We would like to thank the Referees for constructive review, that helped us to improve the manuscript. Written below are our responses to the Referee's comments. The comments were reproduced and are followed by our responses.

Anonymous Referee #1

This paper presents an interesting multiproxy dataset to document the paleoceanography near Svalbard and compares traditional sedimentary and microfossil proxies with a novel approach involving ancient environmental DNA. As such, the dataset certainly deserves publishing, but I have some comments/reservations about the age model and the discussion of the results. The discussion has some writing-technical issues. In several cases the own results are presented, without clear arguments supporting the interpretation (e.g. P12, L9–11 & L28–30; P15, L12–15) but rather followed by a literature review. The own results need to be better used to document the paleoceanographic/ environmental signal that is gained from this new site and data, before comparing to the literature. Figures integrating the own results with key records from previous studies is also advised.

Major comments

Referee's comment: First of all, the raw data needs to be made publicly available and/or presented with the manuscript. Needed are tables that list unique sample labels and relevant metadata such as core coordinates, sampling depths, measured data for each proxy (sedimentology, foraminifer assemblage data, stable isotopes and aDNA), etc.

Response: According to the Reviewer's suggestion, the raw data will be provided as electronic supplementary material.

Referee's comment: Age model. The ages used for the age model seem arbitrary. What is the argument to choose 1500, 2700 and 7890 yr BP? Those ages are not the average of the 2 sigma calibrated yrs BP. The most up-to-date radiocarbon calibration (Calib 7.1) was not used. Why?

Response: The calibration was refined with the use of the latest version of Calib program. However, the calibration dataset (Marine 13, Reimer et al. 2013) remained the same, thus the obtained results of calibration have not changed. The dates used in the age model marked the tops of probability curves on the probability distribution plot provided by Calib 7.1 program (see Fig. 2).

Referee's comment: There is 9 cm sediment between 2700 and 7890 cal yr BP (43.5–52.5 cm), or a sedimentation rate of 0.0017 cm/yr assuming a constant sedimentation rate. Have you considered the possibility of a hiatus? Are there changes in the sedimentology/lithology? Additional dating could help solve this issue. Using your proxies to support the age model (P10, L23), make your environmental interpretation become circular. You need to separate the age model from the environmental proxies.

Response: We agree with the Reviewer that additional dating would improve the age model. According to the linear age model, the beginning of the Neoglacial was recorded at 46 cm sediment depth. Therefore, we decided to provide an additional radiocarbon date from this layer. The dating of foraminiferal tests revealed the age of 4.5 cal ka BP, which confirms our previous age estimation. We also agree that environmental proxies should be separated from the age model, therefore, we decided to remove the sentence considering our proxy record from the mentioned above paragraph.

The low sediment accumulation rate recorded for the period from 7890 to 2700 yr BP was most likely a result of glacial retreat and consequent low delivery of sedimentary material. SAR recorded in the studied core was consistent with the results obtained by Łącka et al. (2015) in Storfjordrenna for this time period. On the other hand, Knies et al. (2017) and Rasmussen and Thomsen (2015) recorded higher accumulation rates in the inner Storfjorden. However, their studied cores were located relatively close to the shore, and, in our opinion, were more affected by sedimentary material delivery.

Referee's comment: Methods. This type of study (aDNA) is still very new in paleoceanography and more details about the aDNA method would be useful. For example, a short account of the bioinformatics (how were sequences translate to OTUs) would be advisable, rather than referring to other papers. How did you determine that the aDNA was in fact ancient?

Response: We have followed the Reviewers suggestion and added a broader description of post-sequencing data analysis. The added text is as follows: The post-sequencing data processing was performed with the use of SLIM web app (Dufresne et al., 2019) and included demultiplexing the libraries, joining the paired-end reads, chimera removal, Operational Taxonomic Units (OTUs) clustering, and taxonomic assignment. Sequences were clustered into OTUs using Swarm module (Mahe et al. 2014) and each OTU was assigned to the highest possible taxonomic level using vsearch (Rognes et al., 2016) against a local database and then reassigned using BLAST (Altschul et al., 1990).

In order to ensure that obtained results represent ancient DNA, we have kept stringent precautions at each step of the analysis, from sampling to laboratory analysis. These include samples storage and processing in a sterile environment, using physically isolated work area at each step of the analysis and providing negative (blank) controls during DNA extraction, PCR amplification, and quantification. The DNA extraction was performed in the laboratory free from foraminiferal and diatom DNA in the Institute of Oceanology PAN, while PCR amplification and DNA sequencing were performed in laboratories adapted for work with ancient environmental DNA at the University of Geneva.

Referee's comment: Discussion. You write in the results section (P7, L18-20): "However, the extremely low time resolution between 9 cal ka BP and 4 cal ka BP precluded making any general conclusion about that interval. Therefore, the manuscript focuses only on the last 4 cal ka BP (the Neoglacial)." It is not clear where the 9 and 4 cal ka BP come from? The only "certain" ages are 7890 and 2700 cal yr BP (but see my comments above) measured in samples that are only 9 cm away from each other, and thus showing an extremely low time

resolution. With only 2 samples analysed in this interval, this is clearly not sufficient to warrant the lengthy discussion (P10–12) on the interval prior to 2700 yr BP. While the fossil assemblages and aDNA may give valuable information about the environment, it is not possible to say something meaningful with regard to timing of events in this interval. That would require analysis of additional samples and ¹⁴C dates (but preferably a record with a higher sedimentation rate).

Response: The date 9 000 results from the linear interpolation of accumulation rate based on SAR calculated for the period prior to 7890 cal ka BP. We agree that it is an oversimplification, therefore we have decided to keep the date 7890 cal ka BP as the oldest certain age.

As mentioned above, we have decided to provide additional radiocarbon date. The obtained date was in accordance with the existing age model and confirmed that the onset of the Neoglacial was recorded at 46 cm sediment depth.

We agree that the Discussion about the period prior to ~ 2.7 cal ka BP is disproportionately long compared to the low number of samples in this interval. Therefore, we decided to shorten this part of the Discussion. Now the text is as follows: During the period prior to ~ 2.7 cal ka BP, the ST_1.5 sedimentary record displayed elevated and variable IRD delivery and coarsening of the 0-63-µm sediment fraction (Fig. 4). These results are in agreement with the record from Storfjordrenna (Łącka et al., 2015), where peaks in IRD were noted during the Neoglacial and were attributed to increased iceberg rafting due to fluctuations in the glacial fronts (e.g. Forwick et al., 2010). Coarser 0-63 µm may suggest winnowing of fine grained sediment, however, foraminiferal fauna showed no clear response for sediment removal.

The ST_1.5 foraminiferal assemblage was dominated by glacier-proximal fauna (primarily C. reniforme) and indicators of frontal zones (primarily M. barleeanum; Fig. 5). The presence of C. reniforme and M. barleeanus is linked to cooled and salty AW (e.g., Hald and Steinsund, 1996; Jernas et al., 2013). Moreover, these species are also associated with the presence of phytodetritus, which may be related to the delivery of fresh organic matter observed in frontal zones and/or near the sea-ice edge (Jennings et al., 2004). Relatively light $\delta^{13}C$ (Fig. 4), followed by the maximum percentage of sea-ice species Thalassiosira antarctica (cf Ikävalko, 2004; Fig. 8) may indicate primary production associated with the presence of sea-ice and/or periodic inflow of ArW

The typical response of a foraminiferal community to high trophic resources is an increase in diversity and standing stock (Wollenburg and Kuhnt, 2000). According to our data, the foraminiferal community showed no clear signs of increased productivity, as the abundance and flux of foraminifera were low prior to ~ 2.7 cal ka BP (Fig. 4). Similarly, Rasmussen and Thomsen (2015) noted a decrease in concentration of benthic foraminifera in Storfjorden at that time, which was attributed to the more extensive seasonal sea-ice cover. Also, Knies et al. (2017) suggested a variable sea-ice cover extent and a fluctuating sea-ice margin in Storfjorden prior to ~ 2.8 cal ka BP. In contrast, our data may suggest the presence of high-energy environment during the interval prior to ~ 2.7 cal ka BP, what may be the major factor limiting the development of the foraminiferal community. However, low

sampling resolution during that period precluded making any general conclusion and the latter assumption should be confirmed by further studies.

Referee's comment: Higher current speeds (i.e. P.11, L5) can strongly influence paleoceanographic records. What is the effect of bottom water currents on the microfossil and aDNA records here? Could this bias your interpretation?

Response: The change in the grain size in the 0-63 μ m fraction may suggest selective removal of sediment due to the winnowing of fine sediments. However, there was no clear response in fossil foraminifera. Foraminiferal flux and abundance were extremely low at that time and the assemblage was strongly dominated by C. reniforme and M. barleeanum, taxa that are associated with the delivery of fresh phytodetritus. Relatively light $\delta^{13}C$, followed by increased % of aDNA sequences of Thalassiosira antarctica may suggest that primary production was associated with the presence of sea ice at that time. Despite potentially high food supply, foraminiferal standing stock remained low, which may result from higher bottom currents speed and winnowing that limited foraminiferal community development.

On the other hand, the flux and abundance of C. lobatulus, which is considered a bottom currents indicator, remained relatively low and stable during the Neoglacial. The major peak in abundance was recorded at ~0.4 cal ka BP, flowed by minor peaks at ~ 2.3 and ~ 1.5 cal ka BP. Our observations are consistent with the record of Łącka et al. (2015) from Storfjordrenna. They observed an increase in the mean grain size (> 63 μ m) during the late Holocene (i.e., after 3.6 cal ka BP), what may indicate more vigorous bottom currents and winnowing of fine-grained sediment. However, it was not followed by the increase in C. lobatulus abundance.

In the case of monothalamous foraminifera, no bottom currents indicators were identified so far. The knowledge about monothalamids' ecology and environmental tolerance is incomplete, and using them as a proxy is still limited. Therefore, no clear information about bottom currents activity can be inferred from aDNA record.

Referee's comment: Do the foram assemblages, and diatom and foram DNA assemblage data show a change supporting the interpreted shift from polynya conditions to densely packed sea ice environment at 2700 cal yr BP?

Response: As explained in the Discussion, our record contradicts other interpretations suggesting that Storfjorden was covered by densely packed sea-ice after ~ 2.7 cal ka BP (cf. Knies et al. 2017). We proposed an alternative scenario that assumed pulsed inflows of AW after ~ 2.7 cal ka BP, which caused a periodic breakup of sea ice cover and allowed primary productivity. These pulses were recorded in the abundance and taxonomic composition of fossil foraminifera assemblages as well as in shifts in monothalamous foraminifera inferred from aDNA. Moreover, the presence of diatom aDNA during the entire Neoglacial suggested continuous primary production (see P13, L9 – P14, L34).

Referee's comment: The AW pulses at 2.3 and 1.7 cal kyr BP show an opposite pattern in foraminifer flux and abundance (Fig. 3, lower two panels): low at 1.7, while high at 2.3 cal kyr BP. Why are these such different patterns to AW pulses? How does this compare to the aDNA records?

Response: Indeed, the response of the foraminiferal community showed differences between ~ 2.3 cal ka BP and ~ 1.7 cal ka BP. The dominant components of foraminiferal assemblage at ~ 2.3 cal ka BP were M. barleeanum and E. excavatum, while at ~ 1.7 cal ka BP, N. labradorica and C. reniforme reached higher percentages. The major difference in environmental conditions between these two "AW episodes" was noticeably coarser 0-63 µm sediment fraction noted ~ 2.3 cal ka BP, what may indicate more intensive winnowing and consequent sediment sorting, what creates favorable conditions for development of highly opportunistic species, such as E. excavatum, which reached its' maximum flux and percentage at that time. Moreover, slightly lighter δ^{18} O and δ^{13} C at ~1.7 cal ka BP suggested a slight difference in AW characteristics. The difference may be supported by the presence of more diverse monothalamous assemblage and the occurrence of sequences of diatom T. hispida at ~ 1.7 cal ka BP. The relevant information has been added to the Discussion.

Referee's comment: You claim an increase in fresh phytodetritus and/or phytoplankton blooms (e.g. P16, L4), but do you actually document this? It seems this is being inferred from the foram assemblages. More cautious wording is advised here.

Response: We agree with the Reviewer's comment. The sentence has been modified to "Warming was associated with pulsed inflows of AW and sea-ice melting, which may stimulate phytoplankton blooms and organic matter supply to the bottom".

Referee's comment: How does the aDNA signal reflect sea ice cover? You refer to the genera Navicula and Thalassiosira as occurring in sea ice, but these genera also occur elsewhere. For example, Thalassiosira is very diverse in temperate regions (Hoppenrath et al. 2007, Eur. J. Phycol.). Did you identify Thalassiosira species that occur in sea ice, or does the aDNA data not allow to classify to species level.

Response: We have manually checked the sequence assignment. The majority of diatom sequences were assigned to Thalassiosira sp., and it was not possible to assign them to species level. However, we identified the sequences belonging to Thalassiosira antarctica, which is a sea-ice species. We have modified the paragraph of the Discussion considering the sea-ice diatoms. Now the text is as follows: The record of diatom aDNA supports the latter assumption, as the percentage of sea-ice species Thalassiosira antarctica (cf. Ikävalko, 2004) reached its maximum during this period.

