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Late Quaternary palaeoceanographic evolution in the Skagerrak, north eastern North Sea

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MSc Thesis

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Abstract

This thesis investigates a radiocarbon dated composite sediment core from the Skagerrak basin (GC372650) and uses foraminifera to reconstructs the late Quaternary palaeoceanographic evolution of the North. The Skagerrak is an ideal location to reconstruct oceanographic change as it is critical in controlling water exchange between the Baltic Sea and the North Sea. Foraminiferal assemblage zones effectively highlight variations in hydrological conditions throughout the core. Sediments deposited between 12,600 and 11,200 cal. BP reflect cooler, ice proximal conditions during the Younger Dryas, with water temperatures warming throughout this period. The opening of a new outlet across central Sweden from the Baltic occurred at c. 11,200 cal. BP, and existed for about 1000 years, before its gradual closure at c. 10,500 cal. BP. Increased Atlantic inflow during the early Holocene is interrupted by a cooling event at c. 9400 cal. BP, though it is unclear if this was part of a wider climatic cooling, or a strengthened North Jutland Current.

The Littorina transgression facilitated the initiation of the modern hydrological system at c. 8500 cal. BP with the opening of the English Channel; this was evidenced by a sudden bloom in *Hyalinea balthica*. Shortly after, around 8300 cal. BP, the opening of the Danish Straits occurred, allowing exchange between the North Sea and the Baltic Sea. Outflow from the Baltic was greatest in the subsequent 2000 years but decreased after 6000 cal. BP. At the same time, a strengthening of the South Jutland Current (SJC) and corresponding drop in water temperatures occurred. After the weakening of the SJC around 3000 years later, conditions were relatively stable with increasing Atlantic Inflow, though a distinct cooling between c. 3000 and 2200 cal. BP may correspond to 'neoglacial' cooling observed elsewhere.

Between 420 and 160 cal. BP, the return of cold water fauna indicate a drop in temperatures due to the Little Ice Age. The duration of this cold phase in GC372650 is considerably shorter than in other investigations, only showing change during the maximum of the LIA. Following this, recent oxygen depletion, evidenced by a sudden increase in *Textulari earlandi*, is probably a result of increased specimen abundance due to additional nutrient input. Although eutrophication cannot be ruled out as a possibility, variations in the NAO index seem to correlate well with the timing of oxygen depletion.

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Acknowledgements

Chapter 1. Introduction

1.1 – Introduction

This investigation aims to reconstruct environmental change in the eastern North Sea during the Late Quaternary by identifying changes in foraminiferal assemblages in a sediment core from the Skagerrak basin.

Whilst the focus of this study is the Skagerrak, the significance of its findings and the initial motives for the research are actually related to the Baltic Sea due to the exchange between these two water bodies. This research is supported by "INFLOW", a European project aiming to understand the mechanisms contributing to environmental change in the region. Immense pressure is placed upon the resources of the Baltic Sea as it supports 85 million people from 14 different countries (Rönnberg & Bonsdorff, 2004). As a result, it has experienced significant change in the 20th/21st century, caused by both environmental and anthropogenic factors. The fragility of the Baltic Sea has long been recognised, with Fonselius (1972) claiming it to be one of the most contaminated seas on the planet, though it is only recently that increased political awareness has led it to become a focus of Baltic Sea research.

One of the largest challenges facing the Baltic Sea is eutrophication. This is not a new problem, with Elmgren (1989) observing an increase in organic carbon of 70-190% and a concurrent increase in productivity of 30-70% between 1900 and 1980. Stålnacke (1996) estimates that around 1.3×10^6 tonnes of nitrogen and 59×10^3 tonnes of phosphorous are released into the Baltic every year. Higher up the trophic ladder, it is believed that fish are adversely impacted. Olsson *et al.*, (2012) suggest environmental change is altering the ecological structure of fish populations in the Skagerrak, whilst fishing practices in the Baltic have put severe stress on stocks (Ådjers *et al.*, 2006). Furthermore, it is expected that climate warming will exert additional stresses on the ecosystem. Increased precipitation, as a result of warmer conditions, will impact upon the transfer of biomass to higher levels in the trophic system, reducing its efficiency (Wilkner & Andersson, 2012).

All these problems are worsened by the limited exchange of water between the Baltic and the North Sea, limiting the renewal of water. This makes the Baltic Sea extremely sensitive to change, both anthropogenic and natural. Given the challenges facing the Baltic Sea, a more sustainable use of its resources is needed. A critical element in achieving this sustainable use is to gain a better understanding of its connection to the surrounding regions, in particular the oceanographic system through the Skagerrak and Kattegat, into the North Sea. This project aims to contribute to that understanding of the natural processes operating in the region.

Firstly, it is necessary to set modern changes in the Baltic in the context of past environmental changes. The Baltic itself can be problematic in terms of reconstructing the palaeoenvironment, mainly due to poor preservation of proxies, whereas the Skagerrak provides extremely well preserved and high-resolution records since the last deglaciation (Knudsen *et al.*, 1996a; Gyllencreutz, 2005; Erbs-Hansen *et al.*, 2011a). By reconstructing these past environmental changes in the Skagerrak it will enable future investigations to assess the sensitivity of the Baltic Sea, enabling more precise calibration of models predicting its response to future environmental changes.

The Skagerrak, however, is not important simply because of its potential for the creation of high resolution records. The Skagerrak itself is fundamental in the circulation of the whole North Sea but, perhaps more importantly, it also controls the exchange of water between the Baltic Sea and the North Sea (Nordberg, 1991). All water flowing in or out of the Baltic passes through the Skagerrak. Hence, understanding the specific palaeoceanographic evolution of the Skagerrak is extremely valuable, as it will store records of variable exchange between the Baltic and the North Sea.

This is particularly important, as one of the threats facing the Baltic Sea is its declining salinity and, hence, productivity. Water renewal in the Baltic Sea is governed largely by topography, differences in sea level and freshwater forcing (Madsen & Højerslev, 2009). It is only in exceptional circumstances that high salinity water from the North Sea is able to flow freely into the Baltic during events referred to as Major Baltic Inflows, MBI (Schinke & Matthäus, 1998). These events have been linked with low sea level in the Baltic and a prolonged period of intensified winds (Matthäus & Franck, 1992; Schinke & Matthäus, 1998), though generally such events are generally poorly understood.

Weak to moderate MBI occur every 1 - 2 years, however strong MBI occur far less regularly, approximately every 5 – 10 years (Matthaüs & Franck, 1992). Despite the irregularity of these MBI, they are fundamental to the ecosystem of the Baltic, ensuring that, every few years, a large volume of high salinity water enters the Baltic. Consequently, a new and extremely important direction in Baltic research is the aim to develop a better understanding of these events. This is made even more critical by recent research suggesting the regularity of these inflow events has declined, with the last MBI occurring over c.20 years ago (Matthäus *et al.*, 2008). Whilst the Skagerrak is ideal for reconstructing general exchange between the North Sea and the Baltic, it may also provide evidence of these MBI's.

In addition, by reconstructing the evolution of the Skagerrak Basin it is possible to develop a picture of the palaeoceanographic evolution of the entire North Sea; this is extremely valuable, not simply for its significance to Quaternary Science or its contribution to the understanding of northern Europe's climatic and oceanographic

development, but because it provides a record of the water properties that will have entered the Baltic. This record is highly important as variations in properties such as salinity and temperature have significant effects on the ecology of the Baltic and surrounding land masses.

Finally, given the high sedimentation rates in the Skagerrak (Gyllencreutz *et al.*, 2005), it is possible to create a high-resolution record of modern environmental change; this is extremely pertinent to the Baltic Sea because, to fully understand the modern changes that are occurring within the Baltic, it is necessary to understand the changes that are occurring around it.

Clearly, this investigation is able directly to support the objectives of INFLOW, and will provide valuable data concerning the relationship between oceanographic changes in the North Sea and environmental changes in the Baltic. However, it is important to note that the primary focus of this research it to reconstruct palaeoceanographic development of the North Sea. Nonetheless, it will pay particular attention to the variations in water entering the Skagerrak, its exchange with the Baltic Sea and more recent, potentially anthropogenic change.

As mentioned earlier, the location of the Skagerrak and the nature of the hydrological system within the North Sea make it an ideal location to reconstruct environmental change through time. Numerous different water masses affect the Skagerrak, with the most significant arriving from the North Atlantic and the English Channel. As a result, sediments deposited in the Skagerrak provide exceptional records of changing environmental conditions through time (Knudsen *et al.*, 1996a; Knudsen *et al.*, 1996b; Jiang *et al.*, 1997; Klitgaard-Kristensen *et al.*, 2001; Gyllencreutz, 2005; Gyllencreutz & Kissel, 2006; Erbs-Hansen *et al.*, 2011a, 2011b etc.). By analysing proxy records from marine sediment cores in the Skagerrak, it is possible to reconstruct changes in the water column and, hence, reconstruct the palaeoceaonographic evolution of the Skagerrak; this is enhanced by the potential for extremely high resolution records.

Given its suitability, it is not surprising that this area is relatively well studied. However, previous work has shown that there are clear variations between

studies, indicating that different areas within the Skagerrak have responded differently to past environmental changes. Discrepancies in dating calibration between studies, as well as variations in the resolution amplify this problem, making precise dating of events difficult. Consequently, additional work in this area is extremely valuable in helping to constrain the timing of events as well as their magnitude and extent, both historic and current.

Additionally, most studies reconstructing the palaeoenvironmental history of the Skagerrak use marine cores taken from depths of less than 350m. This study will examine a marine core from much deeper in the Skagerrak, thus creating a new record of deep water evolution in the Skagerrak. This may provide a better understanding of the timing and magnitude of hydrographic developments, making it a significant contribution towards the scientific understanding of this region.

Overall, It is clear that, given the problems faced in the Baltic Sea, more work is needed to help understand the relationship between the Baltic and its surrounding areas, as well as accurately constrain the relative impacts of modern natural and possibly anthropogenic change. Whilst multiple studies have been carried out in the Skagerrak before, distinct variations in findings mean more work is needed to fully understand the palaeoceanographic evolution of the Skagerrak basin. Additionally, a study in the deep Skagerrak may provide a better record of change through time. Thus, the findings from this research will help to contribute to scientific understanding of the long-term evolution of the areas surrounding the Baltic Sea, as well as to provide valuable data to INFLOW concerning variations in water exchange through time and the relative impact of modern anthropogenic change.

1.2 - Project Aims

The aim of this project is to reconstruct the palaeoceanographic development of the Skagerrak basin. It will reconstruct fluctuations in the hydrological system across the North Sea throughout the late Quaternary, and, in doing so, contribute to the understanding of climatic and oceanographic changes since deglaciation. It also aims to reconstruct variations in exchange between the North Sea and the

Baltic Sea, gaining an understanding of their complex relationship through time. To achieve these aims, a number of objectives have been set out.

1.3 - Research Objectives:

1) To identify changes in benthic foraminiferal assemblages from a gravity core and associated multi-core from the Skagerrak Basin.

2) Based on the ecology of the benthic foraminifera, to identify changes in environmental conditions through time.

3) Using the benthic foraminiferal assemblages, in combination with other proxy data collected as part of the broader project, to identify changes in palaeoceanographic conditions through the late Quaternary.

4) Based on the high resolution data from the multi-core in combination with the longer record from the gravity core, to assess the relative influence of human impact on the environmental conditions within the Skagerrak Basin.

William Dickens

Chapter 2. Environmental Setting

2.1 - Modern Environmental Setting

Figure 1 shows the location of the Skagerrak basin, which forms part of the 900 km long Norwegian Trench that runs along the southern coast of Norway. With a maximum depth of 700 m (Nordberg, 1991) it is considerably deeper than the average of the North Sea which is just 98m, though some parts of the southern Skagerrak are shallower with average depths of around 150 m (Jiang *et al.*, 1997). A sill at 270m separates the basin from the remainder of the North Sea (Rodhe, 1987).

The narrow Kattegat area north of the Danish Straits restricts the flow of water between the Skagerrak and the Baltic Sea and, together, the two act as a large estuary (Nordberg, 1991) between the higher salinity North Sea, 30-35‰, and the more brackish Baltic Sea, 8-12‰ (Jiang *et al.*, 1997). It is this proximity to the Baltic Sea and the restrictions the narrow passage imposes on circulation into the Baltic that make the area so important when examining past and future environmental change in the region.
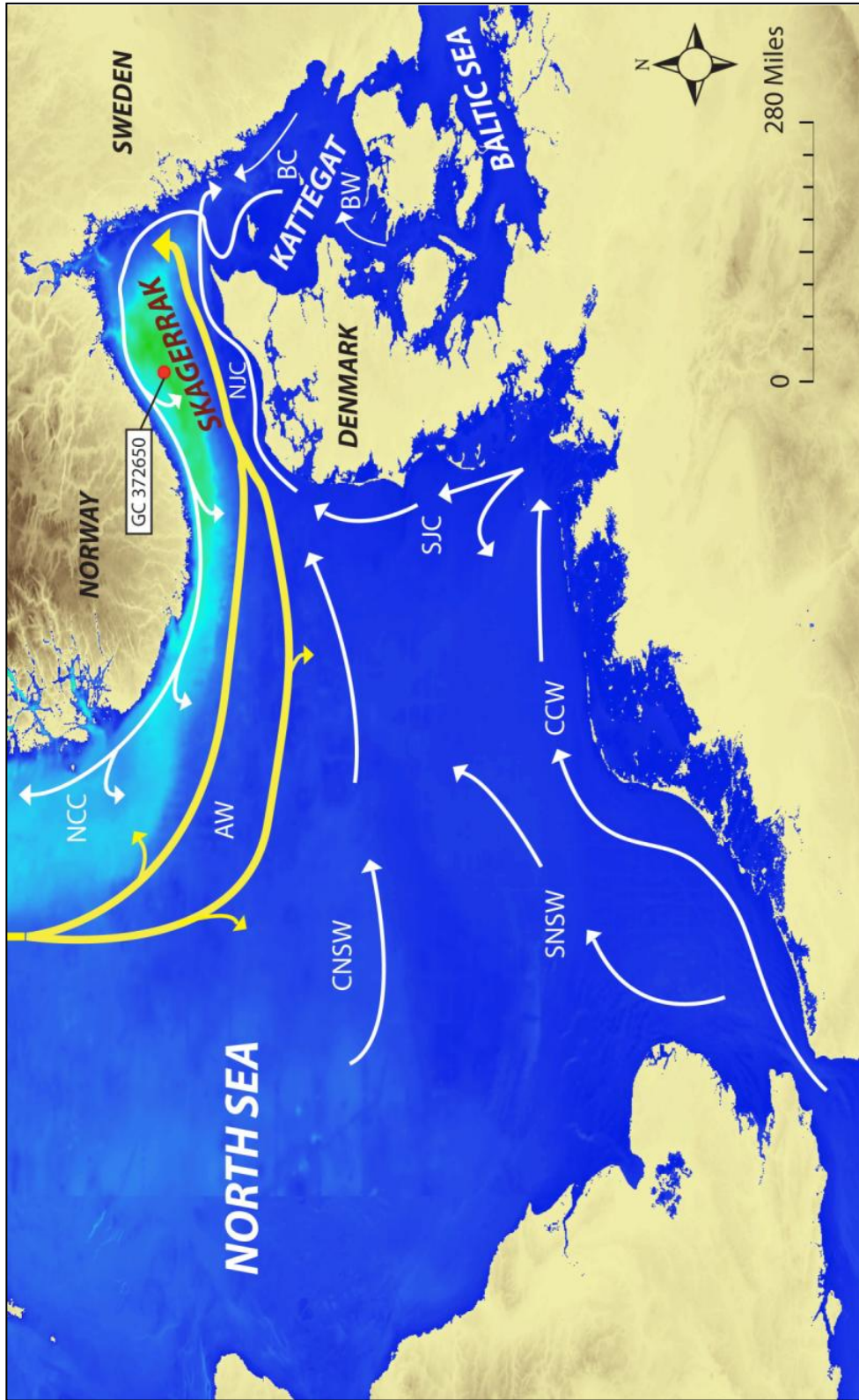
Figure 1: Location of GC372650 and the regional hydrological system in the Skagerrak. Currents are edited from Gyllencreutz *et al.* (2006)
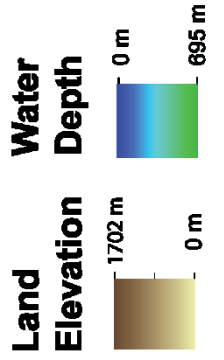
AW — Atlantic Water
BW — Baltic Water
CCW — Continental Coastal Water
CNSW — Central North Sea Water
NCC — Norwegian Coastal Current
NJC — North Jutland Current

SJC — South Jutland Current
SNSW — Southern North Sea Water

2.2 - Modern hydrological system

As shown in figure 1, Skagerrak circulation is cyclonic, driven primarily by the variations in salinity and mixing between the outflowing Baltic water and inflowing North Atlantic water (Rodhe, 1996). Nordberg (1991), however, suggests that the system is more complex than this, and believes it is controlled by three main factors: large scale atmospheric patterns, ocean circulation and the outflow of water from the Baltic Sea. These factors combine to create a complex and dynamic system.

The Atlantic Water (AW) enters the Skagerrak basin via the southern trench current (STC) at a depth of 100m (Talpsepp *et al.*, 1999). The characteristics of this inflowing AW are high salinity (>35‰), stable temperatures between 6.0°C-6.5°C, though this sometimes falls to below 5°C (Mork *et al.*, 1976; Larsson & Rodhe, 1979), and a high oxygen content. As the AW reaches the Swedish coast, it turns north in the Skagerrak and then west along the southern Norwegian trench. It remains close to the coast as it leaves the Skagerrak as the Norwegian Coastal Current (NCC).

Another input of Atlantic-sourced water comes from the Central North Sea Water (CNSW). This water flows into the Skagerrak at a depth of 70 m (Rise *et al.*, 1996). As this flows into the Skagerrak along the north coast of Denmark, it mixes with the North Jutland Current (NJC). This is formed from South North Sea water (SNSW) as well as water from the South Jutland Current (SJC) which is mainly derived from the English Channel. Once the NJC and the CNSW enter the Skagerrak-Kattegat, they mix with the lower salinity water from the Baltic (BW) in the Baltic Current (BC). This water then flows out to join the AW as the NCC. There is only a very small tidal range in the area, limited to around 20 cm (Nordberg 1991), ensuring it has little impact on the current system.

2.3 - Skagerrak bathymetry and sedimentation

Seismic studies have shown the Skagerrak to have a thick infill of sediment, with two plateaux at about 550m and 700m (van Weering *et al.*, 1987). The Norwegian

slope of the trench is relatively steep and irregular, whereas the southern slope has a far more gentle gradient and concave shape (van Weering *et al.*, 1987).

The Skagerrak acts as a sediment trap for material derived from the North Sea, and the Baltic Sea via the Kattegat. This is primarily driven by a reduction in water velocity, as the currents turn anti clockwise in the Skagerrak, shown in figure 1, moving into deeper waters (Rodhe & Holt, 1996). It is typically fine grained material deposited in the deeper areas, with coarser grained material in shallower regions. However, sandy sediments are prevalent down to around 200m on the Danish Skagerrak coast, a result of the hydrographical system (Conradsen *et al.*, 1994). The region also acted as a sediment trap during the Holocene, with postglacial sediment deposits up to 200 m thick around Skagen spit (Fält, 1982), see Skagen 3 core on Figure 3 for approximate location.

Due to the nature of the current system around the Skagerrak, sedimentation rates can be extremely high, with modern deposition rates of around 1 cm yr^{-1} at site MD99-2286 (Gylencreutz *et al.*, 2005). There is, however, considerable spatial variation, with Hass (1996) suggesting the sedimentation characteristics respond to variations in local hydrology and climate. Further to this, temporal variations are also observed, with Jiang *et al.* (1997) noting much slower sedimentation before 9000 BP.

2.4 - Sediment and water flux

In terms of water flux, estimates of mean water inflow into the Skagerrak are between 0.5 – 1.0x10^6 m^{3}s^{-1} (cf. Rodhe, 1996). Rydberg *et al.* (1996) suggest as little as 0.05 x10^6 m^{3}s^{-1} may arrive from the southern North Sea, with up to 90% arriving from the northern North Sea (Otto, 1976). Modelling performed by Winther & Johansson (2006) suggests that around 50% of all Atlantic water inflow mixes with fresh/brackish water before it leaves as the NCC. They suggest that most of this mixing occurs in the inner Skagerrak, where outflowing water from the Baltic Sea meets with the Atlantic water.

In terms of sediment flux, the SJC is the most erosive of the currents and transports extremely high concentrations of suspended sediments (Eisma & Kalf, 1987). This is a result of the easily erodable, sandy sediments that comprise most of the northwest coast of Denmark. Despite the high concentrations of sediment within this water, the SJC is still a relatively small contributor of sediments to the Skagerrak as the volume of water input is low.

2.5 - Deep water renewal

A distinct stratification exists in the Skagerrak, largely due to the sill and, although there is high seasonal variation in the strength of the stratification (Larsson et al, 2007), mixing between the two layers is irregular. It is only during late winter/early spring in certain years that deep water renewal can occur (Ljøen & Svansson, 1972). During cold winters, a large mass of high density water builds and cascades over the edge of the Skagerrak basin. During these renewals of deep water, temperatures can drop by up to 2°C (Ljøen & Svansson, 1972; Aure & Dahl, 1994). These are referred to as cascading events.

This cascading of water is, however, not regular. Consequently, in the deeper parts of the Skagerrak, below about 400 - 500m, deep water renewal can be slow with stagnant water persisting for several years (Ljøen & Svansson, 1972). Aure & Dahl (1994) suggest the renewal occurs every 3-4 years with an average residence time of 25 months. They examinined nutrient cycling in the Skagerrak, showing that the average oxygen depletion rate during the anoxic periods is about 0.04ml l^{-1}month^{-1}. They find no noticeable variation in this depletion rate through time. An oxygen concentration minimum occurred in 1980 (just 4.8ml l^{-1}) due to an abnormaly slow renewal rate which resulted from warmer temperatures the preceeding years. Above the sill depth, water renewal may well be continuous, resulting from the cyclonic circulation (Rodhe, 1987).

Chapter 3 - Palaeoenvironmental development

A detailed review of the current litereature regarding glacialogical history, hydrological development and climatic history of the Skagerrak and wider North Sea basin is presented below. The locations of the sites discussed are presented in figure 3. All ages are expressed in calibrated carbon years BP.

3.1 - Late Glacial

Deglaciation in the Skagerrak began around 18,000 cal. BP (Larsson *et al.*, 2007), though some put this slightly later, between 18,000 – 16,000 cal. BP (Lundqvist & Wohlfarth, 2001). Once deglaciation commenced, it is likely to have been extremely rapid (Björck, 1995; Lundqvist & Wohlfarth, 2001). Figure 2, adapted from Gyllencreutz *et al.* (2005), compiles records from numerous authors, demonstrating the stepped retreat of the ice front away from the Skagerrak after 15,400 cal. BP. It shows that by about 15,000 cal. BP, the ice front had retreated from the central/south Swedish coast, and had retreated to the mouth of Oslo Fjord by around c. 14,000 cal. BP. By c. 10,500 cal. BP, the ice front had retreated beyond Oslo Fjord and both the Norwegian and Swedish coast.

Marine conditions and the inflow of Atlantic water into the North Sea and the Skagerrak occurred around 15,000 cal. BP (Klitgaard-Kristensen *et al.*, 2001; Larsen *et al.*, 2012). This period is represented in figure 3A. During this interval, the Skagerrak is likely to have resembled a fjord like embayment (Gyllencreutz *et al.*, 2006), with relatively weak cyclonic circulation. Sediments deposited in the Skagerrak during this interval show glacimarine conditions (Knudsen *et al.*, 1996a; Larsson, 2007), as do sediments further north off the west coast of Norway (Klitgaard Kristensen et al, 2001). Björck (1995) suggest that an ice calving margin would have existed along the south coast of Norway and eastern Skagerrak – this would account for the glacimarine sediments found in numerous investigations. This is in agreement with Gyllencreutz *et al.* (2005).
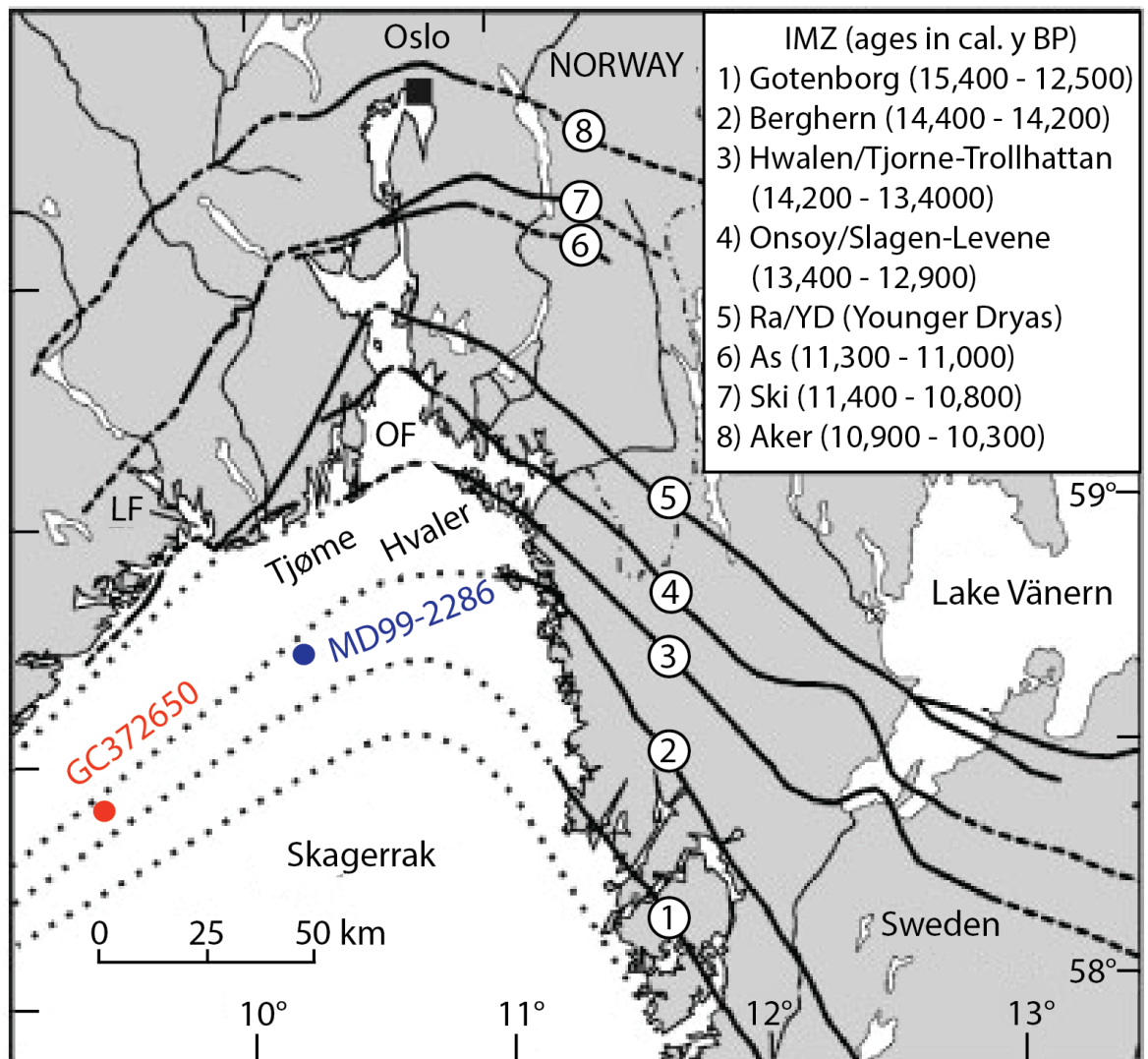
Figure 2: Edited from Gyllencreutz *et al.* (2005): Graphic showing the ice marginal zone over 8 time periods in the north eastern Skagerrak.

The termination of the Younger Dryas at around 11,500 cal. BP, with the transition away from ice proximal conditons, has been observed in the Skagerrak by a number of authors at MD99-2286 (Erbs-Hansen *et al.*, 2011a), Skagen 3/4 (Knudsen *et al.*, 1996a) as well as further north at Troll 8903-2803 (Klitgaard-Kristensen *et al.*, 2011, see figure 3. However, additional work on MD99-2286 showed ice proximal conditions until slightly later, around 11,300 cal. BP (Gyllencreutz, 2005; Gyllencreutz & Kissel, 2006). Larsson (2007), working in the eastern Skagerrak-Kattegat, also found ice proximal sediments deposited up to 11,300 cal. BP, though they inferred reduced glacial meltwater input at this time, indicating significant ice retreat. However, this suggests an ice calving front may still have existed in the Skagerrak. In either case, conditions throughout the water column during this period would have been cool.

The presence or absence of ice rafted debris (IRD) is a good indication of the proximity of an ice calving front. Through acoustic profiling and sedimentological analysis, van Weering (1982) established that IRD deposition had terminated by 11,300 cal. BP in the southwest Skagerrak. This appears to coincide with estimates from Stabell *et al.* (1985) and Werner (1985) who examined grain size characteristics on the GIK cores to infer a decrease in IRD during the early Preboreal. Despite this, Gyllencreutz (2005) found IRD in MD990-2286 up until 10,700 cal. BP. He also observed IRD at 10,200 cal. BP, though this is more likely to have resulted from the Glomma event, a major outburst flood that occurred in southeast Norway, releasing around 100 km^3 of water in approximately 10,200 cal. BP. Iceberg scours and other geomorphological features were used to reconstruct the event by Longva & Bakkejord (1990) and Longva & Thoreson (1991). Excluding this event, Skagerrak records indicate that a discharging ice shelf was still present in the Skagerrak, right up until 11,300 BP and possibly later.

