline Atlantic water (Mackensen et al., 1985) with low concentrations of organic matter (Alve et al., 2016). *L. lobatula*, is, furthermore, associated with strong current activity and coarse-grained sediments (Hess & Jorissen, 2009; Klitgaard Kristensen & Sejrup, 1996; Mackensen et al., 1985).

Apart from samples 280-281 and 270-271 cm (14.3 and 7.9 %, respectively), the lower half of the core is marginal in *L. lobatula*; however, it is present in all samples (Figure 17). However, the upper half shows a general increase in the species, reaching maximum abundance in the youngest samples, where it dominates the sample (18.6 %). Correspondingly, *L. lobatula* was the species that occurred in the highest numbers in both the living and the total population (including fossils) in the Sogndalsfjord samples examined by Grønning (1983). In particular, on the middle and outer threshold (Grønning, 1983). Suggesting that L. lobatula is a highly common species throughout the fjord, at least in recent years.

Sample 0-1 cm is the youngest sample and has the highest concentrations of foraminifera, and diversity value in the core. *L. lobatula* (18.6 %) is largely accompanied by the three other dominant species: *B. marginata* (13.6 %), *H. balthica* (7.3 %), and *C. laevigata* (13.4 %), providing a range of ecological information.

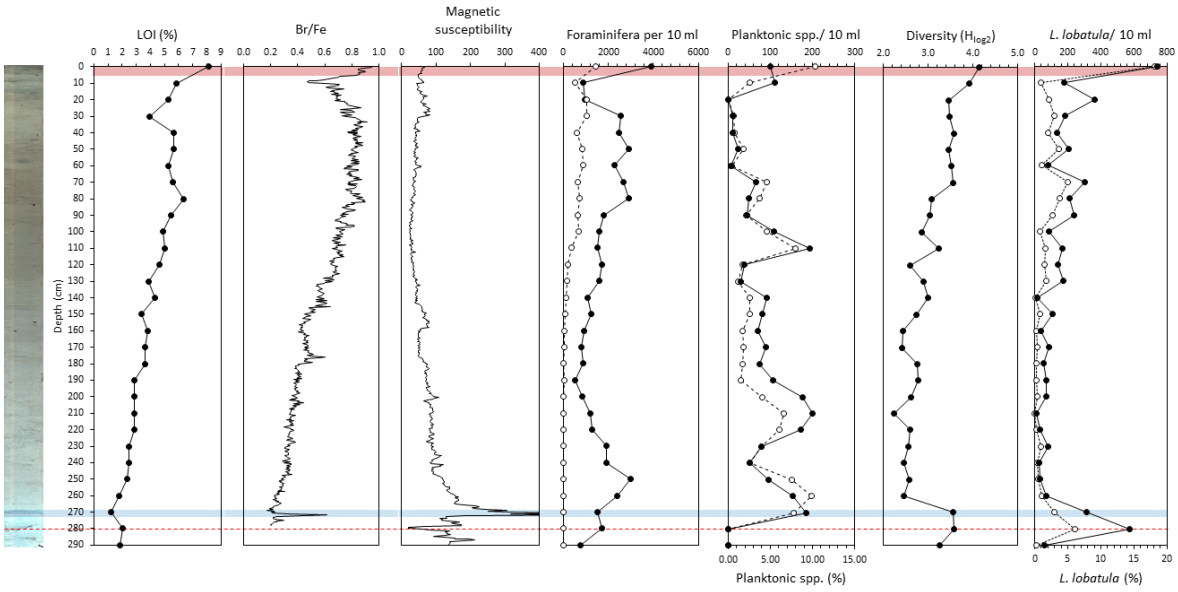

Figure 17. Temporal Distribution of, from left to right, percent loss-on-ignition (LOI), Bromine (Br), magnetic susceptibility, concentration of benthic foraminifera per 10 ml (Black line= calcareous benthic foraminifer, black dashed line= agglutinated benthic foraminifera), planktonic foraminifera (Black line= relative abundance, black dashed line= absolute abundance), diversity (H_{log2}), and Lobatula lobatula *(Black line= relative abundance, dashed line= absolute abundance). Red dashed line= approximate location of bivalve shell, blue line= the sand layer, and red box= samples* lobatula lobatula *dominates. Bromine (Br) and Magnetic susceptibility graphs Courtesy Matthias Paetzel (2021) pers. comm*

6. Conclusion

This study has looked at how the benthic foraminifera community has changed throughout a 291 cm long sediment core from the Sogndalsfjord. An attempt at describing the past environmental conditions in the fjord has been done by identifying and describing the depth distribution of the foraminifera assemblages in the sediment core, i.e., concentration of benthic foraminifera, planktonic foraminifera, diversity, and dominant species, and through characterisation of sediment properties, i.e., dating of the sediments, sediment accumulation rate, and organic matter (loss-on-ignition and bromine) and inorganic material (magnetic susceptibility).

- The foraminifera assemblages do not indicate any sign of oxygen depleted sediments, furthermore the loss-on-ignition results suggests that that oxygen has been continuously present in the Sogndalsfjord. Hence, deep-water renewal has persisted at the site throughout the Holocene.
- The difference in concentration of calcareous benthic foraminifera in the samples are rather explained by different sedimentation rates, then environmental stress.
- *Cassidulina laevigata* and *Bulimina marginata* presumably indicate different oxygen levels throughout the core.
- The foraminifera assemblages suggest warm marine waters throughout the sediment core, however slight indication of high runoff and cooler temperatures in samples 20-21 and 10-11 cm.
- Higher resolution of the samples would perhaps yield more precise ecological information from the foraminifera assemblages.

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8. Appendix

Appendix A

Protocol for the treatment of sediment cores for the purpose of foraminifera analyses:

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Protocol for the treatment of sediment cores for the purpose of Foraminifera analyses

Planning

Sediment cores are stored in darkness in a climate room at 4 °C between sampling and sample preparation. Ensure that other samples needed from the core is taken, or make sure to leave enough material for other purposes.

Make a sampling plan for the separate cores. The plan should define the starting point (cm depth) of the different samples, and how much material (5 mm or 1 cm) that will be sampled at each depth. If (preliminary) dating is known, samples could be taken from depths, i.e. years/time periods, of interest.

Check that all equipment needed is available in due time before sampling start.

Prepare beakers for storing samples beforehand (Sample ID). This is time-consuming if there are many samples. Suggestion for Sample-ID:

Fjord code and sampling date

Core ID (from sampling)

Sampling depth

Sediment sample depth in core (from cm-to cm)

Sieve fraction (250 µm-2mm-, 125-250 µm or 63 -125 µm)

Initials (student or researcher)

Equipment

- Waterproof marker
- 2 m ruler
- Smaller ruler
- 2 Spatula (large)
- Mini-spatula
- Sieves (2mm, 250, 125, 63 µm)
- Histology beakers (100 ml)
- Ethanol (96%) – diluted to 75%
- Pencil
- Wet paper (for the beakers with ID-information)
- Running tap-water
- Spray bottle
- Measuring cylinders, 25 ml and 50 ml
- Pipette
- Tape
- Plastic film

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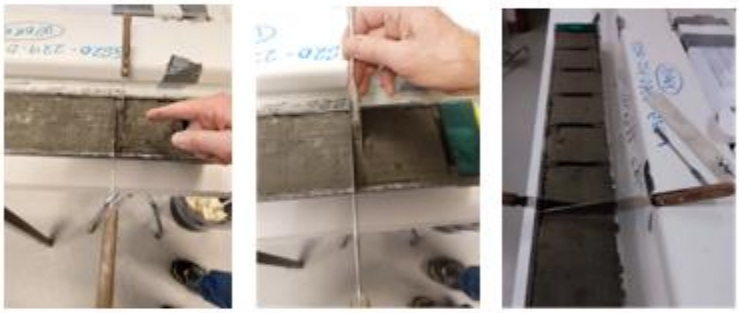
Procedure:

When opening a new core

1. Open sediment cores. Ensure that you know what the top (surface) and the bottom end of the core is.
2. Take a picture of the core, aligned with a ruler.
3. Mark the sediment core tubes with a cm scale, use a waterproof marker (see cm marks in Picture 1 and 2).
4. If needed, gently smooth the sediment surface with a spatula. The smoothing should be performed "crossing" the core, i.e., no mixing of sediments from different core depths.

When subsampling a core

5. **Sample sections from the sediment core**. Choose sections of 5 mm or 1 cm. Place two large spatula at each end of the sampling area (pictures 1 a, 1b). Sample sediment in the sampling area using a mini-spatula. Avoid sampling close to the tube walls (picture 1c).



Picture 1: a) Two spatula defining the sampling area, b) sediment sampling, using a mini-spatula, c) sampled sediment core.

