We would like to thank the Referees for a 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 (in italics).

Referee #1

The manuscript is in places lengthy, incoherent and difficult to follow. The interpretations are on more than one occasion based on a part of the observations, while other (supporting or contradicting) data is not discussed. In a few cases, too much weight is given to minor changes in the data records resulting in not very convincing interpretations. A scenario is presented based on a paper in preparation, which cannot be verified, and integration with existing literature is incomplete. These are substantial problems, and therefore I cannot give a favorable review. I would still like to see this manuscript published, because the multiproxy data definitely deserve publishing. More work is needed on clearly communicating the interpretation (based on all datasets) as well as a better integration with the existing literature. A final small comment: the paper does not address the central question in the title "does aDNA complement traditional methods".

We would like thank the Referee for a critical and constructive review that helped us to improve the manuscript. Following the suggestions of the Referee, we have modified our interpretation by removing or shortening parts of Discussion concerning only minor changes in the dataset and by adding broader explanations whenever necessary. Moreover, we have added more references to the latest literature from the Nordic Seas region.
In our opinion, the question from the title is addressed in the manuscript, as one of our conclusions is that "the molecular record supports and complements sedimentary and microfossil records (...)". Further in the Conclusions section, we highlight the fact that the diatom and foraminiferal aDNA reflected environmental changes inferred from other proxies. However, we did not perform a direct comparison between the microfossil and molecular records. This issue was broadly discussed in our previous studies (Pawłowska et al., 2014; 2016) and it was not our intention to duplicate this discussion in the current manuscript.

Points of concern:
Generally, in terms of data interpretation, the sea ice indicating foraminifers B. frigida and Islandiella are present from 2.7 ka BP. The sea ice diatom T. antarctica seems present in all samples (although Fig 8 is not easy to read). The fluctuations in these species' abundance is limited (0–10%), yet the changes are interpreted as major shifts in the paleoceanography. Such changes could be explained be errors in counting/measuring. This should be considered more carefully. Similarly, page 13 L31-34,

there is strong interpretation based on a minor change in grain size and C. lobulatus percentage (a change, not clear from the figure).

Indeed, the sea ice diatom T. antarctica was present in all analyzed samples, as well as foraminiferal sea ice indicators B. frigida and Islandiella spp (see Fig. 5, Fig. 8 and Supplementary materials). This may indicate that sea ice occurred in Storfjorden at least seasonally during the whole studied period. However, there were some variations in the percentages of sea ice indicators suggesting the formation of more extensive sea ice cover.
We agree with the Referee that some statements are too strong considering the magnitude of sea ice indicators fluctuations. Therefore, we have modified parts of the discussion concerning sea-ice indicators and we have made conclusions more moderate.

The discussion of the period from 4 ka to 2.7 BP has been altered from a previous version, but it remains based on 2 samples in 3 cm of sediment (page 11, table 1). With n=2, it is impossible to discuss variability (IRD delivery, coarsening) nor make a (un)favorable comparison with other records. This is over-interpreting the data and has to be toned down.

We agree that low sampling resolution during this period precluded making general conclusion (what was stated at the end of the paragraph). The discussion considering the period prior to 2.7 cal ka BP have been further shortened and conclusions became more general.

The results remain poorly integrated with the study of Knies et al. 2017 (p. 13, L3 onwards) and are not necessarily contradictory as is claimed. Knies et al. 2017 suggest a permanent sea ice cover in Storfjorden for 2.8–0.5 ka BP, but do not exclude the possibility that AW inflow occurred as their IP25 record has too low resolution. The foram assemblage data of this study records a dominantly glaciomarine setting (up to 0.5 ka BP), with some AW and sea ice influence. In my view, this is not necessarily inconsistent with Knies et al. However, the authors present a scenario based on a paper in preparation (Lacka et al.), which cannot be verified.

We agree with the Referee's comment concerning the interpretation of results of Knies et al. (2017). The broader explanation considering the results of Knies et al. (2017) have been added to the Discussion.
The paper of Łącka et al. (2019) is now published. The reference has been added to the manuscript.

It is also not clear from the lengthy description on p. 14-15 how the foraminiferal DNA data actually supports the interpretation of AW pulses and/or changes in sea ice conditions. The diatom DNA is not discussed here, while T. antarctica was continuously recorded in the core – suggesting a constant presence of sea ice?

Monothalamous species found in the aDNA record may be divided into two groups. During the episodes of AW inflow, the increase in percentage of taxa associated with the delivery of fresh phytodetritus. Conversely, colder periods, characterized by the more extensive sea ice cover were characterized by the dominance of more opportunistic monothalamous taxa.

Indeed, the continuous record of T. antarctica may indicate the presence of at least seasonal ice cover at the study site. Moreover, the pulses of AW were associated with the occurrence of DNA sequences of T. hispida, an open water species. The occurrence of sequences of both these taxa may suggest the formation of ice cover during winter-spring, followed by ice-free summers. Similar scenario was proposed by Berben et al. (2017), who suggested increased AW to the eastern Svalbard and partial summer sea ice occurrence after 2.7 cal ka BP. According to record of Łącka et al. (2019) from Storfjordrenna, the sea-ice melting induced the production of brines that may launch convective mixing and nutrient resupply from the bottom what stimulated primary production. These conditions supported the development of phytodetritus-dependent monothalamous taxa.

Conversely, the colder phases of the Neoglacial were characterized by heavy and densely packed sea ice resulting in limited productivity (Knies et al., 2017). The presence of T. anatrctica sequences and disappearance of T. hispida may suggest that primary production was associated with sea-ice. Furthermore, the monothalamous assemblage was less diverse and was dominated by more opportunistic taxa, what may indicate reduced supply of organic matter to the bottom.
All the explanations written above have been included in the discussion.

Chapter 6.3: It is difficult to call in a major shift at 2.7 ka BP, with the limited data prior to this time (see above). The chapter lists the own observations, next to a few statements from the literature focusing on the AW observations into the region. But it does not present a coherent picture for the Storfjorden area in this time period. Nothing is mentioned about polynyas and sea ice production, and maybe the clearest shift in environmental conditions at 0.5 ka BP (Knies et al. 2017).

In order to make a discussion more clear and easy-to-follow, we have added additional sub-chapter spanning the period after 0.5 cal ka BP, and thus we extended discussion considering this period. Moreover, we have added broader explanations of the relationship between sea-ice, AW inflow and productivity in the discussion concerning time interval from 2.7 cal ka BP to 0.5 cal ka BP.

There are minor spelling and grammatical errors throughout the text. Throughout: figure reference numbers in the text often refer to the wrong figure. Page 12 – it is unclear what is own data and what is from literature.

We have carefully checked and corrected the references to figures in the text. We have also send the manuscript to professional language editor.

Referee #2

In this manuscript, the authors present a paleoreconstruction of environmental conditions for the last ca. 4000 years. They used a marine sediment core retrieved from Storfjorden, eastern Svalbard and a multitude of proxies. In particular, the environmental DNA record offers new information regarding past oceanographic conditions. This novel approach provides interesting new data that adds to the existing records of the area. Therefore, I feel that this study plays a positive role towards multi-proxy studies and certainly deserves to be published. Nonetheless, I do have some concerns regarding the interpretation of the data.

GENERAL COMMENTS:

Chronology:

I wouldn´t say that the chronology is the worst for this area. However, with respect to strengthen it, I wonder if you tried (and if not, why not?) to measure any additional core depths for AMS 14C dating? In particular, it seems to me, from Figure 4 & 5, that there is actually foraminiferal material between 5.5 and 14.5 cm as well as between 14.5 and 43.5 cm so I wonder why this is not used.

The age model is based on AMS^{14}C dates inferred from bivalve shells and benthic Nonionellina labradorica. In order to obtain another ^{14}C dates, we will have to use another foraminifera species, as it'd be difficult to obtain sufficient number of N. labradorica specimens from single sediment layer. Considering the large differences that may occur between ^{14}C dates obtained from foraminifera species, the age model may have high uncertainty.

Methodology and results:

Although the general approach and method on itself seems valid, one of the shortcomings (and/or missed opportunities) of this study is the low resolution. I mean, the core is 55 cm (which is not too much material) and the key proxy of this study (what adds the new knowledge) is only sampled for every 5 cm (i.e. 12 samples if I calculate correctly?). Nonetheless, in addition to that, the data in this study is only presented/discussed for the most recent 4000 years. (In my calculations this should then be less then 12 data points for fig 6-7-8. I find this quite confusing, so please explain this?). Regarding the sensitivity of cross-contamination when dealing with DNA samples, I can imagine it might be too late now. However, I do feel it is a shame that not every cm was investigated. In addition to that, even for the other proxies, despite the core was sampled every cm, the results only shows data for every 2 cm. Something which btw should be better explained in the material and method section.

The aDNA samples were taken every 5 cm, whereas in the other proxies were analyzed every 2 cm. The relevant explanation have been added to the Materials and methods section.

Indeed, the study (especially the aDNA record) will benefit from more data points. Unfortunately, there is no more sedimentary material available for molecular analysis. As Referee mentioned, aDNA samples are very sensitive to contamination and should be subsampled and analyzed according to stringent protocol. At this point, the risk of cross-contamination between the samples and/or the external contamination is high, so it is not possible to obtain material for aDNA analyses in a way that will guarantee the credibility of the results.

Related to this topic, I´m not entirely sure regarding the division/interpretation of the results/discussion. Specifically, the period prior to ca. 2700 years (sub-chapter 6.1) is based on only 2 data points for foram/IRD/isotopes and only 1 for the DNA data. This seems rather low to me to actually base any conclusions/interpretations on. Furthermore, the DNA record is within this time frame (for obvious reasons) not even discussed. I feel this issue should be more acknowledged and explained within the manuscript.

We agree, that due to low sampling resolution, the interpretation is difficult. It is already stated at the end of the paragraph concerning period prior to 2.7 cal ka BP that low sampling resolution during this period precluded making any general conclusion. Moreover, we have shortened this part of the discussion and made it more general to avoid any over-interpretation.

Discussion:

How do you explain the selection of cores you compare your data with? In Figure 1, only very local (in the vicinity of the studied core) marine cores are included. Why not geographically broader? For example, Holocene records on the AW pathway? Such as those presented by studies such as Hald et al., 1996; Hald et al., 2007; Berben et al., 2014; Risebrobakken and Berben, 2019…… OR, what about east of Svalbard? Berben et al., 2017 and references within.

We agree that the comparison with geographically broader records may improve the manuscript. We have added the comparison of our data with recent records from the Nordic Seas. Also, we have added the location of discussed cores to Fig. 1.

When adding sea-ice cover to the discussion… What about the results published in Berben et al., 2017; Belt et al., 2015. There, the authors present a sea ice reconstruction based on sea ice biomarkers and also describe a change of environmental conditions at ca. 2700 years ago with episodic periods of increased AW. This seems to correlate well with the finding of this study and thus, worth to compare with.

Indeed, these results correspond well with our data. We have added the discussion of the results of Belt et al. (2015) and Berben et al. (2017) in comparison to our data.

Regarding the structure of the discussion… why did you gave the period before 2.7 ka (based on 2 data points) an entire sub-chapter and all the rest of your record another sub-chapter? Why not splitting 6.2 into different sub-chapters? I think this would make it easier to bring across the main messages.

Following the suggestion of the Referee, we have added additional sub-chapter spanning the period from 0.5 cal ka BP to present.

Furthermore, I think the statement at Page15 Line30-31 is also quite simplistic considering the fact the "first" period is based on 2 data points. Thereby, I mean that if you have only 2 data points for 1300 years, it is not so surprising the records looks stable. Concluding, based on that, that the variability/alternating periods etc. start only after 2.7 ka is quite short-sighted. Therefore, I suggest to place your discussion into a wider geographical context (like the broader Barents Sea) as previous studies indicated similar things and therefore, might support the conclusions drawn within this manuscript.

We agree with the Referee's comment. We have extended the paragraph "Paleoceanographic implications" by including other studies from the Nordic Seas region to support our findings.

References:
Most of the paleo references within this manuscript are ca. 5 years old (or older) even though this area has been investigated in several more recent studies. Therefore, I recommend including the latest literature within this field both in your introduction and discussion. While doing so, keep a wider geographical area, and not just Storfjorden, in mind.
According the suggestion, we have added references to the latest literature to the manuscript.

Language:
I believe, there is still some room for improvement when it comes to the writing. In particular, grammar mistakes should be avoided. Furthermore, language can be improved and repetition of the same sentence structure should be avoided. With respect to this comment, I made quite some suggestions in the minor comments.

We would like thank the Referee for the language corrections, we have changed the text according to the suggestions. We have also send a manuscript for a professional language editing.

SPECIFIC COMMENTS:

In general, we have followed the Referees suggestions. If necessary, we have added an additional explanations to the Referee's comments.

Abstract

P1L13: Change "was" by "is"

P1L15: Why brine factory between brackets? Plus should it not be plural?

P1L16-17: Remove comma. Rewrite. "…masses: warm saline Atlantic Water (AW) and cold fresh Arctic Water…"

P1L18: "…evidence for existing interactions between the AW inflow and…"

P1L27: "… a decreased productivity. …"

P1L29: Add an "s" after variation

P1L29-P2L1: Rewrite sentence. Possible make two of them.