3. 2 - Formation and drainage of Baltic Ice Lake

An extremely important event in the development of the wider North Sea and Baltic area was the formation, and drainage, of the Baltic Ice Lake (BIL). During the deglaciation of the Scandinavian ice sheet, a proglacial lake formed in front of the retreating ice front, with the outlet in the western Baltic, joining to the North
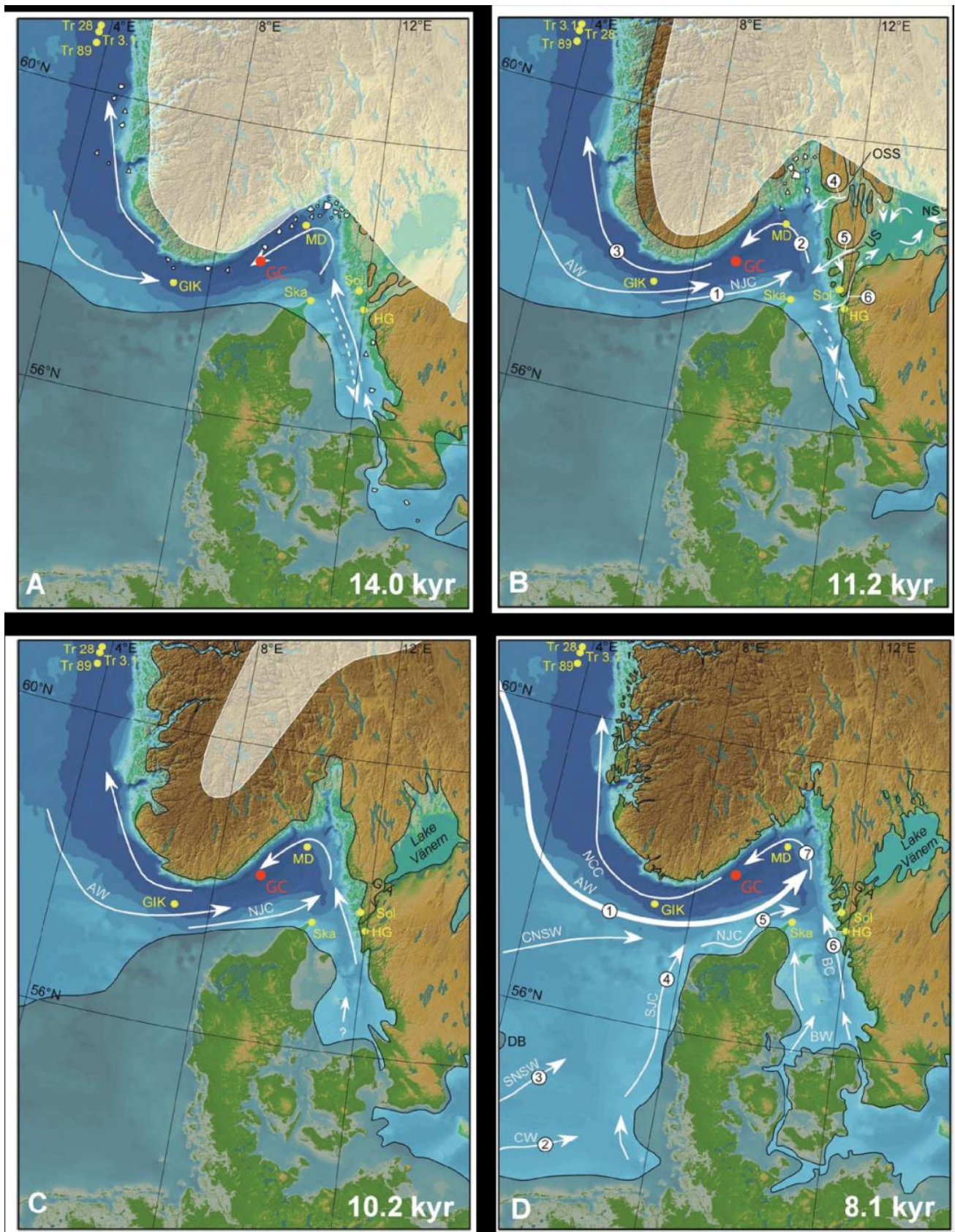
Figure 3: Edited from Gyllenreutz *et al.* (2006) showing the glacial extent (white areas), land configuration (dark shaded areas) and hydrological system at four time slices, 14,000 cal. BP, 11,200 cal. BP, 10,200 cal. BP and 8,100 cal. BP. The graphic also shows the core locations of previous core sites examined in this section (Tr = Troll Cores, GIK = GIK cores, MD = MD99-2286, Sk = Skagen 3/4, HG = Horticultural Garden, Sol = Solberga). In figure 3B, NS = Narke Strait, OSS = Otteid-Steinselva outlet and US = Uddevalla Strait. For reference, the BIL would have been located towards the east, just outside of this image.

The acronyms for the different hydrological currents are the same as in figure 1. For discussion on the numbers, see Gyllencreutz *et al.* (2006)

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Sea through the Öresund outlet, in much the same location as present day. The early history of this proglacial lake is slightly complex. Due to isostatic uplift following deglaciation, the Öresund strait (BIL threshold) began to rise above sea level (Björck, 1995). Compensating this, the sill was initially eroded to remain at sea level (Björck, 2008). However, once all of the glacial, easily erodible sediments had been removed, the bedrock of the sill was reached – it is likely that this produced the modern topography of the Öresund straits. At this point in time, the water depth began to shallow as the sill continued to rise above sea level. Consequently, water velocity through this outlet began to increase (Björck, 2008).

Ultimately, the water velocity would have reached a limit, beyond which it could no longer increase. As a result, the level of the BIL began to rise above sea level. In doing so, it created a waterfall (Björck, 2008) between the BIL and the North Sea. An important development occurred 13,000 cal. BP when the Scandinavian Ice sheet retreated beyond the northern point of Mount Billingen (Björck, 1995). Mount Billingen is just to the south west of the Narke Strait; see figure 3B. Once the ice sheet had retreated north of this feature, the BIL was able to drain more rapidly into the North Sea, initially occurring subglacially but soon occurring proglacially. Björck (2008) believes this could have lowered the level of the BIL by around 10m. It also led to the abandoning of Öresund as the outlet as water would have diverted to flow over south central Sweden. Björck (2008) find no evidence to show the exchange of water was two way during this interval, indicating the Batic basin would have remained a freshwater environment.

Shortly after this, however, the Younger Dryas caused the readvance of the Scandinavian Ice sheet, which subsequently "blocked up" the Baltic Ice Lake around Mount Billingen. Given that the Öresund Strait was still rising faster than sea level, the BIL continued to rise above sea level simultaneously, with the waterfall joining the BIL to the sea growing ever larger. The outlet would have been in much the same place as modern day, shown in figure 1, transporting the cold, ice proximal sediments and water into the Skagerrak, passing through the much shallower Kattegat region. Björck (1995) suggest that this outlet would have remained open right up until the Baltic Ice Lake final drainage at c. 11,600 cal. BP.

The final drainage of the BIL followed warming at the end of the Younger Dryas period, when the Scandinavian ice sheet retreated, exposing Mount Billingen once more. This drainage was considerably more dramatic than the previous event (Björck, 1995). Given that the Öresund Strait had continued to rise above sea level, and the BIL had matched it, the level of the BIL subsequently fell 25m during its final drainage (Jensen *et al.*, 1997; Jakbsson *et al.*, 2007; Hyttinen *et al.*, 2011). By examining elevation models of the region, Jakobsson *et al.*, (2007) used GIS analysis to suggest that the BIL lost 18% of its volume, equivalent to 7800 km^3 of water. This final drainage is believed to have occurred around 11,600 cal. BP (Andren *et al.*, 2002; Kortekaas *et al.*, 2007; Hyttinen *et al.*, 2011).

However, not every author has found evidence for the final drainage, with both faunal and sedimentary parameters from MD99-2286 showing no changes around this time (Gyllencreutz, 2005; Erbs-Hansen *et al.*, 2011). One possible explanation is increased water stratification due to large input of fresh water, limiting any impacts on the deeper waters. Conversely, isostatic modeling performed by Påsse and Anderson (2005) actually indicates the basin would have been at sea level during this period, and thus no BIL would have been present. Clearly, the exact nature of the BIL is not unanimously agreed upon.

3.3 – Younger Dryas - Holocene Transition

During this period, represented in figure 3B, the Skagerrak would still have resembled a large fjord with fairly weak cyclonic circulation (Gyllencreutz *et al.*, 2006). However, there may have been an increase in the strength of Atlantic water inflow into the North Sea (Klitgaard-Kristensen *et al.*, 2001) which could have resulted in a strengthening of the Skagerrak circulation with outflow along the Norwegian coast (Jiang *et al.*, 1997).

Another important development occurred as a result of the aforementioned final drainage. This was the opening up of the Närke Strait, "NS" in figure 3B, which altered sedimentation patterns as the Baltic outflow now entered the Skagerrak via new outlets on the Swedish Coast, "OSS" and "US" on figure 3B. This was intrinsically related to the final drainage of the BIL, but would have had a far

greater, long-term impact on Skagerrak sediments. This drainage change has been identified by a number of different authors (Björck, 1995; Gyllencreutz, 2005; Gyllencreutz & Kissel, 2006; Larsson, 2007). The development had a significant impact upon the Baltic Sea and is referred to as the Yoldia Sea stage. After the outlets opened, Andrén *et al.*, (1999) suggest saline water from the North Sea could not enter the Baltic for 250 years as the sills were too shallow. However, once the outlet was large enough due to the erosion of sediments, high salinity water was able to enter the Baltic; this resulted in a slightly brackish environemnt (Björck, 2008).

As a result of continued isostatic rebound, the new drainage outlet only existed for c. 1000 years, though the exact timing of its closure is unclear, with Larsson (2007) inferring a date of 10,600 cal. BP, and Gyllencreutz & Kissel (2006) inferring its closure at 10,300 cal. BP. This fits with findings from Björck (1995) and Lambeck (1999) who suggested it closed at about 10,300 cal. BP.

In terms of temperatures in the Skagerrak, the period between 11,500 and 10,200 cal. BP is generally viewed as a transitional period from cooler to warmer bottom water conditions (Jiang *et al.*, 1997; Knudsen *et al.*, 1996a; Erbs-Hansen *et al.,* 2011a).

3.4 – Early Holocene

This period generally reflects a continuation of the warming trend experienced over the previous 1000 years (Sejrup *et al.*, 2001). The Skagerrak would still have resembled a fjord like embayment although, as shown in figure 3C, an outlet to the Baltic in the Orësund area cannot be ruled out. This period in the Baltic is referred to as the Ancylus Lake Stage. The Baltic would have been a freshwater lake with no stratification (Björck, 2008). Continued isostatic rebound caused the Baltic to rise, though it is thought a riverine outlet may have existed between the Baltic and the Kattegat through Denmark (Bennike *et al.*, 2004). This may only have lasted 200-300 years (Björck, 2008) before sea level rose to the height of the Baltic basin.

Importantly, this period also witnessed an increase in Atlantic water inflow into the Skagerrak (Conradsen & Heier-Nielsen, 1995; Knudsen *et al.*, 1996b; Gylllencreutz & Kissel, 2006; Gyllencreutz *et al.*, 2006). With this influx of warmer Atlantic water, a concurrent rise in water temperatures occurred, though bottom water conditions probably remained relatively cool, showing only a gradual warming (Conradsen & Heier-Nielsen, 1995).

3.5 – Early to Mid Holocene

Between 9000 and 7500 cal. BP, the North Sea underwent a considerable transformation, which produced a hydrological system very similar to modern day; this is represented by figure 3D. This transformation occurred in a number of steps, the earliest of which was the opening of the Danish and Oresund Straits. This event was likely to have been complex, and may have taken place over an extended period of time (Gyllencreutz, 2005). Some studies have shown the slight influence of saline waters as early as 10,200 cal. BP in the Bornholm Basin, south-western Baltic Sea (Andrén *et al.*, 2002), and 9800 cal. BP from Blekinge, also south western Baltic Sea (Berglund *et al.*, 2005). These are both much earlier than previous estimations of 9200 cal. BP from Björck (1995) or 9000 cal. BP from Winn *et al.*, (1986).

Whenever the Danish Straits fully opened, two-way water exchange between the Baltic and the North Sea was possible; this stage of the Baltic development is called the Littorian Sea (Björck, 1995). With the newly opened connection, the Baltic had a far greater input of high salinity water, resulting in a much more productive ecosystem that probably peaked in biological diversity between 7500 BP and 6000 BP (Berglund *et al.*, 2005; Björck, 2008)

The second stage towards modern circulation occurred in the form of the isolation of Dogger Bank, in the western North Sea. Lambeck *et al.* (1995) suggest this occurred between 9000 – 8700 cal. BP. Following this was a distinct, basin wide shift that completely altered the hydrological regime, the opening of the English Channel. This event has been identified by a number of authors (Bjørklund *et al.*, 1985; Nordberg, 1991; Conradsen & Heier-Nielsen, 1995; Gyllencreutz, 2005;

Erbs-Hansen *et al.*, 2011b) with the timing generally agreed to be around *c.* 8500 – 8000 cal. BP (Conradsen & Heier-Nielsen, 1995; Jiang *et al.*, 1997; Gyllencretutz *et al.*, 2005; Gyllencreutz & Kissel, 2006; Erbs-Hansen *et al.*, 2011). Together, the isolation of Dogger Bank and the opening of the English Channel facilitated the formation of the South Jutland Current. The SJC was almost completely absent before this period (Gyllencreutz, 2005).

3.6 - Mid to late Holocene

After the opening of the English Channel, conditions appeared to have been relatively stable, until approximately 6300 cal. BP. At this time, a number of authors observe a move toward a higher energy environment, at MD99-2286 (Gyllencreutz, 2005; Gyllencreutz & Kissel, 2006) and Skagen 3/4 (Conradsen & Heier-Nielsen, 1995; Knudsen *et al.*, 1996b; Jiang *et al.*, 1997). This move towards a higher energy environment is likely to have resulted from a strengthening of the South Jutland Current, flowing along the coast of Denmark. Though there are a large number of possibilities as to why the SJC strength might have increased, cooling over the North Atlantic has been observed at the same time (Koć Karpuz & Jansen, 1992) and many authors believe this to have altered meteorological patterns over the North Sea (Conradsen & Heier-Nielsen, 1995; Jiang *et al.*, 1997) and, hence, intensified the strength of the SJC.

The subsequent weakening of the SJC is not well constrained, with data from Skagen 3/4 suggesting it may have been around 3000 cal BP (Conradsen & Heier-Nielsen, 1995; Jiang *et al.*, 1997). However, Gyllencreutz & Kissel (2006) on MD99-2286 observed a weakening much earlier, around 4700 cal. BP. Furthermore, Nordberg (1991), from the eastern Kattegat actually observed a reduction in sedimentation rates, inferring a weakening of the SJC far later, just 1600 cal. BP (2000 C^{14} yrs BP). This could, however, actually reflect a decrease in humidity around Scandinavia (Nordberg, 1991), which resulted in a decrease in precipitation. This would have resulted in a reduction in the volume of surface water runoff, reducing erosion and transport and, consequently, lowering sedimentation rates.

Around the same time, regression in the Baltic Sea meant the outlets became shallower and less water exchange was possible (Berglund *et al.*, 2005; Björck, 2008). As a result, salinities in the Baltic began to decrease, as did the productivity. Similarly, a reduced output of Baltic outflow will have occurred. This is in agreement with findings from Gyllencreutz & Kissel (2006) on MD99-2286, who identified a decrease in the strength of Baltic outflow until 4700 cal. BP, combined with weaker coastal currents off Sweden and Norway and stronger bottom currents. However, they then also noted an increase in Baltic outflow, between 4000 and 1500 cal. BP.

Following this, the last significant hydrological development to affect the Skagerrak is the late Holocene increase in Atlantic water inflow. This occurred at approximately 1500 cal. BP (Nordberg, 1990; Gyllencreutz & Kissel, 2006) and would have continued right up to modern day. Following this final alteration, conditions remain relatively stable.

3.7 – Modern environmental change

The changes that have occurred since 1500 cal. BP have largely been climatic variations. The Medieval Warm Period (MWP) has been observed in sediments around the Skagerrak between c.1200 cal. BP and c.650 cal. BP (Hass, 1996; Hebbeln *et al.*, 2006; Polodova *et al.*, 2011). Temperatures during this interval would have been around 0.5 – 2°C warmer (Folland *et al.*, 1990). Hass (1996) identified a cooler period around 1,100 cal. BP, superimposed onto this warmer period. This was followed by the well-known climatic cooling experienced during the Little Ice Age, which has also been identified by a number of authors working in the Skagerrak (Hass, 1996; Hebbeln *et al.*, 2006).

More recent change in the Skagerrak has, however, been attributed to humans. As mentioned previously, eutrophication of the Skagerrak is believed to be a problem, and it has resulted in distinct increased in benthic biomass throughout the region (Josefson, 1990; Alve, 1991 etc.). One of the knock on effects of this increased biomass is a significant reduction in oxygen concentrations in the Skagerrak during the 20th century (Aure *et al.*, 1996).

Chapter 4. Materials & Methods:

4.1 - Core Site & Collection

The sediment cores were collected in September 2009 by the Institute for Baltic Sea Research Warnemunde (IOW) from the research vessel "Maria S. Merian". The core location was 58°29.76´N 09°35.91´E, shown with the red dot on figure 1, and was collected from a water depth of 550 m. Two cores were collected from this location – a longer gravity core (GC372650) and a shorter multi-core (MUC372650). The gravity coring process tends to disturb the upper section of the sediment record and, hence, the multi-corer was used to sample the sediment water interface with minimal disruption. The multi-corer provides a high-resolution record of the recent past that overlaps with the longer record from the gravity core. The gravity core is 527 cm long and the short multi-core is 36 cm long.

4.2 - Core Description

Both the gravity core and the multi core are composed of a fairly homogenous, brown grey sediment. There are no notable variations in the colour or texture of sediments. Total organic carbon varies around 1-2 %, increasing up core.

4.3 – Sampling

The gravity core was initially sampled every 8 cm for the top 400 cm. Following an inspection of the age depth model, see section 5.1.1, it was clear the bottom 120 cm were deposited at a much slower rate. Consequently, sampling resolution below 400 cm was increased to 4 cm. This allowed for a more consistent temporal resolution of sampling. Sampling of the multi core took place every 0.5 cm for the upper 10 cm, and every 1 cm after that. This facilitated the creation of a very high-resolution record of modern environmental changes, particularly more recent, potentially anthropogenic impacts.

4.4 - Foraminifera

Benthic foraminifera were chosen as the main proxy to investigate environmental change for this study as they live in the bottom waters and, hence, provide information on the changes in bottom water conditions through time. Foraminifera are extremely sensitive to ecological parameters such as salinity, temperature, oxygen concentration and food supply (Murray, 1991). It is generally believed that foraminiferal assemblages in the Skagerrak are largely controlled by the influence of different water masses (van Weering & Qvale, 1983; Nordberg, 1991), and detailed studies of modern foraminiferal habitats have been compiled by a number of authors in the Skagerrak (van Weering & Qvale, 1983; Conradsen *et al.*, 1994) and northern North Sea (Klitgaard-Kristensen *et al.*, 2002). Therefore, variations in assemblages can be related to alterations in the relative influence of different currents. This makes foraminifera ideal for reconstructing the palaeoceanographic development of the North Sea.

4.5 - Sample Preparation

For each sample, 5 cm^3 of sediment was taken by measuring the displacement of water in a measuring cylinder. This sediment was then soaked in distilled water for approximately 24 hours to allow the sediment to disaggregate. The samples were

then wet sieved through 63 µm and 500 µm sieves, as it is likely that most foraminifera will fall in this fraction (Scott *et al.*, 2001). Any specimens that are smaller than 63 µm are likely to be juvenile species, which are often extremely difficult to identify. Conversely, if a larger size for the bottom sieve is used then too much material will be lost. It is the material between these two fractions that was retained for analysis under the microscope.

4.6 - Sample Analysis

Once prepared, the samples were examined under a Leica microscope. For each sample 300 specimens were identified and, when identification was more difficult, the specimen was placed on a slide to be examined in more detail later on. The relative abundances were then converted into percentages and displayed against both depth and age in separate figures.

The species identification follows the works of Höglund (1947), Feyling-Hanssen (1964) and Qvale & Nigam (1985). During the identification of the foraminifera, some genus types were grouped together as they provided little or no help in reconstructing the palaeoceanographic development. For example, certain species of single chambered foraminifera were grouped into *Fissurina* spp. or *Parafissurina* spp. This allowed more efficient analysis of the samples. In addition to the 300 specimen counts, the total abundance of the foraminifera in each sample was counted, although a test was only counted if more than 50% remained – this was to avoid double counting. Species diversity is simply the number of different taxa encountered in each sample.

CONISS was used to identify zones of similar foraminiferal assemblages, and these were defined as Foraminiferal Assemblage Zones (FAZ). Two zones (8 and 9), see figure 7, were not created using CONISS, as this was unable to effectively pick them out, probably due to the more subtle changes and increased sample density. However, these were still defined as FAZs as they show important changes in the core.

4.7 - Discrepancies between studies

The chosen sieve fraction is extremely important in this investigation because some previous studies performed within the INFLOW project used 125 μm sieve size and dried the samples, as did other projects whose data will be used as comparisons. Scott *et al.* (2001) suggest that up to 99% of the fauna in samples may be lost when using this 125 μm sieve size and it is also suggested that fragile specimens can become damaged when dried (Bernhard & Sen Gupta, 1999). Obviously, in most regions, the realistic number of foraminifera lost by using this method is unlikely to be anywhere near as great as 99%. Nonetheless, it does raise the issue of comparability between different studies. However, the additional data that is captured by sieving down to this smaller particle size is extremely valuable and choosing the larger sieve size may be detrimental to the quality of the study.

4.8 - Geochemical Analysis

To support the foraminiferal analysis performed in this investigation and help interpret the palaeoceanographic evolution, geochemical analysis was also carried out. The geochemical analysis was performed by the IOW in Germany. Total Carbon (TC), Total Inorganic Carbon (TIC) and Total Nitrogen (TN) were measured. From this, it was possible to calculate Total Organic Carbon (TOC), this was calculated by subtracting the TIC from TC. The Carbon/Nitrogen ratio was also calculated, (TC:TN).

4.9 - Radiocarbon dating

A series of 18 ^{14}C dates were measured from the gravity and multi-core to provide a chronology for this study. For each date, benthic foraminifera were used. Due to the size of the foraminifera, a large number were needed to obtain the necessary amount of Carbon. Consequently, a variety of species were selected for each date, as opposed to an individual species.

The program Oxcal online v. 4.1 was used to calibrate the radiocarbon dates. The calibration curve used was "Marine09" from Reimer *et al.* (2009) which is an ocean modeled average of the last 50,000 years. The samples were defined as 100% marine, which included the 400-year ocean reservoir. A ΔR value of 0 was used as described by Heier-Nielsen (1995). Oxcal was also used to create the age depth model using P sequence with a K value of 0.3. The most recent date from the short core was calibrated using the Bomb spike curve NH1 (Hua & Barbetti, 2004).

All ages expressed in this thesis are in calibrated years BP, except for the more recently deposited sediments, see section 5.1.2. Where earlier investigations used radiocarbon dating but did not calibrate the dates, these have now been calibrated to allow comparison; with the original date shown in brackets. In certain cases, previously uncalibrated dates had been subsequently calibrated by Gyllencreutz *et al.* (2006). In these instances, the calibrated date was taken from Gyllenreutz *et al.* (2006), though this is made clear in each case.

Chapter 5. Results

5.1 – Core Chronologies

5.1.1 - Age Depth Model: GC372650

Table 1 shows details of uncalibrated dates and their associated calibrated ages for the gravity core. As detailed in the method section above, Oxcal online was used to calibrate and create the age model.

In most cases, the calibrated ages fit extremely well with one another and the age depth model has good agreement values. Despite this, the two dates at depths of 500 and 484 cm, with relative calibrated ages of 11,268 - 11,261 and 12,574 - 12,682 cal. BP respectively, are obviously a reversal. When examining the sediment, there is no detectable reworking and no obvious turbidities are present; this is unsurprising given the shallow gradient of the sea floor. Unfortunately, this makes discounting either date difficult.

Assuming, therefore, that only one date can be correct, it is necessary to decide which seems more likely. Low sedimentation rates for the lower 100 cm in either case mean sedimentation rates are not helpful in selecting a date.

Table 1: Uncalibrated C^{14} years and calibrated ages with depths for GC372650. The dates were calibrated using Marine09 100% marine, this includes the 400 year marine reservoir. The date highlighted in red was discounted.

Identifier	Depth	mgC (mixed foraminifera)	Uncalibrated ages	Calibrated max (cal. BP)	Calibrated min (cal. BP)
Poz-34454	24-26	0.26	900 ±50 BP	523	453
KIA 42417	55-57	0.6	1200 ± 25 BP	771	708
KIA 42418	105 - 106	0.6	1655 ± 30 BP	1260	1189
KIA 42419	155 - 157	0.5	2155 ± 30 BP	1804	1717
Poz-34551	199 - 201	0.23	2620 ± 50 BP	2381	2265
LuS 9537	223 - 225	0.82	2985 ± 50 BP	2770	2690
KIA 42420	255 - 257	0.5	3470 ± 35 BP	3219	3084
KIA 42421	299 - 301	0.36	3155 ± 70 BP	3667	3539
LuS 9535	323 - 325	0.7	3660 ± 50 BP	4429	4207
KIA 42422	355 - 357	0.27	4230 ± 90 BP	5312	5134
Poz 48329	384 - 385	0.2	5130 ± 70 BP	5600	5490
KIA 42423	415 - 417	0.4	5880 ± 40 BP	6369	6266
Poz 48331	484 - 485	0.3	11130 ± 70 BP	12574	12682
Poz-34466	499 - 501	0.34	10260 ± 70 BP	11268	11161

Consequently, the best solution in this instance is to look at the faunal assemblages themselves. Clearly, this is difficult as the age depth model created here would help interpret those dates. However, at 453 cm, there is a rapid introduction of *Hyalinea balthica*. Erbs-Hansen *et al.*, (2011) and Nordberg, (1991) have interpreted the appearance of *H. balthica* in near-by cores as evidence for the opening of the English Channel. Independent dating of this event provides an age in the range of 8000 – 8500 cal. BP (Conradsen & Heier-Nielsen, 1995; Jiang *et al.*, 1997; Gyllencreutz, 2005; Gyllencreutz & Kissel, 2006). The precise interpretation of this species will be discussed in considerably more detail later. However this interpretation can help here in deciding which of the two radiocarbon dates above to use in the age model.

With this in mind, the two different dates can be re-examined. With no other information between the date at 416 cm and the two in question, the only option is to use a linear fit line between these two points. Accordingly, if the 484 cm date is used with a linear fit line, it suggests that sediments at 453 cm were deposited at c. 9600 cal. BP. If, on the other hand, the 500 cm date is used, sediments at

453 cm were deposited at c. 8500 cal. BP. Consequently, although the singular date is far from ideal, and it is clear that more radiocarbon dates are required, the date at 500 cm date of 11,200 cal. BP seems more likely to be correct. This suggests that the radiocarbon date at 484 cm is too old and has been contaminated, perhaps by re-worked foraminifera.

As a result, the 500 cm data will be used in the production of the age model used here, with a simple linear sedimentation rate between this point and the date at
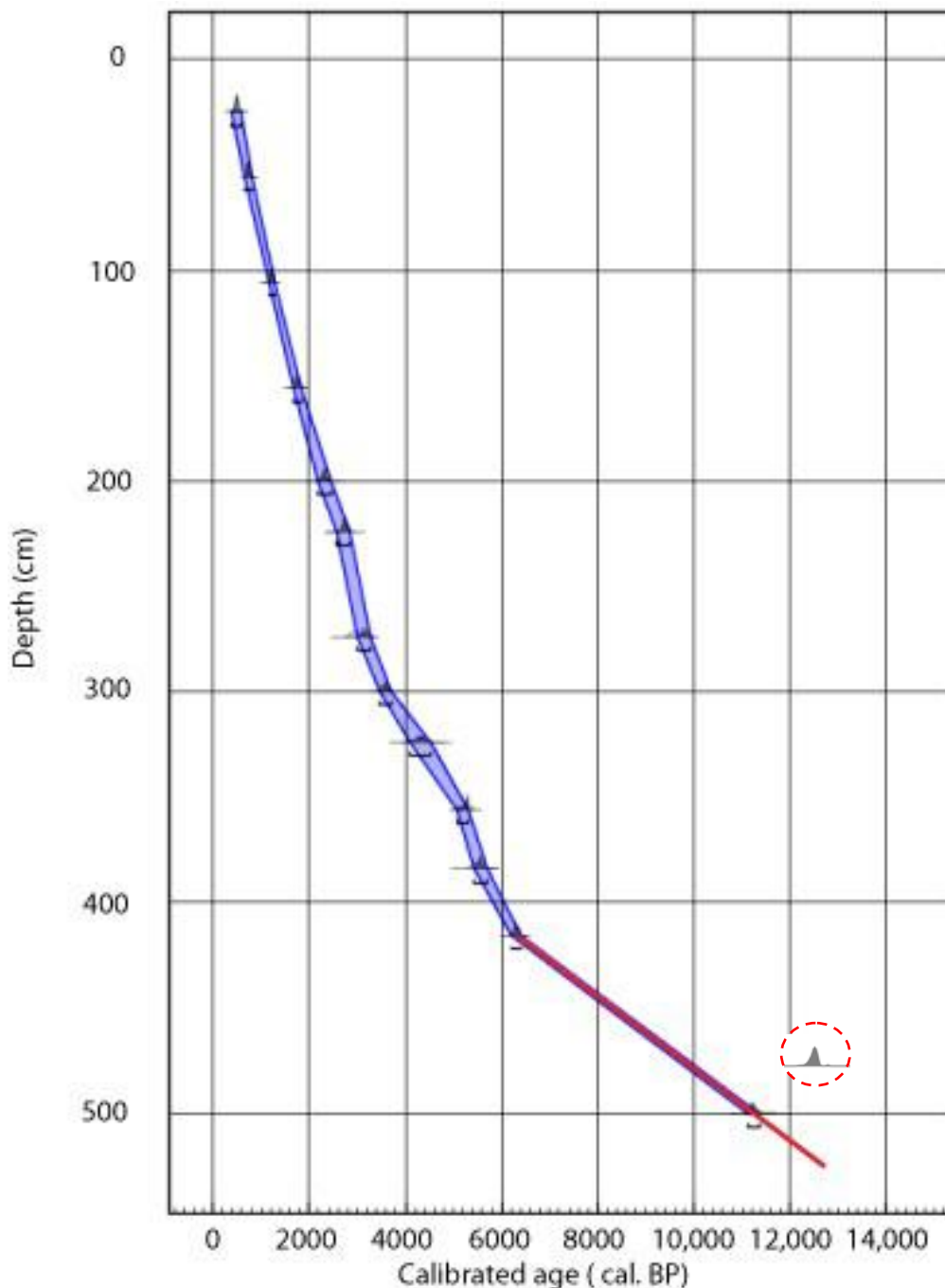
Figure 4: Age depth model produced by Oxcal v 4.1. The blue line represents the Poisson deposition age depth model, created with Oxcal using k=0.3. The date surrounded by the red dashed circle was discounted.

416 cm, shown with the red line in figure 4. The linear sedimentation rate between 416 cm and 500 cm is continued to the base of the core; this suggests the oldest sediments in this core were deposited at c. 12,600 cal. BP.

Due to the method of core extraction, as explained earlier, an unknown amount of sediment will have been lost from the top of the core. As a result, it is not possible to use 0 cm as modern day. For this reason, the multi-core was collected with its own independent age model. The age depth model of both these sediment cores will be 'spliced' together in order to create a seamless, full-length core that extends right up to modern day.

5.1.2 - Age Depth Model: MUC372650

Identifier	Depth	Carbon 14 age	Calibrated Max (cal. BP)	Calibrated Min (cal. BP)	mgC (mixed foraminifera)
Poz-32530	0 – 1	104.13 ± 0.38	Present Day	Present Day	0.48
KIA42424	15 - 16	610 ± 25	291	236	0.35
KIA42425	25 – 26	715 ± 25	417	348	0.25
Poz-36313	30 – 31	840 ± 40	505	449	0.5
Poz-32531	35 - 36	1105 ± 35	686	625	0.46

Table 2: Uncalibrated C^{14} years and calibrated ages with depths for MUC372650. The dates were all carried out on mixed foraminifera and the Marine09 curve has a 400 year reservoir age.

Table 2 shows the uncalibrated C^{14} ages and their associated calibrated ages for the multi core; all of the lower dates have good agreement values. However, the date taken from 0-1 cm showed 104.13% modern Carbon. When calibrated using the bomb spike curve NH1 (Hua & Barbetti, 2004), this value of modern carbon could fall on either the rising or falling limb, though the latter is poorly constrained after c. AD 2000. Due to the method of extraction for this core, it is unlikely much sediment was lost. As a result, for the purposes of this investigation, it is assumed that 0cm represents modern day, though it is noted that this may need additional consideration. The age depth plot is shown in figure 5.