6. **Estimate the sampled sediment volume**. Ideal sediment volume is 8-10 ml.
   - Place the sediment sample in a 50 ml measuring cylinder
   - Add 20 ml tap water
   - Gently mix the sediment and the water to remove air-bubbles and air trapped between the lumps of sediments
   - Read total volume and subtract 20 ml (the water volume) to get the volume of the sediment sample
7. **Prepare a standard sieve set-up**. The setup consist of four stacked sieves with different mesh sizes (from the top): 2 mm, 250 µm (retain fraction 250 µm-2mm), 125 µm (retain fraction 125-250 µm) and 63 µm (retain fraction 63-125 µm, picture 2a, 2b).

   To avoid clogging in the sieves and mixing of material from samples, make sure that the sieves are clean and dry.

Picture 2: *a) The set-up of the sieves, mesh sizes (from the top): 2 mm, 250 µm, 125 µm and 63 µm, b) sieves are placed in a plastic tray in case of spilling of the samples.*

8. **Sieve the sample into the separate fractions**. Fill the material from the measuring cylinder into the sieve setup, make sure that no material is left in the cylinder.
   Gently clean with tap water, using a showerhead (picture 3). Make sure none of the sieves are clogged, i.e., you must adjust the waterflow accordingly. If all the sediments are not "dissolved" using the shower, gently break up the larger lumps into smaller pieces
   - To avoid clogging of the finest mesh, gently tap under the sieve if needed.
   - To avoid vacuum between the sieves, one possibility is to place a small piece of wet paper between the different sieves for air to penetrate.

Picture 3: *Transfer of sediment sample to the sieve set-up. Make sure that no material is left in the measuring cylinder.*

9. **Transfer the material from the sieves to the histology beakers for storage. The different fractions are treated separately.**
   - Use running tap water from below to concentrate the material in a smaller part of the sieve (picture 4).
   - Backwash the material from the separate sieves into separate histology beakers, using ethanol. Make sure that all material is transferred from the sieves.
   - Always double check that the beakers have the correct sample ID. Sample ID should be available both outside the beaker (written with a pencil) and inside the beaker (written with a pencil on waterproof paper).

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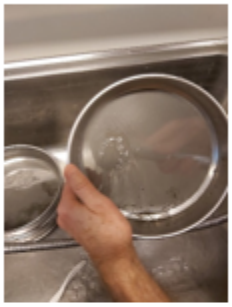


Picture 4: *Concentrating the material in the sieve. Make sure that no material is left in the sieve after transferring it into the beaker.*

10. **Store samples in ethanol (75%) awaiting further identification**. Find a proper place to store them. Make sure that they are placed in a box/locker/shelf that is properly marked with owner and owners contact information (phone number). Also, male sure to cap the samples properly to avoid evaporation of ethanol.
11. **Clean all equipment before sampling the next section**. Start again at nr. 5.
12. **Finishing the sampling of a core.** All equipment should be cleaned and stored where it belongs. The sediment core should be covered with plastic film and placed in a plastic bag wrapped with tape. If a "core container" is available, the core could be stored in this. Store the core in the cold room at 4°C. When you are sure that you (and others) have gotten all the samples you need from a sediment core, the sediment should be disposed.

Appendix B

Protocol for the identification of foraminifera from sediment samples

Protocol for the identification of Foraminifera from sediment samples

Planning:

- Prepare samples from sediment cores, following the procedure described in "Protocol for the treatment of sediment cores for the purpose of Foraminifera analyses".
- Make sure all equipment are in place, and order in due time if anything is missing.
- Book space in the microscope-room for the set-up.

Equipment:

- Stereomicroscope (Wild), magnification range 6X-50X, with base equipped with dark and bright field illumination (also used in the biology lab, and may be found there)
- Counting chamber
- Splitting chamber
- Pipette
- Spray bottle
- 100 ml glass beakers
- 3 ml vials with snap caps (dramsglass)
- 75% Ethanol
- Dissecting needles
- Forceps
- Scheme for species list and abundance
- Printer paper
- Identification guides
    - "Alve" guides
    - Original papers (REFs)

Procedure:

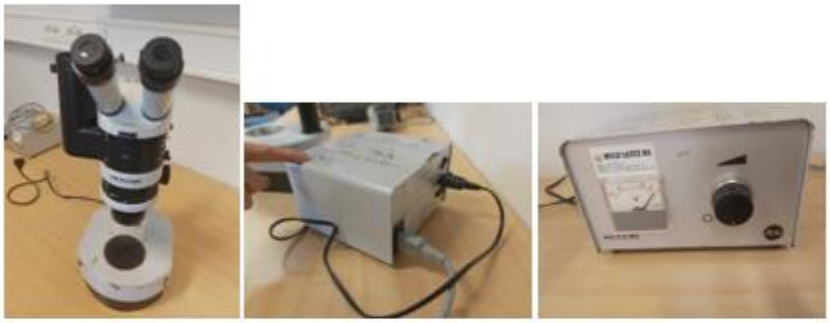
System "set-up"

The set-up should follow the described procedure.

1. Connect the stereomicroscope to the **12 V** power supply.

The stereomicroscope is normally stored in the microscope room or in the biology lab. Be aware to use the correct power supply showing 12V (normally used up to 12 V but may be used at 15 V if necessary; 15 V reduces bulb lifetime more rapidly).

- The oculars can be adjusted according to the user's vision.
- The magnification can be adjusted by turning he magnification wheel
- The handle at the base of the stereomicroscope switches the light from dark field (increased contrast) to bright field (normal) illumination.
- Strength of illumination can be adjusted on the power supply.



Picture 1: a) Stereomicroscope. b) Power supply with position of cables when the system is connected. C) 12 (15) V power supply.

2. Connect the stereomicroscope to the camera, monitor/video, and video printer

Camera, monitor/video and video printer is stored in the microscopy room, and photo paper for the printer can be found in the glass locker.

- The camera is placed in the camera connector at the stereomicroscope (Picture 2a).
- General connecting procedures for the video cables (co-axial) (Pictures 2b and 3b):
    - Incoming signals (cable) to "Video in"
    - Outgoing signals (cable) to "Video out"

Monitor fuse is sensitive to spikes in current, therefore when starting the monitor and the printer: PRINTER FIRST ON/MONITOR LAST ON, MONITOR FIRST OFF/PRINTER LAST OFF

Picture 2: *a) Camera mounted on the stereomicroscope. b) Position of the different cables when the system is connected.*

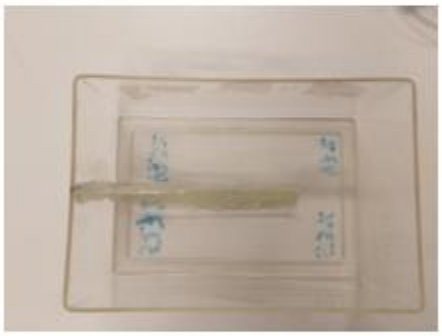
Picture 3: *a) Monitor/video and videoprinter. b) Position of different cables (video in, video out) in monitor when the system is connected.*

Investigation of samples

1. Samples are screened using a specially developed "counting chamber" (Picture 4 a and b). The distances between the lines are suited to 12X magnification.
2. Add an appropriate (sub-)volume of the sample (stored on 75% ethanol in histology beakers) to the counting chamber using a pipette. It is difficult to inspect the sample if more than approximately 50 % of the bottom of the counting chamber is filled up with sample material. Most of the particles should be in "one layer". The (sub-)sample volume is adjusted according to the density of particles in the sample, and the volume of the counting chamber, see step 3
    - For screening and counting individuals, normally use 25X magnification. Follow the lines to make sure that the whole sub-sample is checked. Use dissecting needle or forceps to inspect individuals closer.
    - When the (sub-)sample is checked, use a spray bottle, and flushed the sample into the original histology beaker for storage. If there is more material left in the histology beaker, the analysed material should be stored temporary in a glass beaker.
    - Continue the procedure until the entire sample is checked.

Picture 4: *Counting chamber. Each line is suited to the 12X magnification. a) Empty and cleaned. b) Holding a subsample. This density of the particles in this sample is easy to investigate, but one may use a somewhat higher density of particles*

3. If the density of individuals (and other particles) in the original sample is too high (mostly relevant from the intermediate fractions from the sieving, 125-250 µm), the sample can be split prior to investigation (step 2). The splitting is made using a splitting chamber (Picture 5). The original sample is filled into the chamber, and the chamber is tilted continuously back and forth to keep the particles in suspension and retain a homogenous sample. The sample is initially split in "identical" subsamples of 50% of the original volume. The procedure can be repeated to get subsamples of 25 and 12.5%, etc. Make sure to always make note of split samples/volume.



Picture 5: *The splitting chamber used for splitting the samples if dilution is required.*

Identification and counting

1. Identify and count all individuals in the (sub)sample
    - All foraminifera individuals in the samples should be counted and identified to the lowest possible taxonomic level. Make sure to make notes in species abundance lists.
    - Some foraminifera individuals may be broken because of the sampling treatment, or because of degradation in field. This may be a challenge for the agglutinated species. To avoid counting the same individual twice, if broken, only pieces where (likely) >50% of the original body is found should be counted (alternatively, for some species one can decide to count parts with specific characteristics such as mouth parts).