1. Introduction

P2L7: Rewrite. "The northwards flow of….(AW), transported by the ???Current, is …"

P2L8: Rewrite. "…indicates a warming…" Btw, a warming of what?

P2L9: Rewrite. "…increased inflow of AW towards the Arctic…"

P2L10: Rewrite. "…western Svalbard margin during, at least, the last…"

P2L13: Add spaces after 6.8 and before 1 (consistent with notation in line 12)

P2L15-18: Although it is a correct statement, I suggest to include more references as the study of Slubowska-Woldengen is not only one. So, rewrite to (e.g. Slubowska-Woldengen et al., 2007…ADD OTHERS FROM THE AREA…)

P2L18: "…fluctuations of AW inflow (e.g. references)"

P2L21: From the Barents Sea? Be more specific where the ESC comes from.

P2L24-25: "…Storfjorden, East Spitsbergen (Lydersen…"

P2L25: "…Recently, Hansen et al. (2011) suggested that AW…"

P2L26: "…BP) something that was…"

P2L27-28: Do you have a reference for this statement? What about paleoreconstruction studies from the Barents Sea?

P2L30: "…Arctic is characterized by a declined summer …"

P2L31: "…1978) that correlates to a decline…"

P2L31-32: Again, add "e.g." before the references. There many more studies from this wider area that indicate the same. In particular, include more recent studies.

P2L32: "…. Waters and a limited…"

P2L33: “towards the Nordic…”

P2L33: When you use Müller et al., 2012 as a reference. I suggest you specify the location of this study (i.e. West Spitsbergen).

P2L33-P3L2: With respect to the comment above, other studies (such as Berben et al., 2014; 2017) indicate similar increased sea ice conditions (! Based on similar sea ice proxies (i.e. IP25, biomarkers)) for the SW and E of Svalbard. These studies are with respect to sea ice references more appropriate than Sarnthein et al., 2003. Nonetheless, the latter is probably more correct with respect to changes in water masses. Although, here the same comment as above: this is only 1 of the many studies of this area indicative of water mass changes throughout the Holocene. So, add “e.g.” and other references (!more recent than 2003?).

P3L2: change “has” by “is”

P3L3: “considered to represent a constant cold ….”

P3L3: Do you have a reference for the last part of this sentence?

P3L4-5: Similar comment as before. Include more recent references for the wider area of the Barents Sea.

P3L6: Rewrite. “…2015). In addition for that period, there is…”

P3L7: “…of warm AW inflow towards western Svalbard (e.g. …”

P3L10: Remove “the” before fjord and before AW

P3L16-19: Rewrite sentence!

P3L20: “The aim of this study….

P3L21-24: Rewrite sentence! And again, use more than just 1 study to support this assumption. Plenty of studies from the area to back up this statement.

P3L25: …comprising composed…? These two words in a row does not makes any sense. Revise.

2. Study area

In general, see comments with Figure 1. Also refer to this figure within this chapter.

P4L11: Add brackets around Heleysundet and Freemansundet

P4L16: “Arctic waters as well as mixed…”

P4L16-18: Rewrite this sentence. The current that branches off is not longer the WSC anymore!

P4L19: Explain the 2 passages in the north better. See also comment with Figure 1.

P4L20-21: Add the unit of salinity.

P4L25-28: Rewrite/Revise sentence. Plus add unit of salinity

P4L29-30: “…in Storfjorden is classified as a low-energy and high-accumulation environment, which is characteristic …”

P4L30-32: Rewrite sentence. Explain the last part of the sentence better.

P4L33: “..formation as well as the duration…”

3. Materials and methods

3.1 Sampling

I suggest deleting the subheading “3.1 Sampling” or changing it by “3.1. Marine sediment core”

P5L4: Change “during the cruise” by “retrieved with”

P5L5: Be consistent in using a space or not before degrees (See how you do it within the results chapter)

P5L6: remove space before “of”

P5L7: Extruded? I don´t think this is the correct word here.

The piston extrusion of sediment core is a common method used in the analyses of marine and lacustrine sediments. The ST_1.5 core was extruded, therefore, we assume that the word is correct.

P5L9: “extraneous on and/or cross-contamination of the thin…”

P5L8-10: Explain better. Rewrite sentence.

P5L11: change “in” by “at”

3.2 Sediment dating

P5L13: Change “sediment dating” to “Chronology”

P5L14: Change “sediment layeres” by “marine sediment core”

P5L15: Add “retrieved” after layers

P5L16: Add “core depth” after cm

P5L16-17: Rewrite “…from 46.5 cm core depth.”

P5L18: Change “in” by “at”

P5L20: Change “in” by “at”

P5L21: Remove space before new sentence.

P5L23-24: Explain why you chose this value for delta R. Plus rewrite sentence as it is not entirely correct as you say it. The here given value represents the local reservoir age (DeltaR) that is applied, rather than the difference… I think? Double check!

P5L25: “…BP) (Table 1).”

The ΔR value was applied after Mangerud et al. (2006), because it is the most recently published dataset of reservoir ages from North Atlantic region. However, it should be noted that the reservoir age is based on a few data points from western Spitsbergen, and the age may be different for the eastern coast. No data is available for the latter region. The specific value of 105 ± 24 was applied after Łącka et al. (2015). The core analyzed by Łącka et al. (2015) is located in the vicinity of the ST_1.5 core. Unfortunately, the authors of other studies from Storfjorden (e.g. Rasmussen et al., 2007; Rasmussen and Thomsen, 2015; Knies et al., 2017) did not include the ΔR value in their manuscripts.

3.3 Sediment grain size

P5L27: Change subtitle to “Grain size analysis”

P5L28: “…for grain size…”

P5L29: analyzer… Pay attention to consistent use of z/s (language!)

P5L31-32: Add reference for this method

P5L33: “… was used to reconstruct an ice rafted debris (IRD) record. …”

P6L1-2: “… is reported as concentrations (i.e. the number….”

3.4 Fossil foraminifera

P6L5: I suggest being more specific and thus, changing the subtitle to “Benthic foraminiferal assemblages”

P6L6-7: Rewrite sentence. Same comment as before and thus, be more specific. Literally say what your aim is (i.e. to reconstruct benthic foraminiferal assemblages). Also, make “mesh” plural. You used more than one mesh.

P6L11-12: Similar comment as for Grain size. “…presented as concentration (…) and flux (….).”

3.5 Stable isotope analysis

In general, what about errors for these measurements? In terms of reproducibility. Vital effect corrections?

We directly compare our isotopic data with the $\delta^{18}O$ record of Łącka et al. (2015) and $\delta^{18}O$-based SST record of Sarthein et al. (2003) (see Fig. 4). Łącka et al. (2015) performed isotopic measurements of E. excavatum tests, while Sarntheinet al. (2003) used C. lobatulus for measurements. In both studies no correction was applied, therefore we also did not apply a correction to our results.

P6L20: Change “From” by “Ca. “

P6L21: Delete space before new sentence. “… performed using a …”

3.6 Ancient DNA analysis

I suggest giving a bit more information about this proxy in general. As it is a more recently developed proxy, this might be useful to the readers.

Following the Referee’s suggestion, we have added more information about aDNA anlysis to the Introduction.

4. Results:

Generally, the Results (and later also the Discussion) section should be revised with respect to the

writing style. It contains often the same sentence structure. Something that is getting kind of unpleasant to read.
Furthermore, as they are often wrongly placed and/or used the use of comma´s should be revised. There is no harm in starting a new sentence.
Also, as the chronology is not sufficient enough to claim exact ages, make sure you ALWAYS use "~" when referring to timing/ages.
Then, conjugate your verbs correctly: You might have observed/recorded/noted etc. things in the past; however, your results still ARE what they are as of today. So, make sure to conjugate your verbs in the present tense when necessary.

4.1 Sediment age and type:
P7L20: What is meant with sediment type?
P7L21-22: Rewrite: "All dates were recorded in a chronological order…."
P7L22: Delete "depths of"
P7L23: Add "core depth" after 5.5 cm
P7L23: Delete "that were"
P7L24: Place commas after "was" and after "therefore"
P7L24-28: You say here "three remaining dates". However, even though you don´t present data between 4000 and 9000 years ago later in this study, from Figure 3 it is clear that you still used the last date in your age model. In addition, from Figure 3 it also seems you still use the first date to construct your age model. Hence, that looks like you actually use 5 data points (incl. linear interpolation). I think you should explain this better, both here within the text as well as later in Figure 3 and Table 1.

Indeed, the age model is based on four radiocarbon dates. The text was corrected.
As explained in the legend in Figure 3, ^{14}C *dates are marked with grey silhouttes and the dotted line shows the age-depth model retrieved from the linear interpolation between the dates. The additional explanation has been added to the figure caption.*
The date from 2.5 cm was not calibrated, therefore, we decided not to include both calibrated and non-calibrated dates in the age model. We only assume that the top of the core represents modern age.

P7L26: Change "time" by "temporal"
P7L27: Rewrite …precluded the making of…
P7L27-28: Change "the manuscript" by "this study"
P7L29: Comment here and related to many examples later on. When describing your results be careful with the used tense. Your results still "are" what they are, so no need to write in the past tense about them. Hence, change "was" by "is".
P7L29: Rewrite …An approximately…

P7L30: Rewrite ….where it increases…

P7L31: Rewrite ….decreases…

P7L32: Change “was” by “is”

P7L33: Rewrite ...The IRD flux decreased slightly with….

P8L1-2: ….one peak reaching 0.8 grains g-1 cm-1 at ~ 2.6 cal ka BP.

P8L3: … fraction had its highest…

P8L4: …after ~ 2.4 cal ka BP…

NOTE: For chapter 4.2 to 4.5, (and later also for the discussion) the conjugation of verbs should be double checked as I will not any longer do this in the further review.

4.2 Stable isotopes

Revise this chapter based on general comments stated below results.

4.3 Fossil foraminifera

P8L18: I suggest rethinking this sub-title. From the scope of the journal it is quite obvious this study deals with fossil foraminifera. I would be more specific here in what you present (i.e. benthic foraminiferal assemblages?)

P8L19: A total of 8647 specimens? I assume, this is the total for all samples? However, in which way is this relevant for this study?

P8L20-24: Rewrite sentence. Possibly split into two sentences. Make it more clear what you are trying to say.

P8L23-24: …There are a few… foraminifera recorded. In particular, these peaks lay at ~ 2.0 and ~ 1.8 cal ka BP as well as at the sediment….

P8L24: ….37, 37 and 66%, …

P8L23-25: If you refer here to Figure 4. I would make this also more visible within Figure 4. Right now, it is not clear what you are referring to. Or explain better.

P8L29: …. 2524, 2584 and 2610 ind. g-1, respectively. …

Note: No need to repeat the unit in a summary like this. Apply this within the further manuscript as it occurs more often

P8L30-32: Rewrite sentences more clearly. Clarify that the flux reached 2.2 for both peaks.

P9L3: ….at ~2.3 …

P9L5-9: Rewrite sentence. Too long.

P9L9: Delete “After ~ 2.7 cal ka BP, there were”

P9L10: Add “were” between peaks and recorded

P9L11-15: Rewrite sentence. Too long, too many commas.

4.4 Foraminiferal aDNA sequences

P9L21: A total of … Why is this number relevant?

P9L31-34: Rewrite sentence. ! Grammar.

P10L1-9: Pay attention to the repetition of the same sentence structure.

4.5 Diatom aDNA sequences

P10L12: Same comment as before regarding the total.

P10L17: Delete space before start of new sentence

P10L18: … recorded at ~ 0.4 …

Note: revise entire manuscript wrt adding "at" when you refer to a certain moment in time.

P10L24: Delete "." before start of new sentence.

P10L26: Rewrite sentence. No need for a comma in a sentence this short.

6. Discussion

P10L28: You jump from chapter 4 Results to chapter 6 Discussion?

P10L29-30: Rewrite: …a linear interpolation between four AMS 14C dates and thus, the age control….

However, which fourth date is included now? 2.5 cm or 52.5 cm? Clarify better throughout the manuscript.

P10L30-32: What is meant with this statement? Explain!

P10L34: …correlates…

P10L33-P11L2: Refer to figure 4! With respect to this statement: I can see the maxima in core 23258. However, the minimum in this core is not clear to me. In addition, the temperature minimum and maxima in the GISP2 core are not clear to me at all… So, please explain this statement? Furthermore, what is the reasoning behind the comparison of this record with GISP2? Why comparing it to a Greenland ice core record if you further keep it (geographically speaking) quite local? If comparing it to a Greenland ice core, then why GISP2 and not one of the others?

In addition to this, why did you picked core 23258 for comparison at this point? In your Figure 1, you show the location of several other marine cores, but not the one from Sarnthein et al., 2003. Why? Why adding 23258 to Figure 4 and not one of the records you have added in figure 1, and vica versa?

The core of Sarnthein et al. (2003) is broadly discussed in the manuscript. The timing of AW inflows revealed by their record is a basis of considerable part of our discussion, thus we decided to directly compare the record of Sarntheim et al. (2003) and our proxy record. Also, we have added the location of the 23258 core to Fig. 1.

