Anonymous referee #1

Major comments

1_R#1: *The manuscript entitled 'Benthic foraminifera as tracers of brine production in Storfjorden "sea ice factory" by Eleanor Fossile and others definitely fits within the mission on Biogeosciences.*
The hypothesis tested with the data presented is that the ratio of agglutinated to calcareous benthic foraminifera in Storfjorden, Svalbard archipelago, is largely controlled by brine formation and therefore can be used as a proxy for brine rejection processes and brine overflows in the paleo record. Previous research in the area has established that brine formation and overflow out of Storfjorden happen today and it has been inferred to have occurred in the past. The authors need to show that brine formation causes carbonate dissolution in modern samples and to rule out other processes such as high TOC causing low pH in the porewaters or show how other processes combine with the brine formation and overflow to cause dissolution.

Answer: We thank the reviewer for the provided comments and suggestions that we will mostly follow in the revised version. Hereafter, we answer point-by-point the raised questions.

2_R#1: *I can see that it is important to have a proxy for the brine formation in this area and that it relates to the coastal polynya and the sea-ice factory, but please state clearly why it would be important for paleo studies to know if there were brines forming or not in the past. Why is your study significant? What does brine formation tell us about the sea ice conditions or climate/environment in the larger Arctic?*

Answer: Before answer the question we precise that our study proposes the A/C proxy for historical (e.g., 200-500 yrs) reconstruction of sea-ice production in the fjord, as stated in lines 31-39. We therefore concentrate on time scales much shorter than "paleo".
Studying brine evolution through recent time is important because brine circulation is a proxy for first-year sea-ice production and therefore for the functioning of the polynya system. This last has a crucial role in ocean circulation.
From Knies et al., 2017 "The Arctic Ocean halocline is maintained by the contribution of cold and brine-enriched deep waters (Aagaard et al., 1985; Cavalieri and Martin, 1994), which are formed because of high sea-ice production in coastal polynyas over the continental shelves (Fig. 7). Tamura and Ohshima (2011) showed that the current polar amplification of global warming will lead to negative trends in sea-ice production in most of the Arctic polynyas and with future projections of a summer ice-free Arctic Ocean (IPCC, 2013) sea-ice factories in Arctic coastal polynyas may lose their significance entirely."
The significance of these predictions, largely based on direct observations (i.e., satellite data of the last 50 years) needs to be evaluated on longer time scales, to place the recent trends in a longer-term perspective (i.e., multi-centennial time-scale) (Nicolle et al., 2018).
In our conclusion (lines 607-609) we already suggested the application of the A/C proxy on historical sedimentary records from Storfjorden in order to reconstruct recent changes in BSW intensity and, by extent, in sea ice production.
To satisfy the referee's questions, these different facets will be clarified in the introduction of the revised manuscript.

See lines 45-53

3_R#1: *You use a carefully developed dataset of living (biologically stained) foraminifera and environmental parameters such as various food types, hydrographic parameters and grain size from modern seabed samples to explore the ecology of the modern fauna. I find the paper to be carefully and clearly written in general. The development of the biozones and their association with various qualities of food source and hydrography is well done. However, I am not 100% convinced about the role of brine as the main driver of dissolution, but I think you could hone your arguments. I have some questions with that in mind.*
Is there any chance of dissolution of calcareous faunas during your laboratory methods? Ethanol has a pH of 7.3. Did your samples sit in unbuffered water? You do not mention anything about buffering. Are there dead (unstained) calcareous forams in your samples? It seems like an important missing bit of information.

Answer: We thank the referee for the appreciation of our work. About preservation, there are no reliable chances of dissolution related to our laboratory method. Ethanol is largely used as preservative method in the literature and recently suggested in the official protocol for living foraminiferal sample preservation by the FOBIMO group of specialists (Schönfeld et al., 2012). Moreover, Schönfeld et al. (2013) compared different preservation methods for sediment samples (ethanol and formalin) and no signs of dissolution were observed in samples preserved with ethanol. Also, our samples never sit into unbuffered water during the processing.

Moreover, the preservation of the calcareous shells is much better in the inner fjord stations than in the deep basins, further suggesting that this result is not related to the preservation methods. In the inner fjord the dissolution only concerns some species, while others are not particularly affected (as stated in lines 397-402). Moreover, we observe preservation of calcareous species in the dead faunas, even if we decided not to include these data in the ms because they represent a too large dataset and only marginally useful for the purposes of the present ms. We will add some details about preservation methods in the "material and methods" chapter to clarify these points.

Please see line 206

4_R#1: *Are there large variations in calcareous forams in the fossil record? Is that how people have inferred that there were brines in the past?*

Answer: We did not analyze proper fossil faunas, but only recently dead faunas (up to 6-8 cm depth in the sediment, corresponding to approximatively 40 years in the past; data not included in the ms). Of course the occurrence of taphonomical processes may affect differentially the difference between the dead and living faunas. In our study, the agglutinated fraction is relatively well preserved, and the A/C ratios applied on the dead faunas give coherent results.
As we report in the discussion (lines 540-545), Rasmussen and Thomsen, (2014, 2015) already observed shifts between agglutinated and calcareous ratios in the foraminiferal fossil record from the deep basin of the Storfjorden and suggested that it could reflect the intensification or weakening of brine productions during cold and warm periods respectively, during the last 14 kyr.

5_R#1: *The living fauna at the time of sample collection may not represent only this year or only one season, or it may exclude forams that bloomed earlier in the year. Give some insight into what the living fauna represents in terms of time. It does seem strange that living forams are badly dissolved! Are they really living at the time of collection or are they recently dead and already dissolving?*

Answer: As reported by Schönfeld et al. (2012) Rose Bengal stain is protein specific, and proteins are degraded fairly slowly under certain circumstances (e.g., hypoxic to anoxic conditions). Therefore, Rose Bengal may stain also proteins that are still in the shell after termination of metabolic activity, i.e., the death of the specimen (Bernhard, 1988; Murray and Bowser, 2000). In fact, the cytoplasm can be preserved in the test for some days to some weeks after the death of the foraminifera (Bernhard, 1988, 2000; Hannah and Rogerson, 1997; Murray and Bowser, 2000). Consequently, this method may lead to a slight overestimation of the living assemblages, especially if pale rose staining is considered enough to define vitality.
However, we are confident that the foraminiferal communities observed are representative of the late summer context of the fjord for three main reasons: 1) we only counted as living foraminifera with bright rose staining (assessing the coloration intensity of living specimens for every individual species, as recommended by Schönfeld et al., (2012)); it will be better described in the "materials and methods" chapter; 2) in well oxygenated environment, as our study area is, the residual cytoplasm after death would be quickly remineralised, reducing the possibilities of long term preservation for the necrotic cytoplasm; 3) we also report high abundances of juveniles of the same species found in the large size fraction, supporting the hypothesis that we sampled an active community.
This is not in contrast with the dissolution of calcareous species. In fact, there is a large literature reporting calcareous foraminifera able to survive with dissolved shells, both in natural and experimental setups. For example, Charrieau et al. (2017) report "zombies" foraminifera from the Swedish fjords, where pH was 7.4. Similarly, Pettit et al. (2013) report living (Cell-tracker green stained) foraminifera in environments with low pH (7.5). Bentov et al. (2009) were even able, in experimental conditions, to completely dissolve the

calcareous test of a benthic foraminifer and let the specimen regrow a new test, confirming without doubts that the test dissolution is not inevitably cause of death.

6_R#1: *How do you determine what degree or type of staining points to a 'living' foram at the time of collection.*

Answer: The colour and intensity of Rose Bengal staining varies among species (Schönfeld et al., 2012). However a certain experience and a critical view minimize bias inferred by subjectivity (Murray and Bowser, 2000). According to the FOBIMO protocol we picked under wet conditions, which helps to preserve the brightness of staining and we only counted bright rose colored specimens as alive. All doubtful staining were not taken into account. Some precisions about all that will be added in the revised ms.

Please see lines 211-212

7_R#1: *I suggest you add the word 'living' as a modifier of calcareous, agglutinated etc. more often because you are only presenting living assemblages and that really needs to be made clear. For example 4.5.1 Abundances and diversity of living forams.*

Answer: We think this is not necessary as the entire paper is about living foraminifera and we do not show any dead fauna data. However, we can accept this modification if also the editor thinks this is necessary.

We finally decided not to add this specification because we only focus on living faunas and we think this would not be useful.

8_R#1: *Can you provide a concise summary of why brine is corrosive to $CaCO_3$, along with explanation about how other factors (high CO_2, cold Arctic water and high TOC for example) interplay or potentially play their own role in the dissolution?*

Answer: There are several parameters to take into account to explain why brines are corrosive to $CaCO_3$. Calcite dissolution theoretically occurs when the carbon saturation state (ΩCa) is less than 1. The saturation point depends on pH, alkalinity, dissolved inorganic carbon, salinity and temperature. Brines form from Artic water, and are further enriched in CO_2 due to the rejection of inorganic carbon during the sea-ice production (Rysgaard et al., 2011, as reported in the chapter 2. "Oceanographic and environmental settings", lines 105-127). They are therefore necessarily richer in CO_2 compared to Arctic waters. Concerning the labile organic matter, its mineralization under oxic condition is indeed a cause of pH decrease, which is difficult to decouple from the pH decrease due to brines, as we stated several times in the ms (lines 441-444, 529-555). However, based on our data set we can describe that the higher fresh and labile organic matter contents (the component which is mineralized the fastest), are recorded in the inner fjord stations, where the brine persistence is lesser and the calcareous faunas less affected in terms of dissolution. On the opposite, in the deep basins, where the brines persist all year round and where the organic matter is more refractory, the calcareous species are heavily dissolved. To us, this is a good argument to say that brines are most probably the main, even if surely not the only, controlling factor on calcareous test preservation.

We think this is already quite accurately explained in the presentation of the study area and in the discussions but we can do some slight modification to highlight these arguments in the discussion chapter of the revised ms.

Please see lines 511-538

9_R#1: *Storfjorden is called a fjord and you mention often about glacial meltwater and its influence on the headwaters of the fjord. But glaciers are not shown on your maps and I don't think they are described in your paper. That description is needed because you call on glacial meltwater and sediment delivery as an important part of the environmental gradient. On line 421 and 425 you use the term continental glacier, but I think you mean plateau ice cap or mountain glaciers?*

Answer: Spitsbergen is characterized by the presence of several tidewater glaciers (glaciers terminating with their calving front at the sea) influencing the head of the Storfjorden (see figure 9 in Lydersen et al., 2014). Many glaciers present on Svalbard retreated in the last 100 years because of climate warming

increasing sediment supply and accumulation (Zajączkowski et al., 2004). This supply is in our opinion the source of terrigenous (refractory) organic carbon in the fjord.
With continental glaciers we meant tidewater glaciers. We will change the term in the manuscript. These glaciers are present all around the fjord (we may write in the "study area" chapter to refer to figure 9 in Lydersen et al., (2014) for more details on glacier distribution), but we do not think that it is important for the purpose of our manuscript to show them on the map as we do not identify any of them in particular as direct responsible for sediment supply.

Please see lines 137-140.

10_R#1: *And Storfjorden really looks like a sound as it forms a connection between the Barents and Greenland seas via Heleysundet and Freemansundet. What role do these connections play in the fjord hydrography? How important is the ESC waters that come into the head of the fjord for the formation of brines? Can the differences you see in MC3s be related to its proximity to Freemansundet? Your map figure is so small that I could not easily read the labels.*

Answer: Indeed, the Storfjorden makes a connection with the Northern Barents Sea via Heleysundet and Freemansundet. We explained the role of these sounds at lines 73-75, 94-96. The ESC current carries cold Arctic waters, contributing to maintain an active cyclonic circulation. These waters in winter-early spring, thanks to the katabatic winds enhancing the polynya, contribute to the formation of BSW (Skogseth et al., 2005). The figure was maybe reduced in size during the formatting processes (?). We will take care that the labels are clearly visible in the final version.

11_R#1: *On Figure 1b, add the Atlantic Water..you can use a special arrow or something. Also add the Arctic water. Can you add the polynya to Figure 1a?*

Answer: Atlantic waters are already present on the figure 1a. As stated in the figure caption, they are represented by the red arrows and by the Norwegian Atlantic Current (NAC) and the West Spitsbergen Current (WSC). We prefer not to add the polynya to the map because its extension is hugely variable (interannually and annually). Haarpaintner et al., (2001) clearly explain the variability of the polynya and propose some figures to show that. We will add a short statement to provide this information.

Please see lines 113-114.

12_R#1: *On page 4 you discuss the organic matter composition of the sediments and the potential of a terrestrial component. What is the bedrock geology of this area? Can some refractory carbon be from bedrock erosion and deposition in the fjord?*

Answer: The organic matter we are talking about is the one mainly coming from the continental soil and not from the bedrock. This organic matter is eroded and drained into the fjord especially during the melting season. Please refer to the answer concerning the tidewater glaciers above (comment 9).

13_R#1: *Line 125. How does Storfjorden introduce brine to the Arctic Ocean when it drains to the Greenland Sea?*

Answer: As represented in figure 1, the ESC (blue arrow), enters the Storfjorden, where it is enriched of BSW, then outflows, canalized by the Polar Front, along the western coast of Spitsbergen towards the Arctic Ocean.

13_R#1: *Line 545. Explain what it is about brines that make them corrosive to carbonate. You have said they have high CO_2 content, which is also what the Arctic Surface waters have that enter the fjord. I think you are getting at several factors that converge to make acidic pore waters in the fjord basins one of which is brines. Clarify and organize this argument.*

Answer: please see the answer to the comment 8.

14_R#1 *In your conclusions you also mash together the brine and other factors that can cause dissolution together (Lines 595-597) but the takeaway is that the dissolution is because of the brine formation. Can you clarify this and maybe state that brines are associated with some other conditions that converge to cause dissolution?*

Answer: we already answer this comment above (see comment 8). We will further clarify in the revised version that we cannot exclude the role of other factors (such as organic matter remineralization) on calcareous test dissolution, but we have quite strong argument to say that brines certainly play a major role.

Lines 580-583.

Minor comments

- ***R#1:** 45 in the meantime*

We will modify as requested.

- ***R#1:** 105 clarify this sentence. If there is a persistent polynya then why is there extended winter sea ice cover as well?*

We will modify winter with first year sea-ice.

- ***R#1:** 138 (10 cm diameter)*

We will modify as requested.

- ***R#1:** 150 microelectrode*

We accept the modification requested.

- ***R#1:** 162 'replicate analyses' Not replicated? I find this sentence unclear. How do you know which sample is most representative?*

We will modify as requested. Since the machine measures three times the same samples and we measured two replicates for each layer, at the end we have 6 measures of the same sample. In our opinion, it is not correct to make a mean of the six samples; it is better to select the measure which is the best compromise among the six.

- ***R#1:** 166 Pb dating was. . .*

We will modify as requested.

- ***R#1:** 184 30 µg C µg phytopigment -1. Is this the correct way to state this? It is awkward*

We can say 30 µg C µg per phytopigment.

- ***R#1:** 247 describe the silt % in various samples and its range in percent. Say that 20µm is medium silt and 10 µm is fine silt.*

Slight differences are however noted in terms of the mode (approximately 10 µm, fine silt, in the fjord and 20 µm, medium silt, at the outer station MC7) and the percentage of sand which increases from approximately 4% at MC1 to 10.4% at station MC6.

Please see lines 261-264

- ***R#1:** 249 and declines to 6.8% at MC7*

We will modify as requested.

Please see line 264

- ***R#1:** 258 not lower that (n). . .have to say 'less than or equal to'. . .*

The inner fjord stations (MC1-MC3) present pH_T values generally above 7.95 whereas the deep basin stations display values less than 7.90 units (7.84 and 7.90 for MC4 and MC5 respectively).

Please see line 283

- ***R#1:** 297 Elphidium clavatum is considered to be a separate species now. See Darling et al., 2016 in Marine Micropaleo v. 129, p 1-23.*

We will modify the name in the entire text.

- ***R#1:*** *P.10 suggest you add the word living to modify foraminifera in this section. You need not do this every time, but use this modifier in the top of each section and especially in the heading so that it is clear that your total assemblage is limited to living fauna*.