- Individuals that cannot be identified, can either be documented with picture(s) (step 2) or saved separately in small vials (dramsglass) for later identifications. Make sure to always mark these with ID.

2. Pictures of individuals/specimen
    - Pictures can be taken of individuals/specimen
        - to document identification
        - to create a preliminary identification system, e.g. documenting species type a, species type b etc.
        - to be used for later species identifications
    - Create a picture log with sample ID and picture ID
    - Pictures can be printed directly or stored
        - Printing directly by means of the "black and white" video-printer
        - Storage: The video camera on the stereomicroscope can store 30 pictures. When the storage capacity is reached, pictures can be downloaded to the dedicated computer available in the microscopy room (Picture 7). This computer holds and old operative system adapted to the software of the video camera. No password is required. Beware that this computer is not connected to the internet. This also means that no automatic backup is secured, hence regular backups need to be made manually.

Picture 7: Computer to be used for the downloading of pictures. The computer is not connected to the HVL automatic backup.

Ordering of special equipment

- Photo-paper for printer: 50231102 Registreringspapir Sony UPP-110HD, ordered from Modul Nordic (post@modulnordic.no)

Picture 8: *Details for photo-paper order.*

Appendix C

Report from Poznan Radiocarbon Laboratory, with non-calibrated radiocarbon age om bivalve shell.

POZNAN RADIOCARBON LABORATORY

Poznań, 23-03-2021

Report

on C-14 dating in the Poznań Radiocarbon Laboratory

Customer: **Denise Christina Ruther**
Hogskulen pa Vestlandet Campus Sogndal
Institutt for miljo og naturvtiskap
Royrgata 6
6856- Sogndal
Norway

Job no.: 17057/20

Sample name	*Lab. no.*	*Age 14C*	*Remark*
GS20-229-03GC	Poz-134008	**9630 ± 50 BP**	urgent (31.03)
AVP118-1	Poz-0	**>0 BP**	
AVP118-2	Poz-0	**>0 BP**	
AVP118-3	Poz-0	**>0 BP**	
AVP118-4	Poz-0	**>0 BP**	
AVP118-5	Poz-0	**>0 BP**	
AVP118-6	Poz-0	**>0 BP**	
AVP118-7	Poz-0	**>0 BP**	
AVP118-8	Poz-0	**>0 BP**	
AVP318-1	Poz-0	**>0 BP**	

Comments:

Head of the Laboratory

Prof. dr hab. Tomasz Goslar

23-03-2021 *Job no.: 17057/21* *Page 1 from 1*

Appendix D

List of calcareous benthic foraminifera identified to species or genus level with references (original description). Structured alphabetically with family first, followed by genus, and lastly species.

Example:

1. Family A
    a. *Genus A*
        i. *Species A*
    b. *Genus B* (only identified to genus level)
    c. *Genus C*
        i. *Species B*
        ii. *Species C*

Ammodiscidae (Reuss, 1862)

Ammodiscus (Reuss, 1862)

Bolivinitidae (Cushman, 1927)

Bolivina (d'Orbigny, 1839)

B. difformis (Williamson, 1858)

B. pseudoplicata (Heron-Allen & Earland, 1930)

B. spathulata (Williamson, 1858)

Buliminidae (Jones, 1875)

Bulimina (d'Orbigny, 1826)

B. elongata (d'Orbigny, 1846)

B. marginata (d'Orbigny, 1826)

Cassidulinidae (d'Orbigny, 1839)

Cassidulina (d'Orbigny, 1826)

C. laevigata (d'Orbigny, 1826)

C. obtusa (Williamson, 1858)

Chilostomellidae (Brady, 1881)

Chilostomella (Reuss in Čžjžek, 1849)

C. oolina (Schwager, 1878)

Cibicididae (Cushman, 1927)

Cibicidoides (Thalmann, 1939)

C. pseudoungerianus (Cushman, 1922)

Lobatula (Fleming, 1828)

L. lobatula (Walker & Jacob, 1798)

Ellipsolagenidae (A. Silvestri, 1923)

Favulina (Patterson & Richardson, 1988)

F. hexagona (Williamson, 1848)

Fissurina (Reuss, 1850)

F. laevigata (Reuss, 1850)

F. lucida (Williamson, 1848)

F. marginata (Montagu, 1803)

Homalohedra (Patterson & Richardson, 1988)

H. williamsoni (Alcock, 1865)

Oolina (d'Orbigny, 1839)

Elphidiinae (Galloway, 1933)

Cribroelphidium (Cushman & Brönnimann, 1948)

C. incertum (Williamson, 1858)

Elphidium (Montfort, 1808)

Epistominidae (Wedekind, 1937)

Hoeglundina (Brotzen, 1948)

H. elegans (d'Orbigny, 1826)

Gavelinellidae (Hofker, 1956)

Hansenisca (Loeblich & Tappan, 1987)

H. soldanii (d'Orbigny, 1826)

Glandulinidae (Reuss, 1860)

Glandulina (d'Orbigny, 1839)

G. laevigata (d'Orbigny, 1826)

Globobuliminidae (Hofker, 1956)

Globobulimina (Cushman, 1927)

G. turgida (Bailey, 1851)

Hauerinidae (Schwager, 1876)

Pyrgo (Defrance, 1824)

P. williamsoni (Silvestri, 1923)

Quinqueloculina (d'Orbigny, 1826)

Q. seminulum (Linnaeus, 1758)

Sigmopyrgo (Hofker, 1983)

S. vespertilio (Sclumberger, 1891)

Triloculina (d'Orbigny, 1826)

T. frigida (Lagoe, 1977)

Lagenidae (Reuss, 1862)

Lagena (Walker & Jacob, 1798)

L. hispidula (Cushman, 1913)

L. striata (d'Orbigny, 1839)

Procerolagena (Puri, 1954)

P. distoma (Parker & Jones, 1864)

Melonidae (Holzmann & Pawlowski, 2017)

Melonis (Montfort, 1808)

M. affinis (Reuss, 1851)

Nodosariidae (Ehrenberg, 1838)

Dentalina (Risso, 1826)

Nonionidae (Schultze, 1854)

Nonionellina (Voloshinova, 1958)

N. labradorica (Dawson, 1860)

Nonionoides (Saidova, 1975)

N. turgidus (Williamson, 1858)

Planorbulinidae (Schwager, 1877)

Hyalinea (Hofker, 1951)

H. balthica (Schröter, 1783)

Pulleniinae (Schwager, 1877)

Pullenia (Parker & Jones in Carpenter et al., 1862)

P. bulloides (d'Orbigny, 1846)

P. quinqueloba (Reuss, 1851)

Robertinidae (Reuss, 1850)

Robertina (d'Orbigny, 1846)

R. arctica (d'Orbigny, 1846)

Sphaeroidinidae (Cushman, 1927)

Sphaeroidina (d'Orbigny, 1826)

S. bulloides (d'Orbigny in Deshayes, 1828)

Stainforthiidae (Reiss, 1963)

Stainforthia (Hofker, 1956)

S. concava (Höglund, 1947)

S. fusiformis (Williamson, 1858)

Uvigerinidae (Haeckel, 1894)

Trifarina (Cushman, 1923)

T. angulosa (Williamson, 1858)

Uvigerina (d'Orbigny, 1826)

U. mediterranea (Hofker, 1932)

U. peregrina (Cushman, 1923)

Vaginulinidae (Reuss, 1860)

Amphicoryna (Schlumberger in Milne-Edwards, 1881)

A. scalaris (Batsch, 1792)

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Appendix E

Foraminifera raw-data (counted, absolute abundance per ml, and relative abundance). Including percent analysed for each fraction and volume sediments measured in ml.