Given this, sediments deposited after AD 1950 cannot be referred to using the standard "BP" age reference, as 0 BP relates to AD 1950. Hence, although the age scale "BP" will be used through most of this investigation, the final foraminiferal assemblage zone will be discussed using the AD age scale; this avoids confusion when discussing the most recent sediments deposited after AD 1950.
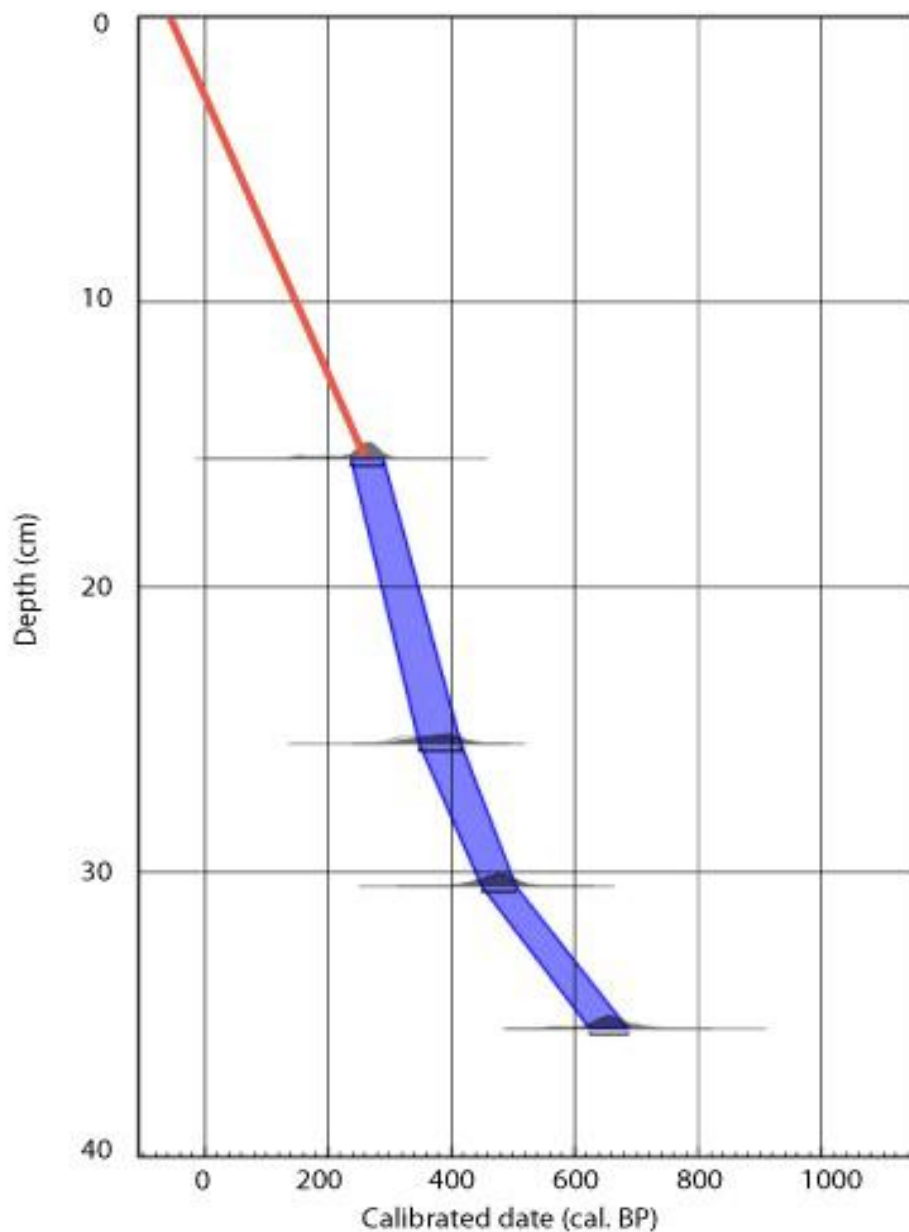
Figure 5: Calibrated ages for MUC372650. The red line represents constant sedimentation between 15 cm and 0 cm.

5.1.3 - Combining the two sediment cores

Having calibrated the dates for both the gravity core and multi core, the two were spliced together to create a continuous record. The gravity core is relatively well dated up until c. 500 cal. BP and the oldest sediments in the short core have been dated to 654 cal. BP. Based on the standard coring methodology for gravity cores and multi-cores it is likely that the multi-core will provide a less disturbed sediment record than the gravity core. Therefore the spliced core will use the multi-core record from modern to 654 cal. BP and the gravity core record will be used from 654 cal. BP onwards. In practice, this means the top six samples of the gravity core will be discounted. The new core will be referred to as GC372650.

5.1.4 - Sedimentation rates
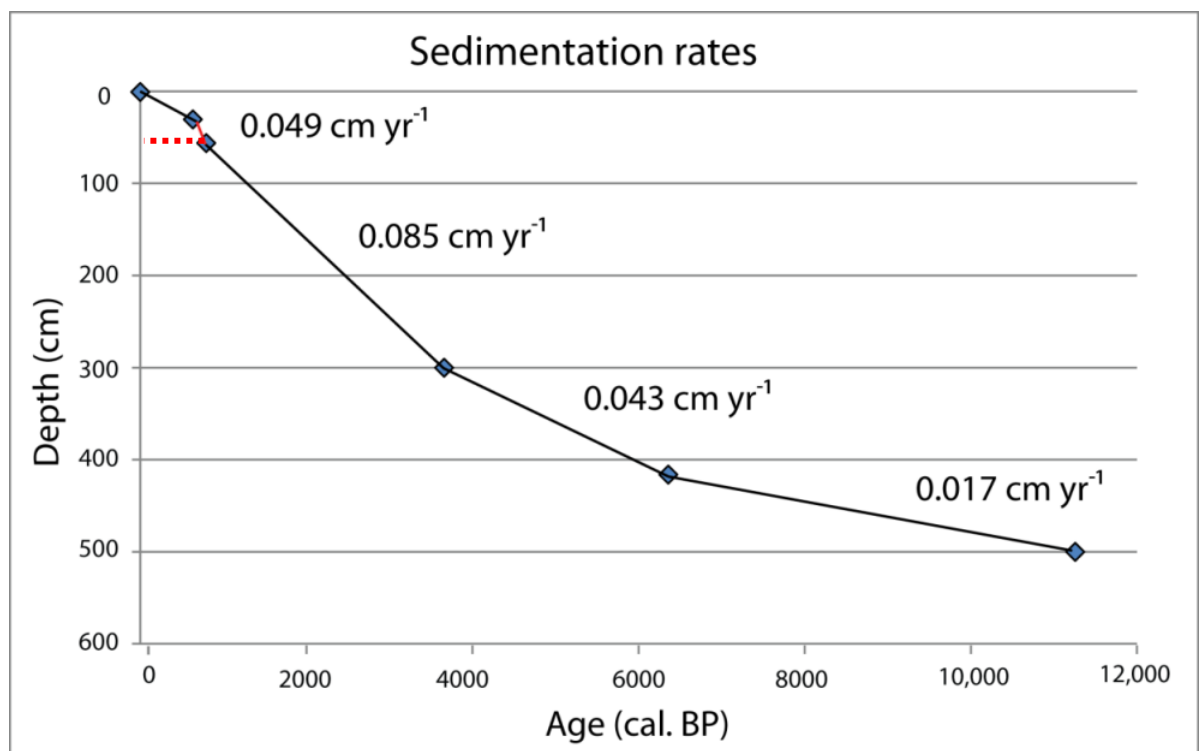
Figure 6: Graphic showing general sedimentation rates in the composite core, GC372650. The dashed red line represents the core splice point whilst the solid red line shows rapid sedimentation just after the core splice.

Sedimentation rates vary considerably down GC372650, shown in figure 6 Between c. 11,200 cal. BP and c. 6,300 cal. BP, sedimentation is relatively slow,

with rates at around 0.017 cm yr^{-1}. Following this, sedimentation rates increase to 0.043 cm yr^{-1} until c. 3,600 cal. BP. Between 3,200 cal. BP and the point at which the core is spliced, 56 cm, sedimentation is even faster, 0.085 cm yr^{-1}.

Above the splice, however, the sedimentation rates change significantly. Between 56 cm and 36 cm, sedimentation rates are 0.25 cm yr^{-1}, a considerable increase, although this is potentially a product of the core splicing and is shown in red on figure 6. The overlying 35 cm of sediment are then deposited at a fairly constant, 0.049 cm yr^{-1}.

5.2 Foraminifera ecology

The main species of foraminifera that were identified in this investigation are discussed below, with their associated ecological tolerances described based on published work.

5.2.1 – Calcareous foraminifera

***Bolivina skagerrakensis* Qvale & Nigam, 1985:** This infaunal species is found predominantly in deeper Skagerrak waters and is not commonly found outside this area (Qvale & Nigam, 1985). It prefers stable bottom water conditions with salinities exceeding 35% and temperatures ranging from 3 – 7°C (Conradsen *et al.*, 1994; van Weering & Qvale, 1983). Nordberg (1991) suggest this species is related to Atlantic water inflow.

***Bulimina marginata* d'Orbigny, 1826** This infaunal species is linked with low oxygen levels and high organic carbon content (Van Weering and Qvale 1983, Klitgaard-Kristensen, 2002). Murray (1991) found this species at temperatures between 5-13°C though it has been found down to temperatures as low as 0°C by Conradsen *et al.*, (1994).

***Buccella frigida* (Cushman, 1921):** This infaunal species is associated with cool water, most often arctic environments (Knudsen, 1984, Leslie, 1965; Konradi, 1976) though some have found it in subarctic or warmer conditions (Murray, 1965). This species seems to be rare in postglacial Skagerrak deposits. However,

when found in the Hudson Bay by Leslie (1965) it was between 37 – 212 m in depth, living in water temperatures between -1.78°C to 2.98°C. Murray (1979) suggests it can tolerate slightly brackish conditions, indicating it can survive in a range of environments.

***Cassidulina laevigata* (d'Orbigny):** This infaunal cosmopolitan species can tolerate a range of environmental conditions (Van Weering & Qvale, 1983). However, Murray (1991) suggests that the species is characteristic of salinities around 35‰ and a large temperature range from -1°C to 17°C. The species has been found in depths of below 100m in the Skagerrak and up to 2,000m along the Norwegian continental margin (Van Weering & Qvale, 1983). Klitgaard-Kristensen *et al.*, (2002) suggest this species prefers more oceanic waters, and is strongly linked with Atlantic waters.

***Cassidulina neoteretis* Seidenkrantz, 1995:** This infaunal specimen is morphologically very similar to *C. laevigata*, though regarded as being an indicator of cooler Atlantic waters (Rytter *et al.*, 2002; Seidenkrantz, 1995; Erbs-Hansen *et al.*, 2011b).

***Elphidium excavatum* (Terquem) forma *clavata* (cf. Feyling-Hanssen, 1972):** Although the different forms are not split in this investigation, it is assumed that *Elphidium excavatum* largely occurs as *E. excavatum* forma *clavata* in these sediments. Given the appearance of this species is largely restricted to the lowermost part of the sediment core (Late glacial – early Holocene), the modern arctic distributions are most relevant. The species is often found on arctic shelves where it is able to survive in extreme environments such as those close to tidewater glaciers (Hald et al. 1994; Korsun & Hald, 1998, 2000). *Elphidium excavatum* is also known to withstand large variations in both temperature, -1.8 to 25°C, as well as salinity 0 – 35‰ (Conradsen *et al.*, 1994; Van Weering & Qvale, 1993). Consequently, the species is generally thought indicative of arctic/subarctic conditions (Hald & Korsun, 1997) and may also indicate reduced salinities.

***Hyalinea balthica* (Schroeter, 1783):** This epifaunal species is very common in the Oslo Fjord area (Feyling-Hanssen, 1964) and is dominant between 200 – 400 m in the Skagerrak (Van Weering & Qvale, 1983) but known to exist between

depths of 40 – 4500 m. This species is believed to be representative of Boreal Lusitanian conditions (Nørvang, 1945, Jansen *et al.*, 1979) and has also been associated with high amounts of organic material and low oxygen levels (Qvale & Van Weering, 1985; Klitgaard-Kristensen *et al.*, 2002).

***Melonis barleeanus* (Williamson, 1858):** This infaunal specimen is most common on the eastern and central sides of the Skagerrak (Van Weering & Qvale, 1983). A review of the literature by Van Weering & Qvale (1983) identified occurrences of *M. barleeanus* at salinities ranging from 33‰-35‰. This species tends to prefer elevated amounts of degraded organic material within the sediment. Erbs-Hansen *et al.* (2011b) suggest this is species is representative of Boreal conditons.

***Nonionella iridea* Heron-Allen & Earland, 1932:** This infaunal species is prevalent throughout this sediment core. Alve & Murray (1995) found this species to be present in water depths deeper than 473 m. Little is known about this species, however, and given that it appears consistently throughout the core with little variation, it provides minimal help in reconstructing the palaeoceanographic evolution.

Pullenia osloensis* Feyling-Hanssen, 1954*: This infaunal species also forms a consistent part of the assemblages throughout the sediment cores in this investigation. Whilst this species is not commonly found in the Skagerrak, Alve & Murray (1995) did find it to be relatively abundant in the northern sides of the Norwegian Trench between depths of 285 – 437 m. Despite this, the ecological preferences of this species are not well understood. Gupta *et al.*, (2006) found in it areas of high food supply whilst Feyling-Hanssen (1954) found it associated with changing environmental conditions. Consequently, it is also able to provide little assistance in paleoceanographic reconstruction (Erbs-Hansen *et al.*, 2011).

Stainforthia fusiformis* (Williamson, 1848)*: This species is relatively small with a thin shell, generally an infaunal species that is able to withstand periods of anoxic conditions (Alve, 2003; Alve, 1994, Conradsen *et al.*, 1994). It is very common in the Skagerrak area (Alve & Murray, 1995) and often associated with salinity levels

greater than 30‰ (Conradsen *et al.*, 1994) but the typical salinity range is roughly 33 − 35‰.

***Uvigerina mediterranea* Hofker, 1932:** This infaunal species prefers stable bottom water conditions – Qvale & Van Weering (1985) find that it inhabits the same area as *C. laevigata* and is associated with stable water masses and low energy conditions. It is also associated with warmer waters (Sejrup *et al.*, 2004) and linked with Atlantic inflow (Klitgaard-Kristensen *et al.*, 2001).

5.2.2 - Agglutinated Foraminifera

***Textularia earlandi* Parker, 1952:** This epifaunal species is known to survive in a wide range of environments and is found across the Skagerrak (Alve & Murray, 1995: Höglund, 1947). However, Bernhard *et al.* (1997) suggest this species is indicative of low oxygen conditions.

5.3 Foraminiferal assemblages and palaeoenvironments

In this investigation a total of 73 species have been identified. Throughout both the gravity and multi core, preservation was extremely good and in only a few samples was it not possible to count 300 specimens. Even in those instances, counts of greater than 200 were achieved. The assemblages are plotted in figure 7 against their associated depths, figure 8 shows the assemblages plotted against age. Only species accounting for > 5% in one or more samples were included in each diagram.

Stratigraphically constrained cluster analysis was performed on the assemblages shown in Figure 8 to identify and classify zones of similar fauna. These are defined as Foraminifera Assemblage Zones (FAZ). The faunal assemblages are shown on Figure 8 and the groups are discussed below. Each FAZ is named after its dominant taxa and given a description based upon these dominant taxa. It is important to note that the environmental conditions reconstructed from these benthic foraminifera only apply to the bottom waters.

William Dickens
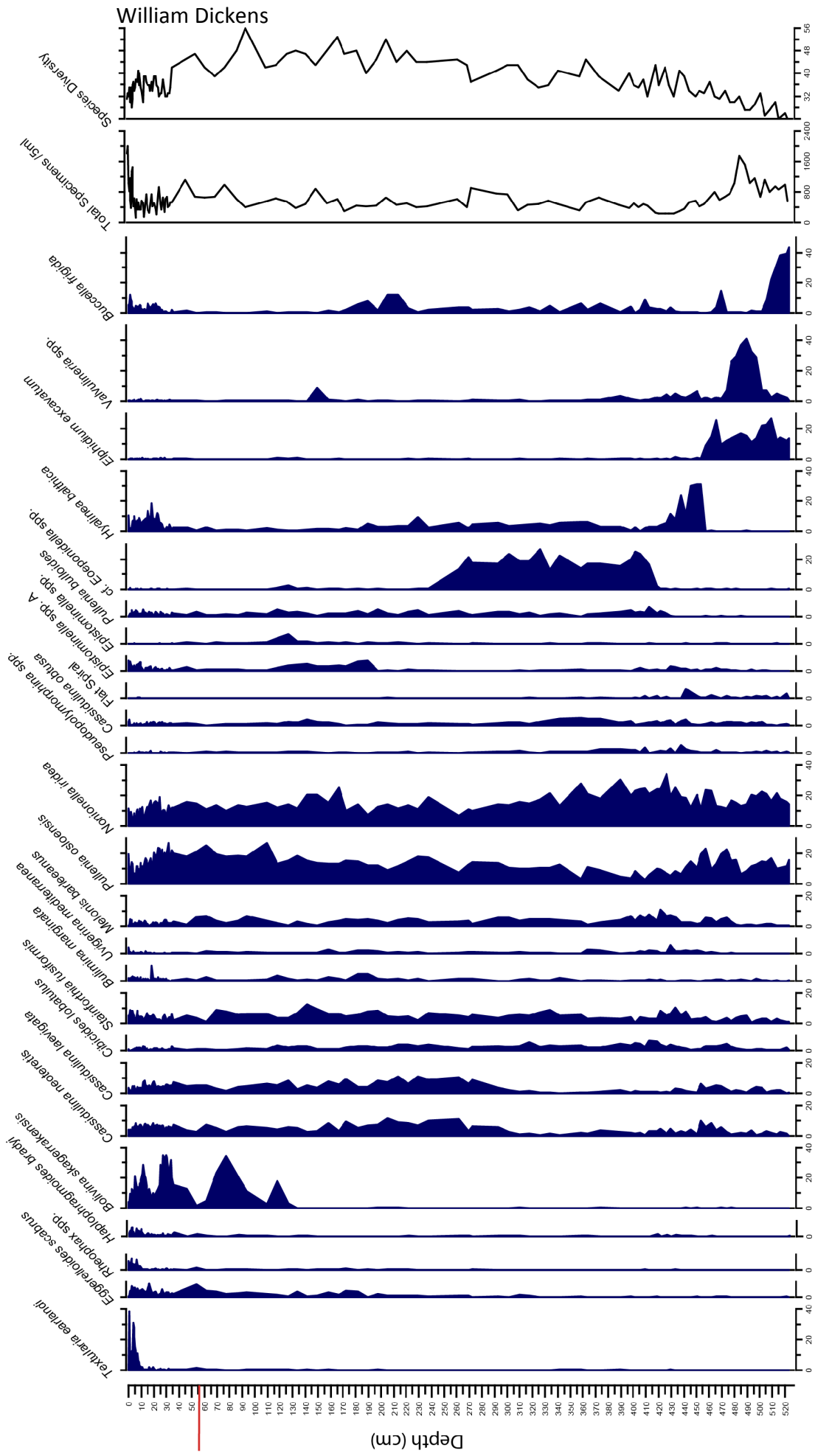
Figure 7: Foraminiferal assemblages from composite core GC372650 shown as relative percentage of the complete fauna. The percentages are plotted against depth. Only species > 5% in one or more samples are shown. Absolute abundance and species diversity are plotted in the last two columns respectively. The red line represent the core splice point.

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FAZ 1 – *Buccella frigida* (524 – 502 cm, 12600 – 11,200 cal. BP)

This zone is dominated by arctic species *Buccella frigida* (1-44%) and to a lesser extent, *Elphidium excavatum* (12-27%), a species characteristic of arctic/subarctic conditions, known to withstand variable salinities (Figure 7). *Nonionella iridea* (c. 14-22%) and *Pullenia osloensis* (10-18%) are present in this assemblage but, as previously mentioned, their value in palaeoenvironmental reconstruction is minimal due to their broad ecological tolerances. Smaller constituents of this assemblage are *Valvulineria* spp. (1-6%), *Cassidulina laevigata*, *Cassidulina neoteretis*, *Melonis barleeanus*, *Stainforthia fusiformis* and *Cibicides lobatulus* (all <5%).

Abundance of *B. frigida* is highest at the bottom of this zone, decreasing significantly towards the top to values of just 8%. Low abundance of *E. excavatum* at the bottom of zone 1 most likely result from the dominance of *B. frigida*, and as relative abundance of this species declines, *E. excavatum* reaches its peak of around 27%.

Species diversity in this zone is lower than at any other point through the sediment core. There is, however, a distinct increasing trend towards the top of the zone. Despite the low species diversity, the species abundance is actually relatively high when compared with the rest of the core. It shows considerable variation but typically remains between 800 – 1000 specimens/5ml.

The dominance of *B. frigida* and *E. excavatum* suggests this zone is characterised by cool bottom water conditions, probably between 0-2°C (Leslie, 1965), but with temperatures warming towards the top of the zone. The dominance of these two species indicate relative proximity of ice with a possible meltwater influence. The low species diversity is indicative of a harsh environment, supporting the probability of low temperatures, and the relatively high specimen abundance compared to the rest of the core is probably related to an additional factor, possibly food. The decreasing abundance of *Buccella frigida* towards the top of FAZ 1 indicates a possible warming in temperatures, though the continued abundance of *Elphidium excavatum* suggests continued presence of cool, low
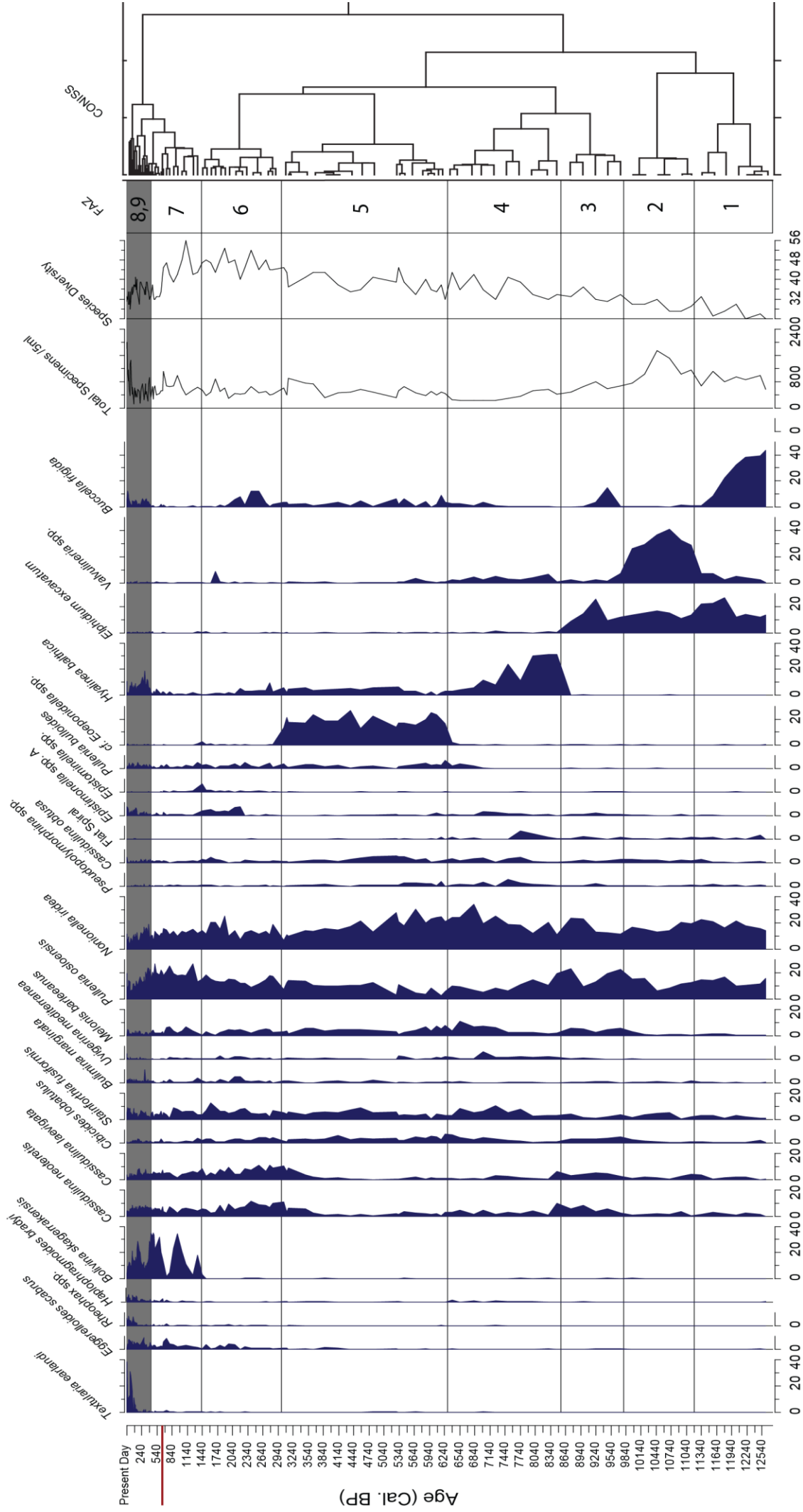
Figure 8: Foraminiferal assemblages from composite core GC372650 plotted against age and shown as relative percentages of the complete fauna. Only species >5% in one or more samples are shown. The foraminifera assemblage zones are shown in the FAZ column. These were defined using CONISS, shown in the final column. The shaded area relates to those FAZ's that were defined manually, not using CONISS; these are shown in more detail in figure 9. The red line represents the core splice point.

salinity bottom water, indicative of meltwater input. The increasing species diversity also suggests ameliorating conditions, moving towards a more habitable environment. Together, these imply the environment has undergone a transition from relatively ice proximal to ice distal conditions.

FAZ 2 – *Valvulineria/Elphidium* (501– 474 cm, 11,200 – 9800 cal. BP)

The most pronounced change in this assemblage is the sudden increase in *Valvulineria* spp. (27-41%), figure 8, replacing *B. frigida*. *Elphidium excavatum* is still present in this zone although its abundance has decreased slightly from the

top of FAZ 1, now it varies slightly 11-17%. *Valvulineria* spp. peaks at c. 10,700 cal. BP and then decreases steadily until c. 10,000 cal. BP at which point it declines dramatically to just 7% by c. 9700 cal. BP. *Pullenia osloensis* and *N. iridea* are at very similar percentages to zone 1 although *N. iridea* does diminish a little in the middle of the zone. Percentages of the minor constituent species remains very similar, though there is an increase in the abundance of *Melonis barleeanus* to around 6% at the top of the core. *Cassidulina obtusa* and *Epistominella* spp. appear for the first time in this assemblage, though both are in relatively low abundances (< 5%).

The species diversity in this zone shows little change overall, ending at a very similar value to the previous zone. Specimen absolute abundance, on the other hand, does show considerable variability, increasing extremely rapidly to c. 1,750 specimens/5 ml in the middle of this zone, the highest abundance throughout the entire core. It then shows an equally rapid decrease to 600 specimens/5ml at the top of the zone. The variations in absolute abundance seem to follow closely the variations in *Valvulineria* spp. relative abundance suggesting the two are related.

The continued presence of *Elphidum excavatum* indicates that conditions are still relatively cool, and perhaps salinities are still slighty reduced, though the latter is difficult to gauge effectively. It is the rapid introduction of *Vavulineria* spp. that distinguishes this zone. Such a dramatic increase is indicative of a fairly major hydrographical shift. Unfortunately, very little is known about this species, as it is

very rare in the Skagerrak. As a result, it is hard to ascertain exactly what the hydrological change is.

The lack of change in the species diversity suggests temperatures have not warmed considerably. This is supported by the continued presence of *E. excavatum* through this zone. The sudden bloom in absolute abundance at c. 10,500 cal. BP is therefore unlikely to relate to any temperature fluctuation. Given how closely it follows the increase in *Valvulineria* spp*.*, it seems logical that the two are related. The subsequent reduction in *Valvulineria* spp*.* and concurrent decrease in total specimens indicates the environment changed once more, with another hydrological development.

FAZ 3 – *Elphidium excavatum* (473 – 454 cm, 9800 – 8500 cal. BP)

Although the magnitude of faunal changes appears relatively minor in this zone, there are still important elements. Figure 8 shows that both *Cassidulina laevigata* (3-5%) and *Cassidulina neoteretis* (3-8%) increase in this zone, as does the boreal species *Melonis barleeanus* (3-6%).

Another important development is the return of cold-water species *B. frigida,* reintroduced at c. 9450 cal. BP, reaching a peak of c. 15%. Given that it was only found in two samples, it is likely to reflect a very short period of time, < 400 years. *Elphidum excavatum* also increases to a peak of 26% at c. 9250 cal. BP. Towards the top of this zone the abundance of *E. excavatum* falls to its lowest yet at just 9%. Abundance of *Valvulineria* spp*.* remain constant and relatively low through this zone, around 3%.

Species diversity in this zone shows a slight reduction in the rate of increase compared to the previous zone. Adjacent samples still show minor variability but generally fluctuate around 33 or 34. The absolute abundance continues to show a decreasing trend observed in the underlying zone. It is worth noting that this coincides with an increase in sedimentation rates; this might explain the reduced abundances as the foraminiferal flux (shells/cm^2/year) would have decreased.

In FAZ 3, the concurrent increase in *Cassidulina laevigata* and *Melonis barleeanus* suggest a slight warming of water temperatures and the influence of a more stable, well-oxygenated ocean current. However, the reintroduction of arctic species *B. frigida* suggests a decrease in temperatures, though this cooling is relatively short-lived, less than 400 years, and is superimposed on the overall warming during this period.

FAZ 4 – *Hyalinea balthica* (453 cm – 419 cm, 8500 cal. BP to 6300 cal. BP)

FAZ 4 contains major changes to the foraminiferal assemblages (figure 8). Arctic/subarctic foraminifera *E. excavatum* is almost completely absent, only appearing in random samples and extremely low counts (<2%). Countering this is the rapid emergence of the warmer water species, *Hyalinea balthica*, often related to 'boreal' conditions (Nørvang, 1945, Jansen *et al.*, 1979). This species increases rapidly to reach a peak of 31% by c. 8500 cal. BP, though abundance decreases after 8100 cal. BP, falling continuously throughout the zone, with minor fluctuations, reaching a low of around 4%, at the top of this zone.

The additional, though slightly less abundant, components of this zone, include an increase in *S. fusiformis* to c. 10%, though this is slightly late in the zone. *Uvigerina mediterranea* also increases to its maximum abundance (c. 5%). *Cibicides lobatulus* reduces in percentage at the bottom of this zone but it increases towards the top. *M. barleeanus* shows a very similar trend, decreasing at the beginning of the zone before returning to levels slightly above the preceding zone. *Valvulineria* spp*.* also shows an increase in this zone to around 5 – 7%.

In terms of the less important constituents, *Nonionella iridea* increases towards the top of the zone, reaching a peak of 34% at c. 6800 cal. BP, whilst *Pullenia osloensis* decreases. *Pseudopolymorphina* spp. is present in low percentages (1-5%). *Cassidulina laevigata* and *Cassidulina neoteretis* are both in relatively low abundances, with both decreasing towards the top of the zone.

Species diversity is once again higher than in the previous zone, but is beginning to show a greater magnitude of variability. Specimen absolute abundance on the other hand, reaches the lowest levels throughout the entire core. This decreasing trend continues from the previous zone until 435 cm at which point the abundance falls below 300 per 5 ml. From this point, right up until the top of this zone, it was not possible to reach a count of 300 specimens, and counts were at or just below 200.

The sudden and dramatic emergence of *H. balthica* is indicative of another major hydrographical shift. Given *H. balthica* is a warmer, boreal species, this hydrographic shift is likely to be characterized by the sudden influx of warmer water. *Hyalinea balthica* can also tolerate low oxygen levels, so it's increase may also relate to a period of increased stratification, resulting in more stagnant bottom waters. The increase in *U. mediterranea*, albeit at low abundances, and decrease in *C. lobatulus* both support the theory of a warmer, more stable bottom water mass with lower energy. The increase in *S. fusiformis* is indicative of increased stratification and reduced deep water renewal, resulting in more regular oxygen depletion. The low absolute abundances during this interval may reflect the increased stratification and reduced oxygen levels.