If it is no too redundant for the editor, we will do this modification.

We finally decided not to add this specification because we only focus on living faunas and we think this would not be useful.

- ***R#1:*** *354 change 'distinguishes also to separate' to distinguishes*

We will modify as requested.

- ***R#1:*** *477 italicize E.*

We will modify as requested.

- ***R#1:*** *478 Melonis has been associated with degraded OM (Caralp, 1989)*

Caralp, 1989 states "A high percentage of *Melonis barleeanum* in deep-sea benthic foraminiferal assemblages is related to the availability of food in the form of abundant, little-altered, marine organic matter." We already wrote (line 511)": In the Atlantic Ocean, this species is described as opportunist in response to good quality organic matter (e.g., Nardelli et al., 2010). We will also add the citation of Caralp (1989), that supports the same.

- ***R#1:*** *479 G. auriculata is often associated with buried OM*

We will add this information about *G. auricolata*.

We added the reference of Alve, 2010 at line 545

- ***R#1:*** *533 I don't know if it is true that the most obvious explanation for the severe dissolution is the brine. You really need to build this argument. This lack of building an argument about the affect of brine and the other factors associated with Arctic water and TOC weakens the paper.*

Please refer to answer 8 in the major comments

- ***R#1:*** *540 change et to and*

We will modify as requested.

R#1: *Figures: The stacked histograms showing species at sites are really hard to read. A major problem is that the key is so small that a person cannot see the pattern. I like the idea, but it may be better to make histograms of species in each site and stack them one above the other. Or choose fewer species. For example, you could use only the species found to be statistically significant*

We prepared a bigger legend to make the textures of the legend more visible. We think that the pdf version corrected by the reviewer probably lost a bit of quality and we are sure that the texture will be understandable once the high definitions figures will be used.

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Referee #2 Shungo Kawagata

Major comments

1_*R#2:* *The paper is fairly well-written, but too long. The presentation of the results and discussions are very tedious and can be shortened considerably.*

Answer: We thank the referee for the positive comments. We will shorten the manuscript as much as possible considering also the comments of the reviewer #1, especially the discussion about the ecological preferences of the benthic species.

We shortened considerably the result and discussion chapters. Please refer to the tracked changed document uploaded to see the modifications.

2_*R#2:* *In Figure 1 (b), the longitudinal bathymetric profile should be redrawn to reflect the actual water depth. In particular, site MC3 is located at a deeper depth than sites MC1 and MC2 despite the shallowest water depth.*

Answer: We will modify the figure as requested.

3_*R#2:* *The agglutinated species composition (>150 microns) at site MC7 is similar to those of sites MC4 and MC5, but different from site MC6. The authors interpreted that the faunal similarity among sites might be caused by overflowing of the corrosive bottom water from the deep basin passing through the sills, but no explanations for the cause of faunal differences between site MC6 and others. (1) Is corrosive bottom water likely to overflow the basin without passing through site MC6, or flow out of the fjord through another path (e.g., channel)? (2) Another question arises about the possibility that basin species once carried outside the fjord have settled at the MC7 site. If so, a scenario overflowing from corrosive bottom water basins is no longer needed.*

Answer: As the results of the CCA (fig. 5) show, stations MC4, MC5 and MC6 are significantly similar, both in terms of fauna and environmental parameters. The agglutinated faunas of deep basins (MC4-MC5) and sill (MC6) stations only differ for the more abundant presence of *A. glomeratum* in this latter. We explain at lines 501-506 that the similarity with the deep basins fauna would be due to brine overflow, while the presence of *A. glomeratum* to the influence of the Atlantic Water especially during summer.

On the opposite, the fauna at station MC7 is significantly different from the others. The similarity between the agglutinated faunas of station MC7 and the deep basins and sill station is limited to the presence of *Reophax species*, but at this station the most abundant agglutinated species is *Lagenammina difflugiformis*, only marginally present in the deep basin stations. This species has been previously reported in wide environmental sets (e.g., Murray, 2006). It is often described as indifferent to organic matter supply (e.g., Alve et al., 2016; Jorissen et al., 2018) and sometimes has been reported in areas with hydro-sedimentary conditions characterized by more or less intermittent near-bottom currents (e.g., Fontanier et al., 2013). However, the most important difference concerning this station is determined by the prevalence of calcareous species and in particular the presence of two exclusive calcareous species: *Melonis barleanuum* and *Globobulimina auriculata*, indicating the strong influence of the Atlantic Water at this station.

With this in mind, we interpret the slightly different fauna of station MC6 as the result of intermittent pulses of BSW outflowing the fjord by-passing the sill during some periods of the year, and the presence of *A. glomeratum* as the evidence of seasonal influence of Atlantic waters.

We do not believe that the BSW outflow has a strong influence on station MC7. The presence of *Reophax* species at this station is more probably due to the widespread character of these agglutinated species (preference/tolerance for low quality organic matter). We do not think that a significant transport of individuals from the inner fjord to this station occurs; the common agglutinated species are quite big (up to 500µm!) and would be easily broken during transport. The silty nature of the sediments (average grain size value is about 14 µm) is clearly indicative of calm hydrodynamic environment at station MC7. Considering this, if transport happens via deep currents, it must be only minor. Moreover, no particular signs of reworking are visible on calcareous species and the same species are present in both large and small size fraction, comforting the absence of grain size sorting that could have happened via currents transport.

14_*R#2:* *The authors conclude that Agglutinated/Calcareous (A/C) proxies are possibly useful for changes in past fjord BSW intensity and sea ice production. However, the past A/C in sediments do not always reflect the marine environment at that time because agglutinated tests are more fragile than calcareous ones in general and are less likely to be preserved as fossils. How do the authors think about this?*

Answer: it is true that agglutinated tests are generally not well preserved in the fossil record. However, Rasmussen & Thomsen (2014, 2015) conducted a study on long cores from the deep basin of Storfjorden dating back to 14kyr and observed that the preservation of agglutinated tests in these environments is particularly good. This is even more reliable for shorter preservation times, as we suggest the application of the A/C proxy on historical sedimentary records (as specified in lines 31-39 and 607-609).

Please see lines 535-538

Minor comments

- **R#*2:*** n text, references and captions “and” and “&” are mixed.

We will modify as requested.

- **R#*2:*** In text, figures, Tables and captions “subsp.” is not required for “Elphidium excavatum subsp. clavatum”.

We will modify as requested.

- **R#*2:*** line 88: Publication year of “Haarpaintner et al., 2001” should be 2001a, 2001b or 2001c.

There was a tiping error. For this sentence the only reference is Polyakov et al. 2012.

- **R#*2:*** line 89: “Polyakov et al., 2012” is missing in References.

We will add the reference as requested.

- **R#*2:*** line 108: “Fer, 2004” is missing in References.

We will add the reference as requested. Fer, I., Skogseth, R. and Haugan, P. M.: Mixing of the Storfjorden overflow (Svalbard Archipelago) inferred from density overturns, J. Geophys. Res., 109(C01005), doi:10.1029/2003JC001968, 2004.

- **R#*2:*** lines 109, 120: Publication year of “Skogseth et al., 2005” should be 2005a or 2005b.

We will correct with Skogseth et al., 2004

- **R#*2:*** line 204: “Pielou Index (1975)” needs author name(s) in the bracket.

We will modify as requested.

- **R#*2:*** line 434: “Rysgaard et al., 2011” is missing in References.

We will add the reference as requested. Rysgaard, S., Bendtsen, J., Delille, B., Dieckmann, G. S., Glud, R. N., Kennedy, H., Mortensen, J., Papadimitriou, S., Thomas, D. N. and Tison, J. L.: Sea ice contribution to the air-sea CO2 exchange in the Arctic and Southern Oceans, Tellus, Ser. B Chem. Phys. Meteorol., 63(5), 823–830, doi:10.1111/j.1600-0889.2011.00571.x, 2011.

- **R#*2:*** lines 536, 841: “Schroder-Adams” should be “Schröder-Adams”.

We will modify as requested.

- **R#*2:*** line 540: “Jennings et Helgadottir, 1994 ” should be “Jennings and Helgadottir, 1994 ”.

We will modify as requested.

- **R#2:** line 662: Fer et al. (2004) is missing in the text.

The reference is cited at line 107. We will cite it again here, as suggested.

- **R#2:** line 683: Haarpaintner et al. (2001c) is missing in the text.

We will add this reference at line 68.

- **R#2:** line 704: Hunt and Corliss. (1993) is missing in the text.

We will modify as requested.

- **R#2:** line 750: Swap “Lloyd et al. (2007)” and “Lloyd (2006)”.

We will modify as requested.

- **R#2:** lines 650, 660: Separate author’s name with “and”.

We will modify as requested.

- **R#2:** Figure 4: In legend “Adercotryma glomerata” should be “Adercotryma glomeratum”, “Cribrostomoides crassimargo” should be “Labrospira crassimargo”.

We will modify as requested.

- **R#2:** Figure S1: What does the difference in the color of the profile line at each sampling point indicate?

Different replicates of profiles. We will specify in the caption.

- **R#2:** Figure S4: For the taxonomy, SEM image of *Globocassidulina subglobosa* seems to be of *Cassidulina reniforme*.

We agree with the referee #2. We revised the taxonomy of those specimens and we assigned to all of them the name of *C. reniforme*. For that reason, we will modify the figure 6, 7 and 9 based on the new assignment of the all individuals to the same species. This modification does not change anything significant to the interpretation of data.

Please see lines 565-567.

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Benthic foraminifera as tracers of brine production in Storfjorden "sea ice factory"

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Abstract. The rapid response of benthic foraminifera to environmental factors (e.g., organic matter quality and quantity, salinity, pH) and their high fossilisation potential make them promising bio-indicators for the intensity and recurrence of brine formation in Arctic seas. Such approach, however, requires a thorough knowledge of their modern ecology in such extreme settings. To this aim, seven stations along a N-S transect across the Storfjorden (Svalbard archipelago) have been sampled using an interface multicorer. This fjord is an area of intense sea ice formation characterised by the production of Brine-enriched Shelf Waters (BSW) as a result of a recurrent latent-heat polynya. Living (Rose Bengal stained) foraminiferal assemblages were analysed together with geochemical and sedimentological parameters in the top five centimetres of the sediment. Three major biozones were distinguished.~~:~~ i) T~~t~~he "inner fjord" dominated by typical glacier proximal calcareous species which opportunistically respond to fresh organic matter inputs.~~;~~ ii) T~~t~~he "deep basins and sill" characterised by glacier distal agglutinated faunas. These latter are either dominant because of the mostly refractory nature of organic matter and/or the brine persistence that hampers the growth of calcareous species and/or causes their dissolution. iii) The "outer fjord" characterised by typical North Atlantic species due to the intrusion of the North Atlantic water in the Storfjordrenna. The stressful conditions present in the "deep basins and sill" (i.e. acidic waters and low food quality) result in a high agglutinated/calcareous ratio (A/C). This supports the potential use of the A/C ratio as a proxy for brine persistence and overflow in Storfjorden.

1 Introduction

The polar regions are particularly sensitive to climate change as evidenced from the several dramatic alterations in recent decades (Peings, 2018). For instance, Arctic surface temperatures have increased at twice the global rate (i.e., Arctic amplification; Holland and Bitz, 2003; Dai et al., 2019) while sea ice cover has been steadily decreasing over recent decades both in extent and volume (IPCC, 2013; Labe et al., 2018). With less ice present, the ocean surface absorbs considerably more sunlight energy. This leads to further warming of the atmosphere and the ocean, therefore enhancing sea ice melting, which, in turn, affects marine and continental ecosystems (Perovich and Richter-Menge, 2009).

~~The short period of historical and satellite observations (~100 yrs) only opens a narrow window on the natural variability of sea ice dynamics. In this context, the uncertainties are larger than for direct measurements, and longer time series are increasingly needed to place the recent trends in a longer-term perspective (i.e., multi-centennial time-scale) (Nicolle et al., 2018).~~ A recent review study compiling several high-resolution terrestrial proxies show that the modern decline in Arctic sea ice is unprecedented since at least the last few thousand years and unexplainable by known natural variability (e.g., Kinnard et al., 2011). To better understand how and how much natural and anthropogenic forcing factors control the sea ice dynamics, there is a need for more high-resolution marine time-series covering the historical period (i.e., hundreds of years), and for robust biological proxies in key areas from the circum-Arctic. Storfjorden, a semi-enclosed bay located in the Svalbard archipelago (Fig. 1a), is one of the Arctic regions particularly suitable for studying first-year sea ice dynamics. Indeed, Skogseth et al. (2004) defined Storfjorden as an “ice factory” because of the presence of a recurrent coastal polynya that contributes to about 5-10% to the total brine waters produced on Arctic shelves (Smedsrud et al., 2006). Brines are salty and CO_2-rich waters (i.e., low pH) (Rysgaard et al., 2011) that are produced when sea ice forms in inner fjords, and for this reason they can be used as proxies for sea ice production. Because of their high density, they cascade after mixing with shelf waters (Skogseth et al., 2005a), and ventilate the deep sea (Rumohr et al., 2001). During cascading, brines may cause sedimentary disturbance as they can release down-slope turbidity flows (Rumohr et al., 2001) and, ~~at~~ in the meantime, export particulate and dissolved inorganic and organic carbon from the productive surface waters down to the seafloor (Anderson et al., 2004).

The brine contribution in maintaining the halocline of the Arctic Ocean (Aagaard et al., 1985; Cavalieri and Martin, 1994) and their influence on the ocean circulation, further underline the need to study brine evolution through recent time in relation to global warming. In fact, the current Arctic amplification will determine a decrease in the production of sea ice in several polynyas from the Arctic region (Tamura and Ohshima, 2011) and, in the future scenario of an ice-free Arctic Ocean during summer (IPCC, 2013), sea ice factories will gradually disappear. However, ~~the significance of~~ these predictions are largely based on direct observations on a short time scale (i.e., satellite data, since 1979), which –only opens a narrow window on the natural variability of sea ice dynamics. The scientific community is now focusing on longer time series to place the recent trends in a longer-term perspective (i.e., multi-centennial time-scale) (Nicolle et al., 2018) and validate these scenarios.

Benthic foraminifera are among the most abundant protists living in marine ecosystems, from brackish waters to abyssal plains (e.g., Murray, 2006). Due to their short life cycle, high diversity and specific ecological requirements, they respond quickly to the physicochemical environmental conditions (e.g., organic inputs, oxygenation, pH) by increasing their density (e.g., Kitazato et al., 2000), changing the faunal composition or modifying their microhabitat (Jorissen et al., 1995; Ohga and Kitazato, 1997). Therefore, benthic foraminifera are potentially good proxies directly for brine waters that bathe the deep-sea A~~a~~rctic environments, and, indirectly, for sea ice production. The existing benthic foraminiferal-based studies in Storfjorden used fossil faunas to interpret late Quaternary paleoenvironmental changes (Rasmussen and Thomsen, 2009, 2014, 2015). Although highlighting major difficulties in the interpretation of most of these paleorecords without modern proxy calibrations, those studies further suggested the ratio of agglutinated to calcareous benthic foraminifera as a potential proxy for brine changes. Living foraminiferal distributions have been, however, studied in several Svalbard fjords, in particular in relation to the distance from ~~continental~~tidewater glaciers and the associated sedimentary supply (Hansen and Knudsen, 1995; Korsun et al., 1995; Hald and Korsun, 1997; Korsun and Hald, 2000; Sabbatini et al., 2007; Ivanova et al., 2008; Forwick et al., 2010; Zajaczkowski et al., 2010; Łącka and Zajączkowski, 2016; Jernas et al., 2018). To our knowledge, none of these studies targeted the influence of Brine-enriched Shelf Waters (BSW).