Sample depth (cm)	0-1			10-11			20-21			30-31			40-41			50-51			60-61		
% Analysed fraction 250 µm–2 mm	50			100			50			50			100			100			50		
% Analysed fraction 125-250 µm	6.25			12.5			6.25			6.25			6.25			6.25			12.5		
ml sediments	11.6			9.6			8.7			11.1			10.5			8.8			9.4		
Counted (C), absolute abundance/ml (A), relative abundance (%)	C	A	%	C	A	%	C	A	%	C	A	%	C	A	%	C	A	%	C	A	%
Taxa																					
Ammodiscus sp. 1													1.00	1.52	0.62						
Amphicoryna scalaris																					
Bolivina difformis	4.00	5.52	1.41	1.00	0.87	0.97										1.00	1.82	0.63	1.00	0.85	0.38
Bolivina pseudoplicata	2.00	2.76	0.71																		
Bolivina spathulata	4.00	5.52	1.41																		
Bolivina sp. 1	3.00	4.14	1.06																		
Bolivina sp. 2													1.00	1.52	0.62				1.00	0.85	0.38
Bolivina sp. 3																					
Bolivina sp. 4																					
Bulimina elongata										1.00	0.18	0.07									
Bulimina marginata	43.00	53.28	13.66	6.00	5.22	5.82	6.00	7.82	8.11	21.00	23.96	9.37	21.00	14.86	6.05	49.00	41.36	14.22	29.00	22.77	10.06
Cassidulina laevigata	38.00	52.41	13.44	20.00	16.63	18.55	7.00	12.87	13.37	43.00	60.72	23.73	40.00	58.10	23.65	32.00	58.18	20.01	57.00	47.87	21.15
Cassidulina obtusa	20.00	27.59	7.07	4.00	3.48	3.88	2.00	3.68	3.82	3.00	4.32	1.69	1.00	1.52	0.62	5.00	9.09	3.13	3.00	2.55	1.13
Cassidulina sp. 1																					
Chilostomella oolina																					
Cibicidoides pseudoungerianus	3.00	2.93	0.75				1.00	1.84	1.91							2.00	0.23	0.08	1.00	0.21	0.09
Cibicidoides sp. 1	23.00	17.24	4.42	5.00	2.83	3.15	1.00	0.23	0.24	4.00	5.77	2.25	8.00	7.90	3.22	7.00	5.91	2.03	9.00	5.74	2.54
Cibicidoides sp. 2													1.00	1.52	0.62				1.00	0.85	0.38
Cibicidoides sp. 3	2.00	0.34	0.09																1.00	0.85	0.38
Cibicidoides sp. 4	1.00	0.17	0.04																		
Cibicidoides sp. 5	2.00	0.34	0.09							1.00	0.18	0.07									
Cibicidoides sp. 6	5.00	0.86	0.22	2.00	0.22	0.24															
Cribroelphidium incertum	1.00	1.38	0.35																		
Dentalina sp. 1													1.00	0.10	0.04						
Dentalina sp. 2																					

Elphidium sp. 1																					
Elphidium sp. 2																					
Favulina hexagona	1.00	1.38	0.35																		
Favulina sp. 1				1.00	0.87	0.97				1.00	1.44	0.56	1.00	1.52	0.62						
Favulina sp. 2	1.00	1.38	0.35																		
Fissurina laevigata																					
Fissurina lucida													1.00	1.52	0.62	1.00	1.82	0.63	1.00	0.85	0.38
Fissurina marginata																1.00	1.82	0.63	1.00	0.85	0.38
Fissurina sp. 1	1.00	1.38	0.35																		
Fissurina sp. 2																			1.00	0.85	0.38
Fissurina sp. 3	1.00	1.38	0.35	1.00	0.87	0.97															
Fissurina sp. 4																			1.00	0.85	0.38
Glandulina laevigata													1.00	0.10	0.04	1.00	0.11	0.04	1.00	0.21	0.09
Globobulimina turgida	34.00	7.07	1.81	37.00	5.54	6.18	37.00	10.11	10.50	32.00	9.55	3.73	103	15.52	6.32	46.00	6.93	2.38	36.00	10.21	4.51
Hansenisca soldanii																					
Hoeglundina elegans				3.00	2.61	2.91	1.00	1.84	1.91	6.00	8.65	3.38	7.00	10.67	4.34	8.00	14.55	5.00	15.00	12.77	5.64
Homalohedra williamsoni																					
Hyalinea balthica	89	28.62	7.34	37.00	8.59	9.58	56.00	20.92	21.72	124.00	62.70	24.51	216.00	47.71	19.43	247.00	72.39	24.89	144.00	62.55	27.63
Lagena hispidula				1.00	0.11	0.12															
Lagena striata													1.00	0.10	0.04				1.00	0.85	0.38
Lagena sp. 1																					
Lobatula lobatula	120.00	72.59	18.61	16.00	4.02	4.48	10.00	8.74	9.07	10.00	11.89	4.65	11.00	8.19	3.33	25.00	14.77	5.08	9.00	4.47	1.97
Melonis affinis	2.00	0.34	0.09				1.00	1.84	1.91												
Nonionellina labradorica	10.00	5.34	1.37	12.00	6.63	7.39	9.00	10.11	10.50	15.00	16.58	6.48	38.00	29.33	11.94	31.00	18.86	6.49	22.00	11.06	4.89
Nonionoides turgidus	4.00	5.52	1.41							1.00	1.44	0.56				5.00	9.09	3.13	2.00	1.70	0.75
Oolina sp. 1																					
Oolina sp. 2																					
Procerolagena distoma				1.00	0.11	0.12				1.00	1.44	0.56	2.00	3.05	1.24				1.00	0.85	0.38
Procerolagena sp. 1																					
Procerolagena sp. 2																					
Procerolagena sp. 3																					
Pullenia bulloides																					
Pullenia quinqueloba	4.00	3.10	0.80	7.00	2.28	2.55	2.00	2.07	2.15	1.00	0.18	0.07				2.00	0.23	0.08			
Pyrgo williamsoni	2.00	0.34	0.09				4.00	0.92	0.95										2.00	0.43	0.19
Quinqueloculina seminulum	3.00	0.52	0.13																		
Robertina arctica																					
Sigmopyrgo vespertilio																			1.00	0.21	0.09
Sphaeroidina bulloides										2.00	0.36	0.14									
Stainforthia concava																					

Stainforthia fusiformis	4.00	5.52	1.41	4.00	3.48	3.88				1.00	1.44	0.56	3.00	4.57	1.86	1.00	1.82	0.63	5.00	4.26	1.88
Stainforthia sp. 1																					
Stainforthia sp. 2																					
Stainforthia sp. 3																					
Trifarina angulosa	15.00	15.86	4.07	5.00	3.59	4.00	5.00	7.59	7.88	12.00	16.04	6.27	1.00	1.52	0.62	4.00	7.27	2.50	4.00	3.40	1.50
Triloculina frigida	1.00	0.17	0.04																		
Uvigerina mediterranea																					
Uvigerina peregrina	8.00	1.38	0.35										14.00	4.19	1.71	23.00	2.61	0.90	10.00	3.40	1.50
UN-ID 1													1.00	0.10	0.04						
UN-ID 2																			1.00	0.21	0.09
UN-ID 3	1.00	1.38	0.35																1.00	0.85	0.38
UN-ID 4																					
UN-ID 5																					
UN-ID 6																					
UN-ID 7																					
UN-ID 8																					
UN-ID 9																					
UN-ID 10										1.00	1.44	0.56				1.00	1.82	0.63	1.00	0.85	0.38
UN-ID 11																					
UN-ID 12																					
UN-ID 13				1.00	0.87	0.97				1.00	1.44	0.56	1.00	1.52	0.62						
UN-ID 14										1.00	1.44	0.56									
UN-ID 15																1.00	1.82	0.63	1.00	0.85	0.38
UN-ID 16	1.00	1.38	0.35																		
UN-ID 17																					
UN-ID 18	9.00	12.41	3.18							1.00	0.18	0.07				1.00	0.11	0.04			
UN-ID 19																					
UN-ID 20							1.00	0.23	0.24												
UN-ID 21										1.00	1.44	0.56									
UN-ID 22																					
UN-ID 23																			1.00	0.85	0.38
UN-ID 24																					
UN-ID 25	1.00	0.17	0.04																		
UN-ID 26	4.00	5.52	1.41																		
UN-ID 27	8.00	11.03	2.83																		
UN-ID 28	1.00	1.38	0.35																		
UN-ID 29																					
UN-ID 30	2.00	2.76	0.71	1.00	0.87	0.97				3.00	4.32	1.69				2.00	3.64	1.25	5.00	4.26	1.88
UN-ID 31	4.00	5.52	1.41																		

UN-ID 32	2.00	2.76	0.71							1.00	1.44	0.56	1.00	1.52	0.62	1.00	1.82	0.63			
UN-ID 33	6.00	8.28	2.12	13.00	11.30	12.61	2.00	3.68	3.82	6.00	8.65	3.38	10.00	15.24	6.20	6.00	10.91	3.75	18.00	15.32	6.77
UN-ID 34	5.00	6.90	1.77	7.00	6.09	6.79				4.00	5.77	2.25	3.00	4.57	1.86	1.00	1.82	0.63			
UN-ID 35				1.00	0.87	0.97													1.00	0.85	0.38
UN-ID 36																					
UN-ID 37													3.00	4.57	1.86						
UN-ID 38	3.00	4.14	1.06	2.00	1.74	1.94	1.00	1.84	1.91	2.00	2.88	1.13	2.00	3.05	1.24						
Agglutinated spp. (*)	166.00	144.48	27.03	111.00	53.15	37.21	107.00	105.06	52.17	103.00	103.06	28.71	90.00	61.43	20.01	92.00	85.45	22.71	154.00	88.30	28.06
Planktonic spp. (**)	15.00	20.69	5.04	6.00	5.22	5.50				1.00	1.44	0.56	1.00	1.52	0.62	2.00	3.64	1.24	1.00	0.85	0.37

*= Relative abundance is calculated from agglutinated + calcareous, not including planktonic spp.