We included GISP2 core in the manuscript to show the correlation between our results and other, geographically broader, studies. We agree that the manuscript is focused on the local environmental changes, therefore, we decided to remove the information about GISP2 core as not relevant for our study.

Also, I think the correct label of the core presented by Sarnthein et al., 2003 is M23258… double check this.

In the manuscript of Sarnthein et al. (2003), the label 23258-2 is used for the core, while the coring station is labeled 23258.

P11L2: Add an enter after this paragraph

6.1 The period from 4 cal ka BP to 2.7 cal ka BP
P11L3: Rewrite subtitle: "Time interval between ~ 4 and ~2.7 cal ka BP"

General comment to this sub-chapter:
This sub-chapter is based on the data retrieved from 2 samples! I genuinely doubt how realistic it is to say this much and interpret environmental conditions for ca. 1300 years based on 2 data points. And thus, if these 2 data points do not reflect 2 cm of sediment (but 4 cm?) I strongly recommend doubling the resolution. Even tough then, it will still be a low temporal resolution, but at least, slightly improved.
We agree that adding two data points may slightly improve resolution. However, it is not possible to obtain additional aDNA data, which is an essential part of the manuscript. In our opinion, adding two more data points of selected proxies will not allow to make any general conclusion about the period prior to ~ 2.7 cal ka BP. Instead, we decided to shorten significantly the discussion about this period and make conclusions more general.

P11L4: Delete "During the period"
P11L5: Delete "variable" This are only 2 data points…
P11L5: What is meant with "coarsening"? more coarse compared to what? Why not just say what it is? "A relatively low mean 0-63-um fraction"
P11L7: Rewrite. "…IRD peaks were noted during the Neoglacial and attributed…"
P11L7: Be more specific on the timing of "during the Neoglacial"
P11L8: Rewrite. "… rafting resulting from glacial front fluctuations (e.g. …"
P11L8: Rewrite. "0-63-µm"
NOTE: Be consistent in the use of the hyphen between 63 and µm. It is mostly there, but not always!
P11L10: What is meant with "response"? Explain.

P11L11: …is dominated…
P11L13: …is associated with cool and salty AW…
P11L19: "." at the end of the sentence
P11L21: Explain "standing stock"
P11L24: "noted a decrease" A decrease compared to when? After/Prior to 2.7 ka? How much is meant with a decrease? Explain/describe this decrease better…
P11L28: Explain what is meant with "high-energy"
P11L29-31: For honesty´s sake, I would mention this in the beginning of the sub-chapter (see general comment to this sub-chapter).

6.2 The period after 2.7 cal ka BP….
I´m not convinced about the sub-chapters titles…. I suggest revising them. Try to make it more concise.

The sub-chapters titles were more concise in the first version of the manuscript. However, one of the previous Referees suggested to extend them and add more information to emphasize the most important information included in the sub-chapter. Therefore, the sub-titles became more descriptive.

P12L3-34: What is the main message of this paragraph? Make that more clear for the reader.
P12L13: Rewrite. "…IRD in ST_1.5 may…"
P12L19: Rewrite. "Both increased ice cover… delivery limit light…"
P12L20: Add a comma after therefore.
P12L22: Replace ";" by a "." Then start a new sentence "The latter may…"
P12L27-30: Rewrite sentence. Also, why referring to this study and not others from the Barents Sea.
P12L31-P13L2: Why not including sea ice reconstruction studies from the wider area (Barents Sea, east of Svalbard)? See general comments.
P13L3: "Knies et al. (2017) suggested…"
P13L6-9: Rewrite sentence. Not clear and a lot of "and´s"
P13L11: "…2.3 and 1.7 cal …melting of the sea ice cover,…"
P13L13: "…by light d18O peaks in benthic…."
P13L17: "…was dominated by both AW/…"
P13L20: "…2.3 and …"
P13L21: "…BP are M. barleeanum…"
P13L23-27: Rewrite sentence. Too many thoughts in one sentence.
P13L33: "…in the 0-63-µm…"
P14L1-2: This sentence is key for this study. So emphasize it more.
P14L2-5: Rewrite sentence.
P14L7: "…in ST_1.5 belong…"

P14L9: "Y were previously noted"
P14L12: Remove ";" and start new sentence. Place hyphen between so and called.
P14L13: "taxa are known"
P14L17: Remove ";" and start new sentence.
P14L20: Remove ";" and start new sentence.
P14L22: "…inflow at ~ 2.4 and ~ 1.7 cal ka BP. Furthermore, the…"
P14L27: "…sp. is commonly found…"
P15L2: Change "have been" by "were"
P15L13: "The decrease…" I would not call it a very pronounced decrease… So verbalize this more carefully.
P15L21-23: What do you exactly try to say here? The high abundances indicate declining sea ice cover OR the highly productive surface waters indicate declining sea ice cover? Clarify.
P15L25: Remove ";" and start new sentence.
P15L28: Add enter after this paragraph.

6.3 Paleoceanographic implications
P15L30: "…revealed a two-phase Neoglacial with…"
P15L31: "ST_1.5 proxy records,…"
P15L32: "…constant cold…
P16L1: When you refer to "evidence" … Due to the limited data points prior to 2.7 ka, I would back this up by more evidence from the literature from a wider geographical area. However still within the vicinity of your core site… And thus, as it is content-wise a bit "thin", I suggest to revise and expand this sub-chapter (see comments Figure 1). I
P16L1: "…region during the mid-Neoglacial.…"
P16L2: "An alkenone.…"
P16L3-6: Rewrite sentence.

7. Conclusions
P16L18: "…steered controlled…" 2 verbs? Pick one.
P16L19: "and sea-ice cover variability. …"
P16L22: "…formation of an extensive…"

Figures:
In general, figure captions are rather "thin". I suggest adding a bit more information to the figure caption in order to make it clearer what is presented.

Figure 1:

With respect to the Introduction/Study area as well as the Discussion later on, I consider this figure as too specific. And thus, I suggest to add a "geographically broader" figure into this figure. Have to panes: a) broad study area; b) a zoom of the fjord (figure as it is now). This will also allow you to add more reference cores used for the discussion within this figure. For example, I suggest to add the cores referred to in the discussion also within this figure.
Furthermore, now it is indicated that red means WSC. However, the current branched off and flowing into the Barents Sea is not any longer the WSC. So add the correct name.
Add reference of ODV in the figure caption.
Rewrite figure caption. Add more info to it as well.

Figure 2:
P27L2: Change "sampling station" by "core location"

Figure 3:
P2L8: Give the core name instead of "studied core"
Is the date at 2.5 cm used? It seems it is. More particular, 2.5 cm is given present day age and further used for the linear interpolation between present and the next dating point. Then, also indicate this in this figure but also in the text and in table 1.
Further, indicate in this figure the difference between foram versus shell dated data points

Figure 4:
Figure caption: Specify on which foraminiferal tests the isotope analysis has been executed (in the caption OR in the figure itself). Specify this study present benthic foraminifera (and not planktic).

Figure: Indicate on the X-axis the location of your 14C dates. (Also do this for Figure 4-5-6-7-8)
Be consistent in the labeling of your units (fe. Xxxx/g vs. XXX g-1). (Also for other figures)
Add hyphen for the grain size label.
Add reference of GISP 2 data.
Further I suggest to label the separate plots by a, b, c, etc. and then also refer to the figure more specifically within the manuscript. This will make it easier for the reader to follow. (Also do this for Figure 4-5-6-7-8)

Figure 5:
Figure: Atlantic Water with a capital letter as has been done within the manuscript.

Figure 6:
P30L4: "a dashed line"

Further, I´m a bit confused. It has been sad that every 5 cm of the core was sampled for DNA analyses. Which makes 12 samples for the entire core. Here, only the data till 3.3 ka is presented. So, how come you still have 12 data points?

There is a typing error in the text, the resolution is 4 cm – it's now corrected. Moreover, sampling depths are presented in the supplementary tables.

I also suggest to add the dotted lines indicating 2.7, 2.3 etc. similar as has been done for Figure 4&5 (This also counts for figure 7 & 8)

We agree that the lines indicating major environmental changes may be helpful. We have added the lines to Figures 5, 6, and 7.

Figure 7:
Please explain a little bit in the figure caption what these clades mean.

What do you actually mean here? Are you asking about definition of clade or the description of environmental preferences etc. of certain clade?

Certain taxa are assigned to clades based on the their phylogenetic relationships. It means that sequences belonging to different clades are more "genetically distant" than sequences belonging to the same clade. Allogromiids are known to be not a coherent taxonomic groups, but are scattered between different clades (for more details, see Journal of Foraminiferal Research 32(4), 2002).

Further, wrt presenting your data in a consistent manner… Why did you switched to present the age on the Y-axis? I suggest presenting it on the X-axis as you did for the previous figures (This also counts for figure 8).

Figure 8:
P31L6: "….taxa plotted versus age" (Be consistent with other figure captions. "… a dashed…"

Table 1:
Change "sediment depth" by "core depth"
Be consistent: Calibrated years BP vs. Cal. a BP
Add information (possibly a new column) wether the dated material is on bivalve (shell) or benthic foraminifera…

Make clear the depth at 2.5 cm is given present day age.
Why the bold dark line between the last two rows? If you want to keep it like this, then explain this line within the figure caption.

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

Joanna Pawłowska[1*], Magdalena Łącka[1], Małgorzata Kucharska[1], Jan Pawlowski[2], Marek Zajączkowski[1]

[1]Institute of Oceanology Polish Academy of Sciences, Sopot, 81-712, Poland
[2]Department of Genetics and Evolution, University of Geneva, Geneva, CH 1211, Switzerland
Correspondence to: Joanna Pawłowska (pawlowska@iopan.pl)

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

known only from environmental sequencing. The diatom aDNA record indicates that primary production was continuous during the Neoglacial, regardless of the 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.

1. Introduction

The northward flow of Atlantic Water (AW) is one of the major contributors of heat to the Arctic Ocean (Polyakov et al., 2017). Recent oceanographic data indicate a warming trend due to an increased inflow of AW towards the Arctic Ocean (Rudels et al., 2015, Polyakov et al., 2017). AW has been present along the western margin of Svalbard for at least the last 12,000 years (e.g., Werner et al., 2011; Rasmussen et al., 2014). One of the major intrusions of AW occurred during the early Holocene (10.8 – 6.8 cal ka BP). A distinct cooling and freshening of the west Spitsbergen shelf 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 the present-day conditions (Ślubowska-Woldengen et al., 2007; Telesiński et al., 2018). The paleoceanographic conditions in the Svalbard margins correlate closely to the sea surface temperature (SST) variations in the Nordic Seas and confirm that the Svalbard area is highly sensitive to fluctuations in the inflow of AW (Ślubowska-Woldengen et al., 2007; Werner et al., 2013). Conversely, until the 1990s eastern Svalbard was recognized as an area exclusively influenced by the East Spitsbergen Current (ESC), which carries cold, less saline Arctic Water (ArW) from the Barents Sea (e.g., Quadfasel et al., 1988; Piechura et al., 1996). However, recent studies have revealed that the oceanography of the area is much more complicated (e.g., Skogseth et al., 2007; Geyer et al., 2010). Oceanographic data obtained from conductivity–temperature sensors attached to *Delphinapterus leucas* show a substantial contribution of AW to Storfjorden, East Spitsbergen (Lydersen et al., 2002). Recently, Hansen et al. (2011) suggested the presence of AW in Storfjorden during the early Holocene warming (11 – 6.8 cal ka BP), which was further confirmed by the foraminiferal and sedimentary records of Łącka et al. (2015).

Usunięto: However, the limited amount of data available for eastern Svalbard often makes paleoceanographic reconstructions of the area speculative.

The latter part of the Holocene, the so-called Neoglacial cooling (~ 4 cal ka BP), in the European Arctic is characterized by a declined summer insolation at northern latitudes (Berger, 1978) that correlates to a decline in summer SST (e.g., Andersen et al., 2004; Risebrobakken et al., 2010; Rasmussen et al., 2014; Ivanova et al., 2019). The cooling of the surface waters and the limited AW inflow towards the Nordic Seas led to the formation of an extended sea-ice cover in West Spitsbergen (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 extensive sea-ice cover (e.g., Sarnthein et al., 2003; Berben et al., 2014). Therefore, the Neoglacial is usually considered a generally cold period (e.g., Consolaro et al., 2018). However, the records from Storfjorden and the Barents Sea suggest that the Neoglacial was a period of variable oceanographic conditions with strong temperature and salinity gradients (Martrat et al., 2003; Sarnthein et al., 2003; Łącka et al., 2015; 2019). In addition, there is evidence of episodic intensifications of the warm AW inflow towards western Svalbard at that time (e.g. Risebrobakken et al. 2010; Rasmussen et al., 2012).