To develop a robust biological marine proxy of environmental variation based on communities of benthic fossil foraminifera, it is beforehand crucial to well constrain their modern ecology in this specific environment. To provide new insights on this issue, here we investigate living (rose Bengal stained) benthic foraminiferal faunas from Storfjorden and their response to various measured environmental variables (e.g. sediment characteristics, organic matter quantity and composition, sediment oxygen and pH micro-profiles) that are further linked with BSW. Furthermore, the interpretation of our results integrates the extended literature of the physical oceanography in this specific semi-enclosed bay (e.g., Haarpaintner et al., 2001a, 2001b, 2001c; Omar et al., 2005; Skogseth et al., 2004, 2005a, 2005b, 2008; Geyer et al., 2009; Jardon et al., 2014).

2 Oceanographic and environmental settings

The Svalbard archipelago, located north of the Arctic circle, extends from 74° N to 81° N and 10° E to 35° E (Fig. 1a). It is surrounded by the Arctic Ocean to the north, the Barents Sea to the south and east, and the Norwegian-Greenland Sea to the west. Storfjorden, the biggest fjord in the Svalbard archipelago, is approximately 190 km long with a maximum water depth of ~190 m present in a central deep glacial trough (referred to as deep basins in Fig. 1b). The northern Storfjorden (i.e., inner fjord; Fig. 1b) is connected with the northwestern Barents Sea by two sounds (Heleysundet and Freemansundet) through where relatively energetic tidal exchanges occur (McPhee et al., 2013). To the south, a sill (77°N-19°E) about 120 m deep separates the inner Storfjorden and the deep basins from the outer Storfjorden trough (Storfjordrenna) (Fig. 1a), a 200-300 m deep glacial paleo-valley that incised the western Barents Sea continental margin during previous sea level low-stands (Pedrosa et al., 2011).

The Svalbard archipelago is influenced by two major water masses. Along the eastern and southern margin of Svalbard, cold and relatively low saline Arctic waters flow out from the Barents Sea via the East Spitsbergen Current (ESC) (Fig. 1a). In the eastern Norwegian-Greenland Sea, the main stream of Atlantic Water which is the most important source of heat and salty water into the Arctic Ocean, is carried northwards by the Norwegian Atlantic Current (NAC) (Fig. 1a). North of Norway, the NAC splits into two branches: i) the Norwegian Current (NC, or Norwegian Coastal Current) that enters the Barents Sea eastward around 70°N (not shown in Fig.1a) along the northern coast of Norway, and ii) the West Spitsbergen Current (WSC) that flows northwards along the western Svalbard coast towards the Fram Strait (Schauer, 1995). Recent studies report fluctuations in heat transport to the Arctic Ocean by the WSC in particular in link with global climate changes (e.g., Holliday et al., 2008; Piechura and Walczowski 2009; Beszczynska-Moller et al., 2012). This current is playing a significant role in the process of recent Arctic warming~~,~~ by influencing the sea ~~-~~ice distribution and cover in Svalbard (~~Haarpaintner et al., 2001;~~ Polyakov et al., 2012).

The water masses in Storfjorden have two main origins: warm Atlantic waters and cold Arctic waters. These are mostly separated by the location of the polar front that shifts seasonally and ~~conditions~~ influences therefore the northward or southward position of these water masses (Loeng, 1991) (Fig. 1a). The warm Atlantic surface waters carried by the NAC enter the Storfjordrenna from the southwest (Wekerle et al., 2016) (Fig. 1a). During spring-summer, this latter flows into Storfjorden along its eastern margin following a cyclonic circulation (Nielsen and Rasmussen, 2018; Piechura and Walczowski, 2009). The cold Arctic waters derived from the ESC enter Storfjorden from the east through narrow topographic gateways (Heleysundet and Freemansundet sounds), and the topographic depression north of Storfjordbanken (Fig. 1a). This Arctic water circulates cyclonically through the fjord, flowing southwards along the western Storfjorden coast and continues northwards as a coastal current along with the west Spitsbergen coast (Nielsen and Rasmussen, 2018; Rasmussen and Thomsen, 2015). ~~-~~Vertically, water masses are usually arranged in three main layers within an Arctic fjord with a sill (Farmer and Freeland 1983): a relatively fresh surface layer, a deep and saline layer below the sill depth, and an intermediate layer in between (Fig. 1b). Profiles from late summer in Storfjorden show a well-mixed fresh surface layer extending down to 40 m depth separated from the intermediate layer (comprising advected Atlantic Water) by a steep halocline. The deepest layer, which sits below the sill depth, is a cold and saline water mass derived from trapped brines (e.g., Skogseth et al., 2005a; Cottier et al., 2010; Rasmussen and Thomsen, 2015).

The shelf sea in the Storfjorden is characterised by an extended winter first year sea ice cover due to the presence of a recurrent winter coastal latent-heat polynya mostly located in the northeast part (Skogseth et al., 2004). These are ice-free areas formed and maintained by advection of ice by off-shore winds, tidal and ocean currents. The presence of northerly winds allows the developing of the polynya, while southerly winds ~~make~~cause the polynya to shrink~~s~~, which makes the extension and the position of the polynya highly variable (Haarpaintner et al., 2001b). The opening of a latent-heat polynya determines an intensive heat loss to the atmosphere that can lead to a persistent ice formation (Fer et al., 2004; Skogseth et al., 2005a). Polynya particularly occurs when north-easterly winds intensify in winter (Skogseth et al., 2004~~5~~). The continuous production of thin, first-year sea ice, which generally starts in December (Smedsrud et al., 2006), ~~-~~leads to a subsequent formation of brine waters in Storfjorden. Brines are cold, dense and well oxygenated waters, enriched in salt and~~,~~ total dissolved inorganic carbon (DIC) (i.e., low pH), that are rejected in under-sea ice waters when sea ice is formed (Rysgaard et al., 2011; Anderson et al., 2004). The shelf convection promotes the mixing of brines with shelf waters, leading to the formation of Brine-enriched Shelf Waters (BSW). In the early winter freezing period, the extremely dense BSW sink, filling the deeper basins and pushing the less dense waters above the sill level causing a weak overflow (Skogseth et al. 2005a) (Fig.1b). During winter the low temperature causes a brine volume contraction and a decrease in the sea ice permeability that prevents the air-sea ice gas exchange; brine volume contraction causes a further increase of brine salinity and $CO_{2(aq)}$ (Rysgaard et al., 2011). The continuous freezing in spring causes the accumulation of BSW in the deep basins and a strong steady overflow period over the sill. Although weaker, the overflow continues even in summer after the end of the freezing period. At the meantime, the fresh melting surface water is warmed by surface heating (Skogseth et al., 2005a). During spring and summer, the ice melting reduces $CO_{2(aq)}$ (Rysgaard et al., 2011) and the increase of light availability (Horner and Schrader, 1982) triggers ice algae photosynthetic activity which further reduces DIC concentrations of surface waters (Gleitz et al.,1995). In autumn, surface waters lose heat and become colder. At this time, the old BSW are trapped in the deep basins, but strong wind events cause occasional discharges over the sill (Skogseth et al., 2005a) (Fig. 1b). The entire Arctic coastal polynyas produce about 0.7-1.2 Sv (1 Sv = 10^6 m^3/s) of BSW (Cavalieri and Martin, 1994) providing about 10% of the deep water formed in the Arctic Ocean and Barents Sea today (Smethie et al., 1986; Quadfasel et al., 1988; Rudels and Quadfasel, 1991). Storfjorden is a major supplier of BSW, producing alone 5-10% of the dense water in the Arctic Ocean (Quadfasel et al., 1988; Skogseth et al., 2004).

Spitsbergen is characterized by the presence of several tidewater glaciers influencing the head of the Storfjorden (see figure 9 in Lydersen et al., 2014). The ongoing climate warming is causing~~determineding~~ the retreat of several glaciers present on Svalbard in the last 100 years, increasing sediment supply and accumulation (Zajaczkowski et al., 2004). In this context, Winkelmann and Knies (2005) classified the inner Storfjorden as a low-energetic environment characterised by high sedimentation rates and organic-rich sediments (total organic carbon content (TOC) >2%) with high proportion of terrestrial component.

3 Material and Methods

3.1 Interface sediment sampling and CTD profiles

In July 2016, seven stations were sampled along a N-S transect in Storfjorden (Fig. 1a, Table 1) during the STeP (Storfjorden Polynya Multidisciplinary Study) cruise onboard the R/V *L'Atalante* (IFREMER). Stations MC1 to MC3 are positioned on the continental shelf at the head of the fjord, stations MC4 and MC5 are located in the deep central basins, station MC6~~ is located~~ on the sill, and station MC7 ~~is located ~~in Storfjordrenna (Fig. 1a, Table 1). At each station, 10 to 40 cm long sediment cores were sampled using a multicorer (10 cm ~~Ø~~inner diameter) in order to get undisturbed sediment-water interfaces. Three replicate cores were sampled at each station (except for station MC3 where only two cores were collected): the first core for geochemical analysis (oxygen, pH and porosity profiles), the second one for $^{210}Pb_{xs}$ dating, grain size, phytopigment and organic matter analyses, and the third one for foraminiferal analysis.

In order to determine the main environmental characteristics of each site, hydrographic casts were performed with a Conductivity-Temperature-Depth (Seabird 911 plus CTD) equipped with a fluorometer. A rosette sampler supplied with 22*12-L Niskin bottles was used for water-column sampling. Bottles were fired at standard depths to measure oxygen, nutrients and Chlorophyll-*a*.

3.2 Geochemical analyses

Immediately after the recovery of sediment cores, oxygen and pH microprofiles have been measured at the sediment-water interface. We used a micromanipulator that can drive O_2 and pH microelectrodes (Unisense®) at the same time with a 200 µm vertical resolution. Oxygen profiles were performed using Clark-type microelectrodes with a 100 µm thick tip (Revsbech 1989), while pH profiles were measured using a glass microelectrode~~s~~ with a 200 µm thick tip. The O_2 concentration of bottom water was analysed by Winkler Titration (Grasshoff et al. 1983). At each station, triplicate samples were analysed with a reproducibility of ± 2 µmol L^{-1}. The pH microelectrodes were calibrated using NBS buffer solutions (pH 4, 7 and 10). The pH of bottom water was also determined by spectrophotometry using mCresol Purple as dye (Dickson et al. 2007). All pH measurements were recalculated at *in situ* temperature, salinity and depth using CO2SYS (Pierrot et al., 2006) and were reported on the total proton scale (pH_T). The measurements for both O_2 and pH profiles, were repeated many times in order to assess the reproducibility of the measurements and the natural heterogeneity of these parameters in the sediment.

3.3 ^{210}Pb dating and grain size analysis

At each station (except for the MC3), one core was sliced on board collecting five sediment layers (0-0.5, 0.5-1, 1-2, 2-5 and 5-10 cm), then stored at -20°C. In the land-based laboratory, an aliquot of sediment was sampled for grain-size analyses and the rest was lyophilised for the $^{210}Pb_{xs}$ analyses. Grain-size analyses were performed using the laser diffraction particle size analyser Malvern Mastersizer 3000. The particle-size distributions were analysed with GRADISTAT 8.0 software program (Blott and Pye, 2001). ~~The~~ R~~r~~eplicated~~d~~ analyses were run for each sample aliquot and the most representative was selected. For the analysis of faunas in response to environmental parameters, the grain size of the superficial sediment layer (0.0-0.5 cm depth) was considered as representative of the sediment-water interface characteristics. Another aliquot of sediment was freeze-dried for gamma spectrometry measurements in order to determine the apparent sedimentation rate by the $^{210}Pb_{xs}$ method (Appleby and Oldfield, 1978). ^{210}Pb dating ~~have been~~was conducted using a gamma spectrometer Canberra® HPGe GX4520 coaxial photon detector. The homogenised samples were weighed and sealed in a defined geometry for at least three weeks to ensure $^{222}Rn/^{226}Ra/^{214}Pb$ equilibration. Sedimentation rate was based on the determination of the excess or unsupported activity ^{210}Pb ($^{210}Pb_{xs}$) and performed through constant flux - constant sedimentation (CFCS) model (Sanchez-Cabeza and Ruiz-Fernández, 2012). $^{210}Pb_{xs}$, incorporated rapidly into the sediment from atmospheric fallout and water column scavenging was calculated as the difference between the total measured ^{210}Pb activity (supported + excess) at 46.54 keV and ^{214}Pb at 351.93 keV.

3.4 Organic matter quantity and biochemical composition

To assess the quantity and biochemical composition of the organic matter, the top half centimetre of the sediment cores was sliced on board and immediately stored at -20°C until analysis. As the redox fronts and foraminiferal microhabitats in the sediment are strictly driven by the organic matter supply at the sediment-water interface (e.g., Jorissen et al.,1995), only the organic matter data for the first upper half centimetre were used to interpret the faunal distribution.

In the laboratory, chlorophyll-*a*, phaeopigment, lipid, carbohydrate and protein contents were determined on three pseudo-replicates (ca. 1 g wet sediment). Chlorophyll-*a* and phaeopigment analyses were carried out according to Lorenzen and Jeffrey (1980). Briefly, pigments were extracted with 90% acetone (12 h in the dark at 4°C). After the extraction, the pigments were fluorometrically analysed to estimate the quantity of Chl-*a* and, after acidification (20 s) with 0.1 N HCl (Plante-Cuny, 1974), to estimate the amount of phaeopigments. Chloroplastic pigment equivalents (CPE) were calculated as sum of Chl-*a* and phaeopigment contents, and carbon associated with CPE (C-CPE) was calculated by converting CPE contents into carbon equivalents using a factor of 30µgC per µg of phytopigment~~$^{-1}$~~ (de Jonge, 1980). Protein, carbohydrate and lipid sedimentary contents were determined by spectrophotometry (Danovaro, 2009) and concentrations reported as bovine serum albumin, glucose and tripalmitin equivalents (mg per gram of dry weight sediment), respectively. Protein, carbohydrate and lipid concentrations were converted into carbon equivalents using the conversion factors 0.49, 0.40 and 0.75 g C g^{-1}, respectively (Fabiano et al., 1995). The sum of protein, carbohydrate and lipid carbon was referred to as biopolymeric Carbon (BPC; Tselepides et al., 2000) that represents the semi-labile fraction of the total organic carbon (Pusceddu et al., 2009; Van Oevelen et al., 2011). The algal fraction of biopolymeric C, proxy for the most labile fraction of sedimentary organic matter (Danovaro and Pusceddu, 2003; Pusceddu et al., 2010) was calculated as the percentage ratio of CCPE on BPC.

3.5 Living foraminiferal fauna sampling and analyses

Immediately after sampling, interface cores were sliced horizontally every 0.5 cm between 0 and 2 cm, every 1 cm from 2 down to 6 cm, and every 2 cm from 6 to 10 cm depth. Each slice was stored in a 500 cm^3 plastic bottle filled with 95% ethanol containing 2 g L^{-1} of Rose Bengal stain (in order to label living foraminifera) following the FOBIMO directive (Schönfeld et al., 2012). In the laboratory, sediment samples were sieved through 63, 125 and 150 µm meshes and the resulting fractions were stored in 95% ethanol. All living (Rose Bengal stained) specimens from the >150 µm fraction were hand-picked in water from the surface layer down to 5 cm depth. Additionally, the living foraminifera of the 63-150 µm fraction were picked only for the first centimetre of sediment, in order to investigate the potential use of this size fraction for ecological consideration. We counted as living foraminifera only the specimens with bright rose staining (assessing the coloration intensity of living specimens for every individual species, as recommended by Schönfeld et al.~~,~~ (2012)).

Samples of the smallest size fraction, showing very high benthic foraminiferal abundance, were dried at 50°C and split with an Otto Microsplitter. Then foraminifera were hand-sorted from an entire split containing a minimum of 300 individuals and the counts were extrapolated for the total sample. Foraminiferal biodiversity was estimated using different diversity indices: species richness (S) measured as the number of species, species diversity ~~(H $\log_e$)~~ measure using the ~~measured by the~~ Shannon–Wiener Index (~~(~~H') ~~information function~~ and species equitability~~evenness~~ (J) measured using the "Pielou Index (1975)". All indices were calculated using the Paleontological Statistics Data Analysis (PAST) software (version 2.17c;

Hammer et al., 2001). Foraminiferal densities are expressed per 50 cm^2 (when considering total densities) and per 50 cm^3 ~~volume~~ (when considering layers of different thickness). The agglutinated species *Spiroplectammina earlandi* and *Spiroplectammina biformis* were not distinguished because these are morphotypes of the same species according to Korsun and Hald (2000).