**= Relative abundance is calculated from planktonic + calcareous, not including agglutinated spp.

Western Norway University of Applied Sciences

Sample depth (cm)	70-71			80-81			90-91			100-101			110-111			120-121			130-131		
% Analysed fraction 250 µm–2 mm	50			50			50			50			50			50			50		
% Analysed fraction 125-250 µm	12.5			12.5			12.5			12.5			12.5			12.5			12.5		
ml sediments	9.5			7.5			9.5			8.8			8.5			9.3			10		
Counted (C), absolute abundance/ml (A), relative abundance (%)	**C**	**A**	**%**	**C**	**A**	**%**	**C**	**A**	**%**	**C**	**A**	**%**	**C**	**A**	**%**	**C**	**A**	**%**	**C**	**A**	**%**
Taxa																					
Ammodiscus sp. 1																			1.00	0.80	0.50
Amphicoryna scalaris													1.00	0.94	0.63						
Bolivina difformis	5.00	4.21	1.57	2.00	2.13	0.73	1.00	0.84	0.47	1.00	0.91	0.57	3.00	2.82	1.88						
Bolivina pseudoplicata													2.00	1.88	1.26						
Bolivina spathulata	1.00	0.84	0.31	1.00	1.07	0.37															
Bolivina sp. 1																					
Bolivina sp. 2																					
Bolivina sp. 3							1.00	0.84	0.47												
Bolivina sp. 4																					
Bulimina elongata				2.00	0.53	0.18															
Bulimina marginata	75.00	54.32	20.22	71.00	60.53	20.77	80.00	55.37	30.98	68.00	50.91	32.09	63.00	52.94	35.32	114.00	80.65	46.82	92.00	64.60	40.27
Cassidulina laevigata	28.00	23.58	8.78	20.00	21.33	7.32	25.00	21.05	11.78	19.00	16.59	10.46	10.00	9.41	6.28	2.00	1.72	1.00	6.00	4.80	2.99
Cassidulina obtusa	4.00	3.37	1.25				2.00	1.68	0.94	1.00	0.91	0.57	3.00	2.82	1.88	2.00	1.72	1.00	2.00	1.60	1.00
Cassidulina sp. 1																					
Chilostomella oolina																					
Cibicidoides pseudoungerianus				1.00	1.07	0.37	2.00	1.68	0.94										6.00	4.80	2.99
Cibicidoides sp. 1	16.00	9.68	3.61	12.00	7.20	2.47	7.00	4.00	2.24	3.00	1.36	0.86	3.00	0.71	0.47	3.00	1.29	0.75	2.00	1.00	0.62
Cibicidoides sp. 2	4.00	1.47	0.55	1.00	0.27	0.09							1.00	0.94	0.63	1.00	0.22	0.12			
Cibicidoides sp. 3	1.00	0.21	0.08	1.00	1.07	0.37															
Cibicidoides sp. 4																					
Cibicidoides sp. 5													1.00	0.94	0.63						
Cibicidoides sp. 6										1.00	0.91	0.57									
Cribroelphidium incertum																					
Dentalina sp. 1																					
Dentalina sp. 2	1.00	0.21	0.08													1.00	0.22	0.12			
Elphidium sp. 1																					
Elphidium sp. 2																					
Favulina hexagona																					
Favulina sp. 1																					
Favulina sp. 2	1.00	0.84	0.31																		
Fissurina laevigata																			1.00	0.80	0.50
Fissurina lucida										1.00	0.91	0.57									
Fissurina marginata	2.00	1.68	0.63													2.00	1.72	1.00			

Fissurina sp. 1																					
Fissurina sp. 2																					
Fissurina sp. 3																					
Fissurina sp. 4																					
Glandulina laevigata							1.00	0.21	0.12	1.00	0.23	0.14				1.00	0.86	0.50	1.00	0.80	0.50
Globobulimina turgida	11.00	2.95	1.10	14.00	3.73	1.28	33.00	6.95	3.89	28.00	9.77	6.16	20.00	6.12	4.08	35.00	8.17	4.74	18.00	3.60	2.24
Hansenisca soldanii																			1.00	0.20	0.12
Hoeglundina elegans	18.00	15.16	5.64	10.00	10.67	3.66	2.00	1.68	0.94	1.00	0.91	0.57									
Homalohedra williamsoni																					
Hyalinea balthica	167.00	68.00	25.31	186.00	107.20	36.78	137.00	47.79	26.74	107.00	48.18	30.37	75.00	33.88	22.61	111.00	40.00	23.22	97.00	41.00	25.56
Lagena hispidula																					
Lagena striata	1.00	0.21	0.08	1.00	1.07	0.37	1.00	0.84	0.47	1.00	0.23	0.14	1.00	0.24	0.16						
Lagena sp. 1																					
Lobatula lobatula	36.00	20.21	7.52	30.00	15.20	5.22	24.00	10.74	6.01	6.00	3.41	2.15	9.00	6.35	4.24	13.00	6.02	3.50	14.00	7.00	4.36
Melonis affinis													1.00	0.94	0.63	1.00	0.22	0.12			
Nonionellina labradorica	40.00	21.05	7.84	19.00	13.07	4.48	8.00	6.11	3.42	2.00	1.14	0.72	2.00	1.88	1.26	1.00	0.22	0.12			
Nonionoides turgidus	10.00	8.42	3.13	8.00	8.53	2.93	2.00	1.68	0.94	6.00	5.45	3.44	5.00	4.71	3.14	13.00	11.18	6.49	11.00	8.80	5.49
Oolina sp. 1																					
Oolina sp. 2																			1.00	0.80	0.50
Procerolagena distoma	1.00	0.84	0.31				1.00	0.84	0.47	1.00	0.91	0.57				1.00	0.86	0.50	1.00	0.80	0.50
Procerolagena sp. 1																					
Procerolagena sp. 2																					
Procerolagena sp. 3																					
Pullenia bulloides	2.00	1.68	0.63																		
Pullenia quinqueloba	4.00	0.84	0.31	2.00	1.33	0.46							4.00	2.35	1.57	6.00	2.58	1.50	4.00	2.60	1.62
Pyrgo williamsoni																2.00	0.43	0.25	2.00	1.00	0.62
Quinqueloculina seminulum																					
Robertina arctica							1.00	0.84	0.47												
Sigmopyrgo vespertilio																					
Sphaeroidina bulloides										1.00	0.23	0.14									
Stainforthia concava																					
Stainforthia fusiformis	5.00	4.21	1.57	5.00	5.33	1.83	1.00	0.84	0.47	5.00	4.55	2.87	9.00	8.47	5.65	2.00	1.72	1.00	7.00	5.60	3.49
Stainforthia sp. 1																					
Stainforthia sp. 2																					
Stainforthia sp. 3																			1.00	0.80	0.50
Trifarina angulosa	9.00	7.58	2.82	14.00	14.93	5.12	4.00	3.37	1.88	3.00	2.73	1.72	4.00	3.76	2.51	2.00	1.72	1.00	4.00	3.20	2.00
Triloculina frigida													1.00	0.24	0.16	2.00	1.08	0.62			
Uvigerina mediterranea																					
Uvigerina peregrina	13.00	2.74	1.02	15.00	5.60	1.92	16.00	4.63	2.59	14.00	3.86	2.44	4.00	0.94	0.63	12.00	3.23	1.87	3.00	1.80	1.12
UN-ID 1																					

UN-ID 2																				
UN-ID 3																1.00	0.22	0.12		
UN-ID 4																1.00	0.22	0.12		
UN-ID 5																				
UN-ID 6																				
UN-ID 7																			1.00	0.80	0.50
UN-ID 8																				
UN-ID 9													1.00	0.94	0.63					
UN-ID 10				1.00	1.07	0.37							2.00	1.88	1.26					
UN-ID 11	1.00	0.84	0.31																	
UN-ID 12	1.00	0.84	0.31																	
UN-ID 13																				
UN-ID 14																				
UN-ID 15																				
UN-ID 16																				
UN-ID 17																				
UN-ID 18																				
UN-ID 19																				
UN-ID 20																				
UN-ID 21																				
UN-ID 22																				
UN-ID 23													1.00	0.94	0.63					
UN-ID 24																				
UN-ID 25	1.00	0.84	0.31																	
UN-ID 26																				
UN-ID 27																				
UN-ID 28																				
UN-ID 29																				
UN-ID 30	4.00	3.37	1.25				2.00	1.68	0.94	5.00	4.55	2.87	1.00	0.94	0.63	7.00	6.02	3.50	3.00	2.40	1.50
UN-ID 31																				
UN-ID 32																				
UN-ID 33	9.00	7.58	2.82	8.00	8.53	2.93	6.00	5.05	2.83											
UN-ID 34	1.00	0.84	0.31										2.00	1.88	1.26				1.00	0.80	0.50
UN-ID 35																				
UN-ID 36																				
UN-ID 37																				
UN-ID 38																				
Agglutinated spp. (*)	106.00	62.74	18.93	91.00	73.87	20.22	100.00	65.26	26.75	104.00	66.59	29.57	52.00	34.82	18.85	40.00	18.92	9.90	28.00	16.40	9.28
Planktonic spp. (**)	11.00	9.26	3.33	7.00	7.47	2.50	5.00	4.21	2.30	10.00	9.09	5.42	17.00	16.00	9.65	4.00	3.44	1.96	3.00	2.40	1.47

*= Relative abundance is calculated from agglutinated + calcareous, not including planktonic spp.