Usunięto: constantly

Usunięto: , with a culmination of cooling during the Little Ice Age

Usunięto: Calvo et al., 2002;

According to Nilsen et al. (2008), the critical parameter controlling the fjord–shelf exchange is the density difference between the fjord water masses and the AW. The local winter ice production and the formation of brine-enriched waters determine the density of local water masses, which is a key factor that enables AW to penetrate into fjords during the spring and summer. Moreover, the production of brine-enriched waters and the associated deep-water overflow are key contributors to large-scale ocean circulation (Killworth, 1983). In this respect, Storfjorden is especially important because it is one of the few areas where brine-enriched waters have been frequently observed (Haarpainter et al., 2001). In recent decades, reduced brine formation has occurred during the periods with the most intensive AW advection to Storfjorden and less sea-ice formation in the Barents Sea, while intense brine formation re-establishes during periods of recurrent cooling (Årthun et al., 2011;Rasmussen and Thomsen, 2014).

The aim of this study is to reconstruct the paleoceanographic development of Storfjorden during the Neoglacial at multicentennial resolution. We assumed that the periodic intensification of the AW inflow to the West Spitsbergen shelf during the Neoglacial resulted in the appearance of AW also in eastern Spitsbergen, similar to the conditions in the early Holocene (e.g., Łącka et al., 2015), affecting the density and extent of sea-ice cover in the area. A multiproxy approach comprising sedimentary, microfossil and molecular records was applied to provide evidence for the interactions between the inflow of AW and sea-ice coverage in Storfjorden. The ancient environmental DNA (aDNA) analysis targeted diatoms and nonfossilized monothalamous foraminifera. Both these of groups are hardly preserved in fossil records from the Svalbard fjords (Pawłowska et al., 2014) and shelf areas (Zimmermann et al., 2019 and references therein). Recent studies have demonstrated that analyses of genetic material obtained directly from environmental samples (so-called environmental DNA) are an efficient method for performing biodiversity surveys across time and space (Thomsen and

Usunięto: Spitsbergen

Usunięto: Łącka M., *pers. commun.*

Willerslev, 2015). The content of environmental DNA samples may be analyzed by DNA metabarcoding, which consists of high-throughput sequencing of taxonomically informative DNA fragments called metabarcodes. The identification of short, species-specific DNA fragments (so called "barcodes") allows us to obtain species-level assignments of modern and ancient DNA sequences (Herbert et al., 2003). The further demonstration that DNA can be preserved in the environment across geological timescales opened new avenues for palaeoclimatic and palaeoceanographic studies. Recent studies have demonstrated the preservation of DNA in marine sediments for tens to hundreds thousands of years. An aDNA approach was successfully applied to trace the Holocene history of dinoflagellates, haptophytes (e.g., Coolen et al., 2009, 2013; Boere et al., 2009) and foraminifera in deep sea (Lejzerowicz et al., 2013) and coastal areas (Pawłowska et al., 2014; 2016). The study of Pawłowska et al. (2016) was the first attempt to utilize foraminiferal aDNA as a paleoenivronmental proxy. This study supported the existence of extremely diverse foraminiferal assemblages. The richness of the foraminiferal community revealed by the molecular record was much higher than that in the fossil record (Pawłowska et al., 2014), mainly due to the detection of nonfossilized monothalamous taxa. The molecular data correlated well with environmental changes and revealed even small changes that were not clearly indicated by other proxy records. The combination of aDNA studies with the analysis of microfossils and sedimentary proxies provides a powerful means to reconstruct past environments more comprehensively.

Usunięto: Our previous studies of foraminiferal aDNA revealed the extraordinary richness of the foraminiferal 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).

2. Study area

Storfjorden is located in southeastern Svalbard between the islands of Spitsbergen, Edgeøya and Barentsøya (Fig. 1). Storfjorden is ~190 km long and its main basin is ~190 m deep. Two narrow and shallow passages (Heleysundet and Freemansundet) connect northern Storfjorden to the Barents Sea. To the south, a 120-m-deep sill separates the main basin from the Storfjordrenna. Storfjordrenna is 245 m long, with a depth varying from 150 m to 420 m.

The water masses in Storfjorden are composed primarily of exogenous Atlantic and Arctic waters as well as mixed waters that have formed locally. Warm AW is transported by the West Spitsbergen Current that branches off near Storfjordrenna and enters the southern part of the fjord as the North Cape Current. Arctic water (ArW) from the Arctic Ocean and the Barents Sea enters Storfjorden via two passages to the northeast and continues along the inner shelf of Svalbard as a Coastal Current (Fig. 1). AW is characterized by temperatures > 3 °C and salinity > 34.95, while the temperature and salinity of ArW are < 0 °C and 34.3-34.8, respectively. The presence of locally formed water masses is a result of the interactions between AW, ArW and melt water. Skogseth et al. (2005) listed six local water masses: melt water (MW), polar front water (PW), East Spitsbergen water (ESW), brine-enriched shelf water (BSW), Storfjorden surface water (SSW), and modified Atlantic water (MAW). BSW is formed due to the release of a large 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 temperatures below -1.5 °C (Skogseth et al., 2005).

The sedimentary environment in Storfjorden is classified as a low-energy, high-accumulation environment, which is characteristic of inner fjords. The area is sheltered from along-shelf 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 as well as the duration of the marginal ice zone (Winkelman and Knies, 2005).

3. Materials and methods

3.1 Marine sediment core

Usunięto: Sampling

The 55-cm-long sediment core ST_1.5 was taken with a gravity corer in Storfjorden retrieved with 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 salinity and temperature of the water column at the coring station was measured with a Mini CTD Sensordata SD 204 at intervals of 1 s. The core was stored at 4°C and shipped to the Institute of Oceanology PAS for further analyses.

Usunięto: during cruise of

In the laboratory, the core was extruded and cut into 1-cm slices. During cutting, sterile subsamples for ancient DNA (aDNA) analyses were taken at 4 cm intervals. To avoid external and/or cross-contamination the thin layers of sediment that were in contact with under- or overlying sediments were removed using a sterile spatula. Samples for aDNA analyses were kept frozen at -20°C. Samples for other proxy analyses were taken every 2 cm.

3.2 Chronology

Usunięto: Sediment dating

The chronology of the marine sediment core is based on high-precision accelerator mass spectrometry (AMS) ^{14}C dating performed on five bivalve shells retrieved from the sediment layers at 2.5, 5.5, 14.5, 43.5, and 52.5 cm core depth and on the foraminifera *Nonionellina labradorica* from the 46.5 cm core depth. The bivalve shells were identified to

Usunięto: sediment layers

the highest possible taxonomic level and processed on the 1.5 SDH-Pelletron Model "Compact Carbon AMS" in the Poznań Radiocarbon Laboratory, Poznań, Poland. Dating of foraminiferal tests was performed at the National Ocean Sciences AMS (NOSAMS) laboratory in the Woods Hole Oceanographic Institution, Woods Hole, MA, USA. The dates were converted into calibrated ages using the calibration program CALIB Rev. 7.1.0 Beta (Stuiver and Reimer, 1993) and the Marine13 calibration dataset (Reimer et al., 2013). A reservoir age correction (ΔR) of 105 ± 24 was applied (Mangerud et al., 2006). The calibrated results are reported in units of thousand calibrated years BP (cal ka BP) (Table 1).

3.3 Grain size analysis

Usunięto: Sediment grain size

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

3.4 Benthic foraminifera assemblages

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

3.5 Stable isotope analysis

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

3.6 Ancient DNA analysis

The total DNA was extracted from approximately 10 g of sediment using a Power Max Soil DNA extraction kit (MoBio). The foraminiferal SSU rDNA fragments containing the 37f hypervariable region were PCR amplified using primers tagged with unique sequences of five nucleotides appended to their 5' ends (denoted by Xs), namely, the foraminifera-specific forward primer s14F1 (5'-XXXXXCGGACACACTGAGGATTGACAG-3') and the reverse primer s15 (5'-XXXXXCCTATCACATAATCATGAAAG-3'). The diatom DNA fragment located in the V4 region was amplified with the forward DIV4for (5'-XXXXXXXXGCGGTAATTCCAGCTCCAATAG-3') and reverse DIV4rev3 (5′-XXXXXXXXCTCTGACAATGGAATACGAATA-3’) primers tagged with a unique combination of eight nucleotides (denoted by Xs) attached at each primer’s 5’-end. The amplicons were purified using the High Pure PCR Cleanup Micro Kit (Roche) and quantified 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). The samples were then loaded into a MiSeq instrument for a paired-end run of 2*150 cycles (foraminifera) and 2*250 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-sequencing data processing was performed with the use of the 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 the 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). The results are presented in OTU-to-sample tables and transformed in terms of the number of sequences, number of OTUs and percentage (%) of sequences.

4. Results

4.1 Chronology & sediment grainsize

Usunięto: Sediment age and type

In total, six radiocarbon dates were obtained, all of which were recorded in chronological order. The uppermost layer contained modern, post-bomb carbon indicating a post-1960 age (Table 1). Samples from the 2.5 cm and 5.5 cm core depths were not calibrated because they revealed ages invalid for the selected calibration curve. The age model was, therefore, based on the four remaining dates using a linear interpolation. The age of the bottom of the core was estimated to be approximately ~ 7.9 cal ka BP (Fig. 3). However, the extremely low temporal resolution between ~ 7.9 cal ka BP and ~ 4 cal ka BP precluded making any general conclusion about that interval. Therefore, this study focuses only on the last ~ 4 cal ka BP (the Neoglacial).

The sediment was classified as medium to coarse silt throughout the core. 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 was noted at ~ 2.7 cal ka BP, where 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. 4). 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 IRD flux decreased slightly over time to 0.37 grains g^{-1} cm^{-1}, except for one peak reaching 0.8 grains g^{-1} cm^{-1} at ~ 2.6 cal ka BP (Fig. 4).

Usunięto: , when it reached 0.8 grains g^{-1} cm^{-1}

The mean grain size of the 0-63-µm fraction had its highest value (5.8 φ) at ~ 2.7 cal ka BP (Fig. 4). 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 φ) was recorded at the top of the core (Fig. 4).

4.2 Stable isotopes

The $\delta^{18}O$ values were relatively stable prior to ~ 2.7 cal ka BP, changing slightly between 3.55‰ and 3.69‰ vs. VPDB. Between ~ 2.7 and ~ 1.5 cal ka BP, $\delta^{18}O$ showed the strongest variation, with values ranging from 3.28‰ to 3.77‰ vs. VPDB. After ~ 1.5 cal ka BP, $\delta^{18}O$ became slightly lighter (3.43‰ - 3.64‰ vs. VPDB), except for one peak noted in the uppermost layer of the core, where $\delta^{18}O$ reached 3.87‰ vs. VPDB (Fig. 4).

In the period prior to ~ 2.7 cal ka BP, $\delta^{13}C$ displayed relatively light values ranging from 0.92‰ to 1.12‰ vs. VPDB. Slightly heavier $\delta^{13}C$ (up to 1.46‰ vs. VPDB) was observed between ~ 2.7 and ~ 1.5 cal ka BP. The gradual decrease was recorded from ~ 1.5 cal ka BP to the present, reaching 0.81‰ vs. VPDB at the top of the core (Fig. 4).

4.3 Benthic foraminifera assemblages

Usunięto: Fossil

A total of 8647 fossil foraminifera specimens belonging to 47 species were identified (Supplement 1; Supplementary Fig. 1). The number of foraminifera individuals varied from 156 to 2610 ind. g^{-1}, and the lowest abundances were observed prior to ~ 2.7 cal ka BP (Fig. 4). A short-term decrease in foraminifera abundance was observed between 2.1 and 1.9 cal ka BP, with values reaching as low as 304 ind. g^{-1}. The abundance maxima were noted at 2.3, 1.5, and 0.6 ka BP, with values reaching 2524, 2584, and 2610 ind. g^{-1}, respectively. The foraminiferal flux was low and relatively stable throughout the core, with values that did not 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 ind cm^{-2} y^{-1} for both peaks (Fig. 4).

Usunięto: The foraminiferal assemblages were dominated by 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 44% (Fig. 4). There were few peaks of agglutinated foraminifera noted at 2.0 cal ka BP, 1.8 cal ka BP and on the sediment surface, where the percentages reached 37%, 37% and 66%, respectively (Fig. 4).

The most abundant species was *Cassidulina reniforme*, with densities reaching up to 900 ind g^{-1}. The other species that constituted the majority of the foraminiferal assemblage were *Bucella frigida*, *Cibicidoides lobatulus*, *Elphidium excavatum*, *Islandiella* spp, *Melonis barleeanum*, and *Nonionellina labradorica*. The abundances of the dominant species followed a general trend, with maxima at ~ 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. 5).

The foraminiferal assemblage prior to ~ 2.7 cal ka BP was dominated by indicators of AW inflow and/or frontal zones and glaciomarine taxa (Fig. 5). The most abundant species were *Nonionellina labradorica* and *Melonis barleeanum*, as well as *Cassidulina reniforme* and *Elphidium excavatum*, which together accounted for up to 60% of the foraminiferal abundance (Fig. 5). 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, respectively. The period between ~ 2.4 cal ka BP and ~ 1.8 cal ka BP was characterized by an increase in the percentage of sea-ice indicators (*B. frigida* and *Islandiella* spp), which accounted for up to 25% of the total foraminiferal abundance. Additionally, a short-term peak in the glaciomarine taxa, reaching up to 49% of the foraminiferal assemblage, was recorded between 2.5 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 single peak in the percentage of bottom current indicators, which reached 42% and 19%, respectively (Fig. 5).