3.6 Multivariate analyses

A Canonical Correspondence Analysis (CCA) was used to investigate the relationships between the environmental parameters (depth, bottom water temperature, salinity, oxygen penetration depth (OPD), sediment porewater pH, sediment grain size and organic matter) and the faunas (>150 µm, 0-5 cm) of all stations considering only the absolute densities (ind. 50 cm^{-2}) of the species which contribute with >5% to the assemblage. We used the grain size characteristics and the organic matter contents and composition of the uppermost sediment layer (0.0-0.5 cm). Values of different environmental variables and different orders of magnitude were homogenised using the following standardisation: *(x-mean x)/sd*, in which *x* is the value of the variable in one station, *mean x* is the mean of the same variable among the stations and *sd* is the corresponding standard deviation.

Non-metric multidimensional scaling (nMDS) bi-plot~~s~~ and cluster analysis (Bray-Curtis similarity) were used to visualize the differences among~~between~~ stations and ~~-~~size fractions. The analyses were conducted on the foraminiferal assemblages of the topmost centimetre of sediment considering separately the smaller fraction 63-150 µm, the >150 µm fraction and the total assemblage (>63 µm fraction).

The densities of the foraminiferal faunas were normalised using the following transformation: $Log_{10}(x+1)$, where *x* is the density expressed in ind. 50 cm^{-2} (considering the 0-5 cm sediment interval for the CCA and the 0-1 cm interval for the nMDS and cluster analysis). All ~~these multivariate~~ analyses were performed using the PAST software (version 2.17c; Hammer et al., 2001).

3.7 Visual characterisation of test dissolution

Using high-resolution SEM images of specimens from the >150 µm size fraction (Fig. S2), we qualitatively distinguish four dissolution stages from weak to severe, following the classification of Gonzales et al. (2017): ~~stage~~ I) no sign of dissolution, transparent tests and smooth surfaces; ~~stage~~ II) whitish tests with visible pores, and frequently, the last chamber is lost as well as the first calcite layers; ~~stage~~ III) several chambers are dissolved and the remaining ones present opaque wall tests; ~~stage~~ IV) nearly complete dissolution of the tests and only the organic material remains. The percentages of specimens belonging to each of the four stages in all samples were not quantified because of the potential loss of information due to the bad preservation characterising the two most severe dissolution stages.

4 Results

4.1 Bottom water properties

In July 2016, bottom waters at the inner fjord stations MC1 and MC2 are cold (below -1.5°C) and relatively salty (34.89 and 34.79 respectively), while station MC3 presents a positive bottom water temperature (1.10°C), the lowest salinity (34.74) and the highest pH$_T$ (8.12) and O$_2$ (350 µmol.L^{-1}) of the fjord transect (Table 1). The two deep basin stations (MC4 and MC5) display the lowest bottom water temperature (both -1.78 °C), the lowest pH$_T$ (7.92 and 7.91, respectively) and the highest salinity (34.92 and 34.93, respectively) (Table 1). The sill station MC6 shows the same range of salinity than in the inner fjord (34.80) with a slightly higher temperature (-1.13°C). The outer fjord station MC7 records the highest temperature (3.53°C) and salinity (35.05) of the sampled transect. The shallowest stations (MC1 and MC3) are well ventilated with O$_2$ concentration higher than 340 µmol L^{-1}. Stations MC2, MC4, MC5 and MC6 show the same bottom water O$_2$ concentration (318 ± 2 µmol L^{-1}). The deepest station (MC7) located outside Storfjorden shows a lower O$_2$ concentration (305 µmol L^{-1}).

4.2 ^{210}Pb dating and grain size analyses

The ^{210}Pb age models show a relatively high sedimentation rate at all stations with an average of 3.6 ± 0.4 mm yr^{-1} (see supplementary materials Table S1 for more details), except at the outer fjord station MC7 where sedimentation rate is much lower (1.3 ± 0.6 mm yr^{-1}; Table S1).

Grain size analyses of the topmost half centimetre of the sediment indicate the dominance of~~presence of fine~~ silt ~~-~~sediments at all stations (around 84 to 89 %, Table S1). Slight differences are however noted in terms of the mode: in the fjord fine silt (~10 µm) is dominant while in the outer station MC7 the mode corresponds to medium silt (~20 µm). Moreover, ~~–~~ the percentage of sand ~~which~~ increases from approximately 4.0% at MC1 to 10.4% at station MC6 and declines to 6.8% at MC7.

4.3 Biogeochemical analyses of the sediment

The sediment oxygen profiles (Fig. S1a) at the inner fjord stations (MC1-MC3) display an average oxygen penetration depth (OPD) of 7.7 ± 1.0 mm (n = 3), 4.9 ± 0.4 mm (n = 4) and 4.8 ± 1.9 mm (n = 6), respectively. The OPD at the deep basin stations (MC4 and MC5) and at the sill station (MC6), are 5.7 ± 1.1 mm (n = 3),~~;~~ 6.2 ± 0.9 (n = 10) and~~;~~ 8.6 ± 3.8 (n = 6), respectively. The outer fjord station (MC7) shows the highest OPD of the sampled transect (15.6 ± 1.0 mm, n = 6).
~~In order to better highlight the differences in~~The porewater pH$_T$ ~~(pH~~ (pH profiles in~~;~~ Fig. S1b) ~~.~~is significantly different among~~between~~ the stations (~~, we conducted a~~ one-way ANOVA, ~~on the pH$_T$ values found at the sediment-water interface (based on pH profiles; Fig. S1b). This analysis shows significant differences among the stations (~~F = 128.8, p < 0.001). The inner fjord stations (MC1-MC3), ~~and~~ the sill (MC6) and outer fjord ~~stations (MC6 and~~ MC7) ~~present~~ have pH$_T$ values generally above 7.95~~–~~, significantly different (Tukey HSD, p < 0.001) from ~~whereas~~ the deep basin stations, ~~which~~ displaying values ~~lower that~~less than or equal to 7.90 units~~(Tukey HSD, p < 0.001). ((7.84 and 7.90 for MC4 and MC5 respectively)~~. ~~The pH$_T$ at the sill station (MC6) is 7.98, while at the outer fjord station (MC7) pH$_T$ is 8.00.Tukey HSD test~~

~~shows that station MC3 presents a porewater pH$_T$ value significantly higher than all the other stations ($p < 0.001$), whereas the two deep basin stations MC4 and MC5 are characterised by the lowest porewater pH values ($p < 0.001$).~~ When considering the entire profiles, pH strongly decreases in the topmost part of the sediment (0-5 mm) at all stations but with different slopes. ~~In fact~~The two extremes gradients are~~,~~ ~~the strongest pH gradient is observed at the MC3 station (~~-0.2 pH unit mm^{-1} at station MC3 and ~~). By contrast, the pH decrease at the outer fjord station MC7 is the slowest found in the transect (~~-0.1 pH unit mm^{-1}~~)~~ at MC7 (see Fig. S2b).

Concerning the organic matter, the results for BPC, PRT, CHO, CPE content and algal fraction of BPC (C-CPE/BPC) are presented in Fig. 2. The complete dataset is reported as average ± standard deviation ($n = 3$) in Table S2. The BPC (Fig. 2a) varies significantly among the stations (one-way ANOVA, $F = 21.72$, $p < 0.001$). Stations MC1 and MC7 have values of BPC significantly lower (5.49 ± 0.49 mgC g^{-1} and 4.71 ± 0.07 mgC g^{-1} respectively, $p < 0.05$) than at all other stations. In these latter, the average BPC varies between 6.86 ± 0.45 mgC g^{-1} and 7.38 ± 0.21 mgC g^{-1}. The PRT contents (%) (Fig. 2a) of the BPC varies significantly among the stations (One-way ANOVA, $F = 6.94$, $p < 0.01$). In particular the deep basins present significantly lower percentages of PRT compared to all the other stations (32.12 ± 4.42 % at MC4 and 30.75 ± 4~~1~~.~~69~~58 at MC5; $p < 0.01$). The CHO contents (%) (Fig. 2a) change significantly among the stations (One-way ANOVA, $F = 46.6$, $p < 0.001$), displaying the highest scores in the deep basins (33.79 ± 1.71 % and 36.08 ± 2.52 % at MC4 and MC5 respectively). The CPE (Fig. 2b) varies significantly among the stations (one-way ANOVA, $F = 52.03$, $p < 0.001$). CPE content is considerably lower in the outer fjord station MC7 (6.43 ± 0.45 µg g^{-}1) compared to all other stations ($p < 0.001$). Inside the fjord, station MC1 differs from MC2 with values of 24.04 ± 3.69 µg g^{-1} and 41.19 ± 9.62 µg g^{-1} respectively ($p = 0.02$), whereas all other CPE contents present intermediate values~~ around 35.03 ± 1.66 µg g^{-1}~~. The C-CPE/BPC (Fig. 2b) in the uppermost half centimetre varies significantly among the stations (one-way ANOVA, $F = 76.82$, $p < 0.001$). In particular, the algal fraction is significantly lower in the outer fjord station MC7 (4.09 ± 0.33%) compared to all other stations ($p < 0.001$). On the contrary, all the stations inside the fjord do not differ significantly and have values between 13% and 17%.

4.4 Foraminiferal assemblages of the 0-5 cm sediment layer (>150 µm fraction)

4.4.1 Abundances and diversity

Considering the total foraminiferal faunas in the 0-5 cm sediment interval (Table 2), the highest absolute abundance is displayed at the inner fjord station MC2 (2249 ind. 50 cm^{-2}) whereas it is reduced by about half at the other two inner fjord stations (1104 and 1353 ind. 50 cm^{-2}at MC1 and MC3 respectively). The absolute abundance increases in the deep basin stations (1861 and 1439 ind. 50 cm^{-2} at MC4 and MC5 respectively) and drastically declines at the sill station MC6 reaching the lowest abundance detected in the transect (940 ind. 50 cm^{-2}). At the outer fjord station MC7, the total absolute abundance is 1238 ind. 50 cm^{-2}.

Both the inner fjord stations MC1 and MC2 present the same number of species (27) (Table 2), and similar Shannon-Wiener index (H' = 1.61 and 1.48) and equitability (J = 0.49 and 0.45). The third inner fjord station MC3 is characterised by the lowest diversity (19 species and H' = 0.92) and the lowest equitability (J = 0.31) whereas the deep basin stations MC4 and MC5 show relative high H' (2.25 and 2.35, respectively) and J values (0.62 and 0.70, respectively). The sill station MC6 shows similar H' and J values compared with the deep basin stations (2.18 and 0.65 respectively). The outer fjord station MC7 shows the highest number of species (44) and H' index (2.40).

In terms of species composition (Fig. 3a), the inner fjord stations are mainly dominated by two calcareous species: *Elphidium* ~~*excavatum subsp.*~~ *clavatum* contributing for 22, 47 and 75% of the total fauna and *Nonionellina labradorica* for 51, 31 and 13% at MC1, MC2 and MC3, respectively. ~~It can be noted that *E. excavatum subsp. clavatum* is predominant at MC2 and MC3 in contrast with the prevalence of *N. labradorica* at MC1.~~ *Cassidulina reniforme* is a secondary species at station MC1 (10%) and *Elphidium bartletti* ~~is a secondary species~~ at station MC2 (8%)~~ however it contributes for less than 2% at the two other inner fjord stations~~. The deep basin stations (MC4 and MC5) are dominated by various agglutinated species that contributes differently to the total assemblages. The most abundant are ~~The relative abundance of~~ *Recurvoides turbinatus* ~~varies from~~ (12 and~~to~~ 18%, respectively at MC4 and MC5), *Reophax fusiformis* ~~from~~ (13 ~~to~~ and 10%) and *Reophax scorpiurus* ~~from f~~(27 ~~to~~ and 17%)~~, at MC4 and MC5 respectively~~. ~~Both~~ *Ammotium cassis* and *Labrospira crassimargo* are less ~~numerous~~ abundant at MC4 compared to MC5 (2 and 11% for *A. cassis* and 6 and 11% for *L. crassimargo* respectively). Additionally, ~~Th~~the calcareous *N.*~~*onionellina*~~ *labradorica* is still quite abundant ~~at MC4~~ (20% at MC4 and ~~) but less at MC5 (~~8% at MC5). The sill station MC6 shows similarity with the deep basin stations because of the presence of the agglutinated *R. turbinatus* (10%) and *R. fusiformis* (24%) but it differs by the presence of the agglutinated *Adercotryma glomeratum* (29%). The outer fjord station (MC7) can be distinguished from all other stations by the exclusive presence of the two calcareous species *Globobulimina auriculata* and *Melonis barleeanus* (9 and 12% respectively) and by the major contribution of the agglutinated species *Lagenammina difflugiformis* (14%). Nevertheless, some species which are abundant inside the fjord are also present at station MC7 (e.g., *N. labradorica* 25%, *R. fusiformis* 6% and *R. scorpiurus* 15%).

4.4.2 Agglutinated vs calcareous foraminifera (0-5 cm, >150 µm)

The comparison between the relative abundances of calcareous and agglutinated species, considering the total living faunas in the 0-5 cm sediment interval (Fig. 3b), shows the strong dominance of calcareous species (between 91 and 94%) in the inner fjord stations (MC1, MC2 and MC3). The opposite is observed in the two deep basin stations (MC4 and MC5) and in the sill station (MC6) where the relative abundances of agglutinated foraminifera vary from 65 to 77%. In the outer fjord station, MC7, calcareous species have higher proportions (60%) although they are not as dominant as at the inner fjord stations.

4.4.3 Vertical distribution

The foraminiferal absolute density displays an overall decreasing trend from the surface sediment down to 5 cm depth at all stations (F~~f~~ig. 4)~~, ~~. T~~In t~~he superficial layers (0-1 cm) of the inner fjord stations (MC1, MC2, MC3; Fig. 4a) ~~superficial~~

~~layers (0-1 cm)~~ are mostly represented by *Elphidium~~.~~ clavatum* ~~(MC1, MC2, MC3)~~, *Cassidulina reniforme* (especially at ~~in~~ MC1), *Nonionellina labradorica* ~~–~~and other accessory species (e.g., *Triloculina oblo~~u~~nga*, *Elphidium bartletti*, *Ammotium cassis*). The deeper layers (down to 5 cm) show much lower abundances and are increasingly occupied by *Nonionellina labradorica*.