Referee's comment: Several studies in the region are mentioned in the discussion (e.g. Sarnthein et al. 2003, Rasmussen and Thomsen 2014, Knies et al. 2017), some of which apparently show comparable signals. This should be discussed in more detail (i.e. what is comparable), and preferably supported by a clear figure showing the key-proxies from those studies that show similarities with the own records.

Response: The data showing temperature and isotopic records from GISP2 core (Cuffey and Clow, 1997; Alley, 2000) and Storfjordrenna (Łącka et al., 2015), as well as temperature records of Sarnthein et al., (2003), have been added to the Figure 3. Moreover, more detailed information about comparable signals has been added to the Discussion.

Referee's comment: Minor comments

P5 – sampling. The core was sampled ever y cm and at 5 cm for aDNA. Were all other proxies also analysed at 5 cm or at 1 cm? A list/table with raw data would help answer this question.

P5, L8&11. aDNA sampling interval at 5 cm – repetition. It would be more informative to have a list of the sample depths.

P6, L16. Please list these 27 levels. And provide raw data.

Response: The repetition has been removed from the text. The raw data including sampling resolution will be added to the manuscript as an electronic supplement.

Referee's comment: P6, L22. What is the primer length?

Response: The length of primers is approximately 20 base pairs (bp): the diatom-specific primers are 22 bp long, while foraminifera-specific primers are 19 bp-long. The full sequences of primers are provided in the Material and methods section in the manuscript.

Referee's comment: P8, L23. Specify "certain species".

Response: Herein, by "certain species" we mean dominant species. To avoid confusion, the phrase "certain species" have been removed.

Referee's comment: P9, L23. Please specify the being and end of the time intervals.

Response: The mentioned above time intervals spanned the period from ~ 4 *cal ka BP to 2.4 cal ka BP and* ~ 1.7 *cal ka BP. The relevant information has been added to the text.*

Referee's comment: P10, L21 (and throughout). Please remove ST_1.5. You analyzed only one core in thisstudy, so that does not have to be repeated.

Response: The repetitions have been removed from the text.

Referee's comment: P11, L17. Codominant – be careful with this term, as it means that the species/groups are equally dominant. Is that always the case?

Response: Each of the mentioned above foraminifera indicators groups made up to 40% of foraminiferal abundance. However, we have decided to change the word "codominated" to "dominated".

Referee's comment: P12, L9–11. What does this mean in terms of environment/paleocenaography?

Response: Our record displayed an almost 10-fold increase in sediment accumulation rate, accompanied with a decrease in IRD delivery and coarsening of <63 μ m fraction. The increase in SAR resulted most likely from glacial advance observed in Storfjorden at that time (cf. Rasmussen and Thomsen, 2015) and consequent settling of sedimentary material. Sediment accumulation may be also enhanced by the slowdown of bottom currents, as indicated by the decrease in <63 μ m fraction. Moreover, glacial advance is typically followed by more intensive IRD delivery (cf. Rasmussen and Thomsen 2015). However, Storfjorden was covered by densely packed sea ice at that time (Knies et al., 2017) and the majority of icebergs may be trapped in the innermost part of Storfjorden. The relevant explanations have been added to the text.

Referee's comment: P12, L28–30. As above. It would help to put P13, LL4–8 first in the paragraph.

Response: Indeed, placing the information about benthic foraminifera abundance and change in diatom community at the beginning of the paragraph will make our interpretation more clear and easy-to-follow. Therefore, we have modified the paragraph according to the Reviewer's suggestion.

Referee's comment: P13, L12-14. What data that you present do you base this interpretation?

Response: The proposed scenario is based on the alkenone record from Storfjordrenna provided by Łącka et al. (article after review)

Referee's comment: P13, L15. Which diatom aDNA sequences? Could these be transported (currents) rather being than reflection of local production?

Response: Herein, we mean diatom sequences in general. Our aim was to pay attention to the continuity of the diatom aDNA record over the Neoglacial. The changes in taxonomic composition were discussed in the other parts of the discussion. We agree that diatoms may be transported by sea currents. However, the record was dominated by one genus (Thalassiosira) and taxonomic composition was relatively stable in the entire record, therefore there are no clear signs of the presence of extraneous taxa.

Referee's comment: P14, L2. . . . are not [a] coherent . . .

Response: The sentence has been corrected.

Referee's comment: P14, L9. This is speculation.

Response: Indeed, Clade Y is still poorly studied, therefore most information about its ecology are assumptions. Therefore, we have decided to remove the latter part of the sentence.

Referee's comment: P14, L24–34. It is not clear what the conclusion is from this list of examples.

Response: The aim of this paragraph was to shortly describe the monothalamous taxa recorded in the studied core and to highlight the relation of listed taxa to the presence of phytodetritus. The general conclusions about the changes in monothalamous assemblages are presented in the following paragraph (P15, L1-11).

Referee's comment: P15, L12–16. it is not clear what are own results and what comes from literature.

Response: There was a mistake in the sentence, the word "and" is unnecessary. Now the text is as follows: The decrease in the percentage of foraminiferal sea-ice indicators that started after ~ 1.7 cal ka BP suggests a gradually diminishing sea-ice coverage in Storfjorden (Fig. 4). Modern-like conditions were established in Storfjorden ~ 0.5 cal ka BP, with seasonally variable sea-ice cover resulting in intensified but variable polynyal activity (Rasmussen and Thomsen, 2014; Knies et al., 2017).

Referee's comment: P15, L16. The IP . . . (capital)

Response: The sentence has been corrected.

Referee's comment: P15, L25. Can you identify the LIA in your record?

Response: Yes, it is possible to identify LIA in our record, however, it spanned only one sample (at 4 cm sediment depth), therefore we avoided making any general conclusion about the LIA.

Referee's comment: P16, L4. Did you actually prove phytoplankton blooms occurred or rather that benthic forams responded to changes in environment and productivity?

Response: We have based our conclusion both on microfossil and molecular records of benthic foraminifera and on molecular record of diatoms. Indeed, microfossil and aDNA record of benthic forams shows response of foraminiferal community to environmental changes, however, the aDNA record of diatoms may be an indicator of the primary production.

Anonymous Referee #2

The authors present new study on multicentennial environmental reconstruction of eastern Svalbard region over the last ca. 4000, the so-called Neoglacial. Well established proxies (sedimentary, geochemical and microfossils) along with very novel molecular approach (foraminifera and diatom derived ancient DNA) were studied in marine sediment core in order to deliver the broad database for the paleo-interpretations.

The study area was already investigated in number of studies, however here the authors tested new molecular proxy, which seems to well support and improve the interpretations based on standard tools. In my opinion, the study is well worth to be published after some, rather minor improvements, particular of the discussion chapter.

Please follow the detailed comments below:

Detailed comments:

Referee's comment: Abstract: Perhaps it could be more pronounced why the authors choose Storfjorden for the area of study and what is the specific importance of the region.

Response: We agree with this comment. We have added more information about Storfjorden to the Abstract. The added text is as follows: Storfjorden is one of the most important "brine factory" in the European Arctic, responsible for the deep water production. Moreover, it is a climate-sensitive area, influenced by two contrasting water masses: warm and saline Atlantic Water (AW) and colder and fresher Arctic Water (ArW)

Referee's comment: Introduction: Page 3, line 27. Wouldn't be enough to refer only to the published study of Pawłowska?

Response: The study of Pawłowska et al. (2014) considers only foraminifera. Unfortunately, the results of diatom analysis from sediment cores have not been published yet, therefore, it was necessary to refer to personal communication.

Referee's comment: Study area: Page 4, lines 27-29. The location of the studied sediment core seems to be rather off the Storfjorden, in the trough, thus I wonder if the study area descriptions, including low energy and high SAR environment, are still applying?

Response: The core is located in the central Storfjorden, off the through. The study of Winkelmann and Knies (2005), where the sedimentary environment in Storfjorden was described, covers also central and outer parts of Storfjorden.

Referee's comment: Do you know what is the thickness of AW branch that enters the core location, does it affect the bottom environment directly, do you have modern bottom temperature and salinity data?

Response: The temperature and salinity profile from the coring site has been added to the manuscript. During the August 2014, AW occupied the uppermost 47 m, while the intermediate layer was dominated by TAW. In the near bottom layer, BSW was observed.

Referee's comment: Sampling: With a relatively short sediment core, the aDNA sampling resolution could be higher.

Response: Material for aDNA analysis have been taken before the core was dated, therefore, we have decided to sample the core with fixed 5-cm interval. Indeed, the sampling resolution could have been higher. Unfortunately, we have no more material suitable for aDNA analysis to provide a higher resolution record.

Referee's comment: Fossil foraminifera: It should be mention somewhere what was the resolution of fossil foraminiferal analysis, I assume it was every 1 cm.

Response: Fossil foraminifera were analyzed every 2 cm. The appendix with raw data, including sampling resolution, will be provided as electronic supplementary material.

Referee's comment: Page 6, line 15. Please provide full name of the species as it is mentioned here for the first time.

Response: The full name has been added to the sentence.

Referee's comment: Do you have any possible explanation for the low time resolution between 7890 and 2700 cal BP? Strong bottom currents or possible sediment slide?

Response: The low sediment accumulation rate recorded for the period from 7890 to 2700 yr BP was most likely a result of glacial retreat and consequent low delivery of sedimentary material. SAR recorded in the studied core was consistent with the results obtained by Łącka et al. (2015) in Storfjordrenna for this time period. On the other hand, Knies et al. (2017) and Rasmussen and Thomsen (2015) recorded higher accumulation rates in the central and inner Storfjorden. However, their studied cores were located relatively close to the shore, therefore, were more affected by sedimentary material delivery.

Referee's comment: Page 8, lines 33-34 to page 9, line 1. The mentioned three percentage values, what are they refer to, it is not clear from the sentence, consider rewording.

Response: The sentence has been corrected as follows: After ~ 2.7 cal ka BP, there were AW/frontal zone indicator peaks recorded at 2.4 and 1.8 cal ka BP, where the percentages increased to 33%, and 28% of the total abundance.

Referee's comment: Foraminiferal aDNA: The authors focus only on soft walled monothalamea group with regard to molecular record. Do the authors plan to relate the fossil and the molecular records of hard walled foraminifera as well? Perhaps the agglutinated taxa which are also difficult to stay preserved could be investigated molecularly.

Response: The relation between the molecular and fossil record has been already studied (see Pawłowska et al., 2014; Geobiology) and it was not our intention to duplicate these results. In our study, we decided to focus on monothalamous foraminifera, as they are the dominant component of aDNA record and may provide the most valuable environmental information.

Referee's comment: Discussion: Overall, I would like to suggest including 'chronological' headlines into the discussion chapter e.g. 'Interval prior to 2.7 ka BP', 'Episodes of enhanced

AW inflow'

et. al. to make it easier for the reader to follow. Response: We agree with this comment, headlines have been added to the Discussion

Referee's comment: Page 10, lines 25-31. It would be highly recommended to provide summary figure that would visualize the correlation between your results and the cited studies.

Response: The data showing temperature and isotopic records from GISP2 core (Cuffey and Clow, 1997; Alley, 2000) and Storfjordrenna (Łącka et al., 2015), as well as temperature records of Sarnthein et al., (2003), have been added to the Figure 3.

Referee's comment: Page 11, line 4-7. Can the strong currents provide also unfavorable conditions for benthic foraminifera and explain generally very low fauna abundance? Or this is related exclusively with heavy sea ice cover? Is there any detectable response from current velocity indicators like C. lobatulus?

Response: The percentage of C. lobatulus remained relatively stable during the Neoglacial, except for the peak ~ 0.4 cal ca BP and minor peaks at ~ 2.3 and ~ 1.5 cal ka BP. Therefore, we were not able to make any unequivocal conclusions.

Moreover, the low number of samples in the interval prior to ~ 2.7 cal ka BP is not sufficient to warrant the lengthy discussion and does not allow to make any general conclusions. Therefore, we decided to shorten the part of the Discussion considering this time interval.

Referee's comment: Line 2-5. Might be that IRD and higher mean grain size can also source from extensive transport of shore sea ice?

Response: Indeed, the sea-ice rafting may be an important source of ice-rafted debris. However, the sampling station was located relatively distant from the shore, therefore, the terrestrial impact was rather minor.

Referee's comment: Page 12, line 6-8. Is it possible to detect the past occurrence of dense brines transport to the bottom in the foraminiferal isotopic signatures measured by the authors?

Response: The ¹⁸O and ¹³C values prior to ~ 2.7 cal ka BP were relatively stable. However, for this period isotopes were measured in 3 sediment layers, which may affect the result. Therefore, we have added to the mentioned above paragraph conclusion that the potential influence of brines on foraminiferal abundance has to be confirmed by other studies.

Referee's comment: Line 24-25. Yet, no clear response from C. lobatulus.

