

Characterizing living (stained) benthic foraminiferal assemblages of the Gullmar Fjord, Sweden

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Abstract

In this study a sediment core from the Gullmar Fjord (SWE) was extracted from 81 m water depth and analyzed for its living (stained) benthic foraminiferal assemblages. The 5 cm long core was sliced into three 1 cm thick layers and one 2 cm layer, respectively. The foraminiferal tests were stained with Rose Bengal. From the 1000-125 μm fraction, the stained tests were dry picked, identified and counted. The Gullmar Fjord is an exceedingly well studied marine area. Recent studies suggest that the foraminiferal fauna has undergone significant changes during the last century. Periods of anoxia in the bottom water layer are linked to the North Atlantic Oscillation, a weather phenomenon that inhibits annual basin water exchange. Together with an increase of bottom water temperature, these factors can influence the foraminiferal fauna. The top sediment layer (0-1 cm) was defined by opportunistic species such as *Bulimina marginata* and *Stainforthia fusiformis*. An abundance of low oxygen tolerating fauna such as *Nonionella stella* was observed in the 2-3 cm layer. The microhabitat distribution of the most common species was analyzed accordingly. The overall assemblage is characterized as a low oxygen tolerating assemblage (LOFA). Comparing these results with literature from the 1940s confirmed that certain species have been newly introduced to this environment (e.g. *N. stella*). Future studies in this area should carry out systematic measurements over the course of several months, to determine how and when foraminiferal assemblages undergo changes.

Zusammenfassung

In dieser Arbeit wurde ein Sedimentkern des Gullmar Fjords aus 81 m Wassertiefe entnommen und bezüglich seiner lebenden (gefärbten) benthischen Foraminiferen-Zusammensetzung analysiert. Der 5 cm lange Kern wurde in drei 1 cm lange Abschnitte und in einen 2 cm langen Abschnitt geteilt. Die Schalen der Foraminiferen wurden mit Bengal Rosa gefärbt. Diese wurden dann aus der 1000-125 µm Fraktion entnommen, bestimmt und gezählt. Der Gullmar Fjord stellt einen idealen Studienort dar. Seit dem frühen 20. Jahrhundert werden hier regelmäßig Studien durchgeführt und chemische als auch physikalische Parameter gemessen. Neue Studien legen nahe, dass die benthische Meiofauna signifikante Änderungen in dem letzten Jahrhundert durchgeführt hat. Die Nordatlantische Oszillation (NAO) verursacht temporäre Sauerstoffmängel im Tiefenwasser, indem sie den regelmäßigen Beckenwasseraustausch inhibiert. Zusätzlich wirken steigende Temperaturen des Tiefenwassers auf die Foraminiferen Fauna ein. Die oberste Sedimentschicht (0-1cm) wird von opportunistischen Spezies wie *Bulimina marginata* und *Stainforthia fusiformis* gekennzeichnet. Spezies, die bekannt dafür sind geringe Sauerstoffgehalte zu tolerieren, wie *Nonionella stella*, dominieren die 2-3 cm Schicht. Des Weiteren wurde die Verteilung der Mikrohabitate analysiert. Die vorgefundene Foraminiferen Vergesellschaftung wird als eine „low oxygen foraminiferal assemblage“ (LOFA) bezeichnet. Durch einen Vergleich mit Literatur aus den 1940er Jahren wurde ersichtlich, dass sich die Foraminiferen-Zusammensetzung tatsächlich verändert hat. Als Beispiel dient hierzu die Einwanderung der Spezies *N. stella*. Zukünftige Studien sollten regelmäßig Sedimentproben entnehmen als auch chemische und physikalische Parameter messen, um Rückschlüsse bezüglich der Änderung der Foraminiferen-Fauna ziehen zu können.

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1. Introduction

Since the 1930s the Gullmar Fjord (SWE) has been extensively studied in terms of the foraminiferal faunal assemblage and its change over time. Several studies have noticed a general shift in the faunal composition over the past years and linked it to changing environmental conditions, possibly induced by climate change. Since the 1980s reoccurring periods of anoxia have had detrimental impacts on the fjord fauna (Nordberg et al., 2000; Polovodova-Asteman and Nordberg, 2013). This work aims to characterize the living benthic foraminiferal assemblage and microhabitat distribution of a 5 cm sediment core, collected at the Gullmar Fjord in August 2018 from a water depth of 81 m. Furthermore, the new findings are compared to past and recent data, to see if changes to the faunal assemblage have occurred. Most studies in this area have directed their attention on large scale foraminiferal assemblage composition within the deepest part of the fjord (Alsbäck Deep, 118 m), with a focus on species occurrence or disappearance in correlation with shifting environmental parameters over the last decade (Gustafsson, 2001; Nordberg et al., 2000; Polovodova Asteman and Nordberg, 2013). Studying species-specific vertical distribution within the sediment outside of the Alsbäck Deep will give new insights on microhabitat distribution or vertical distribution, respectively, in addition to assemblage changes since the 1940s.

1.1 Foraminifera

1.1.1 An Overview

Foraminifera are a group of amoeboid protists. They are unicellular microscopic organisms, usually smaller than 1 mm, however some species have reached sizes up to 14 cm (Grell, 1973, p. 403). First appearing in the Cambrian, they rapidly conquered most marine environments. Today they can be found in various settings ranging from the deep sea through brackish to fresh water. There are two features that separate foraminifera from other protist groups. First being that they possess special pseudopodia. These are fine, threadlike cellular appendages that extend through the aperture (single apical or multiple openings of the foraminiferal shell or test) into the environment. The term granuloreticulopodia refers to the net like, branching feature of their pseudopodia (Bowser and Jeffrey, 2002). They anastomose, split and rejoin, differentiating them from other protist groups (Lee, 1990). The pseudopodia are an essential part of foraminifera, they are used for motility, feeding, structuring tests, reproduction and respiration. The second feature is the construction of shells (tests). These encompass the cytoplasm and isolate the foraminifera from the outside milieu. The tests can either be organic, agglutinated (cemented sediment particles), made of calcium

carbonate (CaCO₃) or even silica (Sen Gupta, 2003, p. 57). Calcareous tests are divided into hyaline (transparent) and porcelaneous/miliolid (opaque). The tests consist of chambers, sutures and an aperture. Pores within the chamber walls facilitate gas exchange (e.g. Kuhnt et al., 2013). The high preservation potential of the tests allows foraminifera to be abundant in the fossil record. The systematics of modern foraminifera are based mostly on test properties. In the 19th century d'Orbigny (1852) solely used the arrangement of chambers to differentiate between groups. Today, a wide variety of morphological traits influence the systematics of foraminifera. The widely accepted classification of Loeblich and Tappan (1992) defines 15 extant groups. With future advances in molecular biology and DNA sequencing the systematics are surely to become more complex. Pawlowski (2000) presents the developments in molecular systematics of foraminifera.

Concerning the lifestyle of foraminifera, they either live in benthic or planktonic habitats. Most authors agree that about 10.000 extant species and nearly 40.000 extinct species of foraminifera exist (Vickerman, 1992). These numbers must be considered with caution, as they are no more than estimates. Murray (2007) proposed that the total number of living benthic species is no higher than 4000. Benthic species dwell on the sediment surface (epifaunal), within the top centimeters (infaunal) or deep down in the sediment (>4 cm, deep-infaunal). Using their reticulopodia, they migrate throughout the sediment column when environmental parameters become hostile. The TROX (Trophic Oxygen) model introduced by Jorissen et al. (1995) combines the influence of food supply and oxygen concentration to explain microhabitat distribution of foraminifera. The term microhabitat refers to the current conditions under which a foraminiferal species is living. It combines the influence of physical, chemical and biological factors. Food availability, food quality and oxygen content are important examples. This results in typical vertical distributions of tests within the sediment column. Most species have preferred microhabitats and only migrate through the sediment when environmental conditions become limiting. It is important to understand that species adapt to environmental conditions and therefore are not always found at the same depth in the sediment, but rather at various depths depending on the season and geographic location (Sen Gupta, 2003, p. 168).

At this point it is worth mentioning that foraminifera generally respire oxygen, since it is the most accessible and efficient electron acceptor. However, certain species can live in oxygen depleted environments deep within the sediment and even thrive off of oxygen depletion (Bernhard et al., 2003). Recent studies have asserted the importance of foraminifera in the marine nitrogen cycle (Geslin et al., 2011; Høglund et al., 2008; Pina-Ochoa et al., 2010). *Globobulimina turgida* and

Nonionella stella are capable of denitrifying, a process formerly thought to be exclusive for prokaryotes (Pina-Ochoa et al., 2010; Woehle et al., 2018). Glock et al. (2013) studied the denitrification rates of foraminifera in the Peruvian oxygen minimum zone and concluded that stored nitrogen within the foraminiferal cytoplasm represents a significant, overlooked reservoir for one of the largest nitrate sinks in the world. A recent study further suggests, that species in oxygen depleted environments prefer nitrate respiration over oxygen respiration (Glock et al., 2019).

Foraminifera feed on a variety of food sources. Depending on their life cycle stage, living environment and food availability, they may graze on algae (Anderson et al., 1991) or diatoms in the photic zone, prey on small animals (such as crustaceans), ingest bacteria, phytodetritus or dissolved organic carbon (DOC) (Lee et al., 1966; Sen Gupta, 2003, p. 39). Foraminifera living within the sediment primarily consume low quality food in exchange for low competition rates. Foraminifera are generally considered to feed selectively (Bradshaw, 1955; Lee et al., 1966). As an example Alve (2010) showed that certain foraminiferal species require the input of fresh phytodetritus to survive.

The life cycle of foraminifera is more varied than in any other protist group, life cycles of only around 30 species are fully understood. Typically, the life cycle consists of a heterophasic alternation of sexual and asexual generations. The different generations vary in size of their proloculus (initial chamber), coining the term dimorphism. This results in a megalospheric (asexual) and a microspheric (sexual) generation (Sen Gupta, 2003, p. 48).

1.1.2 Foraminifera as Proxies

Palaeoclimate reconstruction and palaeoceanography are the main fields that make use of foraminiferal tests. In modern studies benthic foraminifera are employed as proxies for oxygenation, water depth and organic flux. Oxygen is considered to be an important controlling factor regarding species occurrence and organic matter regarding abundance, respectively. This means that once a minimum threshold value of oxygen is reached, food becomes the controlling factor. Although foraminifera feed selectively, to a certain degree, a correlation between organic matter and faunal abundance exists (Altenbach and Struck, 2001; Fontanier et al., 2002; Komosinski et al., 2017; Lee, 1974). Owing to their ability to adapt to a wide range of environmental conditions, their use as proxies for temperature and salinity is declining (Van der Zwaan et al., 1999). Although it is possible to separate brackish from normal marine and hypersaline environments using benthic foraminifera tests (Murray, 2006, p. 249), other methods provide the high resolutions required nowadays. The focus should be set on foraminiferal assemblage characteristics and not individual marker species as palaeoecological tools (Van der Zwaan et al., 1999). Furthermore, the chemical

properties of calcareous foraminifera tests, specifically oxygen and carbon stable isotope compositions, are valuable tools in palaeoceanography (Filipsson et al., 2004; Nordberg et al., 2009). Polovodova Asteman et al. (2018) reconstructed past bottom water temperatures of the Gullmar Fjord using $\delta^{18}\text{O}$ measurements from the tests of *C. laevigata*. Planktonic foraminifera assemblages represent proxies for upper water mass properties and hydrography, often used to reconstruct climate zones in palaeoceanography.

1.1.3 Foraminifera in Fjord Environments

Fjords are glacially formed estuaries found predominantly in high latitude regions, characterized by steep shores, relatively deep basins and a two layered water circulation consisting of a freshwater outflow and deeper saline water. Most fjords have a sill at their entrance, meaning that the seabed is raised to a mound, potentially influencing the water exchange with the open ocean. Sills are a result of isostatic lifting and sediment deposition (Gustafsson and Nordberg, 2002). Rapid sedimentation leads to well stratified sediment within fjords and preserves environmental changes, especially water exchange rates, sea level rise and pollution. The combination of sill characteristics and climate can induce periods of anoxia in fjords (see chapter 1.2).

According to Murray (2006, p. 101), foraminifera in fjords can be divided into shallow and deep water assemblages, based off of water stratification/salinity and temperature (not absolute water depth). Deep water assemblages generally dominate over shallow ones. Species such as *Adercotryma glomeratum*, *Cassidulina reniforme*, *Elphidium clavatum* and *Nonionellina labradorica* are typical. Temperate fjords are found along the coast of Norway and Sweden. Shallow water assemblages include agglutinated, hyaline and even porcelaneous foraminifera and are more diverse than deep water assemblages. Figure 1 shows the species distribution in fjords of southern Norway and Sweden, using combined data from multiple studies. Further specifics of the Gullmar Fjord will be discussed in the following chapter.