Generally, this zone reflects an influx of warmer water with more stable bottom water conditions and a possibility of increased stratification resulting in less regular deep water renewal. Towards the top of the zone, it is likely that the stratification weakened, allowing more regular deep water renewal, also resulting in a higher energy environment.

FAZ 5 – *cf. Eoeponidella* spp. (418 cm – 260 cm, 6300 cal. BP to 3000 cal. BP)

FAZ 5 is characterized by the appearance and rapid increase in abundance of cf. *Eoeponidella* spp. (figure 8), while the abundance of *Hyalinea balthica* remains rather low (< 5%, similar to the top of FAZ 4). Classification of the dominant species in this zone (cf. *Eoeponidella* spp.) is problematical. However it appears similar to a species found by Conradsen and Heier-Nelson (1995) in a nearby core Skagen 3/4, also the timing of the appearance here correlates well with the influx

in Skagen 3/4 - hence it is here classified as cf. *Eoeponidella* spp. The introduction of cf. *Eoeponidella* spp. is extremely rapid, appearing initially at c. 6300 cal BP then remaining at abundances of 17 – 27% through the whole zone before rapidly decreasing in abundance at c. 3000 cal BP. This zone is also characterized by the re-introduction of *Buccella frigida*, albeit in considerably lower abundances and more sporadically than in FAZ 1, typically varying from 0 to 9%. *Cibicides lobatulus* also appears more consistently in this zone and in slightly higher abundances.

Although in very small abundances, typically less than 6%, *Pullenia bulloides* appears almost in tandem with the appearance of cf. *Eoeponidella* spp., just slightly earlier in the sediment core. Abundances of *P. bulloides* then stay constant throughout the remainder of this zone and all subsequent zones. Abundances of both *Cassidulina laevigata* and *Cassidulina neoteretis* are at their lowest in this zone, with both species almost completely absent in many samples. Both species do, however, increase towards the top of zone 5, reaching levels of c. 10%.

Species diversity shows a very minor increase during this zone, though variability is still high. Absolute abundance also shows an increased variability as well as a slight overall increase, with more than 300 specimens counted for each sample.

While the interpretation of cf. *Eoeponidella* spp. is difficult, some of the additional faunal changes provide valuable information in reconstructing environmental change during this interval. The re-introduction of *B. frigida* implies a drop in water temperatures, though the temperature drop is unlikely to be large as only a small population of the species is sustained. The temperature drop probably began a few hundred years prior to the onset of this zone, but continued throughout it. The increase, and more regular and consistent appearance, of *C. lobatulus* could well suggest that conditions have become more variable, and may reflect a higher energy environment. This is supported by the decrease in *U. mediterranea* observed at the top of the underlying zone, indicating unsettled conditions.

Generally, therefore, although the most abundant species is not used at this stage, the rest of the faunal assemblages suggest a reduction in temperatures and a move towards a higher energy, less stable bottom water mass.

FAZ 6 – *Cassidulina/Buccella* (250 cm – 133.5cm, 3000 – 1425 cal. BP)

This zone is marked by the increase in *C. laevigata* and *C. neoteretis*, with their abundances closely matching one another around 10%. It is also characterised by the absence of cf. *Eoeponidella* spp. *Buccella frigida* increases in this zone to around 12%, its highest abundance since 9400 cal. BP. It maintains this peak for c. 800 years, then falls away, the species is absent after c. 2000 cal. BP.

Another minor development in this zone is the introduction of *Eggereloides scabrus*. Although it has appeared sporadically in deeper sections of the core, this is the first time it appears consistently, although the abundances are still extremely low (< 5%). *Pullenia osloensis* and *Nonionella iridea* show little change from the previous zone. Absolute abundance also shows little change, though species diversity does show an increase from the previous zone.

This FAZ, dominated by *Cassidulina species,* probably reflects the increased inflow of well-oxygenated oceanic water. However, the short lived increase in *B. frigida* suggests a short period of reduced temperatures, superimposed onto this general period of increased stability.

FAZ 7 – *Bolivina skagerrakensis* (133.5 cm – 27.5 cm, 1500 – 418 cal. BP)

This zone is characterised by the introduction of *Bolivina skagerrakensis* (figure 8). Whilst this species has appeared in extremely low abundances (<1%) in sporadic intervals throughout the sediment core, it is not until c. 1,500 cal. BP that it forms a notable constituent of the assemblage. The abundance of this species shows considerable variability through this and subsequent zones, with a rapid introduction to 18% by c. 1300 cal. BP and a subsequent range of 2% to 35%.

Aside from *B. skagerrakensis*, this zone is generally characterised by very little change. The other dominant species are *P. osloensis*, *N. iridea*, *C. laevigata* and *C. neoteretis*. Each of these species shows little variability except for *N. iridea* and *P. osloensis*, which show an increase and decrease, respectively, towards the top of the zone. Some of the less important constituents are *S. fusiformis* and *E.*
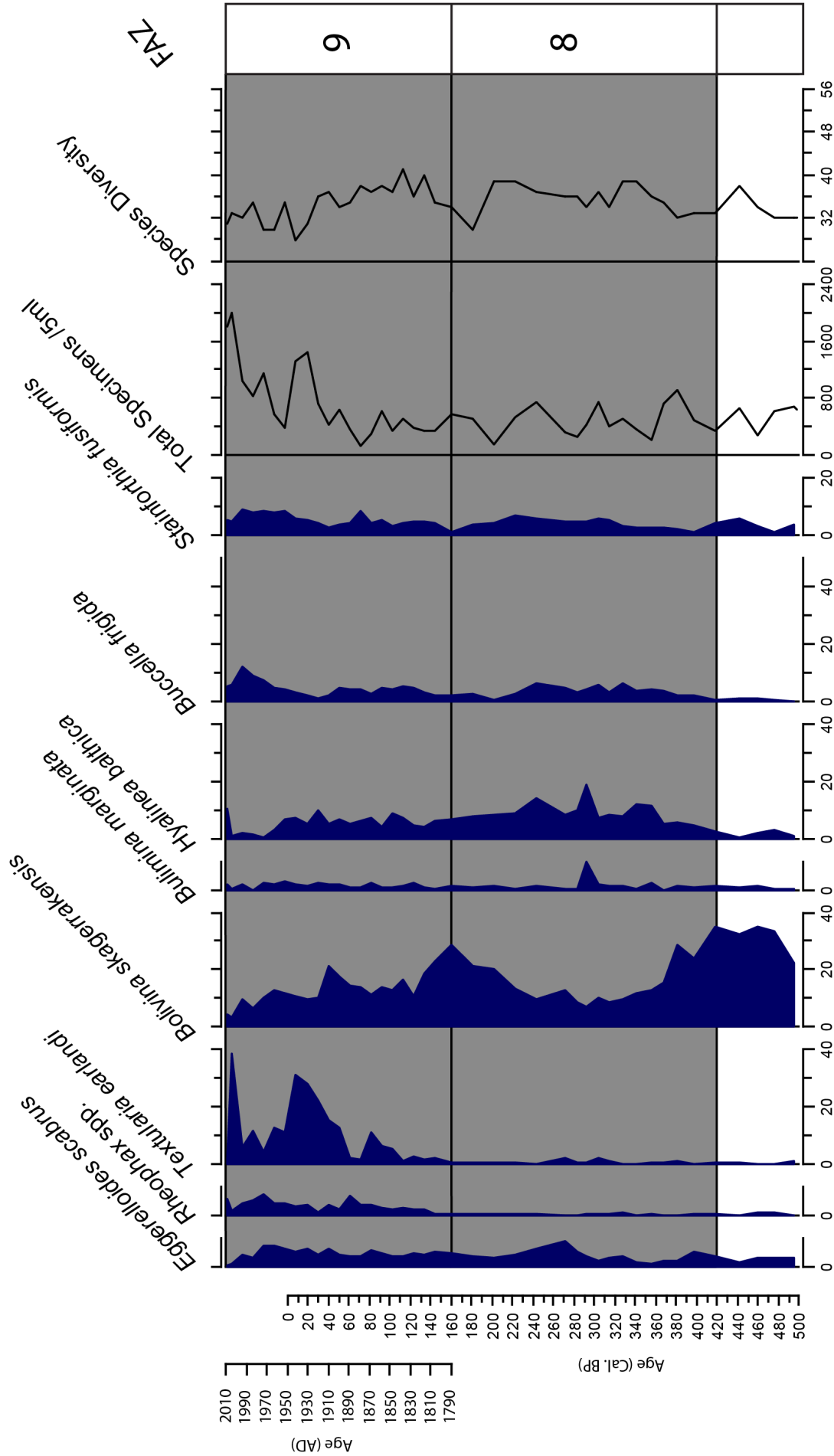
Figure 9: The foraminiferal assemblages of FAZ 8 and 9 from MUC372650 (top of composite GC372650), shown as relative percent of the complete fauna. Only the relevant fauna are shown in this graphic. As mentioned previously, the final FAZ will be discussed using the AD age scale; this is shown to the left of FAZ 9. The shaded areas correspond to the shaded regions in figure 7, the two FAZ's created manually and not using CONISS.

scabrus. E. scabrus actually shows a slight increase from zone 6, increasing in abundance to around 9%, before decreasing once more.

Finally, species diversity in this zone shows an initial increase, peaking at 56, the highest throughout the entire core, before decreasing once more to levels observed in the previous zone. The increased species diversity may be due to increased preservation of agglutinated species, though it is argued in section 6.8 that taphonomic effects are not responsible for changing assemblages in this core. Absolute abundance increases slightly in this zone from 400 to 1100.

The dominant species in this zone, *B. skagerrakensis*, is generally regarded as favouring stable, well oxygenated bottom water conditions. Therefore, this zone is likely to reflect the increased inflow of a well oxygenated, stable water mass, with temperatures most likely between 3 – 7°C (Conradsen *et al.*, 1994). The variations in *B. skagerrakensis* may reflect periods of reduced stability, when conditions became unsuitable to sustain a population of *B. skagerrakensis*.

FAZ 8 – *Buccella frigida/Hyalinea balthica* (27.5 – 11.5 cm, 420 – 160 cal. BP)

This zone appears at the top of the multi-core and is shown in expanded form in figure 9. After reaching its peak in the top of the last zone, *B. skagerrakensis* decreases steadily, falling to just 7% by 290 cal. BP. *Bolivina skagerrakensis* then increases again, returning to similar abundances as the previous zone by 160 cal. BP. *Hyalinea balthica*, although appearing sporadically in low abundances in FAZ 7, forms a consistent part of the assemblage in this zone. *Hyalinea balthica* typically varies between 6-10%, with the peak at 290 cal. BP extending to 19%. After this peak, the species abundance decreases slightly towards the top of the zone (10%). *Bulimina marginata* is also present in this zone in relatively low abundances. This species appeared in extremely low abundances in the previous zone, but has a peak of 10% at 290 cal. BP. However, the species does not prevail for long, as in the overlying sample it is no longer present. .

Buccella frigida is another species to increase in this zone, although its abundances are much lower, around 6%. The species appears in tandem with the reduction in *B. skagerrakensis*, quickly increasing in abundance to its maximum

and then remaining at this level for the rest of the zone, with some very minor variations. *Nonionella iridea* and *Pullenia osloensis* remain important constituents of the assemblages. Species diversity has reduced since FAZ 7, though abundances show little variation.

Generally, this zone reflects the influx of colder water fauna, namely *Buccella frigida*, indicating a decrease in water temperatures. Both *H. balthica* and *B. marginata* are related to reduced oxygen concentrations. This indicates the bottom waters of the Skagerrak may have been less regularly renewed, possibly reflecting an increased stratification.

FAZ 9 – Textularia earlandi (11.5 – 0 cm, 160 cal. BP – Present Day / 1790 - 2009 AD)

As mentioned in this methods section, this zone will be discussed using the Age reference AD. This zone, also shown in figure 9, is characterised by considerably more variability. Firstly, *B. skagerrakensis* shows a steady decrease from its maximum in FAZ 8, reaching its lowest abundances near the top of the core, around 4%. *Buccella frigida, H. balthica* and *S. fusiformis* show minimal change.

The most prominent change of this FAZ is the introduction of agglutinated species. *Eggerelloides scabrus* has been present throughout the core, and it shows little change in this zone. It is the appearance of *Textularia earlandi*, however, that is the most distinct and rapid change observed in FAZ 9. It appears in low abundances at AD 1790, and shows minor variability until c. AD 1850. At this point, the species increased relatively steadily to reach a peak of 31% at c. AD 1940. It subsequently decreases, but peaks again at c. AD 2000, before falling away in the overlying sample.

In terms of the less prominent species, *B. marginata* is also present in this zone with more consistency and slightly higher abundances than in previous zones. Similarly, *Epistominella* spp*. becomes more prominent in this zone, with values nearing 5%. Once again, *C. neoteretis* and *C. laevigata* show very little change, nor do *N. iridea* or *P. osloensis.*

Species diversity shows a general decreasing trend over this period. Conversely, absolute abundance increases dramatically towards the top of the core, peaking at c. 1450 and 2000 specimens, around the same time as *T. earlandi*.

FAZ 9 is generally characterized by the sudden rise in *Textularia earlandi*. This species is considered an opportunistic species (Alve & Goldstein, 2009) and is associated with dysoxic conditions (Berhard *et al.*, 1997). Its dramatic appearance could thus reflect periods of reduced oxygen concentrations. A concurrent decrease in *B. skagerrakensis,* a species known to prefer stable, well-oxygenated bottom water conditions, supports this interpretation.

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Chapter 6. Discussion

In the preceding section, the environmental interpretations of the foraminiferal assemblages zones were examined. This section will now build upon these interpretations, discussing the palaeoceanographic developments that may have caused these foraminiferal changes. This discussion will focus on the palaeoceanographic evolution of the Skagerrak, but it will also consider the development of the Baltic Ice Lake and its effects on the Skagerrak. In a similar vein, the development of the Baltic Sea and its connection with the high salinity waters of the North Sea will be examined. To visualise the changes to the North Sea discussed in this section, a paleo-land reconstruction has been created for the significant developments; these show the land extent during the period discussed, as well as the hydrological regime (figure 12).

Most studies in the Skagerrak have been based on cores from a water depth of less than 350 m. GC372650 was taken from 550 m, considerably deeper than previous work. Consequently, this is one of few investigations to consider the development of the deep Skagerrak, and may provide a record of environmental change less affected by local, short term variations in environmental factors. The core locations of the main studies examined in this discussion are presented in the figure 10.

Figure 10: Map of the Skagerrak showing the location of main core site discussed in this section – see figure 1 for scale of elevation and depth.

6.1 – Late Younger Dryas – early Holocene (12,600 to 11,200 cal. BP; FAZ 1)

This period, FAZ 1, is dominated by cold water fauna, namely *Buccella frigida*, indicating that bottom water temperatures are low, probably below 2°C (Leslie, 1965). Jiang *et al.*, (1997) identified very similar conditions at Skagen 3/4, suggesting summer sea surface temperatures would have been around 2°C. This cold period correlates extremely well with faunal and sedimentary proxies from MD99-2286 (Gyllencreutz, 2005; Gyllencreutz & Kissel, 2006; Erbs-Hansen *et al.*, 2011a), Skagen 3 (Knudsen *et al.*, 1996a) and GIK15530-4 cores (Stabell, 1985), see figure 10 for location. Given the timing of this interval, it probably reflects conditions during this Younger Dryas. The low water temperatures are therefore

likely to result from the cold climate during this period. Given that relative sea level was c. 100 m higher at MD99-2286 than modern day (Erbs-Hansen *et al.*, 2011b), it would most likely have been much higher at GC372650. Consequently, the Skagerrak would have resembled a large fjord, with weak circulation and little input from the Atlantic Ocean.

The cold climate, combined with the presence of *Elphidium excavatum* which is known to tolerate lower salinities, suggests the likely existence of a glacier calving
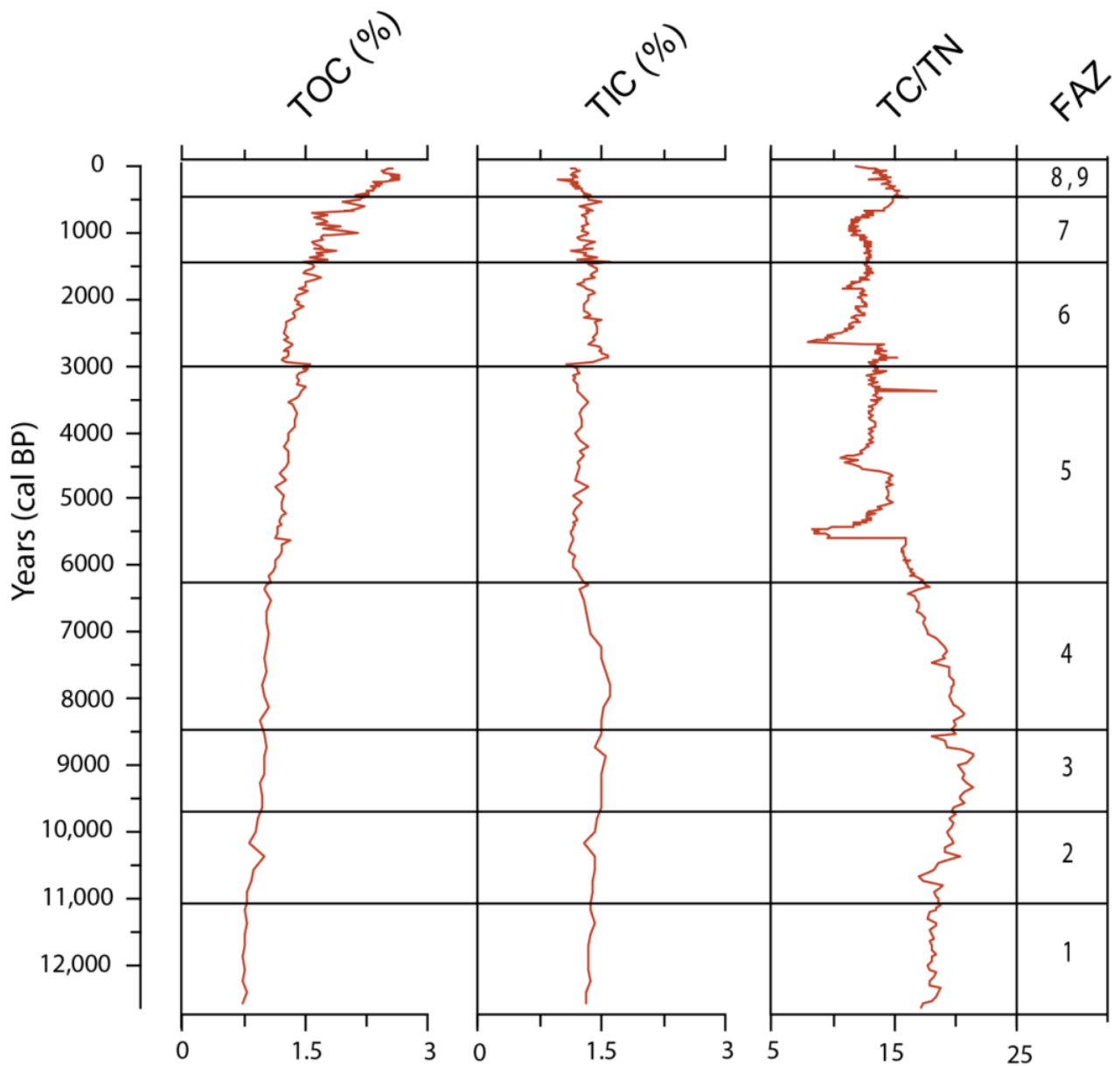
Figure 11: Geochemistry data, collected by IOW on GC372650, with Total Organic Carbon (TOC), Total Inorganic Carbon (TIC) and the Carbon/Nitrogen ration (C/N)

front nearby, inputting cold, freshwater into the Skagerrak. However, *E. excavatum* is very common in late glacial sediments around the Skagerrak (Nagy & Qvale, 1985; Knudsen *et al.*, 1996b), and is not necessary indicative of reduced salinities. Erbs-Hansen *et al.*, (2011a) suggested that, during this interval, the Skagerrak probably experienced cold marine conditions at the sea floor and glaci-marine, meltwater influenced conditions at the surface. However, given that circulation in the Skagerrak was relatively weak around this interval (Gyllencreutz *et al.*, 2006) it seems likely that the cold meltwater would have had time to mix with warmer, high salinity waters and sink into the deep Skagerrak. Therefore, *Elphidium excavatum* is interpreted to reflect the presence of lower salinity water due to the proximity of the Scandinavian Ice Sheet margin and an associated ice shelf. Sedimentological data from MD99-2286 (Gyllencreutz, 2005) supports this theory, showing high clay content during this interval as well as the occurrence of IRD.

The geochemical data collected from this core (figure 11) also tends to support this interpretation. Relatively low TOC values at the base of the core indicate relatively low organic productivity at this time driven by cold ice proximal conditions. The high TC/TN ratio also suggests significant input of terrestrial material most likely from the meltwater flux of the nearby calving ice sheet margin.

Whilst there is general agreement that an ice shelf would have existed in the Skagerrak during the Younger Dryas, determining its location is difficult from these sediments alone. However, previous authors have identified a small drainage event from the Baltic Ice Lake at c. 13,000 cal. BP (Björck, 2008). For this to have occurred, the Scandinavian Ice sheet must have retreated to at least the north-west coast of Sweden, and more likely further inland, away from the Swedish coast. This is supported by Lundqvist & Wohlfarth (2000), who re-examined past investigations into the retreat of the Weichselian ice sheet and concluded that the ice had retreated as far north as the central Oslo Fjord by the Younger Dryas. Gyllencreutz *et al.*, (2005) then extended the ice marginal line drawn by Lundqvist & Wohlfarth (2000), shown in figure 3, indicating the ice calving front would most likely have been on the south coast of Norway and the Oslo Fjord.

It is interesting to note that some previous studies have shown that certain shallower areas in the Skagerrak respond differently during the Younger Dryas. Where this, and many other investigations see cooling, they actually see warming (Bergsten & Nordberg, 1992; Conradsen, 1995). Knudsen *et al.*, (1996a) speculate that this may be a result of the shallower waters where freshwater input may have had more of an effect on the fauna.

6.1.1 - Baltic Ice Lake drainage

It is also worth considering the absence of any evidence of the final drainage of the Baltic Ice Lake, discussed in section 3.2, and thought to have occurred around 11,700 cal. BP (Björck, 1995; Lambeck, 1999; Andrén *et al.*, 2002). When examining the faunal assemblages, there are no distinct, short-lived changes that occur within this interval that might represent the final drainage. A significant faunal change in GC372650, FAZ 2, is discussed in detail in section 6.2, but it is not thought to represent the BIL final drainage.

The drainage of the BIL is believed to have taken place over one to two years (Jakobsson *et al.*, 2007). During this time, Jakobsson *et al.*, (2007) suggest 7800 km^3 of freshwater was released at a relatively constant rate of 0.15 – 0.3 Sv (10^6 m^2s^{-1}). Given the extended duration of the final drainage, it seems logical that the sea floor would have had time to respond to the changing conditions. Despite this, it is possible that any changes to the faunal assemblages may have been short-lived as the freshwater was renewed with more saline waters after the drainage terminated. It is therefore unsurprising that the faunal assemblages show no indication of this event, particularly as the resolution between adjacent samples at this depth is just c.100 years. Furthermore, given the deposition rates during this interval, a 1cm slice represents around 60 years – the signal of the BIL drainage could have been easily suppressed. However, with a large outwash event, one might expect to see an increase in TOC or alterations in the C/N values as terrigenous material is washed into the ocean. This is particularly the case due to the higher resolution of the organic analysis. Despite this, there are no such variations that could be connected with the BIL drainage seen in this study.

Whilst no supporting evidence was identified in GC372650, authors have found evidence for this event from isotope signatures in southwest Sweden (Bodén *et al.*, 1997), sedimentological studies from the Baltic Sea (Andrén *et al.*, 2002) and Finland (Hyttinen *et al.*, 2011) as well as roadside cuttings in Sweden (Johnsen *et al.*, 2010). Clearly, therefore, the BIL drainage is found in a wide variety of cores across the North Sea as well as from on-land exposures. Why, therefore, is it not visible in GC372650? Grain size data is not available to this investigation, which may have shown evidence of the BIL drainage, though the sediment showed no apparent sand layers. Furthermore, no evidence for this final drainage was found from core MD99-2286 in either the grain size data (Gyllencreutz, 2005), or faunal assemblages and geochemistry (Erbs-Hansen *et al.*, 2011a). In fact, no evidence was found in Skagen 3 either (Knudsen *et al.*, 1996a; Jiang *et al.*, 1997). Many of the authors that did find supporting evidence of the drainage found it outside the Skagerrak, much closer to the drainage route.

Given the depth of the core sites, a possible explanation for these disparities is a greatly increased stratification due to a sudden and massive input of freshwater. Such an event would have occurred during the BIL drainage. The sudden influx would have intensified the already strong stratification and, as a result, the sediments in the deep Skagerrak could have been separated from any effects of the drainage. Erbs-Hansen *et al.*, (2011) arrived at the same conclusion in explaining their results. However, given the shallower depth of Skagen 3, this explanation is not valid for all sites. Another possible explanation is that the BIL drainage was not as large an event as many have suggested. The sites of Johnson *et al.*, (2010) and Bodén et al, (1997) were extremely close to the BIL and would have been far closer to the outlet. This would explain why evidence of the BIL drainage is much clearer there, simply because it was closer.

As mentioned previously, Påsse and Anderson (2005) actually question the entire presence of the BIL, using isostatic modeling to suggest that the basin may have been at sea level. Were this the case, it would explain the lack of evidence here for any major outwash around this interval; meaning evidence found elsewhere was from a different event. However, given the considerable amounts of research

into the history of the BIL (Björck, 1995, 2002; Andren *et al.*, 1999, 2002; Hyttinen *et al.*, 2011 etc.), this seems unlikely.

It is probable, therefore, that the lack of evidence constraining, or even supporting, the final BIL drainage may be the outcome of a number of different causes. Any faunal changes that may have occurred could have been short lived, and the signal lost during deposition. This problem is exacerbated by the slow deposition rates meaning a 1cm slice, as investigated here, covers nearly 60 years. A second reason could be increased stratification due to the sudden influx of freshwater, this is in agreement with Erbs-hansen *et al.*, (2011a). Or it may simply be the case that the BIL drainage was not as large as some such as Jakobsson *et al.* (2007) suggest. In any case, the absence of evidence in this investigation is not interpreted as an absence of the event. It seems likely therefore, that different areas were affected differently by the BIL drainage and more work is needed to better constrain its timing and the areas it affected.

6.2 – Baltic Drainage Change (11,200 – 9,800 cal. BP, FAZ 2)

The faunal assemblages from 11,200 – 9,800 cal. BP (FAZ 2) reflect cool, ice distal conditions, with an increase in temperature from the previous zone, as evidenced by the absence of *Buccella frigida*. The ice distal conditions suggest that the ice margin may have retreated on land. The TOC, TIC and C/N ratio measurements from this period are similar to the preceding period (figure 11). As in the earlier period the low TOC values suggest low productivity and the relatively high C/N ratio suggests continued influx of terrestrial derived material from the retreating ice margin.