Response: Indeed, as mentioned above, the percentage of C. lobatulus was rather stable during the Neoglacial. Our observations are consistent with the record of Łącka et al. (2015) from Storfjordrenna. They observed an increase in the mean grain size (> $63 \mu m$) during the

late Holocene (i.e., after 3.6 cal ka BP), which was not followed by the increase in C. lobatulus abundance.

Referee's comment: Page 13, line 12-14. Here, the authors explain brines as a source of water mixing and nutrient supply, with a positive effect of foraminiferal fauna, whereas for the interval prior to 2.7 cal ka BP, brine formation is presented as a hazardous factor, which seems to be a bit confusing.

Response: As mentioned above, the low number of samples in the interval prior to 2.7 cal ka BP precluded making any general conclusion. The Discussion considering the influence of sea-ice on foraminifera during that interval has been modified. Now the text is as follows: The ST_1.5 foraminiferal assemblage was dominated by glacier-proximal fauna (primarily C. reniforme) and indicators of frontal zones (primarily M. barleeanum; Fig. 5). The presence of C. reniforme and M. barleeanus is linked to cooled and salty AW (e.g., Hald and Steinsund, 1996; Jernas et al., 2013). Moreover, these species are also associated with the presence of phytodetritus, which may be related to the delivery of fresh organic matter observed in frontal zones and/or near the sea-ice edge (Jennings et al., 2004). Relatively light δ^{13} C (Fig. 4), followed by the maximum percentage of sea-ice species Thalassiosira antarctica (cf Ikävalko, 2004; Fig. 8) may indicate primary production associated with the presence of sea-ice and/or periodic inflow of ArW

The typical response of a foraminiferal community to high trophic resources is an increase in diversity and standing stock (Wollenburg and Kuhnt, 2000). According to our data, the foraminiferal community showed no clear signs of increased productivity, as the abundance and flux of foraminifera were low prior to ~ 2.7 cal ka BP (Fig. 4). Similarly, Rasmussen and Thomsen (2015) noted a decrease in concentration of benthic foraminifera in Storfjorden at that time, which was attributed to the more extensive seasonal sea-ice cover. Also, Knies et al. (2017) suggested a variable sea-ice cover extent and a fluctuating sea-ice margin in Storfjorden prior to ~ 2.8 cal ka BP. In contrast, our data may suggest the presence of high-energy environment during the interval prior to ~ 2.7 cal ka BP, what may be the major factor limiting the development of the foraminiferal community. However, low sampling resolution during that period precluded making any general conclusion and the latter assumption should be confirmed by further studies.

Referee's comment: Line 29-31. Was the strong bottom current activity reflected also in the changes in grain size fraction?

Response: Indeed, there were slight peaks in the $0-63 \,\mu m$ that coincided with the increase in C. lobatulus. The relevant information has been added to the Discussion.

Referee's comment: Page 15, line 25. The authors mentioned LIA but what about the other prominent climatic events that occurred during the last 2 ka. Can the results be related to them as well, if not, can the authors discuss the possible reason for the lack of larger scale climatic signals, e.g. perhaps local variability. The discussion could improve from a bit broader overview of other Svalbard records, that also underly the AW inflow.

Response: We have followed the Reviewer's suggestion and added a paragraph considering other records from the Nordic Seas. The added text is as follows: Our record revealed two-phase Neoglacial, with a major shift in environmental conditions at ~ 2.7 cal ka BP. According to the ST_1.5 record, the Neoglacial in Storfjorden was not a constantly cold period, but comprised alternate, short-term cooling and warming periods, associated with variability in sea-ice coverage and productivity. There is various evidence of a shift in environmental conditions in the Nordic Seas region in mid-Neoglacial. Alkenone record from the Norwegian Sea revealed a significant drop of sea surface temperature at 2.7 cal ka BP (Calvo et al., 2002). Risebrobakken et al. (2010) recorded a change in oceanographic conditions in the SW Barents Sea ca. 2.5 cal ka BP, followed by the episodes of reduced surface and subsurface salinity after 2.5 cal ka BP, what was attributed to the expansion of coastal waters and the occurrence of more sea-ice.

Moreover, our evidence of the presence of AW in Storfjorden during the Neoglacial supported previous suggestions that AW inflow during the late Holocene was strong enough to reach also the eastern coasts of Svalbard (e.g., Łącka et al., 2015). Moreover, Sarnthein et al. (2003) postulated pulses of AW inflow to the western Barents Sea shelf at 2.2 and 1.6 cal ka BP. According to Perner et al. (2015), the Neoglacial delivery of chilled AW to the Nordic Seas culminated between 2.3 and 1.4 cal ka BP. Also, Rasmussen et al. (2014a) and Jernas et al (2013) recorded slightly warmer and less glacial conditions during the last 2 ka on the western Spitsbergen shelf.

Referee's comment: General comment, can the authors observe a relation of the reconstructed higher bottom current activities and the diversity of fragile, soft organic-walled monothalamids?

Response: The most intensive bottom currents were likely to occur during the interval prior to 2.7 cal ka BP. Unfortunately, the aDNA was analyzed only in one sample during this time interval, therefore, we cannot make any general conclusions. Moreover, the knowledge about monothalamids ecology and environmental tolerance is still scarce and incomplete and no bottom currents indicators have been identified in this group so far.

Referee's comment: Figures:

Fig. 3. Could you perhaps mark the sampling points on the graphs. It seems as for the interval 4 ka BP to 2.7 ka BP there are very few sampling points, thus there is almost no detectable variability in the data. Would it be reasonable to consider sediment turbation and homogenization of the signals in such a small thickness of sediment? The dash lines indicating intervals are very useful, you could probably apply them also to figure 4 and 5 and 7 so it is easier to compare the data.

Response: Sampling points and dashed lines have been added to the graphs, according to the Reviewer's suggestion.

Our sedimentary record indicated more vigorous bottom currents and consequent winnowing of fine sediment. Therefore, the homogenization of signal may be related to selective removal of mineral and organic particles, rather than turbation.

Referee's comment: Fig. 4. I would suggest to change scale down to 30% in order to have better over view for the potential variability, except C. reniforme.

Response: There are two taxa that exceeded 30% of foraminiferal assemblage -C. reniforme and E. excavatum. We have decided to use the scale reaching up to 50% to clearly show the differences between the percentages of certain taxa and to highlight the dominance of species such as C. reniforme or M. barleeanum. Therefore, we would prefer to keep the scale in its current form.

Referee's comment: Fig. 5. The age scale is bit too compacted, please consider stretching it.

Response: We have prepared the figure according to the Reviewers comment, however, stretching the scale resulted also in the increase in the distance between the data bars and, in consequence, graph became less clear and the trends were less visible. Therefore, we would prefer to keep the scale in its current form.

Referee's comment: Fig. 6. 'Clade I' was not mentioned in the result chapter, does it stand for 'environmental clade' (page 9, line 21)?

Response: Clade I does not stand for the environmental clade. Allogromiids belonging to Clade I were noted only in one sample, where they made 0.88% of allogromiid sequences. The information about the occurrence of Clade I have been added to the Results section.

Multiproxy evidence of the Neoglacial expansion of Atlantic Water to eastern Svalbard: Does ancient environmental DNA complement sedimentary and microfossil records?

4

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Abstract. The main goal of this study was to reconstruct the paleoceanographic development 13 14 of Storfjorden during the Neoglacial (~ 4 cal ka BP). Storfjorden is one of the most important "brine factory" in the European Arctic, responsible for deep water production. Moreover, it is 15 a climate-sensitive area, influenced by two contrasting water masses: warm and saline 16 Atlantic Water (AW) and colder and fresher Arctic Water (ArW). Herein, a multiproxy 17 18 approach was applied to provide evidence for interactions between the inflow of AW and seaice coverage, which are the major drivers of environmental changes in Storfjorden. The 19 sedimentary and microfossil records indicate that a major reorganization of oceanographic 20 conditions in Storfjorden occurred at ~ 2.7 cal ka BP. A general cooling and the less 21 pronounced presence of AW in Storfjorden during the early phase of the Neoglacial are 22 prerequisite conditions for the formation of an extensive sea-ice cover. The period after ~ 2.7 23 cal ka BP was characterized by alternating short-term cooling and warming intervals. 24 Warming was associated with pulsed inflows of AW and sea-ice melting that stimulated 25 phytoplankton blooms and organic matter supply to the bottom. The cold phases were 26 27 characterized by heavy and densely packed sea ice resulting in a decrease in productivity. The 28 ancient environmental DNA (aDNA) records of foraminifera and diatoms reveal the timing of 29 the major pulses of AW (~2.3 and ~1.7 cal ka BP) and the variation in sea-ice cover. The AW inflow was marked by an increase in the percentage of DNA sequences of monothalamous 30 31 foraminifera associated with the presence of fresh phytodetritus, while cold and less productive intervals were marked by an increased proportion of monothalamous taxa known 32

only from environmental sequencing. The diatom aDNA record indicates that primary
production was continuous during the Neoglacial regardless of sea-ice conditions. However,
the colder periods were characterized by the presence of diatom taxa associated with sea ice,
whereas the present-day diatom assemblage is dominated by open-water taxa.

5

6 **1. Introduction**

7 The flow of Atlantic Water (AW) is one of the major heat contributors to the Arctic Ocean (Polyakov et al., 2017). Recent oceanographic data indicate warming due to an 8 increase in AW in the Arctic Ocean (Rudels et al., 2015, Polyakov et al., 2017). AW has been 9 present along the western margin of Svalbard during at least the last 12,000 years (e.g., 10 Werner et al., 2011; Rasmussen et al., 2014). One of the major intrusions of AW occurred 11 during the early Holocene (10.8 - 6.8 cal ka BP). A distinct cooling and freshening of the 12 13 bottom water masses occurred during the mid-late Holocene (6.8-1 cal ka BP) and was accompanied by glacier readvances in Svalbard leading to present-day conditions 14 (Ślubowska-Woldengen et al., 2007; Telesiński et al., 2018). The paleoceanographic 15 conditions in the Svalbard margins correlate closely to the sea surface temperature (SST) 16 17 variations in the Nordic Seas and confirm that the Svalbard area is highly sensitive to fluctuations in the inflow of AW (Slubowska-Woldengen et al., 2007). Conversely, until the 18 19 1990s eastern Svalbard was recognized as an area exclusively influenced by the East Spitsbergen Current (ESC), which carries cold and less saline Arctic Water (ArW) from the 20 21 Barents Sea (e.g., Quadfasel et al., 1988; Piechura et al., 1996). Recent studies have revealed that the oceanography of the area is much more complicated (e.g. Skogseth et al., 2007; Geyer 22 et al., 2010). Oceanographic data obtained from conductivity-temperature sensors attached to 23 Delphinapterus leucas show a substantial contribution of AW to Storfjorden (east 24 Spitsbergen; Lydersen et al., 2002). Recently, a suggestion by Hansen et al. (2011) that AW 25 was present in Storfjorden during the early Holocene warming (11 - 6.8 cal ka BP) was 26 confirmed by Łącka et al. (2015). However, the limited amount of data available for eastern 27 Svalbard often makes paleoceanographic reconstructions of the area speculative. 28

The latter part of the Holocene, the so-called Neoglacial cooling (~ 4 cal ka BP), in the European Arctic is correlated with a decline in the summer insolation at northern latitudes (Berger, 1978) and a decline in summer SST (Andersen et al., 2004; Risebrobakken et al., 2010; Rasmussen et al., 2014a). The cooling of the surface waters and the limited AW inflow to the Nordic Seas led to the formation of an extended sea-ice cover (Müller et al., 2012). In addition, the southwestern and eastern shelf of Spitsbergen experienced a strengthening of the

East Spitsbergen Current leading to an intensification of ArW inflow and the formation of an 1 2 extensive sea-ice cover (Sarnthein et al., 2003). Therefore, the Neoglacial has usually considered a constantly cold period, with a culmination of cooling during the Little Ice Age. 3 4 However, the records from Storfjorden and the Barents Sea suggest that the Neoglacial was a 5 period of variable oceanographic conditions with strong temperature and salinity gradients 6 (Calvo et al., 2002; Martrat et al., 2003; Sarnthein et al., 2003; Łacka et al., 2015). There is 7 also evidence of episodic intensifications of the warm AW inflow to western Svalbard at that time (e.g. Risebrobakken et al. 2010; Rasmussen et al., 2012). 8

According to Nilsen et al. (2008), the critical parameter controlling the fjord-shelf 9 exchange is the density difference between the fjord water masses and the AW. The local 10 winter ice production and formation of brine-enriched waters determines the density of local 11 water masses, which is a key factor that enables AW to penetrate into fjords during the spring 12 13 and summer. Moreover, the production of brine-enriched waters and associated deep-water overflow is a key contributor to large-scale ocean circulation (Killworth, 1983). In this 14 15 respect, Storfjorden is especially important because it is one of the few areas where brineenriched waters have been frequently observed (Haarpainter et al., 2001). In the last decades, 16 17 reduced brine formation occurred during periods with the most intensive AW advection to Storfjorden and reduced sea-ice formation in the Barents Sea, while intense brine formation 18 19 was re-established during periods of recurrent cooling (Årthun et al., 2011).