~~except for the outer fjord station MC7 showing a peak at the 3-4 cm sediment interval, mainly determined by the calcareous species *Nonionellina labradorica* (Fig. 4). At the inner fjord station MC1, the foraminiferal assemblage in the top half centimetre is mainly constituted of three species: *Cassidulina reniforme* (~28%), *Elphidium excavatum subsp. clavatum* (~36%) and *Triloculina oblonga* (~17%) (Fig. 4a). From 0.5 cm down to 4 cm depth, *N. labradorica* is the dominant species. At the two other inner fjord stations (MC2 and MC3), the topmost half centimetre is dominated by *E. excavatum subsp. clavatum* (~66% and ~89%, respectively). At the MC2 station, the abundance of this species decreases in the deeper layers whereas *N. labradorica*'s density increases. The MC3 foraminiferal density strongly decreases in the second half centimetre, from ~1830 to ~270 ind.50 cm^{-3} and the fauna is dominated by *E. excavatum subsp. clavatum* in both sediment layers (~89% in the 0.0-0.5 cm layer and ~57% in the 0.5-1.0 cm layer). The deeper layers (from 1.5 to 5 cm) show very low abundances (<100 ind. 50cm^{-3}), mainly represented by *N. labradorica* and *E. excavatum subsp. clavatum*.~~

In the two deep basins (MC4 and MC5; Fig. 4b), ~~three~~ four agglutinated species are dominant in the first ~~half~~ centimetre of sediment: *Reophax scorpiurus*, *Reophax fusiformis*, ~~and~~ *Recurvoides turbinatus*~~,~~ ~~(respectively ~29, 15 and 15% at MC4, and ~20, 10 and 26% at MC5). The fourth agglutinated species~~ and *Labrospira crassimargo*. ~~shows a high density in the first half centimetre at MC5 (~16%) and is less abundant at MC4 (~5%). In the second half centimetre of the sediment at station MC4, a similar species composition to that in the upper half centimetre is present (*R. scorpiurus* 36%, *R. fusiformis* 23% and *R. turbinatus* 10%) but in much lower absolute abundances (~681 ind.50cm^{-3}).~~

At both stations~~this station~~, the infaunal species *N. labradorica* is present in high relative abundance ~~(~57%)~~ in the 1-~~2~~ 3 cm sediment intervals, together with *Nonionella digitata*. While i~~I~~n the deepest sediment layers (3-5 cm), *L. crassimargo*, *R. scorpiurus*. and *R. turbinatus* are dominant. ~~Similarly, the 0.5-1 cm sediment layer at station MC5 is dominated by the same agglutinated species as those in the topmost layer (*R. scorpiurus* ~16%, *R. fusiformis* ~15%, *R. turbinatus* ~11%). In addition, *Ammotium cassis* (~37%), *L. crassimargo* (~7%) and *Lagenammina difflugiformis* (~5%) are found. The dominance of *Nonionella digitata* and *N. labradorica* characterises the intermediate infaunal microhabitat from 1.5 cm to 3 cm depth. Here again, the deeper layers (3 – 5 cm) are dominated by the same agglutinated species as in the topmost layers.~~

At the sill station MC6, the dominant species present in the uppermost centimetre are *R. fusiformis* ~~(~38%)~~, *R. turbinatus* ~~(~16%)~~ and *Adercotryma glomeratum* ~~(~16%)~~ (Fig. 4b). These species are also present ~~in~~with important ~~numbers~~abundances in the deeper layers ~~and~~ where they are accompanied by ~~This later species is also present in relatively high abundances in the deeper sediment layers, from ~29% (in the 1.0-1.5 cm layer) to ~51% (in the 4-5 cm layer), together with~~ *N. labradorica* ~~(~20%~~ at the ~~at~~ 1~~-~~-3 cm depth intervals. ~~)~~ ~~, and *Reophax* spp. (~14 to 30% at 1-5 cm depth).~~ At the outer fjord station MC7, the 0~~.0-0.5~~-1 cm sediment intervals show~~s~~ a dominance of *R. scorpiurus* ~~(~29%)~~, *R. fusiformis* ~~(~11%)~~ and *L. difflugiformis* ~~(~22%)~~ (Fig. 4c). In the deeper layers, ~~In From 1-3 cmthe second half centimetre, t~~these species are accompanied and gradually replaced by significant abundances of the calcareous species *Melonis barleeanus* ~~(~18%). This species shows subsurface peaks (~58 and 49% in the 1.0-1.5 cm and 1.5-2.0 cm layers respectively).~~ and ~~From 1 to 5 cm depth, we observe the increasing presence of~~ *Globobulimina auriculata* ~~(~14 to 34%).~~ ~~(down to 5 cm depth)~~.

4.4.4 Multivariate analysis

The CCA analysis based on the foraminiferal data (0-5 cm, > 150 µm, total absolute densities of 15 species, with a relative abundance > 5%) and 15 measured environmental variables, is presented in Fig. 5. Axes 1 and 2 explain nearly 90% of the total variance. This multivariate analysis clearly divides the stations into three groups based on the differences determined by the foraminiferal assemblages and the environmental variables. Axis 1 strongly separates station MC7 from the rest of the stations. This difference is mainly determined by bottom water parameters (T, S, pH), OPD, percentage of silt and water depth. The negative correlation between the outer fjord station MC7 and the CPE content and algal fraction ~~contributes also to separate~~distinguishes it from all other stations. Axis 2 clearly divides the other six stations into two groups: the inner fjord group (composed by stations MC1, MC2 and MC3), and the deep basins and sill group (stations MC4 and MC5, and station MC6). This separation is mainly based on the organic matter composition of the sediment. The inner fjord group of stations is positively correlated with the percentage of proteins, whereas the deep basins and sill group is mainly correlated with the percentage of carbohydrates and the biopolymeric carbon content. This group of stations MC4-MC6 is also positively correlated with the CPE content and the algal fraction of BPC. These three groups are characterised by different foraminiferal assemblages. The ~~Four~~ calcareous species *Cassidulina reniforme*, *Elphidium* ~~*excavatum subsp.*~~ *clavatum*, *Nonionellina labradorica*, and *Elphidium bartletti* characterise the inner fjord, whereas three agglutinated species *Labrospira crassimargo*, *Adercotryma glomeratum* and *Recurvoides turbinatus*, and one calcareous species *Nonionella digitata* define the deep basins and sill group. Finally, the exclusive presence of the two species *Melonis barleeanus* and *Globobulimina auriculata* characterise the outer fjord station MC7.

4.5 Comparison between the 63-150 µm and >150 µm size fractions (0-1 cm)

4.5.1 Abundances and diversity

Foraminiferal abundances considering the entire >63 µm fraction (63-150 µm + >150 µm fractions) in the topmost centimetre of the sediment are maximal at MC2 and MC4 (4610 and 3936 ind. 50 cm^{-2} respectively) while all other stations present lower values ~~between 2496 (MC7) and 2864~~(<3000 ind. 50 cm^{-2} ~~(MC5~~) (Fig. 6a). ~~The small fraction (63-150 µm) is dominant at all stations and particularly at MC1 (~81%), MC6 (~83%) and MC7 (~77%). The lowest contribution of the 63-150 µm fraction is recorded at MC3 (~59%).~~ When considering only the largest fraction (>150 µm) at the first centimetre, the station MC2 (1467 ind. 50 cm^{-2}) and MC4 (1132 ind. 50 cm^{-2}) still shows the highest abundances followed by ~~stations~~ MC3 and MC5 (1050 and 889 ind. 50 cm^{-2}). For the rest, values are lower ~~vary between 422 and 567 ind. 50c~~than 600 ind. 50 cm^{-2}). The small fraction (63-150 µm) is dominant at all stations contributing with values between 59% (at MC2) and

83% (at MC6) to the total abundances.~~and particularly at MC1 (~81%), MC6 (~83%) and MC7 (~77%). The lowest contribution of the 63-150 µm fraction is recorded at MC3 (~59%).~~

Regarding diversity values, at MC1 and MC7 no significant differences in the H’ and J indices are found between ~~H’ and J indices in~~ the two size fractions ~~between the inner fjord station MC1 and the outer fjord station MC7~~ (Fig. 6b, c). At ~~S~~stations MC2, MC3 and MC6 ~~present lower~~ H’ and J values are lower for the >150 µm fraction, whereas the opposite is observed for stations MC4 and MC5, where small size fractions show lower diversity.

In terms of species composition (Fig. 7), the higher diversity of the 63-150 µm fraction at stations MC2 and MC3 ~~diversity is higher in the 63-150 µm fraction at stations MC2 and MC3 because of~~is due to the additional presence of *Stainforthia feylingi*, *Spiroplectammina biformis* and *Textularia torquata*. However, also at this size fraction, as in the >150 µm one, ~~at the three inner fjord stations (MC1, MC2, MC3),~~ the fauna at the three inner fjord stations (MC1, MC2, MC3) is largely represented by *Elphidium* ~~*excavatum subsp.*~~ *clavatum* (juveniles) ~~is still dominant~~ (~16, 30 and 66%, respectively). Similarly, juveniles of *Cassidulina reniforme* ~~(juveniles) is still highly dominant~~are observed in the small -fraction ~~(~38%)~~ at station MC1 (~38%) ~~in the 63-150 µm fraction~~. At stations MC4 and MC5, the lower diversity of the 63-150 µm fraction is due to the strong dominance of *S. biformis* (~75 and 65% ~~at MC4 and MC5~~, respectively), that is nearly absent in the large size fraction. At station MC7, the small size fraction is characterised by the presence of juveniles of *Cassidulina teretis* (~11%) and *Melonis barleeanus* (~8%), species that are also present in the >150 µm fraction (~5% and ~8% respectively). These species are accompanied by ~~*Globocassidulina*~~ *C.* ~~*subglobosa*~~ *reniforme* (~21% ~~in the 63-150 µm~~), and *Alabaminella weddellensis* (~27%) that are only present in the small size fraction at this site.

4.5.2 Agglutinated vs calcareous foraminifera

The percentage of agglutinated forms is systematically higher in the entire fraction >63 µm compared to the >150 µm at stations MC1 to MC6 (Fig. 8). This is explained by the presence of the small-sized agglutinated species *Spiroplectammina biformis*, and other minor agglutinated species (*Cuneata arctica*, *Textularia torquata*, *Cribrostomoides* sp.). Conversely, the outer fjord station MC7 shows the opposite pattern mainly because of the presence in the small fraction of calcareous species that are absent in the >150 µm size fraction (i.e., *Cassidulina teretis*, ~~*Globocassidulina subglobosa*~~*Cassidulina reniforme*, *Alabaminella weddellensis*).

4.5.3 Multivariate analyses

Coordinate 2 of the nMDS analysis separates the >150 µm fraction from the 63-150 µm and >63 µm fractions (Fig. 9a), and the cluster (Bray-Curtis similarity) analysis shows less than 50% of similarity between the two groups (Fig. 9b). However, nMDS-Coordinate 1 groups all fractions into the three same stations’ groups (Fig. 9a) previously determined by the CCA analysis based on the >150 µm fraction ~~CCA analysis~~ (Fig. 5).

4.6 Visual characterisation of test dissolution

At all stations inside the fjord (from MC1 to MC6) most of the calcareous species display different degrees of dissolution including for small sized specimens. As visualised in the Fig. S2, the species *Elphidium ~~excavatum subsp.~~ clavatum*, *Elphidium bartletti*, *Triloculina oblonga* and *Robertinoides sp.* show the most severe degree of dissolution, whereas *Nonionellina labradorica* seems to be less sensitive to dissolution (individuals classified at stage I or II of dissolution). ~~Moreover~~Interestingly, the highest degree of dissolution (stage IV) is exclusively observed~~ only~~ in the deep basin and the sill stations.

5 Discussion

5.1 Environmental characteristics of the study area

According to the topography of the fjord, distribution of the main water masses and physicochemical characteristics of the sediments, we can separate the fjord into three main areas: the inner fjord (i.e., stations MC1 to MC3), the central deep basins (i.e., stations MC4 and MC5) constrained by the sill (i.e. station MC6) and the outer fjord Storfjordrenna (i.e., station MC7) (Fig. 1b).

In July 2016, the inner fjord sea surface water temperatures and salinities (Fig. S3)~~,~~ are indicative of a mixture between ~~Melt~~ melt ~~Waters~~ waters ~~(MW)~~ and Storfjorden surface water ~~(SSW)~~ as previously indicated by Skogseth et al. (2005b). On the contrary, the recorded inner fjord bottom water parameters ~~recorded~~ are not homogeneous (Table 1). In fact, the stations MC1 and MC2, on the western side of the fjord, are characterised by salinity and temperature within the range of BSW as defined Skogseth et al. (2005b). The location of these stations in small topographic depressions on the shelf may explain the presence of these cold and salty waters. The shallowest station MC3 (99 m depth), located on the eastern side of the inner fjord, seems influenced by ~~Modified~~ modified Atlantic water (as defined Skogseth et al., 2005b).

The bottom water values of salinity and temperature measured in July 2016 in the deep basins, allow to identify the presence of trapped residual BSW still long time after the season of sea ice formation as previously hypothesised by Skogseth et al. (2005b). The bottom water properties at the sill fall into the range of Arctic water (Skogseth et al., 2005b). In contrast with the inner fjord and the deep basins, the outer fjord water column displays typical values of NAW from the surface to the bottom (Skogseth et al., 2005b).

The summer melting of ~~continental~~tidewater glaciers flowing in Storfjorden produces an important supply of terrigenous materials to the head of the fjord (Winkelmann and Knies, 2005). This sedimentary dynamics results in relatively high sedimentation rates of about 3.6~~2~~ ± 0.~~5~~ 4 mm yr^{-1} recorded in the fjord (stations MC1 to MC6, Table S1), although lower than in other Svalbard fjords (e.g., Kongsfjorden 5-10 mm ~~.~~yr^{-1}; Zaborska et al. 2006). Associated to this terrigenous flux, organic matter supply is high in the internal fjord. In contrast, low sedimentation rate (1.3 ± 0.6 mm yr^{-1}, Table S1) and low organic matter supply are recorded in the outer fjord. This clearly indicates a lower influence of ~~continental~~tidewater glacier's inputs in Storfjordrenna (station MC7) compared to the internal fjord (stations MC1-MC6).

Regarding the organic supply, the high concentrations of organic matter at all our stations and particularly in the deep basins, confirm the sedimentary organic-rich character of Storfjorden as previously reported in the literature (Winkelmann ~~&~~ and Knies, 2005; Mackensen et al., 2017). The higher CHO (%) associated to lower PRT (%) in the deep basins (station MC4 and MC5), compared to the other stations, is indicative of the presence of older and more refractory organic matter (Pusceddu et al., 2000). This could be either related to higher continental supplies of more refractory organic matter, higher heterotrophic ~~nutrition~~consumption, and/or the presence of long-residence water masses, influenced by BSW and isolated by a strong chemocline during periods of sea ice melting (Rysgaard et al., 2011). Contrary~~On the opposite,~~ the higher contents of PRT (%) and CPE in the inner fjord (stations MC1-MC3) and at the sill (MC6) could be the result of a recent (summer) phytoplankton bloom. Compared~~ntrary~~ to the inner fjord, the CPE contents in the Storfjordrenna are much lower (Fig. 2b), indicating a ~~lesser~~ less fresh algal input to the bottom, which is consistent with the greater water depth (>300 m) at this outer fjord site.

The oxygen profiles and particularly the OPD (Fig. S1a) reflect the quantity of organic matter supplies. Indeed, the organic carbon accumulation depends on its reactivity with available oxygen (Dauwe et al., 2001) and *vice-versa*, the oxygen consumption is proportional to the organic matter mineralisation rate. Except for the outer fjord, all stations (MC1-MC6) present shallow OPD values (<10 mm) in consistence with the high contents of available organic matter (i.e., BPC) (Fig. 2). Organic matter aerobic respiration is also the reason for the rapid pH decrease in the first mm of the sediment column at these stations (Fig. S1b). At the outer fjord, the slower pH decrease and the higher OPD (>15 mm) would be therefore attributed to lower BCP contents at this station.

5.2 Distribution of foraminiferal species in response to environmental conditions

According to the topography and physical characteristics of the fjord, ~~T~~the foraminiferal distribution and the measured environmental parameters also define three biozones: i) the inner fjord, ii) the deep basins and sill and iii) the outer fjord. The CCA analysis (Fig. 5) shows that the inner fjord faunas are positively correlated to PRT (%) and negatively correlated to CHO (%), meaning that they favourably respond to the ~~availablility~~availability of fresh and labile organic matter.

~~*Cassidulina reniforme* and~~ *Elphidium* ~~*excavatum* subsp.~~ *clavatum* dominate the innermost fjord stations ~~MC1~~ where it ~~they~~ preferentially occupies~~y~~ the superficial ~~infaunal~~ microhabitats. The high dominance of ~~these~~ this species in the inner fjord is consistent with previous findings from other glacier-proximal inner Svalbard fjords (Hald and Korsun, 1997; Korsun and Hald, 2000) and Arctic domains (e.g., Iceland; Jennings et al., 2004). *Elphidium clavatum* is also often described as able to adapt to harsh environments such as near tidewater-glacier fronts and riverine estuaries (e.g., Hald and Korsun 1997; Korsun and Hald, 1998; Forwick et al., 2010). The presence of this species suggests, therefore, quite stressful conditions.