Usunięto: which are species that are considered to be indicators of AW inflow and/or frontal zones, and glaciomarine taxa, primarily

4.4 Foraminiferal aDNA sequences

A total of 1,499,889 foraminiferal DNA sequences were clustered into 263 OTUs, and 20 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.

The most important components of the monothalamous assemblage were *Micrometula* sp., *Cylindrogullmia* sp., *Hippocrepinella hirudinea*, *Ovammina* sp., *Nemogullmia* sp., *Tinogullmia* sp., *Cedhagenia saltatus*, undetermined allogromiids belonging to clades A and Y (herein called “allogromiids”), and sequences belonging to taxa known exclusively from environmental sequencing (herein called “environmental clades”). The sequences belonging to allogromiids were present throughout the core, accounting for 16–31.7% of all the foraminiferal sequences. The exceptions were the intervals from ~ 4.0 to 2.4 cal ka BP, and ~ 1.7 cal ka BP, when the contribution of allogromiid sequences decreased to less than 10% (Fig. 6). The majority of the allogromiids belonged to clade Y, which made up to 100% of the allogromiid sequences. Only at 1.6–1.7 cal ka BP and 2.4–2.6 cal ka BP, most of allogromiid sequences belonged to clade A. Additionally, allogromiids belonging to clade I were noted at ~ 2.4 cal ka BP, where they made up 0.88% of allogromiid sequences (Fig. 7).

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

4.5 Diatom aDNA sequences

A total of 824,697 diatom DNA sequences were clustered into 221 OTUs (Supplement 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 *Chaetoceros* sp. and *T. antarctica*, which made up 8.5% and 11.5% of sequences, respectively. The sequences of *Thalassiosira* sp were most abundant between ~ 2.2 cal ka BP and ~ 1.9 cal ka BP, accounting for up to 85% of all diatom sequences. The lowest percentage (14%) of *Thalassiosira* sp. was recorded at ~ 0.4 cal ka BP. Sequences assigned to *T. antarctica* were recorded throughout the core and their percentages were the highest at ~ 3.3 and ~ 2.6 cal ka BP, reaching up to 13% and 19%, respectively (Fig. 8). Sequences of *T. hispida* were also noted throughout the core and constituted 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 *Chaetoceros* sp. decreased downcore, from 76% at the surface to less than 1% at the bottom of the core (Fig. 8). *Navicula* sp. constituted an important part of the diatom assemblage at ~3.3 cal 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, the abundance of *Navicula* sp. did not exceed 5% (Fig. 8).

5. Discussion

The ST_1.5 age model is based on the linear interpolation between the four AMS^{14}C dates; thus, the age control of the core should be treated with caution. However , the timing of major environmental changes revealed by the ST_1.5 multiproxy record is in agreement with other records from the region (e.g., Sarnthein et al., 2003; Calvo et al., 2002; Risebrobakken et al. 2010; Berben et al. 2017). Moreover, the major pulses of AW that were recorded ~ 2.3 and 1.7 cal ka BP correlated well with winter and summer SST maxima recorded in the 23258-2 core (Sarnthein et al., 2003).

Usunięto: ,)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). ¶

5.1 The period from 4 cal ka BP to 2.7 cal ka BP

Prior to ~ 2.7 cal ka BP, the ST_1.5 sedimentary record displayed relatively higher IRD delivery and a relatively lower 0-63-µm sediment fraction than in the following period (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).The coarser 0-63 µm fraction may suggest the winnowing of fine grained sediment, however, foraminiferal fauna showed no clear response to sediment removal.

Usunięto: elevated and variable

Usunięto: mean

The foraminiferal flux and abundance prior to 2.7 cal ka BP reached their lowest values (Fig. 4). Previous studies reported a decrease in te concentration of benthic foraminifera in Storfjorden at that time, which was attributed to the presence of extensive ice cover (Rasmussen and Thomsen, 2015; Knies et al. 2017). The dominant components of the ST_1.5 foraminiferal assemblage were *C. reniforme*. and *M. barleeanum* (Fig. 5). The presence of *C. reniforme* and *M. barleeanum* is associated with 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

Usunięto: was dominated by glacier-proximal fauna (primarily

Usunięto:) and indicators of frontal zones (primarily matter observed in frontal zones and/or near the sea-ice edge (Jennings et al., 2004). The presence of sea-ice may be indicated also by the relatively light foraminiferal $\delta^{13}C$ (Fig. 4), as well as the highest percentage of the sea-ice species *Thalassiosira antarctica* (cf Ikävalko, 2004; Fig. 8). However, the low sampling resolution during that period precluded us from making a general conclusion, and the latter assumptions should be confirmed by further studies.

5.2 The period from 2.7 cal ka BP to 0.5 cal ka BP. Episodes of AW inflow at ~ 2.3 and 1.7 cal ka BP.

After ~ 2.7 cal ka BP, the increase in SAR was followed by a decrease in the 0-63-µm fraction and in the IRD delivery (Fig. 4). The 10-fold increase in SAR most likely resulted from the intensive supply of turbid meltwater from advancing glaciers and the consequent intensive sedimentation. Moreover, the accumulation of fine sediment may also be enhanced by the slowdown of the bottom currents, indicated by the finer 0-63-µm 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 and Thomsen (2015) suggested glacial advance, followed by intensive ice rafting and meltwater delivery to Storfjorden at that time. According to Knies et al. (2017), the 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 from the presence of a sea-ice cover that reduced iceberg rafting while the majority of coarse-grained material settled in the proximity to the glacial fronts. Similar conclusions have been stated by Forwick and Vorren (2009) and Forwick et al. (2010), who assumed that the enhanced formation of sea ice along the West Spitsbergen coast trapped icebergs inside the Isfjorden system.

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. 4). The latter may suggest favorable conditions for foraminiferal growth. The major peaks in the total foraminiferal abundance (Fig. 4) followed by the peaks in the percentage of AW foraminiferal indicators (Fig. 5) were noted ~ 2.3 cal ka BP and ~ 1.7 cal ka BP. These peaks were associated with the occurrence of sequences of *T. hispida* (Fig. 8), a diatom species characteristic of subpolar and temperate regions (Katsuki et al., 2009). The timing of the changes described above is in accordance with the findings of Sarntheim et al. (2003), who reported two intervals of the remarkably warmer sea surface on the western continental margin of the Barents Sea at ~ 2.2 and ~ 1.6 cal ka BP, which was attributed to short-term

Usunięto: may indicate primary production associated with the presence of sea-ice and/or periodic inflow of ArW

Usunięto: ¶
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.¶

Usunięto: The environmental conditions in central Storfjorden changed noticeably after

Usunięto: distinct surface water cooling during the Neoglacial provides a prerequisite for the presence of more extensive sea-ice cover; therefore inner Storfjorden was covered by densely packed sea ice between ~ 2.8 and 0.5 cal ka BP.

Usunięto: 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, t pulses of warm AW advection. Other records also indicated AW inflow to the western and northern Barents Sea as well as to the western Spitsbergen continental margin during mid-late Holocene (e.g., Risebrobakken et al., 2010; Berben et al., 2014; 2017; Müller et al., 2012). Our foraminiferal and diatom aDNA records confirm the presence of AW intrusions that may have caused an episodic breakup of sea-ice cover and permitted primary production and the development of benthic biota, including foraminifera.

The pulses of AW inflow at 2.3 cal ka BP and 1.7 cal ka BP were marked by the maxima of the foraminiferal flux (Fig. 4) and by peaks in the abundance of species associated with highly productive environments, such as *M. barleeanum* and *N. labradorica* (Fig. 5). Moreover, the presence of diatom aDNA sequences throughout the core (Fig. 8) may suggest continuous primary production. Surprisingly, the presence of AW also coincided with peaks in the light $\delta^{18}O$ (Fig. 4). The likely scenario is that pulses of AW inflow at ~ 2.3 and ~ 1.7 cal ka BP induced melting of the ice cover, leading to the formation of isotopically lighter surface waters and highly productive ice marginal zones. However, the responses of the benthic foraminifera assemblage to the pulses of AW at ~ 2.3 cal ka BP and ~ 1.7 cal ka BP are slightly different. 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* were dominant (Fig. 5). The major difference in environmental conditions between these two "AW episodes" was noticeably coarser 0-63 µm sediment fraction noted at ~ 2.3 cal ka BP, what may indicate more intensive winnowing of fine sediment grains,, which would have created favorable conditions for the development of opportunistic species, such as *E. excavatum*. In contrast, the interval between 2.3 and 1.7 cal ka BP featured variable $\delta^{13}C$ and $\delta^{18}O$ followed by a decrease in the foraminiferal flux and abundance (Fig. 4). The foraminiferal assemblage at this time was dominated by glaciomarine and sea-ice taxa (Fig. 5), which indicate more severe environmental conditions with extensive ice cover and suppressed productivity.

The alternate cooling and warming periods described above were also reflected in the aDNA record of monothalamous foraminifera. During the periods with more severe environmental conditions (i.e., time intervals of 2.2–1.9 cal ka BP and 1.3–0.4 cal ka BP), the monothalamous foraminifera was dominated by allogromiids belonging to clade Y, *Nemogullmia* sp., *C. saltatus* and monothalamids belonging to so called "environmental clades" (Fig. 6). A considerable portion of 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 that have previously been noted in modern sediments in the

Usunięto: Moreover, the westernSpitsbergen continental margin experienced periods of a rapidly advancing and retreating sea-ice margin during the Neoglacial, caused by a temporarily strengthened AW inflow and/or changes in the atmospheric circulation patterns (

Usunięto: the formation of ice free areas

Usunięto: Knies et al. (2017) have suggested that the pulses of advected AW did not influence the persistent sea-ice cover in Storfjorden between ~ 2.8 and 0.5 cal ka BP. However, the ST_1.5 foraminiferal record indicates that central Storfjorden was not constantly covered by sea ice at that time. A more reasonable scenario is surface water cooling and periodic melting 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 production (Łącka et al., in prep.). The presence of diatom aDNA sequences throughout the Neoglacial (Fig. 8) may suggest continuous primary production. It is likely that pulses of AW inflow at 2.3 cal ka BP and 1.7 cal ka BP induced melting of the ice cover, leading to the formation of ice-free areas and highly productive ice marginal zones. This conjecture may be supported by peaks in the light $\delta^{18}O$ in benthic foraminiferal tests, the maxima of the foraminiferal flux (Fig. 4) and peaks in the abundance of species associated with highly 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. The foraminiferal assemblage was codominated by AW/frontal zone indicators and glaciomarine species (Fig. 5) at that time, which may suggest rather ameliorated environmental conditions. However, t

Usunięto: , which reached its' maximum flux and percentage at that time

Usunięto: The sea-ice 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 of *C. lobatulus*, which is considered to be a bottom current indicator (Fig. 5).

Usunięto: Allogromiids are not a coherent taxonomic group but are scattered between several monothalamous clades (Gooday 2002; Pawlowski et al., 2002).

Usunięto: . Sequences belonging to clade Y

Spitsbergen fjords (Pawłowska et al., *unpubl.*). Clade Y has also been abundantly sequenced in the coastal areas off Scotland, characterized by high levels of environmental disturbances (Pawlowski et al., 2014); this might suggest its high tolerance to environmental stress. *C. saltatus* was recently found by Gooday et al. (2011) in the Black Sea and its occurrence in areas with high levels of pollution suggests that it is an opportunistic species with a high tolerance for environmental disturbances. In addition, so called "environmental clades" are composed of monothalamous taxa known exclusively from environmental sequencing (Lecroq et al., 2011). The abovementioned taxa nearly disappeared during the episodes of enhanced AW inflow at ~ 2.4 cal ka BP and ~ 1.7 cal ka BP, and the monothalamous assemblage was dominated at that time by *Micrometula* sp., *Ovammina* sp., *Shepheardella* sp., *Tinogullmia* sp., *Cylindrogullmia* sp., and allogromiids belonging to clade A (Fig. 6; Fig. 7). All these taxa have recently been observed in the fjords of Svalbard and Novaya Zemlya (e.g. Gooday et al., 2005; Majewski et al., 2005; Sabbattini et al., 2007; Pawłowska et al., 2014; Korsun & Hald, 1998; Korsun et al., 1995). *Cylindrogullmia* and *Micrometula* are dependent on the presence of fresh phytodetritus (Alve, 2010). *Ovammina* sp. feeds on 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.

The taxa that dominated the monothalamous assemblage during warm intervals seem to be responsive to the delivery of organic matter and may flourish during phytoplankton blooms associated with the settling of organic matter (e.g., Alve, 2010; Sabbattini et al., 2012, 2013). The pulses of AW inflow may be associated with phytoplankton blooms stimulated by sea-ice melting and with the organic matter supply to the bottom (cf. Łącka et al., 2019). The continuous aDNA record of the sea-ice diatom *T. antarctica* (Fig. 8) suggests the presence of at least seasonal ice cover in the study area. On the other hand, the episodes of AW inflow were associated with the occurrence of the open-water taxa *T. hispida* (Fig. 8). The occurrence of sequences of both these taxa suggests the formation of ice cover during winter-spring, followed by ice-free summers. A similar scenario was proposed by Berben et al. (2017), who suggested increased AW to the eastern Svalbard and partial summer sea ice occurrence after 2.7 cal ka BP. According to the record of Łącka et al. (2019) from Storfjordrenna, the sea-ice melting induced the production of brines that may launch convective mixing and nutrient resupply from the bottom, which stimulated primary production.