The aim of the presented study is to reconstruct the paleoceanographic development of 20 21 Storfjorden during the Neoglacial with multicentennial resolution. We assumed that the periodic intensification of the AW inflow to the West Spitsbergen shelf during the Neoglacial 22 resulted in the appearance of AW also in eastern Spitsbergen, similar to the early Holocene 23 (e.g., Łacka et al., 2015), affecting the density and extent of sea-ice cover in the area. A 24 multiproxy approach comprising composed of sedimentary, microfossil and molecular records 25 26 was applied to provide evidence for interactions between the inflow of AW and sea-ice coverage in Storfjorden. The ancient environmental DNA (aDNA) analysis targeted diatoms 27 and nonfossilized monothalamous foraminifera, groups that are hardly preserved in fossil 28 29 records from the Spitsbergen fjords (Pawłowska et al., 2014, Łącka M., pers. commun.) Recent studies have demonstrated that analyses of genetic material obtained directly from 30 31 environmental samples (so called environmental DNA) are an efficient method for biodiversity surveys across time and space (Thomsen and Willerslev, 2015). Our previous 32 studies of foraminiferal aDNA revealed the extraordinary richness of the foraminiferal 33 34 community, primarily due to the detection of soft-walled monothalamous taxa (Pawłowska et

al., 2014). Furthermore, aDNA has been proven to be an effective tool in paleoceanographic
reconstructions (e.g. Boere et al., 2009; Pawłowska et al., 2016). The molecular data
correlated well with environmental changes and even revealed small changes that were not
clearly indicated by other proxy records (Pawłowska et al., 2016). The combination of aDNA
studies with the analysis of microfossils and sedimentary proxies provides a powerful means
to reconstruct past environments more comprehensively.

7

8 2. Study area

9 Storfjorden is located in southeastern Svalbard between the islands of Spitsbergen, 10 Edgeøya and Barentsøya. Storfjorden is ~190 m long and its main basin is ~190 m deep. Two 11 narrow and shallow passages Heleysundet and Freemansundet connect northern Storfjorden to 12 the Barents Sea. To the south, a 120-m-deep sill separates the main basin from the 13 Storfjordrenna Trough. Storfjordrenna is 245 m long, with a depth varying from 150 m to 420 14 m.

15 The water masses in Storfjorden are composed primarily of exogenous Atlantic and Arctic waters and mixed waters that have formed locally. Warm AW is transported by the 16 17 West Spitsbergen Current branches off near Storfjordrenna and enters the southern part of the fjord. Arctic water (ArW) from the Arctic Ocean and the Barents Sea enters Storfjorden via 18 19 two passages to the northeast and continues along the inner shelf of Svalbard as a coastal currents. AW is characterized by temperatures > 3 °C and salinity > 34.95, while the 20 temperature and salinity of ArW are < 0 °C and 34.3-34.8, respectively. The presence of 21 locally formed water masses is a result of the interactions between AW, ArW and melt water. 22 Skogseth et al. (2005) listed six local water masses: melt water (MW), polar front water (PW), 23 East Spitsbergen water (ESW), brine-enriched shelf water (BSW), Storfjorden surface water 24 25 (SSW), and modified Atlantic water (MAW). BSW is formed due to the release of large 26 amounts of brines during polynya events and the intensive formation of sea ice (Haarpainter et al., 2001; Skogseth et al., 2004, 2005) and is characterized by salinities exceeding 34.8 and 27 temperatures below -1.5 °C (Skogseth et al., 2005). 28

The sedimentary environment in Storfjorden classified as a low-energy, highaccumulation environment, characteristic of inner fjords. The area is sheltered from alongshelf bottom currents and is affected by high terrigenous inputs; therefore deposition prevails over sediment removal by bottom currents (Winklemann and Knies, 2005). The primary productivity is high and strongly depends on the sea ice formation and the duration of the marginal ice zone (Winkleman and Knies, 2005).

1 3. Materials and methods

2 **3.1 Sampling**

The 55-cm-long sediment core ST_1.5 was taken with a gravity corer in Storfjorden during cruise of the R/V *Oceania* in August 2014. The sampling station was located at 76° 53,181' N and 19° 27,559' E at a depth of 153 m (Fig. 1). The core was stored at 4°C and shipped to the Institute of Oceanology PAS for further analyses.

7 In the laboratory, the core was extruded and cut into 1-cm slices. During cutting, 8 sterile subsamples for ancient DNA (aDNA) analyses were taken at 5 cm intervals. To avoid 9 extraneous and/or cross-contamination the thin layers of sediment that were in contact with 10 under- or overlying sediments were removed using a sterile spatula. Samples for aDNA 11 analyses were kept frozen in -20°C.

12

13 **3.2 Sediment dating**

The chronology of the sediment layers is based on high-precision accelerator mass 14 spectrometry (AMS) ¹⁴C dating performed on five bivalve shells from the sediment layers at 15 2.5, 5.5, 14.5, 43.5, 52.5 cm and on foraminifera Nonionellina labradorica from sediment 16 17 depth of 46.5 cm. The bivalve shells were identified to the highest possible taxonomic level and processed on the 1.5 SDH-Pelletron Model "Compact Carbon AMS" in the Poznań 18 19 Radiocarbon Laboratory, Poznań, Poland. Dating of foraminiferal tests were performed at the National Ocean Sciences AMS (NOSAMS) laboratory in the Woods Hole Oceanographic 20 Institution, Woods Hole, MA, USA. The dates were converted into calibrated ages using the 21 calibration program CALIB Rev. 7.1.0 Beta (Stuiver and Reimer, 1993) and the Marine13 22 calibration dataset (Reimer et al., 2013). A difference (ΔR) in the reservoir age correction of 23 105 ± 24 was applied (Mangerud et al., 2006). The calibrated results are reported in units of 24 25 thousand calibrated years BP (cal ka BP), see Table 1.

26

27 **3.3 Sediment grain size**

Samples for the grain size analyses were freeze-dried and milled. Measurements were performed using a Mastersizer 2000 particle laser analyzer coupled to a Hydro MU device (Malvern, UK). Samples were treated with ultrasound to avoid aggregation. Raw data were analyzed using GRADISTAT v.8.0 software (Blott and Pye, 2001). The mean 0-63- μ m grain size [ϕ] was calculated via the logarithmic method of moments. The sediment fraction >500 μ m was used for an ice rafted debris (IRD) analysis. Grains were counted under a stereomicroscope and the amount of IRD is reported as the number of grains per gram of dry sediment [grains g^{-1}] and flux [grains $cm^{-2} y^{-1}$].

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- 4

5 **3.4 Fossil foraminifera**

6 Prior to fossil foraminifera analysis, samples were wet sieved through a mesh with 500-µm and 100-µm openings and dried at 60°C. Samples with large quantities of tests were 7 divided using a microsplitter. At least 300 specimens of benthic foraminifera were isolated 8 from each sample and collected on micropaleontological slides. Benthic foraminifera 9 specimens were counted and identified to the lowest possible taxonomic level. The quantity of 10 for a for a sthe number of individuals per gram of dry sediment [ind. g^{-1}] and 11 flux [ind. cm⁻² y⁻¹]. Foraminifera species were grouped according to their ecological 12 tolerances. Four groups of indicators were distinguished: AW/frontal zone indicators, ArW 13 indicators, bottom current indicators and glaciomarine species (Majewski et al., 2009). 14 15 Morphologically similar species Islandiella norcrossi and Islandiella helenae are reported as Islandiella spp. 16

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18 **3.5 Stable isotopes analysis**

19 Carbon and oxygen stable isotope analyses were performed on *Cibicidoides lobatulus* 20 tests selected from 27 sediment layers. From 10 to 12 specimens were collected from each 21 sample and subjected to ultrasonic cleaning. The measurements were performed on a 22 Finningan MAT 253 mass spectrometer coupled to a Kiel IV carbonate preparation device at 23 the University of Florida. The resulting values are expressed in standard δ notation relative to 24 Vienna Pee Dee Belemnite (VPDB).

25

26 **3.6 Ancient DNA analysis**

Total DNA was extracted from approximately 10 g sediment using a Power Max Soil 27 DNA extraction kit (MoBio). The foraminiferal SSU rDNA fragment containing the 37f 28 hypervariable region was PCR amplified using primers tagged with unique sequences of five 29 nucleotides appended to their 5' ends (denoted by Xs), namely the foraminifera-specific 30 forward primer s14F1 (5'-XXXXCGGACACACTGAGGATTGACAG-3') and the reverse 31 primer s15 (5'-XXXXXCCTATCACATAATCATGAAAG-3'). The diatom DNA fragment 32 DIV4for 33 in the V4 amplified with the forward (5'located region was XXXXXXXGCGGTAATTCCAGCTCCAATAG-3') DIV4rev3 (5'-34 and reverse

XXXXXXXXCTCTGACAATGGAATACGAATA-3') primers tagged 1 with а unique 2 combination of eight nucleotides (denoted by Xs) attached at each primer's 5'-extremity. The amplicons were purified using the High Pure PCR Cleanup Micro Kit (Roche) and quantified 3 4 using a Qubit 2.0 fluorometer. Samples were pooled in equimolar quantities and the sequence library was prepared using a TruSeq library-preparation kit (Illumina). Samples were then 5 6 loaded into a MiSeq instrument for a paired-end run of 2*150 cycles (foraminifera) and 2*250 7 cycles (diatoms). The processing of the HTS sequence data was performed according to procedures described by Lejzerowicz et al. (2013) and Pawłowska et al. (2014). The post-8 sequencing data processing was performed with the use of SLIM web app (Dufresne et al., 9 2019) and included demultiplexing the libraries, joining the paired-end reads, chimera 10 removal, Operational Taxonomic Units (OTUs) clustering, and taxonomic assignment. 11 Sequences were clustered into OTUs using Swarm module (Mahe et al. 2014) and each OUT 12 was assigned to the highest possible taxonomic level using vsearch (Rognes et al., 2016) 13 against a local database and then reassigned using BLAST (Altschul et al., 1990). The results 14 are presented in OTU-to-sample tables and transformed in terms of the number of sequences, 15 number of OTUs and the percentage (%) of sequences. 16

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18 4. Results

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20 4.1 Sediment age and type

21 All dates were in the chronological order and the uppermost layer contained modern, post-bomb carbon indicating a post-1960 age (Table 1). Samples from depths of 2.5 cm and 22 5.5 cm were not calibrated because they revealed ages that were invalid for the selected 23 calibration curve. The age model was therefore based on the three remaining dates using a 24 25 linear interpolation. The age of the bottom of the core was estimated to be approximately 7.9 26 cal ka BP (Fig. 3). However, the extremely low time resolution between 7.9 cal ka BP and 4 cal ka BP precluded making any general conclusion about that interval. Therefore, the 27 manuscript focuses only on the last 4 cal ka BP (the Neoglacial). 28

The sediment accumulation rate (SAR) prior to ~ 2.7 cal ka BP was 0.002 cm y⁻¹. The approximately 10-fold increase in SAR is noted at ~ 2.7 cal ka BP, when it increased to 0.023 (cm y⁻¹). During the last 1.5 cal ka BP, SAR decreased to 0.01 cm y⁻¹ (Fig. <u>4</u>). The amount of IRD was the highest prior to ~ 2.7 cal ka BP, reaching up to 83 grains g⁻¹. After 2.7 cal ka BP, the amount of IRD was relatively stable and did not exceed 18 grains g⁻¹. The flux of IRD

slightly decreased with time to 0.37 grains g^{-1} cm⁻¹, except for one peak ~ 2.6 cal ka BP, when 1 it reached 0.8 grains g^{-1} cm⁻¹ (Fig. 4). 2

The mean grain size of the 0-63-µm fraction had its highest value (5.8 φ) at ~ 2.7 cal 3 ka BP (Fig. 4) and after 2.4 cal ka BP a slight but continuous reduction in the mean 0-63-µm grain size was noted. The minimum grain size $(6.23 \text{ } \phi)$ was recorded at the top of the core.