The station MC1, at the fjord head, is additionally characterised by the presence of~~The species~~ *C. reniforme*. This species ~~is known for its tolerance to~~tolerates high concentration of suspended particulate organic matter (Schäfer and Cole, 1986) and

~~its~~ prefer~~sence for~~ cold water environments (Jernas et al., 2018). ~~. The relationship between these two species in the glaciomarine environments is however not clear.~~ Korsun and Hald (1998) hypothesised that *C. reniforme* becomes dominant when ~~better conditions are present, such as a lower~~ glacier-driven turbidity ~~due to~~is less ~~glacier-driven sediment input~~ and ~~an increased~~ phytoplankton production is higher. ~~In the two other inner fjord stations, MC2 and MC3, *C. reniforme* represents less than 1% of the living assemblage (>150 µm), and *E. excavatum subsp. clavatum* largely dominates the topmost half centimetre at both sites. The species *E. excavatum subsp. clavatum* is often described as able to adapt to harsh environments such as near tidewater-glacier fronts and riverine estuaries (e.g., Hald and Korsun 1997; Korsun and Hald, 1998; Forwick et al., 2010).~~ According to ~~these~~ our findings, therefore, faunas at stations MC2 and MC3 potentially reflect a more stressful environment than station MC1.~~nearer the fjord head (station MC1).~~ ~~Additionally, the~~The strong dominance of these two species is also visible in the small size fraction, suggesting recent reproductive events, probably in response to fresh organic matter inputs to the seafloor. ~~low diversity in the inner fjord mainly determined by the strong dominance of these two species, could be the result of a recent event of reproduction as confirmed by the high abundance of juveniles in the 63-150 µm fraction (>50 % at stations MC1 and MC3). This opportunistic behaviour may be a quick response to fresh organic matter input to the seafloor.~~ This hypothesis also matches with the dominance of *Nonionellina labradorica* in the ~~The~~ intermediate microhabitats. ~~at the three inner fjord stations are dominated by *Nonionellina labradorica*. The ecology of this species is not very well constrained especially in glaciomarine environments.~~In fact, this species is often reported in ~~It is described as an intermediate-deep endobenthic species, found in~~ highly ~~productivity~~ productive area (Lloyd, 2006) because of its preference to feed on fresh phytodetritus and in particular on diatoms (Cedhagen, 1991~~-~~). Korsun ~~&~~ and Hald (2000) suggest that this species may start reproducing during spring in glaciomarine environments possibly following the diatom bloom starting in March under the sea ice (Rysgaard et al., 2011). ~~In some studies, *N. labradorica* is also reported as an Atlantic Water indicator (Hald and Korsun, 1997; Lloyd, 2006). A few paleoceanographical studies draw parallels between its high abundances in the sediment and intensified Atlantic intermediate water circulation (e.g. Łącka &~~ and ~~Zajączkowski, 2016; Rasmussen and Thomsen, 2015). In our study, this species occurs in the glacier-proximal areas (i.e., inner fjord), that were not influenced by Atlantic Water (AW) inflow during the sampling period in July 2016 (except at station MC3 which may be influenced by the MAW; see Fig. S3).~~ Therefore, we rather interpret its presence as a response to meltwater discharge and consequent phytoplanktonic bloom. Also *Elphidium bartletti* that occurs as an accessory species (especially at station MC2) was previously reported in river-affected habitats of the southern Kara Sea, characterised by highly variable environmental conditions (Polyak et al., ~~-~~(2002), further supporting our interpretations. ~~. Polyak et al. (2002) found this species in river-affected habitats of the southern Kara Sea explaining the higher frequency of *E. bartletti* in the off-shore part as dependent on the presence of coarser-grained sediment or on several environmental variables (low salinity, high food availability and high sedimentation rate). We suppose that the presence of *E. bartletti* in the glacier-proximal area is determined by the availability of fresh food present in July 2016 (high percentages of PRT), but it is probably suffering from competition with the more opportunistic species *C. reniforme* and *E. excavatum subsp. clavatum*.~~

The CCA analysis (Fig. 6) shows a negative correlation of the deep basins and sill faunas with ~~the percentages of~~ proteins and a positive correlation with ~~the percentage of~~ carbohydrates, ~~meaning~~ highlighting a ~~targeted~~ response of the fauna to old (refractory) organic matter. The assemblages in the two deep basin stations (MC4 and MC5) display ~~a~~ similar ~~diversity~~ diversities which are in both cases ~~is~~ higher than in the inner fjord. Agglutinated species dominate ~~(>71%)~~ the topmost centimetre of the sediment, in particular ~~the two species~~ *Reophax scorpiurus*, *Reophax fusiformis* and *Recurvoides turbinatus*, occasionally accompanied by *Labrospira crassimargo* and *Ammotium cassis*. These species are often found in the distal part of other Svalbard fjords (e.g., Hald and Korsun, 1997; Murray and Alve, 2011; Jernas et al., 2018), ~~–~~and widely distributed in areas covered with seasonal sea ice in the Arctic Ocean (e.g., Wollenburg and Kuhnt, 2000; Wollenburg and Mackensen, 1998). They ~~,~~are considered to tolerate low food quality, high sedimentation rates, and a wide range of salinities, temperatures and organic matter fluxes (Hald and Korsun, 1997; Murray, 2006; Jernas et al., 2018). ~~Other accessory species such as *Labrospira crassimargo* and *Ammotium cassis* are present in relatively high abundances at station MC5. This group of agglutinated species found in the deep basins, includes some of the most adaptable species to largely different ecological conditions (Murray and Alve, 2011), and is described as widely distributed in areas covered with seasonal sea ice in the Arctic Ocean (e.g. Wollenburg and Kuhnt, 2000; Wollenburg and Mackensen, 1998).~~ This capacity of adaptation may explain the abundance of all these agglutinated species in the deep basins where residual BSW (with high S, low T and pH) and high concentrations of refractory carbohydrates are recorded in the top sediment. Also at station MC4, *N. labradorica* lives ~~also~~ in subsurface microhabitat (from 1 down to 3 cm depth) probably profiting from the phytodetritus supply testified by high CPE contents.

The assemblage composition at the sill (station MC6) is close to those found in the deep basins, except for the dominant presence of *Adercotryma glomeratum* ~~(at each sediment layer at this site)~~. The similarities with the deep basins assemblages are interpreted as the result of intermittent pulses of BSW outflowing the fjord by-passing the sill during some periods of the year, therefore influencing this station.

~~This species~~The opportunist *Adercotryma glomeratum* (e.g., Gooday and Rathburn, 1999; Heinz et al. 2002) ~~is considered as an opportunistic taxon (e.g. Gooday and Rathburn, 1999; Heinz et al. 2002), and it~~ has been reported as positively related to increasing distance from glaciers and from the fjord head (Hald and Korsun, 1997). ~~This feature~~Its dominance at this station suggests a positive relationship with an increase in salinities and temperatures and consequently with Transformed Atlantic Water (TAW) during summer, accordingly to existing literature (e.g., Hald ~~&~~ and Korsun, 1997; Jernas et al., 2018). ~~The dominance of *A. glomeratum* at the sill and the concomitant similarities with the deep basin assemblages~~ It has been therefore interpreted as the consequence of seasonal influence of Atlantic waters on the sill, when BSW overflow is weakened or absent.

~~could suggest a seasonal alternation of water mass influences between summer incursion of Atlantic Water and winter overflow of BSW during brine production. Moreover~~In addition to the assemblage composition, the presence of very badly preserved calcareous foraminifera tests and the dominance of agglutinated species in the deep basins plus the sill, strongly suggest that ~~acidic~~ corrosive BSW ~~is a~~ have a primary control ~~in~~ on the ~~bottom water~~ benthic ecology in this sector of the fjord.

The outer fjord biozone (station MC7) is characterised by a ~~deeper~~ thicker overlying water column (> 300 m), and higher bottom water salinity and temperature compared to the rest of the studied sites. The presence, at this station, of agglutinated species in common with the deep basin stations, is probably due to the widespread character of these species. However, ~~T~~the clear ~~predominance~~ influence of the NAW at this site is indicated by the presence of typical Atlantic species such as *Melonis barleeanus* and *Globobulimina auriculata*. ~~In high latitudes,~~ In the North Atlantic Ocean, *M. barleeanus* is described as ~~as an arctic-boreal~~ infaunal~~-~~ and opportunist toward good quality organic matter (e.g., Caralp et al., 1989; Nardelli et al., 2010). At high latitudes, its presence suggests the influence of relatively warm AW (Caralp, 1989; Polyak et al., 2002; Jennings et al., 2004; Knudsen et al., 2012; Melis et al., 2018). This interpretation is further confirmed by the presence of the deeper dwelling ~~taxon~~, ~~whose presence suggests the influence of relatively warm AW (Caralp, 1989; Polyak et al., 2002; Jennings et al., 2004; Knudsen et al., 2012; Melis et al., 2018). In the Atlantic Ocean, this species is described as intermediate infaunal, with an opportunistic behaviour in response to good quality organic matter (e.g., Nardelli et al., 2010).~~ *Globobulimina auriculata*, ~~is also an infaunal species~~ presumed to be related with increasing bottom water salinity (Williamson et al., 1984; Jernas et al., 2018) and often associated to buried organic matter (e.g., Alve, 2010).

5.3 Agglutinated vs Calcareous taxa: the premise of a paleo-proxy of brine formation

In both size fractions (63-150 µm and >150 µm), low agglutinated/calcareous (A/C) ratios characterise the inner ~~and outer~~ fjord in contrast with the high values observed at the deep basin and sill stations (Fig. 3b; Fig. 8). The exclusive presence of some agglutinated species in the smaller fraction (e.g., *Cuneata arctica*, *Spiroplectammina biformis* and *Textularia torquata*) results in relatively higher A/C ratios for the >63 µm compared to the >150 µm. It is worth mentioning that, in the Storfjordrenna (station MC7), the A/C ratio in the >63 µm is ~~similar~~ lowered by ~~to that found in the >150 µm fraction (Fig. 8), despite~~ the presence of several small calcareous species (e.g., *Stainforthia feylingi*, *Cassidulina teretis*, *Alabaminella weddellensis*, ~~*Globocassidulina subglobosa*~~ *Cassidulina reniforme*) that are not present in the larger fraction (Fig. 8).

Several hypotheses, which are eventually not exclusive, arise to explain the dominance of agglutinated species at the deep basins and sill stations:

(i) **The influence of organic matter quality**. Jernas et al. (2018) suggest that agglutinated species may be more tolerant or less sensitive to the lower quality and/or quantity of food than the calcareous fauna. Following this idea, the dominance of agglutinated species in the deep basins is coherent with the more refractory organic matter (higher CHO %) measured in July 2016 (Fig. 2). However, the lower percentage of CHO observed at the sill station MC6 seems to contradict this hypothesis.

(ii) **The brine-related calcareous test dissolution**. Low relative abundances of calcareous taxa found in the sediment in the deep basins could be attributed either to hampered growth, limited reproduction, and/or to test dissolution~~, which in the latter case leads automatically to an overestimation of the agglutinated populations~~. Indeed, at the deep basins and sill stations we observe ~~a severe~~the most severe degree of dissolution, in particular on ~~living specimens of~~ *Elphidium* ~~*excavatum* subsp.~~ *clavatum*, *Elphidium bartletti*, *Triloculina oblonga* and *Robertinoides* spp. ~~found at the deep basin stations~~ (Fig. S2). The most obvious explanation for ~~the~~ that ~~observed severe dissolution~~ is the corrosive effect of brine ~~waters, that~~waters that persist all year round at stations MC4 and MC5 and may impact station MC6 through episodes of overflow from autumn to spring. In the inner fjord stations, these species also present ~~also~~ some dissolution but largely less severe ~~than at the deep-basin and sill stations~~ (Fig. S2). ~~This~~ In our opinion the dissolution at these sites can but either related to early cascading of BSW during winter or~~may~~ ~~be related~~ to the high seasonal input of meltwater as a factor affecting the preservation of carbonate (Schrö~~o~~der-Adams et al., 1990).

~~Previous studies in the Barents Sea related the prevalence of agglutinated faunas to carbonate dissolution in areas influenced by cold waters (Hald and Steinsund, 1992; Steinsund and Hald, 1994). The same conclusion was drawn in the fjord-shelf areas off eastern Greenland where agglutinated foraminifera are exclusively present beneath Polar Water and mixed assemblages beneath Atlantic Water (Jennings and Helgadottir, 1994). In some paleoceanographical studies from the Arctic, the high proportion of agglutinated taxa in sediment cores was considered to be dependent on bottom-water hydrographical condition (Seidenkrantz et al., 2007) and specifically on corrosive brine production (Rasmussen and Thomsen, 2015). Rasmussen and Thomsen (2015) inferred that the agglutinated species *Reophax scorpiurus* and *Adercotryma glomeratum* may tolerate the CO_2-rich conditions characterising the brine environment because they are the most abundant species found in the historical record from the deep basins of the fjord.~~

(iii) **The combined effect of brines and organic matter mineralisation**. As an alternative, or in parallel, calcareous test dissolution may ~~have~~ result~~ed~~ from decaying organic matter. Indeed, test dissolution of *E.* ~~*excavatum* subsp.~~ *clavatum* species was previously observed in the Adventfjorden (west Svalbard) and was attributed to low pH in the pore waters of upper sediments due to organic matter decay (Majewski and Zajaczkowski, 2007), whereas in the Barents-Kara shelf this process was associated to sinking of brines (Hald and Steinsund, 1992; Steinsund and Hald, 1994). The coupled effect of corrosive brines and organic matter reminerali~~z~~sation probably ~~may~~ contribute simultaneously to the dissolution of the calcareous faunas. It is difficult to decouple the effects of both these factors. However, ~~However~~ we observe the most severe degree of dissolution ~~was observed~~ in the deep basins, where organic matter is less available. This lets conclude that ~~the certain presence o~~ the persistence of brines ~~all year round~~ is the ~~most probable~~main ~~factor determining~~ responsible for the dissolution. This conclusion supports some previous paleoceanographical studies from the Arctic, which supposed the high proportion of agglutinated taxa in sediment cores to be dependent on bottom-water hydrographical condition (Seidenkrantz et al., 2007) and specifically on corrosive brine production (Rasmussen and Thomsen, 2015).

~~To sum up, stressful ambient conditions (i.e. corrosive waters, low quality food) were measured in the deep basin and at the sill stations in summer 2016, and the associated foraminiferal assemblages display high A/C ratios. This result~~ In the light of these arguments we propose ~~strongly supports the high potential of using~~ the A/C ratio as a proxy for brine persistence or/and overflow in historical sedimentary archives. Rasmussen and Thomsen (2014, 2015) reported an exceptional fossilizing potential of agglutinated species in this area on records back to 10 kyrs, therefore it is most likely that the ratio is not affected on a hundreds of years-time scale. ~~). In some paleoceanographical studies from the Arctic, the high proportion of agglutinated taxa in sediment cores was considered to be dependent on bottom-water hydrographical condition (Seidenkrantz et al., 2007) and specifically on corrosive brine production (Rasmussen and Thomsen, 2015).~~

5.4 Insights from the small size fraction

The additional observation of the small size fraction (63-150 µm) results in the definition of the same three biozones and similar A/C ratios as for the larger fraction (except for the outer fjord station where the ratio changes) (Figs. 8; 9a). The cluster analysis (Fig. 9b) further shows that the consideration of the 63-150 µm fraction increases the percentage of similarity among stations belonging to the same biozone and it increases the dissimilarity between the stations inside the fjord (from MC1 to MC6) and ~~the outer~~outside the fjord (MC7). Nonetheless, the study of the 63-150 µm fraction provides new insights into the benthic foraminiferal ecology of Storfjorden.~~ small-sized species that are not found in the larger fraction.~~

At the inner fjord stations MC2 and MC3, the exclusive presence of the calcareous species *Stainforthia feylingi*, and the three agglutinated *Cuneata arctica*, *Spiroplectammina biformis* and *Textularia torquata* in the 63-150 µm fraction increases the overall diversity compared ~~with the large dominance of *Elphidium excavatum subsp. clavatum* in~~to the larger fraction. These four species with individuals of small size, are typical of Arctic and cold boreal environments showing an opportunistic behaviour in response to a wide range of environmental conditions (e.g., Schäfer and Cole, 1986; Hald and Korsun, 1997; Korsun ~~&~~ and Hald 1998, 2000; Lloyd et al., 2007; Leduc et al., 2002; Pawlowska et al., 2016; Jernas et al., 2018). The presence of numerous juveniles (63-150 µm) of *Elphidium*~~.~~ ~~*excavatum* subsp.~~ *clavatum* and *Cassidulina reniforme* in the inner fjord also ~~suggests~~ confirms ~~also an opportunistic response of the fauna~~ recent reproductive events, possibly related to ~~a recent~~ phytoplanktonic bloom and associated fresh organic matter inputs in the benthic system, ~~as suggested~~in agreement with ~~by~~ the high percentages of- PRT measured in the sediment (Fig. 2).