Approximate latitude	55-60°N	55-60°N
	Surface water	Deep water
	S Norway-Sweden	S Norway-Sweden
<i>Adercotryma glomeratum</i>		
<i>Reophax fusiformis</i>		M
<i>Spiroplectammina biformis</i>		
<i>Ammodiscus gullmarensis</i>		
<i>Ammoscalaria pseudospiralis</i>		
<i>Ammoscalaria runiana</i>	M	
<i>Ammotium cassis</i>		M
<i>Astrammmina sphaerica</i>		
<i>Cribrostomoides kosterensis</i>	M	
<i>Eggerelloides medius</i>		M
<i>Eggerelloides scaber</i>		M
<i>Haplophragmoides bradyi</i>		
<i>Liebusella goesi</i>		
<i>Miliammina fusca</i>		
<i>Recurvoides trochamminiforme</i>		
<i>Reophax subfusiformis</i>		M
<i>Textularia earlandi</i>	M	M
<i>Trochamminella bullata</i>		
<i>Leptohalysis catella</i>		
<i>Leptohalysis scottii</i>		M
<i>Nodulina dentaliniformis</i>		
<i>Quinqueloculina seminulum</i>		
<i>Miliolinella subrotunda</i>		
<i>Astrononion gallowayi</i>	M	
<i>Buccella frigida</i>	M	M
<i>Cassidulina reniforme</i>		M
<i>Cibicides lobatulus</i>		
<i>Elphidium clavatum</i>		
<i>Elphidium incertum</i>		
<i>Nonionellina labradorica</i>		M
<i>Elphidium albiumbilicatum</i>		
<i>Ammonia group</i>		M
<i>Brizalina skagerrakensis</i>	M	
<i>Bulimina marginata</i>		
<i>Buliminella elegantissima</i>		M
<i>Cassidulina laevigata</i>		M
<i>Elphidium excavatum</i>		M
<i>Elphidium macellum</i>		
<i>Elphidium magellanicum</i>		
<i>Elphidium williamsoni</i>		M
<i>Epistominella vitrea</i>		
<i>Haynesina germanica</i>		
<i>Hyalinea balthica</i>		
<i>Nonionella turgida</i>		M
<i>Stainforthia fusiformis</i>		
<i>Stainforthia loeblichii</i>	M	
<i>Globobulimina turgida</i>		

Figure 1 Figure modified from Murray (2006, p. 102, Figure 4.14). Distribution in fjords. The surface water includes the transitional layer. Black=dominant, grey=subsidiary, M=minor. Sources of Data: Alve and Nagy, 1990 (WA-101), Alve and Nagy, 1986 (WA-102), Alve, 1995a (WA-103), Gustafsson and Nordberg, 1999 (WA-104), 2000 (WA-105), 2001 (WA-106)

1.2 Study Area

The Gullmar Fjord is a silled fjord located on the western coast of Sweden (Figures 2, 3). The sill depth is 42 m and the deepest part of the fjord is 118 m. It is approximately 25 km long and between one and three kilometers wide. Since the last glacial maximum isostatic lifting and sediment accumulation have led to the development of sills at fjord entrances. Fjord morphology and sill characteristics are detrimental factors influencing the fjord environment (Gustafsson and Nordberg, 2002). The water circulation and stratification within a fjord is controlled by various physical processes such as estuarine circulation, barotropic tidal variations, vertical mixing forced by wind and density differences, etc. Sill depth also plays an important role by inhibiting dense saline bottom waters from exiting the fjord. This leads to typically stratified water columns and basin exchange rates (Bengtsson et al., 2012).

The Gullmar Fjord shows characteristic hydrological traits. The water column can be divided into three distinct layers consisting of riverine water from the Örekilsälven (<1 m), low-salinity (24-27 psu) surface water (1-15 m), normal saline (32-33 psu) water (15-30 m) and stable bottom water (34-35 psu). The turnover time for the surface layer ranges from 12 days to approximately one month, depending on the water depth. The bottom water exchange usually occurs annually between January and March. During the summer months a strong thermocline develops which further strengthens water stratification and inhibits deep water exchange (Arneborg, 2004; Nordberg et al., 2000).

Nordberg et al (2000) propose that there is a causal relation between the North Atlantic Oscillation (NAO) variations and the marine environment. The NAO is a pressure driven weather phenomenon which has an influence on the dominant wind direction over Europe. In the 1970s the NAO switched from a mainly negative to a positive phase, thus changing the predominant wind direction over Europe from easterly to westerly winds. Westerly winds tend to push the water masses into the fjord and prevent an exchange of bottom water. This then leads to the stagnation of bottom water and decreasing oxygen levels over time (Hurrell, 1995; Nordberg et al., 2000). According to Björk and Nordberg (2003) the NAO influences up/downwelling along the Swedish west coast through January-April. Positive and negative NAO indices are largely associated with downwelling and upwelling events, respectively. Therefore, not only the climate over Europe but also primary productivity, oxygen levels and hence the marine fauna, such as foraminifera, are affected.

Primary productivity in the Gullmar Fjord is characterized by major algal blooms which occur during spring (March-April) and autumn (August-September). These algal blooms are typical for fjord environments (Simo-Matchim et al., 2016). When chlorophyll-a levels rise, food supply increases and oxygen content of the water decreases. Some species such as *S. fusiformis* thrive under such conditions and can increase their population up to seven fold within a month (Gustafsson, 2001).

1.3 Study Background

The Gullmar Fjord is an extensively studied marine area. It is of interest to marine biologists, palaeontologists and geochemists. In the summer of 1927 Hans Höglund extracted numerous sediment samples from the Skagerrak region with the aim to identify and describe the foraminiferal fauna. Of these samples 72 were extracted from the Gullmar Fjord at various water depths and locations (Figure 2) (Höglund, 1947).

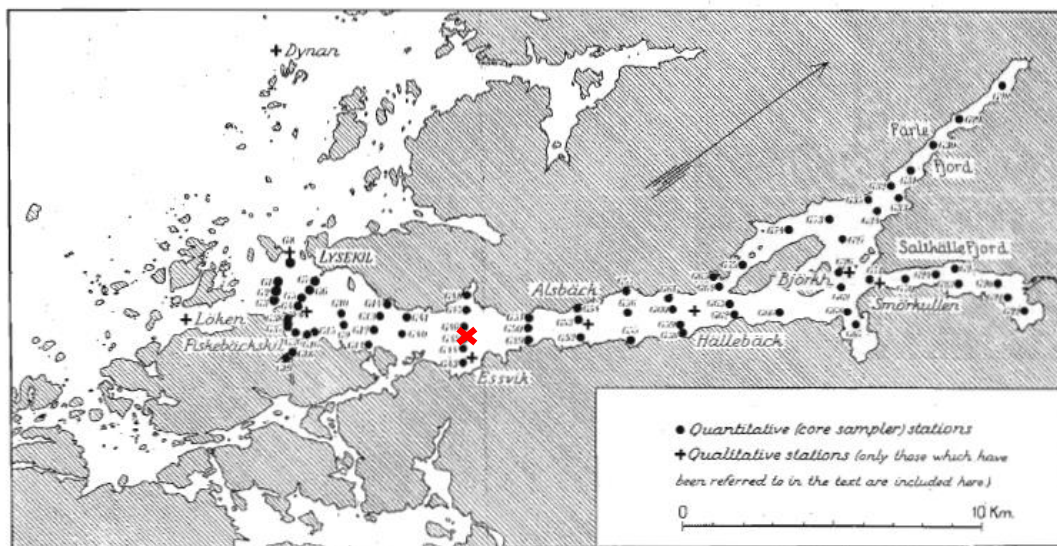


Figure 2 Map showing the sampling sites from Höglund (1947, p. 302) in the Gullmar Fjord (black dots). The red cross indicates the sampling site for the core of this study (OVS18halfway7)

Höglund's dissertation provides an important basis for several studies conducted after the 1940s. By comparing his raw data sets with new findings, quantitative changes in the faunal composition have been discovered. It seems that a general shift towards an increase of a low oxygen tolerating foraminiferal faun has occurred (Alve and Murray, 1995; Gustafsson, 2001).

Until 1966, a sulphite pulp mill had been discharging its effluents through the Örekilsälv river into the inner fjord for over 80 years, with more than 60.000 m³ of waste water per day (Bagge, 1969). This had a detrimental impact on the marine macrobenthos, strongly diminishing the species

diversity and richness. The wastewater from paper mills is generally considered as organic material. Therefore, exposed waters are in danger of becoming oxygen depleted and polluted with fibrous material, eventually turning uninhabitable for most marine macrofauna (Pearson, 1972). Fortunately, the fauna has recovered significantly since the discontinuation of the mill, as numerous studies have shown (Leppäkoski, 1968; Rosenberg, 1973, 1972). The town of Lysekil, located near the fjord threshold region, also contributed to the pollution of fjord waters for many years. Since 1983 the Gullmar Fjord is a designated Nature Conservation Area, leading to further improvement of water quality and species diversity (Marine Conservation Institute, 2019).

Even though the fjord environment has been subjected to anthropogenic input over the past century, wastewater and chemicals are not the only type of factors threatening the ecosystem. Beginning in 1979 the fjord has been experiencing periods of extreme oxygen depletion, leading to anoxic conditions in the bottom water. Several such events have occurred since then (1983/1984, 1987/1988, 1988/1989, 1990/1991, 1994/1995, 1996–1998, 2008, 2014/2015 and 2016) (Polovodova Asteman et al., 2018). As mentioned before, the NAO prevents bottom water exchange through westerly winds. Josefson and Widbom (1988) concluded that the macro and meiofauna of the deep basin (118 m) within the Gullmar Fjord were impacted differently by the hypoxic event. The macrofauna disappeared completely between November and February 1979/80, whereas the meiofauna did not seem to decrease substantially, even though oxygen values fell below 1ml/l. Foraminifera seemed to be the most successful taxa in withstanding the hypoxic event. Nordberg et al. (2000) wrote that the typical SK-Fauna (Skagerrak-Kattegat fauna termed by Filipsson and Nordberg (2004); *Hyalina balthica*, *Cassidulina laevigata*, *B. marginata*, *Nonionella labradorica*, *Quinqueloculina stalkerii*, *Libusella goesii*, *Bolivina pseudopunctata*, etc.) began to decrease after 1976 and was replaced by a *S. fusiformis* dominating assemblage. This increase of low oxygen tolerating species goes markedly well with the change of NAO indices from a primarily negative to positive phase. Other authors have also noted the dramatic increase on *S. fusiformis* in the deep basin of the Gullmar Fjord following the 1979/80 hypoxic event (Gustafsson, 2001; Nordberg et al., 2000; Polovodova Asteman and Nordberg, 2013). According to Nordberg et al. (2009), *S. fusiformis* did not occur in the deepest part of the fjord (118 m) before the 1980s.

In summary, the aim of this thesis was to assess the standing stock and distribution of live foraminifera throughout the uppermost 5 cm of a sediment core taken at 81 m depth. Additionally, environmental data (chlorophyll-a and bottom water oxygen) was generated from a database to support the interpretation of the results. The results were further compared with the faunal

composition in the 1930s, to document major shifts in species occurrence in relation with changing environmental conditions over the last century.

2. Materials and Methods

2.1 Sample Location and Treatment

In August 2018 six sediment samples were taken from a transect through the Gullmar Fjord (Table 1, Figure 3). These samples were collected with the research vessel *Oskar von Sydow* using a box corer and push corer with a 10 cm diameter for the subsamples. The sample OVS18halfway7 (Position: N 58°21.429' / E 11°35.079') is the subject of this study, it consists of a 5 cm long core. This sample was extracted on the 15 of August 2018 from a water depth of 81 m. The exact positions of the sampling sites are shown in Figure 3, the red cross represents sample OVS18halfway7, the black crosses the other five.

Table 1 Sampling stations

Station ID	Sample ID	Date	Technique	Depth (m)	Latitude (DM)	Longitude (DM)	Caption (Fig.)
1	OVS18halfwaycontrol	07.08.2018	Box corer	83	58° 21.429'	11° 35.079'	+
6	/	15.08.2018	Box corer	117	58° 19.381'	11° 32.867'	+
7	OVS18halfway7	15.08.2018	Box corer	81	58° 17.214'	11° 30.449'	+
A	OVS18Dive1	06.08.2018	Diver	29.7	58° 15.324'	11° 26.993'	+
B	OVS18Dive2	06.08.2018	Diver	13	58° 15.118'	11° 26.953'	+
C	OVS18Dive3	06.08.2018	Diver	7	58° 15.002'	11° 26.718'	+
SLÄGGÖ	/	/	/	/	58° 15.500'	11° 26.000'	+

Upon extraction the core was sliced on board into 1 cm thick layers (0-1 cm, 1-2 cm, 2-3 cm, 3-5 cm), however the last two centimeters were combined in order to increase the number of obtainable tests to a minimum of 300. The sediment was then fixed with a mixture of 2 g of Rose Bengal per liter of ethanol (> 70%). Rose Bengal is an organic complex that stains the cytoplasm of living foraminifera pink. This facilitates the differentiation between living and dead individuals. The next step was to wet sieve the samples using the fractions >1000 µm, 1000-125 µm and 125-63 µm, everything smaller than 63 µm was discarded. Sieving the samples is a cautious task, since foraminiferal tests easily break, especially agglutinated ones. Then the samples were dried at 60°C for three days. The 1000-125 µm fraction ended up having to be washed twice, because excessive organic material had caused the sediment to clump together. For the exact specifications concerning the sample treatment I refer to Schönfeld et al. (2012).