Przeniesione w dół [1]: (Gooday et al., 2005; Majewski et al., 2005)

Przeniesione (wstawienie) [1]

Usunięto: and may belong to novel, undescribed foraminiferal lineages (Pawlowski et al., 2014b)

Usunięto: *C. saltatus* was recently found by Gooday et al. (2011) in the Black Sea and until recently, little has been known about its environmental tolerances; however, its occurrence in areas with high levels of pollution suggests that it is an opportunistic species with a high tolerance to environmental disturbances

Usunięto: Specimens of *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 degradation of its fragile, organic-walled tests.(Gooday et al., 2005; Majewski et al., 2005)

Usunięto: *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 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 (Korsun & Hald, 1998; Korsun et al., 1995) and Svalbard (Korsun & Hald, 2000; Gooday et al., 2005; Pawłowska et al., 2014). Moreover, Conversely, the colder phases of the Neoglacial were characterized by heavy and densely packed sea ice resulting in limited productivity (Knies et al., 2017). The presence of *T. anatrctica* sequences and the disappearance of *T. hispida* (Fig. 8) may suggest that primary production was associated with sea-ice. Furthermore, the monothalamous assemblage was less diverse and was dominated by more opportunistic taxa, which may indicate a reduced supply of organic matter to the bottom.

5.3 The period after 0.5 cal ka BP.

Modern-like conditions were established in Storfjorden at ~ 0.5 cal ka BP (Knies et al., 2017). The ST_1.5 record displayed a decrease in SAR compared to the preceding period, a decreasing 0-63 µm fraction and low IRD delivery (Fig. 4), which may indicate reduced glacial impact. Moreover, the peak of heavy $\delta^{18}O$ recorded on the core top (Fig. 4) suggests the presence of isotopically heavier AW or slightly increased salinity. Similarly, Berben et al. (2014) recorded $\delta^{18}O$ values that suggested a minor increase in salinity, while foraminiferal fauna showed slightly lower salinities in the western Barents Sea at that time. The latter is in accordance with records from the Fram Strait (e.g. Werner et al., 2013) and the western Spitsbergen shelf (Cabedo-Sanz and Belt, 2016), which suggest episodes of freshening of the surface water masses associated with alternating sea ice increases and ice-free conditions in the late Holocene. Additionally, the records of Rasmussen and Thomsen (2014) and Knies et al., (2017) from Storfjorden indicated seasonally variable sea-ice cover. Moreover, the majority of diatom aDNA sequences found in the ST_1.5 record after ~ 0.5 cal ka BP belonged to *Chaetoceros* sp. (Fig. 8), a taxa that is observed in surface waters and is almost entirely absent under sea ice (Różańska et al., 2008). High abundances of *Chaetoceros* are often associated with highly productive surface waters (Cremer, 1999). Rigual-Hernández et al. (2017) also noted increased abundance of *Chaetoceros* sp. and enhanced algal productivity in Storfjorden after 2.0 cal ka BP, what was associated to the vicinity of the Arctic Front. However, the aDNA record of the monothalamous foraminifera at ~ 0.4 cal ka BP displayed relatively high percentages of taxa that dominated during the colder intervals of the Neoglacial (Fig. 6). This may be related to the recovery from the Little Ice Age, and consequently, from the temporarily deteriorated environmental conditions (D'Andrea et al., 2012). However, due to the low resolution during the LIA, a detailed interpretation is not possible. Therefore, further studies are required to confirm the latter conclusion.

5.4 Paleoceanographic implications

Usunięto: The enhanced primary productivity supported the development of an organic matter-dependent monothalamous community.

Usunięto: 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 (Fig. 5).

Przeniesione w dół [2]: seasonally variable sea-ice cover resulting in intensified but variable polynyal activity (Rasmussen and Thomsen, 2014b; Knies et al., 2017).

Przeniesione (wstawienie) [2]

Usunięto: resulting in intensified but variable polynyal activity (Rasmussen and Thomsen, 2014b; Knies et al., 2017).The IP_{25} records from the western Spitsbergen shelf also indicate variable sea-ice conditions during the last 2 ka (Cabedo-Sanz and Belt, 2016).

Our record revealed a two-phase Neoglacial, with a major shift in environmental conditions at ~ 2.7 cal ka BP. According to the ST_1.5 proxy records, the Neoglacial in Storfjorden was not a constantly cold period, but comprised alternating short-term cooling and warming periods, associated with variability in sea-ice coverage and productivity. The Neoglacial cooling was documented in various proxy reconstructions from the Nordic Seas (e.g., Jennings et al., 2002; Moros et al., 2004; Consolaro et al., 2018). However, there is growing evidence of shifts in environmental conditions in the Nordic Seas region in the Neoglacial, whose timings are in accordance with our record. Alkenone record from the Norwegian Sea revealed a significant drop in 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. The episodes of reduced surface and subsurface salinity were recorded after 2.5 cal ka BP, what was attributed to the expansion of coastal waters and the occurrence of more sea-ice (Risebrobakken et al., 2010). Berben et al. (2017) recorded a shift ~2.7 cal ka BP, from the marginal ice zone to Arctic frontal conditions in the eastern Barents Sea. They observed continuous cooling trend from ~ 5.9 cal ka BP to 2.7 cal ka BP, with increased seasonal sea ice with less open water conditions, lower temperatures and decreased AW influence. Whereas, after 2.7 cal ka BP, the influence of AW was variable, but generally generally increasing. The period was characterized by low insolation, associated with surface cooling and enhanced formation of sea ice/reduced sea ice melt (Berben et al., 2017).

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). Episodic increases of the AW during the late Holocene were also observed in the western Barents Sea (Duplessy et al., 2001; Lubinski et al., 2001), the eastern Barents Sea (Berben et al., 2014) and the Svalbard margin (Jernas et al., 2013; Werner et al., 2013). 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. These results are in accordance with the timing of major AW inflows revealed by our record.

Usunięto: 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.

6. Conclusions

The ST_1.5 multiproxy record revealed that the environmental variability in Storfjorden during the Neoglacial was controlled primarily by the interplay between AW and ArW and sea-ice cover variability. The molecular record supports and complements sedimentary and microfossil records, which indicate that major changes in the environmental conditions in Storfjorden occurred at ~ 2.7 cal ka BP. The general cooling in the early phase of the Neoglacial initiated conditions for the formation of extensive sea-ice cover. The latter part of the Neoglacial (after ~ 2.7 cal ka BP) was characterized by alternating short-term cooling and warming periods. Warming was associated with pulsed inflows of AW and sea-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 limited productivity.

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

The aDNA record of monothalamous foraminifera is in agreement with the microfossil 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.

Author contributions

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.

Acknowledgements

The study was supported by the National Science Centre grants no. 2015/19/D/ST10/00244 and 2016/21/B/ST10/02308, and Swiss National Science Foundation grant no. 31003A_179125. The Authors would like to thank anonymous Reviewers for constructive comments that helped to improve the manuscript.

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.

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.

Berben, S.M.P., Husum, K., Cabedo-Sanz, P., Belt, T.S.: Holocene sub-centennial evolution of Atlantic water inflow and sea ice distribution in the western Barents Sea, Clim. Past. 10, 181-198, doi:10.5194/cp-10-181-2014, 2014.

Berben, S.M.P., Husum, K., Navarro-Rodriguez, A., Belt, T., Aagard-Sørensen, S.: Semi-quantitative reconstruction of early to late Holocene spring and summer sea ice conditions in the northern Barents Sea, J. Quat Sci., 32, 587-603, doi: 10.1002/jqs.2953, 2017.

Berger, A.L.: Long-term variations of daily insolation and quaternary climatic changes, J. Atmos. Sci., 35, 2362-2367, https://doi.org/10.1175/1520-0469(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, https://doi.org/10.1007/s41063-016-0023-2, 2016.

Consolaro, C., Rasmussen, T.L., Panieri, G.: Palaeocoeanographic and environmental changes in the eastern Fram Strait during the last 14,000 years based on benthic and planktonic foraminifera, Marine Micropaleontology, 139, 84-101, https://doi.org/10.1016/j.marmicro.2017.11.001, 2018.

Coolen, M.J.L., Saenz, J.P., Giosan, L., Trowbridge, N.Y., Dimitrov, P., Dimitrov, D., Eglinton, T.I.: DNA and lipid molecular stratigraphic records of haptophyte succession in the Black Sea during the Holocene, Earth Planet. Sci. Lett., 284, 610-621, https://doi.org/10.1016/j.epsl.2009.05.029, 2009.

Coolen, M.J.L., Orsi, W.D., Balkema, C., Quince., C., Harris, K., Sylva, S.P., Filipova-Marinova, M., Giosan, L.: Evolution of the plankton paleome in the Black Sea from the Deglacial to Anthropocene, PNAS, 10, 8609-8614, https://doi.org/10.1073/pnas.1219283110, 2013.

Boere, A.C., Abbas, B., Rijpstra, W.I.C., Versteegh, G.J., Volkman, J.K., Sinninghe Damsté, 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 U_{37}^{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.

Cremer, H.: Distribution patterns of diatom surface sediment assemblages in the Laptev Sea (Arctic Ocean), Mar. Micropaleontol., 38, 39-67, https://doi.org/10.1016/S0377-8398(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/s12859-019-2663-2, 2019.

Duplessy, J.C., Ivanova, E., Murdmaa, I., Paterne, M., Labeyrie, L.: Holocene paleoceanography of the northern Barents Sea and variations of the northward heat transport by the Atlantic Ocean. Boreas, 30, 2-16, https://doi.org/10.1111/j.1502-3885.2001.tb00984.x, 2001.

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: 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, 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., Bowser, S.S., Cedhagen, T., Cornelius, N., Hald, M., Korsun, S., Pawłowski, J.: Monothalamous foraminiferans and gromiids (Protista) from western Svalbard: A preliminary survey, Mar. Biol. Res., 1, 290 – 312, 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, 14001–14013, 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.

Herbert, P.D., Cywińska, A., Ball, S.L., deWaard, J.R.: Biological identifications through DNA barcodes. Proc. Biol. Sci., 270, 313-321, doi:10.1098/rspb.2002.2218, 2003.

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.

Ivanova, E., Murdmaa, I., de Vernal, A., Risebrobakken, B., Peyve, A., Brice, C., Seitkalieva, Pisarev,: Postglacial paleoceanography and paleoenvironments in the northwestern Barents Sea, Quat. Res., 1-20, https://doi.org/10.1017/qua.2019.18, 2019.

Jennings, A.E., Weiner, N.J., Helgadottir, G., Andrews, J.T.: Modern foraminiferal faunas of the southwestern to northern Iceland Shelf; oceanographic and environmental controls, J. Foramin. Res., 34, 180-207, https://doi.org/10.2113/34.3.180, 2004.

Jernas, P., Klitgaard Kristensen, D., Husum, K., Wilson, L., Koç, N.: Palaeoenvironmental changes of the last two millennia on the western and northern Svalbard shelf, Boreas, 42, 236-255, https://doi.org/10.1111/j.1502-3885.2012.00293.x, 2013.

Katsuki, K., Takahashi, K., Onodera, J., Jordan, R.W., Suto, I.: Living diatoms in the vicinity of the North Pole, summer 2004, Micropaleontol. 55, 137-170, 2009.

Killworth, P.D.: Deep convection in the World Ocean, Rev. Geophys., 21, 1-26, doi:10.1029/RG021i001p00001, 1983.

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., 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 subsurface sediments. Biol. Lett., 9, 20130283, https://doi.org/10.1098/rsbl.2013.0283, 2013.

Lecroq B., Lejzerowicz F., Bachar D., Christen R., Esling P., Baerlocher L., Østerås M., Frinelli L., Pawlowski J.: Ultra-deep sequencing of foraminiferal microbarcodes unveils hidden richness in deep-sea sediments, PNAS, 108:13177-82, https://doi.org/10.1073/pnas.1018426108, 2011.

Lubinski, D.J., Polyak, L., Forman, S.L.: Freshwater and Atlantic water inflows to the deep northern Barents and Kara seas since ca 13 ^{14}C ka: foraminifera and stable isotopes, Quat. Sci. Rev., 20, 1851-1879, https://doi.org/10.1016/S0277-3791(01)00016-6, 2001.

Lydersen, C., Nøst, O., Lovell, P., McConell, B., Gammelsrød, T., Hunter, C., Fedak, M., 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.

Łącka, M., Zajączkowski, M., Forwick, M., Szczuciński, W.: Late Weichselian and Holocene palaeoceanography of Storfjordrenna, southern Svalbard, Clim. Past, 11, 587-603, https://doi.org/10.5194/cp-11-587-2015, 2015.