The most distinctive element of this zone is the sudden increase in abundance of *Valvulineria* spp., though very little is known about its ecological preferences. Despite this, the timing of this significant shift in foraminiferal assemblage at this site (c. 11,200 cal BP) correlates extremely well with a major alteration to the hydrography of the Skagerrak-Kattegat area suggested by Björck (1995) - the opening of a new outlet from the Baltic over central Sweden, the Otteid-Steinselva (see figure 12a). This is intrinsically related to the final drainage of the BIL,
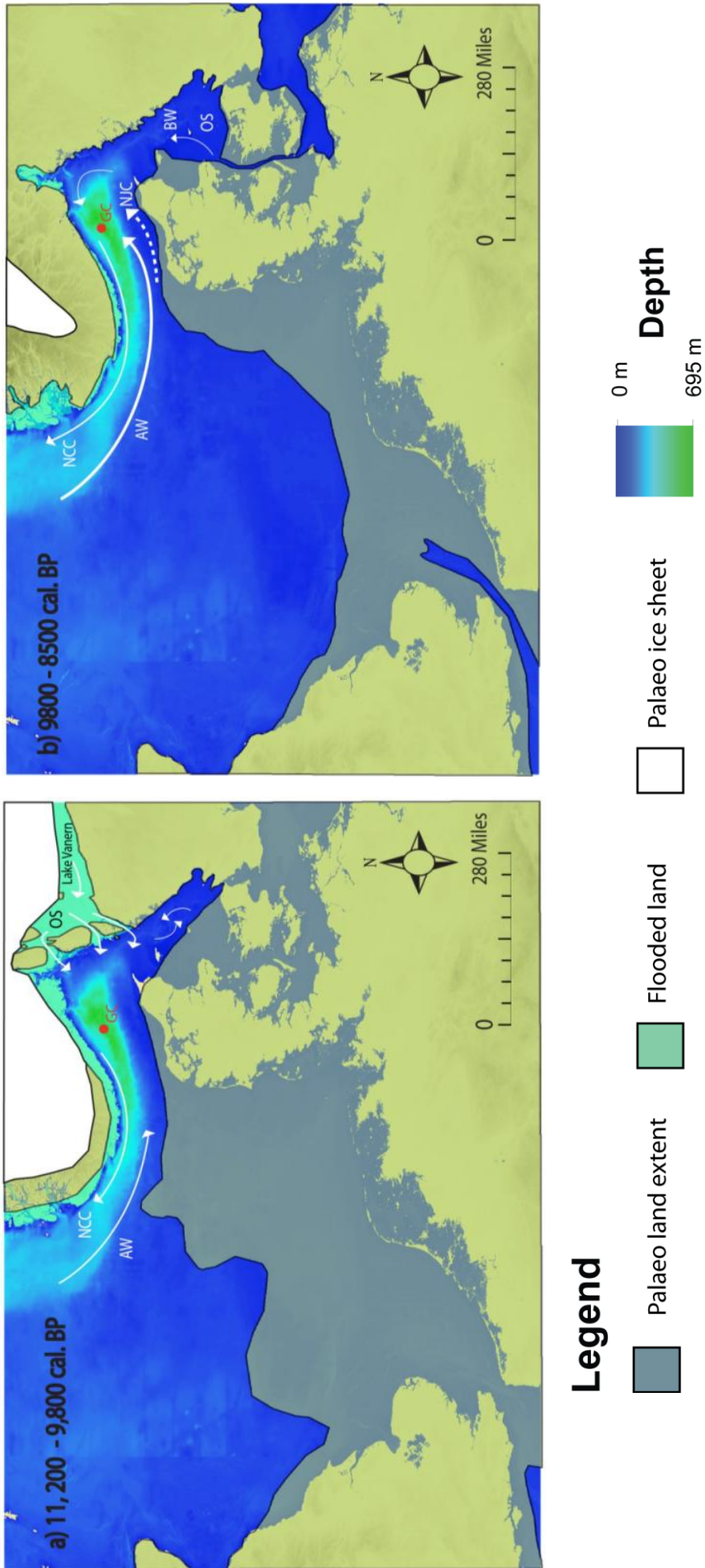
Figure 12: Four time slice maps showing the palaeo reconstruction for the North Sea, as well as variations in the hydrological system. The palaeo land extent is edited from Gyllencreutz (2005) and Behre *et al.* (2007). (AW = Atlantic Water, BW = Baltic Water, CCW = Continental Coastal Water, CNSW = Central North Sea Water, NCC = Norwegian Coastal Current, NJC = North Jutland Current, SJC = South Jutland Current, SNSW = Southern North Sea Water, OS = Otteid-Steinselva outlet, O = Oresund Strait)
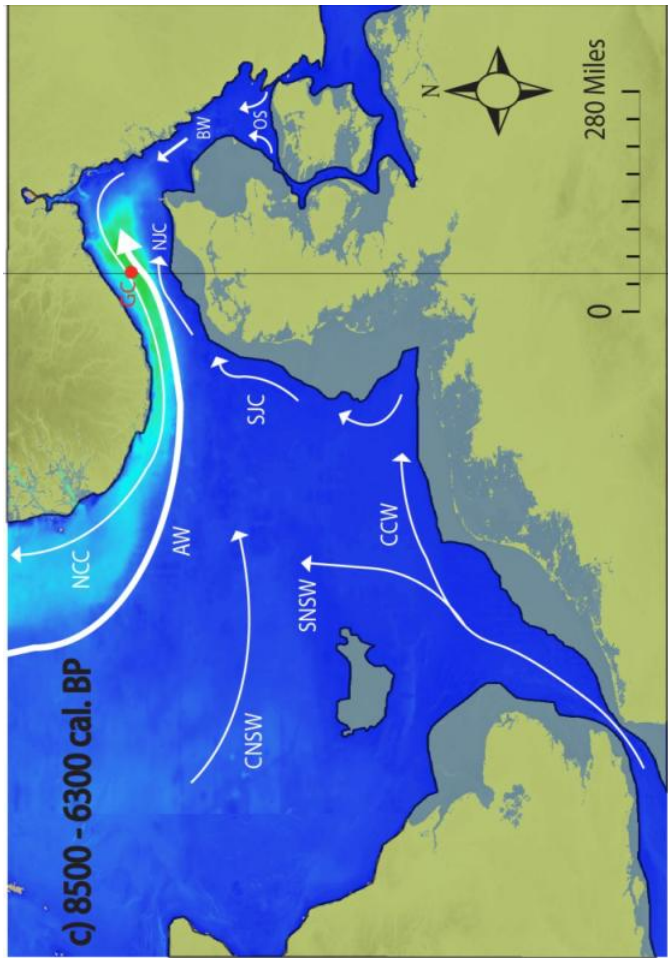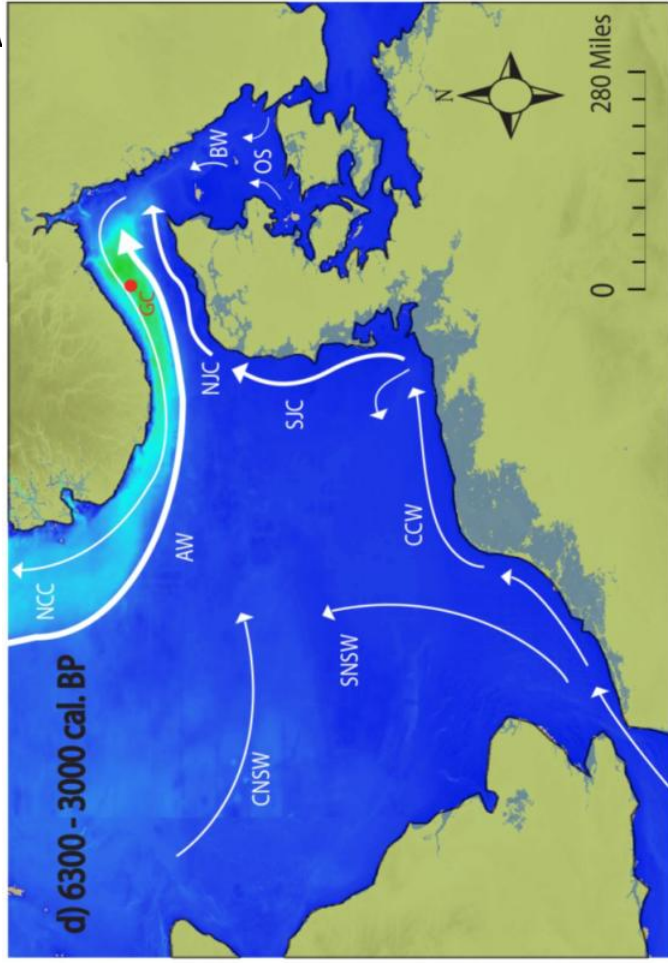
Figure 12 continued.

discussed above. Once the final drainage had occurred, and the level of the Baltic had fallen by 25m (Jakobsson *et al.*, 2007; Hyttinen *et al.*, 2011), the main channel for water to enter the Skagerrak became the Otteid-Steinselva outlet (figure 12a).

Given the coincidental timing of these two events, it is very likely that they are related. The sudden bloom in *Valvulineria* spp. may have been triggered by the increased glacial meltwater outflow from the Baltic, via this new outlet. This outflow would have created an intense pycnocline in the Skagerrak. *Valvulineria* spp. might be a product of this stratification, possibly preferring the more saline, cold, oxygen depleted waters. As shown in figure 12a, there would probably have been 3 outlets into the Skagerrak, but for simplification purposes, they will be classified with one name – the Otteid-Steinselva outlet.

This drainage change from the Baltic Sea has been identified by a number of authors, particularly at site MD99-2286 in the fauna (Erbs-Hansen *et al.*, 2011) and in clay content and magnetic properties of the sediments (Gyllencreutz, 2005; Gyllencreutz & Kissel, 2006), as well as different sites in the Skagerrak (Larsson, 2007). Furthermore, some deposits that were originally correlated directly with the BIL final drainage have subsequently been re-interpreted as being related to the opening of this new outlet, figure 12a, (eg. Bergsten, 1994). Given that these two events are inextricably linked, it seems paradoxical to separate them. However, the initial drainage event of the BIL would have been relatively quick (Björck, 1995) whereas the change in drainage persisted for hundreds of years and is most likely the key process that produced the changes observed in GC372650.

Whilst the Otteid-Steinselva outlet was open, it would have been at sea level. However, Andrén *et al.*, (1999) suggest high salinity water would not have been able to enter the Baltic for 250 years after this outlet opened as it was not large enough. Only when enough sediment had been eroded would two-way exchange have been possible. When this exchange began, the water column was most probably stratified, much like the modern day, with the more dense, higher salinity Atlantic water flowing beneath the fresh Baltic waters.

Based on this interpretation that an increase in *Valvulineria* spp*.* is produced by increased stratification related to the opening of the Otteid-Stenselva outlet, its subsequent decrease is most probably related to the closing of this outlet. The demise of *Valvulineria* spp*.* begins between 10,700 cal. BP and 10,460 cal. BP, occurring gradually until approximately 10,000 cal. BP, after which the species rapidly falls away. This gradual decrease in the abundance of *Valvulineria* spp*.* suggests the closing of the Otteid-Stenselva outlet occurred slowly, causing a gradual decrease in outflow from the Baltic Sea. This is most likely due to continued isostatic rebound, gradually lifting the outlet above sea level, constantly reducing the exchange of water between the two water bodies. This gradual decrease in outflow would have led to a reduction in the strength of the pycnocline, causing greater levels of mixing before its eventual breakdown by c. 10 ka.

Foraminiferal absolute abundance peaked at or around the onset of the decline in *Valvulineria* spp*.* This is probably because once the thermocline began to break down, more mixing occurred in the water column. The species of foraminifera bloomed during this initial mixing, before returning to previous levels. A very similar rise in foraminifera productivity at a similar time was identified by Knudsen *et al.*, (1996a, 2009).

Other authors have found the closure of this outlet to occur at a similar time. Erbs-Hansen *et al.* (2011) observed a transition to warmer foraminifera species at c. 10,300 cal. BP, whilst Gyllencreutz (2005) and Gyllencreutz & Kissel (2006) observe a reduction in clay content at the same time, both indicating the closure of the outlet. Gyllencreutz *et al.*, (2006) calibrated the dates from Björck (1995) and Lambeck (1999), which indicated the closure occurred between 10,400 cal and 10,200 cal. BP in their investigations. Although these dates are within c. 200 years of the initial reduction in output from the Baltic observed in GC372650, they seem to indicate the closure occurred much faster. The discrepancies between the different studies may be explained by depth. The water depth at GC372650 is 550m, far deeper than the core site of MD99-2286. The stratification that was caused by the increased glacial meltwater output from the Baltic may have broken up earlier in the shallower sites, causing more mixing of waters, reducing the effect of the Baltic outflow on the sediments. In the deeper sites, this stratification would

have existed for longer, and may explain why it observes the full duration of the closure.

Interestingly, Gyllencreutz (2005) also finds that these clay rich sediments deposited between 11,300 and 10,300 cal. BP, during the existence of the Otteid-Steinselva outlet, correlate with sediments found elsewhere on the Swedish west coast. However, sediments deposited further south do not show this increased clay content until later. This fits with the theory from Björck (1995), who suggested that varying isostatic rebound in the area led to a southward migration of the main deposition area for Baltic outflow sediments.

It is worth mentioning that faunal assemblages in this zone do not indicate any variations in temperature. This is in contrast to $\delta^{18}O$ based temperature measurements from MD99-2286 that showed an increase in temperature throughout this period (Erbs-Hansen *et al.*, 2011b). Furthermore, the influx of warmer water species at Skagen 3 (Knudsen *et al.*, 1996a) and Troll 8903/28-03 (Klitgaard-Kristensen *et al.*, 2001), during this interval suggest the inflow of warmer, Atlantic water. Given the dominance of *Valvulineria* spp. in GC372650, up to 40% at its maximum, the signature of warming in the foraminiferal assemblages may have been suppressed. However, given the increased depth of this site, it may well be that no warming occurred during this interval. The cold, glacial meltwater that entered the Skagerrak from the Baltic may have caused an intense stratification, keeping temperatures in the bottom water persistently low.

6.3 – Holocene transitional period (9,800 – 8500 cal. BP, FAZ 3)

This period is characterized by the increase in *Cassidulina laevigata*, a species commonly associated with warm Atlantic waters (Klitgaard-Kristensen *et al.*, 2002; Erbs-Hansen *et al.*, 2011b). It is notable that *Cassidulina neoteretis* also increases in the zone, more commonly associated with cool Atlantic waters (Rytter *et al.*, 2002) but given the morphological similarities between these two species, it is possible that occasional misidentification may have occurred. Nonetheless, their concurrent increase is interpreted as an increase in Atlanic inflow. Supporting this

theory is the increase in warmer water species *Melonis barleeanus*. *Melonis barleeanus* was found in MD99-2286 (Erbs-Hansen *et al.*, 2011b) between 9200 and 8000 cal. BP, which was also interpreted as a period of increased Atlantic inflow. The variation in timing between GC372650 and MD99-2286 might reflect slightly different hydrological regimes given their distance apart and variation in depth, or could be due to inaccuracies in the age models.

This increase in Atlantic water inflow has been observed around the same time in the Skagen 3 core (Conradsen, 1995; Conradsen & Heier-Nielsen, 1995; Knudsen *et al.*, 1996b; Jiang *et al.*, 1997), MD99-2286 (Gyllencreutz & Kissel, 2006; Erbs-Hansen *et al.*, 2011b) and Troll 8903/28-04 (Klitgaard-Kristensen *et al.*, 2001). This period is often regarded as the initiation of full interglacial conditions (Knudsen *et al.*, 1996a; Erbs-Hansen *et al.*, 2011a).

There are, however, additional faunal changes in this zone; FAZ 3 sees the rapid but short-lived increase in cold-water fauna at c. 9450 cal. BP. The increase in abundance of *E. excavatum* and *B. frigida* suggests the return of relatively colder waters. However, based on their age, this change in fauna is unlikely to be linked to any cooling associated with advance of local ice, as is the case in the Younger Dryas. Nonetheless, they are clearly indicating a distinct drop in temperatures, which began around 9,450 cal. BP, and probably lasted less than 400 years.

This cool period correlates well with a change in assemblages from Skagen 3, identified in both diatoms (Jiang *et al.*, 1997) and foraminifera (Conradsen & Heier-Nielsen, 1995), dated to 9000-9450 cal. BP (8600 ^{14}C BP). Jiang *et al.* (1997) suggests that these changing assemblages may reflect a period of slightly reduced temperatures caused by a strengthened North Jutland Current. The foraminiferal assemblages from Conradsen & Heier-Nielsen (1995) were interpreted as reflecting a westerly source for the sediments, this is in agreement with Jiang *et al.*, (1997). The cooling observed at Skagen 3 persisted for around 1000 years, whereas the cooling here is thought to have persisted for less than 400 years. This may, however, simply reflect slightly different hydrological regimes, with the deeper Skagerrak responding differently.

This period may also relate to a cooling event discussed by Fleitmann *et al.* (2007, 2008) that also occurred at 9200, cal. BP and is believed to have lasted c. 200 years. Although there is a discrepancy of around 200 years between the onset of cool conditions in GC372650 and the cooling event discussed by Fleitmann *et al.*, (2007, 2008), the low resolution dating during this period means the two may easily be the same event.

Fleitmann *et al.* (2008) identified studies that had showed this cooling event across Europe (von Grafenstein *et al.*, 1999; Korhola, 2002; Spurk *et al.*, 2002), Asia (Fleitmann *et al.*, 2007) and Alaska (Hu *et al.*, 2003). Fleitmann *et al.*, (2007, 2008) suggest a weakening of the North Atlantic Thermohaline Circulation (THC), resulting from a large freshwater input, or meltwater pulse (MWP), may have caused the climatic cooling. The sudden input of freshwater would have caused a reduction in the formation of North Atlantic Deep Water, reducing the strength of the THC. A well-documented example of this is the 8.2 ka event, identified by Erbs-Hansen *et al.*, (2011a) from the Skagerrak, but widely observed outside the region (Alley *et al.*, 1997; Alley & Ágústsdóttir, 2005). Teller & Leverington (2004) identified a similar input of freshwater into the North Atlantic at c. 9200 cal. BP, though a much smaller amount, just 5% of the 8.2 ka event. Fleitmann *et al.* believe the 9.2 ka and 8.2 ka events showed very similar characteristics, indicating that they were caused by the same process, namely a reduction in the THC.

It is therefore difficult to ascertain which process caused the reduction in water temperatures inferred during this period, a strengthened NJC or a weakening of the THC. It may well be that both processes acted together, and that a weakened THC, discussed by Fleitmann *et al.* (2008), was actually a significant factor in the cooling observed by Jiang *et al.* (1997).

Also of interest during this zone is the continued presence of *Valvulineria* spp*.* Despite the uncertainty surrounding the environmental preferences of this species, it was clear in FAZ 2 that its presence was somehow related to the opening of the Otteid-Stenselva outlet and, hence, increased influence of the Baltic Sea. Given, then, that *Valvulineria* spp*.* is still present in this zone, albeit in extremely low abundances, it is reasonable to assume that waters from the Baltic were still reaching the Skagerrak. Given the continual presence of this species through all of

the samples, it seems likely that an outlet remained throughout the whole period, though the extremely low abundances indicate that discharge through this outlet was minimal. This seems to be in agreement with Andrén *et al.*, (2002) and Berglund *et al.*, (2005) who found the inflow of higher salinity water into the Baltic as early as 10,200 cal. BP. The exchange would probably have been two way, accounting for the continued presence of *Valvulineria* spp*.* right through this and the end of the subsequent zone.

6.4 – Opening of the English Channel (8500 – 6300 cal. BP, FAZ 4)

The sudden introduction of *Hyalinea balthica* at 8500 cal. BP is indicative of a considerable alteration to the hydrographic system. This warm water species indicates a distinct and sudden warming of ocean temperatures, and is found at the same time by a number of authors from around the Skagerrak (Hessland, 1943; Brotzen, 1951; Feyling-Hanssen, 1964; Nagy & Qvale, 1985; Erbs-Hansen *et al.*, 2011). The sudden increase suggests a very rapid change in hydrographic conditions. This is unlikely to be linked to a sudden change in climatic conditions and is more likely to be linked to a sudden change in ocean circulation. Supporting this idea of a warmer ocean current is the near complete disappearance of *Elphidium excavatum* and *Buccella frigida*, both cold water species. *Uvigerina mediterranea* also peaks throughout this zone, albeit to values typically less than 5%. According to Klitgaard-Kristensen *et al.* (2001), this species is known to flourish in Atlantic waters. They noted an increase in abundance of this species between 8,500 – 7500 cal. BP in Troll 8903/29-03.

Generally, the fauna shows a distinct shift from colder, lower salinity foraminifera, to those associated with warmer conditions and Atlantic inflow. This zone therefore most likely reflects the flooding of the English Channel (figure 12c). Concurrent changes identified elsewhere from the Skagerrak have also been attributed to this hydrological development (Nagy & Qvale, 1985; Conradsen & Heier-Nielsen, 1995; Jiang *et al.*, 1997; Gyllencreutz, 2005; Gyllencreutz & Kissel, 2006; Erbs-Hansen *et al.*, 2011b). The flooding of the English Channel occurred as a result of eustatic sea level rise (Nagy & Qvale, 1985; Nordberg, 1991; Behre, 2007), termed the Littorina transgression in this region. This hydrological development

was the last significant oceanographic change to occur in the Skagerrak, and resulted in the onset of the modern oceanographic system (Nagy & Qvale, 1985; Conradsen & Heier-Nielsen, 1995; Erbs-Hansen *et al.*, 2011b). It also enabled the creation of the South Jutland Current and the Continental Coastal Current (Nordberg, 1991; Gyllencreutz & Kissel, 2006).

It is worth noting the timing of this hydrological development is not consistent across the North Sea. In GC372650, it occurs at c. 8500 cal. BP, this is in general agreement with findings from MD99-2286 (Gyllencreutz, 2005, Gyllencreutz & Kissel, 2006) and Skagen 3 (Conradsen & Heier-Nielsen, 1995; Jiang *et al.*, 1997). However, Nordberg (1991) in the Kattegat, suggests this may have been earlier, 9000 - 8700 cal. BP, (this is a calibrated date from Gyllencreutz *et al.*, 2006). Furthermore, the faunal assemblages in MD99-2286 do not show this development until 8000 cal. BP (Erbs-Hansen *et al.*, 2011b). Clearly, the impact of this hydrological development was different in different locations, and even different proxies within the same core. However, the records generally indicate the English Channel opened sometime between 8500 – 8000 cal. BP leading to a significant change in hydrography of the entire North Sea region.

Aside from the opening of the English Channel, faunal changes in this zone also reflect the opening of the Danish Straits (figure 12c). In the previous two zones, *Valvulineria* spp. has been associated with outflow from the Baltic Sea. Its increase here, at 8300 cal. BP, is therefore likely to correspond to an increase in outflow from the Baltic. The eustatic sea level rise (Behre, 2007) that caused the opening of the English Channel also resulted in the opening of the Danish Straits, facilitating a connection between the Baltic and the North Sea through these narrow channels. This would probably have resulted in an intensified stratification in the Skagerrak-Kattegat. It would also have allowed much greater volumes of higher salinity water into the Baltic, resulting in an increase in productivity and biodiversity, and encouraged two-way flow between the Baltic and the Skagerrak/Kattegat.

This opening of the Danish Straits has been identified by numerous other authors, with Berglund *et al.*, (2005) and Bennike *et al.*, (2004) suggesting it occurred at

8500 cal. BP and 8100 cal. BP respectively. These dates are relatively close to the 8300 cal. BP suggested here. However, previous investigations identified this event much earlier. Gyllencreutz *et al.* (2006) calibrated the dates interpreted as reflecting the opening of the Danish Straits of previous investigations, finding dates of 9300 – 9000 cal. BP (Björck, 1995) and 9000 – 8700 cal. BP (Conradsen, 1995; Jensen *et al.*, 1997). The large discrepancies in the period of opening of the Danish Straits may be related to resolution of dating, or they may reflect genuine variations in response, dependent on location. In either case, it suggests the opening of the Danish Straits was probably a complex, and lengthy development. Consequently more work is needed to fully understand this event, particularly as it was extremely important in the development of the Baltic Sea.

More recently it has been thought that a combination of the English Channel opening, and the opening of the Danish Straits facilitated the sudden bloom in *H. balthica*. The warming ocean temperatures and opening of the Channel provided a migration route for *H. balthica* (Erbs-Hansen *et al.*, 2011) and the increased stratification resulting from the opening of the Danish Straits created low oxygen bottom water conditions, in which *H. balthica* is known to thrive. This is supported by the increase in *S. fusiformis* during this period. Despite this, the bloom of *H. balthica* occurred slightly earlier than that of *Valvulineria* spp., suggesting that this explanation is not entirely satisfactory. However, if a strong stratification did exist, the resulting low oxygen concentrations may explain the reduced abundances during this period.

The 8200 cal. BP event, a well described cooling over northern Europe (Alley *et al.*, 1997; Alley & Ágústsdóttir, 2005) and observed in other Skagerrak sediments at MD99-2286 (Erbs-Hansen *et al.*, 2011b), is not evident in GC372650. The reason may be related to the opening of the English Channel, discussed above. The sudden and dramatic change to the hydrological system caused by the English Channel opening could well mask any changes linked directly to the 8.2 ka event. It is also possible, however, that the magnitude of the 8.2 ka cooling event was not great enough to have had a significant effect on the deep Skagerrak.

6.5 – Strengthened South Jutland Current (6300 – 3000 cal. BP, FAZ 5)

This period is characterized by slight cooling, evidenced by the increase in *B. frigida*, and the move towards an environment with higher energy, interpreted from the increase and more consistent appearance of *Cibicides lobatulus*. The timing of this zone corresponds extremely well with a period of cooler conditions and strengthened currents off the Danish coast, the South Jutland Current, identified by a number of authors at M99-2286 (Gyllencreutz, 2005; Gyllencreutz & Kissel, 2006), Skagen 3/4 (Conradsen & Heier-Nielsen, 1995; Knudsen *et al.*, 1996b; Jiang *et al.*, 1997), and in the Kattegat (Nordberg, 1991; Conradsen, 1995). The fauna in this investigation support the theory of cooler conditions and an increase in current strength, supporting the interpretation of a strengthened SJC. The mechanism for this increased strength of the SJC is related to meteorological conditions over the North Sea and North Atlantic.

Mid Holocene climatic cooling over the North Atlantic has been identified by a number of authors (Koç Karpuz & Jansen, 1992; Nesje & Dahl, 1993). Given the SJC is susceptible to changing meteorological patterns over the North Atlantic (Kristensen, 1991), it can become more pronounced during periods of increased south-westerlies. Hence, this cooling event in the North Atlantic during the mid-Holocene, which caused a concurrent decrease in surface water temperatures in the North Sea and affected the meteorology, may well have led to a strengthening of the South Jutland Current.

Conradsen & Heier-Nielsen (1995), from Skagen 3/4, also interpreted this interval as reflecting a strengthened SJC. They observed the influx of a new species at c. 6200 cal. BP (5500 ^{14}C BP), *Eoeponidella laesoeensis*. Larsen (1984), from Northern Jutland, observe the influx of a species they refer to as *Astergerinata mamilla* at the same time, though Conradsen & Heier-Nielsen (1995) inspected this species and found it to be exactly the same as *E. laesoeensis*. A similar species was found here with a sudden increase in abundance between *c.* 6300 – 3100 cal BP. This supports the interpretation of a stronger SJC by Conradsen & Heier-Nielsen (1995) for this period (figure 12d).

Given the link between cf. *Eoeponidella* spp*.* and a strengthened SJC, the decline in this species at c. 3100 cal. BP in GC372650 is possibly related to a weakening of the SJC. This date, although close, does appear slightly later than others, with Conradsen & Heier-Nielsen interpreting a weakening at c. 3500 cal. BP (3300 C[14] BP) at Skagen 3/4. Sedimentological work on MD99-2286 also showed a decrease in strength much earlier, around 4700 cal. BP (Gyllencreutz & Kissel, 2006). However, Jiang *et al.*, (1997), also on Skagen 3/4 inferred a weakening slightly later, at c. 2800 cal. BP (3000 C[14] BP), whilst Nordberg (1991), from the Kattegat showed a weakening much later, c. 1600 cal. BP (2000 ^{14}C BP). These records generally indicate that different regions responded differently to variations in the SJC.

Importantly, there is not agreement between all records concerning this change. Erbs-Hansen *et al.* (2011b), on MD99-2286, did not identify any similar evidence for this hydrographic shift in their faunal assemblages, this is in contrast to the sedimentological data on the same core (Gyllencreutz & Kissel, 2006). Instead, they observe an increase in *B. marginata* and a decrease in oxygen isotope values, both pointing towards an increase in freshwater output from the Baltic. Gyllencreutz & Kissel (2006) also inferred increase Baltic outflow during this period from the sedimentological data, though slightly later, around 4000 cal. BP.

The interpretations of Gyllencreutz & Kissel (2006) and Erbs-Hansen *et al.* (2011b) differ slightly from those in this investigation (GC372650). The faunal assemblages in GC372650 show a decrease in *Valvulineria* spp. at c. 6000 cal. BP to its lowest levels throughout the core, with most samples showing its complete removal. As mentioned previously, this species is associated with outflow from the Baltic and, hence, its decrease indicates reduced output. This finding fits extremely well with the reconstruction of the Baltic Sea from Björck (1995). After the Littorina stage, which saw a maximum in water exchange between the North Sea and the Baltic Sea, eustatic sea level rise ceased but isostatic rebound, particular in the southern Baltic, continued. This resulted in lowered sills and, hence, reduced water exchange.

This is also supported by the considerably lower abundances of *H. balthica* in GC372650 compared to the FAZ 4. This species is thought to have bloomed due to the Channel opening and increased Atlantic inflow combining with increased output from the Baltic to cause an intense stratification (Erbs-Hansen *et al.*, 2011). Reduced output from the Baltic would have weakened the stratification; Nordberg & Bergsten (1988) also interpreted a weaker stratification in the Kattegat at c. 4000 cal. BP (Nordberg & Bergsten, 1988). This would explain the consistently low abundances of *H. balthica*. Reduced exchange with the North Sea was an important development in the history of the Baltic Sea, as this would have caused salinity levels to reduce, leading to stagnation of the water column, creating more anoxic conditions and lowering productivity (Björck, 2008).

Generally, therefore, the findings from Gyllencreutz & Kissel (2006) and Erbs-Hansen *et al.* (2011) seem to differ from those here. Site MD99-2286 is further east and shallower than GC372650; this could possibly explain the disparity in results. The outflowing water from the Baltic is likely to have a greater impact upon Site MD99-2286 than GC37650. Once again, this indicates that the deep Skagerrak responds differently to shallower regions.

6.6 - Period of stability with increasing Atlantic Flow (3000 – 418 cal. BP, FAZ 6 and 7)

This period, comprised of FAZs 6 and 7, is indicative of relatively stable oceanographic conditions. FAZ 6, from c. 3000 cal. BP to c. 1500 cal. BP shows the influx of *Cassidulina* species, interpreted as an increased inflow of Atlantic water. There is, however, an increase in *Buccella frigida* between 2800 and 2000 cal. BP; this is inferred to reflect a period of reduced water temperatures. The cooling may be related to neo-glacial cooling, with Emeis *et al.*, (2003) suggesting a sea surface temperature drop of 2°C occurred between 6000 – 2000 cal. BP in the Baltic Sea. This period also witnessed the significant re-advance of glaciers (Nesje & Dahl, 1993). Neo-glacial cooling is also observed in the Skagerrak by Erbs-Hansen *et al.* (2011) between 4350 to 1100 cal. BP, suggesting a cooling over c. 3000 years. In GC372650, evidence of reduced temperatures persisted for around 800 years, indicating that the deep Skagerrak may have responded slower

to the climatic changes, only reacting after a prolonged duration of cooler temperatures.

From 1450 cal BP there is a distinct change with the introduction of *B. skagerrakensis*. This species is reported as preferring stable bottom water conditions, with high oxygen concentrations and salinities (Conradsen *et al.*, 1994). Its increase during the late Holocene in GC372650 is therefore likely to relate to the influence of a more stable water mass with high salinities and temperatures. Numerous authors have also observed the influx of *B. skagerrakensis* around this time from sites around the Skagerrak (Nagy & Qvale, 1985, Qvale & Nigam, 1985; Bjørklund *et al.*, 1985). Nordberg (1991), working in the eastern Kattegat, did not observe this species, though this was probably due to the fact the Kattegat is too shallow to support *B. skagerrakensis*. Nonetheless, Nordberg (1991) still interpreted changes around this period as a result of the inflow of a nutrient rich water source. Therefore, the sudden influx of *B. skagerrakensis* is probably related to a further increase in Atlantic water inflow. Many authors from the Skagerrak also believe Atlantic inflow increased during this period (Nordberg, 1991; Gyllencreutz & Kissel, 2006; Erbs-Hansen *et al.*, 2011b).

Hass (1996) links this increased inflow of Atlantic water to a distinct climatic change, with cool and wetter conditions over the North Atlantic and North Sea. Hass (1996) suggests that these changes would have enabled a stronger inflow of saline water into the North Sea. The predominant wind direction at that time would have been northwesterly, and this could have increased the inflow of water through the South Trench Current (STC); Jiang *et al.*, (1997), proposed a similar interpretation. This would have strengthened circulation in the Skagerrak and increased the inflow of Atlantic Water.

It is of note, however, that Hass (1996) suggested this increased Atlantic inflow through the Southern Trench only occurred between c. 1550 – 1150 cal. BP. The fauna from GC372650 indicate this persisted over a much longer duration. Furthermore, it continues throughout the period known as the Medieval Warm Period (MWP), a well-documented climatic warming across Northern Europe (Hass, 1996; Hebbeln *et al.*, 2006; Gil *et al.*, 2006; Poldova *et al.*, 2011; Erbs-

Hansen *et al.*, 2011b), thought to have occurred between 1200/1000 cal. BP – 700/500 cal. BP (Hass, 1996). These might indicate that a different process has caused the increased Atlantic inflow between c. 1500 and 420 cal. BP.

6.7 – Little Ice Age (420 - 160 cal. BP, FAZ 8)

The increase in *B. frigida* at c. 420 cal. BP, FAZ 8, suggests a distinct drop in water temperatures that lasted throughout this zone. Additionally, abundances of *B. skagerrakensis* decrease, reaching a minimum at c. 290 cal. BP. This species is an indicator of stable and warm bottom water conditions and its decrease in FAZ 8 may therefore also reflect a decrease in temperatures. However, Hass (1994) interpreted *B. skagerrakensis* as an indicator of changing hydrographical conditions, largely because peaks in abundance were found during periods of changing conditions, such as the initiation of the Little Ice Age. In this investigation, *B. skagerrakensis* peaks in the sample underlying the onset of this zone. Therefore, this period is generally characterized by reduced temperatures which probably relate to the Little Ice Age.

On the other hand, *B. skagerrakensis* has been associated with Atlantic water inflow. Therefore, a reduction in abundance could also be a result of decreased Atlantic water inflow. Erbs-Hansen (2011) identify a change around 500 cal. BP which they suggest might be connected to a period of negative and move variable NAO index, as identified by Trouet *et al.* (2009), which may have resulted in reduced Atlantic water inflow. However in GC372650, the reduction in *B. skagerrakensis* occurs later, and for a shorter duration, indicating that this negative NAO index probably had little effect.

Generally, although the impact of a negative NAO index cannot be ruled out, this zone reflects reduced temperatures that probably relate to the LIA. After c. 290 cal. BP, *B. skagerrakensis* increases in abundance once more, reaching pre-LIA levels at c. 160 cal. BP; this is interpreted as a return to wamer temperatures. A similar rise in *B. skagerrakensis*, has been observed elsewhere in the Skagerrak, also attributed to warming following the LIA (Hass, 1994; Jentzen, 2010). This suggests that the LIA terminates at c. 160 cal. BP.