All the stained benthic foraminiferal tests of the 1000-125 µm fraction were dry picked and identified to species level using a light microscope (LM). Höglund (1947) and Jones (1994) proved to be helpful literature for identifying species. Other recent scientific publications that are cited

throughout this work involving the Gullmar Fjord (e.g. Polovodova-Asteman and Schönfeld, 2016) were used as well. Broken tests were not included, except for the species *Reophax subfusiformis*. Here, the counted number of broken tests was divided through the mean number of chambers of the intact tests. The 125-63 µm fraction was only inspected superficially to determine if *S. fusiformis* and *T. earlandi* occur abundantly. Individuals from every species were photographed with the Leica MC 170 HD light microscope camera. The pictures were manipulated using the software CombineZP (Hadley, 2010) and Inkscape (Inkscape, 2019). To aid identification and demonstrate important morphological features Scanning Electron Microscope (SEM) pictures were taken. All microscopes are based at the Department of Palaeontology, University of Vienna.

2.2 Environmental Data

The Swedish Meteorological and Hydrological Institute (SMHI) has been monitoring chemical and physical parameters in the Gullmar Fjord since the 1860s, however only regularly since the 1890s. For this study I have accessed oxygen and chlorophyll-a values from the SLÄGGÖ (N 58° 15.500' E 11° 26.000') measuring station (Figure 3, green cross), located at the fjord entrance (SMHI, 2019). Due to the proximity to my sampling site (OVS18halfway7) I consider the data of this station to be representative of local conditions. The oxygen measurements were obtained at water depths between 60 and 80 m. Water temperature, salinity and pH values were measured locally for every sampling station. Chlorophyll-a and oxygen graphs can be found in Chapter Three and all raw data sets in the appendix.

2.3 Data Analysis

Diversity indices are used to describe and compare the biodiversity of communities. Biological diversity is quantified by evenness (relative abundance of species) and richness (number of species). In addition, following diversity indices: Shannon-Wiener Index (Shannon and Weaver, 1949), Simpson Index (Simpson, 1949), Fisher Alpha Index (Fisher et al., 1943) and the Effective Number of Species and Dominance were calculated accordingly using the program PAST (Hammer et al., 2001). By taking all these indices into consideration one gains a good understanding of how the species are distributed within the sediment. Calculating the Effective Number of Species provides a powerful tool for comparing diversity values of different communities.

Ternary diagrams are used to illustrate the proportions of test composition of an assemblage. Each of the three corners represent a different test material (hyaline, porcelaneous and agglutinated). Additionally, the results obtained from the core taken at similar depth but another position of the

transect (OVS18halfwaycontrol, Leitgeb, unpublished) are compared with the present study in the discussion.

All species mentioned in this work can be viewed in the counting table in the appendix. The material used for this work is part of Alexandra-Sophie Roy's project "Anthropogenic effect on the foraminiferal fauna in the Gullmar Fjord, which has received funding by the University of Gothenburg (The KVA Fund).

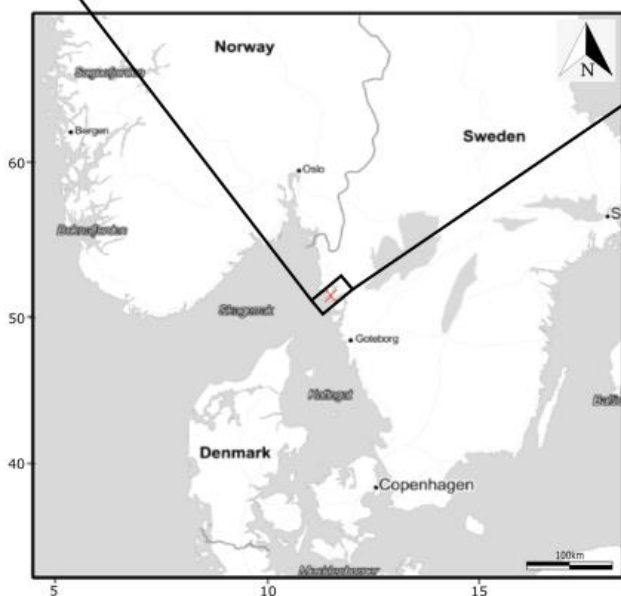
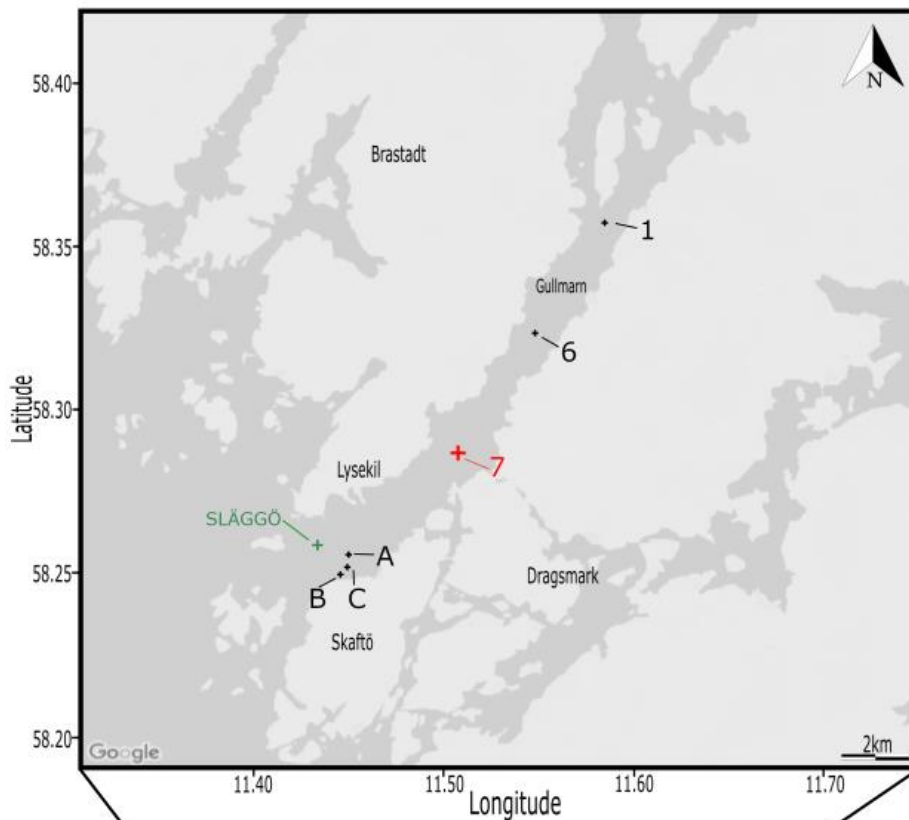


Figure 3 Map of the Gullmar Fjord.

7 = OVS18halfway7

1 = OVS18halfwaycontrol

Släggö = Measuring station

A, B, C = Other sampling sites from this project

3. Results

3.1 Environmental Parameters

3.1.1 Oxygen Data

At sampling site OVS18halfway7 a bottom water temperature of 8.8 °C was measured. The salinity was measured at 34.3 ppm and the pH value at 8.069 (16 °C). Measurements for the other sampling sites are listed in the appendix.

Concerning the oxygen content measured at the SLÄGGÖ station, an increase of oxygen can be noticed from January to March (Figure 4). Following March, the oxygen content steadily declines until November, with a slight peak in October. Oxygen content began to rise from November onwards. According to this data series oxygen content was lowest in September with 3.28 µl/l. In total, 20 oxygen measurements were carried out in 2018.

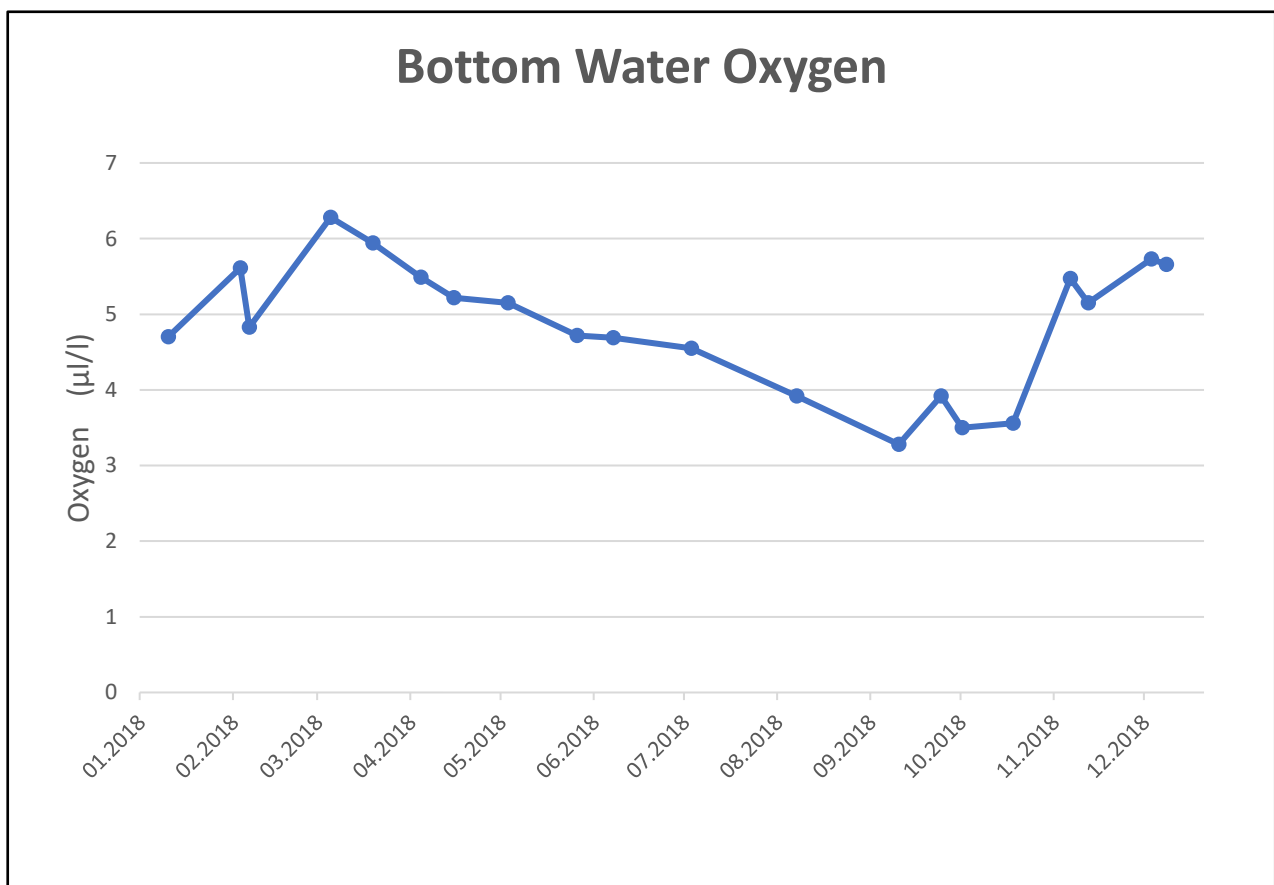


Figure 4 Bottom water oxygen data from SMHI 2019

3.1.2 Chlorophyll-a Data

The chlorophyll-a data set obtained from the measuring station SLÄGGÖ consists of 20 separate measurements in 2018. Three distinct peaks can be observed in Figure 5. The first two occur in March and May, they represent the spring algal blooms. The third peak coincides with the fall algal bloom in September. Maximum values of 14.5 µg/l were measured in March. Minimum values of 0.2 µg/l and 0.3 µg/l were recorded in February and in April and November, respectively.