7 4.2 Stable isotopes

The δ^{18} O values were relatively stable prior to ~ 2.7 cal ka BP, varying slightly 8 between 3.55% and 3.69% vs. VPDB. Between ~ 2.7 and 1.5 cal ka BP, δ^{18} O showed the 9 strongest variation, with values ranging from 3.28% to 3.77% vs. VPDB. After ~ 1.5 cal ka 10 BP, δ^{18} O became slightly lighter and varied between 3.43‰ and 3.64‰ vs. VPDB except for 11 one peak noted in the uppermost layer of the core, where δ^{18} O reached 3.87% vs. VPDB (Fig. 12 4). δ^{13} C values varied throughout the core with slightly lighter values, ranging from 0.92% to 13 1.12‰ vs. VPDB prior to ~ 2.7 cal ka BP. δ^{13} C values reaching up to 1.46‰ vs. VPDB were 14 noted between ~ 2.7 and ~ 1.5 cal ka BP and gradually decreased from ~ 1.5 cal ka BP to the 15 present, reaching 0.81‰ vs. VPDB at the top of the core (Fig. 4). 16

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4.3 Fossil foraminifera 18

19 A total of 8647 fossil foraminifera specimens belonging to 47 species were identified (Supplement 1; Supplementary Fig. 1). The foraminiferal assemblages were dominated by 20 21 calcareous taxa which account for 62-98% of the foraminifera specimens except in the uppermost layer of the core, where the percentage of calcareous foraminifera decreased to 22 44% (Fig. 4). There were few peaks of agglutinated foraminifera noted at 2.0 cal ka BP, 1.8 23 cal ka BP and on the sediment surface, where the percentages reached 37%, 37% and 66%, 24 respectively (Fig. 4). The number of foraminiferal individuals varied from 156 to 2610 ind. g^{-1} 25 and the lowest abundances were observed prior to ~ 2.7 cal ka BP (Fig. 4). A short-term 26 decrease in the foraminiferal abundance was observed between 2.1 and 1.9 ka BP, with values 27 reaching as low as 304 ind. g⁻¹. The abundance maxima were noted at 2.3, 1.5, and 0.6 ka BP, 28 with values reaching 2524 ind. g^{-1} , 2584 ind. g^{-1} , and 2610 ind. g^{-1} , respectively. The 29 foraminiferal flux was low and relatively stable throughout the core with values that did not 30 exceed 1 ind cm⁻² y⁻¹, except for two peaks at 2.3 and 1.5 ka BP, when the flux reached 2.2 31 ind $cm^{-2} y^{-1}$ (Fig. 4). 32

The most abundant species was *Cassidulina reniforme*, with densities reaching up to 33 900 ind g⁻¹. The other species that constituted the majority of the foraminiferal assemblage 34

were *Bucella frigida*, *Cibicidoides lobatulus*, *Elphidium excavatum*, *Islandiella* spp, *Melonis barleeanum*, and *Nonionellina labradorica* The abundances of <u>dominant</u> species followed a
general trend with maxima ~ 2.3 cal ka BP and after ~ 1.7 cal ka BP and minima prior to ~ 2.7
cal ka BP and between 2.3 and 1.7 cal ka BP. (Fig. <u>5</u>).

The foraminiferal assemblage prior to ~ 2.7 cal ka BP was codominated by 5 6 Nonionellina labradorica and Melonis barleeanum, which are species that are considered to be indicators of AW inflow and/or frontal zones, and glaciomarine taxa, primarily 7 Cassidulina reniforme and Elphidium excavatum, which together accounted for up to 60% of 8 the foraminiferal abundance (Fig. 5). After ~ 2.7 cal ka BP, there were AW/frontal zone 9 indicator peaks recorded at 2.4 and 1.8 cal ka BP, where the percentages increased to 33%, 10 and 28% of the total abundance. The period between ~ 2.4 cal ka BP and ~ 1.8 cal ka BP was 11 characterized by an increase in the percentage of sea-ice indicators (B. frigida and Islandiella 12 13 spp), which accounted for up to 25% of the total abundance, and by a short-term peak in the glaciomarine taxa, which accounted for up to 49% of foraminiferal assemblage between 2.5 14 15 and 2.1 cal ka BP. A decrease in the relative abundance of glaciomarine species was observed after ~ 0.5 cal ka BP and was followed by an increase in the AW/frontal zone indicators and a 16 17 single peak in the percentage of bottom current indicators, which reached 42% and 19%, 18 respectively (Fig. 5).

19

20 4.4 Foraminiferal aDNA sequences

A total of 1,499,889 foraminiferal DNA sequences were clustered into 263 OTUs, and remained unassigned. The remaining OTUs were assigned to Globigerinida (5 OTUs), Robertinida (1 OTU), Rotaliida (49 OTUs), Textulariida (18 OTUs), Monothalamea (163 OTUs), and Miliolida (7 OTUs). The majority of sequences belonged to Monothalamea (60%) and Rotaliida (31%) (Supplement 2; Supplementary Fig. 2). Herein, we focus on Monothalamea, which is the dominant component of the foraminiferal aDNA record.

27 The most important components of the monothalamous assemblage were Micrometula sp., Cylindrogullmia sp., Hippocrepinella hirudinea, Ovammina sp., Nemogullmia sp., 28 Tinogullmia sp., Cedhagenia saltatus, undetermined allogromiids belonging to clades A and 29 Y (herein called "allogromiids"), and sequences belonging to taxa known exclusively from 30 environmental sequencing (herein called "environmental clades"). The sequences belonging 31 to allogromiids were present throughout the core, accounting for 16-31.7% of all the 32 for a for a sequences, except during the intervals from ~ 4.0 to 2.4 cal ka BP, and ~ 1.7 cal 33 ka BP, when contribution of allogromiid sequences decreased to less than 10% (Fig. 6). The 34

majority of the allogromiids belonged to clade Y, which accounted for up to 100% of the
allogromiid sequences, except for the two peaks at 1.6–1.7 cal ka BP and 2.4–2.6 cal ka BP,
when the majority of allogromiid sequences belonged to clade A. Also, allogromiids
belonging to Clade I were noted at ~ 2.4 cal ka BP, where they made up 0.88% of allogromiid
sequences (Fig. 7).

6 The periods prior to ~ 2.4 cal ka BP and ~ 1.7 cal ka BP were marked by the
7 disappearance of sequences belonging to *C. saltatus*, *Nemogullmia* sp., and the environmental
8 clades, followed by an increase in the percentages of sequences belonging to *Micrometula* sp.,
9 *Ovammina* sp., *Tinogullmia* sp., *Shepheardella* sp. and *Cylindrogullmia* sp. (Fig. <u>6</u>).

10

11 4.5 Diatom aDNA sequences

A total of 824,697 diatom DNA sequences were clustered into 221 OTUs (Supplement 12 13 3; Supplementary Figure 3). The most abundantly sequenced diatom taxa were Thalassiosira spp, which made up 61.1 % of diatom sequences. Other abundantly sequenced taxa were 14 Chaetoceros sp. and T. antarctica, which made up 8.5% and 11.5% of sequences. The 15 sequences of Thalassiosira sp were most abundant between ~ 2.2 cal ka BP and ~ 1.9 cal ka 16 17 BP, accounting for up to 85% of all diatom sequences. The lowest percentage (14%) of Thalassiosira sp. was recorded ~ 0.4 cal ka BP. Sequences assigned to T. antarctica were 18 19 recorded throughout the core and their percentages were the highest ~ 3.3 and ~ 2.6 cal ka BP, reaching up to 13% and 19%, respectively (Fig. 8). Sequences of T. hispida were also noted 20 21 throughout the core and constitute 4.7% of diatom sequences in the uppermost layer. In the remaining samples, T. hispida sequences did not exceed 1%. The percentage of sequences of 22 Chaetoceros sp. decreased downcore, from 76% at the surface to less than 1% at the bottom 23 24 of the core (Fig. 8). .Navicula sp. constituted an important part of diatom assemblage ~3.3 cal 25 ka BP and ~ 1.9 cal ka BP, accounting for up to 25.5% and 10% of all diatom sequences, respectively. In the remaining samples, its abundance did not exceed 5% (Fig. 8). 26

27

28 **6. Discussion**

The ST_1.5 age model is based on the linear interpolation between the <u>four</u> dates, so the age control of the core should be treated with caution. <u>H</u>owever, the good correlation with other records from the region (e.g., Sarnthein et al., 2003, Rasmussen and Thomsen, 2014<u>b</u>) supports the ST_1.5 age model. The multiproxy record from Storfjorden revealed several intervals of pronounced environmental changes. The major environmental shifts occurred at ~ 2.7, 2.3 and 1.7 cal ka BP, what correlated well with the temperature minimum (2.7 cal ka BP) and maxima (2.3 and 1.7 cal ka BP) recorded in the GISP2 core (Grootes & Stuiver,
 1997) and 23258 core (Sarnthein et al., 2003).

3

6.1. The period from 4 cal ka BP to 2.7 cal ka BP

During the period prior to ~ 2.7 cal ka BP, the ST_1.5 sedimentary record displayed
elevated and variable IRD delivery and coarsening of the 0-63-μm sediment_fraction (Fig. 4).
These results are in agreement with the record from Storfjordrenna (Łącka et al., 2015), where
peaks in IRD were noted during the Neoglacial and were attributed to increased iceberg
rafting due to fluctuations in the glacial fronts (e.g. Forwick et al., 2010). Coarser 0-63 μm
may suggest winnowing of fine grained sediment, however, foraminiferal fauna showed no
clear response for sediment removal.

The ST_1.5 foraminiferal assemblage was dominated by glacier-proximal fauna 11 (primarily C. reniforme) and indicators of frontal zones (primarily M. barleeanum; Fig. 5). 12 The presence of C. reniforme and M. barleeanus is linked to cooled and salty AW (e.g., Hald 13 and Steinsund, 1996; Jernas et al., 2013). Moreover, these species are also associated with the 14 15 presence of phytodetritus, which may be related to the delivery of fresh organic matter observed in frontal zones and/or near the sea-ice edge (Jennings et al., 2004). Relatively light 16 δ^{13} C (Fig. 4), followed by the maximum percentage of sea-ice species *Thalassiosira* 17 antarctica (cf Ikävalko, 2004; Fig. 8) may indicate primary production associated with the 18 19 presence of sea-ice and/or periodic inflow of ArW

The typical response of a foraminiferal community to high trophic resources is an 20 21 increase in diversity and standing stock (Wollenburg and Kuhnt, 2000). According to our data, the foraminiferal community showed no clear signs of increased productivity, as the 22 abundance and flux of foraminifera were low prior to ~ 2.7 cal ka BP (Fig. 4). Similarly, 23 Rasmussen and Thomsen (2015) noted a decrease in concentration of benthic foraminifera in 24 Storfjorden at that time, which was attributed to the more extensive seasonal sea-ice cover. 25 26 Also, Knies et al. (2017) suggested a variable sea-ice cover extent and a fluctuating sea-ice margin in Storfjorden prior to ~ 2.8 cal ka BP. In contrast, our data may suggest the presence 27 of high-energy environment during the interval prior to ~ 2.7 cal ka BP, what may be the 28 major factor limiting the development of the foraminiferal community. However, low 29 sampling resolution during that period precluded making any general conclusion and the latter 30 assumption should be confirmed by further studies. 31

- 32
- 33 <u>6.2 The period after 2.7 cal ka BP. Episodes of AW inflow at ~ 2.3 and 1.7 cal ka BP.</u>

The environmental conditions in central Storfjorden changed noticeably after ~ 2.7 cal 1 2 ka BP. The increase in SAR was followed by a gradual decrease in the 0-63-um fraction and a decrease in the IRD delivery after ~ 2.7 cal ka BP (Fig. 4). The 10-fold increase in SAR 3 4 resulted most likely from the intensive supply of turbid meltwater from advancing glaciers 5 and consequent intensive sedimentation. Moreover, the accumulation of fine sediment may 6 also be enhanced by the slowdown of the bottom currents, indicated by the finer 0-63-µm 7 sediment fraction (Fig. 4). On the other hand, a decrease in IRD delivery may suggest that the central Storfjorden was not impacted by iceberg rafting at that time. In contrast, Rasmussen 8 and Thomsen (2015) suggested glacial advance, followed by intensive ice rafting and 9 meltwater delivery to Storfjorden at that time. According to Knies et al. (2017), the distinct 10 surface water cooling during the Neoglacial provides a prerequisite for the presence of more 11 12 extensive sea-ice cover; therefore inner Storfjorden was covered by densely packed sea ice between ~ 2.8 and 0.5 cal ka BP. Therefore, the decreasing IRD in the ST_1.5 core may result 13 from the presence of a sea-ice cover that reduced iceberg rafting while the majority of coarse-14 15 grained material settled in the proximity of the glacial fronts. Similar conclusions have been stated by Forwick and Vorren (2009) and Forwick et al. (2010), who assumed that the 16 17 enhanced formation of sea ice along the West Spitsbergen coast trapped icebergs inside the Isfjorden system. 18

19 Both heavy ice cover and meltwater delivery may limit light penetration in the water and therefore suppress primary production and organic matter export to the bottom. However, 20 21 the foraminiferal fauna in central Storfjorden revealed more than a 10-fold increase in flux and abundance followed by short-term fluctuations after ~ 2.7 cal ka BP (Fig. 3); this may 22 suggest favorable conditions for foraminiferal growth. The major peaks in the total 23 foraminiferal abundance (Fig. 4) followed by peaks in the percentage of AW foraminiferal 24 indicators (Fig. 5) were noted ~ 2.3 cal ka BP and ~ 1.7 cal ka BP. These peaks were 25 associated with the occurrence of sequences of T. hispida (Fig. 8), a diatom species 26 27 characteristic of subpolar and temperate regions (Katsuki et al., 2009). These results are in accordance with the findings of Sarntheim et al. (2003), who reported two intervals of the 28 remarkably warmer sea surface on the western continental margin of the Barents Sea at ~ 2.2 29 and ~ 1.6 cal ka BP, which was attributed to short-term pulses of warm AW advection. 30 Moreover, the western Spitsbergen continental margin experienced periods of a rapidly 31 advancing and retreating sea-ice margin during the Neoglacial, caused by a temporarily 32 strengthened AW inflow and/or changes in the atmospheric circulation patterns (Müller et al., 33 2012). Our foraminiferal and diatom aDNA records confirm the presence of AW intrusions 34

that may cause an episodic breakup of sea ice cover and permits primary production and
development of benthic biota, including foraminifera.