It is notable that the duration of the LIA in GC372650 appears much shorter than in previous studies around the Skagerrak (Hass *et al.*, 1996; Hebbeln *et al.*, 2006). However, Hass *et al.*, (1996) suggest the maximum of the LIA probably occurred between c. 400 and 170 cal. BP. This corresponds fairly well with the sediments in GC372650, indicating that the deeper Skagerrak sediments responded slightly more slowly to the cooling experienced during the LIA.

Furthermore, Hass (1996) observed a decrease in current strength during the LIA maximum, c.400 – 170 cal. BP. Water depth of core sites in the investigation by Hass (1996) varied, but some were as deep as 450m. The decreased current strength could have resulted in reduced mixing of the water column, a theory supported by the increase in *H. balthica* and *B. marginata* in GC372650, two species which are able to survive in less oxygenated environments.

This in itself is interesting as Hebbeln *et al.*, (2006) observed the opposite, an increase in bottom water current strength throughout the period they define as the LIA. It seems logical that this would have affected the sediments in GC372650 from the outset, though this was clearly not the case. However, Hebbeln *et al.* (2006), who investigated sites from across the Skagerrak and North Sea, were limited to just 338 m water depth. Given that GC372650 is from 550m water depth, it seems likely that the increased bottom water velocities were limited to the upper water column, perhaps down to the maximum depth of Atlantic water inflow.

Consequently, it appears that the deeper Skagerrak responded differently to cooling during the LIA than shallower sites. The duration of cooling appears shorter, and lowered oxygen concentrations resulting from reduced mixing in the water column may have occurred.

6.8 - Present day: Anthropogenic Impacts or NAO index? (c.160 cal BP – Present Day / AD 1790 – 2009).

This section will discuss the environmental changes using the time scale relative to modern day, AD. This is to avoid confusion with dates after ad 1950.
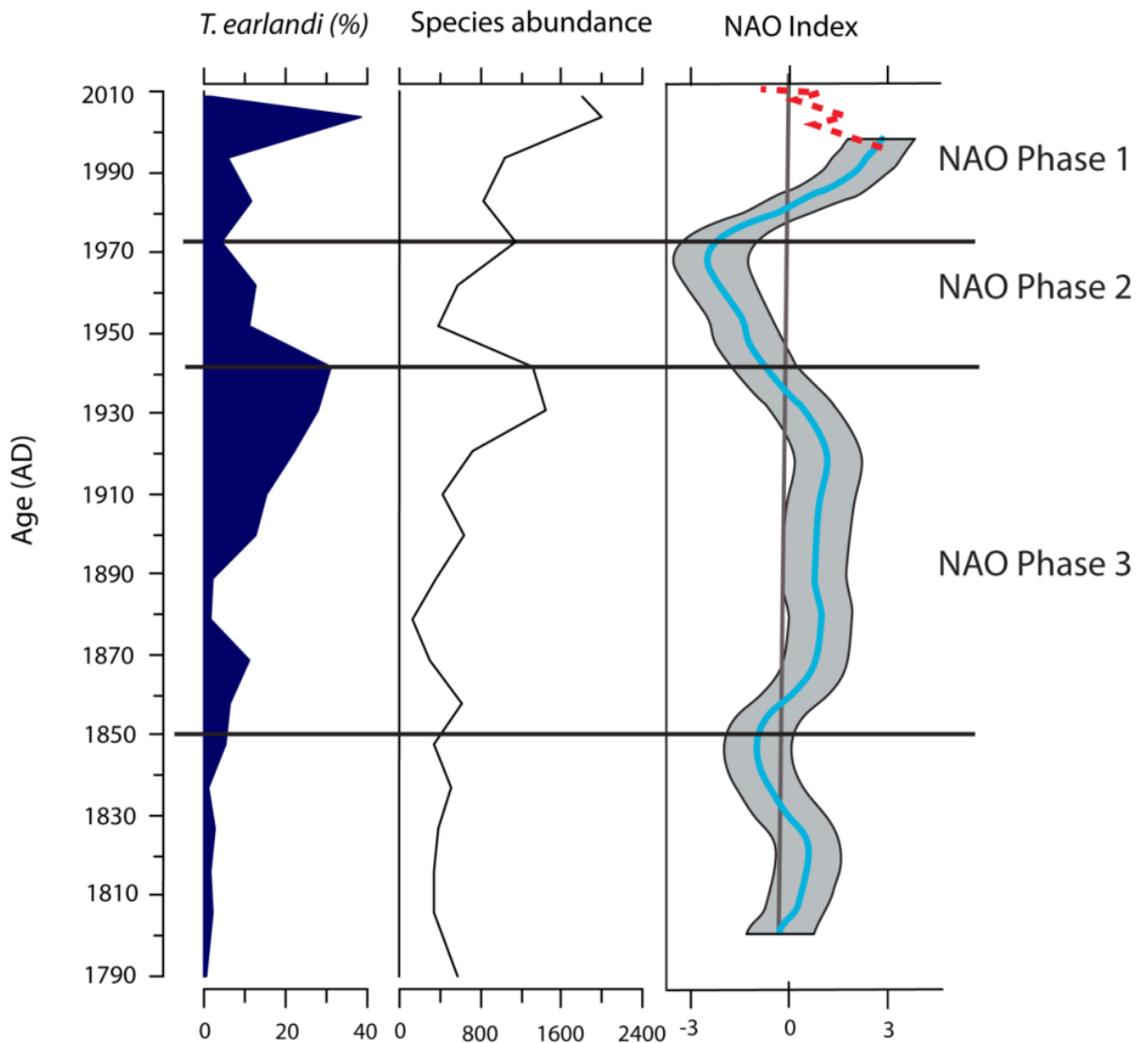
Figure 13: Graphic showing the relative percent of *Textularia earlandi*, specimen abundance and NAO index values over the last 200 years. The blue line represents the reconstructed NAO index by Truet *et al.* (2009) with the shaded area the possible error. The record from Truet *et al.* (2009) only extends to 1995, and the hashed red line is redrawn from Osborn (2011). The red line is used to demonstrate the rapidly reducing NAO values proposed by Osborn (2011), however, given that the two authors used different calibrations methods, it is not possible to correlate the exact values. Hence, the red line is simply used to show a decrease since 1995.

One of the most distinctive elements of this period is the appearance of more agglutinated species and in far higher abundances. Previous investigations have attributed this to variations in preservation (Nordberg, 1991). However, Alve (1996) considered this problem in detail and concludes that the assemblage changes are related to genuine ecological changes rather than taphonomic effects; similar conclusions are reached by Alve & Murray (1995).

The two most dominant faunal changes that occur during this period are the decrease in *B. skagerrakensis* and the increase in *T. earlandi*. As discussed in the results, the concurrent decrease and increase in these two species respectively is likely to relate to a reduction in oxygen levels in the deep Skagerrak. A number of authors have found similar assemblages indicating oxygen depletion from sites around the Skagerrak (Nordberg *et al.*, 2000; Jentzen, 2010). In fact, a number of studies into the Skagerrak have also shown oxygen depletion through direct measurements (Aure *et al.*, 1996; SMHI, 2004, 2007). In GC372650, *B. skagerrakensis* shows a relatively constant decline throughout the duration of FAZ 9. However, *T. earlandi* actually shows significant variation, with peak abundances between c. AD 1850 – 1940 and c. AD 1970 – 2000. This is interpreted as varying levels of oxygen depletion, with lowest oxygen concentrations during the period of increased abundance in *T. earlandi*.

Aure *et al.* (1996) suggests this reduction in oxygen concentration is directly related to an increase in nutrient supply to the deep Skagerrak. The dramatic increase in specimen abundance over the last 50 years supports this theory. An increase in nutrients, often the limiting factor in environments such as this, would promote a bloom in foraminiferal abundance. Concurrent increases in benthic biomass have been reported from across the Skagerrak (Josefon, 1990; Alve, 1991; Alve & Murray, 1995; Rosenberg *et al.*, 1997), all of which have been associated with an increased supply of nutrients. It is worth noting that the oxygen depletion rates

observed in the deep Skagerrak are not actually greater in magnitude than the shallower nearby regions (Aure *et al.,* 1996). However, lower base levels of oxygen concentration mean the Skagerrak is more sensitive to this oxygen depletion (Aure *et al.*, 1996), meaning it has a greater impact on its ecology. Nevertheless, it seems likely that the considerable increase in foraminiferal abundance and changes in foraminiferal assemblages seen throughout this period in G372650 may be linked with an increased supply of nutrients. However, the precise cause of this nutrient enrichment is unclear.

Aure *et al.* (1996) suggested this increased availability of nutrients was a result of eutrophication. Increased run off, more extensive use of fertilisers and an increase in activities such as tree felling all lead to increased input of terrigenous sediments and nutrients into the Skagerrak. Eutrophication increases the food supply, allowing greater populations of benthic biomass, thus increasing the oxygen depletion rate. However, some authors have investigated this possibility in the deep Skagerrak and found inconclusive results (Johannessen & Dahl, 1996), whilst an official report by Eilola (2011) found the Skagerrak to be a "non-problem area" in terms of eutrophication.

Therefore, it is worth considering if there are alternative explanations for the oxygen depletion in the Skagerrak. Brückner (2008) suggests a high NAO index since c. 1980 AD, NAO phase 1 on figure 13, may be a significant factor. Positive NAO index values result in intensified westerlies and warmer temperatures (Brückner, 2008). It would also, however, have caused a greater influx of water with high concentrations of nutrients through the English Channel (Brückner, 2008). Edwards *et al.* (2002) also suggested recent abundance increases in phytoplankton and zooplankton were down to extremely high temperatures and salinities during this period, linked with the positive NAO index. Brückner (2008) demonstrated that negative NAO index phases were associated with cascading events into the Skagerrak (deep water renewal, see section 2.5). Thus, it can be surmised that positive NAO phases could results in fewer cascading events.

Therefore, the oxygen depletion inferred from the bloom in *T. earlandi* at c. 2000 AD may have been related to a positive NAO index. It is clear that an offset of approximately 10 years exists between the maximum in the NAO index values and the peak in *T. earlandi*; however, the reduced sample density during this interval may have caused this. It may also be due to the limited dating resolution during this period, with only two dates covering 15cm of sediment. Regardless, there appears to be a link between the increase in *T. earlandi* and positive NAO index values. The subsequent and extremely rapid reduction in *T. earlandi* correlates well with the rapid drop in NAO index values suggested by Osborn (2011), the hashed red line in figure 13. Again, the reduction in NAO values occurs slightly

before the reduction in *T. earlandi*. Clearly, despite the slight offset in dates, recent fluxes in oxygen levels in the Skagerrak seem to be related to the NAO index.

Given this, it is worth considering if earlier periods of increased oxygen concentration are related to more negative NAO index values. The NAO index, shown in figure 13, shows a distinct drop in values between c. AD 1920 – 1970, NAO index phase 2; this fits relatively well with the minimum in *T. earlandi* between c. AD 1940 – 1970. Edwards *et al.* (2002) suggested that conditions around AD 1970 – 1980 were probably cool, with reduced salinities due to decreased Atlantic inflow. An increase in *Buccella frigida* in GC372650 between c. AD 1930 – 1990, see figure 9, supports the theory of reduced temperatures. Reduced Atlantic inflow may have reduced the supply of nutrient to the deep Skagerrak, causing a subsequent decrease in productivity; this might explain the reduction in *T. earlandi* as oxygen concentrations may have been higher. Finally, the large abundances of *T. earlandi*, between c. AD 1850 – 1940 may also be tentatively linked with a period of higher NAO index values, NAO phase 3 on figure 13.

One argument against the link between NAO index values and oxygen depletion is that the hydrological system in the Skagerrak has varied very little since the opening of the English Channel in c. 8,500 cal. BP. Reconstructions by Truet *et al.*, (2009) suggest there were higher values of the NAO index before the LIA. Why, therefore, did the faunal assemblages not indicate increased oxygen depletion during those earlier periods? One possible explanation is that variations in the NAO index, and more recent, potentially anthropogenic eutrophication of the Skagerrak have combined to cause these greater levels of oxygen depletion.

Overall, oxygen depletion in the Skagerrak over the last 100 years appears to show a good correlation with variations in the NAO index, similar results were found by Fllipson & Nordberg (2004) and Nordberg *et al.* (2000). However, further studies would be needed to confirm this link. Furthermore, higher sampling resolution and additional dates will greatly improve the potential for correlation of these processes. It must also be considered that eutrophication of the Skagerrak

may be a significant factor in the recent faunal changes, and future investigations assessing the relative impact of the two are necessary.

6.9 - Inflow events (MBI's)

One of the original aims for this investigation was to ascertain whether or not MBI events could be examined in sediments deposited in the Skagerrak. As discussed in section 1.1, inflow events occur when extreme low pressure systems preside over the North Sea, leading to increased sea level and a large inflow of water from the North Sea into the Baltic Sea (Matthäus & Franck, 1992; Schinke & Matthäus, 1998). These MBI's are vital for the ecology of the Baltic Sea, particularly given its relatively low salinity water and limited productivity. Recent work suggesting the frequency of these MBI's is decreasing (Matthäus *et al.*, 2008) highlights the need to better understand their frequency and causes.

When examining GC372650, there are no discernible long-term trends in the fauna assemblages that are indicative of these inflow events. Obviously, there is considerable variation throughout the core, but none are easily linked with the MBIs. When examining more recent sediments, there are variations in the inflow of Atlantic water, as discussed in the previous zones, but again these occur on timescales greater than that of MBI. More recent faunal assemblages have shown evidence of increased oxygen depletion that could be related to a decrease in the MBI, but is far more likely to relate to the factors discussed above - a positive NAO index and eutrophication.

The lack of evidence for these Baltic inflows is most likely due to the depth and the topographic nature of the Skagerrak. Any major inflow event may not access the deeper parts of the Skagerrak as the north Atlantic water enters between 100 – 400m. Given the intense stratification in the Skagerrak, this inflowing water would have minimal effect on the deep sediments. Furthermore, if there were to be any evidence of these inflow events, it is possible that they may be suppressed by the cascading events into the Skagerrak. Consequently, it generally seems that the deep Skagerrak is not an effective place to reconstruct these MBI's, although shallower regions directly affected by Atlantic inflow may be more suitable.

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Chapter 7. Conclusion

This study has shown that foraminifera are an extremely valuable tool for reconstructing the palaeoceanogaphic development of the Skagerrak. As set out in objectives 1 and 2 of this investigation, the foraminifera were successfully identified and used to reconstruct changes to the conditions of deep water in the Skagerrak. Their sensitivity to different environmental parameters, particularly temperature, salinity and oxygen concentrations, mean that variations in their assemblages accurately reflect alterations to the hydrological regime. This has allowed for successful reconstruction of the palaeoceanographic and palaeoenvironmental history of the North Sea, objective 3 of this investigation. Finally, as set out in objective 4, the influence of both environmental, and natural changes in recently deposited sediments has been assessed. The findings reported here show a similar development to other cores in the Skagerrak, namely MD99-2286, Skagen 3/4, and the GIK cores, as well as those from the north eastern North Sea, Troll 8903/28-03. However, some variations in the timing and warming shown in these records do exist.

7.1 – Skagerrak paleoceanographic development

Between 12,600 and 11,200 cal. BP, the cold water fauna, *Buccella frigida* and *Elphidium excavatum* reflect particularly cold conditions during the Younger Dryas. The presence of a discharging ice front is inferred from the presence of *E. excavatum*, an indicator of lower salinity, the location of which is probably along the southern coast of Norway and the Oslo Fjord. Water temperatures have warmed by the end of this period, as reflected by the decline in *Buccella frigida*, indicating the end of the Younger Dryas period.

Sediments deposited between 11200 and 9700 cal. BP reflect the Baltic Drainage Change to the Otteid-Steinselva outlet. The increasing temperatures at the end of the Younger Dryas would have triggered a retreat of the Scandinavian ice sheet beyond Mount Billingen, which would have resulted in the subsequent drainage change. Whilst the initiation of this drainage change occurred at similar times around the Skagerrak, its subsequent closure based on the faunal record from GC372650 appears to occur later and over a more extended period of time (between 10,500 and 10,000 cal. BP) than other records around the Skagerrak have shown. The most likely cause for this disparity in results is probably related to depth. The deeper site, GC372650, may have been more affected by the cold meltwater, whereas the shallower sites would have seen the pycnocline brake up more readily when meltwater input decreased.

It is of note that no evidence of the Baltic Ice Lake final drainage was found. This is thought to precede the opening of the Otteid-Steinselva outlet. The absence of evidence for this event is, once again, probably related to depth. The sudden, and considerable, influx of cold, freshwater glacial melt may have caused an intense stratification in the Skagerrak, isolating the bottom sediments from the influence of the cold water. The constant output during this initial drainage meant the stratification would have persisted throughout its duration.

After the closure of the Otteid-Steinselva outlet, increased Atlantic inflow into the Skagerrak is registered by the increase of more boreal species and those associated with Atlantic water, namely *Cassidulina laevigata* and *Melonis*

barleeanus. These findings are generally in agreement with other authors around the Skagerrak, who also see this as a period of increased Atlantic influence. However, the faunal assemblages also indicate the occurrence of a distinct cooling event at approximately 9450 cal. BP.

This climatic deterioration around 9400 cal. BP appears to have lasted less than 400 years, and the timing suggests it may correlate with a cooling observed by Jiang *et al.*, (1997) caused by a strengthening of the North Jutland Current. However, it may also be part of a wider climatic deterioration that occurred across Northern Europe during this period. The cause of the climatic cooling is probably related to the sudden discharge of glacial meltwater into the North Atlantic, which caused a subsequent slowdown of the THC.

At 8500 cal. BP, a sudden influx of boreal species *H. balthica* occurs, this has been interpreted as the opening of the English Channel. This facilitated the formation of the South Jutland Current, which was almost completely absent before the opening. Slightly later, at 8300 cal. BP, the increase in *Valvulineria* spp*.* is probably related to the opening of the Danish Straits. The opening of the English Channel and Danish straits is regarded as the initiation of the modern hydrological system in the North Sea. At c. 6000 cal. BP, the increased abundance of cold water fauna and those associated with increased current strength probably reflect a strengthened South Jutland Current.

Between 3000 and c. 420 cal. BP, the faunal assemblages indicate a period of stable hydrographic conditions with increasing Atlantic inflow. Following this, between c. 420 and 160 cal. BP, the fauna indicates a reduction in temperatures, probably related to the Little Ice Age. It is interesting that the cooler conditions manifest themselves at GC372650 only during the maximum of the LIA. Furthermore, the fauna suggest the Skagerrak experienced reduced oxygen concentrations during this period, in contrast to results from Hebbeln *et al.* (2006) which suggested a strengthened bottom current and more mixing. The data from GC372650 actually indicates a calmer, more stratified environment, more in line with findings from Hass (1996).

Subsequently, between c. AD 1850 and modern day, the fauna suggest significant oxygen depletion in the Skagerrak. At this stage, it is unclear whether this is a result of anthropogenic eutrophication, or a result of more positive NAO index values, or a combination of the two. Additional data is extremely important to help understand these environmental changes and assess the relative impact of the two processes.

7.2 – Variable exchange between the North Sea and Baltic Sea

Based on the benthic foraminiferal record from GC372650 variations in the exchange of water and nutrients between the Baltic Sea and the North Sea have been observed. Output from the Baltic seems to have had its greatest effect on the Skagerrak during the existence of the Otteid-Steinselva outlet. Once this outlet closed, output decreased dramatically. However, importantly, the continued presence of *Valvulineria* spp. indicates that exchange between the Baltic and the North Sea continued to occur. The opening of the Danish Straits around 8300 cal. BP increased the exchange between the two water masses, but this subsequently decreased after about 6000 cal. BP. The exchange then appears to remain at this level until modern day. These variations are extremely important, as they would have had significant impacts upon the productivity and biodiversity within the Baltic basin.

7.3 – Influence of depth on reconstruction

This investigation on GC372650 has observed variations in the timing, duration, and onset of both hydrological and climatological events throughout the North Sea when compared to previous studies. Whilst discrepancies in the resolution and accuracy of dating might explain these variations, in many cases they seem related to depth. The influence of water depth seems to manifest itself in a number of ways. Firstly, GC372650 demonstrates a stratified water column for a longer duration that shallower sites, particularly during the opening of the Otteid-Steinselva outlet. This is probably because it is more readily broken up in shallower areas. Secondly, the onset of climatological cooling in GC372650, particularly during the LIA, seems to occur later and persist for a shorter duration.

This seems to imply that the deeper waters respond slower to climatic cooling, and that it takes a lower magnitude of warming before conditions return to a pre cooling state.

In addition to this, bottom water velocities inferred from GC372650 often differ considerably from those identified in shallower sites. This is particularly the case during the LIA, where Hebbeln *et al.* (2006) observed increased velocities throughout the LIA, whereas GC372650 actually demonstrated increased stratification and reduced oxygen concentrations. This implies that the depth of water inflow into the Skagerrak is extremely important in determining the hydrological environment at different water depths. Overall, it is clear that the deeper Skagerrak responds slightly differently to climatological and hydrological developments, and provides a slightly different palaeoreconstruction of the North Sea.

7.4 – Outlook

Overall, this investigation has provided valuable data to INFLOW concerning the palaeoceanographic development of the North Sea. It has identified, variations in exchange between the Baltic and the North Sea through time, changes in the composition of Skagerrak water that will have entered the Baltic Sea, more recent climatic cooling events as well as a strong correlation between NAO index values and recent oxygen depletion in the Skagerrak. It has, however, highlighted the need for more research into modern foraminiferal studies, higher resolution dating to more accurately constrain the dates of hydrological developments and more studies to effectively determine the relative impact of eutrophication and NAO index variations in recent oxygen depletion. Nonetheless, it provides extremely useful data to INFLOW to help achieve a sustainable use of the Baltic and its resources.

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Appendix 1 – Species list

Calcareous Foraminifera

Ammonia spp.
Astrononion gallowayi Loeblich and Tappan, 1953
Biloculina depressa (d'Orbigny, 1826)
Bolivina albatrossi Cushman, 1922
Bolivina skagerrakensis Qvale and Nigam, 1985
Bolivina spathulata (Williamson, 1858)
Brizalina pseudopunctata (Hoeglund, 1947)
Buccella frigida (Cushman)
Bulimina marginata d'Orbigny, 1826
Buliminella elegantissima (d'Orbigny)
Cassidulina cf. laevigata d'Orbigny, 1826
Cassidulina laevigata d'Orbigny, 1826
Cassidulina neoteretis Tappan, 1951
Cassidulina obtuse Williamson, 1858
Cassidulina reniforme Nørvang
Cassidulina sp. 1
cf. Eoeponidella Wickenden, 1949
Cibicides lobatulus (Walker and Jacob)
Cibicides sp. 1
Cornuspira involvens (Reuss)
Dentalina spp.
*Elphidium excavatum (*Terquem) forma *clavata* (cf. Feyling-Hanssen, 1972)
Epistominella spp.
Epistominella sp. 1
Epistominella sp. 2
Fissurina spp.
Flat Spiral
Globobulimina turgida (Bailey, 1947)
Haynesina germanica (Ehrenberg, 1840)
Hyalinea balthica (Schroeter, 1783)
Islandiella norcrossi (Cushman)
Lagena spp.
Lenticulina cf. angulata Noth, 1951
Lenticulina spp.
Melonis barleeanus (Williamson, 1858)
Miliolinella spp.
Nonionella iridea Heron-Allen and Earland, 1932
Nonionella labrodorica (Dawson, 1860)
Nonionella turgida (Williamson, 1858)
Oolina spp
Parafissurina spp.
Pseudopolymorphina spp.
Pullenia bulloides (d'Orbigny, 1839)
Pullenia osloensis Feyling-Hanssen, 1954
Pullenia osloensis sp. 2
Pullenia subcarinata (d'Orbigny, 1839)

Pyrgo williamsoni (Silvestri, 1923)
Quinqueloculina spp*.*
Rosalina spp*.*
Stainforthia fusiformis (Williamson, 1848)
Trifarina angulosa (Williamson, 1858)
Trioculina tricarinata d'Orbigny, 1826
Uvigerina mediterranea Hofker, 1932
Valvulineria spp*.*
Virgulina loeblichi Feyling-Hanssen, 1954
Virgulina schreibersania　Cžjžek, 1848
Unidentified sp. 1

Agglutinated Foraminifera

Adercotryma glomerata (Brady, 1878)
Eggerelloides scabrus (Williamosn, 1858)
Gaudryina spp*.*
Haplophragmoides bradyi (Robertson, 18　1)
Milliamina fusca (Brady, 1870)
Reophax spp*.*
Reophax sp. 1
Saccammina spp*.*
Textularia earlandi Parker, 1952
Trochammina inflata spp*.*
Trochammina inflata (Montagu, 1808)
Unidentified agglutinated sp. 1
Unidentified agglutinated sp. 2
Unidentified agglutinated sp. 3
Unidentified agglutinated sp. 4

Appendix 2 - Raw foraminifera data

Species	0.25	0.75	1.25	1.75	2.25	2.75	3.25	3.75	4.25
Ammonia spp.	0	0	0	0	0	0	0	0	0
Astrononion gallowayi	0	0	0	0	0	0	0	0	0
Biloculina depressa	0	0	0	0	0	0	1	0	0
Bolivina albatrossi	0	0	0	0	0	0	0	0	0
Bolivina skagerrakensis	13	9	30	18	31	40	36	32	28
Bolivina spathulata	0	1	1	1	1	1	0	0	0
Brizalina pseudopunctata	0	1	0	0	5	3	1	1	1
Buccella frigida	16	18	38	25	23	15	12	10	7
Bulimina marginata	6	1	6	0	8	7	9	6	5
Buliminella elegantissima	0	0	0	5	0	0	0	0	0
Cassidulina cf. Laevigata	0	0	0	0	0	0	0	0	0
Cassidulina laevigata	12	6	6	2	4	7	14	7	6
Cassidulina neoteretis	14	8	13	10	7	10	17	15	15
Cassidulina obtuse	8	13	1	0	1	0	1	1	5
Cassidulina reniforme	0	0	0	0	0	0	0	0	0
Cassidulina sp. 1	0	0	0	0	0	0	0	0	0
cf. *Eoeponidella* spp.	0	0	3	0	0	0	0	0	0
Cibicides lobatulus	3	0	0	0	2	0	2	3	2
Cibicides pseudoungerianus	0	0	0	0	0	0	0	0	0
Cibicides sp. 1	0	0	0	0	1	0	0	0	0
Cornuspira involvens	3	3	3	1	0	1	1	2	0
Dentalina spp.	0	0	0	0	0	0	1	0	0
Elphidium excavatum forma *clava*	0	0	2	1	1	2	1	0	0
Epistominella sp. 1	22	11	20	12	10	4	8	9	5
Epistominella sp. 2	0	0	0	1	0	0	0	0	0
Epistominella spp.	0	0	0	0	0	0	0	0	0
Fissurina spp.	3	2	2	3	0	2	2	1	0
Flat Spiral	0	0	0	0	0	0	0	0	0
Globobulimina turgida	0	0	0	0	2	3	2	1	3
Haynesina germanica	1	0	0	1	0	0	0	0	0
Hyalinea balthica	33	3	7	5	1	10	21	22	15
Islandiella norcrossi	0	0	0	0	0	0	0	0	0
Lagena spp.	4	2	0	1	0	2	3	1	1
Lenticulina cf. angulata	2	3	0	2	0	1	0	1	0
Lenticulina spp.	0	0	0	1	0	0	0	0	1
Melonis barleeanus	2	2	15	11	13	5	4	5	5
Miliolinella spp.	0	0	0	0	0	0	0	0	0
Nonionella iridea	37	23	21	26	19	15	10	13	25
Nonionella labrodorica	0	0	0	0	0	0	0	0	0
Nonionella turgida	2	0	0	0	0	0	0	0	0
Oolina spp	1	1	5	3	3	1	2	0	1
Parafissurina spp.	0	0	1	0	0	0	0	1	2
Pseudopolymorphina spp.	0	0	0	0	0	0	0	0	0
Pullenia bulloides	0	3	7	4	5	13	3	8	1
Pullenia osloensis	61	24	29	30	43	42	39	16	19
Pullenia osloensis sp. 2	0	0	0	0	0	0	0	0	0
Pullenia subcarinata	0	5	9	5	9	8	4	1	5
Pyrgo williamsoni	0	0	0	0	0	0	1	0	0
Quinqueloculina spp.	0	0	0	0	0	0	1	0	0
Rosalina spp.	1	1	0	0	0	0	0	0	0
Unidentified sp. 1	0	0	0	0	0	0	0	0	0
Stainforthia fusiformis	17	14	29	22	26	25	26	18	16
Trifarina angulosa	0	0	0	0	0	0	0	0	0
Trioculina tricarinata	0	0	0	0	0	0	0	0	0
Uvigerina mediterranea	13	3	3	2	1	0	0	4	0
Valvulineria spp.	2	1	1	0	0	0	1	0	3
Virgulina loeblichi	1	0	1	1	0	0	1	0	1
Virgulina schreibersania	0	0	0	0	0	0	0	0	0
Adercotryma glomerata	1	0	1	2	3	0	0	0	0
Eggerelloides scabrus	2	3	14	9	22	23	19	16	19
Gaudryina spp.	0	0	0	1	0	0	0	0	1
Haplophragmoides bradyi	7	11	10	17	18	6	10	4	4
Milliamina fusca	0	0	0	0	0	0	0	0	0
Reophax sp. 1	0	0	0	0	0	0	0	0	0
Reophax spp.	18	5	13	15	23	13	12	9	11
Saccammina spp.	0	1	2	0	0	0	0	0	0
Textularia earlandi	5	117	18	32	13	39	33	94	82
Trochammina inflata	0	0	0	0	0	0	0	0	0
Trochammina inflata spp.	3	3	3	6	3	4	2	0	3
Unidentified agglutinated sp. 1	0	3	0	3	2	1	1	0	1
Unidentified agglutinated sp. 2	1	1	0	1	0	3	0	0	0
Unidentified agglutinated sp. 3	0	2	3	2	3	2	1	3	3
Unidentified agglutinated sp. 4	0	0	0	0	0	0	0	0	0