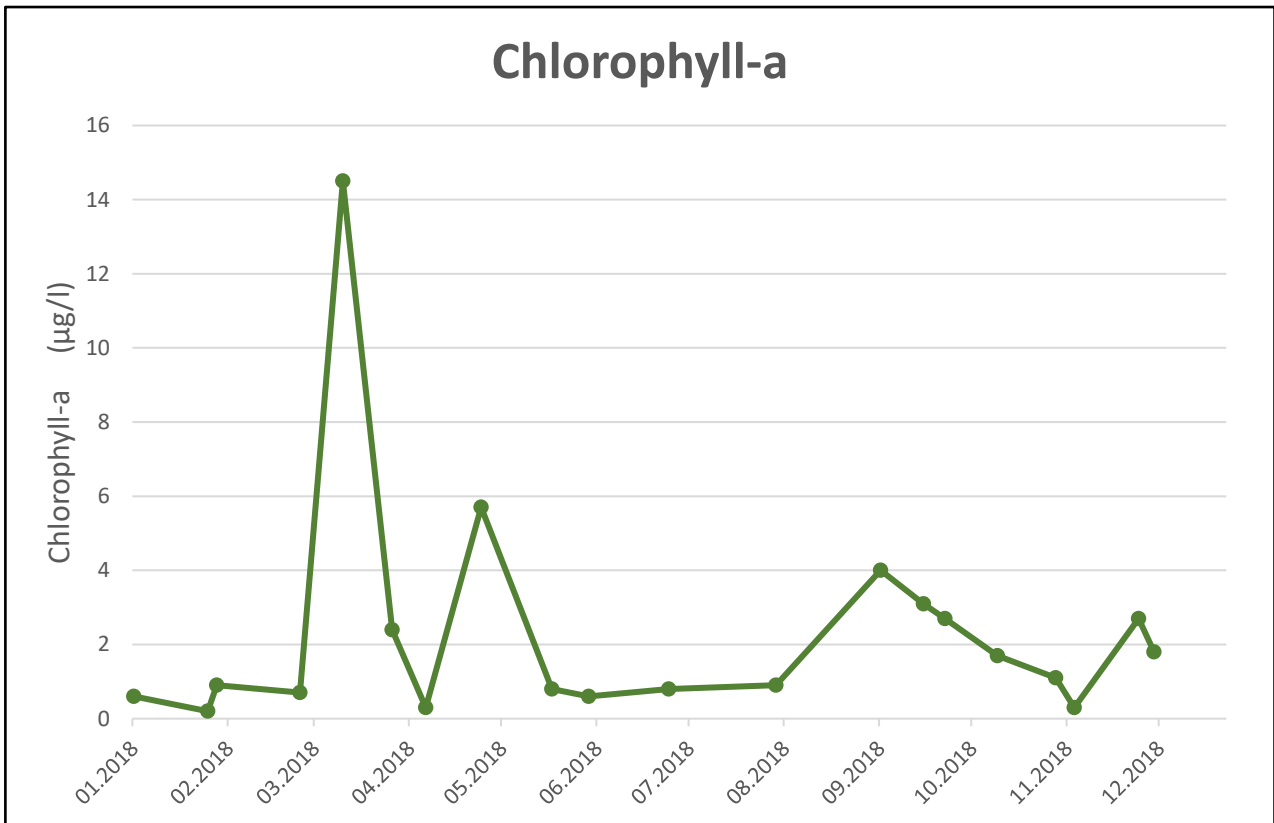


Figure 5 Chlorophyll-a data from SMHI 2019

3.1.3 Temperature, pH, Salinity

These values were measured during the sample extraction on the 15.08.2018 (Table 2).

Table 2 In situ measured physical and chemical parameters

Sample	Temperature (°C)	pH (16°C)	Salinity (ppm)
OVS18halfway7	8.8	8,069	34.3

3.2 Foraminiferal Assemblages

3.2.1 Abundances

A total of 1686 stained foraminiferal tests were counted throughout all five layers. The total abundances decrease steadily from 160.53 ind./10 cm³ to 28.40 ind./10 cm³ in the bottom most layer (Table 3, Figure 6). A slight increase of tests can be noticed in the 2-3 cm layer. The goal of counting at least 300 individuals per layer was reached for all except the 2-3 cm layer. In total 34 separate species were described.

Table 3 Counted tests

Layer	0-1cm	1-2cm	2-3cm	3-5cm	0-5cm
Individuals	610	363	444	262	1679
Ind./10cm ³	160.53	83.20	101.76	28.40	80.96
Species	31	20	20	25	34

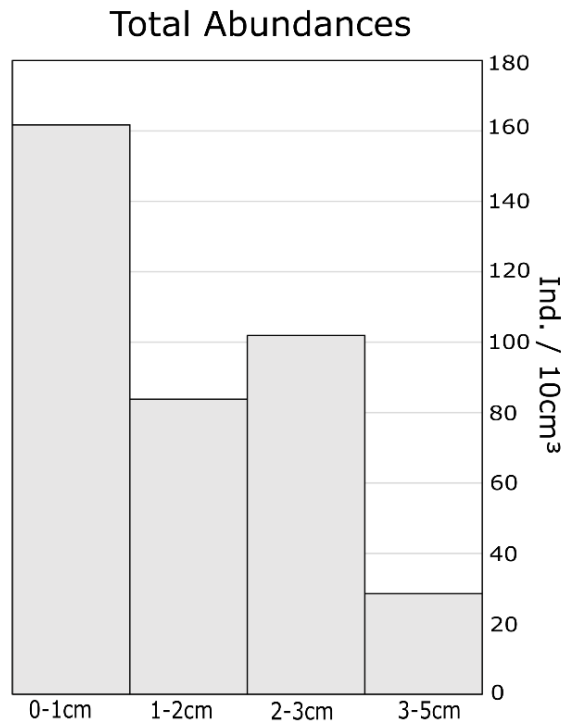


Figure 6 Histogram showing the number of counted living benthic foraminifera in Individuals per 10 cm³.

3.2.2 Test Composition

Figure 7 depicts the proportions for every layer. The diagram shows that the proportion of hyaline tests increases with depth and the proportion of agglutinated tests decreases with depth. The 2-3 cm layer represents the only exception to this observation.

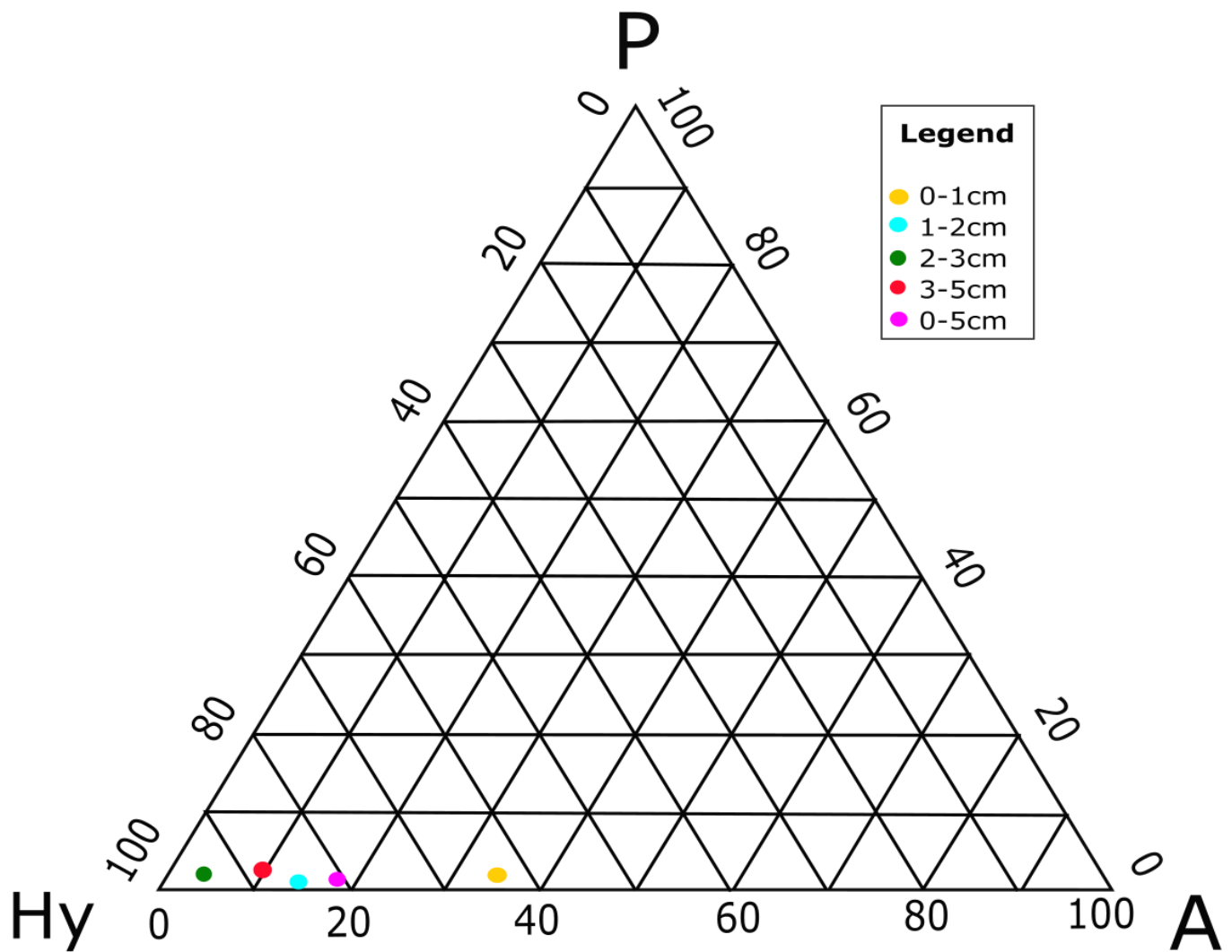


Figure 7 Ternary plot showing the proportion of A=agglutinated, Hy=Hyaline and P=porcelaneous tests.

3.2.3 Dominant Species

The dominant species (>10%) occurring in at least one layer are graphically represented in Figure 8. Layer 0-1 cm has the highest species diversity and richness (Figure 8 and Figure 9). *Bulimina marginata* and *C. laevigata* dominate this layer with 25% and 13%, respectively. *Adercotryma glomeratum* is quite common with 10%. There are 30 species accounted for in this layer, *B. skagerrakensis*, *B. dilatata*, *G. auriculata*, *G. turgida* and *R. rostrata* among others. *Nonionella labradorica*, *N. stella* and *N. turgida* are not widespread. The amount of agglutinated species decreases with depth. Layers 1-2 cm and 2-3 cm show drastic increases in the *Nonionella* genus. *Nonionella stella* represents the most dominant species of this genus, amassing up to 51% in the 2-3 cm layer. Other species become even less common in the 1-3 cm region and increase slightly in layer 3-5 cm. *Bulimina marginata* has its maximum abundance (35%) in the 3-5 cm layer, overpowering the previously dominant *N. turgida* and *N. labradorica*. *Cassidulina laevigata* and *A. glomeratum* both are most common in the top centimeter of sediment; they are almost absent

deeper down. This distribution is also observed in subchapter 3.3. *Stainforthia fusiformis* is absent in the top two centimeters and accounts for only about 3% in the 2-5 cm region. *Textularia earlandi* almost exclusively occurs in the 0-1 cm layer, however only with 1 ind./10 cm³.

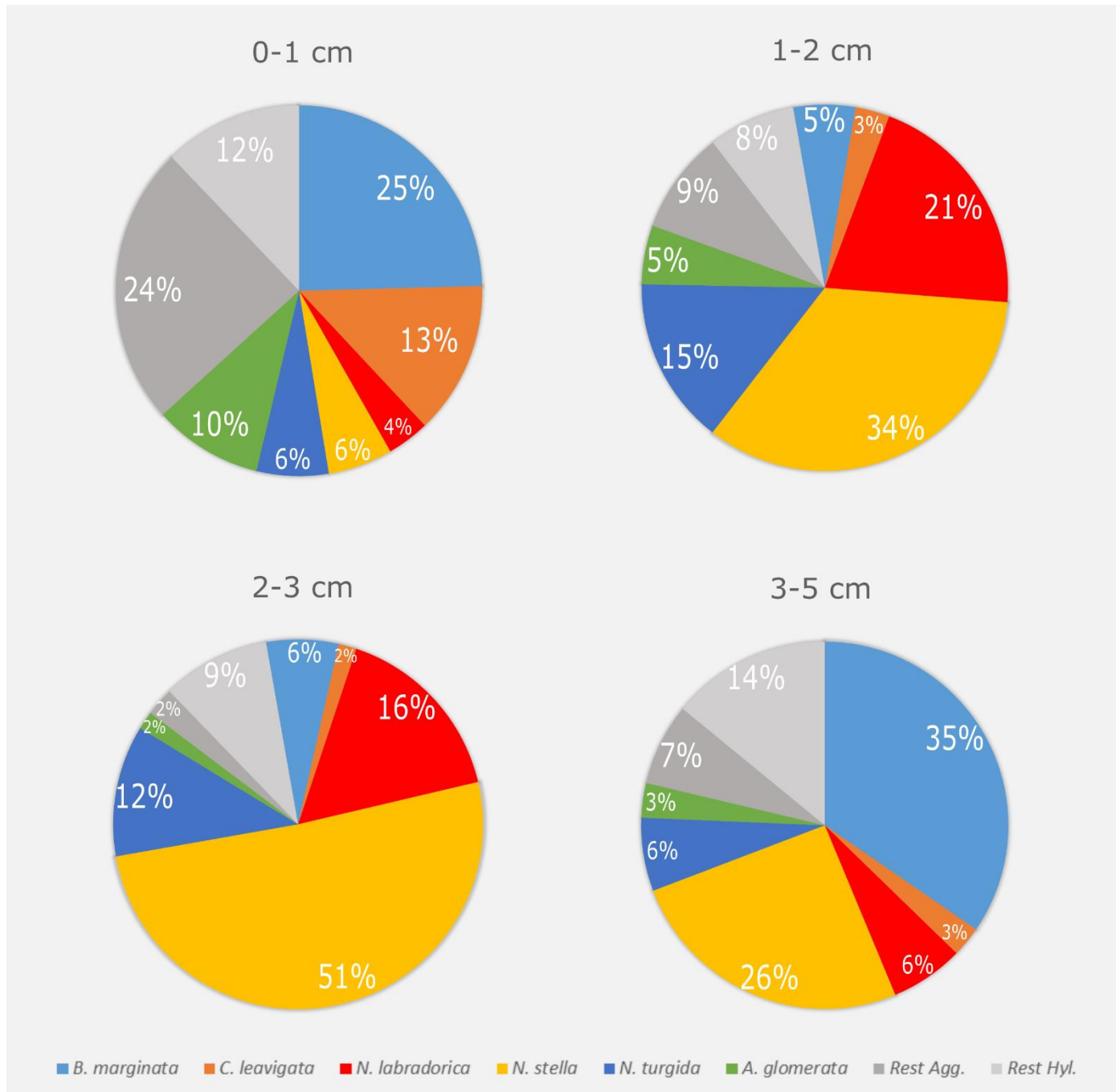


Figure 8 Pie charts showing percentages of dominant species for every layer.