Knies et al. (2017) have suggested that the pulses of advected AW did not influence 3 the persistent sea-ice cover in Storfjorden between ~ 2.8 and 0.5 cal ka BP. However, the 4 ST 1.5 foraminiferal record indicates that central Storfjorden was not constantly covered by 5 6 sea ice at that time. A more reasonable scenario is surface water cooling and periodic melting 7 and freezing of the sea surface and consequent production of brines, which launched convective water mixing and nutrient resupply to the surface, thereby stimulating primary 8 production (Łacka et al., in prep.). The presence of diatom aDNA sequences throughout the 9 Neoglacial (Fig. 8) may suggest continuous primary production. It is likely that pulses of AW 10 inflow at 2.3 cal ka BP and 1.7 cal ka BP induced melting of the ice cover, leading to the 11 formation of ice-free areas and highly productive ice marginal zones. This conjecture may be 12 supported by peaks in the light δ^{18} O in benthic foraminiferal tests, the maxima of the 13 14 foraminiferal flux (Fig. 4) and peaks in the abundance of species associated with highly 15 productive environments such as *M. barleeanum* and *N. labradorica* (Fig. 5). Similarly, the foraminiferal flux and abundance were elevated and slightly variable after ~ 1.7 cal ka BP. 16 17 The foraminiferal assemblage was codominated by AW/frontal zone indicators and glaciomarine species (Fig. 5) at that time, which may suggest rather ameliorated 18 19 environmental conditions. However, the response of benthic foraminifera assemblage to the pulses of AW at ~ 2.3 cal ka BP and ~ 1.7 cal ka BP is slightly different. The dominant 20 21 components of foraminiferal assemblage at ~ 2.3 cal ka BP were M. barleeanum and E. excavatum, while at ~ 1.7 cal ka BP, N. labradorica and C. reniforme reached higher 22 percentages. The major difference in environmental conditions between these two "AW 23 episodes" was noticeably coarser 0-63 µm sediment fraction noted at ~ 2.3 cal ka BP, what 24 may indicate more intensive winnowing and consequent sediment sorting, what creates 25 favorable conditions for development of highly opportunistic species, such as E. excavatum, 26 which reached its' maximum flux and percentage at that time. In contrast, the interval 27 between 2.3 and 1.7 cal ka BP featured variable $\delta^{13}C$ and $\delta^{18}O$ followed by a decrease in the 28 foraminiferal flux and abundance (Fig. 4). The foraminiferal assemblage at this time was 29 dominated by glaciomarine and sea-ice taxa (Fig. 5), which indicate more severe 30 environmental conditions with extensive ice cover and suppressed productivity. The sea-ice 31 32 formation led to a more intensive release of brines and consequently, stronger bottom current activity reflected in a minor increase in 0-63 µm fraction and slight increase in the percentage 33 of C. lobatulus, which is considered to be a bottom current indicator (Fig. 5). 34

1 The above-described environmental changes were also reflected in the aDNA record 2 of monothalamous foraminifera. During the time intervals of 2.2-1.9 cal ka BP and 1.3-0.4 cal ka BP, monothalamous foraminifera was dominated by allogromiids belonging to clade Y, 3 4 Nemogullmia sp., C. saltatus and monothalamids belonging to so called "environmental clades" (Fig. 6). Allogromiids are not a coherent taxonomic group but are scattered between 5 6 several monothalamous clades (Gooday 2002; Pawlowski et al., 2002). Considerable part of 7 the allogromiid sequences in the ST_1.5 core belong to clade Y (Fig. 7), which is primarily composed of taxa known only from environmental sequencing. Sequences belonging to clade 8 Y have previously been noted in modern sediments in the Spitsbergen fjords (Pawłowska et 9 al., in prep.). Moreover, clade Y has been abundantly sequenced in the coastal areas off 10 Scotland, characterized by high levels of environmental disturbances (Pawlowski et al., 11 2014a); this might suggest its high tolerance to environmental stress. In addition, so called 12 "environmental clades" comprised of monothalamous taxa known exclusively from 13 environmental sequencing (Lecroq et al., 2011) and may belong to novel, undescribed 14 foraminiferal lineages (Pawlowski et al., 2014b). C. saltatus was recently found by Gooday et 15 al. (2011) in the Black Sea and until recently, little has been known about its environmental 16 17 tolerances; however, its occurrence in areas with high levels of pollution suggests that it is an 18 opportunistic species with a high tolerance to environmental disturbances. Specimens of 19 Nemogullmia were also found in the Spitsbergen fjords (Gooday et al., 2005; Majewski et al., 2005); however, data on its abundance and distribution may be incomplete due to the 20 21 degradation of its fragile, organic-walled tests. The abovementioned taxa nearly disappeared during episodes of enhanced AW inflow ~ 2.4 cal ka BP and ~ 1.7 cal ka BP, and the 22 monothalamous assemblage was dominated at that time by *Micrometula* sp., *Ovammina* sp., 23 Shepheardella sp., Tinogullmia sp., Cylindrogullmia sp., and allogromiids belonging to clade 24 25 A (Fig. 6; Fig. 7). All these taxa have recently been observed in the fiords of Svalbard (e.g. Gooday et al., 2005; Majewski et al., 2005; Sabbattini et al., 2007; Pawłowska et al., 2014). 26 27 Cylindrogullmia sp. commonly been found in the inner parts of the fjords (Gooday et al., 2005). Hughes and Gooday (2004) suggest that Cylindrogullmia sp. is an infaunal species that 28 29 normally resides in deeper sediment layers of sediment. Micrometula sp. was among the abundantly found organic-walled allogromiids in glacier-proximal sites off Novaya Zemlya 30 (Korsun & Hald, 1998; Korsun et al., 1995) and Svalbard (Korsun & Hald, 2000; Gooday et 31 al., 2005; Pawłowska et al., 2014). Moreover, Cylindrogullmia and Micrometula are 32 dependent on the presence of fresh phytodetritus (Alve, 2010). Ovammina sp. feeds on 33 34 diatoms and other forms of microalgae (Goldstein & Alve, 2011). Similarly, the presence of *Tinogullmia* is largely controlled by the presence of organic material on the seafloor. High
 concentrations of *Tinogullmia* have been found in coastal (Cornelius & Gooday, 2004) and
 deep-sea regions (Gooday, 1993) within phytodetrital aggregates.

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4 The taxa that dominated the monothalamous assemblage during warm intervals seem 5 to be responsive to the delivery of organic matter and may flourish during phytoplankton 6 blooms associated with the settling of organic matter (e.g., Alve, 2010; Sabbattini et al., 2012, 7 2013). The pulses of AW inflow that are associated with sea-ice melting stimulated phytoplankton blooms and organic matter supply to the bottom. The enhanced primary 8 productivity supported the development of an organic matter-dependent monothalamous 9 community. Conversely, the colder phases of the Neoglacial were characterized by heavy and 10 densely packed sea ice resulting in limited productivity (Knies et al., 2017). Therefore, the 11 monothalamous assemblage was less diverse and was dominated by more opportunistic taxa. 12

13 The decrease in the percentage of foraminiferal sea-ice indicators noted at ~ 1.7 cal ka BP and after ~ 1.5 cal ka BP suggests a gradually diminishing sea-ice coverage in Storfjorden 14 (Fig. 5). Modern-like conditions were established in Storfjorden ~ 0.5 cal ka BP, with 15 seasonally variable sea-ice cover resulting in intensified but variable polynyal activity 16 17 (Rasmussen and Thomsen, 2014b; Knies et al., 2017). The IP₂₅ records from the western Spitsbergen shelf indicate variable sea-ice conditions during the last 2 ka (Cabedo-Sanz and 18 19 Belt, 2016). Moreover, the majority of diatom aDNA sequences after ~ 0.5 cal ka BP belonged to *Chaetoceros* sp., a taxa that is observed in surface waters and is almost entirely 20 absent under sea ice (Różańska et al., 2008). Moreover, high abundances of Chaetoceros are 21 often associated with highly productive surface waters (Cremer, 1999), which indicate 22 declining sea-ice cover (Cabedo-Sanz and Belt, 2016). However, the aDNA record of the 23 24 monothalamous foraminifera ~ 0.4 cal ka BP displayed relatively high percentages of taxa 25 that dominated during colder intervals of the Neoglacial (Fig. 6); this may be related to the recovery from the Little Ice Age and consequently, temporarily deteriorated environmental 26 27 conditions (D'Andrea et al., 2012). However, further studies are required to confirm the latter conclusion. 28

29 <u>6.3 Paleoceanographic implications</u>

30 <u>Our record revealed two-phase Neoglacial, with a major shift in environmental</u> 31 <u>conditions at ~ 2.7 cal ka BP. According to the ST_1.5 record, the Neoglacial in Storfjorden</u> 32 <u>was not a constantly cold period, but comprised alternate, short-term cooling and warming</u> 33 periods, associated with variability in sea-ice coverage and productivity. There is various

evidence of a shift in environmental conditions in the Nordic Seas region in mid-Neoglacial. 1 2 Alkenone record from the Norwegian Sea revealed a significant drop of sea surface temperature at 2.7 cal ka BP (Calvo et al., 2002). Risebrobakken et al. (2010) recorded a 3 4 change in oceanographic conditions in the SW Barents Sea ca. 2.5 cal ka BP, followed by the 5 episodes of reduced surface and subsurface salinity after 2.5 cal ka BP, what was attributed to 6 the expansion of coastal waters and the occurrence of more sea-ice.

7 Moreover, our evidence of the presence of AW in Storfjorden during the Neoglacial supported previous suggestions that AW inflow during the late Holocene was strong enough to reach also the eastern coasts of Svalbard (e.g., Łącka et al., 2015). Moreover, Sarnthein et al. (2003) postulated pulses of AW inflow to the western Barents Sea shelf at 2.2 and 1.6 cal ka BP. According to Perner et al. (2015), the Neoglacial delivery of chilled AW to the Nordic Seas culminated between 2.3 and 1.4 cal ka BP. Also, Rasmussen et al. (2014a) and Jernas et 12 al (2013) recorded slightly warmer and less glacial conditions during the last 2 ka on the 13 western Spitsbergen shelf. 14

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7. Conclusions 16

17 The ST_1.5 multiproxy record revealed that the environmental variability in Storfjorden during the Neoglacial was steered controlled primarily by the interplay between AW and ArW 18 19 and changes in the sea-ice cover. The molecular record supports and complements sedimentary and microfossil records, which indicate that major changes in the environmental 20 conditions in Storfjorden occurred at ~ 2.7 cal ka BP. The general cooling at the early phase 21 of the Neoglacial initiated conditions for the formation of extensive sea-ice cover. The latter 22 part of the Neoglacial (after ~ 2.7 cal ka BP) was characterized by alternating short-term 23 cooling and warming periods. Warming was associated with pulsed inflows of AW and sea-24 25 ice melting, which may stimulate phytoplankton blooms and organic matter supply to the bottom. The cold phases were characterized by heavy and densely packed sea ice resulting in 26 27 limited productivity.

Moreover, the aDNA diatom record supports the conclusion that primary production took 28 place continuously during the Neoglacial, regardless of the sea-ice conditions. The early 29 phase of the Neoglacial was characterized by the presence of diatom taxa associated with sea 30 ice, whereas the present-day diatom assemblage was dominated by *Chaetoceros* spp, a taxa 31 32 characteristic of open water.

33 The aDNA record of monothalamous foraminifera is in agreement with the microfossil 34 record and revealed the timing of the major pulses of AW at 2.3 and 1.7 cal ka BP. The AW

inflow was marked by an increase in the percentage of sequences of monothalamous taxa
associated with the presence of fresh phytodetritus. The monothalamous assemblage during
cold intervals was less diverse and was dominated by monothalamous foraminifera known
only from environmental sequencing.

5

6 Author contribution

MZ and Jan P designed the study. Joanna P, MŁ and MZ collected the sediment core. MŁ and
MK performed the sedimentological and micropaleontological analyses. Joanna P performed
the molecular analyses and prepared the manuscript with contributions from all co-authors.

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17 **References**

Alve, E.: Benthic foraminiferal responses to absence of fresh phytodetritus: A two – year
experiment, Mar. Micropaleontol., 76, 67-76, https://doi.org/10.1016/j.marmicro.2010.05.003,
2010.