Species	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75
Ammonia spp.	0	0	0	0	0	0	0	0	0
Astrononion gallowayi	0	0	0	0	0	0	0	0	0
Biloculina depressa	0	0	1	0	0	0	0	0	0
Bolivina albatrossi	0	0	0	0	0	0	0	0	0
Bolivina skagerrakensis	32	62	52	46	40	32	43	39	52
Bolivina spathulata	0	1	0	0	0	0	0	1	0
Brizalina pseudopunctata	1	0	1	0	1	0	1	0	0
Buccella frigida	3	6	14	14	13	8	14	13	17
Bulimina marginata	8	6	6	3	3	7	4	3	5
Buliminella elegantissima	0	0	0	0	0	1	0	0	0
Cassidulina cf. Laevigata	0	0	0	0	0	0	0	0	0
Cassidulina laevigata	15	7	8	9	13	9	12	9	12
Cassidulina neoteretis	19	17	25	15	15	18	18	19	23
Cassidulina obtuse	1	2	2	5	2	2	2	4	3
Cassidulina reniforme	0	0	0	0	0	0	0	0	0
Cassidulina sp. 1	1	0	0	0	0	0	0	0	0
cf. *Eoeponidella* spp.	0	0	1	0	1	2	0	0	0
Cibicides lobatulus	4	4	3	6	3	2	7	5	6
Cibicides pseudoungerianus	0	0	0	0	0	0	0	0	0
Cibicides sp. 1	1	0	0	0	0	0	0	0	0
Cornuspira involvens	2	2	1	1	2	1	0	0	3
Dentalina spp.	0	0	0	0	0	0	0	0	0
Elphidium excavatum forma clava	0	1	0	1	1	1	0	2	1
Epistominella sp. 1	12	4	1	13	5	11	15	14	19
Epistominella sp. 2	0	0	0	0	0	0	3	0	0
Epistominella spp.	1	0	0	0	0	0	0	0	0
Fissurina spp.	1	0	1	2	0	2	3	0	0
Flat Spiral	0	0	0	0	0	1	1	1	1
Globobulimina turgida	3	1	0	0	1	1	1	2	1
Haynesina germanica	0	0	0	0	0	0	0	0	0
Hyalinea balthica	31	15	21	16	19	22	13	28	24
Islandiella norcrossi	0	0	2	1	0	1	1	2	0
Lagena spp.	0	2	3	2	2	4	2	3	2
Lenticulina cf. angulata	0	1	0	0	1	0	3	0	0
Lenticulina spp.	0	2	0	2	0	0	0	0	1
Melonis barleeanus	2	8	4	7	6	6	4	11	7
Miliolinella spp.	1	1	1	2	4	5	5	10	2
Nonionella iridea	23	13	13	30	33	20	29	19	37
Nonionella labrodorica	0	0	0	0	0	0	0	0	0
Nonionella turgida	0	0	0	0	1	0	0	0	0
Oolina spp	0	1	0	0	0	3	2	4	2
Parafissurina spp.	1	0	1	0	0	0	1	0	0
Pseudopolymorphina spp.	1	0	0	0	2	0	1	3	1
Pullenia bulloides	10	5	12	11	9	3	4	6	2
Pullenia osloensis	22	20	16	37	34	26	32	27	22
Pullenia osloensis sp. 2	0	0	0	0	0	0	0	0	0
Pullenia subcarinata	3	8	8	5	7	6	7	9	6
Pyrgo williamsoni	0	3	4	5	5	0	3	3	1
Quinqueloculina spp.	3	0	0	2	1	3	3	5	2
Rosalina spp.	1	1	0	0	0	0	1	0	1
Unidentified sp. 1	0	1	0	0	0	0	0	0	1
Stainforthia fusiformis	14	7	11	14	24	12	17	9	14
Trifarina angulosa	1	1	0	0	0	1	1	1	0
Trioculina tricarinata	0	0	0	2	0	3	0	2	1
Uvigerina mediterranea	1	2	0	2	2	0	1	2	1
Valvulineria spp.	0	0	0	1	1	0	3	3	4
Virgulina loeblichi	0	0	0	0	1	0	0	0	0
Virgulina schreibersania	0	0	0	0	0	0	0	0	0
Adercotryma glomerata	2	3	1	0	0	1	2	4	4
Eggerelloides scabrus	13	18	12	12	10	17	14	11	12
Gaudryina spp.	0	0	0	0	2	1	0	0	0
Haplophragmoides bradyi	2	6	15	12	7	10	11	5	6
Milliamina fusca	0	0	0	0	0	0	0	0	0
Reophax sp. 1	0	0	0	0	0	0	0	0	0
Reophax spp.	4	11	6	21	11	10	9	6	9
Saccammina spp.	0	0	0	0	0	0	0	0	0
Textularia earlandi	70	44	38	6	5	32	19	16	3
Trochammina inflata	0	0	0	0	0	0	0	0	1
Trochammina inflata spp.	3	2	5	4	2	5	0	2	2
Unidentified agglutinated sp. 1	0	0	1	3	1	1	0	0	1
Unidentified agglutinated sp. 2	0	2	1	2	0	0	0	0	1
Unidentified agglutinated sp. 3	1	3	6	1	2	0	0	2	3
Unidentified agglutinated sp. 4	0	0	0	0	0	0	0	0	0

Species	9.25	9.75	10.5	11.5	12.5	13.5	14.5	15.5	16.5
Ammonia spp.	0	0	0	0	0	0	0	0	0
Astrononion gallowayi	0	0	0	0	0	0	0	0	0
Biloculina depressa	1	1	0	0	0	0	0	0	0
Bolivina albatrossi	0	0	0	0	0	0	0	0	0
Bolivina skagerrakensis	33	55	68	86	66	60	42	29	39
Bolivina spathulata	0	0	0	0	0	0	0	0	1
Brizalina pseudopunctata	0	1	0	0	1	2	1	4	1
Buccella frigida	14	10	7	6	8	2	9	19	14
Bulimina marginata	8	3	2	5	4	4	2	5	2
Buliminella elegantissima	0	1	0	0	0	0	0	2	0
Cassidulina cf. Laevigata	0	0	0	0	0	0	0	0	0
Cassidulina laevigata	8	11	10	22	26	16	15	10	17
Cassidulina neoteretis	13	22	15	14	25	23	18	23	20
Cassidulina obtuse	5	3	2	1	3	1	8	3	3
Cassidulina reniforme	0	0	0	0	0	0	0	0	0
Cassidulina sp. 1	0	0	0	0	0	0	0	0	0
cf. Eoeponidella spp.	0	1	0	0	0	0	0	0	0
Cibicides lobatulus	5	5	4	9	8	2	5	1	2
Cibicides pseudoungerianus	0	0	0	0	0	0	0	0	0
Cibicides sp. 1	0	1	2	1	0	0	0	1	0
Cornuspira involvens	3	0	0	0	1	0	0	1	0
Dentalina spp.	0	0	1	0	1	1	0	0	0
Elphidium excavatum forma clava	0	0	3	2	0	1	0	2	0
Epistominella sp. 1	17	10	4	2	1	6	6	6	8
Epistominella sp. 2	0	1	0	0	0	0	3	0	0
Epistominella spp.	0	0	0	0	0	0	0	0	0
Fissurina spp.	0	0	2	2	3	2	3	3	3
Flat Spiral	0	0	0	0	0	0	0	0	0
Globobulimina turgida	1	0	0	1	0	0	1	1	1
Haynesina germanica	0	0	0	0	0	0	0	0	0
Hyalinea balthica	15	13	19	21	25	25	28	43	26
Islandiella norcrossi	1	1	0	0	0	0	0	0	0
Lagena spp.	3	3	1	3	0	1	0	1	1
Lenticulina cf. angulata	0	1	0	0	2	1	0	0	0
Lenticulina spp.	0	1	0	0	0	0	1	0	0
Melonis barleeanus	3	10	7	4	11	10	4	5	0
Miliolinella spp.	8	3	6	1	0	2	1	0	6
Nonionella iridea	28	30	38	20	21	26	40	34	42
Nonionella labrodorica	0	0	0	0	0	0	0	0	0
Nonionella turgida	1	0	0	1	0	0	1	0	0
Oolina s pp	0	2	1	3	4	3	1	1	1
Parafissurina spp.	1	0	0	1	0	0	1	2	1
Pseudopolymorphina spp.	2	1	2	1	0	1	1	0	1
Pullenia bulloides	6	3	8	14	6	8	5	7	9
Pullenia osloensis	42	34	34	30	46	49	46	38	43
Pullenia osloensis sp. 2	0	0	0	0	0	0	0	0	0
Pullenia subcarinata	5	3	9	13	11	4	4	5	1
Pyrgo williamsoni	1	4	2	4	2	1	2	1	0
Quinqueloculina spp.	4	2	3	5	2	1	3	3	2
Rosalina spp.	0	0	1	0	2	0	1	1	0
Unidentified sp. 1	0	0	1	0	0	0	2	0	1
Stainforthia fusiformis	15	14	13	3	11	13	22	18	14
Trifarina angulosa	0	0	0	1	0	1	0	1	1
Trioculina tricarinata	1	0	2	0	0	0	0	0	0
Uvigerina mediterranea	1	3	1	0	0	4	0	2	1
Valvulineria spp.	1	4	0	0	0	1	1	1	1
Virgulina loeblichi	0	1	0	0	0	0	1	0	0
Virgulina schreibersania	0	0	0	0	0	0	0	0	0
Adercotryma glomerata	5	2	3	2	0	1	2	0	1
Eggerelloides scabrus	14	12	15	14	12	10	13	19	27
Gaudryina spp.	0	0	1	0	0	0	1	0	0
Haplophragmoides bradyi	15	10	5	3	2	3	7	6	2
Milliamina fusca	0	0	0	0	0	1	0	0	0
Reophax sp. 1	0	0	0	0	0	0	0	0	0
Reophax spp.	7	6	1	1	1	1	2	2	0
Saccammina spp.	0	0	0	0	0	0	0	0	0
Textularia earlandi	8	5	7	1	2	2	2	0	7
Trochammina inflata	0	0	0	0	0	0	0	0	0
Trochammina inflata spp.	3	1	0	0	0	1	5	3	2
Unidentified agglutinated sp. 1	0	0	0	0	1	1	0	1	2
Unidentified agglutinated sp. 2	0	0	0	0	0	2	0	0	1
Unidentified agglutinated sp. 3	4	3	0	3	2	2	2	1	6
Unidentified agglutinated sp. 4	0	0	0	0	0	0	0	0	0

Species	17.5	18.5	19.5	20.5	21.5	22.5	23.5	24.5	25.5
Ammonia spp.	0	0	0	0	0	0	0	0	0
Astrononion gallowayi	0	0	0	0	0	0	0	0	0
Biloculina depressa	0	1	0	0	0	1	1	0	0
Bolivina albatrossi	0	0	0	0	0	0	0	0	0
Bolivina skagerrakensis	25	21	31	25	29	36	40	48	86
Bolivina spathulata	1	0	0	0	0	0	0	0	0
Brizalina pseudopunctata	3	1	2	2	1	0	0	1	2
Buccella frigida	9	13	18	10	19	11	14	11	7
Bulimina marginata	2	31	7	4	4	1	8	0	4
Buliminella elegantissima	0	0	0	0	0	0	0	0	0
Cassidulina cf. Laevigata	0	0	0	0	0	0	0	0	0
Cassidulina laevigata	10	15	23	23	14	11	15	13	13
Cassidulina neoteretis	15	20	26	19	21	22	20	21	17
Cassidulina obtuse	6	4	9	8	3	2	5	7	2
Cassidulina reniforme	0	0	2	0	1	1	0	1	0
Cassidulina sp. 1	0	0	0	0	0	1	1	0	0
cf. *Eoeponidella* spp.	1	1	0	0	0	1	1	1	0
Cibicides lobatulus	3	2	4	5	4	5	1	3	2
Cibicides pseudoungerianus	0	0	0	0	0	0	0	0	0
Cibicides sp. 1	0	0	0	0	0	0	0	0	1
Cornuspira involvens	1	4	0	0	0	0	0	1	0
Dentalina spp.	1	0	0	0	1	2	2	1	1
Elphidium excavatum forma clava	0	0	1	1	2	1	0	1	3
Epistominella sp. 1	9	1	1	4	8	1	5	2	3
Epistominella sp. 2	0	0	0	0	0	0	0	0	0
Epistominella spp.	0	0	0	0	0	0	0	1	0
Fissurina spp.	2	1	6	3	1	1	3	4	6
Flat Spiral	0	0	0	0	0	0	0	0	0
Globobulimina turgida	0	0	0	0	0	0	1	0	0
Haynesina germanica	0	0	1	0	0	1	0	0	0
Hyalinea balthica	29	59	23	25	23	37	36	17	17
Islandiella norcrossi	0	1	2	2	1	0	1	0	1
Lagena spp.	4	0	0	1	3	4	2	3	4
Lenticulina cf. angulata	0	1	0	0	1	0	2	0	0
Lenticulina spp.	1	2	2	0	0	1	3	2	0
Melonis barleeanus	3	3	9	5	8	7	4	1	7
Miliolinella spp.	3	2	2	1	3	3	5	4	0
Nonionella iridea	49	42	43	45	49	46	32	59	32
Nonionella labrodorica	0	0	0	0	0	0	0	1	0
Nonionella turgida	1	0	1	0	2	0	0	0	0
Oolina spp	2	1	0	3	0	3	0	0	2
Parafissurina spp.	0	0	1	1	1	0	1	0	1
Pseudopolymorphina spp.	4	0	0	0	0	0	0	0	3
Pullenia bulloides	6	8	4	1	9	7	5	0	10
Pullenia osloensis	48	33	48	61	51	61	75	72	53
Pullenia osloensis sp. 2	0	0	0	0	0	0	0	0	0
Pullenia subcarinata	2	3	0	3	4	3	6	2	2
Pyrgo williamsoni	0	1	1	3	1	2	0	0	0
Quinqueloculina spp.	2	5	2	3	1	4	2	1	0
Rosalina spp.	0	0	0	1	1	1	0	3	0
Unidentified sp. 1	0	0	0	0	1	1	0	0	0
Stainforthia fusiformis	13	15	18	15	10	8	9	9	6
Trifarina angulosa	0	0	0	1	0	1	0	3	1
Trioculina tricarinata	1	0	2	0	1	0	0	0	0
Uvigerina mediterranea	1	0	0	1	0	0	0	0	0
Valvulineria spp.	0	2	1	0	1	3	1	1	1
Virgulina loeblichi	0	0	1	0	1	0	0	1	0
Virgulina schreibersania	0	0	0	0	0	0	0	0	0
Adercotryma glomerata	0	0	0	0	1	0	0	0	0
Eggerelloides scabrus	15	12	7	10	11	5	4	6	6
Gaudryina spp.	0	1	1	1	1	0	1	0	1
Haplophragmoides bradyi	4	4	3	3	1	3	2	4	0
Milliamina fusca	0	0	0	0	0	0	0	0	0
Reophax sp. 1	0	0	0	0	0	0	0	0	0
Reophax spp.	0	1	2	2	3	0	1	0	0
Saccammina spp.	0	0	0	0	0	0	0	0	0
Textularia earlandi	2	2	6	3	0	0	1	2	3
Trochammina inflata	0	0	0	0	0	1	0	0	0
Trochammina inflata spp.	4	0	2	1	1	1	1	0	1
Unidentified agglutinated sp. 1	1	0	1	0	0	1	0	1	0
Unidentified agglutinated sp. 2	0	1	0	0	0	0	0	0	0
Unidentified agglutinated sp. 3	5	0	1	0	0	1	3	3	1
Unidentified agglutinated sp. 4	0	0	0	0	0	0	0	0	0

Species	26.5	27.5	28.5	29.5	30.5	31.5	32.5	33.5	34.5
Ammonia spp.	0	0	0	0	0	0	0	0	0
Astrononion gallowayi	0	0	0	0	0	0	0	0	0
Biloculina depressa	0	0	0	2	0	1	0	0	0
Bolivina albatrossi	0	0	0	0	0	0	0	0	0
Bolivina skagerrakensis	73	112	97	107	102	70	77	97	65
Bolivina spathulata	0	0	0	0	0	0	0	0	0
Brizalina pseudopunctata	1	3	0	1	1	0	3	1	5
Buccella frigida	6	2	3	3	2	0	0	2	7
Bulimina marginata	3	5	3	5	2	2	0	0	1
Buliminella elegantissima	0	0	0	0	0	0	0	0	0
Cassidulina cf. Laevigata	0	0	0	0	0	0	0	0	0
Cassidulina laevigata	13	15	12	17	17	16	15	16	14
Cassidulina neoteretis	21	22	11	18	13	19	18	17	12
Cassidulina obtuse	8	3	4	3	4	3	4	5	4
Cassidulina reniforme	0	1	0	1	1	0	0	0	0
Cassidulina sp. 1	0	0	0	1	0	0	0	0	0
cf. Eoeponidella spp.	0	0	0	0	1	0	0	0	0
Cibicides lobatulus	5	3	2	2	2	3	3	4	10
Cibicides pseudoungerianus	0	0	0	0	0	0	0	0	0
Cibicides sp. 1	0	1	0	0	0	0	0	0	0
Cornuspira involvens	0	0	1	0	1	2	0	0	0
Dentalina spp.	1	0	0	0	0	0	3	1	3
Elphidium excavatum forma clava	1	0	3	0	0	0	0	0	0
Epistominella sp. 1	5	2	2	1	3	2	7	2	2
Epistominella sp. 2	0	0	0	0	0	0	0	0	0
Epistominella spp.	0	0	0	0	0	0	0	0	1
Fissurina spp.	3	2	4	5	3	1	2	3	4
Flat Spiral	0	0	0	0	0	0	0	0	0
Globobulimina turgida	0	0	0	2	0	0	0	0	1
Haynesina germanica	0	0	0	0	0	0	0	0	0
Hyalinea balthica	14	8	2	6	9	3	14	6	4
Islandiella norcrossi	2	0	1	1	0	4	0	0	1
Lagena spp.	3	6	2	1	0	2	7	4	0
Lenticulina cf. angulata	1	0	2	1	0	1	1	0	0
Lenticulina spp.	0	1	1	0	1	0	1	2	1
Melonis barleeanus	7	6	13	13	8	6	6	6	7
Miliolinella spp.	1	1	1	0	2	3	1	1	0
Nonionella iridea	24	34	31	17	27	43	36	31	40
Nonionella labrodorica	0	0	0	0	0	0	0	0	0
Nonionella turgida	0	0	0	0	0	0	0	0	0
Oolina s pp	0	1	1	1	1	2	3	1	6
Parafissurina spp.	2	1	0	0	1	2	0	1	1
Pseudopolymorphina spp.	1	0	1	0	0	1	2	1	1
Pullenia bulloides	6	6	1	4	5	3	1	4	8
Pullenia osloensis	69	45	62	55	65	84	60	56	71
Pullenia osloensis sp. 2	0	0	0	0	0	0	0	0	0
Pullenia subcarinata	0	3	3	2	6	3	3	5	0
Pyrgo williamsoni	0	0	1	1	0	0	0	2	1
Quinqueloculina spp.	0	2	2	2	2	2	1	1	1
Rosalina spp.	1	1	1	1	2	1	0	0	2
Unidentified sp. 1	1	0	0	0	1	0	1	0	0
Stainforthia fusiformis	4	13	18	10	3	12	13	12	21
Trifarina angulosa	2	0	2	0	0	0	0	0	0
Trioculina tricarinata	0	0	1	2	0	0	1	0	0
Uvigerina mediterranea	0	0	1	0	0	0	0	0	1
Valvulineria spp.	1	0	1	0	2	2	3	1	2
Virgulina loeblichi	0	0	0	0	0	0	0	2	0
Virgulina schreibersania	0	0	0	0	0	0	0	0	0
Adercotryma glomerata	0	0	0	0	0	0	0	0	0
Eggerelloides scabrus	16	11	4	9	10	9	5	7	8
Gaudryina spp.	0	0	0	0	0	0	0	0	1
Haplophragmoides bradyi	6	1	1	2	5	3	3	2	5
Milliamina fusca	0	0	0	0	0	0	0	0	0
Reophax sp. 1	0	0	0	0	0	0	0	0	0
Reophax spp.	2	1	0	3	3	0	0	1	0
Saccammina spp.	0	0	0	0	0	0	0	0	0
Textularia earlandi	0	1	1	0	0	3	1	1	1
Trochammina inflata	0	0	1	0	0	1	1	0	0
Trochammina inflata spp.	2	1	1	1	0	0	1	1	4
Unidentified agglutinated sp. 1	0	1	0	0	0	0	0	0	0
Unidentified agglutinated sp. 2	0	0	0	0	0	0	1	0	0
Unidentified agglutinated sp. 3	1	3	1	3	1	11	5	9	8
Unidentified agglutinated sp. 4	0	0	0	0	0	0	0	0	0

Species	35.5	37.5	46.5	53.75	61.5	69.5	77.5	86.5	93.5
Ammonia spp.	0	0	0	0	0	0	0	0	0
Astrononion gallowayi	0	0	0	0	0	0	0	0	0
Biloculina depressa	1	0	0	2	2	0	0	1	1
Bolivina albatrossi	0	0	1	0	0	0	0	0	0
Bolivina skagerrakensis	47	58	40	6	15	72	111	67	38
Bolivina spathulata	0	0	0	0	0	0	3	1	3
Brizalina pseudopunctata	2	1	1	0	5	1	0	2	2
Buccella frigida	1	5	5	0	2	1	0	0	0
Bulimina marginata	1	1	5	2	9	1	2	2	1
Buliminella elegantissima	1	2	1	2	2	2	2	2	5
Cassidulina cf. Laevigata	0	2	2	0	0	0	1	0	1
Cassidulina laevigata	22	12	15	17	16	10	5	14	16
Cassidulina neoteretis	22	13	12	8	24	16	8	18	22
Cassidulina obtuse	3	6	5	3	0	1	3	4	4
Cassidulina reniforme	2	0	1	0	0	1	1	0	2
Cassidulina sp. 1	0	0	0	0	0	0	0	0	0
cf. Eoeponidella spp.	0	0	1	0	0	0	0	0	0
Cibicides lobatulus	5	1	2	4	4	1	1	4	6
Cibicides pseudoungerianus	0	0	0	0	0	0	0	0	0
Cibicides sp. 1	0	0	0	7	1	6	4	3	3
Cornuspira involvens	1	1	2	2	2	0	0	1	2
Dentalina spp.	0	0	0	0	1	0	0	1	1
Elphidium excavatum forma clava	1	1	1	0	0	0	0	0	0
Epistominella sp. 1	2	1	8	2	3	3	4	3	2
Epistominella sp. 2	1	5	4	0	0	0	0	0	0
Epistominella spp.	0	6	3	2	0	3	2	1	2
Fissurina spp.	1	4	2	4	7	0	2	2	1
Flat Spiral	0	0	0	0	0	0	0	0	0
Globobulimina turgida	0	1	0	0	0	1	0	1	1
Haynesina germanica	0	0	0	0	0	0	0	0	1
Hyalinea balthica	9	5	8	2	8	1	3	4	2
Islandiella norcrossi	0	1	4	2	1	1	0	2	0
Lagena spp.	3	3	1	3	9	2	4	4	2
Lenticulina cf. angulata	1	2	0	0	1	1	1	0	0
Lenticulina spp.	0	0	1	1	0	1	1	0	1
Melonis barleeanus	10	5	3	20	22	11	6	12	23
Miliolinella spp.	1	2	3	3	1	2	1	4	3
Nonionella iridea	37	42	50	48	34	42	32	44	44
Nonionella labrodorica	1	0	0	0	0	0	0	0	0
Nonionella turgida	0	1	1	3	0	0	2	3	1
Oolina spp	1	0	3	3	0	2	1	1	6
Parafissurina spp.	4	1	0	3	1	0	0	3	3
Pseudopolymorphina spp.	1	4	0	2	4	2	4	1	1
Pullenia bulloides	6	4	4	11	4	3	5	3	9
Pullenia osloensis	62	59	57	68	80	60	57	59	61
Pullenia osloensis sp. 2	0	3	0	1	1	0	1	1	2
Pullenia subcarinata	9	2	7	3	3	3	2	5	4
Pyrgo williamsoni	2	2	1	1	0	0	3	1	1
Quinqueloculina spp.	7	3	3	5	4	3	2	3	6
Rosalina spp.	2	1	1	6	0	1	2	1	1
Unidentified sp. 1	0	1	6	4	9	0	2	1	1
Stainforthia fusiformis	7	14	17	12	3	28	25	18	22
Trifarina angulosa	1	0	0	0	0	0	0	0	0
Trioculina tricarinata	0	0	0	1	0	4	0	2	3
Uvigerina mediterranea	1	1	1	0	5	3	4	2	4
Valvulineria spp.	2	1	1	2	0	0	2	2	1
Virgulina loeblichi	0	1	1	0	1	1	1	0	2
Virgulina schreibersania	0	0	0	1	1	0	0	1	2
Adercotryma glomerata	0	1	2	3	3	0	1	0	1
Eggerelloides scabrus	7	16	19	28	14	12	7	8	11
Gaudryina spp.	0	0	0	0	0	0	0	0	1
Haplophragmoides bradyi	8	3	0	6	2	0	0	3	2
Milliamina fusca	0	0	0	0	2	0	0	0	1
Reophax sp. 1	0	0	0	0	0	0	0	0	0
Reophax spp.	1	2	0	5	0	0	2	2	1
Saccammina spp.	0	0	5	1	4	5	2	1	2
Textularia earlandi	1	2	2	5	1	1	0	0	2
Trochammina inflata	0	0	0	0	0	0	0	0	0
Trochammina inflata spp.	3	3	3	3	2	1	0	5	2
Unidentified agglutinated sp. 1	0	1	0	3	0	0	0	1	0
Unidentified agglutinated sp. 2	0	0	0	2	0	1	0	0	0
Unidentified agglutinated sp. 3	7	1	0	5	2	0	0	0	0
Unidentified agglutinated sp. 4	0	0	0	0	0	0	0	0	1

Species	109.5	117.5	126.5	133.5	141.5	149.5	158.5	166.5
Ammonia spp.	0	0	3	2	2	0	0	0
Astrononion gallowayi	0	0	0	0	0	0	0	0
Biloculina depressa	0	0	0	0	0	0	0	1
Bolivina albatrossi	0	0	0	1	0	0	0	0
Bolivina skagerrakensis	9	56	10	0	0	0	0	0
Bolivina spathulata	0	2	2	0	3	1	2	5
Brizalina pseudopunctata	0	2	0	1	1	0	1	1
Buccella frigida	3	0	1	2	2	0	6	2
Bulimina marginata	4	11	5	2	3	2	9	5
Buliminella elegantissima	1	3	1	2	4	0	2	0
Cassidulina cf. Laevigata	2	3	1	6	2	0	0	0
Cassidulina laevigata	20	16	25	8	16	12	26	18
Cassidulina neoteretis	17	13	17	16	8	10	27	10
Cassidulina obtuse	5	3	8	6	13	9	7	3
Cassidulina reniforme	0	0	0	0	1	1	0	2
Cassidulina sp. 1	0	0	0	0	0	0	0	0
cf. Eoeponidella spp.	0	4	8	2	3	0	1	1
Cibicides lobatulus	4	12	7	9	10	3	4	4
Cibicides pseudoungerianus	0	1	0	0	0	0	0	0
Cibicides sp. 1	3	0	0	4	2	1	6	8
Cornuspira involvens	1	2	1	0	0	0	0	1
Dentalina spp.	0	0	0	0	0	0	0	0
Elphidium excavatum forma clava	0	3	1	3	0	0	0	1
Epistominella sp. 1	2	7	12	12	15	10	11	12
Epistominella sp. 2	0	0	0	0	0	4	1	1
Epistominella spp.	4	11	20	5	4	1	4	1
Fissurina spp.	7	2	2	2	3	1	5	3
Flat Spiral	0	0	0	0	0	0	0	0
Globobulimina turgida	0	0	0	5	0	1	0	2
Haynesina germanica	0	0	0	0	1	0	0	0
Hyalinea balthica	6	3	2	1	3	5	6	4
Islandiella norcrossi	0	2	5	5	0	0	1	4
Lagena spp.	2	2	3	4	3	3	5	1
Lenticulina cf. angulata	0	1	1	3	3	1	1	1
Lenticulina spp.	0	0	0	0	1	9	1	0
Melonis barleeanus	11	7	2	9	4	2	8	12
Miliolinella spp.	3	0	2	3	3	9	2	3
Nonionella iridea	49	37	43	35	62	66	50	78
Nonionella labrodorica	0	0	0	0	0	0	0	0
Nonionella turgida	4	0	2	2	5	8	6	3
Oolina spp	2	2	1	1	0	4	5	1
Parafissurina spp.	0	2	3	3	2	1	2	2
Pseudopolymorphina spp.	2	1	3	3	3	2	0	2
Pullenia bulloides	5	15	8	9	7	2	6	6
Pullenia osloensis	86	41	46	55	47	44	43	40
Pullenia osloensis sp. 2	3	7	12	4	3	0	0	1
Pullenia subcarinata	8	5	0	7	2	6	6	7
Pyrgo williamsoni	0	1	0	2	3	1	1	2
Quinqueloculina spp.	6	3	11	6	2	7	3	3
Rosalina spp.	3	1	5	4	2	2	2	2
Unidentified sp. 1	0	0	0	1	0	1	2	2
Stainforthia fusiformis	21	11	12	20	39	31	20	19
Trifarina angulosa	0	0	1	2	0	4	1	5
Trioculina tricarinata	2	0	4	1	3	4	2	0
Uvigerina mediterranea	1	1	2	2	2	2	8	2
Valvulineria spp.	1	2	1	0	0	29	3	1
Virgulina loeblichi	0	0	1	0	1	0	0	2
Virgulina schreibersania	4	0	1	0	0	0	0	0
Adercotryma glomerata	0	0	0	0	0	0	1	1
Eggerelloides scabrus	7	5	1	11	2	4	11	5
Gaudryina spp.	0	1	2	2	1	2	1	1
Haplophragmoides bradyi	2	0	0	1	1	0	0	0
Milliamina fusca	0	0	0	0	0	0	0	0
Reophax sp. 1	1	4	2	1	1	0	3	2
Reophax spp.	0	0	1	1	0	2	2	1
Saccammina spp.	1	0	0	0	0	0	0	0
Textularia earlandi	1	1	1	0	1	0	1	0
Trochammina inflata	1	0	1	9	3	5	1	3
Trochammina inflata spp.	6	1	2	5	0	12	5	3
Unidentified agglutinated sp. 1	0	0	0	0	0	0	0	1
Unidentified agglutinated sp. 2	0	0	0	0	0	0	0	0
Unidentified agglutinated sp. 3	0	4	0	0	1	1	3	5
Unidentified agglutinated sp. 4	0	1	0	0	0	0	0	0