On the contrary, in the deep basins, the diversity decreases when the small fraction is considered, due to the strong dominance of the agglutinated species *S. biformis*. In the literature, this is an opportunistic species ~~is characteristic of~~in glaciomarine habitats~~,~~, ~~and is usually found in the outer part of fjords as~~ indicative of the presence of cold arctic waters (Hald and Korsun, 1997; Korsun and Hald, 1998, 2000; Schäfer and Cole, 1986). The high numbers of small individuals found in the deep basins coupled with the high percentages of CHO may suggest an eventual positive response of *S. biformis* to refractory organic matter. The relatively high abundances of *T. torquata* at the sill station MC6 suggests high salinity fluctuations (Wollenburg and Kuhnt, 2000), which could be consistent with occasional/seasonal overflow of BSW at this site, further confirming our hypothesis based on the >150 µm assemblages.

In the Storfjordrenna, *Cassidulina teretis*, ~~*Globocassidulina subglobosa*,~~ and *Alabaminella weddellensis*, are exclusively present in the 63-150 µm fraction. These ~~three~~ two species, usually associated to AW (Wollenburg ~~&~~ and Mackensen, 1998), further give evidence of the ~~dominant~~ influence of this water mass in the outer fjord area.~~ However, the inclusion of these species in the estimation of diversity does not change substantially the results obtained from the >150 µm fraction.~~ The presence of *C. reniforme* at this station, exclusively as juveniles, is less easy to interpret. Because of its preference for cold waters (e.g., Jernas et al., 2018), its presence could be the result of an occasional influence of arctic waters on this station.

Taking into consideration the comparison between the 63-150 µm and >150 µm data, the additional information from the small fauna is limited to a ~~bit~~slightly ~~-~~more precise estimation of biodiversity and the confirmation of ecological speculations based on the large fauna (e.g., recent blooming events at inner stations). Therefore, and regarding the high time-consuming character inherent to the investigation of the 63-150 µm fraction, we propose that the small fraction could be neglected in comparable future studies in Storfjorden unless in the aim of answering some very specific questions.

6 Conclusion

Living benthic ~~(rose Bengal stained)~~ foraminiferal faunas from Storfjorden "sea ice factory" were studied in order to determine the response of foraminiferal communities to the major driving factors controlling the sea bottom ecology in this area~~ (e.g. bottom water properties, sediment characteristics, organic matter quantity and composition, sediment oxygen profiles, pH)~~. The benthic ambient conditions were further connected to Brine-enriched Shelf Waters (BSW) production and persistence and indirectly to first year sea ice ~~production~~formation.

The influence of the BSW persistence on benthic foraminiferal assemblages was identified on the base of characteristic faunas inhabiting the two deep basins and the sill of the fjord. At these sites, BSW are respectively trapped for a long part of the year or overflow during the maximum production period. The assemblages at these stations are dominated by agglutinated taxa, resulting in high agglutinated/calcareous ratio (A/C). ~~and t~~The presence of heavily dissolved calcareous tests supports the hypothesis that one of the main responsible for this result is the corrosive character of BSW. ~~Also~~Also, the chemocline related to BSW presence at the bottom~~,~~ could limit the fresh organic matter flux to the seabed and indirectly influence the assemblages.

~~These stations have very different faunas if compared to the "inner fjord" where the biozone is characterised by calcareous faunas and in particular by typical glacier proximal species, able to tolerate turbidity caused by glacier-driven sediment input, and responding to fresh and labile organic matter inputs (summer phytoplankton bloom) to the seafloor after the melting of sea-ice.~~

~~Outside the fjord, the biozone shows species composition partly in common with the "inner fjord" and the "deep basins and sill", suggesting the influence of outflow from the fjord to the Storfjordrenna. However, this area is also characterised by the exclusive presence of typical North Atlantic species confirming the strong influence of the NAW in the area.~~

In the light of these results, ~~the low A/C ratios characterising the "inner fjord" in opposition to the high A/C ratios found in the "deep basins and sill" let suggest the potential use of~~we propose the application of the A/C ratio as a proxy for brine persistence and overflow~~.~~ on historical sedimentary records from Storfjorden, in order to reconstruct past changes in BSW intensity and, by extent, in first year sea ice production.

~~causing stressful conditions (i.e. acidic waters and low food quality). We thus suggest that the A/C proxy can be applied on historical sedimentary records from Storfjorden in order to reconstruct past changes in BSW intensity and, by extent, in sea ice production.~~

Supplement

Table S1, Table S2, Fig. S1, Fig. S2 ~~and Fig. S3~~ as referred in the manuscript can be found in Supplementary Material. Scanning electron micrographs (plates) of the most relevant species are shown in Fig. S4 and Fig. S5 in ~~the~~ Supplementary Material.

Data availability

Raw data are available at the following link: https://doi.pangaea.de/10.1594/PANGAEA.907687~~in Supplementary Material (Table S3, S4).~~

Author contributions

EF, MM, MPN and HH wrote the manuscript which was commented by all co-authors. EM was the cruise leader and field work was performed by HH and BL. EF, MPN, MM, HH, AJ, BL and DM collected the data and EF, MPN, MM, HH, AJ, BL and AP analysed and interpreted the data.

Competing interests

The authors declare that they have no conflict of interest.

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Sampling date	Station	Latitude (N)	Longitude (E)	Depth (m)	Temperature (°C)	Salinity	Density (kg m^{-3})	pH$_T$	O$_2$ (µmol L^{-1})
13/07/2016	MC1	78°15.0	19°30.0	108.0	-1.74	34.89	1028.59	8.00	341
14/07/2016	MC2	77°50.0	18°48.0	117.0	-1.59	34.79	1028.52	7.95	317
14/07/2016	MC3	77°58.6	20°14.6	99.0	1.10	34.74	1028.29	8.12	350
15/07/2016	MC4	77°29.2	19°10.6	191.5	-1.78	34.92	1029.01	7.92	319
17/07/2016	MC5	77°13.2	19°17.9	171.0	-1.78	34.93	1028.91	7.91	317
18/07/2016	MC6	76°53.9	19°30.3	157.0	-1.13	34.80	1028.72	7.97	317
19/07/2016	MC7	76°00.9	17°03.4	321.0	3.53	35.05	1029.33	8.04	305

Table 1: **Geographic coordinates, depths of the seven studied stations and bottom water parameters (temperature, and salinity measured in situ by the CTD, O$_2$ = dissolved oxygen and pH$_T$ measured from Niskin bottles).**

Stations	MC1	MC2	MC3	MC4	MC5	MC6	MC7
Abundance (ind. 50 cm^{-2})	1104	2249	1353	1861	1439	940	1238
Species Richness	27	27	19	37	29	29	44
Shannon-Wiener (H')	1.61	1.48	0.92	2.25	2.35	2.18	2.40
Equitability (J)	0.49	0.45	0.31	0.62	0.70	0.65	0.64

Table 2: **Foraminiferal total abundances (in number of individuals per 50 cm^2) and diversity indexes, considering the total living faunas (>150 µm size fraction) in the 0 to 5 cm core top sediment.**

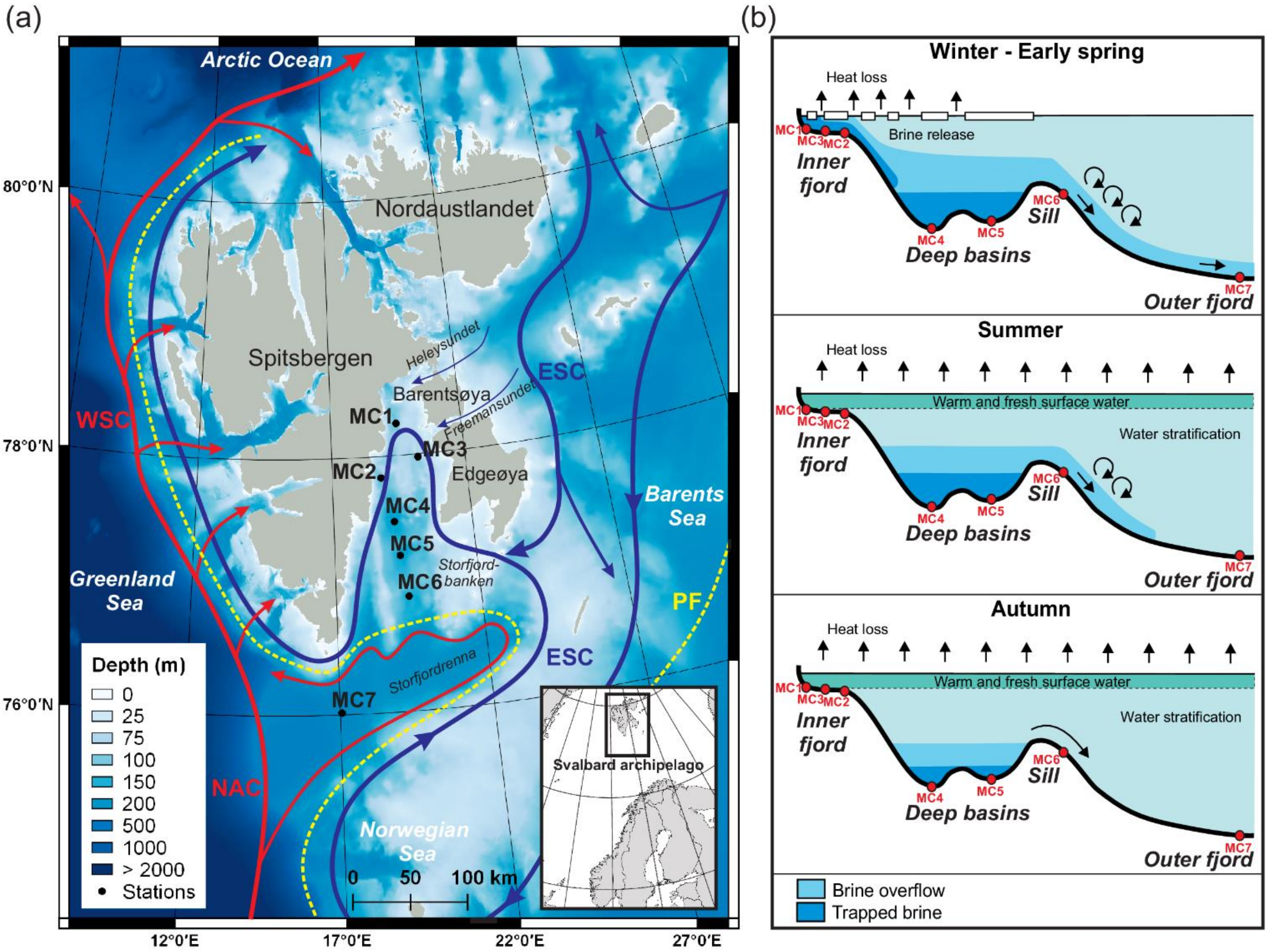


Figure 1: **a) Bathymetric map showing the main currents circulation around the Svalbard archipelago (currents ~~modified~~ from Skogseth et al., 2005b and Misund et al., 2016) and location of the sampling stations. The red lines represent the warm North Atlantic waters carried by the Norwegian Atlantic Current (NAC) and West Spitsbergen Current (WSC). The blue lines represent the cold Arctic waters carried by the East Spitsbergen Current (ESC). Dotted yellow line represents the Polar front (PF). Bathymetry obtained from EMODnet (http://portal.emodnet-bathymetry.eu) and map elaborated with QGIS (made with Natural Earth). b) Longitudinal bathymetric profile sketches showing seasonal formation and flow of brines in the inner and outer Storfjorden (modified from Skogseth et al., 2005a and Rasmussen and Thomsen, 2015) and indicative location of the sampling stations (red dots).**

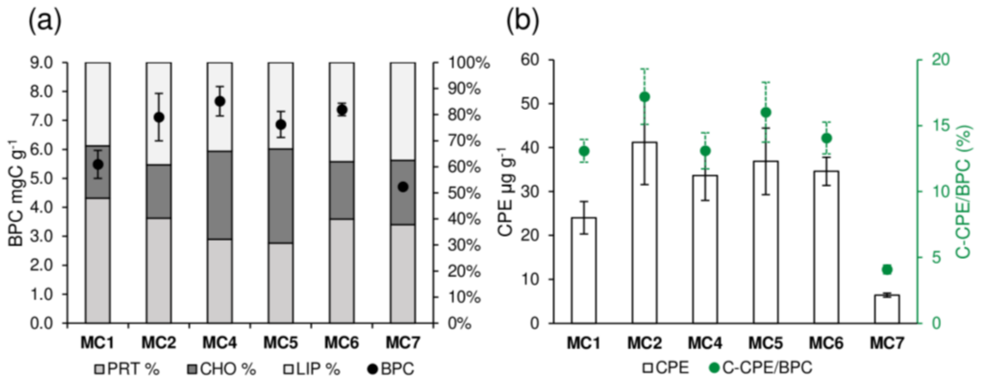


Figure 2: For each sampling station (data are not available at station MC3): a) c~~C~~ontent of biopolymeric carbon (BPC, black dots) and percentage of protein, carbohydrate and lipid (cumulative bars);~~.~~ b) c~~C~~ontent of chloroplastic pigment equivalents (CPE, white bars) and algal fraction of BPC (C-CPE/BPC, green dots).

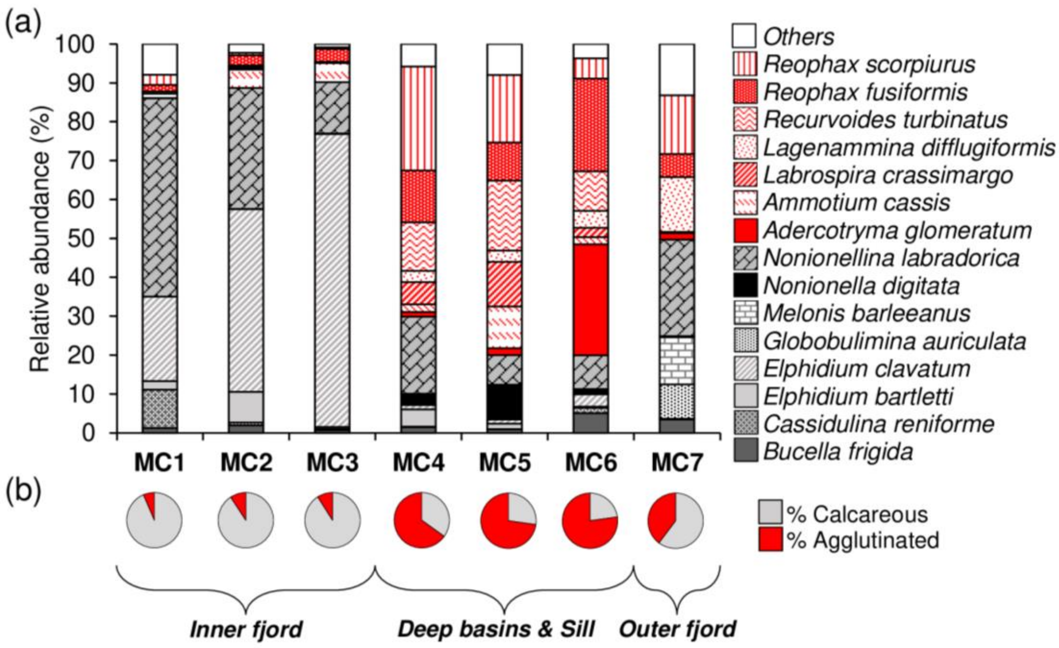


Figure 3: a) Species relative abundances of the total living faunas (>150 µm fraction) in the 0 to 5 cm core top sediment at each station and b) agglutinated species (in red) vs calcareous species (in grey) ratio.