- 21 Altschul, S.F., Gish, W., Miller, W., Myers, E.W., Lipman, D.J.: Basic local alignment search
- tool. J. Mol. Biol. 215, 403-410, https://doi.org/10.1016/S0022-2836(05)80360-2, 1990.
- Andersen, C., Koç, N., Moros, M.: A highly unstable Holocene climate in the subpolar North
 Atlantic: evidence from diatoms, Quat. Sci. Rev., 23, 2155-2166,
 https://doi.org/10.1016/j.quascirev.2004.08.004, 2004.
- Årthun, M., Ingvaldsen, R.B., Smedsrud, L.H., Schrum, C.: Dense water formation and
 circulation in the Barents Sea, Deep Sea Res. Part I: Oceanogr. Res. Pap., 58, 801-817,
 https://doi.org/10.1016/j.dsr.2011.06.001, 2011.
- Berger, A.L.: Long-term variations of daily insolation and quaternary climatic changes, J.
 Atmos. Sci., 35, 2362-2367, https://doi.org/10.1175/15200469(1978)035<2362:LTVODI>2.0.CO;2 1978.
- Blott, S.J., Pye, K.: GRADISTAT: a grain size distribution and statistics package for the
 analysis of unconsolidated sediments, Earth Surf. Process. Landf., 26, 1237 1248,
 https://doi.org/10.1002/esp.261, 2001.

- Cabedo-Sanz, P., Belt, S.T.: Seasonal sea ice variability in eastern Fram Strait over the last
 2000 years, Arktos, 2, 22, doi: 10.1007/s41063-016-0023-2, 2016.
- 3 Boere, A.C., Abbas, B., Rijpstra, W.I.C., Versteegh, G.J., Volkman, J.K., Sinninghe Damsté,
- 4 J.S., Coolen, M.J.L.: Late-Holocene succession of dinoflagellates in an Antarctic fjord using a
- multi-proxy approach: paleoenvironmental genomics, lipid biomarkers and palynomorphs,
 Geobiol., 7, 265-281, https://doi.org/10.1111/j.1472-4669.2009.00202.x, 2009.
- Calvo, E., Grimalt, J., Jansen, E.: High resolution U₃₇^K sea surface temperature reconstruction
 in the Norwegian Sea during the Holocene. Quat. Sci. Rev., 21, 1385-1394,
 https://doi.org/10.1016/S0277-3791(01)00096-8, 2002.
- Cornelius, N., Gooday, A.J.: 'Live' (stained) deep-sea benthic foraminiferans in the western
 Weddell Sea: trends in abundance, diversity and taxonomic composition along a depth
 transect, Deep Sea Res. II, 51, 1571-1602, https://doi.org/10.1016/j.dsr2.2004.06.024, 2004.
- 13 Cremer, H.: Distribution patterns of diatom surface sediment assemblages in the Laptev Sea
- 14 (Arctic Ocean), Mar. Micropaleontol., 38, 39-67, https://doi.org/10.1016/S037715 8398(99)00037-7, 1999.
- D'Andrea, W.J., Vaillencourt, D.A., Balascio, N.L., Werner, A., Roof, S.R., Retelle, M.,
 Bradley, R.S.: Mid Little Ice Age and unpredecented recent warmth in an 1800 year lake
 sediment record from Svalbard, Geology, 40, 1007-1010, https://doi.org/10.1130/G33365.1,
 2012.
- Dufresne, Y., Lejzerowicz, F., Apotheloz Perret-Gentil, L., Pawlowski, J., Cordier, T.: SLIM:
 a flexible web application for the reproducible processing of environmental DNA
 metabarcoding data. BMC Bioinformatics, 20, 88, https://doi.org/10.1186/s12859-019-26632, 2019.
- Forwick, M., Vorren, T.O.,: Late Weichselian and Holocene sedimentary environments and
 ice rafting in Isfjorden, Spitsbergen, Palaeogeogr. Palaeoclimatol. Palaeoecol. 280, 258-274,
 https://doi.org/10.1016/j.palaeo.2009.06.026, 2009.
- Forwick, M., Vorren, T.O., Hald, M., Korsun, S., Roh, Y., Vogt, C., Yoo, K.-C.: Spatial and
 temporal influence of glaciers and rivers on the sedimentary environment in Sassenfjorden
 and Tempelfjorden, Spitsbergen. In: Geological Society, London, Special Publications, vol
 344 (1): 163-193, https://doi.org/10.1144/SP344.13, 2010.
- Geyer, F., Fer, I., Smedsrud, L. H.: Structure and forcing of the overflow at the Storfjorden
 sill and its connection to the Arctic coastal polynya in Storfjorden, Ocean Sci., 6(1), 401-411,
 https://doi.org/10.5194/os-6-401-2010, 2010.

- Goldstein, S.T., Alve, E.: Experimental assembly of foraminiferal communities from coastal
 propagule banks, Mar. Ecol. Prog. Ser. 437, 1-11, https://doi.org/10.3354/meps09296,
 2011.
- Gooday, A.J.: Deep-sea benthic foraminiferal species which exploit phytodetritus:
 Characteristic features and controls on distribution, Mar. Micropaleontol., 22, 187-205,
 https://doi.org/10.1016/0377-8398(93)90043-W, 1993.
- Gooday, A.J.: Organic-walled allogromiids: aspects of their occurrence, diversity and ecology
 in marine habitats, J. Foramin. Res., 32, 384-399, https://doi.org/10.2113/0320384, 2002.
- 9 Gooday, A.J., Bowser, S.S., Cedhagen, T., Cornelius, N., Hald, M., Korsun, S., Pawłowski,
- 10J.: Monothalamous foraminiferans and gromiids (Protista) from western Svalbard: A11preliminary survey, Mar. Biol. Res., 1, 290 312,12https://doi.org/10.1000/17451000510010150_2005
- 12 https://doi.org/10.1080/17451000510019150, 2005.
- Gooday, A.J., Anikeeva, O.V., Pawlowski, J.: New genera and species of monothalamous
 Foraminifera from Bataclava and Kazach'ya Bays (Crimean Peninsula, Black Sea), Mar.
 Biodiv., 41, 481-494, https://doi.org/10.1007/s12526-010-0075-7, 2011.
- Grootes, P.M., and M. Stuiver. 1997. Oxygen 18/16 variability in Greenland snow and ice
 with 10⁻³ to 10⁻⁵-year time resolution. J. Geophys. Res., 102, 26455-26470,
 https://doi.org/10.1029/97JC00880, 1997.
- Haarpainter, J., Gascard, J.C., Haugan, P.M.: Ice production and brine formation in
 Storfjorden, Svalbard, J. Geophys. Res. 106 C7, 14 001–14 013,
 https://doi.org/10.1029/1999JC000133, 2001.
- Hald, M. Steinsund, P.I.: Benthic foraminifera and carbonate dissolution in the
 surface sediments of the Barents and Kara Seas, Berichte zur Polarforschung, 212,
 285–307, 1996.
- Hansen, J., Hanken, N.-M., Nielsen, J.K., Nielsen, J.K., Thomsen, E.: Late Pleistocene and
 Holocene distribution of *Mytilus edulis* in the Barents Sea region and its paleoclimatic
 implications, J. Biogeogr, 38, 1197-1212, https://doi.org/10.1111/j.1365-2699.2010.02473.x,
 2011.
- Hughes, J.A., Gooday, A.J.: Associations between living benthic foraminifera and dead tests 29 30 of Syringammina fragilissima (Xenophyophorea) in the Darwin Mounds region (NE Atlantic), 31 Sea Res. Part I: Oceanographic Research Papers, 51, 1741-1758, Deep https://doi.org/10.1016/j.dsr.2004.06.004, 2004. 32

- Ikävalko, J.: Checklist of unicellular and invertebrate organisms within and closely associated
 with sea ice in the Arctic regions. MERI Report Series of the Finnish Institute of Marine
 Research, 52, Helsinki, Finland, Finnish Institute of Marine Research, 2004.
- 4 Jennings, A.E., Weiner, N.J., Helgadottir, G., Andrews, J.T.: Modern foraminiferal faunas of 5 the southwestern to northern Iceland Shelf; oceanographic and environmental controls, J.
- 6 Foramin. Res., 34, 180-207, https://doi.org/10.2113/34.3.180, 2004.
- 7 Jernas, P., Klitgaard Kristensen, D., Husum, K., Wilson, L., Koç, N.: Palaeoenvironmental
- 8 changes of the last two millennia on the western and northern Svalbard shelf, Boreas, 42, 236-
- 9 255, https://doi.org/10.1111/j.1502-3885.2012.00293.x, 2013.
- 10 Katsuki, K., Takahashi, K., Onodera, J., Jordan, R.W., Suto, I.: Living diatoms in the vicinity
- 11 of the North Pole, summer 2004, Micropaleontol. 55, 137-170, 2009.
- 12 Killworth, P.D.: Deep convection in the World Ocean, Rev. Geophys., 21, 1-26,
 13 doi:10.1029/RG021i001p00001, 1983.
- 14 Knies, J., Pathirana, I., Cabedo-sanz, P., Banica, A., Fabian, K., Rasmussen, T.L., Forwick,
- M., Belt, S.: Sea-ice dynamics in an Arctic coastal polynya during the past 6500 years,
 Arktos, 3, 1, https://doi.org/10.1007/s41063-016-0027-y, 2017.
- Korsun, S., Hald, M.: Modern benthic Foraminifera off Novaya Zemlya tidewater glaciers,
 Arctic and Alpine Research, 30, 61-77, https://doi.org/10.1080/00040851.1998.12002876,
 1998.
- Korsun, S., Hald, M.: Seasonal dynamics of benthic foraminifera in a glacially fed fjord of
 Svalbard, European Arctic, J. Foramin. Res., 30, 251-271, https://doi.org/10.2113/0300251,
 2000.
- Korsun, S., Pogodina, I.A., Forman, S.L., Lubinski, D.J.: Recent foraminifera in glaciomarine
 sediments from three arctic fjords of Novaja Zemlja and Svalbard, Polar Res., 14, 15 31,
 https://doi.org/10.1111/j.1751-8369.1995.tb00707.x, 1995.
- Lejzerowicz, F., Esling, P., Majewski, W., Szczuciński, W., Decelle, J., Obadia, C., Martinez
 Arbizu, P., Pawlowski, J.: Ancient DNA complements microfossil record in deep-sea
- 28 subsurface sediments. Biol. Lett., 9, 20130283, https://doi.org/10.1098/rsbl.2013.0283, 2013.
- 29 Lecroq B., Lejzerowicz F., Bachar D., Christen R., Esling P., Baerlocher L., Østerås M.,
- 30 Frinelli L., Pawlowski J.: Ultra-deep sequencing of foraminiferal microbarcodes unveils
- 31 hidden richness in deep-sea sediments, PNAS, 108:13177-82,
- 32 https://doi.org/10.1073/pnas.1018426108, 2011.
- 33 Lydersen, C., Nøst, O., Lovell, P., McConell, B., Gammelsrød, T., Hunter, C., Fedak, M.,
- 34 Kovacs, K.: Salinity and temperature structure of a freezing Arctic fjord monitored by white

- whales (Delphinapterus leucas), Geophys. Res. Lett., 29, 2119,
 https://doi.org/10.1029/2002GL015462, 2002.
- 3 Łącka, M., Zajączkowski, M., Forwick, M., Szczuciński, W.: Late Weichselian and Holocene
- 4 palaeoceanography of Storfjordrenna, southern Svalbard, Clim. Past, 11, 587-603,
- 5 https://doi.org/10.5194/cp-11-587-2015, 2015.
- 6 Mahé, F., Rognes T., Quince C., de Vargas, C., Dunthorn, M.: Swarm: robust and fast
- 7 clustering method for amplicon-based studies, Peer J, 2, e593, doi: <u>10.7717/peerj.593</u>, 2014.
- 8 Majewski, W., Pawłowski, J., Zajączkowski, M.: Monothalamous foraminifera from West
 9 Spitsbergen fjords: a brief overview, Polish Polar Res., 26(4), 269-285, 2005.
- Majewski, W., Szczuciński, W., Zajączkowski, M.: Interactions of Arctic and Atlantic watermasses and associated environmental changes during the last millennium, Hornsund (SW
 Svalbard). Boreas, 38, 529-544, https://doi.org/10.1111/j.1502-3885.2009.00091.x, 2009.
- Mangerud, J., Bondevik, S., Gulliksen, S., Hufthammer, A.K., Høseter, T.: Marine ¹⁴C
 reservoir ages for 19th century whales and mollusks from the North Atlantic, Quat. Sci. Rev.,
 25, 3228-3245, https://doi.org/10.1016/j.quascirev.2006.03.010, 2006.
- Martrat, B., Grimalt, J.O., Villanueva, J., van Kreveld, S., Sarntheim, M.: Climatic
 dependence of the organic matter contributions in the north eastern Norwegian Sea over the
 last 15,000 years, Org. Geochem., 34, 1057-1070, https://doi.org/10.1016/S01466380(03)00084-6, 2003.
- Müller, J., Werner, K., Stein, R., Fahl, K., Moros, M., Jansen, E.: Holocene cooling
 culminates in sea ice oscillations in Fram Strait. Quaternary Science Reviews, 47,1–14,
 https://doi.org/10.1016/j.quascirev.2012.04.024, 2012.
- Nilsen, F., Cottier, F., Skogseth, R., Mattson, S.: Fjord-shelf exchanges controlled by ice and
 brine production: The interannual variation of Atlantic Water in Isfjorden, Svalbard, Cont.
 Shelf Res. 28, 1838-1853, https://doi.org/10.1016/j.csr.2008.04.015, 2008.
- Pawłowska, J., Lejzerowicz, F., Esling, P., Szczuciński, W., Zajączkowski, M., Pawlowski, J.:
 Ancient DNA sheds new light on the Svalbard foraminiferal fossil record from the last
 millennium, Geobiology, 12, 277-288, https://doi.org/10.1111/gbi.12087, 2014.
- 29 Pawłowska, J., Zajączkowski, M., Łącka, M., Lejzerowicz, F., Esling, P., Pawlowski, J.: Palaeoceanographic changes in Hornsund Fjord (Spitsbergen, Svalbard) over the last 30 31 millennium: from ancient DNA, Clim. Past, 12, 1459-1472, new insights https://doi.org/10.5194/cp-12-1459-2016, 2016. 32