**= Relative abundance is calculated from planktonic + calcareous, not including agglutinated spp.

Western Norway University of Applied Sciences

Sample depth (cm)	140-141			150-151			160-161			170-171			180-181			190-191			200-201		
% Analysed fraction 250 µm–2 mm	50			50			50			50			100			100			100		
% Analysed fraction 125-250 µm	12.5			12.5			12.5			12.5			12.5			34.38			12.5		
ml sediments	9.2			12.5			11.5			10.9			11.9			9.6			10.8		
Counted (C), absolute abundance/ml (A), relative abundance (%)	C	A	%	C	A	%	C	A	%	C	A	%	C	A	%	C	A	%	C	A	%
Taxa																					
Ammodiscus sp. 1													1.00	0.67	0.77						
Amphicoryna scalaris																					
Bolivina difformis							1.00	0.70	0.74												
Bolivina pseudoplicata																					
Bolivina spathulata																					
Bolivina sp. 1																					
Bolivina sp. 2																					
Bolivina sp. 3																					
Bolivina sp. 4																					
Bulimina elongata	1.00	0.22	0.20																		
Bulimina marginata	60.00	42.39	39.31	101.00	58.40	47.71	91.00	50.26	53.72	74.00	40.00	50.93	83.00	34.62	39.54	76.00	20.25	37.84	50.00	33.15	39.65
Cassidulina laevigata	3.00	2.61	2.42	5.00	3.20	2.61	1.00	0.70	0.74				4.00	2.69	3.07	11.00	3.33	6.23	3.00	2.22	2.66
Cassidulina obtusa	2.00	1.74	1.61	3.00	1.92	1.57	1.00	0.70	0.74	1.00	0.73	0.93	2.00	1.34	1.54				3.00	2.22	2.66
Cassidulina sp. 1																					
Chilostomella oolina																1.00	0.30	0.57	7.00	3.24	3.88
Cibicidoides pseudoungerianus	3.00	2.61	2.42										4.00	0.34	0.38	3.00	0.71	1.33			
Cibicidoides sp. 1	2.00	0.43	0.40	8.00	2.72	2.22							3.00	0.84	0.96				1.00	0.09	0.11
Cibicidoides sp. 2																					
Cibicidoides sp. 3										1.00	0.73	0.93									
Cibicidoides sp. 4	2.00	1.74	1.61																		
Cibicidoides sp. 5	1.00	0.87	0.81																		
Cibicidoides sp. 6																					
Cribroelphidium incertum							1.00	0.70	0.74												
Dentalina sp. 1																					
Dentalina sp. 2																					
Elphidium sp. 1																					
Elphidium sp. 2																					
Favulina hexagona																					
Favulina sp. 1																					
Favulina sp. 2																					
Fissurina laevigata							1.00	0.70	0.74												
Fissurina lucida																					
Fissurina marginata	1.00	0.87	0.81													1.00	0.30	0.57			

Fissurina sp. 1																					
Fissurina sp. 2																					
Fissurina sp. 3																					
Fissurina sp. 4																					
Glandulina laevigata	3.00	1.30	1.21				1.00	0.17	0.19	1.00	0.18	0.23	2.00	0.17	0.19	1.00	0.10	0.19			
Globobulimina turgida	22.00	5.43	5.04	19.00	4.00	3.27	25.00	4.35	4.65	37.00	7.34	9.35	32.00	3.28	3.74	12.00	1.45	2.71	6.00	1.20	1.44
Hansenisca soldanii	3.00	0.65	0.60	7.00	1.12	0.92	2.00	0.35	0.37	5.00	0.92	1.17	4.00	0.34	0.38	1.00	0.10	0.19			
Hoeglundina elegans				1.00	0.64	0.52	1.00	0.70	0.74										1.00	0.74	0.89
Homalohedra williamsoni																					
Hyalinea balthica	56.00	28.48	26.41	72.00	24.00	19.61	52.00	17.39	18.59	44.00	14.13	17.99	115.00	20.84	23.80	58.00	14.00	26.16	78.00	23.43	28.02
Lagena hispidula																					
Lagena striata	1.00	0.22	0.20	2.00	0.32	0.26	2.00	0.87	0.93	1.00	0.18	0.23									
Lagena sp. 1				1.00	0.16	0.13															
Lobatula lobatula	2.00	0.43	0.40	9.00	3.36	2.75	2.00	0.87	0.93	3.00	1.65	2.10	7.00	1.18	1.34	3.00	0.91	1.70	2.00	1.48	1.77
Melonis affinis	2.00	1.74	1.61	2.00	0.32	0.26							1.00	0.08	0.10	1.00	0.10	0.19	1.00	0.09	0.11
Nonionellina labradorica				1.00	0.64	0.52							1.00	0.67	0.77						
Nonionoides turgidus	6.00	5.22	4.84	12.00	7.68	6.27	3.00	2.09	2.23	7.00	5.14	6.54	17.00	11.43	13.05	18.00	5.46	10.20	12.00	8.89	10.63
Oolina sp. 1													1.00	0.67	0.77						
Oolina sp. 2																					
Procerolagena distoma				1.00	0.64	0.52										1.00	0.30	0.57			
Procerolagena sp. 1																					
Procerolagena sp. 2																					
Procerolagena sp. 3																1.00	0.30	0.57			
Pullenia bulloides																1.00	0.30	0.57			
Pullenia quinqueloba	4.00	2.17	2.02	3.00	0.96	0.78	1.00	0.70	0.74	2.00	0.37	0.47	2.00	1.34	1.54				1.00	0.74	0.89
Pyrgo williamsoni	1.00	0.22	0.20				1.00	0.70	0.74				1.00	0.67	0.77				3.00	0.28	0.33
Quinqueloculina seminulum													1.00	0.08	0.10				1.00	0.74	0.89
Robertina arctica																					
Sigmopyrgo vespertilio																					
Sphaeroidina bulloides	1.00	0.22	0.20																		
Stainforthia concava																					
Stainforthia fusiformis	2.00	1.74	1.61	7.00	4.48	3.66	9.00	6.26	6.69				2.00	1.34	1.54	9.00	2.73	5.10	3.00	2.22	2.66
Stainforthia sp. 1																					
Stainforthia sp. 2																					
Stainforthia sp. 3				1.00	0.64	0.52															
Trifarina angulosa	1.00	0.87	0.81	5.00	3.20	2.61	5.00	3.48	3.72	5.00	2.57	3.27	7.00	4.12	4.70	3.00	0.91	1.70	1.00	0.74	0.89
Triloculina frigida				2.00	1.28	1.05							1.00	0.08	0.10						
Uvigerina mediterranea																			2.00	0.19	0.22
Uvigerina peregrina	3.00	1.30	1.21	6.00	1.44	1.18	3.00	0.52	0.56				1.00	0.08	0.10	7.00	0.73	1.36	14.00	1.94	2.33
UN-ID 1																					

UN-ID 2																				
UN-ID 3																				
UN-ID 4																				
UN-ID 5																				
UN-ID 6										1.00	0.18	0.23								
UN-ID 7																				
UN-ID 8																				
UN-ID 9																1.00	0.30	0.57		
UN-ID 10	1.00	0.87	0.81							1.00	0.73	0.93								
UN-ID 11																				
UN-ID 12																				
UN-ID 13																				
UN-ID 14																				
UN-ID 15																				
UN-ID 16																				
UN-ID 17							1	0.696	0.743											
UN-ID 18																				
UN-ID 19																1	0.303	0.566		
UN-ID 20																				
UN-ID 21				1.00	0.64	0.52				1.00	0.73	0.93	1.00	0.67	0.77					
UN-ID 22										1.00	0.73	0.93								
UN-ID 23	1.00	0.87	0.81																	
UN-ID 24																				
UN-ID 25																				
UN-ID 26																				
UN-ID 27																				
UN-ID 28																				
UN-ID 29																				
UN-ID 30	2.00	1.74	1.61	1.00	0.64	0.52	1.00	0.70	0.74	3.00	2.20	2.80								
UN-ID 31																				
UN-ID 32																1.00	0.30	0.57		
UN-ID 33																				
UN-ID 34																1.00	0.30	0.57		
UN-ID 35																				
UN-ID 36																				
UN-ID 37	1.00	0.87	0.81																	
UN-ID 38																				
Agglutinated spp. (*)	21.00	11.09	9.32	20.00	8.48	6.48	9.00	2.61	2.71	11.00	3.67	4.46	9.00	1.34	1.51	19.00	4.76	8.17	2.00	0.19	0.22
Planktonic spp. (**)	6.00	5.22	4.62	8.00	5.12	4.02	5.00	3.48	3.58	5.00	3.67	4.46	5.00	3.36	3.70	10.00	3.03	5.36	11.00	8.15	8.88

*= Relative abundance is calculated from agglutinated + calcareous, not including planktonic spp.