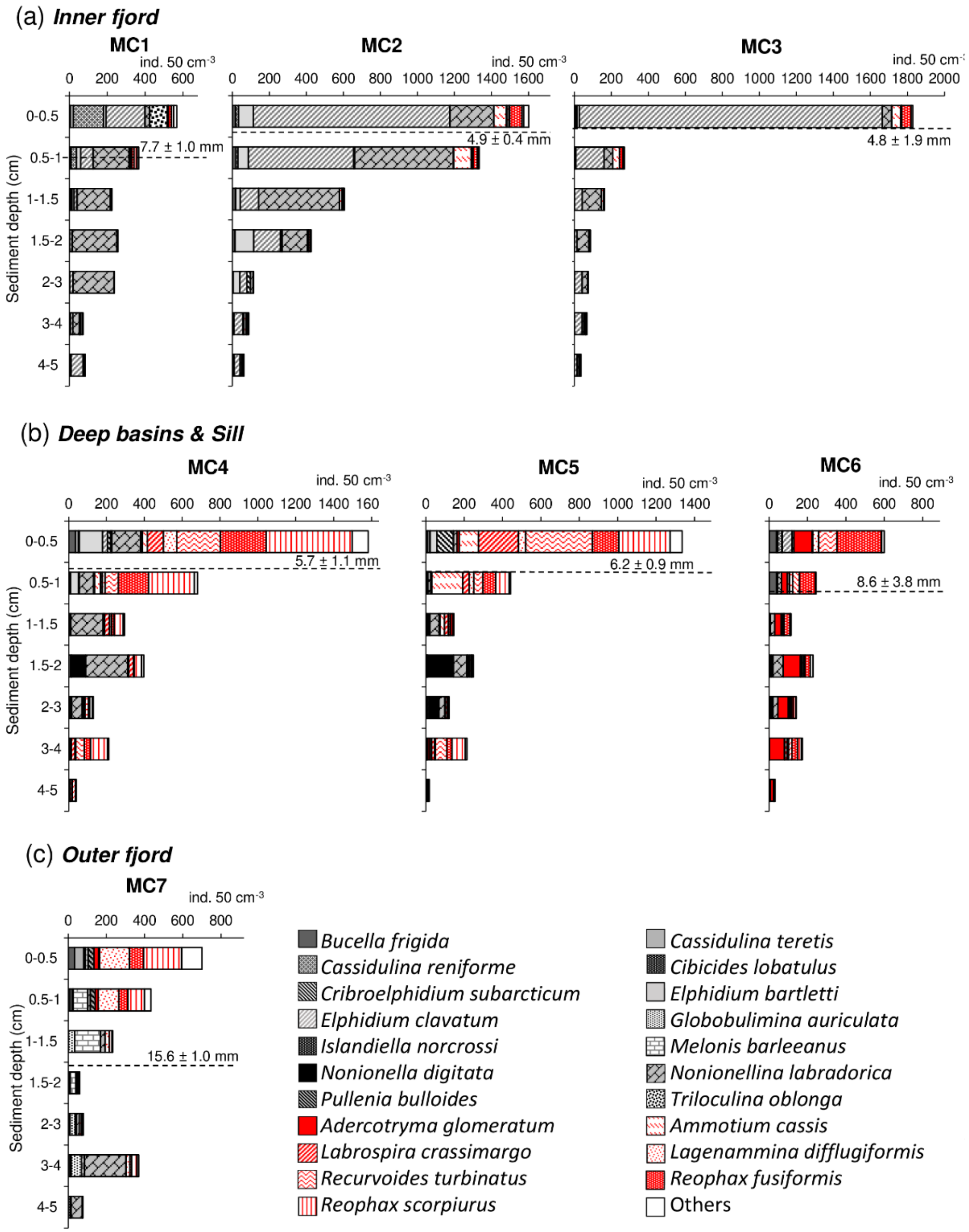


Figure 4: Foraminiferal vertical distribution from 0 down to 5 cm sediment depth (>150 µm fraction) for a) the inner fjord (stations MC1 to MC3) b) deep basins (stations MC4 and MC5) and sill (station MC6) and c) outer fjord (station MC7). Calcareous species are shown using different grey textures, whereas agglutinated species using different red textures. The dashed black line represents the average oxygen penetration depth (OPD) at each station.

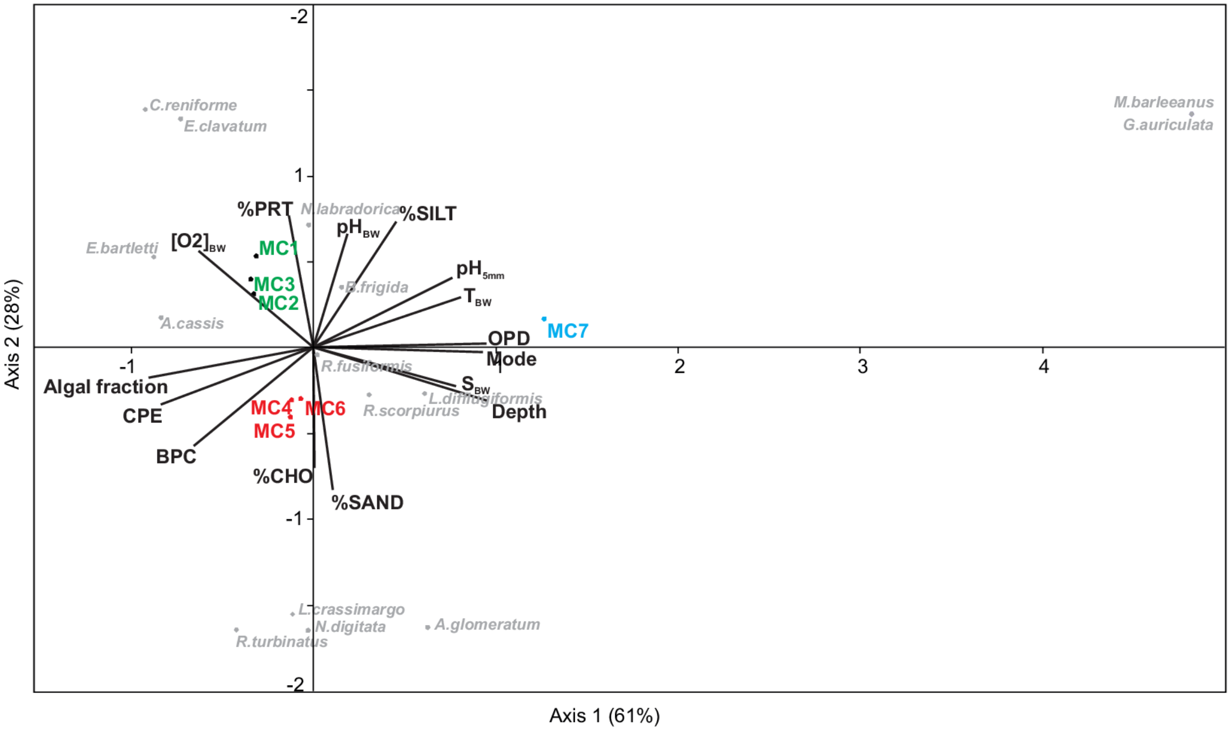
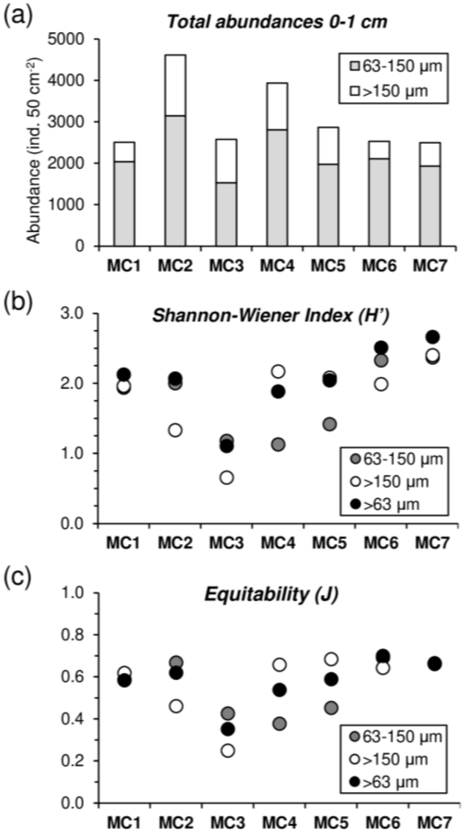


Figure 5: Canonical Correspondence Analysis based on real abundances (ind. 50 cm^{-2}) of the living faunas in the 0-5 cm sediment layer (> 150 µm size fraction) considering the major species (> 5%) vs environmental variables described in tables 1, S2, S3.



<u>Figure 6:</u> a) Foraminiferal cumulative abundances (ind. 50 cm^{-2}) for two size fractions (63-150 µm, grey, and >150 µm, white) of the 0-1 cm sediment layer. b) Shannon-Wiener (H') and c) Equitability (J) indexes comparison among the 63-150 µm, the >150 µm and the >63 µm (black).

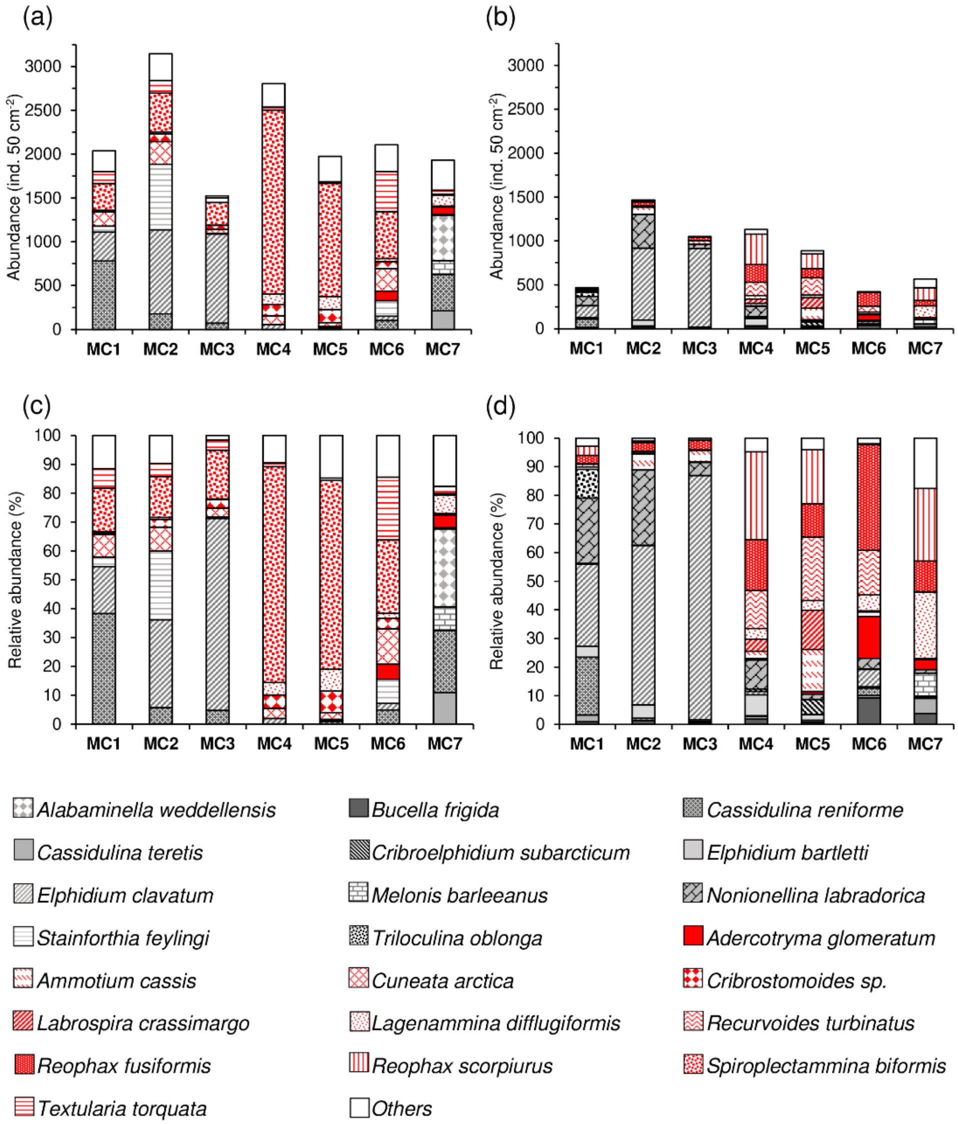


__Figure 7:__ Total abundances (ind. 50 cm^{-2}) and correspondent relative abundances (%) of the dominant species (>5% in at least one station) of the 0-1 cm sediment layer for the 63-150 µm fraction (a, c) and the >150 µm fraction (b, d). The calcareous species are shown using different grey textures, whereas agglutinated species using different red textures.

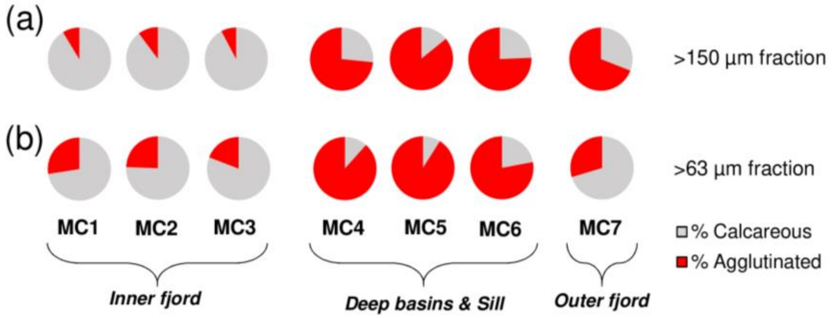


Figure 8: Relative abundances of calcareous foraminifera (in grey) and agglutinated foraminifera (in red) considering the > 150 µm size fraction (a) and the > 63µm size fraction (b).

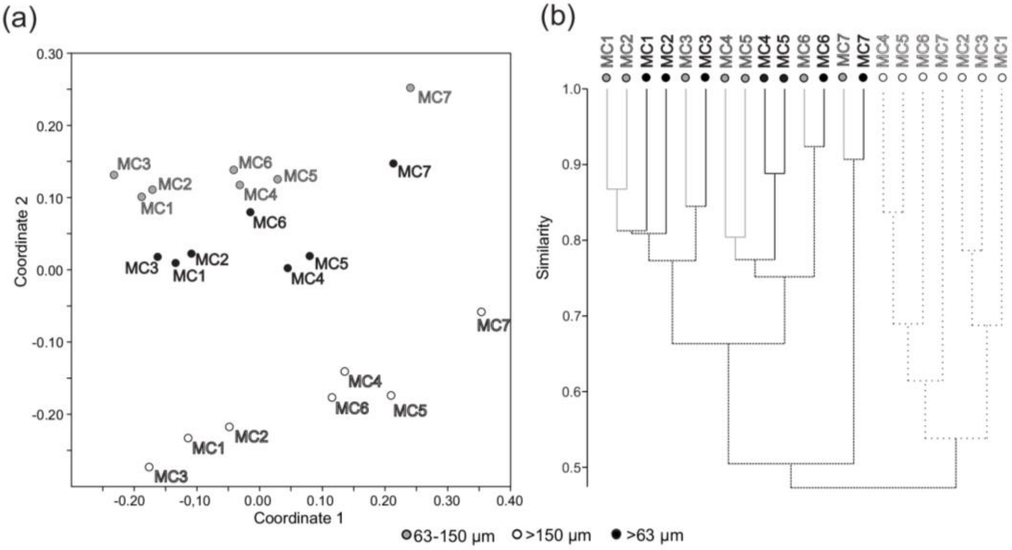


Figure 9: a) Non-metric multidimensional scaling analysis and b) cluster analysis (Bray-Curtis similarity measure) considering the densities (ind. 50 cm^{-2}) of the major foraminiferal species (relative abundance > 5% in at least one station in one size fraction) for the 63-150 µm fraction, the >150 µm and the total fraction >63 µm.