3.2.4 Diversity Indices

The calculated diversity indices are plotted in Figure 9 and 10. Equitability, Evenness, the Simpson Index, the Shannon Index, the Fisher-Alpha Index and the Effective Number of Species all indicate decreasing diversity values down to the 2-3 cm layer. Here *N. stella* is the dominating species resulting in low diversity values. For the 3-5 cm layer diversity increases slightly. The Dominance is the exact counterpart and shows increases where the other indices showed decreases.

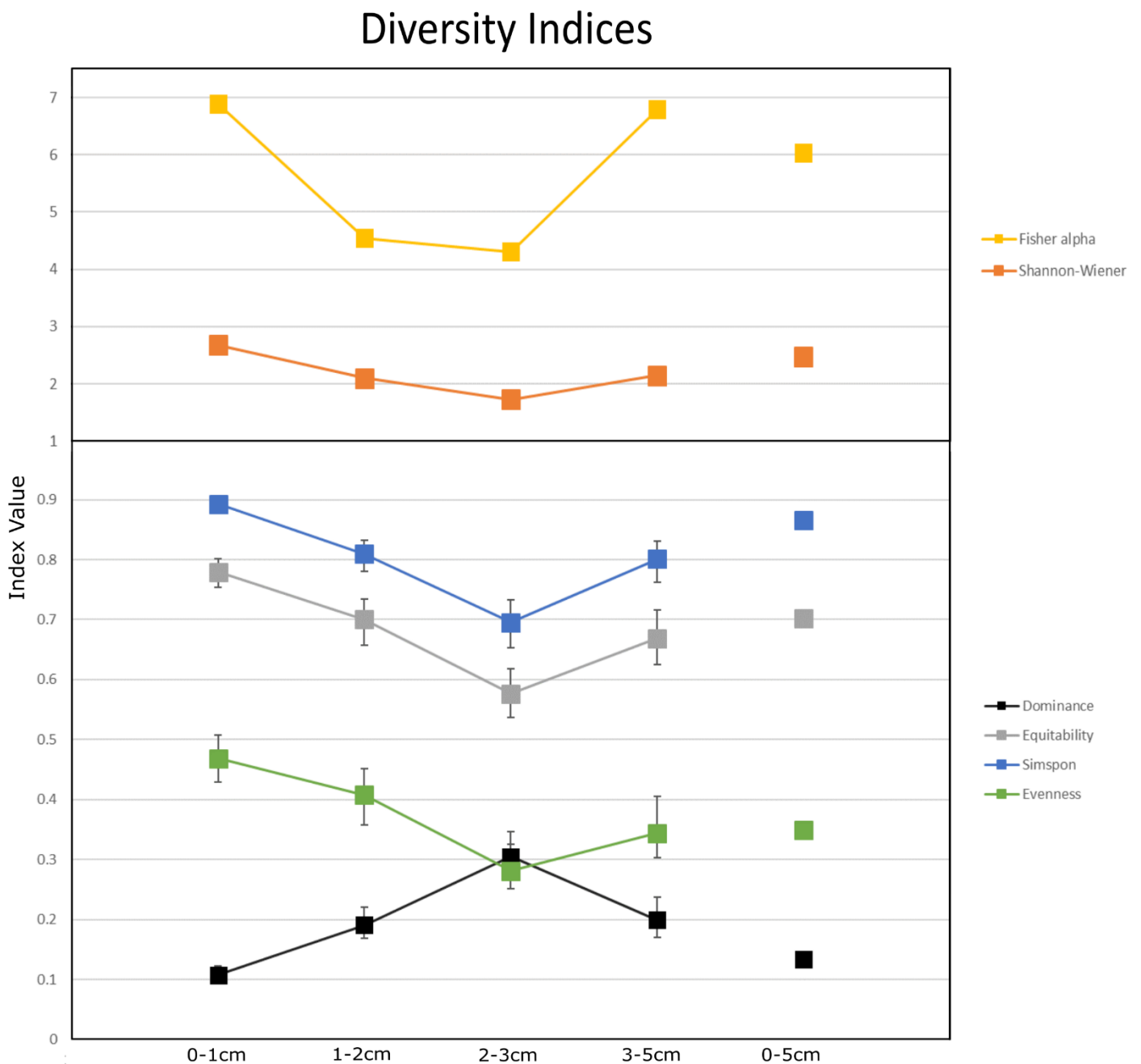


Figure 9 A selection of Diversity Indices. Layer 2-3 cm has the overall lowest values.

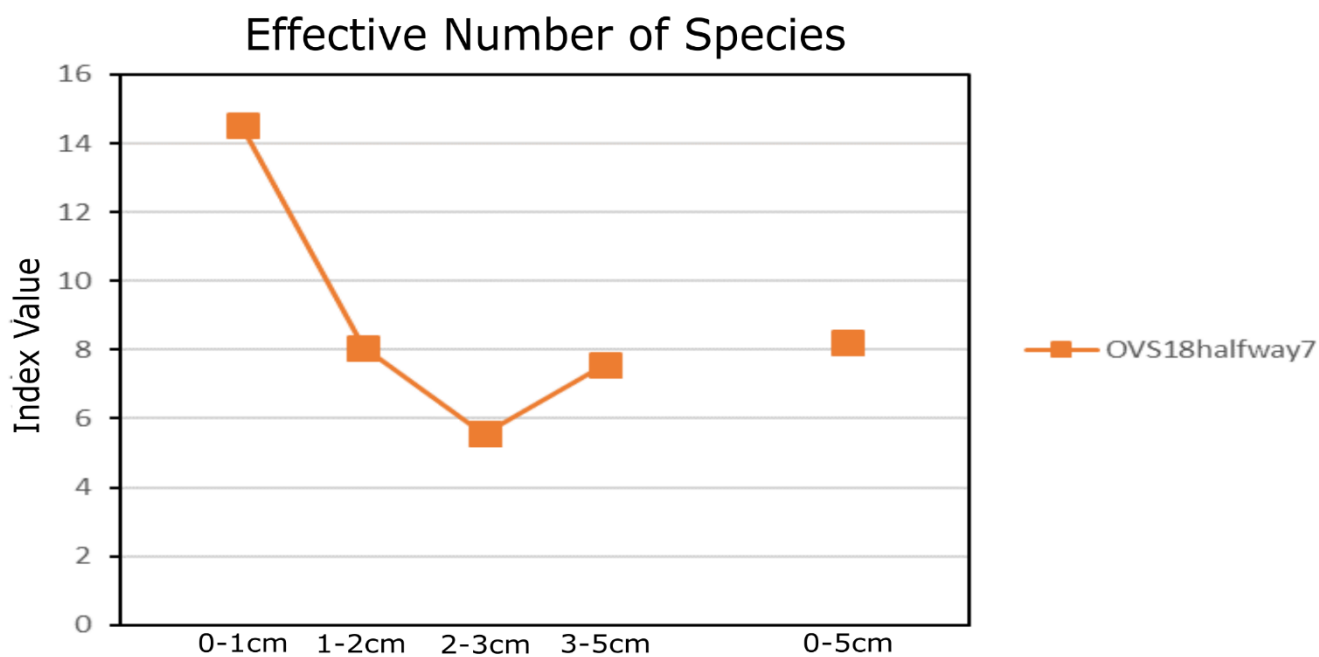


Figure 10 Effective Number of Species

3.3 Microhabitat Distribution

In Figure 11 the vertical distribution of the six dominant species is plotted. *Bulimina marginata*, *C. laevigata* and *A. glomeratum* have clear population maximums in the top sediment layer, with *B. marginata* experiencing a second peak in the 3-5 cm layer. *Nonionella labradorica*, *N. stella* and *Nonionella turgida* have a similar distribution pattern, increasing their abundance down to the 2-3 cm layer and then decreasing. *Nonionella stella* rapidly increases from about 9 ind./10 cm³ up to almost 53 ind./10 cm³ and then plummets down to 7 ind./10cm³ in the deepest layer. All species except *B. marginata* and *N. stella* become nearly nonexistent in the 3-5 cm layer. Here *B. marginata* has the highest abundance with about 10 ind./10 cm³.

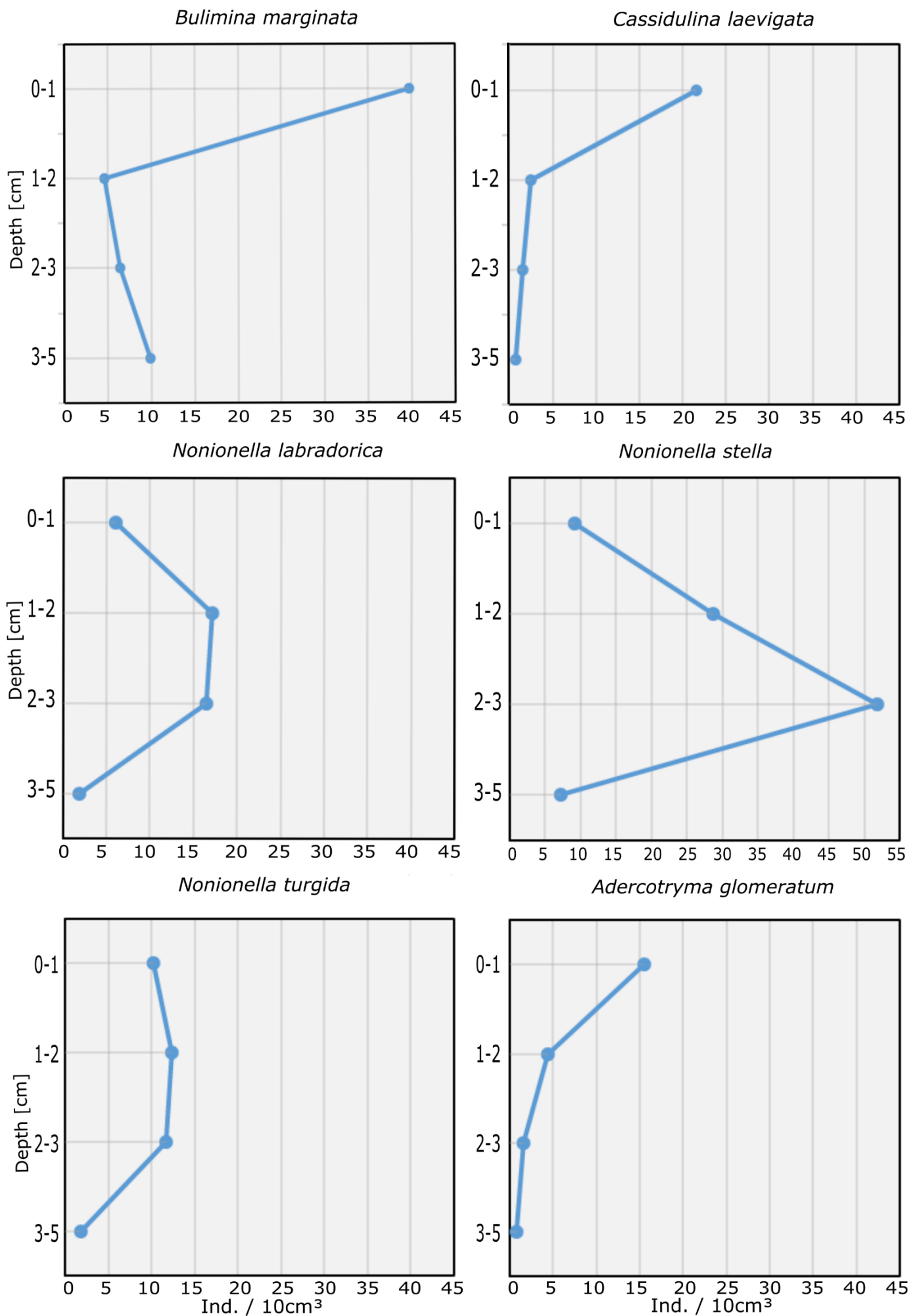


Figure 11 Vertical distribution of dominant species within the sediment column.