**= Relative abundance is calculated from planktonic + calcareous, not including agglutinated spp.

Western Norway University of Applied Sciences

Sample depth (cm)	210-211			220-221			230-231			240-241			250-251			260-261			270-271		
% Analysed fraction 250 µm–2 mm	100			100			100			100			50			50			100		
% Analysed fraction 125-250 µm	12.5			12.5			12.5			12.5			12.5			12.5			12.5		
ml sediments	8.5			9.9			9.1			9.4			9.5			10.5			8.7		
Counted (C), absolute abundance/ml (A), relative abundance (%)	C	A	%	C	A	%	C	A	%	C	A	%	C	A	%	C	A	%	C	A	%
Taxa																					
Ammodiscus sp. 1				1.00	0.81	0.63													1.00	0.92	0.60
Amphicoryna scalaris													1.00	0.84	0.28						
Bolivina difformis										1.00	0.85	0.44				1.00	0.76	0.32	1.00	0.92	0.60
Bolivina pseudoplicata																					
Bolivina spathulata																					
Bolivina sp. 1																					
Bolivina sp. 2																					
Bolivina sp. 3																					
Bolivina sp. 4																1.00	0.76	0.32			
Bulimina elongata																					
Bulimina marginata	79.00	65.29	54.79	108.00	66.06	51.17	156.00	95.60	49.94	170.00	74.68	39.04	174.00	87.79	29.26	164.00	71.24	29.82	42.00	34.60	22.60
Cassidulina laevigata	5.00	4.71	3.95	7.00	5.66	4.38	5.00	4.40	2.30	8.00	6.81	3.56	9.00	7.58	2.53	10.00	7.62	3.19	13.00	11.95	7.81
Cassidulina obtusa	2.00	1.88	1.58	5.00	4.04	3.13	4.00	3.52	1.84	2.00	1.70	0.89	6.00	5.05	1.68	5.00	3.81	1.59	14.00	12.87	8.41
Cassidulina sp. 1																					
Chilostomella oolina	19.00	8.82	7.40	16.00	8.69	6.73	17.00	11.10	5.80	20.00	12.55	6.56	27.00	16.42	5.47	20.00	11.81	4.94	13.00	7.13	4.65
Cibicidoides pseudoungerianus							1.00	0.88	0.46	5.00	0.53	0.28	4.00	0.84	0.28	5.00	2.10	0.88	3.00	1.95	1.28
Cibicidoides sp. 1	2.00	0.24	0.20	3.00	1.72	1.33	12.00	3.63	1.89	4.00	1.91	1.00	1.00	0.21	0.07	3.00	2.29	0.96	3.00	1.15	0.75
Cibicidoides sp. 2	1.00	0.94	0.79				1.00	0.88	0.46										1.00	0.92	0.60
Cibicidoides sp. 3																					
Cibicidoides sp. 4										1.00	0.11	0.06	1.00	0.21	0.07						
Cibicidoides sp. 5																					
Cibicidoides sp. 6							1.00	0.88	0.46							1.00	0.76	0.32	2.00	1.84	1.20
Cribroelphidium incertum																					
Dentalina sp. 1																					
Dentalina sp. 2																					
Elphidium sp. 1																					
Elphidium sp. 2													2.00	1.68	0.56				1.00	0.92	0.60
Favulina hexagona																					
Favulina sp. 1																					
Favulina sp. 2																					
Fissurina laevigata																					
Fissurina lucida																					
Fissurina marginata	1.00	0.94	0.79																		

Fissurina sp. 1																				
Fissurina sp. 2																				
Fissurina sp. 3																				
Fissurina sp. 4																				
Glandulina laevigata																				
Globobulimina turgida	3.00	0.35	0.30	4.00	0.40	0.31	6.00	0.66	0.34	2.00	0.21	0.11	22.00	4.63	1.54	18.00	4.00	1.67	6.00	0.69	0.45
Hansenisca soldanii				2.00	0.91	0.70				1.00	0.11	0.06				1.00	0.19	0.08	1.00	0.11	0.08
Hoeglundina elegans				1.00	0.81	0.63	2.00	1.76	0.92	4.00	3.40	1.78									
Homalohedra williamsoni																					
Hyalinea balthica	43.00	19.88	16.68	94.00	22.93	17.76	176.00	43.19	22.56	310.00	66.49	34.76	368.00	129.26	43.09	272.00	107.24	44.90	118.00	35.29	23.05
Lagena hispidula																					
Lagena striata				1.00	0.10	0.08	1.00	0.11	0.06	1.00	0.11	0.06							1.00	0.11	0.08
Lagena sp. 1																			1.00	0.11	0.08
Lobatula lobatula	2.00	0.24	0.20	4.00	1.11	0.86	7.00	3.85	2.01	6.00	1.38	0.72	8.00	2.32	0.77	7.00	4.19	1.75	21.00	12.07	7.88
Melonis affinis	1.00	0.12	0.10	10.00	1.01	0.78	15.00	2.42	1.26	16.00	2.45	1.28	29.00	9.89	3.30	33.00	10.86	4.55	12.00	2.18	1.43
Nonionellina labradorica				1.00	0.81	0.63										1.00	0.76	0.32			
Nonionoides turgidus	11.00	10.35	8.69	1.00	0.81	0.63	1.00	0.88	0.46	2.00	1.70	0.89							1.00	0.92	0.60
Oolina sp. 1																					
Oolina sp. 2																					
Procerolagena distoma																					
Procerolagena sp. 1																1.00	0.76	0.32			
Procerolagena sp. 2							1.00	0.88	0.46												
Procerolagena sp. 3																					
Pullenia bulloides										1.00	0.11	0.06	1.00	0.21	0.07						
Pullenia quinqueloba				1.00	0.81	0.63				1.00	0.11	0.06	4.00	3.37	1.12						
Pyrgo williamsoni	1.00	0.12	0.10	2.00	0.20	0.16	1.00	0.88	0.46							3.00	1.14	0.48			
Quinqueloculina seminulum																1.00	0.19	0.08			
Robertina arctica																					
Sigmopyrgo vespertilio																					
Sphaeroidina bulloides																					
Stainforthia concava																			1.00	0.92	0.60
Stainforthia fusiformis	1.00	0.94	0.79	5.00	4.04	3.13	2.00	1.76	0.92	1.00	0.85	0.44	8.00	6.74	2.25	1.00	0.76	0.32			
Stainforthia sp. 1										1.00	0.85	0.44									
Stainforthia sp. 2							1.00	0.88	0.46												
Stainforthia sp. 3																					
Trifarina angulosa				4.00	3.23	2.50	8.00	5.49	2.87	13.00	10.32	5.39	11.00	9.26	3.09	3.00	2.29	0.96	11.00	10.11	6.61
Triloculina frigida													2.00	1.68	0.56				1.00	0.11	0.08
Uvigerina mediterranea	1.00	0.12	0.10				10.00	4.18	2.18	13.00	1.38	0.72	11.00	2.95	0.98	5.00	0.95	0.40	3.00	0.34	0.23
Uvigerina peregrina	5.00	1.41	1.18	17.00	1.72	1.33	25.00	2.75	1.44	10.00	1.81	0.95	25.00	6.53	2.18	15.00	2.86	1.20	1.00	0.11	0.08

UN-ID 1																				
UN-ID 2																				
UN-ID 3	2.00	1.88	1.58	1.00	0.81	0.63							1.00	0.84	0.28				1.00	0.92	0.60
UN-ID 4																				
UN-ID 5																				
UN-ID 6																				
UN-ID 7																			1.00	0.92	0.60
UN-ID 8													1.00	0.84	0.28					
UN-ID 9	1.00	0.94	0.79							1.00	0.85	0.44								
UN-ID 10																				
UN-ID 11																				
UN-ID 12																				
UN-ID 13																				
UN-ID 14																				
UN-ID 15																				
UN-ID 16																				
UN-ID 17																				
UN-ID 18																			2.00	1.839	1.201
UN-ID 19																				
UN-ID 20																			4.00	2.87	1.88
UN-ID 21																				
UN-ID 22																				
UN-ID 23																				
UN-ID 24																			2.00	1.84	1.20
UN-ID 25																				
UN-ID 26																				
UN-ID 27																				
UN-ID 28																				
UN-ID 29																			4.00	3.68	2.40
UN-ID 30				3.00	2.42	1.88	1.00	0.88	0.46												
UN-ID 31																				
UN-ID 32																				
UN-ID 33																				
UN-ID 34																				
UN-ID 35																				
UN-ID 36													1.00	0.84	0.28	2.00	1.52	0.64	3.00	2.76	1.80
UN-ID 37																				
UN-ID 38																				
Agglutinated spp. (*)	1.00	0.12	0.10	4.00	1.82	1.39	5.00	0.55	0.29	6.00	2.13	1.10	2.00	0.42	0.14				2.00	1.84	1.19

Planktonic spp. (**)	14.00	13.18	9.96	15.00	12.12	8.58	9.00	7.91	3.97	6.00	5.11	2.60	18.00	15.16	4.81	26.00	19.81	7.66	17.00	15.63	9.26

*= Relative abundance is calculated from agglutinated + calcareous, not including planktonic spp.