Łącka, M., Cao, M., Rosell-Melé, A., Pawłowska, J., Kucharska, M., Forwick, M., Zajączkowski, M.: Postglacial paleoceanography of the western Barents Sea: Implications for alkenone-based sea surface temperatures and primary productivity, Quat. Sci. Rev., 224, 105937, https://doi.org/10.1016/j.quascirev.2019.105973, 2019.

Mahé, F., Rognes T., Quince C., de Vargas, C., Dunthorn, M.: Swarm: robust and fast clustering method for amplicon-based studies, Peer J, 2, e593, doi: 10.7717/peerj.593, 2014.

Majewski, W., Pawłowski, J., Zajączkowski, M.: Monothalamous foraminifera from West Spitsbergen fjords: a brief overview, Polish Polar Res., 26(4), 269-285, 2005.

Majewski, W., Szczuciński, W., Zajączkowski, M.: Interactions of Arctic and Atlantic water-masses 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 ^{14}C 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/S0146-6380(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, Quat. Sci. Rev., 47, 1–14, https://doi.org/10.1016/j.quascirev.2012.04.024, 2012.

Moros, M., Emeis, K., Risebrobakken, B., Snowball, I., Kuijpers, A., McManus, J., Jansen, E.: Sea surface temperatures and ice rafting in the Holocene North Atlantic: climate influences on northern Europe and Greenland, Quat. Sci. Rev., 23, 2113-2126, https://doi.org/10.1016/j.quascirev.2004.08.003, 2004.

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.

Pawłowska, J., Zajączkowski, M., Łącka, M., Lejzerowicz, F., Esling, P., Pawlowski, J.: Palaeoceanographic changes in Hornsund Fjord (Spitsbergen, Svalbard) over the last millennium: new insights from ancient DNA, Clim. Past, 12, 1459-1472, https://doi.org/10.5194/cp-12-1459-2016, 2016.

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, 2014.

Perner, K., Moros, M., Lloyd, J.M., Jansen, E., Stein, R.: Mid to late Holocene strengthening of the East Greenland Current linked to warm subsurface Atlantic water, Quat. Sci. Rev., 129, 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, 1996.

Polyakov, I. V., Pnyushkov, A.V., Alkire, M.B., Ashik, I.M., Baumann, T.M., Carmack, E.C., Goszczko, I., Guthrie, J., Ivanov, V.V., Kanzow, T.T., Greater role for Atlantic inflows on sea-ice loss in the Eurasian Basin of the Arctic Ocean, Science, eaai8204, https://doi.org/10.1126/science.aai8204, 2017.

Quadfasel, D., Rudels, B., Kurz, K.: Outflow of dense water from a Svalbard fjord into the Fram Strait, Deep Sea Res., 35, 1143-1150, https://doi.org/10.1016/0198-0149(88)90006-4, 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.: Brine formation in relation to climate changes and ice retreat during the last 15,000 years in Storfjorden, Svalbard, 76-78°N, Paleoceanography, 29, 911–929, https://doi.org/10.1002/2014PA002643, 2014.

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. Rev., 92, 280-291, https://doi.org/10.1016/j.quascirev.2013.10.034, 2014.

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.

Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Bronk Ramsey, C., van der Plicht, J.: IntCal13 and Marine13 Radiocarbon Age Calibration Curves 0-50,000 Years Cal BP. Radiocarbon, 55(4), 1869-1887, https://doi.org/10.2458/azu_js_rc.55.16947, 2013.

Rigual-Hernández, A.S., Colmenero-Hidalgo, E., Martrat, B., Bárcena, M.A., de Vernal, A., Flores, J.A., Grimalt, J.O., Henry, M., Lucchi, R.G.: Svalabrd ice-sheet decay after the Last Glacial Maximum: New insigths micropalaeontological and organic biomarker paleoceanographical reconstructions, Palaeogeogr., Palaeoclimatol., Palaeoecol., 465, 225-236, http://dx.doi.org/10.1016/j.palaeo.2016.10.034, 2017.

Risebrobakken, B., Moros, M., Ivanova, E.V., Chistyakova, N., Rosenberg, R.: Climate and oceanographic variability in the SW Barents Sea during the Holocene, The Holocene, 20, 609-612, https://doi.org/10.1177/0959683609356586, 2010.

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., Schulz, M.: Centennial-to-millennial-scale periodicities of Holocene climate and sediment injections off the western Barents shelf, 75°N, Boreas, 32, 447-461, https://doi.org/10.1111/j.1502-3885.2003.tb01227.x, 2003.

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, htttps://doi.org/ 10.2113/gsjfr.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, 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.

Skogseth, R., Sandvik, A. D., Asplin, L.: Wind and tidal forcing on the meso-scale circulation in Storfjorden, Svalbard, Cont. Shelf Res., 27, 208-227, https://doi.org/10.1016/j.csr.2006.10.001, 2007.

Stuiver, M., Reimer, P.J.: Extended ^{14}C database and revised CALIB 3.0 ^{14}C age calibration program, Radiocarbon, 35, 215-230, 1993.

Ślubowska-Woldengen, M., Rasmussen, T.L., Koç, N., Klitgaard-Kristensen, D., Nilsen, F., Solheim, A.: Advection of Atlantic Water to the western and northern Svalbard shelf since 17,500 cal yr BP. Quat. Sci. Rev., 26 463-478, https://doi.org/10.1016/j.quascirev.2006.09.009, 2007.

Taberlet, P., Bonin, A., Zinger, L., Coissac, E.: Enviroenmntal DNA: For biodiversity research and monitoring, Oxford University Press, https://doi.org/10.1093/oso/9780198767220.001.0001, 2018.

Telesiński, M.M., Przytarska, J.E., Sternal, B., Forwick, M., Szczuciński, W., Łącka, M., Zajączkowski, M.: Palaeoceanographic evolution of the SW Svalbard shelf over the last 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.

Werner, K., Spielhagen, R.F., Bauch, D., Hass, H.C., Kandiano, E.: Atlantic Water advection versus sea-ice advances in the eastern Fram Strait during the last 9 ka: Multiproxy evidence for a two-phase Holocene, Paleoceanogr., 28, 283-295, doi:10.1002/palo.20028, 2013.

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.

Zimmermann, H.H., Stoof-Leichsering, K.R., Kruse, S., Müller, J., Stein, R., Tiedemann, R., Herzschuh, U.: Changes in the composition of marine and sea-ice diatoms derived from sedimentary ancient DNA of the eastern Fram Strait over the past 30,000 years. Ocean Sci. Discuss., https://doi.org/10.5194/os-2019-113, 2019.

Figures captions

Figure 1: The modern oceanography of the study area (A) and the location of the studied core ST_1.5 (B) and the other cores discussed in this paper (A,B). Abbreviations of the main surface currents: WSC – West Spitsbergen Current, NCaC – North Cape Current, ESC – East Spitsbergen Current, BIC – Bear Island Current, CC – Coastal Current.

Figure 2: Temperature and salinity profile from the core location. Temperature is marked with a dashed line, and salinity is marked with a black line. Abbreviations: AW – Atlantic Water, TAW – Transformed Atlantic Water, BSW – Brine-enriched Shelf Water.

Figure 3: Age–depth model of the ST_1.5 core. The gray silhouettes show the probability distribution of te calendar dates that were obtained by the calibration of the individual ^{14}C dates used for the age model. The dotted line shows the age-depth model derived from linear interpolation between the dates.

Figure 4: Sedimentological and micropaleontological data plotted versus age. The sediment accumulation rate (SAR), mean grain size of the 0-63-µm 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 benthic foraminiferal tests, 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 benthic 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 a dashed line.

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

Usunięto: sampling station

Sformatowano: Czcionka: Pogrubienie

Usunięto: studied

Usunięto: testate

Usunięto:

Usunięto: the

Usunięto:

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

Table captions

Table 1: Raw and calibrated AMS^{14}C dates used in the age model.

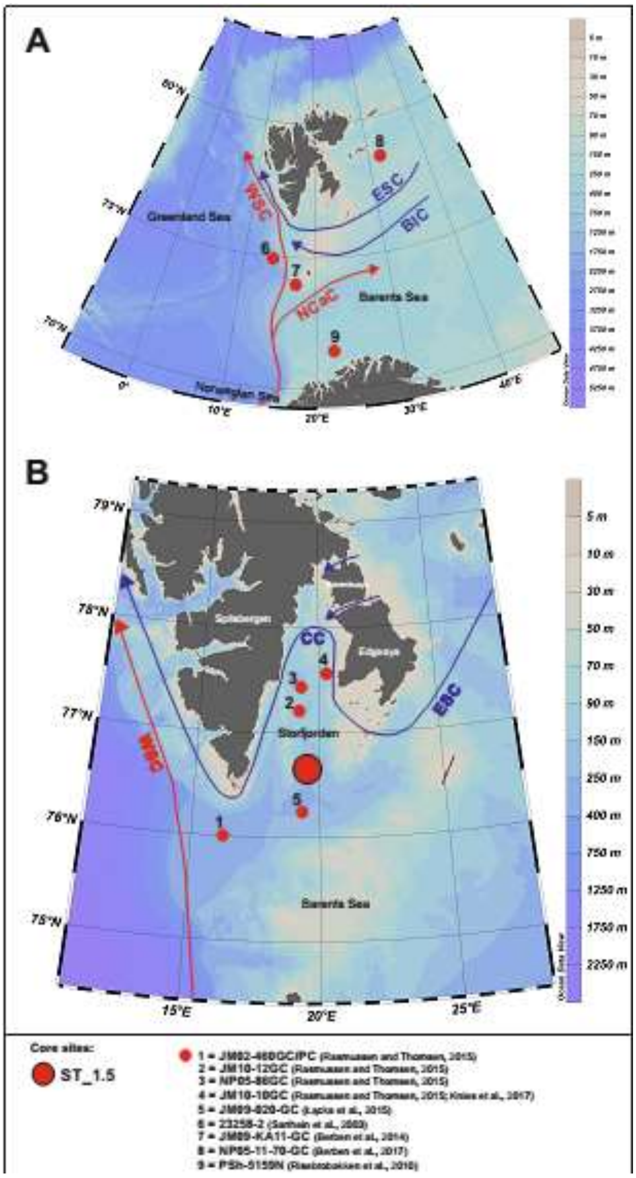

Figure 1: The modern oceanography of the study area (A) and the location of the studied core ST_1.5 (B) and the other cores discussed in this paper (A,B). Abbreviations of main surface currents: WSC – West Spitsbergen

Current, NCaC – North Cape Current, ESC – East Spitsbergen Current, BIC – Bear Island Current, CC – Coastal Current.

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

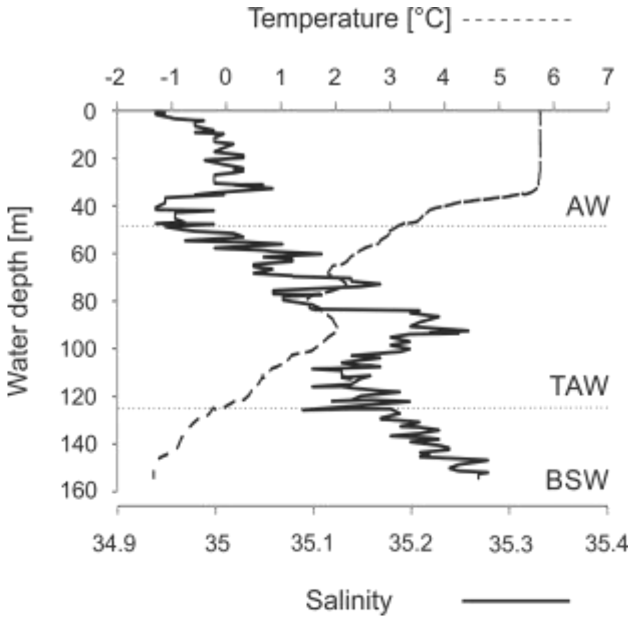

Figure 2: Temperature and salinity profile from the sampling station. Temperature is marked with a dashed line, and salinity is marked with a black line. Abbreviations: AW – Atlantic Water, TAW – Transformed Atlantic Water, BSW – Brine-enriched Shelf Water.

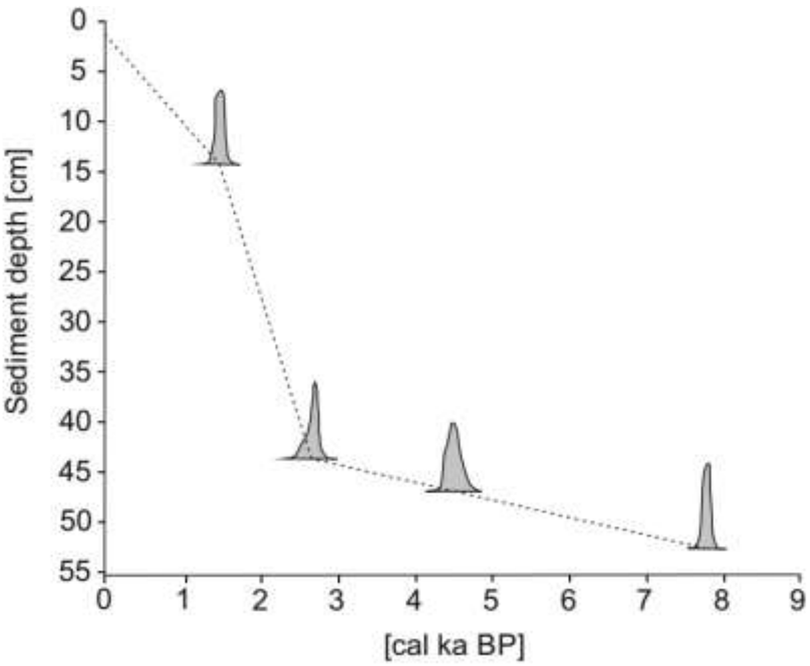

Figure 3: Age–depth model of the ST_1.5 core. The grey silhouettes show probability distribution of calendar dates that were obtained by calibration of individual ^{14}C dates used for the age model. The dotted line shows the age-depth model derived from a linear interpolation between the dates.