3.4 Plates

Figures 12 illustrates some of the most abundant species and important morphological traits. Figures 13 and 14 show all identified species.

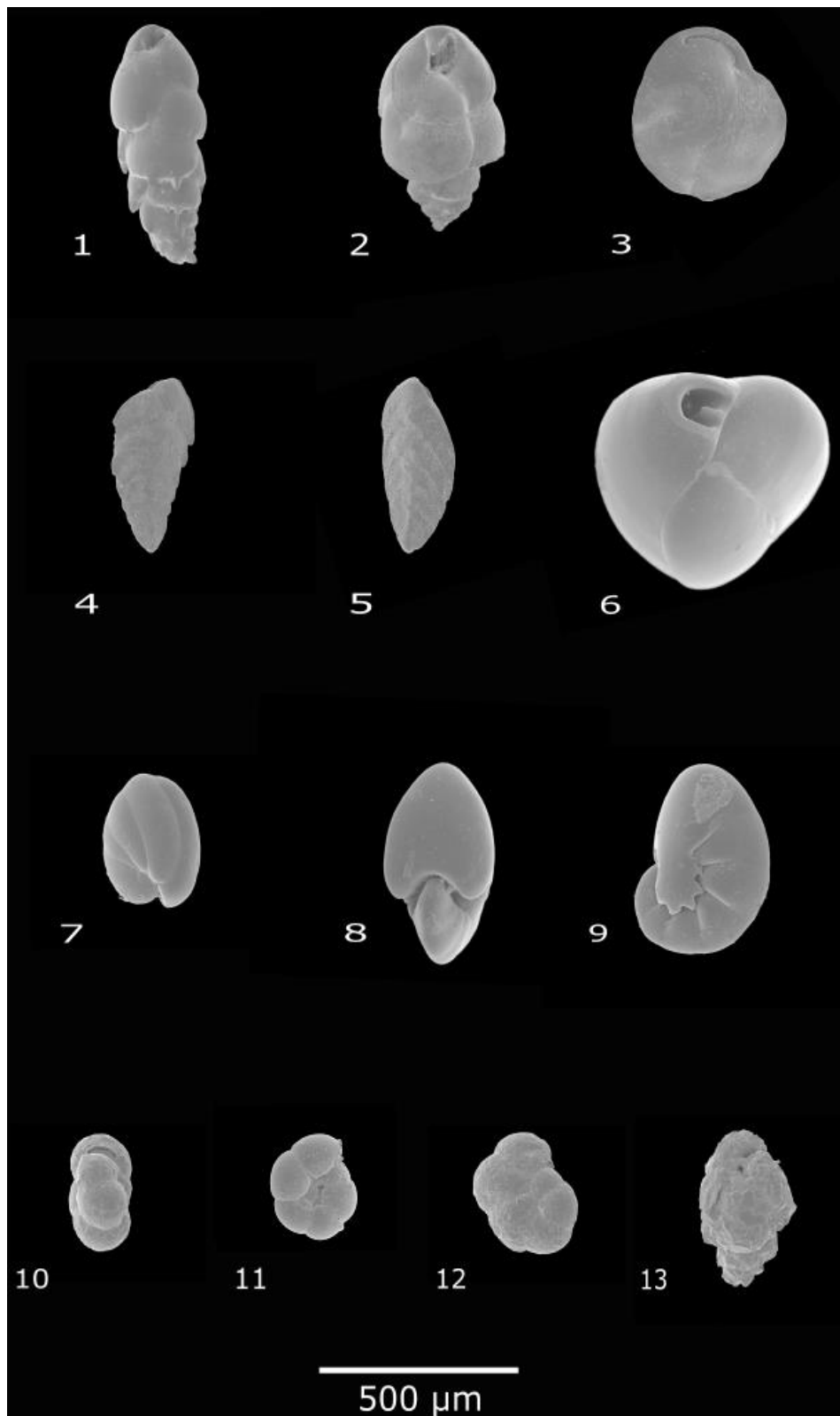


Figure 12 SEM Pictures 1-2 = *B. marginata*, 3 = *C. laevigata*, 4-5 = *B. skagerrakensis*, 6 = *Q. seminulum*, 7 = *N. turgida*, 8 = *N. labradorica*, 9 = *N. stella*, 10-11 = *H. bradyi*, 12 = *R. trochamminiformis*, 13 = *E. scaber*

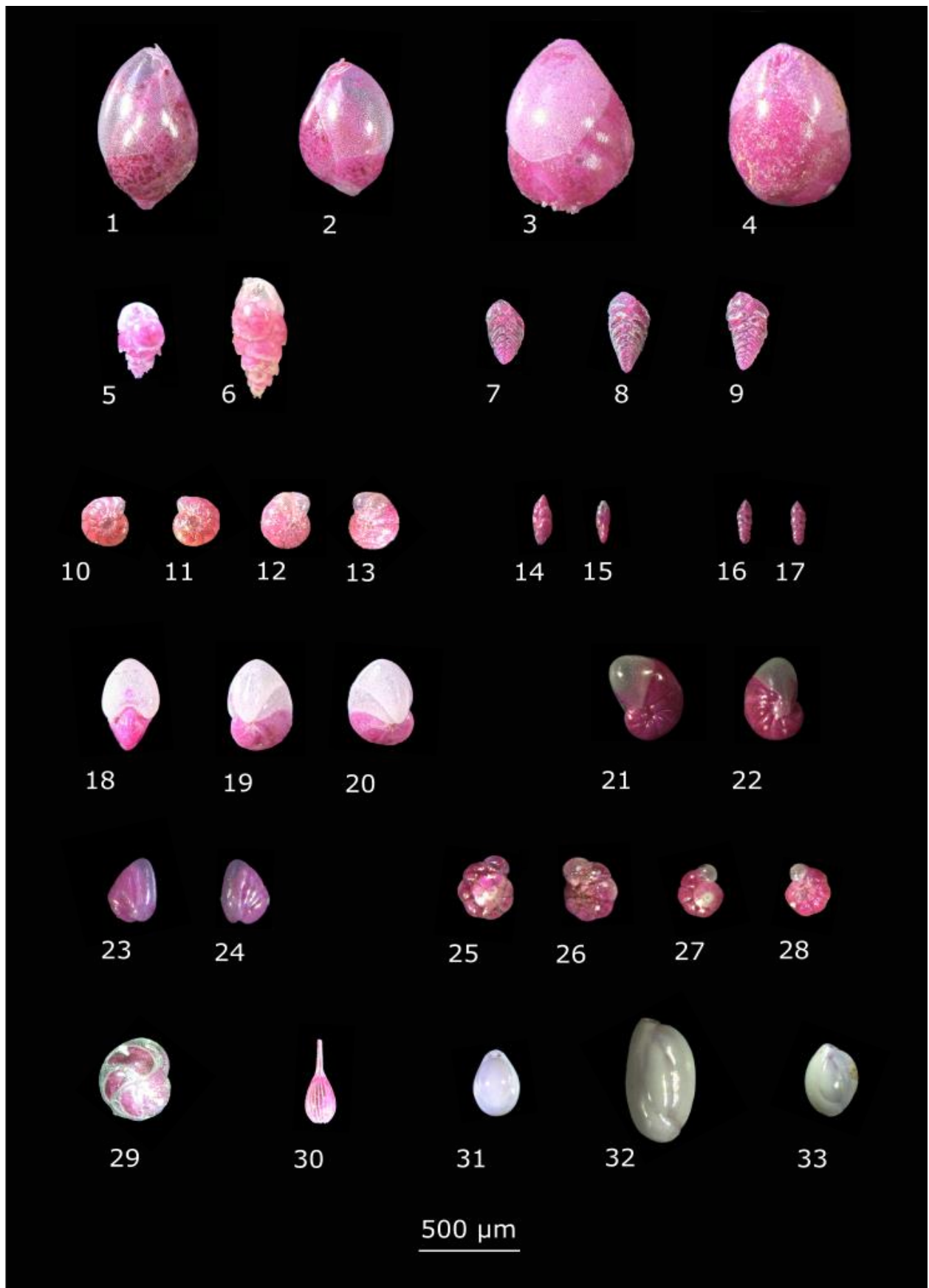


Figure 13 LM Fotos I calcareous, 1-2 = *G. turgida*, 3-4 = *G. auriculata*, 5-6 = *B. marginata*, 7 = *B. dilatata*, 8-9 = *B. skagerrakensis*, 10-13 = *E. excavatum*, 14-15 = *S. fusiformis*, 16-17 = *B. punctata*, 18-20 = *N. labradorica*, 21-22 = *N. stella*, 23-24 = *N. turgida*, 25-28 = *A. beccari*, 29 = *C. laevigata*, 30 = *L. levis*, 31 = *P. williamsoni*, 32-33 = *Q. seminulum*

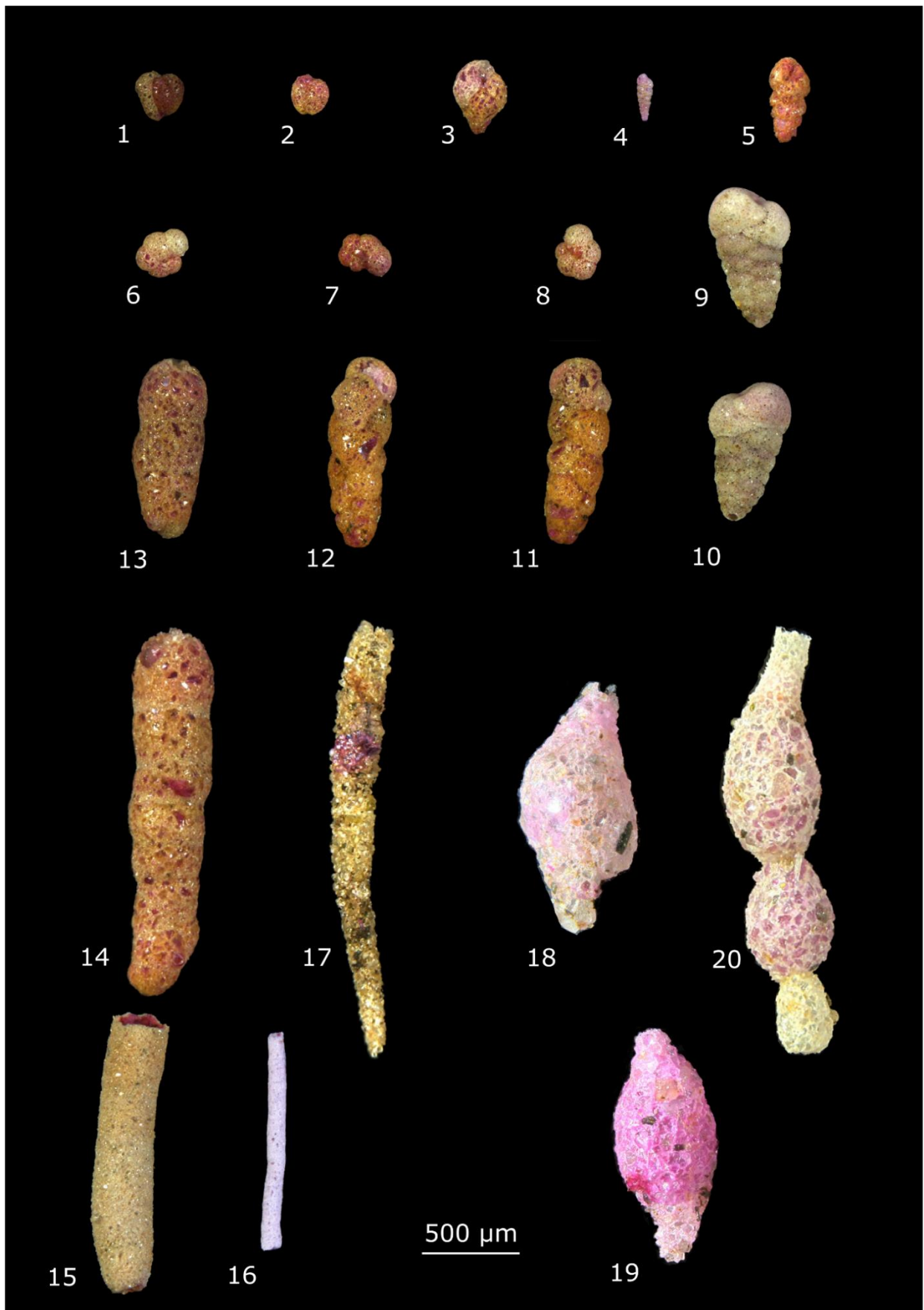


Figure 14 LM Fotos II agglutinated, 1-2 = *A. glomeratum*, 3 = *E. scaber*, 4 = *T. earlandi*, 5 = *E. medius*, 6-7 = *R. trochamminiformis*, 8 = *H. bradyi*, 9-10 = *T. bocki*, 11-12 = *V. advena*, 13-14 = *L. goesi*, 15 = *H. hirudinea*, 16 = *Bathysiphon* sp., 17 = *H. fragilis*, 18-19 = *R. rostata*, 20 = *R. subfusiformis*

4. Discussion

4.1 Foraminiferal Assemblage Characteristics

In total 1679 tests were counted. The goal of counting a minimum of 300 tests per layer was reached for all layers, except for the 3-5cm layer. Figure 6 illustrates the decrease of test with depth. This is a normal observation as food quality and oxygen decrease with depth (Jorissen et al., 1995; Sen Gupta and Machain, 1993). In fjord environments the standing crop in the first centimeter (160.53 ind./ 10cm³, Table 3) can vary strongly depending on the degree of oxygenation (Murray 2003, p. 111). I interpret that the increase of individuals in the 2-3 cm layer (444 ind./ 10 cm³) is caused by superb living conditions for *N. stella*. As mentioned earlier *N. stella* can become very dominant under suboxic conditions (Bernhard et al., 1997).