- Pawlowski, J., Holzmann, M., Berney, C., Fahrni, J., Cedhagen, T., Bowser, S.S.: Phylogeny
 of allogromiid Foraminifera inferred from SSU rRNA gene sequences, J. Foramin. Res., 32,
 334-343, https://doi.org/10.2113/0320334, 2002.
- Pawlowski, J., Esling, P., Lejzerowicz, F., Cedhagen, T., Wildings, T.A.: Environmental
 monitoring through protest next-generation sequencing metabarcoding: assessing the impact
 of fish farming on benthic foraminifera communities, Mol. Ecol. Res., 14, 1129-1140, doi:
 10.1111/1755-0998.12261, 2014a.
- 8 Pawlowski, J., Lejzerowicz, F., Esling, P.: Next-generation environmental diversity surveys
 9 of foraminifera: Preparing the future, Biol. Bull., 227, 93-106,
 10 https://doi.org/10.1086/BBLv227n2p93, 2014b.
- 11 Perner, K., Moros, M., Lloyd, J.M., Jansen, E., Stein, R.: Mid to late Holocene strengthening
- 12 of the East Greenland Current linked to warm subsurface Atlantic water, Quat. Sci. Rev., 129,
- 13 296-307, https://doi.org/10.1016/j.quascirev.2015.10.007, 2015.
- Piechura, J.: Dense bottom waters in Storfjord and Storfjordrenna, Oceanologia, 38, 285-292,
 15 1996.
- 16 Polyakov, I. V., Pnyushkov, A.V., Alkire, M.B., Ashik, I.M., Baumann, T.M., Carmack, E.C.,
- 17 Goszczko, I., Guthrie, J., Ivanov, V.V., Kanzow, T.T., Greater role for Atlantic inflows on 18 sea-ice loss in the Eurasian Basin of the Arctic Ocean, Science, eaai8204, 19 https://doi.org/10.1126/science.aai8204, 2017.
- 20 Quadfasel, D., Rudels, B., Kurz, K.: Outflow of dense water from a Svalbard fjord into the
- 21 Fram Strait, Deep Sea Res., 35, 1143-1150, https://doi.org/10.1016/0198-0149(88)90006-4,
 22 1988.
- Rasmussen, T.L., Forwick, M., Mackensen, A.: Reconstruction of inflow of Atlantic Water to
 Isfjorden, Svalbard during the Holocene: Correlation to climate and seasonality, Mar.
 Micropaleontol., 94-95, 80-90, https://doi.org/10.1016/j.marmicro.2012.06.008, 2012.
- Rasmussen, T.L., Thomsen, E., Skirbekk, K., Ślubowska-Woldengen, M., Klitgaard
 Kristensen, D., Koç, N.: Spatial and temporal distribution of Holocene temperature maxima in
 the northern Nordic seas: interplay of Atlantic-, Arctic- and polar water masses, Quat. Sci.
- 29 Rev., 92, 280-291, https://doi.org/10.1016/j.quascirev.2013.10.034, 2014a.
- 30 Rasmussen, T. L., Thomsen, E.: Brine formation in relation to climate changes and ice retreat
- during the last 15,000 years in Storfjorden, Svalbard, 76-78°N, Paleoceanography, 29, 911-
- 32 929, https://doi.org/10.1002/2014PA002643, 2014b.

- Rasmussen, T.L., Thomsen, E.: Palaeoceanographic development in Storfjorden, Svalbard,
 during the deglaciation and Holocene: evidence from benthic foraminiferal records. Boreas,
 44, 24–44, https://doi.org/10.1111/bor.12098, 2015.
- 4 Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Bronk Ramsey, C., van der
- 5 Plicht, J.: IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0-50,000 Years Cal
- 6 BP. Radiocarbon, 55(4), 1869-1887, https://doi.org/10.2458/azu_js_rc.55.16947, 2013.
- 7 Risebrobakken, B., Moros, M., Ivanova, E.V., Chistyakova, N., Rosenberg, R.: Climate and
- 8 oceanographic variability in the SW Barents Sea during the Holocene, The Holocene, 20,
- 9 609-612, https://doi.org/10.1177/0959683609356586, 2010.
- 10 Rognes, T., Flouri, T., Nichols, B., Quince, C., Mahé, F.: VSEARCH: a versatile open source
- tool for metagenomics. Peer J, 4, e2584, https://doi.org/10.7717/peerj.2584, 2016.
- Różańska, M., Poulin, M., Gosselin, M.: Protist entrapment in newly formed sea ice in the
 Coastal Arctic Ocean, J. Mar. Sys., 74, 887-901,
 https://doi.org/10.1016/j.jmarsys.2007.11.009, 2008.
- Rudels, B., Korhonen, M., Schauer, U., Pisarev, S., Rabe, B., Wisotzki, A.: Circulation and
 transformation of Atlantic water in the Eurasian Basin and the contribution of the Fram Strait
 inflow branch to the Arctic Ocean heat budget, Prog. Oceanogr., 132, 128-152,
 https://doi.org/10.1016/j.pocean.2014.04.003, 2015.
- Sarnthein, M., Van Kreveld, S., Erlenkeuser, H., Grootes, P.M., Kucera, M., Pflaumann, U., 19 Schulz, M.: Centennial-to-millennial-scale periodicities of Holocene climate and sediment 20 21 injections off the western Barents shelf. 75°N. Boreas, 32. 447-461. https://doi.org/10.1111/j.1502-3885.2003.tb01227.x, 2003. 22
- Sabbattini, A., Morigi, C., Negri, A., Gooday, A.J.: Distribution and biodiversity of stained
 Monothalamous foraminifera from Tempelfjord, Svalbard, J. Foramin. Res., 37, 93-106,
 https://doi.org/ 10.2113/gsifr.37.2.93, 2007.
- Sabbattini, A., Bonatto, S., Bianchelli, S., Pusceddu, A., Danovaro, R., Negri A.:
 Foraminiferal assemblages and trophic state in coastal sediments of the Adriatic Sea, J. Mar.
 Syst., 105, 163-174, https://doi.org/10.1016/j.jmarsys.2012.07.009, 2012.
- Sabbattini, A., Nardelli M.P., Morigi C., Negri, A.: Contribution of soft-shelled
 monothalamous taxa to foraminiferal assemblages in the Adriatic Sea, Acta Protozool., 52,
 181-192, https://doi.org/10.4467/16890027AP.13.0016.1113, 2013.
- Skogseth, R., Haugan, P.M., Haarpaintner, J.: Ice and brine production in Storfjorden from
 four winters of satellite and in situ observations and modeling, *J. Geophys. Res.*, 109, C10008,
- 34 https://doi.org/10.1029/2004JC002384, 2004.

- Skogseth, R., Haughan, P.M., Jakobsson, M.: Watermass transformations in Storfjorden,
 Cont. Shelf Res., 25, 667-695, https://doi.org/10.1016/j.csr.2004.10.005, 2005.
- 3 Skogseth, R., Sandvik, A. D., Asplin, L.: Wind and tidal forcing on the meso-scale
- 4 circulation in Storfjorden, Svalbard, Cont. Shelf Res., 27, 208-227,
- 5 https://doi.org/10.1016/j.csr.2006.10.001, 2007.
- 6 Stuiver, M., Reimer, P.J.: Extended ¹⁴C database and revised CALIB 3.0 ¹⁴C age calibration
- 7 program, Radiocarbon, 35, 215-230, 1993.
- 8 Ślubowska-Woldengen, M., Rasmussen, T.L., Koç, N., Klitgaard-Kristensen, D., Nilsen, F.,
- 9 Solheim, A.: Advection of Atlantic Water to the western and northern Svalbard shelf since
- 10
 17,500
 cal
 yr
 BP.
 Quat.
 Sci.
 Rev.,
 26
 463-478,

 11
 https://doi.org/10.1016/j.quascirev.2006.09.009,
 2007.
- 12 Telesiński, M.M., Przytarska, J.E., Sternal, B., Forwick, M., Szczuciński, W., Łącka, M.,
- 13 Zajączkowski, M.: Palaeoceanographic evolution of the SW Svalbard shelf over the last
- 14 14 000 years, Boreas, 47, 410-422, https://doi.org/10.1111/bor.12282, 2018.
- Thomsen, P.F., Willerslev, E.: Environmental DNA An emerging tool in conservation for
 monitoring past and present biodiversity, Biol. Conserv., 183, 4-18,
 https://doi.org/10.1016/j.biocon.2014.11.019, 2015.
- Werner, K., Spielhagen, R.F., Bauch, D., Hass, H., Kandiano, E.S., Zamelczyk, K.: Atlantic
 Water advection to the eastern Fram Strait multiproxy evidence for late Holocene
 variability. Palaeogeogr. Palaeoclimatol. Palaeoecol., 308, 264-276,
 https://doi.org/10.1016/j.palaeo.2011.05.030, 2011.
- Winkelmann, D., Knies, J.: Recent distribution and accumulation of organic carbon on the
 continental margin west off Spitsbergen. Geochem. Geophys. Geosyst., 6, Q09012,
 https://doi.org/10.1029/2005GC000916, 2005.
- Wollenburg, J.E., Kuhnt, W.: The response of benthic foraminifers to carbon flux and primary
 production in the Arctic Ocean, Mar. Micropaleontol., 40, 189-231,
 https://doi.org/10.1016/S0377-8398(00)00039-6, 2000.
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30 Figures captions

Figure 1: Study area and the location of the studied core ST_1.5 and the other cores discussed
in this paper.

- 1 Figure 2: Temperature and salinity profile from the sampling station. Temperature is marked
- 2 with a dashed line, and salinity is marked with a black line. Abbreviations: AW Atlantic
- 3 Water, TAW Transformed Atlantic Water, BSW Brine-enriched Shelf Water.
- 4 **Figure <u>3</u>**: Age–depth model of the studied core.
- **Figure 4:** Sedimentological and micropaleontological data plotted versus age. The sediment accumulation rate (SAR), mean grain size of the 0-63- μ m fraction, ice-rafted debris (IRD) flux and number of grains per gram of sediment, oxygen (δ^{18} O) and carbon (δ^{13} C) stable isotopes in foraminiferal tests, the percentage of calcareous foraminifera individuals and the flux and abundance of foraminifera are presented.
- Figure 5: The abundance (expressed as the number of individuals per gram of dry sediment)
 and the percentage of the dominant testate foraminifera.
- Figure 6: The dominant components of the monothalamous assemblages. The abundance is
 expressed as the percentage of the monothalamous sequences and the most abundantly
 sequenced taxa are presented. The trend is indicated with the dashed line.
- 15 Figure 7: The percentage share of certain clades in the allogromiid sequences.
- 16 Figure 8: The percentage of sequences of dominant diatom taxa vs. time. The trend is
 17 indicated with the dashed line.
- 18

19 Tables captions

- 20 **Table 1:** Raw and calibrated AMS¹⁴C dates used in the age model.
- 21



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2 Figure 7: The percentage share of certain clades in the allogromiid sequences.

Navicula sp. Thalassiosira sp. Thalassiosira spp Chaetoceros sp. others 0 100 0 100 0 100 0 100 0 100 0.0 0.4 0.9 T. antarctica 1.3 1.6 1.7 1.9 2.1 2.2 T. hispida [cal ka BP] 1 2.4 2.6 3.3

[% sequences]

6 Figure 8: The percentage of sequences of dominant diatom taxa vs. time. The trend is indicated with the dashed 7 line.

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Sediment depth [cm]	Material	Raw AMS ¹⁴ C	Calibrated years BP $\pm 2\sigma$	Cal. a BP used in age model
2.5	Nuculana pernula	107.38 ± 0.33 pMC	_	-
5.5	Yoldiella lenticula	$290 \pm 30 \text{ BP}$	-	-
14.5	Turitella erosa	$2020\pm30~BP$	1356-1555	1500
43.5	Yoldiella solituda	$3010 \pm 50 \text{ BP}$	2484-2787	2700
<u>46.5</u>	<u>Nonionellina labradorica</u>	<u>4490± 40 BP</u>	4400-4701	<u>4500</u>
52.5	Yoldiella lenticula	$7545 \pm 35 \text{ BP}$	7803-7989	7890

1 Table 1: Raw and calibrated AMS¹⁴C dates used in the age model.