Usunięto: Age-depth model of the studied core.

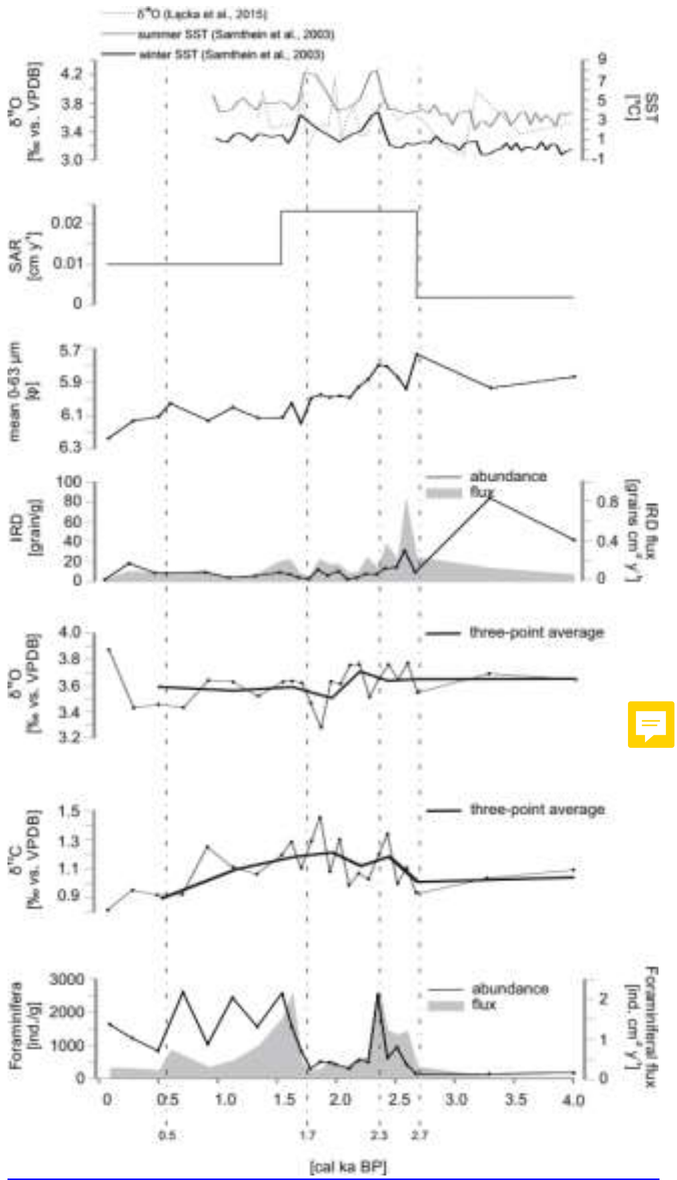

Figure 4: Sedimentological and micropaleontological data plotted versus age. The sediment accumulation rate (SAR), mean grain size of the 0-63-µm fraction, ice-rafted debris (IRD) flux and number of grains per gram of sediment, oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) stable isotopes in benthic foraminiferal tests, and the flux and abundance of foraminifera are presented.

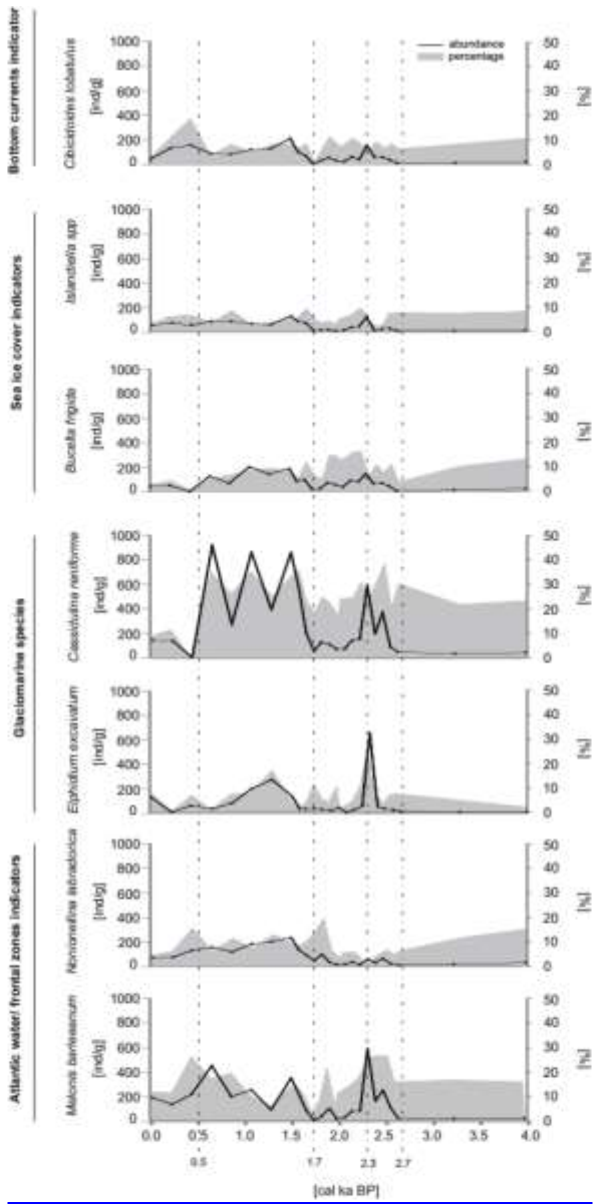

Figure 5: The abundance (expressed as the number of individuals per gram of dry sediment) and the percentage of the dominant benthic foraminifera.

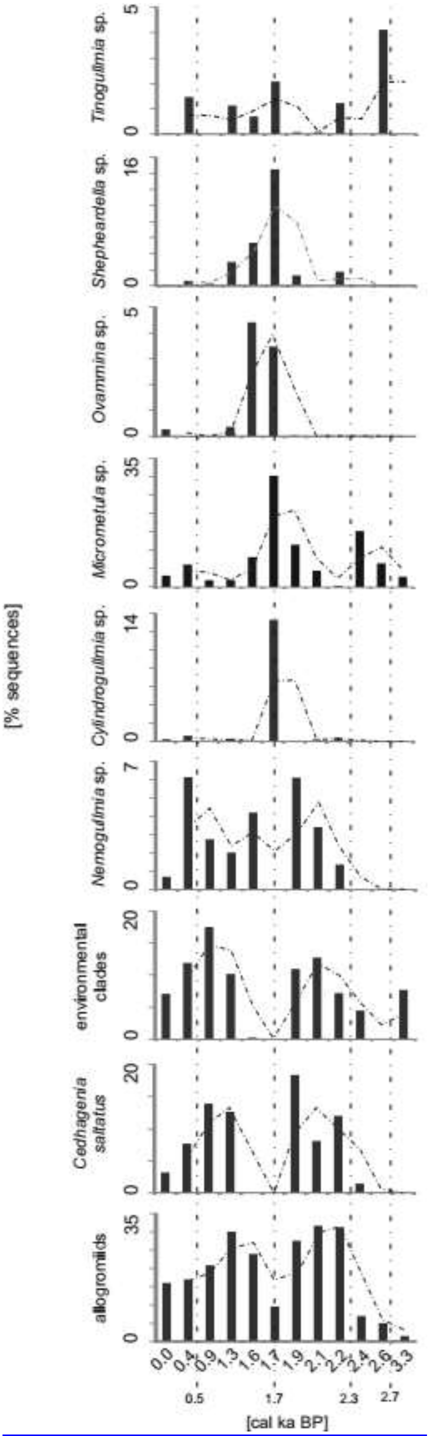

Figure 6: The dominant components of the monothalamous assemblages. The abundance is expressed as the percentage of the monothalamous sequences and the most abundantly sequenced taxa are presented. The trend is indicated with a dashed line.

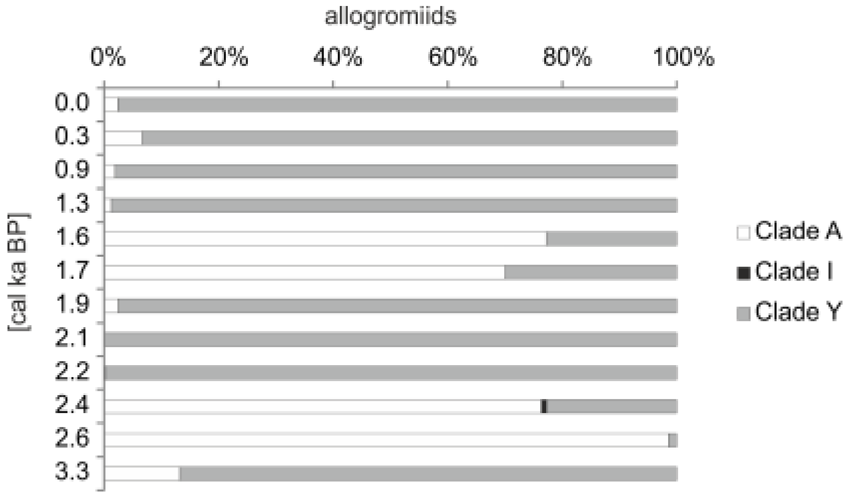

Figure 7: The percentage share of certain clades in the allogromiid sequences.

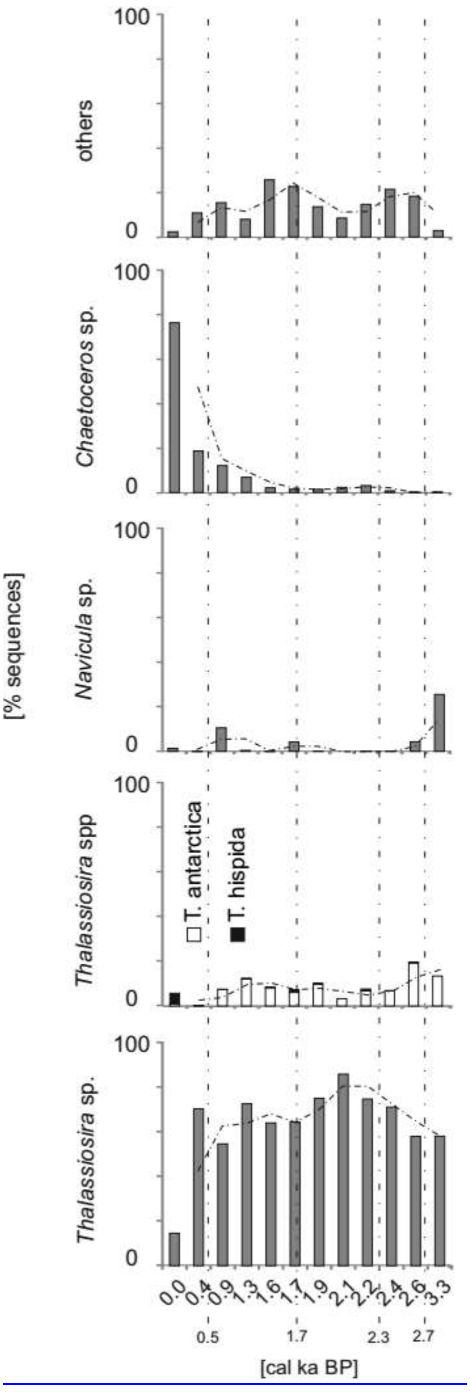

Figure 8: The percentage of sequences of dominant diatom taxa vs. time. The trend is indicated with a dashed line.

Usunięto: the

Table 1: Raw and calibrated AMS^{14}C dates used in the age model. B stands for bivlave shells, while F stands for benthic foraminifera tests.

Core depth [cm]	Material	Raw AMS ^{14}C	Cal. a BP ± 2σ	Cal. a BP used in age model
2.5	*Nuculana pernula* (**B**)	107.38 ± 0.33 pMC	-	-
5.5	*Yoldiella lenticula* (**B**)	290 ± 30 BP	-	-
14.5	*Turitella erosa* (**B**)	2020 ± 30 BP	1356-1555	1500
43.5	*Yoldiella solituda* (**B**)	3010 ± 50 BP	2484-2787	2700
46.5	*Nonionellina labradorica* (**F**)	4490± 40 BP	4400-4701	4500
52.5	*Yoldiella lenticula* (**B**)	7545 ± 35 BP	7803-7989	7890