The ternary diagram (Figure 7) depicts the proportions of different wall types. Normal marine waters, as were encountered in this study, plot along the hyaline-agglutinated side (Murray, 2003, p. 110). The in situ measured environmental parameters (Table 2) indicate normal salinity, pH values and water temperature. The notable decrease of agglutinated tests with depth can be explained by considering that *A. glomeratum* represents 10% (Figure 8) and lives epifaunal, feeding on phytodetritus during algal blooms (Kuhnt et al., 2012) and decreases its occurrence rapidly with depth (Figure 11). Furthermore, *Nonionella* dominate deeper layers, this also has an influence on the proportions. Dominance of calcareous forms have been reported from oxygen depleted environments in the Drammersfjord, Norway (Alve, 1990).

Diversity indices describe the species composition of communities. The index values decrease down to the 2-3 cm layer and then increase again slightly in the 3-5 cm layer. This effect is again due to the dominance of *Nonionella* in the 2-3 cm layer (Figure 9 and Figure 10). As the number of species declines and the abundance of a few species increases, the diversity decreases. Unfortunately, oxygen content within the sediment was not measured, so it can not be said with certainty if this diversity decrease is due to oxygen depletion. Generally, diversity decreases proportionally with oxygen content, as opportunistic species begin to thrive. However, little research has been done on diversity changes within the microhabitats. Therefore, diversity changes since the 1940s in the respective sediment layers can not be thoroughly discussed. The diversity index peak in the 3-5 cm layer goes hand in hand with the increase of *B. marginata* and other species (Figure 8). The slight increase in diversity values for the 3-5 cm layer could come from lower competition rates of *Nonionella*, or from favorable conditions inside of bioturbated sediment.

4.2 Changing Environmental Parameters

The foraminiferal assemblage of core OVS18halfway7 is dominated by the species *B. marginata*, *N. stella*, *N. labradorica*, *N. turgida* and *A. glomeratum*. These species, including *G. auriculata* and *G. turgida*, are tolerant of low oxygen conditions (Bernhard and Alve, 1996; Nardelli et al., 2014; Pina-Ochoa et al., 2010). Kaiho (1994) introduced the concept of a foraminiferal oxygen index, showing that a correlation between the oxygen content of the sediment-water interface and foraminiferal assemblages can be made. Certain criteria such as size, wall thickness and porosity are considered to be indicators of oxygen content. However, caution is advised when trying to assign morphological traits with environmental parameters, as authors often mix observations with speculations. Nardelli et al. (2014) showed that under laboratory conditions *B. marginata* and *C. laevigata* are able to calcify tests in anoxic conditions, partially contradicting the assumption that thin walled tests indicate low oxygen levels. Nevertheless, the given foraminiferal assemblage of the core consists of species typical for low oxygen environments. One species alone would not be indicative of low oxygen conditions, since they can appear in well oxygenated environments as well (Sen Gupta, 2003, p. 212).

Cassidulina laevigata is a shallow infaunal species that is an indicator for warm water of the Atlantic and correlates positively with dissolved oxygen in bottom waters (Mackensen and Hald, 1988; Polovodova Asteman and Nordberg, 2013). It ceases to reproduce under anoxic conditions, however is still able to survive under hypoxic conditions (Nardelli et al., 2014; Pina-Ochoa et al., 2010). Alve (2010) concluded that *C. laevigata* depends on the input of fresh phytodetritus. The occurrence of *C. laevigata*, *B. marginata*, *A. glomeratum* and *Bathysiphon sp.* (etc.) in the top sediment layer indicate high total organic carbon (TOC) (Alve and Bernhard, 1995; Eichler et al., 2014; Gooday et al., 1992; Klitgaard Kristensen and Sejrup, 1996; Polovodova et al., 2011). *Bulimina marginata* is especially well known for showing a strong positive correlation with %TOC (Murray, 2003) and being capable to respond to high food availability (Jorissen et al., 1992). This coincides well with the algal bloom that the fjord experienced in September (Figure 5). Such blooms drastically increase the amount of food available at the sediment water interface and can consume oxygen in the water column (Calliari and Tiselius, 2009).

Figure 11 displays the vertical distribution of *N. labradorica*, *N. stella* and *N. turgida* as being bell shaped. They each have their occurrence maxima at about 2-3 cm in depth. *Nonionella stella* is known to be extremely abundant in poorly oxygenated environments (Bernhard et al., 1997). Similar observations have been made for *N. turgida*, which is able to sustain itself in oxygen depleted

sediment (Moodley et al., 1998). *Nonionella labradorica* and *N. stella* sequester chloroplasts/kleptoplasts that do not photosynthesize, but might be involved in sulfate and nitrate assimilation (Bernhard and Bowser, 1999; Cedhagen, 1991; Jauffrais et al., 2019). *Nonionella stella* and *N. turgida* are capable to respire nitrate (Pina-Ochoa et al., 2010).

Although *G. auriculata* and *G. turgida* are typically infaunal species due to their ability to denitrify, their abundance decreases with depth (Figure 17) (Pina-Ochoa et al., 2010; Woehle et al., 2018). This might be due to the increased competition for food with *N. stella* (Bernhard et al., 1997). However, this observation does not consider the scarce amount of ind./10cm³ that were counted.

The microhabitat distribution for sample OVS18halfwaycontrol (Station 1, 83 m) (Figure 16) shows similar results as sample OVS18halfway7. The dominant species are the same. The slight differences in the curve shapes stem from the significantly lower total amount of tests.

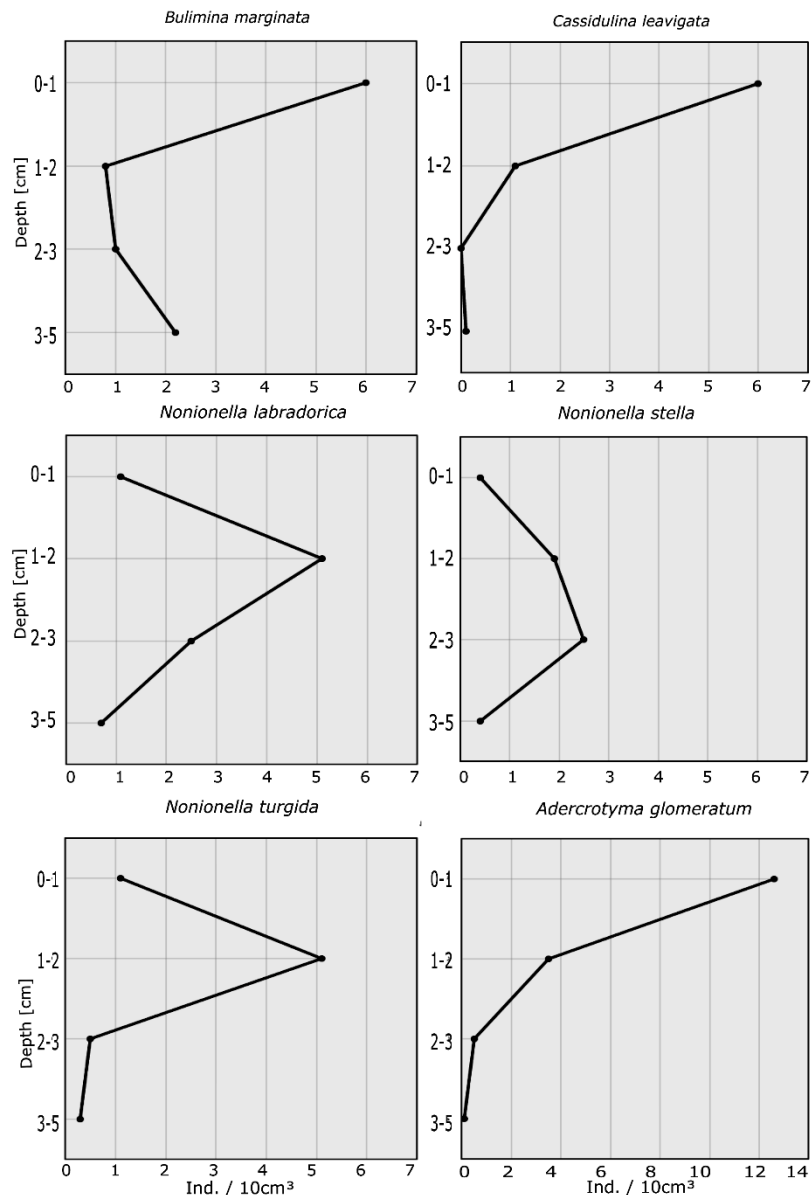


Figure 16 Vertical distribution within the sediment of the dominant species from Sample OVS18halfwaycontrol (Leitgeb, unpublished)

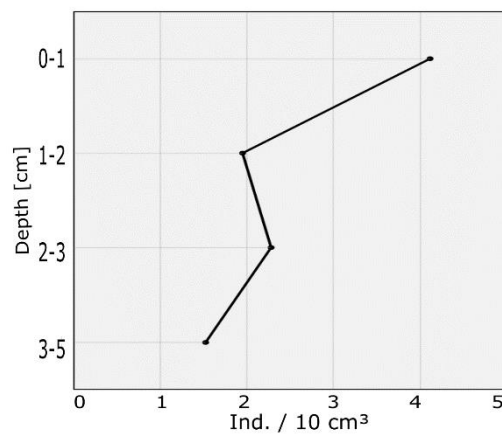


Figure 17 Vertical distribution of *G. auriculata* and *G. turgida*.

Unfortunately, the concentration of O₂ and TOC or chlorophyll-a content were not measured within the core samples of this study. However, I suggest that at the time of sample extraction the local conditions were meso/eutrophic (high food availability) and possibly oxygen depleted (compare Figure 4 and Figure 5). The high food availability can account for high respiration rates at the sediment water interface and rapid oxygen depletion with increasing sediment depth. If that was the case, the results of this study stand in accordance with the TROX model proposed by Jorissen et al. (1995). Here, the amount of food and oxygen determines the penetration depth and occurrence of foraminifera. This explains why the foraminifera occurring in the top centimeter are dominated by opportunistic species adjusted to high food availability (*B. marginata*, *C. laevigata*, *S. fusiformis*, *T. earlandi*, etc.). Furthermore, why the species diversity and abundance decrease strongly with depth, as oxygen is depleted due to remineralization. Therefore *N. stella* could become so abundant in the 2-3 cm layer, thriving off of the low competition with other species. The second peak that *B. marginata* experienced in the 3-5 cm layer, could be explained by food accumulation through bioturbation, or decreased competitive pressure by *Nonionella*.

Polovodova Asteman et al. (2018) reconstructed the winter bottom water temperatures of the Gullmar Fjord over the past 2500 years. They came to the conclusion that the water temperature noticeably increased since the 1960s by ~1,5 °C. This increase of bottom water temperature might be reflected in this study by the occurrence of *E. scaber* (3%), which as mentioned before, was seldom found at depths greater than 50 m in the Gullmar Fjord (Höglund, 1947; Qvale, 1984). According to Nordberg et al. (2000) it is difficult to determine whether the oxygen content of the bottom water is steadily declining or if the observed decline is just caused by temporal shifts in oxygen content induced by climatic factors (such as the NAO).