Species	172.5	181.5	189.5	197.5	205.5	213.5	221.5	229.5
Ammonia spp.	0	0	0	0	0	0	0	0
Astrononion gallowayi	0	0	0	0	0	0	0	0
Biloculina depressa	2	0	2	6	1	3	1	1
Bolivina albatrossi	0	0	0	0	1	0	0	0
Bolivina skagerrakensis	0	0	0	1	1	1	0	0
Bolivina spathulata	4	2	0	1	2	2	1	0
Brizalina pseudopunctata	1	1	2	0	0	1	2	1
Buccella frigida	6	19	25	5	39	39	11	1
Bulimina marginata	2	15	14	4	4	5	2	5
Buliminella elegantissima	2	1	0	1	0	1	1	1
Cassidulina cf. *Laevigata*	3	0	0	1	3	0	1	0
Cassidulina laevigata	28	13	13	26	24	35	20	34
Cassidulina neoteretis	28	17	20	22	37	29	28	21
Cassidulina obtuse	0	1	2	7	5	3	4	3
Cassidulina reniforme	0	1	1	1	0	0	1	0
Cassidulina sp. 1	0	0	0	0	0	0	0	0
cf. *Eoeponidella* spp.	0	2	0	2	0	0	0	1
Cibicides lobatulus	6	10	10	6	6	13	13	9
Cibicides pseudoungerianus	0	0	0	0	0	0	0	0
Cibicides sp. 1	4	8	8	4	3	4	4	8
Cornuspira involvens	2	0	2	0	0	0	0	1
Dentalina spp.	0	0	0	3	1	0	0	0
Elphidium excavatum forma clava	0	0	0	0	0	0	1	0
Epistominella sp. 1	10	21	20	0	1	0	3	2
Epistominella sp. 2	0	1	0	0	2	0	0	0
Epistominella spp.	3	0	3	1	1	3	2	0
Fissurina spp.	5	2	4	3	4	7	4	7
Flat Spiral	0	0	0	0	1	0	0	0
Globobulimina turgida	3	0	1	0	0	1	0	1
Haynesina germanica	0	0	0	0	0	0	0	0
Hyalinea balthica	6	4	16	9	10	12	13	30
Islandiella norcrossi	6	6	9	10	15	4	4	6
Lagena spp.	6	4	7	5	3	1	4	4
Lenticulina cf. *angulata*	1	0	0	0	1	0	1	1
Lenticulina spp.	2	2	1	2	1	2	1	0
Melonis barleeanus	15	13	15	11	7	14	17	15
Miliolinella spp.	0	2	0	7	7	2	4	4
Nonionella iridea	31	45	23	39	45	36	45	35
Nonionella labrodorica	0	0	0	0	0	0	0	0
Nonionella turgida	0	1	1	2	0	0	1	2
Oolina s pp	6	1	6	0	6	5	5	3
Parafissurina spp.	0	1	0	1	2	1	1	0
Pseudopolymorphina spp.	1	0	0	1	1	1	3	0
Pullenia bulloides	6	12	5	15	6	4	11	13
Pullenia osloensis	46	48	37	37	28	36	48	55
Pullenia osloensis sp. 2	1	1	0	0	0	0	1	0
Pullenia subcarinata	5	3	2	1	1	14	16	12
Pyrgo williamsoni	2	1	0	4	1	0	0	0
Quinqueloculina spp.	3	3	2	6	7	5	8	2
Rosalina spp.	1	1	2	0	2	0	2	2
Unidentified sp. 1	0	2	2	0	2	1	1	1
Stainforthia fusiformis	14	19	24	26	15	13	15	7
Trifarina angulosa	0	2	3	0	1	1	1	1
Trioculina tricarinata	0	1	3	2	1	2	3	1
Uvigerina mediterranea	2	6	6	4	2	3	1	3
Valvulineria spp.	0	3	0	1	1	0	0	1
Virgulina loeblichi	1	0	0	0	0	0	0	2
Virgulina schreibersania	1	1	0	4	2	3	4	0
Adercotryma glomerata	0	1	0	0	3	0	0	2
Eggerelloides scabrus	13	11	0	6	3	4	4	4
Gaudryina spp.	1	1	1	0	1	1	3	3
Haplophragmoides bradyi	0	0	0	0	0	0	2	0
Milliamina fusca	1	0	0	0	0	1	0	0
Reophax sp. 1	1	1	1	0	0	1	0	0
Reophax spp.	3	0	2	0	1	1	2	0
Saccammina spp.	2	0	0	0	0	0	0	2
Textularia earlandi	0	0	0	1	0	0	0	0
Trochammina inflata	1	1	0	3	2	2	0	1
Trochammina inflata spp.	7	7	5	7	3	0	4	0
Unidentified agglutinated sp. 1	0	0	0	1	1	0	0	0
Unidentified agglutinated sp. 2	0	0	0	0	0	0	0	0
Unidentified agglutinated sp. 3	9	3	4	5	4	1	4	2
Unidentified agglutinated sp. 4	0	0	0	0	0	0	0	0

Species	237.5	261.5	269.5	272.5	292.5	301.5	309.5	317.5
Ammonia spp.	0	0	0	0	0	0	0	0
Astrononion gallowayi	0	0	0	0	0	0	0	0
Biloculina depressa	1	2	0	1	1	1	0	0
Bolivina albatrossi	0	0	0	0	0	0	0	0
Bolivina skagerrakensis	0	0	0	0	0	0	1	0
Bolivina spathulata	4	1	1	2	0	1	0	2
Brizalina pseudopunctata	1	0	3	1	0	1	0	2
Buccella frigida	6	12	12	7	8	3	7	12
Bulimina marginata	0	6	5	5	0	0	3	6
Buliminella elegantissima	0	1	2	3	1	1	1	1
Cassidulina cf. Laevigata	1	5	1	0	2	0	0	0
Cassidulina laevigata	28	35	20	27	12	6	4	5
Cassidulina neoteretis	31	37	10	19	19	9	4	6
Cassidulina obtuse	5	4	3	2	5	7	7	3
Cassidulina reniforme	0	0	1	1	1	0	2	1
Cassidulina sp. 1	0	0	0	0	0	0	0	0
cf. Eoeponidella spp.	1	44	69	55	54	76	59	61
Cibicides lobatulus	13	6	3	8	10	8	10	19
Cibicides pseudoungerianus	0	0	0	0	0	0	0	0
Cibicides sp. 1	4	2	8	3	4	2	3	2
Cornuspira involvens	0	0	0	0	0	2	4	0
Dentalina spp.	2	1	0	0	1	3	0	0
Elphidium excavatum forma clava	1	0	1	0	0	0	1	0
Epistominella sp. 1	1	0	0	0	0	0	1	0
Epistominella sp. 2	0	0	0	0	3	2	0	0
Epistominella spp.	2	0	0	1	0	0	0	0
Fissurina spp.	4	4	3	7	1	6	6	1
Flat Spiral	0	0	0	0	0	0	0	1
Globobulimina turgida	1	1	0	0	0	0	2	0
Haynesina germanica	0	0	0	0	0	0	0	0
Hyalinea balthica	8	19	7	14	18	12	13	15
Islandiella norcrossi	9	9	6	5	6	2	1	0
Lagena spp.	3	2	4	3	1	5	5	8
Lenticulina cf. angulata	1	1	0	0	3	1	1	3
Lenticulina spp.	0	0	0	0	1	2	1	4
Melonis barleeanus	8	10	12	5	18	18	12	15
Miliolinella spp.	2	5	5	6	4	3	9	7
Nonionella iridea	60	23	35	31	45	45	50	48
Nonionella labrodorica	0	0	0	0	0	0	0	0
Nonionella turgida	5	3	3	2	1	1	5	1
Oolina s pp	2	1	5	9	5	8	4	6
Parafissurina spp.	2	1	3	3	1	6	1	3
Pseudopolymorphina spp.	2	0	1	1	4	3	5	2
Pullenia bulloides	4	12	5	4	10	11	5	8
Pullenia osloensis	54	24	40	44	43	34	32	32
Pullenia osloensis sp. 2	0	0	0	0	0	0	0	0
Pullenia subcarinata	8	10	7	3	8	6	7	9
Pyrgo williamsoni	1	2	0	1	1	2	1	4
Quinqueloculina spp.	6	8	8	6	3	3	10	8
Rosalina spp.	1	1	2	1	0	1	0	4
Unidentified sp. 1	0	1	0	0	1	1	0	0
Stainforthia fusiformis	22	18	14	17	11	17	19	18
Trifarina angulosa	0	5	1	0	1	0	4	0
Trioculina tricarinata	0	1	1	0	0	0	0	0
Uvigerina mediterranea	0	2	3	3	2	1	3	1
Valvulineria spp.	1	0	2	3	2	2	3	0
Virgulina loeblichi	1	0	2	0	0	3	2	0
Virgulina schreibersania	1	1	1	0	0	0	0	0
Adercotryma glomerata	0	2	0	0	0	0	0	1
Eggerelloides scabrus	2	4	4	0	2	0	5	3
Gaudryina spp.	2	2	0	0	0	2	1	1
Haplophragmoides bradyi	0	1	2	0	2	1	1	0
Milliamina fusca	0	0	0	0	0	0	0	0
Reophax sp. 1	0	0	0	0	0	0	0	0
Reophax spp.	0	0	0	1	0	0	0	0
Saccammina spp.	0	0	0	0	0	0	0	0
Textularia earlandi	0	0	0	0	0	0	0	0
Trochammina inflata	1	3	1	0	0	0	0	0
Trochammina inflata spp.	1	1	2	0	2	2	1	0
Unidentified agglutinated sp. 1	0	0	0	0	1	0	0	0
Unidentified agglutinated sp. 2	0	0	0	0	0	0	0	0
Unidentified agglutinated sp. 3	2	1	4	3	0	3	0	4
Unidentified agglutinated sp. 4	0	0	0	0	0	0	0	0

Species	326.5	333.5	341.5	358.5	363.5	373.5	389.5	397.5
Ammonia spp.	0	0	0	0	0	0	0	0
Astrononion gallowayi	0	0	0	0	0	0	0	0
Biloculina depressa	1	1	4	0	2	2	3	2
Bolivina albatrossi	0	1	0	1	0	0	0	0
Bolivina skagerrakensis	0	0	0	0	0	1	0	0
Bolivina spathulata	1	0	3	0	1	0	0	1
Brizalina pseudopunctata	2	0	0	0	1	0	1	1
Buccella frigida	3	16	1	20	6	20	2	13
Bulimina marginata	1	2	7	0	1	2	0	1
Buliminella elegantissima	0	0	1	3	3	1	0	0
Cassidulina cf. Laevigata	0	0	0	0	0	0	0	0
Cassidulina laevigata	1	2	0	1	1	4	6	2
Cassidulina neoteretis	1	5	2	7	5	12	8	6
Cassidulina obtuse	9	13	14	16	15	15	7	9
Cassidulina reniforme	1	0	1	1	2	0	0	0
Cassidulina sp. 1	0	0	0	0	0	0	0	0
cf. Eoeponidella spp.	88	43	68	43	54	55	47	60
Cibicides lobatulus	8	13	9	11	7	7	14	11
Cibicides pseudoungerianus	0	0	0	0	0	0	0	0
Cibicides sp. 1	7	4	6	0	1	2	4	2
Cornuspira involvens	0	0	3	0	0	1	0	2
Dentalina spp.	0	0	0	0	0	2	0	2
Elphidium excavatum forma clava	0	0	1	0	2	0	1	1
Epistominella sp. 1	1	1	1	3	1	1	1	0
Epistominella sp. 2	2	3	0	3	4	0	0	1
Epistominella spp.	0	1	0	0	1	1	0	0
Fissurina spp.	8	7	1	1	0	3	5	10
Flat Spiral	0	0	0	1	0	1	0	0
Globobulimina turgida	0	0	0	0	0	0	0	0
Haynesina germanica	0	0	0	0	0	0	0	0
Hyalinea balthica	17	14	18	20	20	10	9	1
Islandiella norcrossi	0	0	0	0	2	0	0	2
Lagena spp.	5	9	6	2	7	6	2	5
Lenticulina cf. angulata	0	0	0	0	1	3	0	5
Lenticulina spp.	2	3	0	0	2	0	2	2
Melonis barleeanus	15	15	13	10	4	9	12	21
Miliolinella spp.	9	3	1	5	9	7	0	2
Nonionella iridea	57	72	39	86	65	57	92	60
Nonionella labrodorica	0	0	0	0	0	0	0	0
Nonionella turgida	3	6	4	3	2	4	15	9
Oolina s pp	7	7	5	3	1	5	2	1
Parafissurina spp.	1	2	2	4	3	2	3	5
Pseudopolymorphina spp.	0	3	3	4	3	8	8	6
Pullenia bulloides	1	6	6	0	5	6	9	12
Pullenia osloensis	34	34	38	9	34	28	14	11
Pullenia osloensis sp. 2	0	0	0	0	0	0	1	0
Pullenia subcarinata	4	2	1	4	4	10	5	6
Pyrgo williamsoni	1	1	1	2	2	2	0	0
Quinqueloculina spp.	7	3	2	6	5	8	0	4
Rosalina spp.	2	0	0	1	2	0	1	0
Unidentified sp. 1	0	2	4	2	1	2	1	0
Stainforthia fusiformis	25	30	16	18	10	11	9	12
Trifarina angulosa	0	1	1	0	3	0	2	0
Trioculina tricarinata	0	0	0	0	1	0	0	0
Uvigerina mediterranea	1	2	0	0	9	6	0	2
Valvulineria spp.	0	2	1	2	3	4	11	5
Virgulina loeblichi	0	0	1	0	3	0	2	0
Virgulina schreibersania	0	0	0	0	0	0	0	0
Adercotryma glomerata	0	0	0	2	0	0	0	1
Eggerelloides scabrus	0	0	0	1	0	0	0	2
Gaudryina spp.	0	0	1	0	0	1	2	1
Haplophragmoides bradyi	0	0	0	1	2	0	0	0
Milliamina fusca	1	0	0	0	0	0	0	0
Reophax sp. 1	0	0	0	0	0	0	0	0
Reophax spp.	0	0	0	0	0	0	0	0
Saccammina spp.	0	0	1	0	0	1	0	0
Textularia earlandi	0	0	1	1	0	0	1	0
Trochammina inflata	0	0	4	2	0	0	0	0
Trochammina inflata spp.	0	0	6	7	0	0	1	1
Unidentified agglutinated sp. 1	0	0	0	1	0	0	0	0
Unidentified agglutinated sp. 2	0	0	0	0	0	0	0	0
Unidentified agglutinated sp. 3	4	1	2	1	2	0	380	2
Unidentified agglutinated sp. 4	0	0	0	0	0	0	0	0

Species	401.5	405.5	409.5	412.5	418.5	421.5	426.5	429.5
Ammonia spp.	0	0	0	0	0	0	0	0
Astrononion gallowayi	0	0	0	0	1	0	0	0
Biloculina depressa	3	2	2	0	0	0	2	1
Bolivina albatrossi	0	0	0	0	0	0	0	0
Bolivina skagerrakensis	0	0	0	0	0	0	0	0
Bolivina spathulata	1	0	1	1	0	1	1	0
Brizalina pseudopunctata	0	3	0	0	0	0	0	0
Buccella frigida	0	6	29	12	7	6	2	9
Bulimina marginata	1	2	1	3	1	2	0	0
Buliminella elegantissima	0	0	0	0	0	0	0	0
Cassidulina cf. *Laevigata*	0	0	0	0	0	0	0	0
Cassidulina laevigata	5	3	3	3	3	1	3	1
Cassidulina neoteretis	5	7	1	10	8	10	4	12
Cassidulina obtuse	2	3	5	6	8	3	7	9
Cassidulina reniforme	0	1	0	0	1	1	2	1
Cassidulina sp. 1	0	0	0	0	0	1	0	1
cf. Eoeponidella spp.	77	70	63	51	5	1	1	0
Cibicides lobatulus	17	14	8	21	16	9	6	10
Cibicides pseudoungerianus	0	0	0	0	0	0	0	0
Cibicides sp. 1	1	0	1	0	0	2	2	1
Cornuspira involvens	0	1	0	0	0	0	0	0
Dentalina spp.	1	0	0	1	1	1	2	0
Elphidium excavatum forma *clava*	0	1	0	0	1	0	1	0
Epistominella sp. 1	3	6	3	1	2	1	1	8
Epistominella sp. 2	1	0	1	1	1	0	1	0
Epistominella spp.	0	0	0	1	0	0	0	0
Fissurina spp.	8	8	4	4	1	4	6	2
Flat Spiral	2	0	5	0	4	0	2	0
Globobulimina turgida	1	0	0	0	0	0	0	0
Haynesina germanica	0	0	0	0	0	0	0	0
Hyalinea balthica	9	0	6	9	8	10	14	28
Islandiella norcrossi	0	0	0	0	0	2	1	0
Lagena spp.	8	4	5	4	3	9	8	3
Lenticulina cf. *angulata*	0	1	1	0	6	2	1	2
Lenticulina spp.	2	5	4	2	2	3	1	1
Melonis barleeanus	12	22	17	24	9	24	16	18
Miliolinella spp.	7	3	7	6	6	5	2	2
Nonionella iridea	72	72	79	64	60	54	82	47
Nonionella labrodorica	0	0	0	0	0	0	0	0
Nonionella turgida	3	0	4	2	6	0	2	8
Oolina s pp	1	2	4	2	1	1	1	1
Parafissurina spp.	2	2	2	1	2	2	0	3
Pseudopolymorphina spp.	6	1	11	0	3	3	3	8
Pullenia bulloides	8	10	8	20	5	8	5	1
Pullenia osloensis	26	16	8	18	25	21	16	13
Pullenia osloensis sp. 2	0	0	0	0	0	0	0	0
Pullenia subcarinata	3	3	4	5	8	5	2	4
Pyrgo williamsoni	1	4	2	0	1	1	0	1
Quinqueloculina spp.	8	5	6	9	4	2	1	1
Rosalina spp.	1	0	0	1	0	0	1	0
Unidentified sp. 1	0	0	0	0	0	0	0	2
Stainforthia fusiformis	2	12	12	10	8	19	13	15
Trifarina angulosa	2	0	0	2	1	1	2	4
Trioculina tricarinata	0	1	0	0	0	0	0	0
Uvigerina mediterranea	1	4	4	6	4	1	1	14
Valvulineria spp.	3	2	3	4	7	5	11	6
Virgulina loeblichi	0	1	1	2	1	1	2	1
Virgulina schreibersania	0	0	0	0	0	0	0	0
Adercotryma glomerata	0	0	0	0	0	0	2	1
Eggerelloides scabrus	0	0	0	0	1	0	0	0
Gaudryina spp.	0	0	0	0	1	0	1	0
Haplophragmoides bradyi	0	0	0	0	4	0	3	0
Milliamina fusca	0	0	1	0	2	0	0	0
Reophax sp. 1	0	0	0	0	0	0	0	0
Reophax spp.	0	0	1	0	0	0	0	0
Saccammina spp.	0	0	0	0	0	0	2	0
Textularia earlandi	0	0	0	0	0	0	0	1
Trochammina inflata	0	0	0	0	1	0	0	0
Trochammina inflata spp.	4	0	1	0	4	0	0	0
Unidentified agglutinated sp. 1	0	0	0	0	0	0	0	0
Unidentified agglutinated sp. 2	0	0	0	0	0	0	0	0
Unidentified agglutinated sp. 3	0	1	1	0	3	0	2	1
Unidentified agglutinated sp. 4	0	0	0	0	0	0	0	0

Species	433.5	437.5	441.5	445.5	450.5	453.5	457.5	461.5
Ammonia spp.	0	0	0	0	0	0	0	0
Astrononion gallowayi	0	0	0	0	0	0	0	0
Biloculina depressa	1	3	5	1	0	0	1	5
Bolivina albatrossi	0	0	0	0	0	0	0	0
Bolivina skagerrakensis	0	0	1	0	1	0	0	0
Bolivina spathulata	3	0	1	1	0	2	1	0
Brizalina pseudopunctata	0	0	0	0	0	0	0	0
Buccella frigida	2	1	1	1	1	0	0	1
Bulimina marginata	0	1	1	2	0	0	2	2
Buliminella elegantissima	0	1	0	0	0	0	1	0
Cassidulina cf. Laevigata	0	0	0	0	0	0	0	0
Cassidulina laevigata	8	8	4	3	1	20	10	12
Cassidulina neoteretis	4	9	6	12	3	33	18	23
Cassidulina obtuse	1	9	12	3	1	2	4	6
Cassidulina reniforme	0	2	0	0	2	1	0	2
Cassidulina sp. 1	0	0	0	0	1	1	0	0
cf. *Eoeponidella* spp.	1	0	0	0	1	0	1	1
Cibicides lobatulus	7	6	5	2	4	4	10	8
Cibicides pseudoungerianus	0	0	0	0	0	0	0	0
Cibicides sp. 1	0	1	0	0	0	0	1	1
Cornuspira involvens	0	1	2	3	0	2	0	0
Dentalina spp.	1	5	1	0	0	1	0	1
Elphidium excavatum forma *clava*	4	1	1	0	3	1	28	40
Epistominella sp. 1	6	4	5	1	3	0	4	3
Epistominella sp. 2	0	0	1	0	1	0	0	0
Epistominella spp.	0	0	1	0	0	0	0	0
Fissurina spp.	4	6	10	2	5	1	4	8
Flat Spiral	0	0	18	12	5	1	2	6
Globobulimina turgida	0	0	0	0	1	0	0	0
Haynesina germanica	0	0	0	0	0	0	0	0
Hyalinea balthica	19	71	33	89	100	101	0	2
Islandiella norcrossi	0	2	0	3	0	4	0	0
Lagena spp.	5	1	8	1	8	4	7	4
Lenticulina cf. angulata	5	3	1	1	2	2	2	1
Lenticulina spp.	0	6	2	4	6	3	3	7
Melonis barleeanus	15	8	7	7	5	7	18	15
Miliolinella spp.	9	2	4	12	10	3	3	4
Nonionella iridea	60	56	53	36	66	35	74	63
Nonionella labrodorica	0	0	0	0	0	0	0	0
Nonionella turgida	0	3	1	0	1	2	4	4
Oolina spp	3	2	2	1	2	1	2	3
Parafissurina spp.	2	4	2	1	0	2	0	1
Pseudopolymorphina spp.	0	16	7	5	4	1	2	2
Pullenia bulloides	0	0	0	0	0	0	1	0
Pullenia osloensis	20	19	32	43	34	63	72	26
Pullenia osloensis sp. 2	0	0	0	0	0	0	0	0
Pullenia subcarinata	3	3	13	1	1	1	4	1
Pyrgo williamsoni	1	7	3	4	0	1	2	4
Quinqueloculina spp.	6	1	7	13	8	2	5	3
Rosalina spp.	0	1	0	2	0	0	0	2
Unidentified sp. 1	0	0	0	0	0	0	0	0
Stainforthia fusiformis	25	15	23	7	10	11	13	5
Trifarina angulosa	0	2	1	0	0	1	1	0
Trioculina tricarinata	0	0	0	1	0	0	0	0
Uvigerina mediterranea	4	5	6	5	6	5	2	3
Valvulineria spp.	12	9	8	12	22	3	9	3
Virgulina loeblichi	1	1	0	0	0	0	1	1
Virgulina schreibersania	0	0	0	0	0	0	0	0
Adercotryma glomerata	2	0	0	0	0	0	0	1
Eggerelloides scabrus	0	0	0	0	1	0	0	0
Gaudryina spp.	0	1	0	0	0	0	0	0
Haplophragmoides bradyi	2	1	1	1	0	0	0	1
Milliamina fusca	0	0	1	0	0	1	0	0
Reophax sp. 1	0	0	0	0	0	0	0	0
Reophax spp.	1	0	0	0	0	0	0	0
Saccammina spp.	0	0	1	0	0	0	0	0
Textularia earlandi	0	0	0	0	0	0	0	0
Trochammina inflata	0	2	0	0	0	0	0	0
Trochammina inflata spp.	0	0	0	0	0	0	0	0
Unidentified agglutinated sp. 1	0	0	0	0	0	0	0	0
Unidentified agglutinated sp. 2	0	0	0	0	0	0	0	0
Unidentified agglutinated sp. 3	1	0	0	40	50	0	450	0
Unidentified agglutinated sp. 4	0	0	0	0	0	0	0	0

Species	465.5	469.5	473.5	477.5	481.5	485.5	489.5	493.5
Ammonia spp.	0	0	0	0	0	0	0	0
Astrononion gallowayi	0	0	0	0	0	0	0	0
Biloculina depressa	3	1	0	0	0	0	0	1
Bolivina albatrossi	0	0	0	0	0	0	0	0
Bolivina skagerrakensis	0	1	0	1	0	0	0	0
Bolivina spathulata	0	0	1	5	0	2	0	0
Brizalina pseudopunctata	1	0	0	0	0	0	0	0
Buccella frigida	11	46	2	1	1	2	0	5
Bulimina marginata	3	4	0	1	2	5	1	0
Buliminella elegantissima	0	0	2	0	0	0	0	0
Cassidulina cf. *Laevigata*	0	0	0	0	0	1	0	0
Cassidulina laevigata	17	14	7	4	6	6	1	9
Cassidulina neoteretis	11	18	8	3	4	8	6	12
Cassidulina obtuse	4	5	7	9	6	9	3	6
Cassidulina reniforme	0	0	3	0	1	3	1	0
Cassidulina sp. 1	1	0	1	0	0	1	0	0
cf. *Eoeponidella* spp.	0	0	1	0	1	1	0	0
Cibicides lobatulus	10	11	13	9	5	4	1	1
Cibicides pseudoungerianus	0	0	0	0	0	0	0	0
Cibicides sp. 1	0	0	2	2	0	7	0	2
Cornuspira involvens	0	0	0	0	1	0	0	0
Dentalina spp.	0	0	0	1	0	0	1	1
Elphidium excavatum forma *clava*	81	29	34	47	46	65	50	34
Epistominella sp. 1	6	4	3	1	2	0	0	4
Epistominella sp. 2	0	0	0	0	0	0	0	0
Epistominella spp.	2	1	1	0	0	0	0	0
Fissurina spp.	5	5	7	2	5	1	2	4
Flat Spiral	4	0	4	1	2	0	3	1
Globobulimina turgida	0	0	0	0	0	0	0	0
Haynesina germanica	0	0	0	0	0	0	0	0
Hyalinea balthica	0	0	0	0	0	0	1	0
Islandiella norcrossi	1	0	1	2	0	2	0	0
Lagena spp.	6	7	8	7	4	1	4	0
Lenticulina cf. *angulata*	0	1	0	0	0	0	0	1
Lenticulina spp.	1	6	6	1	3	4	6	9
Melonis barleeanus	8	15	17	11	3	3	3	4
Miliolinella spp.	10	7	5	10	2	3	5	6
Nonionella iridea	42	39	33	57	45	52	47	64
Nonionella labrodorica	0	0	0	0	0	0	0	0
Nonionella turgida	1	5	4	2	1	8	2	0
Oolina spp	6	2	4	2	2	1	0	0
Parafissurina spp.	0	0	2	1	1	1	1	0
Pseudopolymorphina spp.	7	1	2	2	1	0	2	1
Pullenia bulloides	0	1	0	0	0	2	0	0
Pullenia osloensis	42	60	64	52	47	24	28	36
Pullenia osloensis sp. 2	0	0	0	0	0	0	0	0
Pullenia subcarinata	1	0	2	0	1	0	1	1
Pyrgo williamsoni	2	1	2	0	0	4	1	1
Quinqueloculina spp.	12	6	5	9	3	4	3	5
Rosalina spp.	0	4	0	0	1	0	0	0
Unidentified sp. 1	0	0	0	0	0	0	0	0
Stainforthia fusiformis	3	7	10	6	11	19	17	2
Trifarina angulosa	0	0	0	0	0	0	0	0
Trioculina tricarinata	0	0	2	0	0	2	1	1
Uvigerina mediterranea	1	0	0	1	0	0	0	0
Valvulineria spp.	9	5	21	90	88	143	133	103
Virgulina loeblichi	0	1	0	0	2	0	0	1
Virgulina schreibersania	0	0	0	0	0	0	0	0
Adercotryma glomerata	0	0	0	0	0	0	0	0
Eggerelloides scabrus	2	1	1	0	0	0	0	0
Gaudryina spp.	0	0	0	0	0	0	0	0
Haplophragmoides bradyi	0	0	0	0	0	0	0	0
Milliamina fusca	0	1	0	0	1	0	2	0
Reophax sp. 1	0	0	0	0	0	0	0	0
Reophax spp.	0	0	0	0	0	0	0	0
Saccammina spp.	0	0	0	0	0	0	0	0
Textularia earlandi	0	0	0	0	0	0	0	0
Trochammina inflata	0	0	0	0	0	0	0	0
Trochammina inflata spp.	0	0	0	0	0	0	0	0
Unidentified agglutinated sp. 1	0	0	0	0	0	0	0	0
Unidentified agglutinated sp. 2	0	0	0	0	0	0	0	0
Unidentified agglutinated sp. 3	1	0	0	0	0	0	0	0
Unidentified agglutinated sp. 4	0	0	0	0	0	0	0	0

Species	497.5	501.5	505.5	509.5	513.5	516.5	521.5	523.5
Ammonia spp.	0	0	0	0	0	0	0	0
Astrononion gallowayi	0	0	0	0	0	0	0	0
Biloculina depressa	0	3	1	0	2	0	0	0
Bolivina albatrossi	0	0	0	0	0	0	0	0
Bolivina skagerrakensis	0	0	0	0	0	0	0	0
Bolivina spathulata	0	0	2	0	0	0	0	0
Brizalina pseudopunctata	0	0	0	0	1	0	0	0
Buccella frigida	4	4	25	71	103	121	127	133
Bulimina marginata	5	1	2	0	1	0	0	1
Buliminella elegantissima	0	0	0	0	0	0	0	0
Cassidulina cf. Laevigata	0	0	0	0	0	0	0	0
Cassidulina laevigata	14	12	2	5	7	6	0	2
Cassidulina neoteretis	1	5	9	6	3	8	5	0
Cassidulina obtuse	5	8	1	1	0	1	3	1
Cassidulina reniforme	0	0	0	0	0	1	0	0
Cassidulina sp. 1	0	0	0	1	0	0	0	0
cf. *Eoeponidella* spp.	0	0	0	1	0	0	0	2
Cibicides lobatulus	4	4	1	2	2	1	6	2
Cibicides pseudoungerianus	0	0	0	0	0	0	0	0
Cibicides sp. 1	1	1	0	1	1	0	0	1
Cornuspira involvens	0	0	1	0	0	0	0	0
Dentalina spp.	2	0	0	1	0	0	1	1
Elphidium excavatum forma *clava*	43	68	67	84	38	45	39	42
Epistominella sp. 1	0	1	1	0	0	0	0	0
Epistominella sp. 2	0	1	0	0	0	0	0	0
Epistominella spp.	0	0	0	0	1	0	0	0
Fissurina spp.	2	1	0	0	0	2	2	1
Flat Spiral	5	4	5	0	3	0	11	0
Globobulimina turgida	0	0	0	0	0	1	0	0
Haynesina germanica	0	0	0	0	0	0	0	0
Hyalinea balthica	0	0	0	0	0	0	0	0
Islandiella norcrossi	0	0	0	1	0	0	0	0
Lagena spp.	1	4	4	4	1	4	0	2
Lenticulina cf. angulata	0	0	0	0	1	0	1	0
Lenticulina spp.	5	4	2	3	2	1	5	4
Melonis barleeanus	1	3	5	5	1	2	2	1
Miliolinella spp.	6	7	11	0	3	2	4	0
Nonionella iridea	61	69	63	51	69	57	52	43
Nonionella labrodorica	0	0	0	0	0	0	0	0
Nonionella turgida	1	6	3	1	4	1	1	0
Oolina spp	1	1	0	4	1	1	3	4
Parafissurina spp.	0	1	0	1	1	0	0	0
Pseudopolymorphina spp.	4	2	4	1	3	0	3	1
Pullenia bulloides	0	0	0	0	0	0	0	0
Pullenia osloensis	40	46	42	54	31	33	37	48
Pullenia osloensis sp. 2	0	1	0	0	0	0	0	0
Pullenia subcarinata	1	1	0	2	3	1	2	4
Pyrgo williamsoni	2	4	0	1	2	5	1	2
Quinqueloculina spp.	6	7	9	2	2	1	4	0
Rosalina spp.	2	1	1	1	0	2	0	0
Unidentified sp. 1	0	0	0	0	0	0	0	0
Stainforthia fusiformis	6	10	10	3	10	6	3	4
Trifarina angulosa	0	0	0	0	0	0	0	0
Trioculina tricarinata	0	2	5	0	1	0	0	0
Uvigerina mediterranea	0	0	0	0	0	0	0	0
Valvulineria spp.	92	23	22	8	17	13	8	2
Virgulina loeblichi	0	2	0	0	0	0	2	0
Virgulina schreibersania	1	0	0	0	0	0	0	0
Adercotryma glomerata	0	0	0	0	0	0	0	0
Eggerelloides scabrus	0	0	0	0	0	0	1	0
Gaudryina spp.	0	0	0	0	0	0	0	0
Haplophragmoides bradyi	0	0	0	0	0	0	0	1
Milliamina fusca	1	0	0	1	2	2	0	3
Reophax sp. 1	0	0	0	0	0	0	0	0
Reophax spp.	0	0	0	0	0	0	0	0
Saccammina spp.	0	0	0	0	0	0	0	0
Textularia earlandi	0	0	0	0	0	0	0	0
Trochammina inflata	0	0	0	0	0	0	0	0
Trochammina inflata spp.	0	0	0	0	0	0	0	0
Unidentified agglutinated sp. 1	0	0	0	0	0	0	0	0
Unidentified agglutinated sp. 2	0	0	0	0	0	0	0	0
Unidentified agglutinated sp. 3	0	0	0	0	0	0	1	0
Unidentified agglutinated sp. 4	0	0	0	0	0	0	0	0