**= Relative abundance is calculated from planktonic + calcareous, not including agglutinated spp.

Western Norway University of Applied Sciences

Sample depth (cm)	280-281			290-291		
% Analysed fraction 250 µm–2 mm	50			100		
% Analysed fraction 125-250 µm	25			25		
ml sediments	8.5			10		
Counted (C), absolute abundance/ml (A), relative abundance (%)	**C**	**A**	**%**	**C**	**A**	**%**
Taxa						
Ammodiscus sp. 1	1.00	0.47	0.28			
Amphicoryna scalaris	1.00	0.47	0.28			
Bolivina difformis						
Bolivina pseudoplicata	2.00	0.94	0.55			
Bolivina spathulata						
Bolivina sp. 1						
Bolivina sp. 2						
Bolivina sp. 3						
Bolivina sp. 4						
Bulimina elongata						
Bulimina marginata	34.00	16.00	9.35	53.00	20.9	27.76
Cassidulina laevigata	90.00	42.35	24.76	23.00	9.2	12.22
Cassidulina obtusa	7.00	3.29	1.93	3.00	1.2	1.594
Cassidulina sp. 1	2.00	0.94	0.55	12.00	4.8	6.375
Chilostomella oolina	1.00	0.47	0.28			
Cibicidoides pseudoungerianus				6.00	2.4	3.19
Cibicidoides sp. 1	6.00	1.88	1.10	6.00	2.4	3.19
Cibicidoides sp. 2						
Cibicidoides sp. 3						
Cibicidoides sp. 4						
Cibicidoides sp. 5	25.00	8.94	5.23			
Cibicidoides sp. 6	25.00	8.71	5.09	7.00	1.3	1.73
Cribroelphidium incertum	1.00	0.47	0.28			
Dentalina sp. 1						
Dentalina sp. 2						
Elphidium sp. 1	1.00	0.47	0.28			
Elphidium sp. 2	3.00	1.41	0.83			
Favulina hexagona	1.00	0.47	0.28			
Favulina sp. 1						
Favulina sp. 2						
Fissurina laevigata						
Fissurina lucida						
Fissurina marginata						

Fissurina sp. 1						
Fissurina sp. 2						
Fissurina sp. 3						
Fissurina sp. 4						
Glandulina laevigata				1.00	0.1	0.13
Globobulimina turgida						
Hansenisca soldanii						
Hoeglundina elegans	9.00	4.24	2.48	2.00	0.8	1.06
Homalohedra williamsoni	1.00	0.47	0.28			
Hyalinea balthica	1.00	0.47	0.28			
Lagena hispidula						
Lagena striata						
Lagena sp. 1				1.00	0.4	0.53
Lobatula lobatula	84.00	24.47	14.31	8.00	1.1	1.46
Melonis affinis	21.00	6.35	3.71	9.00	2.1	2.79
Nonionellina labradorica	1.00	0.47	0.28	5.00	0.5	0.66
Nonionoides turgidus	3.00	1.41	0.83	3.00	1.2	1.59
Oolina sp. 1						
Oolina sp. 2						
Procerolagena distoma						
Procerolagena sp. 1						
Procerolagena sp. 2						
Procerolagena sp. 3						
Pullenia bulloides						
Pullenia quinqueloba						
Pyrgo williamsoni	1.00	0.24	0.14			
Quinqueloculina seminulum						
Robertina arctica						
Sigmopyrgo vespertilio						
Sphaeroidina bulloides	1.00	0.47	0.28			
Stainforthia concava				3.00	1.2	1.59
Stainforthia fusiformis	1.00	0.47	0.28			
Stainforthia sp. 1						
Stainforthia sp. 2						
Stainforthia sp. 3						
Trifarina angulosa	67.00	31.53	18.43	42.00	16.8	22.31
Triloculina frigida						
Uvigerina mediterranea	4.00	0.94	0.55			
Uvigerina peregrina						
UN-ID 1						

UN-ID 2						
UN-ID 3	7.00	3.29	1.93			
UN-ID 4						
UN-ID 5	1.00	0.24	0.14			
UN-ID 6						
UN-ID 7						
UN-ID 8						
UN-ID 9						
UN-ID 10						
UN-ID 11						
UN-ID 12						
UN-ID 13						
UN-ID 14						
UN-ID 15						
UN-ID 16						
UN-ID 17						
UN-ID 18	2.00	0.94	0.55	3.00	1.2	1.59
UN-ID 19						
UN-ID 20	7.00	3.29	1.93	11.00	4.1	5.45
UN-ID 21	2.00	0.94	0.55			
UN-ID 22						
UN-ID 23						
UN-ID 24	2.00	0.71	0.41			
UN-ID 25						
UN-ID 26						
UN-ID 27						
UN-ID 28						
UN-ID 29	4.00	1.88	1.10	9.00	3.6	4.78
UN-ID 30						
UN-ID 31						
UN-ID 32						
UN-ID 33						
UN-ID 34						
UN-ID 35						
UN-ID 36	2.00	0.94	0.55			
UN-ID 37						
UN-ID 38						
Agglutinated spp. (*)	1.00	0.24	0.14			
Planktonic spp. (**)						

*= Relative abundance is calculated from agglutinated + calcareous, not including planktonic spp.

**= Relative abundance is calculated from planktonic + calcareous, not including agglutinated spp.

Appendix F

Loss-on-ignition (LOI) measurement data. WW= wet weight, DW= dry weight, AW= ash weight.

Sample depth (cm)	Crucible weight	WW	DW	AW	LOI	Standardised LOI (%)
0-1	35.50	2.22	1.04	0.96	0.08	8.12
10-11	40.52	1.78	0.94	0.88	0.06	5.87
20-21	38.64	2.06	1.17	1.10	0.06	5.27
30-31	38.45	1.76	1.13	1.09	0.04	3.91
40-41	39.86	2.27	1.20	1.13	0.07	5.69
50-51	39.82	2.59	1.38	1.30	0.08	5.66
60-61	40.63	2.86	1.51	1.43	0.08	5.28
70-71	40.72	2.42	1.29	1.22	0.07	5.59
80-81	41.15	2.16	1.09	1.02	0.07	6.33
90-91	40.40	3.20	1.59	1.51	0.09	5.49
100-101	40.13	3.65	1.87	1.78	0.09	4.91
110-111	39.02	2.83	1.45	1.38	0.07	5.02
120-121	40.94	3.61	1.98	1.89	0.09	4.65
130-131	42.83	3.66	2.15	2.07	0.08	3.85
140-141	40.62	3.79	2.04	1.95	0.09	4.35
150-151	40.37	3.33	2.09	2.02	0.07	3.35
160-161	40.71	3.48	2.06	1.98	0.08	3.80
170-171	39.38	3.42	1.99	1.92	0.07	3.61
180-181	39.76	4.01	2.31	2.22	0.08	3.60
190-191	40.30	3.66	2.31	2.24	0.07	2.87
200-201	38.97	3.53	2.23	2.17	0.06	2.85
210-211	44.31	3.98	2.56	2.49	0.07	2.89
220-221	45.85	4.13	2.48	2.41	0.07	2.86
230-231	46.04	4.32	2.83	2.76	0.07	2.45
240-241	42.44	4.71	2.90	2.83	0.07	2.46
250-251	44.54	3.97	2.63	2.57	0.06	2.33
260-261	46.03	4.32	2.86	2.81	0.05	1.79
270-271	41.85	3.86	3.08	3.05	0.04	1.21
280-281	45.93	3.59	2.27	2.22	0.05	2.03
290-291	43.16	2.97	1.86	1.83	0.03	1.83

Appendix G

Results from correlation tests (Spearman's rank correlation coefficient) of species occurring more than 10 % in at least one sample (the most abundant and frequent species). Correlation coefficient in bottom left triangle, p-values in top right triangle. Significant correlations highlighted in bold.

	B. marginata	*H. balthica*	*C. laevigata*	*L. lobatula*	*T. angulosa*	*N. labradorica*	*G. turgida*	*N. turgidus*
B. marginata	x	0.97	**<0.001**	**<0.001**	0.07	**<0.001**	0.48	**0.001**
H. balthica	-0.01	x	0.33	0.36	0.08	0.57	0.89	0.81
C. laevigata	**-0.85**	-0.18	x	**0.002**	0.19	**<0.001**	0.91	**0.02**
L. lobatula	**-0.61**	-0.17	**0.56**	x	0.05	**0.002**	0.52	0.22
T. angulosa	-0.33	-0.32	0.25	0.37	x	0.46	0.19	0.10
N. labradorica	**-0.72**	-0.11	**0.74**	**0.55**	0.14	x	0.08	0.06
G. turgida	-0.13	0.03	-0.02	0.12	-0.25	0.33	x	0.85
N. turgidus	**0.58**	0.05	**-0.43**	-0.23	-0.31	-0.35	0.04	x