4.3 Assemblage Changes since the 1930s

The samples that Höglund (1947) collected for his dissertation have been analyzed and studied by authors such as Alve and Murray (1995), Gustafsson (2001) and Qvale (1984). Unfortunately, lacking precision and out of date methods lead to Höglund's data only being partly useful in this study. For instance, Höglund did not stain his samples to differentiate between living and dead individuals. He argued that most tests occurring in the upper sediment layer must have lived and died there recently and did not deem the currently living assemblages to be important. Neither did he slice his cores into specific layers, but merely looked at the top detritus layer, which varied in thickness and consistency. Therefore, microhabitat distribution can not be compared. Because Höglund did not publish his raw data, he categorized the important species as rare, few, frequent, common and abundant. This description is generalized for every species throughout the entire fjord, not for specific sampling sites (Höglund, 1947, p. 293). If for instance, a species was found to be abundant at one site but only rare at others it would have termed as common within the fjord. However, some species were not discussed by him in detail and it is not clear to what extent they occurred in the fjord. With this information in mind Höglund's work can still be used to make qualitative comparisons and statements about some of the occurring species.

Although the available information is sparse, I have been able to ascertain the following key points. All species from core OVS18halfway7 except *N. stella* and *H. hirudinea* were documented by Höglund. Other species such as *N. turgida*, *N. labradorica*, *C. laevigata* and *E. excavatum*, which represent essential species in my sample, are only mentioned briefly in a counting sheet. Strangely, these species do not appear in the final species list that he published, neither can information about their abundance be found. Therefore, I can not with certainty say if these species occurred as abundantly back then as they do today. *Eggerelloides scaber* (formerly *Egerella scabra*) was noted to be one of the most common shallow water species in the Gullmar Fjord and Skagerrak, seldom found in depths greater than 60 m. However, this species has an abundance of nearly 3% at 81 m water depth. *Hippocrepinella hirudinea*, which was not recorded by Höglund throughout the Gullmar Fjord or the Skagerrak, occurred six times in the first centimeter. Another species that was newly introduced to my sampling site is *H. fragilis*, this species however did occur at other of Höglund's sampling sites.

Textularia earlandi (formerly *T. tenuissima*) was very abundant and occurred at 65 of the 72 sampling stations. This species barely appears in the 1000-125 μm fraction, however upon further investigation seemed to be quite common in the 125-63 μm fraction. This fraction was not inspected thoroughly, but only briefly in order to gain an overview of the faunal composition (Figure 15). The same effect was observed for *S. fusiformis* (formerly *B. fusiformis*). This species was classified as very abundant and occurred at 63 of the 72 sampling stations. Both *S. fusiformis* and *T. earlandi* form miniscule tests that are not held back by the 125 μm sieve. Therefore, both *T. earlandi* and *S. fusiformis* are abundant in my sample when considering the smaller fraction. This is important because these species are opportunistic and thrive under high organic matter input.

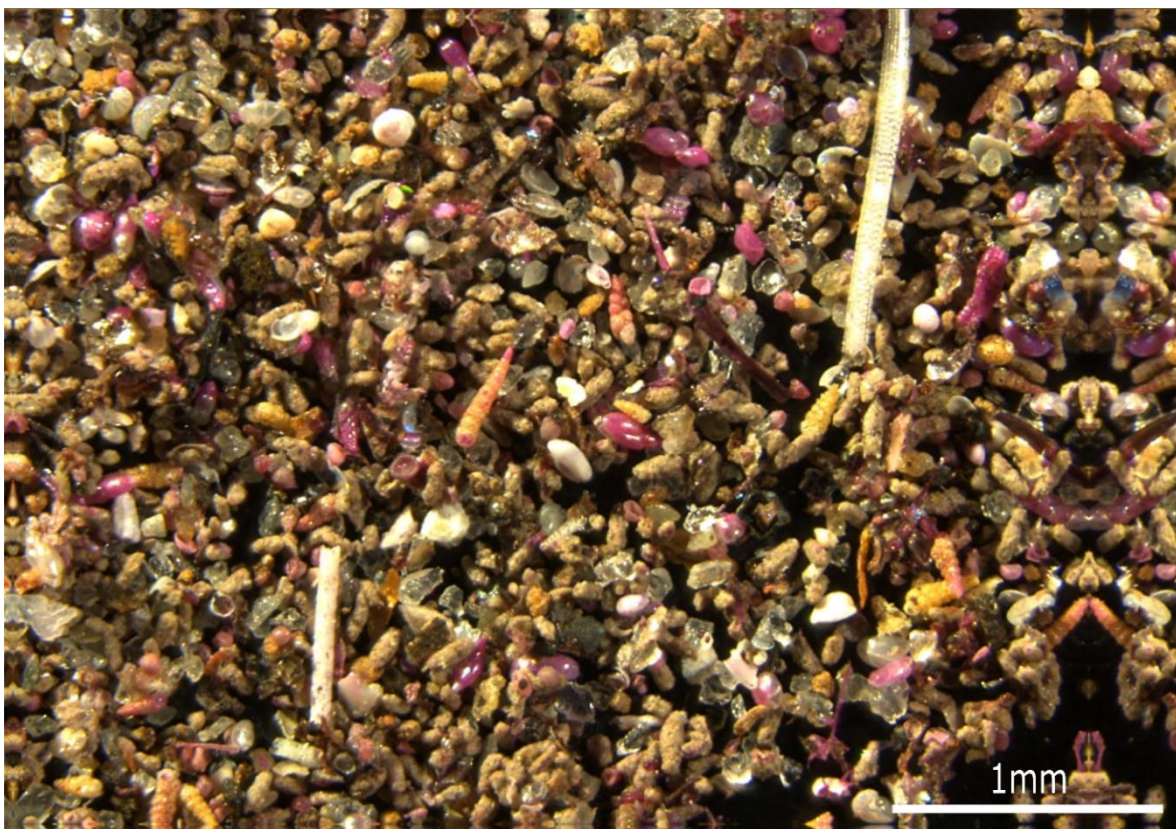


Figure 15 The unpicked 125-63 μm fraction shows a clear abundance of *S. fusiformis* and *T. earlandi*. The brown lumps are sediment particles.

Polovodova-Asteman and Schönfeld (2015) investigated the appearance of *N. stella* in northern European waters, by analyzing cores extracted from the Skagerrak region and Gullmar Fjord (Alsbäck Deep). *Nonionella stella* first appeared in the fjord sediments around 1985, following a hypoxic event. They propose that the species was introduced to the region through ship ballast tanks, as a natural migration seems unlikely. The species originates from the eastern Pacific and can be found in abundance in anoxic basins off California. *Nonionella stella* preferably lives infaunal (1-2 cm) in dysoxic microhabitats (Bernhard et al., 2000, 1997). It can store large amounts of nitrate in its

cytoplasm to be used as an electron acceptor for respiration in anoxic conditions (Risgaard-Petersen et al., 2006). Differentiating between *N. stella* and *N. turgida* can be challenging. *Nonionella stella* displays a hand shaped extension of the last chamber, with finger-like processes, over the umbilicus (Figure 12-9) (Cushman and Moyer, 1930).

Stainforthia fusiformis is a highly opportunistic and adaptive species. It copes exceedingly well with changing environmental conditions and can be one of the most abundant species in the Skagerrak region, especially in formerly anoxic areas (Alve, 2003; Alve and Murray, 1995; Polovodova Asteman and Nordberg, 2013). According to Gustafsson (2001) *S. fusiformis* can increase its population sevenfold within a month after experiencing an increase in food input. This species correlates positively with chlorophyll-a content. Figure 5 shows the increasing chlorophyll-a content of the surface water in September. This is in accordance with the autumn algal bloom typical for fjord environments. The occurrence of *S. fusiformis* does not specifically imply low oxygen content, merely high food input. *Stainforthia fusiformis* is capable of storing high amounts of nitrate in its cytoplasm. *Textularia earlandi* (formerly *T. tenuissima*), also an opportunistic species and the dominant species in the first centimeter of the 125-63 μm fraction, is however outcompeted by *S. fusiformis* when anoxia sets in, possibly due to its higher oxygen demands. Since the Gullmar Fjord is prone to periods of low oxygen content the occurrence of these two species in particular is to be expected.

All other identified species are either only vaguely mentioned by Höglund or do not show any significant change in abundance.

5. Conclusion

The results obtained in this work support the claim of various studies, that the foraminiferal faunal assemblage of the Gullmar Fjord has changed in the past century. Due to insufficient comparable raw data from Höglund (1947) only qualitative comparisons could be made. However, when looking at other similar studies, a percentual increase of low oxygen tolerating benthic foraminifera could be observed. The novel appearance of *N. stella* in the fjord sediments is confirmed. The 2-3 cm layer is dominated by the species *N. labradorica*, *N. stella* and *N. turgida* (79%), species known to be capable of denitrification. The top centimeter is characterized by species accustomed to high food availability. Changing environmental parameters such as bottom water temperature and oxygen content, possibly caused by anthropogenic activity (emission of greenhouse gases), are responsible for these changes. Due to the high variability and adaptiveness of foraminifera to microhabitats and lacking relevant data, all conclusions concerning the changes in diversity with decreasing oxygen content must be speculative. In future studies, yearly sediment samples should be taken and analyzed for living benthic foraminifera. Chemical and physical parameters (O₂ and Nitrate) should also be measured regularly in order to correlate changing microhabitat distribution with species diversity.

6. Acknowledgements

I would like to thank all members of the micropalaeontology work group, especially my supervisors Professor Petra Heinz and Julia Wukovits, who gave me the opportunity to participate in this project and invested countless hours of their time. In addition, I would like to thank my fellow students for their helpful comments and support.

Appendix

Species	Ind./10cm ³				Total individuals
	0-1cm	1-2cm	2-3cm	3-5cm	
calcareous					
<i>Ammonia sp.</i>	0.53	0.23	0.00	0.22	5
<i>Bolivina dilatata</i>	0.53	0.00	0.00	0.00	2
<i>Bulimina marginata</i>	39.74	4.58	6.42	9.86	290
<i>Bolivina punctata</i>	0.53	0.00	1.15	0.22	9
<i>Bolivina skagerrakensis</i>	0.79	0.00	0.69	0.00	6
<i>Cassidulina laevigata</i>	21.58	2.52	1.60	0.76	107
<i>Cibicides Lobatulus</i>	0.00	0.00	0.00	0.11	1
<i>Elphidium excavatum</i>	3.42	1.60	0.46	0.54	27
<i>Globbulimina auriculata</i>	2.37	1.60	2.52	0.76	34
<i>Globbulimina turgida</i>	7.63	2.52	2.29	0.76	57
<i>Lagena annelatrachia</i>	0.26	0.00	0.00	0.00	1
<i>Lagena levis</i>	0.26	0.00	0.00	0.00	1
<i>Nonionella labradorica</i>	6.05	17.19	16.50	1.84	187
<i>Nonionella stella</i>	9.21	28.65	51.80	7.26	453
<i>Nonionella turgida</i>	10.26	12.38	11.69	1.84	161
<i>Pyrgo williamsoni</i>	0.53	0.00	0.46	0.11	5
<i>Quinqueoculina seminulum</i>	2.89	0.46	0.46	0.11	16
<i>Stainforthia fusiformis</i>	0.00	0.00	1.60	1.08	17
<i>Uvigerina peregrina</i>	0.00	0.00	0.00	0.11	1
agglutinated					
<i>Adercotryma glomeratum</i>	15.53	4.35	1.60	0.87	93
<i>Bathysiphon sp.</i>	8.42	0.00	0.00	0.00	32
<i>Eggerelloides medius</i>	0.26	0.46	0.46	0.33	8
<i>Eggerelloides scaber</i>	2.37	0.46	0.46	0.65	19
<i>Haplophragoides bradyi</i>	6.05	1.15	0.69	0.11	32
<i>Hippocrepinella hirudinea</i>	1.58	0.00	0.00	0.00	6
<i>Hyperammina fragilis</i>	1.32	0.00	0.00	0.00	5
<i>Libusella goesi</i>	4.47	0.92	0.23	0.11	23
<i>Recurvoides trochamminiformis</i>	3.95	0.46	0.00	0.00	23
<i>Reophax dentaliniformis</i>	0.26	1.38	0.46	0.11	3
<i>Reophax rostrata</i>	6.58	0.92	0.23	0.43	34
<i>Reophax subfusiformis</i>	0.53	0.49	0.23	0.33	8
<i>Textularia Bocki</i>	1.05	0.00	0.00	0.11	5
<i>Textularia earlandi</i>	1.05	0.00	0.00	0.11	5
<i>Verneuilina advena</i>	0.53	0.23	0.00	0.00	3

Appendix 1 Counting sheet for sample OVS18halfway7

Sample	Sed. depth	Volume (ml)	Mass (g)
OVS18halfway7	0-1 cm	38	
	1-2 cm	33.5	
	2-3 cm	43.63	2.11
	3-5 cm	92.25	3.3
	0-5cm	207.38	

Appendix 2 Volume/Mass measurements OVS18halfway7

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